

## **Session 1**

### **Freshwater Quality and Availability**

**Session Leader: Dr. David Sumner**

# Determining Sources and Timescales of Nitrate Contamination of Spring Waters from Isotopes and Other Chemical Indicators

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Human health and ecological concerns have arisen regarding Florida's spring waters as a steady increase in nitrate concentrations has been observed during the past 30 years. Springs discharge nearly 8 billion gallons per day and provide base flow for many rivers in Florida that flow toward coastal areas. Increased nitrogen loads in spring runs and streams have led to the formation of nuisance algal mats and exotic species of rooted aquatic plants. In response to these concerns by the State of Florida, several research studies have been using naturally-occurring isotopic and other chemical tracers to determine sources of nitrate contamination and age of ground water discharging from springs. Since 1997, more than 60 water samples have been collected from 44 springs and analyzed for isotopes ( $^{15}\text{N}$ ,  $^3\text{H}/^3\text{He}$ ,  $^{18}\text{O}$ ,  $^2\text{H}$ ,  $^{13}\text{C}$ ) and other chemical indicators (chlorofluorocarbons (CFCs), major ions, dissolved gases, and  $\text{SF}_6$ ). Delta  $^{15}\text{N}$  values of nitrate ranged from 2.6 to 12.9 per mil (median = 5.8 per mil) and indicated that nitrate in most spring waters originated from synthetic fertilizers. Mean transit times of ground water from the Upper Floridan aquifer that discharges from these springs ranged from 5 to 39 years, based on measured concentrations of CFCs,  $^3\text{H}/^3\text{He}$ , and  $\text{SF}_6$  and various flow system models. Concentrations of these multiple transient tracers are consistent with a two-component hydrologic model with mixtures of varying proportions of young water (<8 years) from the shallow part of the aquifer and older water (20-50 years) from the deeper part of the flow system. Given residence times of 20 to 40 years for ground water discharging from most springs, it likely will take decades for nitrate concentrations to decrease to near background levels, even with immediate reductions in nitrogen inputs at the land surface.

# Elevated Nitrate, Pesticides, and Pesticide Degradates in Ground Water and Lakes on the Lake Wales Ridge, a Unique Hydrologic and Biologic Region in Central Florida

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The landscape, hydrology, and ecology of Lake Wales Ridge, central Florida, are unique in many respects. The Ridge is the highest and most prominent topographic feature in peninsular Florida and contains one of the largest collections of rare and endangered species in the United States (Dobson and others, 1997), one of the highest concentrations of endemic species in North America (Martin, 1998), and more than 200 lakes, most of which are seepage lakes with significant ground-water inflow. Lake Wales Ridge (subsequently referred to as 'the Ridge') is also one of the most intensely cultivated citrus regions in the world, with citrus groves covering about 25 percent (170 square miles) of the land area. Geologically, the Ridge is underlain by highly permeable marine sands forming relict Miocene-Holocene paleoislands which support some of the oldest ecologic communities in Florida. Ground water and surface water are closely linked in this region where ground-water inflow contributes more than 80 percent of the net water input to some lakes (Sacks and others, 1998). Ground water is the primary drinking-water supply in this region. The unconfined surficial aquifer supplies drinking water for some rural wells, and recharges water to the underlying Upper Floridan aquifer which is the primary municipal water supply.

Ground water on the Ridge is extremely vulnerable to contamination due to several factors including the combination of highly permeable sandy soils and seasonally high rates of rainfall. In addition, these soils contain little organic matter, reducing the potential for sorption of pesticides and for denitrification. During the late 1980s and 1990s, elevated concentrations of nitrate and pesticides in ground water on the Ridge prompted development of restrictions specific to the Ridge on the usage of agricultural chemicals, as well as remedial actions to remove potential contaminants from some rural drinking-water supplies. Elevated nitrate concentrations, locally exceeding 8 milligrams per liter (mg/L), have been observed in Ridge lakes in citrus areas (Romie, 2000), and a statewide survey (USEPA, 1990) indicated that 89 percent of Florida wells yielding nitrate concentrations above the USEPA maximum contaminant level<sup>3</sup> of 10 mg/L occurred in the ridge citrus regions.

Two USGS studies, in partnership with state agencies, focus on agricultural chemicals in ground water and lakes in citrus areas on the Ridge. The ground-water study, initiated in 1998, is a regional assessment of 29 pesticides and degradates that includes ongoing sampling of 31 wells (Choquette and others, 2003; web site: [http://fisc.er.usgs.gov/Lake\\_Wales\\_Ridge/index.html](http://fisc.er.usgs.gov/Lake_Wales_Ridge/index.html)). The lake study, initiated in 2003, is a reconnaissance sampling of eight seepage lakes in Ridge citrus areas. Few previous studies have systematically documented regional short-term and long-term variations in pesticides in ground water, or the occurrence and variability of pesticides in small to moderately sized lakes (5 to 100 acres).

Sampling of ground water and lakes on the Ridge has revealed elevated concentrations of nitrate, pesticides, and pesticide degradates. During 1999 to 2004, nitrate concentrations in ground water exceeded the USEPA MCL one or more times at 90 percent of the network wells. Twelve targeted pesticides and degradates have been detected in ground water from these wells, with as many as eight different pesticides or degradates occurring in ground water from some wells. Concentrations of five targeted pesticides or degradates (aldicarb sulfoxide and sulfoxone, simazine, bromacil, and diuron) have exceeded Florida's

human-health guidance concentrations<sup>4</sup> in one or more samples from the wells, although such exceedances have been limited to less than five percent of all samples. Concentrations of all pesticides detected in Ridge ground water have exceeded national maximums from the USGS National Water-Quality Assessment (NAWQA) monitoring network of more than 3,375 wells for the period 1992-2001 (web site: <http://ca.water.usgs.gov/npsp/>). Pesticide concentrations in ground water often show significant short-term variability and concentrations of some pesticides appear to be increasing over time (Choquette and others, 2005).

Compared to the ground-water study, the lake study includes additional target pesticides and lower laboratory detection limits. Concentrations of pesticides and degradates detected during 2003-2004 reconnaissance sampling from four Ridge lakes generally were lower than the 1999-2004 concentrations observed in ground water. However, the lake concentrations for most detected pesticides appear to be relatively high when compared nationally to streams in agricultural areas sampled by the USGS NAWQA program (web site: <http://ca.water.usgs.gov/npsp/>). Concentrations in the lake samples have not exceeded human-health guidance levels or aquatic-life criteria. A total of nineteen different pesticides and pesticide degradates have been detected in the lake samples, and six or more target pesticides and degradates were detected in most (75%) of the samples. In lake samples, the highest concentrations, ranging from 0.1 to 17.1 µg/L, included: norflurazon, desmethyl norflurazon, 2,4-D, bromacil, aldicarb sulfoxide and sulfone, hydroxysimazine, chlordiamino-s-triazine (CAAT or DDA), chloroethylamino-s-triazine (CEAT or DIA), and diuron. Detection frequencies for these compounds ranged from 25 to 100 percent of the samples.

Furthering our understanding of the transport and fate of agricultural chemicals on the Ridge, and their effects on Ridge ecosystems presents a number of opportunities for interdisciplinary collaboration. Process-oriented, local-scale studies are needed to track the transport and fate of nitrate, pesticides, and pesticide degradates in soils, ground water, and lakes, including the effects of atmospheric transport and of biogeochemical processes in lake sediments. Much is unknown regarding the chronic toxicity of pesticides, chemical mixtures, and pesticide degradates to non-target organisms. There have been no studies to date to assess the potential impacts of elevated concentrations of citrus pesticides and pesticide degradates on the biologic communities of Ridge lakes. Additional factors that make this research particularly compelling include recent data indicating adverse effects of low, ecologically relevant concentrations of pesticides on non-target organisms (Hayes and others, 2002; Gross and others, 2003; Barbash, 2004); the incomplete removal of simazine from standard municipal water-filtration systems (Coupe and Blomquist, 2004); and the potential for increased toxicity of simazine when combined with elevated nitrate concentrations (U.S. Dept. of Health and Human Services, 2004).

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<sup>3</sup> U.S. Environmental Protection Agency maximum contaminant level (MCL) for drinking water.

<sup>4</sup> These values correspond to the USEPA MCL's and, for compounds that do not have a MCL, the Florida Department of Environmental Protection target cleanup levels (<http://fdep.ifas.ufl.edu/>, accessed 3/8/2005)

# Declining Water Levels in the Apalachicola River and Impacts on Floodplain Habitats

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Water levels in the Apalachicola River upstream of tidal reaches have decreased significantly in the past 50 years. Most of the declines are due to channel deepening and widening from dams and navigational improvements on the river, which have lowered river stages throughout most of the river by 2-5 feet. Channel deepening occurred because sediments were trapped in Lake Seminole and other reservoirs upstream, and sediment-starved water scoured the riverbed downstream of Jim Woodruff Dam. Channel widening was caused by a variety of impacts that probably include bank failure associated with riverbed scour, dredging, dredge material disposal, woody debris removal, and other navigational improvements. Flows may also be declining, as preliminary analyses indicate that during periods of low rainfall, less flow reaches the Apalachicola River now than it did several decades ago. Decreased flows that cannot be accounted for by climatic changes may be caused by changes in anthropogenic activities such as water consumption and reservoir evaporation.

Declining river levels have resulted in substantially drier conditions in nontidal floodplain habitats. Most of the floodplain is presently experiencing flood durations that are 5-25 percent less than they were prior construction of Jim Woodruff Dam in the mid-1950's, with the most affected areas suffering declines in flood duration of 40-50 percent. During dry periods in recent decades, over 200 miles of floodplain sloughs, streams, and lakes had shallower water depths or were disconnected from the main channel longer than in dry periods prior to 1955. These off-channel habitats are critical to Apalachicola River fish species, 85 percent of which use the floodplain at some time in their life cycle. The nontidal floodplain forest, covering 82,000 acres, is one of the largest and most valuable wetland resources of the State of Florida. A decline in water levels can change floodplain forest vegetation over time by favoring species that are adapted to drier environments, opportunistic species, or invasive exotics.

Protection efforts should address decreases in water levels from channel changes and decreases in flow from upstream consumption and evaporation. A better understanding of sediment transport and river morphology dynamics is needed to develop recommendations for slowing the rate of channel widening and bed degradation. Quantitative descriptions of the potential impacts of flow reductions on biological habitats are also important, so that a reasonable balance can be achieved between upstream water management and downstream ecological flow needs in water allocation negotiations.

# Effects of Aquifer Heterogeneity on Ground-Water Flow and Chloride Concentrations in the Upper Floridan Aquifer near and within an Active Pumping Well Field, West-Central Florida

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Chloride concentrations have been increasing over time in water from wells within and near the Eldridge-Wilde well field, near the coast in west-central Florida. Variable increases in chloride concentrations from well to well over time are the combined result of aquifer heterogeneity and ground-water pumping within the Upper Floridan aquifer. Deep mineralized water and saline water associated with the saltwater interface appear to move preferentially along flow zones of high transmissivity in response to ground-water withdrawals. The calcium-bicarbonate-type freshwater of the Upper Floridan aquifer within the study area is variably enriched with ions by mixing with introduced deep and saline ground water. The amount and variability of increases in chloride and sulfate concentrations at each well are related to well location, depth interval, and permeable intervals intercepted by the borehole.

Zones of high transmissivity characterize the multilayered carbonate rocks of the Upper Floridan aquifer. Well-developed secondary porosity within the Tampa/Suwannee Limestones and the Avon Park Formation has created producing zones within the Upper Floridan aquifer. The highly transmissive sections of the Avon Park Formation generally are several orders of magnitude more permeable than the Tampa/Suwannee Limestones, but both are associated with increased ground-water flow. The Ocala Limestone is less permeable and is dominated by primary, intergranular porosity. Acoustic televiewer logging, caliper logs, and borehole flow logs (both electromagnetic and heat pulse) indicate that the Tampa/Suwannee Limestone units are dominated by porosity owing to dissolution between 200 and 300 feet below land surface, whereas the porosity of the Avon Park Formation is dominated by fractures that occur primarily from 600 to 750 feet below land surface and range in angle from horizontal to near vertical. Although the Ocala Limestone can act as a semiconfining unit between the Avon Park Formation and the Tampa/Suwannee Limestones, seismic-reflection data and photolinear analyses indicate that fractures and discontinuities in the Ocala Limestone are present within the southwestern part of the well field. It is possible that some fracture zones extend upward from the Avon Park Formation through the Ocala, Suwannee, and Tampa Limestones to land surface. These fractures may provide a more direct hydrologic connection between transmissive zones that are vertically separated by less permeable stratigraphic units.

Ground water moves along permeable zones within the Upper Floridan aquifer in response to changes in head gradients as a result of pumping. Borehole geophysical measurements, including flow logs, specific conductance logs, and continuous monitoring of specific conductance at selected fixed depths, indicate that borehole specific conductance varies substantially with time and in response to pumping stresses. Ground-water mixing between hydrogeologic units likely occurs along highly transmissive zones and within boreholes of active production wells. Ground-water movement and water-quality changes were greatest along the most transmissive zones.

Variable mixing of three water-type end members (freshwater, deepwater, and saltwater) occurs throughout the study area. Both deepwater and saltwater are likely sources for elevated chloride and sulfate concentrations in ground water. Mass-balance calculations of mixtures of the three end members indicate that deepwater is found throughout the aquifer units. Samples from wells within the southwestern part of

the well field indicate that deepwater migrates into the shallow permeable units in the southwestern part of the well field. Deepwater contributes to elevated sulfate and chloride concentrations, which increase with depth and are elevated in wells less than 400 feet deep.

The greatest increases in chloride concentrations over time are found in water from wells closest to the saltwater interface. Ground water with a saltwater influence occurs primarily within the Avon Park producing zone nearest the saltwater interface, deeper in the aquifer system. Because chloride concentrations in saltwater are greater than those associated with deepwater, even small percentages of saltwater have a substantial effect on chloride concentrations. The highest percentages of saltwater are found in ground water from 600 to 750 feet deep within the transmissive zone of the Avon Park Formation. Specific conductance logs and long-term chloride concentration data indicate that saltwater may move preferentially inland along this transmissive zone. Chloride concentrations range from 5,000 to more than 15,000 milligrams per liter between 640-780 feet below land surface in wells less than 1 mile southwest of the well field. Elevated chloride concentrations in the well field are highest in wells where the potentiometric surface has been lowered.

Lowered ground-water levels associated with the Eldridge-Wilde well field affect the regional potentiometric surface of the Upper Floridan aquifer and may provide the potential to induce saltwater movement along transmissive zones of enhanced secondary porosity. From 1997 to 2000, water with elevated chloride concentrations migrated into the Eldridge-Wilde well field within the highly transmissive zone of the Avon Park Formation between 600-750 feet below land surface. In 2000, chloride concentrations reached 250 milligrams per liter in monitor wells tapping this production zone beneath the center of the well field. Isotopic analyses of deuterium, oxygen-18, and strontium-87/ strontium-86 indicate that saltwater mixing is a primary source of the observed chloride.



# Using Numerical Models to Simulate Surface-Water and Ground-Water Movement in South Florida

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This paper presents current numerical modeling efforts of the U.S. Geological Survey in south Florida. The efforts summarized here include the development of numerical models designed to simulate (1) a deep well injection in Miami-Dade County, (2) saltwater interface movement in Broward County, (3) submarine ground-water discharge to Biscayne Bay, and (4) coupled surface-water and ground-water exchange in the southern Everglades.

The South District Wastewater Treatment Plant (SDWWTP) in Miami-Dade County, Florida began operation in 1983. The facility contains 17 Class I underground injection wells for disposal of treated effluent. The treated effluent is injected into the saline Boulder Zone, a highly permeable dolomite unit located at the base of the Lower Floridan aquifer. In 1994, the Miami Dade Water and Sewer Department (MDWASD) detected ammonia and total Kjeldahl nitrogen (TKN) above background levels in samples taken above the injection zone in Floridan aquifer system monitoring wells at the SDWWTP. Two possible explanations for the ammonia plumes have been suggested: 1) treated wastewater may be flowing upward around poorly cemented well casings; or 2) the middle confining unit, located between the Boulder zone and Upper Floridan aquifer, does not provide enough confinement to restrict the upward movement of injectate. Regardless of the pathway, the density difference between the native aquifer water and the injectate probably contributes to the observed flow pattern caused by the buoyancy of less dense fresh-water injected into more dense saline water. The USGS, in cooperation with MDWASD, is developing a variable-density ground-water flow and solute-transport model to: (1) evaluate movement of injected waters within the Floridan aquifer system, (2) estimate the current extent of the injectate within the Upper Floridan aquifer, and (3) predict the future movement of injected fluids under a range of different injection scenarios.

The USGS conducted a study to relate movement of the freshwater/saltwater interface to fluctuations in canal stage in an effort to better manage saltwater intrusion in a shallow aquifer system. In support of the modeling, water levels and fluid variables were measured and recorded at 15-minute intervals at six monitoring wells in Broward County, Florida. The field data suggest tidal fluctuations, rainfall, and changes in canal stage have a measurable effect on ground-water levels and fluid conductance. Data from the field study were used to guide the development and calibration of transient, three-dimensional, variable-density, ground-water flow models based on the SEAWAT code. The model was calibrated by adjusting values of hydraulic conductivity, specific yield, porosity, and dispersivity. Additional simulations have suggested that canal stage changes can have a long-term effect on interface location and intrusion rates in southeastern Florida. Modeling this phenomenon can aid in defining appropriate canal stages to prevent saltwater intrusion under a wide range of hydrologic conditions.

Biscayne National Park (BNP) is the largest national marine park in the United States. Hydrologic investigations have shown that terrestrially derived ground-water is discharging into Biscayne Bay and possibly to the offshore coral reef tract. The quantification of ground-water discharge rates, location of discharge areas, and delineation of ground-water recharge areas is important for reliable water management. The current project is using a previously developed USGS ground-water model of Biscayne Bay

to simulate ground-water discharge patterns to the bay under a variety of conditions. It is expected that simulated flow patterns will correlate with ecological indicators of stressed communities, providing managers with insight into the causes of ecosystem degradation. The ground-water model simulates transient ground-water discharge to Biscayne Bay in three dimensions using a horizontal cell spacing of 1000m x 1000m, and 11 vertical layers. The simulation period for the original model was 10 years, from January 1989 to September 1998, with monthly time steps. For the present study, the model will be linked with the South Florida Water Management District (SFWMD) Natural Systems Model (NSM) and South Florida Water Management Model (SFWMM) to simulate ground-water discharge into the bay under predevelopment conditions, present conditions, and the future alternative management conditions proposed under the Comprehensive Everglades Restoration Plan (CERP).

The USGS began modeling the southern Everglades and northeastern Florida Bay hydrology in 1995 with the development of the Southern Inland and Coastal Systems (SICS) hydrodynamic surface-water flow and solute-transport model. The original surface-water model did not include a ground-water component which was a limitation, considering the documented importance of surface-water and ground-water exchange in southern Florida. Subsequently, the FTLOADDS (Flow and Transport in a Linked Overland Aquifer Density Dependent System) program was designed by linking the SWIFT2D surface-water code with the SEAWAT ground-water code. The integrated simulation was extended to 7 years, representing the period from January 1996 to December 2002. The integrated model was used to evaluate the dominant hydrologic processes, including surface-water and ground-water interactions, and to synthesize a wide range of hydrologic data collected for the area. The specific objective of the model application was to develop a numerical tool that could be used to quantify freshwater discharges to northeastern Florida Bay, predict temporal and spatial variations in coastal salinity patterns, and represent wetland hydroperiods. Presently, this numerical tool is being used to evaluate the effects of CERP on future hydrologic conditions (heads, flows, and salinities) in the coastal wetlands and adjacent Florida Bay estuary. Additionally, the model is being combined with various stochastic schemes in order to enhance its capabilities. Two of these techniques include (1) a fourier-transform method to determine hydrologic forcings on the system and model input errors, and (2) an optimization scheme that will allow the model to be used to assist in the design of water delivery scenarios that meet restoration performance measures.

The methodology used for the SICS model is being expanded and improved for the development of the TIME (Tides and Inflows in the Mangroves of the Everglades) model. The TIME model is coarser in resolution (500-m cell size) than SICS (305-m cell size), but covers a much larger area of the Everglades, including Shark River and Taylor Sloughs that drain to the Gulf of Mexico and northern Florida Bay respectively. The TIME model also is being developed using the FTLOADDS computer program; therefore, the type of output from both models is similar, consisting of discharge, stage, and salinity in the wetlands and underlying aquifer system. As with the SICS model, TIME is being developed as a tool to evaluate the effects of CERP scenarios on freshwater flows to Florida Bay and the Gulf of Mexico. The model is currently simulating the period from 1996 to 2002.

# Surface Water Salinity Mapping of Estero Bay and San Carlos Bay, Lee County, Florida

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## Introduction

Surface water salinity mapping can be used as a qualitative and quantitative tool for evaluating water transport and residence time in rivers and estuaries. Fourteen salinity maps were created from data collected over an 18-month period. These maps show seasonal variability, rivers of significance, and hydrologic barriers, such as islands, ridges, mangrove embankments, that prevent water from going between bays and rivers. We captured periods of high discharge from Lake Okeechobee and surrounding areas, as well as low-flow conditions.

