Florida Water Resources Research Center
Annual Technical Report
FY 2011

Introduction

The mission of the Florida Water Resources Research Center at the University of Florida is to facilitate communication and collaboration between Florida's Universities and the state agencies that are responsible for managing Florida's water resources. A primary component of this collaborative effort is the development of graduate training opportunities in critical areas of water resources that are targeted to meet Florida's short- and long-term needs.

The Florida Water Resources Research Center coordinates graduate student funding that is available to the state of Florida under the provisions of section 104 of the Water Resources Research Act of 1984. Over the past year (Fiscal Year 2011) the Center supported $1.8 million in research, including agreements with two of Florida s universities (Florida Atlantic University and the University of Florida), two state agencies (South Florida Water Management District, St. Johns River Water Management District) one municipality (City of Sanford) and one non-profit foundation (Everglades Foundation).

Recognizing the importance of STEM (Science, Technology, Engineering, and Mathematics) Education initiatives, the Florida Water Resources Research Center is very proud to have supported the research efforts of 12 Ph.D., 4 Masters, and 4 undergraduate students along with 3 post doctoral associates all focusing on water resources issues during the reporting period (March 2011 to February 2012).

During FY 2011, along with providing support to graduate students within the state of Florida, the Center also facilitated development of research at both the state and national level producing 26 peer-reviewed journal articles, 1 book chapter, 19 proceedings and presentations, and 3 PhD dissertations. The Center is a state repository for water resources related publications and maintains a library of technical reports that have been published as a result of past research efforts (Dating back to 1966). Several of these publications are widely used resources for water policy and applied water resources research in the state of Florida and are frequently requested by others within the United States. As part of the WRRC information and technology transfer mission, the library was converted to digital form in 2010 and is provided free to the public through the WRRC Digital Library available on the center website (http://wrrc.ce.ufl.edu/).

Research Program Introduction

During FY 2011 the Water Resources Research Center supported four 104B research projects and four center-affiliated research projects. The supported research projects considered a wide range of water resource related issues while maintaining focus on topics specific to Florida.

104B Research Projects

Coupled Biological/Chemical Systems for Maximizing Phosphorus Removal from Natural Water. Phosphorus (P) remains a primary pollutant in natural waterways. Phosphorus in agricultural and residential fertilizers, cattle feed, and reclaimed water, eventually finds its way into streams, rivers, and lakes. Excessive P loads can cause eutrophic or hyper-eutrophic conditions in these surface waters, which are characterized by excessive primary productivity, reduction or depletion of dissolved oxygen, stressed aquatic organisms, and simplified trophic structure. There are numerous examples of lakes that have become eutrophic as a consequence of excessive P loading. For example, Lake Jesup, near Orlando, Florida, was placed on the verified impaired list by the U.S. Environmental Protection Agency and the Florida Department of Environmental Protection for excessive water-column P concentrations. In developing a total maximum daily load for Lake Jesup, the St. Johns River Water Management District estimated the lake needs a 9-ton reduction in annual P loads to reach natural background conditions (Gao, 2006). A reduction of this magnitude will require imaginative management strategies. Accordingly, the main objective of this project is to develop and test innovative combinations of chemical and biological treatments for P removal from natural surface waters.

Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters. The overall goal of this project is to fund an interdisciplinary cohort of 7 Ph. D. Fellows to develop the new knowledge, and creative engineering, management and policy solutions needed to establish and achieve numeric nutrient criteria (NNC) for Florida's waters. The education and research of each Fellow will evolve from specific problems and research questions related to management of Florida's water and watersheds under NNC. The unique cross-disciplinary environment of our program will allow an integrated whole that will reflect disciplinary facets associated with this complex problem.

Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida. Continued growth in water demand in many parts of the country including Florida has placed significant stress on traditional groundwater and surface water sources for urban water supply. Regional water supply assessments by the water management districts have shown significant negative impacts of these developments including lowered groundwater tables accompanied by reduced flows in rivers and springs, declining lake levels, and increasing nutrient loads on receiving waters. In response to these problems, water utilities are required to evaluate alternative water supplies and water conservation to meet future water needs. Water losses on the utility side of the customer meters can be as high as 15-20%. A similar loss range exists on the customer side of the meter. Improved methods of water loss control can reduce these losses to 5% or less. The City of Sanford will be used as a case study to evaluate innovative methods of water loss control and the addition of water conservation practices. The EZ Guide 2.0 model will be refined to address these needs to find cost-effective solutions. EZ Guide 2.0 has been developed by the Conserve Florida Water Clearinghouse to find the optimal portfolio of traditional and alternative water supply options and demand management.

