Design and implementation of dye-tracer injection test, Cudjoe Key, Florida Keys.

Proposal submitted to:

Florida Keys Aqueduct Authority
Attention: **Tom. G. Walker, PE, BCEE**
Deputy Executive Director
Utility Operations Division

Henry O. Briceño, Reinaldo Garcia, Piero Gardinali, Kevin Boswell
Florida International University

and

Eugene Shinn
University of South Florida

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EXECUTIVE SUMMARY

Monroe County and the Florida Keys Aqueduct Authority (FKAA) are currently constructing the Regional Centralized Wastewater Collection System and the Advanced Treatment Wastewater Facility (AWTF) located at Cudjoe Key, where treated waters would be disposed by injection through four Class V shallow wells (120 ft). Little is known on the specific ground geology of Cudjoe Key. While there is a large volume of information documenting high hydraulic conductivity from injected water to surface waters in other localities in the Florida Keys, there are also references to the existence of impervious layers within the rock pile that preclude vertical flow of ground waters to the surface. Both, high hydraulic conductivity and impervious layers were formed by surficial exposure of the carbonate sediments to weathering processes and karst development, due to past sea level fluctuations. Facing this duality and controversial technical information, and to guarantee that water quality in the ecosystems surrounding AWTF are not impacted by the injection operations, the FKAA requested from Florida International University (FIU) the design and implementation of a dye-tracer injection test. The final objective of this test is to either confirm or rule-out the existence of hydraulic connection between the shallow injection wells discharge and surface waters. The design of the test will be performed with the Environmental Protection Agency's **EHDT** software to estimate tracer mass, sampling frequencies and dye breakthrough curves for selected monitoring sites. Test monitoring samples will be collected at 3 injection wells (IW) and 5 observation wells (OW), and along transects and fixed sites in surface water bodies as recommended by the modeled design.

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INTRODUCTION

The Florida Keys National Marine Sanctuary contains nationally significant marine environments such as mangrove forest, large seagrass beds, and the only living coral barrier reef in North America. Mangrove forests play an important role as nursery for fish and as shoreline protection against storm and sea level rise. The reef tract starts at the Dry Tortugas and extends to Miami to finally continue north to Palm Beach as patch reefs. It contains over fifty species of corals representing over eighty percent of all the coral reef species in the Tropical Western Atlantic. There are over one hundred fifty species of fish reported for this important reef. These reefs make Florida the number one dive destination in the world, which together with industrial and sport fishing and other water-related activities support the economy of Monroe County. Millions of people visit the Florida Keys every year, mostly because of these reefs whose estimated asset value is of $7.6 billion (Johns et al., 2001).

Monroe County is devoting especial effort and funds to curtail pollution to the Sanctuary from runoff and canals, and in conjunction with the Florida Keys Aqueduct Authority (FKAA), is incorporating communities to the Regional Centralized Wastewater Collection System and Advanced Treatment Wastewater Facility. The proposed Wastewater Treatment Facility (AWTF), located in Cudjoe Key, is a step forward to confront and solve the most important source of pollution, human waste (Fig 1). The AWTF will use an advanced, five-stage Bardenpho Wastewater Treatment System. It will provide service to Lower Sugarloaf Key, Upper Sugarloaf Key, Cudjoe Key, Summerland Key, Ramrod Key, Little Torch Key and Big Pine Key. The final objective of the AWTF is to reduce nutrient and bacteria loading and improve water quality in the Sanctuary, and to comply with relevant federal and state regulatory standards.

The AWTF would use Class V shallow well injection for effluent disposal (USACE 2010). In order to guarantee that injected treated waters do not reach the surface and pollute further the valuable water bodies and ecosystem of the Florida Keys National Marine Sanctuary, the FKAA has requested from FIU the design and implementation of a dye-tracer injection test. The proposed dye-tracer injection test is the subject of this document.

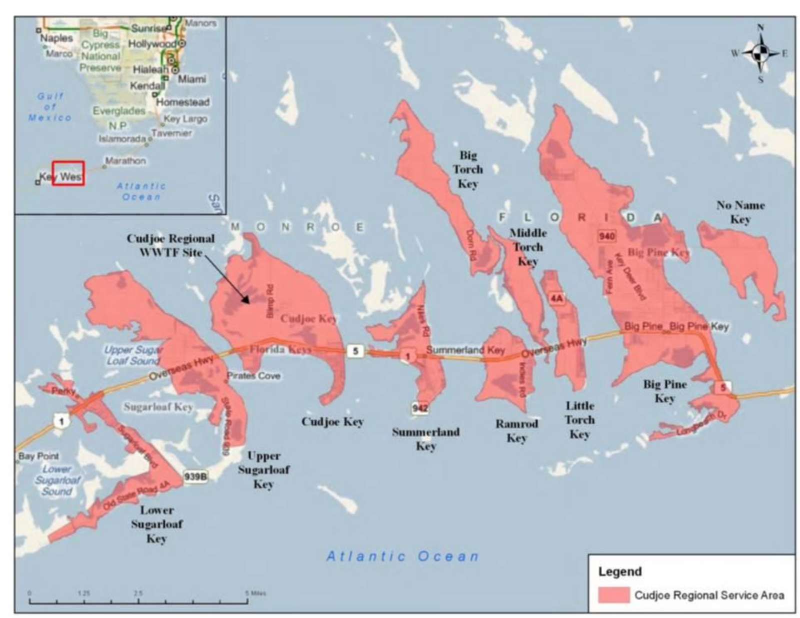

Figure 1: Location of Cudjoe Key AWT Plant in the Lower Keys region and areas to be serviced.

Given the uncertainties in groundwater hydrology and the possibility of initiating treated water injection on March 2015, the project has been conceived to extend for a two-month period, January to February 2015.

Geology

Cudjoe Key has not been the specific subject of geological cartography in the past, and most of the information discussed below comes from regional studies, like that of Hoffmeister and Multer (1968) who reported 20 feet of oolite underlain by 180 feet of Key Largo Limestone in a core drilled on Big Pine Key. According to Cunningham et al. (1998) the expected stratigraphic column for the Cudjoe Key region should contain rocks of the Miami Limestone on surface (up to 30 ft of oolitic carbonates), underlain by thickly bedded coralline boundstones on top of other shallow marine carbonates (wacke-packstone) of the Key Largo Limestone (Fig 2 and 3). The low gamma ray profile, irregular caliper measurements, highly irregular resistivity, low sonic values and varied lithology shown in Figure 3 suggest that the upper portion of the Key Largo Limestone in the region, from 20 to 40 m (65 to 147 ft) is carbonate with high porosity within the coralline rock intervals.

Flow of groundwater usually follows preferential paths within rock units. Such preferential routes may be lithological (i.e. highly permeable rocks), controlled by discontinuities in the rock pile (bedding planes, joints, faults, unconformities) and preferential passages formed by dissolution and collapse of rock units due to karst processes. Carbonates of the Florida Peninsula and the Florida Keys have been subjected to intense karst processes in the last million years driven by climate and sea level fluctuations (White, 1970; Brinkmann and Reeder, 1994; Tihansky, 1999; Shinn et al. 1999a). Karstification processes have played a critical role in the hydrogeology of Florida by developing highly transmissive and heterogeneous zones within carbonate aquifers, sometimes indicating upward movement of groundwater associated with lateral transport to surface water bodies (Shinn 1999a, 1999b; Paul et al 1995, 1997; Reich et al. 2001), with flow rates ranging from 1 to tens of m/day.