## Project Location

Estero Bay and San Carlos Bay (fig. 1) are located on the southwestern coast of Florida at the southern end of Charlotte Harbor. Lake Okeechobee, via the Caloosahatchee River, drains into San Carlos Bay, Matlacha Pass and Pine Island Sound. The watershed of the Caloosahatchee River covers approximately 1,300 square miles. Surface-water discharge to San Carlos Bay during the 2003 water year (October 1, 2002 through September 30, 2003) exceeded 1 million acre-feet, with approximately half coming from Lake Okeechobee. The mean flow for the 1966 to 2003 water years is approximately 600,000 acre-feet, with wide variation between years.

Water from Lake Okeechobee and surrounding areas enters Estero Bay via the Caloosahatchee River through Matanzas Pass. This freshwater can potentially carry large amounts of suspended organic material that can result in the reduction of water clarity, increased sedimentation in certain areas and sharp reductions in salinity. Freshwater discharges from Lake Okeechobee may directly impact the health of estuaries within Estero Bay

## Methods

### Data Collection

To measure salinity and temperature, a flow-through chamber was attached to the transom of a boat 20 cm below the water surface, and a probe was inserted in the chamber. The probe was connected to a data logger with a Global Positioning Satellite (GPS) unit and recorded salinity, temperature, time and location every 5 seconds (about every 5 to 10 meters) while the boat was moving. For salinity surveys, two boats were used simultaneously to reduce the time required for data collection. One boat was used to measure the mouth of the Caloosahatchee River, San Carlos Bay, and the five passes connecting Estero Bay to the Gulf of Mexico. The other boat measured the major tributaries entering Estero Bay, and Estero Bay. One day of sampling typically yielded about 7,000-8,000 measurements.

## Data Analysis

The data were sorted in a spreadsheet to eliminate outliers, and then converted into a shapefile layer using ESRI ArcView. The data in the shapefile were interpolated using the inverse distance weighted (IDW) method in ESRI ArcMap, power of 2, cell size 102, and the default search radius. The IDW method assumes the values closest to each other are most alike and assigns the greatest weight to closest values. Line barriers were used to help keep points in one river from affecting a point in another river that was separated by a hydrologic barrier.

The data were interpreted qualitatively and quantitatively. It was possible to detect spatial and temporal salinity variations by visually inspecting the maps. The impact of hydrologic divides and sources of fresh water were also evaluated using the maps. Statistical variability both temporally and spatially were then determined using analysis of variance (ANOVA).

## Results and Discussion

Certain trends are revealed by the salinity maps (figs. 2 and 3). Salinity in the Gulf of Mexico north of Matanzas Pass is lower than salinity south of Big Carlos Pass. The hydrologic divides that segment Estero Bay and San Carlos Bay greatly affect their salinities. Imperial River discharge flows southward and northward in equal magnitudes (fig. 3). The trends can best be seen during extreme events, such as high discharge periods from Lake Okeechobee (fig. 3).

The salinity north of Matanzas Pass is lower than salinity south of Big Carlos Pass due to two possible scenarios: (1) flow from the northern part of Estero Bay, with a prevailing north current, is great enough to lower salinity, (2) flow from the Caloosahatchee River lowers salinity south of San Carlos Bay. The prevailing evidence suggests that the lower salinity is due to freshwater releases in the Caloosahatchee River and Lake Okeechobee.

The salinity maps illustrate how hydrologic divides interrupt and redirect the flow of water. Islands along the causeway to Sanibel Island prevent much of the water in San Carlos Bay from flowing in a southerly direction, thereby depriving Estero Bay of fresh water. Hell Peckney Bay is hydrologically linked to Matanzas Pass but is divided from the rest of Estero Bay, probably due to changes in elevation. Waters entering Estero Bay from Lake Okeechobee have their greatest impact on this portion of the bay. Mound Key, in the center of Estero Bay, borders a mudflat that constricts the flow from Mullock Creek and Estero River. Because of this, water north of Mound Key has a shorter residence time and lower salinity than water south of Mound Key.

Imperial River conveys freshwater from a large basin and empties out through Big Hickory Pass and Wiggins Pass. During the rainy season (fig. 3) the freshwater discharge extends far beyond the mouth of the river. The symmetric salinity patterns for this outflow (fig. 3) suggest about only half of the freshwater discharge from the river reaches southern Estero Bay.

## **Session I**

**Poster Session Leader: Trudy Phelps**

# Creation of a Geospatially Rectified Digital Archive for South Florida and the Everglades: The 1940 Aerial Photography Photoset

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Historic aerial photographs of South Florida are a source of valuable information of pre-drainage land cover and land use patterns in the Everglades. The U.S. Geological Survey, in partnership with other agencies, is creating a digital archive of historic aerial photography of this area. Work on the digital archive has progressed with the creation of two open file reports publishing maps from 1927 – 1935 and imagery from 1940. Additional imagery has been scanned but is not yet published.

The 1940 photoset includes approximately 920 high quality panchromatic images of south Florida. The 1:40,000-scale photography covers an extensive area south of Lake Okeechobee. Unreferenced imagery (300 dpi) was published in an Open File Report and can be accessed via the Internet at URL: <http://sofia.usgs.gov/publications>. In October 2004, we completed rectifying higher resolution imagery from this set (1 m. pixel). The entire set of high resolution 1940s imagery will be available in the near future on the above mentioned website.

The digital, referenced imagery constitutes a broad-scale, high-resolution record of the Everglades landscape going back six decades. It will form the basis for detecting changes in land use and land cover using geographic information systems and spatial analysis methods. To develop and test change detection methods, we selected the Southern Inland and Coastal System of the Everglades and created a geodatabase of historic photography. This pilot project includes rectified raster images from 1940, 1952, 1964, 1987 and 1995, which we will use to conduct a spatial analysis of changes in vegetation patterns.

# Geophysical and Water Quality Sampling with Depth in a Public Supply Well in Temple Terrace, Florida and Implications for Water Supply Managers

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Flow, water-quality, core, and geophysical data from a 174-foot public-supply well in Temple Terrace, Florida, were compared to provide resource managers with decision-making tools. Previously collected water quality samples from the well contained low concentrations of nitrate, atrazine, chloroform, trichloroethylene, arsenic, uranium, and radon. A steady-state ground-water flow model, calibrated to identify the potential contributing area to this well, does not adequately represent local characteristics of flow. To improve model calibration and identify potential zones of higher contaminant concentrations, depth sampling was undertaken. To perform geophysical logging and obtain water quality samples the turbine and bowls were removed and a small temporary submersible pump was installed in the well in October 2004. Gamma, resistance, caliper, spinmeter, Electromagnetic (EM) flowmeter, temperature, and conductance logs were then run under pumping and ambient conditions throughout the open interval of the well. The results of the caliper log and a previously recorded video log showed multiple small caverns in the open interval between 134 to 152 feet below land surface and a large conduit (approximately 4 by 3 feet aperture, length of conduit undeterminable) at a depth of approximately 164 feet below land surface. The karst features at these depths provided most all of the flow to this well based on results of the EM flowmeter, spinmeter, temperature, and conductance results. The large conduit at 164 feet provided about 70 to 90 percent of the total flow of water under pumping conditions. This information was used to select water quality sampling intervals at 3 depths under pumping conditions and at 2 depths under ambient conditions to study how contaminants enter the well. Preliminary water quality results indicate that water entering the well is on average less than 2 years old. Chloroform and trichloroethylene (TCE), at concentrations less than 1 microgram per liter (ug/L), were detected in all samples. Nitrate (3.6 milligrams per liter (mg/L)) and dissolved oxygen (1.0 mg/L) concentrations peaked in a sample collected from 160 feet below land surface (corresponding to the largest conduit) under non-pumping conditions. Arsenic (18.9 ug/L) and uranium (5.3 ug/L) concentrations were highest in samples from the depth interval 140 to 160 feet under pumping conditions. High arsenic concentrations have been previously found in core samples collected from the Hawthorn Group.

Water quality and flow information collected with depth in public supply wells may be used by water managers to make decisions about specific zones that may be avoided to improve the quality of water from the well. In this particular well, concentrations of contaminants were relatively low and well below USEPA maximum contaminant levels (MCLs)<sup>1</sup>, but were present in the highest production zone (at 140 to 164 feet below land surface). Production would most likely be compromised if this zone was closed off to improve water quality.

<sup>1</sup>U.S. Environmental Protection Agency maximum contaminant level for drinking water.

# The Depositional History of Three Freshwater Lakes in North-Central Florida: Brooklyn Lake, Levys Prairie, and Cowpen Lake

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Florida has approximately 7800 lakes that are heavily concentrated in the north-central part of the state—a mantled karst terrain. Although much research has been conducted in Florida's lakes, there is not much information on the sedimentary infill. The focus of this research is to define the sedimentary infill of three closely spaced lakes (Brooklyn Lake, Levys Prairie, and Cowpen Lake) in north-central Florida and determine the relative importance of the various sedimentary inputs and their associated processes. Interlake lithostratigraphy comparison helped determine if they experienced a similar depositional infilling history or a unique one.

Twenty-three vibracores were taken (12 in Brooklyn Lake; 8 in Levys Prairie; 3 in Cowpen Lake) from which 331 sub-samples were analyzed for grain size, carbonate content, LOI index for total organic content, pollen content, mineralogy, and internal structures. Five sedimentary facies were defined in Brooklyn Lake, four in Levys Prairie, and three in Cowpen Lake. Using lithologic cross sections a depositional scenario was developed for each lake. Subaqueous and subaerial environments in conjunction with groundwater fluctuation and subsidence activity are key factors in lake development. The comparison of sediment infill of these three lakes reveals that Brooklyn Lake and Cowpen Lake are most similar in sediment facies content, basin morphology and the extent of subsidence depicted in the developmental scenarios, whereas, Levys Prairie is much different in sediment facies and basin morphology.

A doubling in pine pollen from Brooklyn Lake and Levys Prairie indicate a change from drier to a wetter environment. This change is present in Sheelar Lake and Mud Lake and carbon-14 dated at 7200 yrs BP and 5070±150 yrs BP (Watts and Stuiver, 1980, Watts, 1969 respectively). This suggests that Brooklyn Lake and Levys Prairie are older than 7200 yrs BP.

Sediment infill from Brooklyn Lake, Levys Prairie and Cowpen Lake is conducive to understanding the depositional processes and environments that contributed to their development. Based on results and evidence presented in this study, it can be expected that lake development in a karst terrain will include subaqueous and subaerial intervals, and times of subsidence that can be recorded in the lake sediments.



# Distribution of Silt and Clay Grain Size and Select Trace Metals in Bottom Sediments of Tampa Bay, July 2003

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We present findings on the distribution of sand/silt/clay in 308 samples collected by the USGS within a 0.5-km shoreline corridor of Tampa Bay, and 84 samples from Middle Tampa, Hillsborough, East, and MacKay Bays, and Palm River collected by the Environmental Protection Commission of Hillsborough County (EPCHC). The percent silt/clay for sediments along a 0.5-km corridor of Tampa Bay ranged from 0 to 100% with a mean value of 16.01. Percent silt/clay for the EPCHC sediments ranged from 2.03 to 66.86% with a mean value of 24.7%. A third of the samples (115) with the highest silt/clay percentage was used for trace metal analyses (Al, As, Cd, Cr, Cu, Ni, Pb, and Zn). Due to the relatively constant proportion of metals to aluminum, metal-to-aluminum graphs were used to evaluate the metal data (Florida Department of Environmental Regulations, 1988); findings were also compared to their Sediment Quality Assessment Guidelines (1944). The findings indicate the presence of some metals with concentrations greater than the 'normal' range for the respective metal:aluminum ratio (i.e., sediments are metal enriched). Some metals, although not enriched, were sufficiently elevated that they could possibly have adverse biological effects.

# USGS Nonindigenous Aquatic Species (NAS) Program Products Produced for NBII

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The Nonindigenous Aquatic Species (NAS) program has been working with two nodes of the National Biological Information Infrastructure: the Pacific Basin Information Node (PBIN) and the Invasive Species Information Node (ISIN). Listed below are some of the products the NAS program produced for these two nodes in 2004.

## **NAS-Hawaii**

<http://pbin.nbii.gov/NASHI/default.asp>

The NAS program created a tailored view of the national database that shows only data for Hawaii. Users may select a species, a taxonomic category, pathway, or status of introduced population. Results returned include species lists, collection information, Hawaii-specific maps, and species fact sheets.

## **NAS-Great Lakes**

<http://nas.er.usgs.gov/GreatLakes>

A second tailored view, this one of the Great Lakes, is being created in partnership with NOAA's Institute for Invasive Species at the Great Lakes Environmental Research Lab in Ann Arbor, Michigan.

## **Pacific Islands Alien Snake Database**

<http://pbin.nbii.gov/databases/snakeindex.html>

The NAS program, in conjunction with the USGS Brown Tree Snake Team, developed an on-line database for snake sightings in the Pacific Islands. No snakes are native to Pacific Islands, so any reports are of introductions. The new database, housed by PBIN, allows on-line data entry for those with permission; and on-line queries by the general public. NAS is coordinating with the Hawaiian Natural Heritage Program to develop mapping of locations using ArcIMS.

## **NISbase- Pacific Portal**

<http://pbin.nbii.gov:8080/NISbase/SpSearchpbin.jsp>

NISbase is a distributed database of nonindigenous invasive species information developed jointly between the NAS program and the Smithsonian Environmental Research Center. The main focus of NISbase has been on aquatic species databases. The two programs worked with PBIN to establish a NISbase Pacific Portal. Four databases were added to the system, consisting primarily of terrestrial weed information and NAS-Hawaii.

## **Nonindigenous Species Alert System**

<http://nas.er.usgs.gov/AlertSystem/>

The NAS program has developed an alert system for new locations of nonindigenous species (species new to: nation, state, county, drainage). Currently the system is working internally and alerts the data entry person of a new location. We are programming the system to allow users to register for alerts. A database will be kept of all alerts so that it can be viewed on the web or queried for new locations in a given time period. This system is now operational to the general public.

# Lake Mead Studies 1995-2001: Evidence of Reproductive Dysfunction in Fish Exposed to Pharmaceuticals and Health-care Byproducts in Wastewater

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An initial survey of fish health was conducted during 1995 and 1998 for multiple sites in Lake Mead. Results suggested potential effects on reproductive function for fish exposed to wastewater effluents in Las Vegas Bay and Wash, which receives the wastewater discharge for the Las Vegas greater metropolitan area. A year-long survey of fish health and reproductive function was conducted during 2000-2001 to assess exposure to and effects of wastewater contaminants in Las Vegas Bay. Las Vegas Bay and multiple sites within the Overton Arm of Lake Mead were utilized for these efforts. Common carp were collected bimonthly (n=12 per sex) and largemouth bass and razorback suckers were collected during the spring reproductive season (n=15 per species and sex). Carp and bass were sacrificed for collection of plasma and tissues. The endangered Razorback sucker specimens were captured and released following the collection of plasma. Samples were analyzed for sex steroids (estradiol, testosterone and 11-ketotestosterone), vitellogenin, gono-somatic index, thyroid hormones (T3 and T4) and sperm quality (motility and morphology). Tissues were analyzed for chemical contaminants. Results indicated significant exposures to a wide variety of chemical contaminants in Las Vegas Bay, including exposure to potential endocrine disruptors, including ethinyl estradiol, triclosan, perchlorate, and brominated fire retardants. Reproductive health biomarkers were (adversely affects) adverse effects for all three species; however, the magnitude of defects was much greater for male fish. Male fish from Las Vegas Bay had decreased concentrations of plasma androgens and thyroid hormones, as well as decreased sperm quality, regardless of species. Concentrations of chemical contaminants were analyzed for correlations to biomarker effects. Significant correlations were indicated for multiple contaminants, including correlations between decreased sperm quality and plasma hormones for both ethinyl estradiol and triclosan. These results indicate endocrine disrupting effects for fish exposed to wastewater effluents. Significant exposure to chemical components of wastewater, such as those of pharmaceutical and health care product origins, are potentially involved in these effects on fish. Future efforts should utilize paired field and laboratory approaches to assess cause-and-effect relationships to wastewater effluents and specific components.

# Bathymetry and Vegetation in Isolated Marsh and Cypress Wetlands in the Northern Tampa Bay Area

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Wetland bathymetry and vegetation mapping have provided two useful lines of evidence for assessing the hydrologic and ecologic status of expansive coastal and riverine wetlands. In smaller isolated fresh-water wetlands, traditional vegetation mapping surveys have been widely used. However, bathymetric data to describe topography has seldom been collected in these systems, despite the prevalence of isolated wetlands in many regions of the United States and the recognized importance of topography as a control on inundation patterns and vegetation distribution.

In the Northern Tampa Bay area of west-central Florida, bathymetry and vegetation were surveyed in ten isolated wetlands: five marshes and five cypress wetlands. The wetlands were grouped into three categories based on the effects due to ground-water withdrawals from municipal well fields: natural (no effect), impaired (drier than natural), and augmented (wetlands with artificially augmented water levels). Bathymetric data were collected using one or more techniques depending on the physical attributes of the wetlands. Delineation of the wetland perimeter was a critical component for estimating wetland surface area and stored water volume. The wetland perimeter was delineated by the presence of *Serenoa repens* (the "palmetto fringe") at nine of the ten sites. At the tenth site, where the palmetto fringe was absent, hydric soils indicators were used to delineate the perimeter. Wetland vegetation was surveyed twice a year for two years in fixed plots located at three distinct elevations in the wetlands. Vegetation surveys determined the community composition and the abundance of obligate, facultative wet, and facultative species at each elevation.

Bathymetry maps were generated, and stage-area and stage-volume relationships were developed for all 10 wetlands. Bathymetric data sets containing a high density of data points collected at frequent and regular spatial intervals provided the most useful stage-area and stage-volume relations. Bathymetric maps of several wetlands were also generated using a low density of data points collected along transect lines alone, or along both transect lines and elevation contour lines. In a comparative analysis of the three mapping approaches, stage-area and stage-volume relations based on transect data alone underestimated the wetland area and volume significantly (50-100 percent) compared to results using a higher density of data points. Adding data points collected along one elevation contour below the wetland perimeter to the transect data set greatly improved the agreement in the resulting stage-area and stage-volume relationships with the higher-density mapping approach.

Stage-area relationships and routinely monitored stage data were used to compare and contrast the weekly average flooded area in a natural marsh and an impaired marsh over a two year period. Vegetation surveys used together with flooded-area information provided the potential for extrapolating vegetation results from points or transects to the wetland as a whole. A comparison of the frequency of flooding of different areas of the wetland and the species composition in vegetation plots at different elevations indicated the dependence of vegetation on inundation frequency. However, because of the broad tolerances of many wetlands plants to a range of inundation conditions, vegetation surveys alone provided less definitive evidence of the hydrologic differences between the two sites, and changes occurring in the two years, than the flooded-area frequencies.

Comparing flooded-area frequencies and vegetation surveys of impaired and augmented wetlands to flooded-area frequencies in natural wetlands could provide a more useful tool for assessing ecological sta-

tus than vegetation and stage data alone can provide. The approach requires that flooded-area frequencies be determined in a population of natural wetlands. When assessing the ecological status of impaired wetlands, the historical rainfall, stage data, and vegetation surveys needed to make comparisons with present-day wetland conditions are often not available. Comparing and contrasting flooded-area frequencies and vegetation in natural and impaired or augmented wetlands that have similar geologic and climatic settings provides a useful method to quantify the impacts of climate or human activities on hydrology and ecology. Such comparisons can be used to interpret the degree of wetland mitigation achieved using augmentation, and to objectively assess the extent of change in wetlands impacted by human activities.

## Pulley Ridge—The U.S.'s Deepest Coral Reef?

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Pulley Ridge is a 100+ km-long series of N-S trending, drowned, barrier islands on the southwest Florida Shelf approximately 250 km west of Cape Sable, Florida (Fig. 1). The ridge has been mapped using multibeam bathymetry, submarines and remotely operated vehicles, and a variety of geophysical tools. The ridge is a subtle feature about 5 km across with less than 10 m of relief. The shallowest parts of the ridge are about 60 m deep. Surprisingly at this depth, the southern portion of the ridge hosts an unusual variety of zooxanthellate scleractinian corals, green, red and brown macro algae, and typically shallow-water tropical fishes.

The corals *Agaricia* sp. and *Leptoceris cucullata* are most abundant, and are deeply pigmented in shades of tan-brown and blue-purple, respectively. These corals form plates up to 50 cm in diameter and account for up to 60% live coral cover at some localities. Less common species include *Montastrea cavernosa*, *Madracis formosa*, *M. decactis*, *Porities divaricata*, and *Oculina tellena*. Sponges, calcareous and fleshy algae, octocorals, and sediment occupy surfaces between the corals. Coralline algae appear to be producing as much or more sediment than corals, and coralline algal nodule and cobble zones surround much of the ridge in deeper water (greater than 80 m).

In addition to coralline algae other abundant macro algae include *Halimeda tuna*, *Lobophora variegata*, *Ventricaria ventricosa*, *Verdigelas peltata*, *Dictyota* sp., *Kallymenia* sp., and particularly striking fields of *Andaymonene menzeii*. The latter algae covers many hectares at densities of tens of individuals per square meter, constructing regions that appear like lettuce fields growing in the dusk at this depth on the sea floor.

