APPENDIX

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Compilation and Synthesis of Existing Data in Support of the Determination of Minimum Flows for Crystal River

Task 1 - Summary of Previous Studies and Data Collection Efforts

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Introduction

This project provides technical assistance to the Southwest Florida Water Management District (District) in support of establishing minimum flows and levels (MFLs) for Crystal River. Kings Bay forms the headspring area of Crystal River, and all references to Crystal River in this report extend upstream from the river mouth to include King's Bay.

The project comprises three tasks:

- Task 1 - Summary of previous studies and data collection efforts,
- Task 2 - Data compilation, and
- Task 3 - Data Synthesis.

To address these tasks, the University of Florida, Program in Fisheries and Aquatic Sciences (FAS) will summarize, and in some cases compile and synthesize, existing data for hydrology, salinity, water quality, aquatic macrophytes and other biological variables (*e.g.*, phytoplankton, benthic invertebrates, and fish) in the Crystal River system. The overall objective of this project is to identify variables that may respond to the quantity and quality of freshwater flow from the river's headsprings and summarize relationships among these variables. ***This report represents Task 1 – Summary of previous studies and data collection efforts.***

Methods

Searches for literature (peer-reviewed journal articles and technical reports) likely to contain data relevant to the District's effort to establish minimum flows and levels for the Kings Bay/Crystal River system were conducted at multiple jurisdictional levels. Federal agencies included the U.S. Army Corps of Engineers, the U.S. Geological Survey (USGS), and the U.S. Fish and Wildlife Service (USFWS). Florida state agencies included the Florida Department of Environmental Protection (FDEP, and sub-divisions) and the Florida Fish and Wildlife Conservation Commission (FWC), whereas the Southwest Florida Water Management District (District, and sub-divisions) represented a regional governmental agency within the state. Other entities queried included Citrus County and City of Crystal River as well as the University of Florida. The following electronic databases were searched using "Crystal River" and "Kings Bay" as key words:

- The Amy H. Remley Foundation, Kings Bay Bibliography
  Web page: http://www.amyhremleyfoundation.org/php/education/resources/Bibliography.php

- The University of Florida dissertation and thesis database
  Web page: http://www.uflib.ufl.edu/

- The University of Florida, Institute of Food and Agricultural Sciences, Center for Aquatic Plants, Aquatic Plant Information Retrieval System (APIRS)
  Web page: http://plants.ifas.ufl.edu/APIRS/

- The Florida Department of Environmental Protection, Bureau of Laboratories Searchable Reports
  Web page: http://www.dep.state.fl.us/labs/cgi-bin/reports/search.asp;

- The Florida Fish and Wildlife Conservation Commission publication list, web page: http://research.myfwc.com/publications/search.asp

- the Southwest Florida Water Management District library
  Web page: http://www15.swfwmd.state.fl.us/dbtw-wpd/mywebqbe/librarybasic.htm

- The U.S. Geological Survey publication warehouse
  Web page: http://pubs.er.usgs.gov/

- ISI Web of Knowledge journal literature database
  Web page: http://apps.isiknowledge.com

Brief summaries (generally one page) of the available literature are provided alphabetically in the body of this report and complete reference list is provided as an appendix.

Summary

The available scientific literature (and associated data) as it relates to the Kings Bay/Crystal River system can largely be grouped into three categories: (1) impact of Progress Energy's Crystal River power plant on the system, (2) management of Kings Bay (water quality, aquatic plants, and manatees), and (3) the river itself.

The Crystal River power plant was constructed in multiple phases (oil/coal powered in the late 1960s and nuclear powered in the 1970s). Operation of the power plant, regardless of phase, necessitated the use of water from the Gulf of Mexico as a cooling agent. Literature concerning the power plant is geographically restricted to the nearshore Gulf of Mexico waters (west of the power plant and sometimes to the mouth of Crystal River), typically reports on water temperature and salinity, and focuses on marine algae, invertebrates, and fish. Data from the power plant category were only available in printed form.

Literature concerning the management of Kings Bay represented the largest collection of material, and its geographic coverage spans much of the bay. Primary topics were water chemistry and quality, management of aquatic plants, and management of manatees. Historical data from the Kings Bay category were available in printed form, and data from projects completed after the 1990s were commonly in electronic format. In general, these studies observed that nutrient concentrations in the water of Kings Bay had decreased since the mid-1990s, but water clarity remained a concern; that aquatic plant management issues peaked in the mid-1980s and continue to this day; and that use of Kings Bay by manatees has increased over the past five decades.

There was less available literature specifically concerning Crystal River, but several studies relevant to the establishment of minimum flows and levels were identified. Yobbi and Knochenmus (1989), for example, examined the effects of river discharge and salinity intrusion in Crystal River between 1982 and 1986, and these authors reviewed historical discharge estimates. Frazer *et al.* (2001) reported a wide variety of physical, chemical, and biological data collected along the length of Crystal River from ten quarterly sampling events between 1998 and 2000. These data are complemented by longer-term monitoring data in the river and adjacent estuarine and nearshore coastal waters (Project COAST, Jacoby et al. 2009). This established program collects data on various water quality parameters at ten stations (two in Crystal River, remainder in the estuary and gulf) on a monthly basis. Final key projects are by Dixon (1986) which collected salinity, stage, and other data along Crystal River; and Dixon (1997) which compiled available data on water chemistry and primary producers for Crystal River (both include other rivers along the Springs Coast). Long-term data from Kings Bay and the mouth of Crystal River are also available from FDEP (2010) and several current and historic USGS stations have collected relevant data.

Following selection of the most relevant projects by the District, Task 2 – Data Compilation, will begin. Task 2 will involve acquisition, compilation, and management of the data in a consistent format. These findings will be presented in a separate report to be submitted by May 1, 2010.

Author: Adams, C. A.

Publication Date: 1972.

Title: Food habits of juvenile pinfish (*Lagodon rhomboides*), silver perch (*Bairdiella chrysura*), and spotted seatrout (*Cynoscion nebulosus*) of the estuarine zone near Crystal River, Florida.

Document Type: M.S. Thesis, University of Florida. 147 pp.

Period of Study: 1971.

Geographic Range: Gulf of Mexico offshore of the Crystal River power plant.

Variables Measured: Stomach contents of three, juvenile fish species.

General Findings:

Data Format: Figures, tables, and appendices in thesis.

Data Location: In thesis.

Document Location: Abstract in project directory.

Abstract: Juvenile *Lagodon rhomboides, Bairdiella chrysura,* and *Cynoscion nebulosus* were collected over a one-year period from seagrass beds near a power station north of Crystal River, Florida. Collecting stations were situated both inside and outside the zone of thermal influence created by the power station. Quantitative gravimetric analyses of stomach contents show distinct ontogenetic changes in food habits.

Stomach contents from 2,970 pinfish show this species to be omnivorous. Pinfish from outside thermally affected waters initially feed on plankton (especially copepods), shifting sequentially to epiphytic algae, macrocrustaceans, and fish as the principal foods. Pinfish within the thermal effluent feed in a similar sequence, replacing epiphytic algae with organic detritus.

Stomach contents of 1.393 silver perch and 321 spotted seatrout indicate these fish are carnivorous. Silver perch inside and outside thermally affected waters feed initially on copepods, shifting to mysids and ultimately to macrocrustaceans and fish. Spotted seatrout first feed on copepods, but the transition to feeding on macrocrustaceans and fish is more precipitous than seen in pinfish or silver perch.

Author: Anderson, D. L., M. Flint, R. Cooper, K. Whitcomb, R. Brown, and G. Means.

Publication Date: 1991.

Title: Evaluation of Nutrient Loading Potential from Wastewater Sources in the Crystal River/Kings Bay Watershed.

Document Type: Final Report by Ayres Associates, Tampa, Fl. Prepared for the Southwest Florida Water Management District, Surface Water Improvement and Management (SWIM) Program. Tampa, Fl. 113 pp.

Period of Study: Up to 1991.

Geographic Range: Crystal River and Kings Bay.

Variables Measured: The contribution of nutrients to Kings Bay/Crystal River from on-site sewage disposal systems (OSDS), effluent from wastewater treatment facilities, and leakage from wastewater collection and transmission facilities.

General Findings: Some of the data are likely out of date now. The report is comprehensive with: Literature Review, Soil Characteristics, Surface Water Assessment, Groundwater Assessment, On-site Wastewater Disposal Systems Evaluation, Evaluation of Wastewater Treatment Facilities, Evaluation of Other Wastewater Sources, Estimated Nutrient Loadings from Wastewater Sources, and Conclusions and Recommendations.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary [Excerpts]: The study identified 895 existing septic tanks and drainfields, most of which serve older residential developments along the shoreline of Crystal River and Kings Bay. It was noted during the evaluation that a potential exists for almost double the amount of OSDS's, if existing areas served by OSDS are built out. Seven wastewater treatment facilities were identified and evaluated based on operation and treatment efficiency, types of effluent disposal, and potential for nutrient loading. Other sources of nutrient loadings considered included exfiltration from sanitary collection systems that serve the City of Crystal River, surrounding subdivisions, and commercial developments. Worst case nutrient contributions from existing OSDS sources were estimated at 5,878 kg/yr nitrogen and 1,616 kg/yr phosphorus based upon estimated concentrations and flows from OSDS discharges. Future potential loadings from OSDS sources may be as much as about 11,000 kg/yr nitrogen and 3,200 kg/yr phosphorus if all areas served by OSDS are built out. Treatment facilities provide the greatest loading of nutrients, followed by OSDS sources, and then by potential exfiltration sources. These wastewater sources may potentially account for approximately 32% of the future phosphorus loading and 12% of the future nitrogen loading from spring sources [identified as the biggest source].

Author: Avineon Inc.

Publication Date: 2010.

Title: Vegetation Mapping of the Crystal River in Support of the Establishment of Minimum Flows and Levels.

Document Type: Scope of Work. Project to be completed August 2010.

Period of Study: April 2010.

Geographic Range: Crystal River and six zones in Kings Bay.

Variables Measured: The primary objective of this project is to produce a geo-referenced vegetation map with line segments (shoreline vegetation) and polygons (SAV) attributed to vegetation species coverage classes in a GIS format. The mapping effort will also result in a spreadsheet of the types of emergent and submersed SAV per river kilometer along the length of the Crystal River.

General Findings: TBD.

Data Format: Figures and tables in report.

Data Location: In report, district will have electronic files

Document Location: Have scope of work, need final report when available.

Abstract:

Authors: Bachmann, R. W., T. K. Frazer, M. V. Hoyer, and D. E. Canfield, Jr.

Publication Date: 2001.

Title: Determination of Areas in Crystal River/Kings Bay Most Susceptible to Wave Disturbance.

Document Type: Final Project Report, Project W458. University of Florida, Institute of Food and Agricultural Sciences, Department of Fisheries and Aquatic Sciences. Submitted to Southwest Florida Water Management District. Tampa, Fl. 25 pp.

Period of Study: 2000.

Geographic Range: Kings Bay.

Variables Measured: Water level records from Crystal River, wind data from Gainesville, Tampa, and Orlando were used to calculate the frequency of wave-induced benthic disturbances.

General Findings: Based on 1985-89 NOAA data, the high tide is 0.93 m or less and the low tide -0.36 m or more 95% of the time (average water level was 0.28 m). Sediments are more likely to be disturbed at low water levels, and disturbances are more likely in shallow areas near the shorelines. Thus, more of the bay sediments are susceptible to disturbance during low tide levels. However, resuspension was not considered to be severe enough to cause existing problems with water clarity.

Data Format: Figures in report.

Data Location: In report, and UF FAS files.

Document Location: Project directory.

Discussion: In conclusion, our findings suggest that wind-driven surface waves and subsequent resuspension of bottom sediments are not likely the reason for chronic reductions in water clarity through Kings Bay. It is more likely that periphyton and detrital material associated with existing vegetation is the major contributor to reduced water clarity and that long-term changes in the vegetative assemblage may have played a role in the decline in water clarity.

Author: Belanger, T., H. Heck, M. Sohn, P. R. Sweets, M. Morris, and N. Julien.

Publication Date: 1993.

Title: Sediment Mapping and Analysis in Crystal River/Kings Bay and Lake Panasoffkee.

Document Type: Final Report. Submitted to Southwest Florida Water Management District. Brooksville, Fl. 228 pp.

Period of Study: 1992 and analysis of data collected in 1991.

Geographic Range: Up to 96 stations sampled in Kings Bay.

Variables Measured: Map and evaluate sediment characteristics (physical, chemical, pollutant levels, and sedimentation rates).

General Findings: Kings Bay sediments were generally shallow (< 3.4 ft) in depth, the average organic matter in the bay was low at 7.5%, and fine sands made up the majority of the samples. Organic pollutants were not detected, but copper was detected in sediment samples.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary: In contrast to Lake Panasoffkee, sediment depths in Crystal River/Kings Bay are shallow, ranging from 0.0 to 3.4 ft. deep. Pb-210 dating and paleo reconstruction data cannot be used in this water body because of sediment disturbance and large runoff and tidal impacts. Results of sediment analyses indicate the sediment is primarily sand in the fine range and smaller. The percent organic and carbonate matter levels are low, averaging only 7.6 and 8.4, respectively. The organic matter inputs at most sites were primarily due to macrophyte and *Lyngbya* die off and sedimentation, although several sites indicated terrestrial inputs from runoff. Cyclical, temperature dependent, seasonal trends in calcite saturation were observed in the surface water of Crystal River/Kings Bay, and historical data indicate the water is usually oversaturated with respect to calcite in the late spring, summer, and early fall.

Nutrient levels (TKN and TP) in both water bodies were low compared to other Florida lakes and estuaries. Organochlorine pesticides and 2,4-D levels were below detectable limits in both water bodies, but sediments were enriched with copper at both sites, particularly at Crystal River/Kings Bay.

Authors: Belanger, T. V., M. Sohn, J. Trefry, and T. Price.

Publication Date: 2005.

Title: Crystal River/Kings Bay Sediment Evaluation.

Document Type: Final Report. Submitted to Southwest Florida Water Management District. Brooksville, Fl. 129 pp.

Period of Study: 2005.

Geographic Range: Up to 100 stations in Kings Bay.

Variables Measured: Sediment depth, particle size, percent organic matter, nutrient content, and organic biomarker characteristics were measured at a variable number of sites.

General Findings: Relative to 1992 measures, sediment depths appear to have increased (ranged from 0 to 4.7 ft. and averaged 1.30 ft., compared to a range of 0 to 3.4 ft. and an average of 0.92 ft. for 1992 data). The average 2005 percent organic matter in the bay was 13.8 percent (0-6 in interval), an increase from the 7.5 percent average recorded in 1992. It appeared that the organic matter content in the central bay area has increased considerably since 1992, however sedimentation rates could not be calculated from Pb-210 sampling due to the mixed nature of sediments. Organic material was believed to be derived from *Lyngbya* and other aquatic plants. Concentrations of ammonia and phosphate in the sediment suggest that a net flux of these nutrients could occur to the water column, although it would be minor compared to spring inputs.

Data Format: Figures, tables, and appendices in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary: As a result of detailed sediment studies made in 1992 and 2005 (this study) in Crystal River/Kings Bay, it appears the sediment depth and percent organic matter content are increasing. Mean depth to hardpan increased from 0.92 to 1.30 ft., and the mean organic matter content increased from 7.50 to 13.8% in that time period. Organic biomarker studies indicated aquatic plant material, primarily *Lyngbya*, is the major contributor to the benthic sediment, although *Hydrilla* and *Myriophyllum* were major contributors at some sites. C-13 NMR analysis of humic acids and GCIMS analysis of n-alkanes also indicated no major terrestrial input to the benthic sediment organic matter. Although the organic matter content varies considerably from site to site in Crystal River/Kings Bay, the sediments are very sandy in nature, as the fine and very fine sand fractions averaged 84.5 % in 2005. Diffusive benthic fluxes of ammonia and phosphate were generally low at the two test sites in Crystal River/Kings Bay, and it is believed that advection of groundwater through the sediment deposits is much more important than diffusion in supplying nutrients to the bay.

Author: Benkert, K. A.

Publication Date: 1980.

Title: Annual productivity and simulation models of the chaetognath, *Sagitta hispida*, exposed to a thermal plume at Crystal River, Florida.

Document Type: M.S. Thesis, University of Florida. 80 pp.

Period of Study: 1979.

Geographic Range: Gulf of Mexico by the Crystal River power plant.

Variables Measured: Zooplankton and phytoplankton abundance.

General Findings: A study of a zooplankton including production estimates.

Data Format: Figures and tables in thesis.

Data Location: In thesis.

Document Location: **Abstract** in project directory.

Abstract: Production of the chaetognath, *Sagitta hispida*, was monitored for twelve months in a shallow bay receiving thermal effluent from three power plants. Production of *S. hispida* in a control bay was approximately equal to that measured in the impacted bay. In the control bay, annual production followed a unimodal pattern while in the impacted bay, annual production shifted into a bimodal pattern. Food was found to be limiting for *S. hispida*. A significant correlation was found between the biomass of chaetognaths and copepods, their major prey item.

A model of the *S. hispida* population was developed and simulated. The simulations suggested that within the tolerance limits of temperature and salinity for *S. hispida,* food availability and predation were major controlling factors of the population. The model simulations also suggested that offshore recruitment was necessary to repopulated both the control and impacted bays following seasonal declines of the population to levels less than 0.1 mg/m^3.

Author: Bishop, J. H.

Publication Date: 1995.

Title: Evaluation of the removal of treated municipal effluent on water chemistry and the abundance of submersed vegetation in Kings Bay, Crystal River, Florida.

Document Type: M. S. Thesis. University of Florida. Gainesville, Fl. 51 pp.

Period of Study: August 1992 through May 1994.

Geographic Range: Multiple stations in Kings Bay.

Variables Measured: Total nitrogen (TN), total phosphorus (TP), chlorophyll (CHL), Secchi visibility. Submersed aquatic vegetation (SAV) frequency of occurrence (bi-monthly 1979-83 and 1985-94).

General Findings: Elimination of the City of Crystal River STP wastewater discharge reduced concentrations of TN and TP in Cedar Cove, but not Kings Bay as a whole. Changes in SAV do not appear to be related to nutrient changes, but to salinity stressors following storm surge.

Data Format: Tables, figures, and appendices in thesis.

Data Location: In thesis and Excel files at UF Florida LAKEWATCH.

Document Location: Project directory.

Abstract: [Excerpts] Treated municipal wastewater effluent was removed from a 16-hectare (40-acre) cove in Kings Bay called Cedar Cove in March, 1992 in an attempt to reduce both ambient nutrient concentrations (total phosphorus and total nitrogen) and the abundance of submersed aquatic plants in Kings Bay. Elimination of the treated municipal effluent from Cedar Cove did not reduce total phosphorus and total nitrogen concentrations in Kings Bay. Mean total phosphorus concentrations in Kings Bay prior to the removal was 26 µg/L and after the removal was 28 µg/L. Mean total nitrogen concentrations prior to and after the removal in Kings Bay were 310 µg/L and 270 µg/L, respectively. Total phosphorus and total nitrogen concentrations, however, were significantly reduced in the immediate area of the discharge. Mean total phosphorus concentration in Cedar Cover prior to the removal was 105 µg/L and after the removal was 27 µg/L. Mean total nitrogen concentrations in Cedar Cover prior to and after the removal were 620 µg/L and 220 µg/L, respectively. Extensive flooding associated with a tidal storm that hit Kings Bay in March, 1993 caused elevated nutrient and specific conductance concentrations throughout the bay. There were no significant changes in the abundance of tape grass (*Vallisneria americana*) and filamentous algae (*Lyngbya* sp.) during the study in either Kings Bay or Cedar Cove. *Hydrilla* (*Hydrilla verticillata*) abundance was significantly reduced and the abundance of Eurasian watermillfoil (*Myriophyllum spicatum*) was significantly increased in both Kings Bay and Cedar Cove between the pre-and post-removal periods. However, significant changes in the abundance of these submersed species are attributed to changes cause by the "No-Name Storm" on March 13, 1993, not removal of the treated wastewater from Cedar Cove.

Authors: Bishop, J. H. and D. E. Canfield.

Publication Date: 1995.

Title: Volunteer water quality monitoring at Crystal River, Florida (August 1992 – August 1995).

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, FL.

Period of Study: August 1992 to August 1995. Florida LAKEWATCH has sampled Kings Bay/Crystal River to some degree through at least 2007.

Geographic Range: Monthly at 21 stations in Kings Bay and upper Crystal River from August 1992 to May 1994 and at 10 stations from June 1994 to July 1994.

Variables Measured: Total nitrogen (TN), total phosphorus (TP), chlorophyll (CHL) concentrations and Secchi disk visibility; and the species composition of SAV (at a variable number of stations from 1979 to 1983 and 1985 to 1994).

General Findings: Average monthly TP ranged from 18 to 68 µg/L, TN ranged from 130 to 500 µg/L, chlorophyll ranged from 2.1 to 11 µg/L, and Secchi visibility ranged from 2 to 22 feet (but the disk was typically visible on the bottom, maximum horizontal Secchi was 58 ft at station 10). Elimination of the City of Crystal River STP wastewater discharge reduced concentrations of TN and TP in Cedar Cove, but not Kings Bay as a whole. Following the "Storm-of-the-Century" passage TN and TP (but not CHL) concentrations increased dramatically for 2 months. There was no significant difference between low and high tide average TN, TP, and CHL concentrations. *Hydrilla* was the dominant SAV prior to the "Storm" and Eurasian milfoil was most abundant afterwards. Changes in SAV in Cedar Cove and Kings Bay do not appear to be related to nutrient changes, but to salinity stressors following storm surge.

Data Format: Table, figures, and appendices in report.

Data Location: Report and Excel data at UF, Florida LAKEWATCH.

Document Location: Project directory.

Executive Summary: [Excerpts] Reduced visibility seems to be primarily associated with increased algal populations in the water column. Ten genera of aquatic plants were identified in Kings Bay. Mean total biomass of submersed vegetation in the bay ranged from 2.6 to 12 kg fresh wt/m^2. The March 13, 1993 tidal storm, not the removal of the City of Crystal River wastewater discharge, was responsible for the differences detected in plant abundances.

Authors: Blackburn, R. D., L. W. Weldon, R. R. Yeo, and T. M. Taylor.

Publication Date: 1969.

Title: Identification and distribution of certain similar-appearing submersed aquatic weeds in Florida.

Document Type: Journal of Aquatic Plant Management. 8: 17-21.

Period of Study: 1958 to 1967.

Geographic Range: Florida.

Variables Measured: How to distinguish *Hydrilla*, *Egeria*, and *Elodea* and the distribution of *Hydrilla* and *Egeria* in 1969 Florida.

General Findings: *Hydrilla* observed in Crystal River system by 1960, reported planted along SW coast [Homosassa?] by tropical aquatic plant dealers in 1958.

Data Format: Text findings.

Data Location: In publication.

Document Location: Project directory.

Abstract: *Hydrilla* (*Hydrilla verticillata* Casp.) and Egeria (*Egeria densa* Planch) are described and compared with American elodea (*Elodea canadensis* Michx.). The distribution of these submersed aquatic weeds in Florida is discussed. *Hydrilla* was first reported in the United States in 1958 along the west coast of Florida. The plant now infests an estimated 35,000 acres and has spread over much of the entire State and into southern Alabama and Georgia. Egeria infests an estimated 10,000 acres in central Florida. Many lakes, ponds, canals and rivers have become useless for recreation, navigation and flood control because of these two aquatic weeds.

Author: Buckingham, C. A.

Publication Date: 1990.

Title: Manatee response to boating activity in a thermal refuge.

Document Type: M.S. Thesis, University of Florida. 83 pp.

Period of Study: November 1988 to March 1989.

Geographic Range: Kings Bay, especially manatee refuge zones.

Variables Measured: Manatee behavior.

General Findings: See Buckingham *et al.* 1999.

Data Format: Figures, tables, and appendices in thesis.

Data Location: In thesis.

Document Location: **Abstract** in project directory.

Abstract: Free-ranging manatees wintering in the natural thermal refuge created by the springs in Kings Bay, Crystal River, Florida, were studied to determine whether their use of established sanctuaries was affected by the number of pleasure boats often using the same area. Observers in small fixed-wing aircraft recorded manatee and boat locations on grid maps. Other observers on elevated platforms recorded manatees and boats passing through entrance channels to the largest, most important spring area in the southern part of the bay. It was determined that manatees continued to be drawn to the springs, particularly those in the South Bay, in response to a decrease in water and air temperatures, regardless of the number of boats present, but that their use of seasonal manatee sanctuaries increased significantly as the number of boats increased. These findings suggest that manatees are being unduly restricted in their movements by human waterborne activities. Because the number of manatees and the number of people using the area have increased since the original sanctuaries were established, additional limits on boating or additional sanctuary areas are needed.

Authors: Buckingham, C. A., L. W. Lefebvre, J. M. Schaefer, and H. I. Kochman.

Publication Date: 1999.

Title: Manatee response to boating activity in a thermal refuge.

Document Type: Wildlife Society Bulletin. 27(2): 514-522.

Period of Study: November 1988 to March 1989.

Geographic Range: Kings Bay, especially manatee protection zones.

Variables Measured: Manatee behavior in relation to human use levels.

General Findings: Boat use affected manatee distribution. Manatee protection zones appeared adequate as refuges.

Data Format: Tables and figures in report.

Data Location: In report.

Document Location: Project directory.

Abstract: Thermal refuges are important for the endangered Florida manatee (*Trichechus manatus latirostris*) during winter cold periods in temperate latitudes. However, little research has examined impacts on manatees from human disturbance during these critical periods. We studied the effect of recreational boating activity on manatee use of established sanctuaries in the natural thermal refuge created by warm-water springs in Kings Bay, Crystal River, Florida. We examined the relationship among manatee use of the study area and sanctuaries, temperature, and level of boating activity. Manatees continued to use the Bay regardless of the number of boats present; however, their use of sanctuaries in the southern portion of the Bay increased ($P<0.001$) as number of boats increased. Temperature, as expected, was inversely related to manatee use of the study area. Human activity patterns were variable, with significantly greater numbers of boats in the study area on weekends (avg. = 32.7, SE = 2.71) than on weekdays (avg. = 10.7, SE = 1.23). We concluded that recreational boating influenced manatee distribution, sanctuaries are important to manatees in Kings Bay, and sanctuaries are an effective management tool to reduce the impact of boating activities on manatees.

Authors: Carr, W. E. S., and C. A. Adams.

Publication Date: 1973.

Title: Food habits juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida.

Document Type: Transactions of the American Fisheries Society. 102(3): 511-540.

Period of Study: October 1970 to August 1971.

Geographic Range: North of the mouth of Crystal River.

Variables Measured: Fish and their stomach contents.

General Findings: Stomach contents are noted from 21 species of common salt water fish. Seagrass and macroalgae were the habitats sampled.

Data Format: Tables and figures in publication.

Data Location: In publication.

Document Location: Project directory.

Abstract: [Excerpts] Quantitative gravimetric analyses of stomach contents were carried out on juveniles of 21 species of fishes that cohabit seagrass beds near Crystal River Florida. Our analyses were based on dry weights of food items and are expressed as percent of total stomach contents. Juveniles of *H. pensacolae, O. oglinum, A. hepsetus, A. mitchilli*, and *M. beryllina* were almost exclusively planktivorous and exhibited a distinct selection for molluscan veliger larvae. Copepods, mysids, and larval crustaceans were the principal plankton consumed by juveniles of other species. Only three species, *D. holbrooki, L. rhomboides*, and *H. unifasciatus*, exhibited herbivorous feeding stages. In both *D. holbrooki* and *L. rhomboides*, the herbivorous habit began quite early in juvenile development and followed a preliminary planktivorous stage. Larger specimens of *L. rhomboides* became carnivorous, whereas adults of *D. holbrooki* (and *H. unifasciatus*) were herbivorous. Juveniles of eight species exhibited carnivorous feeding stages, consuming primarily benthic invertebrates. Of these species, *O. saurus*, *H. plumieri*, *O. chrysoptera*, and *B. chrysura* consumed primarily shrimp and mysids; *E. gula* and *T. maculatus* utilized primarily polychaetes; *C. saburrae* consumed primarily amphipods; and *T. falcatus* consumed mainly crabs after utilizing mysids, small shrimp, and fishes in earlier feeding stages. Juveniles of two species, *L rhomboides* and *C. nebulosus*, exhibited carnivorous stages in which both benthic invertebrates and small fishes were important in the diet. Specimens of *S. marina* and *S. foetens* were primarily piscivorous. Detritus was an important dietary component in six species. In *S. nephelus*, *M. gulosus*, and *C. saburrae*, detritus was a major food item through most of the available size ranges. In *M. beryllina*, detritus was the major food item in the smallest size class examined. Appreciable amounts of detritus were also consumed by juveniles of *O. oglinum* and adults of *H. unifasciatus*.

Author: CH2M Hill.

Publication Date: 1991.

Title: Crystal River/Kings Bay Stormwater Rehabilitation Project. Phase II. Project Evaluation and Conceptual Design.

Document Type: Final Report. Prepared for the Southwest Florida Water Management District. Brooksville, Fl. 225 pp.

Period of Study: Up to 1991.

Geographic Range: Crystal River/Kings Bay and City of Crystal River.

Variables Measured: Identifying stormwater improvement projects within the watershed.

General Findings: The project goal was to develop urban storm water pollutant reduction plans for sub-basin outfalls discharging into Kings Bay. The project had multiple phases (I- data compilation/sub-basin selection, II- conceptual design, design and permitting, and III- project construction/implementation). This report summarizes work accomplished in Phase II. Initially 23 projects were identified, and 12 were selected for conceptual design. It appears that projects 1, 6, 13, 17, 21 were completed by 2006.

Data Format: Figures, tables, and appendices.

Data Location: In report.

Document Location: Project directory.

Executive Summary: [Excerpts] Based on preliminary data and implementation categories, 12 of 23 projects were selected for conceptual design. However, each of these 23 projects could be beneficial and should be considered for future implementation. A standard set of procedures was developed for the conceptual design and pollution reduction calculations. A discussion of site conditions, existing drainage patterns, and the proposed stormwater treatment system is provided for each project. In addition, a conceptual project layout was developed, and estimated cost and pollutant removal calculations were performed. Six of the projects for which conceptual designs were developed are included in the category for immediate implementation.

Authors: Champion, K. M.

Publication Date: 2001.

Title: Chemical characteristics of selected springs in the Southwest Florida Water Management District.

Document Type: An internship project submitted in partial fulfillment of the M.S. degree in geology at the College of Arts and Sciences, University of South Florida. Prepared through the Water Quality Monitoring Program, Southwest Florida Water Management District. 107 pp.

Period of Study: January 1991 through April 2000, with other (1992 and 1996) data sets also.

Geographic Range: Multiple springs in District, including 11 in Kings Bay.

Variables Measured: Temperature, dissolved oxygen, pH, bicarbonate, calcium, fluoride, total organic carbon, chloride, sodium, sulfate, magnesium, potassium, TDS, orthophosphate, and nitrate.

General Findings: Springs in the study area can be segregated into coastal or inland spring systems. Kings Bay springs fall in inland spring category of calcium-bicarbonate waters that have calcite, dolomite, and gypsum saturation indexes characteristic of recent aquifer recharge.

Data Format: Figures, tables, and appendix in report.

Data Location: In report.

Document Location: Project directory.

Conclusions: Spring groups in the study area can be segregated into coastal or inland spring systems. Chloride, sodium, sulfate, magnesium, potassium and TDS increase significantly ($\alpha \leq 0.05$) in coastal spring systems. Orthophosphate and nitrate concentrations decrease significantly as nutrient-rich freshwater mixes with nutrient-poor seawater in the coastal transition zone.

Approximately 77 and 81 percent of the inland and coastal spring samples, respectively, are saturated with calcite. This suggests that diffuse flow systems are conveying ground water to the springs through the Upper Floridan aquifer. Rapid recharge, minimal residence time and short flow paths may lead to under-saturation in some springs.

Most springs in the study area are moderately to highly under-saturated with dolomite, and nearly all springs are highly under-saturated with gypsum. This suggests that ground water discharging at the springs has not dissolved significant amounts of or had a sufficient amount of water-rock interactions with dolomite and gypsum in the Upper Floridan aquifer. Although upwelling along the inner margin of the coastal transition zone and in fractured areas inland of the coast is suggested from sulfate-chloride molar ratios, most of the ground water discharging from the springs has not traveled deep enough to interact with gypsum in the Middle Confining Unit.

Springs in the study area typically plot along mixing lines connecting a freshwater end member with gypsum and seawater end members. Spring samples closely follow these mixing trends because of the averaging of water quality characteristics in the spring discharge.

Many water types are represented in the coastal springs data. These types include calcium-bicarbonate, mixed cation-bicarbonate, mixed cation-mixed anion, mixed cation-chloride and sodium chloride. The pattern in these water types suggests unconfined ground-water flow through the Upper Floridan aquifer. Some spring samples, however, contain elevated proportions of magnesium and sulfate. These samples were collected at springs that discharge ground water that is upwelling from deeper portions of the aquifer.

The temperature of spring samples closely approximates average annual air temperatures in the study area. Dissolved oxygen concentrations and Eh data strongly suggest shallow ground-water flow through the Upper Floridan aquifer. Deeper flow paths are reflected in higher temperatures and lower D.O. concentrations and low Eh.

Elevated concentrations of TOC, organic nitrogen and potassium at Fenney Spring suggest rapid ground-water recharge to the Upper Floridan aquifer from a sinking stream or similar karst feature.

Significant concentrations of trace metals are not detected in the small set of spring samples where trace-metal data were available. Again, this reflects the oxidized nature of the flow system where trace metals precipitate out of Upper Floridan aquifer ground water. Trace metals detected at Sulphur Springs are most likely related to storm water that was introduced into the Upper Floridan aquifer through sinkholes near the spring.

Synthetic organic compounds, pesticide and microbiological data are lacking from springs in the study area.

Authors: Champion, K. M. and R. Starks.

Publication Date: 2001.

Title: Chemical characteristics of selected springs in the Southwest Florida Water Management District.

Document Type: Final Report. Water Quality Monitoring Program, Southwest Florida Water Management District. Brooksville, Fl. 149 pp.

Period of Study: 1991 through 2000.

Geographic Range: Multiple springs in District, including 4 in Kings Bay.

Variables Measured: Temperature, pH, specific conductance, TDS, calcium, bicarbonate, chloride, sulfate, ammonium, nitrite, nitrate, total organic carbon, total phosphorus, iron, tritium, and uranium.

General Findings: The water chemistry of four springs (Black, Tarpon Hole, Hunters, and Idiots Delight) in Kings Bay are presented and graphs of nitrate trends. Kings Bay springs were typically freshwater on the eastern side of Kings Bay, while brackish-water springs occur in the central and western potions; chloride concentrations of springs may range from less than 10 mg/L to greater than 1,000 mg/L across the bay at low tide. Discharge measurements were about 75% of the long-term average. Tide affects water chemistry of Kings Bay springs. Nitrate concentrations vary among springs and were below 0.4 mg/L.

Data Format: Figures, tables, and data CD in report.

Data Location: In report.

Document Location: Project directory.

Summary: Hundreds of springs lie within the boundaries of the Southwest Florida Water Management District (SWFWMD or District). While some of these springs are isolated features, many are clustered into groups, or spring groups, of varying size and areal extent. Large spring groups, such as Rainbow Springs in southwestern Marion County, drain large areas, often draining tens or even hundreds of square miles. In addition, springs throughout the SWFWMD create an ideal environment by which to study and monitor ground-water quality in the Upper Floridan aquifer.

The largest concentration of springs in the SWFWMD can be found in the northern half of the District, where the Upper Floridan aquifer is unconfined and relatively close to the land surface. Because soluble limestones of the Upper Floridan aquifer occur close to the land surface and are not covered by continuing clay layers, the northern half of the District has developed into a karst landscape. This landscape is characterized by an abundance of sinkholes, sinking streams, underground caverns, and springs. Five of Florida's first magnitude largest springs lie within the SWFWMD. Rainbow Springs is, in fact, one of the largest springs in the world.

Prior to development, much of the springs region was covered by high pine forests, hammock forests, and pockets of scrub. Over time, this natural vegetation was replaced by agricultural lands, including livestock pastures, row crops, and citrus. However, over the last several decades, urban development has increased dramatically in the region and altered much of the rural landscape. Thousands of acres of commercial and urban development, including residential areas and golf courses, are spreading rapidly across the region as population continues to grow in the vicinity of the springs.

Water-quality studies conducted within the SWFWMD have shown that nitrate concentrations have been increasing in a number of springs throughout the northern portions of the District. This nitrate, derived primarily from inorganic fertilizers, has leached into the Upper Floridan aquifer within the last 20 years and is now being discharged at springs across the region. With population in the SWFWMD expected to reach 4.6 million by the year 2010, this situation can only become more serious.

It is estimated that springs in the SWFWMD discharge more than 1,000 mgd (one billion gallons per day) of water from the Floridan aquifer, and that prior to development, accounted for over 80% of the ground-water discharge from the Floridian aquifer. As development has occurred, however, this percentage may have decreased due to ground-water withdrawals in the region. Ground-water discharge from the Floridan aquifer is important to springs in the region for several reasons: 1) it provides the springs with adequate ground-water supplies to maintain flow; 2) it is an important component of many aquatic and terrestrial ecosystems throughout the region; and 3) it is an ideal barometer by which to gage the water quality of the Floridan aquifer over large areas (tens to hundreds of square miles).

Springs throughout the District exhibit seasonality in discharge as rainfall recharges the Floridan aquifer inland of the springs. This recharge causes water levels in the aquifer to rise and the spring discharge to increase. Studies by the USGS have shown that spring flow along the coast of Citrus and Hernando Counties can vary considerably during the year. A number of other springs throughout the SWFWMD exhibit similar variations in discharge as well, with lowest flows occurring late in the dry season (May/June) and highest flows occurring late in the wet season (Sept./Oct.).

From numerous water-quality samples collected since 1991, it is apparent that the springs can be divided into two major groups: group A and group B. Group A springs discharge a variety of water types including: 1) calcium-bicarbonate rich ground water derived from aquifer recharge, 2) sodium-chloride rich ground water derived from saltwater influences, and 3) mixtures of fresh and saline ground water. Group A springs discharge ground water that is strongly influenced by the dissolution of limestone inland of the salt-water transition zone; however, as ground water nears and moves into the transition zone, mixtures of fresh and saline ground water are produced. Group A springs may eventually discharge saline ground water that has intruded inland toward the springs.

Group B springs discharge sulfate-rich ground water. This enrichment reflects the upwelling of sulfate along the inner margin of the coastal transition zone and in highly fractured areas inland of the coast. Group B samples occur sporadically throughout the SWFWMD, but are concentrated at Gum Slough Springs and Lithia/Buckhorn Springs, and to a lesser extent at Rainbow and Panasoffkee Spring groups.

Ground water discharging from Warm Mineral Springs is enriched in sulfate due to the deep flow path taken by the ground water through the Floridan aquifer prior to reaching the spring.

Spring waters throughout the District reflect the dissolution of limestone in the Floridan aquifer. Ground water discharging from the springs is generally dominated by calcium-bicarbonate, except along the coast where the coastal transition zone becomes an important influence on water quality. In addition, the pH of spring water typically varies between 7 and 8, indicating that the ground water is at or near chemical equilibrium with limestone in the Floridan aquifer.

Except near the salt-water transition zone, springs throughout the District have chloride concentrations that reflect rapid recharge to the Floridan aquifer. As one approaches the coast, however, the transition zone increases chloride in the ground water dramatically. A good example of this may be found at the King's Bay Springs group where chloride concentrations in the springs may range from less than 10 mg/l to greater than 1,000 mg/l across the bay at low tide.

Sulfate concentrations in most spring waters are low enough to indicate that the flow system in the Floridan aquifer is shallow (probably within the upper 200-300 feet of the aquifer). In addition, the residence time of ground water in the system is short, and upwelling from the deeper flow system is not occurring in many springs. Several inland spring groups, however, discharge ground water that contains elevated amounts of sulfate. This sulfate is most likely derived from localized upwelling of sulfate in the immediate vicinity of the springs.

TDS concentrations vary among spring groups in the District as well as within a given spring group. This is especially important in coastal springs where the freshwater/saltwater transition zone strongly influences ground-water quality (e.g., King's Bay Springs). TDS concentrations also vary significantly in tidally influenced springs where TDS may vary several thousand milligrams per liter over a given tidal cycle.

Nitrate concentrations in spring waters have been a concern in the SWFWMD (as well as other regions of Florida) for a number of years. Increased levels of nitrate are detected at many springs in the District, and may be responsible for the increased growth of nuisance aquatic vegetation such as *Lyngbya* (a filamentous cyanobacteria) in spring runs throughout the region. Since 1991 a number of ground-water studies have been conducted throughout the northern portions of the SWFWMD in an effort to determine the source(s) of nitrate in the spring water. These studies have shown that most of the nitrate discharging from springs in the SWFWMD is derived from inorganic fertilizers. This nitrate was applied to a variety of land uses inland of the springs decades ago as fertilizer for pastures, residential lawns, golf courses, and/or citrus groves.

Nitrate concentrations in spring water throughout the District range from below detection limit (<0.01 mg/l) to slightly greater than 3.0 mg/L. All of the spring samples are well below the primary drinking water standard established by the FDEP for nitrate, 10 mg/L. One exception, however, is Bell Creek Spring in central Hillsborough County. This spring discharges ground water that typically contains nitrate levels in excess of the 10 mg/l drinking water standard. Bell Creek Spring discharges approximately 0.03 mgd and is affected by nitrate derived from a local animal-waste source.

The temperature of spring water throughout the district should reflect the average annual air temperature in the vicinity of the springs. Mean annual air temperatures in the District range from 22-23°C (71-74°F) from north to south across the SWFWMD; springs in the District typically have temperatures that range 23-25°C. The lowest spring temperatures are often found in the extreme northern portions of the District (e.g., Rainbow Springs) where recharged may be rapid and somewhat cooler in temperature. The warmest spring temperatures, not counting Warm Mineral Springs in southern Sarasota County, occur in Central Hillsborough County at Sulphur and Lithia Springs. These springs have temperatures that are typically near 25°C which is slightly elevated above the mean annual air temperature measured in Hillsborough County, 22°C (72°F). This difference in temperature may reflect slightly deeper flow paths taken by ground water through the Floridan aquifer.

Ground water discharging from Warm Mineral Springs is typically near 30°C, while the mean annual air temperature in Sarasota/Charlotte County is 25°C. Therefore, the anomalously warm ground water flowing from Warm Mineral Springs does not reflect the average annual air temperature in southern Sarasota County. Studies have shown that Warm Mineral Springs is a deep-seated spring that discharges water from more than 1,200 feet below the land surface. Its spring water has traveled deep into the Floridan aquifer and has been warmed by the geothermal gradient within the limestone.

Most of the springs in the SWFWMD have not been sampled for tritium. This is because a number of investigations have already determined that ground water in the shallow portion of the Floridan aquifer has entered the aquifer very recently. In the Rainbow Springs area, for example, tritium activities in wells and springs were as high as 174 TU at the same time (1966-68) that rainfall contained activities as high as 158 TU. In addition, tritium activities in Rainbow and Silver Springs ranged from 38 to 85 TU and 25 to 150 TU, respectively. This indicates that a large percentage of the water discharging from Rainbow and Silver Springs in 1966-68 could not have been in the flow system for more than 16 years.

Studies conducted by the USGS in the late 1980's indicate that tritium activities in the Floridan aquifer ground water in the northern half of the SWFWMD reflect relatively recent recharge, with activities of 8 to 10 TU common. The studies strongly implicate rapid recharge to the Floridan aquifer, with subsequent flow of ground water toward the coastal springs.

Twenty-nine springs in the SWFWMD were sampled for uranium isotopes between 1992 and 1999. Most of the spring samples have the low activity ratios (<1.0), and high concentration signatures (>0.1) characteristic of ground water that has recharged rapidly and traveled a relatively short distance (more than several thousand feet) in a shallow flow system. This is consistent with the tritium interpretations which indicate shallow, rapid flow in the karst limestones of the Floridan aquifer.

Based on uranium concentrations and similar activity ratios, spring samples in Citrus and Hernando Counties were grouped into two main clusters; a northern cluster (Citrus County), and a southern cluster (Weeki Wachee and Aripeka). The differentiation of springs along the coast is possibly related to differences in the uranium content of the Hawthorn Group sediments in the northern and southern portions of the Brooksville Ridge. A similar differentiation was identified at Rainbow Springs in Marion

County where three separate geographic regions appeared to contribute ground water to the spring group.

Twenty-four springs in the SWFWMD were sampled for nitrogen isotopes between 1991 and 1999. The nitrogen isotopic ratios found in spring waters throughout the District range from 0.7 and 18.1 ‰. As stated previously, ratios that fall between the +2 to +8 ‰ range could be attributable to natural oxidation of organic materials in soil. However, this is unlikely because the nitrate concentrations in the springs are too high to have originated from natural sources.

Over 80% of the nitrogen-isotopic ratios reported in the SWFWMD since 1991 are below 6.2 ‰. This indicates that inorganic fertilizers are the most significant source of nitrate in the springs region. Much of the fertilizer appears to be derived from: 1) subdivisions and golf courses near the coastal springs, 2) pasture fertilization in the vicinity of Rainbow Springs, and 3) fertilization of citrus in the vicinity of Crystal, Lithia and Buckhorn Springs. Less than 10% of the nitrogen-isotopic ratios are between 6.2 and 9.3 ‰. These ratios indicate that a mixing of inorganic fertilizer nitrogen and animal waste nitrogen, with animal waste nitrogen being the dominant component, is likely occurring at some springs. Three samples collected at Bell Creek Spring in central Hillsborough County were consistently above 10 ‰ (the lower end of the animal waste range), indicating that this spring is influenced by nitrate derived from animal-wastes sources.

Based on increasing nitrate trends and nitrogen isotopic data, it should be apparent that water quality in the Upper Floridan aquifer is already affected by land-use practices within the springs region. Fertilizers that have been applied to urban and agricultural land-use settings near the springs have leached nitrate into the Floridan aquifer. This nitrate has traveled slowly through the aquifer and is now beginning to impact water quality at the springs. In addition, due to the slow movement of ground water through the aquifer (diffuse flow), water-quality changes have been subtle, and even though land uses may have changed in the intervening decades, nitrate continues to discharge from the springs.

Author: Citrus County.

Publication Date: 1997.

Title: Coastal Springs Restoration Project. January 1996 - October 1997.

Document Type: Final Report. Citrus County Board of County Commissioners. Crystal River, Fl. 4 pp.

Period of Study: Conception and permitting began in 1992, dredging began and completed in 1997.

Geographic Range: Kings Bay, Kings and Hunters Springs.

Variables Measured: Sediments and *Lyngbya* removal.

General Findings: Following extensive permitting considerations, a contract was executed between Citrus County and Energy Resources, Inc. on February 27, 1997. The contractor established a staging area and began fusing pipe in April 1997, using an existing borrow pit within the Crystal River State Buffer Preserve for spoil material.

Work on the Kings Spring portion of the project commenced in May 1997. Volunteer divers used handheld vacuum tubes attached to the dredge head to vacuum deep within the King Spring vents. This focused work proved so successful that the planned two day period was expanded to over seven days. After the diver assisted vacuuming was completed, conventional dredging commenced. The project was completed on June 3, 1997 and over 4,000 yd^3 of detritus/sediment was removed in this phase alone. The contractor relocated the dredge to Hunter Springs and began work in mid-June. By June 27th the work was completed with over 4,000 yd^3 of materials removed.

Replanting of native vegetation (*Vallisneria* and *Sagittaria*) was conducted in July. The contractor then moved on to the Crystal Cove area to begin a pilot *Lyngbya* algae project wherein algal mats would be suction-dredged with a follow-up replanting of native vegetation. Early in the *Lyngbya* project, it became obvious that the method utilized did not achieve a high removal rate of the *Lyngbya*. This was due to the loose nature of the mats which quickly broke up and rose into the water column. A number of modifications were tried but removal rates never exceeded 70% which was too low to accommodate replanting. For this reason, only six acres were vacuumed.

During the final month, the contractor returned to the Kings Spring area. Authorization for removal of up to 2,000 yd^3 was given and by the end of September, an additional 2,174 yd^3 was removed.

Lyngbya removal cost about $23K/acre, sediment removal cost about $22/ yd^3.

Data Format: Values in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: Clewell, A. F., M. S. Flannery, S. S. Janicki, R. D. Eisenwerth, and R. T. Montgomery.

Publication Date: 2002.

Title: An analysis of vegetation-salinity relationships in seven tidal rivers on the coast of west-central Florida (Draft)

Document Type: Technical Report. Southwest Florida Water Management District. Brooksville, Fl. 281 pp.

Period of Study: Crystal River utilized 1990 aerial photos, 1984 to 1985 salinity data, and September 1989 and March 1990 field vegetation data.

Geographic Range: Sixty-seven sites along the tidal reaches of Crystal River (0 to 5 miles upstream of the mouth), also Peace Myakka, Little Manatee, Weeki Wachee, Chassahowitzka, and Withlacoochee rivers.

Variables Measured: Used aerial photo analyses and field sampling to note the occurrence of plant communities. Salinity data was obtained from previous study from 1984 to 1985 (Dixon 1986). Field vegetation monitoring utilized quadrats to estimate percent coverage of emergent herbaceous plants.

General Findings: Project was conducted to determine ecological relationships between salinity and the distribution of plants (principally herbaceous) along shorelines of the rivers. Statistical summaries of salinity by river mile are presented. A variety of maps are included showing vegetation communities. There is a listing, by river and plant species, of the location observed and the median and 95th percentile salinity values.

Data Format: Figures, tables, and appendices in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary: None.

Authors: Cowell, B. C., P. S. Botts, B. A. Robinson, J. K. Cooper, and V. L. B. Nations.

Publication Date: 1991.

Title: Factors contributing to the growth of *Lyngbya* at Kings Bay / Crystal River, Florida.

Document Type: Final Report. Submitted to the Southwest Florida Water Management District. Brooksville, Fl. 49 pp.

Period of Study: 1989 to 1990.

Geographic Range: Kings Bay.

Variables Measured: *Lyngbya* growth rates and bioassays.

General Findings: Bioassays indicate that *Lyngbya* can tolerate a wide range of pH values, but preferred pH 7; was intolerant to salinity challenges; had no appreciable internal storage of nutrients; and responded positively to nitrate, ammonium, and calcium additions. Observations that *Lyngbya* was most prevalent in the low salinity portions of Kings Bay. Publication of this report resulted in Cowell and Botts (1994).

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Authors: Cowell, B. C. and P. S. Botts.

Publication Date: 1994.

Title: Factors influencing the distribution, abundance and growth of *Lyngbya wollei* in central Florida.

Document Type: Aquatic Botany. 49: 1-17.

Period of Study: Monthly sampling from April 1989 to March 1990.

Geographic Range: Fifteen stations in Kings Bay.

Variables Measured: Dry weight biomass of SAV was used to correlate with SWFWMD water chemistry data (from Romie 1990).

General Findings: *Lyngbya* or *hydrilla* comprised the dominant biomass at all stations except at the mouth of the bay. Stations dominated by *Lyngbya* had 2.5 x more biomass than other stations. *Hydrilla* biomass was clearly related to Citrus County aquatic weed management. Small floating *Lyngbya* mats first appeared in March, increased during late spring and early summer, remained constant during late summer and early fall, slowly decreased during the fall, and completely disappeared in late November following the passage of a cold front. The best model had four variables and accounted for 57.8% of the variability in *Lyngbya* biomass; biomass was negatively correlated with alkalinity, conductivity and NH_3 and positively correlated with total phosphate. Previous steps of the regression analysis showed that conductivity (R^2=0.513) and conductivity plus alkalinity (R^2= 0.553) accounted for most of the variability; NH_3 and total phosphate only increased the R^2 by 0.025.

Data Format: Tables and figures in report.

Data Location: In report, likely available from Dr. Cowell at USF.

Document Location: Project directory.

Abstract: [Excerpts] Monthly biomass of benthic *Lyngbya* mats was approximately 1 kg m^{-2} during most of the year, decreasing from April to July when large mats were observed floating on the water surface. Multiple regression analyses showed that *Lyngbya* biomass was correlated negatively with conductivity and alkalinity; this is consistent with *L. wollei* being primarily a freshwater species. In regions of the bay with higher salinities, the vascular macrophyte, *Hydrilla verticillata* (L.f.) Royle, prevailed. Nutrient influences appeared to be small even though the northeast portion of Kings Bay/Crystal River has high concentrations of nitrogen, phosphorus and calcium. Controlled laboratory studies were conducted to determine the effects of pH, salinity, and nutrients on growth of *L. wollei*. Optimal growth occurred at a pH of 8.0 and a salinity of 0 ppt; salinities in excess of 5.25 ppt killed more than 99% of the cells within 2 weeks. Growth of *Lyngbya* from five Kings Bay stations in six nutrient sources did not differ among stations, and nutrient additions produced no increases over spring water. Addition of Ca^{2+} increased growth of *L. wollei* at low and intermediate concentrations of nitrogen and/or phosphorus; this partially explains why spring water, derived from the limestone aquifer, produces such good growth of *Lyngbya*.

Authors: Cowell, B. C. and C. J. Dawes.

Publication Date: 2008.

Title: Sources of chlorophyll *a* in the Kings Bay embayment, Crystal River, FL.

Document Type: Final Report. Southwest Florida Water Management District. Resource Management Department. 18 pp.

Period of Study: June 2003 through December 2004.

Geographic Range: 12 stations in Kings Bay.

Variables Measured: Spatial and temporal variability in phytoplankton, periphyton and *Lyngbya*.

General Findings: See summary below.

Data Format: MS Word document with tables and figures.

Data Location: In document.

Document Location: Project directory.

Summary: [Excerpts] Phytoplankton in Kings Bay resembles a mesotrophic water body as shown by the limited number of genera, relatively high biovolumes of cyanobacteria, and development of erratic blooms (Dawes *et al.*, 1987). The Bay appears to have uniform vertical mixing and adequate circulation, which prevents isolation of phytoplankton in discrete regions. The number of phytoplankton genera was low and taxa were similar to eutrophic water bodies, however there still was a broad spectrum of both lake and river algae, and diatoms dominated the biovolume for most sampling periods.

Large phytoplankton blooms in Kings Bay were caused by diatoms and minor ones by cryptomonad and cyanophycean genera. The erratic nature of large blooms suggests they are not easily predictable.

The dominant benthic "macroalga" in Kings Bay is *Lyngbya wollei*, however it did not contribute to phytoplankton biovolume and thus to chlorophyll *a* levels. The chlorophyll levels are correlated with phytoplankton populations. Thus, the eradication or suppression of *L. wollei*, a desire of many of the local inhabitants, would probably result in increases in nutrient concentrations and more intense phytoplankton blooms initially. If rooted aquatic macrophytes subsequently replace the *Lyngbya,* clarity may increase and blooms will be suppressed.

Author: Cutler, J. K.

Publication Date: 1986.

Title: Benthic invertebrates and sedimentology. Volume II in a series: a data collection program for selected coastal estuaries in Hernando, Citrus, and Levy Counties, Florida.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Florida. Southwest Florida Water Management District. Brooksville, Fl. 62 pp. plus 29 Figures, 27 Tables, and 8 Appendices.

Period of Study: 1984 through 1986.

Geographic Range: Four stations: Kings Bay, 3 miles upstream of the mouth, mouth of river, and 4 miles offshore the mouth of Crystal River.

Variables Measured: The identification of benthic macrofauna collected from cores and sieved through 0.5 mm mesh. The grain size distribution and percentage of organics of sediment samples cored at the center and sides of the banks were determined.

General Findings: This study includes data from Waccasassa, Withlacoochee, Crystal, Weeki Wachee rivers (and Aripeka Springs) and as the second report of six, addresses benthic invertebrates and sediments. The goal of the project was to test the hypothesis that benthic invertebrate communities are regulated by salinity regimes. Crystal River exhibited the greatest faunal abundances (mean of all stations), and the station at the mouth of the river had the highest average faunal density. The number of taxa recovered varied spatially and temporally, but was generally greatest offshore and lowest in Kings Bay. Faunal diversity was highest at the more saline stations. The faunal composition and community structure of the stations was highly variable and reflected the various salinity regimes. Polychaetes were the dominant group for the offshore station; the more motile crustaceans (amphipods, tanaids) dominated the middle stations; and chironomids and oligochaetes dominated Kings Bay (which generally represented freshwater conditions). The salinity transition zone was characterized by the dominance of motile crustacean species. The author notes that "These taxa could be utilized as useful indicators of the position of the transitional zone as regulated by relative streamflows."

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: Culter, J. K.

Publication Date: 2010.

Title: An evaluation of the spatial extent and relative density of barnacles in Crystal, Homosassa and Withlacoochee rivers, Florida.

Document Type: Draft Final report. Submitted to Southwest Florida Water Management District. Mote Marine Laboratory. Technical Report No. 53 pp.

Period of Study: March to July 2009.

Geographic Range: Tidal reaches of three springs coast rivers; the lower Withlacoochee, fifteen stations in the Kings Bay portion of Crystal, and the upper reaches of Homosassa.

Variables Measured: Determine the farthest upriver extent of barnacles, the proportion of live vs. dead, their size range, and species. Additionally, artificial substrates were deployed to measure settlement rates, density, size ranges, and biomass.

General Findings: Two species of barnacles were found, primarily Balanus subalbidus, and rarely B. amphitrite, barnacles were observed at most sampling locations, and largest barnacles and highest growth rates were observed at Kings Bay.

Data Format: Figures, tables, and appendices in report.

Data Location: In report.

Document Location: Project directory.

Summary: [Excerpts] In Kings Bay barnacles were found at every sampling site with the exception of KB-7 where freshwater spring flow was still significant. Barnacles are likely to persist at relatively high abundances in areas that do not exhibit long term salinity averages below 1.0 PSU or perhaps even below 0.5 PSU.

Author: Dick, T. H.

Publication Date: 1989.

Title: Crystal River: A "no win" situation.

Document Type: Aquatics. 11(2): 10-13.

Period of Study: Editorial retrospective.

Geographic Range: Crystal River and Kings Bay

Variables Measured: None.

General Findings: *Hydrilla* has been inconsistently controlled by herbicides, and only maintenance controlled by harvesters. Hurricane salt intrusions (Elena and Juan, 1985) killed 92% *hydrilla*; *Lyngbya* returned in its place.

Data Format: n/a.

Data Location: n/a.

Document Location: Project directory.

Abstract: It has been difficult to achieve public satisfaction with aquatic plant management (*hydrilla* and *Lyngbya*). Aquatic herbicide applications have inconsistent results, while mechanical harvesters can only maintain pathways due to growth rates. The presence of manatees compounds the issue, through copper concerns, adequate food supplies, and threatened and endangered species considerations. Storm surges in 1985 (?) killed most *hydrilla*, with *Lyngbya* subsequently becoming dominant.

Author: Dixon, L. K.

Publication Date: 1986.

Title: Water Chemistry. Volume I in a series: a data collection program for selected coastal estuaries in Hernando, Citrus, and Levy Counties, Florida.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Florida. Southwest Florida Water Management District. Brooksville, Fl. 259 pp.

Period of Study: 1984 through 1986.

Geographic Range: Ten stations from Kings Bay to 4 miles offshore the mouth of Crystal River.

Variables Measured: Temperature, salinity, dissolved oxygen, pH, color, suspended solids, turbidity, light penetration, nutrients, and chlorophyll. The salinity and stage data is comprehensive. Discharge was not directly measured and the U. S. Geological Survey station had technical problems during the project.

General Findings: This study includes data from Waccasassa, Withlacoochee, Crystal, Weeki Wachee rivers (and Aripeka Springs) and as the first report of six, addresses water chemistry. Tidal stage was observed to exert a profound influence on salinity profiles in Crystal River. The salinity of Crystal River at high tide could be divided into two distinct regions, above and below Wash Island (see Figure 28, p. 86) and was attributed to a possible physiographic . Upstream of Wash island salinity changes gradually, while downstream of the island, salinity increased rapidly and at a relatively constant rate. The Salt River did not routinely provide a substantial influx of saline waters to the Crystal River during flooding tides. Salinity data varied widely between 1984 and 1985, and the Kings Bay station exhibited the least amount of variation.

Data Format: Figures and tables in report.

Data Location: In report. Unknown if Mote Marine or SWFWMD have electronic files.

Document Location: Project directory.

Abstract: None.

Author: Dixon, L. K.

Publication Date: 1997.

Title: Data inventory, trend analysis, and recommended monitoring: Florida Springs coast.

Document Type: Final Report. Volume I. Mote Marine Laboratory Technical Report no 547. Prepared for Southwest Florida Water Management District. SWIM Program, Tampa, Fl. 166 pp.

Period of Study: Historical data prior to 1997.

Geographic Range: Springs Coast including Kings Bay/Crystal River.

Variables Measured: Available water chemistry and rainfall data for the region.

General Findings: Crystal River data consisted of records from two STORET stations and seven ongoing LAKEWATCH stations (Figure 6A). At the nearshore Crystal River station, trends from 1966 through 1978 indicated increasing concentrations of nitrate-nitrite (Appendix Figures IB-15 and IB-16) and nitrate together with decreasing organic nitrogen and no significant trend in total nitrogen. Some evidence of increasing total and ortho-phosphorus was observed (Appendix Figure IB-17). From 1989 through 1996, however, there were no observed trends in organic nitrogen, ammonium nitrogen, ortho- or total phosphorus, or major ions at the A01 Crystal River Station #1. There were insufficient nitrate data to evaluate at this station.

The Crystal River LAKEWATCH stations provided data from 1992 through early 1997 for stations in and around Kings Bay, downstream to the confluence with the Salt River. There are station differences, but regionally both total nitrogen and total phosphorus have decreased (Appendix Figure IB-18). Total phosphorus has decreased against all independent variables at all stations. Total nitrogen decreases were noted primarily at Three Sisters Spring, SE Kings Bay, Cedar Cove, and north of Buzzard Island (Appendix Figure IB-19).

Using data from Romie (1990), a large decrease in nutrient concentrations was observed at selected stations following the removal of a wastewater treatment plant discharge from the Cedar Cove area in 1992 (Bishop and Canfield, 1995). The continued declines in nutrient concentrations can reflect a less rapid remobilization of nutrients from the organic content of the sediments, reported to be highest in the Cedar Cove and western areas of Kings Bay (Belanger *et al.*, 1993). The organic content of sediments in the Bay appears to be from algae and other aquatic plants, while organics at a canal station have a more terrestrial origin (Belanger *et al.*, 1993).

Despite the decrease in nutrients, however, significant chlorophyll increases were observed at the Cedar Cove station (Appendix Figure IB-20), and to a lesser extent, at the SW Kings Bay station. No chlorophyll trends were observed elsewhere. Efforts to control aquatic vegetation rely on mechanical harvesting, and these efforts complicate the linkage between chlorophyll and water column nutrients.

Overall water clarity and shallow depths prevented trend analysis on Secchi depths at some stations. A decrease in water clarity was observed at the Salt River station (Appendix Figure IB-21), but it was not accompanied by increasing chlorophyll.

Data Format: Figures, tables, and appendices. Data presented in Volume II (Data Summaries) of the report. Electronic data may available from SWFWMD SWIM.

Data Location: In report Volume II (Data Summaries), and may available from SWFWMD SWIM.

Document Location: Project directory.

Executive Summary: Increasing nitrogen concentrations in a number of west-central Florida spring discharges has aroused concern for potential nutrient-related impacts to the comparatively pristine, oligotrophic spring runs downstream. This report documents an inventory, retrieval, and analysis of existing data to determine if nutrient-related trends could be observed in other data sets.

The project was performed within the framework of a conceptual model of nutrient flow within idealized freshwater, estuarine, and coastal environments. Data were summarized and selected for analysis based on the degree of dependence of the monitored parameter on nutrient concentrations, and emphasized water quality and primary producers. Data inventories were prepared by region with descriptions of pertinent sampling efforts. Data selected for further analysis included those from stations maintained in the EPA STORET database and LAKEWATCH data from the Crystal and Withlacoochee rivers. In addition, National Atmospheric Deposition/National Trend Network data on rainfall quality and quantity were analyzed both as concentrations and as weekly loads to evaluate trends of an increasingly recognized nitrogen source.

Trend analyses employed LOWESS (LOcally WEighted Scatterplot Smooth; Cleveland, 1979) to smooth water quality parameters against a variety of independent variables, such as season, temperature, cumulative rainfall amounts, well levels, conductivity, and pH. The residuals from the smoothed line were then tested non-parametrically against sampling date to determine if, with respect to the independent variable, parameter concentrations were increasing. The procedure is particularly suited to non-normal environmental data and the processing of large data sets. More than 5,900 parameter-variable combinations were assessed with approximately 1,000 of these significant at the 0.05 level. Of the significant trends, more than 500 were for nitrogen or phosphorus species.

Where trends in nutrients were significant, they were generally increasing. Increases were observed both for spring runs and in watershed rivers such as the Anclote and Withlacoochee rivers. Increasing nitrogen concentrations in spring discharges, as observed by other investigations, were similarly apparent in the data sets examined for this project. Exceptions to increasing nutrient trends were observed at the Crystal River/Kings Bay LAKEWATCH stations. The rainfall concentrations and loading of nitrogen for a given weekly rainfall amount is increasing in some locations. Data gaps were identified, as were those studies which, on repetition, could provide information on trend.

Author: Evans, J. M.

Publication Date: 2007.

Title: Algae, exotics, and management response in two Florida springs: competing conceptions of ecological change in a time of nutrient enrichment.

Document Type: Ph.D. Dissertation. University of Florida. 168 pp.

Period of Study:

Geographic Range:

Variables Measured:

General Findings: Recommended establishing water hyacinth (*Eichhornia crassipes*) in Kings Bay to shade out filamentous algae and *hydrilla*. The discussion provides an atypical view on the management of non-indigenous SAV.

Data Format: Verbal descriptions and chronology.

Data Location: Full text: http://purl.fcla.edu/fcla/etd/UFE0019675

Document Location: Project directory

Abstract: Interdisciplinary methods based upon principles of participatory action research, systems ecology, and adaptive management were used to create multi-scalar narratives of ecological changes associated with nutrient enrichment in two Florida springs ecosystems: Ichetucknee River and Kings Bay/Crystal River. Review of scientific literature, presentation of historic water quality data, qualitative interviews with stakeholders, and iterative public engagements with stakeholders about ecosystem management policy are integrated in both of the case studies. Patterns of management pathology, or the tendency of management institutions to rigidly adhere to policies that are inappropriate for the maintenance of desired socio-ecological values in the face of emergent environmental changes, were identified at both Ichetucknee River and Kings Bay/Crystal River in relation to ecosystem management policies narrowly based upon the minimization of nonnative plant species. While management of nonnative plants generally is based upon the laudable goal of maintaining native biodiversity and ecological function, a holistic consideration of historical ecology, scientific literature, and stakeholder accounts indicates that emergent conditions associated with nutrient enrichment and other contaminant factors may make aquatic plant management practices an important catalyst in shifting springs ecosystems towards an undesirable stability domain characterized by dominance of filamentous algae and cyanobacteria. Adaptive management experimentation based upon growth and optimum harvest of nonnative plants, particularly water lettuce in Ichetucknee River and water hyacinth in Kings Bay, is recommended as a potential means of facilitating recovery of more desirable stability domains.

Authors: Evans, J. M., A. C. Wilkie, and J. Burkhardt, and R. P. Haynes.

Publication Date: 2007.

Title: Rethinking exotic plants: using citizen observations in a restoration proposal for Kings Bay, Florida

Document Type: Ecological Restoration. 25(3): 199-210.

Period of Study: April 2005 through April 2006.

Geographic Range: Crystal River and Kings Bay area.

Variables Measured: Interviews with local citizens, a review of aquatic plant literature, and research into the history of ecological change in Kings Bay

General Findings: Control of non-indigenous SAV may be unwarranted at Kings Bay. Water hyacinth, water lettuce, and *hydrilla* are discussed in relation to *Lyngbya*, suggesting that the vascular plants may be exotic, but provide beneficial traits and are better than *Lyngbya*. No detailed management plans are provide however.

Data Format: Verbal descriptions and chronology.

Data Location: In publication, authors at UF.

Document Location: In project directory.

Abstract: The Kings Bay, Crystal River complex, located in Citrus County, Florida, is one of the world's largest spring-fed ecosystems and a critical warm-water refuge for endangered Florida manatees. Unfortunately, large areas of Kings Bay are currently in a state of ecological degradation characterized by smothering mats of the filamentous cyanobacterium *Lyngbya wollei*. The causes of this ecosystem shift are not well understood, although it is often suggested that human-caused nutrient loading into the Bay combined with intermittent saltwater intrusions from storm surges may be responsible. In this article, we present results from interviews with local citizens, a review of aquatic plant literature, and research into the history of ecological change in Kings Bay. Our work indicates that management efforts to eradicate invasive exotic aquatic species may also have played an important role in the dominance of L. wollei. We suggest that future restoration efforts should follow a logic of "alternative stable states" that focuses primarily on the recovery of desired ecosystem functions and relaxes the assumption that exotic plants should be minimized. The Kings Bay case study points toward a more adaptive conception of ecological restoration, one informed by local knowledge and open to the utilization of established exotic plants as a tool for maintaining or restoring important ecological attributes.

Authors: Evans, J. M., A. C. Wilkie, and J. Burkhardt.

Publication Date: 2008.

Title: Adaptive management of nonnative species: moving beyond the "either-or" through experimental pluralism.

Document Type: Journal of Agricultural and Environmental Ethics. 21: 521-539.

Period of Study: April 2005 through April 2006.

Geographic Range: Crystal River and Kings Bay area.

Variables Measured: In-depth interviews with 24 Crystal River residents that catalogued local knowledge about the management history and ecological condition of Kings Bay.

General Findings: This publication is a socio-ecological case study of Kings Bay. The author's assert that Kings Bay provides "a clear example in which rigid application of invasion biology's a priori imperative to minimize INS [Invasive Nonnative Species] has become counterproductive from both an ecological and social standpoint". Considerable discussion spent on the background of INS control, language, and assumptions; particularly whether INS are *a priori* harmful and therefore should be removed. The modern history of Kings Bay SAV is summarized. No detailed management plans are provided however.

Data Format: Verbal descriptions and chronology.

Data Location: In publication, authors at UF.

Document Location: Project directory.

Abstract: This paper develops the outlines of a pragmatic, adaptive management-based approach toward the control of invasive nonnative species (INS) through a case study of Kings Bay/Crystal River, a large artesian springs ecosystem that is one of Florida's most important habitats for endangered West Indian manatees (Trichechus manatus). Building upon recent critiques of invasion biology, principles of adaptive management, and our own interview and participant–observer research, we argue that this case study represents an example in which rigid application of invasion biology's a priori imperative to minimize INS has produced counterproductive results from both an ecological and social standpoint. As such, we recommend that INS control in Kings Bay should be relaxed in conjunction with an overall program of adaptive ecosystem management that includes meaningful participation and input from non-institutional stakeholders. However, we also note that adaptive management and INS control are by no means mutually exclusive, in Kings Bay or elsewhere. Instead, we suggest that adaptive management offers a means by which INS control efforts can emerge from-and be evaluated through-ongoing scientific research and participatory dialogue about the condition of specific places, rather than non-contextual assumptions about the harmfulness of INS as a general class.

Authors: Evans, J. M., A. C. Wilkie, and J. Burkhardt.

Publication Date: 2009.

Title: Beneath the straw: in defense of participatory adaptive management.

Document Type: Journal of Agricultural and Environmental Ethics. 22: 169-180.

Period of Study: April 2005 through April 2006.

Geographic Range: Crystal River and Kings Bay area.

Variables Measured: Largely a rebuttal publication to Simberloff (2009)

General Findings: The Evans *et al.* 2008 publication included generalities about invasion biology, to which Simberloff, a recognized expert, takes exception. Simberloff asserts that "Proposing to manage people, manatees, introduced plants, and cyanobacteria in Kings Bay by participative adaptive management, they [Evans *et al.* 2008] ignore the fact that living organisms can both disperse autonomously and hitchhike. Finally, they present few details on any aspect of their management proposal and do not address the myriad problems that have beset previous attempts at scientific adaptive management, especially at large scales. Until such a management approach is fleshed out and implemented, it is impossible to assess its validity for Kings Bay, and it is very premature to suggest it as a general model for dealing with invasive species disputes." This paper provides a rebuttal.

Data Format/Location: Within report.

Document Location: Project directory.

Abstract: Our recent paper advocating adaptive management of invasive nonnative species (INS) in Kings Bay, Florida received detailed responses from both Daniel Simberloff, a prominent invasion biologist, and Mark Sagoff, a prominent critic of invasion biology. Simberloff offers several significant lines of criticism that compel detailed rebuttals, and, as such, most of this reply is dedicated to this purpose. Ultimately, we find it quite significant that Simberloff, despite his other stated objections to our paper, apparently agrees with our argument that proposals for alternative management of established INS (*i.e.*, alternatives to minimization/eradication) should not be rejected on an a priori basis. We argue that more specific development and application of adaptive approaches toward INS management, whether in Kings Bay or other appropriate case studies, would be facilitated if ecosystem managers and invasion biologists follow Simberloff's lead on this key point. While Sagoff largely shares (and, indeed, served as a primary source for developing) our general arguments that challenge common moral and scientific assumptions associated with invasion biology, he does question our suggestion that participatory adaptive management provides an appropriate framework for approaching environmental problems in which science and politics are inherently entangled. We attempt to answer this criticism through a brief sketch of what participatory adaptive management might look like for Kings Bay and how such an approach would differ from past management approaches.

Author: Facemire, C. F.

Publication Date: 1991.

Title: Copper and other contaminants in King's Bay and Crystal River (Florida) sediments: implications for impact on the West Indian manatee.

Document Type: Final Report Publication No. VB-89-4-109A. Prepared for the U. S. Fish and Wildlife Service. Office of Environmental Contaminants. Vero Beach, Fl. 45 pp. plus appendices.

Period of Study: 1989.

Geographic Range: Twenty-five stations in Kings Bay.

Variables Measured: Elemental metals, pesticides, and PCBs.

General Findings: Arsenic, iron, and zinc concentrations at some sampling sites; and copper concentrations (range =< 3.5 – 237 ppm dry weight) at all sample locations; appeared to be elevated due to anthropogenic influence. Highest levels of copper were collected from sediment midway between Buzzards Island and Cedar Cove.

Data Format: Table, figures, and appendices.

Data Location: In report.

Document Location: Project directory.

Abstract: Contaminant concentrations were measured in 25 sediments samples collected from Kings Bay, the headwaters of the Crystal River, Florida. Total organic carbon content ranged from 0.17 to 9.95% dry weight. No organochlorine pesticides, pesticide metabolites or polychlorinated biphenyls (PCBs) were detected at concentrations above the detection limit of 0.01 ppm (0.10 ppm for total PCBs and toxaphene). Antimony, cadmium, silver and tin were not detected; however, arsenic, barium, chromium, iron, magnesium, manganese, selenium, strontium and vanadium were present at above-detection-limit concentrations at all locations sampled. Aluminum data were used to normalize all other metals concentration data. Arsenic, iron, and zinc concentrations at some sampling sites; and copper concentrations (range =< 3.5 – 237 ppm dry weight) at all sample locations; appeared to be elevated due to anthropogenic influence. If transported through the food chain, copper concentrations at the most contaminated sites may be sufficient to adversely impact the West Indian manatee (*Trichechus manatus*).

Author: Facemire, C. F.

Publication Date: 1992.

Title: Copper concentrations in Kings Bay and Crystal River (Florida) sediments and implications to manatees.

Document Type: *In* Proceedings of the Bioavailability and Toxicity of Copper Workshop. *Edited by* J. C. Joyce. September 2, 1992. Gainesville, FL. pp. 147-164. University of Florida, Institute of Food and Agricultural Sciences, Gainesville, Fl. 253 pp.

Period of Study: 1989.

Geographic Range: Twenty-five sites in Kings Bay.

Variables Measured: Aluminum, copper, and several other trace elements from the top 15 cm of sediment.

General Findings: Mean copper concentrations ranged from 13.1 to 27.4 µg/g and there were no significant differences between mean concentrations at central, north, south, and west Kings Bay stations or upper Crystal River stations. Concentrations of copper in the sediments of East Kings Bay were significantly higher, with a maximum concentration of 237 µg/g. All of the copper concentrations found in Kings Bay and Crystal River sediments were above the normal range. Aquatic plants appear to translocate copper from sediments (but they do not bioaccumulate copper) so that copper concentrations in plant material in Kings Bay should seldom exceed sediment concentrations. **Author** reported that there may be sufficient copper in some manatees to produce toxic effects. **Author** recommended that the further use of copper-based herbicides be curtailed in Kings Bay.

Data Format: Figures and text in report.

Data Location: In report.

Document Location: Project directory.

Abstract: none.

Author: Ferguson, G. E., C. W. Lingham, S. K. Love, and R. O. Vernon.

Publication Date: 1947.

Title: Springs of Florida. Bulletin No. 31.

Document Type: State of Florida. Department of Conservation. Florida Geological Survey. Tallahassee, FL. 196 pp.

Period of Study: 1946 and 1947.

Geographic Range: Kings Bay.

Variables Measured: Flow at Hunter Spring, Kings Bay.

General Findings: Flow for Hunter Spring (Kings Bay) was reported as 62.9 cfs (41 mgd), the date of measurement may be from 1939. Picture from 1939 shows abundant water hyacinths (*Eichhornia crassipes*) in Kings Bay.

Data Format: Table (p. 180) and a picture (p. 59).

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: Florida Department of Environmental Protection (FDEP).

Publication Date: 1991.

Title: Biological assessment of Crystal River sewage treatment plant. Citrus County. NPDES #FL0028371

Document Type: FDEP mandated review. FDEP, Bureau of Laboratories. 31 pp.

Period of Study: 1991.

Geographic Range: Sewage treatment plant that feed Kings Bay.

Variables Measured: Class III water chemistry standards, bioassay, receiving stream bioassessment,

General Findings: Effluent from this plant ceased March 9, 1992 per FDEP consent order. The plant had a history of permit violations and was an identified source of pollutants to Kings Bay.

The Citrus Co. Water Resources Department had 5,000 customers in the year 2000 and over 21,400 customers in 2009 (see webpage: http://www.bocc.citrus.fl.us/waterres/utilities/utilities.htm). There are 23 water production facilities capable of pumping up to 32 million gallons per day and nine wastewater treatment facilities capable of treating 1.9 million gallons per day. Key among them is Meadowcrest Waste Water Treatment Facility located in Lecanto, Fl (10 km ESE of Kings Bay).

From webpage (1/21/10): On the water initiative, the Utility Division is extending water mains where practical to interconnect systems for both greater reliability and to reduce costs. On the wastewater treatment initiative, the Utilities Division is expanding its Meadowcrest plant from a capacity of half a million gallons per day to two million gallons per day. This will provide sufficient capacity to handle another eight years of growth and expansion in the central part of the county.

Concurrent with the expansion of Meadowcrest, the county is upgrading the facility to be able to produce treated wastewater of such a quality that it can be reused. The county will similarly be upgrading the wastewater treatment facility in Sugarmill Woods. Both will provide treated water to nearby golf courses, thus reducing the golf courses' groundwater withdrawals for irrigation.

On an annual basis, the two plants will reduce groundwater withdrawals by up to half a billion gallons per year at current flow rates and depending on growth, that figure could eventually double.

Finally, the department is also managing the studies required under state and federal laws to prepare for controlling and treating stormwater runoff. The division is about seven years into a 10 year program in surveying and mapping each of 20 defined drainage basins in the county. In the next three years, these will be completed, and design of stormwater retention and treatment facilities will begin.

The county is also planning and installing improvements where stormwater flows directly from areas such as parking lots into nearby water bodies. The county has purchased land in areas where the division has determined that stormwater retention and treatment will need to occur.

Data Format: Within report.

Data Location: FDEP held.

Document Location: Project directory.

Conclusions: The effluent sample collected from the Crystal River Sewage Treatment Plant was toxic to the invertebrate, *Ceriodaphnia dubia*. The chlorinated effluent killed all the test organisms within 24 hours, and the dechlorinated sample produced and LC50 of 59.63%. This is a violation of 17-302.500(1)(d), 17-302.510(5)(p), and 17-4.244(3)(a) FAC. Organics and metals analysis of the effluent revealed the presence of several compounds which exceed Class III standards, including Gamma-BHC (0.12 µg/L), silver (0.2 µg/L), and zinc (32 µg/L).

Nutrients were uncommonly high in the effluent and at the test site, particularly total and ortho-phosphorus, and nitrate-nitrite. Most nutrient constituents were either undetected or low in waters from the reference site. Algal growth potential was also extremely elevated at effluent and test sites, corresponding with the high bioavailable nutrient concentrations.

The benthic macroinvertebrate community was stressed throughout the receiving canal, but it was more degraded downstream of the discharge. This was demonstrated by decreases in taxa richness and Florida Index, as well as a 72.7% reduction in Shannon-Weaver diversity (a violation of the biological integrity criterion). The downstream community was overwhelmingly dominated by the well-known pollution tolerant chironomid, *Chironomus decorus* group, a violation of 17-302.510(5)(q) FAC, dominance of nuisance species.

Changes in the periphyton and phytoplankton populations also indicated that nutrient induced imbalances of aquatic flora (17-302.560(29) FAC) occurred below the discharge. Taxa richness was reduced, and severe community shifts occurred in both groups. Upstream, the periphyton was dominated by diatoms, while the downstream assemblage consisted almost entirely of the pollution tolerant green alga, *Characium* sp. The phytoplankton at the reference site was composed mostly of diatoms and secondarily, blue-greens. Blue-green algae, mainly *Chroococcus* sp., were in the majority at the test site.

Author: Florida Department of Environmental Protection (FDEP).

Publication Date: 1997.

Title: Development of GIS-based vegetation maps for the tidal reaches of five Gulf Coast rivers.

Document Type: Final report. Prepared for the Southwest Florida Water Management District. Florida Department of Environmental Protection, Florida Marine Research Institute, Coastal and Marine Resource Assessment Section. 39 pp.

Period of Study: Photos made in October to December 1990.

Geographic Range: The tidal reaches of the Withlacoochee, Crystal (from the Gulf of Mexico to upstream near Bagley Cove), Chassahowitzka, Weeki Wachee, and Little Manatee rivers.

Variables Measured: The objective of the report was to generate GIS-based terrestrial vegetation maps and associated digital database for the tidally influenced reaches of the five rivers. Color infrared aerial photographs (1:24,000 scale) were collected during the fall of 1990 by SWFWMD and subsequently stereoscopically photo-interpreted in order to geographically delineate patterns based on the Florida Land Use, Cover, and Forms Classification System (FLUCCS). In 1997 ground truthing of the vegetative communities was conducted and USGS quadrangles and ARC/INFO GIS software were utilized to delineate and categorize terrestrial vegetation. The resulting maps provide a 1990 baseline of terrestrial vegetative conditions.

General Findings: The distribution of vegetative communities along the tidal portions of the Withlacoochee, Crystal, Chassahowitzka, and Weeki Wachee rivers were similar. The Little Manatee River exhibited the most distinct changes and breaks in vegetation due to apparent salinity factors. There was a seven year interval between photo collection and ground truthing that likely affect the accuracy and veracity of the vegetation maps due to storms and freeze events in the intervening years.

Data Format: Figures of terrestrial vegetation by river system, plant list by river, and tables of coverage (ac) by FLUCCS code and river are provided in the report. The District was provided GIS data files.

Data Location: In document and GIS files are potentially located at the District.

Document Location: Project directory.

Conclusions: Project conclusions center on several caveats and suggested improvements relevant to species level mapping efforts: 1) larger scale color infrared aerial photographs should be utilized, 2) photographs and ground truthing should be made during similar time periods, 3) digital imagery may be useful, 4) and expanded FLUCCS classification system should be utilized to distinguish coastal wetland plant species and communities, 5) use of a helicopter to identify vegetation in interior areas which are otherwise physically inaccessible.

Author: Florida Department of Environmental Protection (FDEP).

Publication Date: 2010 (ongoing data collection).

Title: Two long-term water quality monitoring stations at Crystal River. Florida Department of Environmental Protection, St. Martins Marsh Aquatic Preserve. Crystal River, Fl.

Document Type: Available data summary.

Period of Study: 2004 to 2009.

Geographic Range: Two stations: Kings Bay and mouth of Crystal River.

Variables Measured: Temperature, specific conductance, and salinity at both stations; also dissolved oxygen, pH, turbidity, and depth at the Kings bay site.

General Findings: Useful data that is available electronically.

Data Format: Electronic files.

Data Location: FDEP held and UF FAS

Document Location: Data directory has metadata only.

Abstract: None.

Author: Fox, A. M.

Publication Date: 1989.

Title: Crystal River's gentle giants.

Document Type: Aquatics. 11(2): 16-18.

Period of Study: review prior to 1989.

Geographic Range: Crystal River and Kings Bay.

Variables Measured: background of manatee utilization.

General Findings: At the time, about 1,200 animals were estimated to live in Florida. In 1987/88 and 1988/89 winter seasons, over 200 manatees used the combined Chassahowitzka NWR (includes Crystal and Homosassa Rivers).

Data Format: n/a

Data Location: n/a

Document Location: Project directory.

Abstract: Discusses basic biology, population, and mortality of Florida manatees. Mentions the study of copper herbicide uptake through manatee feeding, with inconclusive results. Discusses the use of manatees as bio-control for SAV; estimated 1,000 manatees would need 120 days to remove the standing biomass of submersed plants in Kings Bay.

Authors: Fox, A. M. and W. T. Haller.

Publication Date: 1992.

Title: Improving Herbicide efficacy in spring-fed tidal canals by timing and application methods.

Document Type: Journal of Aquatic Plant Management. 30: 58-62.

Period of Study: 1988 to 1990.

Geographic Range: Three Sisters Canals in Kings Bay.

Variables Measured: *Hydrilla* density and herbicide application method and timing through dye tracing.

General Findings: Herbicides provided longer *hydrilla* control than mechanical harvesting within the same season. Granular and weighted-hose applications of herbicide were more effective than un-weighted hose applications. Dye half-lives in canals ranged from about 0.5 days to 5 days.

Data Format: Tables in publication.

Data Location: Publication and authors at UF.

Document Location: Project directory.

Abstract: Over a three-year period starting 1987, endothall, Rhodamine WT dye and herbicide/dye combinations were applied to tidally influenced canals for aquatic weed control in Crystal River, Florida, in addition to an operational mechanical harvester program. Applications were accomplished using un-weighted-hoses, long weighted-hoses and granules at different times of year, when dye half-lives (indicating rates of water exchange) in the canals varied from 11 to 120 hours. Placement of dye or herbicides by weighted-hoses and granules near the bottom of the canals in summer and winter conditions, reduced rates of tidal dilution and transport out of the canals and increased their theoretical contact time with *hydrilla* (*Hydrilla verticillata*). Comparison of *hydrilla* re-growth following herbicide applications or mechanical harvesting showed that herbicide treatments usually provided acceptable weed control for at least twice as long as mechanical harvesting.

Authors: Fox, A. M., W. T. Haller, and K. D. Getsinger.

Publication Date: 1991.

Title: Factors that influence water exchange in spring-fed tidal canals.

Document Type: Estuaries. 14(4): 404-413.

Period of Study: October 1987 to January 1989.

Geographic Range: Three Sisters Canals

Variables Measured: Rhodamine WT dye concentration, tidal stage, water temperature, and time.

General Findings: The project goal was to evaluate factors that influence the rate of tidal flushing in the Three Sisters canals and make herbicide management recommendations. The type of tide did not affect dilution rates and large amounts vegetation somewhat reduced dilution rates. The most important factor was the temperature of the canal water in relation to spring discharge. The greater the difference in temperature, the faster circulation patterns would flush dye from canals. Circulation times were highest in the summer and lowest in the fall and spring.

Data Format: Publication figures and tables.

Data Location: Publication.

Document Location: Project directory.

Abstract: Environmental factors that influenced the rates of water exchange in a series of tidal, dead-end canals in Crystal River, Florida, were investigated by measuring the rates of dilution of the fluorescent dye Rhodamine WT. Water temperature was the most influential of these factors, with type of tidal cycle (spring or neap) and density of submersed vegetation (dominated by *Hydrilla verticillata*) only affecting dye dilution rates in winter treatments. Dye half-lives were shortest in the summer (12-24 h), longest in the fall and spring (60-120 h), and most sensitive to water temperature patterns in the winter (26-60 h). These data provide useful information relating to the timing of *hydrilla* management using aquatic herbicides in spring-fed tidal systems. A mechanism is proposed that relates the canal water temperatures to tidal water movement and outputs from the adjacent Three Sisters Springs.

Authors: Fox, A. M., W. T. Haller, and K. D. Getsinger.

Publication Date: 1991.

Title: Characterization of water exchange in *Hydrilla*-infested tidal canals of the Crystal River, Florida.

Document Type: Final Report. Aquatic Plant Control Research Program. Miscellaneous Paper A-91-2. Prepared for the Department of the Army, U. S. Army Corps of Engineers, Washington, DC. 54 pp.

Period of Study: October 1987 to January 1989

Geographic Range: Kings Bay residential canals.

Variables Measured: Rhodamine WT dye concentration, tidal stage, water temperature, and time.

General Findings: This is the final report that resulted in the Fox *et al.* 1991 publication in Estuaries, but it has more detail and data.

Data Format: Figures and tables.

Data Location: In report.

Document Location: Project directory.

Abstract: [Excerpts] The objectives of this study were to compare the influence of tides, vegetation, and season on water exchange in dead-end canals and to evaluate herbicide efficacy in the canals as predicted by water exchange patterns. The fluorescent dye Rhodamine WT was used in four dead-end canals to estimate rates of water exchange and to characterize water movement during different tidal cycles. The behavior of the non-adsorptive dye indicated the maximum persistence of a chemical applied to the *hydrilla*-infested canals. The conditions under which dilution rates were slowest were identified. These conditions were predicted to be the optimum times for the application of herbicides, providing maximum herbicide exposure to the plants. Contrary to predictions of a water exchange model based on water level data, there were no significant differences in the rates of dissipation of dye on spring and neap tides. Significant differences in rates of dilution were observed between dye treatments made in the summer, winter, and fall. With only two exceptions, there were no significant differences within a season. A high density of vegetation significantly prolonged the rate of dye dilution in winter but not in summer, when rates of water exchange or dye dilution were greatest. The relative temperatures of the water in the canals and in the adjacent Three Sisters Springs varied with season, as did the difference in temperature between the top and bottom of the water column. Seasonal differences in the vertical distribution of dye were also observed. A hypothesis to explain the effects of water temperature on circulation patterns and rates of tidal dissipation in the canals was proposed. Based on the results of this study, herbicide use should be restricted to fall and springtime, when water in the canals and springs is isothermal. Summer plant control should be limited to mechanical harvesting.

Authors: Frazer, T. K. and J. A. Hale.

Publication Date: 2001.

Title: An atlas of submersed aquatic vegetation in Kings Bay (Citrus County, Florida).

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, FL. Report 99CON000041. pp. 14.

Period of Study: August to October 2001.

Geographic Range: Seventy-one stations in Kings Bay.

Variables Measured: Coverage of submersed aquatic vegetation (SAV) by species.

General Findings: Eight SAV taxa identified in Kings Bay and their areal coverage estimated. Most SAV coverage (all taxa) was less than 5%. Taxa with coverage > 75% include filamentous algae, milfoil, and *hydrilla*. Species with coverage greater than 5% in order of decreasing abundance were: *Myriophyllum*, *Vallisneria*, filamentous algae, *Najas*, *Ceratophyllum*, *Hydrilla*, *Potamogeton*, and *Chara*.

Data Format: Figures and tables in report and ArcInfo interchange format (*.e00 format).

Data Location: District. Maybe able to recover backup data at UF FAS.

Document Location: Project directory.

Abstract: A survey of submersed aquatic vegetation (SAV) in Kings Bay (Citrus County, Florida) was carried out during August-October, 2001. Seventy-one stations were sampled, and the resulting data were interpolated to produce maps depicting areal coverage for the eight dominant taxa in the bay, *i.e. Vallisneria americana*, *Potamogeton* spp., *Myriophyllum spicatum*, *Najas guadalupensis*, *Hydrilla verticillata*, *Ceratophyllum demersum*, *Chara* spp. and filamentous algae (including *Lyngbya* spp.). Percent cover data were reclassified as follows: < 5%, 5 – 25%, 25 – 50%, 50 – 75%, and > 75%, to correspond with a well established Braun-Blanquet index of vegetative cover.

Author: Frazer, T. K., M. V. Hoyer, S. K. Notestein, D. E. Canfield, Jr., F. E. Vose, W. R. Leavens, S. B. Blitch, and J. Conti.

Publication Date: 1998.

Title: Nitrogen, phosphorus and chlorophyll relations in selected rivers and nearshore coastal waters along the Big Bend Region of Florida. Project COAST Data – 1998.

Document Type: Final Report. Submitted to Suwannee River Water Management District, Live Oak, FL; and Southwest Florida Water Management District, Tampa, FL. 326 pp.

Period of Study: Monthly samples collected from November 1996 through April 1998.

Geographic Range: Ten stations at Crystal River (as well as nine other neighboring systems).

Variables Measured: Water temperature, salinity, dissolved oxygen, pH, Secchi disk visibility, total nitrogen (TN), total phosphorus (TP), and chlorophyll (CHL). Nitrate also measured in July 1997.

General Findings: This report is the first of a long-term coastal water chemistry project that continues to date. Physical and chemical parameters from four stations (numbers 1, 2, 3, and 4) are especially relevant as they begin offshore (2 miles, and 1 mile), extend into the lower mouth (1 mile upstream), and terminate about 5 miles upstream, respectively.

Data Format: Figures, tables, and appendices in report. Electronic files available.

Data Location: In report and electronically at UF FAS.

Document Location: Project directory.

Executive Summary: [Excerpts] The data collected and described provide much needed insight into the spatial and temporal ranges of variation for several important physical, chemical and biological parameters. It is clear that nitrate-nitrogen emanating from several springs is quickly assimilated before reaching the Gulf of Mexico. Total nitrogen (TN) and total phosphorus (TP) are recommended as the appropriate eutrophication nutrient parameters to be measured. TN concentrations along the Big Bend coast are fairly uniform, while TP concentrations are not. TP exhibited a latitudinal gradient, with lowest concentrations in the southern study area and highest concentrations near the northern study area. Total chlorophyll concentrations are strongly correlated with TP and only weakly with TN.

Authors: Frazer, T. K., M. V. Hoyer, S. K. Notestein, J. A. Hale, and D. E. Canfield, Jr.

Publication Date: 2001.

Title: Physical, chemical and vegetative characteristics of five Gulf coast rivers. Final Report.

Document Type: Final Report. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 357 pp.

Period of Study: Ten quarterly sampling events from August 1998 through January 2001.

Geographic Range: The Weeki Wachee, Chassahowitzka, Homosassa, Crystal and Withlacoochee Rivers.

Variables Measured: The physical, chemical, and vegetative characteristics of each of the rivers.

General Findings: Each river sampled along its length and into the Gulf of Mexico. Useful for illustrating the range in water quality values over the sampled time period.

Data Format: Figures, tables, and appendices (**Volume II is data appendices**). Excel files also.

Data Location: In report and electronically at UF FAS.

Document Location: Project directory.

Executive Summary: [Excerpts] Mean nitrate concentrations in the upper most portions of each of the rivers (all quarterly sampling events combined) ranged from 51 µg L^{-1} to 524 µg L^{-1}. The highest mean nitrate concentration was calculated from samples taken in the Weeki Wachee River. The lowest mean nitrate concentration was calculated from samples taken in Crystal River.

Within the Crystal and Withlacoochee rivers, mean nitrate concentrations were fairly uniform above their respective marsh complexes. Nitrate present in the upper Weeki Wachee, Crystal and Withlacoochee rivers, on the other hand, was largely discharged into the estuarine environment.

Crystal River, annual mean total vegetative biomass was similar in all three years (0.4 – 0.5 kg wet wt m^{-2}), annual mean macrophyte biomass was similar in all three years (0.3 – 0.5 kg wet wt m^{-2}), and annual mean filamentous macroalgal biomass was similar in all three years (0.03 – 0.05 kg wet wt m^{-2}). Crystal River (exclusive of Kings Bay) is sufficiently deep in many locations that light near the bottom probably precludes plant colonization. In fact, submersed aquatic vegetation in this river was common only in the first 2 km downstream of Kings Bay. Moreover, the substrate characteristics in the middle and lower sections of the river above the marsh complex were not generally favorable for plant and algal growth. Salinity, however, is probably the most important factor affecting the species composition, abundance and distribution of plants and algae in Crystal River. Mean salinities (average value for all ten quarterly sampling events) were greater than 3 ‰ below the area where plants and algae noticeably declined and maximum salinity values were frequently much higher. There was a strong negative relationship between mean total vegetative biomass and salinity in Crystal River.

Authors: Frazer, T. K., M. V. Hoyer, S. K. Notestein, J. A. Hale, and D. E. Canfield, Jr.

Publication Date: 2001.

Title: Physical, chemical and vegetative characteristics of five Gulf coast rivers. Volume 2 – Appendices.

Document Type: Final Project Report. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 225 pp.

Period of Study: Ten quarterly sampling events from August 1998 through January 2001.

Geographic Range: The Weeki Wachee, Chassahowitzka, Homosassa, Crystal and Withlacoochee Rivers.

Variables Measured: The physical, chemical, and vegetative characteristics of each of the rivers.

General Findings: Each river sampled along its length and into the Gulf of Mexico. Useful for illustrating the range in water quality values over the sampled time period.

Data Format: Tables in appendices, **Volume II is only data appendices**. Excel files also.

Data Location: In report and electronically at UF FAS.

Document Location: Project directory.

Executive Summary: None.

Authors: Frazer, T.K., S. K. Notestein, M. V. Hoyer, J. A. Hale, and D. E. Canfield, Jr.

Publication Date: 2001.

Title: Frequency and duration of pulsed salinity events in Kings Bay.

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, Florida. 32 pp.

Period of Study: July 24, 2000 through June 27, 2001.

Geographic Range: Two stations in Kings Bay.

Variables Measured: Salinity, temperature, and depth.

General Findings: Water depth, temperature, and salinity were found to be highly variable at the mouth of Kings Bay. This variability appears to be driven by daily tidal cycles and storm events. Storm surges were responsible for the greatest salinity values observed. This study documents the occurrence of saline waters entering Kings Bay and supports the conclusion that submersed aquatic vegetation (SAV) distribution and abundance is related to these salt water intrusions.

Data Format: Figures and tables in report, and Excel files.

Data Location: Report and UF FAS project files.

Document Location: Project directory.

Conclusions: [Excerpts] Yobbi and Knochenmus (1989) investigated the effects of river discharge and high-tide stage on the salinity characteristics of Crystal River in the mid 1980s and in no instance were salinities greater than 3 ‰ observed at their upper most river station just below Kings Bay. Recent evidence suggests that changes in the salinity characteristics of Kings Bay have since occurred. Hoyer *et al.* (2001) reported that salinity measurements made between 1989 and 2000 were indicative of a long-term increase in the average salinity in the bay. In this investigation, average bottom salinities in the Bay were as high as 7.6 ‰ from July 1999 through July 2000 and well above those measured by Yobbi and Knochenmus (1989). Data reported here indicate that pulses of even higher salinity water are common at the mouth of Kings Bay. Monthly maximum salinity values always exceeded 4 ‰ and monthly maxima were generally greater than 6 ‰. Under typical tidal fluctuations, bottom salinities above 10 ‰ were occasionally recorded at the mouth of Kings Bay. We suggest that an increase in the frequency of pulsed salinity events in the bay may be responsible for the reported decline in plant biomass in Kings Bay during the last decade (Hoyer *et al.* 2001).

Authors: Frazer, T. K., E. J. Phlips, S. K. Notestein, and C. Jett.

Publication Date: 2002.

Title: Nutrient limiting status of phytoplankton in five Gulf coast rivers and their associated estuaries.

Document Type: Final Report. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 21 pp.

Period of Study: 2000 through 2001.

Geographic Range: Six stations (2 river, 2 marsh, and 2 estuary) were sampled at the Crystal, Withlacoochee, Chassahowitzka, Homosassa, and Weeki Wachee rivers.

Variables Measured: The growth of phytoplankton under various nutrient additions.

General Findings: In Crystal River and its associated marsh complex and estuary, algal growth was limited by phosphorus in 29% of all experiments. Phosphorus and nitrogen were the primary limiting nutrients (co-limited) in 29% of all experiments and nitrogen was the primary limiting nutrient also in only 29% of all experiments.

Data Format: Tables and figures in report.

Data Location: In report, and Electronic files at UF FAS.

Document Location: Project directory.

Summary: [Excerpts] The findings reported above are strongly supportive of our hypothesis that phosphorus, rather than nitrogen, often limits the production of phytoplankton in surface waters along much of the Springs Coast of Florida. Nutrient limitation of algal growth by phosphorus was most common in the Weeki Wachee system in the southern portion of the study area. Nutrient limitation of algal growth by nitrogen was most common in the Withlacoochee system in the northern portion of the study area.

Authors: Frazer, T. K., S. K. Notestein, C. A. Jacoby, and J. A. Hale.

Publication Date: 2006.

Title: Water quality characteristics of the nearshore Gulf coast waters adjacent to Citrus, Hernando and Levy Counties, Project COAST 1997–2005.

Document Type: Final Report. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 56 pp.

Period of Study: 1997 to 2005.

Geographic Range: Springs coast, includes ten stations among the Crystal River and estuary.

Variables Measured: Water chemistry including salinity.

General Findings: Chlorophyll concentrations are better correlated to total phosphorus rather than total nitrogen concentrations. Monthly sampling has been conducted at ten Crystal River stations (2 in the river) since 1997. Report contains a record of salinity and other water quality parameters by system.

Data Format: Figures and tables, and Excel files.

Data Location: In report, and at UF FAS.

Document Location: Project directory.

Abstract: None.

Authors: Frazer, T. K., S. K. Notestein, C. A. Jacoby, C. Jones Littles, S. R. Keller, and R. A. Swett.

Publication Date: 2006.

Title: Effects of storm-induced salinity changes on submersed aquatic vegetation in Kings Bay, Florida

Document Type: Estuaries and Coasts. 29(6A): 943–953.

Period of Study: August through December 2004.

Geographic Range: Kings Bay, 2 stations.

Variables Measured: Salinity, temperature, stage time series, and plant/salinity growth experiments.

General Findings: Documents storm surges of high salinity water entering Kings Bay; the experimental results of submersed aquatic vegetation (SAV) survival and growth under different salinity regimes; and the mechanisms for SAV loss following a storm surge of saline water to Kings Bay. Salinity values of 14 and 19 ppt were documented entering Kings Bay. Experimental results showed that *Hydrilla* was killed at 15 ppt exposure and above. *Myriophyllum* and *Vallisneria* could survive 7 days at 15 ppt, but no exposure to 25 ppt. All three SAV species could tolerate 5 ppt up to 7 days with no apparent damage.

Data Format: Excel files.

Data Location: UF FAS.

Document Location: Project directory.