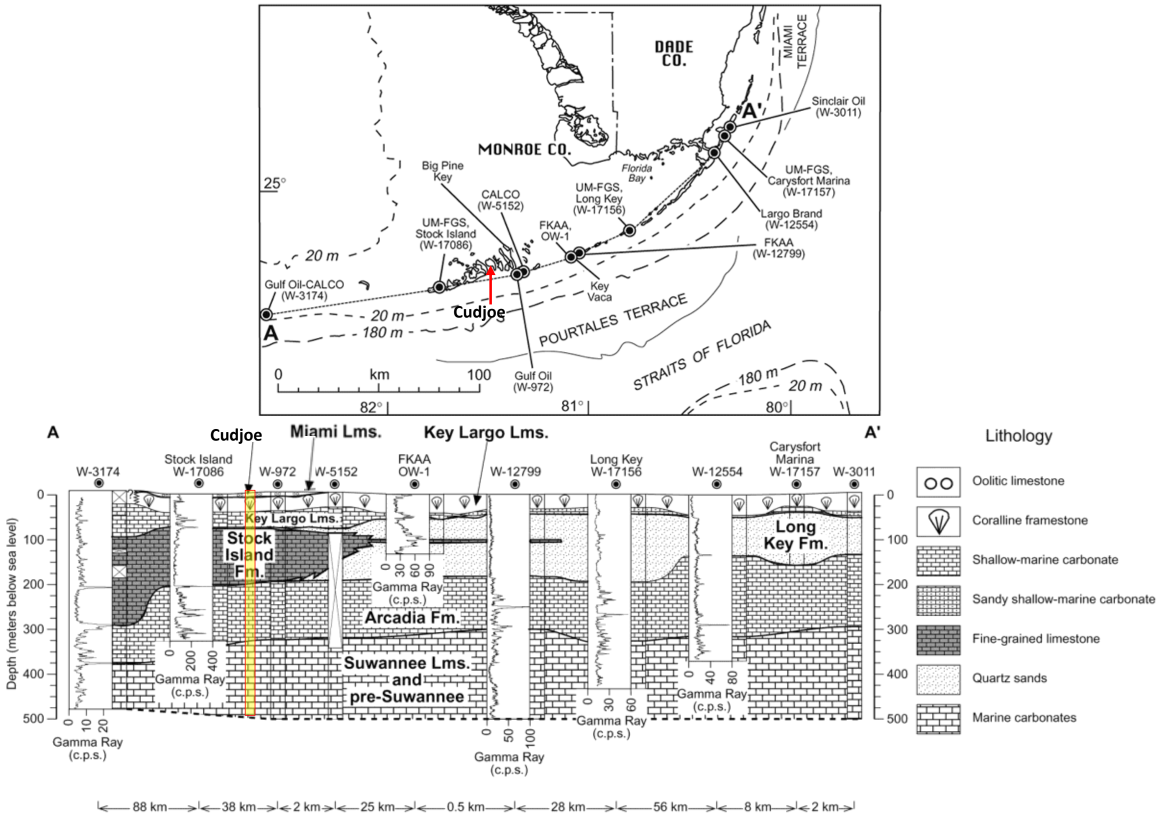

Figure 2: Southwest-to-northeast stratigraphic cross section along the Florida Keys from the Dry Tortugas (A) to Key Largo (A'). Also shown is Cudjoe Key (above) and approximate location of stratigraphic column at Cudjoe (yellow column). Modified from Cunningham et al. 1998.

Böhlke et al. (1999) and Reich et al (2001), studied ground water underlying both, the Florida Bay and the Atlantic coast side of the Keys, at depths of about 3 to 20 m (9 to 66 ft) below the sediment surface. They found that recent fine sediments on top of the bedrock are the most efficient barriers to groundwater migration to the surface. Also, wherever more than one depth could be sampled at the same site the deeper water appeared to be older, suggesting lack of mixing, and hence, lack of vertical migration, at least to those studied depths.

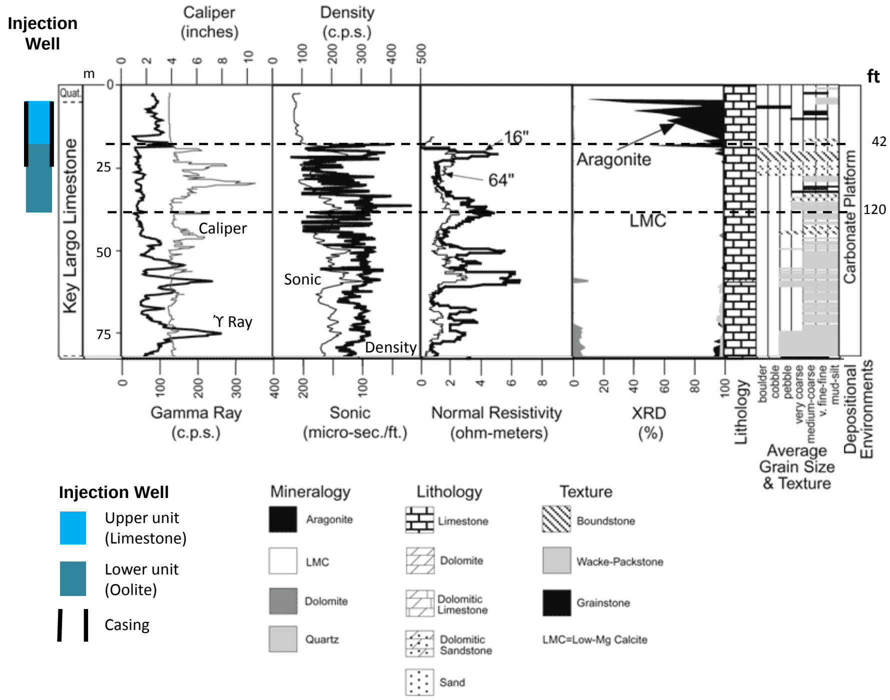

Figure 3: Geophysical and lithological descriptions of the Key Largo Limestone in the Cudjoe Region (modified from Cunningham et al. 1998).

Figure 4: Karst solution on the top of the Key Largo Limestone, Windley Key Quarry State Park. Photo by Eric Hiatt

Coniglio et al (1983a, 1983b) identified the existence of at least five regional caliche intervals within the Key Largo Limestone which "create an impermeable barrier to upward groundwater flow". These barriers while precluding vertical flow of ground waters to the surface, cause lateral flow within the rock pile. Both, high hydraulic conductivity and impervious layers were formed by surficial exposure of the carbonate sediments to weathering processes and karst development, due to past sea level fluctuations.

In summary, there is technical information documenting both, expedite communication between shallow injection wells (up to 90’ deep) and surface waters in some localities, and the existence of impervious layers within the rock pile which drive horizontal flow and could impede injected waters to reach nearby surface water bodies. In summary, it is not possible to extrapolate ground conditions from different localities, and hydraulic properties must be determined at each site. Hence, to guarantee that water quality in the ecosystems surrounding AWTF are not impacted by the injection operations, the FKAA requested from Florida International University the design and implementation of a dye-tracer injection test at the AWTF site. The final objective of this test is to either confirm or rule-out the existence of hydraulic connection between the shallow injection well discharge and surface waters at Cudjoe Key.

PROPOSED DYE-TRACER INJECTION TEST

Several dye-tracer studies have been performed in the Florida Keys in the past (Paul et al. 1995, 1997; Shinn et al. 1999a, 1999b; Böhlke et al. 1999; and Reich et al 2001). In those studies Fluorescein, Rhodamine and other compounds (bacteriophages, sulfur hexafluoride, etc) were used as tracers. In all cases, tracers were detected in wells (5-100 m away), nearby canals or even several hundred meters offshore within days to weeks of dye injection. We do not know the specific hydraulic properties of the rock sequence above the injection depth at Cudjoe Key (80-120 ft), but we must be prepared for all possible outcomes and monitoring would begin soon after injection.

Table 1 shows specific attributes of several of the fluorescent dyes commonly used for tracing ground-water flow. We have pre-selected Sodium Fluorescein (Fluorescein) and Rhodamine WT (Rhodamine) for the test, given these are environmentally friendly dyes approved by EPA, with moderate to very low sorption tendency (conservative tendency), strong spectral intensity, well developed analytical techniques, very distinctive color contrast, and low cost of analysis. Fluorescein has only one handicap, it tends to photodecay. Although it is not a problem for groundwater sampling, surface measurements and sampling need to take this into consideration because sunlight may diminish total mass recovery. The disadvantage of Rhodamine WT is its moderate sorption tendency. Results from the modeling stage to design the dye-tracer test will indicate the best choice of dye.