The fishes of Pulley ridge comprise a mixture of shallow water and deep species sharing this unusual habitat. More than 60 species have been identified. Commercial species include *Epinephelus morio* (red grouper) and *Mycteroperca phenax* (scamp). Typical shallow-water tropical species include *Thalassoma bifasciatum* (bluehead), *Stegastes partitus* (bicolor damselfish), *Cephalopholis fulva* (coney), *Lachnolaimus maximus* (hogfish), *Pomacanthus paru* (French angelfish), and *Holocanthus tricolor* (rock beauty). The deepwater fauna is represented by *Chaetodon aya* (bank butterflyfish), *Sargocentron bullisi* (deepwater squirrelfish), *Bodianus pulchellus* (spotfin hogfish), *Pronotogrammus martinicensis* (rougtongue bass), and *Liopropoma eukrines* (wrasse bass). *Malacanthus plumieri* (sand tilefish) and several other species construct large burrows and mounds that serve as refuge for multiple species. Mounds and pits larger than 1m<sup>2</sup> are apparent on side-scan sonar images and have been counted in excess of 200/km<sup>2</sup> for parts of the ridge.

The extent of algal cover and abundance of herbivores suggest benthic productivity is moderate to high on parts of the ridge. Such productivity is unusual, if not unique at this depth in the Gulf of Mexico

and Caribbean. Several factors help to account for the existence of this community. First, the underlying drowned barrier islands provided both elevated topography and lithified substrate for the hard bottom community that now occupies the southern ridge. Second, the region is dominated by the western edge of the Loop Current that brings relatively clear and warm water to the southern ridge. Third, the ridge is within the thermocline, a water mass that is known to provide nutrients during upwelling to shallow reefs in Florida.

Notwithstanding the positive factors for reef growth listed above, this largely photosynthetic community appears to be thriving on 1-2% (5-30 microEinsteins/m<sup>2</sup>/sec) of the available surface light (PAR) and about 5% of the light typically available to shallow-water reefs (500 – 1000 microEinsteins/m<sup>2</sup>/sec). The corals generally appear to be healthy, with no obvious evidence of coral bleaching or disease. Although the community is clearly one adapted to low light conditions, the variety and extent of photosynthetic organisms between 60 and 70 meters depth is impressive.

Is southern Pulley Ridge the US's deepest coral reef? That depends, of course, on one's preferred definition of a coral reef. There are deeper, ahermatypic coral buildups both in the Gulf of Mexico and Atlantic off Florida coasts. Classically, a coral reef is a wave resistant structure built by hermatypic corals and hazardous to shipping. From a geologist's point of view, Pulley Ridge corals appear to have built a biostrome, an accumulation at least a few meters thick, although they may not account for the bulk of the topography. From that of a biologist, the most abundant corals in the ridge are hermatypic corals but they are lying, mostly unattached, on the surface. Clearly a ship's captain could not run his vessel aground on this reef, so mariners would not consider this a reef. Nevertheless, from the scientific perspective of a structure built from hermatypic corals, southern Pulley Ridge may well be the deepest coral reef in the United States.

# The South Florida Information Access (SOFIA) System

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The South Florida Information Access (SOFIA) system was created by the U.S. Geological Survey (USGS) in 1995. Its mission is to provide easy access to information about research projects and products generated as part of the USGS South Florida Priority Ecosystem Studies (PES) Program and other Federal, state, and local science providers. SOFIA provides this service by integrating information systems and tools enabling efficient storage, organization, and search and retrieval of scientific information about the south Florida ecosystem. SOFIA was designed to benefit three major user groups: USGS program managers and scientists working with the South Florida PES Program, managers and scientists working for other organizations involved with Everglades restoration, and members of the public interested in USGS research and/or the science behind the Everglades restoration effort.

SOFIA is an evolving and dynamic system that builds on the ever-increasing sophistication of new information technology. The current architecture consists of three integrated components: website, data, and metadata. The SOFIA website (<http://sofia.usgs.gov/>) contains links to project descriptions, proposals, publications, data (through links to our data exchange site), metadata, presentations, and contact information, as well as general interest items, such as photographs and posters. The SOFIA site also is a portal through which you can access our extensive database and internet map server (IMS).

Data is served by three mechanisms on the SOFIA website. The Data Exchange (<http://sofia.usgs.gov/exchange/>) provides access to files organized by project. The projects are further organized using six primary themes: biology, chemistry, ecology, geology, hydrology, and mapping. The second mechanism of serving data is through a web interface (<http://www.envirobase.usgs.gov>) to an SQL-based database. The third mechanism of serving data is through a web-based map server. The map server, which is being developed using ArcIMS software, will provide a means of accessing information stored in the SOFIA database and the SOFIA data exchange website through a geospatial query. The map server will provide access to related information stored on the SOFIA website and in the SOFIA database.

Large amounts of data have been collected by USGS personnel in south Florida. With good, FGDC-compliant metadata the data are available to a much wider set of customers through web-based queries. The SOFIA web site has all the available metadata accessible by several methods. There is a navigation button for Metadata and each project home page has a listing for its associated metadata for the project and for the data. All of the projects funded in FY 2003 and FY 2004 have current metadata. Work is continuing on updating the metadata for completed projects and for remaining data sets that do not have metadata yet.



# Geologic Evolution of South Florida Pleistocene-Age Deposits with an Interpretation of the Enigmatic Rock Ridge Development

Todd Donald Hickey

This study addresses two related research problems involving Pleistocene sediment accumulation on the south Florida inner-platform.

- Underlying lithologies of elevated ridges were studied to understand possible development and control.
- Pleistocene sea level cyclicity was evaluated through sedimentary facies changes.

## Rock Ridges

Aerial photography and satellite imagery reveal that 20 rock ridges appear in the south-central Everglades with a general northwest-southeast trend. These features typically have lengths of 0.5 - 17 km, widths usually 100 m or less, and topographic relief generally 0.5 - 1.5 m. The rock reefs of Everglades National Park and south Florida retard southward flow of surface water and support a change in vegetation along the axis of each ridge.

Rotary core drilling, ground penetrating radar, and rock hardness analyses were conducted along specific transects to acquire rock-core samples and subsurface structural information and relative hardness. Core analyses identified sequences defined by subaerial exposure surfaces bounding alternating freshwater, brackish, and/or marine limestones. Ground penetrating radar profiles determined that sequences were not offset by faulting parallel to the trend of the rock reefs.

Rock ridge surface and subsurface results discount depositional models and demonstrate that pre-Pleistocene sediment compaction is responsible for the evolution of the topographically higher features. Limestone accumulation throughout the Pleistocene compacted underlying uncemented sand and mudstone causing the Pleistocene limestone to settle and fracture. Through preferential cementation, the limestone along the fracture zone became more resistant to dissolution. The surrounding less well cemented limestone eroded over time causing the topographic ridges to remain higher.

## Pleistocene Stratigraphy

Marine limestone accumulation on the south Florida inner-platform reflects the peaks of sea level highstands. Core data revealed that five sequences are present. Lithologic subdivisions of the sequences suggest that ten sea level flooding events occurred within the Pleistocene. These higher-frequency cycles within the "Q-units" were correlated with marine isotope stages and/or substages. Previous interpretations have placed the oldest Pleistocene accumulations coincident with marine isotope stage 11. Forward modeling in this study pushes the correlation back as far as marine isotope stage 37.

# Digitally Enhanced Water-Resources Data for Southwest Florida

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The U.S. Geological Survey (USGS), Florida Integrated Science Center (FISC), Coastal and Watershed Studies (CCWS), Tampa Office in cooperation with Federal, State, and local partners, has historically published water-resources data on an annual basis in either a large volume book format report or electronically in a printable document format (PDF) file. The annual publication contains surface-water, ground-water, and quality-of-water data. In 2003, the Annual Data Report was released as a digitally enhanced compact disk (CD) similar in format to one produced by the USGS, Georgia Science Center. The “enhanced” format has an easy to use GIS interface based on ArcView software, which allows the data to be analyzed spatially. In addition, more information can be included on a CD than in the traditionally included in the book format; including period of record daily values, statistics, gage photographs, hydrographs, and a PDF version of the Annual Data Report. The enhanced CD also can be downloaded to a desktop or portable laptop computer, and can be easily adapted for integrated science presentations. The CD contains internet links that direct users to specific web sites for additional information. The 2003 Annual Data Report CD includes both Volumes 3A (surface-water data) and 3B (ground-water data), which were formerly published in two large volumes.

# Streamflow Losses through Karst Features in the Upper Peace River Hydrologic Area, Polk County, Florida

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In October 2001, the U.S. Geological Survey in cooperation with the Southwest Florida Water Management District began a study to evaluate streamflow losses in the Upper Peace River Hydrologic Area. Historically, the Upper Peace River was a gaining stream---ground-water levels were above surface-water levels, wells and second-order magnitude springs flowed, and tributaries drained the surrounding highlands (scarps). However, strip-mining of phosphate ore (1) altered the landscape, (2) changed the natural surface-water drainage patterns, and (3) changed the ground-water flow patterns by removing the upper 50 feet of sediments and lowering the potentiometric surface of the aquifers. Today (2005), this area of the Peace River is a losing stream. Streamflow losses are predominately through karst features found in the low-water channel and flood plain. The features range in size from isolated, small pipes and fractures to numerous, large interconnected horizontal and vertical fractures, large enough for an adult to enter.

Streamflow losses through karst features were measured at selected sites in May-June 2002 and May 2004. Portions of the Peace River ceased flowing during these low-flow periods, and intermittent flow was observed with the commencement of summer rain. During the period of intermittent flow, the river was drained by way of karst features downstream from the Peace River at Bartow gage. Streamflow losses to karst features ranging from 9 to 16 cubic feet per second were measured between the Peace River at Bartow and Peace River at Clear Springs gaging stations. South of the Clear Springs gaging station, the Peace River received surface-water inflow from mine outfalls (6 to 14 cubic feet per second) and tributaries (3 to 18 cubic feet per second). Locations of streamflow losses and gains were spatially consistent among the three seepage runs.

The potential for the exchange of water between the river and the ground-water system was evaluated for the period November 2002 through October 2004 using a single existing pair of wells located in close proximity to the river. Preliminary analysis indicates that the river stage is higher than the aquifer heads, indicating the potential for the river to be a losing stream. The head difference varies seasonally and is smaller during the wet season and larger during the dry season. This seasonal fluctuation is reflected in variations in the measured losses and gains.

To enhance our understanding of the distribution, timing, and volume of surface-water exchange with ground-water throughout the study area, three new well clusters located on the Peace River flood plain are being drilled. The hydrogeologic framework and permeability distribution is being evaluated from geologic core analysis, geophysical logging, and aquifer testing. The potential for the exchange of water between the river and the ground-water system will be evaluated from continuous measurements of river stage and aquifer heads at the new well sites.

# Water Quality in Arthur R. Marshall Loxahatchee National Wildlife Refuge—Trends and Spatial Characteristics of Selected Constituents

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Water has historically entered Florida's Arthur R. Marshall Loxahatchee National Wildlife Refuge from rainfall and from two large pumping stations, S-5A and S-6. Water from the two pumping stations drains agricultural lands and often has relatively high concentrations of dissolved solids, nutrients, and pesticides. Water from the pump stations flows into perimeter canals and marshes of the Refuge. Water quality in the Refuge is affected by water from the nearby canals and by natural seasonal processes. The influences of canal waters extend up to 5 km or more into the marshes, depending on location in the Refuge and on water levels in the canals. The greatest influence from the canals occurs in the west and southwest parts of the Refuge, where conservative constituents such as specific conductance, chloride, and sulfate are elevated compared with background levels of the interior marshes. Nutrient concentrations are an order of magnitude higher in canal waters than in marsh waters, but, unlike conservative ions, the high concentrations are much more restricted to the marshes near the canals. Water quality of the interior marshes is affected primarily by seasonal processes such as evapotranspiration, rainfall, and biological activity.

Our analysis of water-quality data focused on a comprehensive review of all water-quality data collected in Loxahatchee National Wildlife Refuge. Data were primarily from the South Florida Water Management District (SFWMD) DBHYDRO database. Other sources of water-quality data, such as early data from the USGS, were reviewed and integrated into the analysis. Data related to water quality, such as water levels and flow, also were compiled.

We used the uncensored seasonal Kendall test and Tobit regression procedures, provided with the S-ESTREND program, to analyze historical water-quality data for trends. A 95-percent confidence level ( $p = 0.05$ ) was used for all of the statistical tests. Generally, the interior marsh sites had few significant long-term trends, because of their isolation from agricultural and urban impacts. The interior site, LOX8, had a significant upward trend for 1978-2003 for specific conductance and for total phosphorus for 1993-2003; however, the phosphorus trend was done using Tobit regression that is not stage adjusted and could give trends caused by long-term wet and dry periods. Major canal inflow sites such as S-5A and S-6 had several significant long-term trends. S-5A, for example, had a significant downward trend in specific conductance, chloride, and total nitrogen for 1974-2003. Total phosphorus and sulfate showed no significant trend for this period. For the same period, S-6 had a significant downward trend for specific conductance, chloride, total phosphorus, and total nitrogen. Sulfate had no trend. Trend analysis for all five parameters were done using uncensored seasonal Kendall tests and were stage adjusted.

Concentrations of pesticides and other organic compounds in waters and sediments have been measured at inflow pumping stations more frequently and over a longer time span than at Refuge marsh sites. Pesticides in water have been measured at pump stations S5A and S-6 from the early 1980's. Most determinations are reported as less than values (nondetects). At S-5A, the most commonly detected pesticides in water were atrazine, total ametryn, metachlor, and simazine. Atrazine (unfiltered) was detected in 57 out of 75 samples (1987-2002), with a maximum concentration of 12.3  $\mu\text{g/L}$ . At S-6, the most commonly detected pesticides were atrazine, total ametryn, and dieldrin. Atrazine (filtered) was detected in 83 out of 84 samples between 1996 and 2004, with a maximum concentration of 7.8  $\mu\text{g/L}$ . Only a few water samples for pesticide analysis have been collected from the Refuge marshes, and none contained detectable

concentrations. Bed sediment samples for pesticide analyses were collected annually at S-6 and S-5A, beginning as early as 1976 at S-6, and at two marsh sites, LOX8 and LOX16. Samples were analyzed for many pesticide compounds; but most did not contain measurable amounts of pesticides.

A number of detections were reported, especially for p,p' -DDD, p,p' -DDE, p,p' -DDT, and ametryn. The highest concentrations of DDT compounds were at the pumping stations (the maximum concentration was 300 µg/kg for p,p' -DDE at S-5A; most pesticide concentrations were less than 100 µg/kg)

Proposed increases in canal inflow to the Refuge associated with Everglades Restoration could adversely affect water quality over greater expanses of marsh. Even inflow of water with relatively low nutrient concentrations could adversely affect water quality of interior marshes if this additional water has high concentrations of pesticides and common ions such as chloride or sulfate that are not easily removed in Stormwater Treatment Areas. Increased sulfate concentrations could result in higher concentrations of methylmercury.

# Characterization of the Hydrology, Water Quality, and Aquatic Communities of Selected Springs in the St. Johns River Water Management District, Florida

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As the population of Florida grows, the demand for water for public supply and other uses continues to increase. Ground water traditionally has been the main source of water supply. Projections by water managers of the St. Johns River Water Management District (SJRWMD) and ground-water flow models developed by the SJRWMD and the U.S. Geological Survey (USGS) indicate that increased pumping of ground water is likely to result in decreased discharge from most of Florida's many springs. Recent droughts have exacerbated the situation and will continue to do so in the future; in 2000, many springs had record record-low discharge. Springs support fragile aquatic ecosystems that are vulnerable to hydrologic change. Some spring ecosystems have been studied at various levels of detail. Many others remain unstudied, yet water managers are required by State law to set minimum flows and levels (MFLs) for all first, second and third magnitude springs. A better understanding of the hydrologic and ecologic conditions of springs is needed — but springs can differ greatly in such attributes as channel length and area of adjacent wetlands, effects of backwater from other streams, water chemistry, and land use in the springshed, so monitoring a standard set of criteria is not feasible. As a result, this study was initiated to (1) create a baseline snapshot of the aquatic ecosystems of selected springs in the SJRWMD, (2) establish a list of key measurable indicators of ecosystem health for possible use in determining MFLs for each spring studied, and (3) investigate possible correlations between composition/abundance of the aquatic communities and associated water chemistry.

Four springs were selected by the SJRWMD during 2004, based on the need for data to establish appropriate MFLs: the Silver Springs group (average discharge 798 cubic feet per second, ft<sup>3</sup>/s), DeLeon Spring (formerly Ponce de Leon; 30 ft<sup>3</sup>/s), Gemini Springs (7 ft<sup>3</sup>/s), and Green Spring (1 ft<sup>3</sup>/s). Water-chemistry sampling at each spring was tailored to supplement sampling by the SJRWMD and the Florida Department of Environmental Protection (FDEP). Each spring was sampled three times for major constituents, nutrients, color, turbidity, biochemical oxygen demand BOD, total organic carbon TOC, and chlorophyll-*a* and -*b* and twice for pesticides, wastewater constituents, dissolved gases, sulfur hexafluoride, and the nitrogen and oxygen isotopes of nitrate. Samples from the spring runs also were collected and analyzed for major ions, nutrients, color, turbidity, BOD, TOC and chlorophyll-*a* and -*b*. Benthic invertebrate samples were collected during three sampling events using FDEP protocols; vegetation and fish population surveys, and passive sampling of benthic algae were done once.

Nitrate concentrations ranged from about 1 milligram per liter (mg/L) in each of the Silver Springs group and in both boils of Gemini Springs to about 0.7 mg/L at DeLeon Spring to less than the detection limit of 0.02 mg/L at Green Spring. Delta N-15 values ranged from 5.6 per mil at the Abyss Spring of the Silver Springs group (indicating inorganic nitrogen sources) to 10.6 per mil at De Leon Spring (indicating organic sources). The ratios at the other springs are indicative of mixed sources of nitrogen. No analyses could be made for Green Spring because nitrate concentrations were below detection limits. The phosphate concentration of spring water was about 0.03 mg/L in the Silver Springs group, about 0.05 mg/L at DeLeon Spring, and about 0.07 mg/L in Green Spring and Gemini Springs.

Results of sampling for a group of 54 pesticide compounds indicated that atrazine and 2-chloro-4-isopropylamino-6-amino-s-triazine (CIAT) were present in water from Silver Springs and Gemini Springs

during both sampling events. No pesticides were detected in Green or DeLeon Springs. Water samples also were analyzed for 63 organic compounds commonly found in wastewater. During the first sampling of Silver Springs, phenol was found in a low but quantifiable concentration. Also detected, but at levels too low to quantify, were tetrachloroethene, benzophenone, N,N-diethyl-*meta*-toluamide (DEET), camphor, indole, and p-Cresol. During the second sampling at Silver Springs, bisphenol-a, tetrachloroethene, DEET, para-Cresol, and diethoxyoctylphenol, a known endocrine disruptor, were detected. At DeLeon Spring, the first sampling resulted in detection of 3-methyl-1(H)-indole (skatol), indole, and para-Cresol. During the second sampling, ethoxyoctylphenol, a detergent metabolite and endocrine disruptor, was detected. At Green Spring, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, benzophenone, bisphenol-a, methyl salicylate, DEET, para-Cresol, and para-nonylphenol (total) were detected in the first sampling. Phenol and DEET were detected at Green Spring during the second sampling. At Gemini Springs, 2-methyl-naphthalene, naphthalene, benzophenone, methyl salicylate, DEET, and triphenyl phosphate were detected during the first sampling. Phenol and DEET were detected at Gemini Springs during the second sampling.

The fish surveys indicated that Green Spring was depauperate with the exception of a dense population of mosquitofish and possibly other poeciliids. At DeLeon Spring, multiple individuals of a nonindigenous armored catfish (Callichthyidae, *Hoplosternum littorale*) not previously reported from this system were observed. Although usually associated with wetlands, this recently introduced species is rapidly colonizing the St. Johns drainage and other areas of the Florida peninsula. In Gemini Springs, large numbers of another non-native catfish (Loricariidae, *Pterygoplichthys disjunctivus*) were observed; this species also has rapidly expanded its range, and is especially prevalent in springs in the St. Johns River. Common carp (*Cyprinus carpio*) were observed in Gemini Spring; this is a species that is not known to be established in the St. Johns drainage. The ecology of these exotics in springs is unknown, but the armored catfish are of particular concern because of possible interactions with native species and alteration of habitats.

Passive periphyton sampling devices were installed at Gemini and DeLeon Springs to better understand the abundance and composition of benthic algae. Grab samples also were collected at the time the samplers were deployed. In DeLeon Spring, the dominant periphyton was *Lyngbya wollei*, a nitrogen-fixing Cyanobacterium that can produce saxitoxins. At Gemini Springs, the dominant periphyton was *Rhizoclonium* sp., a green alga with no known toxin-producing capabilities. The samplers showed evidence of substantial growth of algal mats which may have affected the experiment by preventing phytoplankton from becoming attached to the filters on the sampling devices.

Results of sampling for benthic invertebrates indicated that the overall diversity and abundance appeared to be moderately high (compared with unperturbed oligotrophic springs) and, combined with sample composition, may provide some insight into relative eutrophication (especially at Gemini Springs). At Gemini Springs, one troglomorphic amphipod was collected, probably *Crangonyx hobbsi* (a cave species primarily distributed through the Florida panhandle, Suwannee drainage, and Biscayne aquifer, but with few records from the St. Johns drainage). At Gemini Springs, a gerreid (water strider), *Halobates* sp., was collected; this species is found primarily in marine habitats. At DeLeon Spring, a single specimen of a dragonfly (Libellulidae, *Erythemis plebeja*, pin-tailed pondhawk), considered rare by FDEP, was collected.; this species has not previously been reported from Volusia County. Most samples were dominated by amphipods (*Hyalella azteca* and *Gammarus fasciatus*) that appeared to fluctuated seasonally in relative abundance.