Abstract: Hurricanes and other major storms cause acute changes in salinity within Florida's streams and rivers. Wind-driven tidal surges that increase salinities may have long-lasting effects on submersed aquatic vegetation (SAV) and the associated fauna. We investigated potential effects of salinity pulses on SAV in Kings Bay, Florida, by subjecting the three most common macrophytes, *Vallisneria americana*, *Myriophyllum spicatum*, and *Hydrilla verticillata*, to simulated salinity pulses. In Kings Bay, we documented changes in salinity during three storms in September 2004 and measured biomass and percent cover before and after these storms. During experiments, macrophytes were exposed to salinities of 5%, 15%, or 25% for 1, 2, or 7 d, with a 28-d recovery period in freshwater. Relative to controls, plants subjected to salinities of 5% exhibited few significant decreases in growth and no increase in mortality. All three species exhibited decreased growth in salinities of 15% or 25%. *H. verticillata* exhibited 100% mortality at 15% and 25%, irrespective of the duration of exposure. *M. spicatum* and *V. americana* exhibited increased mortality after 7-d exposures to 15% or any exposure to 25%. Maximum daily salinities in Kings Bay approached or exceeded 15% after each of the three storms, with pulses generally lasting less than 2 d. Total aboveground biomass and percent cover of vascular plants were reduced following the storms. *M. spicatum* exhibited an 83% decrease in aboveground biomass and an 80% decrease in percent cover. *H. verticillata* exhibited a 47% and 15% decline in biomass and percent cover, respectively. *V. americana* exhibited an 18% increase in aboveground biomass and a 37% increase in percent cover, suggesting greater tolerance of salinity.

Author: Goodfriend, D. S.

Publication Date: 2004.

Title: The relative value of seagrass, marsh edge, and oyster habitats to the brackish grass shrimp, *Palaemonetes intermedius*, along the Gulf coast of Florida.

Document Type: M.S. Thesis. University of Florida. 58 pp.

Period of Study: July 2002 to August 2003.

Geographic Range: Outside the mouth of Crystal River (and other Gulf Coast rivers).

Variables Measured: Grass shrimp fitness, habitat conditions, and limited field parameters.

General Findings: See abstract below.

Data Format: In thesis.

Data Location: Full text: http://purl.fcla.edu/fcla/etd/UFE0004787

Document Location: Project directory.

Abstract: [Excerpts] This study examined the relative value of seagrass beds, marsh edge habitats, and oyster bars to the brackish grass shrimp, *Palaemonetes intermedius*, using a variety of metrics that either directly measure, or provide surrogate measures for, fecundity, mortality, and growth rates. These metrics were compared with measures of relative abundance to determine whether abundance might be an effective indicator of habitat quality. Sampling was done during July, August, and November 2002, and February, May, July, and August 2003, in the St. Martin's Marsh Aquatic Preserve (SMMAP) near Crystal River, Florida. This provided an assessment of temporal variability in the quality of these habitat types as well as their overall relative value. In August 2003, the study was broadened to include the Weeki Wachee and Steinhatchee estuaries in order to assess the degree of regional variability in the quality of these habitats for grass shrimp.

In contrast with several other studies, *P. intermedius* was never collected from oyster habitat. In the SMMAP, seagrass beds provided higher quality habitat for grass shrimp than marsh edges in the July/August, November, and May, when seagrass beds had greater abundances of shrimp, as well as higher proportions of gravid females than marsh edges. In February 2003, the two habitats were determined to be of similar value to grass shrimp. Seagrass beds in Weeki Wachee provided a higher quality habitat than marsh edges for grass shrimp. Within the Steinhatchee estuary, however, the quality of marsh edge habitats was similar to, or marginally higher than, that of seagrass beds. Differences in seagrass characteristics, (species composition), may account for the lower abundance of *P. intermedius* in the sampled seagrass beds within the Steinhatchee estuary. Generally, grass beds were determined to provide higher quality habitat than adjacent marsh edges in the broad study area.

Authors: Gorzelany, J. F.

Publication Date: 1986.

Title: Oyster associated fauna. Volume V in a series: a data collection program for selected coastal estuaries in Hernando, Citrus, and Levy counties, Florida.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Fl. Southwest Florida Water Management District, Brooksville, Fl. 124 pp.

Period of Study: 1984 and 1985.

Geographic Range: Three stations running offshore of the Waccasassa, Withlacoochee, Crystal, Weeki Wachee rivers and one station off Hammock Creek (Aripeka) as per an accompanying study of oysters.

Variables Measured: Animals found on and in oyster clumps were identified to varying taxonomic levels and enumerated. A subsample was used to relate numbers of animals and taxa to clump volume. Shannon-Weaver diversity indices and Morisita's indices (a measure of similarity between assemblages) were calculated. Water quality data from an accompanying study were used to characterize the conditions, including salinities, at the sampling stations.

General Findings: Sampling stations with similar exposure to freshwater tended to have similar assemblages, and sampling stations at a single location with differing exposures, *i.e.*, further offshore, tended to have different assemblages. Numbers of organisms varied among quarters, with some evidence of repeated temporal patterns. Decreased flow leading to increased salinity has the potential to alter assemblages found on oyster bars.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: Grimes, C. B.

Publication Date: 1971.

Title: Thermal addition studies of the Crystal River steam electric station.

Document Type: Professional Papers Series. Number Eleven. February 1971. Florida Department of Natural Resources. Marine Research Laboratory. St. Petersburg, FL. 65 pp.

Period of Study: Throughout 1969.

Geographic Range: 21 stations in the nearshore waters (out to 10 mi) of the Gulf of Mexico off the Crystal River power plant.

Variables Measured: Three objectives of study: 1) To determine the occurrence and abundance of certain nektonic and benthonic marine organisms in the vicinity of the Florida Power Corporations Crystal River steam electric station. 2) To monitor certain chemical and physical properties of the water in the vicinity of the plant. 3) To provide oyster samples for trace metals and pesticide residue analysis.

General Findings: Shallow areas were most affected by thermal plume, with occasional inversions of stratification following salinity rather than temperature. Generally native species not impacted by thermal plume and fish utilized the plume during fall and winter.

Data Format: Tables, figures, and appendices in report.

Data Location: In document.

Document Location: Project directory.

Abstract: [Excerpts] A field investigation was made throughout 1969 to determine the ecological effects of hot water discharge by a steam electric generating plant in Crystal River, Florida. Temperature monitoring revealed the occasional existence of inverse thermal stratification in the discharge area apparently due to the greater salinity of intake waters. Trawl sampling disclosed that only shallow inshore areas near the discharge were thermally affected.

The linear regression of the annual growth of age 0 *Bairdiella chrysura* [silver perch], *Lagodon rhomboides* [pinfish], and *Orthopristis chrysopterus* [pigfish] collected at affected and non-affected stations was calculated. Statistical comparisons of the coefficients of regression (affected vs. non-affected) revealed no significant differences in annual growth. Comparison of the relative abundance of *O. chrysopterus*, *B. chrysura*, *L. rhomboides*, and *Opsanus beta* [gulf toadfish] from affected and non-affected stations revealed no significant changes in relative species abundance. The diversity index (S-1)/lnN was used to compare species diversity of fishes at stations of increasing distance from the point of discharge. Slight shifts in diversity toward the discharge in winter and away in summer were noted. Trace metal analysis of oyster meats from the discharge and intake canals revealed substantial increases of copper and zinc. These increase are believed related to increased ion presence in discharge waters as well as increased water temperatures.

Authors: Grimes, C. B. and J. A. Mountain.

Publication Date: 1971.

Title: Effects of thermal effluent upon marine fishes near the Crystal River steam electric station.

Document Type: Professional Papers Series. Number Seventeen. October 1971. Florida Department of Natural Resources. Marine Research Laboratory. St. Petersburg, FL. 74 pp.

Period of Study: 1969 through 1970.

Geographic Range: 21 stations in the nearshore waters (up to 10 mi) of the Gulf of Mexico off the Crystal River power plant.

Variables Measured: Trawl fisheries data and physico-chemical water data at stations.

General Findings: Occasional inverse thermal stratifications observed. The frequency of occurrence for the four most common fish species showed no difference between temperature affected vs. non-affected sampling stations. Species diversity was higher during winter and lower during summer in affected areas.

Data Format: Tables, figures, and appendices in report.

Data Location: In document.

Document Location: Project directory.

Abstract: [Excerpts] The field investigation begun in 1969 to determine ecological effects of hot water discharge of a steam electric generating plant in Crystal River, Florida was continued throughout 1970. Effects of the effluent upon Gulf of Mexico fishes in the vicinity of the plant were studied. Temperature and salinity monitoring continued to reveal the occasional existence of inverse thermal stratification in the discharge area, apparently due to higher salinity of intake waters. Higher water temperatures in 1970 were due partially to increased volume of discharge water and partially to increased ambient Gulf temperatures. Bi-monthly trawl sampling indicated that influence of the thermal plume had extended into previously unaffected intermediate depth areas. Suppressed summer diversity may be due to thermal stress on the community. Greatest diversity in both winter and summer occurred at affected intermediate depth stations. A pattern of increasing diversity from north to south in trawl station transects (shallow and intermediate depth) was also observed. The pattern was apparently related to salinity, which also increased from north to south, and/or to habitat destruction from dredging operations which was greatest at northern stations. Frequency of occurrence of the four most abundant species (*Orthopristis chrysoptera* [pigfish], *Bairdiella chrysura* [silver perch], *Leiostomus xanthurus* [spot croaker], and *Lagodon rhomboides* [pinfish]) in affected vs. non-affected areas was statistically analyzed and did not differ significantly. Spawning, movement, age, and growth of these species from affected vs. non-affected stations were also considered.

Authors: Haller, W. T., J. V. Shireman, and D. E. Canfield, Jr.

Publication Date: 1983.

Title: Vegetative and herbicide monitoring study in Kings Bay, Crystal River, Florida.

Document Type: Project Report. Center for Aquatic Weeds, University of Florida. Prepared from U. S. Army Corps of Engineers. 169 pp.

Period of Study: 1980 to 1981.

Geographic Range: Kings Bay.

Variables Measured: Submersed aquatic vegetation biomass and species on four events. The copper (and diquat) content of water, plants, and soil samples (~ 4,000) were measured before and following herbicide treatments.

General Findings: Copper and diquat residues in water as a result of treatment of the plots were short-term in nature, dissipating within 12 to 48 hours. Residues in the target plant species (*hydrilla*) were longer and remained for 4 to 8 weeks after treatment. Soil copper residues were too variable to discern any trends in residue accumulation. Also, herbicides remained in the plots or dissipated out only a short distance (approximately 150 ft.) from the plots, most notably in a downstream direction. Subsequent studies (Facemire 1991 and 1992), found higher levels of copper in Kings Bay sediments and the potential for aquatic plants to sequester copper.

Data Format: Figures, tables, and appendices in report.

Data Location: In report, maybe UF CAIP files.

Document Location: Project directory.

Summary: [Excerpts] Submersed vegetation in Kings Bay was sampled at various times between September 1980 and August 1981 to determine annual changes in species composition and biomass estimates. Two 10 acre plots were treated with the herbicides diquat and copper in September 1980 to control *hydrilla*. Over 4, 000 plant, water, and soil samples were collected at various times before and after treatment and at various distances and directions from the plots. Samples were analyzed for copper and diquat content. Bay wide random sampling before, and 1, 2, and 4 weeks after treatment showed no significant bay wide effects resulting from the chemical treatments. Herbicide residues in the water in and near the plots dissipated rapidly, generally within 12 to 48 hours after treatment. Herbicide residues in the plants generally increased after treatment as the plants apparently absorbed both lethal (in those plants that were killed) and sub-lethal doses of the herbicides. In the period between 28 and 56 days after treatment, however; the herbicide content of the plants returned to pre-treatment levels. Copper content of the hydrosoils in Kings Bay and in the plots varies widely as soil types changed from sand to highly organic silts. No definite trends were noted in copper content of the soils after herbicide treatment.

Authors: Hammett, K. M., C. R. Goodwin, and G. L. Sanders.

Publication Date: 1996.

Title: Tidal-Flow, Circulation, and Flushing Characteristics of Kings Bay, Citrus County, Florida.

Document Type: Open-File Report 96-230. U. S. Geological Survey. Tallahassee, Fl. Prepared in cooperation with the Southwest Florida Water Management District. 63 pp.

Period of Study: June 7-8 and June 15-16, 1990.

Geographic Range: Kings Bay and upper Crystal River.

Variables Measured: Tidal stage, water velocity, discharge data, and particle tracking simulations.

General Findings: Circulation and flushing characteristics of Kings Bay were simulated under three scenarios: low-inflow conditions (net spring discharge of 735 cfs), typical inflow conditions (net spring discharge of 975 cfs), and low-inflow conditions with reduced bottom roughness (no plants). Modeled results suggest that springs discharge transported particles out of Kings Bay and tidal effects added an oscillatory component to the particle paths. Average particle residence time was 59, 50, and 56 hours for the three modeled scenarios, respectively. Average flushing times (to remove 95% of simulated particles) took 94, 71, and 94 hours for the three modeled scenarios, respectively. Circulation and flushing characteristics in Kings Bay are primarily determined by discharge from springs in the bay. Tides modulate water level, water velocity, and advective transport, but spring discharge is the most significant factor affecting residual circulation and flushing.

Data Format: Figures and tables in report.

Data Location: In report. Electronic data may be available from USGS.

Document Location: Project directory.

Abstract: Kings Bay is an estuary on the Gulf coast of peninsular Florida with a surface area of less than one square mile. It is a unique estuarine system with no significant inflowing rivers or streams. As much as 99 percent of the freshwater entering the bay originates from multiple spring vents at the bottom of the estuary.

The circulation and flushing characteristics of Kings Bay were evaluated by applying SIMSYS2D, a two-dimensional numerical model. Field data were used to calibrate and verify the model. Lagrangian particle simulations were used to determine the circulation characteristics for three hydrologic conditions: low inflow, typical inflow, and low inflow with reduced friction from aquatic vegetation. Spring discharge transported the particles from Kings Bay through Crystal River and out of the model domain. Tidal effects added an oscillatory component to the particle paths. The mean particle residence time was 59 hours for low inflow conditions, 50 hours for typical inflow conditions, and 56 hours for low inflow with reduced friction; therefore, particle residence time is affected more by spring discharge than by bottom friction. Circulation patterns were virtually identical for the three simulated hydrologic

conditions. Simulated particles introduced in the southern part of Kings Bay traveled along the eastern side of Buzzard Island before entering Crystal River and exiting the model domain.

The flushing characteristics of Kings Bay for the three hydrodynamic conditions were determined by simulating the injection of conservative dye constituents. The average concentration of dye initially injected in Kings Bay decreased asymptotically because of spring discharge, and the tide caused some oscillation in the average dye concentration. Ninety-five percent of the injected dye exited Kings Bay and Crystal River within 94 hours for low inflow, 71 hours for typical inflow, and 94 hours for low inflow with reduced bottom friction. Simulation results indicate that all of the open waters of Kings Bay are flushed by the spring discharge. Reduced bottom friction has little effect on flushing.

Authors: Hauxwell, J., T. K. Frazer, and C. W. Osenberg.

Publication Date: 2003.

Title: Effects of herbivores and competing primary producers on *Vallisneria americana* in Kings Bay: implications for restoration and management.

Document Type: Final Report. Submitted to the Southwest Florida Water Management District. Tampa, Fl. 79 pp.

Period of Study: January to November, 2001.

Geographic Range: Kings Bay, 3 stations.

Variables Measured: The growth and biomass of transplanted and colonizing submersed aquatic vegetation (SAV).

General Findings: Transplanted *Vallisneria* did not persist unless protected from grazing by manatees. Competition from other SAV species also reduced the density, growth, and biomass of *Vallisneria*. Findings suggest that large scale *Vallisneria* planting and restoration of Kings Bay is not feasible.

Data Format: Table and figures in report, also Excel files.

Data Location: UF FAS holdings.

Document Location: Project directory.

Executive Summary: [Excerpts] To determine the effects of herbivores and other primary producers on *Vallisneria* transplants, we conducted a 2 × 2 factorial design experiment at three sites (Cedar Cove, south of Buzzards Island and north of Parkers Island) in which we allowed or denied: (1) relatively large herbivores (*e.g.*, manatees, turtles, waterfowl, large fishes) and (2) other primary producers (*e.g.*, *Myriophyllum*, *Hydrilla*, *Lyngbya*) access to 1.5 × 1.5 m transplanted plots of *Vallisneria*. Within one month, *Vallisneria* disappeared from 80% of herbivore-access plots due to consumption by manatees.

In combination, the results from this work suggest that large-scale restoration of *Vallisneria* in Kings Bay is not feasible at this time. Not only has the naturally occurring population of *Vallisneria* declined, but our experimental tests have demonstrated that effects of herbivory and competition will likely preclude establishment of *Vallisneria* in new areas.

Authors: Hauxwell, J., T. K. Frazer, and C. W. Osenberg.

Publication Date: 2004.

Title: Grazing by manatees excludes both new and established wild celery transplants: implications for restoration in Kings Bay, FL, USA.

Document Type: Journal of Aquatic Plant Management. 42: 49-53.

Period of Study: August 2001 and February 2002.

Geographic Range: Kings Bay, 3 stations.

Variables Measured: The growth and biomass of transplanted and colonizing SAV

General Findings: Transplanted *Vallisneria* did not persist unless protected from grazing by manatees. Findings suggest that large scale *Vallisneria* planting and restoration of Kings Bay is not feasible.

Data Format: Table and figures in report, also Excel files.

Data Location: UF FAS holdings.

Document Location: Project directory.

Abstract: We conducted a field experiment between August 2001 and February 2002 in Kings Bay, FL, USA, designed to determine whether the amount of time allowed for wild celery (*Vallisneria americana* Michx.) transplants to establish altered the effect of herbivorous manatees (*Trichechus manatus* L.) on their survival. We employed a 2 by 2 factorial design in which we allowed or denied manatees access to (1) newly transplanted plots of wild celery or (2) plots that had been planted 5 months earlier and allowed to establish. Upon removal of protective fencing, a significant effect of manatees was observed in unprotected plots, regardless of level of establishment. Within 1 month, all exposed plots were void of plants. In contrast, density of plants in plots that had been protected from herbivores showed very little change over the study period. Results of this experiment indicate that success of any future larger-scale transplant effort in Kings Bay is contingent upon adequate protection from manatees. If, in fact, transplants become more resistant to uprooting by manatees over time, it is beyond the duration tested in this experiment (>5 months).

Authors: Hauxwell, J., C. W. Osenberg, and T. K. Frazer.

Publication Date: 2004.

Title: Conflicting management goals: manatees and invasive competitors inhibit restoration of a native macrophyte.

Document Type: Ecological Applications. 14(2): 571–586.

Period of Study: January to November 2001.

Geographic Range: Kings Bay, 3 stations.

Variables Measured: Submersed aquatic vegetation (SAV) growth rates, density, and biomass.

General Findings: Planted SAV was consumed by manatees unless cages protected the plants. Competition between aquatic plant species could also reduce planted SAV growth.

Data Format: In report and Excel.

Data Location: UF FAS holdings.

Document Location: Project directory

Abstract: [Excerpts] *Vallisneria americana* is a native macrophyte in freshwater and oligohaline ecosystems, often forming meadows that significantly affect ecosystem carbon and nutrient cycling and provide structural habitat. *Vallisneria* has declined in abundance in several Florida lakes, rivers, and estuaries. We conducted an 11-month field experiment in Kings Bay, Florida, USA, to determine factors that might affect successful transplantation of *Vallisneria* and to guide potential future restoration efforts by water resource management agencies. To determine the effects of herbivores and other primary producers on *Vallisneria* production, we conducted a 2 x 3 x 2 factorial experiment at three sites in which we allowed or denied: (1) relatively large herbivores (.3 cm) and (2) other primary producers (*e.g.*, *Myriophyllum spicatum*, *Hydrilla verticillata*, *Lyngbya sp*.) access to 1.5 x 3 x 1.5-m transplanted plots of *Vallisneria*. Within one month, *Vallisneria* disappeared from 80% of herbivore-access plots due primarily to consumption by manatees. *Vallisneria* density was reduced a variable amount (0–50%) in response to competitors, due to site-specific variation in natural abundance of other primary producers (at two sites, we observed extensive colonization by other primary producers and a strong treatment effect). Most of this competitive effect was attributable to Eurasian watermillfoil (*Myriophyllum spicatum*); after pooling *Vallisneria* density data across sites, we observed a negative exponential relationship between shoot density of *Vallisneria* and stem density of *Myriophyllum* for every sampling date. We observed a probable mechanism by which *Myriophyllum* reduces *Vallisneria* occurs via space limitation, and reduction in *Vallisneria* densities and/or recruitment and growth of new shoots. We conclude that two different management goals (restoration of *Vallisneria* and protection of manatees) are in conflict and must be simultaneously considered to devise effective and sustainable ecosystem management scenarios.

Authors: Hauxwell, J., T. K. Frazer, and C. W. Osenberg.

Publication Date: 2007.

Title: An annual cycle of biomass and productivity of *Vallisneria americana* in a subtropical spring-fed estuary.

Document Type: Aquatic Botany. 87: 61–68.

Period of Study: March 2001 and June 2002.

Geographic Range: Kings Bay, 1 station, just south of Buzzards Island.

Variables Measured: *Vallisneria* biomass and production rates.

General Findings: *Vallisneria* grows year round in Kings Bay, with little evidence of seasonal patterns in density and biomass, and most recruitment through vegetative reproduction.

Data Format: Figures and tables in publication.

Data Location: In publication.

Document Location: Project directory.

Abstract: An annual cycle of biomass and productivity of wild celery (*Vallisneria americana*) was studied in Kings Bay, FL, USA. *In situ* growth rates were measured monthly between March 2001 and June 2002 in high-density stands, using a modified hole-punching technique, and applied to shoot density data to obtain areal estimates of production. Mean shoot density varied greatly over the study period, ranging between 200 and 800 shoots m^{-2}. Mean total biomass ranged between 162 and 1013 g m^{-2}, with aboveground material comprising, on average, 70% of total biomass. Total annual estimated production of new attached shoots was 519 g m^{-2}. Leaf growth rates peaked at >50 mg $shoot^{-1}$ d^{-1}, and mass specific leaf growth ranged 0.6–1.8% d^{-1}. Annually, individual shoots produced 7.4 g of leaf material and completely replaced standing leaf biomass 3.5 times. Areal leaf production was highest in late spring/summer of 2001, and ranged between 3.6 and 23.0 g m^{-2} d^{-1}. Annual total leaf production was 2704 g m^{-2}. Seasonality was not apparent in most variables monitored monthly; only 1 of the 64 relationships we examined between environmental variables (nutrients, chlorophyll a, and irradiance) and *Vallisneria* biological variables were significant, with relative growth rate increasing linearly with irradiance. Peak biomass and productivity of *Vallisneria* in Kings Bay were high compared to literature values for other *Vallisneria* populations as well as global averages for well-studied seagrasses, emphasizing the potential importance of *Vallisneria* to whole ecosystem functioning in springs, lakes, and oligohaline reaches of many estuaries.

Author: Hornbeck, D. A.

Publication Date: 1979.

Title: Metabolism of salt marshes and their role in the economy of a coastal community.

Document Type: M.S. Thesis, University of Florida. 174 pp.

Period of Study: 1977 to 1978.

Geographic Range: Salt marshes near the Crystal River power plant.

Variables Measured: Metabolism, biomass, and density of salt marsh grasses.

General Findings: Measurements of marsh community metabolism and emergent species biomass.

Data Format: Figures, tables, and appendices in thesis.

Data Location: In thesis.

Document Location: **Abstract** in project directory.

Abstract: Measurements of metabolism and biomass of salt marshes were made at Crystal River, Florida, to assess the effects of hot water from power plant effluent. An annual record of *in situ* community metabolism measurement by diurnal CO_2 gas analysis in *Juncus* and *Spartina* zones is given. Data were used to construct a model of a coastal community at Cedar Key, Florida. This was evaluated to examine the importance of the marsh to the regional economy.

Gross metabolism ranged from 1.3 to 8.5 grams carbon/m^2 day for *Juncus* and 0.2 to 5.0 grams carbon/m^2 day for *Spartina*. Although much of photosynthesis was concurrently used as day and night respiration, gross production indicates these marshes to be as efficient in converting solar energy as northern salt marshes. P/R ratios were highest (2.4) in the summer and lowest (0.8) in the fall and winter. Respiration per gram of biomass was found to increase to a maximum at about 25° then fall off.

In response to higher water temperatures in thermally affected marshes, plants metabolized more rapidly, with shorter turnover times. Aboveground biomass was the same in both sites; except for fall *Spartina* values which were less in thermally affected sites. Stem densities were greater and plants were shorter in thermally affected sites. Thermal effects were greater in *Spartina* marshes than *Juncus* marshes, since *Spartina* was at a lower elevation and received more hot water.

Regional energy analysis for the Cedar Key area of Levy County included estimates of flows of energy from the marine ecosystem and from activity of the human economy. The marsh was 10% of the area of coastal and marine ecosystems in the region and contributed and estimated 14% of the gross primary production. The amount of detritus produced in the marshes annually could potentially support and estimated 55% of the commercial fish catch.

Author: Hoyer, M. V., L. K. Mataraza, A. B. Munson, and D. E. Canfield, Jr.

Publication Date: 1997.

Title: Water clarity in Kings Bay/Crystal River.

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, FL. 99 pp.

Period of Study: August 1996 through October 1997.

Geographic Range: Variable number of stations in Kings Bay and canals.

Variables Measured: Concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll (CHL), total suspended solids (TSS), color, water temperature, salinity, dissolved oxygen, Secchi visibility, and submersed aquatic vegetation (SAV) biomass and assemblage composition.

General Findings: Water chemistry (TN, TP, CHL, color, DO, temp, and TSS) values were similar between bay and canal stations, however salinity was higher among the bay stations. Secchi visibility was negatively correlated to CHL and TSS values and to wind speed. Aquatic plant biomass was negatively correlated to CHL concentrations.

Data Format: Figures, tables, and appendices in report. Excel files should be available.

Data Location: Report, and UF LAKEWATCH.

Document Location: Project directory.

Summary: The water clarity in Kings Bay/Crystal River is primarily determined by the concentrations of suspended solids in the water column, with solids contributed by algal cells the primary fraction. The hypothesis that the canals attached to Kings Bay/Crystal River are the main source of these solids does not appear to be supported by the data. Average suspended solids, chlorophyll, and nutrient concentrations in the canal are not significantly different from the corresponding averages in the bay. The total volume of water in the canals located in the southeast corner of Kings Bay/Crystal River is only about 25% of the volume of the bay southeast of Banana Island. Thus, concentrations of solids, chlorophyll, or nutrients in the canals would have to be four times as high as the bay and all of that water would have to mix with the bay to cause a one unit increase in the concentrations of solids, chlorophyll, or nutrients of the bay. In addition, the long term monitoring of water chemistry in Kings Bay/Crystal River show that the nutrient concentrations have been steadily decreasing since 1993.

Author: Hoyer, M. V., T. K. Frazer, D. E. Canfield, Jr., and J. M. Lamb.

Publication Date: 2001.

Title: Vegetation evaluation in Kings Bay/Crystal River.

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, Florida. 75 pp.

Period of Study: August 1999 through August 2000. Historical data were examined.

Geographic Range: Twenty-one stations in Kings Bay.

Variables Measured: Concentrations of total nitrogen (TN), total phosphorus (TP), chlorophyll (CHL), total suspended solids (TSS), color, water temperature, salinity, dissolved oxygen, Secchi visibility, and submersed aquatic vegetation (SAV) biomass and assemblage composition.

General Findings: Chlorophyll (CHL) concentrations were negatively correlated to Secchi visibility. Total phosphorus (TP) and total nitrogen (TN) concentrations were positively correlated with CHL but only explained 11% of the variance in CHL. Aquatic plant biomass and average daily wind speed were both negatively correlated with CHL concentrations. Water salinity was negatively correlated to SAV biomass and a trend of increasing specific conductance was observed over the past decade in Kings Bay.

Data Format: Figures, tables, and appendices in report. Excel files of data also.

Data Location: In report. Excel files with UF LAKEWATCH.

Document Location: Project directory.

Summary: The empirical relationship established between horizontal Secchi distance and chlorophyll (a proxy measure of suspend algal solids) implicates the latter as a primary determinant of water clarity in Kings Bay/Crystal River. There is sufficient phosphorus in Kings Bay/Crystal River for chlorophyll concentrations to exceed those that are currently observed, however, chlorophyll concentrations appear to be near the maximum that would be predicted from existing nitrogen concentrations. Both total phosphorus and total nitrogen concentrations in Kings Bay/Crystal River are directly related to chlorophyll concentrations but account for only a small percentage of the variance in chlorophyll concentrations. This suggests that other factors are likely influencing chlorophyll concentrations within Kings Bay/Crystal River.

Long-term monitoring of vegetation abundance and water chemistry suggests that fluctuations in aquatic plant biomass are inversely related to chlorophyll concentrations, *i.e.*, algal solids in the water column. Therefore, fluctuations in the aquatic plant biomass in Kings Bay/Crystal River may be responsible, in part, for reported fluctuations in water clarity. When aquatic plant biomass was at its highest in Kings Bay/Crystal River water clarity was improved.

Several studies have documented direct relations between aquatic plant abundance and water clarity in freshwater bodies around the world. Two of three major mechanisms posed in this report to explain the direct relation between aquatic plant biomass and water clarity are strongly influenced by wind. Aquatic plants dampen wave action in the water column and, as a consequence, decrease wind-driven resuspension of sediments and associated nutrients, and allow open-water algal cells to settle (in this case, often on the plants themselves). Data presented herein demonstrate that, in Kings Bay/Crystal River, the total amount of suspended solids in the water column is directly related to wind speed, whereas, water clarity is inversely related to wind speed. We suggest, based on our findings, that wind can and does resuspend detrital material and periphyton associated with aquatic plants, but not necessarily the bay bottom (see Bachmann *et al.* 2001). Other factors, such as recreational activities and grazing by large herbivores in the Bay, are also likely to dislodge detrital and algal solids associated with aquatic vegetation and may, at times, be an important determinant of water clarity in the systems. Although this study was not intended to address these other factors, they merit further study.

Data from previous investigations in the Kings Bay/Crystal River system suggest that major storm events influence the abundance of aquatic plants in Kings Bay/Crystal River. Storm surges likely increase the salinity in Kings Bay/Crystal River and, as a consequence, reduce the abundance of submersed aquatic vegetation. Findings presented here indicate that more subtle changes in specific conductance/salinity (possibly related to long-term climate cycles) can also influence the abundance and species composition of aquatic vegetation in this system. A qualitative inspection of data collected over the past decade suggests that water in Kings Bay has become more saline and vegetative biomass has declined. This change, in light of the data generated here, may be, in large part, responsible for the reported reduction in water clarity in Kings Bay over the same timeframe.

Authors: Hoyer, M. V., T. K. Frazer, S. K. Notestein, and D. E. Canfield, Jr.

Publication Date: 2004.

Title: Vegetative characteristics of three low-lying Florida coastal rivers in relation to flow, light, salinity and nutrients.

Document Type: Hydrobiologia. 528: 31-43.

Period of Study: 1998 to 2000.

Geographic Range: Crystal River (and Chassahowitzka and Homosassa Rivers).

Variables Measured: Water chemistry, light, flow, and sediments in relation to submersed aquatic vegetation (SAV) biomass and coverage.

General Findings: Paper focused on Crystal River below Kings Bay and observed that flow, substrate type, light, and salinity controlled the distribution and abundance of SAV.

Data Format: Tables and figures in report and Excel files.

Data Location: In report and electronically at UF FAS.

Document Location: Project directory.

Abstract: The Chassahowitzka, Homosassa and Crystal rivers along the central Gulf coast of Florida were studied from 1998 to 2000 to identify factors controlling the abundance and distribution of submersed aquatic vegetation (SAV). Each of these three low-lying coastal rivers are spring-fed and exhibit low to moderate absolute flow rates (flows in either direction because of tidal influences, 0.06–0.46 m s^{-1}) with only 14% of the stations sampled for SAV having flow rates in excess of 0.25 m s^{-1}. At those stations where flow rates exceeded 0.25 m s^{-1}, the substrate was generally comprised of exposed limestone outcroppings and did not provide a favorable habitat for either submersed macrophytes or macroalgae. The remaining sampling stations, where flow rates were less than 0.25 m s^{-1}, had suitable substrates (*e.g.* mud, mud/sand, and sand) for the colonization and subsequent growth of SAV. Light availability and salinity were determined to be major factors affecting the distribution and abundance of SAV. Sampling stations, where the percent of incident light at the surface reaching the substrate was less than 10%, had little or no SAV biomass. Low SAV biomass was also linked to sites where annual average salinities exceeded 3.5%. Nutrient loads and nutrient concentrations accounted for little variance in SAV biomass after accounting for flow and related substrate type, light and salinity. These latter factors control the distribution and abundance of SAV in these three Florida coastal rivers.

Authors: Hoyer, M. V., S. K. Notestein, T. K. Frazer, and D. E. Canfield, Jr.

Publication Date: 2006.

Title: A comparison between aquatic birds of lakes and coastal rivers in Florida.

Document Type: Hydrobiologia. 567: 5-18.

Period of Study: 1998 to 2001.

Geographic Range: Springs coast rivers, including Crystal River.

Variables Measured: Variety of physical, chemical, and biological factors, especially aquatic bird species and numbers.

General Findings: Aquatic bird abundance and biomass along these coastal rivers were similar to values observed for Florida lakes. Water depth was inversely correlated and submersed aquatic vegetation (SAV) was positively correlated with bird density, biomass, and species richness.

Data Format: Tables and figures in report.

Data Location: In report and Excel files at UF FAS.

Document Location: Project directory.

Abstract: Aquatic birds were counted on five Gulf coast Florida rivers to determine if these river systems supported densities, biomass and species richness similar to those found on Florida lakes. Forty-two species were identified and for the species that were found on both Florida streams and lakes similar densities and biomass were encountered. As with Florida lakes, stream bird abundance and species richness were higher in winter months than in summer months, a consequence of migratory bird populations. Total bird abundance, biomass per unit of phosphorus, and species richness per unit of area were similar to data collected on Florida lakes. Thus, Florida rivers are capable of supplying sufficient resources to maintain bird densities, biomass and species richness values similar to lakes of equal size and nutrient concentrations and are therefore important habitats for aquatic bird populations. An examination of individual habitat characteristics indicates that water depth was inversely correlated and submersed aquatic vegetation was positively correlated with bird density, biomass and species richness within the river systems. While both habitat characteristics are important they are also inversely related making it difficult to separate the individual significance of each characteristic.

Authors: Jacoby, C. A., T. K. Frazer, R. A. Swett, S. R. Keller, and S. K. Notestein.

Publication Date: 2007.

Title: Kings Bay vegetation evaluation.

Document Type: Final Report. Project W457. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 172 pp.

Period of Study: February, May, July and October of 2004, 2005 and 2006.

Geographic Range: Seventy-one stations in Kings Bay.

Variables Measured: Percent coverage and biomass of submersed aquatic vegetation (SAV) were measured directly. Additional data were obtained for sediment depth (Belanger *et al.* 2005), salinity pulses from hurricanes (Frazer *et al.* 2006), the District (water quality), Citrus County Aquatic Services Division (aquatic vegetation), and the Chassahowitzka National Wildlife Refuge (manatees numbers). Data were analyzed with multivariate ordinations, analyses of variance and GIS interpolations.

General Findings: SAV species distribution patterns were related to water quality.

Data Format: Figures, tables, and appendices, also Excel files.

Data Location: In report and UF FAS.

Document Location: Project directory.

Executive Summary: [Excerpts] Vegetation was more diverse at one group of stations in the southern and western portions of the bay. Filamentous algae (including *Lyngbya*) and *Hydrilla verticillata* characterized the other group of stations and were prevalent near spring vents. This spatial pattern was not correlated with sediment depth or management of aquatic vegetation; it was correlated with water quality. An acute decrease in coverage and biomass of most SAV occurred in October 2004 following saline water (up to 15 ‰) entering Kings Bay from three hurricanes in September 2004. *Vallisneria americana* and filamentous algae (including *Lyngbya*) appeared to tolerate the pulses of high salinity water. The native *V. americana* is known to be tolerant of salinity pulses (as are some filamentous algae), and *Lyngbya* may have to survived the salinity pulses due greater freshwater input near spring vents were the algae is prevalent. A chronic spatial pattern emerged as there was a repeated decrease in the coverage and biomass of angiosperms during February sampling periods. It appeared that manatees grazing in the bay led to these changes and that filamentous algae (including *Lyngbya*) was not grazed where it was dominant.

Impacts from storms and manatees need to be considered as part of plans to restore SAV in Kings Bay. Secondly, diagnostic studies, such as conductivity, concentrations of nitrate-nitrite and water clarity, could explain the persistent spatial pattern in submersed aquatic vegetation in Kings Bay. Lastly, other diagnostic studies that compare and contrast coastal systems should help explain the persistence of submersed aquatic vegetation in Kings Bay while other coastal systems exhibit significant declines.

Authors: Jacoby, C. A., Frazer, T. K., and D. D. Saindon.

Publication Date: 2009.

Title: Water quality characteristics of the nearshore Gulf coast waters adjacent to Citrus, Hernando and Levy Counties, Project COAST 1997–2008.

Document Type: Final Report. Southwest Florida Water Management District, Surface Water Improvement and Management Program. Tampa, FL. 17 pp.

Period of Study: Monthly sampling at ten Crystal River stations (2 in the river) from 1997 to 2008.

Geographic Range: Springs coast, includes ten stations among the Crystal River and estuary.

Variables Measured: Water chemistry including salinity.

General Findings: Chlorophyll (CHL) concentrations are correlated to total nitrogen (TN) and more so to total phosphorus (TP) concentrations. Temporal patterns in TN, TP, and CHL are related to rainfall inputs. Crystal River stations experienced a wide range in salinity values.

Data Format: Figures and tables, and Excel files.

Data Location: In report, and at UF FAS.

Document Location: Project directory.

Executive Summary: [Excerpts] Sampling of water quality along the coast of Citrus, Hernando and Levy Counties began in 1997 and this report summarizes key results from sampling through 2008. Chlorophyll concentrations increased as concentrations of total nitrogen and total phosphorus increased, with a stronger relationship to total phosphorus. Thus, concentrations of total nitrogen, total phosphorus and chlorophyll represent three valuable indicators of eutrophication.

Increased rainfall during the 1998 El Niño event created short-term increases in total nitrogen, total phosphorus, chlorophyll, and decreases in water clarity across all systems. However, the systems recovered from this natural disturbance within 6–8 months.

Analyses indicated that rainfall also affected concentrations of nitrogen, phosphorus and chlorophyll at the level of months. Concentrations differed among wet months and dry months in the Homosassa and Chassahowitzka systems, a pattern likely related to an increased delivery of fresh water containing nutrients. Wet–dry temporal patterns in the Withlacoochee, Crystal and Weeki Wachee were less obvious, but further examination of salinity data revealed spatial patterns in exposure to fresh water. Total nitrogen concentrations increased significantly in the Withlacoochee, Crystal and Homosassa systems, especially during wet months, while increases in total phosphorus concentrations were not as widespread., and a expected, chlorophyll concentrations in these systems increased in response to increased nutrients. In contrast, decreases in nutrient and chlorophyll concentrations were prevalent in the Chassahowitzka and Weeki Wachee systems.

Authors: Jones, G. W. and S. B. Upchurch.

Publication Date: 1994.

Title: Origin of nutrients in groundwater discharging from the Kings Bay Springs.

Document Type: Ambient ground-water quality monitoring program. Southwest Florida Water Management District. 144 pp.

Period of Study: 1950 to 1994.

Geographic Range: Kings Bay surface and groundwater.

Variables Measured: Water chemistry, groundwater levels, loading rates of nitrate.

General Findings: A thorough review of the hydrogeology and groundwater chemistry of Kings Bay. The springshed partially delineated, a monitoring well network established (> 100 wells over ~290 square miles), and the limited historical water chemistry data were compiled. A variable number of water samples were analyzed for 11 ions, 6 nutrients, and several drinking water standards as well as uranium, tritium, and nitrogen isotopes for aging purposes. Results indicate that water discharged is likely < 50 years old based on tritium, and uranium data suggest rapid recharge and flow in a shallow aquifer. Widespread, but on the whole, relatively low nitrate concentrations (0.2 mg/L) prevented N-isotope data from meaningful interpretation. Among the well samples, 7% had nitrate concentrations > 0.6 mg/L. Nitrate isopleths indicate that groundwater concentrations increase both easterly and southerly of Kings Bay. These groundwaters are moving west and expected to raise nitrogen levels in Kings Bay within 20 years. Ground water flow path and nutrient loading models were both developed for Kings Bay. Rates of nitrate loading are discussed by source, concluding that septic tanks, sewage effluent disposal, and turf fertilization are significant sources.

Data Format: Paper tables, district likely has data electronically.

Data Location: In report and possibly at District.

Document Location: Project directory.

Executive Summary: Previous studies have determined that the numerous springs and seeps in the Kings Bay discharge groundwater at the rate of approximately 975 cfs (630 mgd).

Approximately 196 tons of nitrate as N are contained in groundwater discharging from the Kings Bay Springs every year.

The average nitrate concentration of groundwater discharging from the eleven largest springs in Kings Bay is approximately 0.2 mg/L as N. Although this level is low relative to many springs in more developed counties, it is considerably elevated over nitrate concentrations in groundwater in the undeveloped portions of the study area.

One hundred and two wells were sampled for nitrate in the study area. Thirty-two percent had concentrations between 0.2 and 0.6 mg/L NO_3 as N and seven percent had concentrations exceeding 0.6 mg/L. These figures indicate that areas where nitrate in groundwater is significantly elevated above naturally occurring levels (generally < 0.01 mg/L) are widespread.

Historical nitrate data for the study area spring water and groundwater are extremely limited. However, a sample collected in 1975 from Tarpon Hole, the main spring in Kings Bay, indicates that nitrate concentrations have increased by a factor of three between 1975 and the present [1994]. In addition, 3 dedicated monitor wells sampled for this study in 1992 were also sampled for nitrate in 1985. Although the 1992 sampling indicates that nitrate concentrations are still low relative to the drinking water standard of 10 mg/L, they have shown rapid and significant increases in the intervening 7 years.

Ground water in the springs is largely derived from the drainage basin bounded by the Withlacoochee River and a flow-line divergence in south-central Citrus County. Water in the Floridan aquifer to the north of this divergence will discharge in the vicinity of the Kings Bay Springs while water south of the line will discharge in the vicinity of Homosassa Springs.

Sulfate concentration and isotopic data reflect a shallow flow system. Water that is discharging from the Kings Bay Springs entered the Floridan aquifer flow system within the last 50 years.

Sodium/chloride, nitrogen-concentration, and hydrochemical facies data show significant groundwater recharge in the Beverly Hills area.

Ground water in the Coastal Swamp and Brooksville Ridge physiographic provinces is nutrient- and TOC-rich, indicating local recharge.

Nutrient data from groundwater suggest that losses from Lake Tsala Apopka may have served as a low-level natural nitrogen source for the springs for thousands of years.

A plume of what is probably naturally occurring nitrogen is moving toward the springs from Lake Rousseau. Because the lake was constructed relatively recently, it has probably not yet affected the springs.

Nitrogen isotopic data suggest that a portion of the nitrogen in the springs and groundwater in the study area is natural.

There are small, localized sources of development-related nitrogen in the eastern portion of the City of Crystal River. This development-related nitrogen along with naturally occurring nitrogen are probably the sources of the low levels of nitrogen in groundwater discharging from the springs.

The nitrogen sources on the eastern side of the City of Crystal River should be located and mitigated.

The many nitrogen releases resulting from land uses that exist in the study area are elevating groundwater nitrogen concentrations. Groundwater that has been enriched in nitrogen from both development-related and natural sources is moving toward the coast in well-defined plumes from the

east-central and north-central portions of the study area. Within 20 years this nitrogen will reach the Kings Bay Springs and probably increase nitrogen concentrations significantly.

Ten development-related sources of nitrogen common to the study area were investigated. Of these, four sources (septic-tank effluent, effluent disposal from sewage treatment, golf-course fertilization, and residential turf fertilization) are probably contributing the majority of nitrogen to groundwater. These sources are associated with residential and commercial development and can be correlated to areas where nitrogen concentrations are elevated in groundwater. Although the nitrogen contributed by these sources is significantly attenuated by the various vegetative and soil-removal mechanisms, enough reaches groundwater to elevate concentrations to the 0.5 to 1.0 mg/L range, the upper concentration limits in the developed portion of the study area.

The rapid increase in the number of the four principal sources listed above insures that nitrogen concentrations will continue to increase.

Planning for elimination of septic tanks in central Citrus County should begin immediately, with target for county sewer service by the year 2015. First priority should be given to the areas where high nitrogen is present in the Floridan aquifer.

Municipal wastewater treatment facilities should either go to advance wastewater treatment (AWT) or other nutrient-removal technologies.

Monitor-well networks should be installed around golf courses and residential areas to determine the effect of turf fertilization on groundwater quality.

Stormwater runoff in the karst terrain may be responsible for feeding fertilizer-derived nitrogen into the groundwater system.

Stormwater runoff should not be routed directly to sinkholes. Runoff retention and plant fixation of nutrients is a necessary management alternative for sinkholes that receive stormwater from suburban and urban areas.

Authors: King, J. M. and J. T. Heinen.

Publication Date: 2004.

Title: An assessment of the behaviors of overwintering manatees as influenced by interactions with tourists at two sites in central Florida.

Document Type: Biological Conservation. 117: 227–234.

Period of Study: Conducted over two winter seasons, early January to early March of 2001 and 2002.

Geographic Range: Three Sisters Spring of Kings Bay and Blue Waters of Homosassa River.

Variables Measured: Weather, tide, and temperature measured during observation of the numbers of manatees both inside and outside sanctuaries, and the numbers of swimmers and boats outside sanctuaries were recorded.

General Findings: Unlike the studies by Sorice *et al.* (2003, 2006), this study observed measurable negative impacts on manatees from human interaction. Total manatee counts at the Three Sisters site were negatively correlated with water temperature in the Gulf of Mexico and in the sanctuary; and total manatee counts were positively correlated with high tide levels and weather conditions (incoming cold fronts with heavy thunderstorms). Manatee use of the protected sanctuary was positively correlated with both swimmer and boat numbers outside the sanctuary. **Authors** advocated increasing the number of no-entry sanctuaries, more enforcement of manatee harassment, and less in-water tourism.

Data Format: Tables in publication.

Data Location: In publication.

Document Location: Project directory.

Abstract: [Excerpts] Focal animal and scan samples over the course of two winter seasons were used to assess behavioral patterns of manatees as a function of the presence and activities of recreational swimmers and boats in and around Crystal River National Wildlife Refuge, Florida. The nature and outcome of human–manatee interactions and the frequency of harassment of manatees by swimmers were recorded. The use of no-entry sanctuaries by manatees was significantly greater when both the numbers of swimmers and boats increased, and when water temperatures were lower in surrounding areas. Time manatees spent bottom-resting and nursing decreased while the time spent milling and swimming increased when swimmers were present compared with when they were absent. Over half of the direct interactions recorded between swimmers and manatees constituted some form of harassment as defined by USFWS guidelines, and manatees were far more likely to terminate these interactions than were swimmers. We conclude that the existence of no-entry sanctuaries is very important for the conservation of manatees in the area and thought must be given to expanding the sanctuary network. We address, qualitatively, several potential management options to better secure manatees at this critical time of the year.

Authors: Knochenmus, L.A. and D. K. Yobbi

Publication Date: 2001.

Title: Hydrology of the coastal springs ground-water basin and adjacent parts of Pasco, Hernando, and Citrus Counties, Florida.

Document Type: USGS Water-Resources Investigations Report 01-4230. 95 pp.

Period of Study: 1997 through 1998.

Geographic Range: Groundwater of Pasco, Hernando, and Citrus Counties

Variables Measured: Groundwater levels and spring discharge rates.

General Findings: See abstract below.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory

Abstract: The coastal springs in Pasco, Hernando, and Citrus Counties, Florida consist of three first-order magnitude springs and numerous smaller springs, which are points of substantial ground-water discharge from the Upper Floridan aquifer. Spring flow is proportional to the water-level altitude in the aquifer and is affected primarily by the magnitude and timing of rainfall. Ground-water levels in 206 Upper Floridan aquifer wells, and surface water stage, flow, and specific conductance of water from springs at 10 gaging stations were measured to define the hydrologic variability (temporally and spatially) in the Coastal Springs Ground-Water Basin and adjacent parts of Pasco, Hernando, and Citrus Counties. Rainfall at 46 stations and ground-water withdrawals for three counties, were used to calculate water budgets, to evaluate long-term changes in hydrologic conditions, and to evaluate relations among the hydrologic components.

Predictive equations to estimate daily spring flow were developed for eight gaging stations using regression techniques. Regression techniques included ordinary least squares and multiple linear regression techniques. The predictive equations indicate that ground-water levels in the Upper Floridan aquifer are directly related to spring flow. At tidally affected gaging stations, spring flow is inversely related to spring-pool altitude. The springs have similar seasonal flow patterns throughout the area.

Water-budget analysis provided insight into the relative importance of the hydrologic components expected to influence spring flow. Four water budgets were constructed for small ground-water basins that form the Coastal Springs Ground-Water Basin. Rainfall averaged 55 inches per year and was the only source of inflow to the Basin. The pathways for outflow were evapotranspiration (34 inches per year), runoff by spring flow (8 inches per year), ground-water outflow from upward leakage (11 inches per year), and groundwater withdrawal (2 inches per year). Recharge (rainfall minus evapotranspiration)

to the Upper Floridan aquifer consists of vertical leakage through the surficial deposits. Discharge is primarily through springs and diffuse upward leakage that maintains the extensive swamps along the Gulf of Mexico. The ground-water basins had slightly different partitioning of hydrologic components, reflecting variation among the regions.

Trends in hydrologic data were identified using nonparametric statistical techniques to infer long-term changes in hydrologic conditions, and yielded mixed results. No trend in rainfall was detected during the past century. No trend in spring flow was detected in 1931-98. Although monotonic trends were not detected, rainfall patterns are naturally variable from month to month and year to year; this variability is reflected in ground-water levels and spring flows. A decreasing trend in ground-water levels was detected in the Weeki Wachee well (1966-98), but the trend was statistically weak. At current ground-water withdrawal rates, there is no discernible effect on ground-water levels and spring flows. Sporadic data records, lack of continuous data, and inconsistent periods of record among the hydrologic components impeded analysis of long-term changes to the hydrologic system and interrelations among components. The ongoing collection of hydrologic data from index sites could provide much needed information to assess the hydrologic factors affecting the quantity and quality of spring flow in the Coastal Springs Ground-Water Basin.

Authors: Kochman, H. I., G. B. Rathbun, and J. A. Powell

Publication Date: 1985.

Title: Temporal and spatial distribution of manatees in Kings Bay, Crystal River, Florida.

Document Type: The Journal of Wildlife Management. 49(4): 921-924.

Period of Study: November 1977 to October 1981.

Geographic Range: Kings Bay.

Variables Measured: The number and location of manatees.

General Findings: See abstract below.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: The spatial distribution of manatees in Kings Bay is influenced by several factors; most important is the location of artesian springs. The largest and earliest winter aggregations form in the warm-water area around the Main Spring. Although November aggregations may be relatively diffuse, density around the Main Spring increases with the onset of colder weather. Smaller groups that develop at Magnolia Spring during January and February may be caused by human disturbance at the Main Spring (Hartman 1979, p. 25). The low use of Tarpon Spring throughout the winter may relate to its smaller size and limited discharge. Other springs in the bay are associated with cul-de-sacs and narrow, shallow, or weed-choked passes; manatees generally avoid such conditions, especially in the presence of humans (Hartman 1979, pp. 36-41).

Authors: Langtimm, C. A. and C. A. Beck.

Publication Date: 2003.

Title: Lower survival probabilities for adult Florida manatees in years with intense coastal storms.

Document Type: Ecological Applications. 13(1): 257-268.

Period of Study: 1982 to 1997.

Geographic Range: Central west coast of Florida, including Crystal River.

Variables Measured: The number of manatees by location and tropical storm occurrence.

General Findings: Intense coastal storms reduced the survival of adult manatees.

Data Format: Tables and figures In report.

Data Location: In report, and held by USGS Sirenia project.

Document Location: Project directory.

Abstract: The endangered Florida manatee (*Trichechus manatus latirostris*) inhabits the subtropical waters of the southeastern United States, where hurricanes are a regular occurrence. Using mark-resighting statistical models, we analyzed 19 years of photo-identification data and detected significant annual variation in adult survival for a subpopulation in northwest Florida where human impact is low. That variation coincided with years when intense hurricanes (Category 3 or greater on the Saffir-Simpson Hurricane Scale) and a major winter storm occurred in the northern Gulf of Mexico. Mean survival probability during years with no or low intensity storms was 0.972 (approximate 95% confidence interval = 0.961-0.980) but dropped to 0.936 (0.864-0.971) in 1985 with Hurricanes Elena, Kate, and Juan; to 0.909 (0.837-0.951) in 1993 with the March "Storm of the Century"; and to 0.817 (0.735-0.878) in 1995 with Hurricanes Opal, Erin, and Allison. These drops in survival probability were not catastrophic in magnitude and were detected because of the use of state-of-the-art statistical techniques and the quality of the data. Because individuals of this small population range extensively along the north Gulf coast of Florida, it was possible to resolve storm effects on a regional scale rather than the site-specific local scale common to studies of more sedentary species. This is the first empirical evidence in support of storm effects on manatee survival and suggests a cause-effect relationship. The decreases in survival could be due to direct mortality, indirect mortality, and/or emigration from the region as a consequence of storms. Future impacts to the population by a single catastrophic hurricane, or series of smaller hurricanes, could increase the probability of extinction. With the advent in 1995 of a new 25- to 50-yr cycle of greater hurricane activity, and longer term change possible with global climate change, it becomes all the more important to reduce mortality and injury from boats and other human causes and control the loss of foraging habitat to coastal development.

Authors: Langtimm, C. A., T. J. O'Shea, R. Pradel, and C. A. Beck.

Publication Date: 1998.

Title: Estimates of annual survival probabilities for adult Florida manatees (*Trichechus manatus latirostris*).

Document Type: Ecology. 79(3): 981-997.

Period of Study: 1970s to 1998.

Geographic Range: Crystal River, Volusia Blue Spring, and Atlantic Coast manatee populations.

Variables Measured: Observation records for manatees.

General Findings: Annual survival estimates for adult manatees were high at Crystal River and appear likely to maintain growing populations.

Data Format: Some finding in publication.

Data Location: Held by USGS Sirenia project.

Document Location: Project directory.

Abstract: [Excerpt] This paper reports a detailed analysis of annual adult survival in the Florida manatee (*Trichechus manatus latirostris*), an endangered marine mammal, based on a mark-recapture approach. Natural and boat- inflicted scars distinctively "marked" individual manatees that were cataloged in a computer-based photographic system. Photo-documented resightings provided "recaptures." Using open population models, annual adult-survival probabilities were estimated for manatees observed in winter in three areas of Florida: Blue Spring, Crystal River, and the Atlantic coast. After using goodness-of-fit tests in Program RELEASE to search for violations of the assumptions of mark-recapture analysis, survival and sighting probabilities were modeled under several different biological hypotheses with Program SURGE. Estimates of mean annual probability of sighting varied from 0.948 for Blue Spring to 0.737 for Crystal River and 0.507 for the Atlantic coast. At Crystal River and Blue Spring, annual survival probabilities were best estimated as constant over the study period at 0.96 (95% ci = 0.951-0.975 and 0.900-0.985, respectively). On the Atlantic coast, where manatees are impacted more by human activities, annual survival probabilities had a significantly lower mean estimate of 0.91 (95% ci = 0.887-0.926) and varied unpredictably over the study period. For each study area, survival did not differ between sexes and was independent of relative adult age. The high constant adult-survival probabilities estimated for manatees in the Blue Spring and Crystal River areas were consistent with current mammalian life history theory and other empirical data available for large, long-lived mammals. Adult survival probabilities in these areas appeared high enough to maintain growing populations if other traits such as reproductive rates and juvenile survival were also sufficiently high. Lower and variable survival rates on the Atlantic coast are cause for concern.

Author: Lehman, M. E.

Publication Date: 1974.

Title: Oyster reefs at Crystal River, Florida and their adaptation to thermal plumes.

Document Type: M.S. Thesis, University of Florida. 197 pp.

Period of Study: 1973.

Geographic Range: Oyster reefs adjacent to the Crystal River power plant.

Variables Measured: Biomass, diversity, and metabolism of oyster reefs.

General Findings: Oyster reef community metabolism, biomass, and species composition.

Data Format: Figures, tables, and appendices in thesis.

Data Location: In thesis.

Document Location: **Abstract** in project directory.

Abstract: Intertidal oyster reefs receiving thermal effluent from the Crystal River power plant were compared with those unaffected nearby. Field measurements of biomass gave area-weighted estimates of 253 g/m^2 (dry meat weight) for the thermal area, and 256 g/m^2 for the control area. The American oyster, *Crassostrea virginica*, comprised 78% of the total consumer biomass in the thermal area, and 47% in the control area. Lower species diversity in the thermally-affected area may reflect the greater oyster dominance. Oyster spat setting rates were similar in both areas with less seasonal variation in the plume-warmed waters. Total community respiration of reefs in the thermal plume was 20.9 g O_2/m^2/day. Respiration of reefs not in the thermal plume was 15.7 g O_2/m^2/day. Underwater metabolic rates of thermally-affected reefs were six time greater than rates during exposed periods at low tides. The underwater rate was three times the exposed rate for reefs not receiving thermal effluent.

Simple models evaluated and simulated to help understand reef function showed higher turnover rates with the thermal plume model. Simulation of effects of adding thermal waters of another power plant suggested reduced seasonal variation of reef standing stocks. When temperatures were increased 4°C, reef stocks were decreased by 20%. Similarities of reef system structure and function, and comparable energy budgets, of thermally-affected and unaffected reefs, suggest successful adaptation of reefs at Crystal River to thermal plumes.

Food chain diagrams indicated the organic budget of oyster reefs to be as high as 46% of the total organic matter in the water column of the Crystal River estuary.

Author: Littles, C. J.

Publication Date: 2005.

Title: Effects of rapid salinity change on submersed aquatic plants.

Document Type: M.S. Thesis. University of Florida. 42 pp.

Period of Study: August 2004 to October 2004.

Geographic Range: Off-site experimental tanks.

Variables Measured: Aquatic plant growth in response to salinity gradients.

General Findings:

Data Format:

Data Location: Full text: http://purl.fcla.edu/fcla/etd/UFE0011820

Document Location: Project directory.

Abstract: Tropical storms and hurricanes affect pronounced, although acute, changes in the salinity of Florida's many tidally influenced streams and rivers. I examined the responses of *Vallisneria americana*, *Myriophyllum spicatum* and *Hydrilla verticillata* to rapid salinity change to better understand how a dynamic salinity regime can affect macrophyte assemblages. Though this study focused on several key plants that occur in Kings Bay, Florida, results are likely to be applicable to a large number of tidally influenced systems. Macrophytes were exposed to salinities of 5, 15 or 25 ‰ for 1, 2, or 7 days. Following exposure, plants were allowed to recover in freshwater for 28 days. Growth response measurements were then recorded. Plants subjected to salinities of 5 ‰, regardless of exposure period, exhibited no significant responses in growth related measures. *Hydrilla verticillata* exhibited 100% mortality at 15 and 25 ‰, irrespective of exposure duration. Relative to controls, *M. spicatum* and *V. americana* exhibited declines in growth at 15 ‰ after 1 and 2 day exposures; both exhibited significant mortality after a 7-day exposure.

All three species experienced significant mortality at 25 ‰. Storm events are likely to have a marked influence on the vegetative structure of this tidally influenced system.

Author: Lucas, J. R.

Publication Date: 1982.

Title: Feeding Ecology of the Gulf silverside, *Menidia peninsulae*, Near Crystal River, Florida, with notes on its life history.

Document Type: Estuaries. 5(2): 138-144.

Period of Study: Between September 1976 and August 1977.

Geographic Range: Two stations in the Gulf, west of the FPL Crystal River Power Plant were sampled monthly; two marsh supplementary stations and the mouth of Crystal River were sampled once each.

Variables Measured: Gulf silversides (*Menidia peninsulae*) were collected to determine feeding ecology. Plankton tows, temperature, and salinity also collected at stations.

General Findings: No fish were collected during December/January while April-July had highest catches. Young-of-the-year fish appeared in the spring in bays, migrated to the marshes in summer, and in the fall migrated back out into the bays. Migration out of the bays in summer corresponded to peak salinity values for bay waters (28.5 to 31.5 ‰ from June through August). Salinity at all the marsh stations averaged 21.0 ‰ during this time. In September, gulf silversides reappeared in the intake bay when the salinity dropped to 27 ‰. At the mouth of Crystal River on July 15, 1977 salinity was 20.9 ‰ and temperature was 31.7 °C.

Data Format: Tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: Feeding habits of *Menidia peninsulae* were analyzed monthly over a one year period and compared to planktonic prey available at the capture site. Three feeding stages were found: (1) In early spring, young-of-the-year fed on tychoplankton and detritus. (2) From late spring through winter, *M. peninsulae* preyed selectively on calanoid copepods and cypris larvae. (3) Gravid *M. peninsulae* fed primarily on amphipods and larval silversides. In the Crystal River area, *M. peninsulae* reproduce in early spring. Silversides apparently migrate from the higher salinity bays to the lower salinity marshes in the summer, and then move back into the bays in fall.

Authors: Lyons, W. G., S. P. Cobb, D. K. Camp, J. A. Mountain, T. Savage, L. Lyons, and E. A. Joyce, Jr.

Publication Date: 1971.

Title: Preliminary inventory of marine invertebrates collected near the electrical generating plant, Crystal River, Florida, in 1969.

Document Type: Professional Paper Series, Number Fourteen, June, 1971. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Fl. 55 pp.

Period of Study: 1969.

Geographic Range: 21 stations in the nearshore waters (out to 10 mi) of the Gulf of Mexico off the Crystal River power plant.

Variables Measured: The relative abundance of trawl sampled invertebrates and bottom temperature and salinity.

General Findings: Salinity was considered an important factor in distribution, with north vs. south differences and inshore vs. offshore differences.

Data Format: Tables and figures in text.

Data Location: In report

Document Location: Project directory.

Abstract: Two hundred and eight-six taxa of invertebrates from the estuarine area near Crystal River, Florida are reported. The majority of these are mollusks and arthropods. Local distribution of most species is given. Changes in faunal composition between nearshore and offshore stations and between northern and southern stations is related to local salinity gradients. Temperature is not found to be as important as salinity in determining local distributions during the study period. Most species observed have widespread distributions in the western Atlantic, with only a few showing more restricted Carolinian or West Indian affinities.

Authors: Mataraza, L. K, J. B. Terrell, A. B. Munson, and D. E. Canfield, Jr.

Publication Date: 1999.

Title: Changes in submersed macrophytes in relation to tidal storm surges.

Document Type: Journal of Aquatic Plant Management. 37: 3-12.

Period of Study: 1979 through 1997.

Geographic Range: 15 stations in Kings Bay.

Variables Measured: Presence and absence data by submersed aquatic vegetation (SAV) species.

General Findings: Storm surges in Crystal River and Kings Bay cause dramatic reductions in SAV abundance and structure the SAV community in response to salinity tolerance.

Data Format: In report and Excel.

Data Location: UF FAS HOLDINGS, Florida LAKEWATCH.

Document Location: Project directory.

Abstract: We analyzed long-term submersed macrophyte presence-absence data collected from 15 stations in Kings Bay/Crystal River, Florida in relation to three major storm events. The percent occurrence of most species declined immediately after storm events but the recovery pattern after the storm differed among species. *Hydrilla* (*Hydrilla verticillata* (L. F.) Royle) and Eurasian watermillfoil (*Myriophyllum spicatum* L.) exhibited differing recolonization behaviors. Eurasian watermillfoil recolonized quickly after storms but declined in abundance as *hydrilla* began to increase in abundance. Natural catastrophic events restructure submersed macrophyte communities by eliminating the dominant species, and allowing revegetation and restructuring of communities. Tidal surges may also act to maintain species diversity in the system. In addition, catastrophic events remove dense nuisance plant growth for several years, altering the public's perception of the nuisance plant problem of Kings Bay/Crystal River.

Author: Mattson, R. A.

Publication Date: 1995.

Title: Submerged macrophyte communities. Volume VI in a series: a data collection program for selected coastal estuaries in Hernando, Citrus and Levy Counties.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Florida. Southwest Florida Water Management District, Brooksville, Fl. 73 pp. including 47 Figures and 4 Tables.

Period of Study: 1984-1985.

Geographic Range: Estuaries of three river systems and a smaller creek were surveyed: Withlacoochee, Crystal and Weeki Wachee river systems and Hammock Creek. Three sampling stations were established and monitored in the three river-fed estuaries, and single station in the Hammock Creek site. At each of the three river-fed sites, inshore stations were located inside the river mouth (oligohaline), middle stations were located in mesohaline to polyhaline zones, and offshore stations were polyhaline.

Variables Measured: Seagrasses and rooted and drift macroalgae were sampled quarterly in the three river-fed estuaries. The Hammock Creek estuary was sampled quarterly only during 1984. Measures of macrophyte coverage and above-ground biomass are reported. Physical and chemical characteristics of the sampling sites were taken from Dixon (1986) and provided only in summarized table format.

General Findings: [excerpted summary] Seagrass/macrophyte communities in the four estuaries displayed some common characteristics. Inshore sites at river mouths were dominated by *Ruppia maritima*. At Crystal River and Weeki Wachee inshore sites, freshwater macrophytes with some salinity tolerance (*Myriophyllum spicatum* and *Vallisneria americana*) were also present. Middle and offshore stations were comprised of mixed seagrass assemblages, but *Syringodium filiforme* was the dominant species offshore at the two northern sites. *Thalassia testudinum* was the dominant species offshore at Weeki Wachee. The Weeki Wachee estuary supported seagrass beds with the highest cover and standing crop, whereas the lowest cover and standing crop was generally observed in the Withlacoochee estuary. Benthic algae were interspersed in the seagrass beds within each estuary, but comprised a larger portion of the community in the two northernmost estuaries. *Ruppia maritima* was negatively associated with salinity and the author suggests that higher salinities due to freshwater flow reductions may negatively affect *Ruppia* beds in the inshore regions of the study estuaries; freshwater macrophytes in might also be negatively impacted. *Syringodium* and *Halophila* were positively associated with salinity, while *Halodule* and *Thalassia* standing crop had no association with salinity.

Data Format: Figures and tables.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: McKellar, H. N.

Publication Date: 1975.

Title: Metabolism and models of estuarine bay ecosystems affected by the Crystal River power plant.

Document Type: Ph.D. Dissertation, University of Florida. 270 pp.

Period of Study:

Geographic Range: Gulf of Mexico nearshore waters by the Crystal River power plant.

Variables Measured: Community and plankton metabolism, phosphorus, chlorophyll, temperature, salinity, and light penetration.

General Findings: The power plant thermal discharge appeared to favor planktonic rather than benthic communities. Phosphorus concentrations were higher in the power plant areas.

Data Format: Figures, tables, and appendices.

Data Location: In dissertation.

Document Location: **Abstract** in project directory.

Abstract: Effects of coastal power plants on an adjacent estuarine bay ecosystem at Crystal River on the west coast of Florida were evaluated with measurements and models to help understand relationships and predict the consequences of adding an additional power plant. An energy circuit model, including metabolism, migrations, and water exchange, was used to address issues concerning the interface of power plants and estuarine ecosystems. Field measurements were taken from "discharge" and "control" bays. Comparisons and inferences are made concerning the effect of the power plant on ecosystem structure and function, especially production, community respiration and nutrient relations.

Plankton populations dominated total metabolism in the discharge bay while benthic systems dominated in the control bays. Annual average gross planktonic production was 3.06 and 1.93 g O_2/m^2/day in the discharge and control bays, respectively. Annual average planktonic chlorophyll in the discharge bay (2.97 g/m^3) was 34% higher than in the control bay (2.21 g/m^3). Zooplankton respiration was between 3 and 9% of total planktonic respiration and between 0.5 and 1.5% of total community respiration.

Power plant influence on total community metabolism was small with less than 10% difference in annual averages 2 (5.22 and 5.58 g O_2/m^2/day in the discharge and control bays, respectively).

During most of the year total phosphorus concentrations in the discharge bay water were more than 20% higher than in the control bay although the annual averages were similar (44.1 and 40.9 mg/m^3 for the discharge and control bays, respectively). Dissolved inorganic phosphorus was consistently higher (10%) in the discharge bay, suggesting power plant effect on the regeneration of inorganic nutrients.

Concentrations o f chlorophyll, phosphorus, and zooplankton were measured along transects from the bays at Crystal River to stations on the outer Gulf Shelf. Distinct gradients existed from the more concentrated waters in the bays to the dilute waters of the outer shelf. The seaward effects of the power plant could not be distinguished from these gradients.

Biomass in the discharge bay system was less but with higher rates of organic turnover. The total biomass of producers in the discharge bay during the summer (36.5 g/m^2) was about 20% lower than in the control bay (45.9 $gm/^{m2}$). The productive turnover time of the producers was 4.9 days in the discharge bay and 5.6 days in the control bay.

The model was programmed to simulate seasonal aspects of energy flow and storage in the bay ecosystem; responses to coefficient settings representing control conditions were found to be similar to those observed in the control bays. When the isolated effects of increased temperature were simulated, the model responded with slight increases in total metabolism and some component biomass. The simulated detritus compartment reached lower steady concentrations with each increase in temperature. The detritus storage perhaps played a significant role in the system's capacity to increase metabolism and component biomass when temperatures increased. These simulations also showed increased nutrient stocks in the water and temperature-induced changes in migrations.

In the simulation model water exchange dampened large fluctuations in zooplankton, phosphorus, and detritus stocks and thus was a stabilizing factor.

Simulation of the effects of future power plants on the bay showed no large changes in total community metabolism. The major changes resulted from programmed effects of plankton entrainment mortality and temperature-induced migrations.

Author: Meigs-Friend, G.

Publication Date: 2003.

Title: Manatee winter distribution in Kings Bay, Crystal River, FL and its application to the design of manatee speed zones and sanctuaries in the bay.

Document Type: Master's Thesis. Duke University. Durham, NC. 35 pp.

Period of Study: 1997 to 2002

Geographic Range: From the Crystal River power plant south to the Chassahowitzka River, including Kings Bay.

Variables Measured: The number and location of manatees.

General Findings: The objective of this study was to understand winter distributional patterns of manatees in Kings Bay and use this information to determine whether existing manatee sanctuaries and speed zones are appropriate or need to be modified. Manatees are found throughout Kings Bay in the winter, although some portions of the bay are used more than others. The Magnolia Springs area, the Three Sisters Springs area, and the waters between Banana Island and Sunset Shores have the highest manatee use. The largest aggregations occur near the main spring, where over 100 manatees have been seen in one location. Areas where the highest densities of manatees occur are consistent across each of the five years. Manatees begin using the bay in large numbers in November and disperse from the bay in April. In winter, manatees concentrate in the southern and eastern portions of the Bay, aggregating near important springs in the largest numbers during the coldest months.

Four areas identified as potential sites for new sanctuaries. Two would be additions to existing sanctuaries: Magnolia Springs and south Banana Island. The other two would be in totally new locations, but both are intended to protect manatees using the Three Sisters Springs area. The addition to the south Banana Island sanctuary would add 1.75 hectares to the sanctuary. The addition to the Magnolia Springs sanctuary would add 0.34 hectares to the sanctuary. New Sanctuary # 3, located along the shore just east of existing sanctuary at Three Sisters Springs, would only have an area of 0.06 hectares. New Sanctuary # 4, located in the residential canal just south of Three Sisters Springs would total 0.18 hectares.

Data Format: Figures in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Author: Mountain, J. A.

Publication Date: 1972.

Title: Further thermal addition studies at Crystal River, Florida with an annotated checklist of marine fishes collected 1969 to 1970.

Document Type: Professional Paper Series, Number Twenty, December, 1972. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Fl. 109 pp.

Period of Study: 1970 through 1971.

Geographic Range: 21 stations in the nearshore waters (out to 10 mi) of the Gulf of Mexico off the Crystal River power plant.

Variables Measured: Trawl sampling for fish, temperature and salinity data, and trace metals in oysters.

General Findings: This report (5 of 5) contains the most data regarding temperature and salinity of the Gulf waters west of the Crystal River power plant. A wide range of salinities occurred in the study area. An annotated list of fish observed over the project is provided.

Data Format: Table, figures, and appendices.

Data Location: In report.

Document Location: Project directory.

Abstract: Hydrographic and biological data collected during the first six months of 1971 are presented. These, plus 1969 and 1970 data, complete an ecological survey of estuarine and coastal areas near Florida Power Corporation's Crystal River steam electric generating station. This base line information should be compared with data collected after a nuclear generator becomes operational (mid-1974 or later).

Discharge canal temperature was directly related to electrical power output, with two daily peaks and a notable decrease from late night to early morning. A wide range of salinities occurred in the study area.

Trace metal levels were recorded near the power plant are also presented. Highest copper levels were recorded in April 1971 (63.0 ppm) and October 1969 (80.0 ppm). Correlatives may include spawning activity, increased metabolic rates, and copper ions in coal pile runoff water.

Distribution of benthic algae and invertebrates was similar to that previously reported.

An annotated checklist of fishes collected during the 2 ½ year study is appended. Based on some 33,000 specimens (53 families), the list includes 95 identified species plus 9 either grouped together or identified to genus only. Diversity indices ($S-1/L_e N$) were calculated from 1971 fish data and comparable periods in 1969 and 1970. The pattern of values for stations nearer river influence differed from the pattern at more remote stations.

Author: Munson, A. B.

Publication Date: 1999.

Title: Water clarity in Kings Bay/Crystal River Florida.

Document Type: M.S. Thesis. University of Florida. 142 pp.

Period of Study: Monthly from August 1996 to October 1997, December 1997, March, and May 1998.

Geographic Range: Stations in Kings Bay.

Variables Measured: Temperature, dissolved oxygen, conductivity, TN, TP, CHL, Secchi, and light.

General Findings: Water clarity in Kings Bay is a function of suspended solids, most of which are algal.

Data Format: In thesis, electronic files available from UF LAKEWATCH.

Data Location:

Document Location: Text copy in project directory.

Summary: [Excerpts] The water clarity in Kings Bay/Crystal River is primarily determined by the concentrations of suspended solids in the water column, with solids contributed by algal cells the primary fraction. The hypothesis that the canals attached to Kings Bay/Crystal River are the main source of these solids does not appear to be supported by the data. Average suspended solids, chlorophyll and nutrient concentrations in the canal are not significantly different from the corresponding averages in the bay. The total volume of water in the canals located in the southeast corner of Kings Bay/Crystal River is only about 25% of the volume of the bay southeast of Banana Island. Thus, concentrations of solids, chlorophyll, or nutrients in the canals would have to be four times as high as the bay and all of that water would have to mix with the bay to cause a one unit increase in the concentrations of solids, chlorophyll or nutrients of the bay. In addition, the long term monitoring of water chemistry in Kings Bay/Crystal River show that the nutrient concentrations have been steadily decreasing since 1993.

Long term monitoring of aquatic plant biomass suggests that major storm events are a strong force determining the abundance of aquatic plants in Kings Bay/Crystal River. Combining these data with long term monitoring of water chemistry from the Florida LAKEWATCH program suggests that the fluctuations in aquatic plant biomass are inversely related to chlorophyll concentrations that are indicators of algal abundance. Suspended solids, primarily suspended solids due to algal abundance, was the primary factor determining water clarity in Kings Bay /Crystal River. Therefore, fluctuations in the aquatic plant biomass in Kings Bay/Crystal River could be responsible, in part, for reported fluctuations in water clarity. Thus, when aquatic plant abundance is high in Kings Bay/Crystal River then water clarity is high and when aquatic plant abundance is low so is water clarity.

Author: Notestein, S. K., T. K. Frazer, S. R. Keller, and R. A. Swett.

Publication Date: 2005.

Title: Kings Bay vegetation evaluation 2004.

Document Type: Annual Report, Project W457. Southwest Florida Water Management District, Brooksville, FL. pp. 94.

Period of Study: February, May, July, and October of 2004.

Geographic Range: Seventy-one stations in Kings Bay.

Variables Measured: Percent coverage and biomass of submersed aquatic vegetation (SAV).

General Findings: Eight angiosperms, one attached macroalga, and a mix of filamentous algae were observed in Kings Bay during four sampling events in 2004. Filamentous algae were recorded most frequently, occurring in 69% of all sample quadrats. The non-native plants *Myriophyllum spicatum* and *Hydrilla verticillata* occurred in 59% and 45% of all sample quadrats, respectively. Native plants were less common, with *Najas guadalupensis* and *Potamogeton pusillus* observed in 38% and 29% of all sample quadrats, respectively. *Vallisneria americana*, occurred in 16% of the quadrats sampled.

Based on the 2004 data, it appears that macroalgal coverage peaks during spring while angiosperm coverage was maximal in summer. Average above-ground biomass of SAV in 2004 was 0.165 kg dry wt/m^2, with peak biomass values during the summer, *i.e.* 0.227 kg dry wt/m^2. Filamentous algae constitute the majority of SAV biomass (~ 90%) in Kings Bay, regardless of season. The reduction in coverage and biomass values observed during the fall for both macroalgae and angiosperms may be a consequence of the tropical storms preceding the fall sampling. Lowest mean coverage and biomass estimates occurred in winter and likely reflect temporal reductions of light and temperature as well as increased manatee foraging.

Data Format: Figures, tables, and appendices in report, and electronic files.

Data Location: In report and UF FAS.

Document Location: Project directory.

Abstract: None.

Author: Notestein, S. K., T. K. Frazer, S. R. Keller, and R. A. Swett.

Publication Date: 2006.

Title: Kings Bay vegetation evaluation 2005.

Document Type: Annual Report, Project W457. Southwest Florida Water Management District, Brooksville, FL. pp. 96.

Period of Study: February, May, July, and October of 2005.

Geographic Range: Seventy-one stations in Kings Bay.

Variables Measured: Percent coverage and biomass of submersed aquatic vegetation (SAV).

General Findings: Eight angiosperms, one attached macroalga, and a group of filamentous algae were observed in Kings Bay during four sampling events in 2005. Filamentous algae occurred in 58% of sample quadrats (69% in 2004). Non-native plants *Myriophyllum spicatum* and *Hydrilla verticillata* both occurred in approximately 36% of sample quadrats (59% and 45% in 2004). Native plants were slightly more common, with *Najas guadalupensis* and *Potamogeton pusillus* observed in 48% and 39% of sample quadrats, respectively (38% and 29% in 2004). *Vallisneria americana*, occurred in 16% of the quadrats sampled as it did in 2004.

Patterns of macroalgal coverage in Kings Bay were fairly consistent across the seasonal sampling periods. Coverage by angiosperms, were more variable and generally lowest during winter (likely a consequence of seasonal reductions in light availability and increased manatee foraging). Estimates of biomass, in general, followed the patterns reported for coverage.

Average above-ground biomass of SAV in 2005 was 0.112 kg dry wt/m^2, with peak biomass values during the fall, *i.e.* 0.150 kg dry wt/m^2. The majority of SAV biomass was comprised of macroalgae, though the percent contribution (60-90%) varied depending on the seasonal sampling period, while angiosperms accounted for only 16% of the SAV biomass in Kings Bay during 2005. Estimates of SAV biomass are low in comparison to historical data (Haller *et al.* 1983; Terrell and Canfield 1996; Mataraza *et al.* 1999; Hoyer *et al.* 2001).

Data Format: Figures, tables, and appendices in report, and electronic files.

Data Location: In report and UF FAS.

Document Location: Project directory.

Abstract: None.

Author: O'Shea, T. J., J. F. Moore, and H. I. Kochman.

Publication Date: 1984.

Title: Contaminant concentrations in manatees in Florida.

Document Type: The Journal of Wildlife Management. 48(3): 741-748.

Period of Study: 1977 to 1981.

Geographic Range:

Variables Measured: Various organic compounds and trace elements contained in manatee tissues.

General Findings: Determining geographic trends in copper concentrations in the livers of manatees stemmed from concern over exposure of manatees to copper used as an aquatic herbicide in Crystal River. Except for copper, findings indicate that manatees are not excessively contaminated by the substances studied. Copper concentrations in livers of manatees were highly variable. Significant effects due to herbicide use (regions of probable high, moderate, or low exposure to copper herbicides) and a significant negative correlation with size (higher values in smaller animals) were found.

Data Format: Tables and figures in publication.

Data Location: In publication.

Document Location: In project directory.

Abstract: The status of the endangered manatee (*Trichechus manatus*) in relation to organochlorine pesticides, polychlorinated biphenyls, mercury, lead, cadmium, copper, iron, and selenium was investigated in Florida from 1977 to 1981. Concentrations of organochlorines in blubber, mercury in muscle and liver, lead in liver, and lead and cadmium in kidneys did not indicate high exposure to these contaminants. Only cadmium in kidneys showed a positive correlation with relative age. No significant relationship existed between iron and copper in liver; selenium concentrations in liver were low. Copper concentrations in livers of these aquatic herbivores were significantly elevated in areas of high herbicidal copper usage after adjustment for significant age-related effects; upper values of 1,200 ppm dry weight exceeded all previously reported concentrations in livers of any species of wild mammals from free-ranging populations. Liver copper concentrations comparable to those associated with toxic effects in some domestic species were found in manatees from areas of high copper herbicide use. The use of copper herbicides for control of aquatic plants should be carefully managed in areas used intensively by manatees.

Author: Packard, J. M. (*editor*).

Publication Date: 1983.

Title: Proposed research/management plan for Crystal River manatees.

Document Type: Technical Report no. 7. Volumes I - Summary, II - Technical Plan, and III - Compendium. Florida Cooperative Fish and Wildlife Research Unit. University of Florida. Gainesville, Fl. 549 pp.

Period of Study: Review of data up to 1983.

Geographic Range: Springs Coast, with emphasis on Crystal River/Kings Bay.

Variables Measured: A wide variety of biological, physical, chemical, geopolitical, legal, and sociologic data as they apply to manatees.

General Findings: A broad and comprehensive report primarily concerning manatee preservation in Crystal River. Probably not directly relevant to MFL, but there are numerous sub-reports within this file (*e.g.* Kochman *et al*. 1983 Use of Kings Bay, Crystal River, Florida, by the West Indian Manatee).

Data Format: Figure, tables, and appendices in report (Three volumes).

Data Location: In report. Electronic files may be at UF

Document Location: Project directory.

Abstract: None.

Author: Phillips, T.D.

Publication Date: 1986.

Title: Fishes and macroinvertebrates. Volume III in a series: a data collection program for selected coastal estuaries in Hernando, Citrus and Levy Counties.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Florida. Southwest Florida Water Management District, Brooksville, Fl. 31 pp. plus 3 Figures, 10 Tables and 21 Appendices.

Period of Study: 1984 to 1985.

Geographic Range: Study area spanned 120 km of the central Florida Gulf coast, including the region from Aripeka (Hammock Creek) to Waccasassa Bay. During 1984, fish sampling was focused on Crystal River and Aripeka from April through August. Sampling was modified in 1985 to encompass the months of February through November. In addition, Waccasassa River and Bay replaced Aripeka as a study location.

Variables Measured: Fish and macroinvertebrate abundance as determined from various sampling gears (seines, otter trawls, and cast nets); temperature, salinity, and dissolved oxygen at selected depths at each site.

General Findings: [from summary section] Each of the three rivers surveyed varied in respect to their source and amount of freshwater inflow, their general morphology, and types and quantities of SAV present. Crystal River was reported to be heavily vegetated along its entire length, whereas Aripeka was sparely vegetated and Waccasassa had little or no SAV. Physical data are reported only in tabular form and the reader is referred to the companion Volume I of the report series (Dixon 1986) for a discussion of salinity structure and water chemistry data in each of the rivers. The same species of fishes and macroinvertebrates were collected from all three systems. Temporal patterns of abundance (suggestive of seasonality) were apparent and similar among the three river systems. Major differences in the areal extent of submersed habitat types were reported to result in differences in the relative abundance of the species collected. Juvenile fish and shellfish were found to use various portions of each river (presumably as important nursery areas). A number of interacting factors, including water temperatures, salinities, and the presence/absence of SAV, were implicated as determinants of the distribution and abundance of fishes and macroinvertebrates within the three river systems.

Data Format: Figures, tables, and tabulated data in appendices.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Authors: Rathun, G. B., J. P. Reid, and G. Carowan.

Publication Date: 1990.

Title: Distribution and movement patterns of manatees (*Trichechus manatus*) in northwestern peninsular Florida.

Document Type: Florida Marine Research Publications. Number 48. Department of Natural Resources. Florida Marine Research Institute. St. Petersburg, Fl. 39 pp.

Period of Study: 1981 to 1985.

Geographic Range: Between Suwannee and Chassahowitzka Rivers.

Variables Measured: Manatee numbers and movement.

General Findings: See abstract below.

Data Format: Tables and figures in report.

Data Location: Report.

Document Location: Project directory.

Abstract: [Excerpts] This paper presents information on the distribution and movement patterns of manatees in northwestern peninsular Florida (defined herein as the western coast between the Suwannee and the Chassahowitzka rivers). Data were obtained by aerial surveys conducted at least monthly from April 1981 through August 1985, radio-tracking studies from winter 1978-79 through winter 1985-86, and re-sightings of recognizable individual manatees from April 1981 through August 1985.

The data from these three types of surveys show that manatees in the northwestern Florida use primarily the headwaters of the Homosassa and Crystal rivers as their winter, warm-water refuges. Of the 100 manatees studied that had recognizable scar patterns, an average of 92.4% of the females and 84.2% of the males returned to the same winter refuges each year. Intensive 24-h radio tracking of three individuals indicated that all three spent most of their daylight hours near these warm-water refuges, but on some nights they traveled downstream as far as 7 km to feed on *Ruppia maritima* and *Potamogeton pectinatus* in estuarine areas. The 24-h tracking studies also showed that the use of downriver areas was more extensive than results of the aerial and daylight surveys indicated.

Manatees were observed moving away from their winter, warm-water habitats as early as March. They dispersed into the Waccasassa and Withlacoochee rivers, the Florida Power Corporation Crystal River power plant effluent canal, and the Cross Florida Barge Canal (these areas were used mainly during the spring and summer as routes between principal winter and summer habitats. The manatees then entered their summer habitats in estuaries associated with the Suwannee, Crystal, Homosassa, and Chassahowitzka rivers.

Authors: Rodgers, J. H. and B. M. Johnson.

Publication Date: 2008.

Title: Crystal River *Lyngbya* risk and management assessment.

Document Type: Final report submitted to Florida Department of Environmental Protection. Tallahassee, Fl. 17 pp.

Period of Study: April and June to September, 2007 and February and April, 2008.

Geographic Range: 7 stations in Kings Bay.

Variables Measured: Evaluation of *Lyngbya* toxin production and toxicity to aquatic organisms. Evaluation of costs and risks of ongoing mechanical harvesting, evaluation of chemical control tactics, and other potential control methods.

General Findings: The study was limited in temporal and spatial scope. *Lyngbya wollei* was identified but laboratory toxin studies were not rigorous and generally found to be inconclusive. Laboratory herbicide tests reported chlorophyll-*a* as response variable and observed significant decreases relative to controls for Hydrothol and copper-containing herbicides (at levels exceeding label restrictions). Physical management tactics deemed feasible include diver dredging, hand rake harvesting, and current mechanical harvesters. No biological control measures were deemed feasible. Herbicides deemed feasible include copper-based and peroxide-based formulations at levels that would be prohibited.

Data Format: As tables and figures in report.

Data Location: Prime author is Clemson faculty.

Document Location: Project directory.

Abstract: [Excerpts] A study of problematic *Lyngbya* in Kings Bay in Crystal River, FL was conducted, with emphasis on accurate characterization of risks as well as development of risk mitigation strategies. To accomplish this, the objectives of this study were: 1) *Lyngbya* assessment, 2) *Lyngbya* management assessment, 3) Evaluation of potential chemical control tactics, and 4) Evaluation of other control options. *Lyngbya* assessment involved identification of the problematic species of *Lyngbya* and evaluation of potential toxin production. *Lyngbya* management assessment examined the cost effectiveness and potential risks of current mechanical efforts to control *Lyngbya* in Kings Bay and included and economic and environmental assessment of the harvesting tactic. Laboratory phytotoxicity experiments were used to measure the efficacy of algaecides to control this problematic strain of *Lyngbya*. Biological, physical, chemical, and mechanical control tactics or potential uses of combinations of these tactics were investigated. Because of its heterogeneous distribution, a uniform or homogeneous solution for the *L. wollei* problem is unlikely. The outcome of this study was data and information organized to facilitate informed water resource management decisions.

Author: Romie, K. F.

Publication Date: 1990.

Title: An evaluation of factors contributing to the growth of *Lyngbya* sp. In Kings Bay/Crystal River, Florida.

Document Type: Southwest Florida Water Management District. August 23, 1990. Final Report submitted to Florida Department of Environmental Regulation. Tallahassee, Fl. 142 pp.

Period of Study: Prior 1989 to 1990.

Geographic Range: Kings Bay, multiple stations.

Variables Measured: Three part study: 1) water quality and loadings of nutrients measured by SWFWMD; 2) growth and bioassay of *Lyngbya* by B. Cowell; 3) water motion and retention by USGS.

General Findings: This report (year 1 of 3) includes three other reports as appendices: 1) B. Cowell on *Lyngbya* population dynamics and distribution; 2) B. Cowell on factors contributing to *Lyngbya* growth; and 3) water motion and retention times by USGS. SWFWMD observed negative impacts of STP point source and stormwater runoff into canals on Kings Bay water quality. SWFWMD recommend reducing nutrient loading to Kings Bay by closing the City of Crystal River STP, disposal of STP sludge outside watershed, treating stormwater runoff, and connecting septic systems to central sewers. Cowell observed that salinity was the best predictor of *Lyngbya* distribution, in that, *Lyngbya* was not salt tolerant (nor is *hydrilla*). Nutrient concentrations were not good predictors of *Lyngbya*, but *hydrilla* was negatively correlated to total phosphorus. Cowell recommended removal of *Lyngbya* mats and organic sediments with macrophyte re-planting.

Data Format: Tables in report.

Data Location: In report, and maybe at SWFWMD electronically.

Document Location: Project directory.

Executive Summary: *Lyngbya majuscula*, a filamentous blue-green alga, became established in portions of Kings Bay in the mid-1980s. *Lyngbya* grows on the bottom o f the bay, and also forms large floating mats. These surface mats have several negative effects: they impair navigation and recreational uses of the water body, and decay of the algae produces a foul, musty odor. Portions of these algal mats may wash up on banks and canals, further impairing the aesthetic quality of Kings Bay. This project was initiated in March, 1989, to find the causes of the *Lyngbya* infestation, and to identify possible management actions to control the growth and expansion of this alga in Kings Bay. The first year of this three-year was funded by a U.S. Environmental Protection Agency 205J Grant, administered by the Florida Department of Environmental Regulation (FDER). The remainder of the project is supported by the Southwest Florida Water Management District's Surface Water Improvement and Management (SWIM) Program, funded by the State of Florida, and administered by the FDER. The project is

comprised of three elements: (1) Southwest Florida Water Management District study of the water quality of Kings Bay/Crystal River and an estimate of the nutrient loading to Kings Bay; (2) population dynamics of *Lyngbya* in Kings Bay/Crystal River and the response of *Lyngbya* to nutrient enrichment, a study performed by Dr. Bruce Cowell, Department of Biology, University of South Florida; and (3), water motion and retention times in Kings Bay, a study undertaken by the United States Geological Survey (USGS). The project is to be completed in March 1992. This report details the findings of project cooperators for the first year of the study, in fulfillment of 205J Grant requirements.

Water Quality- Increased loading of nitrogen and phosphorus due to development of the watershed is a suspected cause of infestations of *hydrilla* and *Lyngbya* in Kings Bay. It has been well documented that the nutrients nitrogen and phosphorus most commonly limit the growth of aquatic macrophytes and algae in fresh water ecosystems (Hutchinson 1973, Dillon and Rigler 1974, Canfield 1983). There are four major sources of these nutrients entering Kings Bay: (1) the springs discharge; (2) the city sewage treatment plant which discharges treated effluent in the northwest quarter of the bay; (3) stormwater runoff from residential and commercial developments, roads, and parking lots; and (4) leachate from septic tanks systems and package plants in the vicinity of Kings Bay. Springs in Kings Bay contribute a large proportion of the total nutrient loads of both total nitrogen and total phosphorus to Kings Bay. However, Kings Bay is tidally affected through its entire length, and is a flowing water system. Tidal cycle affects the residence time of water in canals and bays, the current velocity, direction, and patterns of water motion in the bay, as well as head differences between surficial groundwater and bay waters. Water motion and water retention times vary throughout the bay, which affects whether nutrients are flushed from, or accumulate in areas of Kings Bay. Point discharges such as the sewage treatment plant, stormwater outfalls, and to some extent septic system leachate, most likely have their greatest potential for impacting water quality in the immediate areas of their discharge. Effluent from the City of Crystal River Sewage Treatment Plant is discharged into Cedar Cove, a small area (approximately 40 acres) of Kings Bay. Mean concentration of ortho-phosphate and total phosphorus were significantly greater in Cedar Cove than for other Kings Bay stations. The highest mean concentrations of nitrate-nitrite were associated with stations in Cedar Cove and a larger area extending outside of Cedar Cove. It can be concluded that ambient concentrations of nitrate-nitrite, ortho-phosphate, and total phosphorus in the vicinity of Cedar Cove are impacted by the discharge from the city sewage treatment plant. The network of canals in the City of Crystal River convey stormwater runoff directly into Kings Bay. Water samples collected from the canals typically had higher concentrations of nitrogen and phosphorus than receiving waters. No direct evidence was found that suggested the canals had an impact on nutrient concentrations in Kings Bay, however, no Kings Bay water samples were collected during rain storms, and regular sampling stations were not in the immediate areas of stormwater outfall. It is likely that the canals impact nutrient concentrations in the immediate areas of their outfall, particularly during periods of rainfall and in receiving waters that are not well-flushed. Septic tank systems are poorly suited to waterfront development built on Kings Bay and adjoining canals, due to severe soil limitations for septic systems and the extremely shallow depth (< 5 feet) to tidally-influenced groundwater. Nitrate, and to a lesser extent ortho-phosphate from septic tank/package plant systems ultimately enter the bay, through nutrient contamination from these sources is more diffuse than point sources and may, therefore, be difficult to detect.

Factors Affecting the Growth of *Lyngbya*- Large benthic mats and surface mats of *Lyngbya* were observed in Cedar Cove, suggesting a relationship between the sewage treatment plant effluents and nuisance biomasses of *Lyngbya*. However, nutrient-*Lyngbya* relationships were not revealed by multiple regression methods (Dr. Bruce Cowell, Attachment A). Cowell found specific conductivity and the abundance of *hydrilla* accounted for 61.8 percent of the variability in the biomass of *Lyngbya* (dry weight) in Kings Bay. Other variables only accounted for an additional 4 percent of the total variability of *Lyngbya* biomass. *Hydrilla* biomass (dry weight) in Kings Bay was negatively related to total phosphorus and the presence of *Lyngbya* and other macrophytes. *Lyngbya* biomass and total phosphorus together explained 40.7 percent of the total variability of *hydrilla* biomass. The addition of other variables caused only small increases (1.1 to 2.9 percent) in the proportion of the variability explained by the respective models. Neither *hydrilla* biomass nor *Lyngbya* biomass seemed to be significantly affected by nutrient concentrations, with the exception of the negative relationship between *hydrilla* biomass and total phosphorus. Finally, Dr. Cowell suggested that changes in substrate composition and redox potential may inhibit the establishment and growth of more desirable aquatic macrophytes.

Water Motion and Retention Time- The U.S. Geological Survey have completed development of a preliminary model of Kings Bay, and have collected much of the necessary data for calibrating a final model. Preliminary results estimate that particles take from 3 to 7 weeks to flush from Kings Bay, depending upon the area in the bay the particle is introduced. A preview of the preliminary model in May 1990 revealed that Cedar Cove may be somewhat isolated from the general flow of water out of the bay due to the action of currents and eddies which form at the mouth of the cove. This may result in greater flushing times, and the possible accumulation of nutrients in the cove. The model will be completed and a report issued in March 1992.

Management Considerations- Recommendations for the improvement of water quality in Kings Bay include: (1) Diversion of the City of Crystal River Sewage Treatment Plant effluents from Kings Bay. Overland spraying of effluent, if outside the immediate watershed, would reduce ambient concentrations of nutrients in Cedar Cove. (2) Disposal of treatment plant sludge outside of the immediate watershed. Sludge is currently stored in piles on the banks of the discharge canal. Nutrient-rich leachate from these piles may enter the canal system during periods of rainfall. (3) Appropriate pre-treatment of stormwater runoff would reduce nutrient and organic sediment loading of outfall areas in Kings Bay. (4) Residences utilizing septic tank/package plant systems should be sewered to a regional facility. If this is not feasible, mounded drainfield systems might be utilized to ensure that adequate drainfield depth exists for the effective treatment of effluents. A regular program of inspection would ensure that systems are properly maintained and operating at optimum efficiency.

Dr. Cowell's recommendations for the management and restoration of *Lyngbya*-infested areas include: (1) Remove benthic *Lyngbya* mats. (2) Prevent the influx of rafting *Lyngbya* mats. (3) Hydraulic dredging of sediments, and planting of new macrophytes. An investigation of Crystal River sediments, funded by the District's SWIM Program is currently underway to document the extent of this problem, and identify areas in Kings Bay which have been adversely impacted by increased sediment loading.

Author: Rosenau, J. C., G. L. Faulkner, C. W. Hendry, Jr., and R. W. Hull.

Publication Date: 1977.

Title: Springs of Florida.

Document Type: Bulletin No. 31 (Revised). Department of Natural Resources, Division of Resource Management, Bureau of Geology. Tallahassee, FL. 461 pp.

Period of Study: 1975 and review of earlier data.

Geographic Range: Kings Bay.

Variables Measured: Water chemistry and discharge reported.

General Findings: Average discharge was 916 cfs (Oct 1964 to Sep 1975); water chemistry values for January 8, 1975 presented.

Data Format: Tables and text in document.

Data Location: In document.

Document Location: Project directory.

Abstract: None.

Author: Sagoff, M.

Publication Date: 2009.

Title: Environmental harm: political not biological.

Document Type: Journal of Agricultural and Environmental Ethics. 22: 81-88.

Period of Study: n/a.

Geographic Range: n/a.

Variables Measured: n/a.

General Findings: This publication is a response to Evans *et al*. 2008. Sagoff concludes by saying "The recent history of the Kings Bay/Crystal River ecosystem poses the question whether environmental management involves principally scientific or political decisions. To appeal to the analytic framework of adaptive management is to punt this question. This framework may produce a decision either (1) that is not scientifically valid, insofar as the scientific community has had to cave into the stakeholder community, or (2) that is not politically legitimate, insofar as the scientific community has used its authority to trump the stakeholder community. More likely, different scientists will align with different stakeholders, resulting in no decision but a process of indecision, influenced by unexpected events, and affected by changing interests. As far as I can see, this method of adaptive ecosystem management provides an academic blessing for this kind of ''group grope''—a way to institutionalize paralysis by analysis and to guarantee indecision over the long run. The managers of the Kings Bay/Crystal River ecosystem, even without the benefit of the methodology of adaptive management, appear to have reached this result. Perhaps without knowing it, they have been applying the method all along".

Data Format and Location: n/a.

Document Location: Project directory.

Abstract: In their fine paper, Evans *et al.* (2009) discuss the proposition that invasive non-native species (INS) are harmful. The question to ask is, ''Harmful to whom?'' Pathogens that make people sick and pests that damage their property—crops, for example— cause harms of kinds long understood in common law and recognized by public agencies. The concept of ''harm to the environment,'' in contrast, has no standing in common law or legislation, no meaning for any empirical science, and no basis in a political consensus other than might be drawn from the Endangered Species Act. As a generalization, the proposition that INS cause ''environmental harm''—since this concept is empty of legal, scientific, and political meaning—must rest on definition, diktat, or diatribe. As Evans *et al.* suggest, however, the idea of ''harm to the environment'' is not always and certainly need not be arbitrary; it might gather significance in the context of a particular place through a political process that weighs economic concerns with cultural, religious, aesthetic, and other relevant beliefs, practices, and commitments that people who care about that place present. It is not clear, however, that adaptive management, which Evens *et al.* propose, will provide that democratic political process.

Author: Saindon, D.

Publication Date: 2005.

Title: Quantifying the magnitude of nutrient limitation on phytoplankton in Kings Bay, Florida, USA.

Document Type: M.S. Thesis. University of Florida. 41 pp.

Period of Study: October 11, 2004.

Geographic Range: Two stations in Kings Bay.

Variables Measured: Nutrient limitation of phytoplankton

General Findings:

Data Format: In report, and Excel files.

Data Location: Full text: http://purl.fcla.edu/fcla/etd/UFE0013336

Document Location: Project directory

Abstract: [Excerpts] In this study, nutrient addition and dilution assays were used to quantify the magnitude of nutrient (nitrogen and phosphorus) limitation, and characterize the two-dimensional response surface of phytoplankton across a broad range of nutrient concentrations and N:P ratios. Water from two sites in Kings Bay, Florida (USA) was filtered using a Millipore® stirred cell concentrator, which allowed a fixed percentage of site water and nutrients to be removed while maintaining ambient abundances of plankton. DI water and stock solutions of nitrogen and phosphorus were added to return samples to their original volumes and create nutrient concentration treatments that ranged from one half to 10 times the ambient concentration of phosphorus, and one quarter to 15 times the ambient concentration of nitrogen. Growth rates and maximum biomass were estimated using *in vivo* fluorescence measures. Magnitude of limitation was quantified by estimating how much the response variable changed per unit of nutrient concentration. Phytoplankton growth rates were not limited by nitrogen or phosphorus at one site, but limited by both nitrogen and phosphorus at the other site. The overall estimated magnitude of limitation for this latter site was a 0.1011 change in per capita algal growth (d^{-1}) for each mg L^{-1} of nitrogen, and a 1.1268 change in per capita algal growth (d^{-1}) for each mg L^{-1} of phosphorus. Neither site showed significant nitrogen/phosphorus interaction effects on growth rate responses. However, there was a significant interactive effect of nitrogen and phosphorus on maximum biomass responses at both sites. Qualitative assessment of the response surfaces for maximum biomass suggests that this variable is affected by both the N:P ratio of nutrient treatments as well as the total amount of nutrients supplied. Since the magnitude of limitation of one nutrient is determined by the concentration of the other nutrient, an overall magnitude of limitation may either overestimate or underestimate the expected maximum biomass response for specific co-occurring changes in nutrient concentrations. Magnitude of limitation should be determined on a case by case basis.

Author: Simberloff, D.

Publication Date: 2009.

Title: Moving beyond strawmen and artificial dichotomies: adaptive management when an endangered species uses an invasive one.

Document Type: Journal of Agricultural and Environmental Ethics. 22: 73-80.

Period of Study: n/a.

Geographic Range: n/a.

Variables Measured: n/a.

General Findings: This publication is a response to Evans *et al*. 2008. Simberloff has four main points of contention: 1) mischaracterization of Simberloff's views and Kings Bay (he does not believe non-indigenous species are *a priori* harmful, disputes that invasion biologist have generally advocated aggressive control of invasive species, rather that it is difficult to identify harmful invaders early and precaution is warranted, and the unique aspect of Kings Bay is quashed, because he provides examples where non-indigenous plant species are used by endangered animals or used for conservation purposes elsewhere); 2) inaccurate and inappropriate focus on extinctions (*e.g.* failing to note the role of plants in bird extinction); 3) living organisms get around (dangerous to propose use of non-indigenous submersed aquatic vegetation; and 4) adaptive management is more easily said than done (terms are not defined and vague about implementation).

Data Format: n/a.

Data Location: n/a.

Document Location: Project directory.