Quantitative hydrological tracer testing is perhaps the most reliable methods for defining solute-transport trajectories and for assessing solute-transport parameters. Determination of the tracer mass, where the tracer will arrive, travel distances and sampling frequencies necessary for a successful tracer test is a complicated task, especially in karstic terrains like Cudjoe Key.

Table 1. Data on some common fluorescent tracer dyes.

	Maximum Excitation (nm)	(1)Maximum emission (nm)	Fluorescence intensity (%)	(2)Detection Limit (µg L−1)	Sorption tendency
sodium fluorescein	**492**	**513**	**100**	**0.002**	**ver low**
eosin	515	535	18	0.01	low
Rhodamine B	555	582	60	0.006	strong
Rhodamine WT	**558**	**583**	**25**	**0.006**	**moderate**
Sulpho Rhodamine G	535	555	14	0.005	moderate
Sulpho Rhodamine B	560	584	30	0.007	moderate
Tinopal CBS-X	355	435	60	0.01	moderate
Phorwite BBH Pure	349	439	2	?	?
Diphenyl Brilliant Flavine 7GFF	415	489	?	?	?
Lissamine Flavine FF	422	512	1.6	?	?
pyranine	460 (3)	512	18	?	?
	407 (4)	512	6	?	?
amino G acid	359	459	1	?	?
sodium napthionate	325	420	18	0.07	low

1. Values are approximate only. Different instruments will yield slightly different results.
2. Typical values for tracer detection in clean water using spectrofluorometric instrumentation.
Values may be adversely affected by augmented fluorescence and/or scattered light background.
Values will be lower when using filter fluorometric instrumentation.
3. pH . 10
4. pH . 4.5

Estimation of water volume and degree of dispersal can be performed without major complications for surface water bodies, but aquifer hydraulics, volume and underground dispersal network are practically unknowns until a quantitative tracer test is conducted and numerically evaluated (EPA 2003). Calculations for these parameters have been performed in the past using a diverse set of equations, but results from those equations are wide-ranging, given the assumption that they could be applied to any hydrologic setting. Additionally, those equations fail to properly account for the important effects of axial dispersion and solute-transport theory (EPA 2003). The Environmental Protection Agency developed software to address specifically those uncertainties, the Efficient Hydrologic Tracer-test Design software (EHTD; EPA 2003). We will apply this software to Cudjoe Key.

BASELINE ASSESSMENT

Fluorescein has been used to color automobile antifreeze for many years and it may be present in the sanitary fill and ground waters at Cudjoe Key. Additionally several organic compounds may interfere with the spectral response of dyes. Hence, given the possibility of interference by substances already in the system, a 3 day pre-dye tracer injection monitoring period will be conducted, designed to measure the magnitude and variability of in situ fluorescence of well and surface waters at the selected monitoring sites. Detected background concentrations in samples will be averaged. This averaged value will be subtracted from every sample of recovered tracer from subsequent tracing efforts as recommended by EPA (2003).

Before dye-injection we will perform a series of activities to define a baseline and characterize the system as follows;

1- Baseline assessment of physicochemical properties of water in observation (5) and injection (4) wells. Wells will be purged and left to recover. Once wells have recovered their water level, samples will be collected. For the collection from wells we will use ISCO Autosamplers programmed to collect water samples pumped every hour for 72 hours from a depth of 80-100 ft for four IWs and at a depth of 18 ft for OW (Fig 5). Samples collected from the wells will be placed in dark amber polypropylene bottles and analyzed on site.

2- Baseline assessment of water physicochemical properties in lake waters located North of AWTF, as well as the ponds located immediately to the South of AWTF. The assessment will be done with continuous recording of physicochemical properties and dye concentrations along transects. Instruments will be deployed on an unmanned surface vessel (USV) to transit approximately 6 miles of transects (Fig 6). We will deploy a submersible fluorometer to measure dye concentration, and a multi-sensor, water quality monitoring instrument (YSI sonde) to measure physiochemical parameters of water quality. The USV (Fig 7) was developed to support autonomous survey missions in shallow and coastal marine habitats. The specific purpose is to provide a stable platform to acquire high-resolution in waters that are difficult to maneuver within or dangerous to operate with a traditional vessel. The USV was designed to be modular, in that it can be disassembled and shipped to a working destination. We have shipped to several research locations in Alaska as well as Iceland to support nearshore research projects. When assembled it is approximately 4m in length and can be outfitted with an array of devices which provide realtime data back to the base station. Under normal operating conditions, the USV has an endurance of approximately 6 hrs between battery changes. The USV can operate in waters as shallow as ~0.5 m

3- Photogeological interpretation of Cudjoe Key satellite and Lidar images to map linear features and epikarst structures, with potential to act as conduits for ground water flow. This information is intended to help the selection of surface monitoring sites.

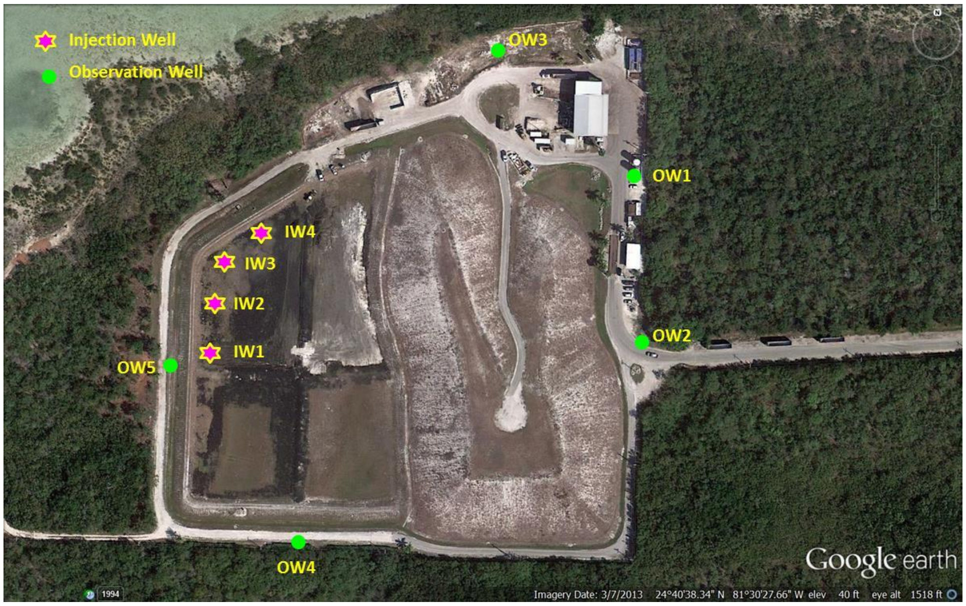

Figure 5: Advanced Wastewater Treatment Facility site at Cudjoe Key. Location of Injection (IW) and Observation (OW) wells

Figure 6: Transects to be measured in water bodies North and South of AWTF. Transect N= 3.2 mi; Transect S=0.8 mi

Field measurements

Technological advances in the last decade allow the determination of dye-tracer in water at extremely low concentration (parts per trillion). We will use two types of fluorometers to measure dye-concentration in waters, a field deployable Turner C3® Submersible Fluorometer, and an Aqualog® Benchtop Fluorometer to be installed in a trailer at Cudjoe Key. The field fluorometer will be deployed on a floating platform together with an YSI sonde, a GPS and a datalogger. From this platform we will measure dye and physicochemical variables along transects in water bodies to the North and South of the AWTF. The multi-sensor, water quality monitoring instrument (YSI sonde) will measure physiochemical parameters of water quality including salinity (PSU), specific conductance (µS cm^{-1}), temperature (°C), dissolved oxygen (DO; mg l^{-1}), %DO Saturation and pH.