# Marine Groundwater Studies in Biscayne National Park, South Florida

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Submarine groundwater discharge (SGD) is spatially and temporally variable along a coastal margin where the influence of marine tides and onshore hydraulic gradients converge. There are numerous methods of monitoring and quantifying groundwater dynamics along a coastal margin. Three methods have been used to define the system in Biscayne National Park. Biscayne National Park (BNP), located south of Miami, Florida, encompasses 172,000 acres of which more than 95% is located in a marine environment containing mangrove, seagrass, and coral reef ecosystems. That waters in BNP consist of both marine and estuarine systems has made the use of Radon ( $^{222}\text{Rn}$ ), seepage meters, and ground- and surface-water sampling key components in the study of groundwater/surface-water exchange.

The most common method used in delineating SGD is the placement of seepage meters at various locations along the coast. The USGS has acquired two electromagnetic seepage meters (ESM) that can be programmed to operate autonomously, have high sampling rates (1 per min), and can measure relatively low flows ( $<0.2$  L/min). The instruments have been used in various environments ranging from estuaries in Tampa Bay and Biscayne Bay to salt ponds on Rhode Island and in the Florida Everglades. Groundwater discharge measured in Biscayne Bay at Cutler Ridge was on the order of 10 to 45 cm/d (mean=25.2 cm/d). These discharge values resemble values calculated from a groundwater/surface-water model for the same site. This technique, however, gives only point data, and results can be influenced by various forcing factors (e.g., wave action, tidal pumping, local hydraulic gradient). A second method, which shows promise, is the utilization of an instrument (RAD7) that continuously monitors  $^{222}\text{Rn}$  (half life=3.8 days) in the water column. Whereas seepage meters only provide point data, continuous mapping of  $^{222}\text{Rn}$  can be conducted from a boat running track lines normal or parallel to shore. In BNP, six RAD7s connected in series allowed for close discretization of samples (i.e., 5-min averages). Inference to ground water seeping into overlying waters can be made when  $^{222}\text{Rn}$  is high in surface water. This assumption can be made because  $^{222}\text{Rn}$ , an inert gas, is continuously produced in the subsurface. Concentrations of  $^{222}\text{Rn}$  can be 10 times greater in the limestone aquifer underlying the bay. Average  $^{222}\text{Rn}$  values in BNP surface and ground water were 3 dpm/L and 256 dpm/L, respectively.

Monitoring wells have also been employed in offshore coastal settings to identify both chemical constituents (nutrients, trace metals, organics, etc.) and pressure gradients that may prove to be useful in understanding offshore hydraulic gradients. Monitoring wells installed below the surface of Biscayne Bay and on the reef tract of BNP have been sampled five times during a period from August 2002 to March 2004. Data from these wells show that marine salinities are common in the mid-bay and offshore reef wells, but fluctuate somewhat along Elliott Key (east side of Biscayne Bay) and along the mainland (west side of Biscayne Bay). The nutrients analyzed in this study are ammonium, nitrates, nitrites, soluble reactive phosphorus, and soluble silicates. Ammonium, soluble reactive phosphorus and soluble silicates concentrations are elevated in ground water relative to surface water. However, based on other groundwater studies, these three nutrients are also elevated in nearby systems such as Florida Bay and the Florida Keys.



# Hydrology and Quality of Water in Polk County, Florida

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Local water managers usually rely on information produced at the State and regional scale to make water-resource management decisions. Current assessments of hydrologic and water-quality conditions in Polk County commonly end at the boundaries of three water management districts (St. Johns, South Florida, and Southwest Florida Water Management Districts), which make it difficult for local managers to determine conditions throughout the County. The last comprehensive water-resources assessment of Polk County was published almost 40 years ago. To address the need for current county-wide information, the U.S. Geological Survey began a 4-year study in 2002 to evaluate the current hydrologic and water-quality conditions in Polk County and identify changes that have occurred.

The study area, a 1,823-square-mile area of central Florida, is underlain by three principal hydrogeologic units. The uppermost water-bearing unit of the study area is the surficial aquifer system, which is unconfined and composed primarily of clastic deposits. The surficial aquifer system is underlain by the intermediate confining unit or by the intermediate aquifer system, which consists of up to two water-bearing units composed of interbedded clastic and carbonate rocks. The lowermost hydrogeologic unit is the Floridan aquifer system. The Floridan aquifer system, a sequence of permeable limestone and dolostone, consists of the Upper Floridan aquifer, a middle semiconfining unit, a middle confining unit, and the Lower Floridan aquifer. The Upper Floridan aquifer provides most of the water required to meet current (2005) demand in Polk County.

Data from about 350 geophysical and geologist's logs were used to construct detailed hydrogeologic maps showing the tops and thicknesses of the aquifers and confining units within Polk County. Thickness of the surficial aquifer system ranges from less than 25 feet in parts of western Polk County to more than 200 feet along the southern part of the Lake Wales Ridge in eastern Polk County. Thickness of the intermediate aquifer system/intermediate confining unit is highly variable throughout the study area because of past erosional processes and sinkhole formation. Thickness of the unit ranges from less than 25 feet in the extreme northwestern part of the County to more than 300 feet in southwestern Polk County. The altitude of the top of the Upper Floridan aquifer ranges from about 50 feet above National Geodetic Vertical Datum of 1929 (NGVD29) in the northwestern part of the County to more than 250 below NGVD29 in the southern part.

The Upper Floridan aquifer is the primary source of water supply in the study area. In 2000, withdrawals totaled about 331 million gallons per day in Polk County. Of the total ground water used in 2000, 48 percent was for agricultural irrigation, 23 percent for public supply, 21 percent for commercial/industrial self-supplied, 4 percent for domestic self-supplied, 3 percent for recreational, and 1 percent for thermoelectric power generation.

The potentiometric surface of the Floridan aquifer system is constantly fluctuating, mainly in response to seasonal variations in rainfall and ground-water withdrawals. In September 2003, the altitude of the potentiometric surface of the Upper Floridan aquifer ranged from about 46 to 130 feet above NGVD29. Potentiometric surface altitudes in May 2004 were about 1 to 17 feet lower than those measured in September 2003. Water levels in the Upper Floridan aquifer have risen in some wells in Polk County since 1975. The rise in water levels is associated with the decrease in pumpage related mostly to phosphate mining; however, some wells in the northern part of the County have shown small declines in water levels. The decline in water levels is probably related to increases in water use associated with public supply or agricultural irrigation.

Ground-water quality was assessed by compiling data collected by State and Federal agencies. Also, monitoring wells were installed at key locations in the County where data had not been collected. Inorganic constituents were the focus of water-quality analysis. Concentrations of total dissolved solids, sulfate, and chloride in water samples from the surficial and intermediate aquifer systems generally were below State and Federal drinking water standards. Nitrate concentrations, however, were elevated (as high as 26 milligrams per liter (mg/L)) in the surficial aquifer system along the Lake Wales Ridge. The application of fertilizers related to citrus farming is a likely source of nitrate to the ground water in this area.

Constituent concentrations in water from the Floridan aquifer system generally were below State and Federal drinking water standards. Water from the Upper Floridan aquifer in most of the County is hard and has a dissolved-solids concentration of less than 500 mg/L. Chloride concentrations in water from the Upper Floridan aquifer range from 4.2 to 61 mg/L, and sulfate concentrations range from about 0.2 to 44 mg/L. In contrast to results from the surficial aquifer system, nitrate concentrations in the Upper Floridan aquifer generally were low and exceeded 1.0 mg/L in only three wells. Lower nitrate concentrations in the Upper Floridan aquifer indicate that denitrification may be occurring in the ground water.

Polk County contains the headwaters of the Peace River, which is a major source of fresh water to Charlotte Harbor and a source of drinking water to people in Charlotte, DeSoto, and Sarasota Counties. Human activities, especially phosphate mining, have resulted in decreased streamflows in the headwaters of the Peace River. Mean annual streamflows in the Peace River at Bartow have decreased substantially over the last 60 years from about 200 cubic feet per second (ft<sup>3</sup>/s) in 1940 to about 75 ft<sup>3</sup>/s in 2000. Decreased streamflows likely are related to lowered ground-water levels in the Upper Floridan aquifer. Historically, the Peace River was a gaining stream that received springflow from the Upper Floridan aquifer along its entire length. Pumpage from the Upper Floridan aquifer in the County has lowered ground water-levels; a major spring (Kissengen Spring) no longer contributes flow to the Peace River. Reduced water use has resulted in stabilized streamflows in the Peace River at Bartow over the last 20 years; however, streamflows have not returned to 1940s conditions.

There are about 900 lakes or open-water features in Polk County greater than 10 acres. Ground-water inflow is important to sustain lake levels, particularly on the ridge areas. Many of these lakes naturally have no surface-water inlet or outlet and rely on the ground-water system to transport inflow and outflow to the lakes. Ground-water inflow to the lakes on the ridges varies substantially, ranging from 4 to 285 inches per year (1999-2000) or 7 to 83 percent of the total inflows. From 1960 to 2003, lake levels declined in 5 of the 14 lakes in the County in which sufficient data are available for trend analysis. Lowered lake levels also have been attributed to lowered ground-water levels in the Upper Floridan aquifer.

# Forecasting Coastal Vulnerability to Hurricanes: Application to the 2004 Hurricane Season

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The number and intensity of hurricanes are predicted to increase over the next decade. Evidence of this is the 2004 hurricane season wherein four major hurricanes impacted the State of Florida within a six-week period, causing significant destruction to beaches and coastal property. The coast's vulnerability and spatially variable response to hurricanes may be predicted by examining the relationship between spatial variations in coastal topography and hurricane-driven fluid forcings. The relative elevations of foreshore dunes and extreme wave runup are compared using Sallenger's storm impact scaling model (2000) in a forecasting mode to determine the likelihood of the occurrence of dune erosion and overwash for hurricane conditions. Data collected after hurricanes Charley, Frances, Ivan, and Jeanne are used to help test and further develop the hurricane vulnerability-assessment model.

Hurricane Charley, a Category 4 storm, came ashore August 13, 2004, as a significant wind event with limited storm surge. This narrow storm moved quickly onshore, carving a 450-m-wide breach across Captiva Island. Hurricanes Frances and Jeanne made landfall near Vero Beach, FL, within three weeks of each other during September 2004. Frances, a Category 2 storm, did not cause as severe impacts as have been observed during other recent Category 2 landfalls. However, it eroded much of the protective beach and fore-dunes along Florida's central east coast, leaving coastal structures more vulnerable to the arrival of Category 3 Jeanne. In this area, the impact of successive hurricanes and the timing of storm events can be examined. Hurricane Ivan, a Category 3 storm that made landfall on September 16, 2004, was a major surge event that caused significant dune erosion and overwash along the panhandle of Florida. Offshore wave heights of 14 m and a broad, strong wind field created significantly elevated water levels along 100 km of coastline.

Dense measures of dune height and beach slope along the Florida coast were extracted from lidar-based surveys of beach topography collected prior to hurricane season. Estimated extreme water levels associated with each category hurricane were calculated as the combined effects of wave runup, storm surge, and tide using a field-data-based empirical parameterization. Areas where predicted water-level elevation exceeds the dune elevation are expected to overwash during the hurricane; other areas are expected to experience dune erosion. Detailed comparisons of lidar surveys of beach topography collected before and after hurricane landfall were used to test the performance of the vulnerability model as well as to measure the nature, magnitude, and variability of coastal change in response to the hurricanes.

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# Effect of El Niño Southern Oscillation Weather Patterns on Central Florida Lake Water Budgets—Lessons from Lake Starr

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El Niño Southern Oscillation (ENSO) events between 1997 and 2003 had substantial effects on lake hydrology in central Florida. The first event (1997-1998) was one of the strongest occurrences of the warm condition of ENSO this century (Australian Government Bureau of Meteorology, 2005). In central Florida, this event came after a series of wetter than normal years, generating record high stages for many lakes and streams and causing widespread flooding. Lake Starr on the Lake Wales Ridge in Polk County reached the highest stage of the past 35 years in 1998 (Swancar and others, 2000). The 2002-2003 warm event was not as intense and generally produced less rainfall, but it provided much-needed relief from the residual effects of the drought of 1999-2001. Many rivers in the area set new record low levels during this drought (Stoker and others, 2002), which was associated with a La Niña (cold) ENSO event.

ENSO warm events (El Niños) originating in the Pacific Ocean generate higher than average winter rainfall in Florida and other states surrounding the Gulf of Mexico. During warm events, the jet stream tends to stay farther south during the winter months, driving more storm systems across central Florida (Kahya and Dracup, 1993). The additional rain occurs during the typically dry winter at a time when evaporation is low, leading to greater net precipitation and ground-water recharge. Greater net precipitation from both warm events produced greater recharge to the ground-water system. Many lakes and rivers in Central Florida are well connected to the ground-water system because the geology consists of cavernous limestone that is thinly covered by clays and sand in a karst setting characterized by sinkholes and springs. Most central Florida lakes are similar to Lake Starr; they are seepage lakes with no surface water inflows or outflows, and rely on ground-water inflow to maintain their stages. Net ground-water exchange with Lake Starr was calculated as the residual of a water budget where rainfall, evaporation, and change in stage were measured from 1996-2004.

The Southern Oscillation Index (SOI) is a monthly normalized value that reflects the magnitude of the ENSO phenomenon (National Weather Service Climate Prediction Center, 2005). The value of the SOI is more negative during warm events (El Niños) and more positive during cold ones (La Ninas). Net ground-water flow to Lake Starr is greater during periods when the Southern Oscillation Index (SOI) is more negative, and less when the index is positive (fig. 1). Changes in the direction of the SOI from negative to positive correspond to declines in net ground-water flow to the lake (fig. 2). While the trend in net ground-water flow is related to changes in the SOI, the magnitude is not well-predicted based on the SOI. The best linear regression model ( $r^2=0.45$ ) to predict net ground-water flow to the lake was based on a 6-month running average of each of the variables, with the net ground-water value lagged 3 months (fig. 3). The lag in ground-water exchange with the lake is due to the time it takes for rainfall to reach the ground-water system, which is up to 3 months at this site where depths to water can be as high as 40 m, as well as the time for water to move through the surficial sands to the lake.

The ability to predict the onsets of droughts or wetter than normal periods and their effects on lakes and rivers based on a global index is useful for residents, scientists, engineers, and water managers. Some of the variability in net ground-water flow to the lake that cannot be explained by the SOI is probably attributable to individual extreme rain events that affected ground-water inflow to Lake Starr disproportionately. Figure 3 supports this statement; variability is greater when SOI is negative. Isolated heavy rainfall events are common in Central Florida; days with rainfall between 50 and 100 mm occurred 23 times at Lake Starr between 1996 and 2004.

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# Hydrologic Effects of the 2004 Hurricane Season in Northwest Florida

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During August and September 2004, northwest Florida experienced impacts from five tropical storm systems: Tropical Storm Bonnie, and Hurricanes Charley, Frances, Ivan and Jeanne. Hurricanes Frances and Jeanne had a significant impact on the Suwannee and Waccasassa River Basins with heavy rainfall, storm surge, and flooding. Hurricane Ivan primarily affected the Perdido, Escambia, and Yellow River Basins in the western-most panhandle with high winds and the associated storm surge. Tropical Storm Bonnie produced abundant rainfall across the Suwannee Basin. Hurricane Charley's landfall in south Florida and its northeastern storm track across central Florida did not noticeably affect northwest Florida.

Significant rainfall from some of the storms resulted in high water on many rivers and streams in northwest Florida. Hurricane Frances produced an average of 8.80 inches of rain over the Suwannee River Basin, but 18 inches of rain was reported at some locations. Hurricane Jeanne produced about 6 inches, again primarily in the Suwannee and Waccasassa River Basins. Hurricane Ivan produced 3-11 inches in the Chipola, Choctawhatchee, Shoal, Blackwater, Perdido, Escambia, and Yellow River Basins in the western panhandle. Tropical Storm Bonnie produced an average of about 2-3 inches in the Suwannee River Basin. Rainfall from Hurricane Charley was negligible in northwest Florida.

Hydrographs of data collected at several stream gages in the Big Bend region of Florida documented storm surges. Surge from Hurricane Frances was the greatest, with a 9-foot rise at the Waccasassa River near Gulf Hammock. Hurricane Ivan produced 9 feet of storm surge at Escambia River near Gonzales, and a 6-foot surge upstream near Molino.

Monthly mean flows for September 2004 in northwest Florida ranged from 143 to 458 percent of normal, the highest in the Suwannee River Basin, and the lowest in the Steinhatchee River Basin. Peaks from rainfall associated with Tropical Storm Bonnie, and Hurricanes Frances and Jeanne were observed in the discharge hydrographs for several gages in the Suwannee River Basin. The greatest increase in flow was associated with Hurricane Frances, which produced the most rainfall. Significant overland flooding occurred in the Santa Fe and middle Suwannee River Basins, with a small rise in flow occurring before the larger one observed in the discharge hydrograph at the Suwannee River at Branford gage. At the Waccasassa River near Gulf Hammock gage, peak flow estimated at 8,330 cubic feet per second occurred, the second highest peak for the period of record (1963-present).

# Florida Integrated Science Center Hydrologic Data Program, 2004

Shaun M. Wicklein

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As the primary Federal science agency for water-resource information, the U.S. Geological Survey (USGS) monitors the quantity and quality of water in the Nation's rivers and aquifers, develops tools to improve the application of hydrologic information, and provides the information and tools to the public, cooperating agencies, and other potential users. The Florida Hydrologic Data Program supports the overall mission of the USGS and science priorities of the Florida Integrated Science Center (FISC) by providing the public with impartial, reliable information which is used for many purposes. These purposes include forecasting floods; managing river, groundwater, and reservoir levels; monitoring water-supply and water-quality conditions; and providing a hydrologic database upon which scientific studies can be developed.

A staff of 88 hydrologists, hydrologic technicians, and students work in support of the Florida Hydrologic Data Program at four locations in the State--Miami, Orlando, Tallahassee, and Tampa. Skilled scientific staff collect data using state-of-the-art instrumentation, analyzes and computes hydrologic records, maintains a long-term and consistent database, and provides access to historic and real-time data. Hydrologic Data Program scientists maintain over 2,300 stations that collect surface-water, ground water, water quality, and meteorological data. The data are archived in the National Water Information System (NWIS) database and published annually in the USGS report series entitled "Water Resources Data--Florida." Satellite, telephone, and radio telemetry at over 500 stations provide provisional data in near real-time to meet critical water-management needs.

Florida Hydrologic Data Program priorities are developed to meet Federal, regional, State, and local water-resources needs. Forty cooperative agencies work with the USGS in Florida to provide reliable, impartial, and timely information. Operating funds for individual stations in the Florida Hydrologic Data Program come from a blend of Federal funds appropriated to the USGS and other federal agencies, and from funds from State and local agencies. Greater than 30 percent of the operational funds for the Florida Hydrologic Data Program are provided through the USGS Cooperative Program. For fiscal year 2004, State and local cooperators matched the \$3.7 million appropriated to the USGS and contributed an additional \$4.2 million, for total program funding of \$11.6 million.

# Estimates of Spring Flow in Citrus and Hernando Counties, Florida

Dann Yobbi<sup>1</sup>, and Kevin Hubbs<sup>1</sup>

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The coastal springs in Citrus and Hernando Counties consist of three first order magnitude springs and numerous smaller springs that discharge about 840 million gallons per day from the Upper Floridan aquifer to the Gulf of Mexico. Spring flow is proportional to the water-level altitude in the Upper Floridan aquifer, which in turn is affected primarily by the magnitude and timing of rainfall. Spring flow data are used to provide information about seasonal flow patterns and the spatial distribution of spring flow into the Gulf of Mexico. Continuous spring flow data are required to accurately describe hydrologic trends.

Spring discharge usually cannot be reliably rated by a traditional stage-discharge rating. Instead, the potentiometric level of the Upper Floridan aquifer in wells located near the springs, along with other variables, can be used to estimate instantaneous discharge. Predictive equations to estimate instantaneous spring flow were developed for selected gaging stations at coastal springs in Citrus and Hernando Counties. Regression techniques included ordinary least squares and multiple linear regression techniques. At tidally affected gaging stations, spring flow was inversely related to water-level altitude of the spring pool.

Discharge at selected springs also was estimated based on acoustic velocity measurements downstream of the spring vents. Calibrated equations for index-to-mean velocity relations were developed based on acoustic discharge measurements, acoustic index velocity, and water level.

Acoustic-velocity discharge measurements and well-regression discharge estimates at individual spring sites compared favorably with standard current meter measurements near the spring orifice. Well-regression estimates of discharge compared poorly with other measurements at sites located downstream from the spring, therefore, acoustic velocity sensors are required to accurately estimate spring-flow discharge at the downstream sites.