Abstract: Evans *et al.* (Journal of Agricultural and Environmental Ethics, 2008) have attempted to enmesh me in their dispute with the Florida Bureau of Invasive Plant Management about a specific system, Kings Bay/Crystal River. In so doing, they repeatedly mischaracterize my positions in order to depict, incorrectly, invasion biology as monolithic and me as a representative of one extreme of a false dichotomy about management of introduced species. In addition, they introduce an issue irrelevant in this case (extinctions) and cite incorrect data. Proposing to manage people, manatees, introduced plants, and cyanobacteria in Kings Bay by participative adaptive management, they ignore the fact that living organisms can both disperse autonomously and hitchhike. Finally, they present few details on any aspect of their management proposal and do not address the myriad problems that have beset previous attempts at scientific adaptive management, especially at large scales. Until such a management approach is fleshed out and implemented, it is impossible to assess its validity for Kings Bay, and it is very premature to suggest it as a general model for dealing with invasive species disputes.

Author: Smith, W. H. B.

Publication Date: 1976.

Title: Productivity measurements and simulation models of a shallow estuarine ecosystem receiving a thermal plume at Crystal River, Florida.

Document Type: Ph. D. Dissertation. University of Florida. 426 pp.

Period of Study: 1974 to 1976.

Geographic Range: Gulf of Mexico near the Crystal River power plant.

Variables Measured: Community (plankton and benthic) metabolism measured.

General Findings: Benthic populations dominated total metabolism in both heat-affected and non-affected areas of the Crystal River bay.

Data Format: Figures, tables, and appendices in dissertation.

Data Location: In dissertation.

Document Location: Permanent Link: http://www.uflib.ufl.edu/ufdc/?b=UF00084178&v=00001

Abstract: The effects of the heated discharge of two power plants on the receiving estuarine ecosystem near Crystal River on the west coast of Florida were investigated with measurements and simulation models to help understand relationships and predict the consequence of a third power plant under construction. Energy circuit models emphasizing diurnal and seasonal aspects of ecosystem responses were used to assess the effects of power plant operation on estuarine ecosystems. Field measurements were taken in the discharge-affected and –unaffected areas nearby.

Benthic populations dominated total metabolism in both systems. Community gross primary production varied seasonally in the unaffected areas from a winter low o 3.3 g O_2/m^2 day to a spring high of 8.8 g O_2/m^2 day. In the discharge area it was relatively constant, remaining about 4 g O_2/m^2 day in all seasons. Phytoplankton production normally was about 5% of total production in the unaffected areas and about 23% in the discharge area. In the spring its contribution increased greatly to 25% in the unaffected area and 70% in the discharge area.

Total biomass was less in the discharge than in unaffected areas. Lower standing stock of primary producers and benthic invertebrates in the discharge area accounted for almost all the difference.

Diversity was lower in the discharge bay than in the unaffected area. Mixed macroalgae and seagrasses were the dominant benthic producers in the unaffected areas, while seagrass *Halodule wrightii* was virtually the only species in the discharge bay. Species diversity was lower for oyster reef organisms, and fewer species of fish were caught in drop nets in the discharge bay than in the unaffected bay.

A shift toward more cycling of material and energy through the phytoplankton and filter feeders and away from the benthic components of the system may have occurred in the discharge area as an adaptation to the thermal plume.

Simulation of the model of diurnal system properties with coefficients representing those for discharge conditions gave patterns similar to those measured in the discharge bay. The model was relatively insensitive to adjustments in water temperature within the range expected in the future at Crystal River. A change in the quantity of daily insolation producer a larger change in model response.

The simulation model of seasonal system properties was also more sensitive to light than to water temperature. Increasing temperature alone increase primary production and total respiration somewhat, especially in the spring. Fish and invertebrate biomass remained the same, while detrital storages declined, perhaps indicating their importance as an energy source for offsetting increased respiratory drains on consumers because of increased temperature. Increases in light alone greatly increased system storages and flows, suggesting the importance of turbidity in controlling metabolism in the discharge area. Increasing temperature by decreasing light lowered metabolism.

Adjustments to the seasonal model tested the theory that systems with prominent seasonal pulses may be exploited by populations that move in during the period of plenty, experience rapid exponential growth, and then move away. With some migration the fish stock could maintain itself in the stable oscillating yearly pattern.

Results of other adjustments to the seasonal model suggested that seasonal substitution of species of primary producers may be the most effective way to make a maximum use of available energies at all times of the year.

Authors: Sorice, M. G., C. S. Shafer, and D. Scott.

Publication Date: 2003.

Title: Managing endangered species within the use/preservation paradox: understanding and defining harassment of the West Indian manatee (*Trichechus manatus*).

Document Type: Coastal Management. 31: 319-338.

Period of Study: January to March 2000.

Geographic Range: Kings Bay and Crystal River.

Variables Measured: Human observation, 34 interviews, and Citrus County Chronicle and St. Petersburg Times newspaper archives analyzed from 1996 to 2000.

General Findings: How human interaction might "significantly disrupt normal behavioral patterns" of manatees (as defined in the Endangered Species Act and Florida Manatee Sanctuary Act) and the meaning and application of the term harassment in Crystal River are explored in this publication. This study addressed some of these questions by evaluating how different stakeholder groups viewed the concept relative to the manatee and then by analyzing data to determine how applying and enforcing harassment policy might be implemented. The term "harassment" in relation to manatees is defined and enforcement issues explored. Generally the terms are vague and enforcement is a gray area. A higher level of specificity is needed as well as the development of policy that is less vague and more easily enforceable.

Data Format: Discussion in publication.

Data Location: In publication.

Document Location: Project directory.

Abstract: As the popularity of interacting with marine mammals in the wild increases, managers face the challenge of providing use while simultaneously protecting the target species. Because the West Indian manatee (*Trichechus manatus*) is protected from harassment by formal legislation, there is some concern regarding manatee encounters in Crystal River, Florida, USA, where tourists swim with the endangered animals. This study examined how the construct of harassment is defined and specifically applied to manatee encounters. Three major themes emerged: stakeholders impose their own values when interpreting formal definitions of harassment; a definition of harassment is difficult to apply in the field; and enforcement efforts are confounded by these and other variables in the setting. Thus, the issue of harassment is not a technical one but largely an issue of social value. Management implications are discussed and a management framework is recommended to find common ground and establish best practices. This publication stems from the lead authors MS Thesis: Sorice, M. 2001. A multistakeholder perspective on human interactions with the West Indian manatee (*Trichechus manatus*) in Crystal River, Florida, U.S.A. Master's thesis, Texas A&M University, College Station, TX.

Authors: Sorice, M. G., C. S. Shafer, and R. B. Ditton.

Publication Date: 2006.

Title: Managing endangered species within the use-preservation paradox: the Florida manatee (*Trichechus manatus latirostris*) as a tourism attraction.

Document Type: Environmental Management. 37(1): 69-83.

Period of Study: January and March 2000.

Geographic Range: Kings Bay.

Variables Measured: Human observation, in-depth interviews, and literature review.

General Findings: Education and enforcement of human/manatee encounters at Kings Bay are increasingly compounded as visitation rates increase. Identifies options that U. S. Fish and Wildlife Service has to protect manatees further: 1) declare all of Kings Bay as a manatee refuge; 2) use language in the Marine Mammal Protection Act to regulate human/manatee interaction. Advocates best practices to 1) spread human use better across time of day and day of week; 2) identify inappropriate human behavior and consequences; 3) use smaller fins to make it harder for people to pursue manatees.

Data Format: Limited quantitative data are presented.

Data Location: In report.

Document Location: Project directory.

Abstract: A significant challenge to wildlife managers in tourism settings is to provide visitors with opportunities to observe rare and endangered wildlife while simultaneously protecting the target species from deleterious impacts. Nearly 100,000 people annually visit Crystal River, Florida, USA to observe and swim with the Florida manatee, an endangered species. This research aimed to investigate and describe human–manatee interactions in a tourism context, to understand the salient issues related to such interactions as identified by stakeholders, and to recommend a course of action to address multiple interests in the planning and management of human–manatee interactions. Five issues were identified by all stakeholder groups: water quality, harassment, density and crowding, education, and enforcement. Currently, the U.S. Fish and Wildlife Service, which is responsible for manatee management, does not have mechanisms in place to manage the tourism component of the manatee encounter. Although a regulatory approach can be taken, a better approach would be to create an organization of tour operators to establish ‘‘best practices’’ that reflect the goal of the managing agency to enhance manatee protection (and thus ensure their livelihood) and to enhance the visitor experience.

Author: Southwest Florida Water Management District (SWFWMD).

Publication Date: 1989.

Title: Crystal River/Kings Bay surface water improvement and management plan.

Document Type: Final Report. Southwest Florida Water Management District, Resource Management Department. Tampa, Florida. 86 pp.

Period of Study: Prior to 1989.

Geographic Range: Kings Bay.

Variables Measured: Review of goals, initiative, programs, and projects.

General Findings: See executive summary below. This report reviews findings to date.

Data Format: Figures, tables, and appendices in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary [Excerpts]: The four goals of the 1989 SWIM plan were: To preserve and enhance environmentally sensitive areas of the Crystal River/Kings Bay system. To reverse the environmental degradation of the system. To optimize water quality and other habitat values, thereby promoting the sustained existence or re-establishment of thriving, integrated biological communities. To promote the uses of the natural resources such that a healthy ecosystem is maintained and provide stable economic input to the area. Four sets of initiatives include: water quality–addressing water quality improvement; natural systems–addressing habitat protection/restoration and fisheries/shellfish management; land and public use- addressing land uses affecting the use of the resource; and water body management–addressing the legal framework for comprehensive management and public education.

Seventeen project areas are listed, many of which appear to have been completed.

Author: Southwest Florida Water Management District (SWFWMD).

Publication Date: 2000.

Title: Crystal River/Kings Bay surface water improvement and management (SWIM) plan.

Document Type: Final Report. Southwest Florida Water Management District, Resource Management Department. Tampa, Florida. 60 pp.

Period of Study: Review of data prior to 2000.

Geographic Range: Kings Bay and Crystal River.

Variables Measured: Review of the state-of-knowledge concerning Kings Bay.

General Findings: see **Executive Summary** below.

Data Format: Figures, tables, and appendices in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary: SWIM legislation requires the water management districts to protect the ecological, aesthetic, recreational, and economic value of the state's surface water bodies. Crystal River/Kings Bay was selected as a priority SWIM water body and is also classified by the state as Class Ill waters and as an Outstanding Florida Water (OFW). The first management plan was prepared and approved in 1989. Many of the projects identified in the original plan were studies and data collection efforts. The results of this diagnostic work provided the necessary technical information to develop the management strategies for this first update. Twenty-one species of amphibians, 47 species of reptiles, 191 species of birds, and 22 species of mammals were documented from the Crystal River/Kings Bay watershed including 26 state or federally listed species.

Reductions in water clarity and the presence and spreading of *Lyngbya* sp., a nuisance aquatic cyanobacteria are the major management issues for the Crystal River/Kings Bay system. Water clarity in Kings Bay is primarily affected by the concentration of suspended solids in the water column. The suspended solids are primarily the result of bottom sediments being re-suspended by either wind action or physical disturbance. While aquatic vegetation is important to the water clarity of the system, undesirable aquatic vegetation has presented a problem for the residents of Crystal River since the introduction of *Hydrilla* in 1960 and *Lyngbya* sp. in the mid 1980's.

The Crystal River/Kings Bay SWIM Plan has established the following goals: achieve and maintain water clarity that will provide an annual average bottom depth horizontal Secchi reading of 45 feet; stabilize or remove the sediment from areas which have been demonstrated to contribute to reduced water clarity as a result of sediment resuspension; re-vegetate denuded areas with desirable submersed aquatic vegetation; and restore vital aquatic habitat.

Studies completed under the original plan concluded that there was no direct relationship found between nutrient concentrations and aquatic plant biomass in Kings Bay (Bishop and Canfield 1995). Additional work performed under the original plan determined that chlorophyll concentrations are weakly related to nutrients in Kings Bay (Hoyer *et al.* 1997). Total phosphorus and total nitrogen accounted for only 8 percent and 4 percent of the variance in chlorophyll concentrations respectively. This weak relationship suggests that factors other than nutrients are accounting for the variance in chlorophyll and as such support a proposed Pollutant Load Reduction Goal (PLRG) of "zero" for nutrients. For the Crystal River/Kings Bay system, suspended sediments are affecting water clarity and an interim goal for suspended solids, based on available data would be to reduce the suspended sediment component in the water column by 50 percent to allow for an annual average horizontal Secchi reading of 45 feet.

Strategies to achieve the goals include: projects to improve water clarity primarily through sediment management efforts such as sediment removal, sediment stabilization through revegetation, stormwater retrofit projects and habitat restoration projects. This plan is a logical extension of the original plan and provides a clear strategy towards reaching the described goals.

Author: Southwest Florida Water Management District (SWFWMD).

Publication Date: 2001.

Title: Springs Coast comprehensive watershed management plan.

Document Type: Final Report. Southwest Florida Water Management District, Brooksville, Florida. 128 pp.

Period of Study: 1950 to 2000.

Geographic Range: Springs coast (Pasco, Hernando, and Citrus Counties).

Variables Measured: Summary of the region.

General Findings: Report is organized into five chapters: 1) introduction and watershed description, 2) water supply, 3) flood protection, 4) water quality, and 5) natural systems.

Data Format: Limited to a few tables and text values.

Data Location: In report.

Document Location: Project directory.

Executive Summary: [Excerpts] Water supply goals include assessment and establishment of minimum flows and levels and prevention of groundwater contamination. Water quality goals include the reduction of nitrate concentrations, development of a water quality monitoring network, continue implementation of restoration plans for water bodies including the Crystal River/Kings Bay surface water and improvement plan. Natural system goals include limiting the destruction and fragmentation of natural systems, control of invasive exotic plants, address declining groundwater and lake levels, and actively manage publicly-owned lands.

Author: Southwest Florida Water Management District (SWFWMD).

Publication Date: 2004.

Title: Crystal River/Kings Bay technical summary, 1966 - 2004.

Document Type: Final Report. Southwest Florida Water Management District, Resource Management Department, SWIM Program. Tampa, FL. pp. 48.

Period of Study: Review of knowledge prior to 2004.

Geographic Range: Kings Bay.

Variables Measured: Review of knowledge prior to 2003.

General Findings: This is a revised version of the SWFWMD (2003) report. This report summarizes the technical studies completed to date for Crystal River/Kings Bay and provides historical and current information on the system.

Data Format: Figures in report.

Data Location: In report.

Document Location: Project directory.

Executive Summary: Crystal River/Kings Bay is located in Citrus County approximately 60 miles north of Tampa, Florida. The first magnitude spring system that forms the 600-acre Kings Bay embayment has an average total discharge rate of 975 cubic feet per second (cfs) and is the second largest spring system, as measured by discharge, in the state of Florida. This tidally influenced embayment is the headwater of Crystal River, which terminates approximately 6 miles west in the Gulf of Mexico. The Crystal River/Kings Bay watershed supports numerous listed and unlisted wildlife species, including the West Indian manatee. Accordingly, the unique ecological attributes of Crystal River/Kings Bay were recognized by the state of Florida in 1983 through its designation as an Outstanding Florida Water (OFW). To date, commercial and recreational activities associated with the distinctive habitat and wildlife of Kings Bay have supported the local economy. However, rapid development of the watershed has occurred, coincident with increases in the County's population from approximately 9,268 in 1960 to approximately 118,085 in 2000. This development has increased human-related activities that are impacting water quality and natural systems in Kings Bay.

In 1988, the Southwest Florida Water Management District (District) included Crystal River/Kings Bay in the list of priority water bodies established for the Surface Water Improvement and Management (SWIM) Program. Subsequently, four primary management issues were identified and incorporated in the original Crystal River/Kings Bay SWIM Plan (SWFWMD 1989). These issues included septic tank/wastewater treatment plant effluent, urban and agricultural stormwater, recreational uses, and sediment/aquatic vegetation. Collaborative projects between the District and partners, to address the management issues, were initially diagnostic in nature with limited implementation/monitoring efforts.

Results of these early projects, completed from 1991 through 1995, provided much needed information on groundwater quality discharging from the Kings Bay springs, sediment contamination, sediment composition and factors affecting growth of *Lyngbya* sp. in the bay. In 1991 and 1992, prioritization of stormwater projects and installation of channel markers to protect manatees and facilitate boat traffic were implemented, respectively, in Kings Bay. A volunteer water quality monitoring program, LAKEWATCH, was initiated by the District and University of Florida in 1992; which continues at a reduced scale to date. Implementation of stormwater projects by the District and City of Crystal River and the cessation of effluent discharge, in 1992, from the City of Crystal River's wastewater treatment plant into Kings Bay were initial strides in addressing the wastewater effluent and stormwater issues.

However, by the mid-1990's growing concerns led to the initiation of diagnostic and implementation projects aimed at improving water clarity in Kings Bay. Results of the diagnostic studies characterized the bay's complex circulation and flushing patterns and identified suspended solids as the leading factor impacting water clarity. A dredging project to remove sediments and *Lyngbya* mats from Hunters Spring and Tarpon Hole was completed in 1997. Anecdotal reports indicated that the springs quickly silted in following completion of the dredging project.

In 2000, the first update of the Crystal River/Kings Bay SWIM Plan (SWFWMD 2000) redefined the management issues to emphasize projects addressing water clarity, proliferation of *Lyngbya* and resuspension of sediments. Continued diagnostic studies from 2001 through 2003 focused on water clarity and aquatic plants, including the possible relationship between these management issues. A pilot restoration effort to replant native tape grass (*Vallisneria americana*) in areas of Kings Bay indicated that large-scale plantings would likely fail because of manatee grazing. In 2003, the District and City of Crystal River completed implementation of three stormwater improvement projects designed to reduce nutrients and suspended solids entering the bay through stormwater runoff

Recognizing the need to improve the coordination of restoration and management activities in Kings Bay, the District facilitated the formation of an inter-agency advisory group that includes public participation. From the initial meeting on October 2, 2003, the advisory group has reviewed the results of diagnostic studies, data from water quality monitoring programs and success of implementation projects completed to date in Kings Bay. Additionally, the advisory group has evaluated impacts on rooted aquatic plants from the use of mechanical harvesters to remove benthic algal mats and proposed a cooperative shoreline restoration project to buffer seawalls with stands of emergent plants. Collectively, the advisory group supports active management of nitrogen loading, in the form of nitrate, within the Kings Bay watershed through implementation of stormwater improvement projects and public education activities. District activities proposed and/or initiated in 2004 to address nitrate management include continued implementation of stormwater projects, origination of education and outreach programs and identification of land uses within the watershed with potentially elevated nitrate concentrations. Discussions with the advisory group have led District staff to propose three studies to address the effects of light, sediments and natural shoreline on the growth and success of rooted aquatic plants in the bay. Results of these studies will help determine if sustainable aquatic plant communities can be established, based on the current light and sediment conditions, in Kings Bay.

Authors: Sprinkel, J.

Publication Date: 1986.

Title: Oyster reefs. Volume IV in a series: a data collection program for selected coastal estuaries in Hernando, Citrus, and Levy Counties, Florida.

Document Type: Report prepared by Mote Marine Laboratory, Sarasota, Fl. Southwest Florida Water Management District, Brooksville, Fl. 80 pp.

Period of Study: 1984 and 1985.

Geographic Range: Three stations running offshore of the Waccasassa, Withlacoochee, Crystal, Weeki Wachee rivers and one station off Hammock Creek (Aripeka).

Variables Measured: Cover of suitable substrate was measured, numbers of live oysters in three size classes and numbers of gaping oysters were recorded, and an estimate of condition was calculated based on oyster size and dry weight of oyster tissue. Water quality data from an accompanying study were used to characterize the conditions, including salinities, at the sampling stations.

General Findings: Locations with higher freshwater inflows, *i.e.*, Withlacoochee and Crystal rivers, had more extensive and numerous reefs. Larger oysters occurred where salinities were lower, *i.e.*, river mouths. Offshore reefs displayed higher levels of infestation with boring sponges *Cliona* spp. Flow that yields food supply and exposure to lower salinity that reduces infestation by boring sponges aids in the development and persistence of oyster reefs.

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Authors: Stavros, Hui-Chen W., R. K. Bonde, and P. A. Fair.

Publication Date: 2008.

Title: Concentrations of trace elements in blood and skin of Florida manatees (*Trichechus manatus latirostris*).

Document Type: Marine Pollution Bulletin. 56(6): 1215-1233.

Period of Study: January 4-5, 2007.

Geographic Range: Upper Crystal River.

Variables Measured: Eight manatees captured with blood and tissue samples collected. Sediment and aquatic vegetation samples also collected. All samples analyzed for trace elements.

General Findings: First report on free-ranging manatee baseline trace element levels. Of the trace elements determined in this study, thallium (Tl) and uranium (U) were not detected in any blood samples and levels of cadmium (Cd), cobalt (Co), lithium (Li), nickel (Ni), tin (Sn), vanadium (V) and total mercury (Hg) were generally low in the blood and skin tissues, compared to those in plant and sediment. Significantly higher antimony (Sb) and zinc (Zn) concentrations were found in blood and skin tissue than those measured in plant samples. Additionally, significantly higher selenium (Se) levels were found in skin tissue than those in plants. For manatees, significantly higher trace element concentrations were found in the skin tissue than those in the blood, except for arsenic (As), copper (Cu) and iron (Fe). No differences between blood and skin tissues were found for barium (Ba), lithium (Li), lead (Pb), Sn, Hg, and Zn. Concentrations of Cd, Cu, Fe, Pb and Hg in skin of Florida manatees were lower than those previously reported in liver and kidney of stranded manatees. However, free-ranging manatees did show approximately six times higher Se levels in their skin compared to those in liver tissue of stranded manatees.

All trace element concentrations measured in blood and skin tissue of the manatees were lower and/or within the range of other studies of free-ranging marine mammals, except for As and Zn in blood and aluminum (Al) in skin tissue. Different dietary exposure and foraging habits may be the primary factors which contribute to differences in trace element concentrations between Florida manatees and other marine mammals. Relatively higher Al concentrations in the skin tissue of manatees warrant further investigation on exposure source, trophic transfer, and potential adverse effects of this element to Florida manatees.

Data Format: Tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Authors: Steidinger, K. A. and J. F. Van Breedveld.

Publication Date: 1971.

Title: Benthic marine algae from waters adjacent to the Crystal River electric power plant (1969 and 1970).

Document Type: Professional Papers Series. Number 16, June 1971. Florida Department of Natural Resources. Marine Research Laboratory. St. Petersburg, Fl. 56 pp.

Period of Study: Monthly collections, February to December, 1969 and February, April, June, August, October, and December, 1970.

Geographic Range: 21 stations in the nearshore waters (out to 10 mi) of the Gulf of Mexico off the Crystal River power plant.

Variables Measured: Macroalgae collected in a 15 ft try net with 1" mesh.

General Findings: Bottom temperatures and salinities measured during 1970 sampling. Species list of algae generated. Red algae dominated the collections at 50 to 80% of the samples.

Data Format: Marine macroalgae species list.

Data Location: In report.

Document Location: Project directory.

Abstract: One hundred and six taxa of marine algae were identified from Gulf of Mexico waters adjacent to the Florida Power Corporation electrical generating plant at Crystal River, Florida, in 1969 and 1970. Of the 106 taxa, 19 belong to Chlorophyta, 24 to Phaeophyta, and 63 to Rhodophyta.

Reductions in species diversity, as well as incidence of occurrence, were noted in 1970. Causes of these reductions are not known. However, increased temperature does not appear to be a factor since deeper water stations, which were also affected, are not exposed to the thermal plume.

The study area is semi-tropical or warm-temperate, with a primarily seasonal flora. Winter appeared to be the season of lowest species diversity. Several new distribution records are reported.

Authors: Terrell, J. B. and D. E. Canfield, Jr.

Publication Date: 1996.

Title: Evaluation of the effects of nutrient removal and the "Storm of the Century" on submersed vegetation in Kings Bay–Crystal River, Florida.

Document Type: Journal of Lake and Reservoir Management. 12(3): 394–403.

Period of Study: 1989 to 1994.

Geographic Range: Kings Bay, multiple stations.

Variables Measured: Water chemistry and submersed aquatic vegetation (SAV) composition and abundance.

General Findings: Water chemistry examined throughout Kings Bay. In Cedar Cove, total nitrogen (TN) and total phosphorus (TP) concentrations decreased after Crystal River sewage treatment plant stopped inputs (southern Kings Bay TN and TP concentrations did not decline however). SAV occurrence patterns did not appear to follow water chemistry patterns and instead, storm surge was anecdotally implicated in changes in SAV abundance.

Data Format: Tables and figures in report.

Data Location: In report and Excel files at UF FAS.

Document Location: Project directory.

Abstract: Municipal wastewater effluent was removed in 1992 from a cove (Cedar Cove) of Kings Bay in an attempt to reduce the bay's ambient total phosphorus (TP) and total nitrogen (TN) concentrations. Many citizens and professionals viewed nutrient removal as the solution to reducing the bay's nuisance growths of aquatic macrophytes and filamentous algae. Wastewater removal reduced average TP from 105 µg/L to 27 µg/L and average TN from 620 µg/L to 220 µg/L in Cedar Cove. TP (24 µg/L to 28 µg/L) and TN (300 µg/L to 260 µg/L), however, were not significantly reduced in southern Kings Bay. There were no significant changes in mean frequency of occurrence of *Vallisneria* in Cedar Cover (0% to 1%) or southern Kings Bay (19% to 22%). Average *hydrilla* occurrence decreased significantly after wastewater removal in Cedar Cove (54% to 36%) and southern Kings Bay (61% to 35%). Eurasian watermillfoil occurrence significantly increased in Cedar Cove (6% to 24%) and southern Kings Bay (11% to 32%). Filamentous algal occurrence in Cedar Cove averaged 34% prior to and 40% after wastewater removal. In southern Kings Bay, the frequencies of occurrence averaged 5% and 2%, respectively. If removal of Crystal River's wastewater discharge was responsible for the differences detected in plant abundances, the same reductions/increase in species abundance should not occur in Cedar Cove as in southern Kings Bay. Significant changes in plant occurrence were attributed to the March 13, 1993 "Storm of the Century," not to the removal of wastewater. Further nutrient control is not recommended as an option for reducing nuisance growths of submersed aquatic vegetation in Kings Bay-Crystal River, Florida.

Author: USF and FFWCC.

Publication Date: 2010.

Title: An Investigation of freshwater inflow effects on fish and invertebrate use of the Crystal River Estuary.

Document Type: Scope of work. Final due to SWFWMD April 9, 2010.

Period of Study: Monthly collections March 2008 to February 2009, bi-monthly collections March 2009 to January 2010.

Geographic Range: Six zones from Kings Bay to the near shore Gulf of Mexico.

Variables Measured: Fish and invertebrates collected with plankton, seine, and trawl nets. Water quality profiles of temperature, conductivity, salinity, pH and dissolved oxygen at 1-m intervals. GPS coordinates of sampling locations.

General Findings: TBD.

Data Format: Figures and tables in report.

Data Location: In report, district will have electronic files.

Document Location: Have scope of work, need final report when available.

Abstract: TBD.

Author: United States Geological Survey (USGS).

Publication Date: Data collection efforts as of February 2010.

Title: Data review from the USGS Florida Water Science Center.

Document Type: Florida Water Science Center. Available data summary from four active sites and six historic sites. Web page: http://fl.water.usgs.gov/ and http://waterdata.usgs.gov/fl/nwis/dv. Accessed February 2010.

Period of Study: Variable durations as listed below; both current and historic data.

Geographic Range: Crystal River, Salt River, and Kings Bay.

Variables Measured: Variables as listed below.

General Findings: Provides a source of historical and current data.

Data Format: Electronic files of various formats for much of the data.

Data Location: Online or via request to USGS Florida Integrated Science Center–Tampa, Fl.

Document Location: Data so no document. See summaries that follow.

Abstract: None.

USGS 02310742. **Crystal River at the mouth of Kings Bay**

Latitude 28°53'36.1", Longitude 82°36'20.0", NAD83

Citrus County, Florida, Hydrologic Unit 03100207

Drainage area: 46.0 square miles

Datum of gage: 0.00 feet above sea level, NGVD29

Available data:

Real-time–previous 120 days

Daily data

Temperature, water, degrees Celsius, top, 2006-12-01 to 2010-02-09, 1163 records

Temperature, water, degrees Celsius, bottom, 2006-12-01 to 2010-02-09, 1163 records

Gage height, feet, 2006-12-01 to 2010-01-31, 2181 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius, top, 2006-12-01 to 2010-02-09, 1163 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius–bottom, 2006-12-01 to 2010-02-09, 1163 records

Field/lab water-quality samples, 2006-12-18 to 2009-12-09, 44 records

Additional data sources:

Annual water-data report (pdf), not online, 2007 to 2008, 2 records

USGS 02310747. Crystal River at Bagley Cove near Crystal River, estuary site.

Latitude 28°54'23", Longitude 82°37'26", NAD83

Citrus County, Florida, Hydrologic Unit 03100207

Available data:

Real-time–previous 120 days

Daily data

Temperature, water, degrees Celsius, near bottom, 2002-08-14 to 2010-02-09, 5196 records

Stream velocity, feet per second, 2005-10-01 to 2010-02-09, 1498 records

Discharge, cubic feet per second–not filtered for tide, 2002-10-01 to 2010-02-09, 2589 records

Gage height, feet, 2002-08-14 to 2010-01-25, 5206 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius–near bottom, 2002-08-14 to 2010-02-09, 5192 records

Discharge, tidally filtered, cubic feet per second–residual, 2002-08-16 to 2009-10-13, 2456 records

Daily statistics

Stream velocity, feet per second, 2005-10-01 to 2009-10-13, 1392 records

Discharge, cubic feet per second–not filtered for tide, 2003-10-01 to 2009-10-13, 2118 records

Discharge, tidally filtered, cubic feet per second-residual, 2002-08-16 to 2009-10-13, 2456 records

Monthly statistics

Stream velocity, feet per second, 2005-10 to 2009-10

Discharge, cubic feet per second–not filtered for tide, 2003-10 to 2009-10

Discharge, tidally filtered, cubic feet per second–residual, 2002-08 to 2009-10

Annual statistics

Stream velocity, feet per second, 2006 to 2010

Discharge, cubic feet per second–not filtered for tide, 2004 to 2010

Discharge, tidally filtered, cubic feet per second–residual, 2002 to 2010

Field measurements, 2002-09-23 to 2010-01-07, 272 records

Field/lab water-quality samples, 2006-10-03 to 2009-12-08, 20 records

Additional data sources:

Instantaneous-data archive, not online, 2003-10-01 to 2007-09-30, 136596 records

Annual water-data report (pdf), not online, 2006 to 2008, 3 records.

USGS 02310750. Crystal River near Crystal River, stream site.

Latitude 28°54'16", Longitude 82°38'25", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Available data:

Daily data

Discharge, cubic feet per second, 1964-03-01 to 1977-09-30, 4962 records

Gage height, feet, 1970-10-01 to 1989-09-30, 8038 records

Salinity, water, unfiltered, parts per thousand, 1984-05-18 to 1985-08-28, 1185 records

Tide stage, above datum, feet, 1982-10-01 to 1989-09-30, 4222 records

Elevation above NGVD 1929, feet, 1977-10-01 to 1986-09-30, 4383 records

Daily statistics

Discharge, cubic feet per second, 1964-03-01 to 1977-09-30, 4962 records

Salinity, water, unfiltered, parts per thousand, 1984-05-19 to 1985-08-28, 393 records

Monthly statistics

Discharge, cubic feet per second, 1964-03 to 1977-09

Salinity, water, unfiltered, parts per thousand, 1984-05 to 1985-08

Annual statistics

Discharge, cubic feet per second, 1964 to 1977

Salinity, water, unfiltered, parts per thousand, 1984 to 1985

Peak streamflow, 1965-02-26 to 1977-08-22, 13 records

Field/lab water-quality samples, 1966-01-21 to 1984-09-11, 98 records

USGS 02310752 Salt River near Crystal River FL, Stream Site.

Latitude 28°54'05.6", Longitude 82°38'44.9" NAD83

Citrus County, Florida, Hydrologic Unit 03100207

Datum of gage: 0.00 feet above sea level, NAVD88.

Available data:

Real-time – Previous 120 days

Daily Data

Temperature, water, degrees Celsius, TOP, 2006-09-28 to 2010-02-09, 2383 records

Temperature, water, degrees Celsius, BOTTOM, 2006-09-28 to 2010-02-09, 2453 records

Gage height, feet, 2006-09-28 to 2010-02-09, 3533 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius, TOP, 2006-09-28 to 2010-02-09, 2397 records; BOTTOM, 2006-09-28 to 2010-02-09, 2458 records

Daily Statistics

Gage height, feet, 2006-09-29 to 2009-10-06, 1101 records

Monthly Statistics

Gage height, feet, 2006-09 to 2009-10, 1101 records

Annual Statistics

Gage height, feet, 2006 to 2010, 1101 records

Field/Lab water-quality samples, 2006-10-13 to 2009-12-09, 56 records

Additional Data Sources

Annual Water-Data Report (pdf), **offsite** 2007 and 2008, 2 records.

USGS 285531082412600. Crystal River at mouth near Shell Island near Crystal River FL.

Latitude 28°55'31", Longitude 82°41'26.3", NAD83

Citrus County, Florida, Hydrologic Unit 03100207

Available data:

Real-time - Previous 120 days

Daily Data

Temperature, water, degrees Celsius -- TOP 2006-09-23 to 2010-03-04, 2464 records

Temperature, water, degrees Celsius -- MIDDLE 2006-09-23 to 2010-03-04, 2480 records

Temperature, water, degrees Celsius -- BOTTOM 2006-09-23 to 2010-03-04, 2480 records

Gage height, feet 2006-10-07 to 2010-03-04, 3477 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius -- TOP 2006-09-23 to 2010-03-04, 2458 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius -- MIDDLE 2006-09-23 to 2010-03-04, 2478 records

Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius -- BOTTOM 2006-09-23 to 2010-03-04, 2476 records

Daily Statistics

Gage height, feet, 2006-10-07 to 2009-10-05, 1054 records

Monthly Statistics

Gage height, feet, 2006-10 to 2009-10

Annual Statistics

Gage height, feet, 2007 to 2010

Field/Lab water-quality samples, 2007-10-15 to 2010-02-10, 45 records

Annual Water-Data Report (pdf), 2007 to 2009, 3 records

USGS 285344082362800. Crystal River at Crystal River, stream site.

Latitude 28°53'44", Longitude 82°36'28", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Available data:

Daily data

Salinity, water, unfiltered, parts per thousand, 1984-03-10 to 1985-10-18, 1589 records

Daily statistics

Salinity, water, unfiltered, parts per thousand, 1984-03-11 to 1985-10-18, 527 records

Monthly statistics

Salinity, water, unfiltered, parts per thousand, 1984-03 to 1985-10

Annual statistics

Salinity, water, unfiltered, parts per thousand, 1984 to 1986

USGS 285413082343201. Crystal River well, well site.

Latitude 28°54'13", Longitude 82°34'32", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Well depth: 175 feet

Hole depth: 175 feet

Land surface altitude: 10.00 feet above sea level, NGVD29.

Well completed in "Floridan aquifer system" (S400FLORDN) national aquifer.

Well completed in "Floridan Aquifer System" (120FLRD) local aquifer

Available data:

Field/lab water-quality samples, 1980-05-25 to 1980-05-25, 1 record

USGS 285417082381330. Crystal River at mouth near Crystal River, stream site.

Latitude 28°54'17", Longitude 82°38'13", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Available data:

Daily data

Salinity, water, unfiltered, parts per thousand, 1985-07-21 to 1985-10-26, 108 records

Daily statistics

Salinity, water, unfiltered, parts per thousand, 1985-07-22 to 1985-10-26, 35 records

Monthly statistics

Salinity, water, unfiltered, parts per thousand, 1985-07 to 1985-10

Annual statistics

Salinity, water, unfiltered, parts per thousand, 1985 to 1986

USGS 285421082361602. Crystal River deep well at Crystal River, well site.

Latitude 28°54'22.3", Longitude 82°36'13.6", NAD83

Citrus County, Florida, Hydrologic Unit 03100207

Well depth: 176 feet. Land surface altitude: 8.15 feet above sea level, NGVD29.

Well completed in "Floridan aquifer system" (S400FLORDN) national aquifer and (120FLRD) local aquifer.

Available data:

Daily Data

Elevation above NGVD 1929, feet–Tampa data, 1977-10-20 to 1991-09-30, 4994 records

Field ground-water-level measurements, 1964-07-14 to 2009-09-22, 323 records

Field/lab water-quality samples, 1964-07-14 to 2001-09-24, 280 records

Additional data sources

Annual water-data report (pdf), not online, 2006 to 2008, 3 records

Ground-water watch, not online, 1969 to 2009, 322 records

USGS 285447082445100. Gulf of Mexico near Crystal River FL.

Latitude 28°54'47", Longitude 82°44'51", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Ocean: Coastal Site

Available data:

Daily Data

Salinity, water, unfiltered, parts per thousand, 1984-08-14 to 1985-08-30, 813 records

Daily Statistics

Salinity, water, unfiltered, parts per thousand, 1984-08-16 to 1985-08-30, 278 records

Monthly Statistics

Salinity, water, unfiltered, parts per thousand, 1984-08 to 1985-08

Annual Statistics

Salinity, water, unfiltered, parts per thousand, 1984 to 1985

USGS 285550082414400. Crystal Bay near Cedar Cove near Crystal River, estuary site.

Latitude 28°55'50", Longitude 82°41'44", NAD27

Citrus County, Florida, Hydrologic Unit 03100207

Available data: Field/lab water-quality samples, 1991-05-06 to 1991-05-15, 7 records

Author: Vanasse Hangen Brustlin, Inc.

Publication Date: 2009.

Title: An inventory of spring vents in Kings Bay, Crystal River, Florida.

Document Type: Final Report. Submitted to Southwest Florida Water Management District. Brooksville, Fl. 14 pp.

Period of Study: October 14-16, 27-29, 2008 and January 26-27, 2009.

Geographic Range: Multiple locations in Kings Bay.

Variables Measured: The location (latitude and longitude) of all spring vents in Kings Bay.

General Findings: A total of 70 springs were documented, many of which occurred in adjacent spring vents, which resulted in an aggregation of 52 springs in Kings Bay. This is more than previously documented (42 spring/spring groups). For each of the spring/spring groups a physical description of the vent/s is provided.

Data Format: Figure and table in report of the spring locations.

Data Location: In report, District has electronic files of report, the field data, GIS files, and photographs collected during the project as well.

Document Location: Project directory.

Abstract: None.

Author: Vanasse Hangen Brustlin, Inc.

Publication Date: 2010.

Title: Flow measurements from spring vents in Kings Bay, Crystal River, Florida

Document Type: Final Report. Submitted to Southwest Florida Water Management District. Brooksville, Fl. 40 pp.

Period of Study: July 27-31, August 17-20, September 21-25, and October 5-8,of 2009.

Geographic Range: Multiple locations in Kings Bay.

Variables Measured: The discharge, temperature, salinity, and conductivity of all spring/spring groups in Kings Bay. Discharge computed from acoustic doppler profiler (ADP) flow measurements and cross-sectional areas.

General Findings: Flow and selected water quality measurements were made at 40 spring/spring groups identified in the 2009 inventory report. These measurements were conducted near low tide when possible. At two canal sites (G1 and G2), continuous flow/stage readings were made to characterize the discharge of multiple springs over multiple tidal cycles. Discharge and physico-chemical data are provided in tables and figures 6 and 7 respectively. Figure 6 illustrates spring discharge by various categories of cubic feet per second (CFS), and reveals the lack of discharging springs west of Buzzards Island. Figure 7 illustrates the conductivity isopleths for Kings Bay (eastward of Buzzard Island primarily) based on in situ measurements. Conductivity is lowest in the northeast and highest in the southwest sections of Kings Bay.

Data Format: Figure and table in report of the spring locations.

Data Location: In report, District has electronic files of report, GIS files, spreadsheets of stage, discharge and water quality measurements, vent measurement output and copies of the field notes as well.

Document Location: Project directory.

Abstract: None.

Author: Water and Air Research, Inc.

Publication Date: 2010.

Title: Sampling and analysis of oyster distributions and benthic macroinvertebrate populations in the Crystal River.

Document Type: Scope of Work. Project to be completed July 2010.

Period of Study: July 2009.

Geographic Range: From the river mouth to Kings Bay. Four locations in the Gulf near the river mouth and benthic sampling transects will be established at 2.5 km intervals in the river up to km 10 near the entrance to Kings Bay. Several stations in Kings Bay.

Variables Measured: The goal of the project is to map the distribution of oyster populations in the Crystal River from the river mouth to their upstream extent and to describe and quantify relationships between physical parameters, particularly salinity, and the spatial distribution of benthic macroinvertebrates in the Crystal River and Kings Bay.

General Findings: TBD.

Data Format: Figures and tables in report.

Data Location: In report, district will have electronic files

Document Location: Have scope of work, need final report when available.

Abstract: TBD.

Author: Whitford, L. A.

Publication Date: 1956.

Title: The communities of algae in the springs and spring streams of Florida.

Document Type: Ecology. 37(3): 433-442.

Period of Study: 1951 to 1954.

Geographic Range: Thirty springs across the state.

Variables Measured: Qualitative data on the identification of algae (planktonic, attached), epiphytes, and flowering plants.

General Findings: The algal flora of Florida's springs are diverse and vary in conjunction with water chemistry. Whitford includes the springs of Crystal River in the group of "hard, freshwater" springs. He reported that plankton begins to develop in "…the broad quiet estuary at Crystal River. [Where up to] six genera of plankton organisms were collected." Also of note is the statement, "The presence in considerable abundance of the green alga, *Hydrodictyon reticulatum*, in a few springs such as Weeki Wachee and Crystal River;" suggests that filamentous algae could be historically abundant in Kings Bay. The epiphytic algal community of Kings Bay should be determined and compared to Whitford's list. Whitford noted that "next to light [current] is the most important variable habitat factor."

Data Format: In text and a species table.

Data Location: In publication.

Document Location: In project directory.

Summary: Evidence is presented that there are the following types of Florida springs, as indicated by water quality and algal flora: hard, freshwater; oligohaline; mesohaline; and sulfide. There are probably two other types" soft, freshwater; and mesohaline-sulfide.

There is one important algal community in each type of spring and its run, or stream- a lotic *aufwuchs* (or periphyton) community in which diatoms are usually dominant. The importance of current in constantly renewing minerals and gases at the plant surfaces is emphasized. The species of algae attaching to various types of substrata are given as well as succession on young to older leaves.

The following algal communities are recognized: 1) The *Cocconeis* - *Stigeoclonium* community of hard, freshwater springs; 2) the *Cladophora* – *Cocconeis* – *Enteromorpha* community of oligohaline springs; 3) the *Enteromorpha* – *Lyngbya* – *Licmophora* community of mesohaline springs; 4) the *Phormidium* – *Lyngbya* community of sulfide springs.

Author: Wolfe, S. (*Editor*)

Publication Date: 1990.

Title: An ecological characterization of the Florida Springs Coast: Pithlachascotee to Waccasassa rivers.

Document Type: U. S. Fish and Wildlife Service Biological Report 90(21). 342 pp.

Period of Study: prior to 1990.

Geographic Range: Springs Coast.

Variables Measured: Document composed of seven chapters: general introduction, geology and physiography, climate, hydrology and water quality, terrestrial and freshwater habitats, saltwater wetland, estuarine, and marine habitats, and summary.

General Findings: Not specific to Kings Bay and Crystal River.

Data Format: Imbedded in report.

Data Location: In report.

Document Location: Project directory.

Abstract: This report provides a comprehensive ecological characterization of the "springs coast", a term coined by the authors to characterize the region located on the west coast of peninsular Florida contained between the Waccasassa River to the north and the Pithlachascotee River to the south. Much of the area overlies karstic limestone allowing surface outflows from the Floridan aquifer, resulting in a collection of numerous spring groups (18) which collectively discharge immense volumes of water, much of which supports an extensive estuarine habitat. The document is composed of seven detailed chapters: general introduction, geology and physiography, climate, hydrology and water quality, terrestrial and freshwater habitats, saltwater wetland, estuarine, and marine habitats, and summary. In addition to characterizing the region, emphasis is placed on the increasing development of the region and the need to preserve its ecosystems and the water resources. Particularly relevant chapters are four and five, by Wolfe (Hydrology and Water Quality) and Simons (Terrestrial and Fresh Water Habitats) respectively. Nitrate pollution is not a focus in this report, although the linkage between human land use activities and the pollution of the water resources is repeatedly described. This report provides a comprehensive overview of the springs coast region.

Authors: Wooding, J. B. and R. R. Carthy.

Publication Date: 1998.

Title: Interactions of humans and manatees in Crystal River, Florida.

Document Type: Southeastern Association of Fish and Wildlife Agencies. 52: 260-264.

Period of Study: January and February 1997.

Geographic Range: Three Sisters Springs and Magnolia Springs, Kings Bay.

Variables Measured: Observations of human/manatee interactions.

General Findings: Manatee use was greatest between dusk and dawn at the sites and 80% of boat traffic was associated with manatee viewing. Manatees responded negatively to boat presence, with 59% leaving within 30 minutes of boat arrival to a spring. Manatees used the Magnolia Springs sanctuary more consistently than the public-access Three Rivers Springs.

Data Format: In document.

Data Location: In document.

Document Location: Project directory.

Abstract: Manatee/human interactions were observed at a freshwater spring in Crystal River, Florida, in January and February 1997 to evaluate the contrasting needs of manatees, an endangered species, with the values of tourists and the tourist industry. Tourists interested in swimming with manatees heavily used the site, and in some instances, the tourists displaced manatees. A temporary sanctuary, off-limits to humans, was created at the spring during the 1997-1998 winter season.

Author: Wright, S.

Publication Date: 1992.

Title: Recent analysis of manatee tissues for copper.

Document Type: *In* Proceedings of the Bioavailability and Toxicity of Copper Workshop. *Edited by* J. C. Joyce. September 2, 1992. Gainesville, FL. pp. 213-228. University of Florida, Institute of Food and Agricultural Sciences, Gainesville, Fl. 253 pp.

Period of Study: Up to 1992.

Geographic Range: Springs coast and Crystal River.

Variables Measured: Copper concentrations in manatee livers.

General Findings: There is anecdotal evidence of a correlation between the location of manatee carcasses, their liver copper concentrations, and the amount of copper herbicide use in the same location. Data from a Florida Marine Research Institute study suggest that carcasses recovered from the Crystal River area have copper tissue concentrations evenly distributed about the mean concentration and are lower than those values reported by O'Shea *et al*. (1984). The normal concentration of copper in manatee liver tissue is unknown. O'Shea *et al*. (1984) reported average liver copper concentrations (n=54, from 1977 to 1981) at 175.0 mg/kg and ranged from 4.4 to 1,200 mg/kg. FMRI data (n=31, from 1990 to 1992) had average liver concentrations of copper at 16.7 mg/kg and ranged from 3.4 to 58.0 mg/kg. There is no conclusive data, but it appears that copper herbicides could bioaccumulate in manatees, hence the cessation of this herbicide in Kings Bay.

Data Format: Figures and text in report.

Data Location: In report.

Document Location: Project directory.

Abstract: None.

Authors: Yobbi, D. K.

Publication Date: 1992.

Title: Effects of tidal stage and ground-water levels on the discharge and water quality of springs in coastal Citrus and Hernando Counties, Florida.

Document Type: U.S. Geological Survey Water-Resources Investigations Report 92-4069. 44 pp.

Period of Study: 1987 to early 1989.

Geographic Range: Homosassa Springs southward to the Hernando-Pasco County line, not Crystal River.

Variables Measured: Discharge, stage, and water chemistry (temperature, pH, Eh, dissolved oxygen, alkalinity, and specific conductance, nutrients, and cations) at 25 springs, 3 wells, and 4 surface water sites.

General Findings: Seasonal spring flow patterns were observed, with peak discharges in late summer and early fall followed by gradual declines in flow toward winter and spring. Flow in tidal springs is generally greater at low tidal stages than at high or intermediate tidal stages. The primary processes affecting the chemistry of spring water are solution of carbonate minerals and mixing with saltwater. Regression models indicated that changes in specific conductance are caused primarily by changes in ground water levels and to a lesser degree changes in tidal stage.

Data Format: Figures, tables, and appendices in report.

Data Location: In **report**.

Document Location: Project directory.

Abstract: Coastal Citrus and Hernando Counties are located along the west-central coast of peninsular Florida. The area is primarily a zone of groundwater discharge and contains 3 first-order magnitude springs (springs that discharge 100 cubic feet per second or more) and at least 23 smaller springs. The Upper Floridan aquifer is the source of these springs, and discharge is from a regional flow system that encompasses an area of about 3,400 square miles.

Mean discharge per spring is about 26 cubic feet per second based on measurements at 25 springs. Most springs have similar seasonal flow patterns, with peak discharges in late summer and early fall followed by gradual declines in flow toward winter and spring. Flow from springs is related to the altitude of groundwater levels in the Upper Floridan aquifer. Tides in the Gulf of Mexico affect the flow of most springs. Flow in tidal springs is generally greater at low tidal stages than at high or intermediate tidal stages.

Most tidal springs lie near or within the zone of diffusion in the Upper Floridan aquifer and discharge a mixture of saltwater and freshwater. The chloride concentrations of spring water generally decrease

with distance from the coast as a result of higher fresh ground-water levels and a deeper saltwater-freshwater interface.

Sampled springs discharge three types of water: calcium bicarbonate, sodium chloride, and a transitional type. The primary processes affecting the chemistry of spring water are solution of carbonate minerals and mixing with saltwater. There is a significant seasonal difference in water chemistry in some of the springs. Generally, the seasonal variability in water chemistry increases with the salinity of spring discharge. Sampled springs have similar stable isotope and tritium concentrations that also are similar to concentrations in groundwater in the basin. No appreciable variation in isotope composition of the freshwater feeding the springs was observed between sampling periods, and groundwater flowing to the springs is of very recent origin.

Springs at the coast are subject to wide variation in specific conductance and stage. Specific conductance can increase by 5,000 to 20,000 microsiemens per centimeter in a few hours between low and high tides, whereas stage can increase by 1 to 2 feet between low and high tides. Multilinear regression models were developed by using independent variable that were suspected to affect specific conductance of spring waters. The model that accounted for the greatest variation in specific conductance included tidal stage and groundwater levels. The regression models indicate that changes in specific conductance are caused primarily by changes in ground water levels.

Spring water quality and quantity could change with continued development of groundwater. A program of long-term monitoring at selected springs would provide a data base for assessing regional effects of increased development.

Authors: Yobbi, D. K. and L. A. Knochenmus.

Publication Date: 1989.

Title: Effects of river discharge and high-tide stage on salinity intrusion in the Weeki Wachee, Crystal, and Withlacoochee River estuaries, southwest Florida.

Document Type: U.S. Geological Survey Water-Resources Investigations Report 88-4116, 68 pp.

Period of Study: Several time periods from 1982 to 1986.

Geographic Range: Multiple stations in Kings Bay and Crystal River.

Variables Measured: River discharge, high-tide stage, and salinity.

General Findings: The average discharge of Crystal River, measured about 3 miles downstream from Kings Bay, was 975 cfs for the 13-year period from 1965-77 and represents total spring discharge. During summer and fall months, when rainfall and tides are high, river flow is low; and during winter and spring months, when rainfall and tides are low, flow is high. The anomalous timing of the flow of Crystal River is probably caused by seasonal tide (Mann and Cherry, 1969). The mean daily discharges exceeded 5, 50, and 95 percent of the time were 2,100, 928, and 38 cfs, respectively.

The mineral content of water from the main spring at the head of Crystal River varied from 200 to 1,100 mg/L, whereas the observed range of dissolved solids at the gaging station below the main spring in Crystal River (site 36) was 300 to 15,000 mg/L during January 1964 through June 1976 (Mann and Cherry, 1969).

The maximum saltwater intrusion (2.0-ppt salinity) was observed at the head of the river in Kings Bay on numerous occasions. At flows of less than 640 cfs and tide stages above 1.39 feet, the 2-ppt salinity was found upstream of river mile 5.3. At flows greater than 725 cfs and high tide stages of less than 2.52 feet, the 2-ppt salinity did not reach river mile 4.0 and was at mile 2.18 at a flow of 1,399 cfs and a tide stage of 0.82 foot. Minimum saltwater intrusion was observed on May 9, 1984, by Mote Marine Laboratory (Southwest Florida Water Management District, written commun., 1985), at river mile 0.60 at a high-tide stage of 0.61 foot.

Salinity above 2 ppt was present about 39 percent of the time at river mile 3.92 and about 6 percent of the time at river mile 5.92. The salinity, equaled or exceeded 10 percent of the time at river mile 3.92 (6.1 ppt), was almost four times as great as the salinity at river mile 5.92 (1.6 ppt).

Data Format: Figures and tables in report.

Data Location: In report.

Document Location: Project directory.

Abstract: The Weeki Wachee, Crystal, and Withlacoochee Rivers are coastal streams flowing into the Gulf of Mexico that may be affected by either future surface-water or ground-water withdrawals.

Reduction of river discharge may affect the upstream extent of saltwater intrusion in the three rivers; however, under certain reduced low-flow discharges, the estimated change in upstream extent of saltwater intrusion is on the order of several tenths of a mile and frequently is within the range of predicted error.

Data on river discharge, high-tide stage, and salinity are used to characterize salinity distributions in the Weeki Wachee, Crystal, and Withlacoochee River Estuaries. Salinity of the rivers increases downstream. The difference between surface and bottom salinities varies from river to river. Vertical differences in salinity are smallest in the Weeki Wachee River and largest in the Withlacoochee River Estuary.

Multiple linear-regression analysis was used to relate the maximum upstream extent of the vertically averaged 5- and 0.5-part-per-thousand salinities in the Weeki Wachee and Withlacoochee Rivers and the vertically averaged 5- and 2-parts-per-thousand salinities in Crystal River to daily discharge of each river and high-tide stage of the Gulf of Mexico. For the Weeki Wachee River, two linear equations were developed for different ranges of discharge for each salinity position. Streamflow was the most significant variable in each equation. For the Crystal River, one linear equation was developed for each salinity location. High-tide stage was the most significant variable in each equation. For the Withlacoochee River, linear equations were developed for the surface, bottom, and vertically averaged salinity locations. Discharge was the most significant variable in locating the bottom salinity position, and high-tide stage was the most significant variable for locating the surface salinity position. The mean location of both salinities responded slightly more to tide stage than to discharge.

Pumping 40 million gallons per day (61.9 cubic feet per second) from a well field near the springs would result in a 43-cubic-foot-per-second reduction of discharge in the Weeki Wachee River. This reduction is estimated to cause an upstream movement of the vertically averaged 5- and 0.5-part-per-thousand salinities of about 0.3 and 0.2 mile, respectively, at the 25-percent flow- duration interval (199 cubic feet per second). The frequency of a salinity intrusion greater than 0.5 part per thousand at mile 1.5 is estimated to increase from 6 to 65 percent. The well-field pumpage would result in a 61-cubic-foot-per-second reduction in discharge in the Crystal River. The reduction in flow would cause an insignificant upstream movement of the vertically averaged 5- and 2-parts-per-thousand salinities at the 90-day, 20-year low flow.

Withdrawal of 208 cubic feet per second (50 percent of the 90-day, 2-year low flow) from the Withlacoochee River is estimated to cause an upstream movement of both the vertically averaged 5- and 0.5-part-per-thousand salinities of about 0.2 mile. It would also increase the frequency of daily salinity intrusion (0.5-part-per-thousand salinity) at mile 3.0 from 33 to 85 percent. For the 7-day, 2-year low flow (670 cubic feet per second), 50-percent reduction of flow would cause an upstream movement of the vertically averaged 5- and 0.5-part-per-thousand salinities of about 0.4 and 0.3 mile, respectively.

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APPENDIX

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Kings Bay vegetation evaluation 2010: historical narrative and ecological synthesis

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EXECUTIVE SUMMARY

Kings Bay comprises approximately two square kilometers (500 acres) of embayments and canals in Citrus County, Florida, with Crystal River originating from its northwest end to flow approximately six miles northwestward to the Gulf of Mexico. The bay and river constitute a tidally influenced, spring-fed system that ranks first among Florida's springs in terms of extent and second or third in terms of discharge. Citrus County has experienced rapid population growth, with an increase from approximately 9 thousand to over 140 thousand residents between 1960 and 2010. To meet the demand for waterfront, residential property and boat access, extensive dredging and filling began in the 1950s, and ultimately, these activities altered much of the Kings Bay shoreline and Crystal River. The public has voiced their concerns regarding water quality and proliferation of undesirable plant and algal species in the Kings Bay–Crystal River system since the late 1980s. Declining water clarity represented a widespread and high priority concern, although it was supported only by anecdotal evidence. Nevertheless, this concern merits attention because even a perceived loss of aesthetics can impact eco-tourism, especially diving activities. Over time, the biomass of vegetation in Kings Bay has varied widely, peaking in the mid-1990s when invasive plants were widespread and declining during the last decade. The spatial and temporal patterns of submersed aquatic vegetation in Kings Bay and the influence of these patterns on the ecology of the bay and Crystal River reflect interactions between a complex suite of physical, chemical and biological factors and key ecological processes. Historically, non-native plants, e.g., *Hydrilla verticillata* and *Myriophyllum spicatum*, have exerted undesirable pressure on native macrophytes. Acute variations in salinity caused by tropical storms and hurricanes led to marked changes in the submersed aquatic vegetation within Kings Bay, and similar events can be expected to reoccur. Grazing by manatees exerts pressure on native macrophytes, with major reductions in biomass and coverage recorded during winters when manatees seek a thermal refuge. In addition, evidence suggests complex feedbacks between diminished water clarity and decreased coverage of rooted aquatic macrophytes. Based on available evidence, flows in the Kings Bay–Crystal River system will interact with multiple aspects of the ecology of submersed aquatic vegetation. Lower flows will increase residence times, which will promote accumulation of phytoplankton biomass leading to reduced light penetration and stress on vegetation, including *Vallisneria americana*. Lower flows also will increase salinities, which will decrease competition between *V. americana* and other less tolerant vegetation potentially leading to an expansion of this desirable macrophyte. Lower flows also may benefit *V. americana* if water temperatures in Kings Bay become less stable, which will make it a less desirable thermal refuge for manatees leading to reduced grazing pressure. Ultimately, establishing a balanced and self-sustaining assemblage of submersed aquatic vegetation in the Kings Bay–Crystal River system will require ongoing management that maintains suitable, background environmental conditions, including appropriate residence times for water, concentrations of nutrients, concentrations of suspended particles and sediment conditions. Success also may require more drastic, short-term interventions to remove the legacy of past events and reset the system, e.g., sediment removal and the transplanting of *V. americana* or other native macrophytes. In all cases, the efficiency and effectiveness of management actions will be improved by science that evaluates options, guides implementation, and assesses success to inform adaptation.

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THE KINGS BAY–CRYSTAL RIVER SYSTEM

Kings Bay comprises approximately two square kilometers (500 acres) of embayments and canals in Citrus County, Florida, with Crystal River originating from its northwest end to flow approximately six miles northwestward to the Gulf of Mexico (Figure 1). The bay and river constitute a tidally influenced, spring-fed system that contains at least 70 unique vents or vent-clusters (Vanasse Hangen Brustlin, Inc. 2009). Geographically, the spatial extent and total number of vents make it Florida's largest spring-fed system. In terms of discharge, the complex ranks second or third among Florida's springs. The groundwater feeding the springs originates from the upper Floridan aquifer (Jones and Upchurch 1994).

Figure 1. Map showing the location of Kings Bay and Crystal River in Citrus County, Florida.

The system's springshed is bordered by the Withlacoochee River to the north, a line of divergence in groundwater flow in south-central Citrus County to the south, and the Tsala Apoka chain of lakes to the east (Jones and Upchurch 1994). Recharge rates are highest along the Brooksville Ridge that lies east of the system, where well-drained soils overlay karst. Due to low topography and the proximity of a saltwater-freshwater transition zone in the underlying aquifer, the quantity and chemistry of water discharged into Kings Bay varies. Historic measurements, made approximately three miles downstream from Kings Bay over a 13-year period (1965 to 1977), estimated average discharge at 975 cubic feet per second (Yobbi and Knochenmus 1989). During the summer of 2009, measurements taken in spring vents, vent complexes and canals with acoustic Doppler current meters and other methods estimated aggregated discharge as 488 cubic feet per second (Vanasse Hangen Brustlin, Inc. 2010). The number, complex geometry and variable flow rates of springs and spring vents in Kings Bay and Crystal River make assessing discharge rates challenging.

CHANGES IN LAND USE

Like most coastal areas in the United States, Citrus County has experienced rapid population growth. Between 1960 and 2010, the population of Citrus County grew from little more than 9 thousand to over 140 thousand residents, which ranked among the six fastest percentage growth rates for coastal counties in the country (Wilson and Fischetti 2010). To meet the demand for waterfront, residential property and boat access, extensive dredging and filling began in the 1950s, and ultimately, these activities altered much of the Kings Bay shoreline and Crystal River (Figures 2, 3 and 4). During this time, extensive dead-end canal systems were created, significant amounts of natural fringing marsh were converted to hardened shorelines, and about 40 percent of the Kings Bay springshed became urbanized (Southwest Florida Water Management District 2004).

Similar urbanization throughout the jurisdiction of the Southwest Florida Water Management District resulted in increased nutrient loading to all regional springs (Jones and Upchurch 1994; Champion and Starks 2001; Frazer et al. 2001a). Eventually, concerns about groundwater contamination and resulting degradation of aquatic ecosystems pervaded all water management districts with substantial spring resources (see Chellette et al. 2002 for the Northwest Florida Water Management District; Cohen et al. 2007 for the St. Johns River Water Management District; and Hornsby and Ceryak 1999 for the Suwannee River Water Management District).

The public has voiced their concerns regarding water quality and proliferation of undesirable plant and algal species in the Kings Bay–Crystal River system since the late 1980s (Citrus County Chronicle 1985a, 1985b and 1986). Declining water clarity represented a widespread and high priority concern, although it was supported only by anecdotal evidence. Nevertheless, this concern merits attention because even a perceived loss of aesthetics can impact eco-tourism, especially diving activities.

Figure 2. Aerial photographs of Kings Bay from 1944 and 1960 (Southwest Florida Water Management District). Between 1944 and 1960, portions of the shoreline and marshes were modified for residential and commercial development.

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MANAGEMENT ACTIONS

The Kings Bay–Crystal River system was designated as an Outstanding Florida Water in 1983 by the State, and in 1989 the Southwest Florida Water Management District designated the area as a Surface Water Improvement and Management (SWIM) Priority Water Body (Southwest Florida Water Management District 2000). In the resulting SWIM plans, the district identified establishing a favorable submersed plant assemblage in Kings Bay as a primary management objective required for improved water clarity and wildlife habitat (Southwest Florida Water Management District 2000, 2004). SWIM plans also addressed related issues, including the spread of invasive and exotic submersed aquatic vegetation, increased groundwater pollution within the region, reduced water clarity, and increased use of the bay as a thermal refuge during winters by the largest population of manatees along the west coast of Florida.

A subsequent management action targeting these issues bears on the status of submersed aquatic vegetation in the Kings Bay–Crystal River system. Prior to March 1992, the City of Crystal River discharged 0.75 million gallons of treated wastewater per day into Cedar Cove, an embayment along the northern shoreline of Kings Bay. These discharges were blamed for declines in water clarity and concomitant proliferation of *Lyngbya* sp. and other filamentous algae (Nearhoof 1989; Romie 1990). In response, the City of Crystal River diverted the effluent to an upland spray field. Elimination of the discharges did lead to a four-fold decrease in total phosphorus concentrations and a three-fold reduction in total nitrogen concentrations within Cedar Cove and at sites considered to be downstream (Bishop and Canfield 1995; Terrell and Canfield 1996). Nutrient concentrations in the southern portion of the bay, considered to be upstream of Cedar Cove, remained similar to those measured in the discharges of springs found there, which indicated they had never been affected by the wastewater inputs (Bishop and Canfield 1995; Terrell and Canfield 1996).

Many concerns expressed by the public and managers revolve around the distribution and composition of the submersed aquatic vegetation in the Kings Bay–Crystal River system. In particular, loss of native macrophytes, such as *Vallisneria americana*, and proliferation of invasive or nuisance plant and algal species, e.g., *Myriophyllum spicatum* and *Lyngbya* sp., form the core of many claims citing environmental degradation in this system (Frazer and Hale 2001b; Hauxwell et al. 2003; Jacoby et al. 2007).

HISTORICAL CHANGES IN THE VEGETATIVE ASSEMBLAGE

Submersed aquatic vegetation includes species that grow or float to the surface and reduce open water areas (e.g., *Hydrilla verticillata*, *Myriophyllum spicatum* and filamentous algae, such as *Lyngbya* sp.). Categories of submersed aquatic vegetation (SAV) include rooted macrophytes, large bodied "macroalgae" and filamentous algae. Exotic, introduced or non-indigenous refer to vegetation that is not native to the system, and invasive typically applies to introduced species that grow rapidly.

There are no published reports describing the aquatic vegetation in the Kings Bay–Crystal River system prior to the 1960s; however, recent collections, including those from nearby, spring-fed systems yield insights into the native assemblage. The assemblage likely included flowering plants, such as tape grass or wild celery (*Vallisneria americana*), pondweeds (*Potamogeton pectinatus* and *P. pusillus*), southern naiad (*Najas guadalupensis*), hornwort (*Ceratophyllum demersum*), and widgeon grass (*Ruppia maritima*). Common macroalgae probably included musk grass (*Chara* sp.) and a variety of filamentous forms (species of *Lyngbya*, *Chaetomorpha*, *Enteromorpha*, *Vaucheria* and *Gracillaria*). Filamentous

algae have become so abundant that they are considered an undesirable nuisance, but they are native to Florida and have been present in many of Florida's springs for decades (Whitford 1956).

During the first decade of large-scale development around Kings Bay, aquatic plants become an issue for managers. Interviews with long-term residents suggest that although non-native water hyacinth (*Eichhornia crassipes*) was present in Kings Bay, it was only during the mid to late 1950s that floating mats expanded rapidly throughout the bay and made boating difficult (Evans et al. 2007). In response, broadcast herbicides were applied in aggressive eradication program (Evans et al. 2007).

A second wave of problematic vegetation in Crystal River and Kings Bay arose after the introduction of *Hydrilla verticillata* in 1960 (Blackburn et al. 1969). This macrophyte was documented simultaneously in this system and a canal near Miami lending credence to a report that it was planted by tropical plant dealers as a crop (Blackburn et al. 1969; Langeland 1990). By 1965, the abundance of *H. verticillata* was so problematic that it prompted dramatic control measures. In one notable example, 3,600 gallons of concentrated sulfuric acid were introduced into canals along the east side of Kings Bay and north of Paradise Point Road (Phillippy 1966). Although the local abundance of *H. verticillata* was reduced, the application was not repeated.

During the 1970s and 1980s, Hydrilla remained a problem in Kings Bay and Crystal River, and it was joined by *Myriophyllum spicatum* or Eurasian watermilfoil, a new exotic species (Haller 1978; Langeland 1990). Eurasian watermilfoil appears to have been introduced into the system as early as the 1960s (Blackburn and Weldon 1967; Southwest Florida Water Management District 2004). Efforts to control these plants primarily relied on copper-based herbicides that did not yield long-term success (Haller et al. 1983; Dick 1989). Application of copper based herbicides was discontinued by the middle of the 1980s in response to concerns about bioaccumulation and toxicity in manatees grazing within Kings Bay (Haller et al. 1983; Facemire 1991, 1992).

During the latter half of the 1980s and throughout the 1990s, aquatic herbicides containing photosynthetic inhibitors (e.g., diquat, endothall and fluridone) were applied by multiple agencies, including the Southwest Florida Water Management District, the Florida Department of Natural Resources and the United States Army Corps of Engineers. In the last decade, herbicides have been applied primarily to small beds of floating water hyacinth and water lettuce (*Pistia stratiotes*), which may have been introduced to Florida before 1765 (http://www.invasivespeciesinfo.gov/aquatics/waterlettuce.shtml). Mechanical harvesters, which were first employed by the Citrus County Division of Aquatic Services in 1978, have replaced herbicide applications as a means of maintaining navigable paths.

During the middle 1980s, filamentous algae became a nuisance within Kings Bay leading to complaints from citizens. Filamentous algae form dense mats that trap gasses, which eventually accumulate to the point where the mats float to the surface. These floating mats are unaesthetic, and filamentous algae may outcompete rooted macrophytes leading to a loss of vertically complex habitats. *Lyngbya* sp. (a cyanobacterium or blue-green alga) has received the most attention, but other species contribute to the formation of mats (Jacoby et al. 2007). By the end of 1980s, *Lyngbya* and other filamentous algae represented a key concern for the public and managers (Southwest Florida Water Management District 2004).

In parallel with changes in the composition of the submersed aquatic vegetation assemblage in the Kings Bay–Crystal River system, various short-term perturbations have been noted. In particular, decreases in vegetative cover and biomass follow salinity intrusions caused by storms and hurricanes (Bishop 1995; Terrell and Canfield 1996; Mataraza et al. 1999; Frazer et al. 2001b, 2006a; Jacoby et al. 2007) and grazing by manatees (Hauxwell et al. 2003, 2004a, 2004b; Jacoby et al. 2007). Species differ in their

susceptibility to these pressures and their resilience, but most species recover once salinities or grazing decrease.

Over time, the biomass of vegetation in Kings Bay has varied widely, with a recent peak in the mid-1990s when invasive plants were widespread and a decline during the last decade (Figure 5; Haller et al. 1983; Terrell and Canfield 1996; Mataraza et al. 1999; Hoyer et al. 2001; Jacoby et al. 2007). After 1994, samples typically yielded less than 5 kg wet weight m^{-2}. In addition, the composition of the submersed aquatic vegetation assemblage appears to have changed, with filamentous algae that was limited to the northern edge of Kings Bay in the early 1980s (Haller et al. 1983) becoming more widespread and abundant in 2004–2006 (Jacoby et al. 2007). Overall, available data corroborate claims by residents and resource managers that submersed aquatic vegetation has declined in Kings Bay over the past decade.

Figure 5. Biomass of submersed aquatic vegetation in Kings Bay (Haller et al. 1983; Terrell and Canfield 1996; Mataraza et al. 1999; Hoyer et al. 2001; Jacoby et al. 2007). Gaps are months within years that lack data.

The mean biomass of submersed aquatic vegetation in nearby, tidally influenced, spring-fed systems also has declined, although these systems typically support less biomass than Kings Bay. Since 1998–2000, biomass of all submersed aquatic vegetation has declined from 4.0 to 1.0 kg wet weight m^{-2} in the Weeki Wachee River, 0.7 to 0.2 kg wet weight m^{-2} in the Homosassa River, and 1.4 to 0.9 kg wet weight m^{-2} in the Chassahowitzka River (Frazer et al. 2006b). In the upper half of the Homosassa, Chassahowitzka and Weeki Wachee rivers (reaches with conditions comparable to Kings Bay), the average biomass of all submersed aquatic vegetation in August 2004 was 0.3, 1.3 and 0.9 kg wet weight m^{-2}, with angiosperms contributing 24%, 72% and 30% of this biomass, respectively (Frazer unpublished data). In July 2004, the mean biomass for all submersed aquatic vegetation in Kings Bay was 2.4 kg wet weight m^{-2}, with angiosperms accounting for approximately 10% of this value (Jacoby et al. 2007). In comparison to the Ichetucknee River, which is less affected by salinity but does harbor manatees, Kings Bay supports far lower average biomass per unit area. In 2004, the average biomass for all submersed aquatic vegetation in the Ichetucknee was 5.3 kg wet weight m^{-2}, more than double the estimate for Kings Bay (Kurz et al. 2004). In addition, samples from the Ichetucknee comprise two native angiosperms, *Vallisneria americana* and *Sagittaria kurziana* almost entirely. The standardized areal biomass of *Vallisneria americana* in the Ichetucknee River was approximately 15-fold greater than in Kings Bay, 0.47 kg dry weight m^{-2} and 0.03 kg dry weight m^{-2}, respectively (Kurz et al. 2004; Jacoby et al. 2007).

ECOLOGY OF SUBMERSED AQUATIC VEGETATION IN THE KINGS BAY–CRYSTAL RIVER SYSTEM

The spatial and temporal patterns of submersed aquatic vegetation in Kings Bay and the influence of these patterns on the ecology of the bay and Crystal River reflect interactions between a complex suite of physical, chemical and biological factors and key ecological processes. Historically, an over-abundance of non-native plants, e.g., *Hydrilla verticillata* and *Myriophyllum spicatum*, has been problematic. Acute variations in salinity caused by tropical storms and hurricanes have led to repeated and marked changes in submersed aquatic vegetation within Kings Bay, and similar events can be expected to reoccur (Mataraza et al. 1999; Frazer et al. 2001b, 2006a). Grazing by manatees exerts additional pressure on native plants (Hauxwell et al. 2004a, 2004b), with major reductions in biomass and coverage recorded during winters when manatees seek a thermal refuge (Jacoby et al. 2007). In addition, evidence suggests complex feedbacks between diminished water clarity and decreased coverage of rooted aquatic macrophytes (Hoyer et al. 2001).

Interactions with light availability

The distribution and abundance of submersed aquatic vegetation is influenced by the prevailing light regime. Species vary in their capacity to cope with reduced light, but all species require light to support photosynthesis.

Non-volatile, algal and detrital suspended solids all are inversely related to horizontal Secchi distance, a measure of water clarity and available light (Hoyer et al. 1997; Munson 1999). For example, chlorophyll concentrations below 6 $\mu g\ L^{-1}$ yield horizontal Secchi distances greater than 10 m (Hoyer et al. 2001). During a period of low visibility in Kings Bay, surface water collected near Kings Spring contained suspended particles comprised primarily of microscopic algal cells (Bishop 1995, Bishop and Canfield 1995). Horizontal Secchi distances were negatively correlated with chlorophyll concentrations, with minimum (10 ft) and maximum (58 ft) readings recorded on days when chlorophyll concentrations were 20 $\mu g\ L^{-1}$ and 1.7 $\mu g\ L^{-1}$, respectively. In other data, non-volatile and detrital solids accounted for 30% and 12% of the variance in horizontal Secchi readings, respectively, whereas algal solids accounted for approximately 40% of the variance (Hoyer et al. 1997; Munson 1999). Overall, these findings indicated that phytoplankton abundance was the primary factor determining water clarity in Kings Bay during the 1990s. Although the source of the algae was not determined, several mechanisms might explain the occurrence of elevated chlorophyll concentrations in Kings Bay.

Phosphorus and nitrogen are often primary factors determining the abundance of algal cells in waters around the world (Aizaki et al. 1981). Data from seven Florida LAKEWATCH stations sampled monthly from 1992 to 2000 showed that both total phosphorus and total nitrogen concentrations correlated positively with chlorophyll concentrations in Kings Bay–Crystal River system (Florida LAKEWATCH 2000; Hoyer et al. 2001). Total phosphorus, total nitrogen and chlorophyll concentrations averaged 28 $\mu g\ L^{-1}$, 229 $\mu g\ L^{-1}$, and 8 $\mu g\ L^{-1}$, respectively (Florida LAKEWATCH 2000). Compared to other LAKEWATCH water bodies, chlorophyll concentrations in the Kings Bay–Crystal River system were low relative to total phosphorus concentrations (Brown et al. 2000). In contrast, chlorophyll concentrations were near the predicted maximum given the observed total nitrogen concentrations. In Crystal River, both nitrogen and phosphorus limited phytoplankton growth in nutrient bioassays, with the frequency of nitrogen limitation being relatively high compared to other spring-fed, coastal rivers (Frazer et al. 2002). Thus, changes in nutrient concentrations, especially nitrogen, may influence phytoplankton abundance, which, in turn, influences water clarity in Kings Bay–Crystal River system. Dissolved, inorganic nitrogen concentrations in Kings Bay typically have been low relative to the Weeki Wachee,

Chassahowitzka and Homosassa systems (Frazer et al. 2001a). However, ongoing monitoring by the Southwest Florida Water Management District indicates that nitrogen concentrations have increased recently. These increases were predicted by Jones and Upchurch (1994) who stated, "The many nitrogen releases resulting from land uses that exist in the [Kings Bay] study area are elevating ground-water nitrogen concentrations. Ground water that has been enriched in nitrogen from both development-related and natural sources [Tsala Apopka Lake chain] is moving toward the coast in well-defined plumes from the east-central and north-central portions of the study area. Within 20 years this nitrogen will reach the King's Bay Springs and probably increase nitrogen concentrations significantly."

Flushing can remove phytoplankton before standing crops reach levels limited by nutrient concentrations (Swanson and Bachmann 1976). Chlorophyll bioassays using samples from 20 Florida rivers suggested that chlorophyll concentrations can approach levels limited by nutrients within 3–7 days (Canfield and Hoyer 1988). Other controlled bioassays using samples from Kings Bay suggested that maximum chlorophyll concentrations are reached in 2 to 3 days (Frazer et al. 2002). Flushing rates vary with spring discharge, rainfall and tides, with tides adding an oscillatory component to spring discharge that is the dominant flushing force in Kings Bay because it supplies approximately 90% of the freshwater and (Hammett et al. 1996). A model calibrated with data collected during a period of low rainfall and spring discharge estimated at 735 cfs predicted that water in Kings Bay was replaced in 2–4 days (Hammett et al. 1996). This estimated discharge was about 25% less than a previously calculated long-term average of 975 cfs (Yobbi and Knochenmus 1989), which would have generated faster flushing. Nevertheless, recent periods of low rainfall and apparent decreases in spring discharge, as suggested by increases in salinity and an estimated median daily discharge of 490 cfs for August 2002 through October 2011 (http://waterdata.usgs.gov/usa/nwis/uv?site_no=02310747), may mean the flushing rate is at or above 4 days. Overall, flushing rates appear to be low enough for chlorophyll concentrations to reach levels where nutrients become limiting, which will decrease water clarity (Hoyer et al. 2001).

Analysis of data from 1993–1994, 1996–1997 and 1997–2000 indicated that chlorophyll concentrations decreased as aquatic plant biomass increased (Terrell and Canfield 1996; Hoyer et al. 1997; Hoyer et al. 2001). Aquatic plant biomass accounted for 11% of the variance in chlorophyll concentrations suggesting that nutrients and other factors also affected phytoplankton production in this system (Hoyer et al. 2001). A similar inverse relationship was found in a study of two macrophyte dominated lakes in central Florida (Lamb 2000). Several mechanisms can contribute to the inverse relationship between biomass of benthic plants and chlorophyll concentrations in the water column: (1) aquatic plants and their associated epiphytic algae compete for nutrients that might otherwise be assimilated by phytoplankton, (2) aquatic plants dampen wave energy and cause phytoplankton to settle, and (3) aquatic plants stabilize sediments and lessen the likelihood of resuspension of benthic microalgae (Hoyer et al. 2001). Two of these mechanisms involve wind, which suggests that wind speed could be a factor determining water clarity in Kings Bay–Crystal River system.

Average daily wind speed at the mouth of Crystal River was related positively to concentrations of chlorophyll and total suspended solids in the water of Kings Bay and Crystal River (Hoyer et al. 1997). Given water depths and fetch in Kings Bay, very few wind events would create waves capable of resuspending bottom sediments in the bulk of Kings Bay; therefore, increases in chlorophyll and suspended solids most likely arise from previously settled algae, previously settled detritus, or periphyton being dislodged from the surfaces of aquatic vegetation (Bachmann et al. 2001; Hoyer et al. 2001). A positive relationship between wind and concentrations of chlorophyll and suspended solids also was found in a study of two macrophyte dominated lakes in central Florida (Lamb 2000). Additional periphyton and detritus can be dislodged by power boats, swimmers, divers and foraging manatees.

Effects of high salinity

Salinity represents a primary determinant of long-term patterns in the abundance and distribution of plants in spring-fed rivers along Florida's Gulf coast (Hoyer et al. 2004). For example, in Crystal River, both *Hydrilla verticillata* and *Myriophyllum spicatum* were present at the head of the river near Kings Bay, but *H. verticillata* disappeared in the lower river and *M. spicatum* became dominant, with evidence from laboratory experiments pointing to salinity tolerance as the likely cause of these distributions (Haller et al. 1974). Survival of *H. verticillata* was decreased in salinities as low as 7‰ in a study using static conditions for 4 weeks, whereas, *M. spicatum* tolerated 13‰ and died when exposed to 17‰ (Haller et al. 1974). Growth of *Vallisneria americana* was suppressed by salinities as low as 7‰ and mortality was observed at 13‰ in a study using static conditions for 4 weeks (Haller et al. 1974). In experiments with plants from Kings Bay, *H. verticillata* was particularly sensitive because all plants died following 1-d exposures to 15‰ (Table 1; Frazer et al. 2006a). In contrast, *V. americana* and *M. spicatum* survived 1-d and 2-d exposures to 15‰, but 25–100% of these plants died following 7-d exposures to 15‰ or any exposure to 25‰ (Table 1; Frazer et al. 2006a). In addition, *V. americana* exposed to salinities ≥ 15‰ exhibited less blade elongation, added fewer blades, generated fewer clones, and produced less aboveground and belowground biomass (Frazer et al. 2006a). Overall these results lead to a prediction that this species would be stressed, but able to tolerate rapid, short-lived (< 2 d) pulses of high salinity water. Similar tolerances were observed in studies done elsewhere. For example, results of multiple studies of *V. americana* were summarized, with extreme stress reported from 1 d exposure to 18‰ and essentially no evidence of stress from exposures to 10‰ over 128 d (Figure 6; Dobberfuhl et al. 2012; Jacoby 2012). Growth of *V. americana* was not affected by salinities up to 12–15‰, and mortality was recorded at 18‰ only in longer exposures (Twilley and Barko 1990; Doering et al. 1999, 2001; Kraemer et al. 1999). Field observations also suggested that *M. spicatum* can withstand salinities up to 15‰, with growth reduced at 16‰ (Twilley and Barko 1990; McGahee and Davis 1971).

Table 1. Percent mortality of *Vallisneria americana*, *Hydrilla verticillata* and *Myriophyllum spicatum* after exposures to different salinities and a 28-d recovery period (Frazer et al. 2006a).

Salinity	*Vallisneria*			*Hydrilla*			*Myriophyllum*		
	1 d	2 d	7 d	1 d	2 d	7 d	1 d	2 d	7 d
Control	0	0	0	0	0	0	0	0	0
5‰	0	0	0	0	0	0	0	0	0
15‰	0	0	75	100	100	100	0	0	50
25‰	100	100	100	100	100	100	100	100	100

Figure 6. Impacts of salinity on *Vallisneria americana* (Jacoby 2012). ES = extreme stress; MS = moderate stress; LS = low stress; NE = no effect

Experimental observations appeared to translate to real-world events. The Kings Bay–Crystal River system is tidally influenced, flow reversals are common and they reach the manmade canals (Mann and Cherry 1969; Yobbi and Knochenmus 1989; Hammet et al. 1996; Frazer et al. 2001b). In response to typical tidal oscillations, water in Kings Bay stages up and down less than 1.2 m (Hammett et al. 1996). In contrast, Hurricane Donna in 1964 generated a stage of 1.5 m above mean sea level, which demonstrates that large amounts of saline water can be forced up the river and into Kings Bay by storms and high winds (Mann and Cherry 1969). Based on such phenomena, a series of studies related noticeable decreases in vegetation in Kings Bay to the "Storm of the Century" in 1993, Hurricane Elena in 1985, and Tropical Storm Josephine in 1996 (Bishop 1995; Terrell and Canfield 1996; Mataraza et al. 1999; Hoyer et al. 2001). These early attempts to link changes in vegetation to storm surges remained speculative because measurements of salinity were not available.

Salinity was measured at two locations in Kings Bay in 1999–2001 and 2004, with the results clearly capturing pulses of salinity that influenced the vegetation in Kings Bay (Figure 7; Frazer et al. 2001b; Frazer et al. 2006a; Jacoby et al. 2007). Hurricanes Frances, Ivan and Jeanne forced dense, saline water into the bay, and the shallow sill near the mouth of the bay acted as a natural barrier to its exit. In the bay's interior, salinities near the bottom remained elevated for more than 2 d following each storm, with a gradual decrease attributed primarily to dilution by groundwater discharging from springs. Aboveground biomass and percent cover of vascular plants were reduced after the series of hurricanes. *Myriophyllum spicatum* exhibited an 83% decrease in aboveground biomass and an 80% decrease in percent cover. *Hydrilla verticillata* exhibited 47% and 15% declines in biomass and percent cover, respectively. *Vallisneria americana* exhibited an 18% increase in aboveground biomass and a 37% increase in percent cover, which suggests greater tolerance of salinity pulses and release from competition with the invasive *H. verticillata* and *M. spicatum* as has been suggested by field observations and laboratory experiments (Lind and Cottam 1969; McFarland and Rogers 1998; Van et al. 1999; Rybicki and Carter 2002; Hauxwell et al. 2003).

Figure 7. Locations of sondes recording salinity data and values recorded during hurricanes Frances, Ivan, and Jeanne (Frazer et al. 2001b). Station 1 = KB1; Station 2 = KB2

More subtle variations in salinity, which arise when weather patterns alter rainfall, groundwater supply and spring discharge, also affect the ecology of this system. For example, ten species of submersed aquatic plants were found in the Kings Bay–Crystal River between July 1999 and July 2000, with over 98% of the quadrats containing some vegetation (Hoyer et al. 2001). During this time, *Myriophyllum spicatum*, *Hydrilla verticillata*, *Lyngbya* sp., and *Vallisneria americana* occurred in 90, 85, 64, and 59% of the quadrats, respectively. Locations with higher mean specific conductances yielded more *M. spicatum* and *V. americana* than *H. verticillata* or *Lyngbya* sp. Thus, elevated salinities may favor the expansion of *M. spicatum* and *V. americana*. In addition, multivariate ordinations of quarterly data collected in 2004–2006 indicated that 71 stations fell into three groups distinguished by patterns in the percentage cover and biomass of vegetation (Figure 8; Jacoby et al. 2007). Vegetation comprised filamentous algae; non-native *H. verticillata* and *M. spicatum*; and native *Chara* spp., *Ceratophyllum demersum*, *Najas guadalupensis*, *Potamogeton pectinatus*, *Potamogeton pusillus*, *Ruppia maritima*, *Vallisneria americana*, and *Zannichellia palustris*. Analyses based on percentage cover and biomass separated 63 stations into a group of 35 stations and a group of 28 stations, with the remaining 8 stations alternating between these groups depending on whether percentage cover or biomass data were analyzed. Submersed aquatic vegetation of some type was found in approximately 90% of the quadrats sampled at 71 stations over 3 years, but quadrats from stations in the group of 35 contained native plants and algae about 1.6 times as often and non-native plants and algae about 1.2 times as often as quadrats from stations in the group of 28. In contrast, quadrats from stations in the group of 28 contained filamentous algae about 2.0 times as often as quadrats from stations in the group of 35. Multivariate ordinations of water quality data indicated that the spatial patterns in vegetation within Kings Bay were most strongly related to variation in freshwater inputs from springs located primarily among the 28 stations with large quantities of filamentous algae (Figure 8). Near springs, horizontal Secchi readings and concentrations of nitrate and nitrite were higher, whereas conductivities were lower. Analyses based on available data did not indicate a relationship to sediments (Belanger et al. 2005; Jacoby et al. 2007).

Figure 8. Groups of stations derived from multivariate ordinations of percentage cover and biomass data for 11 types of vegetation (left-hand map) and water quality data (right-hand map). Black circles = group of 35 stations; Yellow stars = group of 28 stations; Orange boxes = group of 8 stations; Blue hexagons = springs; Triangles = water quality sites, with sites marked by yellow triangles having longer horizontal Secchi readings, higher nitrate and nitrite concentrations and lower conductivities than sites marked by black triangles and the site marked by a red triangle being very shallow, surrounded by marshes and characterized by lower temperatures and higher color readings

Responses to grazing

The 2004–2006 surveys of vegetation in Kings Bay also identified a repeated temporal pattern in percentage cover and biomass (Figure 9; Jacoby et al. 2007). In February of all years, percentage cover and biomass decreased at the stations with less filamentous algae, with those decreases corresponding to times when large numbers of manatees sought refuge and food in the bay. Stations characterized by filamentous algae exhibited less of a response, suggesting that manatees primarily feed on other plants and algae.

Figure 9. Mean percentage cover for total submersed aquatic vegetation for stations in Kings Bay without (left-hand graph) and with (right-hand graph) large amounts of filamentous algae, along with mean numbers of manatees observed in the bay. Black lines without symbols = percentage cover; Black lines with boxes = numbers of manatees

The effects of manatee grazing were examined directly in an experiment assessing the feasibility of large-scale restoration of *Vallisneria americana* in Kings Bay (Hauxwell et al. 2003, 2004a and b). To determine the effects of herbivores and other primary producers on *V. americana* transplants, a 2 × 2 factorial experiment was conducted in Cedar Cove, south of Buzzards Island and north of Parkers Island (Figure 10). At each site, 1.5 × 1.5 m plots of transplanted *V. americana* were either subjected to or protected from grazing by relatively large herbivores (e.g., manatees, turtles, waterfowl and large fishes) and the presence of other primary producers (e.g., *Myriophyllum spicatum*, *Hydrilla verticillata* and filamentous algae that included *Lyngbya* sp.). Plants not protected by cages were consumed by manatees, with 80% of the *V. americana* removed in one month (Figure 11). Densities of *Vallisneria americana* were reduced by 0–50% in plots that included other plants, with the strongest effects at Buzzard Island and Parker Island where more *M. spicatum* was present. Established *V. americana* grew even though *M. spicatum* was present, so competition for space was more likely than competition for light. Given the abundance of manatees in 2003, their energetic requirements, and the productivity of *V. americana*, it was estimated that 18,400,000 shoots would be required to meet the needs of the existing population. Extant *V. americana* beds contained approximately 730,000 shoots or only 4% of the required standing crop. Therefore, approximately 18 million shoots would need to be transplanted to Kings Bay if the goal was to create a self-sustaining population that could cope with existing grazing pressure. Based on an average dry mass of 1 g and an average density of 200 shoots m^{-2}, successful restoration would require planting 90,000 m^2 or 22.2 acres of *V. americana*.

Figure 10. Locations of plots containing transplanted *Vallisneria americana* (Hauxwell et al. 2003, 2004a).

Figure 11. Mean densities of transplanted *Vallisneria americana* shoots ± standard errors (n = 3) in plots in Kings Bay (Hauxwell et al. 2003, 2004b). + herb = manatees allowed access; - herb = manatees excluded by cages

In summary, anecdotal accounts describe *Vallisneria americana* as the dominant species of submersed aquatic vegetation in Kings Bay, but this native macrophyte is now restricted to limited, patchy meadows (Jacoby et al. 2007). Decreased water clarity and light availability, stress from storm-induced salinity events, grazing by herbivores, and competitive exclusion by macroalgae and non-indigenous macrophytes probably all contributed to the displacement of this native macrophyte (Haller and Sutton 1975; Bowes et al. 1977; Barko et al. 1991; Blanch et al. 1998; Hauxwell et al. 2004a).

THE FUTURE OF SUBMERSED AQUATIC VEGETATION IN THE KINGS BAY–CRYSTAL RIVER SYSTEM

Based on available evidence, flows in the Kings Bay–Crystal River system will interact with multiple aspects of the ecology of submersed aquatic vegetation. Lower flows will increase residence times, which promotes the accumulation of phytoplankton biomass that can lead to reduced light penetration and stress on vegetation, including *Vallisneria americana*. Lower flows also will increase salinities, which will decrease competition between *V. americana* and other less tolerant vegetation potentially leading to an expansion of this desirable macrophyte.

Ultimately, establishing a balanced and self-sustaining assemblage of submersed aquatic vegetation in the Kings Bay–Crystal River system will require ongoing management that maintains suitable, background environmental conditions, including appropriate residence times, concentrations of nutrients, concentrations of suspended particles, and sediment conditions. Success also may require more drastic, short-term interventions to remove the legacy of past events and reset the system, e.g., sediment removal and the transplanting of *Vallisneria americana* or other native macrophytes. In all cases, the efficiency and effectiveness of management actions will be improved by science that evaluates options; guides implementation, including scaling from pilot studies; and assesses success to inform adaptation.

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APPENDIX

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Comparison of Nekton Community Structure Among Spring- and Surface-Fed Estuarine Rivers of Florida's West Coast

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SUMMARY

Estuaries and coastal rivers are highly productive habitats that provide nursery areas and refugia for ecologically and economically important fish and crustaceans (Steele 1974, Blaber & Blaber 1980, Comp & Seaman 1985). Nekton assemblages in these systems are dynamic in that they reflect the changing environmental conditions to which they are exposed on short-term and seasonal scales (Tremain & Adams 1995, Able & Fahay 1998). Brackish portions and other low-salinity portions of estuaries are of particular interest in relation to their importance as nursery areas for juvenile stages for many species (Lewis & Estevez 1988, Peebles & Flannery 1992).

There exists considerable trophic heterogeneity among tidal rivers on Florida's west coast. Some estuarine rivers derive flow from freshwater surface runoff whereas others are supplied by groundwater flow from springs. Surface-fed rivers often have highly colored waters due to tannins from the surface runoff and sandy or muddy bottoms. In contrast, spring-fed rivers typically have clear water and large amounts of dense macrophytic and macroalgal growth attached to the bottom. Another substantial difference between the two systems is the stability of temperature regimes and flows (Matheson et al. 2005; Greenwood et al. 2007; Greenwood et al. 2008; Peebles et al. 2009). Spring-fed rivers receive a fairly stable supply of ground water flow from subsurface aquifers whereas surface-fed rivers tend to be flashier due to their reliance on rainfall patterns and surface flow. The Homosassa, Chassahowitzka, Crystal and Weeki Wachee rivers lie within a region commonly referred to as the springs coast (Fig. 1), an area of western peninsular Florida extending from the Pithlachascotee River basin (North of Tampa Bay) to the Waccasassa River (South of the Suwannee River Basin). The springs coast watershed covers an area of approximately 2072 km^2 (SWFMD 2001). All four rivers are fed by first magnitude springs (>2.8 m^3/sec) and discharge directly to the Gulf of Mexico. Typically these spring-fed rivers are considered oligotrophic (Hollander et al. 2005). Given the unique characteristics of spring-fed rivers, associated nekton communities may be particularly sensitive to watershed disturbance, therefore, the objectives of this study were to use a comparative database of fisheries-independent nekton abundance from four spring-fed and surface-fed estuarine rivers to examine differences in community structure, including comparisons of similarity/dissimilarity of community structure, identifying indicator species, and testing a conceptual model of pelagic-to-demersal biomass ratios (P/D).

Despite similarities in the taxa collected in the two types of estuaries there were clear differences in abundance and community structure. Species richness of fish was greater (n=153) in surface-fed rivers than in spring-fed rivers (n=125). Likewise, richness of invertebrates was greater in surface-fed rivers (n=18) than spring-fed (n=14). Dendrograms from hierarchical cluster analyses indicate a clear separation in nekton community structure between spring- and surface-fed rivers with nekton communities in surface-fed rivers tending to be more dissimilar than those in spring-fed rivers. There also appears to be an indication of seasonal changes in community structure across all rivers with the greatest difference in seasonal separation occurring between winter and spring. Seven species may be candidates for indicator species for either spring- or surface-fed systems. Five demersal species were indicators for spring-fed rivers and one demersal and one pelagic species were indicators of surface-fed systems. Pelagic-demersal ratios (P/D) calculated across all months indicate higher proportions of pelagic species within spring-fed rivers.

Clear separations between community structure in spring- and surface-fed rivers are likely driven by inherent differences in water quality, light attenuation, and geomorphology of the two types of systems leading to greater abundances of some species in either spring- or surface-fed rivers. There is a much greater degree of variability in the diversity of the surface-fed rivers in comparison to spring-fed rivers. Indicator values for taxa were uniformly low due to overlap of species encountered in both systems and should be scrutinized carefully. Indicator species candidates for spring-fed systems were all demersal/benthic species that generally rely on benthic or allocthonus productivity facilitated by increased water clarity and light penetration of spring-fed systems, while candidates for surface-fed systems were pelagic and demersal suggesting that neither pelagic nor benthic productivity are limiting in these systems. Pelagic-to-demersal ratio s tended to be higher in spring-fed river systems mainly due to an increased abundance of the pelagic visual piscivores in the genus *Strongylura*. The lack of distinct differences in P/D is likely related to essentially non-existent hypoxic conditions in the habitats sampled.

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INTRODUCTION

Estuaries and coastal rivers are highly productive habitats that provide nursery areas and refugia for ecologically and economically important fish and crustaceans (Steele 1974, Blaber & Blaber 1980, Comp & Seaman 1985). Nekton assemblages in these systems are dynamic in that they reflect the changing environmental conditions to which they are exposed on short-term and seasonal scales (Tremain & Adams 1995, Able & Fahay 1998). Brackish portions and other low-salinity portions of estuaries are of particular interest in relation to their importance as nursery areas for juvenile stages for many species (Lewis & Estevez 1988, Peebles & Flannery 1992). The benefits provided by such habitats (e.g. food resources, refugia, reduced predation threat) outweigh potential disadvantages such as fluctuating environmental conditions (Day et al. 1989). However, these systems continually exist under intense pressure from anthropogenic stressors such as nutrient enrichment, organic matter loadings, shoreline development and habitat alteration.

Increased nutrient loading accompanied by warm water temperatures can lead to rapid and extensive bottom-water dissolved oxygen (O_2) depletion (Malone et al. 1988, Cooper & Brush 1991, Parker & O'Reilly 1991, Welsh & Eller 1991) and often result in hypoxia or anoxia. Hypoxia can be physiologically stressful for estuarine biota and prolonged exposure to anoxia is fatal for most endemic fauna (Van Dolah & Anderson 1991, Winn & Knott 1992). Increasing trends in estuarine hypoxia/anoxia have been linked to nutrient enrichment, increased primary productivity, eutrophication, and increased organic matter loadings from urban development of watersheds (Ambio 1990, Cooper & Brush 1991, De Jonge et al. 1994). Nutrient enrichment, hypoxia/anoxia and other anthropogenic alterations associated with development have been linked to alterations in primary production (Notestein et al. 2003), submerged aquatic vegetation

(SAV; Hoyer et al. 2004), macrobenthic communities (Lerberg et al. 2000, Bilkovic et al. 2006), egg and larval fish survival (Limburg & Schmidt 1990), and overall trophic and community structure (Livingston et al. 1997, Paerl et al. 1998, Toft et al. 2007, Bilkovic & Roggero 2008). Recent studies have attempted to link land-based activities to fish communities in surrounding areas. de Leiva Moreno et al. (2000) used an extensive database to examine the impact of eutrophying water bodies on the ratio of pelagic-to-demersal (P/D) fisheries landings, given that pelagic species will likely benefit from increased production associated with increased nutrient levels while demersal species will be limited due to increased hypoxia/anoxia. The authors found evidence for this relationship and determined that $P/D < 1.0$ typifies oligotrophic conditions while $1.1 < P/D < 6.0$ are mesotrophic and $P/D > 6.0$ are eutrophic in semi-enclosed seas around Europe. Due to the importance of estuarine areas as nursery habitat for many economically and ecologically important species it is essential to understand biological response to continued anthropogenic stressors.

There exists considerable trophic heterogeneity among tidal rivers on Florida's west coast (Estevez et al. 1991). Some estuarine rivers derive flow from freshwater surface runoff whereas others are supplied by groundwater flow from springs. Surface-fed rivers often have highly colored waters due to dissolved organic matter from the surface runoff and sandy or muddy bottoms. In contrast, spring-fed rivers typically have clear water and large amounts of dense macrophytic and macroalgal growth attached to the bottom. Another substantial difference between the two systems is the stability of temperature regimes and flows (Matheson et al. 2005; Greenwood et al. 2007; Greenwood et al. 2008; Peebles et al. 2009). Spring-fed rivers receive a fairly stable supply of ground water flow from subsurface aquifers whereas surface-fed rivers tend to be flashier due to their greater reliance on rainfall patterns and surface flow. Spring-fed

estuaries are typically considered to be oligotrophic while surface-fed estuaries are often considered eutrophic to hypereutrophic (Hollander et al. 2005). Spring-fed rivers along Florida's west central (springs) coast exist in areas with relatively little urban development (Southwest Florida Water Management District [SWFMD] 2001). The springs coast, especially along the US-19 corridor, however, has been experiencing rapid urbanization since the early 1970's (SWFMD 2001). There is concern that increased nutrient loads associated with urbanization (Ham & Hatzell 1996, Jones et al. 1997), will result in eutrophication of rivers and their receiving waters (i.e., shallow coastal waters of the Gulf of Mexico) and have deleterious effects on aquatic life. Ground-water nitrate and phosphorus enrichment is occurring throughout Florida, particularly in the north central region of the state (Ham & Hatzell 1996, Jones et al. 1997) which is the source water for many spring-fed rivers along Florida's springs coast. Additionally, the entire springs coast has been subjected to rapid increases in on-site sewage treatment (septic tank/drain fields) and centrally-sewered communities (SWFMD 2001).

Principle spring-fed rivers within the springs coast include the Homosassa, Chassahowitzka, Crystal and Weeki Wachee (Wolfe 1990). These rivers are fed by first magnitude springs or spring complexes and serve as important nursery areas for many aquatic and marine invertebrate and fish species (Greenwood et al. 2008; Peebles et al. 2009). Frazer et al. (1998) provided preliminary evidence that common eutrophication parameters (nitrogen and phosphorus) showed significant spatial and temporal variation within the springs coast. Likewise, increasing trends in nitrate concentrations attributed to anthropogenic sources have been found in the Homosassa, Chassahowitzka, Crystal and Weeki Wachee rivers (SWFMD 2001). Elevated nitrate concentrations in ground-water can result from past and present land use activities, such as commercial or residential fertilizer use (Jones et al. 1997). Due to lag-times

associated with ground-water movements, it is likely that further increases in nutrient loadings to springs will occur because of past and present human activities (Notestein et al. 2003). As these watersheds continue to be urbanized, it is important to establish baseline data that can be used to evaluate biological response to anthropogenic stressors. This information will be essential to the conservation of ecosystem structure and function and to successfully manage fisheries populations in the era of an ecosystem approach to management.

The effect of watershed development and nutrient enrichment on estuarine biological communities is of critical importance in ecosystem management. Given the unique characteristics of spring-fed rivers, associated nekton communities may be particularly sensitive to watershed development and nutrient enrichment. Our objectives were to 1) examine the similarities and differences between nekton communities in spring- and surface-fed rivers along Florida's spring coast; 2) identify indicator species for spring- and surface-fed rivers; and 3) test a conceptual model of pelagic-to-demersal biomass ratio (P/D).

MATERIALS AND METHODS

*Study area and sampling methods***.** The Homosassa, Chassahowitzka, Crystal and Weeki Wachee rivers lie within a region commonly referred to as the springs coast (Fig. 1), an area of western peninsular Florida extending from the Pithlachascotee River basin , North of Tampa Bay, to the Wacasassa River, South of the Suwannee River Basin (Wolfe 1990). All four rivers are fed by first magnitude springs or spring complexes (>2.8 m^3/sec), and discharge directly to the Gulf of Mexico. Typically these spring-fed rivers are considered oligotrophic (Hollander et al. 2005). The water for each river is derived directly from the upper Floridan aquifer and chemical composition is strongly influenced by tidal cycles (Yobbi & Knochenmus 1989, Yobbi 1992). Land use within the immediate vicinity of the rivers is largely undeveloped with

extensive coastal marshes and wetlands (SWFMD 2001). However, development is increasing rapidly throughout the region leading to concerns that potential impacts of anthropogenic nutrient enrichment may be detrimental to aquatic life (SWFMD 2001, Hoyer et al. 2004).