Table 2: Technical specifications for field fluorometer (ppb= parts per billion)

	Detection Limit	ConcentrationRange
Fluorescein Dye	0.01 ppb	0-500 ppb
Rhodamine Dye	0.01 ppb	0-1000 ppb

Figure 7: Unmanned surface vessel (USV) in Alaska. It will transit Cudjoe Key lakes and ponds deploying a submersible fluorometer to simultaneously measure dye concentration, and a multi-sensor, water quality monitoring instrument (YSI sonde) to measure physiochemical parameters of water quality.

DYE-TRACER TEST DESIGN

We will use the EPA-EHTD software for the basic design of the tracer test at Cudjoe Key. This software (EPA 2003) is based on the assumption that field-measured parameters (e.g., discharge, distance, cross-sectional area) can be combined in functional relationships that are coupled with the concept of a “continuous stirred tank reactor” and solute-transport theory to produce a detailed assessment of expected tracer-test results (Field 2001). In summary, root determination of the one-dimensional advection–dispersion equation using a preset average concentration provides a theoretical basis to estimate tracer mass. Introduction of the calculated tracer mass with the hydraulic and geometric parameters in the advection-dispersion equation render an initial sample-collection time and subsequent sample collection frequency. From these, a likely tracer-breakthrough curve for each sampling station is calculated. Location of sites to be sampled at surface water bodies (lake and ponds) will be optimized with the EDHT design software, in conjunction with results from photo-geological interpretation of remote sensing images to outline discontinuities and karst features acting as potential conduits for ground water flow.

Once the results of the EHTD are available, the recommended mass of dye, either Fluorescein or Rhodamine will be injected through the screened depth of one injection well (80 to 120 ft), followed by the injection of a specific volume of chaser water to force the dye into the aquifer. To mimic as much as possible future operations, freshwater should be used as carrier of the dye. This water must be supplied by the FKAA.

Initial monitoring sites would include the remaining three injection wells, the existing five observation wells constructed for monitoring ground water around the landfill, and sites located in lakes and ponds to the north and south of the injection wells. The final location of these sites and the required tracer mass, specific volume of chaser water to force the dye into the aquifer, sampling frequency, and the tracer-breakthrough curves at the selected sampling sites will be established from results of the EHTD model.

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TIME CONSTRAINTS

The FKAA is considering the initiation of treated water injection no later than March 2015. Hence there are only two months to design and implement the dye-tracer test. Additionally, the final duration of the test is at this time unpredictable given the wide range of hydraulic conductivities reported for the Florida Keys, which span from a fraction of centimeter to hundreds of meters per day. In this context, and for budgetary purposes, this proposal considers only the following initial stages for the dye-tracer test:

1- Baseline Study
2- Dye-tracer test design
3- Injection of dye and monitoring for one (1) month

Additional monitoring time may be accommodated according to FKAA needs and request. A six-month monitoring module will be added to this proposal as reference in case of project continuation beyond February 2015.

DATA MANAGEMENT

The principal investigator will develop and maintain protocols and procedures under a data management program for water sampling/monitoring to ensure that the data generated are reported to the

FKAA in a timely manner. All original and ancillary data produced under this project will be generated, processed, stored, and archived in a manner that provides detailed documentation of the procedures used at all stages of data collection, reduction, processing, analysis, and storage. Field data gathering will follow the protocols and guidance of the "National Field Manual for the Collection of Well Water-Quality Data" (USGS 2006). The data will be analyzed using appropriate statistical tests of significance to meet the specific objectives of the monitoring program.

Given the special characteristics of this test and the expected high sampling/measuring frequency, the Principal Investigator will produce a weekly summary of the data in a logical format based on the design. The principal investigator will submit a data and narrative report documenting the results.

RESULTS AND DELIVERABLES

Baseline of Dye-tracer and physicochemical parameters

Upon completion of the data gathering and analysis of samples from each well and transect, before dye injection, the PI will submit the gathered and calculated data and narrative reports documenting the results of the baseline analyses. The data report will include the raw data and statistical summaries in hard copy and electronic format. Results of the photogeological interpretation of satellite and Lidar images will also be included in the report.

Modeling Outcomes

At the end of the first month the results of the implementation of the EHTD model (EPA 2003) will be presented in a report, together with the plan of activities for the dye-tracer test which will immediately follow. The report will include the estimated tracer mass to be injected, sample-collection time and subsequent sample collection frequency, as well as tracer-breakthrough curve for each selected sampling station.

Extended Monitoring Program

Once the modeling results are available we will prepare and submit a proposal of monitoring program in case the dye-tracer test extends beyond the end of February 2015. This monitoring program would take into consideration the beginning of operations of the AWTF and the injection of treated waters as scheduled by the FKAA.

Dye-tracer injection test results

Brief weekly reports will be submitted to the FKAA describing the advances of the dye-tracer test, and updated data files of dye determinations in well and surface waters.

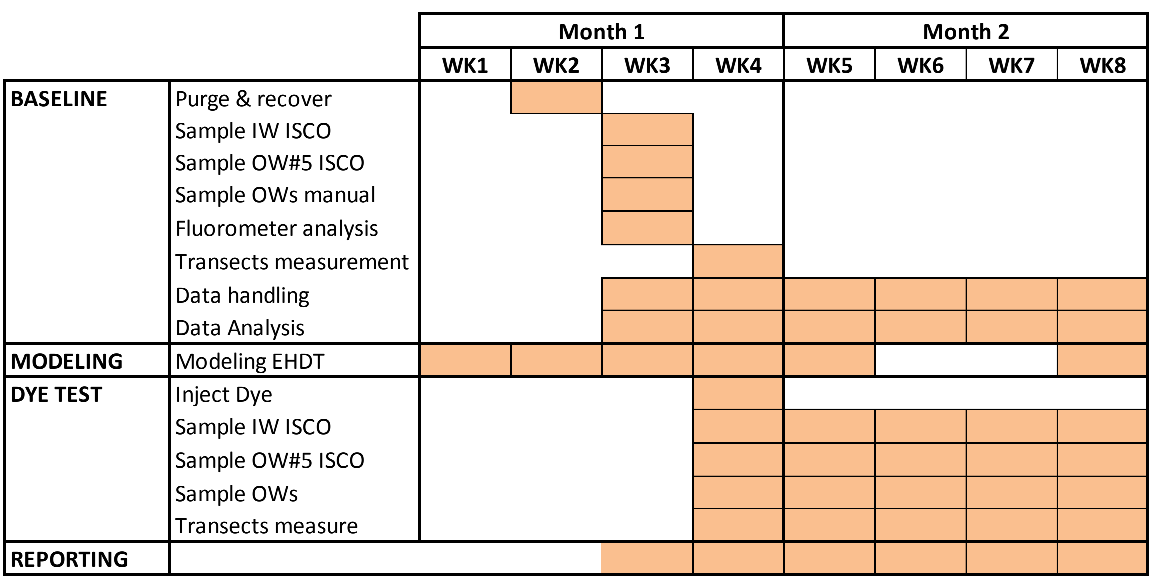

Figure 8: Project Time-table

Final Report

A final report, containing the design, implementation and results of the dye-tracer injection test will be delivered two weeks after conclusion of test, either due to detection and quantification of dye migration to the surface, or before initiation of injection of treated waters from the AWTF. The draft Final Report should summarize the objectives, methods, and results of the dye-tracer injection test. The report should interpret the results in relation to the objectives of the baseline definition and dye-tracer injection study. The draft Final Report will be reviewed by the FKAA and returned with comments to FIU. The PI will address the comments and submit the Final Report with revisions.

PROJECT MANAGEMENT

The Principal Investigator (PI) will be responsible for administration of all contract activities, financial budgeting, procurement of services, supplies, and equipment, compliance with QA/QC, and reporting.