## **Session 2**

### **Coastal Science**

**Session Leader: Chris Reich**

# Investigating Benthic Habitats in the Florida Reef Tract with Lidar

J.C. Brock<sup>1</sup>, A. Nayegandhi<sup>1</sup>, D. Hickey<sup>1</sup>, L. Mosher<sup>1</sup>, and M. Harris<sup>1</sup>

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The topographic variability of reef substrates and the composite three-dimensional thicket structure of their variable benthic communities are morphologic components of habitat complexity. The NASA Experimental Advanced Airborne Research Lidar (EAARL) is designed to survey these components of habitat complexity simultaneously at high horizontal (< 1 m) and vertical spatial resolution (< 0.2 m). In early August 2002, an intensive USGS - NASA EAARL survey was conducted over a broad swath of the northern Florida reef tract, extending from north of Triumph Reef to south of Carysfort Reef. Algorithms were developed to analyze the one-nanosecond temporal-resolution laser reflections that are provided at rates up to 5000 Hz by the NASA EAARL. Two highly complementary types of information on benthic morphologic complexity were extracted from the EAARL active optical soundings acquired over the northern Florida reef tract: 1) substrate optical rugosity, and 2) the range-amplitude characteristics of the laser bottom reflections. These two measurements are used to quantify the instantaneous vertical thicket structure of the benthic community. Optical rugosity was determined by converting each across-track lidar raster scan into a submarine topographic transect, followed by computing the ratio of surface contour length to direct geometric length along each transect. The time-amplitude reflection history of each laser-pulse bottom reflection was converted to a range-backscatter record and normalized for attenuation using water-column thickness derived from the full laser reflection. Bottom-reflection metrics, including total reflection length, integrated backscatter, and weighted-mean backscatter, were calculated for each optical sounding. The validity of these bottom-reflection metrics as proxies for the thicket density and height of branching or leafy organisms is being evaluated through the detailed *in-situ* measurement of patch-reef communities surveyed by the EAARL.

# Multi-Decadal to Century-Scale Climate Variability in the Gulf of Mexico Region: Links Between Continental and Marine Records

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Better documentation of change in the climate of the southwestern United States (U.S.) during the current interglacial interval is needed to understand the natural variability of the current climate system, identify possible climate forcing, and thus help anticipate future changes. Historical records demonstrate that precipitation in the southwestern U.S. is quite variable. Several decades-long droughts have occurred in the recent past, and severity of fires has been linked to variability in amount and seasonal distribution of precipitation (e.g., Grissino-Mayer and Swetnam, 2000). Terrestrial paleoclimate records from the southwestern U.S. indicate significant climate variability has occurred during the current interglacial interval or Holocene (last 10,000 years) (e.g., Benson et al., 2002), but the pre-instrumental record of the wet southwest monsoon is poorly known (Meko and Baisan, 2001). Studies based on tree rings can provide highly resolved records of past conditions, but separating temperature and precipitation signals can be difficult, and determining seasonality of precipitation is challenging. In addition, tree-ring records usually represent short intervals of the Holocene, and they often reflect local conditions. Studies of pollen in lake sediments, lake shoreline deposits, and vegetation in packrat middens are available, but these records are often discontinuous, many are difficult to date, and they are sometimes contradictory (e.g., see summaries in Betancourt et al., 1993; Metcalfe et al., 2000; and Thompson et al., 1993).

Comparison of abundance variations in the planktic foraminifer *Globigerinoides sacculifer* in marine cores from the western and northern Gulf of Mexico (GOM) with terrestrial proxy records of precipitation (tree-ring width and packrat-midden occurrences) from the southwestern United States indicate that variations in *G. sacculifer* abundance are a proxy for the average position of the Intertropical Convergence Zone (ITCZ) and the intensity of the southwest monsoon on millennial and sub-millennial time scales. Northward migration of the ITCZ results in increased presence of warm tropical waters in the northern and western GOM and a stronger southwest monsoon; southward migration of the ITCZ results in decreased presence of warm tropical waters in the northern and southern GOM and a weaker southwest monsoon.

The marine record confirms the presence of a severe multi-century drought centered at ~1600 calendar years BP, as well as several multi-decadal droughts that have been identified in a long tree-ring record from west-central New Mexico spanning the last 2000 calendar years. The marine record further suggests that monsoon circulation, and thus summer rainfall, was enhanced in the mid-Holocene (~ 6500 to 4500 <sup>14</sup>C yrs BP; ~6980 to 4710 calendar years BP).

Spectral analyses of *G. sacculifer* abundance variations in Gulf of Mexico cores and tree-ring precipitation records from New Mexico reveal periodicities that are similar to the periodicities observed in proxy records of solar luminosity. The GOM and New Mexico proxy records suggest that the average position of the ITCZ and changes in intensity of the southwest monsoon are linked to solar variability.

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# Recent Shoreline Comparisons, Analyses, and Preliminary Products of the National Assessment of Shoreline Change Project

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Beach erosion is a chronic problem along most open-ocean shores of the United States. As coastal populations continue to grow, and community infrastructures are threatened by erosion, there is increased demand for accurate information regarding past and present shoreline changes. There is also need for a comprehensive analysis of shoreline movement that is regionally consistent. To meet these national needs, the Coastal and Marine Geology Program of the U.S. Geological Survey (USGS) is conducting an analysis of historical shoreline changes along open-ocean sandy shores of the conterminous United States and parts of Hawaii. A primary goal of this work is to develop standardized methods for mapping and analyzing shoreline movement so that internally consistent updates can periodically be made to record shoreline erosion and accretion.

This presentation summarizes the USGS shoreline change project and introduces completed map products for the Gulf of Mexico, the first in a series that will eventually include the Atlantic Coast, Pacific Coast, and Hawaii. Shoreline change evaluations are based on a comparison of three historical shorelines (generally from the 1800s, 1920s-1930s, 1970s) with a recent shoreline derived from lidar (light detection and ranging) topographic surveys (1998-2002). Long-term rates of change are calculated using linear regression with all four shorelines, and short-term rates of change are calculated using the end-point method with the two most recent shorelines. A 44-page, full-color report discusses shoreline change along the U.S. Gulf of Mexico, describes methods of analysis, interprets the results, provides explanations regarding historical and recent shoreline change trends, and describes community responses to coastal erosion. An Internet Map Server (IMS) provides access to the data generated by the project by allowing users to view and manipulate data layers interactively in a web browser, including vector shorelines and transects, associated short- and long-term rates of change, statistical uncertainties, and areas of beach nourishment. A data catalog complements the report and the IMS by offering downloadable data layers for each state.

The Gulf of Mexico Internet Map Server, the data catalog, and the full report, National Assessment Of Shoreline Change: Part 1, Historical Shoreline Changes and Associated Coastal Land Loss along the U.S. Gulf of Mexico (USGS Open-File Report 2004-1043) can be accessed via the project website at: <http://coastal.er.usgs.gov/shoreline-change/>.

# Determining Vegetation Metrics Using a Temporal Waveform-Resolving Lidar at Assateague Island National Seashore

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The NASA Experimental Advanced Airborne Research Lidar (EAARL) acquired airborne lidar data for beach and vegetated communities at Assateague Island, Maryland, in September 2002 and August 2004. The EAARL system is a raster-scanning, temporal-waveform-resolving, green-wavelength lidar designed to map nearshore bathymetry, topography, and vegetative structure simultaneously. The NASA EAARL sensor records the time history of the return waveform for each laser pulse, enabling characterization of canopy structure and “bare earth” under a variety of vegetation types. Each lidar waveform describes the time-resolved amplitude of a reflected laser pulse as a function of the laser pulse time of flight at 1-nanosecond duration. The EAARL system also includes a 3-band color-infrared (CIR) multi-spectral camera that is tightly coupled with lidar acquisition. Information from EAARL overflights and accompanying ground-based field measurements is used to evaluate the capability of lidar data to determine the vertical distribution of canopy and sub-canopy across a diverse set of vegetation classes.

The EAARL small-footprint waveform represents the amount of energy returned to the sensor as a function of a series of equally spaced time intervals. At the nominal flying altitude of 300 m, a single EAARL laser pulse illuminates a small horizontal sampling area (20-cm-diameter footprint). As a result, in a forest environment, the information content of the returned laser signal includes a small portion of the canopy, which may describe the vertical distribution starting from the side of a tree crown *versus* the top or peak of the crown. This principle is in contrast to large-footprint lidars, where the returned waveform contains information on forest canopy and multiple forest elements rather than individual trees. To describe the vertical structure of a vegetated canopy, several individual small-footprint laser pulses are combined to make a composite “large-footprint” waveform that defines a larger horizontal area. The size of this composite footprint is a variable and can be determined in post-flight processing software, unlike the large-footprint lidar systems, where footprint size is determined by optical laser-beam-divergence hardware prior to data acquisition. The reflected amplitude backscatter within each vertical bin (also defined in post-processing software) for all the individual waveforms comprising the composite waveform are averaged, and the resulting composite waveform is normalized for the number of individual waveforms.

Composite waveforms (5-m or 10-m diameter) describing a significant horizontal area, were determined from the EAARL small-footprint waveforms for the September 2002 EAARL survey at Assateague Island National Seashore. The 5-m composite footprint waveforms were used to derive three metrics: ground elevation, canopy height, and canopy reflection ratio (or canopy closure). Ground elevation is the elevation of the peak or mode of the last return in the waveform that is inferred to be from the ground. Canopy height is the distance from the first return to the ground. Canopy reflection ratio is the sum of the portion of the waveform return reflected off the canopy divided by the sum of the portion of the waveform return reflected off the canopy and the ground. The canopy reflection ratio is a relative measure of canopy closure. Independent knowledge of the average reflectance of the canopy and ground surfaces within the footprint is necessary to convert the canopy reflection ratio to an absolute measure of canopy closure.

The lidar-derived metrics of canopy height and canopy reflection ratio were used to classify vegetated regions with significant vertical information on the island. Results show that the vegetation metrics derived from a waveform-resolving lidar system can reliably differentiate among forests, woodlands, and shrublands, which are difficult to discern from digital camera imagery, thereby improving the capability to classify vegetation on this barrier island.

# Submarine Ground-Water Discharge (SGD) and Associated Nutrient Fluxes to the Coastal Ocean

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Submarine ground-water discharge (SGD) is an almost ubiquitous coastal feature that is driven by a composite of climatologic, hydrogeologic, and oceanographic processes. For example, terrestrial hydraulic gradients that reflect both short- and long-term climatic conditions almost always transport both surface and ground water toward the coast. In coastal waters, physical oceanographic processes such as wave set-up, tidal pumping, and density-driven circulation may impact these hydraulic gradients and thus affect rates of submarine ground-water discharge. Although only fresh ground-water discharge has traditionally been accounted for in numerical simulations of coastal water budgets, saline ground-water discharge may be equally or even more important in terms of material transport (i.e., nutrients, metals, organics) across land/sea margins. For this presentation, we therefore define SGD to consist either of fresh ground water, re-circulated seawater, or a composite therefore, and will evaluate and present SGD in terms of a vector for nutrient delivery to coastal waters.

Until the mid-1990s, studies on SGD did not receive widespread attention, because it was generally thought that SGD rates were not large enough to be a direct influence ocean water budgets. This omission may in part be due to the inherent difficulty in identifying sites and quantifying rates of SGD, because most SGD occurs as diffusive flow, rather than discrete spring flow. This is in sharp contrast to studies of river discharge or river chemistry, which are obviously more easily sampled and quantified. However, there is a growing recognition that the submarine discharge of fresh, brackish, and marine ground water into coastal oceans is just as important as river discharge in some areas of the coastal ocean. In this presentation, we will thus review the progress made in SGD science, with emphasis on new applications of geochemical tracers and novel geophysical tools, and will examine nutrient fluxes through SGD. The eventual goal of our SGD science is to develop some forecasting or predictive capability based on being able to de-couple climatic and seasonal signatures from SGD rates.



# Contrasting Nitrogen Biogeochemistry and Fluxes to Coastal Waters from a Temperate and Subtropical Coastal Aquifer

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Eutrophication of coastal waters due to non-point-source land-derived nitrogen (N) loads is a world-wide phenomenon and perhaps one of the greatest agents of coastal ecological change. Within the U.S., a majority of estuaries has recently been determined to be moderately to severely impaired by eutrophication associated with increasing nutrient loads (Bricker et al. 1999).

In coastal watersheds with soils of high hydraulic conductivity and permeable coastal sediments, groundwater is a major route of transport of freshwater and its solutes from land to sea. Freshwater flowing down gradient from aquifers may either discharge from a seepage face near the intertidal zone or flow directly into the sea as submarine groundwater discharge (SGD). The hydraulic gradient that drives freshwater toward the sea also drives saltwater back to sea, creating a saltwater circulation cell. In addition, entrainment of saline pore water occurs prior to discharge, producing a gradient in groundwater salinity from land to sea, referred to as a subterranean estuary (Moore 1999). Hence, SGD often consists of a substantial amount of recirculating seawater, and that mixing of fresh and saline groundwaters in the context of coastal sediments may alter the chemical composition of the discharging fluid. Depending on the biogeochemical setting, removal of fixed N due to N<sub>2</sub> gas-producing processes in the nearshore aquifer and subterranean estuary may significantly attenuate land-derived N loads. On the other hand, processes such as ion exchange and tidal pumping in the subterranean estuary may substantially accelerate the transport of both land-derived and sediment re-mineralized N to estuarine water columns.

We are contrasting nitrogen transport and biogeochemistry in nearshore portions of coastal aquifers in west-central Florida and on Cape Cod, Massachusetts. The N biogeochemical investigations are being carried out in concert with radiochemical and isotopic-tracer approaches, seepage-meter studies, and streaming-resistivity surveys to identify locations and sources of SGD and to quantify fluxes to receiving estuaries. Examination of N biogeochemistry has included measurements of concentrations, natural-abundance stable isotopic ratios, N<sub>2</sub> and argon gas concentrations, and preliminary experiments employing a modification of the isotope pairing technique.

Results to date suggest that conditions in the Florida surficial aquifer are generally much more reducing than in the Cape Cod aquifer, so that both fresh and saline groundwater are devoid of nitrate and high in ammonium and dissolved organic nitrogen (DON). There has been very little prior study of the surficial aquifer discharging to Tampa Bay, yet our early results suggest that it may be a substantial source for loading of reduced N species (ammonium and DON) to Tampa Bay. In contrast, fresh groundwater in the Cape Cod aquifer contains high nitrate concentrations in many locations. Advection associated with SGD entrains saline, reducing, ammonium-rich pore waters, and creates a salinity gradient within discharging water. Dilution and removal of mineralization products occurs to > 6 m below sediment surface. A plot of ammonium vs. salinity in brackish to saline groundwater is approximately linear, suggesting that ammo-

nium may transport conservatively (without transformation) during mixing of water masses. Advection introduces dissolved oxygen and nitrate into the saline pore waters, yet nitrate is largely absent in brackish to saline pore waters. Where nitrate and ammonium do co-occur, concentration and natural-abundance stable-isotope data consistently suggest substantial loss of both species through a fractionating process. Examination of  $N_2$ -gas concentrations suggest that excess  $N_2$  is present both at the low-salinity portion of the subterranean estuary and in saline groundwater near the sediment/water interface. Preliminary experiments employing a modification of the isotope-pairing technique support the hypothesis that fixed N loss occurs with mixing of nitrate and ammonium-bearing waters, and that denitrification may co-occur with an anammox-type process. In-situ energetics calculations suggest anammox is, indeed, favored over nitrification in zones of N loss.

Our results, therefore, suggest that N is actively cycled in nearshore portions of coastal aquifers, and that mixing of fresh and saline groundwater prior to discharge may result in transport to the water column of mineralization products from estuarine sediments. In addition, in some locations, land-derived N loads to estuaries may be modified by fixed N loss.

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## **Session 3**

### **Population and Ecosystem Studies**

**Session Leader: Dr. Bob Dorazio**

# Distributions and Ecology of Deep Coral Habitat in the Southeastern United States

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Beginning in 1991 until present we have investigated several unique and difficult to sample deep water habitats off North Carolina and the SE US. Studies have concentrated in the following areas: a canyon system just north of Cape Hatteras, known as “the Point” (200-1200 m), from 1991-2001; deep coral banks (mostly *Lophelia*) from Cape Lookout through south-central Florida (360-800 m) from 1993-present; and outer shelf hardgrounds, between Cape Lookout and Cape Fear, in 80-200 m from 2001-present. The first priority of these studies is to describe community structure and distributions, followed by trophodynamics work, emphasizing the fish communities. Most sampling was during summer to early fall, and in each area we sampled the full water column using a variety of nets (plus other gear) and research submersibles. Either because of unique oceanography and/or habitats these areas harbor fish communities that were both poorly known and that displayed characteristics apparently controlled by the habitats. Data analysis is still in progress and field work also continues at the deep coral banks. I will present results of analyses to date from these areas, comparing their fish communities throughout the water column. Emphasis will be placed on describing our coral bank research.

# Seasonal Fish-Community Patterns in Upstream Reaches of Coastal Rivers in Everglades National Park, Florida

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The role of abiotic factors in the organization of communities is one of the most fundamental questions in ecology. At large temporal scales, heterogeneity of abiotic conditions affects patterns of species abundance and distribution. At smaller temporal scales, those abiotic conditions determine patterns of species movement and habitat use.

The structuring effect of abiotic conditions may be particularly important along transition zones or ecotones. In the Everglades ecosystem, mangrove-lined creeks link freshwater marshes to estuarine habitats. Previous studies have shown that these rivers are used by a diverse array of saltwater and estuarine fishes. The rivers may also represent critical habitat for freshwater-marsh fishes (including non-indigenous taxa) during seasonal dry periods. Historically, channels and pools at this ecotone served to concentrate fishes for avian predators, making this region very important for wading-bird feeding and nesting. This study examines seasonal and long-term dynamics in the fish community of the oligohaline to mesohaline reaches of rivers within the southwest region of Everglades National Park. In particular, we ask: (a) how does use of the upper river habitat by fishes change over long and short time scales; (b) how do these changes relate to variation in abiotic conditions; and (c) how do changes in the fish community relate to anthropogenic activity (previous drainage or impoundment effects and ongoing restoration)?

Sampling is conducted in two drainages: the Rookery Branch/Otter Creek sections of Shark River, and the North/Watson rivers. Those drainages differ in freshwater inflows and the degree of anthropogenic impact. Rookery Branch drains longer hydroperiod marshes than the North/Watson drainage, and has been affected by water management to a greater extent. Six rivers are sampled in each system, and all sampling is conducted in the uppermost 600 m stretch accessible to a motorboat. In each stretch, we systematically sample three 100 m-long sections by electrofishing. In addition to electrofishing, the upper 100-m reach of each river is sampled by two passive techniques: experimental gill nets that target large and mobile fishes, and minnow traps that target small fishes (SL < 10 cm). Sampling is conducted three times per year: November (wet season), February (transition), and April (dry season). Physical and chemical data are collected during each sampling event. The study began in 2004 and will continue through 2007, after which the methodology will be suggested for incorporation into the long-term monitoring for the Comprehensive Everglades Restoration Plan (CERP). Here, we report results from the 2004-2005 sampling season.

Fish catches were lower, as expected, during the wet season sampling in November, 2004, than in later samples. In November, wetlands surrounding the upper reaches of the streams were flooded, but were dry or drying when subsequent samples were taken. We assume that this forces fishes into the channels for refuge. Physicochemical changes were noted in the streams with the change in seasons. In particular, dissolved-oxygen levels were lower in the transition and dry seasons, and water clarity decreased. Salinities were higher in the North/Watson drainage than in Shark River. Large fishes included common freshwater species such as largemouth bass, bowfin, and Florida gar, and estuarine species such as snook, tarpon, striped mullet, and striped mojarra. Catch of the large freshwater species increased greatly from the November to February samples. Similarly, small fishes, particularly eastern mosquitofish, dollar sunfish, and bluefin killifish, increased in the minnow-trap samples. Catches in Shark River were much larger than in North/Watson rivers as the dry season progressed.

# Habitat Use by Estuarine Fish Assemblages: Assessing Community Structure in Natural and Altered Wetlands in Tampa Bay, Florida

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To assess fish-community response to habitat alteration, ecologists have initiated a 3-year sampling program at fixed sites in Tampa Bay. The primary hypothesis is that fish communities in natural wetland creeks differ from fish communities in wetlands altered by mosquito-control ditches. To address this hypothesis, our objectives include: (1) establishing a species inventory of wetland fishes, pink shrimp, and blue crabs; (2) characterizing habitats based on substrate, vegetation, hydrology, and water quality; and (3) determining spatial/temporal use of habitats by fish assemblages.

Fifty-four sites (creeks, ditches) randomly selected in three county or state preserves along a north-south gradient were sampled quarterly with a center bag seine. Each site was restricted at both ends (with block nets) and then seined three times consecutively to allow depletion estimates of relative fish abundance. Upon capture, fauna were identified, measured, counted, and released. During the first 10 months of sampling, 101,560 individuals representing 75 species were collected. Fourteen species composed 90% of the total catch. Overall fish density was similar between creeks (13.7 fish/m<sup>2</sup>) and ditches (14.0 fish/m<sup>2</sup>). Mosquitofish (*Gambusia holbrooki*), sailfin mollies (*Poecilia latipinna*), and rainwater killifish (*Lucania parva*) were the most abundant species in both habitats. The 13 most abundant species were the same between habitats, with minor rank differences. Species richness for economically valuable fishes was similar between creeks (n=15) and ditches (n=13), and the most abundant species were the same: young-of-the-year spot (*Leiostomus xanthurus*), blue crab (*Callinectes sapidus*), mullet (*Mugil* spp.), and red drum (*Sciaenops ocellatus*). Economically valuable species contributed a larger portion of the fish assemblage in creeks (15.8%) compared to ditches (9.7%), mostly because of greater spot abundance in creeks (1.05 fish/m<sup>2</sup>) compared to ditches (0.39 fish/m<sup>2</sup>). The results of this study will be used by reserve managers in planning restoration activities and in assessing restoration success from a fisheries viewpoint.