The Anclote, Alafia and Myakka rivers are surface-fed rivers draining lands to the south of the springs coast, while the Suwannee River derives most of its flow from surface run off north of the springs coast (Fig. 1). Degradation of water quality in each of these river's watersheds have occurred over time due to increased nutrient loads from point and non-point sources (SWFMD 2002; Water Resource Associates 2005). Generally, these rivers are considered eutrophic to hypereutrophic due to the high nutrient loads from the surface source waters (Hollander et al. 2005). Substantial development has occurred in the lower reaches of the Anclote River watershed (290 km^2) with the remainder consisting of wetlands and open/agricultural areas (SWFMD 2002; SWFMD 2010a). The Alafia River watershed (1,092 km^2) is a major tributary of Tampa Bay with major land uses including agriculture, phosphate mining and residential housing (Parsons Engineering Science Inc. 2002). Phosphate concentrations in the Alafia are the highest of any Tampa Bay tributary (Lewis and Estevez 1988; SWFMD 2008a). The Myakka River watershed (1,560 km^2) is a major tributary of Charlotte Harbor and drains a large expanse of land south of Tampa Bay to Charlotte Harbor. Land use within the Myakka River watershed consists of wetlands, agriculture and residential areas (Hammet 1990; SWFMD 2010b). Groundwater contributions to the overall flow of the Anclote and Myakka Rivers are negligible and source water is mainly from overland flows (Lewis & Estevez 1988, Hammet 1990, SWFMD 2002). Alafia River flows during the wet season are surface runoff driven, but a significant portion of dry season flows are derived from Lithia and Buckhorn springs (SWFMD 2008a). The Suwannee River represents the largest

watershed in this study (25,770 km^2) and is the northern most river in this study. Major land uses within the Suwannee River watershed include managed pine forests, upland and wetland forests, and agriculture (Water Resource Associates 2005). The Suwannee differs from other surface-fed river systems in that dry season flows are typically high and stable resulting from substantial contributions from several springs upriver (SRWMD 1998). The Suwannee also has limited salt penetration and may have lower chlorophyll a values in comparison. However, the Suwannee is the only large surface influenced system geographically similar to the spring-fed systems and is included to preclude latitudinal differences between spring- and surface-fed systems.

Data for this study were collected from the estuarine sections of four spring- (2003-2010) and four surface-fed (2003-2009) rivers by the Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute's Fisheries-Independent Monitoring Program (FIM) as part of minimum flow studies sponsored by the Southwest and Suwannee Water Management Districts [Table 1]. A stratified-random, multi-gear sampling design was employed in each river to provide a comprehensive data set encompassing a wide range of habitats and life history stages as well as spatial and temporal patterns of abundance for nekton communities. The area sampled in the rivers ranged from the upper limits of salt penetration in tidal freshwater reaches to marine waters at the river's mouth (salinity>35 ppt). Nekton were collected during this study using 21.3-m center bag seines (3.2-mm stretched mesh) that principally target small-bodied animals (i.e., juveniles of larger species and juveniles and adults of smaller species) along shoreline habitats and with water depths $\leq$ 1.8 m. In total, 3,170 samples from the eight systems were included in this analysis.

At each sampling site, fish and selected macroinvertebrates (e.g., blue crab, *Callinectes sapidus*, ornate blue crab, *C. ornatus*, pink shrimp, *Farfantepenaeus duorarum*) were identified (generally to species), enumerated, and a subsample ($\leq$ 40 individuals per species) were measured (standard length for teleosts, disc width for rays, carapace width for crabs, and postorbital head length for shrimps). At each sample site temperature, salinity, pH, conductivity and dissolved oxygen were recorded with a Hydrolab or YSI multiprobe at the water's surface and bottom and at every 1-m increment in between. When water depth was < 0.4 m only a surface reading was taken. Additionally, physical habitat measurements (e.g., secchi depth, shoreline vegetation, bottom type, etc) were recorded at each site.

Data Analysis. Water quality measures were compared among river systems with a Kolmogorov-Smirnov test and differences were considered significant at the $\alpha = 0.05$ level. Species-level analysis may not be sufficient to characterize ontogenetic shifts in habitat use (Livingston 1988). Therefore, early and late stage juveniles of large-bodied species and adults and juveniles for small-bodied species were separated into size classes, hereto referred to as pseudospecies. For this study, a relatively simple nonparametric approach was taken to examine differences in community structure among spring- and surface-fed rivers as evidenced by nekton community change. The average abundance (by month) of each pseudospecies was square-root transformed to reduce the influence of common species. Matrices of pairwise Bray-Curtis similarities (Bray and Curtis 1957) were computed between all rivers. Simple agglomerative, hierarchical clustering was performed on the Bray-Curtis similarities to produce successively smaller numbers of clusters as similarities decrease (Clarke & Gorley 2006). Similarity profile (SIMPROF) permutation tests were computed to identify statistically significant evidence of genuine clusters that were not *a priori* determined (Clarke & Gorley 2006). Nonmetric

multidimensional scaling (MDS; Clarke 1993; Clarke and Warwick 2001) was conducted on the Bray-Curtis similarity matrix to produce ordination plots depicting the similarities in community structure between rivers. The ordination plots are based on ranked similarities in community structure between rivers and as such are nonmetric and plotted on unitless axes. The proximity of the monthly river increment labels to each other in the ordination plots is an indication of community structure similarity over the spectrum of the months and rivers; large distances between points indicate greater differences in community structure. Ellipses representing similarity from the cluster analyses were overlain on the ordination plots and the plots were visually inspected for evidence of community structure differences between rivers. In an attempt to interpret differences in observed community structure and examine the role of individual species in contributing to the average dissimilarity between rivers, similarity percentages analysis (SIMPER: Clarke and Warwick 2001) was conducted on the average monthly abundance of species in each river system. Similar analyses were performed on the data set averaged over river and season (e.g., Winter, Spring, Summer, Fall) and over source water type (predominately spring- or surface-fed) and season. Standard diversity measures (Shannon and Simpson) were calculated for each river and species richness for each river and month. All diversity and non-parametric analyses were computed using PRIMER-E (Clarke & Gorley 2006).

For the purposes of determining indicator pseudospecies and depicting abundance comparisons of said pseudospecies, abundance measures from individual stations were used (i.e., numbers were not averaged across an entire estuary to obtain a single monthly average). Indicator pseudospecies for *a priori* groups of spring-fed and surface-fed river systems were identified via the method of Dûfrene and Legendre (1997) using the R statistical program (R

Development Core Team 2008) on square root transformed data. An indicator value (IV) of >25 was arbitrarily chosen as the level at which a pseudospecies was chosen as being an indicator. For each "indicator" pseudospecies, a generalized linear model (GLM) was used to compare average abundance between spring- and surface-fed river systems. The response variable (abundance) and water quality variables (i.e., salinity, dissolved oxygen, temperature, pH) were log transformed to improve normality. Other independent variables included secchi depth, water depth, year, bottom type (e.g. sand, mud), shore vegetation type, and source flow (i.e. spring- or surface-fed). A backwards step-wise algorithm was used to determine the best fit model for each species. Least-squares means (adjusted means) and Fisher's least-significant difference (LSD) intervals were calculated. The Least-squares means estimate the marginal means over a balanced population while Fisher's LSD were used to determine all pairwise comparisons of mean abundances. Least-squares means were used to test for differences in abundance between spring- and surface-fed rivers using a Kruskal-Wallis test. Abundance was deemed significant at the $\alpha = 0.05$ level. Generalized linear models, least-squares means, Fisher's LSD, and Kruskal-Wallis tests were computed using SAS software (SAS Institute Inc. 1999).

To determine if pelagic to demersal ratios (P/D) were different between spring- and surface-fed systems, length and abundance data for each species were converted to biomass. Conversion to biomass for most marine and estuarine taxa were accomplished with an extensive database of length-weight regressions from regular FIM stratified random sampling (FWRI, unpublished data). For freshwater species collected from these systems, length-weight regressions were obtained from Florida Fish and Wildlife Conservation Commission Freshwater Fisheries Division (FFWCC, unpublished data). In the case of exotic species, length-weight regressions were gleaned from fishbase (www.fishbase.org). Each species was then grouped into

either pelagic or demersal groups based on trophic ecology and life history characteristics (Richard Matheson Jr., personal communication). Pelagic and demersal/benthic biomass and P/D was calculated for each river system and for seasonal shifts. Seasons were defined by water temperature and four distinct changes were observed: winter (December – February), spring (March-May), summer (June-August), and fall (September – November).

RESULTS

Overall, 192 species of fish and invertebrates were collected with the 21.3-m shoreline seines. Species richness of fish was greater (n=153) in surface-fed rivers than in spring-fed rivers (n=125; Appendix I). Likewise, richness of invertebrates was greater in surface-fed rivers (n=18) than spring-fed (n=14). There were no significant differences in species diversity across rivers but diversity was generally more variable in surface-fed systems with the Suwannee and Myakka exhibiting the greatest variability and periodically reaching the lowest diversity values (Fig. 2). Species richness varied across months in all of the rivers, but tended to be highest in the summer and fall months (Fig. 3). Mean water temperatures (°C) among spring- and surface-fed rivers were marginally significantly different ($p = 0.08$) with the greatest differences observed during winter (Fig. 4a). Temperature minima occurred from November-February (14-22 °C) and maxima from June-September (26-30 °C). Mean secchi depth (m) was marginally significantly different between spring- and surface-fed rivers through all months ($p = 0.07$) with the greatest differences between systems occurring in the summer months when spring-fed systems had greater secchi depth measurements (Fig. 4b). Mean salinity (ppt) was not significantly different across all rivers but generally exhibited higher values in surface-fed systems during May and June while spring-fed systems remained fairly constant (Fig. 4c). Overall, salinity was more consistent between spring-fed than surface-fed rivers. Mean dissolved oxygen (mg/l) was not

significantly different among spring- and surface-fed rivers over months (Fig. 4d), but was slightly higher in spring- than surface-fed rivers. Not surprisingly, dissolved oxygen shows an inverse relationship to temperature with minima occurring during June-August and maxima from November-February.

Dendrograms from hierarchical cluster analyses indicate a clear separation in nekton community structure between spring- and surface-fed rivers (Fig 5). With a few deviations for the Suwannee River, different months within each river tended to group closer together. Spring- and surface-fed rivers separate at ~35% Bray-Curtis similarity ($P<0.01$). The nonmetric multidimensional scaling (MDS) plots with 35% similarity clusters overlain as ellipses clearly indicate separation in nekton community structure (Fig. 6). Nekton communities in surface-fed rivers tended to be more dissimilar than those in spring-fed rivers as indicated by the proximity of individual river points and the 35% similarity overlay.

There appears to be an indication of seasonal changes in community structure across all rivers when pseudospecies abundances were averaged over river source flow and season (Fig. 7). There is a vertical progression in community change in both surface- and spring-fed systems with the greatest difference in seasonal separation occurring between winter and spring. Cluster analysis overlaid as ellipses (60%) indicate that spring-fed river systems are more dissimilar between fall/winter and spring/summer than are surface-fed river systems (Fig. 7).

Results from the analysis of similarity (ANOSIM) routine also indicated greater variability in community structure in surface-fed than in spring-fed systems. The average ANOSIM *R* statistic was 0.577 for comparisons of nekton community structure between surface-fed systems, 0.297 between spring-fed systems and 0.652 for comparisons between spring- and surface-fed systems (Table 2). SIMPER results identified several species that contributed greatly

to the average dissimilarity between spring- and surface-fed systems (Table 3). Of the top 35 species contributing to 75% of the overall dissimilarity, 22 were more abundant in spring-fed rivers than surface-fed ones. In order of contribution to overall dissimilarity, the top five contributors were the grass shrimp *Palaemonetes intermedius*, juvenile (≤ 30 mm) mojarras *Eucinostomus* spp., rainwater killifish *Lucania parva*, and two size classes (≤ 30 mm, 51-100 mm) of pinfish *Lagodon rhomboides* which were more than twice as abundant in spring-fed systems. Conversely, small and medium-sized (≤ 30 mm, 31-50 mm) bay anchovy *Anchoa mitchilli*, and small, medium and larger sized (≤ 30 mm, 31-50 mm, 51-100 mm) hogchokers *Trinectes maculatus*, were more than three times as abundant in surface-fed rivers.

Seven species had an indicator value (IV) greater than 25 and might be candidates of indicator species for either spring- or surface-fed systems. Of the seven species, five demersal species were indicators for spring-fed rivers (rainwater killifish *Lucania parva*, blue crab *Callinectes sapidus*, grass shrimp *Palaemonetes intermedius*, tidewater mojarra *Eucinostomus harengulus*, and juvenile mojarras *Eucinostomus* spp.). The remaining two species with IV values > 25 were indicators for surface fed systems (hogchoker *Trinectes maculatus*, and bay anchovy *Anchoa mitchilli*). The hogchoker is a demersal species and bay anchovy is classified as pelagic. Although there is both inter- and intra-system variance among spring- and surface-fed rivers, there is a significant difference in abundance between spring- and surface-fed rivers for four of the five spring-fed indicators and both of the surface-fed indicators (Kruskal-Wallis, $p < 0.0001$; Fig. 8 and Fig. 9).

Pelagic-demersal ratios (P/D) calculated across all months indicate higher proportions of pelagic species within spring-fed rivers (Fig. 10). The Myakka River had the lowest P/D while the Weeki Wachee had the highest. An examination of P/D for all rivers and seasons revealed

seasonal changes in biomass composition (Fig. 10). For spring-fed rivers P/D was generally lower in the spring and fall and higher during the winter and summer, although there is some individual variation amongst rivers. The Weeki Wachee River had the greatest P/D observed in the winter months, but was similar to other spring-fed rivers throughout the rest of the year. The P/D for surface fed rivers was lowest in the spring and higher through the rest of the seasons. Pelagic-demersal ratios for the Weeki Wachee River increased more than 10x in the winter as compared to summer months. While increases in P/D from summer to winter were observed in all spring-fed rivers except the Chassahowitzka, the magnitude of change in the Weeki Wachee is unique among the systems studied. Overall, variation in P/D was greater across seasons in spring-fed rivers and more consistent in surface-fed rivers.

DISCUSSION

There were broad similarities in the faunas of both the spring- and surface-fed river systems. Species diversity and richness were similar amongst spring- and surface-fed rivers and many species were present and abundant in both types of systems. Despite these apparent similarities, spring- and surface-fed river systems have inherent differences in their associated faunas. There is a much greater degree of variability in the diversity of the surface-fed rivers in comparison to spring-fed rivers. The non-metric muldimensional scaling, cluster analysis and SIMPROF results indicate a separation of the two with little overlap of community structure. Similarly, ANOSIM results clearly indicate that there is much more dissimilarity between spring- and surface-fed systems than amongst the two groups. Although there is considerable overlap of pseudospecies present in each of the two system types, abundances of these pseuodspecies differ significantly between spring- and surface-fed rivers. Inherent differences in physical and chemical characteristics between the two are likely to drive these differences in

community structure. Differences in temperatures regimes, habitat, submerged aquatic vegetation, primary productivity, and variations in flows, among other factors likely contribute to habitat being more suitable for pseudospecies in either spring- or surface-fed systems.

Indicator values (IV) were uniformly low for both spring- and surface-fed systems. Indicator values can assume values from 0 to 100 with larger values indicative of strong fidelity. There were only seven species from both types of systems with IV's greater than 25. Five species were indicators of spring-fed rivers and two were from surface-fed rivers. Overall, IV's were generally higher for spring-fed than surface-fed rivers. The pattern of higher IV values for spring-fed systems is likely related to the fact that there is much more variability in species caught, abundance, and community structure between surface-fed systems than between spring-fed systems. The greater similarity of nekton communities in spring-fed rivers means that a species that is a good indicator for one spring-fed river is likely a good indicator for the other three as well. The greater dissimilarity between surface-fed rivers makes it more unlikely that an indicator species from one surface-fed river will also a good indicator for the other three.

Greater nekton community dissimilarity of surface-fed systems may be related to variance in flows, salinity or geography among other factors. Since collections for each system were conducted in different years, differences in rainfall and therefore source water flow likely contribute to significant differences in salinities of the relevant river systems. Similarly, the Myakka and Alafia Rivers both empty into large estuarine bay systems whereas the Anclote and Suwannee Rivers empty directly into the Gulf of Mexico. These estuarine bays create a more gradual transition from low salinities to full marine salinities. In essence, there is the potential for the salinity gradient to be more contracted for those rivers emptying directly into the Gulf of

Mexico. This contracted estuarine zone may lead to some of the dissimilarity between surface-fed river systems.

There are also differences in geomorphology, hydrology, water quality and unknown drivers of inter-annual recruitment variability between spring- and surface-fed rivers that likely contribute to differences in nekton communities. For example, Suwannee River samples were more dissimilar than any other river sampled. Further examination of the MDS plots indicates that samples collected from January to May separate from all other river samples. The Suwannee River is unique in the fact that it has flow pattern more typical of southeastern U.S. rivers, while the other rivers have flow patterns typical to central Florida (Kelly 2004; Kelly & Gore 2008). Spring rains contribute to higher flows during spring months. The other river systems included in this study either have relatively steady flows (spring-fed rivers) or are driven by higher rain fall in the summer months (e.g. Anclote, Alafia, Myakka). In this study, the spring-fed rivers are much shorter than the surface-fed rivers resulting in a smaller watershed in comparison to surface-fed rivers. Due to source water derived directly from spring outputs, spring-fed river systems have a more consistent water flow, relative to surface-fed rivers. Surface-fed rivers, by definition are dependent upon rainfall and runoff resulting in higher variability and flashier flows. Flashy flows can be a source of disturbance which can have a significant impact on abundance and distribution of organisms (Matheson et al. 2005; Peebles et al. 2006; Greenwood et al. 2007). The two types of systems also differ in some water quality measures with differences in secchi depth and temperature being marginally significant (Kolmogorov-Smirnov test, $p = 0.07$ and 0.08 respectively). Other studies have shown that surface- -fed rivers tended to have higher measures of color, turbidity and chlorophyll a (SWFMD 2008a, SWFMD 2008b. SWFMD 2010a, SWFMD 2010b, SWFMD 2010c, SWFMD

2010d, Burghart et al. 2011) suggesting that these systems are reliant upon productivity derived within the water column.

The optical properties of the water, which are closely linked to trophic state, can exert strong control over planktonic or benthic primary production (Meyercordt et al. 1999). The abundant taxa collected, and the indicator species identified in this study reflect these differences in physical parameters. The ten most numerically abundant taxa collected in spring-fed rivers were demersal/benthic species. Indicator species for spring-fed systems were all demersal/benthic species that generally rely on benthic or allocthonus productivity. Other studies have found that fauna of spring-fed systems tend to be dominated by benthic production and organisms (Jacoby et al. 2008; Burghart et al. 2011). In contrast, one of the indicator species for surface-fed systems was pelagic while the other was demersal/benthic. The pelagic species, *A. mitchilli*, is a predator of pelagic zooplankton and thus indirectly dependent upon water column primary productivity. The other indicator of surface-fed rivers, *T. maculatus*, is an obligate benthic species, and as such relies on benthic production. *Anchoa mitchilli* is the only pelagic species amongst the ten most abundant taxa in these surface-fed rivers. The other nine taxa in the top ten are demersal/benthic species, suggesting that greater planktonic primary production in surface-fed systems does not diminish benthic production or abundance of species that rely upon it.

Examination of the IV and indices of abundance lends little support for describing the majority of the indicator species candidates as indicator species. Three of the five spring-fed indicator species candidates had low IV (<40) and inconsistent abundance trends among the four spring-fed systems. The two remaining spring-fed indicator species candidates (*L. parva* and *P. intermedius*) had IV > 40 and clear difference in abundance between spring- and surface-fed

systems. The two strongest spring-fed indicators (*L. parva* and *P. intermedius*) had abundances in the Crystal River that were more similar to surface-fed systems than to the other spring-fed rivers. For surface-fed rivers, the designation of *T. maculatus* as an indicator species is also suspect. Abundance of hogchokers in three of the four surface-fed systems are similar to those of spring-fed rivers, however abundance in the Alafia River is extremely high and likely driving the higher surface-fed river IV for this species. *Anchoa mitchilli* seems a likely candidate for an indicator species of surface-fed rivers; in three of the four spring-fed systems, bay anchovy indices were lower than in three of the four surface-fed systems. The utility of the bay anchovy as a surface-fed indicator species does not hold for the Anclote River, for which indices of abundance were relatively low, and the spring-fed Crystal River, for which indices of abundance were relatively high, Overall, IV's were likely low because most species were present at similar frequency of occurrence from collections in both spring- and surface-fed rivers. Those species with higher IV's were more numerically abundant in samples of either surface-fed or spring-fed systems.

Declining water quality along the springs coast and the possibility for associated nekton community change has been of great concern in recent years. Florida's spring-fed rivers and associated estuaries have been thought to be oligotrophic systems with low nutrient loads and high water quality measures. Recent agricultural activity and increasing urbanization in the area has led to significant concerns over maintaining the trophic conditions of spring-fed rivers (Katz 2004, Brown et al. 2008). Recent increases in nitrate and phosphorus concentrations, light attenuation, periphyton biomass, chlorophyll a concentrations and decreased submerged aquatic vegetation biomass has led to expressed concern from many in the scientific community that Florida's spring-fed rivers are undergoing important structural and functional changes (FDEP

2006, Frazer et al. 2006, Jacoby et al. 2008, Harrington et al. 2010). The absence of pre-urbanization nekton community data precludes the ability to draw firm conclusions in regards to how nekton community structure may be altered in response to increased nutrient loading and associated changes in primary production and submerged aquatic vegetation. However, analyses of current nekton community structure show a clear difference between spring- and surface-fed communities. Similarly, examination of SIMPROF and MDS results indicate separation of community structure at roughly 35% similarity with minimal overlap. Of the spring-fed systems, the Crystal River community was most similar to those of surface-fed systems and it may be possible that it is showing early signs of nekton community response to increased nutrient loading. Although differences in physicochemical habitat variables are likely to contribute to the dissimilarity in community structure, that type of analysis is beyond the scope of this paper.

It is also reasonable that changes in the fauna of spring-fed rivers would be most evident in lower trophic level species that are more directly tied to primary production. A concurrent analysis of ichthyoplankton and zooplankton from the same spring-fed river systems found that the community structures of the Homosassa and Crystal rivers were intermediate between the other spring-fed rivers and surface-fed rivers (Burghart et al. 2011). Frazer et al. (2006) reported that, of the three spring-fed systems they studied between 1998 and 2005, the Homosassa River had the highest phytoplankton biomass and was the only one of the three with increasing chlorophyll a concentrations, and there may be anecdotal evidence suggesting changes in phytoplankton levels in the Homosassa River. These plankton community findings lend support to water quality and primary productivity studies that have indicated that spring-fed rivers are becoming more eutriphied due to anthropogenic nutrient loading and the results are being transmitted through the flora and fauna.

We examined the pelagic to demersal/benthic (P/D) ratios for similarities in community structure between spring- and surface-fed systems as a possible indicator of increased nutrification. It has been suggested that the composition of fisheries landings may be an important indicator of the effects of nutrient enrichment on fish and mobile invertebrates (Caddy 1993; de Leiva Moreno et al. 2000). These studies have relied upon fisheries-dependent data because fisheries-independent data of comparable spatial and temporal scales are not widely available. The biomass based P/D ratio is thought to be sensitive to eutrophication with higher P/D values expected as pelagic species biomass increases in response to eutrophication. de Leiva Moreno et al. (2000) classified systems with P/D ratio's < 1.0 as oligotrophic, P/D ratio's from 1.0-6.0 as mesotrophic, and P/D's > 6.0 as eutrophic. In the current study, in all cases the spring-fed rivers had higher P/D ratio's than those of the surface-fed rivers with spring-fed rivers falling within the mesotrophic category and surface-fed rivers considered oligotrophic.

Cleary, the P/D does not apply to the systems and habitat studied here. The conceptual model for the P/D ratio is that as water quality declines so does light penetration resulting in decreased benthic productivity, increased hypoxia and reduced benthic biomass (de Leiva Moreno et al. 2000; Hondorp et al. 2010). In light of the concepts we would expect P/D ratios to be much higher in surface-fed rivers, especially the Alafia river which has higher phosphorus levels than any other river in Florida. The studied surface-fed systems, have higher levels of chlorophyll a, total color (Burghart et al. 2011), and decreased secchi depth indicating that they should have greater primary production and pelagic biomass. Our results seem to indicate that greater nutrient enrichment of surface-fed rivers plays little role in structuring nekton communities.

The traditional tenants of the P/D ratio concept do not seem to hold true for the fluvial, shallow water nekton communities in this study. Hondorp (2010), in a study of 22 estuaries, coastal areas and semi-enclosed seas, found that persistent hypoxia was more highly correlated with high P/D than was nutrient enrichment. In the estuarine river systems studied here, hypoxic events were observed sporadically during summer months in deeper habitats not considered for this study. The sampling gear employed here was limited to depths less than 1.8m and rarely sampled these hypoxic events. It is likely that the severity of these hypoxic events would be mollified by the sampling design and availability of low D.O. refugia in the shallow water areas along the shorelines. .

In spring-fed rivers, peaks in monthly P/D ratio's and overall P/D were strongly influenced by *Strongylura* spp. (needlefish) Needlefish are pelagic piscivores that spend the majority of their time at the surface. As visual predators, it is reasonable to assume that they would be more abundant in spring-fed systems where the greater water clarity would increase predation efficiency. The P/D ratios in spring- and surface-fed rivers with needlefish removed were very similar. Overall, there seems to be little difference in overall pelagic and demersal/benthic biomass between the two types of systems, indicating that nutrient loading is not a limiting factor in either system type. Increased nutrient loads may, in the short term, benefit both pelagic and demersal/benthic taxa by providing additional productivity up until declines in benthic habitat quality (i.e., hypoxia) and adequate refugia become limiting (Hondorp et al. 2010).

The data presented here were collected over a period of years and do not represent a continuous time series, thus precluding the ability to draw conclusions concerning trends in nutrient enrichment on community structure of mobile nekton. Spring-fed rivers could not be

consistently sampled with trawls and, therefore we can not speculate on the community structure or biomass of the deeper habitats (>1.8m) within these systems. This comparison of shallow-water, shoreline-oriented nekton communities did not sample the deeper areas where perturbations from nutrient loading, such as hypoxia, would be expected to be greatest. These data do, however, allow for a broad comparison of the shallow-water, shoreline associated habitats of these estuarine river systems. There are overarching differences in nekton community structure between spring- and surface-fed estuarine rivers. These differences likely result from inherent differences in physicochemical variables within the systems. There is some evidence that at least one of the spring-fed systems, Crystal River, is more similar to the surface-fed systems than to the other spring-fed systems. Directly linking these similarities to increases in nutrient loading, however, would require a long-term data set on this system that included pre-urbanization data. It is quite possible that these similarities in community structure are the result of greater variability in salinity in the Crystal River in comparison to other spring-fed rivers, or some other water quality measures (FWRI unpublished data). It is difficult to accurately assess the utility of the P/D ratio for these eight shallow-water, Floridian estuary systems. Previous studies have focused on exploited species and their associated landings, which are heavily influenced by fishing practices and regulations, and by hypoxic events. Neither fishing pressure nor hypoxia is likely to have a significant effect on the nekton captured in this study. Further investigations of the P/D conceptual model in fluvial estuarine systems will likely provide additional insight into nekton community response to increased eutrophication. Since this study represents only a snapshot of nekton community within spring- and surface-fed estuarine river systems we recommend continued monitoring of these systems to document any shifts that may occur over time due to nutrient enrichment, increased urbanization, habitat alteration and inflow

changes. The understanding of community response to these stressors will be vital for managers when making decisions regarding conservation or management of Florida's spring- and surface-fed estuarine river systems and their associated communities.

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Table 1. Summary of river morphometrics and sampling effort for four spring-fed* and surface-fed rivers sampled during this study. River kilometer zero occurs at the river mouth; therefore any negative river kilometer indicates sampling occurred beyond the river mouth. Spring-shed size is difficult to determine due to the expanse of the source aquifer. Therefore, watershed size for spring-fed rivers is undetermined.

River System	River Km's sampled	Start date	End date	Watershed Size (km^2)	# of Nekton Samples
Crystal*	-0.9 to 12.1	Mar. 2008	Feb. 2010	NA	356
Homosassa*	0.0 to 13.4	Dec. 2006	Nov. 2008	NA	433
Chassahowitzka*	-3.5 to 8.6	Aug. 2005	Aug. 2007	NA	357
Weeki Wachee*	-1.5 to 3.8	May 2003	Dec. 2004	NA	247
Suwannee	-1.0 to 12.3	Dec. 2007	Dec. 2009	25,770	250
Anclote	-1.8 to 16.1	Oct. 2004	Sep. 2005	290	217
Alafia	0.0 to 14	Jan. 2006	Dec. 2008	1,092	801
Myakka	-6.5 to 35.3	May 2003	Dec 2004	1,560	509

Table 2. ANOSIM results for comparisons of similarity amongst surface-fed estuarine rivers, spring-fed rivers, and between spring- and surface-fed rivers. Larger R values indicate greater dissimilarity between systems.

Groups	***R***	***p***
Surface-fed vs. Surface-fed		
Alafia, Anclote	0.742	0.001
Alafia, Myakka	0.485	0.001
Alafia, Suwannee	0.692	0.001
Anclote, Myakka	0.808	0.001
Anclote, Suwannee	0.349	0.001
Myakka, Suwannee	0.386	0.001
Spring-fed vs. Spring-fed		
Chassahowitzka, Homosassa	0.201	0.004
Chassahowitzka, Weeki Wachee	0.271	0.001
Chassahowitzka, Crystal	0.235	0.001
Homosassa, Weeki Wachee	0.374	0.001
Homosassa, Crystal	0.433	0.001
Weeki Wachee, Crystal	0.273	0.001
Surface-fed vs. Spring-fed		
Alafia, Chassahowitzka	0.717	0.001
Alafia, Homosassa	0.708	0.001
Alafia, Weeki Wachee	0.774	0.001
Alafia, Crystal	0.370	0.001
Anclote, Chassahowitzka	0.587	0.001
Anclote, Homosassa	0.801	0.001
Anclote, Weeki Wachee	0.424	0.001
Anclote, Crystal	0.611	0.001
Myakka, Chassahowitzka	0.833	0.001
Myakka, Homosassa	0.905	0.001
Myakka, Weeki Wachee	0.876	0.001
Myakka, Crystal	0.748	0.001
Suwannee, Chassahowitzka	0.539	0.001
Suwannee, Homosassa	0.525	0.001
Suwannee, Weeki Wachee	0.639	0.001
Suwannee, Crystal	0.379	0.001

Table 3. Simper results indicating average abundance (Avg. Abund.) of nekton in spring- and surface-fed estuarine river systems, average dissimilarity (Avg. Diss.) between the two types of systems, dissimilarity/standard deviation (Diss/SD), percent contribution of the pseudospecies to overall dissimilarity (% Contr.), and cumulative percent of total dissimilarity (Cum. %).

	Surface-fed	Spring-fed				
Pseudospecies	Avg. Abund.	Avg. Abund.	Avg. Diss.	Diss/SD	% Contr.	Cum. %
Palaemonetes intermedius *	0.15	4.41	5.85	0.90	6.71	6.71
Eucinostomus spp. ≤ 30 mm *	0.60	3.37	5.16	0.68	5.91	12.62
Anchoa mitchilli ≤ 30 mm **	3.25	0.23	4.68	0.75	5.36	17.97
Lucania parva ≤ 30 mm *	0.20	2.95	3.88	0.85	4.44	22.41
A. mitchilli 31-50 mm **	2.71	0.17	3.80	0.78	4.35	26.76
Lagodon rhomboides ≤ 30 mm	0.52	1.67	2.87	0.58	3.29	30.06
Trinectes maculatus ≤ 30 mm **	1.48	0.20	2.29	0.71	2.63	32.68
L. rhomboides 51-100 mm	0.65	1.45	2.23	0.75	2.56	35.24
Farfantepenaeous duorarum ≤ 15 mm	1.11	1.39	2.16	1.01	2.48	37.72
Eucinostomus spp. 31-40 mm *	0.28	1.41	2.16	0.65	2.47	40.19
Callinectes sapidus ≤ 30 mm *	0.46	1.42	2.14	0.82	2.45	42.63
C. sapidus 31-50 mm *	0.80	1.58	2.08	0.95	2.38	45.02
T. maculatus 31-50 mm **	1.25	0.15	1.97	0.88	2.26	47.28
C. sapidus > 100 mm *	0.93	1.56	1.89	0.96	2.16	49.44
L. rhomboides 31-50 mm	0.34	1.17	1.82	0.55	2.08	51.52
T. maculatus 51-100 mm **	0.76	0.20	1.31	0.78	1.51	53.03
Cynoscion arenarius ≤ 30 mm	0.80	0.00	1.31	0.62	1.50	54.53
C. arenarius 31-50 mm	0.83	0.00	1.30	0.64	1.49	56.02
C. sapidus 51-100 mm *	0.35	0.74	1.21	0.87	1.38	57.40
E. harengulus 51-100 mm *	0.34	0.55	1.13	0.63	1.30	58.70
Syngnathus scovelli 51-100 mm	0.11	0.74	1.04	0.87	1.19	59.89
A. mitchilli 51-100 mm **	0.61	0.05	0.97	0.44	1.11	61.00
Ariopsis felis > 100 mm	0.60	0.14	0.97	0.91	1.11	62.12
E. gula 51-100 mm	0.33	0.49	0.96	0.66	1.09	63.21
Leiostomus xanthurus ≤ 30 mm	0.57	0.17	0.94	0.36	1.07	64.28
C. arenarius 51-100 mm	0.55	0.00	0.84	0.47	0.96	65.25
Microgobius gulosus ≤ 30 mm	0.20	0.46	0.83	0.56	0.95	66.20
E. harengulus 40-50 mm *	0.16	0.43	0.8	0.54	0.92	67.11
Dasyatis sabina > 100 mm	0.35	0.17	0.65	0.91	0.74	67.85
Mentichirrus americanus ≤ 30 mm	0.40	0.00	0.61	0.54	0.69	68.55
Gobiosoma spp. ≤ 30 mm	0.10	0.40	0.61	0.58	0.69	69.24
Sphoeroides nephelus ≤ 30 mm	0.08	0.32	0.58	0.50	0.67	69.90
Symphurus plagiusa 51-100 mm	0.23	0.25	0.57	0.70	0.65	70.56
Microgobius gulosus 31-50 mm	0.15	0.30	0.54	0.62	0.62	71.18
Lutjanus griseus > 100 mm	0.09	0.27	0.52	0.53	0.60	72.39

Figure 1. Location of estuarine river systems included in this study.

Figure 2. Shannon and Simpson diversity indices for spring- and surface-fed estuarine river system samples. Lines represent median values, gray boxes represent the 25th and 75th percentiles and bars represent the 5th and 95th percentiles. Spring-fed rivers include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 3. Monthly change in species richness of spring- and surface-fed estuarine river systems. Spring-fed rivers (gray) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (black) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 4. Monthly water quality measures collected during sampling events for spring- and surface-fed estuarine river systems. Mean and standard error bars are presented. Spring-fed rivers (gray) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (black) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 5. Dendrogram representing similarity of nekton community structure from monthly sampling of spring- and surface-fed estuarine rivers. Spring-fed rivers (open) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (filled) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 6. Multi-dimensional scaling plot of square-root transformed nekton abundance averaged over month for spring- (open) and surface-fed (filled) estuarine river systems. Thirty five percent similarity ellipses are overlain.

Figure 7. Multidimensional scaling plot of square-root transformed nekton abundance data averaged over source flow (spring-fed: open vs. surface-fed: filled) for estuarine river systems. Sixty percent similarity ellipses are overlain.

Figure 8. Indicator species for spring-fed rivers as determined by the method of Dûfrene and Legendre (1997). Catch-per-unit-effort (log number of individuals captured per set) and Fisher's least significant differences are shown. CPUE for taxa with an asterisk were significantly different between spring- and surface-fed estuarine river systems (Kolmogorov-Smirnov test, $P < 0.05$). Spring-fed rivers (gray) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (black) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 9. Indicator species for surface-fed rivers as determined by the method of Dûfrene and Legendre (1997). Catch-per-unit-effort (log number of individuals captured per set) and Fisher's least significant differences are shown. CPUE for taxa with an asterisk were significantly different between spring- and surface-fed estuarine river systems (Kolmogorov-Smirnov test, $P < 0.05$). Spring-fed rivers (gray) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (black) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

Figure 10. Overall and seasonal pelagic-to-demersal biomass ratio for spring- and surface-fed estuarine river systems. Conceptual models (de Leiva Moreno et al. 2000) suggest oligotrophic systems have P/D's < 1.0, mesotrophic systems P/D's are from 1.1 – 6.0, and eutrophic systems P/D's are > 6.0. Spring-fed rivers (solid bars) include the Crystal, Homosassa, Chassahowitzka, and Weeki Wachee Rivers. Primarily surface-fed rivers (patterned bars) include the Suwannee, Anclote, Alafia, and Myakka Rivers.

APPENDIX I. Scientific names, common names, habitat classification, and presence/absence data for nekton captured within spring- and surface-fed estuarine river systems in this study. Habitat classifications (P = pelagic, D = demersal, B = benthic) were provided by Richard Matheson Jr. (personal communication). Fish and invertebrate species richness was greater in surface-fed rivers (n=153, 18 respectively) than in spring-fed rivers (n=125, 14 respectively).

Fish Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Acanthostracion quadricornis	scrawled cowfish	P	X	X
Achiridae spp.	American soles	B		X
Achirus lineatus	lined sole	B	X	X
Acipenser oxyrinchus	Atlantic sturgeon	B	X	
Adinia xenica	diamond killifish	D	X	X
Aluterus schoepfii	orange filefish	P	X	
Ameiurus catus	white catfish	D	X	
Amia calva	bowfin	P	X	
Anarchopterus criniger	fringed pipefish	B		X
Anchoa cubana	cuban anchovy	P		X
Anchoa hepsetus	striped anchovy	P	X	X
Anchoa lyolepis	dusky anchovy	P		X
Anchoa mitchilli	bay anchovy	P	X	X
Anchoa spp.	anchovies	P	X	
Ancylopsetta quadrocellata	ocellated flounder	B	X	
Archosargus probatocephalus	sheepshead	D	X	X
Ariopsis felis	hardhead catfish	D	X	X
Astroscopus y-graecum	Southern stargazer	B	X	
Bagre marinus	gafftopsail catfish	D	X	X
Bairdiella chrysoura	silver perch	D	X	X
Balistidae spp.	triggerfish	D	X	
Bathygobius soporator	frillfin goby	B	X	X
Brevoortia spp.	menhaden	P	X	X
Calamus arctifrons	grass porgy	D	X	
Caranx hippos	crevalle jack	P	X	X
Caranx latus	horse-eye jack	P	X	
Centropomus undecimalis	common snook	P	X	X
Centropristis striata	black sea bass	D	X	X
Chaetodipterus faber	Atlantic spadefish	P	X	X
Chasmodes saburrae	Florida blenny	B	X	X
Chilomycterus schoepfii	striped burrfish	P	X	X
Chloroscombrus chrysurus	Atlantic bumper	P	X	X

Fish Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Cichlasoma spp.	cichlids	D	X	
Cichlidae spp.	cichlids	D	X	
Ctenogobius boleosoma	darter goby	B	X	
Ctenogobius smaragdus	emerald goby	B	X	X
Cynoscion arenarius	sand seatrout	D	X	X
Cynoscion nebulosus	spotted seatrout	P	X	X
Cyprinidae spp.	minnows	P		X
Cyprinodon variegatus	sheepshead minnow	D	X	X
Cyprinodontidae spp.	killifishes	D		X
Dasyatis sabina	Atlantic stingray	B	X	X
Dasyatis say	bluntnose stingray	B	X	X
Diplectrum formosum	sand perch	D	X	
Dorosoma petenense	threadfin shad	P	X	X
Echeneis neucratoides	whitefin sharksucker	P	X	X
Echeneis spp.	sharksuckers	P		X
Elassoma evergladei	everglades pygmy sunfish	D	X	X
Elops saurus	ladyfish	P	X	X
Enneacanthus gloriosus	bluespotted sunfish	D	X	
Erimyzon sucetta	lake chubsucker	D		X
Etheostoma fusiforme	swamp darter	B	X	
Etropus crossotus	fringed flounder	B	X	X
Eucinostomus gula	silver jenny	D	X	X
Eucinostomus harengulus	tidewater mojarra	D	X	X
Eucinostomus spp.	mojarras	D	X	X
Eugerres plumieri	striped mojarra	D	X	
Floridichthys carpio	goldspotted killifish	D	X	X
Fundulus chrysotus	golden topminnow	D	X	X
Fundulus confluentus	marsh killifish	D	X	X
Fundulus grandis	gulf killifish	D	X	X
Fundulus majalis	striped killifish	D	X	X
Fundulus seminolis	seminole killifish	D	X	X
Fundulus similis	longnose killifish	D	X	X
Gambusia holbrooki	Eastern mosquito fish	P	X	X
Gobiidae spp.	gobies	B	X	
Gobionellus oceanicus	highfin goby	B	X	
Gobiosoma bosc	naked goby	B	X	X
Gobiosoma longipala	twoscale goby	B	X	
Gobiosoma robustum	code goby	B	X	X
Gobiosoma spp.	gobies	B	X	X
Haemulon plumierii	white grunt	D	X	X
Harengula jaguana	scaled sardine	P	X	X
Heterandria formosa	least killifish	P	X	X

Fish Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Hippocampus erectus	lined seahorse	B	X	X
Hippocampus zosterae	dwarf seahorse	B	X	X
Hoplosternum littorale	brown hoplo	B	X	
Hypleurochilus caudovittatus	feather blenny	B		X
Hyporhamphus meeki	American halfbeak	P	X	X
Hyporhamphus spp.	halfbeaks	P		X
Hyporhamphus unifasciatus	Atlantic silverstripe halfbeak	P	X	
Ictalurus punctatus	channel catfish	D	X	
Jordanella floridae	flagfish	D	X	
Labidesthes sicculus	brook silverside	P	X	
Lachnolaimus maximus	hogfish	D	X	X
Lactophrys spp.	trunkfish	P		X
Lagodon rhomboides	pinfish	D	X	X
Leiostomus xanthurus	spot	D	X	X
Lepisosteus osseus	longnose gar	P	X	X
Lepisosteus platyrhincus	Florida gar	P	X	X
Lepisosteus spp.	gars	P		X
Lepomis auritus	redbreast sunfish	P	X	
Lepomis gulosus	warmouth	P	X	X
Lepomis macrochirus	bluegill	P	X	X
Lepomis marginatus	dollar sunfish	P	X	X
Lepomis microlophus	redear sunfish	D	X	X
Lepomis punctatus	spotted sunfish	D	X	X
Lepomis spp.	sunfish	PD	X	X
Lophogobius cyprinoides	crested goby	B		X
Loricariidae spp.	suckermouth catfish	B	X	
Lucania goodei	bluefin killifish	P	X	X
Lucania parva	rainwater killifish	D	X	X
Lutjanus griseus	gray snapper	D	X	X
Lutjanus synagris	lane snapper	D	X	X
Membras martinica	rough silverside	P	X	X
Menidia spp.	silversides	P	X	X
Menticirrhus americanus	Southern kingfish	D	X	X
Menticirrhus saxatilis	Northern kingfish	D	X	X
Microgobius gulosus	clown goby	B	X	X
Microgobius thalassinus	green goby	B	X	
Micropogonias undulatus	Atlantic croaker	D	X	
Micropterus salmoides	largemouth bass	P	X	X
Monacanthus ciliatus	fringed filefish	D	X	X
Mugil cephalus	striped mullet	P	X	X
Mugil curema	white mullet	P	X	X
Mugil gyrans	fantail mullet	P	X	X

Fish Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Mugil spp.	mullet	P		X
Myrophis punctatus	speckled worm eel	B	X	X
Nicholsina usta	emerald parrotfish	B	X	
Notemigonus crysoleucas	golden shiner	P	X	X
Notropis harperi	redeye chub	P		X
Notropis maculatus	taillight shiner	P	X	
Notropis petersoni	coastal shiner	P	X	X
Notropis spp.	shiners	P	X	X
Ocyurus chrysurus	yellowtail snapper	P	X	
Ogcocephalus cubifrons	polkadot batfish	B		X
Ogcocephalus pantostictus	roughback batfish	B	X	
Ogcocephalus spp.	batfish	B		X
Oligoplites saurus	leatherjacket	P	X	X
Opisthonema oglinum	Atlantic thread herring	P	X	X
Opsanus beta	gulf toadfish	B	X	X
Oreochromis aureus	blue tilapia	P	X	
Orthopristis chrysoptera	pigfish	D	X	X
Paraclinus fasciatus	banded blenny	B	X	X
Paralichthys albigutta	gulf flounder	B	X	X
Paralichthys lethostigma	Southern flounder	B	X	
Poecilia latipinna	sailfin molly	D	X	X
Pogonias cromis	black drum	D	X	X
Pomatomus saltatrix	bluefish	P	X	
Pomoxis nigromaculatus	black crappie	P	X	
Prionotus scitulus	leopard searobin	B	X	X
Prionotus tribulus	bighead searobin	B	X	X
Pterygoplichthys disjunctivus	armored catfish	B	X	
Pterygoplichthys multiradiatus	armored catfish	B	X	
Rhinoptera bonasus	cownose ray	P	X	
Sarotherodon melanotheron	blackchin tilapia	P	X	
Sciaenops ocellatus	reddrum	D	X	X
Scomberomorus maculatus	Sspanish mackerel	P	X	X
Scorpaena brasiliensis	barbfish	B	X	
Selene vomer	lookdown	P		X
Serranidae spp.	sea basses and groupers	D	X	
Sphoeroides nephelus	Southern puffer	P	X	X
Sphyraena barracuda	great barracuda	P	X	X
Sphyraena borealis	Northern sennet	P	X	X
Stephanolepis hispidus	planehead filefish	D	X	X
Strongylura marina	Atlantic needlefish	P	X	X
Strongylura notata	redfin needlefish	P	X	X
Strongylura spp.	needlefish	P	X	X

Fish Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Strongylura timucu	timucu	P	X	X
Symphurus plagiusa	blackcheek tonguefish	B	X	X
Syngnathus floridae	dusky pipefish	B	X	X
Syngnathus louisianae	chain pipefish	B	X	X
Syngnathus scovelli	gulf pipefish	B	X	X
Synodus foetens	inshore lizardfish	B	X	X
Tilapia spp.	cichlid	P	X	X
Trachinotus falcatus	permit	D	X	X
Trinectes maculatus	hogchoker	B	X	X
Urophycis floridana	southern hake	D	X	X

Invertebrate Taxa

Scientific Name	Common Name	Habitat Classification	Surface	Spring
Alpheidae spp.	caridean snapping shrimp	B	X	X
Ambidexter symmetricus	caridean shrimp	B	X	
Argopecten spp.	scallops	B		X
Callinectes ornatus	ornate blue crab	D	X	
Callinectes sapidus	blue crab	D	X	X
Farfantepenaeus duorarum	pink shrimp	B	X	X
Hippolyte zostericola	zostera shrimp	B		X
Limulus polyphemus	horseshoe crab	B	X	
Lysmata rathbunae	peppermint shrimp	B	X	
Lysmata wurdermanni	peppermint shrimp	B	X	
Palaemon floridanus	Florida grass shrimp	B	X	X
Palaemon intermedius	striped grass shrimp	B	X	X
Palaemon paludosus	grass shrimp	B	X	X
Palaemon pugio	daggerblade grass shrimp	B	X	X
Palaemon vulgaris	marsh grass shrimp	B		X
Palaemonetes spp.	grass shrimp	B	X	X
Periclimenes longicaudatus	longtail grass shrimp	B	X	X
Portunus spp.	portunid swimming crabs	D	X	X
Rimapenaeus constrictus	roughneck shrimp	B	X	X
Thor dobkini	squat grass shrimp	B	X	
Tozeuma carolinense	seagrass arrow shrimp	B	X	

APPENDIX

Herrick, G. 2017. Uncertainty in flow and habitat in the Crystal River/Kings Bay system. Southwest Florida Water Management District, Brooksville, Florida.

Uncertainty in Flow and Habitat in the Crystal River/Kings Bay System

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April 2017

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1 Introduction

1.1 Purpose

The District composed a draft minimum flow recommendation report for the Crystal River/Kings Bay system in compliance with Florida Statutes (Herrick et al. 2016). This draft was reviewed by an independent, scientific peer-review panel. The panel called for an analysis of uncertainty in data and estimation of habitat response to changes in flow (SWFWMD 2016), noting "[t]he District needs to do a better job of identifying the uncertainty in both methods of flow determination and the limitations this creates."

The purpose of this report is to present an analysis of uncertainty in methods of flow determination and subsequent analyses as suggested by the peer-review panel. The converse of uncertainty is confidence. Thus, an analysis of uncertainty is necessarily also an analysis of confidence. Much of the information presented here can also be found in the draft minimum flow report. However, the information is organized here to draw attention to District acknowledgement of uncertainty in the data, analysis, and conclusions supporting the recommended minimum flow. Rather than brashly dismissing uncertainty as inconsequential or unavoidable, this document directly addresses potential sources and consequences of uncertainty. In so doing, the information summarized here also articulates confidence in District conclusions about this system.

This analysis is a step-by-step discussion of the factors that are important for consideration of discharge and other selected factors used for developing the minimum flow recommendation for the Crystal River/Kings Bay system, what constitutes the best information available about these factors, and how they are predicted in cases where data is unavailable or impossible, e.g., for future predictions. This is not a mathematical quantification of uncertainty. Rather, this is an explanation of District rationale for data use, methods of analysis, and development of conclusions.

1.2 Depth, salinity, and temperature

Water depth, salinity, and temperature are important factors affecting habitat in the Crystal River/Kings Bay system. As a source of fresh, warm spring water, spring flow affects water depth, salinity, and temperature throughout the system. Water depth determines direction and magnitude of water movement between the bay, spring vents, the Crystal River, and the Gulf of Mexico. Salinity also influences water movement and distribution and limits the distribution and abundance of all life in this estuarine system. Water temperature similarly affects water movement and distribution, which in turn affects most or all components of the system. Relatively high water temperatures associated with spring flows are an important attractant for manatee and other species seeking refuge from cold water during winter months.

Available water depth, salinity and temperature data are not sufficient to fully characterize effects of spring flow changes on the habitats assessed for minimum flow analyses. Data collection at USGS gages and other sites address these parameters only at fixed locations and only during limited periods of record. To estimate local water depth, salinity, and temperature throughout the Crystal River/Kings Bay system in the past, present, and future, a hydrodynamic model can be, and was used to fill in spatial and temporal data gaps.

1.3 Hydrodynamic Modeling Data Needs

1.3.1 Model Description

The hydrodynamic model "UnLESS3D" was used by the District to predict water level, salinity, and temperature throughout the Crystal River/Kings Bay system (Figure 1). This model uses measured data along with the principles of fluid dynamics to estimate depth, salinity, and at places and times for which no data are available (Chen 2011; Chen 2012; Chen 2016a). Measured data input to the model comes from boundary conditions at USGS sites "Salt River" and "Shell Island". Data input to the hydrodynamic model also must include an estimate of freshwater spring discharge. Uncertainty in data collected and input to the hydrodynamic model will contribute to uncertainty in the predictions of the model.

Figure 1. The UnLESS3D model grid. This hydrodynamic model divides the entire system into a series of three-dimensional boxes, each with values for temperature, salinity, and depth, updated with data on 15-minute intervals.

1.3.2 Discharge as an Input to the Hydrodynamic Model

In addition to measured boundary conditions, the UnLESS3D model requires continuous measurement of spring flow to the system. There are several sources of discharge data that can be used as input to the hydrodynamic model -see Table 2-2 of minimum flow report (Herrick et al. 2016). Each of these reported discharge measurements carries with it a degree of uncertainty. Furthermore, there is are issues of suitability/location of measurement, period of record, equipment, analytical techniques, and frequency of measurement that will affect the quality of model predictions.

Table 1. Discharge and spring flow estimates for Kings Bay and Crystal River.

Source	Citation	Period of Record	Mean Flow (cfs)
"Old Crystal River" gage: USGS 02310750, Crystal River near Crystal River, FL	(USGS 2017a)	3/1964 – 9/1977	971
	(Yobbi and Knochenmus 1989)	1965-1977	975
	(Rosenau et al. 1977; Fretwell 1983)	10/1964 – 9/1975	916
	(Yobbi 2014)	1983-1985	534
"Bagley Cove" gage: USGS 02310747, Crystal River at Bagley Cove near Crystal River, FL	(USGS 2017b)	10/6/2006 – 10/13/2015 (only "approved" and tidally filtered data included)	356
Water budget analysis	(Hydrogeologic, Inc. 2008)	1995	455
Empirical formula Submarine Groundwater Discharge (SGD)	(Chen 2016b)	10/6/2006 – 10/13/2015	332
Northern District Model version 5	(Hydrogeologic, Inc. 2016)	2010 pumping, 1995 rainfall	442
		2014 pumping, 1995 rainfall	444
Spring vent measurements (total)	(VHB 2010)	7/28/2009 – 10/8/2009	467

2 Sources of Discharge/Flow Records

2.1 Old Crystal River gage, USGS 02310750 Crystal River near Crystal River FL

Daily discharge is reported for the Old Crystal River gage from March 1, 1964 through September 30, 1977. This gage was located approximately 3 miles downstream of Kings Bay (Figure 2). The Old Crystal River gage used a deflection meter during the period of record for USGS discharge reporting. Yobbi (2014) also reports data from acoustic velocity meter readings at the site made from 1983-1985. Long-term averages from this site have been reported as estimates of spring discharge by Rosenau et al.(1977) and Fretwell (1983). Data for the site can be downloaded from USGS National Water Information System Web Interface (USGS 2017a).

2.2 Bagley Cove gage, USGS 02310747 Crystal River at Bagley Cove near Crystal River FL

2.2.1 Gage Description

The Bagley Cove gage is a currently operating, long-term source of measured data on discharge and water level in this system (Figure 2). Discharge is reported both as "unfiltered" and "tidally-filtered"

values. Unfiltered discharge is reported in 15-minute intervals, while tidally-filtered discharge, developed after low-pass filtering of unfiltered data, is reported as daily averages. Data for the site can be downloaded from USGS National Water Information System Web Interface (USGS 2017b).

Figure 2. Location of USGS gages in Crystal River.

2.2.2 Tidally-Filtered Discharge at Bagley Cove

The USGS reports tidally-filtered discharge at the Bagley Cove gage. This tidally-filtered discharge corrects daily mean values for asynchrony between the 24-hour solar day and the 24.8412-hour tidal day (USGS 2010). Tidally-filtered, mean daily discharge values are an improvement over unfiltered discharge in that they do not show oscillations that are the result of this difference between the tidal day and the solar day over which measurements are averaged. Thus, tidally-filtered discharge is a better indicator of daily net flow past the gage compared with unfiltered discharge. The average tidally-filtered discharge for all dates with “approved” data during the model period of record from 10/6/2006 – 10/13/2015 is 356 cfs.

Although tidal-filtering eliminates the aliasing in unfiltered discharge, it does not convert measured discharge into an estimate of spring flow. Remarks from the 2016 USGS water-year summary explain that discharge is not a measure of spring flow (USGS 2017b):

> “REMARKS - Streamflow at this site is significantly affected by astronomical tides. The residual discharges are not total "freshwater" flow, but are a combination of freshwater flow and water storage caused by higher or lower Gulf of Mexico mean water levels. By convention, the U.S. Geological Survey has established ebb (seaward) flows as positive flow and flood (landward) flows as negative flows.”

In addition to the above remarks, the USGS water-year summaries for 2006-2013 rate the residual (tidally-filtered) discharge as “fair” (USGS 2017b).

2.3 Water Budget Analysis

Another approach for estimating discharge for the Crystal River Springs group involves examining the water budget for the springshed. Hydrogeologic, Inc. (2008) developed a water budget for the Crystal River springshed. Their estimated average flow in 1995 for springs in the Crystal River/Kings Bay system totaled 455 cfs. This value is based on an analytical water budget for the Crystal River springshed (310 square miles), where recharge to the Upper Floridan aquifer (UFA) is expected to be approximately 20 inches per year. This amount of groundwater recharge will result in a mean Crystal River Springs group discharge of 455 cfs, assuming no change in storage and no other discharges from the groundwater system (Hydrogeologic, Inc. 2008). This recharge value is at the high end of reasonable flux to the Upper Floridan aquifer, and matches the USGS recharge value of 20 in yr^{-1} for the adjacent Homosassa Spring group basin in their estimation of the 1997-98 water budget (Knochenmus and Yobbi 2001). Larger estimates of discharge, such as the mean 916 cfs estimated for the 1960s and 1970s by Fretwell (1983) for Crystal River spring group (based on the Old Crystal River gage data) flow would require recharge in excess of 40 in yr^{-1}, which is an unrealistically high number.

2.4 Northern District Model version 5

The Northern District Model (NDM) is a three-dimensional, regional groundwater flow model. This model is unique for west-central Florida in that it is the first regional flow model that represents the groundwater system as fully three dimensional. The NDM was originally developed in 2008 by HydroGeoLogic, Inc. (2008). Since that time, there have been several refinements to the original model. Version 5 (NDM5) was recently completed in August 2016 (Hydrogeologic, Inc. 2016). In an independent peer review, Dr. Mark Stewart, P.G. stated that the Northern District Model version 5 "is the best numerical groundwater flow model currently available for assessing the effects of withdrawals in the central springs region." Application of the NDM5 for minimum flow analyses is more fully explained in section 1.4 of the minimum flows report (Herrick et al. 2016). Estimates of annual average spring flow derived with the NDM5 for 2010 and 2014 water-withdrawal conditions are 442 and 444 cfs, respectively. These flow numbers represent pumping condition springflow rates in those respective years under average recharge conditions. They do not represent actual calibrated values for the climatic regimes that occurred during those two years. In other words, they are used to determine pumping impacts under a presumed average rainfall condition (in this case 1995 recharge).

2.5 District empirical formula for Submarine Groundwater Discharge (SGD)

Use of the UNLESS3D hydrodynamic model for predicting environmental conditions on short time scales for a recent simulation period, requires a source of accurate, frequently reported, and recent spring flow data. To meet these data needs, the District developed a method for estimating submarine groundwater discharge (SGD) based on the difference between the tidal elevation in Kings Bay compared to the Upper Floridan aquifer water level at a nearby monitor well (Chen 2014a; Chen 2014b).

Results presented in the minimum flow report (Herrick et al. 2016) use empirical-formula-derived submarine groundwater discharge (SGD) as a source of spring flow into the system. Estimating spring flow using this method is a multi-step process. First, springs were mapped and discharge for individual vents was measured (VHB 2009; VHB 2010). Discharge records at individual vents are limited to a few instantaneous measurements because such surveys are time, labor, and equipment intensive. The District funded the only complete survey of such measurements (VHB 2009; VHB 2010). Instantaneous vent measurements were taken from July 2009 through October 2009. In

addition, discharge was measured continuously from July 27, 2009 through August 20, 2009 at two canals (G1 and G2) receiving discharge from several vents each (Figure 3). These measurements provide the raw material from which discharge can be estimated over longer time frames.

Given a set of discharge measurements over a limited time and spatial scale, how can one predict discharge at other locations and times? To predict discharge, the following data are needed:

- Head difference driving spring flow. Head difference can be determined by measurements of groundwater level and surface water level above each spring vent.
- A set of measurements of spring flow to develop and calibrate a mathematical relationship between head difference and spring flow.

Armed with these two sources of information, one can predict discharge. As a starting point, discharge (q) could be estimated as equivalent to that measured (q_0) during the limited time frame of the VHB field study. The sum across all sites for time-averaged spring flows was 467 cfs. However, this value is not responsive to changes in water level, and would result in poor hydrodynamic model fit. Therefore, it is desirable to create an estimate of spring flow that accounts for fluctuations in water levels.

The District developed an empirical formula to estimate spring flow as a function of changing water levels in the aquifer and the surface of Kings Bay (

Equation 1) (Chen 2014b). This equation predicts discharge at any given time and location (q) based on measured discharge during a discrete time interval (q_0). This equation shows that discharge at any time (q) is dependent upon head difference (the second term in brackets) and the rising or falling of the tide (the third term in brackets).

It is useful to sequentially consider the terms in the equation brackets (see Chen 2014b for additional details). The first term assumes flow at any time is equal to flow during the period when measurements were taken. The second term adjusts measured flow for changes in water level. With the second term, we can predict flow at any time more accurately if we know water level in the bay and groundwater level at the ROMP TR21-3 well. The third term accounts for propagation of the tidal signal into spring vents. Without this third term, there is a phase mismatch between predicted and observed measurements at canal cross sections. Using the district formula, discharge has been hindcasted to 1969 (Chen 2016b).

Figure 3. Location of spring vents. Numbered circles show groups of spring vents. Some groups have multiple vents. G1 and G2 are locations of continuous measurements across channels (image source VHB (2010)).

$$q = q_0 \left[1 + C_1(G - \Delta G - \eta) + C_2 \frac{\partial \eta}{\partial t}\right]$$

Equation 1. Empirical equation for submarine groundwater discharge. Notation: q denotes estimated spring flow at any time, q_0 is average spring flow over measurement period, G is groundwater level, ΔG is long term average head difference between groundwater and surface water, η is surface water level in Kings Bay at any time. C_1, C_2, and ΔG are adjustable parameters for specific spring/vent sites. The parameter ΔG varies based on distance from the groundwater well.

3 Defining Suitability and Uncertainty

3.1 Suitability of Discharge as an Estimate of Spring Flow

Is discharge at any given point in the Crystal River a suitable estimate of spring flow into the system? The entire reach of Kings Bay and the Crystal River is tidal. Gulf water moves into the system with the incoming tide and water flushes out with falling tide. A perfect measurement of discharge at Bagley Cove or any other site in the system will perfectly capture this tidal flux. However, error-free discharge measurement alone will not be able to separate spring flow from tidal flux.

The water flowing past a stream flow gage or any other site within the system is a mixture of water discharged from springs at any time in the past two-to-three weeks and marine gulf water that

moves in and out with the tides. Separation of these water sources is not possible from discharge measurements at most sites. Average residence time varies from approximately 8 days to 16 days throughout the system (Herrick et al. 2016). This means that at any given time, the water discharging past a gage or other site may have spent anywhere from a few hours to over two weeks in the system. Thus, discharge reported in 15 minute intervals is not an accurate measurement of spring flow over the prior 15 minutes. Over longer time scales, such as a month or longer, the average discharge should, however, represent spring flow to the system.

One way to check long-term measurements as estimates of spring discharge is to look for negative values. Over long periods (over any period greater than a few hours) all average spring flow estimates should be non-negative. Therefore, negative long-term averages of reported discharge are an indication that reported discharge is not solely representative of spring flow.

3.2 Uncertainty in Discharge

3.2.1 Discharge at Gage Sites and Canals

Reported discharge at USGS gages in the Crystal River has historically been calculated from measurements of water velocity and stage along with surveyed cross-sectional area data. Reported discharge (Q) is the product of cross-sectional area (A) and velocity (V); (Q = AV). Thus, discharge reported at gages includes measurement uncertainty associated with velocity, stage, and area.

The application of this discharge model (Q = AV) is dependent upon several assumptions. First, the stage-area relationship must remain constant. This assumption is violated as the river channel geometry changes due to sediment transport and erosion typical in shallow estuarine systems such as the Crystal River. Second, measured velocity must represent the average across the entire cross-section. This assumption is violated as variation in vegetation, salinity, temperature, and density cause stratification and heterogeneity in flux. Third, the equipment measuring velocity and stage must be functioning properly. This assumption is violated as equipment is fouled with vegetation or otherwise malfunctions.

Empirical formula SGD was calibrated using discharge measured at two cross sections (G1 and G2) in Kings Bay (Figure 3) (VHB 2010; Chen 2014b). These measurements are subject to the same uncertainty present at USGS gage sites. In addition, there is uncertainty associated with the short period of record at these sites. It is not known how well the conditions measured during the period of record characterize long term conditions in the bay. It is known that no extreme events were captured. Storm surges and other events are likely to result in conditions not measured during the short period of record at these two channels.

3.2.2 Discharge at Spring Vents

There are several sources of uncertainty in discharge measurements at spring vent sites in Kings Bay. First, velocity measurements were taken during limited field sampling dates from July-October, 2009 (VHB 2010). These estimates of velocity were taken only once at some vents, and as many as 26 times at others. Discharge was calculated from velocity by measuring cross-sectional area of spring vent mouth and these area estimates could be subject to measurement error. Finally, the field measurements of discharge were taken over a limited range of water depths relative to the full range experienced by the system over the long term.

Adding to uncertainty of spring flow estimation for the Crystal River/Kings Bay system is that not all spring vents within the system may have been mapped and accounted for. Spring vents were

comprehensively surveyed, but there may be additional, undiscovered vents and diffuse seepage throughout the bay. The hydrodynamic model accounts for diffuse seepage and potential undiscovered vents by including an amount of diffuse seepage.

3.3 Uncertainty of Empirical-Formula-Derived Submarine Groundwater Discharge

How accurate is the District empirical formula for predicting SGD (Equation 1)? This formula was used to match predicted flow (q) with net spring flow as measured across two canals at points G1 and G2. Parameters for this equation were selected by a trial-and-error process which attempted to minimize the difference between predicted and observed values during the measurement period.

Uncertainty can be quantified through use of linear regression to compare measured and predicted spring flows (Figure 4). Coefficient of determination (R^2) values quantify the uncertainty during the measurement period. For Group 1, 71.5% of the variation in estimated spring flow is captured by measured spring flow, but the remaining 28.5% of variation in estimated spring flow remains unexplained. Group 2 was better explained with an R^2 of 0.94, leaving only 6% of the variation unexplained. Group 1 measurement was limited to the first 228 hours due to equipment malfunction which probably also affected the weaker association in these measurements.

Spring flow at each vent is a unique prediction based on measurements taken at each vent. Spring flow at each vent is calculated using the empirical formula, with q_0 calculated as the average of instantaneous discharge measurements for that site. The parameter ΔG has a unique value for each vent based on distance to the monitor well ROMP TR21-3. For spring vents located closer to G1, the fitted values of C_1 and C_2 from that site were applied to the vent. Likewise, for the vents closer to G2. Thus, each spring vent is predicted to have a unique discharge based on its field measurements and its location relative to G1, G2, and the groundwater well. There is some uncertainty associated with applying parameter values in this way.

It is unknown how well the district formulae predict spring flow at individual vents. The best estimate comes from the R^2 values at G1 and G2 (Figure 4). Uncertainty in flows at these sites may be the product of the structure of each empirical formula, measurement of depth at the mouth of Kings Bay, measurement of depth at ROMP TR21-3, and water velocity and cross-sectional area measurements at the G1 and G2 sites.

Figure 4. Linear regression of estimated spring flow compared with measured spring flow across two spring groups G1 and G2 from July 27, 2009 through August 20, 2009.

3.4 Prediction Uncertainty of the UnLESS3D Hydrodynamic Model

3.4.1 Measurement Uncertainty in UnLESS3D

Measurement uncertainty exists in all sources of input data that feed the UnLESS3D model (**Error! R eference source not found.**). Boundary conditions measured at USGS gages are subject to measurement uncertainty for depth, salinity, and temperature. In addition, because empirical formula SGD is used to drive the UnLESS3D model, the hydrodynamic model inherits all uncertainty associated with estimating spring flow into the system.

3.4.2 Calibration-Verification Uncertainty in UnLESS3D

The UnLESS3D hydrodynamic model has parameters than can be adjusted to fit model output to measured data during a calibration period. The calibration period for the model runs used in the minimum flow recommendation is Dec 28, 2007 – May 26, 2008. During this period, model parameters were manipulated to achieve a match between predicted and observed values for water depth, salinity, and temperature. Even with calibration to match model output to observed data, there is uncertainty in model predictions. However, this uncertainty can be quantified during model verification. In model verification, model output is compared to observed values for a period outside of the calibration period.

The verification period used for minimum flow recommendation was Apr 24, 2007 – Feb 23, 2010. During verification, model output was compared with measured observations at the Bagley Cove and Mouth of Kings Bay gages (**Error! Reference source not found.**). Verification results using e mpirical formula SGD as input shows agreement between model simulation results and observed data (Table 2) (2016a). The skill parameter, called “index of agreement” by Willmott (1981), is a relative average error, where perfect agreement equals 1 and complete disagreement equals zero.

The calibration and verification periods are important contributors to total model uncertainty. Ideally, conditions during calibration and verification would represent the range of conditions present in the modeled system. Rare and infrequent events are, however, not likely to be captured. In addition, verification is only possible at locations with existing data. It is unknown how well the model predicts depth, salinity, and temperature at locations where no data exists.

The values in Table 2 succinctly quantify the uncertainty in the hydrodynamic model predictions. Because the model was run using estimated empirical formula SGD, these verification values also quantify all uncertainty associated with predicting spring flow.

Table 2. Measures of fit between hydrodynamic model output and measured values during verification (Chen 2016a).

Location	R-squared	Mean Error	Mean Abs Error	Skill	Parameter
Bagley	0.995	1.01	3.21	0.99	Water depth (cm)
Mouth	0.994	0.79	4.51	0.99	
Average	0.995	0.90	3.86	0.99	
Bagley	0.714	1.15	2.41	0.80	Salinity (psu)
Mouth -Top	0.732	-0.48	0.86	0.76	
Mouth-Bottom	0.657	-0.85	1.35	0.70	
Average	0.701	-0.06	1.54	0.75	
Bagley	0.919	0.15	0.73	0.99	Temperature (°C)
Mouth-Top	0.892	-0.04	0.70	0.98	
Mouth-Bottom	0.897	-0.02	0.77	0.98	
Average	0.903	0.03	0.73	0.98	

3.5 Uncertainty in Baseline Flow

3.5.1 Calculating Baseline Flow

Baseline flow was calculated using an estimate of withdrawal impacts derived using the NDM5 model and empirical-formula-derived SGD. Uncertainty in the baseline flow record is therefore a function of uncertainty associated with the two types of model output.

Withdrawal impacts were determined as a percentage-of-flow using the Northern District Model version 5. The impact percentage was determined by taking the difference between predicted spring flows in model runs with “pumps on” (impacted) and “pumps off” (Table 3). For 2014 withdrawal conditions, the percent difference between the pumps off and impacted flows was 1.1 percent, and for 2010 conditions it was 1.5 percent. Predicted impacts for withdrawal demand projected for 2035 are 2.1 percent with conservation and reuse and 2.4 percent without. More detail is provided in section 1.4 of the minimum flow report (Herrick et al. 2016).

Table 3. Predicted impacts from groundwater withdrawals derived using the NDM5 model. Relative impacts as percentages can be applied to different flow records.

Year	Domain-wide Groundwater Withdrawals (mgd)	Non-pumping Flow (cfs)	Pumping Flow (cfs)	Difference (cfs)	Difference (percent)
2010	479.1	448.99	442.07	6.92	-1.5
2014	403.9	448.99	443.83	5.16	-1.1
2035	635.1	448.99	438.14	10.85	-2.4
2035 with Conservation & Reuse	576.6	448.99	439.42	9.57	-2.1

The relative impact of groundwater withdrawals as calculated by the NDM5 was subsequently used to estimate baseline flow relative to empirical formula SGD. First, impacts from 2010 and 2014 were rounded up to 2%. This is conservative of environmental resources as it overestimates impact. Next, each fifteen-minute estimate of SGD was divided by 0.98 to get unimpacted flow. For example, if SGD at a given time is 100 cfs, this is an impacted flow. Thus, to find what the unimpacted value would be for that time, we must calculate 100/0.98 = 102 cfs. Since groundwater withdrawal impacts occur over a longer time scale, the use of longer term data is appropriate. Therefore, we assumed this impact was constant throughout the baseline period used for the minimum flow analyses.

The NDM5 simulates average flow conditions within two percent of estimated flow (455 cfs mean annual flow under average rainfall conditions) for the King's Bay group of springs (Hydrogeologic and Dynamic Solutions, 2016). However, that is the error with matching a flow rate - not the likely error associated with a change in flow due to an applied stress (groundwater withdrawals). Research has shown that the error associated with a change in stress is less than when matching water level elevations or flow rates. In the peer review report for the NDM5, an analysis of model uncertainty due to a change in stress resulted in a model uncertainty of $\pm$ 0.6% for springflow in the NDM5 domain (Andersen and Stewart 2016).

4 Selection of a Record of Spring Discharge

The hydrodynamic model requires frequently updated record of discharge as an input for frequent, iterative calculation of depth, salinity, and temperature. There are five sources of discharge listed in Table 2. Of these, the water budget analysis (Hydrogeologic, Inc. 2008) and output from the Northern District Model (Hydrogeologic, Inc. 2016) can be eliminated as they only provide annual averages for 1995, 2010 and 2014. The remaining candidate discharge records come from the Old Crystal River gage, the Bagley Cove gage, and the empirical formula SGD. In addition to a source of spring flow data, the model requires boundary conditions which became available starting October 2006 (Chen 2012).

4.1 Old Crystal River Gage

Discharge measurements from the Old Crystal River gage are much higher than from all other sources. Because of the large difference between more recent estimates of discharge including

reported values at Bagley Cove and District empirical-formula SGD compared to reported discharge at the Old Crystal River gage, Dann Yobbi (2014) conducted a review of discharge from the Old Crystal River gage. To accurately represent Yobbi's findings, his relevant comments are quoted in full:

> "There are several problems in the estimation of discharge at this site. The large variation from 507 to 975 ft^3/s reflect changes in equipment, error introduced from equipment malfunction, rating development difficulties (poor site), period of record, and method of analysis used to calculate means. Difficulties (lack of precision) when estimating discharge are errors associated with the cross-sectional area and mean-velocity ratings. Sources of measurement error are from instrument issues and rating difficulties related to natural hydrologic conditions at the site. The measurement of deflection meter index velocity (1965-77) is problematic due to the vane design. The most serious design flaw is the tendency to collect floating debris, affecting calibration of the vane. This debris problems also occurred during 1983-85 and as a result most of the velocity data collected using an advanced acoustic velocity meter at the site were unusable.
>
> It appears that the reported discharge for Crystal River during 1965-77 may be overestimated, based on the significantly lower discharge data calculated using better instrumentation during the generally higher ground-water hydrologic conditions in 1983-85, as compared to 1965-77. Instrument precision and rating accuracies are critical for accurate calculations of discharge for Crystal River below Kings Bay."

Yobbi's (2014) review was based on assessment of available USGS records. As an example of this type of information, remarks for the Old Crystal River gage from the USGS water resources data report for the 1972 water year (USGS 1972) were as follows:

> "REMARKS. – Records poor. Aquatic growth accumulated around the deflection meter and partially restricted its movement on many days. Discharge computed from continuous velocity record obtained from recording deflection meter. Flow is affected by tide. See page [blank] for table of maximum and minimum gage heights."

The Old Crystal River gage is not suitable as an estimate of spring discharge for input to the hydrodynamic model. This conclusion contradicts those authors who have used this gage as an estimate of spring flow (Rosenau et al. 1977; Fretwell 1983; Yobbi and Knochenmus 1989). The District has good reasons for lack of confidence in this record as a measure of spring flow. First, the reported discharge values are grossly overestimated as explained above (USGS 1972, Yobbi 2014). Second, the period of record for this gage ended in 1977. The hydrodynamic model is meant to predict changes to the system that will occur in the future. Thus, the model will make better predictions if it is calibrated to measurements taken more recently than 1977. Furthermore, the model requires boundary conditions and meteorological data that are concurrent with flow records for the model period of record Oct 6, 2006 –Oct 13, 2015. These other sources of data are not available for the period of record of the Old Crystal River gage.

4.2 Comparison of Range and Negative Values in Bagley Cove Gage and Empirical Formula SGD

Discharge not filtered for tide is reported at 15-minute intervals for the Bagley Cove gage. Daily average discharge filtered for tide is also reported for the gage site. Long term summary statistics based on USGS-approved values for the two records are similar for the model period (October 6, 2006 – October 13, 2015) used for the District minimum flow analyses (Table 4). The average empirical formula SGD (332 cfs) is 6.7 percent lower than tidally-filtered daily discharge (356 cfs) for the modeled period. The median empirical formula SGD (326 cfs) is 5.2 percent lower than tidally-filtered daily discharge (344 cfs) for the modeled period.

One criticism of the District empirical formula SGD is that it shows variation and a range of discharges beyond that shown in field measured data reported by VHB (2010). However, by comparison with Bagley Cove data, the SGD record has a much more compact distribution of values (Figure 5). If one is looking for an estimate of spring discharge that does not frequently extend beyond the range of field measurements, empirical formula SGD is a much better choice than Bagley Cove data.

A related criticism of empirical formula SGD is that convincing field evidence to support the existence of negative flows does not exist. The empirical formula predicts short-duration negative flows when water level in Kings Bay exceeds the potentiometric surface at spring vents. However, there are no negative daily averages for SGD, while the Bagley Cove gage reports negative flows well within the lower whisker representing 1.5 times the interquartile range (Figure 5). Thus, negative daily flows are not a statistical outlier for the Bagley Cove discharge record. Negative values are so frequent and extreme within the Bagley Cove record that several monthly average values for discharge are negative (Figure 6). These negative averages make the Bagley Cove discharge record unsuitable as an estimate of spring flow to the system. District empirical formula SGD, because it is based on direct field measurements of spring flow and does not include the frequent negative discharge values of the Bagley Cove gage record.

Remarks from a recent USGS water-year summaries provide additional support the District's decision to use empirical formula SGD rather than reported discharge for the Bagley Cove gage in our minimum flow analyses. For example, the 2016 water-year summary remarks (USGS 2017b) are as follows:

> "REMARKS - Streamflow at this site is significantly affected by astronomical tides. The residual discharges are not total "freshwater" flow, but are a combination of freshwater flow and water storage caused by higher or lower Gulf of Mexico mean water levels. By convention, the U.S. Geological Survey has established ebb (seaward) flows as positive flow and flood (landward) flows as negative flows."

Table 4. Summary statistics for gaged discharge and empirical formula submarine groundwater discharge (SGD). Values shown are discharge in cfs associated with non-exceedance percentiles (25%, 50%, 75%), the average over the period of record (avg), and the total number of discharge measurements (n).

Record	25%	50%	75%	avg	n
Bagley tidally-filtered	155	344	553	356	2,934
Bagley unfiltered	123	349	580	361	3,085
SGD	281	326	376	332	3,288

Figure 5. Distribution of empirical formula submarine groundwater discharge (SGD) values is more compact than for unfiltered and tidally-filtered Bagley Cove daily discharge. Data are daily averages for period from October 6, 2006 through October 13, 2015.

Figure 6. Monthly average discharge reported at the USGS Bagley Cove gage and for empirical formula submarine groundwater discharge (SGD). Negative reported monthly averages for tidally filtered (Bag-filt) and unfiltered (Bag-UnFilt) Bagley Cove records occurred in 2009, 2012, and 2015. These negative monthly averages make this record unsuitable as an estimate of spring flow on short time scales.

4.3 Comparison of Discharge as Input to the Hydrodynamic Model

Despite the fact that gaged discharge captures tidal flow on short time scales, the District attempted to use Bagley Cove gage discharge data as an input to the hydrodynamic model. The District found these data unsuitable for hydrodynamic modeling, as their use resulted in poor predictions of water level, salinity, and temperature at reference sites during model calibration and verification (Figure 7) (Chen 2014b). The District empirical formula SGD produced much better verification results (Table 2).

Figure 7. Use of Bagley Cove gage discharge data yielded poor fit during hydrodynamic model verification. Both panels show measured bottom salinity at the Bagley Cove gage in black and model predictions in red. The top panel model predictions (red) use Bagley Cove discharge data. The bottom panel model predictions (red) use empirical formula submarine groundwater discharge (SGD). In the top panel, note large mismatch visible with predicted salinity using Bagley Cove discharge (red) frequently much lower than measured salinity (black). This mismatch is reduced in the bottom panel where SGD is used as model input.

5 Summary

The empirical formula based on groundwater and surface water elevations is the best available method for estimating submarine groundwater discharge to the system. Downstream gages measure a mixture of tidal flow and spring flow and have relatively discontinuous records. These gages, particularly the Bagley Cove gage, provide useful information about the movement of water into and out of the Bay. On a long time scale, discharge at Bagley Cove should represent a measure of spring flow. However, the hydrodynamic model requires continuous, short term spring flow to estimate continuous, short term changes to habitat. The overall uncertainty in flow estimation and hydrodynamic model predictions is captured in the verification parameters for the hydrodynamic model (Table 2). These verification parameters have been found by a peer review panel as within normal ranges for salinity and temperature and better than normal for water level (SWFWMD 2016). The use of empirical formula submarine groundwater discharge minimizes uncertainty in predictions of changes to ecologically important habitats, and thus constitutes the best available information for minimum flow development in the Crystal River/Kings Bay system at this time.

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APPENDIX

Janicki Environmental, Inc. 2012. Salinity and isohaline regressions for Crystal River. St. Petersburg, Florida. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Salinity and Isohaline Regressions for Crystal River

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April 2012

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1 Background

Florida law requires the water management districts to establish minimum flows and levels (MFLs) for surface waters and aquifers within their jurisdictions (Section 373.042(1), F.S.). According to state law, minimum flows and levels are to be established based upon the "…best available information…" and shall be developed with consideration of "...changes and structural alterations to watersheds, surface waters and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer... (Section 373.0421, F.S.). While the legislature has explicitly identified the need to consider physical changes, existing potable water withdrawals are not to be considered when developing minimum flows and levels. In essence, during development of an MFL existing uses will not be „grandfathered" but the District is directed to evaluate and account for the effects of previous structural alterations on a watercourse when assessing the potential for withdrawals to cause significant harm.

Each water management district must also consider, and at its discretion may provide for, the protection of non-consumptive uses in the establishment of MFLs (Section 373.042, F.S.). In addition, a baseline condition for the protected resource functions must be identified through consideration of changes and structural alterations in the hydrologic system (Section 373.042(1), F.S.).

1.1 Objective

The objective of this task is to develop series of empirical models to predict salinity in the Crystal River as a function of appropriate explanatory variables. The work order consists of four tasks:

1. Develop an empirical model(s) of near bottom salinity at the Crystal River at Bagley Cove near Crystal River, FL gage (USGS, i.e., United States Geological Survey, 02310747).
2. Develop an empirical model(s) of near bottom and near surface salinity at the Crystal River at Mouth of Kings Bay, FL gage (USGS 02310742).
3. Develop empirical models to predict the locations of the 2, 5, 10, 15, and 20 ppt isohalines in the near surface, near bottom, and water column average.
4. Develop a "whole river" empirical model that can be used to predict near surface, near bottom, and water column average salinities as a function of location in the river and other relevant variables.

2 Available Data

As was mentioned in section one, two gages on the Crystal River have been used for this work order. In addition to data at the two gage locations, additional salinity data were obtained for longitudinal salinity samples throughout the river. For each longitudinal run, a series of samples were collected on the same day, throughout the river. Longitudinal samples were collected between March 2008 and October 2010. Lastly, nearby well level and wind data were obtained and used for the analyses.

2.1 Gage Data

As was mentioned in section one, daily gage records were obtained and analyzed for the Crystal River at Bagley Cove near Crystal River, FL gage (tidally-filtered flow, bottom salinity, and gage height) and the Crystal River at Mouth of Kings Bay, FL gage (bottom salinity, surface salinity, and gage height).

2.1.1 Gage Data - Flows

Daily flow estimates were obtained for the Crystal River at Bagley Cove near Crystal River, FL (02310747) gage. The gage is located approximately eight kilometers upstream of the mouth of the Crystal River and approximately 2.3 km downstream of the Mouth of Kings Bay. The drainage area of the gage is not determined (http://waterdata.usgs.gov/nwis/uv/?site_no=02310747&agency_cd=USGS). Flow measurements began in 2002 and have continued to the present. According to the USGS website, "Streamflow at this site is significantly affected by astronomical tides." Therefore, in addition to continuous recorder estimates of flow at the gage, the USGS has estimated the daily flow at the gage using a tide filtering algorithm to account for the fact that the gage is tidally influenced. Tidally-filtered flow estimates are available from March 2002 through August 2010.

To better understand the estimates of tidally-filtered flows at the Crystal River at Bagley Cove near Crystal River gage, the flow duration curve is presented in Figure 2-1 and a time series plot of the monthly mean flow is presented in Figure 2-2 for the period of record (2002-2010). Additionally, summary statistics are presented in Table 2-1. According to the estimated flows, there are periods (approximately 2% of the time) when the daily flow at Bagley Cove is negative (i.e., water is flowing from the Gulf of Mexico upstream toward Kings Bay). For the period August 2002 through August 2010, the daily, tidally-filtered flows ranged from a minimum of -1,050 cfs to a maximum of 2,840 cfs. The daily mean flow for the period was 815 cfs, while the median flow was 821 cfs. The inter-quartile range was from 584 cfs to 1,040 cfs.

Questions have been raised as to the accuracy of the tidally-filtered flows at the Crystal River at Bagley Cove (HydroGeoLogic, 2011; Chen, personal communication). The consensus is that the tidally-filtered flows are an over estimate of the actual flows at

Bagley Cove. As is discussed in Section 2.1.3, these flows were revised by the USGS and the revised flows were used in regression analyses.

Figure 2-1. Crystal River at Bagley Cove (02310747) tidally-filtered flow duration curve.

Figure 2-2. Monthly average flow (cfs) at Crystal River at Bagley Cove (tidally-filtered).

Table 2-1. Crystal River at Bagley Cove (02310747) tidally-filtered flow statistics (2002-2010).

Period of Record (# of obs)	Statistic (cfs)							
	mean	minimum	10 %	25 %	50 %	75 %	90 %	maximum
Aug'02-Aug'10 (2,530)	815	-1,050	331	584	821	1,040	1,260	2,840

Further analysis of the tidally-filtered flow at the Crystal River at Bagley Cove gage is presented in the form of a box and whisker plot (Figure 2-3). The lower and upper edges of the box represent the 25th and 75th percentiles, respectively (i.e., the inter-quartile range). The line inside the box represents the median and the plus sign represents the mean. The minimum and maximum are represented by the lower and upper extents of the whisker, respectively. This plot agrees with the observation of Yobbi and Knochenmus (1989), who found that during summer and fall months (when tides are typically higher, leading to greater head pressure over spring vents) flows are lower and during winter and spring months (when tides are typically lower, leading to less head pressure over spring vents) flows are higher. This is contrary to the typical pattern of increased river flows during the late summer and fall in central Florida.

Figure 2-3. Box and whisker plot of daily flow (cfs) at Crystal River at Bagley Cove (tidally-filtered) by calendar month.

2.1.2 Gage Data - Salinity and Elevation

As was mentioned in section one, two gages on the Crystal River have been used for this work order. In addition to estimates of flow at the Crystal River at Bagley Cove near Crystal River, FL gage (USGS 02310747), observed bottom salinity and gage height were available for the Crystal River at Bagley Cove near Crystal River, FL gage (USGS 02310747) and observed bottom salinity, surface salinity and gage height were available for the Crystal River at Mouth of Kings Bay, FL gage (USGS 02310742).

Summary statistics for salinity at the two gages are presented in Table 2-2. Additionally, time series plots of the monthly average salinity are presented in Figures 2-4 through 2-6. Bottom salinities at the Crystal River at Bagley Cove gage (02310747) are typically between 0.3 and 7.5 ppt, while the mean and median are 3.38 and 2.53 ppt, respectively. More than three-quarters of the bottom salinity observations at the Crystal River at Bagley Cove gage are less than 5 ppt (i.e., 75th percentile = 4.55 ppt). As can be seen in Figure 2-4, salinities were lower during the 2003 through 2006 period and higher during the 2007 through 2010 period. This roughly corresponds to the trend of decreasing flows which are seen between 2004 and 2010 (Figure 2-2). As expected, the salinities at the Crystal River at the Mouth of Kings Bay (Figures 2-5 and 2-6) were lower than the salinities at Bagley Cove. The bottom salinities at the mouth of Kings

Bay correlated well with the bottom salinities at Bagley Cove for the overlapping period of record (December 2006 through August 2010). However, at Bagley Cove, a period of decreasing flows was accompanied by decreasing salinities (circled in red in Figure 2-7). This apparent anomaly was cause for concern when trying to develop statistical relationships between salinity and potential explanatory variables. After discussions with District and USGS staff, the USGS decided to revisit the tidally-filtered flows for the Bagley Cove gage now that additional data were available.

Table 2-2. Summary of Crystal River continuous recorder salinity data.

Gage (level)	Period of Record (Number of observations)	Statistic (ppt)							
		mean	1 %	10 %	25 %	50 %	75 %	90 %	99 %
02310747 (bottom)	Aug'02-Aug'10 (263,226)	3.38	0.00	0.34	1.18	2.53	4.55	7.48	14.93
02310742 (surface)	Dec'06-Aug'10 (130,305)	1.72	0.00	0.23	0.61	1.26	2.41	3.82	6.83
02310742 (bottom)	Dec'06-Aug'10 (130,305)	2.42	0.02	0.43	0.91	1.91	3.44	4.99	9.65

Figure 2-4. Monthly average bottom salinity (ppt) at Crystal River at Bagley Cove (02310747).

Figure 2-5. Monthly average surface salinity (ppt) at Crystal River at Mouth of Kings Bay (02310742).

Figure 2-6. Monthly average bottom salinity (ppt) at Crystal River at Mouth of Kings Bay (02310742).

Figure 2-7. Comparison of flows and bottom salinity at Crystal River at Bagley Cove (02310747).

2.1.3 Gage Data – Revised Flows

The USGS revised the algorithm used to estimate the tidally-filtered daily flows at the Bagley Cove gage and the revised flows were obtained. The revised flows for Bagley Cove were substantially lower than the originally reported flows. To better understand the differences between the original and revised flows for the Bagley Cove gage, a series of comparative plots and statistics were developed.

Flow duration curves of the original and revised tidally-filtered flows at Bagley Cove are presented in Figure 2-8. As can be seen in this figure, the revised flows are substantially lower than the original flows. Summary statistics for the original and revised flows are presented in Table 2-3. As anticipated, the revised flows are less than the original flows for the mean (815 cfs vs 496 cfs) and all other flow statistics.

Figure 2-8. Original and revised Crystal River at Bagley Cove (02310747) tidally-filtered flow duration curves.

In addition to the flow duration curves, which give a general understanding of the distributions of the original and revised flows at Bagley Cove, time series plots of the monthly mean flows and box and whisker plots of the original and revised flows by calendar month and by year are presented. A time series plot of the monthly mean original and revised flows is presented in Figure 2-9. The original flows are generally greater than the revised flows with the exception of the beginning of the period of record (2002-2003), where the revised flows are typically greater than the original flows. As was pointed out in Figure 2-7, the original flows in the 2002-2003 period were not consistent with the salinities and were part of the reason that the flows were revisited. The same general seasonal pattern of flows can be seen in both the original and revised flows.

Table 2-3. Crystal River at Bagley Cove (02310747) tidally-filtered flow statistics (2002-2010).

Flow Record (# of obs)	Statistic (cfs)							
	mean	minimum	10 %	25 %	50 %	75 %	90 %	maximum
Original Flows Aug"02-Aug"10 (2,530)	815	-1,050	331	584	821	1,040	1,260	2,840
Revised Flows Aug"02-Aug"10 (2,530)	496	-1,100	92	278	492	704	926	1,790

Figure 2-9. Original and revised monthly average flow (cfs) at Crystal River at Bagley Cove (tidally-filtered).

Box and whisker plots of the original and revised flows are presented by calendar month (Figure 2-10) and by year (Figure 2-11). With the exception of the extremes (minimums and maximums), which have similar values for a couple of months, the inter-quartile range, median and mean are all consistently lower for the revised flows (Figure 2-10). Looking at the annual box and whisker plot (Figure 2-11), the original and revised flows are more similar in 2002 and 2003 and are distinctly different 2004 onward, with the revised flows being lower than the original flows. After discussions with District and USGS staff, it was decided to use the revised flows for developing regressions to satisfy this work order.

Figure 2-10. Box and whisker plot of original and revised daily flow (cfs) at Crystal River at Bagley Cove (tidally-filtered) by calendar month.

Figure 2-11. Box and whisker plot of original and revised daily flow (cfs) at Crystal River at Bagley Cove (tidally-filtered) by year.

In addition to flow at Bagley Cove, gage height (expressed in feet, relative to NAVD88) was measured at Bagley Cove (02310747) and Kings Bay (02310742). In a previous study (Yobbi and Knochenmus, 1989), gage height was found to be a more significant contributor to isohaline locations then flow in the Crystal River system. Box and whisker plots of gage height at Bagley Cove by calendar month and by year are presented in Figures 2-12 and 2-13 respectively. Higher gage heights were recorded between May and October and lower values were documented from December to March. As anticipated, the gage height in consistent from year to year, but with higher variability in certain years due to weather and atmospheric conditions (Figure 2-13). Box and whisker plots of gage height at Kings Bay are presented in Figures 2-14 and 2-15 by calendar month and by year, respectively. As with gage height at Bagley Cove, higher gage heights were recorded between May and October and lower values were documented from December to March. A summary of gage height statistics is presented in Table 2-4 for Bagley Cove and Kings Bay. Due to the proximity of these two gages, the statistics are very similar.

Figure 2-12. Box and whisker plot of gage height (NAVD88 ft) at Crystal River at Bagley Cove (02310747) by calendar month.

Figure 2-13. Box and whisker plot of gage height (NAVD88 ft) at Crystal River at Bagley Cove (02310747) by year.

Figure 2-14. Box and whisker plot of gage height (NAVD88 ft) at Crystal River at Mouth of Kings Bay (02310742) by calendar month.

Figure 2-15. Box and whisker plot of gage height (NAVD88 ft) at Crystal River at Mouth of Kings Bay (02310742) by year.

Table 2-4. Summary of Crystal River continuous recorder gage height data.

Gage	Period of Record (Number of observations)	Gage Height (ft NAVD88)							
		mean	1 %	10 %	25 %	50 %	75 %	90 %	99 %
02310747	Aug"02-Aug"10 (263,226)	0.12	-2.03	-1.15	-0.60	0.12	0.84	1.40	2.22
02310742	Dec"06-Aug"10 (130,305)	0.09	-2.07	-1.22	-0.65	0.10	0.84	1.40	2.21

As was discussed in Section 2.1.1, the typical regional pattern of higher flows in the summer and fall is not present in Crystal River. In fact, the highest flows in the Crystal River system are typically in the winter and spring (Figure 2-10).

Further analysis of salinity data is presented in the form of box and whisker plots of salinity by calendar month for bottom salinity at Crystal River at Bagley Cove (Figure 2-16) and for surface and bottom salinity at Crystal River at the Mouth of Kings Bay (Figures 2-17 and 2-18, respectively). Because the lowest gage heights and highest flows typically occur in the winter and spring period, the lowest salinities typically occur in the winter and spring period in the Crystal River. Inversely, highest gage heights and lowest flows typically occur in the summer and fall period, leading to higher salinities in the summer and fall period in the Crystal River. As discussed above, the salinities are higher at Bagley Cove because it is downstream of Kings Bay.

Figure 2-16. Box and whisker plot of bottom salinity (ppt) at Crystal River at Bagley Cove (02310747) by calendar month.

Figure 2-17. Box and whisker plot of surface salinity (ppt) at Crystal River at Mouth of Kings Bay (02310742) by calendar month.

Figure 2-18. Box and whisker plot of bottom salinity (ppt) at Crystal River at Mouth of Kings Bay (02310742) by calendar month.

2.1.4 Well Data - Elevation

Daily well level data were available for one well (ROMP TR 21-3) near Kings Bay. Additional monthly data were available for a neighboring well (ROMP TR 21-2). Because these two wells yielded similar results in terms of levels, inter-annual variation, and intra-annual variation, only ROMP TR 21-3 data were used for further analyses based on the availability of daily water levels (in feet relative to NGVD29). The intra-annual variation in well level (Figure 2-19) is similar to flows in typical central Florida rivers, with highest values in the summer and fall and lower values during the winter and spring. The intra-annual variation in well data (Figure 2-19) is also similar to the intra-annual variation in gage height at both gages in this study (Figures 2-12 and 2-14). The influence on rainfall can be clearly seen in Figure 2-20, with higher well levels during the wetter, early portion of the study period (2002-2005) and lower levels during the drier, later portion of the study period (2006-2010). The highest average condition for well 21-3 was in 2003 and the lowest average condition was in 2007. Since the low in 2007, the well levels have increased annually, but have not returned to the high values of 2003-2005.

Figure 2-19. Box and whisker plot of well height (ft NGVD29) for ROMP TR 21-3 by calendar month.

Figure 2-20. Box and whisker plot of well height (ft NGVD29) for ROMP TR 21-3 by year.

Table 2-5. Summary statistics for well levels (ft NGVD29) at ROMP TR 21-3.									
Well	Period of Record (Number of observations)	Well Height (ft NGVD29)							
		mean	1 %	10 %	25 %	50 %	75 %	90 %	99 %
21-3	Aug"02-Sep"10 (2,938)	3.38	2.37	2.79	3.03	3.35	3.65	4.04	4.79

2.2 Longitudinal Data

In addition to the gaged data described above, salinity data were available from two studies on the Crystal River. The District MFL and the University of South Florida/Florida Fish and Wildlife Conservation Commission (USF/FFWCC) fish and invertebrate studies included collection of salinity profile data over the length of Crystal River between March 2008 and October 2010. An example of a daily sampling event for bottom salinity is presented in Figure 2-21, which shows salinities at sampling locations based on a river kilometer (rkm) system developed for the District and USF/FFWCC studies. The river kilometer system is centered around a site (rkm = 0) at the mouth of the river, near Shell Island. As expected and exemplified in Figure 2-21, salinities within the river decrease in an upstream direction. Plots for all longitudinal samples (bottom, surface, and water-column average) are presented in Appendix 1.

Figure 2-21. Example of longitudinal salinity samples from the USF/FFWCC fish and invertebrate study.

Reference lines were plotted to represent the 2, 5, 10, 15, and 20 ppt isohaline locations along the length of the river, based on the longitudinal salinity data. In order to identify the location of isohalines of interest, individual samples were connected using linear interpolation for each sampling event. The locations of the isohalines of interest were then calculated for each individual sampling event for bottom, surface, and water-column average salinities. Sampling was conducted between river km -4.1 to 11.2, however the isohaline locations were often outside the downstream extent of the sampling range. Therefore, isohalines beyond the downstream extent of the sampling area were classified as river km -4.2. Summary statistics for surface, bottom, and water-column average salinities are presented in Table 2-6 through 2-8. The lowest surface, 2 ppt isohaline location was rkm 5.1, while the median location for the surface 2 ppt isohaline was rkm 9.5. The median location of the 20 ppt surface isohaline was outside of the sampling area (-4.2*). As anticipated, the bottom and water-column average isohaline locations were slightly upstream of the surface isohaline locations (Tables 2-6 through 2-8).

Table 2-6. Crystal River Isohaline location statistics for surface salinity.

Isohaline (ppt)	n	Statistic (river km)							
		mean	min	10 %	25 %	50 %	75 %	90 %	max
2	51	9.3	5.1	8.0	8.9	9.5	9.9	10.4	11.0
5	55	5.4	-4.2 *	1.9	3.6	6.3	7.6	8.6	9.5
10	54	2.6	-4.2 *	-1.0	1.0	2.3	4.9	7.0	8.6
15	54	-0.2	-4.2 *	-4.2 *	-4.2 *	0.4	1.4	5.1	7.2
20	54	-2.7	-4.2 *	-4.2 *	-4.2 *	-4.2 *	-1.6	1.0	6.7

Table 2-7. Crystal River Isohaline location statistics for bottom salinity.

Isohaline (ppt)	n	Statistic (river km)							
		mean	min	10 %	25 %	50 %	75 %	90 %	max
2	49	9.5	6.0	8.1	9.1	9.7	10.2	10.9	11.2
5	54	6.0	-4.1	2.4	3.8	6.5	8.3	9.3	11.1
10	54	3.1	-4.2 *	-0.6	1.4	3.2	5.3	7.5	9.3
15	54	0.6	-4.2 *	-4.2 *	-4.2 *	0.9	3.0	5.2	8.8
20	54	-1.6	-4.2 *	-4.2 *	-4.2 *	-3.6	0.8	2.2	7.5

Table 2-8. Crystal River Isohaline location statistics for water column average salinity.									
Isohaline (ppt)	n	Statistic (river km)							
		mean	min	10 %	25 %	50 %	75 %	90 %	max
2	50	9.5	5.3	8.1	9.2	9.7	10.2	10.7	11.2
5	55	5.8	-4.1	2.1	3.7	6.4	7.9	8.8	9.8
10	54	2.9	-4.2 *	-0.7	1.4	3.1	4.9	7.2	9.0
15	54	0.3	-4.2 *	-4.2 *	-4.2 *	0.8	2.5	5.1	7.5
20	54	-2.1	-4.2 *	-4.2 *	-4.2 *	-4.2 *	0.3	1.7	7.0

** value was outside the downstream extent of the sampling area*

2.3 Wind Data

In addition to gage and longitudinal salinity data, wind data were obtained as wind can contribute to water surface elevations. Wind data were available for Homosassa (USF COMPS station HOM), however these data were not appropriate as data are not available after August 2009 and due to data gaps. Therefore, the Cedar Key meteorological station (NOAA station CDRF1) was used, as a complete set of hourly wind speed and direction data are available for the period of record where gage and longitudinal salinity data are available. The Cedar Key wind data consists of wind speed and wind direction. For the purpose of the analyses, the wind speed and wind direction were broken into x- and y-components as shown in Figure 2-12.

Figure 2-22. Decomposition of wind speed and direction into x- and y-components.

3 Regression Development

A step-wise approach was used to develop linear regressions for this work order. For this approach, the first statistical model consisted of only one explanatory variable, the second statistical model consisted of combinations of two explanatory variables, etc. Out of these models, the best statistical models were further investigated. The final models were chosen based on the model R^2, adjusted R^2, and Mallow"s C(p) statistic. The potential explanatory variables that were included in model development included: the daily average gage height, daily maximum gage height, daily minimum gage height, higher order gage height terms (i.e., daily maximum squared), tidally-filtered flows, lag averages of tidally filtered flows, and the x- and y-components of Cedar Key wind speed. After development of preliminary regression models based on the variables described above, diagnostic plots were employed to identify potential issues with the preliminary models (e.g., curvature or seasonal patterns in residuals). Analyses of residuals by calendar month were used to identify seasons where over- or under-prediction existed. In these instances, seasonal terms were used to improve the fit of the models. Additionally, the variance inflation factor was examined to preclude autocorrelation of independent variables.

3.1 Salinity at the Crystal River at Bagley Cove Gage

As discussed in Section 2.1.2, only bottom salinity are available for the Crystal River at Bagley Cove gage. A preliminary regression model between daily average bottom salinity at the Crystal River at Bagley Cove gage and potential explanatory variables was developed. The residuals from this model were examined to identify any potential issues that might contribute to the overall variance accounted for by the model. The residual analysis revealed a seasonal influence that was negatively impacting the fit of the regression. In addition, there was a curvature that is indicative of quadratic behavior. Therefore, seasonal terms were added to the model. These seasonal terms act as dummy variables that are equal to one during the season and zero otherwise. To address the curvature of the residuals, a quadratic term was added to the regression equation. The final regression equation is:

$$\text{Salinity}_{bottom} = 15.20 + 0.81\, Gage_{max}^2 - 0.90\, F_2 - 2.66\, Well - 0.51\, S1 + 0.89\, S2$$

where:

Salinity_{bottom}	= Daily average bottom salinity at Bagley Cove (ppt)
F_2	= log of 2-day average tidally-filtered flow at Bagley Cove (cfs)
$Gage_{max}^2$	= Daily max gage height (ft NAVD88) at Bagley Cove squared
$Well$	= well height at ROMP TR 21-3 (ft NGVD29)
$S1$	= dummy variable for January through July
$S2$	= dummy variable for September through November

The model was fit with 2,213 observations and resulted in an R^2 value of 0.71. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. The results of this regression are in agreement with the work of Yobbi and Knochenmus (1989) in that both studies found that gage height is an important variable when predicting salinity and that increased gage height results in increased salinity in the Crystal River. However, in the current study, tidally-filtered flow at Bagley Cove was the most important variable when predicting salinity at Bagley Cove as opposed to Yobbi and Knochenmus (1989) who found that gage height was the most important variable when predicting salinity at Bagley Cove. In the current study, well level at the nearby ROMP TR 21-3 well was also a significant variable and was negatively correlated with bottom salinity at Bagley Cove. Therefore, the results of the proposed regression are logical as salinity and gage height are positively correlated and salinity and flow and salinity and well height are negatively correlated.