REQUIRED SUPPORT FROM FKAA

We at FIU understand that the performance of this kind of test is very disruptive of normal FKAA operations, and interventions with equipment and installations beyond simple interactions. Also, the test is very demanding and labor intensive, so the presence of FIU staff is going to be almost permanently for the two months following contract approval. In order to facilitate the test, save time and money, and avoid complications and delays, we respectfully request the following support from the FKAA:

1- In order to define a Baseline of water quality for indicators of potential change caused by treated water injection, we must collect and analyze well waters from both, injection and observation wells. The initial collection of these samples entails a previous purge of each well and a period of recovery of 24 hours. Purge of wells is a delicate operation which requires especial equipment and knowhow, not available from the FIU team. Hence, purging of wells and disposal of purge water would be requested from the FKAA.

2- FIU will prepare all the available information to be delivered to the FDEP in order to proceed with the dye-test. FIU will submit the information package to the FKAA, which, in turn, would request permission from Monroe County, owner of the wells, and would inform the FDEP.

3- FIU personnel would need 24/7 free access to the wells and surroundings, including water bodies to the North and South of the AWTF site.

4- Given the special characteristics of this project, which requires FIU staff almost permanently in that remote site, we will rent a motor home to be used as laboratory and as quarters. We would appreciate if the FKAA allowed us to park the RV by your facilities at Cudjoe Key, and to hook-up the bench-top fluorometer to your electrical grid.

5- The recommended mass of dye, either Fluorescein or Rhodamine will be injected through the screened depth of one injection well (80 to 120 ft), followed by the injection of a specific volume of chaser freshwater to force the dye into the aquifer. The chaser water and injection would be supplied by the FKAA

6- Four ISCO Autosamplers will draw water samples from three injection wells and one observation well (OW#5) during the Baseline characterization and also after dye injection. For the Baseline stage, samples will be automatically collected every hour for three days. Sampling frequency for after injection stage will be established during the modeling stage. In any case it's foreseeable that we will have ISCOs connected for at least one month to the selected wells. ISCO Autosamplers have a small pump able to lift samples under 80 ft of head, using a ½ inch pipe or tubing. Then, we would not need additional pumps from FKAA, but we will need the installation of the necessary tubing and technical support at the wellhead to make a safe connection and to avoid any clogging of the well. We are counting on FKAA to supply the technical help when introducing the polyurethane tubing into the wells.

PERSONNEL SUMMARIES

### Henry Briceño, PhD		Principal Investigator		Water Quality

Southeast Environmental Research Center (SERC)
Florida International University
11200 SW 8th Street, Miami, FL 33199
Email: bricenoh@fiu.edu
Phone: +305-348-1269

Summary

Currently, Dr. Briceño is a Research Professor at the Southeast Environmental Research Center of Florida International University, after being professor at Universidad Central de Venezuela since 1976. His research activities along his 37 years of professional career include Geochemical Watershed Assessment, Biogeochemistry of Coastal and Estuarine waters, Tropical Weathering, Engineering Geology, Geochemical Exploration, Geomorphology and Remote Sensing. He was in charge of the Low-Temperature Geochemistry Laboratory, the X-Ray Laboratory and the Remote Sensing Lab, and was Head of the Geochemistry of the Tropical Environment Center at the Earth Sciences Institute in Venezuela. Dr. Briceño was Director of the Venezuelan Association for the Advancement of Science. The last 11 years at Florida International University he has monitored coastal water quality in South Florida and Bermuda, and is currently the Principal Investigator for the Florida Keys National Marine Sanctuary Water Quality Monitoring Program. From 1988 to 2005, Dr. Briceño held managerial and executive positions in service and industrial companies, both public and private. He was Advisory Board Member and Geology Supervisor for the Regional Resource Inventory of the Guayana Region (over 400,000 km2), and prepared or coordinated environmental audits and impact studies in diverse mining, engineering, hydrocarbon and hydroelectric operations in Venezuela.

### Eugene, Shinn, PhD		Co-PI		Groundwater Hydrogeology

University of South Florida
College of Marine Science
140 7th Ave South, MSL 119
St. Petersburg, FL 33701

Dr. Shinn recently retired from his position as a research geologist with the U.S. Geological Survey (USGS) Center for Coastal Geology in St. Petersburg, Florida. Currently he is a Courtesy Professor at the University of South Florida, College of

Marine Sciences. After obtaining his degree, Shinn spent a year at the University of Miami's Marine Laboratory. In 1958, he began working for Shell Oil Company as a research geologist. During his 15 year career with Shell he worked in Florida and the Bahamas, the Persian Gulf and Holland. He finished that career at Shell Headquarters in Houston, TX in the environmental affairs department. Gene joined USGS in 1974 and started the USGS Fisher Island Station off Miami, which he directed for 15 years. He and associates did extensive geological research on living coral reefs, carbonate sediment production, Pleistocene geology and environmental effects of offshore petroleum drilling. In the early 1990s he installed over 100 groundwater monitoring wells in the Florida Keys, the reef tract and in Florida Bay, where he conducted dye tracer experiments to determine flow rate and flow direction of saline groundwater. His work highlighted the problems of sewage disposal in the porous limestone that underlies the Florida Keys. He has authored about 200 peer-reviewed publications and recent studies with the USGS include: Determination of Groundwater-Flow Direction and Rate Beneath Florida Bay, the Florida Keys and Reef Tract; and, Groundwater Seepage in the Florida Keys.

Reinaldo Garcia, PhD CoPI Modeling Specialist

NASA Waterscapes Research Center
Southeast Environmental Research Center (SERC)
Florida International University
e-mail: rgarcia@fiu.edu

Summary

Dr. Garcia is a Senior Engineer and Model Developer with 33 years of research and professional experience and has participated in hundreds of environmental modeling studies worldwide. He has developed and applied models to simulate 2D and 3D free and subsurface surface flows, pollutants discharges including oil spills and sediment transport dynamics. He has developed and applied numerical models using advanced and novel methods including finite differences, finite element and neural networks models. Dr. Garcia is co-designer and co-developer of the Federal Emergency Management Agency (FEMA) approved FLO-2D flood and mudflow model. He has developed the RiverFLO-2D, a flexible sediment transport model that is being applied in rivers and estuaries worldwide. He has published numerous articles in journals, books and conference proceedings on pollutant transport and dispersion, sediment transport modeling, free surface flow models, finite element computation, floods, and oil spill trajectory and fate models. Dr. Garcia has been professor for more than 25 years teaching courses at graduate levels in pollutant dynamics, hydrology, and numerical modeling. From 2004 to 2006 he was Visiting Professor at the Department of Civil, Architectural and Environmental Engineering of the University of Miami. As a Senior Engineer provides technical leadership and technical software development guidelines, support and training for a wide variety of government and private entities worldwide. Reinaldo develops and executes customer specific strategies for fluid and environmental modeling applications, software and services, and is responsible for upgrades and new product development.

Piero R. Gardinali, Ph.D. Co-PI Pollution Specialist

Department of Chemistry & Biochemistry
Southeast Environmental Research Center (SERC)
Florida International University
e-mail: gardinal@fiu.edu

Summary

Dr. Gardinali's research focuses on studies regarding the origin, fate and transport of anthropogenic organic compounds in freshwater and coastal environments. His group is particularly interested in highly toxic halogenated compounds such as co-planar polychlorinated biphenyls, dioxins and furans as well as pesticides, herbicides and polycyclic aromatic hydrocarbons and their metabolites and degradation products in aquatic organisms and soil/sediments. Dr. Gardinali's group is also involved in the development of analytical techniques for the analysis of trace organic compounds in environmental samples.