# Improving Removal-Based Estimates of Local Abundance in a Metapopulation of Endangered Fishes

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A statistical modeling framework is described for estimating the abundances of spatially distinct subpopulations of animals surveyed using removal sampling. To illustrate this framework, hierarchical models are developed using the Poisson and negative-binomial distributions to model variation in abundance among subpopulations and using the Beta distribution to model variation in capture probabilities. These models are fitted to the removal counts observed in a survey of a federally endangered fish species. The resulting estimates of abundance have similar or better precision than those computed using the conventional approach of analyzing the removal counts of each subpopulation separately. Extension of the hierarchical models to include spatial covariates of abundance is straightforward and may be used to identify important features of an animal's habitat or to predict the abundance of animals at unsampled locations.

# The 2004 Hurricanes—Storm Attributes, Impacts to Manatee Survival Rates, and Scenarios for Population and Ecosystem Models

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In a 2003 published analysis of 19 years of mark-resighting data for Florida manatees (Langtimm and Beck, 2003), we detected significantly lower adult apparent survival probabilities in the northwest panhandle of Florida in the three years with major hurricanes (Category 3 and above on the Saffir-Simpson scale) or a severe winter storm (Fig. 1). In 2004, four hurricanes impacted manatee habitat for three of the four Florida manatee subpopulations managed by the U. S. Fish and Wildlife Service. These storms had the potential for similar effects on apparent manatee survival that we observed in our 2003 study, and could affect manatee population dynamics and recovery of the species. Our hypothesis is that the magnitude of impact on the manatee subpopulations should vary with the destructiveness of the storms, which depends on wind intensity, storm surge height, size, speed of forward motion, proximity to the coast, track direction relative to the coast, and coastal and ocean bottom topography. Other factors can then exacerbate or ameliorate apparent survival risk, such as density of manatees in the strike area, multiple storms within a season, or coincidence with other mortality factors (i.e., cold stress, red tide, or changes in watercraft mortality).

The primary objectives of this research are to (1) assess the magnitude of impact to apparent manatee survival rates relative to storm characteristics, (2) identify and test hypotheses concerning the mechanisms operating to produce these impacts; and ultimately (3) develop predictive and risk assessment models to describe impact under different storm scenarios and the consequences to manatee population dynamics and persistence.

Data necessary to estimate regional manatee survival probabilities during the 2004 storm year are already being collected as part of an ongoing study by the USGS Sirenia Project (CARS), Florida's Fish and Wildlife Research Institute, and Mote Marine Laboratory to assess manatee population status and trends. Prior to the survival analysis, we are developing predictions of the relative magnitude of change in survival rates expected in each subpopulation, based on known manatee distribution patterns and analysis of storm-specific characteristics hypothesized to affect apparent survival. Our analyses of data and models describing physical storm characteristics currently focus on surface wind fields, wave action and impact to coastal erosion, storm surge, and sea surface temperature changes.

As this research develops we anticipate incorporating hurricane effects and manatee population data into various manatee management models and FISC ecosystem models. Currently a set of nested hydrodynamic models are being developed as part of the Tampa Bay Integrated Science Project. The Gulf of Mexico model, forcing the pre-conditions of the Tampa Bay model, may have sufficient resolution and specificity to provide gross constraints on conditions that may affect apparent manatee mortality. Incorporating these nested hydrodynamic models to models of manatee population dynamics could provide valuable information to managers assessing the long-term stability of the Florida manatee and its habitat along the Florida shoreline.

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# Predicting Vegetation Change in the Everglades

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Plant communities are key components of the Greater Everglades. In addition to providing food and shelter to higher trophic-level species, plants influence abiotic ecosystem processes such as fires and soil formation. The hydrologic modifications proposed as part of Greater Everglades restoration will affect both the spatial distribution of plants through time and the fire regime. Understanding the complex inter-relationships among these components and processes is an important part of evaluating hydrologic restoration. Across Trophic Level System Simulation (ATLSS) has developed models for vegetation succession and fire that incorporate the effects of hydrology. These models examine relative differences under proposed hydrologic changes in (1) the number, diversity and spatial configuration of Everglades plant communities and (2) the number, size, frequency and distribution of fires in the Everglades. Hydrologic input for the models is based on the output of the South Florida Water Management Model (SFWMM), the standard tool for projecting hydrologic patterns resulting from changes in water management in South Florida. ATLSS High Resolution Hydrology (HRH) interpolates SFWMM output, provided at a 2-mile scale of resolution, over a high-resolution topographic map to create water depths at a 500-meter scale over the model area.

The ATLSS Vegetation-Succession Model (VSMoD), developed at the University of Tennessee by S. Duke-Sylvester, simulates the pattern of spatial and temporal changes in the distribution of vegetation in the Greater Everglades landscape as a function of the hydrologic regime, patterns of fire disturbance, and nutrients. A primary goal is to quantify the relative differences among various hydrologic scenarios as reflected in their effects on vegetation succession. VSMoD incorporates a spatially explicit, stochastic cellular automata model to simulate vegetation succession. At any given time, each 500x500 meter plot is in one of a finite number of states. The transition between states occurs with a probability that varies in both space and time, dependent on local hydrologic and fire history as well as on the current vegetation. The model runs on a yearly time-step, synchronized with the fire model, and produces annual maps of projected vegetation over the model area. Three modeled factors influence the succession of one plant association to another: fire, nutrient change, and prolonged hydrologic change.

The purpose of the ATLSS fire model is to provide annual estimates of the spatial distribution of the areas burned by naturally occurring fires in the Florida Everglades. The fire model provides input for the ATLSS vegetation succession model, VSMoD, while VSMoD provides local vegetation information for the fire model, simulating the effects of feedback between fire history and vegetation. The fire model's yearly time step ends on May 31 - the end of the natural fire season. The fire model provides estimates of the spatial distribution of both hot and cool fires. Hot fires are those that result in the death of trees and/or the burning of soils and peat material. These fires reset the successional process to "early" vegetation types. Cool fires are those that do not kill trees or burn soils. These fires burn only above-ground portions of plants, and arrest succession at different stages of development depending on fire frequency.

The fire model simulates landscape-scale fire patterns by modeling fire spread as a collection of local stochastic processes. Each plot is represented by a stochastic cellular automata model. Each plot is in one of three states: unburned; burned by cool fire; or burned by hot fire. Transitions between these states are stochastic and depend on local environmental conditions and the presence or absence of fire in the neighborhood of each plot. The model assumes that all natural fires are caused by lightning strikes. The spatial distribution of area burned for each year is estimated by computing for each plot in the landscape the number of lightning strikes, the probability of burning, and the number of resulting fires. Finally, fire spread is simulated by incorporating a locally determined conditional probability of burning given that a neighboring plot is burning.

## **Session II**

**Poster Session Leader: Trudy Phelps**

# An Interagency Database for Manatee Population Research: The Manatee Individual Photo-Identification System (MIPS)

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Many individual Florida manatees are recognizable by the unique features, primarily scars and mutilations from collisions with boats, which they acquire during their lifetime. In the late 1970s, the Sirenia Project, USGS, began a long-term study to photographically document individual manatees to answer various life history and population biology questions. As a result, a database was developed to automate the management of images, sighting records, and life history information of approximately 2,000 individually recognized manatees. This database, the Manatee Individual Photo-identification System (MIPS), has been employed for nearly two decades to enhance manatee population research. The MIPS provides the individual life histories currently used to estimate population parameters and to model manatee population dynamics for state and federal population assessments. In 1988, the Florida Fish and Wildlife Conservation Commission, Florida Wildlife Research Institute (FWRI), joined the effort and began to photograph manatees in SW Florida. Likewise, researchers at Mote Marine Laboratory (MML) also joined the collaboration in the SW region in 1993. USGS has been responsible for collection and maintenance of data for the Atlantic Coast, St. Johns River, NW Florida, and sites outside of Florida.

Because coordinating the management of separate databases at each agency proved complex and inefficient, a solution incorporating a secure, integrated database server was developed. To support remote access by Partners outside of the USGS, including FWRI and MML, efforts began in 2003 to migrate from a MS Access database to a multi-agency relational database using MS-SQL Server 2000. A distributed MIPS MS-SQL database that includes data contributed by each agency will significantly improve the efficiency of data management, while maximizing data availability, security, and reliability. The resulting multi-user database will be fully integrated with data and images from all participating institutions, and will be accessible to all cooperators based on predefined security roles.

Recovery of the endangered Florida manatee will benefit from this interagency database collaboration. Integration of data archived by each agency into a single, replicated database will ensure appropriate data use for analysis and research, will greatly facilitate efforts to further advance manatee research, respond to the needs of state and federal managers, and contribute to meeting the prescribed research goals and timelines.

# Recent Discoveries of Elevated Mg within Coral Skeletons and Other Applications of Laser Ablation and the Scanning Electron Microscope

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High-resolution laser-ablation inductively coupled plasma mass spectrometry (LA ICP-MS) was used to analyze a small portion of the large framework coral *Montastraea faveolata* to determine the geochemical signatures within and among specific skeletal structures. Data reveal potential problems in geochemical analysis and interpretation. Depending upon sample size and location of sampling within the skeleton, results may differ. Vertical transects (spot/raster sampling) were conducted along three parallel skeletal structures: endothecal (septal flank), corallite wall, and exothecal (costal flank) areas. The results reveal that trace-element levels vary among the three structures. The amount of magnesium (Mg) varied prominently among the adjacent structures and is most abundant within the exothecal portion of the skeleton.

Using a scanning electron microscope (SEM), we found hexagonal crystals forming discs, pairs, and rosettes in several samples. High levels of Mg within these crystals have been confirmed with energy dispersive spectrometry (EDS) and LA ICP-MS. The chemical composition is consistent with the mineral brucite [ $\text{Mg}(\text{OH})_2$ ]. The crystals, located exclusively in the exothecal area of the skeleton, are associated with green endolithic algae and are commonly associated with increased Mg levels found in the adjacent corallite walls. The excess Mg precipitated within the microenvironment of the exothecal area may be a result of photosynthetic processes. The presence and locations of high-Mg crystals found within microenvironments of the coral may explain anomalous Mg data researchers have been questioning for years.

In addition, the laser-ablation technique along with the SEM/EDS allows us the opportunity to collect historical chemical information from the coral skeleton. Trace elements that are either incorporated into the skeleton or found as inclusions within the skeleton may record environmental variables influencing the growth of a particular coral. In addition to using particular elements as proxies for paleothermometry and freshwater/groundwater influence, other elements may show “contamination” of the coral. For example, African dust particles may get incorporated into the skeleton and show a record of dust flux. Also, the Flower Garden Reef corals, located in the Gulf of Mexico southwest of the Mississippi River delta, may record sediment fluxes of the Mississippi and Atchafalaya Rivers.

# High-Resolution Holocene Stratigraphy of the Nueces River Bayhead Delta and Incised Valley of the Southwestern Texas Gulf Coast

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The Nueces-Corpus Christi Bay complex lies within Nueces and San Patricio Counties, near the city of Corpus Christi, Texas, and is located on the western Gulf of Mexico coastal plain. The modern Nueces-Corpus Christi Bay complex is an incised valley of the Nueces River that cut across the continental shelf during the last glacial period and was flooded during the ensuing sea-level rise. The depositional history and identification of five deltas within Nueces Bay are described. Geologic features such as oyster bioherms and delta clinoform bedding were identified from seismic-reflection patterns (or characteristics) and geometries. Seismic-reflection patterns define erosional or depositional features such as fluvial incision, channel fill, and erosional truncation of valley walls with onlapping deposition. Identifying geologic features and erosional and depositional environments provides the data necessary to develop the geologic framework and history of the area. <sup>14</sup>C dates indicate the oldest two deltas were deposited before Cal BC 4330 years and the youngest two deltas by Cal BC 1120 years. The Nueces River bay-head deltas and incised valley provide an excellent example of a preserved, transgressive, incised-valley-fill sequence. The incised-valley stratigraphy has similar analogs in the northern Gulf of Mexico (i.e., Mobile Bay), although few systems compare in degree of preservation and type of structural framework.

# Understanding the Shallow Stratigraphic Architecture of the Louisiana Coastal Zone: the Key to Identifying Potential Sources for Shoreline Renurishment

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The Louisiana coastline west of the modern Mississippi River delta is the product of the complex processes of delta progradation, abandonment, and marine transgression. The stratigraphic architecture of the deltaic plain represents depositional facies associated with each of these processes. Progradational units include prodelta, delta front, distributary channel, and marsh deposits. Transgressive facies are present as tidal inlet channel fills, shoal deposits and nearshore marine deposits. The occurrence of these different facies varies in prominence, lateral and vertical extent. Thus, locating material suitable for remediation projects is complex and understanding the geologic framework is necessary to characterize the distribution of these deposits. For the purpose of shoreline remediation, these deposits can be classified into distinct units of varying grain size and texture. The dominance of mud in the area is due to the fine-grained sediment load of the Mississippi River. The coarse-grained material within distributary channels and tidal inlet deposits is restricted to high-energy current regimes and generally is spatially distinct from the muddy environments.

As part of a shoreline restoration effort, two sand resource studies were conducted in the Barataria and Timbalier regions. More than 1870 line-kilometers of high-resolution single-channel seismic-reflection profiles and 281 vibracores were collected. The surveys identified 14 potential sand sources within an overall fine-grained marine, prodelta, and interdistributary framework. Several of these deposits are associated with delta progradation, backbarrier, and flooding deposits. The delta front and distributary network contribute the majority of coarse-grained material within the overall fine-grained environment. Analyses of these components indicate that these systems can be targeted as suitable sediment resources for shoreline remediation.

# Integrating Ecology and Genetics to Define Population Structure for a Continuously Distributed Species, Diamondback Terrapins (*Malaclemys terrapin*)

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The diamondback terrapin (*Malaclemys terrapin*) is distributed along the U.S. coast from Massachusetts to Texas in brackish-water habitats. This long-lived, sexually dimorphic turtle is subject to both terrestrial and aquatic threats, including by-catch in fishing gear, and roadkill on highways adjacent to salt-marsh habitat. Until now, no clear population definition had been established for this continuously distributed species. Therefore, effective conservation efforts to mitigate population-level threats have not been realized.

To determine ecologically and evolutionarily relevant management units, we used molecular techniques (i.e., microsatellite DNA) to test the hypothesis that *M. terrapin* in the U.S. exists as a single homogeneous population. To assess the magnitude of the threat that actively fished commercial crab pots pose for terrapins, we conducted experimental fishing studies with crab fishers in North Carolina and tested the ability of several by-catch-reduction devices (BRDs) to exclude terrapins but retain valuable blue crabs. We also used elasticity analyses to rank different BRDs among several management options. Finally, to estimate adult survival rate, capture probability, and population size for the elusive mangrove terrapin, we conducted a mark-recapture study in the Big Sable Creek (BSC) complex of the Florida Everglades and analyzed individual encounter histories.

Results indicate that *M. terrapin* comprises at least six distinct metapopulations or regional management units (MUs) throughout its range. These MUs do *not* coincide with previous morphologically based subspecies designations. Additionally, microsatellite analysis elucidated that male-biased dispersal exists in *M. terrapin*. Field studies revealed that terrapin interaction with blue-crab-fishery activity primarily occurs in the early spring, close (i.e., < 250 m) to shore. Terrapin by-catch in crab pots can be mitigated by using BRDs, although some BRDs still allow adult males to enter. Larger (i.e., 5.0 cm) BRDs did not significantly affect catch rates of crabs, but smaller (i.e., 4.5 and 4.0 cm) BRDs did ( $p < 0.001$ ). Finally, we established that the adult survival rate ( $\phi$ ) for terrapins in BSC is = 0.79 (95% CI 0.60-0.91), and it is constant across time and gender. Mean probability of capture was 0.41, and this parameter varied seasonally (winter = 0.28, summer = 0.53). The distribution of terrapins in BSC lies largely in first-order tidal streams that contain an abundance of submerged, algal-covered logs.

# An Evaluation of an Enclosed Method for the Determination of Total Mercury in Aquatic Life

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While past studies have addressed exposure levels in some species from locations in the Everglades ecosystem very few studies have attempted to comprehensively explore exposure levels on a large scale and no study has examined the strengths and weaknesses for existing analytical methods of measuring mercury in biological species. Although methods for analysis of mercury in biological samples already exist, combining historical datasets for comparison purposes are difficult because of the differences in the approach of sample preservation, analysis (i.e., fresh, wet, dry), and errors caused due to pre-treatment and handling of samples.

The overall objective of this study was to survey mercury concentrations in multiple trophic groups (alligator, largemouth bass, and frog) from several areas in south Florida to look for mercury exposure levels and potential differences in tissue mercury concentrations among locations. It is vitally important to use the most accurate sampling and analytical techniques to acquire mercury data for evaluating the magnitude of exposure and its impact on the health of wildlife species therefore the Direct Mercury Analyzer-80® was the instrumental choice for the analytical validation study. Finally, an evaluation of existing conventional analytical method was conducted that will provide the U.S. Geological Survey with an integrated approach for assessing trends of mercury exposure to biological organisms and allow comparisons of large data sets. These efforts strive to standardize methods for the purpose of understanding exposure levels in the Everglades ecosystem.

Multiple treatment (i.e., drying, chemical digestion, and oxidation) steps are often required during preparation of biological matrices for quantitative analysis of mercury. These multiple steps could potentially lead to systematic errors and poor recovery of the analyte. Presented in this study, a clean all-inclusive method was utilized to measure total mercury in fish tissue by integrating steps of drying, sample combustion and successive identification with atomic absorption spectrometry. We also evaluated the differences between the mercury concentrations found in samples that were homogenized and samples with no preparation. These results were confirmed with cold vapor atomic absorbance and fluorescence spectrometric methods of analysis. Finally, total mercury in wild captured largemouth bass (n=20) were assessed using the DMA-80 to examine interrelationships between mercury concentrations in muscle, liver and brain organs. Direct analysis of total mercury measured in muscle tissue was strongly (positively) correlated with muscle tissue that was homogenized before analysis ( $r=0.81$ ,  $p<0.0001$ ). Additionally, results using our integrated method compared favorably ( $p<0.05$ ) with conventional cold vapor spectrometry with atomic absorbance and fluorescence detection methods. Mercury concentrations in brain were significantly lower than concentrations in muscle ( $p<0.001$ ) and liver ( $p<0.05$ ) tissues. This integrated method can measure a wide range of mercury concentrations (0-500  $\mu\text{g}$ ) using small sample sizes. Total mercury measurements in this study are comparative to the methods (cold vapor) commonly used for total mercury analysis and are devoid of laborious sample preparation and expensive hazardous waste.



# Assessing the Consequence of Hurricane-induced Habitat Conversion on Fish and Decapod Crustacean Assemblages in the Big Sable Creek Complex of Southwest Florida

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Hurricanes routinely cause damage to mangrove forests, generally by breaking and toppling trees. Normally, forests recover through growth of new plants from seedling germination. For reasons that are not completely understood, the passage of two Category 4-5 hurricanes across the Cape Sable peninsula in SW Florida (1935, 1960) resulted in permanent damage to some mangrove forests: in certain locations adult trees were killed and no seedlings rejuvenated. The net result was conversion of mangrove forests to unvegetated mud flats. Mangroves are generally considered to be critical nursery habitat to both small resident forage fishes, and to the juveniles of many species of estuarine transient fishes whose adults spawn offshore and whose young life-history stages use mangrove environments. This project asks the question, “What is the consequence of the conversion of mangrove to mud flat habitat on intertidal assemblages of fish and decapod crustaceans within the creeks in the Big Sable Creek complex?”

The Big Cape Sable Creek complex consists of six tidal creeks that are a mosaic of mangrove forest and mud flats, both inundated at high tide. Rivulets are depressions in the substrate that are up to 1 m deeper than the forest floor or mud flat around them. Rivulets fill earlier on flood tides and retain water later on ebb tides. Rivulets are “hotspots” for the entry and egress of fish and decapod crustaceans (shrimp, crabs) from intertidal habitats and are a convenient location for sampling these animals. We use block nets across intertidal rivulets to compare the fish and decapod fauna leaving replicate forest and mud flat sites.

The statistical design was a repeated-measures ANOVA with creek the unit of replication. The dependent variable was catch-per-unit effort (CPUE); the independent variable was habitat type: catch was quantified as both numbers and biomass. We sampled three replicate creeks, each with a forested and a mud flat site. The rivulet sites were fixed and drained an unknown area that varied both with tidal height and location. We have sampled every 2 months for 18 months.

Preliminary analyses indicate that the species composition of the two habitat types is different. We compare species composition using an ordination technique, multidimensional scaling (MDS), followed by analysis of similarity (ANOSIM) to ascertain statistical significance of ordination groupings. We are in the process of upgrading our measurement of catch by developing stage-discharge curves for each net site. Once completed, these curves will permit expression of results as fish per cubic meter of water discharged through a net on a given tide. Final analysis of abundance differences awaits this standardization process. This study is designed to assist management in predicting long-term fisheries impacts of severe-hurricane landfall in mangrove-dominated environments.