A plot of regression predicted versus observed salinities is presented in Figure 3-1. Additional diagnostic plots and output for the regression relating bottom salinity at Bagley Cove to appropriate explanatory variables are presented in Appendix 2. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-1. Predicted versus observed bottom salinity for Crystal River at Bagley Cove.

3.2 Salinity at Crystal River at mouth of Kings Bay Gage

As salinity observations are available for surface and bottom salinity at the Crystal River at the mouth of Kings Bay gage, regressions were developed for both surface and bottom salinity at this gage. A preliminary regression model between daily average surface salinity at the Crystal River at the mouth of Kings Bay gage and potential explanatory variables was developed. The residuals from this model were examined to identify any potential issues that might contribute to the overall variance accounted for by the model. As with the model developed for Bagley Cove, a residual analysis revealed a seasonal influence that was negatively impacting the fit of the regression. In addition, there was a curvature that is indicative of quadratic behavior. Therefore, seasonal terms were added to the model. These seasonal terms act as dummy variables that are equal to one during the season and zero otherwise. To address the curvature of the residuals, a quadratic term was added to the regression equation. The final regression equation is:

$$\text{Salinity}_{surf} = 6.38 - 0.43\,F_3 + 0.28\,Gage_{max}^2 - 0.42\,Well - 0.28\,S1 + 0.34\,S2 - 0.51\,Delta\ Gage$$

where:

Salinity_{surf}	= Daily average surface salinity at Kings Bay (ppt)
F_3	= log of 3-day average tidally-filtered flow at Bagley Cove (cfs)
$Gage_{max}^2$	= Daily max gage height (ft NAVD88) at Kings Bay squared
$Well$	= well height at ROMP TR 21-3 (ft NGVD29)
$S1$	= dummy variable for May through August
$S2$	= dummy variable for October through November
Delta Gage	= ROMP TR 21-3 (ft NGVD29) – gage height (NAVD88) at Kings Bay

The model was fit with 867 observations and resulted in an R^2 value of 0.58. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. As with the results of the Bagley Cove bottom salinity regression, the tidally-filtered flow at Bagley Cove was the most important variable in explaining the variation in salinity at Kings Bay. However, gage height (gage max squared), well levels and the difference between well levels and the gage heights at Kings Bay were all significant explanatory variables. As with Bagley Cove salinity, the same positive correlation (between gage height and salinity) and negative correlations (between flow and salinity and between well height and salinity) were documented.

A plot of regression predicted versus observed salinities is presented in Figure 3-2. Additional diagnostic plots and output for the regression relating surface salinity at the mouth of Kings Bay to appropriate explanatory variables are presented in Appendix 3. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-2. Predicted versus observed surface salinity for Crystal River at mouth of Kings Bay.

A preliminary regression model between daily average bottom salinity at the Crystal River at the mouth of Kings Bay gage and potential explanatory variables was developed. The residuals from this model were examined to identify any potential issues that might contribute to the overall variance accounted for by the model. As with the models discussed above, a residual analysis revealed a seasonal influence that was negatively impacting the fit of the regression. In addition, there was a curvature that is indicative of quadratic behavior. Therefore, seasonal terms were added to the model. These seasonal terms act as dummy variables that are equal to one during the season and zero otherwise. To address the curvature of the residuals, a quadratic term was added to the regression equation. The final regression equation is:

$$\text{Salinity}_{bot} = 6.61 - 0.55\,F_2 + 0.31\,Gage_{max}^2 - 0.26\,S1 + 0.49\,S2 - 0.63\,Delta\ Gage$$

where:

Salinity_{bot}	= Daily average bottom salinity at Kings Bay (ppt)
F_2	= log of 2-day average tidally-filtered flow at Bagley Cove (cfs)
$Gage_{max}^2$	= Daily max gage height (ft NAVD88) at Kings Bay squared
$S1$	= dummy variable for May through August
$S2$	= dummy variable for October through January
Delta Gage	= ROMP TR 21-3 (ft NGVD29) – gage height (NAVD88) at Kings Bay

The model was fit with 867 observations and resulted in an R^2 value of 0.54. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. As with the results of the Kings Bay surface salinity regression, the tidally-filtered flow at Bagley Cove was the most important variable in explaining the variation in bottom salinity at Kings Bay. However, gage height (gage max squared) and the difference between well levels and the gage heights at Kings Bay were also significant explanatory variables. As with Kings Bay surface salinity, the same positive correlation (between gage height and salinity) and negative correlation (between flow and salinity) were documented.

A plot of regression predicted versus observed salinities is presented in Figure 3-3. Additional diagnostic plots and output for the regression relating bottom salinity at the mouth of Kings Bay to appropriate explanatory variables are presented in Appendix 4. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-3. Predicted versus observed bottom salinity for Crystal River at mouth of Kings Bay.

3.3 Isohaline Regressions

As was discussed in Section 2.2, longitudinal data were obtained from two studies of the Crystal River system. In these studies, salinity data were collected throughout the Crystal River system on the same day, thus producing longitudinal salinity profile data. Samples were collected between March 2008 and October 2010. Regressions were developed for surface, bottom, and water column average salinities for the 2 ppt, 5 ppt, 10 ppt, 15 ppt, and 20 ppt isohaline locations. As with the salinity regressions developed for Bagley Cove and Kings Bay, a stepwise approach was employed and the same set of potential explanatory variables were investigated. A summary of the regressions is presented in Table 3-1. Diagnostic plots and output for the regressions relating isohaline location and level to appropriate explanatory variables are presented in Appendix 5.

With the exception of the 2 ppt isohaline regressions, which were highly significant, the other isohalines ranged from significant (5 ppt) to not significant (10, 15, and 20 ppt). The weakness of the statistical relationships is likely due to the small sample size that was collected under widely varying tidal and atmospheric conditions and the hydraulic complexity of this large, tidally influenced, spring-fed system.

Table 3-1. Crystal River isohaline location regression equations.

Isohaline	Level	n	Regression Equation	p > F	r^2
2 ppt	Surface	32	Iso = 17.39 – 2.64 Delta Gage	<0.0001	0.40
	Bottom	32	Iso = 12.91 – 0.61 F_3 – 0.25 $Wind_y$	0.002	0.34
	WC avg	32	Iso = 17.39 – 2.64 Delta Gage	<0.0001	0.40
5 ppt	Surface	33	Iso = 20.18 – 4.72 Delta Gage + 0.31 $Wind_x$	0.004	0.31
	Bottom	33	Iso = 17.96 – 4.01 Delta Gage + 0.32 $Wind_x$ – 0.21 $Wind_y$	0.008	0.33
	WC avg	33	Iso = 17.96 – 4.02 Delta Gage + 0.32 $Wind_x$ – 0.21 $Wind_y$	0.008	0.33
10 ppt	Surface	30	Iso = 4.84 + 1.32 $Gage_{min}$ + 0.29 $Wind_x$ – 0.48 $Wind_y$	0.04	0.27
	Bottom	30	Iso = 12.34 – 2.98 Delta Gage + 0.31 $Wind_x$	0.19	0.11
	WC avg	30	Iso = 12.34 – 2.98 Delta Gage + 0.31 $Wind_x$	0.19	0.11
15 ppt	Surface	24	Iso = 1.28 + 0.33 $Wind_x$	0.12	0.11
	Bottom	24	Iso = 2.47 + 1.15 $Gage_{min}$ + 0.43 $Wind_x$ – 0.16 $Wind_y$	0.26	0.18
	WC avg	24	Iso = 2.70 + 1.24 $Gage_{min}$ + 0.40 $Wind_x$	0.15	0.16
20 ppt	Surface	13	Iso = 1.81 + 2.12 $Gage_{min}$ + 0.22 $Wind_x$	0.08	0.40
	Bottom	13	Iso = 1.81 + 2.12 $Gage_{min}$ + 0.22 $Wind_x$	0.08	0.40
	WC avg	13	Iso = -5.77 + 1.68 Well	0.14	0.19

where:

F_n	= log of n-day average tidally-filtered flow at Bagley Cove (cfs)
$Gage_{min}$	= Daily minimum gage height (ft NAVD88) at Bagley Cove
Well	= well height at ROMP TR 21-3 (ft NGVD29)

$Wind_x$	= x-component of daily average wind at Cedar Key
$Wind_y$	= y-component of daily average wind at Cedar Key
Delta Gage	= ROMP TR 21-3 (ft NGVD29) – gage height (NAVD88) at Bagley Cove

3.4 Whole River Regression

The final task in the work order was to develop regressions to predict surface, bottom and water column average salinity longitudinally based on appropriate explanatory variables. The salinity data set used for this task was the same data set that was developed for the isohaline regressions. Longitudinal salinity samples were collected throughout Crystal River. A dataset was then created by using linear interpolation to estimate the salinity at 100 meter increments from the downstream extent (rkm -4.1) to the upstream extent of sampling (rkm 12.2).

Preliminary regression models between surface, bottom, and water column average salinities in the Crystal River and potential explanatory variables were developed. The residuals from these models were examined to identify any potential issues that might contribute to the overall variance accounted for by the model. For surface salinity, the final regression equation is:

$$\text{Ln Salinity}_{surf} = 5.40 - 0.21rkm - 0.68Delta\ Gage + 0.06Wind_x - 0.02Wind_y - 0.09F_4$$

where:	Ln Salinity_{surf}	= log of surface salinity (ppt)
	rkm	= river km
	F_4	= log 4-day average tidally filtered flow at Bagley Cove (cfs)
	$Wind_x$	= x-component of daily average wind (m/s) at Cedar Key
	$Wind_y$	= y-component of daily average wind (m/s) at Cedar Key
	Delta Gage	= ROMP TR 21-3 (ft NGVD29) – gage height (NAVD88) at Bagley Cove

The model was fit with 4,690 observations and resulted in an R^2 value of 0.75. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. As anticipated, river kilometer (rkm) and surface salinity are inversely related, as are flow and surface salinity. In addition, surface salinity and wind in the x-direction are positively correlated as wind from the west to east (positive x-direction) results in higher water levels as water is driven from the Gulf of Mexico toward Kings Bay and therefore higher salinities in Crystal River.

A plot of regression predicted versus observed surface salinities is presented in Figure 3-4. Additional diagnostic plots and output for the regression relating surface salinity to

appropriate explanatory variables are presented in Appendix 6. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-4. Predicted versus observed surface salinity for Crystal River.

For bottom salinity, the final regression equation is:

$$\text{Ln Salinity}_{bot} = 4.87 - 0.20rkm - 0.61Delta\ Gage + 0.06Wind_x - 0.04Wind_y - 0.02F_3$$

where:

Ln Salinity$_{bot}$	= log of bottom salinity (ppt)
rkm	= river km
F_3	= log 3-day average tidally filtered flow at Bagley Cove (cfs)
$Wind_x$	= x-component of daily average wind (m/s) at Cedar Key
$Wind_y$	= y-component of daily average wind (m/s) at Cedar Key
Delta Gage	= ROMP TR 21-3 (ft NGVC29) – gage height (ft NAVD88) at Bagley Cove

The model was fit with 4,575 observations and resulted in an R^2 value of 0.71. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. As with surface salinity, river kilometer (rkm) and bottom salinity are inversely related, as are flow and bottom salinity. In addition, salinity and wind in the x-direction are positively correlated as wind from the west to east (positive x-direction) results in higher salinities.

A plot of regression predicted versus observed bottom salinities is presented in Figure 3-4. Additional diagnostic plots and output for the regression relating bottom salinity to appropriate explanatory variables are presented in Appendix 6. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-5. Predicted versus observed bottom salinity for Crystal River.

For water column average salinity, the final regression equation is:

$$\text{Ln Salinity}_{wc} = 4.96 - 0.21rkm - 0.43Delta\ Gage + 0.07Wind_x - 0.08Wind_y - 0.14F_7$$

where:

Ln Salinity$_{wc}$	= log of water column average salinity (ppt)
rkm	= river km
F_7	= log 7-day average tidally filtered flow at Bagley Cove (cfs)

$Wind_x$	= x-component of daily average wind (m/s) at Cedar Key
$Wind_y$	= y-component of daily average wind (m/s) at Cedar Key
Delta Gage	= ROMP TR 21-3 (ft NGVD29) – gage height (NAVD88) at Bagley Cove

The model was fit with 4,352 observations and resulted in an R^2 value of 0.76. The regression was highly significant with a probability of a greater |F| value of < 0.0001. The slope and parameter coefficients were all highly significant. As with surface and bottom salinity, river kilometer (rkm) and water column average salinity are inversely related, as are flow and water column average salinity. In addition, salinity and wind in the x-direction are positively correlated as wind from the west to east (positive x-direction) results in higher salinities.

A plot of regression predicted versus observed water column average salinities is presented in Figure 3-4. Additional diagnostic plots and output for the regression relating water column average salinity to appropriate explanatory variables are presented in Appendix 6. Analysis of the variance inflation factors indicated a lack of autocorrelation between independent variables (VIF<<10).

Figure 3-6. Predicted versus observed water column average salinity for Crystal River.

4 Conclusions

The objective of this work order was to develop regressions to predict salinity and isohaline locations in Crystal River. Therefore, the regressions were developed using available, appropriate explanatory variables. The project was delayed when problems were identified with the tidally-filtered flows at Bagley Cove. After discussions with District and USGS staff, the USGS decided to revisit the equation used to estimate tidally-filtered flows for the Bagley Cove gage. The revised tidally-filtered flows at Bagley Cove were used for regression development

4.1 Bagley Cove Bottom Salinity Regression

The Bagley Cove bottom salinity regression related salinity to log transformed, tidally-filtered flows at Bagley Cove, well levels (ROMP TR 21-3), gage height at Bagley Cove, and seasonal terms. As discussed in section 3.1, the results of the regression developed for this work order are in agreement with the work of Yobbi and Knochenmus (1989) in that both studies found that gage height is a significant variable when predicting salinity and that increased gage height results in increased salinity in the Crystal River. However, in the current study, tidally-filtered flow at Bagley Cove was the most important variable when predicting salinity at Bagley Cove as opposed to Yobbi and Knochenmus (1989) who found that gage height was the most important variable when predicting salinity at Bagley Cove. In the current study, well level at the nearby ROMP TR 21-3 well was also a significant variable and was negatively correlated with bottom salinity at Bagley Cove. Results of the current regression analyses are logical, as salinity and gage height are positively correlated and salinity and flow and salinity and well height are negatively correlated. The Bagley Cove bottom salinity regression may be used in parallel with other tools that have been developed for the Crystal River system to provide a weight of evidence approach when developing minimum flows for the Crystal River.

4.2 Kings Bay Salinity Regressions

The Kings Bay surface and bottom salinity regressions related salinities to log transformed, tidally-filtered flows at Bagley Cove, well levels (ROMP TR 21-3), gage heights at Kings Bay, and seasonal terms. These regressions agreed with the regression developed for bottom salinity at Bagley Cove in that flows were the principle variable for predicting salinity at Kings Bay. However, as was found by Yobbi and Knochenmus (1989), gage height is also a significant variable when predicting salinity in the system. As with the regression for Bagley Cove, salinity and gage height were positively correlated as higher tides during the summer months result in higher salinities due to the influence of water from the Gulf of Mexico. The regressions developed for Kings Bay leave a significant amount of the variation unexplained (R^2 = 0.58 and 0.54 for surface and bottom, respectively). This is not an unexpected outcome as the only available flow record is the tidally-filtered flow at Bagley Cove, which is downstream of the Kings Bay gage. Therefore, caution should be used when applying these regressions to minimum flow development in the Crystal River system.

4.3 Isohaline Regressions

Based on the available longitudinal salinity data collected in the Crystal River, regressions were developed for surface, bottom, and water column average salinities for the 2 ppt, 5 ppt, 10 ppt, 15 ppt, and 20 ppt isohaline locations. With the exception of the 2 ppt isohaline regressions, which were highly significant, the other isohalines ranged from significant (5 ppt) to not significant (10, 15, and 20 ppt). Though the 2 ppt regressions were highly significant, they still left the majority of the variation unexplained (R^2 = 0.34 – 0.40). The weakness of the statistical relationships is likely due to the small sample size that was collected under widely varying tidal and atmospheric conditions. Therefore, extreme caution should be used when applying these regressions to minimum flow development in the Crystal River system.

4.4 Whole River Regression

The whole river regression models related log transformed surface, bottom, and water column average salinities to log transformed Bagley Cover tidally-filtered flow lags, the difference between well height and Bagley Cove gage height, river kilometer, and x and y components of the wind at Cedar Key. As was found in regression development for Bagley Cover and Kings Bay, tidally-filtered flows and gage heights were important explanatory variables in predicting salinity in the system. In addition, well heights and wind influence salinities in the system. As anticipated, river kilometer and salinity are negatively correlated, with lower salinities as you move upstream. Therefore, the results of the proposed regressions are logical as salinity and flow and salinity and river kilometer are negatively correlated. As with the Bagley Cove regression, the whole river regressions may be used in conjunction with the mechanistic model (Chen, personal communication) and other tools that have been developed for the Crystal River system. The combination of these tools will provide a weight of evidence approach when developing minimum flows for the Crystal River.

5 References

Chen, X. 2011. Personal Communication.

HydroGeoLogic, Inc. 2010. Groundwater flow and saltwater transport model for the northern District water resources assessment project area. Prepared for: Southwest Florida Water Management District.

Yobbi, D.K and L.A. Knochenmus. 1989. Effects of river discharge and high-tide stage on salinity intrusion in the Weeki Wachee, Crystal, and Withlacoochee river estuaries, southwest Florida. U.S. Geological Survey, Water-Resources Investigations Report 88-4116. Prepared in cooperation with the Southwest Florida Water Management District. pp 71.

Appendix 1

Longitudinal Data

Crystal River Bottom Salinty, 18MAR08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 19MAR08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
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2
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4
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6
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8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 02APR08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
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5
6
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8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 11APR08
Bottom Salinity (ppt)
30
25
20
15
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0
-5
-4
-3
-2
-1
0
1
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3
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9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 22APR08
Bottom Salinity (ppt)
30
25
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15
10
5
0
-5
-4
-3
-2
-1
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1
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3
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6
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8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 22MAY08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
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5
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7
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9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 29MAY08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
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6
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8
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10
11
12
13
River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River Bottom Salinty, 17JUN08
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 19JUN08
Bottom Salinity (ppt)
30
25
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5
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-5
-4
-3
-2
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 10JUL08
Bottom Salinity (ppt)
30
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-5
-4
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-1
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 17JUL08
Bottom Salinity (ppt)
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-5
-4
-3
-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 29JUL08
Bottom Salinity (ppt)
30
25
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-5
-4
-3
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 14AUG08
Bottom Salinity (ppt)
30
25
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15
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-5
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 27AUG08
Bottom Salinity (ppt)
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25
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-5
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 11SEP08
Bottom Salinity (ppt)
30
25
20
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-5
-4
-3
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-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 24SEP08
Bottom Salinity (ppt)
30
25
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15
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-5
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-3
-2
-1
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 07OCT08
Bottom Salinity (ppt)
30
25
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-5
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-3
-2
-1
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 22OCT08
Bottom Salinity (ppt)
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 23OCT08
Bottom Salinity (ppt)
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25
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15
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-3
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-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 05NOV08
Bottom Salinity (ppt)
30
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-5
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-2
-1
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 19NOV08
Bottom Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 08DEC08
Bottom Salinity (ppt)
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25
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15
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-5
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-1
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 11DEC08
Bottom Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 18DEC08
Bottom Salinity (ppt)
30
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 06JAN09
Bottom Salinity (ppt)
30
25
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15
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-5
-4
-3
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-1
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10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 21JAN09
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 22JAN09
Bottom Salinity (ppt)
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-5
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 17FEB09
Bottom Salinity (ppt)
30
25
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15
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 19FEB09
Bottom Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 19MAR09
Bottom Salinity (ppt)
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25
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-5
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 09APR09
Bottom Salinity (ppt)
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25
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-5
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 20APR09
Bottom Salinity (ppt)
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-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 30APR09
Bottom Salinity (ppt)
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25
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15
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-5
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River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 16JUN09
Bottom Salinity (ppt)
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 17JUN09
Bottom Salinity (ppt)
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 24JUN09
Bottom Salinity (ppt)
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 30JUL09
Bottom Salinity (ppt)
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-5
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River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 06AUG09
Bottom Salinity (ppt)
30
25
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15
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5
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-5
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-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 13AUG09
Bottom Salinity (ppt)
30
25
20
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10
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-5
-4
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-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 15SEP09
Bottom Salinity (ppt)
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25
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-5
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-3
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River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 01OCT09
Bottom Salinity (ppt)
30
25
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15
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5
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-5
-4
-3
-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 27OCT09
Bottom Salinity (ppt)
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25
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5
0
-5
-4
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 10DEC09
Bottom Salinity (ppt)
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25
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10
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0
-5
-4
-3
-2
-1
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10
11
12
13
River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River Bottom Salinty, 14DEC09
Bottom Salinity (ppt)
30
25
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10
5
0
-5
-4
-3
-2
-1
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10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 26JAN10
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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1
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9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 04FEB10
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 23FEB10
Bottom Salinity (ppt)
30
25
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0
-5
-4
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-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Bottom Salinty, 09MAR10
Bottom Salinity (ppt)
30
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15
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0
-5
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 06MAY10
Bottom Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
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-2
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 08JUN10
Bottom Salinity (ppt)
30
25
20
15
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0
-5
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 05AUG10
Bottom Salinity (ppt)
30
25
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5
0
-5
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Bottom Salinty, 19OCT10
Bottom Salinity (ppt)
30
25
20
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10
5
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-5
-4
-3
-2
-1
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 18MAR08
Surface Salinity (ppt)
30
25
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-5
-4
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 19MAR08

Crystal River Surface Salinty, 02APR08
Surface Salinity (ppt)
30
25
20
15
10
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-5
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-3
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11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 11APR08
Surface Salinity (ppt)
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25
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-5
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 22APR08
Surface Salinity (ppt)
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-5
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11
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 22MAY08
Surface Salinity (ppt)
30
25
20
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5
0
-5
-4
-3
-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 29MAY08
Surface Salinity (ppt)
30
25
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River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River Surface Salinty, 17JUN08
Surface Salinity (ppt)
30
25
20
15
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-5
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 19JUN08
Surface Salinity (ppt)
30
25
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15
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 10JUL08
Surface Salinity (ppt)
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-5
-4
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 17JUL08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 29JUL08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 14AUG08
Surface Salinity (ppt)
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 27AUG08
Surface Salinity (ppt)
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-5
-4
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 11SEP08
Surface Salinity (ppt)
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-5
-4
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 24SEP08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 07OCT08
Surface Salinity (ppt)
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25
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-5
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 22OCT08
Surface Salinity (ppt)
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-5
-4
-3
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 23OCT08
Surface Salinity (ppt)
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-5
-4
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 05NOV08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 19NOV08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 08DEC08
Surface Salinity (ppt)
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 11DEC08
Surface Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 18DEC08
Surface Salinity (ppt)
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-5
-4
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 06JAN09
Surface Salinity (ppt)
30
25
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15
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0
-5
-4
-3
-2
-1
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 21JAN09
Surface Salinity (ppt)
30
25
20
15
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0
-5
-4
-3
-2
-1
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 22JAN09
Surface Salinity (ppt)
30
25
20
15
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5
0
-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 17FEB09
Surface Salinity (ppt)
30
25
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15
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0
-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 19FEB09
Surface Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 19MAR09
Surface Salinity (ppt)
30
25
20
15
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0
-5
-4
-3
-2
-1
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 09APR09
Surface Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 20APR09
Surface Salinity (ppt)
30
25
20
15
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5
0
-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 30APR09
Surface Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 16JUN09
Surface Salinity (ppt)
30
25
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-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 17JUN09
Surface Salinity (ppt)
30
25
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15
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-5
-4
-3
-2
-1
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 24JUN09
Surface Salinity (ppt)
30
25
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15
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0
-5
-4
-3
-2
-1
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 30JUL09
Surface Salinity (ppt)
30
25
20
15
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5
0
-5
-4
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 06AUG09
Surface Salinity (ppt)
30
25
20
15
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0
-5
-4
-3
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 13AUG09
Surface Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 15SEP09
Surface Salinity (ppt)
30
25
20
15
10
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0
-5
-4
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-2
-1
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 01OCT09
Surface Salinity (ppt)
30
25
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0
-5
-4
-3
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 27OCT09
Surface Salinity (ppt)
30
25
20
15
10
5
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-5
-4
-3
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-1
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 10DEC09
Surface Salinity (ppt)
30
25
20
15
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-5
-4
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13
River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River Surface Salinty, 14DEC09
Surface Salinity (ppt)
30
25
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-5
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 26JAN10
Surface Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 04FEB10
Surface Salinity (ppt)
30
25
20
15
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0
-5
-4
-3
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13
River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 23FEB10
Surface Salinity (ppt)
30
25
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15
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-5
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River km
Study
Fish and Invertebrate Project

Crystal River Surface Salinty, 09MAR10
Surface Salinity (ppt)
30
25
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15
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-5
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13
River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 06MAY10
Surface Salinity (ppt)
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 08JUN10
Surface Salinity (ppt)
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 05AUG10
Surface Salinity (ppt)
30
25
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River km
Study
Crystal River Minimum flows stations

Crystal River Surface Salinty, 19OCT10
Surface Salinity (ppt)
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River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 18MAR08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 19MAR08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 02APR08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 11APR08
WC Average Salinity (ppt)
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River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 22APR08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 22MAY08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 29MAY08
WC Average Salinity (ppt)
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River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River WC Average Salinty, 17JUN08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 19JUN08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 10JUL08
WC Average Salinity (ppt)
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13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 17JUL08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 29JUL08
WC Average Salinity (ppt)
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 14AUG08
WC Average Salinity (ppt)
30
25
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-5
-4
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River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 27AUG08
WC Average Salinity (ppt)
30
25
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13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 11SEP08
WC Average Salinity (ppt)
30
25
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13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 24SEP08
WC Average Salinity (ppt)
30
25
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-5
-4
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 07OCT08
WC Average Salinity (ppt)
30
25
20
15
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-5
-4
-3
-2
-1
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12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 22OCT08
WC Average Salinity (ppt)
30
25
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-5
-4
-3
-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 23OCT08
WC Average Salinity (ppt)
30
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-4
-3
-2
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13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 05NOV08
WC Average Salinity (ppt)
30
25
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-5
-4
-3
-2
-1
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12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 19NOV08
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 08DEC08
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 11DEC08
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 18DEC08
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 06JAN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 21JAN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 22JAN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 17FEB09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 19FEB09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 19MAR09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 09APR09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 20APR09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 30APR09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 16JUN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 17JUN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 24JUN09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 30JUL09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 06AUG09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 13AUG09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 15SEP09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 01OCT09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 27OCT09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 10DEC09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations
Fish and Invertebrate Project

Crystal River WC Average Salinty, 14DEC09
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 26JAN10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 04FEB10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 23FEB10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Fish and Invertebrate Project

Crystal River WC Average Salinty, 09MAR10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 06MAY10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 08JUN10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 05AUG10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Crystal River WC Average Salinty, 19OCT10
WC Average Salinity (ppt)
30
25
20
15
10
5
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
River km
Study
Crystal River Minimum flows stations

Appendix 2

Regression Diagnostics

Bagley Cove Bottom Salinity

Bagley Cove Bottom Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: sal_ppt_b

Number of Observations Read	3401
Number of Observations Used	2213
Number of Observations with Missing Values	1188

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	5	5725.31850	1145.06370	1076.48	<.0001
Error	2207	2347.60361	1.06371		
Corrected Total	2212	8072.92210			

Root MSE	1.03136	**R-Square**	0.7092
Dependent Mean	3.10774	**Adj R-Sq**	0.7085
Coeff Var	33.18689		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	15.20005	0.29710	51.16	<.0001	0
gagemax2	1	0.81264	0.02017	40.29	<.0001	2.24503
F2	1	-0.90187	0.03990	-22.60	<.0001	1.59823
well21_3_ft	1	-2.53963	0.05655	-44.91	<.0001	1.77628
s1	1	-0.55510	0.06047	-9.18	<.0001	1.87072
s2	1	0.88695	0.06796	13.05	<.0001	1.81426

Bagley Cove Bottom Salinity
Residual
7.5
5.0
2.5
0
-2.5
-5.0
1
2
3
4
5
6
7
8
9
10
11
12

Bagley Cove Bottom Salinity
Residual
7.5
5.0
2.5
0
-2.5
-5.0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011

Bagley Cove Bottom Salinity
Residual
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
1
2
3
4
5
6
7
8
9
10
Predicted Value of sal_ppt_b

Bagley Cove Bottom Salinity
Predicted
Observed
0
1
2
3
4
5
6
7
8
9
10

Appendix 3

Regression Diagnostics

Kings Bay Surface Salinity

Kings Bay Surface Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: sal_ppt_t

Number of Observations Read	3400
Number of Observations Used	867
Number of Observations with Missing Values	2533

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	6	417.38902	69.56484	194.05	<.0001
Error	860	308.30400	0.35849		
Corrected Total	866	725.69302			

Root MSE	0.59874	**R-Square**	0.5752
Dependent Mean	1.71861	**Adj R-Sq**	0.5722
Coeff Var	34.83886		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	6.37696	0.29621	21.53	<.0001	0
gagemax2	1	0.28339	0.02244	12.63	<.0001	3.61999
F3	1	-0.42916	0.03261	-13.16	<.0001	1.56191
well21_3_ft	1	-0.41693	0.09096	-4.58	<.0001	3.49556
s1	1	-0.27909	0.04897	-5.70	<.0001	1.42142

Kings Bay Surface Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: sal_ppt_t

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
s2	1	0.33796	0.06499	5.20	<.0001	1.32676
delta_gage	1	-0.51250	0.09040	-5.67	<.0001	1.82832

Kings Bay Surface Salinity
Residual
3
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12

Kings Bay Surface Salinity
Residual
3
2
1
0
-1
-2
-3
2007
2008
2009
2010

Kings Bay Surface Salinity
Residual
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
Predicted Value of sal_ppt_t

Kings Bay Surface Salinity
Predicted
Observed
0
1
2
3
4
5

Appendix 4

Regression Diagnostics

Kings Bay Bottom Salinity

Kings Bay Bottom Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: sal_ppt_b

Number of Observations Read	3400
Number of Observations Used	867
Number of Observations with Missing Values	2533

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	5	711.18319	142.23664	202.17	<.0001
Error	861	605.74772	0.70354		
Corrected Total	866	1316.93091			

Root MSE	0.83877	**R-Square**	0.5400
Dependent Mean	2.37956	**Adj R-Sq**	0.5374
Coeff Var	35.24908		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	6.60943	0.37887	17.45	<.0001	0
gagemax2	1	0.30359	0.02105	14.42	<.0001	1.50983
F2	1	-0.54652	0.04369	-12.51	<.0001	1.64899
s1	1	-0.26301	0.07230	-3.64	0.0003	1.57351
s2	1	0.48589	0.07624	6.37	<.0001	1.52036
delta_gage	1	-0.62592	0.10747	-5.82	<.0001	1.30718

Kings Bay Bottom Salinity
Residual
4
3
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12

Kings Bay Bottom Salinity
Residual
4
3
2
1
0
-1
-2
-3
2007
2008
2009
2010

Kings Bay Bottom Salinity
Residual
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
Predicted Value of sal_ppt_b

Kings Bay Bottom Salinity
Predicted
Observed
0
1
2
3
4
5
6

Appendix 5

Regression Diagnostics

Isohaline Locations

2 ppt Surface Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_2 2 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	32
Number of Observations with Missing Values	22

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	1	19.35436	19.35436	20.19	<.0001
Error	30	28.76064	0.95869		
Corrected Total	31	48.11500			

Root MSE	0.97913	**R-Square**	0.4023
Dependent Mean	9.26250	**Adj R-Sq**	0.3823
Coeff Var	10.57086		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	17.38662	1.81638	9.57	<.0001	0
delta_gage		1	-2.63957	0.58747	-4.49	<.0001	1.00000

2 ppt Surface Isohaline

2 ppt Surface Isohaline

2 ppt Surface Isohaline

2 ppt Surface Isohaline

2 ppt Bottom Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_2 2 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	32
Number of Observations with Missing Values	22

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	16.49305	8.24652	7.56	0.0023
Error	29	31.62195	1.09041		
Corrected Total	31	48.11500			

Root MSE	1.04423	**R-Square**	0.3428
Dependent Mean	9.26250	**Adj R-Sq**	0.2975
Coeff Var	11.27372		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	12.91478	1.75030	7.38	<.0001	0
ws_y		1	-0.24891	0.11243	-2.21	0.0349	1.16792
F3		1	-0.61042	0.28804	-2.12	0.0428	1.16792

2 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12
Month

2 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
-3
2008
2009
2010
Year

2 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
-3
7
8
9
10
11
12
Predicted Value of iso_2

2 ppt Bottom Isohaline

2 ppt WC Avg Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_2 2 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	32
Number of Observations with Missing Values	22

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	1	19.35436	19.35436	20.19	<.0001
Error	30	28.76064	0.95869		
Corrected Total	31	48.11500			

Root MSE	0.97913	**R-Square**	0.4023
Dependent Mean	9.26250	**Adj R-Sq**	0.3823
Coeff Var	10.57086		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	17.38662	1.81638	9.57	<.0001	0
delta_gage		1	-2.63957	0.58747	-4.49	<.0001	1.00000

2 ppt WC Avg Isohaline
Residual
2
1
0
-1
-2
-3
1
2
3
4
5
6
7
8
9
10
11
12
Month

2 ppt WC Avg Isohaline

2 ppt WC Avg Isohaline
Residual
2
1
0
-1
-2
-3
7
8
9
10
11
Predicted Value of iso_2

2 ppt WC Avg Isohaline

5 ppt Surface Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_5 5 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	33
Number of Observations with Missing Values	21

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	60.44659	30.22329	6.84	0.0036
Error	30	132.50250	4.41675		
Corrected Total	32	192.94909			

Root MSE	2.10161	**R-Square**	0.3133
Dependent Mean	5.86818	**Adj R-Sq**	0.2675
Coeff Var	35.81359		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	20.18425	4.12820	4.89	<.0001	0
delta_gage		1	-4.72238	1.35831	-3.48	0.0016	1.07190
ws_x		1	0.30576	0.14411	2.12	0.0422	1.07190

5 ppt Surface Isohaline

5 ppt Surface Isohaline

5 ppt Surface Isohaline

5 ppt Surface Isohaline

5 ppt Bottom Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_5 5 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	33
Number of Observations with Missing Values	21

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	63.47214	21.15738	4.74	0.0083
Error	29	129.47695	4.46472		
Corrected Total	32	192.94909			

Root MSE	2.11299	**R-Square**	0.3290
Dependent Mean	5.86818	**Adj R-Sq**	0.2595
Coeff Var	36.00756		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	17.95763	4.95412	3.62	0.0011	0
delta_gage		1	-4.01770	1.61177	-2.49	0.0186	1.49306
ws_x		1	0.32195	0.14622	2.20	0.0358	1.09166
ws_y		1	-0.20765	0.25224	-0.82	0.4171	1.48815

5 ppt Bottom Isohaline

5 ppt Bottom Isohaline
Residual
5
4
3
2
1
0
-1
-2
-3
-4
-5
2008
2009
2010
Year

5 ppt Bottom Isohaline

5 ppt Bottom Isohaline

5 ppt WC Avg Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_5 5 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	33
Number of Observations with Missing Values	21

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	63.47214	21.15738	4.74	0.0083
Error	29	129.47695	4.46472		
Corrected Total	32	192.94909			

Root MSE	2.11299	**R-Square**	0.3290
Dependent Mean	5.86818	**Adj R-Sq**	0.2595
Coeff Var	36.00756		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	17.95763	4.95412	3.62	0.0011	0
delta_gage		1	-4.01770	1.61177	-2.49	0.0186	1.49306
ws_x		1	0.32195	0.14622	2.20	0.0358	1.09166
ws_y		1	-0.20765	0.25224	-0.82	0.4171	1.48815

5 ppt WC Avg Isohaline

5 ppt WC Avg Isohaline

5 ppt WC Avg Isohaline

5 ppt WC Avg Isohaline
Predicted
Observed
0
1
2
3
4
5
6
7
8
9
10

10 ppt Surface Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_10 10 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	30
Number of Observations with Missing Values	24

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	42.25854	14.08618	3.14	0.0424
Error	26	116.70013	4.48847		
Corrected Total	29	158.95867			

Root MSE	2.11860	**R-Square**	0.2658
Dependent Mean	3.50667	**Adj R-Sq**	0.1811
Coeff Var	60.41635		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	4.84120	1.15306	4.20	0.0003	0
gage_min		1	1.32017	0.84208	1.57	0.1290	1.06734
ws_x		1	0.28988	0.16263	1.78	0.0864	1.08747
ws_y		1	-0.47913	0.24207	-1.98	0.0585	1.14570

10 ppt Surface Isohaline

10 ppt Surface Isohaline

10 ppt Surface Isohaline

10 ppt Surface Isohaline

10 ppt Bottom Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_10 10 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	30
Number of Observations with Missing Values	24

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	17.93092	8.96546	1.72	0.1987
Error	27	141.02775	5.22325		
Corrected Total	29	158.95867			

Root MSE	2.28544	**R-Square**	0.1128
Dependent Mean	3.50667	**Adj R-Sq**	0.0471
Coeff Var	65.17423		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	12.34086	5.72748	2.15	0.0403	0
delta_gage		1	-2.97964	1.91905	-1.55	0.1321	1.28992
ws_x		1	0.31074	0.19108	1.63	0.1155	1.28992

10 ppt Bottom Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
1
2
3
4
5
6
7
8
9
10
11
12
Month

10 ppt Bottom Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
2008
2009
2010
Year

10 ppt Bottom Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
6
7
Predicted Value of iso_10

10 ppt Bottom Isohaline

10 ppt WC Avg Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_10 10 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	30
Number of Observations with Missing Values	24

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	17.93092	8.96546	1.72	0.1987
Error	27	141.02775	5.22325		
Corrected Total	29	158.95867			

Root MSE	2.28544	**R-Square**	0.1128
Dependent Mean	3.50667	**Adj R-Sq**	0.0471
Coeff Var	65.17423		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	12.34086	5.72748	2.15	0.0403	0
delta_gage		1	-2.97964	1.91905	-1.55	0.1321	1.28992
ws_x		1	0.31074	0.19108	1.63	0.1155	1.28992

10 ppt WC Avg Isohaline

10 ppt WC Avg Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
2008
2009
2010
Year

10 ppt WC Avg Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
0
1
2
3
4
5
6
7
Predicted Value of iso_10

10 ppt WC Avg Isohaline

15 ppt Surface Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_15 15 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	24
Number of Observations with Missing Values	30

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	1	13.72432	13.72432	2.63	0.1194
Error	22	115.02026	5.22819		
Corrected Total	23	128.74458			

Root MSE	2.28652	**R-Square**	0.1066
Dependent Mean	1.44583	**Adj R-Sq**	0.0660
Coeff Var	158.14578		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	1.27792	0.47810	2.67	0.0139	0
ws_x		1	0.33285	0.20544	1.62	0.1194	1.00000

15 ppt Surface Isohaline

15 ppt Surface Isohaline

15 ppt Surface Isohaline

15 ppt Surface Isohaline

15 ppt Bottom Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_15 15 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	24
Number of Observations with Missing Values	30

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	22.86203	7.62068	1.44	0.2610
Error	20	105.88255	5.29413		
Corrected Total	23	128.74458			

Root MSE	2.30090	**R-Square**	0.1776
Dependent Mean	1.44583	**Adj R-Sq**	0.0542
Coeff Var	159.13986		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	2.47332	1.35536	1.82	0.0830	0
gage_min		1	1.14757	1.06483	1.08	0.2940	1.09543
ws_x		1	0.43421	0.22276	1.95	0.0654	1.16116
ws_y		1	-0.16073	0.27453	-0.59	0.5648	1.13644

15 ppt Bottom Isohaline

15 ppt Bottom Isohaline

15 ppt Bottom Isohaline
Residual
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-2
-1
0
1
2
3
4
5
6
7
Predicted Value of iso_15

15 ppt Bottom Isohaline

15 ppt WC Avg Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_15 15 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	24
Number of Observations with Missing Values	30

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	21.04744	10.52372	2.05	0.1535
Error	21	107.69714	5.12844		
Corrected Total	23	128.74458			

Root MSE	2.26460	R-Square	0.1635
Dependent Mean	1.44583	Adj R-Sq	0.0838
Coeff Var	156.62974		

Parameter Estimates							
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	Intercept	1	2.69811	1.27933	2.11	0.0471	0
gage_min		1	1.23886	1.03673	1.19	0.2454	1.07194
ws_x		1	0.39806	0.21066	1.89	0.0727	1.07194

15 ppt WC Avg Isohaline

15 ppt WC Avg Isohaline

15 ppt WC Avg Isohaline

15 ppt WC Avg Isohaline

20 ppt Surface Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_20 20 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	13
Number of Observations with Missing Values	41

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	9.88580	4.94290	3.31	0.0789
Error	10	14.93728	1.49373		
Corrected Total	12	24.82308			

Root MSE	1.22218	**R-Square**	0.3983
Dependent Mean	-0.57308	**Adj R-Sq**	0.2779
Coeff Var	-213.26657		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	1.80502	1.14300	1.58	0.1454	0
gage_min		1	2.11564	0.93780	2.26	0.0477	1.06280
ws_x		1	0.21771	0.12457	1.75	0.1111	1.06280

20 ppt Surface Isohaline
Residual
2
1
0
-1
-2
1
2
3
4
5
6
7
8
9
10
11
12
Month

20 ppt Surface Isohaline

20 ppt Surface Isohaline
Residual
2
1
0
-1
-2
-4
-3
-2
-1
0
1
2
3
4
5
Predicted Value of iso_20

20 ppt Surface Isohaline
Predicted
5
4
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
Observed

20 ppt Bottom Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_20 20 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	13
Number of Observations with Missing Values	41

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	9.88580	4.94290	3.31	0.0789
Error	10	14.93728	1.49373		
Corrected Total	12	24.82308			

Root MSE	1.22218	**R-Square**	0.3983
Dependent Mean	-0.57308	**Adj R-Sq**	0.2779
Coeff Var	-213.26657		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	1.80502	1.14300	1.58	0.1454	0
gage_min		1	2.11564	0.93780	2.26	0.0477	1.06280
ws_x		1	0.21771	0.12457	1.75	0.1111	1.06280

20 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
1
2
3
4
5
6
7
8
9
10
11
12
Month

20 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
2008
2009
2010
Year

20 ppt Bottom Isohaline
Residual
2
1
0
-1
-2
-4
-3
-2
-1
0
1
2
3
4
5
Predicted Value of iso_20

20 ppt Bottom Isohaline
Predicted
5
4
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
Observed

20 ppt WC Avg Isohaline

The REG Procedure
Model: MODEL1
Dependent Variable: iso_20 20 ppt Isohaline

Number of Observations Read	54
Number of Observations Used	13
Number of Observations with Missing Values	41

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	1	4.69198	4.69198	2.56	0.1376
Error	11	20.13110	1.83010		
Corrected Total	12	24.82308			

Root MSE	1.35281	**R-Square**	0.1890
Dependent Mean	-0.57308	**Adj R-Sq**	0.1153
Coeff Var	-236.06114		

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	1	-5.77433	3.26998	-1.77	0.1051	0
well21_3_ft		1	1.67824	1.04813	1.60	0.1376	1.00000

20 ppt WC Avg Isohaline

20 ppt WC Avg Isohaline
Residual
2
1
0
-1
-2
-3
2008
2009
2010
Year

20 ppt WC Avg Isohaline
Residual
2
1
0
-1
-2
-3
-2
-1
0
1
2
Predicted Value of iso_20

20 ppt WC Avg Isohaline

Appendix 6

Regression Diagnostics

Whole River

Whole River Surface Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: lnint_sals_ppt

Number of Observations Read	6588
Number of Observations Used	4690
Number of Observations with Missing Values	1898

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	5	2796.35641	559.27128	2772.51	<.0001
Error	4684	944.85897	0.20172		
Corrected Total	4689	3741.21538			

Root MSE	0.44913	**R-Square**	0.7474
Dependent Mean	1.56480	**Adj R-Sq**	0.7472
Coeff Var	28.70232		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	5.39982	0.09077	59.49	<.0001	0
rkm	1	-0.21148	0.00193	-109.56	<.0001	1.00035
delta_gage	1	-0.67886	0.03421	-19.84	<.0001	2.49040
ws_x	1	0.05851	0.00244	23.98	<.0001	1.10675
ws_y	1	-0.02346	0.00444	-5.28	<.0001	1.78807
F4	1	-0.09056	0.01250	-7.24	<.0001	1.66876

Whole River Surface Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12

Whole River Surface Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
2008
2009
2010

Whole River Surface Salinity Residuals

Whole River Surface Salinity

Whole River Bottom Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: lnint_salb_ppt

Number of Observations Read	6588
Number of Observations Used	4575
Number of Observations with Missing Values	2013

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	5	2464.35495	492.87099	2267.59	<.0001
Error	4569	993.09491	0.21735		
Corrected Total	4574	3457.44987			

Root MSE	0.46621	**R-Square**	0.7128
Dependent Mean	1.69058	**Adj R-Sq**	0.7125
Coeff Var	27.57713		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	4.86689	0.09735	49.99	<.0001	0
rkm	1	-0.20225	0.00203	-99.75	<.0001	1.00013
delta_gage	1	-0.61412	0.03584	-17.13	<.0001	2.47759
ws_x	1	0.06333	0.00292	21.66	<.0001	1.21214
ws_y	1	-0.04352	0.00462	-9.43	<.0001	1.79154
F3	1	-0.02188	0.01288	-1.70	0.0893	1.97003

Whole River Bottom Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12

Whole River Bottom Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
2008
2009
2010

Whole River Bottom Salinity Residuals

Whole River Bottom Salinity

Whole River Water Column Salinity

The REG Procedure
Model: MODEL1
Dependent Variable: lnint_salwc_ppt

Number of Observations Read	6588
Number of Observations Used	4352
Number of Observations with Missing Values	2236

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	5	2646.59415	529.31883	2715.45	<.0001
Error	4346	847.15877	0.19493		
Corrected Total	4351	3493.75292			

Root MSE	0.44151	**R-Square**	0.7575
Dependent Mean	1.70254	**Adj R-Sq**	0.7572
Coeff Var	25.93231		

Parameter Estimates						
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	1	4.95656	0.09097	54.49	<.0001	0
rkm	1	-0.20579	0.00196	-104.79	<.0001	1.00032
delta_gage	1	-0.42657	0.03250	-13.13	<.0001	2.32961
ws_x	1	0.07296	0.00240	30.38	<.0001	1.09954
ws_y	1	-0.08111	0.00472	-17.18	<.0001	1.93640
F7	1	-0.13531	0.00914	-14.80	<.0001	1.33886

Whole River Water Column Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
7
8
9
10
11
12

Whole River Water Column Salinity Residuals
Residual
15
10
5
0
-5
-10
-15
2008
2009
2010

Whole River Water Column Salinity Residuals

Whole River Water Column Salinity

APPENDIX

MacDonald, T.C., Peebles, E.B., Guenther, C.B., Burghart, S.E., McMichael, R.H, Jr., and Davis, J. 2011. Freshwater inflow effects on fishes and invertebrates in the Crystal River and estuary. Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute and University of South Florida College of Marine Science, St. Petersburg, Florida. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Note: *This 2011 report includes previously reported discharge records for the U.S. Geological Survey Crystal (USGS) River at Bagley Cove, FL gage site that were revised by the USGS in November 2011, and also includes analyses based on the previously reported records.*

FRESHWATER INFLOW EFFECTS ON FISHES AND INVERTEBRATES IN THE CRYSTAL RIVER AND ESTUARY

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SUMMARY

Quantitative ecological criteria are needed to establish minimum flows and levels for rivers and streams within the Southwest Florida Water Management District (SWFWMD), as well as for the more general purpose of improving overall management of aquatic ecosystems. As part of the approach to obtaining these criteria, the impacts of managed freshwater inflows on downstream estuaries are being assessed. A two year study of freshwater inflow effects on habitat use by estuarine organisms in the Crystal River estuary was undertaken from March 2008 to February 2010.

The general objective of the present data analysis was to identify patterns of estuarine habitat use and organism abundance under variable freshwater inflow conditions and to evaluate responses to these inflows. Systematic monitoring was performed to develop a predictive capability for evaluating potential impacts of proposed freshwater withdrawals and, in the process, to contribute to baseline data. The predictive aspect involves development of regressions that describe variation in organism distribution and abundance as a function of natural variation in inflows. These regressions can be applied to any proposed alterations of freshwater inflows that fall within the range of natural variation documented during the data collection period.

For sampling purposes, the Crystal River estuary was divided into six zones from which plankton-net and seine-net samples were taken. Sampling was conducted on a monthly basis for the first year of the study (March 2008 to February 2009) and every other month for the remainder of the study (March 2009 to February 2010). Salinity, water temperature, dissolved oxygen and pH measurements were taken in association with each net deployment. Daily freshwater inflow estimates for the Crystal River estuary were calculated as tidally filtered residual flow based on the gauged streamflow records from Crystal River at Bagley Cove near Crystal River Florida (USGS gauge 02310747). Missing flow data (~13% of daily records) were interpolated using an iterative running average of the three days before and after the missing data. A large body of descriptive habitat-use information was generated and is presented in accompanying appendices.

Seine sampling was limited to depths of ≤1.8-m and sampled an average depth of approximately 0.7-m during this study. Plankton nets were not depth limited and sampled to over 5-m at some stations. Differences in flow and circulation patterns between the depths sampled by these two surveys were apparent in some physico-chemical (salinity, pH, and dissolved oxygen) trends. In the shallow seine survey, pH and dissolved oxygen had similar trends, while in the deeper waters sampled by plankton-nets the two parameters were out of phase. Water with a much higher salinity (17ppt higher than median salinity during entire seine study) was encountered during seine sampling on September 11, 2008 as Hurricane Ike pushed a high salinity pulse of water into the Crystal River system. Salinity for the plankton-net survey increased in November 2008 and remained relatively higher than previous sampling events through October 2009 despite there being no reduction in spring inflow.

Larval gobies dominated the plankton net's larval fish catch with the genus *Gobiosoma* being most common, followed distantly by *Microgobius* spp. and *Bathygobius soporator*. Anchovies, dominated by the bay anchovy (*Anchoa mitchilli*), were also present in fairly large numbers although the catch was low compared to surface-fed systems in west-central Florida. Other abundant larval fishes included menhaden (*Brevoortia* spp.), silversides (*Menidia* spp.), rainwater killifish (*Lucania parva*), eucinostomus mojarras (*Eucinostomus* spp.), spot (*Leiostomus xanthurus*), skilletfish (*Gobiesox strumosus*), and blennies. The plankton-net invertebrate catch was dominated by larval crabs (decapod zoeae and megalopae), gammaridean amphipods, cumaceans, the mysids *Americamysis almyra* and *Bowmaniella dissimilis*, the copepod *Acartia tonsa*, and larval shrimps (decapod mysis). The phantom midge larva *Chaoborus punctipinnis* and cyclopoid copepod *Mesocyclops edax*, which are indicative of reservoir waters and other lacustrine settings, were rarely encountered in the spring-fed Crystal River estuary. The river-plume-associated calanoid copepod *Acartia tonsa* was regularly encountered near the river mouth in low to moderate numbers, but other plume-associated taxa were less common than they typically are in more nutrient-rich estuarine plumes along the west-central Florida coast.

The seine catch of fishes in the Crystal River estuary was dominated by small-bodied resident and transient taxa with silversides (*Menidia* spp.), bay anchovy (*A.*

mitchilli), rainwater killifish (*L. parva*), and eucinostomus mojarras (*Eucinostomus* spp.) comprising over 70% of the total catch of fishes. Although present, freshwater oriented taxa such bluefin killifish (*Lucania goodei*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), redear sunfish (*Lepomis microlophus)*, and spotted sunfish (*Lepomis punctatus*) did not represent a large portion of the catch and were almost exclusively collected in Kings Bay. Invertebrates collected by seines were dominated by grass shrimp (*Palaemonetes intermedius* and *Palaemonetes. pugio*), blue crabs (*Callinectes sapidus*) and pink shrimp (*Farfantepenaeus duorarum*).

Use of the area as spawning habitat was indicated by the presence of fish eggs or newly hatched larvae. The eggs of the bay anchovy (*A. mitchilli*), the rainwater killifish (*L. parva*), other killifishes (*Fundulus* spp.), unidentified gobies, and unidentified percomorph (primarily sciaenid) fishes were collected with the plankton net from the survey area. None of these fish eggs were abundant, but the bay anchovy and sciaenid eggs were more abundant than the other types – both were most abundant near the river mouth and especially in the Gulf of Mexico. If it is assumed that the relative abundances of different species of early-stage sciaenid larvae reflect the local, relative spawning intensity, then kingfishes (*Menticirrhus* spp.), sand seatrout (*Cynoscion arenarius*) and spotted seatrout (*Cynoscion nebulosus*) are the sciaenids that are most likely to have spawned in the study area. Larval distributions also suggest that skilletfish (*Gobiesox strumosus*) spawn near the river mouth and that gobies (primarily *Microgobius* spp. and *Gobiosoma* spp.) and silversides have spawned throughout much of the interior of the tidal river. The presence of rainwater killifish eggs upstream suggests upstream spawning by this species, a pattern that is supported by the distribution of subsequent developmental stages. The collection of very small juveniles of live-bearing pipefishes suggests that these species also reproduce within the local area.

Estuary-dependent taxa are spawned at seaward locations and migrate into tidal rivers during the late larval or early juvenile stage. Overall, seven of the twelve most abundant taxa in the seine catch (28% of total abundance) can be considered estuary-dependent. These abundant estuary-dependent taxa included species of direct economic importance (spot *L. xanthurus*, striped mullet *Mugil cephalus*, and blue crabs

C. sapidus) and taxa of ecological importance due to high abundance (eucinostomus mojarras *Eucinostomus* spp., tidewater killifish *Eucinostomus harengulus*, striped anchovy *Anchoa hepsetus*, and pinfish *Lagadon rhomboides*).

Based on plankton-net data, alteration of flows would appear to have the lowest potential for impacting many taxa during the period from November and February, which are the months when the fewest estuarine taxa were present. The highest potential to impact many species would appear to be from April through October. Some species were present throughout the year, whereas others had more seasonal spawning and recruitment patterns.

Taxon richness was lowest from December to April and highest from May to August for the nearshore habitat sampled with seine nets in the Crystal River estuary. Abundance data from the seine nets suggested that the Crystal River estuary was important to nekton throughout the year, with no obvious period where flow alterations would have the least potential to impact the nekton community.

Nine (14%) of the 66 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. Six of these were negative responses, wherein animals moved downstream as inflows increased. The remaining three taxa demonstrated positive responses, moving upstream as freshwater flows increased. The time lags for these responses were highly variable, ranging from 1 to 120 days.

Fifteen percent (n=6) of the 26 seine-caught pseudo-species evaluated for distributional responses to freshwater inflow exhibited significant responses to at least one lagged flow period. Five of the six pseudo-species moved upstream in response to increased inflow (positive response) whereas the sixth pseudo-species moved downstream in response to increased inflow (negative response). The majority of the responses were to same day inflow. A single sampling trip during an extreme weather event (Hurricane Ike, 9/11/2008) had considerable influence over three of the six significant responses; removal of this sampling trip from the analysis resulted in no significant responses for redfin needlefish (*Strongylura notata*), tidewater mojarra (*E. harengulus*), and large pinfish (*L. rhomboides*).

Six (9%) of the 66 plankton-net taxa evaluated for abundance relationships with freshwater inflow exhibited significant responses. Abundance decreases in response to

increased inflow (negative response) were most common (n=4). The three taxa with the strongest negative responses were planktonic copepods. The positive response by chironomid larvae, which are primarily freshwater organisms in this case, reflects the creation of more freshwater habitat during high-inflow periods. A similar relationship may have existed for the mysid *Taphromysis bowmani*, which tends to occupy freshwater and oligohaline habitats.

Eleven (52%) of the 21 pseudo-species analyzed from the seine catches had a significant abundance response to average inflow. Six of these pseudo-species had linear responses and the remaining 5 had quadratic responses of abundance to inflow. Linear responses for pink shrimp (*F. duorarum*), silver jenny (*E. gula*), large pinfish (*L. rhomboides*), and clown goby (*Microgobius gulosus*) were negative such that abundance increased with decreasing inflow. The negative response in these pseudo-species most likely indicates an increase in the amount of slightly higher salinity habitats as flows decreased. The two positive linear regressions were for small bay anchovy (*A. mitchilli*) and timucu (*Strongylura timucu*). The most common quadratic response was an intermediate-minimum where the minimum abundance occurred at intermediate inflows and abundance was higher at both lower and higher inflows. The percentage of significant abundance responses to inflow ranged from 20% of tested pseudo-species in nearshore spawners to 100% in offshore spawners. One of the nearshore spawners and both of the offshore spawners had negative linear responses to inflow. The majority of the best-fit responses were to long-term lagged inflows (98-364 days).

There was no indication of a relationship between flow and community heterogeneity in the plankton-net data. The inflows that occurred during the survey period were large enough and stable enough to prevent strong, landward invasions of planktonic, marine-derived organisms from seaward waters. A fairly strong community gradient was always present along the Crystal River estuary‘s survey transect.

There were significant differences in seine-caught nekton community structure between the zones of the study area and also between year-month combinations. The overall change between zones was slow and progressive such that adjacent zones were very like each other but separated zones were less like each other. Temporal changes in community structure correlated to annual cycles of physicochemical change

(especially temperature) better than with flow. There was no discernible relationship between inflow or salinity and community heterogeneity, or dispersion. The overall lack of distinct community change between adjacent zones, the slow progression of change with movement upriver, and lack of highly significant correlations with physicochemical variables suggest that there are either important environmental driving factors unaccounted for within this analysis or that difference between environmental variables between zones are small.

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1.0 INTRODUCTION

Rivers export nutrients, detritus, and other productivity promoting materials to the estuary and sea. Freshwater inflows also strongly influence the stratification and circulation of coastal waters, which in itself may have profound effects on coastal ecosystems (Mann and Lazier 1996). Estuary-related fisheries constitute a very large portion of the total weight of the U.S. fisheries yield (66% of finfish and shellfish harvest, Day et al. 1989; 82% of finfish harvest, Imperial et al. 1992). The contribution of estuary-related fisheries is consistently high among U.S. states that border the Gulf of Mexico, where the estimates typically exceed 80% of the total weight of the catch (Day et al. 1989). Examples from around the world indicate that these high fisheries productivities are not guaranteed, however. In many locations, large amounts of fresh water have been diverted from estuaries to generate hydroelectric power or to provide water for agricultural and municipal use. Mann and Lazier (1996) reviewed cases where freshwater diversions were followed by the collapse of downstream fisheries in San Francisco Bay, the Nile River delta, James Bay, Canada, and at several inland seas in the former U.S.S.R. Sinha et al. (1996) documented a reversal of this trend where an increase in fisheries landings followed an increase in freshwater delivery to the coast.

Fishery yields around the world are often positively correlated with freshwater discharge at the coast (Drinkwater 1986). These correlations are often strongest when they are lagged by the age of the harvested animal. In south Florida, Browder (1985) correlated 14 years of pink shrimp landings with lagged water levels in the Everglades. Associations between river discharge and fisheries harvests have also been identified for various locations in the northern and western Gulf of Mexico (Day et al. 1989, Grimes 2001). Surprisingly, discharge-harvest correlations sometimes extend to non-estuarine species. Sutcliffe (1972, 1973) reported lagged correlations between discharge of the St. Lawrence River and the harvest of non-estuarine species such as American lobster and haddock. In recognition of the potential complexities behind these correlations, Drinkwater (1986) advised that the effect of freshwater inflows be considered on a species-by-species basis.

Freshwater influence on coastal ecosystems extends beyond its immediate effects on fisheries. Because of the intricate nature of many food web interactions, changes in the abundance of even a single species may be propagated along numerous pathways, some anticipated and some not, eventually causing potentially large changes in the abundance of birds, marine mammals and other groups of special concern (Christensen 1998, Okey and Pauly 1999). Mann and Lazier (1996) concluded —one lesson is clear: a major change in the circulation pattern of an estuary brought about by damming the freshwater flows, a tidal dam, or other engineering projects may well have far reaching effects on the primary and secondary productivity of the system."

This project was conducted to support the establishment of minimum flows for the Crystal River by the Southwest Florida Water Management District (SWFWMD). Minimum flows are defined in Florida Statutes (373.042) as the —limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." In the process of establishing minimum flows for an estuarine system, the SWFWMD evaluates the effects of the freshwater inflows on ecological resources and processes in the receiving estuary. The findings of this project will be used by the SWFWMD to evaluate the fish nursery function of the Crystal River and its receiving estuary in relation to freshwater inflows. It is not the purpose of this project to determine the level of effect that constitutes significant harm, as that determination will be made by the Governing Board of the SWFWMD.

This project uses plankton-net and seine surveys to document the abundance and distribution of fishes and invertebrates that use the Crystal River and receiving estuary as habitat. The objectives for this project were to:

1. produce descriptive databases that could serve as a baseline for comparison with future ecological change. These baseline data also provide seasonality records that identify the times of year when the risk of adverse impacts would be greatest for specific organisms.
2. develop regressions to model the responses of estuarine organisms to variations in freshwater inflows. The resulting models would then be available for evaluating proposed minimum flows or the potential impacts of proposed freshwater management plans. These models would be developed for both

estuarine fishes and the invertebrate prey groups that sustain young fishes while they occupy estuarine nursery habitats.

3. evaluate changes in community structure that are associated with variations in freshwater inflow.

2.0 METHODS

2.1 Study Area

The Crystal River estuary is a spring-fed river system in west central Florida (Citrus County). The spring-head is a first-order magnitude cluster of at least 30 springs that flow directly or indirectly through creeks into Kings Bay at an average rate of 975cfs (Scott et. al. 2004, Frazer 2001). The river flows northwest from Kings Bay for approximately 11km to the Gulf of Mexico (*Fig. 2.1.1*). The river is relatively wide (100 – 400m) and deep (maximum >4m) compared to other nearby spring-fed systems (Frazer 2001). The entire length of the river is tidally influenced.

Bottom substrates in the river are comprised largely of fine-grained particles that are low in organic matter (Belanger et al., 1993) but with limestone outcroppings common in and around the river channel (Frazer 2001). Submerged aquatic vegetation (*Vallisneria americana*, *Myriophyllum spicatum*, and *Potamogeton pectinatusa*) is prevalent in Kings Bay and the upper portions of the river (Frazer 2001), but became much less common downstream where salinities tend to be too high for SAV to grow. Kings Bay and much of the upper Crystal River have developed shorelines with businesses, such as marinas and dive shops, and residential housing (Frazer 2001). The lower portion of the river is mostly undeveloped and its shorelines are comprised largely of salt marsh. and has no canopy cover.

Figure 2.1.1. Map of the Crystal River study area with sampling zones (circled numbers), centerline, and river kilometers.

2.2 Survey Design

Two gear types were implemented to monitor organism distributions: a plankton net deployed during nighttime flood tides and a bag seine deployed during the day under variable tide stages. The plankton-net surveys were conducted by the University of South Florida College Of Marine Science, and the seine surveys were conducted by the Fisheries-Independent Monitoring (FIM) program of the Fish and Wildlife Research Institute (Florida Fish and Wildlife Conservation Commission). Bottom habitat in the Crystal River estuary was not suitable for sampling with otter trawls, so trawling was not attempted as part of this study.

The small organisms collected at night by the plankton net represent a combination of the zooplankton and hyperbenthos communities. The term *zooplankton* includes all weakly swimming animals that suspend in the water column during one or more life stages. The distribution of such animals is largely subject to the motion of the waters in which they live. The term *hyperbenthos* applies to animals that are associated with the bottom but tend to suspend above it, rising higher into the water column at night or during certain times of year (vertical migrators). The permanent hyperbenthos of estuaries (non-transient hyperbenthos) tends to be dominated by peracarid crustaceans, especially mysids and amphipods (Mees et al. 1993). Many types of hyperbenthos are capable of actively positioning themselves at different places along the estuarine gradient by selectively occupying opposing tidal flows.

The faunal mixture that forms in the nighttime water column includes the planktonic eggs and larvae of fishes (ichthyoplankton). One of the most common reasons for using plankton nets to survey estuarine waters is to study ichthyoplankton. Although fish eggs and larvae are the intended focus of such studies, invertebrate plankton and hyperbenthos almost always dominate the samples numerically. The invertebrate catch largely consists of organisms that serve as important food for juvenile estuary-dependent and estuarine-resident fishes. In an effort to characterize the invertebrate catch more completely, all water-column animals collected by the plankton net were enumerated at a practical taxonomic level.

Seines were used to survey larger organisms that typically evade plankton nets. Generally speaking, the data from seine hauls document habitat use by shallow-water organisms. The dominant seine catch are juvenile fishes, although the adults of smaller species are also commonly caught. The seines also regularly collect several species of larger macroinvertebrates from tidal rivers, notably juvenile and adult blue crabs (*Callinectes sapidus*) and juvenile pink shrimp (*Farfantepenaeus duorarum*), as well as smaller invertebrates such as grass shrimp (*Palaemonetes* spp.).

Sampling in the Crystal River occurred monthly from March 2008 to February 2009 and bimonthly from April 2009 to February 2010. The study area was divided into six collection zones (*Fig. 2.1.1* and *Table 2.2.1*). Twelve plankton tows (two per zone) were collected during each sampling event. Within zones one through five, three seine hauls were deployed during each sampling event. Zone six (King‘s Bay), which is larger than the other five zones and has extensive and varied shoreline habitat, was subdivided into two subzones for seine sampling; during each sampling event five seine hauls were collected in zone six, two in the western subzone and three in the eastern subzone.

Table 2.2.1.Number of samples collected within each zone of the Crystal River estuary (March 2008–February 2010). Zone position is measured relative to the river mouth.

Zone	***River Kilometer***	***Plankton***	***Seine***
1	-3.00 to 1.79[1]	36	54
2	1.80 to 3.79	36	54
3	3.80 to 5.69	36	54
4	5.70 to 7.59	36	54
5	7.60 to 9.89	36	54
6	9.90 to 12.10	36	90
Totals		216	360

[1] FWRI seine sampling in zone 1 only extended from -0.9km to 1.79km

The locations for seine deployment were randomly selected within each zone during each sampling event, whereas the plankton-net collections were made at fixed stations within each zone. The longitudinal position of each station was measured as

the distance from the mouth of the tidal river, following the geometric centerline of the channel.

2.3 Plankton Net Specifications and Deployment

The plankton gear consisted of a 0.5-m-mouth-diameter 500-µm-mesh conical (3:1) plankton net equipped with a 3-pt nylon bridle, a calibrated flow meter (General Oceanics model 2030R or SeaGear model MF315), a 1-liter plastic cod-end jar, and a 9-kg (20-lb.) weight. The net was deployed between low slack and high slack tide, with sampling beginning within two hours after sunset and typically ending less than four hours later. Tow duration was 5 min, with tow time being divided equally among bottom, mid-water and surface depths. The fishing depth of the weighted net was controlled by adjusting the length of the tow line while using tachometer readings to maintain a constant line angle. The tow line was attached to a winch located on the gunnel near the transom. Placement of the winch in this location caused asymmetry in the steering of the boat, which caused propeller turbulence to be directed away from the towed net. Tow speed was approximately 1.3 m s^{-1}, resulting in a tow length of >400 m over water and a typical filtration of 70-80 m^3. Upon retrieval of the net, the flowmeter reading was recorded, and the contents of the net were rinsed into the cod-end jar using an electric wash-down pump and hose with an adjustable nozzle. The samples were preserved in 6-10% formalin in ambient saline.

The net was cleaned between surveys using an enzyme solution that dissolves organic deposits. Salinity, temperature, pH and dissolved oxygen were measured at one-meter intervals from surface to bottom after each plankton-net deployment.

2.4 Seine Specifications and Deployment

The gear used in all seine collections was a 21.3-m center-bag seine with 3.2-mm mesh and leads spaced every 150 mm. To deploy the seine along shoreline habitats (i.e., shorelines with water depth ≤1.8 m), the boat dropped off a member of the seine crew near the shoreline with one end of the seine, and the boat then payed out the net in a semicircle until the boat reached a second drop-off point near the shoreline. The lead line was retrieved simultaneously from both ends, with effort made to keep the

lead line in contact with the bottom. This process forced the catch into the bag portion of the seine. Area sampled by each seine collection was approximately 68 m^2.

2.5 Plankton Sample Processing

All aquatic taxa collected by the plankton net were identified and counted, except for invertebrate eggs and organisms that were attached to debris (sessile stages of barnacles, bryozoans, sponges, tunicates and sessile coelenterates). During sorting, the data were entered directly into an electronic database via programmable keyboards that interfaced with a macro-driven spreadsheet. Photomicrographs of representative specimens were compiled into a reference atlas that was used for quality-control purposes.

Most organisms collected by the plankton net fell within the size range of 0.5-50 mm. This size range spans three orders of magnitude, and includes mesozooplankton (0.2-20 mm), macrozooplankton/micronekton (>20 mm), and analogous sizes of hyperbenthos. To prevent larger objects from visually obscuring smaller ones during sample processing, all samples were separated into two size fractions using stacked sieves with mesh openings of 4 mm and 250 µm. The >4 mm fraction primarily consisted of juvenile and adult fishes, large macroinvertebrates and large particulate organic matter. In most cases, the fishes and macroinvertebrates in the >4 mm fraction could be identified and enumerated without the aid of microscopes.

A microscope magnification of 7-12X was used to enumerate organisms in the >250 µm fraction, with zoom magnifications as high as 90X being available for identifying individual specimens. The >250 µm fraction was usually sorted in two stages. In the first sorting stage, the entire sample was processed as 10-15 ml aliquots that were scanned in succession using a gridded petri dish. Only relatively uncommon taxa (n<50) were enumerated during this first stage. After the entire sample had been processed in this manner, the collective volume of the aliquots was recorded within a graduated mixing cylinder, the sample was inverted repeatedly, and then a single 30-60 ml aliquot was poured. The aliquot volume typically represented about 12-50% of the entire sample volume. The second sorting stage consisted of enumerating the relatively abundant taxa within this single aliquot. The second sorting stage was not required for

all samples. The second stage was, however, sometimes extended to less abundant taxa (n<50) that were exceptionally small or were otherwise difficult to enumerate.

2.5.1 Staging Conventions

All fishes were classified according to developmental stage (*Fig. 2.5.1.1*), where

preflexion larval stage = the period between hatching and notochord flexion; the tip of the straight notochord is the most distal osteological feature.

flexion larval stage = the period during notochord flexion; the upturned notochord or urostyle is the most distal osteological feature.

postflexion larval stage = the period between completion of flexion and the juvenile stage; the hypural bones are the most distal osteological feature.

metamorphic stage (clupeid fishes) = the stage after postflexion stage during which body depth increases to adult proportions (ends at juvenile stage).

juvenile stage = the period beginning with attainment of meristic characters and body shape comparable to adult fish and ending with sexual maturity.

Decapod larvae were classified as zoea, megalopa or mysis stages. These terms are used as terms of convenience and should not be interpreted as technical definitions. Planktonic larvae belonging to Anomura and Brachyura (crabs) were called zoea. Individuals from these groups displaying the planktonic to benthic transitional morphologies were classified as megalopae. All other decapod larvae (shrimps) were classified as mysis stages until the uropods differentiated into exopods and endopods (5 total elements in the telsonic fan), after which they were classified as postlarvae until they reached the juvenile stage. The juvenile stage was characterized by resemblance to small (immature) adults. Under this system, the juvenile shrimp stage (e.g., for *Palaemonetes*) is equivalent to the postlarval designation used by some authors.

In many fish species, the juvenile stage is difficult to distinguish from other stages. At its lower limit, the juvenile stage may lack a clear developmental juncture that distinguishes it from the postflexion or metamorphic stage. Likewise, at its upper limit, more than one length at maturity may be reported for a single species or the reported

length at maturity may differ between males and females. To avoid inconsistency in the staging process, length-based staging conventions were applied to the more common taxa. These staging conventions agree with stage designations used by the U.S. Fish and Wildlife Service (e.g., Jones et al. 1978). The list in *Table 2.5.1.1* is comprehensive, representing the conventions that have been required to date by various surveys. Some of the species or stages in the list were not encountered during the surveys covered by this report.

Table 2.5.1.1. Length-based staging conventions used to define developmental stage limits. Fish lengths are standard length (SL) and shrimp length is total length.

Postflexion-juvenile transition (mm):	
Lucania parva	10
Menidia spp.	10
Eucinostomus spp.	10
Lagodon rhomboides	10
Bairdiella chrysoura	10
Cynoscion arenarius	10
Cynoscion nebulosus	10
Sciaenops ocellatus	10
Menticirrhus spp.	10
Leiostomus xanthurus	15
Orthopristis chrysoptera	15
Achirus lineatus	5
Trinectes maculatus	5
Gobiesox strumosus	5
Eugerres plumieri	10
Prionotus spp.	10
Symphurus plagiusa	10
Anchoa mitchilli	15
Sphoeroides spp.	10
Chilomycterus schoepfii	10
Lepomis spp.	10
Micropterus salmoides	10
Membras martinica	10
Chloroscombrus chrysurus	10
Hemicaranx amblyrhynchus	10
Micropogonias undulatus	15
Chaetodipterus faber	5

Juvenile-adult transition (mm):	
Anchoa mitchilli	30
Lucania parva	15
Gambusia holbrooki	15
Heterandria formosa	10
Menidia spp.	35
Eucinostomus spp.	50
Gobiosoma bosc	20
Gobiosoma robustum	20
Microgobius gulosus	20
Microgobius thalassinus	20
Gobiesox strumosus	35
Trinectes maculatus	35
Palaemonetes pugio	20
Membras martinica	50
Syngnathus spp.	80
Poecilia latipinna	30
Anchoa hepsetus	75

Metamorph-juvenile transition (mm):	
Brevoortia spp.	30
Dorosoma petenense	30

Fig. 2.5.1.1 Fish-stage designations, using the bay anchovy as an example. Specimens measured 4.6, 7.0, 10.5, 16 and 33 mm standard length.

Fig. 2.5.1.1. Fish-stage designations, using the bay anchovy as an example. Specimens measured 4.6, 7.0, 10.5, 16, and 33 mm standard length.

2.6 Seine Sample Processing

Fish and selected crustaceans collected in seine samples were removed from the net into a bucket and processed onboard. Animals were identified to the lowest practical taxonomic category, generally species. Representative samples (a minimum of three individuals of each species during each sampling event) were brought back to the FWC/FWRI laboratory to confirm field identification. Species for which field identification was uncertain were also brought back to the laboratory. A maximum of 10 measurements (mm) were made per taxon, unless distinct cohorts were identifiable, in which case a maximum of 10 measurements were taken from each cohort; for certain economically valuable fish species, twenty individuals were measured. Standard length (SL) was used for fish (total length [TL] for seahorses and disk width [DW] for rays), post-orbital head length (POHL) for pink shrimp, and carapace width (CW) for crabs. Animals that were not measured were identified and counted. When large numbers of individuals (>> 1,000) were captured, the total number was estimated by fractional expansion of sub-sampled portions of the total catch split with a modified Motoda box splitter (Winner and McMichael 1997). Animals not chosen for further laboratory examination were returned to the river.

Due to frequent hybridization and/or extreme difficulty in the identification of smaller individuals, members of several abundant species complexes were not identified to species. We did not separate menhaden, *Brevoortia*, species. *Brevoortia patronus* and *B. smithi* frequently hybridize, and juveniles of the hybrids and the parent species are difficult to identify (Dahlberg 1970). *Brevoortia smithi* and hybrids may be the most abundant forms on the Gulf coast of the Florida peninsula, especially in coastal embayments (Dahlberg 1970), and we treated them as one functional group. The two abundant silverside species (genus *Menidia*) tend to hybridize, form all-female clones, and occur in great abundance that renders identification to species impractical due to the nature of the diagnostic characters (Duggins et al. 1986; Echelle and Echelle 1997; Chernoff, personal communication). Species-level identification of mojarras (genus *Eucinostomus*) was limited to individuals ≥ 40 mm SL due to great difficulty in separating *E. gula* and *E. harengulus* below this size (Matheson, personal observation).

The term —ucinostomus mojarras" is used for these small specimens. Species-level identification of gobies of the genus *Gobiosoma* (i.e., *G. robustum* and *G. bosc*) was limited to individuals ≥ 20 mm SL for the same reason; smaller individuals are hereafter referred to as —gobiosoma gobies". Similarly, needlefishes (*Strongylura* spp.) other than *S. notata* were only identified to species at lengths ≥ 100 mm SL. *Lepomis* spp. (sunfishes; <20mm SL) and species of the genera *Oreochromis* and *Sarotherodon* (tilapia; <40mm SL) were similarly not identified to species because of difficulties in species-level identifications at these small sizes.

2.7 Data Analysis

2.7.1 Freshwater Inflow (F)

Inflow rates to the study area include data from one gauged streamflow site, USGS sites 02310747 (Crystal River at Bagley Cove near Crystal River, FL). Freshwater discharge at this station is reported as tidally filtered residual flow. Missing data (12.8% of daily records) were interpolated using an iterative running average of the three days before and after the missing data. All flow rates were expressed as average daily flows in cubic feet per second (cfs).

2.7.2 Organism-Weighted Salinity (SU)

The central salinity tendency for catch-per-unit-effort (CPUE) was calculated as

$$S_U = \frac{\sum (S \cdot U)}{\sum U}$$

where U is CPUE (No. m^{-3} for plankton data and No. 100 m^{-2} for seine data) and S is water-column average salinity during deployment.

2.7.3 Center of CPUE (kmU)

The central geographic tendency for CPUE was calculated as

$$km_U = \frac{\sum (km \cdot U)}{\sum U}$$

where km is distance from the river mouth.

2.7.4 Organism Number (N) and Relative Abundance ($\bar{N}$)

Using plankton-net data, the total number of organisms in the Crystal River study area was estimated by summing the products of mean organism density (, as No. m-3) and tide- corrected water volume (V) from the six collection zones as

$$N = \sum (\overline{U} \cdot V)$$

Volumes (m^3) corresponding to NAVD88 and depth-specific surface areas (m^2) were provided by SWFWMD. Using a reference depth of NAVD88 = 0.0 m, volumes were amended to the water levels at the time of collection using surface areas at 0.0 m and data from a water-level recorder located at Bagley Cove. The Bagley Cove data were first corrected to NAVD88 by adding 12.177 ft. to the records, and the resulting elevations were converted to meters. Adjoining creeks were not included in the volume estimates for the main channel. Only the upstream location within Zone 1 was included (i.e., the location that was offshore in the Gulf of Mexico was not included). In addition, volume data were available from the mouth of the estuary (km = 0.0) upstream, as defined by the SWFWMD centerline. Summation of abundances was therefore limited to volumes and collection locations that were upstream of km 0.0.

For seine data, relative abundance (mean number per 100 m^2 sampled area) in the Crystal River estuary was calculated as

$$\overline{N} = 100 \times \frac{N_{total}}{A_{total}}$$

where N_{total} = total number of animals captured in that month and A_{total} is the total area sampled in that month. $\overline{N}$ is also referred to as catch-per-unit-effort, or CPUE, in some instances.

2.7.5 Inflow Response Regressions

Regressions were run for km_U on F, N on F (plankton-net data only), and $\overline{N}$ on F (seine data only). N, $\overline{N}$, km_U (seine data only) and F were Ln-transformed prior to regression to improve normality. To avoid censoring zero values in seine regressions, a constant of 1 was added to $\overline{N}$ *and* F prior to transforming the data. Centers of CPUE (km_U) values could be negative since sampling extended west of the river mouth (river

kilometer 0; *Fig. 2.1.1*), so a constant of 1.9 (seines only) was added prior to transforming these values.

Regressions using plankton-net data were limited to taxa that were encountered during a minimum of 10 of the surveys. The fits of the following regression models were compared to determine if an alternative model produced consistently better fit than the linear model (Y = a + b*F):

Square root-Y: Y = (a + b*F)^2

Exponential: Y = exp(a + b*F)

Reciprocal-Y: Y = 1/(a + b*F)

Square root-F: Y = a + b*sqrt(F)

Reciprocal-F: Y = a + b/F

Double reciprocal: Y = 1/(a + b/F)

Logarithmic-F: Y = a + b*ln(F)

Multiplicative: Y = a*F^b

S-curve: Y = exp(a + b/F)

where Y is km_U or N. In these regressions, F was represented by same-day inflow and by mean inflows extending as far back as 120 days prior to the sampling date. The combination of consecutive dates that produced the maximum regression fit was used to model the N and km_U responses to F for each taxon. This approach provided an indication of the temporal responsiveness of the various taxa to inflow variations. An organism was considered to be responsive if the regression slope was significantly different from zero at $p<0.05$.

Seine regressions were limited to taxa that were reasonably abundant (total abundance>100) and frequently collected (present in at least 5% of collections). Monthly length-frequency plots (Appendix C) were examined to assign appropriate size classes (‗pseudo-species‘) and recruitment periods for each of these taxa. For distribution regressions (km_U), all months were considered when a pseudo-species was collected in at least one sample from that month. For abundance regressions ($\overline{N}$), all samples collected within arecruitment period determined from monthly length-frequency plots (Appendix C) were considered. Mean flows from the date of sampling, as well as

continuously lagged seven day averages from the day of sampling to 364 d before sampling (i.e., average flow of sampling day and preceding 6 days, average flow of sampling day and preceding 13 days, etc.), were considered and linear and quadratic regressions were evaluated.

2.7.6 Community-level Analyses

2.7.6.1. Plankton. To investigate the effects of varying freshwater inflow on the ichthyoplankton/zooplankton communities as a whole, an analysis of variation in community heterogeneity was undertaken using PRIMER 6 software (PRIMER-E Ltd.; Clarke & Gorley 2006). A complete estuarine gradient has freshwater organisms at its upstream end and marine organisms at its downstream end. When inflows are reduced, marine organisms tend to invade riverine estuaries, causing the local community composition to resemble that of seaward locations. Under these conditions, the compositions of the samples collected along the estuarine gradient become more similar to each other. In contrast, a high degree of community heterogeneity (compositional variation among such samples) is an indication the tidal river contains a more diverse continuum of communities. The concept of community heterogeneity is well established in scientific disciplines associated with the landscape ecology of terrestrial plants. This quality was examined using the Index of Multivariate Dispersion (MVDISP routine in PRIMER 6; Warwick and Clarke 1993). Although Warwick and Clarke refer to their index of community heterogeneity as a "dispersion" index, the term "community heterogeneity" will be substituted for "dispersion" to prevent confusion with dispersion as a measure of the spread within statistical probability distributions (e.g., standard deviation). Community heterogeneity was regressed against the average inflow of three days ending on the day of sampling. The strength and spatial structure of community gradients were further explored using multidimensional scaling plots (MDS routine in PRIMER 6). All analyses were based on Bray-Curtis dissimilarity of square-root transformed CPUE.

2.7.6.2 Seines. To investigate the effects of varying freshwater inflow on the plankton and nekton communities, various multivariate analyses were undertaken using PRIMER

v6 software (PRIMER-E Ltd. [UK]; Clarke and Gorley 2006). Taxa were divided into the same pseudo-species used for regression analyses. Data were ln(x+1)-transformed to reduce the influence of patchy, abundant species. Inflow data were the same as used for regression analyses.

Bray-Curtis similarities (Bray and Curtis 1957) were calculated between each pair of samples. Spatial and temporal differences in community structure were investigated using two-way Analysis of Similarities (ANOSIM; Clarke 1993) with zone and year-month as factors. The data were also displayed graphically using Non-metric Multidimensional Scaling (MDS; Clarke 1993). Pseudo-species characterizing each zone of the sampling area were determined using Similarity Percentages Analysis (SIMPER; Clarke 1993).

To investigate the extent that monthly changes in community structure correlated with changes in physicochemical variables and annual cycles, the community and physicochemical data were averaged by year-month. Community similarities between months were again calculated with Bray-Curtis similarity (Bray and Curtis 1957). The extent to which change in community structure represented regular annual cycles was investigated using the RELATE routine (see Greenwood et al. [2007] for details). Correlations between nekton community change over the study period and 7-day mean inflow were assessed using the BIO-ENV routine (Clarke 1993). BIO-ENV was also used to assess the correlation between community change and physicochemical variables (temperature, salinity, dissolved oxygen, pH, water depth [at seine center bag and seine wing], and quantity of bycatch). The analysis was initially conducted for up to five physicochemical variables at once, and was then repeated to assess the highest correlating single variable. The RELATE and BIO-ENV analyses in tandem allowed the relative importance of regular annual cycles (e.g., spawning seasonality) and physicochemical variables to be elucidated.

It was hypothesized that variability in nekton community structure would increase with increasing inflow. This hypothesis was examined using the MVDISP routine in PRIMER (Warwick and Clarke 1993; Travers and Potter 2002), an index of relative dispersion that increases with increasing community variability (heterogeneity).

2.7.7 Data Limitations and Gear Biases

All nets used to sample aquatic organisms are size selective. Small organisms pass through the meshes and large organisms evade the gear altogether. Intermediate-sized organisms are either fully retained or partially retained. When retention is partial, abundance becomes relative. However, temporal or spatial comparisons can still be made because, for a given deployment method and size of organism, the selection process can usually be assumed to have constant characteristics over space and time. The 500-µm plankton gear retains a wide range of organism sizes completely, yet it should be kept in mind that many estimates of organism density and total number are relative rather than absolute. Organism measurements from Little Manatee River and Tampa Bay plankton samples (Peebles 1996) indicate that the following taxa will be collected selectively by 500-µm mesh: marine-derived cyclopoid copepods, some cladocerans, some ostracods, harpacticoid copepods, cirriped nauplii and cypris larvae, the larvacean *Oikopleura dioica*, some decapod zoeae, and some adult calanoid copepods. Taxa that are more completely retained include cumaceans, chaetognaths, insect larvae, fish eggs, most fish larvae and postlarvae, some juvenile fishes, gammaridean amphipods, decapod mysis larvae, most decapod megalopae, mysids, isopods, and the juveniles and adults of most shrimps. This partitioning represents a very general guide to the relative selectivities of commonly caught organisms.

The plankton nets were deployed during nighttime flood tides because larval fishes and invertebrates are generally more abundant in the water column at night (Colton et al. 1961, Temple and Fisher 1965, Williams and Bynum 1972, Wilkins and Lewis 1971, Fore and Baxter 1972, Hobson and Chess 1976, Alldredge and King 1985, Peebles 1987, Haney 1988, Lyczkowski-Shultz and Steen 1991, Olmi 1994) and during specific tide stages (Wilkins and Lewis 1971, King 1971, Peebles 1987, Olmi 1994, Morgan 1995a, 1995b). Organisms that selectively occupy the water column during flood tides tend to move upstream, and organisms that occupy the water column during all tidal stages tend to have little net horizontal movement other than that caused by net estuarine outflow (Cronin 1982, McCleave and Kleckner 1982, Olmi 1994). The plankton catch was therefore biased toward organisms that were either invading the coastal embayments or were attempting to maintain position within the coastal embayments. This bias would tend to exclude the youngest larvae of some estuarine

crabs, which are released at high tide to facilitate export downstream with the ebb tide (Morgan 1995a). However, as the young crabs undergo their return migrations at later larval stages, they become most available for collection during nighttime flood tides (Olmi 1994, Morgan 1995b).

Seines tend to primarily collect small fish, either adults of small-bodied species or juveniles of larger taxa. Sampling efficiency inevitably varies by species and size class (Rozas and Minello 1997), but we assume reasonable consistency between samples collected with a given gear type. We acknowledge that movement of various taxa (e.g. killifishes, Fundulidae and Cyprinodontidae) into emergent vegetation at high water levels occurs (Rozas and Minello 1997) and could complicate interpretation of some results.

3.0 RESULTS AND DISCUSSION

3.1 Streamflow Status during Survey Years

The flow record for Crystal River at Bagley Cove near Crystal River, FL (USGS 02310747) was missing average daily flow values for almost 13% of the days during this study period (March 18, 2008 to February 23, 2010). Flows for these missing time periods were extrapolated using an iterative running average of the three days before and after the missing value. Where long periods of flow data were missing, this method used extrapolated data to extrapolate subsequent missing flow days. This approach resulted in a flow record that appears to be overly smoothed during extended periods of extrapolated flows (Fig. 3.1.1). Flow data at the end of the study period (February 8, 2010 to February 23, 2010) could not be extrapolated because there were no flow values available at the end of the study period.

Groundwater inflows into the Crystal River estuary had distinct annual cycles that were out of phase with annual rainfall patterns; inflows were highest during winter and lowest during summer (*Fig. 3.1.1*). Flows from the Crystal River are tidal influenced and the flows used in this report (Crystal River at Bagley Cove near Crystal River, FL; USGS 02310747) are tidally filtered residual flows. Tidal ranges are generally both higher and

more variable during winter, which agrees with the observed flow pattern for this spring-fed system. Similar to other spring-fed rivers in this area (Chassahowitzka and Homosassa), flows in the Crystal River estuary underwent relatively minor variation when compared to systems with larger watersheds and greater surface inflows. Flows in the Crystal River estuary had a coefficient of variation (CV) of 42.3% during this study period (March 18, 2008 to February 8, 2010), whereas flows in the surface-fed Anclote River (Anclote River near Elfers, FL; USGS 02310000) to the south had a CV of 183.2% during this same time period.

Fig. 3.1.1. Crystal River streamflow (USGS 02310747) and plankton and nekton collection dates. Extrapolated flows are designated with dashed magenta line.

3.2 Physico-chemical Conditions

Summary statistics from the electronic meter data collected during plankton and seine sampling are presented in *Table 3.2.1* and *Table 3.2.2*, respectively. Plankton stations tended to be deeper than the seine stations, but the means and standard deviations for water quality parameters were relatively similar. Mean salinity tended to decrease and be less variable (std. dev.) for upstream locations. The maximum salinity

tended to be quite a bit higher in the shallow waters sampled with seines than in the deeper areas sampled with plankton-nets.

Temperature and salinity demonstrated considerable variablitiy during this study period. Temperatures underwent seasonal variation within a typical range (*Fig. 3.2.1* and *Fig. 3.2.2*), but were far less variable upstream (see standard deviations in *Table 3.2.1* and *Table 3.2.2*), reflecting the thermal stability of the spring flows. Salinity measurements taken during plankton-net sampling decreased during the summer and fall of 2008 (*Fig. 3.2.1*) in association with relatively sustained high spring flows. The extended period of increase in salinity that followed this decrease (November 2008 – October 2009), however, did not correspond with a reduction in spring flows. Seine collections, which sampled much shallower depths than the plankton net, displayed a different trend in salinity with higher values and greater variability through October 2008 than in subsequent sampling events (*Fig. 3.2.2*). These differences likely have to do with differences in flow and circulation between the deeper waters sampled by the plankton net and the shallower waters sampled by the seines.

Salinity was distinctly higher for seine collections made on September 11, 2008 (*Fig. 3.2.2*), with a median value of almost 22psu. On September 11, 2008, a category 2 hurricane (Ike) was moving away from Florida through the Gulf of Mexico over 750km away from Crystal River. On the 10th and 11th of September the Crystal River flows were -11 and 68cfs, respectively. This relatively minor, although large, tropical system pushed Gulf of Mexico waters into the Crystal River estuary increasing the median salinity by almost 10psu over the second highest median salinity recorded during seine sampling (12.7psu on 10/23/2008) and almost 18psu higher than the median salinity during the entire sampling period. Frazer (2001) had previously reported pulses of higher salinity (10psu) water reaching as far upstream as Kings Bay during extreme high tide events.

Trends in dissolved oxygen (DO) and pH were similar in the shallow waters sampled with seines (*Fig. 3.2.2*), but were decoupled in the deeper waters sampled with plankton nets (*Fig. 3.2.1*). As with salinity, these differences likely arise because of differences in circulation and flow, but also because of the presence of SAV in the shallower depths. Decoupling of DO and pH is unusual for estuaries in west-central

Florida. Except in high-alkalinity estuaries where carbonate precipitation is common (e.g., Florida Bay), pH often serves as a negative proxy for carbon dioxide (Yates et al. 2007), most or all of which is immediately converted to bicarbonate or carbonate at higher pH values. The temporal trends in DO reflect temperature-related (seasonal) variation in gas solubility, but do not reflect the type of biological domination that is often apparent as instability in the ratio of respiration (CO_2 production, DO consumption) to photosynthesis (CO_2 consumption, DO production). Mineral-based alkalinity from karst may be causing the decoupling between DO and pH (Yates et al. 2007).

Table 3.2.1. Electronic meter summary statistics during plankton net deployment. Mean depth is mean depth at deployment. Sample sizes (n) reflect the combination of survey frequency (18 surveys) and depths of measurement. Measurements were made at surface, bottom and at one-meter intervals between surface and bottom. Std. Dev. Is standard deviation, min is minimum, and max is maximum.

Location	Mean	Salinity (psu)					Water Temperature (°C)					Dissolved Oxygen (mg/l)					pH				
(km from mouth)	Depth (m)	n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.	n	mean	std. dev.	min.	max.
-3.0	2.5	75	23.0	5.5	8.8	29.4	75	23.8	5.0	16.9	32.1	75	8.4	2.0	5.3	14.5	75	8.1	0.2	7.3	8.5
0.1	2.7	85	15.6	4.5	4.5	21.9	85	24.3	4.7	17.5	32.2	85	7.8	1.9	5.2	14.3	85	8.0	0.2	7.2	8.5
1.9	4.7	88	11.5	4.6	2.4	19.2	88	24.3	4.4	17.5	32.2	88	7.7	1.8	5.1	13.1	88	8.0	0.2	7.3	8.4
2.8	4.5	90	9.8	4.4	2.1	17.8	90	24.3	4.3	17.4	32.1	90	7.7	1.8	5.1	12.9	90	8.0	0.2	7.4	8.3
3.9	4.5	93	8.8	4.0	2.2	16.3	93	23.9	4.1	18.1	31.6	93	7.7	1.8	5.1	12.8	93	8.0	0.2	7.4	8.3
0.0	4.9	89	7.3	3.4	2.2	16.0	89	24.0	4.1	18.3	31.4	89	7.7	1.8	5.2	12.1	89	8.0	0.2	7.5	8.3
5.9	5.4	82	6.0	2.9	1.4	13.5	82	24.3	3.8	18.9	31.3	82	7.6	1.6	5.1	11.6	82	8.0	0.2	7.4	8.4
0.0	4.6	85	4.7	2.2	1.2	11.5	85	24.3	3.6	19.3	31.2	85	7.9	1.6	5.3	11.4	85	8.0	0.2	7.6	8.5
7.9	2.8	71	4.0	1.8	1.2	8.8	71	24.1	3.4	19.7	31.2	71	7.8	1.5	5.3	11.8	71	8.0	0.2	7.6	8.6
8.9	2.6	85	3.4	1.7	1.2	10.7	85	24.1	3.3	19.9	31.3	85	8.1	1.7	4.8	12.3	85	8.1	0.3	7.5	8.6
10.3	2.8	69	2.1	0.9	0.7	5.7	69	24.3	2.8	20.4	30.5	69	8.2	1.5	4.6	12.3	69	8.2	0.3	7.5	8.6
11.2	1.9	44	1.6	0.4	1.0	2.4	44	23.9	1.9	20.7	29.0	44	7.8	1.7	4.7	11.3	44	8.2	0.3	7.6	8.6

Table 3.2.2. Electronic meter summary statistics during seine deployment. Mean depth is mean depth at deployment. Sample sizes (n) reflect the combination of survey frequency (18 surveys), number of hauls per zone, and depths of measurement. Measurements were made at surface, bottom and at one-meter intervals between surface and bottom. Std. Dev. Is standard deviation, min is minimum, and max is maximum.

Zone	River Kilometer	Mean Depth (m)	n	Salinity (psu)				Temperature (°C)				Dissolved Oxygen (mg/l)				pH			
				mean	std. dev.	min	max	mean	std. dev.	min	max	mean	std. dev.	min	max	mean	std. dev.	min	max
1	-0.9 to 1.79	0.5	103	17.1	5.7	4.3	27.4	23.5	5.7	11.4	31.2	7.5	1.9	4.1	14.1	7.9	0.2	7.5	8.3
2	1.80 to 3.79	0.4	94	11.5	6.6	3.1	24.9	24.3	5.1	11.5	31.1	7.2	2.0	4.4	12.6	7.9	0.2	7.5	8.5
3	3.80 to 5.69	0.5	106	9.3	6.6	2.5	24.6	24.1	4.6	13.2	30.5	7.2	1.8	3.7	11.2	7.9	0.2	7.5	8.5
4	5.70 to 7.59	0.5	95	6.6	5.1	1.5	23.0	24.5	4.3	14.2	30.7	7.5	1.6	4.7	10.9	8.0	0.2	7.7	8.5
5	7.60 to 9.89	0.5	102	3.7	2.7	1.2	17.8	24.5	4.3	14.9	30.9	8.0	1.6	2.2	13.4	8.1	0.2	7.6	8.5
6	9.90 to 12.10	0.5	185	1.7	0.9	0.2	7.0	24.0	3.1	16.1	30.4	7.6	1.9	1.8	11.9	8.1	0.3	7.3	8.7

Fig. 3.2.1. Electronic meter data from the plankton-net surveys of the Crystal River estuary, where the cross identifies the mean, the horizontal line identifies the median, the box delimits the interquartile range, and the whiskers delimit the total range.

Fig. 3.2.2. Electronic meter data from the seine surveys of the Crystal River estuary, where the horizontal line identifies the median, the box delimits the interquartile range, and the whiskers delimit the 10th to 90th percentiles.

3.3 Catch Composition

3.3.1 Fishes.

3.3.1.1 Plankton net. Larval gobies dominated the larval fish catch (*Appendix Table A1*). Gobies of the genus *Gobiosoma* were the dominant gobies, distantly followed by *Microgobius* spp. and then the frillfin goby (*Bathygobius soporator*). Anchovies, notably the bay anchovy (*Anchoa mitchilli*) were also collected in fairly large numbers, although the catch was low compared to surface-fed estuaries in west-central Florida. Other well-represented fishes included menhaden (*Brevoortia* spp.), silversides (*Menidia* spp.), rainwater killifish (*Lucania parva*), mojarras (*Eucinostomus* spp.), spot (*Leiostomus xanthurus*), skilletfish (*Gobiesox strumosus*), and blennies (only the Florida blenny, *Chasmodes saburrae*, and highfin blenny, *Lupinoblennius nicholsi* were positively identified). *Menidia* can be exceptionally abundant within estuaries, but can also complete its life cycle within fresh water. Juvenile spot (*Leiostomus xanthurus*) were abundant relative to other tidal rivers in west-central Florida. Spot spawn far offshore and move landward during the late larval and early juvenile stages. Perhaps the proximity of the Crystal River survey area to the Gulf of Mexico resulted in relatively high numbers of juvenile, offshore-spawned spot. Only 11 larvae of the strongly estuarine-dependent sand seatrout (*Cynoscion arenarius*) were collected, which is a low catch relative to surface-fed estuaries in west-central Florida.

3.3.1.2 Seine. The seine catch (*Appendix Table B1*) of fishes in the Crystal River estuary was dominated by silversides (*Menidia* spp.), bay anchovy (*A. mitchilli*), rainwater killifish (*L. parva*), and eucinostomus mojarras (*Eucinostomus* spp.) less than 40mm. These four taxa comprised over 70% of the total seine catch of fishes. Freshwater oriented taxa such as bluefin killifish (*Lucania goodei*), largemouth bass (*Micropterus salmoides*) and several species of sunfishes (bluegill *Lepomis macrochirus*, redear sunfish *Lepomis microlophus*, and spotted sunfish *Lepomis punctatus*) were encountered almost exclusively in King‘s Bay (zone 6) (*Appendix Table B3*) and comprised a relatively small portion of the total catch even within this zone (<2%). Shiners (*Notropis petersoni*, *Notropis harperi*, and *Notemigonus crysoleucas*) a

freshwater taxanomic group typically encountered in other spring (Weeki Wachee, Homosassa, and Chassahowitzka rivers) and surface (Anclote, Alafia, and Little Manatee rivers) fed systems, were not collected during sampling in the Crystal River estuary.

3.3.2. Invertebrates.

3.3.2.1. Plankton net. The plankton-net invertebrate catch (*Appendix Table A1*) was dominated by larval crabs (decapod zoeae and megalopae), gammaridean amphipods, cumaceans, the mysids *Americamysis almyra* and *Bowmaniella dissimilis*, the copepod *Acartia tonsa*, and larval shrimps (decapod mysis). The phantom midge larva *Chaoborus punctipinnis* and cyclopoid copepod *Mesocyclops edax*, which are indicative of reservoir waters and other lacustrine settings, were rarely encountered in the spring-fed Crystal River estuary. The river-plume-associated calanoid copepod *Acartia tonsa* was regularly encountered near the river mouth in low to moderate numbers, but other plume-associated taxa such as the calanoid coepod *Labidocera aestiva*, the chaetognaths *Sagitta* spp., the planktonic shrimp *Lucifer faxoni*, and the ostracod *Parasterope pollex*, were less common than they typically are in more nutrient-rich estuarine plumes along the west-central Florida coast.

3.3.2.2. Seine. The seine catch (*Appendix Table B1*) of select invertebrate taxa was dominated by brackish grass shrimp (*Paleomonetes intermedias*), daggerblade grass shrimp (*P. pugio*), blue crab (*Callinectes sapidus*), and pink shrimp (*Farfantepenaeus duorarum*). These four taxa comprised over 97% of the total invertebrate catch in seines.

3.4 Use of Area as Spawning Habitat

This analysis is restricted to estuarine and marine fishes – a diversity of freshwater fishes also reproduce within the freshwater reaches of the survey area (i.e., one or more species of gar, eastern mosquitofish, bluefin killifish, various sunfishes, and largemouth bass). The eggs of the bay anchovy (*A. mitchilli*), the rainwater killifish (*L. parva*), other killifishes (*Fundulus* spp.), unidentified gobies, and unidentified percomorph (primarily sciaenid) fishes were collected from the survey area (Table A1).