Kevin Boswell, Ph.D. Co-PI Ecologist-ROV Specialist

Marine Sciences Program
Department of Biological Sciences
Florida International University, North Miami, FL 33181
Email: kevin.boswell@fiu.edu
Tel: (225) 485-8181
Web: http://www.fiu.edu/~kmboswel/

Summary

Kevin M. Boswell is an Assistant Professor in the Department of Biological Sciences and faculty member in the Marine Sciences Program at Florida International University He currently runs the Fisheries Ecology and Acoustics Laboratory at Florida International University and has co-founded the SouthEast Regional Acoustics Consortium. He has greater than 10 years of experience in practical fisheries research, has authored nearly 30 scientific peer-reviewed publications and procured, along with colleagues, more than $9 million in funded research. He routinely serves as a reviewer for scientific journals (e.g., Marine Ecology Progress Series, Canadian journal of Fisheries and Aquatic Sciences, ICES Journal of Marine Science) and sits on several proposal review panels. He applies advanced sampling techniques such as active acoustics and remotely operated vehicles to collect high-resolution data to simultaneously describe abundance, behavior and distributional patterns of the nekton community.

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APPENDIX 1

PERSONNEL

Henry Briceño, PhD Principal Investigator Water Quality

Southeast Environmental Research Center (SERC)
Florida International University
11200 SW 8th Street, Miami, FL 33199
Email: bricenoh@fiu.edu
Phone: +305-348-1269

Summary

Currently, Dr. Briceño is a Research Professor at the Southeast Environmental Research Center of Florida International University, after being professor at Universidad Central de Venezuela since 1976. His research activities along his 37 years of professional career include Geochemical Watershed Assessment, Biogeochemistry of Coastal and Estuarine waters, Tropical Weathering, Engineering Geology, Geochemical Exploration, Geomorphology and Remote Sensing. He was in charge of the Low-Temperature Geochemistry Laboratory, the X-Ray Laboratory and the Remote Sensing Lab, and was Head of the Geochemistry of the Tropical Environment Center at the Earth Sciences Institute in Venezuela. Dr. Briceño was Director of the Venezuelan Association for the Advancement of Science. The last 11 years at Florida International University he has monitored coastal water quality in South Florida and Bermuda, and is currently the Principal Investigator for the Florida Keys National Marine Sanctuary Water Quality Monitoring Program. From 1988 to 2005, Dr. Briceño held managerial and executive positions in service and industrial companies, both public and private. He was Advisory Board Member and Geology Supervisor for the Regional Resource Inventory of the Guayana Region (over 400,000 km2), and prepared or coordinated environmental audits and impact studies in diverse mining, engineering, hydrocarbon and hydroelectric operations in Venezuela.

Current Appointment

- Research Professor. Florida International University, Southeast Environmental Research Center, Miami, Florida

Education

- Doctor of Philosophy in Geology, Ph.D. Remote Sensing and Exploration (Minor in Mineral Economics). Colorado School of Mines. Golden, Colorado, USA. 1982.
- Master of Science in Geology, Ore deposits and Geochemistry. Colorado School of Mines. Golden, Colorado, USA. 1975
- Bachelor of Science in Geology, Colorado School of Mines, Golden, Colorado, USA. 1973

Research Relevant to Proposal

PI: Water Quality Monitoring Project for the Water Quality Protection Program of the Florida Keys National Marine Sanctuary. For Environmental Protection Agency and US Fish & Wildlife Service

PI: Ecological Impacts on Biscayne National Park from Proposed South Miami-Dade Development (including Box-Modeling). For National Park Service

PI: Water Quality Monitoring Program for Bermuda's Coastal Resources. For Government of Bermuda, Ministry of Public Works, Dept of Conservation Services.

Co-PI: Water Quality Sampling Program for the Little Venice Sewage Collection and Treatment Project in Marathon, Florida. For Florida Department of Environmental Protection

Co-PI: South Florida Coastal Water Quality Monitoring Program, including Coastal Everglades, Florida Bay and Biscayne Bay. For South Florida Water Management District

PI: Geochemical Characterization of the Pastaza-Corrientes Basin Waters, Peru. For Global Water for Sustainability Program. USAID and World Wildlife Fund.

PI: Derivation of Protective Numeric Nutrient Criteria for South Florida Estuaries and Coastal. Southeast Environmental Research Center & NPS

PI: Water Quality Assessment of Fluvial Ecosystems and Impact of Mining Activities in the Cuyuni River Basin Venezuela. For Cisneros Foundation, Venezuela

Recent Publications Relevant to Proposal

BRICEÑO, H.O., J.N. BOYER AND P. HARLEM. 2013. Biogeochemical Classification of South Florida's Estuarine and Coastal Waters. Marine Pollution Bulletin, Volume 75, Issues 1–2, 15 October 2013, Pages 187–204

BRICEÑO, H.O., G. MILLER AND S. DAVIS III. 2013. Relating restored freshwater flow with estuarine water quality in the southern Everglades mangrove ecotone. WETLANDS, DOI 10.1007/s13157-013-0430-0

WACHNICKA, A., E. GAISER, L. WINGARD, H. BRICEÑO AND P. HARLEM. 2013. Impact of the late Holocene climate variability and anthropogenic activities on Biscayne Bay (Florida, U.S.A.) environment: evidence from diatoms. Palaeogeography, Palaeoclimatology, Palaeoecology 371:80-92

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PISAPIA, D., A. MORA, O. FARINA, C. LASSO, R. JAFFE AND H. O. BRICEÑO. 2009. Geoquímica de los ecosistemas acuáticos de la Cuenca alta del río Cuyuní, Estado Bolívar, Venezuela: RAP Alto Cuyuní 2008. In Evaluación Rápida de la Biodiversidad de los Ecosistemas Acuáticos de la Cuenca Alta del Río Cuyuní, Guayana Venezolana, C. Lasso, J. Señaris, A. Rial and A. L. Flores (edit). RAP Bulletin of Biological Assessment 55. Conservation International, Arlington, VA, USA. ISBN # 978-1-934151-36-5

BRICEÑO, H.O., ABRAHAN MORA Y RUDOLF JAFFÉ. 2008. Geoquímica de las aguas de la cuenca alta del río Paragua, Estado Bolívar, Venezuela. In Señaris, J.C., C.A. Lasso y A.L. Flores (eds.). Evaluación Rápida de la Biodiversidad de los Ecosistemas Acuáticos de la Cuenca Alta del Río Paragua, Estado Bolívar, Venezuela. RAP Bulletin of Biological Assessment 49. Conservation International, Arlington, VA, USA.

Recent Reports Relevant to Proposal

BOYER, J. N. AND H. O. BRICEÑO. 2013. FY2012 Annual Report of the Water Quality Monitoring Project for the Florida Keys National Marine Sanctuary. EPA Agreement #X795469410-2 SERC Tech. Report #T-628.

BRICEÑO, H. O.and J.N. BOYER. 2013. Water quality monitoring program for Bermuda's coastal resources. Bermuda Dept. Conservation Services. SERC Tech. Report #T-591.

BRICEÑO, H. O., J. N. BOYER AND P. HARLEM. 2011. Ecological Impacts on Biscayne Bay and Biscayne National Park from Proposed South Miami-Dade County Development, and Derivation of Numeric Nutrient Criteria for South Florida Estuaries and Coastal Waters. U.S. DOI, National Park Service, Task Agreement: J5297-08-0085 Cooperative Agreement: H5000-06-0104

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Reinaldo Garcia, PhD CoPI Modeling Specialist

NASA Waterscapes Research Center
Southeast Environmental Research Center (SERC)
Florida International University
e-mail: rgarcia@fiu.edu

Summary
Dr. Garcia is a Senior Engineer and Model Developer with 33 years of research and professional experience and has participated in hundreds of environmental modeling studies worldwide. He has developed and applied models to simulate 2D and 3D free and subsurface surface flows, pollutants discharges including oil spills and sediment transport dynamics. He has developed and applied numerical models using advanced and novel methods including finite differences, finite element and neural networks models. Dr. Garcia is co-designer and co-developer of the Federal Emergency Management Agency (FEMA) approved FLO-2D flood and mudflow model. He has developed the RiverFLO-2D, a flexible sediment transport model that is being applied in rivers and estuaries worldwide. He has published numerous articles in journals, books and conference proceedings on pollutant transport and dispersion, sediment transport modeling, free surface flow models, finite element computation, floods, and oil spill trajectory and fate models. Dr. Garcia has been professor for more than 25 years teaching courses at graduate levels in pollutant dynamics, hydrology, and numerical modeling. From 2004 to 2006 he was Visiting Professor at the Department of Civil, Architectural and Environmental Engineering of the University of Miami. As a Senior Engineer provides technical leadership and technical software development guidelines, support and training for a wide variety of government and private entities worldwide. Reinaldo develops and executes customer specific strategies for fluid and environmental modeling applications, software and services, and is responsible for upgrades and new product development.