# A Several-Century Record of Low-Oxygen Conditions on the Louisiana Continental Shelf

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Hypoxia occurs in continental-shelf subsurface waters when the uptake of oxygen by respiration exceeds its resupply. Measurements of Louisiana continental-shelf waters have indicated that hypoxia (oxygen content <2mg/L) has increased since 1985 (Rabalais et al., 1999). Sediment cores taken from the Louisiana shelf have provided a record of hypoxic and low-oxygen conditions over longer time intervals of 50-100 years (Sen Gupta et al., 1996; Blackwelder et al., 1996; Osterman et al., 2005).

Our previous work established the use of the relative abundance of three low-oxygen-tolerant benthic foraminifers (*Pseudonion atlanticum*, *Epistominella vitrea*, and *Buliminella morgani*) as a proxy for the present hypoxic conditions on the Louisiana shelf (Osterman, 2003). This proxy, named the PEB index, can be used in sediment cores to document low-oxygen conditions. The analysis of the PEB index in four sediment cores provided evidence for low-oxygen events that pre-date the start of extensive use of commercial fertilizer in the Mississippi Basin (~1950). Fluctuations in the amount of these low-oxygen-tolerant species between 1817 A.D. and 1910 A.D. correspond with increased discharge/flooding events in the Mississippi River drainage. In most cases, high river discharge correlates with high percentage values of the low-oxygen-tolerant PEB species (Osterman et al., 2005).

The results from the newly analyzed lower section of Louisiana shelf core PE0305-GC1 (60-164 cm) indicate that the percent of the low-oxygen-tolerant species records significant fluctuations of bottom-water oxygen in the past. At times, the PEB values in the lower core exceed the values that are found in the upper fertilizer-driven hypoxia interval (post 1900). Using a sedimentation rate extrapolated from <sup>210</sup>Pb data in the top 20 cm, low-oxygen events may extend back to ~1500 A.D.

In addition, analyses of carbon stable-isotope compositions of sedimentary organic matter have also been completed for core PE0305-GC1. In the upper 100 cm of the core, negative excursions in %  $\delta^{13}\text{C}$  generally correspond to increases in PEB. The very negative values of %  $\delta^{13}\text{C}$  (<-28) found in the core record most likely represent incorporation of biomass from anaerobic microbial recycling communities to the bulk sediment and support the interpretation that high PEB values represent low-oxygen bottom-water conditions. Below 100 cm core depth, the correspondence of %  $\delta^{13}\text{C}$  and PEB is more variable. Sampling for carbon-isotope analyses and foraminifer census was done at different times. Thus, the offset in isotope and foraminifer records in deeper levels of the core could be caused by offsets in sampling levels.

These preliminary results show a correlation between geochemical proxies and benthic foraminifers. Abundance fluctuations in low-oxygen-tolerant benthic foraminifers, supported in part by %  $\delta^{13}\text{C}$  data, indicate low-oxygen bottom-water events have developed periodically on the Louisiana shelf for approximately the last 400 years. The foraminifer data indicate that low-oxygen conditions near the Mississippi Delta, as severe as conditions associated with hypoxia events of the last 50 years, occurred in the 1700s. Our preliminary results suggest that development of low-oxygen bottom waters is a complex natural process that has been altered by human activities.

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# Tools Assessing Risks: Ongoing Efforts to Evaluate Potential Harm of Introduced Aquatic Organisms

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A number of relatively recent fish introductions into the United States have caused considerable concern among government agencies, resource managers, researchers, and the public. A few of the more notorious are three species of Asian or Chinese carps (i.e., black carp, bighead carp, and silver carp), and members of the families Channidae (snakeheads) and Synbranchidae (swamp eels). U.S. Geological Survey (USGS) researchers have conducted or are finalizing risk assessments on these and other fishes following procedures developed by the former Risk Assessment and Management Committee of the Aquatic Nuisance Species Task Force. Based on past experience, there are a variety of risks associated with a species' arrival into areas where it is not native. The risks are evaluated by estimating the probability of several factors, such as whether the organism is present in a given pathway and capable of surviving the journey, and whether it can successfully colonize and subsequently expand its range. Other factors to evaluate include environmental and economic impacts, and social and political consequences. The intended use of these risk assessments is to provide government agencies with the necessary information to make informed decisions. A biological synopsis and risk assessment of snakeheads is already available, published by the U.S. Geological Survey in 2004 as Circular 1251. A biological synopsis and risk assessment of the black carp (*Mylopharyngodon piceus*) is currently in press and should be available by the spring 2005 (as a Special Publication of the American Fisheries Society). A detailed assessment of bighead and silver carps (*Hypophthalmichthys* species) is in preparation. Closely allied with these risk assessments are other USGS publications and products. Included is a guide to introduced foreign cyprinid fishes (currently in press) as well as our long-established and continually updated database which houses geographically referenced data and information on aquatic introductions in the United States.

# Wetland Loss and Land Subsidence Related to Hydrocarbon Production, South-Central Louisiana

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Extensive wetland losses have occurred in coastal Louisiana during the last half century, with estimated rates as high as 75 to 100 km<sup>2</sup>/yr. Analysis of historic aerial photographs and satellite images suggests that the most rapid wetland loss and collapse of the delta plain occurred during the late 1960s and 1970s. Since 1956, the emergent land area at five wetland-loss hotspots in the Terrebonne-Lafourche region of the Mississippi River delta plain has, on average, decreased by 45 to 50%.

Formerly emergent marshes at the wetland-loss hotspots are now submerged beneath water that averages 0.5 to 1.0 m deep. Correlation of the shallow subsurface stratigraphy shows that land subsidence has been the primary physical process contributing to wetland loss. Subsequent erosion of the submerged delta-plain marsh has been relatively minor at most of the hotspots.

The widespread and nearly simultaneous collapse of marshes across the Mississippi delta plain appears to be an unprecedented event in the recent geological record. Average historical rates of subsidence, determined from analysis of leveling surveys conducted by the National Geodetic Survey between 1965 and 1993, range from 8 to 12 mm/yr. In contrast, average rates of subsidence inferred from radiocarbon dates range from 1 to 5 mm/yr over the last 5000 years.

Surface and subsurface data strongly indicate that the rapid subsidence and associated wetland loss were largely induced by the production of hydrocarbons and associated formation water. The areas of greatest wetland loss and highest subsidence rates show good spatial correlation with the location of large oil and gas fields; and the period of most rapid wetland loss (late 1960s to 1970s) is nearly coincident with the timing of peak oil and gas production. The most recent rates of wetland loss are substantially lower than the peak rates, which is also consistent with significantly lower rates of fluid production.

# Measuring the Quantity and Quality of Surface-Water Resources in West-Central Florida: the Minimum Flows Network

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Florida statutes require that the Southwest Florida Water Management District (SWFWMD) adopt minimum levels for those water resources that are experiencing or will likely experience adverse impacts because of surface- and ground-water withdrawals. In response to this legislative mandate, SWFWMD has established a Minimum Flows and Levels (MFL) Rule (40D-8), which specifies minimum levels for cypress wetlands, lakes, and aquifers, and minimum flows in rivers and streams.

In keeping with the U.S. Geological Survey (USGS) mission of providing high quality long-term data for the management of water resources, the Florida Integrated Science Center for Coastal and Watershed Studies (CCWS), Tampa office in cooperation with the SWFWMD, maintains a network of minimum flow stations that monitor the quantity and quality of surface-water flows within selected river basins located within the SWFWMD area. In addition to providing the data, the USGS also provides information on the technological methods used to collect the data.

The primary purpose for establishing the MFL network was to provide long-term, high-quality data for use in setting minimum flows and levels for surface waters. However, there are many additional benefits of having long-term MFL data available. Long-term data can contribute to our understanding of saltwater/freshwater interactions, the extent of tidal effects on river systems, the effects of rainfall-runoff associated with hurricanes and storms on tidal estuaries, storm surge effects, constituent loads associated with stream discharge, flood inundation, and biological zonation related to salinity. The MFL data also may contribute to an improved understanding of how Florida streams respond to larger scale climatic signals such as global oscillations and climatic trends including the El Nino effect.

# Creation of GIS Data of Everglades National Park's Fire History from 1948 to 1979

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Since 1948 the Everglades National Park has been accumulating vast amounts of fire history data. This data is in the form of paper records, mylar maps and hand drawn maps of the fire perimeters that occurred for each year. All types of fires were documented, whether they were prescribed, suppression, fire use or incendiary and are included in this project. The purpose of this project is for the U.S. Geological Survey to take the paper records and hand drawn maps from the Everglades National Park to develop Geographic Information System (GIS) data layers in ArcGIS 8.3 of the fire history. These data layers will be created in accordance with the National Fire Standards of the National Park Service (NPS). The creation of the layers is being done by extracting out vital information from the records and building a geodatabase from the attributes gathered. The next step is taking the paper maps to digitize polygons for each fire perimeter. These polygons are being created by using the best available source of data, which in most cases is obtained from the maps that were within the fire report. A point data layer will also be produced for each fire to represent the location at which the fire began. When this project is complete the creation of this dataset can play a significant role in park planning of fire management activities, fire ecology studies and many other issues concerning the behavior of wildfires.

# Utilizing Select U/Th Series Radionuclides as Tracers of Hyporheic Exchange within Florida's Coastal Rivers

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Florida's coastal rivers are unusual in that they most often have small watersheds, wherein the bi-directional exchange of groundwater with surface water is often ubiquitous and hard to quantify. This active exchange of groundwater and surface water (hyporheic flow) across the sediment/water interface within the lower reach of a coastal river or stream may be important in terms of the delivery of water and associated constituents to coastal receiving waters. Hydrogeologists and resource managers alike can thus benefit from the development and application of new tools and methods that enable the accurate separation of groundwater from surface-water budgets in such streams and rivers.

We have recently utilized  $^{222}\text{Rn}$  and the Ra quartet ( $^{223,224,226,228}\text{Ra}$ ) to identify and also quantify rates of submarine groundwater discharge within coastal bottom waters of select Florida estuaries. Radon-222 has a short half-life (3.8 d), is inert as a gas, and is produced by radioactive decay of its immediate parent ( $^{226}\text{Ra}$ ,  $t_{1/2} = 1600$  y) at a predictable rate within bottom sediments. The activity of excess radon in a coastal water column has been shown to be proportional to the rate of submarine groundwater discharge. By measuring near-continuous  $^{222}\text{Rn}$  activities, one can thus obtain information on the geographical distribution of submarine groundwater discharge. Results from such  $^{222}\text{Rn}$  surveys in Tampa Bay, Loxahatchee River estuary, and the Suwannee River delta are compared. Concurrent radium isotope systematics can provide regional-scale submarine groundwater-discharge estimates.

Results suggest that  $^{222}\text{Rn}$  is particularly well suited as a groundwater tracer in Florida's coastal waters and rivers that are often rich in phosphatic (i.e., U/Th series isotopes) deposits. For example, groundwater  $^{222}\text{Rn}$  activities can range above 5000 dpm L<sup>-1</sup> below the Alafia River, Tampa Bay. In comparison, background  $^{222}\text{Rn}$  activities in coastal waters are generally < 5 dpm L<sup>-1</sup>. Observed elevated Rn upstream in all river systems suggests that this isotope could be very useful as a tracer of groundwater in such river systems. The application of Ra isotope systematics yields submarine groundwater discharge rates that are in the range of other coastal settings, and when multiplied by representative groundwater nutrient concentrations, provide at least a first-order submarine groundwater-discharge-derived nutrient flux to coastal receiving waters.



# Habitat Use by Benthic Fishes on Shallow-Water Ridges and Shoals in the Northwest Gulf of Mexico from a Landscape Perspective

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Many of the natural ridge/shoal features found on the continental shelf have been identified as containing exploitable sand deposits. As nearshore reserves become depleted, offshore sand resources are becoming more important. For example, it is estimated that Ship Shoal, located off of Louisiana, contains 1.6 billion cubic yards of sand appropriate for beach renourishment and land stabilization projects. The MMS is planning to use sediments mined from offshore sources to keep up with increased beach renourishment cycles, repair storm damage, prevent erosion, and prevent wetland loss due to anthropogenic alteration and sea level rise. Such areas may be important to biological communities and represent essential fish habitat (EFH) yet little information is available relative to the use of these offshore shoal areas by fish. There is potential long-term adverse impact to organisms as a result of offshore dredging if the physiography of a shoal feature is altered significantly. Before sand resources are exploited, detailed and specific geo-referenced information on biological communities and habitat relationships of organisms is needed. This information is vital if adverse impacts to fish species that inhabit the shoal regions are to be avoided or mitigated in the future.

In this on-going study, fish assemblages are quantitatively evaluated in potential sand resource areas in the northwestern Gulf of Mexico to assess the relationships among sediment types and the spatial distribution of communities. The specific objectives of this study are to: 1) Map and physically characterize discrete sediment-based habitats on Sabine Bank, Texas, 2) Conduct a quantitative assessment of any dominant demersal fish community (including juvenile red snapper) differences between the Sabine Bank habitat versus adjacent deeper waters, and 3) Conduct a quantitative assessment of any dominant demersal fish community (including juvenile red snapper) differences between center versus edge habitat of Sabine Bank.

A mapping contract was awarded by the USGS to Dr. Tim Dellapenna of Texas A&M University – Galveston to both produce high resolution side-scan sonar maps and physically characterize discrete benthic habitats in target areas of Sabine Bank. The data collected thus far displays a fairly homogenous low reflectance, or dark color, over most of the bank, indicative of muddy substrate. However, several ridges of high reflectance can be found on the western portion of the image indicative of hard substrate, most likely sand or shell hash ridges. A second mapping and ground-truthing cruise is presently being conducted.

The USGS has conducted two sampling cruises on Sabine Bank so far. Fifty-four trawls have been made targeting the demersal fish community. The two dominant demersal fish species found thus far are *Arius felis* (hardhead catfish) and *Micropogonias undulatus* (Atlantic croaker). Overall, very few flat-fishes (e.g., flounder, tongue fish), gobies, blennies, or searobin species have been recorded on the bank. Preliminary analysis shows some differences in the species composition and abundance of the demersal fish caught relative to landscape location. The final round of benthic fish sampling by the USGS, which is expected to be conducted this spring, will target the hard substrate areas identified by side-scan imagery.

# Ground-Water Flow Patterns of Augmented Lakes and Wetlands in the Northern Tampa Bay Area, Florida

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Over the past several decades, pumping from the Upper Floridan aquifer for municipal water supply in the Northern Tampa Bay area has accelerated downward leakage from the overlying surficial aquifer, lowering the water table and the water level of many lakes and wetlands. To restore the water levels, selected lakes and wetlands have been augmented with ground water from the Upper Floridian aquifer. The hydrologic consequences of using ground water to maintain lake and wetland water levels were investigated in two cooperative studies between the U.S. Geological Survey and Southwest Florida Water Management District. These studies generated detailed descriptions of the hydrogeologic framework and ground-water interactions at augmented and non-augmented lakes and wetlands in the Northern Tampa Bay area.

Similar ground-water flow patterns were observed around both augmented lakes and augmented wetlands. In comparison to non-augmented sites, the water levels of augmented lakes or wetlands were as much as 15 feet higher than the surrounding water-table elevation. Thus, the majority of the water used to augment lake and wetland water levels leaks into the surficial aquifer, raising the level of the water table. Augmentation maintains a sizeable, conical, ground-water mound around the lake or wetland. The water-table mounds mapped around lakes and wetlands typically extended 150 to approximately 500 feet laterally from the water's edge. The lateral outflow gradient is controlled by the horizontal and vertical hydraulic conductivity distribution, and is an important control on the augmentation rate required to maintain lakes and wetland water levels.

Hydrogeologic data from wells completed at various depths were used to compare the stratigraphy and the vertical flow patterns in augmented and non-augmented basins. The total vertical head loss beneath lakes or wetlands, and the distribution of this head loss within the surficial aquifer and the intermediate confining unit, varied at each site depending upon the hydrogeologic framework. Typically larger vertical head losses within the surficial aquifer indicated poorer confinement by the clay intermediate confining unit separating the surficial and Upper Floridan aquifers.

Net ground-water flow estimates provided insight into the differences in ground-water leakage rates at augmented and non-augmented sites. Leakage dominated the water budget at augmented sites, exceeding both rainfall and evaporation rates. For example, the monthly net ground-water outflow rates for two augmented sites (Round Lake and Duck Pond) were 8 and 20 times greater than the typical rate at non-augmented sites.

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# Simulation of Transient Ground-Water Recharge in Deep Water-Table Settings: A Simple Water-Balance/Transfer-Function Model

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A relatively simple method is needed that provides estimates of transient ground-water recharge in deep water-table settings that can be incorporated into other hydrologic models. Deep water-table settings are areas where the water table is below the reach of plant roots and virtually all water that is not lost to surface runoff, evaporation at land surface, or evapotranspiration in the root zone eventually becomes ground-water recharge. The complexities of meteorological variations and unsaturated flow processes make it very difficult to estimate short-term recharge rates, thereby confounding calibration and predictive use of transient hydrologic models.

A simple water-balance/transfer-function (WBTF) model was developed for simulating transient ground-water recharge in deep water-table settings. The WBTF model represents a one-dimensional column from the top of the vegetative canopy to the water table and consists of two components: (1) a water-balance module that simulates the water storage capacity of the vegetative canopy and root zone; and (2) a transfer-function module that simulates the traveltime of water as it percolates from the bottom of the root zone to the water table. Input data requirements include two time series for the period of interest—precipitation (or precipitation minus surface runoff if surface runoff is not negligible) and evapotranspiration—and values for five parameters that represent water storage capacity or soil-drainage characteristics.

A limiting assumption of the WBTF model is that the percolation of water below the root zone is a linear process. That is, percolating water is assumed to have the same traveltime characteristics, experiencing the same delay and attenuation, as it moves through the unsaturated zone. This assumption is more accurate if the moisture content, and consequently the unsaturated hydraulic conductivity, below the root zone does not vary substantially with time.

Results of the WBTF model were compared to those of the U.S. Geological Survey model VS2DT (a physics-based variably saturated flow model) and to field-based estimates of recharge to demonstrate the applicability of the WBTF model for a range of conditions relevant to deep water-table settings in central Florida. Field-based estimates of daily recharge were computed for a 334-day period by analysis of water-table fluctuations at a site with well drained sand and a water table that ranged from 2 to 3.5 meters below land surface. Recharge was simulated for 1- to 2-year periods for eight hypothetical field sites by using VS2DT and synthesized values of precipitation, ET, and soil properties for combinations of two soil types (sand and loamy sand) and four water-table depths (2.5, 5, 10, and 20 meters). The WBTF model reproduced independent estimates of recharge reasonably well for the range of soil types and water-table depths tested: coefficient of determination ( $r^2$ ) was 0.80 and standard error (SE) was 3.2 millimeters per day for the field-based estimates of recharge; and  $r^2$  ranged from 0.73 to 0.90 and SE ranged from 0.48 to 1.6 millimeters per day for VS2DT-simulated estimates of recharge.

# Florida Evapotranspiration Network

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Evapotranspiration (ET) returns to the atmosphere anywhere from 50 to 100 percent of average, annual rainfall in Florida, depending on location and surface cover. The relative magnitude of ET in Florida suggests the importance of temporal and spatial quantification of this atmospheric water flux for water resources management and analysis. However, ET traditionally has been the most difficult water budget term to quantify and has frequently been estimated through inference, rather than through direct measurement. This shortcoming in hydrologic knowledge limits construction of reliable hydrologic models for use as water management tools.

In response to the need for direct measurements of ET, the United States Geological Survey (USGS) began developing a network of micrometeorological stations for direct measurement of ET in 2000. The 11 stations operating as of March 2005 are located in four of the five State of Florida Water Management Districts (WMDs) and are funded cooperatively between the USGS and the WMDs. The primary objective of the network is to develop a database of long-term ET measurements at daily (at least) resolution in a variety of geographic and environmental settings in Florida. Two micrometeorological methods have been used for ET measurement: eddy correlation and Bowen-ratio energy-budget approaches. A secondary objective is to define the cause-and-effect relation between the environment and ET. Toward this goal, meteorological (air temperature, relative humidity, net radiation, solar insolation, soil/water temperature, and wind speed and direction), vegetative (leaf-area index and speciation), and hydrologic (soil moisture and water-table depth) measurements are made to develop links between the environment and ET.

The available data indicate a wide range in ET rates both temporally and spatially. Most variability in ET can be explained by variations in available energy and moisture status. For example, annual ET from a site on the Lake Wales Ridge with droughty sandy soils, a deep water-table, and shallow-rooted grass was 680 mm, roughly half of the average 1,470 mm of evaporation from a nearby lake. Strong diurnal and seasonal patterns in ET from vegetated sites were the result of corresponding variations in available energy primarily related to varying solar angle and cloud cover. Diurnal variations in open water evaporation were modest because of the buffering effect of changes in stored heat energy in the water body, whereas seasonal variations in evaporation were large (for example, 2- to 3-fold change from winter to late-spring at a lake in central Florida).