None of these fish eggs were abundant, but the bay anchovy and sciaenid eggs were more abundant than the other types – both were most abundant near the river mouth and especially in the Gulf of Mexico (Table A3). If it is assumed that the relative abundances of different species of early-stage sciaenid larvae reflect the local, relative spawning intensity, then kingfishes (*Menticirrhus* spp.), sand seatrout (*Cynoscion arenarius*) and spotted seatrout (*C. nebulosus*) are the sciaenids that are most likely to have spawned in the study area (*Appendix Table A3* and *Table 3.4.1*). The data in Tables A3 and 3.4.1 also suggest blennies and skilletfish (*Gobiesox strumosus*) spawned near the river mouth – probably in association with oyster-shell substrates. Gobies (primarily Gobiosoma spp. and *Microgobius* spp.) and *Menidia* appear to have spawned throughout much of the interior of the tidal river. The presence of rainwater killifish eggs upstream (*Appendix Table A3*) suggests upstream spawning by this species, a pattern that is supported by the distribution of subsequent developmental stages (*Appendix Table A3*). The collection of very small juveniles of live-bearing pipefishes near the river mouth (*Syngnathus louisianae*), throughout much of the interior of the tidal river (*S. scovelli*), and in upstream areas (*S. floridae*) suggests that these species also reproduce within the local area. *Table 3.4.1* indicates menhaden (*Brevoortia* pp.) and spot (*L. xanthurus*) migrated into the survey area from distant spawning locations, which is a pattern that agrees with the published literature. Less is known about the spawning of mojarras (*Eucinostomus* spp.), but these fishes also appeared to spawn in the Gulf of Mexico away from the tidal river. *Table 3.4.1*'s indication that the rainwater killifish also spawned at a distant location is misleading – the rainwater killifish hatches at a relatively advanced developmental stage and, as mentioned above, appears to have spawned within the survey area. A review of trends in spawning habitat among coastal fishes is presented by Peebles and Flannery (1992).

Table 3.4.1. Relative abundance of larval stages for non-freshwater fishes with a collection frequency >10 for the larval-stage aggregate, where *Pre* = preflexion (youngest larval stage), *Flex* = flexion stage (intermediate larval stage) and *Post* = postflexion (oldest larval stage). **X** identifies the most abundant stage and x indicates that the stage was present.

Taxon	**Common Name**	**Pre**	**Flex**	**Post**
Anchoa spp.	anchovies	**X**	x	x
Gobiesox strumosus	skilletfish	**X**	x	x
Menidia spp.	silversides	**X**	x	x
gobiids	gobies	**X**	x	x
blenniids	blennies	**X**	x	x
Bathygobius soporator	frillfin goby	**X**		x
Cynoscion nebulosus	spotted seatrout	x	x	**X**
Trinectes maculatus	hogchoker		x	**X**
Lucania parva	rainwater killifish			**X**
Brevoortia spp.	menhaden			**X**
Leiostomus xanthurus	spot			**X**
Eucinostomus spp.	mojarras			**X**

3.5 Use of Area as Nursery Habitat

Estuarine-dependent taxa that spawn in offshore and nearshore waters were present, but not prominent in the seine collections. Seven of the twelve most abundant taxa collected can be considered estuary-dependent taxa that spawn in offshore or nearshore waters. The abundant estuarine-dependent taxa accounted for 28% of the total abundance. Tidal river residents (*Menidia* spp. and *L. parva*) and estuarine spawners (*A. mitchilli*, *Palaemonetes intermedius*, and *Palaemonetes pugio*) comprised the five remaining taxa in the top ten and represented almost 65% of the total abundance. The estuarine-dependent taxa included spot (*L. xanthurus*), striped mullet (*Mugil cephalus*) and blue crabs (*C. sapidus*), species that are of direct economic importance. The remaining four abundant estuarine-dependent taxa represent

ecologically important taxa such as eucinostomus mojarras, tidewater mojarra (*Eucinostomus harengulus*), and striped anchovy (*Anchoa hepsetus*).

3.6 Seasonality

3.6.1. Plankton Net

The number of taxa collected during an individual survey is not a true measure of species richness because many taxa could not be identified to species level. Nevertheless, this index produces a clear seasonal pattern. Specifically, more taxa tend to be collected during the warmer months than during winter (*Fig. 3.6.1.1*).

Species diversity tends to be highest near the mouths of tidal rivers due to an increased presence of marine-derived species and at the upstream end due to the presence of freshwater species. This creates a low-diversity zone in the middle reaches of tidal rivers (Merriner et al. 1976). Changes in streamflow can shift this pattern downstream or upstream.

For a given species of fish, the length of the spawning season tends to become shorter at the more northerly locations within a species‘ geographic range, but the time of year when spawning takes place is otherwise consistent for a given species. Among species with long or year-round spawning seasons, local conditions have been observed to have a strong influence on egg production within the spawning season (Peebles 2002). Local influences include seasonally anomalous water temperature, seasonal variation in the abundance of prey, and seasonal variation in retention or transport of eggs and larvae after spawning. The latter processes (prey availability and retention and transport) are influenced by freshwater inflows at the coast.

Alteration of flows would appear to have the lowest potential for impacting many taxa from November to February, which are the months when the fewest estuarine taxa were present. The highest potential to impact many species would appear to be from April through October. Some species were present throughout most of the year (bay anchovy, *Fig. 3.6.1.2*), whereas others had more seasonal spawning and recruitment patterns (menhaden and spot, *Fig. 3.6.1.2*).

Fig. 3.6.1.1. Number of taxa collected per month by plankton net.

Fig. 3.6.1.2. Examples of species-specific seasonality from individual plankton-net tows, including species that spawn most heavily A) during early spring, B) winter, and C) throughout much of the year

3.6.2. Seine

Seasonal patterns of taxon richness were evident in the nearshore (seined) area of the Crystal River estuary (*Fig. 3.6.2.1*). Richness in the nearshore area was low from January to April, increased in May, peaked in June–August and again in October and November, and decreased in December. June 2009 was particularly species rich with 57 taxa collected. Five of these taxa (bumper *Chloroscombrus chrysurus*, fringed flounder *Etropus crossotus*, southern kingfish *Menticirrhus americanus*, Spanish mackerel *Scomberomorus maculatus*, and lookdown *Selene vomer*) were collected only during the June 2009 sampling event. Overall abundance and abundance of newly recruiting nekton taxa indicate extensive use of the study area during all months (see *Appendices B* and *C*).

Twenty-six relatively abundant (≥100 collected) and frequently occurring (≥5% occurrence) species were assessed to determine seasonality. Most species of tidal river residents were collected in the Crystal River estuary during eight or more months (*Fig. 3.6.2.2*), but peaks in abundance occurred in June through August and in October and November. Most species of estuarine spawners were present in the estuary during all months with peaks in abundance during February, April, June, August, October, November and December. Three of the four species of nearshore spawners (species spawning in coastal waters outside the estuary) were present in the estuary year round, but with abundance peaks in February, May, June, August, October and December. Offshore spawners had peaks in abundance from December to February and in April, June, August, October, and December.

Newly recruited nekton (i.e., the smallest size classes captured by our gears) were present in the study area throughout the year (*Fig. 3.6.2.3*). Of the 24 species for which these trends were assessed, offshore spawners recruited to the study area mostly from October to February and in August; nearshore spawners had recruitment peaks throughout the year (February, June, August, October, November and December); estuarine spawners typically did not have strong peaks but those that did had peak recruitment between August and October; and recruitment of tidal-river residents occurred throughout the year with peaks in August, and from October to

December . Overall, the results suggested that the study area was important for nekton throughout the year.

Fig. 3.6.2.1. Number of taxa collected per month by seine in the Crystal River estuary, March 2008 – February 2010.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Offshore Spawners												
Farfantepenaeus duorarum		1.3%	1.2%	1.7%		**16.9%**	1.5%	**29.7%**	3.4%	**38.1%**	3.2%	3.0%
Lagodon rhomboides	0.6%	14.9%	3.1%	**22.2%**	1.7%	**37.8%**	1.6%	9.2%	0.1%	8.4%		0.5%
Leiostomus xanthurus	2.5%	**95.6%**	0.0%	1.6%	0.1%	0.0%						0.1%
Sciaenops ocellatus	1.5%	4.1%						1.0%		**26.7%**	9.2%	**57.4%**
Mugil cephalus	**42.4%**	**54.6%**	0.2%	1.3%	0.0%	0.4%		0.7%				0.5%
Total Peaks	1	2		1		2		1		2		1
Nearshore Spawners												
Callinectes sapidus	4.3%	**30.6%**	4.9%	11.5%	1.7%	2.3%	0.2%	7.2%	0.2%	14.9%	14.2%	8.0%
Anchoa hepsetus				3.0%	**16.9%**	**71.9%**	4.7%	3.3%	0.1%			
Eucinostomus gula	0.1%	4.6%	1.0%	0.6%	0.1%	0.1%	1.5%	14.7%	2.3%	**35.3%**	2.6%	**37.1%**
Eucinostomus harengulus	0.4%	11.0%	1.7%	12.6%	6.1%	4.8%	2.0%	**20.4%**	0.9%	**18.0%**	0.3%	**21.7%**
Total Peaks		1			1	1		1		2		2
Estuarine Spawners												
Palaemonetes intermedius	1.3%	**29.2%**	0.3%	**16.9%**	1.5%	7.6%	12.9%	0.9%	0.0%	**16.0%**	2.7%	10.6%
Palaemonetes pugio	13.0%	**34.7%**	0.7%	**17.7%**	0.3%	**19.3%**	0.9%	3.6%	0.1%	2.2%	6.6%	0.7%
Anchoa mitchilli		**31.9%**	0.1%	5.7%	4.7%	**20.1%**	3.5%	6.0%	5.9%	**19.8%**	0.8%	1.5%
Strongylura notata	4.9%	10.4%	0.9%		2.4%	**15.9%**	5.2%	**30.6%**	1.5%	6.7%	1.8%	**19.6%**
Strongylura timucu	6.0%	**24.0%**	1.8%	1.5%	0.4%	5.5%	2.6%	**19.3%**	0.2%	13.5%	3.8%	**21.5%**
Floridichthys carpio	1.9%	8.0%		1.7%	0.6%	5.7%		0.7%		**15.4%**	**63.5%**	2.6%
Trinectes maculatus	4.9%	0.5%	2.2%	**31.1%**	1.1%	7.1%	12.0%	**25.6%**	0.5%	2.2%	3.0%	9.8%
Total Peaks		4		3		3		3		3	1	2
Tidal River Residents												
Cyprinodon variegatus	2.5%	7.0%		6.1%	4.2%	**20.9%**	5.0%	11.0%	1.1%	6.4%	**28.6%**	7.3%
Fundulus grandis	14.3%	10.7%	0.1%	0.7%	4.3%	**33.1%**		0.5%		0.5%	**26.2%**	9.7%
Fundulus similis	4.2%	6.0%		3.6%	1.2%	**20.4%**		1.2%		4.8%	**55.1%**	3.6%
Lucania parva	0.9%	1.1%	1.9%	7.9%	5.5%	12.9%	8.7%	**29.6%**	2.8%	13.4%	0.7%	14.5%
Lucania goodei			3.7%	1.1%		**43.5%**	5.6%	6.9%	0.5%	12.7%	**22.8%**	3.2%
Gambusia holbrooki		0.9%		0.9%		0.9%	4.8%	2.3%		0.9%	**88.0%**	1.4%
Heterandria formosa				9.0%		1.3%	**19.2%**	**15.4%**	1.3%	**39.7%**	12.8%	1.3%
Micropterus salmoides	0.3%	1.0%	0.5%	4.6%	4.3%	**41.5%**	**27.3%**	9.6%	0.3%	4.1%	2.5%	4.1%
Gobiosoma bosc	8.3%	7.1%	2.4%	4.7%	1.8%	11.8%	5.3%	**18.9%**		10.7%	**23.1%**	5.9%
Microgobius gulosus	0.6%	2.8%	0.8%	12.8%	12.1%	**38.9%**	2.6%	**22.4%**	0.8%	4.7%	0.9%	0.6%
Total Peaks						6	2	4		1	6	

Fig. 3.6.2.2. Top months of relative abundance for abundant species collected in the Crystal River estuary, March 2008 – February 2010. Values associated with each species and month represent the percentage of the total relative abundance that was collected during that month. Dark gray shading indicates peak months (>=15% of total relative abundance), light gray shading indicates occurrence (>0%), and the absence of shading indicates that the species was not captured during that month. Values associated with Total Peaks are counts of the species with peaks (dark gray shading; >=15%) during each month.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Offshore Spawners												
Farfantepenaeus duorarum						□		■	□	■		
Lagodon rhomboides	□	■	□	□								
Leiostomus xanthurus	□	■	□	□								
Sciaenops ocellatus	□	□								■	■	■
Mugil cephalus	■	■	□									□
Total Peaks	1	3						1		2	1	1
Nearshore Spawners												
Callinectes sapidus	□	■	□	□		□		□		■	■	□
Anchoa hepsetus				□	□	■						
Eucinostomus gula	□	□					□	■	□	■	□	□
Eucinostomus harengulus	□	□	□	□	□	□	□	■	□			■
Total Peaks		1				1		2		2	1	1
Estuarine Spawners												
Anchoa mitchilli					□			■	■			
Strongylura notata					□	□		□				
Strongylura timucu						□	□	□			□	□
Floridichthys carpio		□				□		□		■	□	□
Trinectes maculatus	□		□	□			□	□	□	□	□	□
Total Peaks								1	1	1		
Tidal River Residents												
Cyprinodon variegatus		■		□	□	□	□	■	□	■	□	■
Fundulus grandis	□			□	□	□					□	
Fundulus similis				□		□				■	□	
Lucania parva	□	□	□	□	□	□	□	■	□	■	□	■
Lucania goodei			□	□		■	□	□	□	□	■	□
Gambusia holbrooki		□		□		□	□				■	□
Heterandria formosa							□	□			■	■
Micropterus salmoides				□	□							
Gobiosoma bosc	□	□	□	□	□	□	□	■	□	□	■	□
Microgobius gulosus		□		□	■	□	□		□	□	□	
Total Peaks		1			1	1		3		3	3	3

Fig. 3.6.2.3. Months of occurrence (□) and peak abundance (■) for newly recruited nekton collected in the Crystal River estuary, March 2008 – February 2010.

3.7 Distribution (km_U) Responses to Freshwater Inflow

3.7.1 Plankton Net

Nine (14%) of the 66 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. Six of these were negative responses, wherein animals moved downstream as inflows increased (*Table 3.7.1.1*). Downstream movement is the typical inflow response seen in tidal rivers on Florida's west coast. Three taxa moved upstream as freshwater flows increased. The time lags for these responses were highly variable, ranging from 1 to 120 days.

Table 3.7.1.1. Plankton-net organism distribution (km_U) responses to mean freshwater inflow (Ln *F*), ranked by linear regression slope. Other regression statistics are sample size (*n*), intercept (*Int.*), slope probability (*P*) and fit (r^2, as %). *DW* identifies where serial correlation is possible (x indicates p<0.05 for Durbin-Watson statistic). *D* is the number of daily inflow values used to calculate mean freshwater inflow.

Description	***Common Name***	***n***	***Int.***	***Slope***	***P***	***r^2***	***DW***	***D***
Microgobius spp. flexion larvae	gobies	14	58.389	-7.837	0.0208	37		120
Menidia spp. preflexion larvae	silversides	12	28.399	-3.315	0.0471	34	x	3
decapod zoeae	crab larvae	17	23.438	-2.823	0.0120	35		4
gobiid preflexion larvae	gobies	16	19.407	-2.141	0.0327	29		2
Acartia tonsa	copepod	18	14.798	-2.060	0.0221	29		2
ostracods, podocopid	ostracods, seed shrimps	13	21.688	-1.726	0.0452	32		1
Americamysis bahia	opossum shrimp, mysid	12	-13.622	1.869	0.0455	34		2
Taphromysis bowmani	opossum shrimp, mysid	18	-10.413	2.930	0.0228	28	x	2
decapod megalopae	post-zoea crab larvae	16	-18.537	3.025	0.0494	25		56

3.7.2 Seine.

Twenty-three percent (n=6) of the 26 pseudo-species evaluated for distributional responses to freshwater inflow exhibited significant response for at least one lagged flow period. For the purposes of this discussion, we refer only to the best fit models for each of these six pseudo-species (i.e., statistically significant [α<0.05] models with normally distributed residuals that explain the greatest proportion of the variance [highest adjusted r^2 value] for each pseudo-species) (*Table 3.7.2.1*). Best fit models are plotted for each pseudo-species in *Appendix F*.

Five of the six pseudo-species with significant distributional responses to inflow showed an atypical pattern of upstream movement in response to increasing inflow (*Table 3.7.2.1*). Only the pink shrimp (*F. duorarum*) demonstrated the typical negative response to increased inflow (downstream movement with increased inflow). Most (67%) of the best-fit significant responses occurred for same day inflow. Although several of the regressions relied upon a relatively high percentage of interpolated flow data (≥33%; *Table 3.7.2.1* and *Appendix F*), regressions with the interpolated flow data removed resulted in the same response, but with an improved fit (adj. r^2). The center of abundance for three of the taxa (*S. notata*, *E. harengulus*, and large *L. rhomboides*) occurred farthest downstream when an extreme weather event (Hurricane Ike) pushed Gulf of Mexico waters into the Crystal River estuary, resulting in abnormally high salinity (*Fig. 3.2.2*) and the lowest inflow during any of the seine survey event (68cfs). Regressions on these three taxa with data for the extreme weather event removed did not result in a significant regression; the regressions for these three taxa should not be considered representative of normal responses to inflow.

The range in the predicted distributional changes (maximum to minimum change) tended to be relatively large (3.7 – 5.1 km) for all taxa. The species with the largest change in predicted distribution was the offshore spawner, large *L. rhomboides* (pinfish) which moved 5.1 km downstream as flows decreased from 1,041 to 68 cfs. This response was heavily influenced by the extreme weather event (Hurricane Ike) and likely does not represent a typical response to freshwater inflow for this species.

Table 3.7.2.1. Best-fit pseudo-species distributional response to continuously-lagged mean freshwater inflow (ln(km_U) vs. ln(inflow)) for the Crystal River estuary. Life History categories are Estuarine Spawners (ES), Nearshore Spawners (NS), and Offshore Spawners (OS). Degrees of freedom (*df*), intercept (Int.), slope, probability that the slope is significant (*P*), and fit (Adj-r^2) are provided. The number of days in the continuously-lagged mean inflow is represented by *D*. An —"xin *DW* indicates that the Durbin-Watson statistic was significant (p<0.05), a possible indication that serial correlation was present. The percentage of flow data that was extrapolated is indicated (% Ext. Flows).

Species	***Common name***	***Life History***	***Size (mm)***	***df***	***Int.***	***Slope***	***P***	***Adj. r2***	***DW***	***D***	***% Ext. Flows***
Farfantepenaeus duorarum	Pink shrimp	OS	≤20	12	5.0043	-0.4025	0.0224	0.3107		91	12.22
Palaemonetes pugio	Daggerblade grass shrimp	ES	All	15	0.0808	0.3620	0.0278	0.2355		21	11.64
Strongylura notata	Redfin needlefish	ES	≥151	13	0.3637	0.2636	0.0349	0.2450	x	1	33.33
Eucinostomus harengulus	Tidewater mojarra	NS	≥40	16	1.6787	0.1223	0.0284	0.2204	x	1	33.33
Lagodon rhomboides	Pinfish	OS	≤40	8	-1.6097	0.5953	0.0054	0.5955		1	33.33
Lagodon rhomboides	Pinfish	OS	≥41	13	0.5762	0.2514	0.0442	0.2206		1	33.33

3.8 Abundance (N, $\bar{N}$) Responses to Freshwater Inflow

3.8.1 Plankton Net

Six (9%) of the 66 plankton-net taxa evaluated for abundance relationships with freshwater inflow exhibited significant responses (*Table 3.8.1.1*). Only two of these were positive responses. Negative responses were more common; these are usually caused by elevated flows washing marine-derived taxa out of the survey area, which is consistent with all taxa except gammaridean amphipods – the three taxa with the strongest negative responses (movement downstream during relatively elevated flows) were planktonic copepods. Gammaridean amphipods are a diverse group, but many species are associated with decomposing vascular plant detritus, which is often particularly abundant near wetlands. Downstream movement of plant detritus, in the form of bedload or suspended particles, during periods of elevated inflow is one mechanism that could explain the seaward movement of these amphipods during high-inflow periods. The positive response by chironomid larvae, which are primarily freshwater organisms in this case, reflects the creation of more freshwater habitat during high-inflow periods. A similar relationship may have existed for the mysid *Taphromysis bowmani*, which tends to occupy freshwater and oligohaline habitats (*Figure 3.8.1.1*).

Table 3.8.1.1. Plankton-net organism abundance responses to mean freshwater inflow (Ln *F*), ranked by linear regression slope. Other regression statistics are sample size (*n*), intercept (*Int.*), slope probability (*P*) and fit (r^2, as %). *DW* identifies where serial correlation is possible (x indicates $p<0.05$ for Durbin-Watson statistic). *D* is the number of daily inflow values used to calculate mean freshwater inflow.

Description	***Common Name***	***n***	***Int.***	***Slope***	***P***	***r^2***	***DW***	***D***
Monstrilla sp.	copepod	12	69.484	-8.581	0.0265	40	x	120
Temora turbinata	copepod	14	31.563	-3.042	0.0042	51	x	4
Pseudodiaptomus coronatus	copepod	18	24.892	-1.690	0.0162	31		14
amphipods, gammaridean	amphipods	18	29.484	-1.559	0.0169	31		24
dipterans, chironomid larvae	midges	18	6.391	0.976	0.0268	27		2
Taphromysis bowmani	opossum shrimp, mysid	18	1.409	1.721	0.0171	31		4

Fig. 3.8.1.1. Time series of the abundances of the low-salinity mysid *Taphromysis bowmani* and primarily freshwater midge larvae (chironomids) in relation to flow from the main spring in the Crystal River estuary. The estimates of number are estimates of the total number of individuals in the channel of the surveyed transect, as described in Section 2.7.4.

3.8.2 Seine.

Among the 21 pseudo-species considered in these analyses, abundances of over 50% (n=11) were significantly related to inflow (*Table 3.8.2.1*). The greatest proportion of variance in abundance (best fit model; *Appendix H*) was explained by linear regressions for six pseudo-species and by quadratic regressions for five pseudo-species. Of the six linear models, two were negative relationships, indicating increasing abundance with decreasing inflow and four were positive relationships. Pseudo-species with quadratic relationships between inflow and abundance were split between situations with the greatest abundance at intermediate inflows (‘intermediate-maximum‘, n=2) and minimum abundance at intermediate inflows (‘intermediate-minimum‘, n=3).

The percentage of significant abundance responses to inflow ranged from 20% of tested pseudo-species in nearshore spawners to 100% in offshore spawners (*Fig.*

3.8.2.1). Most life history categories exhibited linear responses to inflow (28.6%) with more negative (i.e., abundance increased with decreasing inflow, n=4) than positive (n=2) responses. Relationships between inflow and abundance showed an intermittent maximum response in approximately 17% and 13% of the best fit relationships for tidal river residents and estuarine spawners, respectively. Intermittent minimum relationships were the most common response in estuarine spawners (n=3).

Long-term lag periods accounted for the highest percentage of the best-fit regression responses in tidal river residents (*Fig. 3.8.2.2*). Taxa characterized as offshore spawners were split between short and long inflow lag periods. Only intermediate inflow lags (21-91 days) provided best-fit regression models for nearshore spawners. The low occurrence of short-term inflow lag periods resulted in relatively few regressions that had a high percentage of interpolated flow data (≥33%; *Table 3.8.2.1* and *Appendix H*). As with the distributional regressions, abundance regressions run with the high percentage (>25%) of interpolated flow data omitted resulted in the same responses and better fits (adj. r^2).

Six of the eleven pseudo-species had greater than 50% of the variance in their abundance explained by inflow. These pseudo-species with the strongest relationships to inflow included three estuarine spawners (*S. notata*, *S. timucu*, and goldspotted killifish *Floridichthys carpio*), two offshore spawners (*F. duorarum* and large *L. rhomboides*) and one nearshore spawner (*E. gula*). Relationships of abundance to flow in these six pseudo-species were positive linear (n=1; *Appendix Fig. H6*), negative linear (n=3; *Appendix Figs. H1*, *H9* and *H10*), and intermediate-minimum (n=2; *Appendix Figs. H5* and *H8*). An increase in abundance with increased flow (positive linear response) may suggest beneficial aspects of increased nutrient input, better detection of the tidal-river nursery area, or possibly increased prey-capture success for visual predators in clearer water. A decrease in abundance with increased inflow (negative linear response) could indicate a physical displacement to unsuitable habitats, a movement into flooded habitats that have become available (emergent marshes), a dilution of the chemical cues that draw animals into the tidal-river nursery areas, or decreased predation success by visual predators in more opaque waters. Intermediate-

minimum relationships, where abundance is greatest at either low or high flows and least at intermediate flows, are difficult to explain in ecological terms

Table 3.8.2.1. Best-fit seine -based pseudo-species abundance ($\overline{N}$) response to continuously-lagged mean freshwater inflow (ln(cpue) vs. ln(inflow)) for the Crystal River estuary. Life History categories are Estuarine Spawners (ES), Tidal River Residents (TRR), Nearshore Spawners (NS), and Offshore Spawners (OS). The type of response (*Resp*) is either linear (L) or quadratic (Q). Degrees of freedom (*df*), intercept (*Int.*), slope (*Linear coef.*), probability that the slope is significant (*Linear P*), quadratic coefficient (*Quad. coef.*), probability that the quadratic coefficient is significant (*Quad. P*) and fit (*Adj.* r^2) are provided. The number of days in the continuously-lagged mean inflow is represented by *D*. An "x" in *DW* indicates that the Durbin-Watson statistic was significant (p<0.05), a possible indication that serial correlation was present. The percentage of flow data that was extrapolated is indicated (% Ext. Flows).

									Linear		Quadratic					%
Species	**Common name**	**Life History**	**Zones**	**Size**	**Period**	**Res.**	**df**	**Int.**	**Coef.**	**P**	**Coef.**	**P**	**Adj-r^2**	**DW**	**D**	**Ext. Flows**
Farfantepenaeus duorarum	Pink shrimp	OS	1,2,3,4,5,6	≤20	Jun. to Nov.	L	7	21.872	-3.096	0.000	.	.	0.885		161	11.67
Palaemonetes pugio	Daggerblade grass shrimp	ES	4,5,6	All	Jan. to Dec.	Q	15	1762.310	-528.665	0.045	39.672	0.045	0.140		364	12.18
Anchoa mitchilli	Bay anchovy	ES	1,2,3,4,5,6	≤30	Feb. to Dec.	L	15	-38.745	6.169	0.042	.	.	0.197		308	12.56
Anchoa mitchilli	Bay anchovy	ES	1,2,3,4,5,6	≥31	Feb. to Dec.	Q	14	-674.183	203.462	0.004	-15.268	0.004	0.402		28	12.40
Strongylura notata	Redfin needlefish	ES	1,2,3,4,5,6	≥151	Sep. to Mar.	Q	7	381.087	-116.169	0.001	8.849	0.001	0.764		210	9.67
Strongylura timucu	Timucu	ES	1,2,3,4,5,6	≥151	Aug. to Mar.	L	10	-1.487	0.365	0.002	.	.	0.596	x	1	33.33
Lucania parva	Rainwater killifish	TRR	4,5,6	All	Jan. to Dec.	Q	15	-2029.768	608.502	0.002	-45.492	0.002	0.445	x	364	12.18
Floridichthys carpio	Goldspotted killifish	ES	1,2,3,4,5,6	All	Oct. to Feb.	Q	5	1004.994	-300.479	0.012	22.452	0.012	0.670		1	37.50
Eucinostomus gula	Silver jenny	NS	1,2,3,4,5	≥40	Jul. to Dec.	L	7	22.046	-3.000	0.001	.	.	0.778		238	11.86
Lagodon rhomboides	Pinfish	OS	1,2,3,4,5,6	≥41	May to Oct.	L	7	18.987	-2.633	0.007	.	.	0.617		7	1.59
Microgobius gulosus	Clown goby	TRR	1,2,3,4,5,6	All	Apr. to Aug.	L	6	97.100	-14.107	0.033	.	.	0.486		287	14.04

Fig. 3.8.2.1. Summary of regression results by response type and life history category for the 21 pseudo-species assessed for abundance ($\overline{N}$) in relation to inflow from the Crystal River estuary. Positive and negative indicate a linear increase and decrease in abundance with increasing inflow, respectively, while intermediate-maximum and intermediate-minimum indicate maximum and minimum abundance at intermediate inflows, respectively. The number of pseudo-species within each life history category that did not have significant abundance responses to inflow are also displayed (Not Significant). The numbers at the top of the graph indicate the number of pseudo-species assessed within each life history category.

Fig. 3.8.2.2. Summary of best-fit regression results by lag period and life history category for the 21 pseudo-species assessed for abundance ($\bar{N}$) in relation to inflow from the Crystal River estuary. Lag periods were categorized as short (1 to 14 days), medium (21 to 91 days), and long (98 to 364 days). The number of pseudo-species within each life history category that did not have significant abundance responses to inflow are also displayed (Not Significant). The numbers at the top of the graph indicate the number of pseudo-species assessed within each life history category.

3.9 Community structure

3.9.1 Plankton net: Community Heterogeneity (*H*) Responses to Freshwater Inflow

Invertebrates collected by plankton net (*Fig. 3.9.1.1*, lower panel) always formed a fairly strong community gradient along the Crystal River estuary's principal axis, whereas fishes collected by the same gear did not (*Fig. 3.9.1.1*, upper panel). Variation in diversity along this gradient (i.e., beta diversity or "community heterogeneity") did not correspond to the observed variation in spring flow for either fishes or invertebrates. In other words, there was no indication of a relationship between flow and community heterogeneity (H) – at least as indicated by plankton-net data – within the Crystal River estuary. The inflows that occurred during the survey period were large enough and stable enough to prevent strong, landward invasions of planktonic, marine-derived organisms from seaward waters.

Fig. 3.9.1.1. Comparison of fish (upper panel) and invertebrate (lower panel) similarity among sampling zones, with two observations (plankton-net tows) per zone for each of 18 collection events.

3.9.2 Seines

Community structure changed spatially and temporally in all of the surveyed habitats of the Crystal River. In the shallow shoreline (seined) area, community structure was significantly different between zones (ANOSIM R = 0.467, P = 0.001). Similarity between the lowermost zone of the Crystal River and other river zones decreased steadily with distance upstream. The overall change in community structure was fairly slow and progressive (*Table 3.9.2.1*). In general, pairwise comparisons revealed that the difference in community structure between adjacent zones was greatest between zones 3 and 4 and between zones 4 and 5. There were moderate differences between zone 1 and 2 and zones 5 and 6 (ANOSIM R = 0.224 and R = 0.259, P = 0.001 and P = 0.001, respectively), whereas there was a somewhat greater difference in community structure between zones 3 and 4 and zones 4 and 5 (ANOSIM R = 0.347 and R = 0.327, P = 0.001 and P = 0.001, respectively) and minimal difference between zones two and three (ANOSIM R = 0.031, P = 0.31) (*Table 3.9.2.1*). However, the maximal differences between zones were moderate, indicating somewhat minimal changes in community structure among adjacent zones. This was reflected in the MDS plot, wherein the samples from all zones have considerable overlap. There is a very general pattern of progression from zone 1 on the bottom of the plot to zone 6 on the top of the plot (*Fig. 3.9.2.1*). The main drivers of community change between adjacent zones were shifts in abundance of *Menidia* spp., *A. mitchilli, E. harengulus, Eucinostomus* spp., *L. parva*, and *P. intermedius* (*Table 3.9.2.2*). The maximal difference between zones occurred between zones 3 and 4. The top species contributing to dissimilarity include all three size classes of *Menidia spp., E. harengulus* from 51-80 mm, and *A. mitchilli* from 31-50 mm (*Table 3.9.2.2*).

There were also significant differences in community structure between month-years in the shoreline habitat (ANOSIM R = 0.490, P = 0.001). Community structure in the seined habitat changed annually in a regular, cyclical manner (RELATE ρ = 0.432, P = 0.001); the correlation with an annual cycle was similar in magnitude to the correlation with monthly physicochemical changes but greater than the correlation with flow (*Table 3.9.2.3*). Correlations with physicochemical variables were greatest with a single variable (temperature). Correlations with lagged flows of different periods were greatest

with 364-day lagged flows (*Table 3.9.2.3*). In general individual river zones were more highly correlated with physicochemical variables than with flow or an annual regular cycle. Physicochemical variables such as depth, percent bottom vegetation cover, dissolved oxygen (D.O.), temperature, salinity and total shore cover all significantly impacted nekton community structure (*Table 3.9.2.3*).

Table 3.9.2.1. Pairwise differences in community structure from 21.3-m seines set along shorelines of the Crystal River.

Zone Pairs	River Km	Anosim *R*	*P*
CR1 - CR2	-0.9-1.79 km, 1.80-3.79 km	0.224	0.001
CR1 - CR3	-0.9-1.79 km, 3.80-5.69 km	0.334	0.001
CR1 - CR4	-0.9-1.79 km, 5.70-7.59 km	0.492	0.001
CR1 - CR5	-0.9-1.79 km, 7.60-9.89 km	0.573	0.001
CR1 - CR6	-0.9-1.79 km, 9.90-12.10 km	0.744	0.001
CR2 - CR3	1.80-3.79 km, 3.80-5.69 km	0.031	0.303
CR2 - CR4	1.80-3.79 km, 5.70-7.59 km	0.468	0.001
CR2 - CR5	1.80-3.79 km, 7.60-9.89 km	0.570	0.001
CR2 - CR6	1.80-3.79 km, 9.90-12.10 km	0.743	0.001
CR3 - CR4	3.80-5.69 km, 5.70-7.59 km	0.347	0.001
CR3 - CR5	3.80-5.69 km, 7.60-9.89 km	0.505	0.001
CR3 - CR6	3.80-5.69 km, 9.90-12.10 km	0.700	0.001
CR4 - CR5	5.70-7.59 km, 7.60-9.89 km	0.327	0.001
CR4 - CR6	5.70-7.59 km, 9.90-12.10 km	0.561	0.001
CR5 - CR6	7.60-9.89 km, 9.90-12.10 km	0.259	0.001

Fig. 3.9.2.1. Nonmetric Multidimensional Scaling (MDS) ordination plot of the shoreline 21.3-m-seine nekton community structure in the Crystal River.

Table 3.9.2.2. Pseudo-species characterizing dissimilarity between adjacent zones in the Crystal River. Abundance (Abd.) represents the mean of the square root-transformed abundance per seine. Average dissimilarity (Avg. Diss) represents the dissimilarity between adjacent river zones.

CR1 - CR2 (-0.9 - 1.79 km & 1.80 - 3.79 km)

Species	CR1 Abd.	CR2 Abd.	Avg. Diss
Menidia spp. 51-80 mm	1.85	0.90	4.74
A. mitchilli < 31 mm	1.07	1.47	3.53
A. mitchilli 31-50 mm	1.55	1.15	3.42
P. intermedius	1.56	0.49	2.83
Menidia spp. 31-50 mm	1.51	0.70	2.79
C. sapidus < 31 mm	0.21	0.74	2.21
M. cephalus < 31 mm	0.15	0.76	1.83
E. harengulus 51-80 mm	0.88	0.86	1.71
Eucinostomus spp. < 31 mm	1.09	0.52	1.70
E. gula 51-80 mm	1.03	0.64	1.62

CR2 - CR3 (1.80 - 3.79 km & 3.80 - 5.69 km)

Species	CR2 Abd.	CR3 Abd.	Avg. Diss
E. harengulus 51-80 mm	0.86	1.95	3.91
A. mitchilli 31-50 mm	1.15	1.69	3.86
A. mitchilli < 31 mm	1.47	2.35	3.32
Menidia spp. 31-50 mm	0.70	1.36	1.83
Eucinostomus spp. 31-39 mm	0.26	0.75	1.62
Menidia spp. 51-80 mm	0.90	1.16	1.55
C. sapidus < 31 mm	0.74	0.69	1.52
M. cephalus < 31 mm	0.76	0.22	1.43
A. hepsetus < 31 mm	0.27	0.73	1.43
A. hepsetus 31-50 mm	0.69	0.90	1.37

CR3 - CR4 (3.80 - 5.69 km & 5.70 - 7.59 km)

Species	CR3 Abd.	CR4 Abd.	Avg. Diss
*Menidia spp. 3*1-50 mm	1.36	3.14	4.96
E. harengulus 51-80 mm	1.95	3.04	3.81
Menidia spp. 51-80 mm	1.16	1.41	3.51
Menidia spp. < 31 mm	0.08	1.24	2.68
A. mitchilli 31-50 mm	1.69	0.39	2.48
A. mitchilli < 31 mm	2.35	1.02	2.29
Eucinostomus spp. < 31 mm	0.58	1.72	2.18
E. harengulus 31-39 mm	0.45	1.27	2.06
P. pugio	0.27	1.61	1.82
P. intermedius	0.40	1.42	1.76

CR4 - CR5 (5.70 - 7.59 km & 7.60 - 9.89 km)

Species	CR4 Abd.	CR5 Abd.	Avg. Diss
A. mitchilli < 31 mm	1.02	3.73	4.74
A. mitchilli 31-50 mm	0.39	2.90	3.95
*Menidia spp. 3*1-50 mm	3.14	5.84	3.76
Eucinostomus spp. < 31 mm	1.72	2.70	3.36
Eucinostomus spp. 31-39 mm	1.52	3.65	3.08
L. parva < 31 mm	0.70	2.87	3.02
E. harengulus 51-80 mm	3.04	2.86	2.90
P. pugio	1.61	1.59	2.00
Menidia spp. < 31 mm	1.24	2.67	1.92
P. intermedius	1.42	1.96	1.85

CR5 - CR6 (7.60 - 9.89 km & 9.90 - 12.10 km)

Species	CR5 Abd.	CR6 Abd.	Avg. Diss
L. parva < 31 mm	2.87	8.49	6.13
*Menidia spp. 3*1-50 mm	5.84	8.39	4.43
A. mitchilli < 31 mm	3.73	2.58	3.15
Menidia spp. < 31 mm	2.67	4.10	2.92
Eucinostomus spp. < 31 mm	2.70	3.65	2.54
E. harengulus 51-80 mm	2.86	3.52	2.43
L. xanthurus < 31 mm	1.62	0.31	2.29
Eucinostomus spp. 31-39 mm	3.65	2.59	2.21
*Menidia spp. 5*1-80 mm	2.01	1.41	1.98
A. mitchilli 31-50 mm	2.90	1.43	1.98

Table 3.9.2.3. Summary of results correlating monthly change in nekton community structure with seasonal and physicochemical changes in the shoreline (21.3-m seines) habitats of the Crystal River.

Zone	Correlation with regular annual cycle (Relate)	BIO-ENV (Up to 5 Physicochemical variables)	BIO-ENV (1 Physicochemical variable)	BIO-ENV (flow)
CR1	0.388	0.438 (Depth, % Bottom Veg Cover, D.O.)	0.276 (Depth) *0.075 (Salinity)*	0.159 (364-day lag)
CR2	0.419	0.530 (Secchi depth, Total Shore Cover, Temp., Salinity, D.O.)	0.332 (Total shore cover) *0.266 (Salinity)*	0.184 (364-day lag)
CR3	0.302	0.501 (% Bottom veg. cover, Total shore cover, Temp., Salinity, D.O.)	0.338 (Temp.) *0.319 (Salinity)*	0.158 (364-day lag)
CR4	0.344	0.454 (Total shore cover)	0.454 (Total shore cover) *-0.054 (Salinity)*	0.312 (364-day lag)
CR5	0.285	0.473 (Depth, Temp., D.O.)	0.295 (D.O.) *0.209 (Salinity)*	0.229 (354-day lag)
CR6	0.307	0.532 (% Bottom veg. cover, Temp.)	0.503 (Temp.) *0.236 (Salinity)*	0.394 (364-day lag)
All Zones	0.432	0.496 (Temp.)	0.496 (Temp.)	0.329 (364-day lag)

The heterogeneity in nekton community structure of the shoreline habitat of the Crystal River was not significantly related to freshwater inflow (although there was a non-significant positive trend at 7 day lagged inflow, P = 0.89; *Fig. 3.9.2.3*). When the relationship between heterogeneity in nekton community structure and 364-day lagged freshwater inflow was examined the relationship was not significant, but negative (P = 0.15; *Fig. 3.9.2.3*). Similarly, the relationship between nekton community heterogeneity and salinity was negative but not significant (*Fig. 3.9.2.4*). Comparison of the same

month with different flows between years did not show the hypothesized trend of increasing similarity between the shoreline nekton community of the lower and uppermost Crystal River zones as flows decreased (*Fig. 3.9.2.5*). Instead similarity was relatively unchanged and the regression line was fairly flat (*Fig. 3.9.2.5*).

The overall lack of distinct community change between adjacent zones, the slow progression of change with movement upriver, and lack of highly significant correlations with physicochemical variables suggest that there are either important environmental driving factors unaccounted for within this analysis or that there is little difference in environmental variables between zones. An examination of the SIMPER results lends credence to the hypothesis that environmental variables are not sufficiently different between zones to effect significant community change. The pseudo-species driving community structure change are largely similar across zones, with changes in abundance being the main determining factor of community change. Abundances do not change in a linear fashion with distance upstream but instead fluctuate up and down in an irregular pattern. This irregular fluctuation in abundance may be related to movements in pseudo-species center of abundance in relation to changes in flow or other physic-chemical variables.

There is also considerable intra-annual variation in community structure. A comparison of community structure between months of successive years reveals significant dissimilarity of community assemblage (*Figure 3.9.2.6*: example comparing October 2008 and 2009). The greatest separation in these comparisons occurs at the lowermost river zones. That is to say zones 5 and 6 were more similar between successive years than were zones 1 and 2. This intra-annual variation is likely responsible for some of the lack of separation in the comprehensive analysis.

Fig. 3.9.2.3. Relationship between spring inflows and nekton community heterogeneity in the Crystal River (measured as relative dispersion). Fitted regression lines (—) and 95% confidence intervals (—) are plotted.

Fig. 3.9.2.4. Relationship between average monthly salinity and nekton community heterogeneity in the Crystal River (measured as relative dispersion). Fitted regression lines (—) and 95% confidence intervals (—) are plotted.

Fig. 3.9.2.5. Bray-Curtis similarity of nekton community structure between Crystal River zone 1 (km -0.90 - 1.79) and Crystal River zone 6 (km 9.90 – 12.10) for 21.3-m shoreline seines from a given month in year 1 of the study compared to the same month in year 2 (with similarity in year 2 expressed as a percentage of year 1), in relation to flows in year 2 expressed as a percentage of flows in year 1.

Fig. 3.9.2.6. Nonmetric Multidimensional Scaling (MDS) ordination plot of the shoreline 21.3-m-seine nekton community structure in the Crystal River in the same month from successive years.

4.0 CONCLUSIONS

4.1 Descriptive Observations

1) **Physico-chemical Conditions.** Salinity and pH trends differed between the plankton and seine surveys, most likely because of differences in the depths (seines ≤1.8m, plankton nets ≤6-m), flows and circulation patterns in the areas sampled. A tropical system (Hurricane Ike) pushed Gulf of Mexico waters into the Crystal River estuary from 9/10/2008 – 9/11/2008 resulting in a large peak in salinity in this system when seine samples were collected on 9/11/2008. A longer-term (8 month) increase in salinity in the deeper waters sampled by plankton-nets could not be easily explained by changes in inflow or specific weather patterns. It is likely that short- and long-term salinity changes like these have the potential to impact critical fishery habitats such as submerged aquatic vegetation in these relatively stable spring-fed systems.

2) **Dominant Catch.** In the plankton-net collections, the fish catch was dominated by gobies, with the genus *Gobiosoma* being most common, distantly followed by *Microgobius* spp. and then the frillfin goby (*Bathygobius soporator*). Anchovies, notably the bay anchovy (*Anchoa mitchilli*) were also collected in fairly large numbers, although the catch was low compared to surface-fed estuaries in west-central Florida. Other well-represented fishes included menhaden (*Brevoortia* spp.), silversides (*Menidia* spp.), rainwater killifish (*Lucania parva*), eucinostomus mojarras (*Eucinostomus* spp.), spot (*Leiostomus xanthurus*), skilletfish (*Gobiesox strumosus*), and blennies (only the Florida blenny, *Chasmodes saburrae*, and highfin blenny, *Lupinoblennius nicholsi* were positively identified).

The plankton-net invertebrate catch was dominated by larval crabs (decapod zoeae and megalopae), gammaridean amphipods, cumaceans, the mysids *Americamysis almyra* and *Bowmaniella dissimilis*, the copepod *Acartia tonsa*, and larval shrimps (decapod mysis). The phantom midge larva *Chaoborus punctipinnis* and cyclopoid copepod *Mesocyclops edax*, which are indicative of reservoir waters and

other lacustrine settings, were rarely encountered in the spring-fed Crystal River estuary. The river-plume-associated calanoid copepod *Acartia tonsa* was regularly encountered near the river mouth in low to moderate numbers, but other plume-associated taxa such as the calanoid coepod *Labidocera aestiva*, the chaetognaths *Sagitta* spp., the planktonic shrimp *Lucifer faxoni*, and the ostracod *Parasterope pollex*, were less common than they typically are in more nutrient-rich estuarine plumes along the west-central Florida coast.

The seine catch of fishes in the Crystal River estuary was dominated by small-bodied resident and transient taxa with most being typical of a Florida gulf coast estuary such as silversides (*Menidia* spp.), bay anchovy (*Anchoa mitchilli*), rainwater killifish (*Lucania parva*), and eucinostomus mojarras (*Eucinostomus* spp.). Freshwater oriented taxa such as bluefin killifish (*Lucania goodei*), largemouth bass (*Micropterus salmoides*) and sunfishes (*Lepomis macrochirus*, *L. microlophus*, and *L. punctatus*) were present but did not represent a large portion of the catch. The seine catch of invertebrates was dominated by grass shrimp (*Palaemonetes intermedius* and *P. pugio*), blue crabs (*Callinectes sapidus*) and pink shrimp (*Farfantepenaeus duorarum*).

3) **Use of Area as Spawning Habitat.** The eggs of the bay anchovy (*Anchoa mitchilli*), the rainwater killifish (*Lucania parva*), other killifishes (*Fundulus* spp.), unidentified gobies, and unidentified percomorph (primarily sciaenid) fishes were collected from the survey area. None of these fish eggs were abundant, but the bay anchovy and sciaenid eggs were more abundant than the other types – both were most abundant near the river mouth and especially in the Gulf of Mexico. If it is assumed that the relative abundances of different species of early-stage sciaenid larvae reflect the local, relative spawning intensity, then kingfishes (*Menticirrhus* spp.), sand seatrout (*Cynoscion arenarius*) and spotted seatrout (*C. nebulosus*) are the sciaenids that are most likely to have spawned in the study area. Blennies and skilletfish (*Gobiesox strumosus*) spawned near the river mouth – probably in association with oyster-shell substrates. Gobies (primarily Gobiosoma spp. and *Microgobius* spp.) and *Menidia* appear to have spawned throughout much of the interior of the tidal river. The presence of rainwater killifish eggs upstream suggests upstream spawning by this species, a pattern that was supported by the distribution of subsequent developmental stages. The

collection of very small juveniles of live-bearing pipefishes suggests that these species also reproduce within the local area.

4) **Use of Area as Nursery Habitat.** Estuarine-dependent taxa that spawn in offshore and nearshore waters were present, but not prominent in the seine samples. Seven of the twelve most abundant taxa collected can be considered estuary-dependent but only comprised 28% of the total seine catch. These include taxa of direct economic importance such as spot (*Leiostomus xanthurus*), striped mullet (*Mugil cephalus*), and blue crabs (*Callinectes sapidus*) and numerically abundant taxa that undoubtedly play a vital ecological role in the Crystal River estuary (*Eucinostomus* spp., *E. harengulus*, *Anchoa hepsetus*, and *Lagodon rhomboides*). Although not among the dominant taxa, there are a couple of estuarine dependent taxa that have been absent or collected very infrequently in other spring-fed systems (Homosassa, Chassahowitzka, and Weeki Wachee rivers) that were relatively more common and abundant (*S. ocellatus*) or were at least collected (*C. arenarius*) from the Crystal River estuary.

5) **Plankton Catch Seasonality.** Alteration of flows would appear to have the lowest potential for impacting many taxa from November to February, which are the months when the fewest estuarine taxa were present. The highest potential to impact many species would appear to be from April through October. Some species were present throughout most of the year, whereas others had more seasonal spawning and recruitment patterns.

6) **Seine Catch Seasonality.** Seasonality in seine catches was obvious with the highest species richness occurring during the summer months and the lowest during the winter months. The succession of species throughout the annual cycle indicates that species recruit into the Crystal River estuary year round; flow alterations to the study area have the potential to impact nekton at any time of the year.

4.2 Responses to Freshwater Inflow

1) **Plankton Catch Distribution Responses.** Nine (14%) of the 66 plankton-net taxa evaluated for distribution responses to freshwater inflow exhibited significant responses. Six of these were negative responses, wherein animals moved downstream as inflows increased. Three taxa moved upstream as freshwater flows increased. The time lags for these responses were highly variable, ranging from 1 to 120 days.

2) **Seine Catch Distribution Responses.** Fifteen percent (n=6) of the 26 seine collected pseudo-species evaluated for distributional responses to freshwater inflow exhibited a significant response to at least one lagged flow period. Five of the significant responses were atypical with animals moving upstream in response to increased inflow (positive response). The majority of the best-fit responses were to same day inflow. Removing data from a single, extreme weather event (Hurricane Ike, 9/11/2008), resulted in three of these pseudo-species (*S. notata*, *E. harengulus*, and large *L. rhomboides*) having no significant distributional responses to inflow.

3) **Plankton Catch Abundance Responses.** Six (9%) of the 66 plankton-net taxa evaluated for abundance relationships with freshwater inflow exhibited significant responses. Only two of these were positive responses. The three taxa with the strongest negative responses (abundance decreased in response to elevated flows) were planktonic copepods. The positive response by chironomid larvae, which are primarily freshwater organisms in this case, reflects the creation of more freshwater habitat during high-inflow periods. A similar relationship may have existed for the mysid *Taphromysis bowmani*, which tends to occupy freshwater and oligohaline habitats.

4.) **Seine Catch Abundance Responses.** Fifty-two percent (n=11) of the 21 seine collected pseudo-species examined for abundance response to inflow had at least one significant response to a lagged inflow period. Over half of the best-fit responses (n=6) were linear with the majority of these (n=4) having an abundance increase with decreased inflow (negative response). The five quadratic responses were split between intermediate minimum (n=3) and intermediate maximum (n=2). Of the six best-fit

responses that had more than 50% of abundance explained by inflow, there were three estuarine spawners, two offshore spawners, and one nearshore spawner.

4.3 Community Structure

1) **Plankton Net Community Responses to Freshwater Inflow.** There was no indication of a relationship between flow and community heterogeneity in the plankton-net data. The inflows that occurred during the survey period were large enough and stable enough to prevent strong, landward invasions of planktonic, marine-derived organisms from seaward waters. A fairly strong community gradient was always present along the Crystal River estuary‘s survey transect. Invertebrates collected by plankton net always formed a fairly strong community gradient along the Crystal River estuary‘s principal axis, whereas fishes collected by this same gear did not. Variation in diversity along this gradient (i.e., beta diversity or ~~c~~ommunity heterogeneity”) did not correspond to the observed variation in spring flow for either fishes or invertebrates. In other words, there was no indication of a relationship between flow and community heterogeneity – at least as indicated by plankton-net data – within the Crystal River estuary.

2) **Seine Catch Community Analyses.** There were significant differences in community structure between the zones in the Crystal River estuary. The overall change was slow and progressive such that adjacent zones were very like each other but separated zones were less like each other. There were also significant differences in community structure between month-years that correlated to an annual cycle of physic-chemical (especially temperature) changes better than with flow. The heterogeneity of the nekton community structure was not significantly related to inflow or salinity. The overall lack of distinct community change between adjacent zones, the slow progression of change with movement upriver, and lack of highly significant correlations with physic-chemical variables suggest that there are either important environmental driving factors unaccounted for within this analysis or that there is little difference in environmental variables between zones.

4.4 Synthesis

The Crystal River estuary had a relatively stable salinity distribution during this study. Despite being tidally influenced and experiencing a fairly wide range of inflows, the median salinity was typically below 10 psu during plankton and seine sampling events. The seine sampling event on September 11, 2008 with a median salinity of almost 22 psu and the longer-term salinity increase (November 2008 to October 2009) identified in the plankton data demonstrate, however, that this spring-fed system may be susceptible to large, short-term and and smaller, long-term changes to salinity.

The majority of the plankton-net (6 of 9) and one of the six seine-net collected taxa with significant distributional responses to inflow demonstrated the typical negative response, such that the center of abundance moved upstream with decreased inflow. Centers of abundance most likely shifted upstream in response to reduced inflow because lower salinity habitats shifted upstream and individuals relocated to areas of optimal salinity. The remaining three plankton-net, and five of the six seine-net collected taxa moved downstream in response to decreased inflow (positive response). Regressions for three of the seine-net collected taxa that demonstrated positive responses were strongly influenced by an extreme weather event (Hurricane Ike) that sent a large pulse of high salinity water into the Crystal River estuary on September 11, 2008; this response is likely not representative of typical conditions. The lag period for significant responses was typically 14 days or less for both plankton and nekton.

Linear responses of abundance to inflow tended to be negative (abundance increased with decreasing inflow) for both plankton-net (4 of 6) and seine-net (4 of 6) collected taxa. Two taxa each for seines-net and plankton-net collected taxa had positive linear responses to inflow, with the abundance decreasing with decreasing inflow. The two plankton-net collected taxa with the positive response were taxa that tended to occupy freshwater habitats and were likely responding to increases in freshwater and oligohaline habitat as flow increased. Quadratic responses of abundance to inflow were identified for five of the seine-collected taxa, with three taxa having intermediate minimum and two taxa having intermediate maximum response to inflow.

The structure of the nekton community sampled with seines changed between zones, but the change was very gradual with adjacent zones being very similar to each other. The relationship between flow and community heterogeneity was not evident in either the planktonic or nektonic communities. The overall lack of distinct community change between adjacent zones, the slow progression of community change with movement upriver, and lack of highly significant correlations with physicochemical variables suggest that there are either important environmental driving factors unaccounted for within this analysis or that there is little difference between environmental variables between zones.

As with many of the estuaries for which plankton and nekton sampling has been conducted, the Crystal River estuary appears to have its own defining characteristics. The lack of a strong gradient in community structure and the paucity of significant distributional and abundance responses to inflow is indicative of a relatively stable environment in which neither inflow nor salinity vary to any great degree. The pulse of high salinity water that entered the system on September 11, 2008 and the longer-term salinity increase identified in the plankton-net survey suggests that this system is vulnerable to extreme short- and long-term salinity modification. That neither of these occurrences resulted in identifiable differences in community structure would seem to indicate that these estuarine nekton and plankton communities were resilient to these types of salinity changes.

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Appendix A: Plankton-net summary tables

Table A1, page 1 of 5.

Plankton-net catch statistics (March 2008 through February 2010, n = 216 samples)

Organisms are listed in phylogenetic order.

Taxon	Common Name	Number Collected	Collection Frequency	*Kmu* (km)	*Su* (psu)	Mean CPUE (No./10³ m³)	Max CPUE (No./10³ m³)
foraminiferans	foraminiferans	3	2	2.8	15.8	0.17	23.79
medusa sp. a	hydromedusa	1	1	-3.0	29.3	0.08	16.22
medusa sp. d	hydromedusa	64	17	4.3	6.8	3.81	148.08
medusa sp. e	hydromedusa	634	3	-3.0	27.4	35.81	7499.70
medusa, Obelia sp.	hydromedusa	33	4	-2.9	28.1	2.12	391.12
medusa, Bougainvillia sp.	hydromedusa	32	8	-1.7	24.1	2.06	153.65
Clytia sp.	hydromedusa	8	3	2.1	16.1	0.55	56.47
medusa, Eutima sp.	hydromedusa	96	8	-1.9	23.1	5.73	425.43
Liriope tetraphylla	hydromedusa	1	1	-3.0	24.6	0.06	13.79
turbellarians	flatworms	6	2	8.2	4.0	0.36	54.02
nematodes	roundworms, threadworms	130	32	5.5	9.8	8.20	371.64
polychaetes	sand worms, tube worms	3,910	146	7.9	6.1	234.35	18678.88
oligochaetes	freshwater worms	111	8	11.1	1.5	6.82	1073.84
hirudinoideans	leeches	67	41	7.4	4.3	3.99	64.49
Limulus polyphemus larvae	horsehoe crab	1	1	0.1	14.0	0.05	11.43
pycnogonids	sea spiders	3	2	-3.0	24.4	0.18	24.27
acari	water mites	327	53	8.8	2.5	19.79	627.86
collembolas, podurid	springtails	8	1	11.2	1.3	0.49	106.57
ephemeropteran larvae	mayflies	47	13	11.0	1.6	2.95	234.00
odonates, zygopteran larvae	damselflies	15	12	8.8	3.0	0.85	33.96
hemipterans, corixid adults	water boatmen	1	1	11.2	1.6	0.06	12.96
hemipterans, gerrid adults	water striders	5	3	2.6	9.3	0.30	38.87
hemipterans, belostomatid adults	giant water bugs	1	1	11.2	2.0	0.06	13.08
coleopterans, noterid adults	burrowing water beetles	2	2	7.5	5.7	0.12	12.94
coleopterans, elmid adults	riffle beetles	1	1	11.2	2.2	0.06	12.05
neuropterans, Climacia spp. larvae	spongillaflies	1	1	10.3	3.4	0.06	12.25
dipterans, pupae	flies, mosquitoes	585	61	10.5	2.2	35.27	693.26
dipteran, Chaoborus punctipennis larvae	phantom midge	1	1	11.2	1.4	0.06	13.76
dipterans, chironomid larvae	midges	473	75	9.6	3.1	29.02	914.76
dipterans, ceratopogonid larvae	biting midges	147	43	9.4	3.0	8.74	294.99
dipterans, tipulid larvae	crane flies	3	1	7.0	10.8	0.17	36.00
dipterans, muscid larvae	muscid flies	2	1	7.0	7.2	0.13	27.79
dipterans, ephydrid larvae	shore flies	1	1	11.2	1.6	0.06	12.96
trichopteran larvae	caddisflies	3	2	8.7	6.0	0.18	27.66
Pseudevadne tergestina	water flea	1	1	-3.0	24.6	0.06	13.79
Penilia avirostris	water flea	11	2	-3.0	26.6	0.70	108.50
cladocerans, Daphnia spp.	water fleas	2	2	9.6	2.9	0.12	13.49
Simocephalus vetulus	water flea	290	17	11.1	1.5	17.06	2679.35
Ilyocryptus sp.	water flea	17	3	11.1	1.9	1.02	143.88
Diaphanosoma brachyurum	water flea	9	3	10.5	1.7	0.56	82.54
Sida crystallina	water flea	1	1	0.1	11.8	0.06	12.78
cirriped nauplius stage	barnacles	3,484	16	-2.6	26.7	204.99	30156.80
cirriped cypris stage	barnacles	10	7	1.4	16.1	0.64	41.91
branchiurans, Argulus spp.	fish lice	28	19	2.6	10.2	1.65	41.16
Labidocera aestiva	copepod	12,469	40	-2.9	27.7	819.97	76073.81
Acartia tonsa	copepod	63,039	185	1.4	15.0	3845.10	69952.60
calanoid sp. a	copepod	2	1	3.9	10.4	0.12	26.95
Centropages velificatus	copepod	2	2	-0.3	19.5	0.12	13.95
Pseudodiaptomus coronatus	copepod	3,014	130	1.2	15.8	177.87	5348.24
paracalanids	copepods	12	7	-0.5	22.3	0.74	41.91
Diaptomus spp.	copepods	3	2	4.8	4.3	0.19	27.20
Calanopia americana	copepod	86	10	-2.1	21.0	5.35	327.06
Eurytemora affinis	copepod	1,083	50	8.5	3.5	63.27	3712.57
Temora longicornis	copepod	24	2	1.0	12.4	1.46	160.77
Temora turbinata	copepod	294	32	-0.0	17.3	17.61	1429.33
Osphranticum labronectum	copepod	1	1	1.9	13.6	0.06	13.39
unidentified freshwater cyclopoids	copepods	9	6	9.6	4.3	0.54	52.08
Oithona spp.	copepods	41	9	-1.7	23.7	2.56	158.02
Mesocyclops edax	copepod	11	5	9.3	2.7	0.68	55.03
Orthocyclops modestus	copepod	13	7	10.3	2.2	0.78	53.03
Macrocyclops albidus	copepods	21	12	8.1	3.2	1.30	96.82

Table A1, page 2 of 5.

Plankton-net catch statistics (March 2008 through February 2010, n = 216 samples)

Organisms are listed in phylogenetic order.

Taxon	Common Name	Number Collected	Collection Frequency	*Kmu* (km)	*Su* (psu)	Mean CPUE (No./10³ m³)	Max CPUE (No./10³ m³)
Cyclops spp.	copepods	1	1	8.9	3.2	0.06	12.78
Saphirella spp.	copepods	5	3	3.0	5.7	0.30	27.20
Oncaea sp.	copepod	7	4	1.0	13.3	0.42	38.50
unidentified harpacticoids	copepods	199	38	1.4	14.9	11.88	484.48
siphonostomatids	parasitic copepods	42	23	0.8	14.8	2.61	57.86
Monstrilla sp.	copepod	6,513	29	1.3	18.4	409.85	42441.78
Parasterope pollex	ostracod, seed shrimp	361	31	-1.3	18.2	21.36	948.44
Sarsiella zostericola	ostracod, seed shrimp	28	18	-0.3	17.2	1.72	41.16
ostracods, podocopid	ostracods, seed shrimps	417	31	10.5	2.6	24.42	1867.92
Squilla empusa larvae	mantis shrimp	3	2	-3.0	26.4	0.20	27.58
unidentified Americamysis juveniles	opossum shrimps, mysids	72,792	206	4.4	7.0	4357.06	59796.03
Americamysis almyra	opossum shrimp, mysid	53,428	192	5.7	5.5	3225.80	45156.50
Americamysis bahia	opossum shrimp, mysid	2,441	20	-1.1	12.9	146.47	12458.84
Americamysis stucki	opossum shrimp, mysid	25	7	-2.5	25.5	1.51	111.75
Bowmaniella dissimilis	opossum shrimp, mysid	62,459	170	3.9	7.7	3747.14	44039.91
Mysidopsis furca	opossum shrimp, mysid	66	5	-2.7	27.1	4.06	544.77
Taphromysis bowmani	opossum shrimp, mysid	677	78	8.9	3.3	40.85	848.05
amphipods, gammaridean	amphipods	304,083	213	7.7	4.6	18317.57	135923.32
amphipods, caprellid	skeleton shrimps	51	25	-0.7	16.7	3.01	72.74
Munna reynoldsi	isopod	1,470	34	11.1	1.3	93.22	18792.13
Xenanthura brevitelson	isopod	4	4	0.4	13.3	0.24	13.79
Cyathura polita	isopod	173	32	8.3	4.4	10.51	491.74
Sphaeroma quadridentata	isopod	12	7	3.3	10.2	0.73	41.16
Harrieta faxoni	isopod	936	85	1.6	12.4	56.02	1459.14
Sphaeroma terebrans	isopod	15	11	7.7	4.1	0.91	29.27
Dynamenella sp.	isopod	20	5	-1.9	13.1	1.26	150.93
Cassidinidea ovalis	isopod	281	90	7.7	4.6	16.94	136.89
Edotia triloba	isopod	2,049	161	7.1	5.3	123.89	1803.03
Erichsonella attenuata	isopod	469	103	3.2	9.3	28.31	712.62
cymothoid sp. a (Livoneca) juveniles	isopod	390	97	5.4	5.8	23.90	297.94
Anopsilana jonesi	isopod	20	12	4.6	7.1	1.22	56.13
Gnathia sp.	isopod	1	1	-3.0	23.6	0.06	12.14
Isopod, Paracerceis caudata	isopod	4	2	-2.4	26.7	0.28	47.73
Hargeria rapax	tanaid	827	115	4.0	7.4	50.15	871.60
Sinelobus stanfordi	tanaid	52	25	5.8	6.0	3.16	95.20
Apseudes sp.	tanaid	333	56	3.3	7.2	20.30	589.05
Hoplomachus propinquus	tanaid	1	1	-3.0	22.3	0.06	13.63
cumaceans	cumaceans	61,331	161	1.4	13.0	3653.90	44701.44
Lucifer faxoni juveniles and adults	shrimp	3,836	70	-0.6	21.0	235.99	12781.11
Lucifer faxoni mysis	shrimp	14	2	-3.0	28.3	0.88	153.65
penaeid postlarvae	penaeid shrimps	3,779	25	-0.2	16.4	211.37	36531.19
penaeid metamorphs	penaeid shrimps	239	46	1.6	9.1	14.60	607.70
Farfantepenaeus duorarum juveniles	pink shrimp	15	14	3.4	7.3	0.90	27.01
Farfantepenaeus duorarum adults	pink shrimp	4	4	3.5	6.8	0.24	13.49
Palaemonetes spp. postlarvae	grass shrimps	584	65	0.2	15.3	37.10	2514.32
Palaemonetes pugio juveniles	daggerblade grass shrimp	148	52	4.6	6.0	8.98	219.54
Palaemonetes pugio adults	daggerblade grass shrimp	17	15	6.3	5.0	1.01	27.53
Palaemonetes vulgaris juveniles	grass shrimp	6	4	0.6	9.2	0.38	41.16
Palaemonetes vulgaris adults	grass shrimp	1	1	-3.0	9.5	0.06	13.72
Palaemonetes paludosus juveniles	grass shrimp	2	1	0.1	18.2	0.13	27.24
Periclimenes spp. postlarvae	shrimps	1	1	-3.0	22.1	0.06	13.59
Periclimenes spp. juveniles	shrimps	153	10	-2.6	11.3	9.60	1660.26
Palaemon floridanus postlarvae	Florida grass shrimp	7	3	-2.3	26.5	0.43	41.91
alphaeid postlarvae	snapping shrimps	772	32	-2.6	25.6	49.11	4888.95
alphaeid juveniles	snapping shrimps	51	11	-0.4	8.7	3.19	246.98
Alpheus estuariensis juveniles	snapping shrimp	2	1	0.1	17.3	0.12	26.47
Hippolyte zostericola postlarvae	zostera shrimp	1,134	31	-2.6	25.1	69.56	4888.95
Hippolyte zostericola juveniles	zostera shrimp	267	13	-2.7	15.6	16.89	1811.20
Hippolyte zostericola adults	zostera shrimp	44	6	-2.6	11.4	2.80	466.52
Tozeuma carolinense juveniles	arrow shrimp	5	2	-3.0	27.9	0.30	48.62
Ogyrides alphaerostris juveniles and adults	estuarine longeye shrimp	53	12	-0.6	10.6	3.23	219.54

Table A1, page 3 of 5.

Plankton-net catch statistics (March 2008 through February 2010, n = 216 samples)

Organisms are listed in phylogenetic order.

Taxon	Common Name	Number Collected	Collection Frequency	*Kmu* (km)	*Su* (psu)	Mean CPUE (No./10³ m³)	Max CPUE (No./10³ m³)
Ambidexter symmetricus juveniles	shrimp	28	5	-2.0	14.8	1.70	178.38
processid postlarvae	night shrimps	36	5	-2.9	27.9	2.58	318.17
callianassid postlarvae	ghost shrimps	3	2	4.6	4.3	0.18	25.89
callianassid juveniles	ghost shrimps	20	5	5.2	5.2	1.25	126.30
Callianassa spp. juveniles	ghost shrimps	91	15	2.3	11.1	5.20	248.11
Callianassa spp. adults	ghost shrimps	5	1	3.9	4.5	0.30	64.72
Upogebia spp. postlarvae	mud shrimps	1,762	21	-2.8	27.7	114.11	20854.87
Upogebia spp. juveniles	mud shrimps	732	13	-0.5	7.6	46.42	4783.63
decapod mysis	shrimp larvae	28,821	159	0.1	19.0	1870.40	126582.88
shrimps, unidentified juveniles	shrimps	3	1	-3.0	22.3	0.19	40.88
paguroid megalops larvae	hermit crabs	19	1	-3.0	27.5	1.07	230.95
paguroid juveniles	hermit crabs	56	14	-2.3	22.1	3.62	190.90
Petrolisthes armatus juveniles	porcelain crab	5	2	0.6	16.4	0.31	52.94
Euceramus praelongus juveniles	olivepit porcelain crab	2	1	-3.0	22.3	0.13	27.26
Callinectes sapidus juveniles	blue crab	24	14	7.7	5.1	1.49	71.68
Portunus sp. juveniles	swimming crab	6	6	5.1	9.4	0.33	13.64
Rhithropanopeus harrisii juveniles	Harris mud crab	3	3	4.3	7.3	0.19	13.64
Uca spp. juveniles	fiddler crabs	7	1	-3.0	23.6	0.39	84.96
decapod zoeae	crab larvae	896,237	174	4.5	7.3	54752.21	433732.88
decapod megalopae	post-zoea crab larvae	22,493	149	1.3	11.9	1347.53	44259.91
pelecypods	clams, mussels, oysters	70	40	5.3	8.8	4.23	108.46
gastropods, prosobranch	snails	1,098	83	7.5	6.0	69.00	4674.97
gastropods, opisthobranch	sea slugs	25	16	4.3	10.2	1.50	60.22
brachiopod, Glottidia pyramidata larvae	lamp shell	2	1	-3.0	29.3	0.15	32.44
appendicularian, Oikopleura dioica	larvacean	13,748	16	-1.9	25.6	902.93	45450.60
chaetognaths, sagittid	arrow worms	6,534	56	-2.3	24.1	408.27	15044.00
Lepisosteus sp. flexion larvae	gar	7	4	10.3	2.2	0.40	25.69
Lepisosteus sp. postflexion larvae	gar	2	1	11.2	1.7	0.12	25.69
Elops saurus postflexion larvae	ladyfish	9	9	8.4	2.7	0.53	13.60
Myrophis punctatus juveniles	speckled worm eel	3	3	4.6	7.1	0.18	13.09
Anchoa hepsetus postflexion larvae	striped anchovy	5	1	2.8	4.3	0.30	65.86
Anchoa hepsetus juveniles	striped anchovy	1	1	-3.0	15.3	0.05	11.86
Anchoa mitchilli eggs	bay anchovy	325	11	-2.4	21.6	19.97	2564.81
Anchoa mitchilli postflexion larvae	bay anchovy	554	66	3.0	9.5	34.06	1146.09
Anchoa mitchilli juveniles	bay anchovy	4,892	156	7.4	4.0	307.70	7171.92
Anchoa mitchilli adults	bay anchovy	120	45	5.6	4.4	7.35	312.32
Anchoa spp. preflexion larvae	anchovies	1,283	51	-0.2	14.8	79.95	2901.33
Anchoa spp. flexion larvae	anchovies	190	24	1.7	9.7	11.95	696.36
clupeid eggs	herrings	26	3	-3.0	27.5	1.81	190.90
clupeid preflexion larvae	herrings	2	2	-0.5	14.7	0.13	14.51
Brevoortia smithi juveniles	yellowfin menhaden	1	1	8.9	1.7	0.06	12.86
Brevoortia spp. postflexion larvae	menhaden	431	40	6.7	4.7	26.07	616.04
Brevoortia spp. metamorphs	menhaden	42	12	6.7	3.6	2.55	217.60
Harengula jaguana postflexion larvae	scaled sardine	1	1	3.9	10.4	0.06	13.48
Synodus foetens postflexion larvae	inshore lizardfish	1	1	3.9	9.6	0.06	12.94
Synodus foetens metamorphs	inshore lizardfish	1	1	2.8	11.8	0.06	12.53
Synodus foetens juveniles	inshore lizardfish	1	1	1.9	5.2	0.07	14.51
Opsanus beta juveniles	gulf toadfish	3	2	2.4	10.1	0.18	25.91
Mugil cephalus postflexion larvae	striped mullet	1	1	7.0	3.2	0.06	12.28
Mugil cephalus juveniles	striped mullet	9	8	6.3	7.3	0.52	24.60
Mugil curema juveniles	white mullet	1	1	5.9	4.3	0.05	11.25
Membras martinica preflexion larvae	rough silverside	9	7	3.9	10.0	0.53	30.23
Membras martinica juveniles	rough silverside	26	15	6.5	5.8	1.57	54.64
Membras martinica adults	rough silverside	2	2	1.0	10.0	0.12	12.96
Menidia spp. preflexion larvae	silversides	133	50	7.5	4.7	7.90	131.32
Menidia spp. flexion larvae	silversides	2	1	2.8	4.9	0.13	27.20
Menidia spp. postflexion larvae	silversides	4	2	6.6	6.0	0.24	26.50
Menidia spp. juveniles	silversides	14	9	8.9	3.4	0.86	55.06
Strongylura marina juveniles	Atlantic needlefish	1	1	8.9	3.6	0.06	12.04
Strongylura spp. postflexion larvae	needlefishes	6	2	7.7	2.3	0.36	65.51
Fundulus spp. eggs	killifishes	3	3	9.1	2.9	0.18	14.05

Table A1, page 4 of 5.

Plankton-net catch statistics (March 2008 through February 2010, n = 216 samples)

Organisms are listed in phylogenetic order.

Taxon	Common Name	Number Collected	Collection Frequency	*Kmu* (km)	*Su* (psu)	Mean CPUE (No./10³ m³)	Max CPUE (No./10³ m³)
Fundulus spp. postflexion larvae	killifishes	5	3	9.4	4.0	0.31	27.79
Lucania goodei postflexion larvae	bluefin killifish	1	1	11.2	2.3	0.06	13.02
Lucania parva eggs	rainwater killifish	10	7	9.6	2.7	0.62	27.53
Lucania parva postflexion larvae	rainwater killifish	47	23	10.1	2.0	2.83	89.78
Lucania parva juveniles	rainwater killifish	32	8	10.9	1.6	1.94	216.17
Lucania parva adults	rainwater killifish	33	2	11.2	1.5	1.97	356.05
Gambusia holbrooki juveniles	eastern mosquitofish	4	1	11.2	1.2	0.25	55.03
Cyprinodon variegatus postflexion larvae	sheepshead minnow	1	1	5.9	4.0	0.06	13.60
Syngnathus floridae juveniles	dusky pipefish	1	1	8.9	1.7	0.06	13.03
Syngnathus louisianae juveniles	chain pipefish	5	3	-1.8	20.3	0.31	26.27
Syngnathus scovelli juveniles	gulf pipefish	38	25	4.1	8.2	2.32	41.16
fish eggs, percomorph	sciaenid eggs (primarily)	383	10	-2.9	24.7	24.80	4550.47
Prionotus tribulus juveniles	bighead searobin	1	1	0.1	7.1	0.06	12.16
Lepomis auritus juveniles	redbreast sunfish	2	2	6.5	5.9	0.12	12.96
Lepomis spp. preflexion larvae	sunfishes	1	1	11.2	2.0	0.06	13.08
Lepomis spp. postflexion larvae	sunfishes	1	1	7.0	7.2	0.06	13.90
Lepomis spp. juveniles	sunfishes	1	1	7.0	5.5	0.06	12.95
Micropterus salmoides juveniles	largemouth bass	1	1	3.9	6.4	0.05	11.62
Chloroscombrus chrysurus postflexion larvae	Atlantic bumper	2	1	-3.0	27.5	0.11	24.31
Eucinostomus gula juveniles	silver jenny	1	1	7.0	4.6	0.06	13.54
Eucinostomus harengulus juveniles	tidewater mojarra	1	1	8.9	3.9	0.06	12.64
Eucinostomus spp. postflexion larvae	mojarras	33	16	4.8	8.9	2.01	81.96
Eucinostomus spp. juveniles	mojarras	84	26	6.6	5.1	5.64	218.22
gerreid preflexion larvae	mojjaras	2	2	0.1	17.9	0.14	16.22
Eugerres plumieri postflexion larvae	striped mojarra	3	1	-3.0	28.4	0.19	41.91
Archosargus probatocephalus juveniles	sheepshead	3	3	0.8	16.4	0.17	12.46
Orthopristis chrysoptera juveniles	pigfish	3	1	3.9	6.0	0.20	43.62
Bairdiella chrysoura flexion larvae	silver perch	8	2	0.4	16.3	0.53	67.10
Bairdiella chrysoura postflexion larvae	silver perch	6	3	-0.7	21.5	0.41	47.73
Bairdiella chrysoura juveniles	silver perch	2	2	3.6	5.7	0.13	13.72
Lagodon rhomboides postflexion larvae	pinfish	2	2	9.6	2.5	0.12	12.78
Lagodon rhomboides juveniles	pinfish	18	4	6.4	4.5	1.03	110.71
Cynoscion arenarius preflexion larvae	sand seatrout	6	5	1.4	10.5	0.36	26.34
Cynoscion arenarius flexion larvae	sand seatrout	2	2	1.0	8.3	0.13	14.51
Cynoscion arenarius postflexion larvae	sand seatrout	3	3	2.5	13.8	0.17	14.47
Cynoscion arenarius juveniles	sand seatrout	7	5	5.3	5.9	0.42	27.28
Cynoscion nebulosus preflexion larvae	spotted seatrout	7	4	-1.6	24.7	0.48	47.73
Cynoscion nebulosus flexion larvae	spotted seatrout	9	4	3.3	10.8	0.48	53.94
Cynoscion nebulosus postflexion larvae	spotted seatrout	16	9	3.5	7.3	0.94	44.16
Leiostomus xanthurus postflexion larvae	spot	28	15	5.0	7.5	1.71	84.78
Leiostomus xanthurus juveniles	spot	116	19	4.7	11.4	6.37	191.98
Menticirrhus spp. preflexion larvae	kingfishes	10	4	-2.2	25.6	0.70	95.45
Sciaenops ocellatus postflexion larvae	red drum	3	2	6.3	9.3	0.18	26.51
Sciaenops ocellatus juveniles	red drum	2	1	5.0	13.3	0.12	26.55
blenniid preflexion larvae	blennies	192	62	1.1	15.1	11.66	264.69
Chasmodes saburrae flexion larvae	Florida blenny	2	1	-3.0	29.3	0.15	32.44
Chasmodes saburrae postflexion larvae	Florida blenny	5	3	0.4	14.2	0.32	27.20
Chasmodes saburrae juveniles	Florida blenny	1	1	-3.0	12.1	0.06	12.92
Lupinoblennius nicholsi flexion larvae	highfin blenny	2	1	-3.0	29.3	0.15	32.44
Lupinoblennius nicholsi postflexion larvae	highfin blenny	1	1	3.9	6.2	0.07	14.13
Lupinoblennius nicholsi juveniles	highfin blenny	1	1	5.9	1.7	0.04	9.40
Gobiesox strumosus preflexion larvae	skilletfish	76	26	0.3	14.4	4.56	102.25
Gobiesox strumosus flexion larvae	skilletfish	8	4	3.1	5.2	0.52	43.62
Gobiesox strumosus postflexion larvae	skilletfish	17	10	3.7	7.8	1.05	40.05
Bathygobius soporator preflexion larvae	frillfin goby	66	13	1.9	9.2	4.07	526.87
Bathygobius soporator postflexion larvae	frillfin goby	1	1	-3.0	12.1	0.06	12.92
gobiid eggs	gobies	4	2	-1.3	8.3	0.25	41.16
gobiid preflexion larvae	gobies	35,546	140	5.0	6.8	2166.46	45261.00
gobiid flexion larvae	gobies	6,544	134	5.1	6.7	400.76	8086.97
Gobiosoma bosc postflexion larvae	naked goby	2	2	6.5	3.9	0.12	13.49
Gobiosoma bosc juveniles	naked goby	23	17	8.0	3.6	1.44	42.92

Table A1, page 5 of 5.

Plankton-net catch statistics (March 2008 through February 2010, n = 216 samples)

Organisms are listed in phylogenetic order.

Taxon	Common Name	Number Collected	Collection Frequency	*Kmu* (km)	*Su* (psu)	Mean CPUE (No./10³ m³)	Max CPUE (No./10³ m³)
Gobiosoma robustum juveniles	code goby	1	1	7.9	5.0	0.06	13.69
Gobiosoma spp. postflexion larvae	gobies	16,701	120	5.1	6.4	1028.06	56860.67
Microgobius gulosus juveniles	clown goby	13	8	7.7	3.9	0.77	40.98
Microgobius spp. preflexion larvae	gobies	6	2	1.3	7.7	0.37	53.63
Microgobius spp. flexion larvae	gobies	258	50	5.0	5.6	15.87	415.56
Microgobius spp. postflexion larvae	gobies	659	76	3.6	7.4	39.33	899.48
Achirus lineatus flexion larvae	lined sole	1	1	-3.0	29.3	0.08	16.22
Achirus lineatus postflexion larvae	lined sole	30	8	0.1	17.5	1.77	97.28
Achirus lineatus juveniles	lined sole	2	1	10.3	1.9	0.13	27.32
Symphurus plagiusa juveniles	blackcheek tonguefish	1	1	5.9	5.5	0.06	13.26
Trinectes maculatus flexion larvae	hogchoker	2	2	2.3	12.4	0.10	11.72
Trinectes maculatus postflexion larvae	hogchoker	70	33	5.1	6.6	4.23	110.62
Trinectes maculatus juveniles	hogchoker	6	5	8.9	3.0	0.39	29.27

Table A2. Page 1 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
foraminiferans	foraminiferans	2	1										
medusa sp. a	hydromedusa					1							
medusa sp. d	hydromedusa				4	1	15	16	25	2	1		
medusa sp. e	hydromedusa		3								631		
medusa, Obelia sp.	hydromedusa					1					32		
medusa, Bougainvillia sp.	hydromedusa				2		11		5		14		
Clytia sp.	hydromedusa				1	3	4						
medusa, Eutima sp.	hydromedusa				31				5		60		
Liriope tetraphylla	hydromedusa				1								
turbellarians	flatworms				6								
nematodes	roundworms, threadworms	3	18	1		9	1		8	37	31	19	3
polychaetes	sand worms, tube worms	57	536	6	1131	89	188	1455	82	28	218	46	74
oligochaetes	freshwater worms		18					5	2	3	81	2	
hirudinoideans	leeches	2	13	2	9	7	8	9	9	3	1		4
Limulus polyphemus larvae	horsehoe crab												1
pycnogonids	sea spiders						2					1	
acari	water mites	5	9	7	6	6	41	103	122	6	2	4	16
collembolas, podurid	springtails		8										
ephemeropteran larvae	mayflies	1			1	1	14	2	3	17	5		3
odonates, zygopteran larvae	damselflies	1	1	1			1	1	4	3			3
hemipterans, corixid adults	water boatmen						1						
hemipterans, gerrid adults	water striders						4		1				
hemipterans, belostomatid adults	giant water bugs							1					
coleopterans, noterid adults	burrowing water beetles					2							
coleopterans, elmid adults	riffle beetles												1
neuropterans, Climacia spp. larvae	spongillaflies												1
dipterans, pupae	flies, mosquitoes	39	61	12	92	25	55	96	122	11	26	11	35
dipteran, Chaoborus punctipennis larvae	phantom midge									1			
dipterans, chironomid larvae	midges	7	19	43	33	56	34	26	112	14	96	14	19
dipterans, ceratopogonid larvae	biting midges	3	6	1	15	13	26	31	34	10	4	1	3
dipterans, tipulid larvae	crane flies	3											
dipterans, muscid larvae	muscid flies		2										
dipterans, ephydrid larvae	shore flies						1						
trichopteran larvae	caddisflies	1					2						
Pseudevadne tergestina	water flea				1								
Penilia avirostris	water flea										3	8	
cladocerans, Daphnia spp.	water fleas			1									1
Simocephalus vetulus	water flea			8	9	11	14	17	229	1	1		
Ilyocryptus sp.	water flea		4					13					
Diaphanosoma brachyurum	water flea							3	6				
Sida crystallina	water flea				1								
cirriped nauplius stage	barnacles		3				22		1		3456	1	1
cirriped cypris stage	barnacles		5								4	1	
branchiurans, Argulus spp.	fish lice	1	1	1	3	1	5		3	1	9	2	1
Labidocera aestiva	copepod			4	74	1323	4834		35	12	6043	140	4
Acartia tonsa	copepod	69	16335	2124	17066	2201	6569	72	1884	47	15570	490	612
calanoid sp. a	copepod						2						
Centropages velificatus	copepod		1			1							

Table A2. Page 2 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
Pseudodiaptomus coronatus	copepod	226	160	27	45	118	429	85	295	59	1428	49	93
paracalanids	copepods	1					2				9		
Diaptomus spp.	copepods								2			1	
Calanopia americana	copepod						8	24		10	38	6	
Eurytemora affinis	copepod	43	706	71	52	7	14	77	44	1	7	5	56
Temora longicornis	copepod										24		
Temora turbinata	copepod			1	52	12	142	29	33	1	20	1	3
Osphranticum labronectum	copepod												1
unidentified freshwater cyclopoids	copepods	2									1		6
Oithona spp.	copepods		1				16				22		2
Mesocyclops edax	copepod		1			2			8				
Orthocyclops modestus	copepod			1		1					4	2	5
Macrocyclops albidus	copepods		4		1		7	2	5	1	1		
Cyclops spp.	copepods		1										
Saphirella spp.	copepods						3		2				
Oncaea sp.	copepod		5						1				1
unidentified harpacticoids	copepods	40	83		2	6	1	1	10		26	8	22
siphonostomatids	parasitic copepods	2	1	1	5		4		1	6	12	2	8
Monstrilla sp.	copepod				7	3	4	2	50	33	6377	37	
Parasterope pollex	ostracod, seed shrimp	10		69	51	87	32	23	13	2	46	17	11
Sarsiella zostericola	ostracod, seed shrimp	1	1	2	1	4	2		4		8	3	2
ostracods, podocopid	ostracods, seed shrimps	11	98		43	38	27	14	4		7	7	168
Squilla empusa larvae	mantis shrimp				2	1							
unidentified Americamysis juveniles	opossum shrimps, mysids	377	2700	2400	33511	5898	5014	5079	13054	1615	2166	202	776
Americamysis almyra	opossum shrimp, mysid	423	5143	373	11461	7826	6134	4370	13951	2395	709	143	500
Americamysis bahia	opossum shrimp, mysid	6		13	121	540	11		908	177	649	9	7
Americamysis stucki	opossum shrimp, mysid	1				2		1			16		5
Bowmaniella dissimilis	opossum shrimp, mysid	35	36	639	8469	9902	14386	8116	13324	2241	4071	909	331
Mysidopsis furca	opossum shrimp, mysid										62	2	2
Taphromysis bowmani	opossum shrimp, mysid	96	17	73	102	28	18	33	14	74	45	19	158
amphipods, gammaridean	amphipods	16791	14301	6864	34411	22041	43244	19033	50187	10934	31193	9738	45346
amphipods, caprellid	skeleton shrimps	3		3	8	9	5	3	3	2	14		1
Munna reynoldsi	isopod	3		7	11	8	8	18	1400	3	6	2	4
Xenanthura brevitelson	isopod			1	1		1	1					
Cyathura polita	isopod	2	10		18	101	35	2		2			3
Sphaeroma quadridentata	isopod	3	1		3				4		1		
Harrieta faxoni	isopod	26	1	16	41	358	179	83	92	6	56	48	30
Sphaeroma terebrans	isopod		2		3	1	3	1	5				
Dynamenella sp.	isopod							4	11	2		3	
Cassidinidea ovalis	isopod	16	9	3	47	57	40	25	27	12	10	5	30
Edotia triloba	isopod	34	45	48	439	459	437	66	189	47	109	27	149
Erichsonella attenuata	isopod	22	4	17	148	54	112	30	43	10	16	7	6
cymothoid sp. a (Livoneca) juveniles	isopod	1		4	28	109	93	18	29	67	23	13	5
Anopsilana jonesi	isopod				3	1	2	7	2	1	2	2	
Gnathia sp.	isopod						1						
Isopod, Paracerceis caudata	isopod	1					3						
Hargeria rapax	tanaid	21	42	100	472	58	40	15	23	4	18	8	26
Sinelobus stanfordi	tanaid	1	1	5	19		1	8	11	1	3		2

Table A2. Page 3 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
Apseudes sp.	tanaid			7	38	30	40	137	32	35	14		
Hoplomachus propinquus	tanaid							1					
cumaceans	cumaceans	4051	4617	5562	10091	7117	9024	961	11294	186	3058	2355	3015
Lucifer faxoni juveniles and adults	shrimp	14	1	43	41	6	3	2	4	82	1846	1663	131
Lucifer faxoni mysis	shrimp										14		
penaeid postlarvae	penaeid shrimps				186	10	38	57	36	17	3326	109	
penaeid metamorphs	penaeid shrimps				2			62	126	2	39	7	1
Farfantepenaeus duorarum juveniles	pink shrimp	1							8	2	1	1	2
Farfantepenaeus duorarum adults	pink shrimp			1					2			1	
Palaemonetes spp. postlarvae	grass shrimps			69	179	8	15	9	67	12	216	9	
Palaemonetes pugio juveniles	daggerblade grass shrimp	5	1	3	10	16	12	7	22	35	18		19
Palaemonetes pugio adults	daggerblade grass shrimp			3		2	5		2	3			2
Palaemonetes vulgaris juveniles	grass shrimp								4		1		1
Palaemonetes vulgaris adults	grass shrimp								1				
Palaemonetes paludosus juveniles	grass shrimp								2				
Periclimenes spp. postlarvae	shrimps								1				
Periclimenes spp. juveniles	shrimps			2		1	3	3	124		19	1	
Palaemon floridanus postlarvae	Florida grass shrimp										7		
alphaeid postlarvae	snapping shrimps			1	178	61	47	45	9		423	8	
alphaeid juveniles	snapping shrimps					2		20	29				
Alpheus estuariensis juveniles	snapping shrimp						2						
Hippolyte zostericola postlarvae	zostera shrimp	1	1		52	16	141	14	56	3	686	164	
Hippolyte zostericola juveniles	zostera shrimp							108	133	6	15	5	
Hippolyte zostericola adults	zostera shrimp							3	37		2	1	1
Tozeuma carolinense juveniles	arrow shrimp					1					4		
Ogyrides alphaerostris juveniles and adults	estuarine longeye shrimp			2			1	8	27	1	14		
Ambidexter symmetricus juveniles	shrimp								13	1	14		
processid postlarvae	night shrimps					9	20		1		6		
callianassid postlarvae	ghost shrimps								3				
callianassid juveniles	ghost shrimps						2	16	2				
Callianassa spp. juveniles	ghost shrimps				1		24	14	49		3		
Callianassa spp. adults	ghost shrimps								5				
Upogebia spp. postlarvae	mud shrimps		4	1	25	85	18		40		1587	2	
Upogebia spp. juveniles	mud shrimps					3		3	1	689	35	1	
decapod mysis	shrimp larvae	2	58	1204	3296	2188	15978	589	2487	41	2637	332	9
shrimps, unidentified juveniles	shrimps							3					
paguroid megalops larvae	hermit crabs										19		
paguroid juveniles	hermit crabs				2	2	12	5	4	11	4	16	
Petrolisthes armatus juveniles	porcelain crab		1				4						
Euceramus praelongus juveniles	olivepit porcelain crab							2					
Callinectes sapidus juveniles	blue crab				3		1			3	14		3
Portunus sp. juveniles	swimming crab	4								2			
Rhithropanopeus harrisii juveniles	Harris mud crab								1	2			
Uca spp. juveniles	fiddler crabs						7						
decapod zoeae	crab larvae		732	66607	271878	72971	164689	49059	202086	11632	46270	10296	17
decapod megalopae	post-zoea crab larvae	20		3	6561	538	3736	934	5248	3756	1449	245	3
pelecypods	clams, mussels, oysters	6	5	3		4	4	10	13	2	9	1	13
gastropods, prosobranch	snails	15	37	11	14	98	431	84	301	74	20	4	9

Table A2. Page 4 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
gastropods, opisthobranch	sea slugs	1	3		7	6	3	1			1		3
brachiopod, Glottidia pyramidata larvae	lamp shell					2							
appendicularian, Oikopleura dioica	larvacean				28	1432	2461	2			9823	2	
chaetognaths, sagittid	arrow worms	11	64	15	1095	266	1170	92	470	38	2526	650	137
Lepisosteus sp. flexion larvae	gar				7								
Lepisosteus sp. postflexion larvae	gar				2								
Elops saurus postflexion larvae	ladyfish			1	8								
Myrophis punctatus juveniles	speckled worm eel		1		2								
Anchoa hepsetus postflexion larvae	striped anchovy				5								
Anchoa hepsetus juveniles	striped anchovy		1										
Anchoa mitchilli eggs	bay anchovy		9	58	255		3						
Anchoa mitchilli postflexion larvae	bay anchovy			6	397	7	79	22	8	2	30	2	1
Anchoa mitchilli juveniles	bay anchovy	246	87	6	878	407	242	29	63	778	1043	748	365
Anchoa mitchilli adults	bay anchovy	4	5	1	18		4	8	1	38	19	8	14
Anchoa spp. preflexion larvae	anchovies			12	753	29	130	183	173		3		
Anchoa spp. flexion larvae	anchovies			3	150		27	9				1	
clupeid eggs	herrings		12			2	12						
clupeid preflexion larvae	herrings				2								
Brevoortia smithi juveniles	yellowfin menhaden				1								
Brevoortia spp. postflexion larvae	menhaden	1	180	35	213	1	1						
Brevoortia spp. metamorphs	menhaden		1	3	36	1		1					
Harengula jaguana postflexion larvae	scaled sardine						1						
Synodus foetens postflexion larvae	inshore lizardfish					1							
Synodus foetens metamorphs	inshore lizardfish					1							
Synodus foetens juveniles	inshore lizardfish				1								
Opsanus beta juveniles	gulf toadfish				1		2						
Mugil cephalus postflexion larvae	striped mullet			1									
Mugil cephalus juveniles	striped mullet	2	6		1								
Mugil curema juveniles	white mullet												1
Membras martinica preflexion larvae	rough silverside	1	5		1		1			1			
Membras martinica juveniles	rough silverside					15	8			3			
Membras martinica adults	rough silverside						2						
Menidia spp. preflexion larvae	silversides	1	50	7	47	1	1	10	14		2		
Menidia spp. flexion larvae	silversides								2				
Menidia spp. postflexion larvae	silversides				4								
Menidia spp. juveniles	silversides				2	6				5			1
Strongylura marina juveniles	Atlantic needlefish				1								
Strongylura spp. postflexion larvae	needlefishes				6								
Fundulus spp. eggs	killifishes			2		1							
Fundulus spp. postflexion larvae	killifishes		2					1	2				
Lucania goodei postflexion larvae	bluefin killifish										1		
Lucania parva eggs	rainwater killifish		2	1		1	2		2	2			
Lucania parva postflexion larvae	rainwater killifish		3	1	11	2	4	16	7	1	2		
Lucania parva juveniles	rainwater killifish					24	3	1	1	1	1		1
Lucania parva adults	rainwater killifish					28	5						
Gambusia holbrooki juveniles	eastern mosquitofish								4				
Cyprinodon variegatus postflexion larvae	sheepshead minnow				1								
Syngnathus floridae juveniles	dusky pipefish							1					

Table A2. Page 5 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
Syngnathus louisianae juveniles	chain pipefish				4	1							
Syngnathus scovelli juveniles	gulf pipefish	2			6	2	9	1	9	3	2	2	2
fish eggs, percomorph	sciaenid eggs (primarily)		2	8	333	15	24	1					
Prionotus tribulus juveniles	bighead searobin							1					
Lepomis auritus juveniles	redbreast sunfish				1		1						
Lepomis spp. preflexion larvae	sunfishes							1					
Lepomis spp. postflexion larvae	sunfishes		1										
Lepomis spp. juveniles	sunfishes				1								
Micropterus salmoides juveniles	largemouth bass				1								
Chloroscombrus chrysurus postflexion larvae	Atlantic bumper										2		
Eucinostomus gula juveniles	silver jenny					1							
Eucinostomus harengulus juveniles	tidewater mojarra					1							
Eucinostomus spp. postflexion larvae	mojarras					6	1	1	3	5	12	5	
Eucinostomus spp. juveniles	mojarras	1				8	9	1	1	41	2	21	
gerreid preflexion larvae	mojjaras				1	1							
Eugerres plumieri postflexion larvae	striped mojarra										3		
Archosargus probatocephalus juveniles	sheepshead	2		1									
Orthopristis chrysoptera juveniles	pigfish			3									
Bairdiella chrysoura flexion larvae	silver perch				5		3						
Bairdiella chrysoura postflexion larvae	silver perch					2	3		1				
Bairdiella chrysoura juveniles	silver perch					1			1				
Lagodon rhomboides postflexion larvae	pinfish		2										
Lagodon rhomboides juveniles	pinfish		18										
Cynoscion arenarius preflexion larvae	sand seatrout				5				1				
Cynoscion arenarius flexion larvae	sand seatrout				2								
Cynoscion arenarius postflexion larvae	sand seatrout								2		1		
Cynoscion arenarius juveniles	sand seatrout		1						3	2	1		
Cynoscion nebulosus preflexion larvae	spotted seatrout					3	3		1				
Cynoscion nebulosus flexion larvae	spotted seatrout								9				
Cynoscion nebulosus postflexion larvae	spotted seatrout					1		3	8	4			
Leiostomus xanthurus postflexion larvae	spot	3	9								13		3
Leiostomus xanthurus juveniles	spot	77	39										
Menticirrhus spp. preflexion larvae	kingfishes					2	8						
Sciaenops ocellatus postflexion larvae	red drum										3		
Sciaenops ocellatus juveniles	red drum										2		
blenniid preflexion larvae	blennies		8	20	29	3	47	1	40		8	5	31
Chasmodes saburrae flexion larvae	Florida blenny					2							
Chasmodes saburrae postflexion larvae	Florida blenny				2	1			2				
Chasmodes saburrae juveniles	Florida blenny									1			
Lupinoblennius nicholsi flexion larvae	highfin blenny					2							
Lupinoblennius nicholsi postflexion larvae	highfin blenny										1		
Lupinoblennius nicholsi juveniles	highfin blenny									1			
Gobiesox strumosus preflexion larvae	skilletfish		1	10	30	3	5		5	2	12	8	
Gobiesox strumosus flexion larvae	skilletfish			3	5								
Gobiesox strumosus postflexion larvae	skilletfish				12	1	2			2			
Bathygobius soporator preflexion larvae	frillfin goby			1	47	1	14	1	2				
Bathygobius soporator postflexion larvae	frillfin goby									1			
gobiid eggs	gobies							1	3				

Table A2. Page 6 of 6.

Plankton net catch by month (March 2008 to February 2010).

Number of monthly samples is indicated in parentheses.