Education

- Doctor in Engineering Sciences (PhD), 1999. Degree with Honors. Universidad Central de Venezuela/Wessex Institute of Technology. Thesis title: Three dimensional mathematical model to simulate hydrodynamics, sediment transport and pollutant transport in surface waters.
- Master of Science, Ecole Polytechnique de Montréal, 1983. Université de Montréal, Québec, Canada. Thesis title: Mathematical modeling of two-dimensional hydraulic problems using a fully dense finite-difference scheme.
- Civil Engineer (Major in Hydraulic Engineering), Universidad Central de Venezuela (U.C.V.) 1980

Current Appointments

Hydronia	Director of Model Development, Miami, Florida
NASA Waterscapes Research Center	Senior Advisor Scientist. Florida International University.

Associations Memberships

- American Society of Civil Engineers
- American Geophysical Union
- International Association of Hydraulic Research

Languages

Spanish, English, and French.

Selected Project Experience

- Mercury Transport Model to support TMDL regulations at East Fork Poplar Creek Watershed in TN, USA.
- Hydrodynamic and Thermal Discharge Modeling in La Unión Bay El Salvador, Gulf of Fonseca.
- Environmental modeling of the heated water discharge from the AES power plant in La Union Bay, El Salvador (for URS Corporation, Miami, FL). 2005-2007.
- Design of the CORPOVEN Treatment plant submerged discharge of the El Palito Refinery, Edo. Carabobo Venezuela.
- Unsteady flow simulation in the 156 km long PTO-Jose ORIMULSION Pipeline. For INTEVEP, Caracas, Venezuela.
- Simulation of submerged sewage discharges in the central Venezuelan coast..
- Effluent dispersion study in the surf zone of the DFT discharge, CORPOVEN, Jose, Edo. Anzoátegui. For CORPOVEN. Veneuela.
- Mathematical Simulations of ORIMULSION Spills scenarios in Chaleur Bay, New Brunswick, Canada. For New Brunswick Power. Canada.
- Unsteady flow analysis to determine extreme pressures in the water injection lines of the RESOR Project. For LAGOVEN Oriente

Selected Publications

Garcia, R., Espinoza, R. Valera, E. & Gonzalez, M. An Explicit Two-Dimensional Finite Element Model to Simulate Short and Long Term Bed Evolution in Alluvial Rivers. *Journal of Hydraulic Research.* (6) 2006.

Garcia, F., Garcia, R., & Joseph, D.D. Composite power law holdup correlations in horizontal pipes. *International Journal of Multiphase Flow*. Vol. 31, Issue 12, December 2005, pp. 1276-1303.

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García, F., Segura, J., Morán, f., & Garcia, R. Heat Transfer in Gas-Liquid Two-phase Flow. Part II: Vertical Pipelines and annular conduits. Part I: Horizontal wells and Pipelines. Revista de la Facultad de Ingeniería de la U.C.V., Vol. 19, N° 3, pp.83 – 99, 2004

Garcia, F., Garcia, R., Padrino J.C., Mata C., Trallero J.L., and Joseph, D.D. Power Law and Composite Power Law Friction Factor Correlations for Laminar and Turbulent Gas-Liquid Flow in Horizontal Pipelines. *International Journal of Multiphase Flow*. Vol. 29, October 2003, pp.1606-1624.

Saavedra , I. López, J.L. & Garcia, R. Dynamic Wave Study of Flow in the Tidal Channel

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Garcia-Martinez, R. & Flores, H. “Computer modeling of oil spill trajectories with a high accuracy method". *Spill Science and Technology Bull*. Vol. **5**, pp. 323-330, 1999.
Rodríguez, J.J. & Garcia, F.R. “HydroTrack: A Graphical Software System for the Simulation of Pollutant Discharges in Water*". Journal of Environmental Modelling and Software*, Vol. **13**. pp. 211-223, 1998.
Power, H., Garcia, F. R., & Miranda, G. “Integral Equation Solution for the Flow of a Body of Arbitrary Shape near a plane Interface at Small Reynolds Number*". Applied Numerical Mathematics*., Vol. **2**. pp. 79-94. 1986.
Garcia, F.R. & Kahawita, R. “Numerical Solution of the St. Venant Equations with the MacCormack Finite-Difference Scheme*" Int. Journal for Numerical Methods in Fluids*. Vol. **6**(5), pp. 259-274., 1986.
Martinez, C., Miralles-Wilhelm, F. & Garcia, R. Verification of a 2D finite element debris flow model using Bingham and Cross rheological formulations. Debris Flows 2008. Wessex Institute, Ashurst, UK. June 2008. (Invited paper).
Martinez, C., F.Miralles-Wilhem and R. Garcia-Martinez. *A 2D finite element debris flow model based on the cross rheology formulation*. Fourth International Conference on Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment. Chendu, China, September, 2007.
Rodriguez, C., Blanco, A. & Garcia R. Comparison of 1D debris flow modelling approaches using a high resolution and non-oscillatory numerical scheme based on the finite volume method. Monitoring, Simulation, Prevention and Remediation of Dense and Debris Flows. Ed. By Lorenzini, G., Brebbia, C. & Emmanouloudis, D. WIT Press, Southamptom, UK, 2006.
Findikakis, A., Imberger J., Hansen I.S., Delgado L., Garcia-Martinez R., Gundlach E *Evaluation of Water Quality Impacts of Alternative Options for Lake Maracaibo.* XXX IAHR Congress, Thessaloniki, Grece, Aug. 2003.
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Garcia, F.R. “Numerical simulation of dredged sediments and contaminant disposal in the sea from a moving vessel**"** *4th International Congress on Energy, Environment and Technological Innovation.* Roma, Italia, 20 al 24 de September de 1999.
Garcia, R., & Flores, H. “Computer Modeling of the Nissos Amorgos Oil Spill with OilTrack*". 2nd International SINTEF Marine Environmental Modeling Seminar*. Lillehammer, Norway. March 2-6, 1998.
Garcia, R. “Some recommendations for testing oil spill computer models” OILSPILL 98. *International Conference on Oil and Hydrocarbons Spills, Modeling, Analysis and Control*. Southampton, U.K. 29-31 Jul, 1998.
Garcia, R. & Rodriguez, J.J. “A Visual Tool to Simulate Hydrodynamics, Pollutant and Suspended Sediment Transport in Rivers a Coastal Regions”. *Hydroinformatics 98*. Copenhagen, Denmark, August 24-26, 1998.
Garcia, R., Rodriguez, J.J., Camacho, F. & Masciangioli, P. “OriTrack: A Mathematical Model for ORIMULSION™ Spills in Water”*. 19th Artic and Marine Oilspill Program Technical Seminar (AMOP)*. Calgary, Canada. June 12-14, 1996.
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Findikakis, A.N., Imberger, J. Hansen, I.S., Delgado, L., Garcia, R. & Gundlach, E. "A Study of Environmental Remediation Options for Lake Maracaibo, Venezuela". XXIX World Hydraulic Congress of the IAHR. Beijing, China. 2001.

Garcia, F.R. "Numerical simulation of dredged sediments and contaminant disposal in the sea from a moving vessel**"** 4^{th} *International Congress on Energy, Environment and Technological Innovation.* Roma, Italia, 20 al 24 de September de 1999.