Remote sensing methods offer the potential to estimate ET “everywhere” in the State. Towards this goal, the database developed during this study is serving as ground-truthing for an on-going effort managed by the USGS, executed by research personnel at University of New Hampshire, University of Alabama, and Tufts University, and funded by all five WMDs to estimate Statewide potential and reference ET from 1995 through 2004 at 2-kilometer spatial and daily temporal resolution. Statewide estimation of actual ET is scheduled to begin in a follow-up phase of this effort. The approach relies on measurements of incoming solar radiation derived from Geostationary Operational Environmental Satellites (GOES) data, along with ground-based meteorological measurements to provide input for Priestley-Taylor and Penman-Monteith ET equations. The USGS is scheduled to assume complete operation of this effort for 2005 and beyond. The availability of the resulting database will establish a major milestone – potential and reference ET will be based on an approach shared by all of the State of Florida WMDs, allowing for a more unified and coherent approach to simulating, interpreting, and allocating the State’s water resources.

# The Rocky Glades: An Endangered Landscape and its Fishes

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The Rocky Glades is the remnant of a large, short-hydroperiod karst wetland that lies between Shark River and Taylor sloughs. It remains structurally intact and expansive only within Everglades National Park (ENP). Pre-drainage accounts indicated that this region was wetter and likely provided better habitat for aquatic species. Drainage has reduced wet- and dry-season water levels, and today, hydroperiods rarely exceed six months. To persist in this landscape, aquatic animals must disperse, find refuge, or perish. Few data had been collected to describe aquatic-animal community composition and successional patterns on the wetland surface until our study began in 2000. We developed a new trapping method, using drift fences with minnow traps, to document the relative abundance and catch per unit effort (CPUE) of animals during the wet season. Our objectives were to address several questions: how rapidly do different species appear in the traps; how does composition, size-structure, and recruitment of aquatic animals change during the flooding period; and what are the sources of colonizing fishes in the wet season? When the wetland surface dried in autumn, we began to sample solution holes, which are numerous karst cavities of varying areas and depths, in which access to groundwater offered a chance for survival to aquatic animals during the dry season. Historically, groundwater levels apparently were higher than under current management. We wished to learn if the holes were refuges for fishes under today's hydrological conditions.

On the wetland surface, we documented a rich community of 38 fish species, comprised mainly by small-bodied livebearers, killifishes, and sunfishes. With the advent of flooding, fishes and Everglades crayfish were collected with one or two days of wetland flooding. Each year, adults appeared first in the traps, followed by juveniles within one month. Juveniles of larger-bodied species were collected later in the wet seasons. Peak catches occurred within one to two weeks of re-flooding, and again as the sites dried. We documented the colonization and expansion of three newly introduced cichlid and catfish species, and two native species that are moving in from the north. There is evidence that these expansions are the result of recent water-delivery changes.

The numerous karst solution holes in this region once may have been effective dry-season refuges. However, our data demonstrated that nearly all fishes that entered the holes died as the waters receded simply because most holes dried. Most fishes that survived to the beginning of the wet season were introduced species, and were not the species that first colonized surface habitats. This suggests that initial wet-season colonists disperse into the Rocky Glades from elsewhere. The region appears to be a "sink" habitat for aquatic fauna under today's hydrologic conditions, dependent on connections to other landscape units for the replenishment of its fauna each wet season. We are investigating methods to determine the sources of those colonists.

We hypothesize that restoration of higher water levels in both the wet and dry seasons will lead to the enhancement of the biotic characteristics of the Rocky Glades by providing more persistent connections to other landscapes, causing longer flooding of the wetlands to allow animals to build up populations, and allowing better animal survival in the dry season as solution holes remain flooded and animals are confined within them for shorter periods.

# SLIC – When it is Good it's Very Very Good and When it is Bad, it's Horrid

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Short-Lived Isotopic Chronologies using  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  to assess surface processes has come into common use over the last four decades. Although produced by different processes, both become attached to sediment in a similar manner.  $^{210}\text{Pb}$  chronologies are based on mathematical models relating the decrease in activity with depth.  $^{137}\text{Cs}$ , a solely anthropogenic radioisotope, did not come into wide use until the late 1960's when it was recognized that atmospheric nuclear testing had produced significant concentrations.  $^{137}\text{Cs}$  chronologies are primarily based on the identification of the 1963/64 activity peak.

Most of the chronologic studies rely on one of these isotopes. Unfortunately, this does not supply enough information needed. The activity of an isotope may be affected by factors such as: sediment source(s), episodic or event-related deposition and post-depositional disturbance. Therefore, basic knowledge of the depositional controls is necessary in order to interpret sediment isotopic profiles. For example, in a core off the Bonnet Carré spill-way in Lake Pontchartrain, the  $^{210}\text{Pb}$  profile using the isotopic age models yielded a date of greater than 100 years at 70cm depth. However,  $^{137}\text{Cs}$  was present below this horizon. Since  $^{137}\text{Cs}$  did not exist prior to 1954, its presence in the lower portion of the core negates the date obtained using  $^{210}\text{Pb}$ . Upon further analysis of the core, it was determined that the  $^{210}\text{Pb}$  profile was an artifact of the chaotic flow regime during the opening of the spill way. A similar situation was found in the northern Everglades. In this case, the  $^{210}\text{Pb}$  started out low at the surface, rose to a peak mid-core then decreased with logarithmic decay. A standard explanation for this profile would be that the upper portion of the core had been physically or biologically disturbed. The  $^{137}\text{Cs}$  distribution showed no indication of disturbance and dated the change in  $^{210}\text{Pb}$  at approximately 1960. The  $^{210}\text{Pb}$  peak occurred at transition from a saw-grass dominated to a cattail dominated marsh. As the cattail peat accumulated at a higher rate, the lower concentration of  $^{210}\text{Pb}$  was attributed to the dilution of the isotopes due to the vegetative changes. These and like examples demonstrate the importance in using both isotopes coupling with knowledge of the sedimentary dynamics to properly ascertain a valid chronology.

# Modeling Manatee Response to Restoration in the Ten Thousand Islands and Everglades National Park

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We are developing a spatially explicit, individual-based model of the Florida manatee (*Trichechus manatus latirostris*) in southwestern Florida. This model is being used to project the potential effects of altered hydrologic regimes on manatees in southwest Florida. This model is parameterized with telemetry data for 30 manatees tracked between June 2000 and Dec 2003 in the Ten Thousand Islands area. These manatees showed a consistent pattern of feeding on marine seagrass beds in offshore zones for 1 to 7 days, followed by large movements of 5 to 30 km or more up rivers and canals to assess fresh water. A network data structure is used to model manatee movement between nodes representing destination sites for feeding, drinking, and thermal sheltering, all connected by arcs representing travel corridors. The travel corridors were developed from GPS telemetry points fixed at 15-30 minute intervals. The movement of manatees between different zones is simulated using a Markov Chain approach to transition manatees into different behavioral states that drive the movement patterns of individuals. Transition probabilities are derived using a mark-recapture (program MARK) Multi-State model. Virtual manatees are allocated home ranges comprising different portions of the total network that includes one or more freshwater sites, thermal refugia, and offshore seagrass beds. Salinities, water temperature, and water depth also are modeled along this network to reflect natural environmental variation and changes due to restoration. Manatees can shift their home range to different parts of the network if freshwater, thermal refugia, or seagrass become unavailable within their home range. These shifts are modeled using a reinforcement model which controls how manatees respond to changes in the availability of critical resources. Sensitivity analyses are used to evaluate the importance of different assumptions and uncertainty associated with poorly understood model parameters. As additional telemetry data are collected, the model will be refined to incorporate new insights from these data. Radiotracking and aerial surveys will provide an important means of monitoring manatee response to natural environmental fluctuations and human-induced alterations associated with restoration activities.

# Long-Term Stability of the Coastal Everglades: Disturbance, Sea-Level Rise, and Peat Collapse

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The majority of Everglades National Park is comprised of marine and estuarine habitats, a fact often overlooked by resource managers. The mangrove forests and salt marshes of the southwest Everglades provide important habitat for a variety of species, many of commercial or recreational importance and some endangered. Analysis of historical maps, charts, and aerial photographs indicates that portions of the coastal Everglades have undergone rapid change from one habitat type to another. For example, since 1927, 1,496 ha of marl-prairie marsh on Cape Sable have converted to open water, and 645 ha of fringing mangrove forest along Big Sable Creek have converted to barren, intertidal mudflats. In the region between Chatham and Lopez Rivers, large tracts of marsh have converted to mangrove forest, whereas between the Chatham and Lostmans Rivers, mangrove forest has become open water. These changes may be the result of a 22-cm rise in sea level over the past 75 years, the passage of several hurricanes across southern Florida, or, for Cape Sable, the construction of canals for drainage purposes. To assess the specific causes of habitat change, we compared 1927 and 1999 aerial photos to quantify and classify the type of habitat loss, examined core samples to assess subsurface processes contributing to these phenomena, measured sediment accretion and/or erosion, and assessed mangrove vegetation growth. Our preliminary findings indicate little correlation between the subsurface stratigraphy and habitat loss for interior marshes on Cape Sable. For the mangrove wetlands along Big Sable Creek, sediment elevation is decreasing, and mangrove vegetation has low growth and high mortality. We hypothesize that this habitat loss may be the result of hurricanes in 1935 and 1960, combined with sea-level rise, which led to peat collapse and conversion from mangrove forest to intertidal mudflat.



## **Session 4**

### **Environmental Health and Degradation**

**Session Leader: Dr. Ken Rice**

# Waste Water and Reef Health in the Florida Keys

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The islands that form the Florida Keys are adjacent to the only major coral reef within the territorial borders of the continental United States. Currently there are approximately 40,000 septic tanks, 10,000 cesspits, and 1,000 Class IV injection wells utilized for sewage disposal in the Keys. Due to the porous nature of limestone (which makes up the strata of the islands), coupled with natural physical dynamics of the region such as substrate flushing from precipitation and tidal pumping, these types of sewage-disposal systems are inadequate for protection of ground and surface waters from sewage-associated pollutants (e.g., nutrients, toxins, microorganisms, etc.).

Several studies conducted in the Florida Keys have demonstrated movement of contaminants from septic tanks and injection wells to the surrounding nearshore marine environment. In one study, 95% of the 19 samples sites (ranging from Key Largo to Key West) were positive for at least one of four pathogenic human virus groups (enteroviruses, HAV, Norwalk, Norwalk-like viruses). These results demonstrated that the canals and nearshore waters throughout the Florida Keys were being impacted by human fecal material carrying human enteric viruses through regional use of inadequate wastewater-disposal systems. Other studies showed that human enteroviruses could also be detected in coral mucus in nearshore environments. Recent and current studies have demonstrated the presence of the same viruses in offshore groundwater and the offshore reef environment.

This presentation will cover historical and ongoing microbiological research in the Florida Keys, which addresses the presence of waste water in nearshore and offshore sites throughout the Keys coral reef system. The primary focus will be the occurrence of indicator and pathogenic organisms in Keys marine waters and the use of molecular source tracking to identify point of origin (human versus animal).

# The Effects of Ecological Changes in South Florida: Are These Problems for Restoration?

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The goal of the landmark Everglades Restoration Act, signed by President Clinton on December 11, 2000, is to restore the nationally significant and unique natural resources of the Florida Everglades ecosystem. The gradual decline in water flow over the past 50 years has caused significant changes in ecosystem habitats. By returning at least 50% of historic water flow through South Florida, the Comprehensive Everglades Restoration Plan (CERP) aims to reverse the course of declining health of the ecosystem and reestablish the biological diversity of the Everglades. To meet these targets, it is imperative to understand how the habitats have changed and the rate at which the changes have occurred.

Over the past few decades, short-lived isotopes ( $^7\text{Be}$ ,  $^{210}\text{Pb}$ , and  $^{137}\text{Cs}$ ) have been used extensively to define the rates of habitat changes. In a 10-year study, short-lived isotopes were used to establish historical records and baseline information at 102 sites in the southern Everglades and Florida Bay. The most profound discovery was the recognition of distinct habitat changes in the lakes and mud islands along the northern boundary of the bay. Prior to 1950, the bay floor was rock: a hardbottom habitat. Beginning around 1950, concurrent with decrease in freshwater flow, the environment changed from estuarine to marine. With this shift, marine carbonate sediment began to accumulate, creating a soft-bottom ecosystem. In addition, because of the subsurface geology of South Florida and the nuances of the short-lived isotope systematics, it was determined that subsurface freshwater retreat had coincided with the estuarine-to-marine change.

The increasingly marine nature of the bay due to decreased freshwater influx also affected the central part of the bay by increasing production of carbonate sediment. Sediment accreted to the mud islands, extending tidal flats. As a result, passes between islands were closed. The effect was restricted circulation.

In the southern bay, the sediment accumulation record showed that deposition was not as affected by the change in hydrology but was controlled by variations in progressive sea-level rise. The sea-level record at Key West shows that sea-level rise has not been constant but has varied with periods of relatively rapid rise followed by periods of no change. On the leeward side of mud banks within Florida Bay, the variations in sea level result in shifts in sediment accumulation rates from an increased rate during rising sea level to a decreased rate during stable periods.

# The Role of Macroalgae in Perpetuating the Degraded State of Coral Reefs in the Florida Keys

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Prior to the 1980's, macroalgae were fairly inconspicuous members of most coral reef communities. During the last three decades, coral reef degradation resulting from a multitude of stressors has occurred on a global scale, usually manifested as a decrease in live coral, followed by a lasting proliferation of algae (termed a phase shift). A Florida Keys-wide monitoring program of 40 sites showed that coral cover declined by 38% between 1996 and 2000 (Porter et al. 2002). During this same period, the brown macroalgae *Dictyota* spp. became the dominant benthic organisms at depths between 0 and 25 m on many of these reefs, covering up to 56% of the bottom during the summer months. While increased competition between corals and algae is often assumed on reefs that have undergone phase shifts from coral to algal dominance, there is very little evidence that macroalgae are competitively dominant over adult scleractinian corals. Competitive interactions during early life history stages remain largely unexplored.

Coral recruitment is a key process in the maintenance and recovery of coral reef ecosystems, and recruitment failure could be a major reason why reefs in the Florida Keys remain degraded despite conservation efforts. While based at the Keys Marine Laboratory in Layton, FL, we conducted a series of field and outdoor seawater table experiments to test the hypothesis that some weedy species of macroalgae and cyanobacteria can inhibit coral recruitment. We studied the larvae of the hard coral *Porites astreoides* and the octocoral *Briareum asbestinum* from the time of release through to successful recruitment when subjected to treatments with various weedy algae. Specially designed larval recruitment chambers (n = 10 per treatment) were deployed in the field, supplying coral larvae with access to suitable settling habitat (conditioned terra cotta tiles) in a contained environment, while allowing natural water circulation via the 180 µm mesh sides, and natural solar irradiance through the clear, extruded acrylic tubing. Successfully settled larvae were further tested by attaching algae (or a mimic control) to the tiles to examine their prospects for survival and growth.

Six out of seven species tested caused either settlement inhibition or an avoidance behavior in larvae of the hard coral *Porites astreoides*. Further, *Lyngbya confervoides* and *Dictyota menstrualis* significantly increased mortality rates of *P. astreoides* recruits. Exposure to *Lyngbya majuscula* reduced survival and settlement in larvae of the octocoral *Briareum asbestinum*. These findings indicate that competitive interactions beyond simple space occupation between weedy primary producers and coral larvae could be important in perpetuating phase shifts from coral dominated communities, allowing algae to persist as the dominant benthic organisms. Thus, on Florida Keys reefs that are experiencing phase shifts or temporary algal blooms, coral settlement rates may be reduced despite the availability of appropriate substrate.

# Microbial Ecology of Sediments and Pore Waters of Tampa Bay

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Tampa Bay, located on the subtropical west coast of Florida, is one of the largest estuaries in the Gulf of Mexico. The Tampa Bay watershed supports recreational, agricultural, and industrial activities, and unique and sensitive coastal environments. Recreational, agricultural and industrial activities, in addition to the commercial and residential development that has taken place during the past 25 years, put increasing degrees of environmental stress on the natural resources and ecosystems within the bay. All of the activities have collectively contributed to an overall decrease in the water quality of the bay.

A central charge of the Tampa Bay Integrated Science Project is to develop baseline data that will assist in the modeling of changes in chemical, physical, and biological parameters within Tampa Bay. Bacteria have been shown to play a central role in the cycling of nutrients and minerals and in the mineralization of pollutants in all aquatic systems that have been studied to date. However, there are no data on even the most basic aspect of the microbial ecology of bacteria in the water column or sediment systems of Tampa Bay. The purpose of this talk is to present the results of a study to provide baseline data on the abundance and productivity of bacteria on sediments and within the pore waters of sediments in Tampa Bay.

Three sites were selected to collect baseline data: (1) an area impacted by a spill of acidic process water ( $50\text{-}56 \times 10^6$  gallons) from a phosphoric acid and fertilizer production facility in 1997 and still devoid of vegetation, (2) an area impacted by stream effluent from urban and agricultural regions, and (3) an area not impacted by human activities and minimally impacted by runoff and stream discharges. Samples were collected from the sediment surface and at 2.5-cm intervals to a depth of 7.5-cm in March and August, 2003. Temperature, pH, salinity, and redox potential were measured in the field. Laboratory analyses included total direct counts, secondary productivity ( $^3\text{H}$ -leucine incorporation), community-level physiological profiles (CLPP), and analyses for manganese and iron.

Bacterial abundance in the pore water was relatively consistent at all sites and depths, averaging  $2.10 \times 10^6$  cells  $\text{ml}^{-1}$  of pore water and  $2.50 \times 10^6$  cells  $\text{gr}^{-1}$  dry weight of sediment. However, there were significant differences in porewater bacterial productivities at the acid and urban discharge-impacted sites ( $161.9 \mu\text{g C L}^{-1}\text{d}^{-1}$ ) when compared to the non-impacted site ( $7.6 \mu\text{g C L}^{-1}\text{d}^{-1}$ ). The bacterial productivity values for the sediments from the same areas were not significantly different ( $5.0 \mu\text{g C kg}^{-1}\text{d}^{-1}$  and  $4.0 \mu\text{g C kg}^{-1}\text{d}^{-1}$ , respectively). There was also a general trend of increasing Mn and Fe concentrations with depth at all sites, with greater concentrations of both metals at the impacted sites. Both metals were significantly correlated with redox potential. The relationship between the two impacted sites and the non-impacted site, as determined by bacterial-community activities, is also supported by the CLPP analyses, with both impacted sites being closely related but significantly different from the non-impacted site.

In summary: 1) the sediment systems of Tampa Bay become anoxic and reduced  $< 2.5$  cm from the surface, 2) the pore waters of the Tampa Bay sediment system have bacterial abundances and productivities that are greater than those associated with the sediments, 3) there is a significant difference in the data trends between the non-impacted site and the other two sample sites. The differences are presumed to be the result of higher organic loads (i.e., higher and more complex food sources for bacteria) at the urban-runoff site and alterations in the bacterial community at the site impacted by the acid spill that have adapted those communities to the extreme conditions, 4) the CLPP analyses indicated that there were

significant differences among each site and vertically within each site during the time of both sample events. There was a general shift in preferential substrate utilization from the carboxylic acid to the carbohydrate group in the August samples, 5) bacterial productivity in the sediment systems of Tampa Bay is relatively high year round, with greater productivity during August when water temperatures are higher, 6) based on redox potential and Mn and Fe concentrations in the pore waters, there is a general trend of increasing cycling and utilization of these metals for bacterial metabolism during August when water temperatures are warmer and bacterial abundances and productivities are greatest.

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# Integrating Information for Environmental Decision Making

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Resource managers and decision makers clamor for better scientific information in an environmental crisis, and science agencies strive to produce better information in a timely fashion. However, research on the use of information in decision making reveals that in any real-world situation, there always seems to be too much information but not enough pertinent information. Existing information is frequently not integrated and is inevitably designed to address a previous crisis. Even if a particular project succeeds in integrating a large number of datasets, the integrated information may not necessarily be useful in future studies. Information has a short half-life.

This presentation reports on a social science research project that examined the context surrounding the creation of a shared regional database of rivers and streams in the Pacific Northwest salmon crisis in the late 1990s. This database, which formed the backbone for integrating watershed information from many different scientific disciplines, was essential to show the geographic context of habitat problems in the region's watersheds and to display different management scenarios. Federal, state, and local government agencies, Native American tribes, private companies and non-governmental organizations participated in this project. Project analysis reveals that integrating and maintaining different types of information that had been collected piecemeal over the years by these many different groups created both opportunities and problems.

The process of shared database creation forged new and lasting relationships among organizations that had historically not cooperated. Difficulties were encountered in the formalization process due to strong linkages between local disciplinary practices and data creation; in the deployment of standards; in eliciting buy-in for Internet-based forms of participation; and in envisioning situations in which users might need to become creators of data and thus have ownership and partial control of the database.

This case study demonstrates that opportunities and problems are applicable to most large-scale data-and-information integration projects, and that engaging social scientists in the construction of these systems is essential.

# **Air, Water, and Corals: Integrated Research at Dry Tortugas National Park**

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Ten groundwater-monitoring wells were installed in and around Fort Jefferson, 65 miles west of Key West, Florida. The wells were continuously cored to depths between 6 to 18 m below sea level. The screened wells encountered pre-Holocene coralline limestone beneath overlying Holocene coral and carbonate sand at 16 m below sea level. Ground water, surface water, air, and coral mucous are sampled quarterly to determine bacterial and viral content and to compare with coral vitality and human influence. Salinity and nutrient analyses of well and surface water monitors determine efficiency of sewage treatment and fluctuations of the fresh water lens under the island.