Taxon	Common Name	Jan (12)	Feb (24)	Mar (12)	Apr (24)	May (12)	Jun (24)	Jul (12)	Aug (24)	Sep (12)	Oct (24)	Nov (12)	Dec (24)
gobiid preflexion larvae	gobies	2	6	398	10838	9912	6890	774	6543	134	45	3	1
gobiid flexion larvae	gobies	1	6	66	1417	1669	923	365	1909	146	36	5	1
Gobiosoma bosc postflexion larvae	naked goby						1		1				
Gobiosoma bosc juveniles	naked goby				2	7	5	3		4	1		1
Gobiosoma robustum juveniles	code goby						1						
Gobiosoma spp. postflexion larvae	gobies		2	28	1059	7976	2916	1462	2830	287	135	6	
Microgobius gulosus juveniles	clown goby					7	2	2		2			
Microgobius spp. preflexion larvae	gobies						2	4					
Microgobius spp. flexion larvae	gobies		3	59	89		29	29	16	4	24	5	
Microgobius spp. postflexion larvae	gobies		1	26	134	65	52	129	188	45	16	3	
Achirus lineatus flexion larvae	lined sole					1							
Achirus lineatus postflexion larvae	lined sole					8	12		10				
Achirus lineatus juveniles	lined sole					2							
Symphurus plagiusa juveniles	blackcheek tonguefish					1							
Trinectes maculatus flexion larvae	hogchoker								2				
Trinectes maculatus postflexion larvae	hogchoker					14	10	7	36	3			
Trinectes maculatus juveniles	hogchoker					1	3	1			1		

Table A3, page 1 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
foraminiferans	foraminiferans	0.00	0.00	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
medusa sp. a	hydromedusa	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
medusa sp. d	hydromedusa	0.67	7.43	1.64	1.39	4.16	15.18	10.36	2.78	0.74	1.34	0.00	0.00
medusa sp. e	hydromedusa	427.51	0.00	0.00	0.00	0.00	0.00	2.19	0.00	0.00	0.00	0.00	0.00
medusa, Obelia sp.	hydromedusa	24.66	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
medusa, Bougainvillia sp.	hydromedusa	18.52	2.93	0.60	0.00	1.37	0.00	1.34	0.00	0.00	0.00	0.00	0.00
Clytia sp.	hydromedusa	2.70	0.71	0.00	0.00	0.00	0.00	0.00	3.14	0.00	0.00	0.00	0.00
medusa, Eutima sp.	hydromedusa	47.83	18.24	0.00	1.30	0.00	0.00	0.67	0.67	0.00	0.00	0.00	0.00
Liriope tetraphylla	hydromedusa	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
turbellarians	flatworms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.34	0.00	0.00
nematodes	roundworms, threadworms	1.31	37.21	3.70	1.56	2.18	2.49	1.46	1.33	3.19	9.39	8.10	26.53
polychaetes	sand worms, tube worms	270.01	149.98	51.68	25.02	16.64	9.79	14.81	23.09	414.44	559.63	134.69	1142.43
oligochaetes	freshwater worms	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.46	3.56	76.83
hirudinoideans	leeches	0.00	0.00	0.00	1.36	2.23	6.43	7.09	5.74	9.48	7.68	2.73	5.10
Limulus polyphemus larvae	horsehoe crab	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pycnogonids	sea spiders	2.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
acari	water mites	0.00	0.00	10.48	2.09	11.56	10.74	19.03	10.02	21.47	22.86	40.23	88.94
collembolas, podurid	springtails	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.92
ephemeropteran larvae	mayflies	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.72	1.33	32.60
odonates, zygopteran larvae	damselflies	0.00	0.00	0.00	0.00	0.00	1.32	1.24	0.00	1.40	0.70	3.23	2.29
hemipterans, corixid adults	water boatmen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
hemipterans, gerrid adults	water striders	0.00	2.16	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70
hemipterans, belostomatid adults	giant water bugs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73
coleopterans, noterid adults	burrowing water beetles	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.71
coleopterans, elmid adults	riffle beetles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
neuropterans, Climacia spp. larvae	spongillaflies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00
dipterans, pupae	flies, mosquitoes	0.90	0.00	0.60	0.75	0.70	0.00	3.61	9.26	18.70	15.91	139.88	232.96
dipteran, Chaoborus punctipennis larvae	phantom midge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76
dipterans, chironomid larvae	midges	1.38	15.84	2.07	1.33	2.89	6.65	6.61	8.31	31.30	16.68	49.89	205.25
dipterans, ceratopogonid larvae	biting midges	0.00	2.25	0.68	2.31	0.73	1.42	4.79	5.03	4.35	10.63	46.60	26.07
dipterans, tipulid larvae	crane flies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00
dipterans, muscid larvae	muscid flies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	0.00	0.00	0.00	0.00
dipterans, ephydrid larvae	shore flies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
trichopteran larvae	caddisflies	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54
Pseudevadne tergestina	water flea	0.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penilia avirostris	water flea	8.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cladocerans, Daphnia spp.	water fleas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.71	0.00
Simocephalus vetulus	water flea	0.00	0.00	0.00	0.70	0.00	0.72	0.00	0.00	0.00	1.45	9.24	192.60
Ilyocryptus sp.	water flea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	10.79
Diaphanosoma brachyurum	water flea	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	6.04
Sida crystallina	water flea	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cirriped nauplius stage	barnacles	2197.16	129.10	130.17	2.73	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00
cirriped cypris stage	barnacles	2.33	1.50	1.45	0.82	0.00	0.00	0.74	0.00	0.00	0.00	0.81	0.00
branchiurans, Argulus spp.	fish lice	5.69	1.98	0.79	0.00	2.21	3.54	1.20	2.87	0.74	0.00	0.84	0.00
Labidocera aestiva	copepod	9611.48	168.37	32.32	7.68	11.62	2.95	2.21	0.73	0.00	0.00	0.00	2.25
Acartia tonsa	copepod	15272.40	6395.12	3069.75	1965.63	6641.11	6842.03	2976.51	1547.18	1135.27	196.73	45.99	53.46
calanoid sp. a	copepod	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A3, page 2 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
Centropages velificatus	copepod	0.77	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudodiaptomus coronatus	copepod	579.58	437.76	205.74	257.01	360.82	143.90	91.68	30.74	8.67	2.79	4.27	11.48
paracalanids	copepods	4.35	0.80	3.06	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diaptomus spp.	copepods	0.00	0.00	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00
Calanopia americana	copepod	49.49	6.70	7.33	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eurytemora affinis	copepod	0.00	5.70	12.37	14.01	13.06	34.14	63.06	58.78	217.01	36.26	82.47	222.32
Temora longicornis	copepod	0.00	8.53	8.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Temora turbinata	copepod	69.91	102.49	5.21	4.91	10.06	9.03	2.23	0.00	0.00	0.00	7.49	0.00
Osphranticum labronectum	copepod	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unidentified freshwater cyclopoids	copepods	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.69	0.00	0.00	2.19	2.89
Oithona spp.	copepods	19.51	8.16	2.28	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mesocyclops edax	copepod	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	2.13	1.50	3.06
Orthocyclops modestus	copepod	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.62	0.00	0.00	8.00
Macrocyclops albidus	copepods	0.00	2.25	0.82	0.00	0.00	0.74	0.00	1.37	0.00	2.14	0.71	7.52
Cyclops spp.	copepods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.00
Saphirella spp.	copepods	0.00	0.00	0.00	2.89	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oncaea sp.	copepod	0.00	2.90	1.45	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unidentified harpacticoids	copepods	22.79	52.52	30.27	10.09	4.74	2.20	5.11	8.38	4.86	0.00	0.81	0.77
siphonostomatids	parasitic copepods	9.38	7.58	8.58	0.66	1.41	0.00	1.47	0.73	0.00	0.00	0.00	1.51
Monstrilla sp.	copepod	64.14	2480.45	1014.70	773.69	473.14	101.77	8.84	0.73	0.80	0.00	0.00	0.00
Parasterope pollex	ostracod, seed shrimp	129.21	113.20	9.20	1.33	1.97	0.00	0.00	0.70	0.00	0.00	0.00	0.75
Sarsiella zostericola	ostracod, seed shrimp	6.23	9.29	3.14	1.33	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ostracods, podocopid	ostracods, seed shrimps	4.51	0.68	1.45	0.00	0.00	1.97	0.00	0.70	25.05	1.38	27.25	229.99
Squilla empusa larvae	mantis shrimp	2.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unidentified Americamysis juveniles	opossum shrimps, mysids	3616.36	4903.27	6929.30	8122.88	3787.73	5854.05	4330.33	1973.16	1790.64	4751.86	3820.59	2404.55
Americamysis almyra	opossum shrimp, mysid	462.60	1350.42	5518.89	4245.66	3656.57	4276.14	4302.20	2353.74	1658.06	3981.80	4969.38	1934.12
Americamysis bahia	opossum shrimp, mysid	815.04	729.67	212.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Americamysis stucki	opossum shrimp, mysid	14.88	3.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bowmaniella dissimilis	opossum shrimp, mysid	561.05	4328.52	9099.71	6588.03	6085.44	5218.83	5639.29	4510.96	1283.12	1184.29	443.62	22.85
Mysidopsis furca	opossum shrimp, mysid	44.51	4.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taphromysis bowmani	opossum shrimp, mysid	8.36	5.42	9.77	15.61	22.97	21.76	4.23	41.06	23.92	23.54	89.26	224.33
amphipods, gammaridean	amphipods	1891.92	4426.00	7218.06	9022.02	8213.66	14216.21	18618.64	25537.76	24922.50	32537.42	39519.99	33686.64
amphipods, caprellid	skeleton shrimps	16.12	10.36	5.42	3.56	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Munna reynoldsi	isopod	0.77	0.00	0.00	2.97	0.74	3.56	1.51	2.73	0.75	2.15	13.52	1089.99
Xenanthura brevitelson	isopod	0.77	0.72	0.73	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyathura polita	isopod	1.52	0.00	2.34	4.94	5.09	9.73	8.86	1.44	5.95	30.02	38.75	17.48
Sphaeroma quadridentata	isopod	2.29	2.38	0.00	0.00	0.00	0.00	0.00	2.00	0.67	0.00	0.00	1.47
Harrieta faxoni	isopod	63.47	223.34	128.68	109.75	76.80	26.81	31.22	4.94	2.20	3.55	1.48	0.00
Sphaeroma terebrans	isopod	0.00	0.00	0.00	0.00	0.00	1.43	1.41	3.71	0.67	0.72	2.28	0.72
Dynamenella sp.	isopod	11.41	2.37	0.82	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00
Cassidinidea ovalis	isopod	0.75	6.19	2.99	5.72	9.85	15.53	21.02	17.78	26.54	38.49	35.39	23.01
Edotia triloba	isopod	11.77	29.89	67.54	86.74	83.65	131.97	146.51	146.88	191.87	234.62	286.74	68.51
Erichsonella attenuata	isopod	17.76	56.80	68.47	63.08	33.71	17.41	22.05	21.25	12.02	19.65	6.81	0.72
cymothoid sp. a (Livoneca) juveniles	isopod	5.21	21.08	30.05	16.35	30.78	22.55	39.23	39.85	28.75	33.13	16.96	2.90
Anopsilana jonesi	isopod	0.00	0.00	0.00	5.72	0.00	2.98	5.11	0.82	0.00	0.00	0.00	0.00
Gnathia sp.	isopod	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isopod, Paracerceis caudata	isopod	2.65	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A3, page 3 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
Hargeria rapax	tanaid	2.94	68.20	79.07	120.01	65.25	100.95	63.63	45.38	33.18	14.76	3.42	4.99
Sinelobus stanfordi	tanaid	2.77	5.99	0.81	0.00	0.00	2.90	6.63	2.82	4.39	3.61	3.40	4.59
Apseudes sp.	tanaid	4.41	19.36	56.70	60.78	35.14	22.54	29.64	9.20	3.69	1.42	0.71	0.00
Hoplomachus propinquus	tanaid	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cumaceans	cumaceans	5609.12	9529.32	14176.25	8450.10	4107.11	1631.93	163.08	86.63	60.80	20.76	1.34	10.41
Lucifer faxoni juveniles and adults	shrimp	1467.35	595.33	238.04	209.75	162.04	116.45	26.42	10.69	3.66	0.00	0.68	1.44
Lucifer faxoni mysis	shrimp	10.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
penaeid postlarvae	penaeid shrimps	310.67	2088.00	132.22	4.23	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
penaeid metamorphs	penaeid shrimps	30.90	48.60	29.07	19.51	15.14	11.83	12.60	3.09	3.01	0.00	0.00	1.47
Farfantepenaeus duorarum juveniles	pink shrimp	0.64	2.29	0.74	1.49	1.43	1.55	0.52	0.67	1.42	0.00	0.00	0.00
Farfantepenaeus duorarum adults	pink shrimp	0.69	0.00	0.74	0.00	0.00	0.00	0.00	0.74	0.75	0.00	0.00	0.00
Palaemonetes spp. postlarvae	grass shrimps	186.43	38.34	113.65	40.48	27.92	15.53	17.09	1.47	0.00	1.38	1.49	1.47
Palaemonetes pugio juveniles	daggerblade grass shrimp	12.20	11.52	12.71	8.30	5.84	1.47	9.43	15.41	14.28	2.22	3.09	11.27
Palaemonetes pugio adults	daggerblade grass shrimp	1.45	1.39	0.00	0.00	0.70	0.70	1.44	0.00	0.67	0.76	2.01	3.02
Palaemonetes vulgaris juveniles	grass shrimp	2.29	0.77	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74
Palaemonetes vulgaris adults	grass shrimp	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonetes paludosus juveniles	grass shrimp	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Periclimenes spp. postlarvae	shrimps	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Periclimenes spp. juveniles	shrimps	101.49	12.98	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemon floridanus postlarvae	Florida grass shrimp	4.35	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
alphaeid postlarvae	snapping shrimps	536.96	35.43	5.34	5.06	2.16	1.40	0.00	0.00	1.50	0.00	0.00	1.47
alphaeid juveniles	snapping shrimps	15.38	8.78	12.66	0.70	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alpheus estuariensis juveniles	snapping shrimp	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hippolyte zostericola postlarvae	zostera shrimp	737.14	88.62	4.75	1.39	0.66	1.44	0.00	0.74	0.00	0.00	0.00	0.00
Hippolyte zostericola juveniles	zostera shrimp	190.14	9.56	1.61	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75
Hippolyte zostericola adults	zostera shrimp	28.90	4.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tozeuma carolinense juveniles	arrow shrimp	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ogyrides alphaerostris juveniles and adults	estuarine longeye shrimp	13.58	18.55	3.18	3.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ambidexter symmetricus juveniles	shrimp	15.31	2.63	2.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
processid postlarvae	night shrimps	30.30	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
callianassid postlarvae	ghost shrimps	0.00	0.00	0.00	0.00	1.44	0.00	0.72	0.00	0.00	0.00	0.00	0.00
callianassid juveniles	ghost shrimps	0.00	0.00	1.49	0.00	1.50	3.58	7.02	1.41	0.00	0.00	0.00	0.00
Callianassa spp. juveniles	ghost shrimps	2.33	14.78	13.78	14.27	8.63	3.91	4.02	0.72	0.00	0.00	0.00	0.00
Callianassa spp. adults	ghost shrimps	0.00	0.00	0.00	0.00	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upogebia spp. postlarvae	mud shrimps	1316.83	27.97	11.37	8.74	0.79	0.00	0.00	0.00	0.00	0.00	0.71	2.96
Upogebia spp. juveniles	mud shrimps	254.50	32.59	265.76	3.58	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
decapod mysis	shrimp larvae	13068.34	1899.67	1001.92	638.08	953.99	1051.59	1444.68	626.68	704.20	490.47	353.40	211.78
shrimps, unidentified juveniles	shrimps	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
paguroid megalops larvae	hermit crabs	12.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
paguroid juveniles	hermit crabs	36.58	3.97	1.42	0.74	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00
Petrolisthes armatus juveniles	porcelain crab	0.00	2.94	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Euceramus praelongus juveniles	olivepit porcelain crab	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Callinectes sapidus juveniles	blue crab	0.00	0.72	0.00	0.67	0.00	0.66	1.25	2.78	6.17	2.73	0.00	2.92
Portunus sp. juveniles	swimming crab	0.00	0.67	0.00	0.66	0.73	0.00	0.46	0.00	0.00	1.43	0.00	0.00
Rhithropanopeus harrisii juveniles	Harris mud crab	0.00	0.76	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.76	0.00	0.00
Uca spp. juveniles	fiddler crabs	4.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
decapod zoeae	crab larvae	52911.85	51468.12	58488.20	60618.99	77043.14	85977.95	73853.88	56244.96	50452.16	41256.88	26201.28	22509.09

Table A3, page 4 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
decapod megalopae	post-zoea crab larvae	4363.87	3362.15	2415.67	1756.50	1329.91	898.87	1029.44	414.79	265.60	191.18	84.29	58.03
pelecypods	clams, mussels, oysters	9.25	1.34	1.50	5.57	4.23	3.53	5.26	0.00	2.81	0.75	1.53	14.97
gastropods, prosobranch	snails	77.36	79.26	10.83	12.38	21.57	40.97	31.67	14.37	46.76	9.96	40.44	442.47
gastropods, opisthobranch	sea slugs	0.90	0.68	4.66	3.49	1.37	1.40	0.00	0.75	0.00	3.35	0.69	0.73
brachiopod, Glottidia pyramidata larvae	lamp shell	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
appendicularian, Oikopleura dioica	larvacean	7453.27	2539.30	834.44	7.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77
chaetognaths, sagittid	arrow worms	4044.15	630.26	168.15	28.27	9.90	0.00	0.75	0.00	6.85	0.75	0.00	10.21
Lepisosteus sp. flexion larvae	gar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34	1.31	2.16
Lepisosteus sp. postflexion larvae	gar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43
Elops saurus postflexion larvae	ladyfish	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.73	2.16	1.38	0.65	0.74
Myrophis punctatus juveniles	speckled worm eel	0.00	0.00	0.73	0.00	0.00	0.70	0.00	0.72	0.00	0.00	0.00	0.00
Anchoa hepsetus postflexion larvae	striped anchovy	0.00	0.00	0.00	3.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anchoa hepsetus juveniles	striped anchovy	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anchoa mitchilli eggs	bay anchovy	203.70	26.31	3.65	5.22	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00
Anchoa mitchilli postflexion larvae	bay anchovy	62.98	26.98	83.40	47.29	53.61	45.29	28.31	14.48	21.63	9.14	14.93	0.73
Anchoa mitchilli juveniles	bay anchovy	70.76	147.52	356.37	164.94	179.87	151.64	137.53	316.40	177.41	172.87	1322.34	494.75
Anchoa mitchilli adults	bay anchovy	0.00	18.08	4.09	2.65	5.20	4.24	5.94	10.43	19.10	7.78	7.75	2.90
Anchoa spp. preflexion larvae	anchovies	362.45	292.87	145.09	89.02	26.92	20.86	11.22	5.07	3.72	1.44	0.71	0.00
Anchoa spp. flexion larvae	anchovies	19.81	26.70	43.03	15.33	21.87	11.45	1.52	1.44	0.76	0.72	0.71	0.00
clupeid eggs	herrings	21.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
clupeid preflexion larvae	herrings	0.77	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brevoortia smithi juveniles	yellowfin menhaden	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.00
Brevoortia spp. postflexion larvae	menhaden	2.30	1.54	18.73	11.71	52.65	47.65	24.82	21.25	22.65	20.35	63.16	25.97
Brevoortia spp. metamorphs	menhaden	0.76	0.00	0.00	0.00	0.00	1.45	12.83	7.92	1.35	4.96	1.40	0.00
Harengula jaguana postflexion larvae	scaled sardine	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synodus foetens postflexion larvae	inshore lizardfish	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synodus foetens metamorphs	inshore lizardfish	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Synodus foetens juveniles	inshore lizardfish	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opsanus beta juveniles	gulf toadfish	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00
Mugil cephalus postflexion larvae	striped mullet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.00	0.00	0.00
Mugil cephalus juveniles	striped mullet	0.00	0.71	0.68	0.00	0.61	0.00	0.68	1.37	0.00	0.71	0.74	0.74
Mugil curema juveniles	white mullet	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00
Membras martinica preflexion larvae	rough silverside	0.00	0.71	1.68	1.40	0.00	0.00	1.23	0.00	1.33	0.00	0.00	0.00
Membras martinica juveniles	rough silverside	0.67	0.00	0.00	0.69	2.89	3.54	0.52	1.50	4.48	1.46	3.04	0.00
Membras martinica adults	rough silverside	0.00	0.72	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Menidia spp. preflexion larvae	silversides	0.00	1.38	3.52	2.14	4.82	5.77	14.63	13.62	8.63	15.52	12.57	12.19
Menidia spp. flexion larvae	silversides	0.00	0.00	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Menidia spp. postflexion larvae	silversides	0.00	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47
Menidia spp. juveniles	silversides	0.00	0.00	0.72	0.00	0.00	0.00	2.21	0.00	0.73	0.70	0.72	5.19
Strongylura marina juveniles	Atlantic needlefish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00
Strongylura spp. postflexion larvae	needlefishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64	0.00	0.00	0.00	0.74
Fundulus spp. eggs	killifishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.00	0.70	0.00	0.78
Fundulus spp. postflexion larvae	killifishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.54	0.00	0.00	0.00	2.12
Lucania goodei postflexion larvae	bluefin killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
Lucania parva eggs	rainwater killifish	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	0.73	0.00	0.69	4.61
Lucania parva postflexion larvae	rainwater killifish	0.00	0.00	0.00	0.00	0.00	1.42	0.68	0.73	2.92	1.45	10.58	16.20
Lucania parva juveniles	rainwater killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.65	16.58

Table A3, page 5 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
Lucania parva adults	rainwater killifish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.62
Gambusia holbrooki juveniles	eastern mosquitofish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.06
Cyprinodon variegatus postflexion larvae	sheepshead minnow	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00
Syngnathus floridae juveniles	dusky pipefish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00
Syngnathus louisianae juveniles	chain pipefish	2.25	1.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Syngnathus scovelli juveniles	gulf pipefish	3.04	3.70	2.32	4.26	0.79	0.00	4.39	2.19	2.10	4.31	0.75	0.00
fish eggs, percomorph	sciaenid eggs (primarily)	292.44	2.09	0.81	0.75	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00
Prionotus tribulus juveniles	bighead searobin	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lepomis auritus juveniles	redbreast sunfish	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
Lepomis spp. preflexion larvae	sunfishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73
Lepomis spp. postflexion larvae	sunfishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00
Lepomis spp. juveniles	sunfishes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00
Micropterus salmoides juveniles	largemouth bass	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloroscombrus chrysurus postflexion larvae	Atlantic bumper	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucinostomus gula juveniles	silver jenny	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00
Eucinostomus harengulus juveniles	tidewater mojarra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00
Eucinostomus spp. postflexion larvae	mojarras	2.21	3.58	1.20	3.60	0.79	2.21	0.00	2.89	1.56	0.00	5.39	0.74
Eucinostomus spp. juveniles	mojarras	0.64	2.37	4.64	0.00	8.74	4.41	6.24	13.41	5.85	12.92	5.39	3.06
gerreid preflexion larvae	mojjaras	0.90	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eugerres plumieri postflexion larvae	striped mojarra	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Archosargus probatocephalus juveniles	sheepshead	0.69	0.00	0.68	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orthopristis chrysoptera juveniles	pigfish	0.00	0.00	0.00	0.00	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bairdiella chrysoura flexion larvae	silver perch	2.65	0.00	0.00	3.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bairdiella chrysoura postflexion larvae	silver perch	2.65	1.35	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00
Bairdiella chrysoura juveniles	silver perch	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00
Lagodon rhomboides postflexion larvae	pinfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.69	0.00
Lagodon rhomboides juveniles	pinfish	0.00	0.00	0.00	0.00	0.00	2.13	3.42	6.15	0.67	0.00	0.00	0.00
Cynoscion arenarius preflexion larvae	sand seatrout	0.77	0.71	0.60	1.46	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cynoscion arenarius flexion larvae	sand seatrout	0.00	0.71	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cynoscion arenarius postflexion larvae	sand seatrout	0.00	0.80	0.60	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
Cynoscion arenarius juveniles	sand seatrout	0.00	0.71	0.00	0.00	2.10	0.00	0.00	0.73	0.00	1.52	0.00	0.00
Cynoscion nebulosus preflexion larvae	spotted seatrout	4.45	0.68	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
Cynoscion nebulosus flexion larvae	spotted seatrout	0.00	0.00	3.00	0.65	1.37	0.00	0.00	0.00	0.00	0.71	0.00	0.00
Cynoscion nebulosus postflexion larvae	spotted seatrout	0.72	0.00	4.85	1.30	0.00	0.00	2.97	0.00	1.42	0.00	0.00	0.00
Leiostomus xanthurus postflexion larvae	spot	0.00	0.87	0.74	0.70	7.28	2.87	4.36	0.82	1.43	1.46	0.00	0.00
Leiostomus xanthurus juveniles	spot	1.91	3.34	12.70	6.27	13.99	5.45	8.21	14.08	4.17	4.12	1.37	0.77
Menticirrhus spp. preflexion larvae	kingfishes	6.20	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sciaenops ocellatus postflexion larvae	red drum	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.73	0.00	0.00	0.00	0.00
Sciaenops ocellatus juveniles	red drum	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00
blenniid preflexion larvae	blennies	33.76	40.99	21.11	14.43	9.28	5.98	7.94	0.69	2.84	2.16	0.00	0.78
Chasmodes saburrae flexion larvae	Florida blenny	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chasmodes saburrae postflexion larvae	Florida blenny	0.90	1.46	0.00	1.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chasmodes saburrae juveniles	Florida blenny	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lupinoblennius nicholsi flexion larvae	highfin blenny	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lupinoblennius nicholsi postflexion larvae	highfin blenny	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lupinoblennius nicholsi juveniles	highfin blenny	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00
Gobiesox strumosus preflexion larvae	skilletfish	13.90	23.96	6.93	3.68	1.29	0.00	4.24	0.73	0.00	0.00	0.00	0.00

Table A3, page 6 of 6. Location specific plankton-net catch.

Data are presented as mean number per 1,000 cubic meters.

Organisms are listed in phylogenetic order.

		Location (km from mouth)											
Description	Common Name	-3.0	0.1	1.9	2.8	3.9	5.0	5.9	7.0	7.9	8.9	10.3	11.2
Gobiesox strumosus flexion larvae	skilletfish	0.00	0.00	1.61	1.46	3.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiesox strumosus postflexion larvae	skilletfish	1.48	1.46	2.43	0.00	0.00	1.40	3.70	0.75	0.00	1.34	0.00	0.00
Bathygobius soporator preflexion larvae	frillfin goby	5.74	10.80	0.00	29.27	0.00	0.00	0.00	0.70	0.76	1.59	0.00	0.00
Bathygobius soporator postflexion larvae	frillfin goby	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
gobiid eggs	gobies	2.29	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
gobiid preflexion larvae	gobies	304.29	837.81	757.47	1920.88	5278.67	8113.14	3947.56	2078.09	988.43	672.12	796.12	302.89
gobiid flexion larvae	gobies	145.94	174.93	179.62	213.00	1108.83	1112.05	757.03	372.99	185.93	190.82	301.88	66.16
Gobiosoma bosc postflexion larvae	naked goby	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.75	0.00	0.00	0.00
Gobiosoma bosc juveniles	naked goby	0.00	0.00	0.00	0.74	0.73	1.43	2.31	2.19	0.73	3.09	3.11	2.90
Gobiosoma robustum juveniles	code goby	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00
Gobiosoma spp. postflexion larvae	gobies	279.62	792.38	417.60	369.93	782.41	3400.54	3818.07	1644.25	371.62	197.04	180.02	83.25
Microgobius gulosus juveniles	clown goby	0.00	0.00	0.00	0.00	0.72	0.71	3.34	0.00	0.73	0.00	2.28	1.44
Microgobius spp. preflexion larvae	gobies	0.00	1.44	2.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Microgobius spp. flexion larvae	gobies	0.00	11.52	26.30	28.93	15.23	38.39	9.99	13.30	21.13	13.78	4.72	7.18
Microgobius spp. postflexion larvae	gobies	20.09	79.38	42.62	102.32	64.63	49.27	43.18	17.20	8.50	16.90	12.45	15.41
Achirus lineatus flexion larvae	lined sole	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achirus lineatus postflexion larvae	lined sole	5.67	8.35	4.29	1.38	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Achirus lineatus juveniles	lined sole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.52	0.00
Symphurus plagiusa juveniles	blackcheek tonguefish	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00
Trinectes maculatus flexion larvae	hogchoker	0.00	0.00	0.60	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trinectes maculatus postflexion larvae	hogchoker	1.66	2.03	2.55	2.73	11.94	6.07	7.93	7.69	2.87	1.40	3.85	0.00
Trinectes maculatus juveniles	hogchoker	0.00	0.00	0.00	0.00	0.00	0.00	1.49	0.00	0.00	0.00	3.22	0.00

Appendix B: Seine summary tables

Table B1, page 1 of 3.

Seine catch statistics (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order.

Scientific name	Common Name	Number Collected	Collection Frequency	km_u (km)	S_u (psu)	CPUE (No./100m^2) Average	CPUE (No./100m^2) Maximum
Farfantepenaeus duorarum	Pink shrimp	324	22.8	6.65	5.78	1.32	35.29
Palaemonetes spp.	Palaemonetes grass shrimps	70	3.6	6.33	7.29	0.29	35.29
Palaemonetes intermedius	Brackish grass shrimp	2,511	36.4	5.21	8.26	10.26	630.88
Palaemonetes paludosus	Riverine grass shrimp	117	3.3	11.04	1.43	0.48	82.35
Palaemonetes pugio	Daggerblade grass shrimp	2,442	26.4	8.15	3.04	9.98	870.59
Palaemon floridanus	Florida grass shrimp	1	0.3	0.10	24.23	0.00	1.47
Callinectes sapidus	Blue crab	1,132	45.6	6.88	3.66	4.62	161.76
Dasyatis sabina	Atlantic stingray	4	1.1	3.50	11.36	0.02	1.47
Lepisosteus spp.	Gars	3	0.6	11.00	1.41	0.01	2.94
Lepisosteus platyrhincus	Florida gar	2	0.6	11.00	1.95	0.01	1.47
Elops saurus	Ladyfish	5	0.8	4.52	8.04	0.02	2.94
Brevoortia spp.	Menhadens	318	5.6	9.38	3.23	1.30	200.00
Opisthonema oglinum	Atlantic thread herring	23	1.1	0.52	22.57	0.09	19.12
Harengula jaguana	Scaled sardine	156	3.9	2.90	14.34	0.64	75.00
Anchoa hepsetus	Striped anchovy	1,751	13.6	3.97	12.46	7.15	602.94
Anchoa mitchilli	Bay anchovy	19,790	33.9	7.83	6.69	80.84	3,410.29
Anchoa cubana	Cuban anchovy	30	0.8	1.61	26.49	0.12	35.29
Synodus foetens	Inshore lizardfish	93	13.6	3.39	11.54	0.38	10.29
Ariopsis felis	Hardhead catfish	1	0.3	2.40	9.50	0.00	1.47
Opsanus beta	Gulf toadfish	6	1.7	6.37	6.03	0.02	1.47
Urophycis floridana	Southern hake	1	0.3	4.00	3.70	0.00	1.47
Hyporhamphus spp.	Halfbeak	5	0.8	2.36	16.10	0.02	2.94
Hyporhamphus meeki	False silverstripe halfbeak	1	0.3	-0.60	23.30	0.00	1.47
Strongylura spp.	Needlefishes	19	3.6	4.02	10.63	0.08	4.41
Strongylura marina	Atlantic needlefish	36	3.9	9.42	3.34	0.15	14.71
Strongylura notata	Redfin needlefish	191	19.4	4.78	8.55	0.78	23.53
Strongylura timucu	Timucu	315	23.6	7.92	4.42	1.29	35.29
Cyprinodon variegatus	Sheepshead minnow	954	15.6	8.32	2.42	3.90	430.88
Fundulus confluentus	Marsh killifish	1	0.3	12.10	2.10	0.00	1.47
Fundulus grandis	Gulf killifish	625	14.7	6.09	4.01	2.55	217.65
Fundulus similis	Longnose killifish	134	8.6	3.31	7.32	0.55	72.06
Fundulus seminolis	Seminole killifish	36	2.2	10.56	1.72	0.15	20.59
Lucania parva	Rainwater killifish	15,537	39.4	11.15	2.05	63.47	3,282.35
Lucania goodei	Bluefin killifish	250	6.1	10.77	1.03	1.02	126.47

Table B1, page 2 of 3.

Seine catch statistics (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order.

Scientific name	Common Name	Number Collected	Collection Frequency	km_u (km)	S_u (psu)	CPUE (No./100m^2) Average	CPUE (No./100m^2) Maximum
Adinia xenica	Diamond killifish	4	0.6	4.58	4.33	0.02	4.41
Floridichthys carpio	Goldspotted killifish	702	12.2	3.10	7.02	2.87	429.41
Gambusia holbrooki	Eastern mosquitofish	426	5.0	10.49	1.15	1.74	195.59
Poecilia latipinna	Sailfin molly	60	3.3	9.96	1.90	0.25	39.71
Heterandria formosa	Least killifish	104	5.6	11.41	1.91	0.42	44.12
Membras martinica	Rough silverside	963	4.7	5.95	10.98	3.93	419.12
Menidia spp.	Menidia silversides	31,015	68.9	9.55	3.38	126.70	5,870.59
Syngnathus scovelli	Gulf pipefish	60	10.6	7.75	4.16	0.25	8.82
Prionotus tribulus	Bighead searobin	5	1.1	5.42	6.18	0.02	2.94
Centropomus undecimalis	Common snook	13	1.4	9.07	2.44	0.05	13.24
Lepomis spp.	Sunfishes	5	1.1	11.86	1.86	0.02	2.94
Lepomis macrochirus	Bluegill	16	1.7	11.36	1.40	0.07	10.29
Lepomis microlophus	Redear sunfish	18	2.8	10.46	2.00	0.07	4.41
Lepomis punctatus	Spotted sunfish	15	2.2	11.19	1.51	0.06	10.29
Micropterus salmoides	Largemouth bass	267	11.1	10.95	1.91	1.09	73.53
Chloroscombrus chrysurus	Atlantic bumper	1	0.3	3.80	8.70	0.00	1.47
Oligoplites saurus	Leatherjack	77	14.4	5.98	8.91	0.31	7.35
Selene vomer	Lookdown	3	0.3	0.50	16.40	0.01	4.41
Trachinotus falcatus	Permit	2	0.3	7.90	2.70	0.01	2.94
Lutjanus griseus	Gray snapper	30	5.8	6.49	6.23	0.12	5.88
Eucinostomus spp.	Eucinostomus mojarras	11,673	55.6	9.40	3.64	47.68	3,500.00
Eucinostomus gula	Silver jenny	719	25.6	2.80	11.30	2.94	117.65
Eucinostomus harengulus	Tidewater mojarra	7,307	65.3	8.85	3.89	29.85	572.06
Orthopristis chrysoptera	Pigfish	27	2.8	2.33	12.26	0.11	11.76
Lagodon rhomboides	Pinfish	1,128	37.5	6.16	7.13	4.61	254.41
Archosargus probatocephalus	Sheepshead	67	6.9	9.97	3.08	0.27	17.65
Cynoscion nebulosus	Spotted seatrout	38	5.0	6.90	5.85	0.16	8.82
Cynoscion arenarius	Sand seatrout	2	0.6	8.20	3.28	0.01	1.47
Bairdiella chrysoura	Silver perch	85	2.8	9.66	4.88	0.35	92.65
Leiostomus xanthurus	Spot	6,566	16.4	5.86	4.10	26.82	2,002.94
Menticirrhus americanus	Southern kingfish	1	0.3	3.70	8.80	0.00	1.47
Menticirrhus saxatilis	Northern kingfish	1	0.3	1.00	11.30	0.00	1.47
Pogonias cromis	Black drum	4	1.1	1.75	19.55	0.02	1.47
Sciaenops ocellatus	Red drum	108	5.6	9.52	2.29	0.44	36.76

Table B1, page 3 of 3.

Seine catch statistics (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order.

Scientific name	Common Name	Number Collected	Collection Frequency	km_u (km)	S_u (psu)	CPUE (No./100m^2) Average	CPUE (No./100m^2) Maximum
Tilapia spp.	Tilapias	1	0.3	11.90	2.60	0.00	1.47
Mugil spp.	Mullets	3	0.3	0.10	15.00	0.01	4.41
Mugil cephalus	Striped mullet	1,464	10.3	4.39	3.32	5.98	1,026.47
Mugil curema	White mullet	10	1.4	6.87	4.61	0.04	5.88
Mugil gyrans	Whirligig mullet	6	1.7	4.35	5.27	0.02	1.47
Chasmodes saburrae	Florida blenny	1	0.3	1.90	7.40	0.00	1.47
Ctenogobius smaragdus	Emerald goby	1	0.3	0.40	12.35	0.00	1.47
Gobiosoma spp.	Gobiosoma gobies	38	5.8	9.94	2.30	0.16	5.88
Gobiosoma bosc	Naked goby	119	11.9	10.45	1.74	0.49	27.94
Gobiosoma robustum	Code goby	1	0.3	-0.60	23.30	0.00	1.47
Microgobius gulosus	Clown goby	379	25.3	9.84	2.96	1.55	41.18
Bathygobius soporator	Frillfin goby	4	1.1	4.63	6.42	0.02	1.47
Scomberomorus maculatus	Spanish mackerel	1	0.3	5.40	7.70	0.00	1.47
Etropus crossotus	Fringed flounder	1	0.3	0.50	16.40	0.00	1.47
Paralichthys albigutta	Gulf flounder	19	2.2	-0.05	15.63	0.08	7.35
Symphurus plagiusa	Blackcheek tonguefish	42	6.4	4.31	6.31	0.17	7.35
Trinectes maculatus	Hogchoker	227	16.1	9.72	2.31	0.93	51.47
Achirus lineatus	Lined sole	6	1.4	2.55	18.78	0.02	2.94
Stephanolepis hispidus	Planehead filefish	1	0.3	0.30	14.55	0.00	1.47
Sphoeroides nephelus	Southern puffer	16	3.3	2.06	10.42	0.07	4.41

Table B2, page 1 of 4.

Seine catch by month (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order. Number of monthly samples is indicated in parentheses.

Scientific name	*Common Name*	*Jan* (20)	*Feb* (40)	*Mar* (20)	*Apr* (40)	*May* (20)	*Jun* (40)	*Jul* (20)	*Aug* (40)	*Sep* (20)	*Oct* (40)	*Nov* (20)	*Dec* (40)	*Total* (360)
Farfantepenaeus duorarum	Pink shrimp	.	4	7	5	.	50	9	88	20	113	19	9	324
Palaemonetes spp.	Palaemonetes grass shrimps	.	.	.	1	4	24	4	9	.	28	.	.	70
Palaemonetes intermedius	Brackish grass shrimp	57	618	12	358	64	160	545	20	1	339	113	224	2,511
Palaemonetes paludosus	Riverine grass shrimp	.	.	7	2	.	1	14	.	.	10	83	.	117
Palaemonetes pugio	Daggerblade grass shrimp	523	696	29	356	14	387	38	73	3	44	264	15	2,442
Palaemon floridanus	Florida grass shrimp	.	.	.	1	.	.	.	.	.	.	.	.	1
Callinectes sapidus	Blue crab	78	276	88	104	30	21	4	65	3	134	257	72	1,132
Dasyatis sabina	Atlantic stingray	.	.	.	1	.	1	.	2	.	.	.	.	4
Lepisosteus spp.	Gars	.	.	.	3	.	.	.	.	.	.	.	.	3
Lepisosteus platyrhincus	Florida gar	.	.	.	.	.	.	.	1	.	.	.	1	2
Elops saurus	Ladyfish	.	4	.	.	.	1	.	.	.	.	.	.	5
Brevoortia spp.	Menhadens	.	181	.	44	44	47	2	.	.	.	.	.	318
Opisthonema oglinum	Atlantic thread herring	.	.	.	.	.	9	13	.	1	.	.	.	23
Harengula jaguana	Scaled sardine	.	.	.	1	71	82	1	.	.	.	.	1	156
Anchoa hepsetus	Striped anchovy	.	.	.	43	487	1,035	136	48	2	.	.	.	1,751
Anchoa mitchilli	Bay anchovy	.	5,498	19	974	1,630	3,464	1,206	1,036	2,019	3,403	287	254	19,790
Anchoa cubana	Cuban anchovy	.	.	.	.	.	.	.	.	30	.	.	.	30
Synodus foetens	Inshore lizardfish	.	.	.	4	27	33	3	4	3	13	2	4	93
Ariopsis felis	Hardhead catfish	.	.	.	.	.	.	.	1	.	.	.	.	1
Opsanus beta	Gulf toadfish	.	.	1	.	.	4	.	1	.	.	.	.	6
Urophycis floridana	Southern hake	.	1	.	.	.	.	.	.	.	.	.	.	1
Hyporhamphus spp.	Halfbeak	.	.	.	.	3	2	.	.	.	.	.	.	5
Hyporhamphus meeki	False silverstripe halfbeak	.	.	.	.	.	.	1	.	.	.	.	.	1

Table B2, page 2 of 4.

Seine catch by month (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order. Number of monthly samples is indicated in parentheses.

Scientific name	*Common Name*	*Jan* (20)	*Feb* (40)	*Mar* (20)	*Apr* (40)	*May* (20)	*Jun* (40)	*Jul* (20)	*Aug* (40)	*Sep* (20)	*Oct* (40)	*Nov* (20)	*Dec* (40)	*Total* (360)
Strongylura spp.	Needlefishes	.	.	.	3	12	3	.	1	.	.	.	.	19
Strongylura marina	Atlantic needlefish	.	.	.	.	10	1	3	4	.	.	14	4	36
Strongylura notata	Redfin needlefish	16	17	3	.	8	26	17	50	5	11	6	32	191
Strongylura timucu	Timucu	33	66	10	4	2	15	14	53	1	37	21	59	315
Cyprinodon variegatus	Sheepshead minnow	34	47	.	41	56	141	68	74	15	43	386	49	954
Fundulus confluentus	Marsh killifish	.	.	.	.	.	.	.	1	.	.	.	.	1
Fundulus grandis	Gulf killifish	123	46	1	3	37	143	.	2	.	2	226	42	625
Fundulus similis	Longnose killifish	7	5	.	3	2	17	.	1	.	4	92	3	134
Fundulus seminolis	Seminole killifish	.	.	.	1	.	3	15	16	.	.	.	1	36
Lucania parva	Rainwater killifish	238	141	494	1,012	1,429	1,658	2,253	3,810	719	1,730	184	1,869	15,537
Lucania goodei	Bluefin killifish	.	.	14	2	.	82	21	13	2	24	86	6	250
Adinia xenica	Diamond killifish	.	.	.	.	.	1	.	.	.	.	3	.	4
Floridichthys carpio	Goldspotted killifish	16	34	.	7	5	24	.	3	.	65	537	11	702
Gambusia holbrooki	Eastern mosquitofish	.	2	.	2	.	2	21	5	.	2	389	3	426
Poecilia latipinna	Sailfin molly	.	1	.	.	.	1	12	10	.	.	36	.	60
Heterandria formosa	Least killifish	.	.	.	7	.	1	30	12	2	31	20	1	104
Membras martinica	Rough silverside	.	.	.	.	80	593	290	.	.	.	.	.	963
Menidia spp.	Menidia silversides	366	862	55	5,546	3,839	6,930	3,305	3,856	685	2,858	673	2,040	31,015
Syngnathus scovelli	Gulf pipefish	4	6	2	10	.	4	6	5	.	4	3	16	60
Prionotus tribulus	Bighead searobin	.	.	.	.	.	.	.	.	.	1	4	.	5
Centropomus undecimalis	Common snook	.	.	.	.	.	.	.	2	.	1	.	10	13
Lepomis spp.	Sunfishes	.	.	.	.	.	1	.	2	1	1	.	.	5
Lepomis macrochirus	Bluegill	.	.	.	.	.	4	.	4	.	1	7	.	16

Table B2, page 3 of 4.

Seine catch by month (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order. Number of monthly samples is indicated in parentheses.

Scientific name	*Common Name*	*Jan* (20)	*Feb* (40)	*Mar* (20)	*Apr* (40)	*May* (20)	*Jun* (40)	*Jul* (20)	*Aug* (40)	*Sep* (20)	*Oct* (40)	*Nov* (20)	*Dec* (40)	*Total* (360)
Lepomis microlophus	Redear sunfish	.	.	3	.	.	3	1	7	.	.	1	3	18
Lepomis punctatus	Spotted sunfish	.	.	2	.	1	.	1	2	.	1	8	.	15
Micropterus salmoides	Largemouth bass	1	2	2	9	17	82	108	19	1	8	10	8	267
Chloroscombrus chrysurus	Atlantic bumper	.	.	.	.	.	1	.	.	.	.	.	.	1
Oligoplites saurus	Leatherjack	.	.	.	.	.	10	19	26	5	16	.	1	77
Selene vomer	Lookdown	.	.	.	.	.	3	.	.	.	.	.	.	3
Trachinotus falcatus	Permit	.	.	.	.	.	.	.	2	.	.	.	.	2
Lutjanus griseus	Gray snapper	.	.	.	.	6	4	2	4	1	7	.	6	30
Eucinostomus spp.	Eucinostomus mojarras	84	630	118	211	43	1,225	303	817	219	2,575	409	5,039	11,673
Eucinostomus gula	Silver jenny	1	31	13	4	1	1	20	98	31	236	35	248	719
Eucinostomus harengulus	Tidewater mojarra	51	722	220	827	805	318	263	1,340	112	1,184	42	1,423	7,307
Orthopristis chrysoptera	Pigfish	.	.	.	10	3	8	2	3	.	1	.	.	27
Lagodon rhomboides	Pinfish	12	157	66	234	35	398	33	97	3	88	.	5	1,128
Archosargus probatocephalus	Sheepshead	.	.	.	.	2	20	29	5	1	7	3	.	67
Cynoscion nebulosus	Spotted seatrout	.	.	.	.	.	4	8	16	2	8	.	.	38
Cynoscion arenarius	Sand seatrout	.	.	.	1	.	.	.	1	.	.	.	.	2
Bairdiella chrysoura	Silver perch	.	.	.	1	.	81	2	1	.	.	.	.	85
Leiostomus xanthurus	Spot	322	6,116	3	104	11	3	.	.	.	.	.	7	6,566
Menticirrhus americanus	Southern kingfish	.	.	.	.	.	1	.	.	.	.	.	.	1
Menticirrhus saxatilis	Northern kingfish	.	.	.	1	.	.	.	.	.	.	.	.	1
Pogonias cromis	Black drum	.	.	.	.	.	.	.	1	1	2	.	.	4
Sciaenops ocellatus	Red drum	3	4	.	.	.	.	.	1	.	26	18	56	108
Tilapia spp.	Tilapias	.	.	.	.	.	.	1	.	.	.	.	.	1

Table B2, page 4 of 4.

Seine catch by month (March 2008 through February 2010, n=360).

Organisms are listed in phylogenetic order. Number of monthly samples is indicated in parentheses.

Scientific name	*Common Name*	*Jan* (20)	*Feb* (40)	*Mar* (20)	*Apr* (40)	*May* (20)	*Jun* (40)	*Jul* (20)	*Aug* (40)	*Sep* (20)	*Oct* (40)	*Nov* (20)	*Dec* (40)	*Total* (360)
Mugil spp.	Mullets	.	3	.	.	.	.	.	.	.	.	.	.	3
Mugil cephalus	Striped mullet	870	560	4	13	1	4	.	7	.	.	.	5	1,464
Mugil curema	White mullet	.	.	2	.	.	5	1	.	.	.	.	2	10
Mugil gyrans	Whirligig mullet	1	.	.	.	2	.	.	.	.	.	3	.	6
Chasmodes saburrae	Florida blenny	.	.	.	.	.	.	.	.	.	1	.	.	1
Ctenogobius smaragdus	Emerald goby	.	.	.	.	.	.	.	.	.	1	.	.	1
Gobiosoma spp.	Gobiosoma gobies	5	5	.	.	4	2	1	5	.	7	7	2	38
Gobiosoma bosc	Naked goby	14	6	4	4	3	10	9	16	.	9	39	5	119
Gobiosoma robustum	Code goby	.	.	.	.	.	.	1	.	.	.	.	.	1
Microgobius gulosus	Clown goby	4	9	5	41	78	125	17	72	5	15	6	2	379
Bathygobius soporator	Frillfin goby	.	.	1	.	.	1	.	.	.	.	2	.	4
Scomberomorus maculatus	Spanish mackerel	.	.	.	.	.	1	.	.	.	.	.	.	1
Etropus crossotus	Fringed flounder	.	.	.	.	.	1	.	.	.	.	.	.	1
Paralichthys albigutta	Gulf flounder	2	7	9	.	.	.	1	.	.	.	.	.	19
Symphurus plagiusa	Blackcheek tonguefish	2	3	1	1	.	12	.	7	1	1	11	3	42
Trinectes maculatus	Hogchoker	18	1	8	57	4	13	44	47	2	4	11	18	227
Achirus lineatus	Lined sole	.	.	.	.	.	2	.	.	3	.	1	.	6
Stephanolepis hispidus	Planehead filefish	.	.	.	.	1	.	.	.	.	.	.	.	1
Sphoeroides nephelus	Southern puffer	.	.	.	.	8	1	.	.	.	2	4	1	16
Totals		2,885	16,761	1,203	10,056	8,879	17,310	8,897	11,866	3,899	13,098	4,322	11,560	110,736

Table B3, page 1 of 3.

Location specific seine catch (March 2008 through February 2010, n=360).

Data are presented as mean catch per 100m^2. Organisms are listed in phylogenetic order. Number of samples by location is indicated in parentheses.

Scientific name	*Common Name*	*1* (54)	*2* (54)	*3* (54)	*4* (54)	*5* (54)	*6* (90)	*Total* (360)
Farfantepenaeus duorarum	Pink shrimp	31	23	47	88	77	58	324
Palaemonetes spp.	Palaemonetes grass shrimps	26	1	.	4	26	13	70
Palaemonetes intermedius	Brackish grass shrimp	923	90	57	480	584	377	2,511
Palaemonetes paludosus	Riverine grass shrimp	.	1	.	.	1	115	117
Palaemonetes pugio	Daggerblade grass shrimp	16	25	27	1,087	582	705	2,442
Palaemon floridanus	Florida grass shrimp	1	.	.	.	.	.	1
Callinectes sapidus	Blue crab	30	120	145	334	377	126	1,132
Dasyatis sabina	Atlantic stingray	1	1	1	1	.	.	4
Lepisosteus spp.	Gars	.	.	.	.	.	3	3
Lepisosteus platyrhincus	Florida gar	.	.	.	.	.	2	2
Elops saurus	Ladyfish	2	.	.	2	1	.	5
Brevoortia spp.	Menhadens	2	37	3	7	19	250	318
Opisthonema oglinum	Atlantic thread herring	21	1	1	.	.	.	23
Harengula jaguana	Scaled sardine	54	59	28	13	2	.	156
Anchoa hepsetus	Striped anchovy	432	241	863	50	160	5	1,751
Anchoa mitchilli	Bay anchovy	2,018	1,257	2,770	575	5,250	7,920	19,790
Anchoa cubana	Cuban anchovy	29	1	.	.	.	.	30
Synodus foetens	Inshore lizardfish	35	17	15	21	5	.	93
Ariopsis felis	Hardhead catfish	.	1	.	.	.	.	1
Opsanus beta	Gulf toadfish	.	1	1	3	1	.	6
Urophycis floridana	Southern hake	.	.	1	.	.	.	1
Hyporhamphus spp.	Halfbeak	2	2	.	1	.	.	5
Hyporhamphus meeki	False silverstripe halfbeak	1	.	.	.	.	.	1
Strongylura spp.	Needlefishes	8	1	4	1	5	.	19
Strongylura marina	Atlantic needlefish	.	1	5	.	6	24	36
Strongylura notata	Redfin needlefish	54	32	29	22	16	38	191
Strongylura timucu	Timucu	27	19	41	43	28	157	315
Cyprinodon variegatus	Sheepshead minnow	2	30	311	59	76	476	954
Fundulus confluentus	Marsh killifish	.	.	.	.	.	1	1
Fundulus grandis	Gulf killifish	43	67	234	126	46	109	625
Fundulus similis	Longnose killifish	41	22	60	5	4	2	134
Fundulus seminolis	Seminole killifish	.	.	.	.	.	36	36
Lucania parva	Rainwater killifish	5	3	2	113	1,003	14,411	15,537

Table B3, page 2 of 3.

Location specific seine catch (March 2008 through February 2010, n=360).

Data are presented as mean catch per 100m^2. Organisms are listed in phylogenetic order. Number of samples by location is indicated in parentheses.

Scientific name	*Common Name*	*1* (54)	*2* (54)	*3* (54)	*4* (54)	*5* (54)	*6* (90)	*Total* (360)
Lucania goodei	Bluefin killifish	.	.	.	.	.	250	250
Adinia xenica	Diamond killifish	.	.	4	.	.	.	4
Floridichthys carpio	Goldspotted killifish	292	53	314	20	13	10	702
Gambusia holbrooki	Eastern mosquitofish	.	2	.	.	8	416	426
Poecilia latipinna	Sailfin molly	.	.	5	1	1	53	60
Heterandria formosa	Least killifish	.	.	.	1	1	102	104
Membras martinica	Rough silverside	.	189	494	19	.	261	963
Menidia spp.	Menidia silversides	1,642	320	701	2,024	5,536	20,792	31,015
Syngnathus scovelli	Gulf pipefish	5	1	5	13	20	16	60
Prionotus tribulus	Bighead searobin	.	.	2	3	.	.	5
Centropomus undecimalis	Common snook	1	.	.	.	2	10	13
Lepomis spp.	Sunfishes	.	.	.	.	.	5	5
Lepomis macrochirus	Bluegill	.	.	.	.	.	16	16
Lepomis microlophus	Redear sunfish	.	.	.	.	2	16	18
Lepomis punctatus	Spotted sunfish	.	.	.	.	.	15	15
Micropterus salmoides	Largemouth bass	.	.	.	.	9	258	267
Chloroscombrus chrysurus	Atlantic bumper	.	.	1	.	.	.	1
Oligoplites saurus	Leatherjack	14	17	3	13	11	19	77
Selene vomer	Lookdown	3	.	.	.	.	.	3
Trachinotus falcatus	Permit	.	.	.	.	2	.	2
Lutjanus griseus	Gray snapper	1	3	8	10	3	5	30
Eucinostomus spp.	Eucinostomus mojarras	701	105	307	805	3,029	6,726	11,673
Eucinostomus gula	Silver jenny	268	149	200	85	17	.	719
Eucinostomus harengulus	Tidewater mojarra	150	156	518	1,148	1,807	3,528	7,307
Orthopristis chrysoptera	Pigfish	15	1	7	4	.	.	27
Lagodon rhomboides	Pinfish	302	63	63	169	199	332	1,128
Archosargus probatocephalus	Sheepshead	.	2	3	.	6	56	67
Cynoscion nebulosus	Spotted seatrout	2	6	1	15	8	6	38
Cynoscion arenarius	Sand seatrout	.	.	.	1	1	.	2
Bairdiella chrysoura	Silver perch	1	2	.	2	65	15	85
Leiostomus xanthurus	Spot	843	576	273	3,027	1,732	115	6,566
Menticirrhus americanus	Southern kingfish	.	1	.	.	.	.	1
Menticirrhus saxatilis	Northern kingfish	1	.	.	.	.	.	1

Table B3, page 3 of 3.

Location specific seine catch (March 2008 through February 2010, n=360).

Data are presented as mean catch per 100m^2. Organisms are listed in phylogenetic order. Number of samples by location is indicated in parentheses.

Scientific name	*Common Name*	*1* (54)	*2* (54)	*3* (54)	*4* (54)	*5* (54)	*6* (90)	*Total* (360)
Pogonias cromis	Black drum	2	1	1	.	.	.	4
Sciaenops ocellatus	Red drum	1	.	.	3	72	32	108
Tilapia spp.	Tilapias	.	.	.	.	.	1	1
Mugil spp.	Mullets	3	.	.	.	.	.	3
Mugil cephalus	Striped mullet	34	776	105	501	39	9	1,464
Mugil curema	White mullet	.	.	3	4	2	1	10
Mugil gyrans	Whirligig mullet	1	1	2	2	.	.	6
Chasmodes saburrae	Florida blenny	.	1	.	.	.	.	1
Ctenogobius smaragdus	Emerald goby	1	.	.	.	.	.	1
Gobiosoma spp.	Gobiosoma gobies	1	1	1	1	4	30	38
Gobiosoma bosc	Naked goby	.	1	1	5	15	97	119
Gobiosoma robustum	Code goby	1	.	.	.	.	.	1
Microgobius gulosus	Clown goby	6	5	18	18	68	264	379
Bathygobius soporator	Frillfin goby	.	1	1	2	.	.	4
Scomberomorus maculatus	Spanish mackerel	.	.	1	.	.	.	1
Etropus crossotus	Fringed flounder	1	.	.	.	.	.	1
Paralichthys albigutta	Gulf flounder	18	1	.	.	.	.	19
Symphurus plagiusa	Blackcheek tonguefish	.	17	16	9	.	.	42
Trinectes maculatus	Hogchoker	.	1	.	12	61	153	227
Achirus lineatus	Lined sole	3	1	1	1	.	.	6
Stephanolepis hispidus	Planehead filefish	1	.	.	.	.	.	1
Sphoeroides nephelus	Southern puffer	7	6	1	2	.	.	16
Totals		8,125	4,512	7,705	10,955	21,002	58,437	110,736

Appendix C: Length-frequency plots for selected taxa

Farfantepenaeus duorarum (pink shrimp)

Fig. C1. Monthly length frequencies of pink shrimp collected in the Crystal River estuary.

Callinectes sapidus (blue crab)

Fig. C2. Monthly length frequencies of blue crab collected in the Crystal River estuary.

Anchoa hepsetus (striped anchovy)

Fig. C3. Monthly length frequencies of striped anchovy collected in the Crystal River estuary.

Anchoa mitchilli (bay anchovy)

Fig. C4. Monthly length frequencies of bay anchovy collected in the Crystal River estuary.

Synodus foetens (inshore lizardfish)

Fig. C5. Monthly length frequencies of inshore lizardfish collected in the Crystal River estuary.

Strongylura notata (redfin needlefish)

Fig. C6. Monthly length frequencies of redfin needlefish collected in the Crystal River estuary.

Strongylura timucu (timucu)

Fig. C7. Monthly length frequencies of timucu collected in the Crystal River estuary.

Cyprinodon variegatus (sheepshead minnow)

Fig. C8. Monthly length frequencies of sheepshead minnow collected in the Crystal River estuary.

Fundulus grandis (Gulf killifish)

Fig. C9. Monthly length frequencies of Gulf killifish collected in the Crystal River estuary.

Fundulus similis (longnose killifish)

Fig. C10. Monthly length frequencies of longnose killifish collected in the Crystal River estuary.

Lucania parva (rainwater killifish)

Fig. C11. Monthly length frequencies of rainwater killifish collected in the Crystal River estuary.

Lucania goodei (bluefin killifish)

Fig. C12. Monthly length frequencies of bluefin killifish collected in the Crystal River estuary.

Floridichthys carpio (goldspotted killifish)

Fig. C13. Monthly length frequencies of goldspotted killifish collected in the Crystal River estuary.

Gambusia holbrooki (eastern mosquitofish)

Fig. C14. Monthly length frequencies of eastern mosquitofish collected in the Crystal River estuary.

Heterandria formosa (least killifish)

Fig. C15. Monthly length frequencies of least killifish collected in the Crystal River estuary.

Syngnathus scovelli (Gulf pipefish)

Fig. C16. Monthly length frequencies of Gulf pipefish collected in the Crystal River estuary.

Micropterus salmoides (largemouth bass)

Fig. C17. Monthly length frequencies of largemouth bass collected in the Crystal River estuary.

Oligoplites saurus (leatherjack)

Fig. C18. Monthly length frequencies of leatherjack collected in the Crystal River estuary.

Eucinostomus gula (silver jenny)

Fig. C19. Monthly length frequencies of silver jenny collected in the Crystal River estuary.

Eucinostomus harengulus (tidewater mojarra)

Fig. C20. Monthly length frequencies of tidewater mojarra collected in the Crystal River estuary.

Lagodon rhomboides (pinfish)

Fig. C21. Monthly length frequencies of pinfish collected in the Crystal River estuary.

Archosargus probatocephalus (sheepshead)

Fig. C22. Monthly length frequencies of sheepshead collected in the Crystal River estuary.

Fig. C23. Monthly length frequencies of spot collected in the Crystal River estuary.

Sciaenops ocellatus (red drum)

Fig. C24. Monthly length frequencies of red drum collected in the Crystal River estuary.

Mugil cephalus (striped mullet)

Fig. C25. Monthly length frequencies of striped mullet collected in the Crystal River estuary.

Gobiosoma bosc (naked goby)

Fig. C26. Monthly length frequencies of naked goby collected in the Crystal River estuary.

Microgobius gulosus (clown goby)

Fig. C27. Monthly length frequencies of clown goby collected in the Crystal River estuary.

Trinectes maculatus (hogchoker)

Fig. C28. Monthly length frequencies of hogchoker collected in the Crystal River estuary.

Appendix D: Seine catch overview plots for selected taxa

Farfantepenaeus duorarum (pink shrimp) in seines

Fig. D1. Relative abundance of pink shrimp collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Palaemonetes intermedius (brackish grass shrimp) in seines

Fig. D2. Relative abundance of brackish grass shrimp collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Palaemonetes pugio (daggerblade grass shrimp) in seines

Fig. D3. Relative abundance of daggerblade grass shrimp collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Callinectes sapidus (blue crab) in seines

Fig. D4. Relative abundance of blue crab collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Anchoa hepsetus (striped anchovy) in seines

Fig. D5. Relative abundance of striped anchovy collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Anchoa mitchilli (bay anchovy) in seines

Fig. D6. Relative abundance of bay anchovy collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Synodus foetens (inshore lizardfish) in seines

Fig. D7. Relative abundance of inshore lizardfish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Strongylura notata (redfin needlefish) in seines

Fig. D8. Relative abundance of redfin needlefish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Strongylura timucu (timucu) in seines

Fig. D9. Relative abundance of timucu collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Cyprinodon variegatus (sheepshead minnow) in seines

Fig. D10. Relative abundance of sheepshead minnow collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Fundulus grandis (Gulf killifish) in seines

Fig. D11. Relative abundance of Gulf killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Fundulus similis (longnose killifish) in seines

Fig. D12. Relative abundance of longnose killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Lucania parva (rainwater killifish) in seines

Fig. D13. Relative abundance of rainwater killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Lucania goodei (bluefin killifish) in seines

Fig. D14. Relative abundance of bluefin killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Floridichthys carpio (goldspotted killifish) in seines

Fig. D15. Relative abundance of goldspotted killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Gambusia holbrooki (eastern mosquitofish) in seines

Fig. D16. Relative abundance of eastern mosquitofish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Heterandria formosa (least killifish) in seines

Fig. D17. Relative abundance of least killifish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Syngnathus scovelli (Gulf pipefish) in seines

Fig. D18. Relative abundance of Gulf pipefish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Micropterus salmoides (largemouth bass) in seines

Fig. D19. Relative abundance of largemouth bass collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Oligoplites saurus (leatherjack) in seines

Fig. D20. Relative abundance of leatherjack collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Eucinostomus gula (silver jenny) in seines

Fig. D21. Relative abundance of silver jenny collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Eucinostomus harengulus (tidewater mojarra) in seines

Fig. D22. Relative abundance of tidewater mojarra collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Lagodon rhomboides (pinfish) in seines

Fig. D23. Relative abundance of pinfish collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Archosargus probatocephalus (sheepshead) in seines

Fig. D24. Relative abundance of sheepshead collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Leiostomus xanthurus (spot) in seines

Fig. D25. Relative abundance of spot collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Sciaenops ocellatus (red drum) in seines

Fig. D26. Relative abundance of red drum collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Mugil cephalus (striped mullet) in seines

Fig. D27. Relative abundance of striped mullet collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Gobiosoma bosc (naked goby) in seines

Fig. D28. Relative abundance of naked goby collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Microgobius gulosus (clown goby) in seines

Fig. D29. Relative abundance of clown goby collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Trinectes maculatus (hogchoker) in seines

Fig. D30. Relative abundance of hogchoker collected with seines (water depths <= 1.8-m) in the Crystal River estuary. Box: average relative abundance; error bars: 95% CI.

Appendix E: Plots of the plankton-net distribution responses in Table 3.7.1.1 with 95% confidence limits for predicted means

Microgobius spp. flexion larvae

Menidia spp. preflexion larvae

decapod zoeae

gobiid preflexion larvae

Acartia tonsa

ostracods, podocopid

Americamysis bahia

Taphromysis bowmani

decapod megalopae

hirudinoideans

gastropods, prosobranch

Appendix F: Plots of the seine distribution responses in Table 3.7.2.1 with 95% confidence limits for predicted means

Fig. F1. Distribution response of pink shrimp (<=20 mm) in the Crystal River estuary to 91-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. F2. Distribution response of daggerblade grass shrimp (. to . mm) in the Crystal River estuary to 21-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. F3. Distribution response of redfin needlefish (>=151 mm) in the Crystal River estuary to 1-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. F4. Distribution response of tidewater mojarra (>=40 mm) in the Crystal River estuary to 1-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. F5. Distribution response of pinfish (<=40 mm) in the Crystal River estuary to 1-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. F6. Distribution response of pinfish (>=41 mm) in the Crystal River estuary to 1-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Appendix G: Plots of the plankton-net abundance responses in Table 3.8.1.1 with 95% confidence limits for predicted means

Monstrilla sp.

Temora turbinata

Pseudodiaptomus coronatus

amphipods, gammaridean

dipterans, chironomid larvae

Taphromysis bowmani

Appendix H: Plots of the seine abundance responses in Table 3.8.2.1 with 95% confidence limits for predicted means

Fig. H1. Abundance response of pink shrimp (<=20mm) in the shoreline habitat of the Crystal River to 161-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig. H2. Abundance response of daggerblade grass shrimp (. to .mm) in the shoreline habitat of the Crystal River to 364-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig. H3. Abundance response of bay anchovy (<=30mm) in the shoreline habitat of the Crystal River to 308-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig. H4. Abundance response of bay anchovy (>=31mm) in the shoreline habitat of the Crystal River to 28-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. H5. Abundance response of redfin needlefish (>=151mm) in the shoreline habitat of the Crystal River to 210-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig. H6. Abundance response of timucu (>=151mm) in the shoreline habitat of the Crystal River to 1-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. H7. Abundance response of rainwater killifish (all sizes) in the shoreline habitat of the Crystal River to 364-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig. H8. Abundance response of goldspotted killifish (all sizes) in the shoreline habitat of the Crystal River to 1-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. H9. Abundance response of silver jenny (>=40mm) in the shoreline habitat of the Crystal River to 238-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. Blue circles represent collections where less than 25% of the flow data was interpolated while red triangles represent collections where 25% or more of the flow data were interpolated.

Fig. H10. Abundance response of pinfish (>=41mm) in the shoreline habitat of the Crystal River to 7-day-lagged inflow. Solid Lines: predicted values; dashed Lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

Fig.H11. Abundance response of clown goby (all sizes) in the shoreline habitat of the Crystal River to 287-day-lagged inflow. Solid lines: predicted values; dashed lines: 95% CI. All collections had less than 25% of the flow data interpolated (blue circles).

APPENDIX

Serviss, G. and Van Fleet, R. 2017. Technical memorandum to Sid Flannery and Xinjian Chen from Gary Serviss and Ronnie Van Fleet, dated March 8, 2013 (revised March 7, 2017). Re: Supplemental Kings Bay spring flow measurement. Vanasse Hangen Brustlin, Inc., University Park, Florida. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Technical Memorandum

To: **Sid Flannery, Chief Environmental Scientist, Southwest Florida Water Management District**
XinJian Chen, Ph.D., P.E., Senior Professional Engineer, Southwest Florida Water Management District

From: **Gary Serviss, Principal Scientist, VHB**
Ronnie Van Fleet, Senior Scientist, VHB

Date: **March 8, 2013 (Revised March 7, 2017)**

Re: **Supplemental Kings Bay Spring Flow Measurements**

Background:

VHB has completed the Supplemental Kings Bay Spring Flow Measurements requested by the Southwest Florida Water Management District (District) Minimum Flows and Levels Group. The purpose of this project is to provide supplemental spring flow measurement data for use in a hydrodynamic model of Kings Bay, Crystal River, Florida. The model is being used by the District to establish a Minimum Flow for Kings Bay. The discharge from spring vents within Kings Bay and its watershed are the primary sources of baseflow to the system. The following technical memorandum summarizes the methods for flow measurements and water quality monitoring for each spring vent and two spring runs selected by the District. This memorandum also includes summary tables and all data with calculations, field notes, and summary tables in excel workbooks.

(This Technical Memorandum, and the associated electronic data submission, were revised in March 2017 when an error in the electronic data was uncovered. The discharge hydrograph for the Group 2 continuous monitoring, as shown in Figure 2, has been revised in this updated technical memorandum to reflected corrected discharge data for that monitoring effort. In addition, the electronic file containing the data has been revised to provide the corrected discharge data for the Group 2 location).

Methods:

The measurement of spring vent discharge is complicated by the nature, complexity and depth of the vents/vent complexes, as well as the tidal nature of Kings Bay. The exact method to determine discharge for each vent/vent complex was selected based upon its ability to provide the most accurate data for the calculation of discharge. In some cases, more than one form of measurement was used to strengthen the confidence of the measurement.

Two pieces of information, area and velocity, are required to accurately determine discharge. After determining the vent shape and taking the appropriate measurements required to determine its area, the area was computed by using common geometric formulas. Under open channel flow conditions the standard USGS mid-section method was generally used to compute discharge. The measured velocity tends to be parallel with the channel bottom under open channel flow conditions. However, discharging spring velocities may be perpendicular to the channel bottom thus complicating the velocity measurement.

Based upon the previous Kings Bay spring flow measurement project conducted by VHB (VHB, 2010), three different types of acoustic doppler current profiler (ADCP) meters were used for the measurement of velocity: a Sontek Flow Tracker (generally used for wading), a Sontek Shallow Water (SW) velocity meter (mounted on the bottom of stream to continuously record velocity or mounted on a PVC frame to collect spring vent measurements), and a Sontek RiverSurveyor M9 (for measuring deeper stream velocity). As demonstrated during the 2009 measurements (VHB, 2010), the ADCP meters can be positioned such that they are capable of recording velocities vertical to vent flow direction.

A few sites have open channel flow conditions and the standard USGS method for the determination of discharge was used. Those springs discharging through a run (Three Sisters, Parker Island Spring, etc.) can be accurately measured with the standard USGS method. A Sontek current meter was used to collect the discharge data using this method. This type of measurement is referred to as an instantaneous cross-section measurement.

At two locations there are several springs that discharge through a single canal. These areas are subject to tidal flow influences; consequently, these sites were monitored continuously over a two-week period which included a spring and a neap tide. A Sontek Shallow Water velocity meter was anchored to the bottom and recorded velocity at 15-minute intervals. Periodic discharge measurements were conducted under different tidal conditions using the RiverSurveyor M9 for the purpose of developing rough area and velocity ratings to compute discharge. These types of measurements are referred to as diurnal cross-section measurements. For this study, diurnal cross-section measurements were conducted for two sets of springs discharging through canals. Group 1 is located in the canal that receives flow from Springs 8, 9, and 10, and the Group 2 canal includes flows from Springs 15, 16, 18, 19, 20, 21, 22 and 23. A former USGS monitoring location that was used in previous studies was used for the Group 1 site. Because Group 1 equipment was destroyed on three separate occasions, the data for this group was collected in two different time frames. The location of Group 1 and 2 sites and all spring and spring complexes are provided in **Figure 1** and are at the same location as the original study.

Velocity measurements were made at vent openings to determine a representative mean velocity to be used with the measured area in the computation of discharge for the vent. A SCUBA diver placed an ADCP device appropriately near the vent such that one or more readings were taken to determine a representative mean velocity for the vent. Accurate measurements of the vents dimensions were taken prior to the velocity measurement to determine the area of the vent. Multiple measurements of velocity were taken for larger vents with diffuse flow to develop an average velocity for that vent. For vent complexes, a series of measurements for multiple vents was necessary. These types of measurements are referred to as vent measurements. The emphasis of the vent measurement effort was followed a list that prioritized spring vents with higher discharge. Based upon the average discharge measured during the original VHB study for the District (*Spring Flow Evaluation in Kings Bay, Crystal River, Florida*), five discharge categories were utilized. Specifically, Low = < 2 cfs (cubic feet per second), Low-Medium = 2 - 10 cfs, Medium = 10 - 20 cfs, Medium High = 20 - 40 cfs, and High = > 40 cfs. These discharge categories are provided for each spring/spring complex in the priority list (**Table 1**). In some cases, vent measurements were conducted to supplement the measurement methods discussed above.

Date: January, 2010

Revised:

Figure 1
Kings Bay Spring Vent Flow Measurement
Location Map
Citrus County, Florida

Vanasse Hangen Brustlin, Inc.
8043 COOPER CREEK BLVD., SUITE 201
UNIVERSITY PARK, FLORIDA 34201

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Table 1. Measurement Method(s) for each Spring

Measurement Method	Estimated Flow	Site	Site Name	Latitude	Longitude
Diurnal-Group 1					
D, I and V	L-M	8	Hammett 4/House Spring	28° 53'45.44"N	82° 35'22.84"W
D and V	M-H	9	Hammett 5/Jurassic Spring	28° 53'42.08"N	82° 35'23.93"W
D and V	M-H	10	Hammett 3/Hunters Spring/American Legion Spring	28° 53'40.41"N	82° 35'32.91"W
Diurnal-Group 2					
D and V	L	15	Hammett 7/Paradise Isles	28° 53'27.18"N	82° 35'42.02"W
D and V	H	16	Hammett 8/Manatee Sanctuary/Gator Hole/Magnolia Spring/Crystal Spring	28° 53'26.50"N	82° 35'33.27"W
D, I and V	L-M	18	Hammett 10/Three Sisters #1/Three Sisters Springs/Middle Springs # 1	28° 53'19.46"N	82° 35'21.37"W
D, I and V	M-H	19	Hammett 28/Three Sisters #2/Three Sisters Springs/Middle Springs # 2	28° 53'18.70"N	82° 35'20.87"W
D, I and V	H	20	Hammett 28/Three Sisters #3/Three Sisters Springs/Middle Springs # 3	28° 53'18.14"N	82° 35'20.16"W
D and V	L-M	21	Hammett 9/ Kings Bay #1/ Idiots Delight #1	28° 53'17.22"N	82° 35'23.03"W
D and V	L-M	22	Hammett 11 /Idiots Delight #2	28° 53'16.55"N	82° 35'22.04"W
D and V	L	23	Hammett 11A/Idiots Delight #3/ Three Sisters Run	28° 53'16.24"N	82° 35'22.55"W
Instantaneous					
Instantaneous	M	2	Fountain Spring/City Hall Spring	28° 54'01.29"N	82° 35'43.60"W
Instantaneous	M	H24	Hammett 24	28° 53'58.30"N	82° 36'05.95"W
D, I and V	L-M	8	Hammett 4/House Spring	28° 53'45.44"N	82° 35'22.84"W
D, I and V - Group 1	L-M	18	Hammett 10/Three Sisters #1/Three Sisters Springs/Middle Springs # 1	28° 53'19.46"N	82° 35'21.37"W
D, I and V - Group 1	H	19	Hammett 28/Three Sisters #2/Three Sisters Springs/Middle Springs # 2	28° 53'18.70"N	82° 35'20.87"W
D, I and V - Group 1	H	20	Hammett 28/Three Sisters #3/Three Sisters Springs/Middle Springs # 3	28° 53'18.14"N	82° 35'20.16"W
I and V - Group 2	L	25	Hammett 12/Parker Island Springs/Little Hidden Spring	28° 53'08.84"N	82° 35'38.69"W
I and V - Group 2	L	25	Hammett 12/Parker Island Springs/Little Hidden Spring	28° 53'08.74"N	82° 35'38.47"W
I and V - Group 2	L	25	Hammett 12/Parker Island Springs/Little Hidden Spring	28° 53'08.48"N	82° 35'38.26"W
I and V	L-M	38	Hammett 18/Black Spring	28° 52'39.08" N	82° 35'57.28"W
Vent Only					
V	L	11	Hammett 21/Magnolia Circle Spring	28° 53'38.49"N	82° 35'58.84"W
V	H	31	Hammett 2/Tarpon Hole/Big Hole/Crystal Spring	28° 52'54.68"N	82° 35'39.37"W
V	H	32	Hammett 16/King Spring/Grand Canyon Spring	28° 52'54.37"N	82° 35'41.64"W
V	M-H	30	Hammett 15/Mullets Gullet Spring/Tarpon Hole #2	28° 52'54.82"N	82° 35'39.29"W
V	M	6	Hammett 1/Catfish Spring	28° 53'53.50"N	82° 35'55.54"W
V	M	24	Parker Island North Spring Complex	28° 53'13.30"N	82° 35'38.33"W
V	M	24	Parker Island North Spring Complex	28° 53'13.23"N	82° 35'38.51"W
V	M	24	Parker Island North Spring Complex	28° 53'13.21"N	82° 35'38.76"W
V	M	24	Parker Island North Spring Complex	28° 53'13.10"N	82° 35'38.30"W
V	M	24	Parker Island North Spring Complex	28° 53'12.33"N	82° 35'41.58"W
V	M	35	Hammett 17/Golfview	28° 52'45.02"N	82° 35'30.70"W
V	M	39	Hammett 19/Sid's Springs	28° 52'36.66"N	82° 35'50.99"W
V	M	40	Gary's Grotto	28° 52'35.51"N	82° 35'56.35"W
V	M	40	Gary's Grotto	28° 52'35.38"N	82° 35'56.18"W
V	L-M	1	Hammett 23/Miller's Creek Spring	28° 54'05.10"N	82° 36'12.49"W
V	L-M	5	Hammett 27/Pool Spring	28° 53'54.48" N	82° 35'43.02"W
V	L-M	26	Banana Island North Spring Complex	28° 53'05.92"N	82° 35'46.10"W
V	L-M	26	Banana Island North Spring Complex	28° 53'05.46"N	82° 35'46.09"W
V	L-M	26	Banana Island North Spring Complex	28° 53'04.48"N	82° 35'47.12"W
V	L-M	26	Banana Island North Spring Complex	28° 53'04.40"N	82° 35'45.35"W
V	L-M	27	Hammett 13/FWS Spring Complex	28° 53'03.29"N	82° 35'36.87"W
V	L-M	27	Hammett 13/FWS Spring Complex	28° 53'01.98"N	82° 35'37.11"W
V	L-M	34	Dave's Quest Springs	28° 52'49.54"N	82° 35'42.92"W
V	L-M	34	Dave's Quest Springs	28° 52'49.24"N	82° 35'43.29"W
V	L-M	34	Dave's Quest Springs	28° 52'48.41"N	82° 35'42.71"W
V	L	3	Charlie's Fish House Spring	28° 53'57.32"N	82° 35'44.23"W

Table 1. Measurement Method(s) for each Spring

Measurement Method	Estimated Flow	Site	Site Name	Latitude	Longitude
Vent Only					
V	L	4	Hammett 25/Birds Underwater Spring	28° 53'56.05" N	82° 35'47.56"W
V	L	7	Hammett 26/NW 9th Avenue Springs	28° 53'52.93"N	82° 36'04.75"W
V	L	7	Hammett 26/NW 9th Avenue Springs	28° 53'52.93"N	82° 36'04.96"W
V	L	7	Hammett 26/NW 9th Avenue Springs	28° 53'52.91"N	82° 36'04.97"W
V	L	12	Pete's Pier Spring	28° 53'37.85"N	82° 35'55.60"W
V	L	13	Hammett 6/Moray Spring	28° 53'37.03"N	82° 35'41.57"W
V	L	13	Hammett 6/Moray Spring	28° 53'37.01"N	82° 35'41.40"W
V	L	13	Hammett 6/Moray Spring	28° 53'36.99"N	82° 35'41.09"W
V	L	17	Buzzard Island Spring	28° 53'24.97"N	82° 35'53.64"W
V	L	28	Banana Island East Springs	28° 52'58.18"N	82° 35'40.51"W
V	L	28	Banana Island East Springs	28° 52'58.09"N	82° 35'39.95"W
V	L	28	Banana Island East Springs	28° 52'57.85"N	82° 35'40.45"W
V	L	28	Banana Island East Springs	28° 52'57.65"N	82° 35'40.27"W
V	L	28	Banana Island East Springs	28° 52'57.38"N	82° 35'39.76"W
V	L	28	Banana Island East Springs	28° 52'57.03"N	82° 35'40.16"W
V	L	29	Banana Island West Springs	28° 52'55.63"N	82° 35'48.63"W
V	L	29	Banana Island West Springs	28° 52'55.53"N	82° 35'48.62"W
V	L	37	Wynn Court Springs	28° 52'42.41"N	82° 35'50.60"W
V	L	37	Wynn Court Springs	28° 52'42.31"N	82° 35'47.33"W
V	L	37	Wynn Court Springs	28° 52'42.18"N	82° 35'49.62"W
V	L	37	Wynn Court Springs	28° 52'42.00"N	82° 35'50.68"W
V	L	37	Wynn Court Springs	28° 52'41.34"N	82° 35'48.20"W

Flow: L - Low, M - Medium, H – High
Measurement Method: I - Instantaneous USGS mid-section method measurement across a defined channel; D - Diurnal measurement through at least two tide cycle with ACDP. V - direct measurement of vent discharge, one or more times.

Specific conductance, salinity, temperature and depth were measured and recorded, along with time and approximate tide stage, concurrent with each flow measurement. An YSI sonde was calibrated daily and used to obtain the specific conductance, salinity, temperature and depth readings. Tide stage was initially estimated from tide charts of Kings Bay, but was corrected to actual tide stage using the time of the measurement and measured stage at the USGS gage at the mouth of Kings Bay (Site 02310742- Crystal River at Mouth of Kings Bay FL).

Diurnal vent measurements were conducted at three spring vents over a tidal cycle during both a spring tide and a neap tide to document changes over the course of tidal variation. Monitoring consisted of vent discharge measurements and water quality measurements, as described above, on an approximately two-hour basis over two separate 12 hour periods. These types of measurements are referred to as diurnal vent measurements.

Data Files:

The data files on the enclosed cds include all raw data, field notes, flow calculations, summary tables and figures. All discharge data are presented in cubic feet per second (cfs) units. The file labels identify the specific data/information, as such:

Diurnal Cross Section Monitoring

Group 1 Discharges and Plot 2013 WY.xlsx
Group 2 Discharges and Plot 2013 WY.xlsx

Diurnal Vent Measurements

October 29, Diurnal Spring Vents 2012.xlsx
November 6, 2012 Diurnal Spring Vents.xlsx

Vent and Cross-section Instantaneous Measurements

October 22-31, Spring Vents 2012.xlsx
October 29, Diurnal Spring Vents 2012.xlsx
November 1-2, Spring Vents 2012.xlsx
November 6, 2012 Diurnal Spring Vents.xlsx
November 7, 2012 Spring Vents.xlsx
November 8, 2012 Spring Vents.xlsx
November 12, 2012 Spring Vents.xlsx
November 13, 2012 Spring Vents.xlsx
November 14, 2012 Spring Vents.xlsx
November 15, 2012 Spring Vents.xlsx
Compilation of all 2013 WY Vent Measurements.xlsx

Water Quality Data

Water Quality Results YSI Oct-Nov 2012 Crystal River.xls

Data Summary:

Diurnal Cross Section Monitoring

Data for the diurnal cross-sectional monitoring for the Group 1 and Group 2 springs are provided in two excel files. The Group 1 measurements were taken for two different periods: 1) October 22, 2012 - October 25, 2012 and 2) December 5, 2012 – December 20, 2012. The Group 1 site was done on two separate days because equipment was damaged/destroyed during the October 2012 data collection period. Hydrographs of these two periods are shown for numerous tide cycles (**Figure 2**). The Group 2 measurements were taken for the period October 22, 2012 - November 8, 2012. A Group 2 hydrograph summarizing flows during the low and high tides for greater than two weeks is also provided on Figure 2. The Group 1 and 2 Discharges and Plot files contain the 15-minute values of stage and discharge and a plot of the computed unit values of discharge.

Diurnal Vent Measurements

Data for the diurnal vent measurements are provided for Kings Spring (SV32), Golfview Spring (SV35), and Sid's Spring (SV39) during two dates: October 29, 2012 and November 6, 2012. Two discharge measurements were taken from one large vent at Kings Spring, one measurement was made for one medium sized vent in Golfview Spring, and one measurement was taken from each of two separate vents in Sid's Spring. The October 29th monitoring was conducted for six completed sets of data over the range of low and high tides for this neap tide. The November 6th monitoring was conducted for seven completed sets of data over the range of low and high tides for this spring tide. The discharge data are summarized for each of the measurements in **Table 2**.

The salinity and temperature data for diurnal vent measurements are included in the excel file "Water Quality Results YSI Oct-Nov 2012 Crystal River.xlsx"

Figure 2. Group 1 and 2 Spring diurnal cross-sectional monitoring for Kings Bay in 2012. (Revised March 7, 2017)

Table 2. Diurnal vent measurement summaries for October 29, 2012 and November 6, 2012.

Site	Site Name	Date	Time	Discharge (cfs)
SV32121029	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	850 EST	43.86
SV32121029b	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	1048 EST	51.19
SV32121029d	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	1229 EST	42.26
SV32121029f	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	1433 EST	37.35
SV32121029i	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	1555 EST	26.75
SV32121029k	King Spring/Grand Canyon Spring "Manatee sign"	10/29/12	1659 EST	23.85
SV3220121106	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	0808 EST	29.41
SV3220121106b	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	0922 EST	32.68
SV3220121106d	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	1036 EST	32.35
SV3220121106f	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	1148 EST	39.63
SV3220121106j	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	1406 EST	43.83
SV3220121106l	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	1542 EST	39.47
SV3220121106o	King Spring/Grand Canyon Spring "Manatee sign"	11/06/12	1703 EST	37.46
SV35121029	Golfview	10/29/12	0659 EST	2.67
SV35121029a	Golfview	10/29/12	0942 EST	3.53
SV35121029c	Golfview	10/29/12	1114 EST	5.53
SV35121029d	Golfview	10/29/12	1336 EST	2.42
SV35121029e	Golfview	10/29/12	1457 EST	1.68
SV35121029f	Golfview	10/29/12	1615 EST	2.26
SV3520121106	Golfview	11/06/12	0716 EST	1.82
SV3520121106a	Golfview	11/06/12	0830 EST	2.98
SV3520121106b	Golfview	11/06/12	0945 EST	3.10
SV3520121106c	Golfview	11/06/12	1058 EST	1.74
SV3520121106d	Golfview	11/06/12	1213 EST	2.44
SV3520121106e	Golfview	11/06/12	1457 EST	2.44
SV3520121106f	Golfview	11/06/12	1604 EST	5.10
SV3520121106g	Golfview	11/06/12	1615 EST	3.66
SV39121029	Sid's Spring	10/29/12	0735 EST	1.87
SV39121029a	Sid's Spring	10/29/12	0746 EST	5.39
SV39121029b	Sid's Spring	10/29/12	1018 EST	2.45
SV39121029c	Sid's Spring	10/29/12	1020 EST	4.97
SV39121029d	Sid's Spring	10/29/12	1159 EST	2.01
SV39121029e	Sid's Spring	10/29/12	1201 EST	4.33
SV39121029f	Sid's Spring	10/29/12	1402 EST	2.22
SV39121029g	Sid's Spring	10/29/12	1405 EST	1.78
SV39121029h	Sid's Spring	10/29/12	1525 EST	2.16
SV39121029i	Sid's Spring	10/29/12	1527 EST	2.61
SV39121029j	Sid's Spring	10/29/12	1638 EST	1.62
SV39121029k	Sid's Spring	10/29/12	1640 EST	1.93
SV3920121106	Sid's Spring	11/06/12	0739 EST	1.97
SV3920121106a	Sid's Spring	11/06/12	0741 EST	2.22
SV3920121106b	Sid's Spring	11/06/12	0857 EST	2.37
SV3920121106c	Sid's Spring	11/06/12	0859 EST	2.12
SV3920121106d	Sid's Spring	11/06/12	1010 EST	2.04
SV3920121106e	Sid's Spring	11/06/12	1012 EST	3.52

Table 2. Diurnal vent measurement summaries for October 29, 2012 and November 6, 2012.

Site	Site Name	Date	Time	Discharge (cfs)
SV3920121106f	Sid's Spring	11/06/12	1124 EST	2.92
SV3920121106g	Sid's Spring	11/06/12	1126 EST	2.03
SV3920121106h	Sid's Spring	11/06/12	1339 EST	2.95
SV3920121106i	Sid's Spring	11/06/12	1341 EST	2.09
SV3920121106j	Sid's Spring	11/06/12	1455 EST	2.49
SV3920121106k	Sid's Spring	11/06/12	1458 EST	4.67
SV3920121106l	Sid's Spring	11/06/12	1634 EST	1.35
SV3920121106m	Sid's Spring	11/06/12	1636 EST	2.87
SV3920121106n	Sid's Spring	11/06/12	1746 EST	2.01
SV3920121106o	Sid's Spring	11/06/12	1748EST	1.85

Vent and Cross-section Instantaneous Measurements

Data for individual Vent and Cross-section Instantaneous Measurements were collected from October 22, 2012 to November 15, 2012. The data have been sorted by the date the measurements were made, but can be re-sorted to suit the user's needs. In cases where two or more velocity readings were made across the length or width of a vent, the computed discharges were averaged. Average flow for each of the vents is summarized in **Table 3** (the diurnal vent measurements listed in Table 2 are not repeated in Table 3). The excel workbook files with a leading date and ending in "Spring Vents" or "Diurnal" contain a leading Summary worksheet with the computed discharges. Subsequent worksheets show the discharge calculations and field notes for each vent measurement.

Generally, for submerged vents, the velocity sensor was placed about 0.23 ft. from edge of vent and about 1.0 ft. above the bottom. The distances from beginning of vent to end of cell were used to determine which cells to use for average velocity data and were determined by the measured size of each vent opening. The velocities were 10 second averages for each data set and were taken for 60 seconds. This generally provided six velocity data sets across the vent at five cell points. For some spring runs, the conventional USGS mid-section method was used to determine the discharge.

Water Quality Data

Temperature, pH, dissolved oxygen, salinity, and conductivity were recorded during flow measurements for each of the vents. Water quality results for all instantaneous and diurnal vent measurements are included as one excel file for each of the spring systems. A pivot table summary is provided as **Table 4**.

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV10121022	Hunters Spring	10/22/12	1504 EST	10.675
SV10121022b	Hunters Spring	10/22/12	1511 EST	2.962
SV10121022c	Hunters Spring	10/22/12	1516 EST	22.352
SV10121022d	Hunters Spring	10/22/12	1519 EST	1.714
Three Sisters Outfall	Three Sisters Spring Outfall	10/23/12	1237 EST	23.400
SV21121023	Hammett 9/Idiots Delight #1	10/23/12	1502 EST	6.320
SV21121023b	Hammett 9/Idiots Delight #1	10/23/12	1519 EST	5.040
SV22121023	Hammett 11/Idiots Delight #2	10/23/12	1532 EST	0.153
SV22121023a	Hammett 11/Idiots Delight #2	10/23/12	1534 EST	0.846
SV22121023c	Hammett 11/Idiots Delight #2	10/23/12	1543 EST	0.702
SV22121023d	Hammett 11/Idiots Delight #2	10/23/12	1550 EST	0.858
SV22121023e	Hammett 11/Idiots Delight #2	10/23/12	1552 EST	0.940
SV15121023	Paradise Isles	10/23/12	1030 EST	0.687
SV15121023a	Paradise Isles	10/23/12	1037 EST	0.205
SV15121023b	Paradise Isles	10/23/12	1039 EST	0.097
SV15121023c	Paradise Isles	10/23/12	1041 EST	0.118
SV15121023d	Paradise Isles	10/23/12	1042 EST	0.049
SV16121023	Manatee Sanctuary	10/23/12	1134 EST	1.325
SV16121023a	Manatee Sanctuary	10/23/12	1136 EST	1.085
SV16121023b	Manatee Sanctuary	10/23/12	1138 EST	1.257
SV16121023c	Manatee Sanctuary	10/23/12	1140 EST	5.192
SV20121023	Three Sister's Spring #3	10/23/12	1318 EST	0.000
SV20121023a	Three Sister's Spring #3	10/23/12	1320 EST	3.472
SV20121023b	Three Sister's Spring #3	10/23/12	1321 EST	2.624
SV20121023c	Three Sister's Spring #3	10/23/12	1323 EST	2.315
SV20121023d	Three Sister's Spring #3	10/23/12	1325 EST	0.752
SV19121023	Three Sister's Spring #2	10/23/12	1359 EST	3.719
SV19121023a	Three Sister's Spring #2	10/23/12	1401 EST	1.896
SV18121023	Three Sister's Spring #1	10/23/12	1420 EST	0.293
SV18121023	Three Sister's Spring #1	10/23/12	1420 EST	0.293
SV18121023a	Three Sister's Spring #1	10/23/12	1422 EST	0.247
SV18121023b	Three Sister's Spring #1	10/23/12	1423 EST	0.386
SV18121023c	Three Sister's Spring #1	10/23/12	1425 EST	0.629
SV18121023d	Three Sister's Spring #1	10/23/12	1427 EST	0.355
SV18121023e	Three Sister's Spring #1	10/23/12	1429 EST	0.377
SV08121024	House Spring	10/24/12	1037 EST	2.070
SV09121024	Jurassic Springs	10/24/12	1101 EST	11.516
SV09121024c	Jurassic Springs	10/24/12	1106 EST	0.728
SV35121024	Golfview	10/24/12	1324 EST	6.190

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV35121024a	Golfview	10/24/12	1347 EST	0.215
SV27121024	FWS Spring Complex	10/24/12	1451 EST	0.209
SV11121025	Magnolia Circle Spring	10/25/12	1041 EST	0.396
SV11121025a	Magnolia Circle Spring	10/25/12	1043 EST	0.164
SV06121025	Catfish Spring	10/25/12	1125 EST	10.415
SV08121030	House Spring	10/30/12	0911 EST	5.620
SV05121030	Hammett 27/Swimming Pool	10/30/12	1316 EST	2.312
SV03121030	Charlies Fish House Spring	10/30/12	1401 EST	0.008
H2420121030	Hammett 24/ Spring Run at Culverts west of Best Western Motel	10/30/12	1126 EST	15.700
SV13121031	Morey Springs	10/31/12	0944 EST	0.162
SV13121031a	Morey Springs	10/31/12	0950 EST	0.097
SV13121031b	Morey Springs	10/31/12	0952 EST	0.100
SV13121031c	Morey Springs	10/31/12	0954 EST	0.037
SV13121031d	Morey Springs	10/31/12	0955 EST	0.058
SV13121031e	Morey Springs	10/31/12	0957 EST	0.055
SV13121031f	Morey Springs	10/31/12	0959 EST	0.027
SV13121031g	Morey Springs	10/31/12	1000 EST	0.143
SV13121031h	Morey Springs	10/31/12	1002 EST	0.019
SV07121031a	NW 9 th Ave. Springs	10/31/12	1110 EST	0.003
SV07121031b	NW 9 th Ave. Springs	10/31/12	1115 EST	0.004
SV07121031c	NW 9 th Ave. Springs	10/31/12	1132 EST	0.048
SV07121031d	NW 9 th Ave. Springs	10/31/12	1135 EST	0.117
SV25121031	Parker Island Springs Outlet	10/31/12	1227 EST	1.460
SV26121101	Banana Island North	11/01/12	1022 EST	0.89
SV26121101a	Banana Island North	11/01/12	1023 EST	1.56
SV26121101b	Banana Island North	11/01/12	1107 EST	0.33
SV26121101c	Banana Island North	11/01/12	1112 EST	0.37
SV26121101e	Banana Island North	11/01/12	1134 EST	0.35
SV24121101	Parker Island North Complex	11/01/12	1230 EST	0.11
SV24121101a	Parker Island North Complex	11/01/12	1234 EST	0.30
SV24121101b	Parker Island North Complex	11/01/12	1311 EST	1.37
SV24121101c	Parker Island North Complex	11/01/12	1313 EST	0.80
SV24121101e	Parker Island North Complex	11/01/12	1333 EST	0.85
SV23121101	Hammett 11A/ Idiots Delight #3	11/01/12	1418 EST	0.03
SV23121101a	Hammett 11A/ Idiots Delight #3	11/01/12	1426 EST	0.14
SV23121101b	Hammett 11A/ Idiots Delight #3	11/01/12	1429 EST	0.01
SV17121101	Buzzard Island Spring	11/01/12	1515 EST	0.34
SV17121101a	Buzzard Island Spring	11/01/12	1520 EST	1.06

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV27121101	FWS Spring Complex	11/01/12	851 EST	1.90
SV27121101a	FWS Spring Complex	11/01/12	856 EST	0.99
SV27121101b	FWS Spring Complex	11/01/12	920 EST	0.74
SV27121101c	FWS Spring Complex	11/01/12	923 EST	3.08
SVPP121101	Paul's Paradise Springs	11/01/12	940 EST	0.21
SVPP121101a	Paul's Paradise Springs	11/01/12	940 EST	0.41
SV12121101	Pete's Pier Springs	11/01/12	1603 EST	0.23
SV12121101a	Pete's Pier Springs	11/01/12	1605 EST	0.52
SV12121101b	Pete's Pier Springs	11/01/12	1608 EST	0.34
SV31121102	Tarpon Hole/Big Hole/Crystal Spring Complex	11/02/12	1006 EST	3.16
SV31121102a	Tarpon Hole/Big Hole/Crystal Spring Complex	11/02/12	1009 EST	2.86
SV31121102b	Tarpon Hole/Big Hole/Crystal Spring Complex	11/02/12	1013 EST	28.18
SV34121102	Dave's Quest Springs	11/02/12	1134 EST	4.84
SV34121102a	Dave's Quest Springs	11/02/12	1142 EST	0.67
SV34121102b	Dave's Quest Springs	11/02/12	1145 EST	0.55
SV34121102c	Dave's Quest Springs	11/02/12	1202 EST	0.48
SV40121102	Gary's Grotto	11/02/12	1335 EST	3.59
SV40121102a	Gary's Grotto	11/02/12	1338 EST	1.51
SV40121102b	Gary's Grotto	11/02/12	1347 EST	1.15
SV40121102d	Gary's Grotto	11/02/12	1351 EST	1.24
SV38121102	Black Spring	11/02/12	1430 EST	0.61
SV38121102a	Black Spring	11/02/12	1432 EST	1.21
SV38121102b	Black Spring	11/02/12	1434 EST	1.57
SV30121102	Mullet's Gullet/Tarpon Hole	11/02/12	927 EST	21.27
SV30121102a	Mullet's Gullet/Tarpon Hole	11/02/12	930 EST	6.95
SV30121102b	Mullet's Gullet/Tarpon Hole	11/02/12	933 EST	14.22
SV2920121107b	Banana Island West Springs	11/07/12	1105 EST	0.08
SV2720121107	FWS Spring Complex	11/07/12	1201 EST	0.00
SV2720121107a	FWS Spring Complex	11/07/12	1203 EST	0.02
SV2720121107b	FWS Spring Complex	11/07/12	1205 EST	0.00
SV2720121107c	FWS Spring Complex	11/07/12	12210 EST	0.44
SV0120121107a	Hammett 23/Miller's Creek Spring	11/07/12	1525 EST	1.83
SV2920121107	Banana Island West Springs	11/07/12	1100 EST	0.36
SV2920121107a	Banana Island West Springs	11/07/12	1102 EST	0.13
SV2720121107d	FWS Spring Complex	11/07/12	1215 EST	0.05
SV0120121107	Hammett 23/Miller's Creek Spring	11/07/12	1512 EST	1.33
SV0420121107	Hammett 25/Birds Underwater Spring	11/07/12	1620 EST	0.05
SV0420121107a	Hammett 25/Birds Underwater Spring	11/07/12	1623 EST	0.00
SV0920121108c	Jurassic Springs	11/08/12	1209 EST	0.79

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV1020121108	Hunters Spring	11/08/12	1245 EST	3.99
SV1020121108a	Hunters Spring	11/08/12	1248 EST	1.50
SV1020121108b	Hunters Spring	11/08/12	1251 EST	5.49
SV3020121108a	Mullet's Gullet/Tarpon Hole	11/08/12	1419 EST	19.05
SV33120121108a	Tarpon Hole/Big Hole	11/08/12	1430 EST	4.14
SV3120121108b	Tarpon Hole/Big Hole	11/08/12	1433 EST	20.92
SV0920121108	Jurassic Springs	11/08/12	1159 EST	11.80
SV1020121108c	Hunters Spring	11/08/12	1253 EST	2.18
SV3020121108	Mullet's Gullet/Tarpon Hole	11/08/12	1417 EST	37.12
SV3020121108b	Mullet's Gullet/Tarpon Hole	11/08/12	1421 EST	2.18
SV3120121108	Tarpon Hole/Big Hole	11/08/12	1427 EST	0.34
SV1320121112d	Moray Springs	11/12/12	0829 EST	0.01
SV1320121112e	Moray Springs	11/12/12	0835 EST	0.02
Three Sisters Outfall	Three Sisters Spring Outfall	11/12/12	1002 EST	25.40
SV2020121112d	Three Sisters #3	11/12/12	1103EST	0.72
SV1920121112	Three Sisters #2	11/12/12	1117 EST	3.74
SV1920121112a	Three Sisters #2	11/12/12	1119 EST	1.33
SV1820121112b	Three Sisters #1	11/12/12	1140 EST	0.26
SV1820121112c	Three Sisters #1	11/12/12	1142 EST	0.29
SV1820121112d	Three Sisters #1	11/12/12	1145 EST	0.23
SV1820121112e	Three Sisters #1	11/12/12	1147 EST	0.17
SV1820121112f	Three Sisters #1	11/12/12	1150 EST	0.23
SV2220121112	Hammett 11/Idiots Delight #2	11/12/12	1200 EST	1.12
SV2220121112a	Hammett 11/Idiots Delight #2	11/12/12	1205 EST	0.22
SV2220121112b	Hammett 11/Idiots Delight #2	11/12/12	1210 EST	0.22
SV2220121112c	Hammett 11/Idiots Delight #2	11/12/12	1215 EST	2.51
SV2120121112	Hammett 9/Idiots Delight #1	11/12/12	1309 EST	6.69
SV2120121112a	Hammett 9/Idiots Delight #1	11/12/12	1311 EST	0.48
SV2120121112b	Hammett 9/ Idiots Delight #1	11/12/12	1313 EST	0.10
SV1320121112	Moray Springs	11/12/12	0821 EST	0.02
SV1320121112a	Moray Springs	11/12/12	0823 EST	0.02
SV1320121112b	Moray Springs	11/12/12	0825 EST	0.06
SV1320121112c	Moray Springs	11/12/12	0827 EST	0.21
SV1320121112f	Moray Springs	11/12/12	0836 EST	0.04
SV1320121112g	Moray Springs	11/12/12	0846 EST	0.26
SV2020121112b	Three Sisters #3	11/12/12	0957 EST	0.26
SV2020121112	Three Sisters #3	11/12/12	1051 EST	4.42
SV2020121112c	Three Sisters #3	11/12/12	1100 EST	1.19
SV1820121112	Three Sisters #1	11/12/12	1134 EST	0.14

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV1820121112a	Three Sisters #1	11/12/12	1137 EST	0.07
SV2320121112	Hammett 11A/ Idiots Delight #3	11/12/12	1337 EST	0.27
SV2320121112a	Hammett 11A/ Idiots Delight #3	11/12/12	1342 EST	0.14
SV2320121112b	Hammett 11A/ Idiots Delight #3	11/12/12	1347 EST	0.03
SV1520121112	Hammett 7/Paradise Isles	11/12/12	1515 EST	0.07
SV1520121112a	Hammett 7/Paradise Isles	11/12/12	1517 EST	4.16
SV1520121112b	Hammett 7/Paradise Isles	11/12/12	1519 EST	2.87
SV1520121112c	Hammett 7/Paradise Isles	11/12/12	1521 EST	2.61
SV1520121112d	Hammett 7/Paradise Isles	11/12/12	1524 EST	2.40
SV1120121112	Magnolia Circle Spring	11/12/12	1557 EST	0.42
SV1120121112a	Magnolia Circle Spring	11/12/12	1559 EST	0.09
SV0620121112	Catfish Spring	11/12/12	1625 EST	9.99
SV10A20121113d	Small cove below GP 01 SW	11/13/12	0845 EST	0.25
SV10A20121113e	Small cove below GP 01 SW	11/13/12	0900 EST	0.05
SV2420121113	Parker Island North Spring Complex	11/13/12	1049 EST	1.14
SV2420121113a	Parker Island North Spring Complex	11/13/12	1117 EST	1.12
SV2620121113a	Banana Island North Spring Complex	11/13/12	1323 EST	0.09
SV2720121113	FWS Spring Complex	11/13/12	1420 EST	2.94
SV2720121113a	FWS Spring Complex	11/13/12	1427 EST	2.14
SV2720121113b	FWS Spring Complex	11/13/12	1437 EST	4.21
SV2720121113c	FWS Spring Complex	11/13/12	1442 EST	0.19
SV10A20121113	Small cove below GP 01 SW	11/13/12	0823 EST	0.11
SV10A20121113a	Small cove below GP 01 SW	11/13/12	0825 EST	0.04
SV10A20121113b	Small cove below GP 01 SW	11/13/12	0830 EST	0.11
SV10A20121113c	Small cove below GP 01 SW	11/13/12	0840 EST	0.20
SV1620121113	Manatee Sanctuary	11/13/12	0947 EST	1.84
SV1620121113a	Manatee Sanctuary	11/13/12	0951 EST	7.57
SV1620121113b	Manatee Sanctuary	11/13/12	0953 EST	3.90
SV1620121113d	Manatee Sanctuary	11/13/12	0959 EST	7.57
SV1620121113e	Manatee Sanctuary	11/13/12	1005 EST	3.70
SV1620121113c	Manatee Sanctuary	11/13/12	1011 EST	0.83
SV2420121113c	Parker Island North Spring Complex	11/13/12	1137 EST	2.11
SV2620121113	Banana Island North Spring Complex	11/13/12	1321 EST	1.15
SV402012114c	Gary's Grotto	11/14/12	0946 EST	2.39
SV3920121114c	Additional vent found and not previously measured at this site (SV 39)	11/14/12	1010 EST	0.47
SV4020121114b	Gary's Grotto	11/14/12	1048 EST	1.41
SV382012114	Black Springs	11/14/12	1059 EST	0.53
SV3820121114a	Black Springs	11/14/12	1102 EST	1.60

Table 3. Compilation of all 2012 flow measurements for each spring system in Kings Bay.

Site / Spring Vent No.	Site Name	Date	Time	Discharge (cfs)
SV2520121114	Parker Island	11/14/12	1200 EST	1.25
SV3420121114	Golfview	11/14/12	1225 EST	1.01
SV3420121114c	Golfview	11/14/12	1240 EST	0.41
SV2920121114	Banana Island West Springs	11/14/12	1305 EST	0.15
SV2920121114a	Banana Island West Springs	11/14/12	1310 EST	0.12
SV2920121114b	Banana Island West Springs	11/14/12	1315 EST	0.11
SV2820121114	Banana Island East Springs	11/14/12	1400 EST	0.10
SV2820121114a	Banana Island East Springs	11/14/12	1405 EST	0.04
SV2820121114b	Banana Island East Springs	11/14/12	1410 EST	0.22
SV2820121114c	Banana Island East Springs	11/14/12	1413 EST	0.49
SV4020121114	Gary's Grotto	11/14/12	0934 EST	3.85
SV4020121114a	Gary's Grotto	11/14/12	0937 EST	1.61
SV3820121114c	Black Springs Total flow below vent area	11/14/12	1030 EST	10.60
SV3820121114b	Black Springs	11/14/12	1105 EST	1.37
SV3420121114a	Golfview	11/14/12	1229 EST	0.59
SV3420121114b	Golfview	11/14/12	1232 EST	2.04
SV0120121115	Hammett 23/Millers Creek Spring	11/15/12	0847 EST	0.93
SV0120121115a	Hammett 23/Millers Creek Spring	11/15/12	0911 EST	1.04
H2420121115	Hammett 24/Spring Run at Culverts west of Best Western Motel	11/15/12	1030 EST	22.10
SV0220121115a	Fountain Spring/City Hall Spring	11/15/12	1100 EST	0.81
SV0220121115	Spring Run Above Fountain Spring/City Hall Spring Run	11/15/12	1125 EST	8.40
SV1220121115	Pete's Pier	11/15/12	1228 EST	1.06
SV1220121115a	Pete's Pier	11/15/12	1231 EST	0.40
SV1220121115b	Pete's Pier	11/15/12	1233 EST	0.34
SV1720121115	Buzzard Island Spring	11/15/12	1319 EST	1.54
SV1720121115a	Buzzard Island Spring	11/15/12	1321 EST	0.38
SV0520121115	Hammett 27/Swimming Pool	11/15/12	1415 EST	1.07

Table 4. Water quality summaries for all spring systems for 2012 Kings Bay Flow Measurements.