Garcia, R., & Flores, H. "Computer Modeling of the Nissos Amorgos Oil Spill with OilTrack*". 2^{nd} International SINTEF Marine Environmental Modeling Seminar*. Lillehammer, Norway. March 2-6, 1998.

Garcia, R. "Some recommendations for testing oil spill computer models" OILSPILL 98. *International Conference on Oil and Hydrocarbons Spills, Modeling, Analysis and Control*. Southampton, U.K. 29-31 Jul, 1998.

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Garcia, R., Mata, L.J. & Flores, H. "A Correction to the Mackay Oil Spreading Formulation". *19^{th} Artic and Marine Oilspill Program Technical Seminar (AMOP).* Calgary, Canada. June 12-14, 1996.

Garcia, R. & Rodriguez, J.J. "OilTrack: A Computational Model to Simulate for Oil Spills in Water". *ENVIROSOFT 96*. pp. 705-715, 1996.

Piero R. Gardinali, Ph.D. **Co-PI** **Pollution Specialist**

Department of Chemistry & Biochemistry
Southeast Environmental Research Center (SERC)
Florida International University
e-mail: gardinal@fiu.edu

Summary

Dr. Gardinali's research focuses on studies regarding the origin, fate and transport of anthropogenic organic compounds in freshwater and coastal environments. His group is particularly interested in highly toxic halogenated compounds such as co-planar polychlorinated biphenyls, dioxins and furans as well as pesticides, herbicides and polycyclic aromatic hydrocarbons and their metabolites and degradation products in aquatic organisms and soil/sediments. Dr. Gardinali's group is also involved in the development of analytical techniques for the analysis of trace organic compounds in environmental samples.

Educacion

Texas A&M University,	Ph. D. Chemical Oceanography	1996
Universidad Simón Bolívar, Venezuela,	M.Sc. Analytical Chemistry	1989
Universidad Simón Bolívar, Venezuela	B.Sc. Chemistry	1986

Appointments

Since 2014	Professor, Florida International University, North Miami, FL
2004-2014	Associate Professor, Florida International University, Miami, FL
1998-2004	Assistant Professor, Florida International University, Miami, FL
1996-1997	Lab Manager/Research Associate, Texas A&M University
1989-1991	Assistant Professor, Universidad Simón Bolívar, Caracas

Synergistic Activities

Co-Editor in Chief, Environmental Nanotechnology, Monitoring and Management (ENMM). Elsevier (2013-2016).
Associate Editor, Bulletin of environmental Contamination and Toxicology (BCET). Springer (2013-present)
Voting Member, Technical Advisory Committee, Southeast Florida Coral Reef Initiative (SEFCRI)(2007-2013; 2013-present).

Publications Related to Proposal

Rani Batchu, S., N. Quinete, V. R. Panditi and P. R Gardinali (2013) “Online solid phase extraction liquid chromatography tandem mass spectrometry (SPE-LC-MS/MS) method for the determination of Sucralose in reclaimed and drinking waters and its photo degradation in natural waters from South Florida" _Chemistry Central Journal_. 7:141

Wang, J. and Gardinali, P. R. (2014) "Identification of phase II pharmaceutical metabolites in reclaimed water using high resolution benchtop Orbitrap mass spectrometry". _Chemosphere,_ 107(0), 65-73.

Ramirez, C.,Wang, C. and Gardinali, P.R. (2014) "Fully automated trace level determination of parent and alkylated PAHs in environmental waters by online SPE-LC-APPI-MS/MS". _Analytical and Bioanalytical Chemistry_, 406(1), 329-344.

Wang, J. and Gardinali, P.R. (2013). "Uptake and Depuration of Pharmaceuticals in Reclaimed Water by Mosquito Fish (Gambusia Holbrooki): A Worst Case Multiple Exposure Scenario." _Environmental Toxicology and Chemistry_. 32(8):1752-1758.

Wang, C. and Gardinali, P. R. (2013). "Detection and occurrence of microconstituents in reclaimed water used for irrigation–a potentially overlooked source." _Analytical and Bioanalytical Chemistry_. 405(18):5925-5935.

Ramirez, C.E., Bellmund, S. and Gardinali, P.R. (2014) "A simple method for routine monitoring of glyphosate and its main metabolite in surface waters using lyophilization and LC-FLD+MS/MS. Case study: canals with influence on Biscayne National Park.". In press. _Science of the Total Environment_.

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Batchu, S., Panditi, V. , O'Shea, K. and Gardinali, P. R. (2013) "Photodegradation of selected antibiotics in natural waters by simulated solar radiation: Implications for their environmental fate". _Science of the Total Environment._ 470-471(0), 299-310

Eugene Shinn, Ph.D. Co-PI Dye-tracer test Specialist

University of South Florida
College of Marine Science
140 7th Ave South, MSL 119
St. Petersburg, FL 33701
e-mail: eshinn@marine.usf.edu

Dr. Shinn came to the USGS after a distinguished career at Shell Oil and, in 1974, established the Fisher Island Field Station, Miami Beach, Fla. During his years at the field station, Gene won a USGS award for developing a hydraulic drilling device, and he published extensively on coral-reef ecosystems and modern and ancient carbonate sediments. Gene's groundbreaking research on carbonates showed that widespread submarine lithification is occurring on the sea floor in the Persian Gulf, producing features that previously were believed to form only during subaerial exposure. Gene was a co-discoverer of modern giant submarine stromatolites (similar to the dominant fossils of the Precambrian) that are forming in the Exuma Islands, Bahamas (*Nature* v. 324, no. 6092, p. 55-58). Ever the pioneer in exploring environmental issues, **Gene** also led a project from 1991 to 1994 that helped determine the pathways and movement of sewage-contaminated ground water in the Florida coral-reef tract. These data have been used widely and are the basis for several court cases and environmental hearings. Later, Gene continued to work on ground-water-seepage rates and flow direction in Florida Bay and the Florida Keys. Eugene Shinn's extraordinary contributions to our understanding of carbonate sedimentology and coral-reef ecosystems were recognized in 1991 by the Meritorious Service Award of the Department of the Interior, in 1998 by Honorary Membership in the Society for Sedimentary Geology, and in 1998 by an Honorary Doctoral Degree bestowed by the University of South Florida.

Kevin Boswell, Ph.D. Co-PI Ecologist-ROV Specialist

Marine Sciences Program
Department of Biological Sciences
Florida International University, North Miami, FL 33181
Email: kevin.boswell@fiu.edu
Tel: (225) 485-8181
Web: http://www.fiu.edu/~kmboswel/

RESEARCH INTERESTS
I am a marine ecologist, with general interests in the ecology and population dynamics of coastal and marine nekton. Specifically, I am interested in the role of habitat (physical and hydrodynamic) in structuring coastal and marine communities at various spatial and temporal scales, connectivity among habitats and ecosystems and interactions across multiple trophic levels. To address many of these interests, I apply advanced sampling techniques such as active acoustics and remotely operated vehicles to collect high-resolution data to simultaneously describe abundance, behavior and distributional patterns of the nekton community.

EDUCATION
PhD, Oceanography and Coastal Sciences (2006), Louisiana State University, Baton Rouge, LA. Minor- Experimental Statistics
BS, Marine Fisheries (1998), Texas A&M University, Galveston, TX

PROFESSIONAL APPOINTMENTS
2011-Present Assistant Professor, Marine Science Program, Department of Biological Sciences, Florida International University
2012- Present Assistant Professor- Adjunct, Department of Oceanography and Coastal Sciences, Louisiana State University
2011 Assistant Professor- Research, Department of Oceanography and Coastal Sciences, Louisiana State University
2007- 2010 Postdoctoral Research Associate, Department of Oceanography and Coastal Sciences, Louisiana State University; *Advisor: Dr. James H. Cowan, Jr.*
2001- 2006 Graduate Research Assistant- Department of Oceanography and Coastal Sciences, Louisiana State University; *Advisor: Dr. Charles A. Wilson*

PUBLICATIONS (GGraduate Student Author; UUndergraduate student author)
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