Official Spring Number	Average of Temperature (^{O}C)	Average of pH	Average of Dissolved Oxygen (mg/L)	Average of Salinity (ppt)	Average of Conductivity (*u*mhos/cm)
SV1	23.0	7.7	2.74	1.04	2053
SV2	21.9	8.6	8.69	0.12	247
SV3	23.3	8.5	4.08	0.10	218
SV4	23.2	8.7	4.03	0.13	267
SV5	23.2	8.6	7.87	0.09	194
SV6	23.2	8.2	5.30	0.30	629
SV7	23.0	8.3	4.53	0.45	906
SV8	21.1	7.7	6.26	0.13	266
SV9	23.3	8.1	5.62	0.12	243
SV10	23.5	8.0	4.55	0.21	431
SV11	23.3	8.0	5.58	0.61	1218
SV12	23.3	6.1	4.91	0.52	1050
SV13	23.2	8.3	6.52	0.20	448
SV15	23.3	8.0	5.25	0.52	1060
SV16	23.4	8.0	4.60	0.26	544
SV17	22.7	5.8	6.83	0.93	1851
SV18	23.5	8.0	3.71	0.18	379
SV19	23.5	7.9	3.64	0.14	300
SV20	23.3	8.0	3.95	0.19	403
SV21	23.4	8.3	4.70	0.19	387
SV22	23.4	8.1	4.13	0.15	316
SV23	23.4	8.3	3.79	0.14	286
SV24	22.8	8.1	3.53	1.08	2084
SV25	23.3	8.1	4.33	0.59	1172
SV26	23.1	7.9	1.91	1.82	3391
SV27	23.6	8.1	3.05	0.34	675
SV28	23.3	8.1	2.84	0.59	702
SV29	23.2	7.9	2.39	1.72	3276
SV30	23.3	7.9	2.55	0.68	1449
SV31	23.3	7.9	2.47	0.79	1562
SV32	23.2	8.2	2.96	1.21	2646
SV34	23.2	8.0	2.95	0.84	1669
SV35	23.5	8.3	3.65	0.58	1170
SV38	23.2	7.9	2.59	2.95	4677
SV39	23.1	8.1	3.90	2.66	4952
SV40	23.1	7.7	1.68	4.19	7580

REFERENCE LITERATURE

Vanasse Hangen Brustlin, Inc. 2010. Springs Flow Evaluation in Kings Bay, Crystal River, Florida. Prepared for Southwest Florida Water Management District.

APPENDIX

Southwest Florida Water Management District. 2016. Crystal River/Kings Bay minimum flow and level Peer Review Panel report. Brooksville, Florida.

CRYSTAL RIVER/KINGS BAY
MINIMUM FLOW AND LEVEL
PEER REVIEW

TWA NOS: 16TW0000363, 16TW0000364, AND 16TW0000411

SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT
2379 BROAD STREET
BROOKSVILLE, FLORIDA 34604

DECEMBER 2016

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EXECUTIVE SUMMARY OF PEER REVIEW

The Southwest Florida Water Management District (District) contracted with an independent panel of experts to provide a technical peer review of the proposed Minimum Flows and Levels (MFL) for the Crystal River/Kings Bay Springs system. The Kings Bay/Crystal River system is located in Citrus County on Florida's Springs Coast. The system consists of Kings Bay, an approximately 600-acre estuarine embayment fed by more than 70 spring vents that discharge fresh to slightly saline water. From Kings Bay, the system flows out approximately 6 miles to the Gulf of Mexico through Crystal River. The system is tidally influenced throughout its extent.

Two critical components of the MFL analyses are: a hydrodynamic model developed by the District used to evaluate the changes in salinity and temperature under varied inflow conditions; and a methodology to calculate the submarine groundwater discharge (SGD) to the system. The SGD calculations constitute the long-term flows utilized as the basis for the MFL development. The U.S. Geological Survey (USGS) flow measurements on the system at Bagley Cove were deemed unreliable by the District.

The proposed MFL for the Kings Bay Crystal River system is based primarily on having less than a 15 percent change in salinity habitat (volume, shoreline length, and bottom area), with the key metric being a 15 percent change in the volume of water under 2 parts-per-thousand (ppt) salinity. Other metrics directly assessed included the volume of thermal manatee habitat, residence time, and some components of water quality. The flow reduction defined for the MFL was determined to be protective of these other components.

Overall, the Peer Review Panel supports the conclusions presented within the MFL report and the use of the salinity habitat as the primary metric. A key component of the MFL analyses, the hydrodynamic model, was generally found to be sufficiently developed and calibrated for use in evaluating the changes in the temperature and salinity as a function of SGD. Additionally, the methodology utilized for the calculating the SGD, while containing some degree of uncertainty and potential errors, represents the best available information for use in estimating the present and historical flows from the spring vents.

The Peer Review Panel did identify key comments/recommendations to improve the MFL report, supporting documentation, and associated analyses. The full document provides detailed comments and recommendations including grammatical edits. A summary of some of the key recommendations are listed below;

- The calculation and validation of the historical and present flows from the spring vents remain an issue for this system. The District has determined that the Bagley Cove data, collected by USGS, is not reliable. The SGD methodology developed by the District also has a level of uncertainty, and ancillary calculations of long-term flow using alternate methodologies do not fully support either the USGS or District calculations. The District needs to do a better job of identifying the uncertainty in both methods of flow determination and the limitations this creates.
- The salinity habitat change analyses relied upon a system-wide assessment of change. The District should consider if any habitats aggregated into the volume, area and length categories should be further parsed. One recommendation is to consider the difference between sloped and sediment and vegetated shoreline and hardened vertical shoreline (i.e., seawall). The District should assess (for all habitats) if this type of parsing makes sense and would strengthen the MFL conclusions.
- While the hydrodynamic model was deemed sufficient for use in determining the changes in salinity and temperature habitat as of function of SGD, there were some issues identified within the review that should be resolved before final submission of the MFL report and supporting documentation. Some specific issues include: evaluation of the sensitivity of the offshore boundary to changes in flows (initial results of this have been provided to the Peer Review Panel); removal of periods of the model runs from the calibration statistics where boundary data are not available; and more complete documentation of the volume of additional flow added into the model to account for seepage and as a tuning parameter for the model calibration.

A component of the Peer Review Panel scope of work was to provide an assessment of the MFL report and supporting documentation against specific listed criteria. These are outlined in Section 3 of the report. The findings of the Peer Review Panel are that, with the implementation of some of the edits/recommendations made within this report, there are no

fatal flaws within the MFL report and supporting documentation relative to the specified criteria.

1.0 INTRODUCTION

1.1 BACKGROUND AND SYSTEM DESCRIPTION

The Southwest Florida Water Management District (District) contracted with an independent panel of experts to provide a technical peer review of the proposed Minimum Flows and Levels (MFL) for the Crystal River/Kings Bay Springs system. The peer review panel includes:

- Dr. Steven Peene (panel chair)
- Dr. Ken Watson
- Dr. Adam Munson

The Kings Bay/Crystal River system is located in Citrus County on Florida's Springs Coast. The system consists of Kings Bay, an approximately 600-acre estuarine embayment fed by more than 70 spring vents that discharge fresh to slightly saline water. From Kings Bay, the system flows out approximately 6 miles to the Gulf of Mexico through Crystal River. Figure 1-1, taken from the MFL Report (SWFWMD, 2016), shows the layout of Kings Bay and Crystal River along with the locations of the numerous spring vents to the system. Based upon historic studies, the District has identified that the spring vents provide more than 99 percent of the freshwater entering the system in Kings Bay. Crystal River connects to the Gulf of Mexico at two locations: near Shell Island and through the Salt River (Figure 1-1).

Figure 1-1. Location and Layout of Crystal River/Kings Bay System (SWFWMD, 2016)

The discharge from the spring vents derives from groundwater within the system's springshed. The Crystal River/Kings Bay springshed spans approximately 310 square miles in northern Citrus County (Figure 1-2).

Flow measurements within the system have consisted of long-term monitoring at Bagley Cove (see Figure 1-1) by the U.S. Geologic Survey (USGS) and more recent data the District collected on direct flows from the spring vents. USGS flow measurement techniques have been modified throughout their period of record and, as identified by discussions with USGS staff, changes are ongoing. Additional data collection has included water level and salinity measurements at Shell Island, Salt River, Bagley Cove, and the Kings Bay Mouth, along with groundwater levels at three wells located near Kings Bay (Figure 1-1).

Figure 1-2. Extent of the Crystal River/Kings Bay Springshed (SWFWMD, 2016)

The accurate determination of the long-term total flow record is a critical component of the MFL development and is discussed in detail in the MFL report and supporting documentation. Discussions center on the use of the data from the USGS station at Bagley Cove (raw and tidally filtered) versus empirically derived direct flows from the spring vents based upon direct vent measurements and water levels in Crystal River and a nearby monitoring well.

A key component of the MFL development was a hydrodynamic model of the system that was utilized to assess the impacts of flow reductions from the spring vents on salinity and thermal habitat. The development, calibration, and application of the hydrodynamic model is discussed in detail in the MFL report and supporting documentation. The assessment of the development, calibration and application of the hydrodynamic model is a primary focus of the peer review.

The Florida Department of Environmental Protection (FDEP) has designated the Crystal River/Kings Bay system as a Class III surface water body, an Outstanding Florida Water (OFW), and a Surface Water Improvement and Management (SWIM) Priority Water Body. The Crystal River Springs group is also classified as an Outstanding Florida Spring. Key environmental resources in the area that were specifically targeted for protection in this MFL include submerged aquatic vegetation (SAV) as well as manatee thermal habitat. The MFL also examined water quality conditions in the system and the impacts of flow reductions on residence times.

The final MFL presented within the report was based on allowance of a 15 percent reduction in the volume of salinity habitat for the most sensitive salinity isohaline [2 parts per thousand (ppt)] using the hydrodynamic model. Based on the 15 percent habitat reduction, an allowable flow reduction of 12 percent was identified. Current water withdrawals are at or less than 2 percent of the baseline flow condition. Based on the comparison of the current withdrawals with the allowable, the MFL document concluded that no recovery strategy was needed.

1.2 REGULATORY BASIS FOR MFL AND PEER REVIEW

Florida Statutes (F.S.) mandate that the District must establish MFLs for state surface waters and aquifers within its boundaries for the purpose of protecting the water resources

and the ecology of the area from “significant harm.” Section 373.042, F.S., provides that the minimum flow for a given watercourse is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area and the minimum water level is the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area.

Section 373.042, F.S., also provides that MFLs shall be calculated using the best information available, that the Governing Board shall consider and may provide for non-consumptive uses in the establishment of MFLs and, when appropriate, MFLs may be calculated to reflect seasonal variation. The law also requires that when establishing MFLs, changes and structural alterations to watersheds, surface waters, and aquifers shall also be considered (Section 373.0421, F.S.). The State Water Resource Implementation Rules (Chapter 62-40, Florida Administrative Code) includes additional guidance for establishing MFLs, providing that “…consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic, and wetlands ecology, including:

a) Recreation, in and on the water;
b) Fish and wildlife habitats and the passage of fish;
c) Estuarine resources;
d) Transfer of detrital material;
e) Maintenance of freshwater storage and supply;
f) Aesthetic and scenic attributes;
g) Filtration and absorption of nutrients and other pollutants;
h) Sediment loads;
i) Water quality; and
j) Navigation.”

Section 373.042, F.S., also addresses independent scientific peer review of MFLs, specifying the review of all scientific or technical data, methodologies, and models, including all scientific and technical assumptions employed in each model, used to establish a minimum flow or minimum water level. In addition, the law requires that FDEP or the District Governing Board shall give significant weight to the final peer review panel report when establishing MFLs.

1.3 DOCUMENTS AND DATA UTILIZED IN THE PEER REVIEW

The following documents and data were provided to the panel members to be utilized in the peer review.

- Recommended Minimum Flow for the Crystal River/Kings Bay System – Draft Report for Peer Review (SWFWMD, 2016a)
- Chapter 6 – Appendices: Recommended Minimum Flow for the Crystal River/Kings Bay System – Draft Report for Peer Review (SWFWMD, 2016b)
- Estimate of Submarine Groundwater Discharge to Crystal River/Kings Bay in Florida with the Help of a Hydrodynamic Model (Chen, 2014)
- On the Estimation of Submarine Groundwater Discharge to Kings Bay (Chen, 2014)
- SWFWMD Presentation – King's Bay – Simulated Spring Flow History
- Northern District Groundwater Flow Model, Version 5.0 (SWFWMD, 2016c)
- Peer Review of the Northern District Model Version 5 and Predictive Simulations, October 10, 2016, Final Report (SWFWMD, 2016d)
- Comparison of Bagley Cove Qs (graphs developed by Dr. Chen of SWFWMD)
- Excel data files from Dr. Chen of Bagley Cove, Salt River, Kings Bay Mouth, and Shell Island measured flows, levels, temperature and conductivity.

1.4 PEER REVIEW PANEL SCOPE AND APPROACH

The Peer Review Panel was scoped to complete the following tasks as part of the MFL Peer Review:

- Review draft of the Crystal River/Kings Bay MFL Report along with available supporting documentation and data
- Participate in Public Meetings including:
    - Kickoff Meeting and Site Visit (November 4, 2016)
    - Web-Meetings (November 15,16, and 21, and December 5, 2016)
- Post written review comments and collaborate with other panelists to develop a single peer review panel report
- Review and provide support in development of meeting agendas and meeting summaries

Following the process outlined in the scope above, the following sections present the results, comments, and recommendations of the Peer Review Panel.

Section 2 of this report utilizes a tabular template (completed by each of the three peer reviewers) to meet the District's peer review requirements. The tabular comments are presented for each section of the MFL report, as well as key supporting documentation within the appendices. Narrative comments on various key aspects of the MFL report and supporting documentation, precedes the tabularized comments. The tabularized comments include the specific comment, whether the comment has significant impact on the conclusions of the MFL, and recommendations on how to address the comment.

Section 3 presents tabularized results of the panel member's comments concerning the District's peer review assessment criteria, which are outlined in Attachment A of this report. These criteria were specific scoped sub-tasks outlined by the District for the panel members to address.

Section 4 presents referenced literature.

2.0 REVIEW OF MFL REPORT, APPENDICES, AND EXTERNAL REPORTS

The following sections provide detailed review and comments on the MFL report and supporting documentation provided by the District for use by the Peer Review Panel. Section 2.1 presents the review of the MFL Report. Section 2.2 presents the review of the appendices and supporting documentation. A narrative review is provided relative to key aspects of the MFL development as identified by the review panel. Following the narrative comments, tables are provided for each Chapter of the report and for the supporting documentation with detailed comments, identifying if the comment is significant (i.e., impacts the MFL determination), and proposed action items to address the comments.

2.1 MFL REPORT

Specific components of the MFL report and supporting documentation were identified by the peer review panel as critical in the MFL development. These were identified for specific review and discussion. These included;

- Determination of the Submarine Groundwater Discharge
- Development, Calibration and Application of the Hydrodynamic Model

The following presents the reviewers discussion of these items. Following the narrative discussion, tables are provided with detailed comments from each of the reviewers along with the significance of the comment and recommendations for resolution.

Determination of Submarine Groundwater Discharge

Discharge measurements at USGS gage 02310750 Crystal River Near Crystal River FL (1964 to 1977) were determined to be unreliable and were not used in the MFL study. Average flow during that period was estimated to be 971 cfs. A new gage was activated in 2002 (USGS gage 02310747 Crystal River at Bagley Cove) and tidally adjusted average flow between 2002 and 2015 was calculated to be 447 cfs. This value is the result of adjustments made to the rating curves in 2011. The District concluded for the MFL that the Bagley Cove record, including the most recent adjustments, was unreliable for this MFL work. Discussions with USGS personnel identified that USGS has recently installed new instrumentation at Bagley Cove to obtain more complete data at the cross-section. In the

future, a revised rating curve will be developed using the new data and new flow projections can be evaluated.

The District estimated an average flow of 374 cfs for the period of 1969 to 2015 using direct field flow measurements at select spring vents and at two channels which contain the input from multiple spring vents. The channel measurements were taken during July-August 2009. At this same time, water level measurements were collected at the mouth of Crystal river and in groundwater wells adjacent to Kings Bay. The District developed relationships between the water level measurements at the mouth, the water level in the wells and the measured flow at the channels. The relationships developed reflected approximately 60 percent of the flow coming into the system. The relationships were then extrapolated to the other vents to calculate the remaining 40 percent of flow. The flows were then checked using the hydrodynamic model to assure salinity predictions were reasonable and from those simulations a remaining approximately 10% additional flow was added to the system to account for seepage.

Based on the above, the MFL flow record and various metrics for developing the MFL are based on empirically derived results without verification against a complete gaged flow record, and the independent drivers are tidal stage, water temperature, and salinity; groundwater elevation at a tidally influenced well; and salinity assigned to spring flow.

The USGS results were defined as unreliable in the MFL document, but discussions with USGS personnel identified that USGS does not believe the data, following the 2011 corrections, and if averaged over a sufficient period, are unreliable. Additionally, the predictions from the Northern District Groundwater Model are closer to the long-term average from the USGS gage (450 cfs versus 447 cfs). Also, the USGS flow at Bagley Cove for the model time period (2006 to 2015) was about 354 cfs and the District estimated springs discharge was 332 cfs, or about a 6% less but reasonably similar.

Looking at how the differences impact the MFL development, if the MFL results are used to estimate available water (i.e., 12% of say 374 cfs), then the result is conservative compared to using the USGS estimated flow. However, if the MFL result is viewed as a flow (i.e., 88% of 374 cfs), then it is not conservative.

As there is a level of uncertainty with both the USGS gaged flow and the SWFWMD empirically derived flow, the MFL must note the uncertainty in both, recognize that the impact evaluation is a relative one, i.e., based on percent reductions, and identify that future efforts must be focused on verifying what the total flow into the system is.

Hydrodynamic Model Development, Calibration and Application

A 3-dimensional hydrodynamic model was applied to the Crystal River/King's Bay system to simulate time dependent water levels, currents, salinity and temperature throughout the system. The model utilized is called UnLESS3D. This is an unstructured Cartesian grid model. Within the MFL Report Appendices a report entitled "An Evaluation of Effects of Flow Reduction on Salinity and Thermal Habitats and Transport Time Scales in Crystal River/Kings Bay" was provided. The report included write ups on the UnLESS3D model equations, the physical characteristics of the Crystal River/Kings Bay system and the available field data, the hydrodynamic model calibration and verification, the model scenarios for the flow reduction, and simulations based upon the sea level rise.

The hydrodynamic model boundary inputs include; tides, temperature and salinity at two boundaries (Salt River at the bridge and at the mouth of Crystal River where it meets the Gulf of Mexico); groundwater discharge, temperature and salinity at multiple vent locations along the eastern and southern ends of Kings Bay; and atmospheric forcing at the water surface. The data for the tidal boundaries came from measured data at the two locations. The groundwater discharge came from empirically derived submarine groundwater discharge (SGD) (see previous discussion) and the temperatures and salinities associated with these inflows came from available measured data. As the modeled groundwater discharge includes inputs of water surface elevation at the mouth, this value is a dynamic parameter that is calculated for each model time step using the model equations. The atmospheric inputs came from measurements at a nearby meteorologic station.

The model was calibrated to data collected at two interior stations. The first station is at Bagley Cove. The Bagley Cove station is approximately two-thirds of the way up Crystal River between the mouth at the gulf and the entrance to Kings Bay. At the Bagley Cove station, continuous water level, salinity, discharge, and temperature data were available for the calibration. The salinity and temperature data at this station were from the bottom. The second station was located at the mouth of Kings Bay. This station had continuous water

level, salinity and temperature data. The salinity and temperature data were at the bottom and surface. The total simulation period was a 34-month period (1037 days), from April 24, 2007 to February 23, 2010. The model was calibrated against real-time data of water level, salinity and temperature for a 150-day period during December 28, 2007 – May 26, 2008 after a spin-up run for 25 days. It was then verified for the remaining days before and after the 150-day calibration period.

Comparisons of the modeled and measured data are presented in the report along with statistics including the R^2 (correlation coefficient), the mean error, the mean absolute error, and the skill assessment. The following bullets discuss the evaluation of the calibration.

- Water Level: The graphical comparisons as well as the various statistical analyses are within acceptable ranges of error for the water level. Generally, the statistics show better than normal results.
- Salinity: The statistical analyses show that the calculated statistics of the errors are within acceptable ranges. The graphical plots show that the model generally captures the temporal and spatial changes in salinity in the system, indicating that the behavior of the salinity under varying tidal and flow conditions is reasonable.
- Temperature: The statistical analyses show that the calculated statistics of the errors are within acceptable ranges and generally better than usual. The graphical plots show that the model generally captures the temporal and spatial changes in temperature in the system, indicating that the behavior of the temperature under varying tidal and flow conditions is reasonable. One comment is that the model results presented in the report should focus on the critical winter period so that the reader can see how the model performs graphically during this time.
- Cross-Sectional Flux: The comparisons of the simulated and measured cross-sectional flux shows that the model consistently under predicts the maximum flows passing at Bagley Cove. These maximums as seen in the data are generally short lived. Similar statistical analyses performed on the other data should be performed on the discharge data.

Examination of some of the results in the appendices identified that there are periods of time where the model boundary conditions were not available. During these periods the model was simply run through the two points (start and end of missing data) and used linear

interpolation between as it ran. While most likely this is not causing significant issues with the model predictions outside of these periods and some period after, this is highly unusual and it is recommended that these periods be filled in as best as possible with reasonable forcing data, or these periods be taken out of the calibration/verification periods.

The hydrodynamic model was applied from October 6, 2006 through October 13, 2015 for the scenario analyses. This is a 9-year period where measured data were available for the forcing functions. The flow reductions were then applied through this period. One issue identified is that the boundary conditions at the mouth of Crystal River and at Salt River Bridge are not altered under the flow reductions. Examination of the salinity time series at these locations does show that they are influenced by the freshwater flow coming out of the system, i.e., they are close enough to shore to be impacted by the flows. A sensitivity analysis should be performed to determine the degree to which these boundaries are expected to increase in salinity overall as a result of the flow reductions. If the differences are significant, the model scenarios should be re-run with the increased downstream boundary salinities.

The hydrodynamic model has been applied to determine the change in volume, bottom area, and shoreline length associated with different salinity ranges, when modeled flows are reduced. The criteria applied is a 15% reduction in the volume, area, or shoreline length of any one of the modeled salinity ranges. While it would be preferable to link changes in flow directly to changes in ecology, the difficulty of measuring or expressing this causality is well established and the use of habitat as a more easily measured proxy is reasonable. However, it is desirable to delineate habitat when reasonable since not all habitat offers equal ecologic benefit. This is consistent with the district historical mapping of wetland communities and substrate mapping used in riverine systems in conjunction with HEC-RAS and PHABSIM models. The challenges of the estuarine systems are different and the District has documented the difficulty with identify some community-specific thresholds in its discussion of SAV. However, the District should consider if any habitats aggregated into the volume, area and length categories should be further parsed. One recommendation is to consider the difference between sloped and sediment and vegetated shoreline and hardened vertical shoreline (i.e., seawall). While this may not alter the recommended MFL on Crystal River, it is suggested that, in other applications, there might exist unique or critical

habitats that decline over 15% if they are aggregated into the broader categories of volume length and area.

The following tables present detailed comments by chapter and appendices and supporting documentation.

Table 2-1. Review of Executive Summary

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
1	SP	Paragraph 5	No – Because the data seem to not exist but could potentially be considered during re-evaluation.	The report states "These models allowed evaluation of salinity-based habitats, manatee thermal refuge, and residence time as potential indicators of significant harm. Each of these three factors are related to the 10 environmental values put forth in the State Water Resource Implementation Rule. Particular importance was placed on the effect of salinity on promoting submerged aquatic vegetation and reducing algal blooms to promote water clarity.". While the salinity intrusion and the thermal refuge were evaluated fully relative to the MFL development, the residence time and any potential impacts on the system water quality and algal blooms were not fully evaluated in relation to the MFL. This section should be reworded to reflect this.	At this time, based on discussions with District staff, it appears that data are not available to fully quantify the relationship between decreased residence time and specific water quality parameters impacted by residence time (i.e., Chl a). Based on this, the recommendation is that the District acknowledge in the MFL report that a full evaluation of the potential impacts on water quality are not feasible at this time and recommend that future work focus on attempting to quantify the impacts through additional data collection.
2	SP	Paragraph 6	No	The report states "In addition to model outputs, we also investigated water quality measurements related to the	See resolution recommended for Comment 1.

Table 2-1. Review of Executive Summary

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				recent Total Maximum Daily Loads established by the Florida Department of Environmental Protection. Our analysis found no consistent relationship between spring flow and water quality measurements for nitrogen, phosphorus, or dissolved oxygen. As such, these water quality measures were not considered as criteria for setting the minimum flow for this system." Chl a and/or other nuisance macro-algal species were not assessed and these are key parameters that may be impacted by the residence time changes. This will be outlined in more detailed comments in the specific chapters.	
3	KW	Executive Summary Page v	No	The sufficiency of manatee thermal habit as expressed may be arguable.	Reconsider how thermal habitat is evaluated.
4	KW	Executive Summary Page v	No	Define the baseline time period.	Explicitly define.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
5	SP	Page 13, first paragraph	No	In the first sentence after the parenthesis, need to bring line back up.	Correct in report.
6	SP	Page 14, Section 1.4.3, first paragraph	No	The text states "Starting in August 2002, tide-corrected flows have been continuously recorded in the river by the USGS at the Crystal River at Bagley Cove near Crystal River, FL gage #02310747". A more accurate description of the measured flows would be that USGS utilized their Index Velocity Method to calculate flows and reference the USGS publication on index velocity. Additionally, it may be appropriate to further elaborate on the potential errors in the previous flow measurements (prior to 2002).	Reword.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

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				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
7	SP	Page 15, Section 1.4.3, 3rd paragraph	No	The document states "Based on the information described here, we concluded that discharge estimates based on the historic flow record for the Crystal River near Crystal River gage (#02310750), and the currently reported flows at the Crystal River at Bagley Cove gage #02310747 include a mixture of groundwater, stormwater runoff, and marine water, and are not reliable estimates of groundwater discharge from the Crystal River spring group for use in minimum flow analyses." This is an overstatement on the issues with the USGS data. There is uncertainty with both the USGS and SWFWMD data. There is also evidence showing at times where each appears to agree with other analyses. The report should not discount the USGS data outright, but should acknowledge the uncertainty in both, state why, at this time, the SWFWMD data were used, and identify the need for more comprehensive verification of the actual flow.	Reword.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
8	SP	Page 19, Figure 1-13	No	Need to identify the time scale (averaging) of these data, i.e., is this a plot of the annual averages or some type of running average. Given the tidal signal identified in the later measurements, I assume these plots must be some form of averaged data.	Reword graph figure, title, or identify in text.
9	SP	Page 25, Section 1.4.7.2, second to last paragraph	No	The text states "although 566 animals were observed in Kings Bay on a the extremely cold day of January 13, 2010 (Kleen 2014)." Grammatical fix.	Delete the "a."
10	SP	Page 32, Table 1-6	No	The table lists the water quality criteria for the system. While mentioned in the paragraphs above, the chl *a* criteria are not listed in the table. Also, the table needs to include the applicable criteria for Crystal River (1341I) including the Chl *a* criteria. Additionally, some of these criteria have time scales (i.e., annual mean, annual geometric mean) associated with them that need to be properly identified.	Include the appropriate time scales in the criteria table.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
11	SP	Page 35, Table 1-7	No	For the Recreation in and on the Water in the table, only protection of salinity habitats is identified. As manatee are a part of the recreational value of the system, manatee thermal refuge should be listed here also.	Reword.
12	SP	Page 35, Table 1-7	No	Salinity habitats are identified for navigation. As this is a tidal system and water levels are dominated by tides rather than freshwater inflow, is this Use applicable to this system relative to freshwater withdrawal.	Potentially reword.
13	SP	Page 35, Section 1.7.1, first paragraph	No	As in the previous comment on Table 1-7, as manatee are part of recreation (as identified in the paragraph) the thermal analyses apply here.	Reword.
14	SP	Page 36, Section 1.7.4	No	After the second sentence, there appears to be text "*However, managing*." That should be deleted.	Delete text.
15	SP	Page 36, Section 1.7.6	No	The text states "Residents and users of Kings Bay and Crystal River are concerned with water clarity and preventing / reducing algal blooms (Evans et al. 2007; SWFWMD 2015)." The text indicates that these issues are	Reword, see suggestions in Comment 1.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

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				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				dealt with in the MFL through the salinity and thermal analyses. The analyses performed in this MFL do not directly address the issue of impacts of flow reduction on algal blooms. The model is used to evaluate the impacts of flow reduction on residence time, but no analyses are performed to relate flow and Chl *a*. Based upon conversations during the public meeting on this topic, it was identified that data at present are limited for this analysis, but efforts are underway to collect more. The text here may need to be modified to reflect this.	
16	SP	Page 37, Section 1.7.9	No	The previous comment on the evaluation of Chl *a* should also be addressed in this section.	Reword. See recommendations in Comment 1.
17	KW	Page 3, Section 1.3.2	No	Consider adding definitions for tidally filtered flow and spring/neap tides; throughout report change tide-corrected to tidally filtered.	Define terms.
18	KW	Page 2, Section 1.3.1	No	Can harm to WRVs be measured or are we measuring criteria linked to harm – e.g., change in salinity?	Reword.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
19	KW	Page 3, Section 1.3.2 and Page 66, Section 4.5	No	Consider adding an explanation of how an allowable flow reduction expressed as a percent flow reduction would be applied to the SGD "flow regime" per item #8 in Section 1.3.2 may be helpful.	Explain further.
20	KW	Page 3, Section 1.3.2	No	Do historical flows occur in the absence of withdrawal impacts? Historical flows would seem to include impacts.	Reword.
21	KW	Page 5, Section 1.4	No	Maps of land surface topography within CR/KB watershed/springshed and KB bathymetry may be useful.	Consider adding graphic.
22	KW	Page 11, Section 1.4.1 Figure 1-5	No	Callout(s) for CR/KB may be helpful.	Add to figure.
23	KW	Pages 12 13, Section 1.4.2	No	As a companion to Figures 1-6 and 1-7, a cumulative deviation plot might be helpful to show persistence. Annual rainfall volumes on Figure 1-6 would be useful. The Y-axis of Figure 1-7 is the departure from long-term average rainfall.	Consider adding graphic.
24	KW	Page 14, Section 1.4.3	No	Are tide corrected flows recorded or calculated? Suggest changing tide corrected to tidally filtered.	Reword.
25	KW	Page 15, Section 1.4.3	Maybe	The two gages include runoff as part of flow measurement. The measured flows	Consider additional analysis now or in the future.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL					
Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
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				are stated to not be reliable estimates of groundwater discharge from the springs group. Is runoff otherwise included in the hydrodynamic model? How well do average tidally filtered flows (or unfiltered over longer time periods) at Bagley Cove correlate with rainfall, perhaps based on weekly, monthly, or annual averages? This may be another way of evaluating tidally filtered flow records.	
26	KW	Page 15, Section 1.4.3	Maybe	Has the USGS weighed in on the assertion that current gaged tidally filtered flow (and unfiltered flow) is unreliable? It would be useful to see the index-velocity ratings for the Bagley Cove station and open-channel sites G1 and G2.	Provide ratings.
27	KW	Page 21, Section 1.4.4.1	No	How were "observed" CR Spring Group flows determined? The definition of mean error (enclosed by parentheses) is missing a "divided by…" term.	Reword.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

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28	KW	Page 23, Section 1.4.6	No	The top paragraph is a little confusing – Crystal River group versus Crystal River Spring Group discussion. It may be useful to add a column in Table 1-2 for the withdrawals located within the CR/KB springshed.	Reword.
29	KW	Page 24, Section 1.4.7	No	Is Crystal River an impounded estuary or just the Kings Bay portion?	Explain.
30	KW	Page 29, Section 1.5.1.1	No	Do the references regarding SAV salinity tolerance differentiate between bottom salinity and water-column average salinity?	Explain.
31	KW	Page 34, Section 1.6.2	No	It may be useful to discuss the mean sea level trend NOAA has documented for one of the tide stations (e.g., Cedar Key) and impact on model and hindcasting.	Explain.
32	KW	Page 35, Section 1.7, Table 1.7, and Page 37, Section 1.7,	No	Clarify in the table that the factor evaluated for Sediment Load is the stability of bottom sediment. It is not clear (in table and text) how protection of native SAV is applicable to Navigation.	Clarify.
33	KW	Page 37, Section 1.7.8	No	Consider re-phrasing "positive impacts".	Reword.

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34	AM	Page 4	No	The District does a good job providing some of the history and buttressing the 15% reduction criterion.	No action needed.
35	AM	Page 4	No	The District states "it is preferable when possible, to explicitly link reductions in flow to critical resources; this is the approach we used with our 15% resource reduction standard" Would it be more correct to say the District protects habitat than resource?	Reword.
36	AM	Page 24	Likely not	The District lists several habitats that are less mobile than others (i.e., Oysters Beds, Hydric Hammocks, and Mangroves). However, the report is not clear concerning the location of these habitats or that salinity changes that occur at their current location. If the goal is to protect these habitats in place, further discussion might be warranted.	Provide further discussion either explaining why it is not an issue or that while this is generally true, data for Crystal river do not exist to assess these habitat specifically.
37	AM	Page 24	No	Suggest referring to one plant by one name. *Vallisneria Americana* for example is listed as both Eelgrass and native wild celery.	Word consistently.
38	AM	Page 24	No	The last sentence on the page is confusing and I only bring it up because	In light of our conversations, this is not likely to change the outcome of the

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL					
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				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				it is contrary to a verbal statement during the field trip that Lynbya is declining.	current MFL recommendation, but it Is related to the recreational value and to residence time, which has the potential of connecting flow to water quality. If there is evidence that Lynbya is diminishing in the bay, it should be documented in the report.
39	AM	Page 28	No	Makes the case that it is important to manage shoreline habitat for emergent and shoreline species. This is true but the model contains significant hardened shore length (such as the sea walls in the finger canals near the three sisters), which possibly, because of their location within the bay, will not likely experience significant changes in what are likely to be low salinity conditions due to a reduction in flow. This may add to the shoreline length at low salinities and buffer the percent reduction calculated. It would be useful to run the model and isolate the cells that border naturally vegetated shoreline.	Dr. Chen has provided model output suggesting this issue not likely to change the MFL. However, where the District has the data to delineate markedly different habitats, it should consider disaggregation of the volume, area and length categories to provide more specific habitat protection. For example, as mentioned here, vertical hardened shoreline might be too different a habitat from vegetated shoreline to aggregate the two. Further, the District should review its available data and determine if further disaggregation is appropriate or feasible.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

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				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
40	AM	Page 32	No – Because the data seem to not exist but could potentially be considered during re-evaluation.	Question…. A significant water quality concern in the past at Crystal River was water clarity and thus in part chlorophyll. There is also a 4.4 microgram per liter target for chlorophyll-a in the river and 5.7 for Kings Bay. On Page 34 it is noted that Burghart and Peebles (2011) recommended that residence time be managed to limit phytoplankton blooms. Finally, the author's note that chlorophyll-a is potentially related to residence time and that substantial increases in residence time is potentially harmful. It is partially addressed in section 2.8 and table 2-6 and again in 3.4 and table 3-5 but perhaps a more full discussion of why it is not a factor in the MFL.	Buttress the current discussion.
41	AM	Page 32	No – Because the data seem to not exist but could potentially be considered during re-evaluation.	A recommendation for future work might be to understand how the increases in ERT potentially correlate with environmental values (specifically Chl-a).	See earlier recommendation, Comment 1.

Table 2-2. Review of Chapter 1 – Introduction: Purpose and Background of MFL

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				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
42	AM	Page 35, Table 1-7	No	Aesthetic and scenic – Would include protection of natural shoreline vegetation.	Reword.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
43	SP	Section 2.2	Maybe	The equations that are utilized to define all the flows into the system have some basic error associated with them as well as certain levels of uncertainty. For example, in Figure 2-4 looking at plot (a), it is clear that for the period when measured flows were available, there are errors in the estimated flow that would indicate that the model under-predicts the overall net flow out. This error is then carried through an additional level of uncertainty as the equations and coefficients are extrapolated out to other vents in the system. Based on these known errors and uncertainty, it would be important to developed additional ways to verify the total flows. This could be done using the Bagley data, if this data is demonstrated to be useful for this. Still working on the evaluation of the Bagley data. The equations are utilized to hindcast flows so some additional verification (beyond the model predictions of salinity) of the modeled flows would be beneficial.	The report needs to be more definitive in outlining the uncertainty associated with the SGD calculations and the errors in the various steps and how those might impact the calculated flows. The Figure 2-4a differences are a good example. The graph clearly shows there are errors between the predicted and measured flows at this cross-section. Simple visual inspection indicates that this error would tend to make the calculations under-predict the long-term net flow out. This relationship is then potentially extrapolated to other vents and this error carries over. Also, some more definitive discussion of the degree of variation in the direct vent measurements and how they were used to carry the calculations forward is needed. Again, highlighting how the errors might impact the ultimate flow calculation.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
44	SP	Section 2.2	Maybe	The groundwater model predictions of flow from the springs group is on the order of 440 cfs under present conditions. The hindcast flows show averages more around 350 cfs. This further supports the need for verification of the total flow.	See previous recommendations on dealing with uncertainty in the flow measurements, i.e., Comment 43
45	SP	Page 44, Section 2.3, Paragraph 2	No	The text identifies that the model statistics indicate that the model agrees well with measured data based on R2 values and other statistical analyses. I am in agreement with the statement that the statistics are reasonable given the type of data (continuous) being compared to for salinity and temperature.	No action required.
46	SP	Section 2.3, Paragraph 3	No	Based upon the materials in the appendix on the model, along with conversations with District Staff, there was around 10% of the flow that was utilized as a tuning parameter, i.e., to represent the unmeasured flows coming in through diffuse flow and flow from hairline fractures. Not sure if that was included in the flows presented in Table 2-1.	Clarify.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
47	SP	Section 2.3	Maybe	The salinity boundary conditions utilized for the scenario runs assume that there will be no change in the salinity conditions at the locations of the boundaries from the reductions in flows. Need to test the validity of that assumption by doing some sensitivity tests on changes in that area based on flow reductions.	Some results of sensitivity tests were provided by Dr. Chen showing that this issue would not have a significant impact on the MFL conclusions. Document the sensitivity tests in the report and/or the appendices.
48	SP	Section 2.6	No	The section discusses analyses of water quality data through trend analyses as well as correlation of flow with water quality data. The methods identify that flows weren't available unless a hindcasting were done. As this was done ultimately for the MFL report, I assume the water quality analyses were done before the hindcasting so they were not available. Additionally, the methods do not discuss analyses of Chl a data which are assumed to be part of the long-term monitoring. If these data were not available, the text should state that.	Clarify and address the issue of the availability of Chl a data for analyses.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
49	SP	Section 2.8	No	The method used for the residence time calculations were based on dye releases at specific times and tide conditions. The number of periods appear sufficient to characterize the residence times using dye. Another potential method would be to examine water age. This would allow the use of the complete simulation to examine the change in the overall water age in the same way salinity or temperature were evaluated, i.e., over the full simulation cycle.	Consider using the water age method, but if not feasible, the existing method is sufficient. In a re-evaluation, where more data are available for evaluation of the impacts of residence time on Chl a, consider using water age.
50	KW	Page 40, Section 2.2	No	Reference to the third term (i.e., partial derivative) in Equation 1 relating to pressure is contrary to Equation 1 caption note and Chen (2014) report that describe the term as relating to tidal flux. Define "long term".	Clarify.
51	KW	Page 41, Section 2.2	No	Would N be needed if the groundwater elevation at the "G" well were not influenced by tide? I.e., a true background well. Or is the term needed because of the short time frames being analyzed with the model?	Clarify.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
52	KW	Page 41, Section 2.2	No	Clarify that the flows from two subsets of springs, G1 with 3 springs and G2 with 8 springs, were evaluated to determine C1 and C2 for each group. Clarify that Figure 2-4 represents the flows from just 11 of the 70 springs and that Figure 2-5 represents the combined flow from all 70 springs.	Clarify.
53	KW	Page 43, Section 2.2, Figure 2-5	No	The daily average line in the graph is missing,	Modify.
54	KW	Page 43, Section 2.3	No	Is the vertical coordinate system a fixed z-grid or sigma grid? it is useful to know when interpreting water-quality and AVF point velocity data collected using a fixed-position monitoring device.	Clarify.
55	KW	Page 44, Section 2.3	No	Is the diffuse flow about 10% or so? Runoff? Direct rainfall?	Clarify.
56	KW	Page 44, Section 2.3	No	It may be useful to mention spin up period for establishing a numerically balanced initial condition?	Clarify.
57	KW	Page 46, Section 2.3, Table 2.2	No	Is rainfall included as a meteorological input?	Clarify.
58	KW	Page 47, Section 2.4	No	A volume exceedance curve may be helpful.	Consider adding.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
59	KW	Page 47, Section 2.5	No	For what time period were instantaneous measurements of water temperature evaluated?	Clarify.
60	KW	Page 47, Section 2.4	No	"averaged across time" how much time? Daily, POR?	Clarify.
61	KW	Page 47, Section 2.4	No	How was shoreline length calculated?	Clarify.
62	KW	Page 48, Section 2.6, second paragraph	No	It is not clear how many water quality samples are associated with concurrent measurements of both groundwater level and sea level versus the number of samples associated with measured values for GW level or sea level.	Clarify.
63	KW	Page 50, Section 2.7	No	It may be useful to compare the ACOE tide projections with the mean sea level change which has occurred over the past 9 and/or 46 years at the Cedar Key tide station.	Consider adding.
64	KW	Page 51, Section 2.8, Table 2.6	No	Explain the tide terminology (i.e., spring, neap, average) and whether neap and spring are winter-time lows or summer-time highs; explain the spring discharge percentiles (i.e., exceedance or non-exceedance).	Clarify.

Table 2-3. Review of Chapter 2 – Methods

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
65	AM	General	No	No current concerns except the note about residence time above (Comment 39).	No action required.

Table 2-4. Review of Chapter 3 – Results

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
66	SP	Section 3.4, Table 3-5	Maybe	Table 3-5 shows that there are some relatively significant changes in residence time associated with the flow reductions. As such, the impact of these residence times on water quality (specifically algal blooms) could be important. This needs to be identified in the report and if data are insufficient to do this type of analyses, that needs to be stated.	See recommendations in previous comments.
67	SP	Section 3.5	No	The analyses of the data do show that Chl a values are above the criteria a significant portion of the time. One issue is that the analyses should examine the Chl a against the time scale of the criteria, i.e., annual average time frame. If the data still show the system in violation, then the residence time becomes even more important.	If the criteria are going to be used in analyses, and presented in the report, they need to be used properly, accounting for the value and how the data should be compared to the value, i.e., time averaging, etc.
68	SP	Section 3.5	Maybe	Analyses of correlations of nutrients and flow were presented, but no analyses of flow versus Chl a were presented.	See previous recommendations in dealing with evaluation of Chl a data.
69	KW	Page 52, Section 3.1	No	Is the volume calculation across all layers? Or bottom layers for SAV for	Clarify.

Table 2-4. Review of Chapter 3 – Results

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				example or bottom area for benthic. Or does it matter? Well mixed?	
70	KW	Page 52, Section 3.1	No	Is bottom area in Table 3-1 associated with salinity in the bottom layer of the model?	Clarify.
71	KW	Page 52, Section 3.1	No	Confirm that the < 2 ppt includes the freshwater portions <0.5 ppt.	Confirm.
72	KW	Page 52, Section 3.1, Table 3.1	No	The values listed for <2 ppt appear to be inconsistent with values for preceding and succeeding salinities, although I can see how it is possible.	Confirm.
73	KW	Page 52, Section 3.1	No	Is average volume most appropriate? What about the change in the occurrences of high salinity, short term events - like the acute thermal refuge analysis?	Consider addressing.
74	KW	Page 53, Section 3.2 and elsewhere	No	The statements regarding the sufficiency of manatee thermal refuge for much larger populations may be overreaching; same for the two right-most columns that list manatee capacity in Table 3-3 on Page 54. As a reality check, do we think there would be no impact to manatee use of system if flows were reduced to levels such that the thermal refuge	Consider rewording.

Table 2-4. Review of Chapter 3 – Results

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				volume just exceeded the manatee space requirements? What about habitat volume reduced to twice the volume estimated to be needed? I agree that it would be difficult to make this metric a driver given the overall volume of suitable habitat. It seems that the assumption of a 15 % reduction in habitat causing significant harm is not appropriate in the case of manatee thermal refuge. Perhaps calculate the amount (as a percent) of habitat reduction needed to impact the known manatee population, and then state that manatee habitat is therefore not a limiting metric.	
75	KW	Page 53, Section 3.2, Figure 3.2, caption	No	The maps illustrate the spatial distribution of warm water, not volumes.	Reword.
76	KW	Page 55, Section 3.3	No	Should the flow reduction be 12% not 9%; clarify that "habitat" is represented by volume of salinity <2 ppt as opposed to bottom area salinity <2 ppt.	Clarify.
77	KW	Page 55, Section 3.3	No	The model input data for the 9-year simulation period reflect a sea level rise	Consider new language.

Table 2-4. Review of Chapter 3 – Results

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				of about 0.06 feet, hence the baseline period includes some habitat loss attributable to sea level rise. This is not substantial but it may be useful to mention/discuss the sea level rise that occurred during the model and historic period.	
78	KW	Page 55, Section 3.4	No	Would looking at percentile flows be appropriate for salinity as well?	Consider adding.
79	KW	Page 56, Section 3.4, Table 3-5	No	Define the SGD percentiles as exceedances or non-exceedances.	Define.
80	KW	Page 58, Section 3.5.2	No	Define "spring flow" and how it was determined (i.e., measured or calculated).	Define.
81	KW	Page 58, Section 3.5.2	No	Rephrase "over the time period" to "over the course of 91 dates…" similar to Figure 3-4 caption.	Reword.
82	AM	Page 52, Table 3-1	No	Table 3-1 is the linkage between the model and the ecology. As mentioned in the meeting, the District should consider including absolute volume, area, and length, and not just percent. How much habitat is being preserved and how much is being lost?	Dr. Chen has already provided the Panel these numbers. Recommend including them in the report.

Table 2-4. Review of Chapter 3 – Results

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
83	AM	General	No	It would be interesting to understand the uncertainty in the model as it applies to length, area, and volume, though this information is not necessary for the purposes of using the model to recommend an MFL.	None – Just a note.
84	AM	General	No	The discussion of Manatee habitat is thorough enough to make compelling argument that Manatee habitat will not be limiting even if other habitat assumptions were used.	The manatee discussion is sometimes distracting from the factors that directly limit the MFL. However, manatees are also an important factor to many CR/KB stakeholders. Recommend considering if the manatee information should be compiled as a single appendix or left in the report.

Table 2-5. Review of Chapter 4 – Discussion: Using Results to Set Minimum Flow

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
85	SP	Section 4.1, Paragraph 1, third sentence	No	There is an extra "the" in the sentence.	Delete text.
86	SP	Section 4.1	No	The estimated long-term flow for the 46-year period based on the hindcast flow projection from the modeled equations is 374 cfs. Based on the Bagley Cove site the median flow from 2002 to 2015 is 437 cfs. The output from the groundwater flow model for the present conditions is around 440 cfs. The text states "The cross-sectional flux through Bagley Cove is a combination of tidal fluxes, spring flows entering Kings Bay during the preceding 6 – 20 days, stormwater runoff, wind action, and nonlinear interactions among factors affecting circulation and transport processes in the estuary. Furthermore, these previous estimates of discharge do not match the water budget for the springshed, which is able to account for 455 cfs of spring flow from the Crystal River Springs group given 20 inches of recharge per year." While this statement	Reword.

Table 2-5. Review of Chapter 4 – Discussion: Using Results to Set Minimum Flow

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
				is true for the previously uncorrected Bagley Cove data, it is not accurate relative to the corrected data, which in the text above it is stated that the median flow is 437 cfs, which does agree with the recharge rates. It is important to note that the methodology utilized to develop the modeled flow equations (index velocity measurements at G1 and G2) was the same as that utilized to measure the flows at the Bagley Station. The uncertainty in both measurements needs to be outlined in the report and the USGS gage flow not fully dismissed.	
87	SP	Section 4.4	No	Reiterate the comment that the analyses do not address the potential for changes in water quality (specifically Chl a) due to changes in residence time. If data are insufficient for this analysis at this time, which was identified through conversations with District personnel, then this should be stated within the report and identified for future evaluation.	See previous recommendations on dealing with impact of residence time on Chl a.

Table 2-5. Review of Chapter 4 – Discussion: Using Results to Set Minimum Flow

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
88	KW	Page 62, Section 4.2	No	Resolve the possible inconsistency in Table 3-1 noted previously and revise text if necessary.	Check.
89	KW	Page 64, Section 4.3	No	It may be helpful to list the allowable flow reductions determined for the Homosassa (3%) and Weeki Wachee (10%).	Add reference.
90	KW	Page 65, Section 4.4.2, paragraph beginning with "None of the vents…."	No	Clarify what "effect of date was removed" means.	Clarify.
91	KW	Page 66, Section 4.5	No	The thermal refuge "is" (not "seems to be") more conservative regardless of the hypothetical manatee populations that might be supported.	Clarify.
92	KW	Page 69, Section 5.7	No	Clarify that groundwater pumping impacts are from regional pumping.	Clarify.

2.2 APPENDICES AND EXTERNAL REPORTS

Table 2-5. Review of Appendices and External Reports

Comment No.	Peer Reviewer	Figure, Table, or Page and Paragraph Number	Does Comment Directly and Materially Affect Conclusions of Report? (Yes/No)	To be completed by Reviewer(s)	
				A. Reviewer's Specific Comments	B. Reviewer's Specific Recommended Corrective Action
93	KW	VHB (2010)	No	Report Appendixes A and B are missing. It would be useful to see the index-velocity ratings developed for open-channel locations G1 and G2.	Consider adding the ratings.
94	KW	Chen (2014) Pages 12 – 14 and Figures 4 and 5	No	Confirm if the graphics illustrate the total open-channel flow measured at locations G1 and G2 (i.e., spring flow plus the tidal flux component).	Confirm.

3.0 SUMMARY OF FINDINGS AND MFL REVIEW GUIDELINES RESPONSE

A component of the Peer Review Panel scope of work was to provide an assessment of the MFL report and supporting documentation against specific listed criteria. The following items outline those specific criteria.

1. Determine whether the conclusions in the Crystal River/Kings Bay springs system MFLs report are supported by the analyses presented.
2. Supporting Data and Information: Review the relevant data, and information that support the conclusions made in the report to determine whether:
    a. The data and information used were properly collected;
    b. Reasonable quality assurance assessments were performed on the data and information;
    c. Exclusion of available data from analyses was justified; and
    d. The data used were the best information available.
3. Technical Assumptions: Review the technical assumptions inherent to the analysis used in the Crystal River/Kings Bay springs system MFLs report to determine whether:
    a. The assumptions are clearly stated, reasonable and consistent with the best information available;
    b. The assumptions were eliminated to the extent possible, based on available information; and
    c. Other analyses that would require fewer assumptions but provide comparable or better results are available.
4. Procedures and Analyses: Review the procedures and analyses used in the Crystal River/Kings Bay system MFLs report to determine whether:
    a. The procedures and analyses were appropriate and reasonable, based on the best information available;
    b. The procedures and analyses incorporate all necessary factors;
    c. The procedures and analyses were correctly applied;
    d. The procedures and analyses are repeatable; and
    e. Conclusions based on the procedures and analyses are supported by the data.

5. If a proposed method used in the Crystal River/Kings Bay Springs system MFLs report is not scientifically reasonable, the CONSULTANT shall:
    a. List and describe scientific deficiencies and, if possible, evaluate the error associated with the deficiencies;
    b. Determine if the identified deficiencies can be remedied.
    c. If the identified deficiencies can be remedied, then describe the necessary remedies and an estimate of time and effort required to develop and implement each remedy.
    d. If the identified deficiencies cannot be remedied, then, if possible, identify one or more alternative methods that are scientifically reasonable. If an alternative method is identified, provide a qualitative assessment of the relative strengths and weaknesses of the alternative method(s) and the effort required to collect data necessary for implementation of the alternative methods.
6. If a given method or analyses used in the Crystal River/Kings Bay Springs system MFLs report is scientifically reasonable, but an alternative method is preferable, the CONSULTANT shall:
    a. List and describe the alternative scientifically reasonable method(s), and include a qualitative assessment of the effort required to collect data necessary for implementation of the alternative method(s).

Table 3-1 presents the detailed assessments by each of the Peer Review Panelists for each of the criteria. The findings of the Peer Review Panel are that, with the implementation of some of the edits/recommendations made within this report, there are no fatal flaws within the MFL report and supporting documentation relative to the specified criteria.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
Determine whether the conclusions in the Crystal River/Kings Bay Springs system MFLs report are supported by the analyses presented.			KW: The report documents a comprehensive and complex analysis that was concise and well done. Although conclusions are supported by analyses, an explanation of how an allowable flow reduction expressed as a percent flow reduction would be applied to the SGD "flow regime" per item #8 in Section 1.3.2 is not provided and may be helpful. AM: Overall the report is reasonable and the analysis presented is consistent with other MFL efforts within the District. At times the repost is inclusive of information which is ancillary to the MFL determination and that information could be shifted to the appendix and play a less prominent role in the report. SP: Overall the MFL conclusions are supported by the analyses presented. One area in the report that need to be clarified is the present uncertainty in both available flow measurements (USGS and SWFWMD) and this needs to be reworded in the report along with recommendations for verification in future work. Another area is to recognize the potential impacts to water quality (specifically Chl a and residence time) and that at present the data are not available to quantify.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
	2. Supporting Data and Information: Review the relevant data, and information that support the conclusions made in the report to determine whether:	a. The data and information used were properly collected;	KW: Much of the data used were collected by entities with established field SOPs and are presumed to have been properly collected. AM: A majority of the data have been collected by agencies other than SWFWMD or in the pursuit of other studies. However, all data seems to be collected by entities with trained samplers and SOPs and while, likely not error free, are likely to represent the best available data. SP: The data collected by the SWFWMD for this project appears to have been collected properly. Also the data from outside groups appears to have been collected properly based on existing protocols. Issues with the data are primarily related to limitations in collection methodology and processing.
		b. Reasonable quality assurance assessments were performed on the data and information;	KW: It may be helpful to prepare double-mass curves to characterize associations between rainfall, SGD, and river discharge reported by the USGS. SP: Saw no issues with the quality assurance on the data collected. More explanation (especially on the direct flow and vent measurements) of the uncertainty associated with the data should be provided.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
		c. Exclusion of available data from analyses was justified; and	KW: The data for the reported discharge for the Crystal River gage (#02310750) and for the USGS gage at Bagley Cove (#02310747) were determined to be unreliable estimates of groundwater discharge. Both gages record a mixture of groundwater, storm water runoff, and marine water. Tidal filtering is used in an attempt to exclude the marine water flux and, to the extent runoff is important, a means of accounting for runoff is needed. We take no exception to excluding the gage #2310705 data. However, we think the gage #02310747 data may be useable to help verify the groundwater discharge with either appropriate tide filtering or as an estimate of long term total freshwater discharge (i.e., groundwater discharge and surface water runoff). SP: There is clearly uncertainty in both sets of the data for the SGD (USGS and SWFWMD). Complete exclusion or dismissal of this data does not seem warranted. This would not alter how the analyses were performed, as it is recognized that the SWFWMD data works better in the analyses, but the report should identify the potential uncertainty in both and not just completely dismiss the USGS data.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
		d. The data used were the best information available.	KW: In Section 1.4.4 it would be helpful to mention whether groundwater level data are available for locations in the springshed that are more distant from the CR/KB system and tidal influences. Bagley Cove gage data may be usable in some form. AM: Vegetation: The District provides some significant information from historic SAV studies. Because of the importance of SAV it is appropriate to include it in the report since this is presumably some of the habitat protected by the change in area and volume analysis. While SAV information is documented, the historic concern of filamentous algae could be more thoroughly addressed in the report or the appendix. Especially, if it is less of a concern than in the past as indicated during a field trip. SP: The data used in the hydrodynamic modeling, and the calculation of the flows was the best available with the caveat of the comments on the USGS in earlier sub-tasks.
	3. Technical Assumptions: Review the technical assumptions inherent to the analysis used in the Crystal River/Kings Bay springs system MFLs report to determine whether:	a. The assumptions are clearly stated, reasonable and consistent with the best information available;	KW: The definition of baseline and historical flows occurring" in the absence of withdrawal impacts" (i.e., Section 1.3.2) should be qualified. The baseline period of time should be clearly stated in the text. AM: The largest assumption is the 15% loss of habitat criteria as a harm threshold. This criterion has been discussed for well over a decade and it has continuously been determined to be reasonable and consistent with other environmental flow standards. SP: The assumptions are generally clearly stated and other than the complete exclusion of the USGS data are consistent with the best available information. The sensitivity associated with the offshore boundary for the hydrodynamic scenarios needs to be addressed to complete the analyses.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
		b. The assumptions were eliminated to the extent possible, based on available information; and	KW: The assumption that 15% habitat reduction causing significant harm could be explicitly eliminated for manatee thermal refuge. SP: No unjustified assumption eliminations were identified
		c. Other analyses that would require fewer assumptions but provide comparable or better results are available.	SP: No alternate analyses that would require fewer assumptions were identified through this review.
	4. Procedures and Analyses: Review the procedures and analyses used in the Crystal River/Kings Bay system MFLs report to determine whether:	a. The procedures and analyses were appropriate and reasonable, based on the best information available;	KW: The thermal analysis for manatee could be simplified and presented differently. Based on the space requirements of manatee, the known manatee population, and the available thermal refuge, the default 15% allowable reduction in habitat does not appear to be appropriate – i.e., a much greater reduction in habitat would be needed to cause significant harm and therefore a much greater reduction in flow would be allowable. This a relevant concept because it points out that scenario specific information should be used when available and that default values (i.e., 15 % reduction in habitat) should only be used in the absence of better information. In my view, the report correctly deduces that manatee thermal refuge is not a limiting metric for an MFL. SP: The salinity habitat volume change determination was based upon the best available information. The exclusion of the manatee thermal habitat was based upon the best available information.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
		b. The procedures and analyses incorporate all necessary factors;	KW: It is unclear whether direct rainfall on the CR/KB system is an input variable in the hydrodynamic model (see Section 2.3). AM: As discussed during the third meeting natural shorelines should be delineated from hardened shoreline or that case should be made that they may appropriately substitute for one another as the location of isohalines shift.
		c. The procedures and analyses were correctly applied;	KW: Discuss procedure for estimating relative change in shoreline habitat.
		d. Limitations and imprecisions in the information were reasonably handled;	KW: Insufficient information is provided from the SGD regression analysis to evaluate the reasonableness of the SGD hindcasted for a 46-year period. It may be helpful to include plots of residuals vs. predictions and observed vs. predicted values. SP: The limitations in the flow calculations were not sufficiently identified in relation to the USGS flow measurements.
		e. The procedures and analyses are repeatable; and	SP: The procedures and analyses seem repeatable for all aspects. Further clarification of key analyses could be provided within the report and these are outlined in the detailed comments.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
		f. Conclusions based on the procedures and analyses are supported by the data.	KW: Conclusions are supported by best available data and repeatable procedures and analyses. The relative flow reductions determined for a salinity regime <2 ppt (i.e., Table 3-1) appear inconsistent (although possible) with those for the <1 and <3 ppt regimes and should be checked. SP: The conclusions relative to salinity habitat and manatee thermal habitat are supported by the analyses and the data. Conclusions on the lack of impact upon water quality in the system are not supported by the data because the key aspects, Chl a versus residence time changes is not presented.

5. If a proposed method used in the Crystal River/Kings Bay Springs system MFLs report is not scientifically reasonable, the CONSULTANT shall:	a. List and describe scientific deficiencies and, if possible, evaluate the error associated with the deficiencies; b. Determine if the identified deficiencies can be remedied. c. If the identified deficiencies can be remedied, then describe the necessary remedies and an estimate of time and effort required to develop and implement each remedy. d. If the identified deficiencies cannot be remedied, then, if possible, identify one or more alternative methods that are scientifically reasonable. If an alternative method is identified, provide a qualitative assessment of the relative strengths and weaknesses of the alternative method(s) and the effort required to collect data necessary for implementation of the alternative methods.		KW: Methods are scientifically reasonable. AM: While some methods seem debatable all methods incorporate uncertainty and the ones use by the district are reasonable. SP: The final verification of the total flow remains a deficiency, but at present there is no better data to be utilized. This should be identified as a future need for this system. SP: Another are identified as having some deficiency is the evaluation of the impacts to water quality. The deficiency is in the establishment of the relationship between flow reduction, residence times, and the water quality parameters (Chl a for example) that would be impacted by longer residence times. At present based upon discussions with District personnel, the data to support this analysis is not available. Within the report the District needs to first determine that there are not data that weren't used which might allow this analysis to be completed at this time. If not, then identify this as potential future work.
6. If a given method or analyses used in the Crystal River/Kings	a. List and describe the alternative scientifically reasonable method(s),		KW: Percent change in habitat is appropriate for this system. By selecting the most conservative salinity regime, other salinity regimes are protected.

Table 3-1. Responses to SWFWMD's Peer Review Assessment Requirements			
Task	**Subtask**	**Sub-Subtask**	**Reviewer's Specific Comments** **SP = Steven Peene, KW = Ken Watson, AB = Adam Munson**
Bay Springs system MFLs report is scientifically reasonable, but an alternative method is preferable, the CONSULTANT shall:	and include a qualitative assessment of the effort required to collect data necessary for implementation of the alternative method(s).		SP: No preferred alternate method with the available data has been identified through this review.

Attachment A

MFL Review Guidelines

MFL Review Guidelines

1. Determine whether the conclusions in the Crystal River/Kings Bay Springs system MFLs report are supported by the analyses presented.
2. Supporting Data and Information: Review the relevant data, and information that support the conclusions made in the report to determine whether:
    a. The data and information used were properly collected;
    b. Reasonable quality assurance assessments were performed on the data and information;
    c. Exclusion of available data from analyses was justified; and
    d. The data used were the best information available.
3. Technical Assumptions: Review the technical assumptions inherent to the analysis used in the Crystal River/Kings Bay springs system MFLs report to determine whether:
    a. The assumptions are clearly stated, reasonable and consistent with the best information available;
    b. The assumptions were eliminated to the extent possible, based on available information; and
    c. Other analyses that would require fewer assumptions but provide comparable or better results are available.
4. Procedures and Analyses: Review the procedures and analyses used in the Crystal River/Kings Bay system MFLs report to determine whether:
    a. The procedures and analyses were appropriate and reasonable, based on the best information available;
    b. The procedures and analyses incorporate all necessary factors;
    c. The procedures and analyses were correctly applied;
    d. Limitations and imprecisions in the information were reasonably handled;
    e. The procedures and analyses are repeatable; and
    f. Conclusions based on the procedures and analyses are supported by the data.
5. If a proposed method used in the Crystal River/Kings Bay Springs system MFLs report is not scientifically reasonable, the CONSULTANT shall:
    a. List and describe scientific deficiencies and, if possible, evaluate the error associated with the deficiencies;
    b. Determine if the identified deficiencies can be remedied.

c. If the identified deficiencies can be remedied, then describe the necessary remedies and an estimate of time and effort required to develop and implement each remedy.
d. If the identified deficiencies cannot be remedied, then, if possible, identify one or more alternative methods that are scientifically reasonable. If an alternative method is identified, provide a qualitative assessment of the relative strengths and weaknesses of the alternative method(s) and the effort required to collect data necessary for implementation of the alternative methods.

6. If a given method or analyses used in the Crystal River/Kings Bay Springs system MFLs report is scientifically reasonable, but an alternative method is preferable, the CONSULTANT shall:
    a. List and describe the alternative scientifically reasonable method(s), and include a qualitative assessment of the effort required to collect data necessary for implementation of the alternative method(s).

APPENDIX

Southwest Florida Water Management District. 2017. Analysis of water quality in Crystal River/Kings Bay. Brooksville, Florida.

Analysis of Water Quality in Crystal River/Kings Bay

April 2017
Springs and Environmental Flows Section
Natural Systems & Restoration Bureau
Southwest Florida Water Management District
Brooksville, Florida 34604-6899

The Southwest Florida Water Management District (District) does not discriminate on the basis of disability. This nondiscrimination policy involves every aspect of the District's functions, including access to and participation in the District's programs and activities. Anyone requiring reasonable accommodation as provided for in the Americans with Disabilities Act should contact the District's Human Resources Bureau Chief, 2379 Broad St., Brooksville, FL 34604-6899; telephone (352) 796-7211 or 1-800-423-1476 (FL only), ext. 4703; or email ADACoordinator@WaterMatters.org. If you are hearing or speech impaired, please contact the agency using the Florida Relay Service, 1(800)955-8771 (TDD) or 1(800)955-8770 (Voice).

CHAPTER 1 - WATER QUALITY DATA

The purpose of this report is to a) provide an overview of the estuarine water quality status relative to Florida Department of Environmental Protection (FDEP) criteria, b) characterize how the water quality has changed over time, c) characterize how the discharge relates to water quality, and finally d) determine if apparent water quality relationships with discharge are the result of temporal changes in vent water quality or are truly flow-dependent relationships. The discussion is limited to total nitrogen (TN), nitrite + nitrate nitrogen (NO_x-N), nitrate nitrogen (NO_3-N) total phosphorus (TP), inorganic phosphorus (PO_4-P), dissolved oxygen (DO) and salinity.

The estuarine portion of the Crystal River/Kings Bay system (CRKB) water quality study area encompasses the area shown and extends from the outer limit of sampling stations illustrated in Figure 1-1. A total of thirteen zones were defined, with the upper six zones representing the area of abundance springs and seeps tabulated in Table 1-1 and illustrated in Figure 1-2. Distances or location within the estuary were defined in 0.1 km increments from a point at 28.927° North latitude / 82.694° west longitude. Distances upstream and downstream form the datum location were represented by positive and negative river kilometer (Rkm) values. Water quality sampling stations were assigned the nearest 0.1 Rkm using GIS and color-coded to zone designation as shown in Figures 1-1 and 1-2.

Table 1-1. CRKB Water Quality Zones / River Kilometer Range

Zone	1-6	7	8	9	10	11	12	13
Rkm	12.2 - 7.9 (See Fig 4-2)	≥8 <10.2	≥ 6.0 < 8.0	≥ 4.0 < 6.0	≥2.0 < 4.0	≥ 0.0 < 2.0	≥ -3.0 < 0	≥ -3.0 <- 6.0

CRKB_WQTables_revised.xlsx

Figure 1-1. Location of CRKB Water Quality Sampling Stations

Sampling station locations were also compared with the FDEP springs GIS database[1]. Stations located within 0.001 degree (~9 meters at latitude 28°) of a spring or vent in the FDEP spatial database were assigned a station type of "vent". Additional stations that exceeded this distance based coordinates were manually assigned a designation of 'vent' based on equivalency of station text descriptions, for a total of 26 candidate stations designated 'vent_possible' with an average distance for plotted spring/vent position of 15 meters. In the final analysis, eight were designated 'vent' stations associated with Tarpon Springs, Black Springs, Idiot's Delight, House Spring and Catfish Spring. It should be noted that FDEP (Bridger 2014) analyzed nitrate data from Hunters Spring, but the present database did not include nitrate results for Hunters Spring.

[1] FDEP Springs GIS database http://www.dep.state.fl.us/gis/datadir.htm

Figure 1-2. Stations Located in Zones One through Six.

Five hundred and thirty-five sampling locations and 9,104 station/date/depth entries spanning the period January 5, 1984 through December 22, 2014 were included in the evaluations. Results were obtained from multiple sources/reports (See Table 1-2). The majority of the compilation was completed by Dr. Tom Frazier and his students at the University of Florida under contract to the District (Frazer et al. 2010). District staff added additional results[2] which were unavailable when the base compilation was completed.

[2] Available from http://www18.swfwmd.state.fl.us/ResData/Search/ExtDefault.aspx

Table 1-2. Data Source Table

Data Source	Project name/identifier	Report	Data Source*
FDEP	Data sonde monitoring	Florida Department of Environmental Protection (FDEP). 2010. Two long term water quality monitoring stations at Crystal River. Florida Department of Environmental Protection, St. Martins Marsh Aquatic Preserve. Crystal River, Fl.	from FDEP
FFWCC	Fish and Invertebrate Project	USF and FFWCC. 2010. An Investigation of freshwater inflow effects on fish and invertebrate use of the Crystal River Estuary.	from District via Sid Flannery
Mote Marine	Crystal Profiles 80s	Dixon, L. K. 1986. Water Chemistry. Volume I in a series: a data collection program for selected coastal estuaries in Hernando, Citrus, and Levy Counties, Florida.	from District via Sid Flannery
SWFWMD	Crystal River Minimum flows stations	n/a	from District via Sid Flannery
SWFWMD	Kings Bay and Crystal River WMIS Data	n/a	from District via Sid Flannery
SWFWMD radar rainfall data	n/a	n/a	from District via Sid Flannery
SWFWMD rainfall data	A0020061	n/a	from District via Sid Flannery
SWFWMD rainfall data	A0020973	n/a	from District via Sid Flannery
SWFWMD rainfall data	A0022955	n/a	from District via Sid Flannery
SWFWMD rainfall data	A0023445	n/a	from District via Sid Flannery
UF	Florida Lakewatch	n/a	from UF
UF	Frazer Kings Bay salinity project	Frazer, T. K., et al. 2001. Frequency and duration of pulsed salinity events in Kings Bay.	from UF
UF	Frazer Project Coast	Frazer, T. K., et al. 2006. Water quality characteristics of the nearshore Gulf coast waters adjacent to Citrus, Hernando and Levy Counties, Project COAST 1997–2005.	from UF
UF	Frazer River Project	Frazer, T. K., et al. 2001. Physical, chemical and vegetative characteristics of five Gulf coast rivers. Final Report.	from UF
USF	Fish and Invertebrate Project	USF and FFWCC. 2010. An Investigation of freshwater inflow effects on fish and invertebrate use of the Crystal River Estuary.	from District via Sid Flannery
USFWS	Kings Bay SAV monitoring	n/a	from USFWS
			CRKB_WQTables.xlsx

Sample depth and water column depth was missing for approximately 83 percent of the observations in the database, rendering it difficult to determine if the results represent a surface, mid-depth or near-bottom observation. Average station water column depths (relative to mean sea level) were estimated using the bathymetry from the District's Crystal River/Kings Bay system UNLESS3D hydrodynamic model grid. Station depths ranged from 0.1 to 10.7 meters with and average depth of 2.8 m and a median of 2.7 m.

Conductivity was reported for 77 percent of the observations and salinity was reported directly in 68 percent of the observations. A plot of conductivity vs. reported salinity revealed some potential units issues and or the use of varying algorithms to estimate salinity from conductivity. Salinity was calculated for all observations containing conductivity using the equations of Cox et al. (1967) which produced results equivalent to the practical salinity equations published by Standard Methods for the Examination of Water and Wastewater ("Standard Methods", 20th edition. 1999). A standardized estimate of salinity was established in the priority of a) reported salinity, or if missing, b) salinity calculated as described. Using the standardized salinity (2.4 ppt) equivalent to 4,580 µmho/cm at 25°C, each observation was classified as "fresh" or "marine" in accordance with the FDEP definitions (Rule 62-302.200 (29) and Rule 62-303.200 (30), Florida Administrative Code, F.A.C.). All waters in CRKB have a Class III (Fish Consumption; Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife) designated use except for a small area of Class II (Shellfish Propagation of Harvesting) at the confluence of the Gulf of Mexico which is outside the domain of the present water quality discussion. Except for very small areas[3] around Cedar Cove (Water Body Identification, WBID 1341B), Crystal Spring (WBID 1341E), Hunter Spring (WBID 1341C) and Idiot's Delight Spring (WBID 1341F) the remainder of CRKB is considered marine waters by FDEP.

[3] http://www.dep.state.fl.us/water/watersheds/assessment/basin411.htm

Compilation of the water quality data from multiple sources results in an uneven spatial and temporal distribution of data. Table 1-3 provides a summary of counts (where a 'count' represents a station/date/depth entry) by zone with beginning and ending dates. Table 1-3 also includes an estimate of the percentage of 'fresh water' observations. Table 1-4 summarizes the number of observations by zone and month while Figure 1-3 illustrates the total number of samples by year.

Table 1-3. Crystal River/Kings Bay Water Quality Observations by Zone and Date

Zone	Start Date	Number	Stop Date	Percent Classifiable	Percent Fresh
1	08/14/88	558	10/28/14	59%	97%
2	02/11/91	249	12/22/14	82%	100%
3	08/14/88	625	10/28/14	64%	75%
4	08/14/88	580	10/28/14	79%	90%
5	01/05/84	762	10/28/14	71%	73%
6	08/14/88	998	10/28/14	42%	80%
7	01/05/84	875	10/23/14	96%	59%
8	01/05/84	913	08/05/10	75%	29%
9	01/05/84	737	10/19/10	98%	16%
10	01/05/84	1182	08/05/10	99%	10%
11	01/05/84	925	10/19/10	98%	4%
12	01/05/84	264	12/10/09	100%	0%
13	01/05/84	436	02/23/10	99%	0%

CRKB_WQTables_revised.xlsx

Table 1-4. Crystal River/Kings Bay Water Quality Observations by Zone and Month

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Zone 1	75	21	46	64	44	47	72	31	34	64	25	35	558
Zone 2	42	6	16	32	14	15	45	11	14	34	12	8	249
Zone 3	68	23	64	57	62	69	63	43	49	54	24	49	625
Zone 4	76	28	48	59	49	48	74	37	29	66	25	41	580
Zone 5	85	35	66	71	69	81	91	62	48	74	36	44	762
Zone 6	107	52	80	102	106	92	117	80	50	111	41	60	998
Zone 7	67	70	71	82	66	94	59	80	46	104	62	74	875
Zone 8	59	82	75	89	78	92	64	89	49	91	58	87	913
Zone 9	42	77	68	52	55	82	51	76	36	79	52	67	737
Zone 10	74	107	85	95	76	124	89	114	61	146	77	134	1182
Zone 11	73	93	76	79	83	101	52	76	45	113	57	77	925
Zone 12	17	29	22	15	31	13	14	23	8	37	35	20	264
Zone 13	32	43	26	37	33	34	27	42	26	55	37	44	436
Total	817	666	743	834	766	892	818	764	495	1028	541	740	9104

CRKB_WQTables_revised.xlsx

Figure 1-3. Number of Water Quality Samples by Year.

CHAPTER 2 - WATER QUALITY STATUS

2.1 Florida Water Quality Criteria

FDEP has published a hierarchy of water quality criteria relevant to CRKB in Chapters 62-302 and 62-304, F.A.C. Some are written as 'the maximum not to be exceeded at any time . . .' (Rule 62-302.530, F.A.C) while others are expressed as average values not to be exceeded during a specified time period, or frequency. For example, the turbidity criterion is exceeded every time an activity results in a >29 NTU increase over background, while spring vent nitrate+ nitrite nitrogen is expressed as *" is 0.35 mg/l of nitrate-nitrite (NO_3 + NO_2) as an annual geometric mean, not to be exceeded more than once in any three calendar year period*" (Rule 62-302.531(2) (b.) 2, F.A.C.). Some specify the frequency of sampling required. For example, dissolved oxygen (DO) is expressed separately for different time periods (daily average, diel, 7-day average, and 30-day average). The criteria for evaluating the seven day average states ". . . *there shall be a minimum of three full days of diel data collected within the seven-day period, or a minimum of ten grab samples collected over at least three days within that seven-day period, with each sample measured at least four hours apart*" (Rule 62-302.533(2)(a)1, F.A.C.). These frequency and temporal requirements associated with Florida's water quality criteria cannot be rigidly evaluated with the current CRKB water quality database because the data was not collected for the purpose of determining compliance. The discussion that follows is not intended to determine compliance, but rather to broadly characterize historical data in terms of current regulations.

2.2 Total Maximum Daily Load (TMDL)

The final water quality criteria in FDEP's hierarchy is a total maximum daily load (TMDL). In 2014, FDEP completed a TMDL evaluation[4] (Bridger 2014) which was codified as Rule 62-304.645(17), F.A.C., for King's Bay (water body identification number (WBID) 1341) and several of the springs (Hunter Spring-WBID 1341C , House Spring-WBID 1341D, Idiot's Delight Spring-WBID 1341F, Tarpon Spring-WBID 1341G and Black Spring-WBID 1341H) contained therein (Figure 2-1). The TMDL is based on water quality data collected from January 1, 2004 through June 30, 2011. The analysis resulted in verifying that Kings Bay and the springs contained therein are impaired for nutrients as evidenced by the presence of algal mats. The TMDL established TN, TP and chlorophyll criteria for Kings Bay, and nitrate (NO_3-N) and ortho-phosphate phosphorus (PO_4-P) criteria for the springs. Crystal River estuary (WBID 1341I) was not included in the TMDL, but pertinent criteria for this segment are found in Rule 62-302.532, F.A.C. Pertinent criteria are summarized in Table 2-1.

[4] http://www.dep.state.fl.us/water/tmdl/docs/tmdls/final/gp5/KingsBay-1341-nutr-tmdl.pdf

Figure 2-1. Crystal River/Kings Bay with FDEP WBID Designations.

Table 2-1. Pertinent FDEP Water Quality Criteria.

Waterbody	TN (mg/l-N)	TP (mg/l-P)	NO3-N (mg/l)	PO4-P (mg/l)	Chlorophyll a ug/l	Current Study Location
Hunter Spring (WBID 1341C) House Spring (WBID 1341D) Idiot's Delight (WBID 1341F) Tarpon Springs (WBID 1341G) Black Springs (WBID 1341H)			0.23	0.028		FDEP GIS Spring 'Vents'
Kings Bay (WBID 1341)	0.28	0.032			5.7	Rkm 6.8 - 12.1
Crystal River Estuary (WBID 1341I)	0.37	0.047			4.4	Rkm 0.0 - 6.8

Adapted From Table 6.3 FDEP 2014. CRKB_WQTables.xlsx

2.3 Dissolved Oxygen (DO) Status

The minimum FDEP DO saturation criteria for Class III marine waters in the Peninsula bioregion (which includes CRKB) is:

- Daily average below 42 percent in more than 10 percent of values
- Seven day below 51 percent once in twelve week period
- Thirty-day average below 56 percent more than once per year.

The minimum DO saturation criteria for Class III fresh water is 38 percent.

Table 2-2 summarizes the frequency of critical saturation values for each zone. Low DO does not occur often in CRKB, but supersaturation is a common observation in several zones. Supersaturation occurs as a result of high rates of photosynthesis associated with submersed aquatic vegetation (SAV) or algal blooms. Super saturation is limited to 110% as described in Rule 62-302.530(67), F.A.C.

Table 2-2. Frequency of High and Low DO Saturation in CRKB by Zone

Zone	N observations Marine	Percent < 42% Saturation	N observations Fresh	Percent < 38% Saturation	Percent >110% Saturation
1	10	0%	317	2%	15%
2	1	0%	204	0%	19%
3	98	2%	299	1%	10%
4	45	4%	413	2%	9%
5	145	13%	398	2%	13%
6	84	52%	336	19%	3%
7	342	1%	495	3%	11%
8	488	0%	195	0%	7%
9	605	0%	114	0%	4%
10	1053	2%	121	2%	5%
11	870	0%	37	0%	7%
12	264	0%	0	0%	6%
13	433	3%	0	0%	9%

CRKB_WQTables_revised.xlsx

2.4 Nitrate Nitrogen (NO_3-N) Status

FDEP has not established a nitrate nitrogen criterion for Class III marine or Class III fresh waters, but has established a spring vent limit of 0.35 mg/l (Rule 62-302.531(2) (b.)2, F.A.C.) for the sum of nitrogen as nitrate plus nitrogen as nitrite, expressed as annual geometric mean not to be exceeded more than once in a three calendar year period (notated 'AGM-1/3yr' hereafter). However, for six named springs in CRKB this criterion has been superseded as the result of the codified TMDL[5]. The TMDL established a nitrate nitrogen concentration of 0.23 mg/l in lieu of a total nitrogen limit in these springs.

As described in chapter 1, eight sampling points included in the working database were designated 'vent' stations. These eight stations are located in the headwaters of CRKB as shown in Figure 2-2 and correspond to the FDEP WBIDs previously identified in Table 2-1.

[5] http://www.dep.state.fl.us/water/watersheds/assessment/basin411.htm

Nitrate has been measured 205 times in these 8 stations. Fifty-one percent (104 observations) exceeded 0.23 mg/l. (The relationship to flow and temporal trend of nitrate concentration at the vent sites is discussed in chapter 4).

Figure 2-2. Location of Vent Sampling Stations and FDEP Spring WBIDs.

2.5 Total Phosphorus (TP) Status

As part of the hierarchy of water quality standards, FDEP has both narrative water quality criteria (Rule 62-302.530, F.A.C.) and has established estuary-specific numeric interpretation of the narrative requirements in 62-302.532 F.A.C. For example, the narrative limitation for nutrients) states "*In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations and aquatic flora or fauna*." (Rule 62-302.530(48)(b), F.A.C.)

The estuary-specific interpretation specifies that the maximum allowable concentration of total phosphorus in the estuarine portion of CRKB (WBID 1341I corresponding to Rkm 0.0 through 6.8 in the present evaluation) is 0.047 mg/l as AGM-1/3yr. FDEP estuarine definition includes all of zones 9 and 10, most of zone 11 and the seaward 30% of zone 8 in the present study. FDEP defines the portion of CRKB upstream of Rkm 6.8 as Kings Bay (WBID 1341) and has established a total phosphorus limit of 0.032 mg/l AGM-1/3yr for this reach. These estuary-specific criteria were developed as part of the TMDL described in section 2.2.

Twenty four (24) of 549 TP observations (four percent) in the estuary WBID exceeded 0.047 mg/l and 656 of 2,740 observations (24 percent) in King's Bay (excluding 'vent' stations) exceeded 0.032 mg/l TP.

2.6 Total Nitrogen (TN) Status

FDEP has established a maximum allowable concentration of total nitrogen in the CRKB estuary of 0.37 mg/l and a maximum concentration of 0.28 for Kings Bay, both expressed as AGM-1/3yr. Sixty-nine (69) of 494 TN observations (14 percent) in the estuary WBID exceeded 0.37 mg/l and 852 of 2,477 observations (34 percent) in King's Bay (excluding 'vent' stations) exceeded 0.28 mg/l TN.

2.7 Chlorophyll a Status

FDEP has defined the maximum allowable concentration of chlorophyll a in the estuarine portion of CRKB as 4.4 µg/l as AGM-1/3yr, and a maximum of 5.7 µg /l for King's Bay (see Rule 62.302.532, F.A.C.). Forty-one percent (212 out of 520 observations) of the estuarine chlorophyll a observations exceeded 4.4 µg /l. A slightly higher percentage (56 percent) of the 2,277 King's Bay observations (excluding 'vent' stations) were in excess of 5.7 µg /l.

2.8 Ortho-Phosphate Phosphorus (PO_4-P) Status

As part of the TMDL, FDEP established a standard for inorganic phosphorus (PO_4-P) as a surrogate for total phosphorus. The maximum concentration in the eight named CRKB springs is 0.028 mg/l AGM-1/3yr. Of the 438 PO_4-P vent observations in the current database, this value was exceeded 128 times (29 percent of the time).

CHAPTER 3 - WATER QUALITY TRENDS

3.1 Temporal Correlations

A formal evaluation of a time-series trend requires an approximately equal interval between observations, an assumption that is not met with the structure of the current CRKB water quality database. In lieu of a formal time-series analysis, the correlation of select water quality parameters with time was conducted for each established zone using a non-parametric Kendall's tau evaluation. The results are given in Table 3-1. Fifty six percent of the one hundred one possible trends were significant at $p \leq 0.05$.

Changes in chlorophyll over time generally indicates an increasing pattern as six of the eight zones exhibiting significant relationships were positive. All of the seven significant trends in dissolved oxygen saturation values were decreasing with time. The significant trends are occurring mostly in down-river (zones $\geq$ 7).

All of ten significant salinity trends are increasing. This is consistent with the general decline in spring flow noted over the study period (n=9,104, tau-b =-0.067, p=0.0000) and is also consistent with an increasing sea level.

Table 3-1. CRKB Water Quality Correlations with Time (1984-2014)

Date vs. Temp			
Zone	taub	n	p
1	-0.058	328	0.117
2	-0.085	208	0.068
3	-0.013	397	0.699
4	-0.069	458	**0.027**
5	-0.034	543	0.236
6	-0.101	420	**0.002**
7	-0.074	853	**0.001**
8	-0.080	683	**0.002**
9	-0.089	719	**0.000**
10	-0.044	1,146	**0.026**
11	-0.005	907	0.822
12	-0.054	264	0.191
13	0.060	400	0.073

Date vs. DO sat			
Zone	taub	n	p
1	-0.112	290	**0.004**
2	0.015	175	0.769
3	-0.037	365	0.292
4	-0.063	409	0.057
5	-0.001	482	0.974
6	0.031	374	0.371
7	-0.032	705	0.204
8	-0.103	549	**0.000**
9	-0.124	577	**0.000**
10	-0.086	985	**0.000**
11	-0.187	664	**0.000**
12	-0.203	156	**0.000**
13	-0.106	381	**0.002**

Date vs. Ortho-P			
Zone	taub	n	p
1	-0.191	237	**0.000**
2	-0.118	166	**0.024**
3	-0.328	158	**0.000**
4	-0.304	221	**0.000**
5	-0.336	228	**0.000**
6	-0.165	262	**0.000**
7	0.246	41	**0.024**
8	-0.030	37	0.804
9	0.122	18	0.503
10		0	
11	0.140	18	0.439
12		0	
13		0	

Date vs. TP			
Zone	taub	n	p
1	0.164	402	**0.000**
2	-0.099	168	0.057
3	0.240	335	**0.000**
4	0.161	302	**0.000**
5	0.327	412	**0.000**
6	0.162	758	**0.000**
7	0.240	233	**0.000**
8	-0.097	271	**0.017**
9	0.248	57	**0.007**
10	0.120	314	**0.002**
11	-0.213	37	0.065
12	-0.191	40	0.085
13	-0.006	153	0.914

Date vs. Salinity			
Zone	taub	n	p
1	0.243	327	**0.000**
2	0.057	205	0.225
3	0.112	397	**0.001**
4	0.185	458	**0.000**
5	0.323	543	**0.000**
6	0.182	420	**0.000**
7	0.275	837	**0.000**
8	0.239	683	**0.000**
9	0.166	719	**0.000**
10	0.130	1,174	**0.000**
11	0.174	907	**0.000**
12	0.047	264	0.255
13	-0.023	433	0.475

Date vs. Chla			
Zone	taub	n	p
1	0.309	304	**0.000**
2	0.044	95	0.530
3	0.185	323	**0.000**
4	0.521	210	**0.000**
5	0.276	372	**0.000**
6	0.069	649	**0.009**
7	0.208	212	**0.000**
8	-0.036	221	0.426
9	-0.303	58	**0.001**
10	0.072	315	0.057
11	-0.179	38	0.117
12	-0.312	40	**0.005**
13	0.073	153	0.181

Date vs. NOx			
Zone	taub	n	p
1	0.208	186	**0.000**
2	0.315	120	**0.000**
3	0.000	158	1.000
4	0.072	171	0.163
5	-0.016	199	0.738
6	0.019	194	0.695
7	0.492	62	**0.000**
8	0.086	59	0.339
9	0.103	58	0.256
10	-0.035	20	0.855
11	-0.141	38	0.217
12	0.026	40	0.822
13	-0.086	20	0.619

Date vs. TN			
Zone	taub	n	p
1	0.251	352	**0.000**
2	0.239	127	**0.000**
3	-0.115	329	**0.002**
4	0.080	249	0.060
5	-0.040	392	0.237
6	0.075	689	**0.003**
7	0.245	224	**0.000**
8	-0.019	239	0.662
9	-0.074	56	0.425
10	0.174	278	**0.000**
11	-0.330	36	**0.005**
12	-0.380	40	**0.001**
13	-0.058	117	0.355

CRKB_WQTables_revised.xlsx

There is no data for inorganic phosphorus downstream of Zone 7 which begins approximately 2 kilometers downstream (Rkm 10.2) from the head (Rkm 12.2) of Kings Bay. Six of the seven significant inorganic phosphorus exhibited decreasing trend while eight of the nine significant total nitrogen trends were in the opposite (positive) direction.

3.2 Flow Correlations

Additional withdrawals or alterations to discharge in CRKB have the potential to result in changes in water quality, either directly by removing nutrients within or introduce to the system or indirectly as changes in residence time. Residence time is directly related to flow and the most common estimation is simply the volume of water in the system (or subset) divided by the volumetric flow rate passing through the system. Thus, as long as the system volume remains relatively constant, flow may be used directly as a surrogate for residence time.

If the concentration(s) of the parameters of interest are changing with time, interpretation of the results may become more complex as described in the next chapter. However, general trends can be evaluated without assigning causes for the observations. As in the evaluation of water quality with time, a Kendall's tau-b correlation was chosen for the evaluation of water quality response to discharge. Evaluations were conducted by zones in an attempt to minimize the effect of the salinity gradient from Gulf water to fresher spring water.

Development of the spring discharge (technically submarine groundwater discharge, or SGD) time series is described in Chen (2014). Development of these discharge values was based on differences in the ground water elevation and the surface water level above the spring vents. Hindcasting from available water levels was limited to available historical data, which often consisted of only a monthly ground water level observations. Thus, in order to estimate a daily discharge for each of the water quality sampling dates, interpolation was required. Linear interpolation of daily discharge between the calculated values results was used to generate Figure 3-1, which suggest that the general pattern of discharge is retained in the interpolated data.

Calculated and interpolated values of spring discharge were matched with the dates of water quality sampling. Eighty-four percent of the matching discharge values were calculated values and sixteen percent were interpolated values because the periods of higher frequency water quality sampling (e.g., 1984-1986 and 2008-2010; see Figure 1-3) correspond to periods when interpolation of spring discharge was not required.

Figure 3-1. Calculated and Interpolated Spring Flows

The correlation results of daily SGD flows with observed water quality are provided in Table 3-2. As expected, salinity correlation (not shown) is universally negative (11 of the 13 possible zone results). Other parameters lack clear interpretation. Of the remaining 75 flow/water quality zones tested, less than half (29) exhibited a significant relationship with spring discharge.

Table 3-2. CRKB Water Quality Correlations with Spring Discharge (1984-2014)

Discharge vs. Ortho-P			
Zone	taub	n	p
1	0.087	237	**0.046**
2	-0.060	168	0.249
3	0.164	158	**0.002**
4	-0.010	221	0.826
5	0.183	228	**0.000**
6	0.096	262	**0.021**
7	0.008	41	0.950
8	0.053	37	0.654
9	0.258	18	0.145
10		0	
11	0.340	18	0.053
12		0	
13		0	

Discharge vs. TP			
Zone	taub	n	p
1	0.017	402	0.611
2	-0.109	168	**0.036**
3	0.009	335	0.806
4	-0.028	302	0.468
5	-0.019	412	0.565
6	-0.005	758	0.837
7	0.025	233	0.571
8	0.136	271	**0.001**
9	-0.081	57	0.377
10	0.015	314	0.396
11	0.052	37	0.660
12	-0.066	40	0.556
13	0.066	153	0.227

Discharge vs. DO sat			
Zone	taub	n	p
1	-0.022	290	0.577
2	-0.090	175	0.077
3	-0.107	365	**0.002**
4	-0.125	409	**0.000**
5	-0.079	482	**0.010**
6	-0.096	374	**0.006**
7	-0.098	705	**0.000**
8	-0.053	549	0.063
9	0.043	577	0.122
10	0.082	985	**0.000**
11	0.046	664	0.076
12	0.096	156	0.076
13	0.079	381	**0.021**

Discharge vs. Chla			
Zone	taub	n	p
1	0.015	304	0.697
2	-0.137	95	**0.050**
3	0.020	323	0.592
4	0.019	210	0.683
5	0.029	372	0.404
6	-0.065	649	**0.013**
7	0.063	212	0.173
8	0.059	221	0.192
9	0.113	58	0.213
10	0.200	315	**0.000**
11	0.085	38	0.460
12	0.363	40	**0.001**
13	0.240	153	**0.000**

Discharge vs. NOx			
Zone	taub	n	p
1	0.025	186	0.613
2	-0.079	120	0.202
3	0.122	158	**0.023**
4	0.078	171	0.130
5	0.173	199	**0.000**
6	0.059	194	0.222
7	0.299	62	**0.001**
8	0.295	59	**0.001**
9	0.381	58	**0.000**
10	0.460	20	**0.005**
11	0.171	38	0.134
12	-0.164	40	0.139
13	-0.086	20	0.619

Discharge vs. TN			
Zone	taub	n	p
1	0.060	352	0.093
2	-0.132	127	**0.028**
3	0.003	329	0.936
4	0.042	249	0.324
5	0.041	392	0.226
6	0.014	689	0.583
7	0.014	224	0.756
8	0.098	239	**0.024**
9	-0.012	56	0.902
10	0.072	278	0.074
11	0.007	36	0.963
12	0.295	40	**0.008**
13	0.144	117	**0.022**

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CHAPTER 4 - VENT WATER QUALITY

4.1 Nitrate+Nitrite (NO_x-N) Nitrogen

The fact that spring flow (Figure 4-1) is correlated with time could lead to erroneous interpretation of water quality to flow correlations. Because of this, a more in-depth analysis is presented in this chapter for the quality of water issuing from the vents using data extracted from the District's Water Information Management System (WMIS). A graphic comparison of nitrite+nitrate dissolved and nitrite+nitrate total (both expressed as nitrogen) indicated negligible difference, and the two forms were averaged to extend the period of record. The number of vent water quality observation dates is 133 ranging from February 1991 to August 2015. A significant (tau-b= 0.0.017, p = 0.000. rho=0.221 p= 0.011) relationship (Figure 4-2.) with time was noted for the 133 subset of sample days when vent water quality was measured.

Figure 4-1. CRKB Vent Discharge vs. Date

Initially, all vent stations were pooled and an evaluation of NO_3-N to flow was conducted. With n= 444, the relationship with flow was found to be significant (tau-b p = 0.020, rho p = 0.017). Next an evaluation of pooled vent station NO_3-N data vs. date was conducted. Both tests returned highly significant positive relationship (rho p = 0.000, tau-b p = 0.0000) Both comparisons are shown in Figure 4-2.

Figure 4-2. Nitrate Response to Flow and Date, CRKB Spring Vents

In a step-wise procedure, the effect of time was removed from the NOx-N observations with a LOWESS smoother (tension = 0.5) and the residuals tested against flow. The relationship was not significant (tau-b p = 0.176, rho p= 0.159). In the next step, the effect of flow was removed and NO_3-N residuals were correlated with time. This relationship was also non-significant (tau-b p = 0. 0.975, rho p = 0.705). This outcome was inconsistent with the FDEP TMDL (Bridger 2014) evaluation and with results obtained by the District (Heyl 2012) for six other spring systems. Response for individual sites (Table 4-1) reveals that the response varies by individual vent and when taken collectively, the overall response masks the individual responses, but when analyzed separately, a weak pattern emerges (Figure 4-3).

Table 4-1. CRKB Vent NOx-N Response to Date and Flow.

NOx-N Response to Time and Flow After Correcting for the Other Response Variable							
Evaluation	**Date Corrected Residual vs. Flow**	**Flow Corrected Residual vs. Date**	**n=**	**tau**	**tau p=**	**rho**	**rho p=**
All Vents		x	444	-0.001	0.975	-0.018	0.705
All Vents	x		444	-0.043	0.176	-0.067	0.159
Black Spring		x	32	0.052	0.688	0.074	0.687
Black Spring	x		32	-0.056	0.664	-0.058	0.753
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole		x	98	0.378	0.000	0.511	0.000
Tarpon Hole	x		98	-0.118	0.086	-0.170	0.094
Parker Island Spring		x	31	0.415	0.001	0.542	0.002
Parker Island Spring	x		31	-0.075	0.565	-0.093	0.619
Tarpon Spring G4		x	10	-0.200	0.474	-0.188	0.603
Tarpon Spring G4	x		10	-0.156	0.590	-0.176	0.627
Idiots Delight		x	35	0.180	0.132	0.277	0.107
Idiots Delight	x		35	0.032	0.798	0.036	0.837
Idiots Delight G5		x	10	0.067	0.857	0.176	0.627
Idiots Delight G5	x		10	-0.022	1.001	0.018	0.961
Hunters Spring		x	83	0.625	0.000	0.819	0.000
Hunters Spring	x		83	0.005	0.950	0.006	0.957
House Spring		x	10	0.200	0.474	0.309	0.385
House Spring	x		10	-0.244	0.372	-0.309	0.385
Magnolia Circle Spring		x	31	0.394	0.002	0.440	0.013
Magnolia Circle Spring	x		31	0.028	0.838	0.034	0.856
Catfish Spring		x	78	0.623	0.000	0.803	0.000
Catfish Spring	x		78	-0.044	0.572	-0.051	0.657
Millers Creek Spring		x	22	0.281	0.072	0.411	0.057
Millers Creek Spring	x		22	-0.065	0.693	-0.064	0.777

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Figure 4-3. CRKB Vent NO_x-N Response to Date and Flow.

The majority of the relationships were not significant at the 0.05 significance level. The only significant relationships identified were a temporal increase in residuals once the flow signal was removed. This response is consistent with previous District observations and others. Upchurch et al. (2008) investigated 52 springs in the Suwannee River Management District and concluded that *'Forty-five percent of the remaining springs show no correlation between discharge and nitrate, and only 5% (2 springs with poor data) have relationships where high discharge was related to lower nitrate concentrations.'* The 'strength' of NO_3-N in the vent water is increasing over time, possibly in response to changes land use practices in the recharge area.

4.2 Total Phosphorus (TP)

A plot (Figure 4-4) of vent TP concentrations suggest that virtually all results were below the analytical limit of detection in use by the various laboratories/agencies from which data were compiled. However, the database prepared by the University of Florida (Frazer et al. 2010) did not include data quality codes and the apparent reporting of method detection limit cannot be verified. No additional analysis was attempted for vent TP results.

Figure 4-4. Total Phosphorus Concentration - CRKB Vent Results

4.3 Salinity

The relationship between flow corrected salinity was also evaluated for correlation with time and with the converse. The results are given in Table 4-2. Only Black Spring exhibited a significant relationship with date once the relationship with flow was removed. Taken collectively, the evaluation of all vent data demonstrated the same relationship.

Table 4-2. CRKB Vent Salinity Response to Flow and Time.

Salinity Response to Time and Flow After Correcting for the Other Response Variable							
Evaluation	**Date Corrected Residual vs. Flow**	**Flow Corrected Residual vs. Date**	**n=**	**tau**	**tau p=**	**rho**	**rho p=**
All Vents		x	378	-0.084	0.015	-0.112	0.029
All Vents	x		378	-0.008	0.817	-0.011	0.831
Black Spring		x	32	0.351	0.005	0.544	0.001
Black Spring	x		32	-0.157	0.213	-0.256	0.157
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole		x	78	-0.035	0.653	-0.047	0.683
Tarpon Hole	x		78	0.027	0.730	0.043	0.709
Parker Island Spring		x	29	-0.049	0.723	-0.092	0.635
Parker Island Spring	x		29	-0.015	0.924	-0.016	0.934
Tarpon Spring G4	Less than 10 observations						
Tarpon Spring G4	Less than 10 observations						
Idiots Delight		x	35	0.042	0.733	0.101	0.564
Idiots Delight	x		35	-0.137	0.253	-0.230	0.184
Idiots Delight G5	Less than 10 observations						
Idiots Delight G5	Less than 10 observations						
Hunters Spring		x	76	-0.119	0.129	-0.178	0.124
Hunters Spring	x		76	-0.107	0.173	-0.159	0.170
House Spring		x	10	-0.360	0.174	-0.547	0.102
House Spring	x		10	0.360	0.174	0.498	0.143
Magnolia Circle Spring		x	29	-0.133	0.320	-0.205	0.286
Magnolia Circle Spring	x		29	-0.040	0.775	-0.054	0.781
Catfish Spring		x	65	0.077	0.368	0.100	0.428
Catfish Spring	x		65	0.027	0.755	0.031	0.806
Millers Creek Spring		x	20	-0.116	0.495	-0.167	0.482
Millers Creek Spring	x		20	0.138	0.413	0.221	0.349

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4.4 Dissolved Oxygen Saturation

The response of flow corrected dissolved oxygen saturation to time and flow on time-corrected dissolved oxygen was also investigated. Only one significant relationship exists. Results are given in Table 4-3.

Table 4-3. CRKB Vent Dissolved Oxygen Saturation Response to Flow and Time.

Dissolved Oxygen Saturation Response to Time and Flow After Correcting for the Other Response Variable							
Evaluation	**Date Corrected Residual vs. Flow**	**Flow Corrected Residual vs. Date**	**n=**	**tau**	**tau p=**	**rho**	**rho p=**
All Vents		x	253	-0.006	0.888	-0.003	0.962
All Vents	x		253	-0.023	0.586	-0.038	0.000
Black Spring		x	17	-0.206	0.266	-0.377	0.136
Black Spring	x		17	0.162	0.386	0.267	0.300
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole 2	Less than 10 observations						
Tarpon Hole		x	44	-0.072	0.497	-0.081	0.601
Tarpon Hole	x		44	-0.034	0.753	-0.039	0.802
Parker Island Spring		x	29	0.015	0.924	0.006	0.975
Parker Island Spring	x		29	0.044	0.752	0.050	0.797
Tarpon Spring G4	Less than 10 observations						
Tarpon Spring G4	Less than 10 observations						
Idiots Delight		x	17	0.022	0.935	0.007	0.979
Idiots Delight	x		17	0.258	0.160	0.412	0.100
Idiots Delight G5	Less than 10 observations						
Idiots Delight G5	Less than 10 observations						
Hunters Spring		x	56	-0.095	0.304	-0.146	0.283
Hunters Spring	x		56	0.018	0.850	0.025	0.855
House Spring	Less than 10 observations						
House Spring	Less than 10 observations						
Magnolia Circle Spring		x	29	-0.188	0.158	-0.252	0.187
Magnolia Circle Spring	x		29	-0.227	0.087	-0.305	0.108
Catfish Spring		x	39	0.158	0.160	0.224	0.170
Catfish Spring	x		39	-0.026	0.825	-0.039	0.814
Millers Creek Spring		x	16	-0.109	0.587	-0.168	0.534
Millers Creek Spring	x		16	-0.126	0.525	-0.194	0.472

CRKB_WQTables_revised.xlsx

4.5 Discussion

Salinity and DO in water discharging from the CRKB spring vents does not appear to be influenced by rate of flow and has remained relatively stable throughout the period evaluated. The response of TP could not be evaluated with the current database, but appears to have remained at, or below the analytical limit of detection since the mid-1980s. Since PO_4-P is a component of TP, it can be reasonably expected to also be below the limits of detection within the datasets contained in the present database. Nitrate changes with time (after removing discharge signal) are limited to only three vents.

CHAPTER 5 - REFERENCES

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