In-Filling Missing Daily Rain Gauge Data Using Radar Rainfall Data: Influence of Homogeneous Rain Areas. The use of NEXRAD rainfall data for providing information about the extreme rainfall amounts resulting from storms, hurricanes and tropical depressions is common today. Often corrections are applied to this rainfall data-based on what was actually measured on the ground by rain gages (generally referred to as "ground truth"). Understanding and modeling the relationships between NEXRAD and rain gage data are

essential tasks to confirm the accuracy and reliability of the former surrogate method of rainfall measurement. Traditional non-linear regression models in many situations are found to be incapable of capturing these highly variant non-linear spatial and temporal relationships. This study proposes to investigate the use of emerging computational data modeling techniques and assess these functional approximation methods for this purpose. The project's objective is to develop a method that would be used to in-fill the historical daily missing rain gauge data. The proposed method would use NEXRAD rainfall data, for this purpose, and it will be applied to the existing available data and its performance would be evaluated and assessed. Upon successful development and verification of the model, the model will be used in filling the missing daily rain data for rain gauge stations. This project involves developing methodology for filling of the missing historical daily rain data from rain gauge stations. This research is highly relevant and critical to a number of water resources management agencies that use NEXRAD based rainfall data for modeling and management of day-to-day operations of water resources systems (SFWMD).

Center Affiliated Projects

Development of new tools for characterizing groundwater contaminant source zones. University of Florida flux meter research has received national recognition and as such, two research projects are ongoing to further the field of characterizing subsurface contaminant flux. The Department of Defense has funded a multi-year $700,000 project to develop a fractured rock passive flux meter, and the Department of Energy has funded a multi-year 1.2 million dollar project for investigation of subsurface uranium flux.

NSF funded US-Brazil Collaboration: NSF project to develop collaborative water resources research between University of Florida and Brazil, with the objective of providing education and training through a graduate student exchange program and creation of a teaching laboratory in Brazil.

Coupled Biological/Chemical Systems for Maximizing Phosphorus Removal from Natural Waters

Basic Information

Title:	Coupled Biological/Chemical Systems for Maximizing Phosphorus Removal from Natural Waters
Project Number:	2011FL267B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	6
Research Category:	Engineering
Focus Category:	Nutrients, Surface Water, None
Descriptors:	None
Principal Investigators:	Treavor H Boyer, Mark T Brown

Publications

1. Sindelar, H.R., Boyer, T.H., Brown, M.T. 2012. Transformation of recalcitrant phosphorus to biologically labile compounds using UV/H2O2. Journal of Hazardous Materials. (In Review).
2. Sindelar, H.R., Boyer, T.H., Brown, M.T. 2011. Evaluating advanced oxidations processes for the transformation of organic phosphorus into biologically liable compounds. 2011 Association of Environmental Engineering and Science Professors Research and Education Conference, University of South Florida, Tampa, Florida, 10-12 July 2011, 1 p. http://aeesp2011.com/proceedings/index.html
3. Sindelar, H., Boyer, T.H., and Brown, M.T. 2011. Evaluating advanced oxidation processes for the transformation of organic phosphorus to more biologically labile compounds. Florida Lake Management Society 22nd Annual Conference, St. Augustine, Florida, 13-16 June 2011.
4. Sindelar, H., Boyer, T.H., Brown, M.T. 2012. Evaluating advanced oxidation processes for the transformation of organic phosphorus into biologically labile compounds. UF Water Institute Symposium, University of Florida, Gainesville, Florida, 15 16 February 2012.

WRRC 104B Annual Report for FY2011

Coupled Biological/Chemical Systems for Maximizing Phosphorus Removal from Natural Water

May 22, 2012

Principal Investigators: Treavor Boyer and Mark Brown, UF Environmental Engineering Sciences

Ph.D. Student: Hugo Sindelar, UF Environmental Engineering Sciences

Student's Ph.D. dissertation topic: Coupled biological/chemical systems for sustainable phosphorus management (expected graduation date May 2013).

Project Background

Phosphorus (P) remains a primary pollutant in natural waterways. Phosphorus in agricultural and residential fertilizers, cattle feed, and reclaimed water, eventually finds its way into streams, rivers, and lakes. Excessive P loads can cause eutrophic or hyper-eutrophic conditions in these surface waters, which are characterized by excessive primary productivity, reduction or depletion of dissolved oxygen, stressed aquatic organisms, and simplified trophic structure. In addition, high P loads can change an ecosystem's biotic community by altering the nutrient balance. This latter phenomenon has been documented in the Florida Everglades, where high P loads promoted the growth of *Typha latifola* (cattail) at the expense of previously abundant *Cladium jamaicense* (sawgrass).

There are numerous examples of lakes that have become eutrophic as a consequence of excessive P loading. For example, Lake Jesup, near Orlando, Florida, was placed on the verified impaired list by the U.S. Environmental Protection Agency and the Florida Department of Environmental Protection for excessive water-column P concentrations. In developing a total maximum daily load for Lake Jesup, the St. Johns River Water Management District estimated the lake needs a 9-ton reduction in annual P loads to reach natural background conditions (Gao, 2006). A reduction of this magnitude will require imaginative management strategies. Accordingly, the *main objective* of this project is to develop and test innovative combinations of chemical and biological treatments for P removal from natural surface waters.

Project Status

Advanced Oxidation Processes

Many current P treatment technologies cannot adequately remove recalcitrant forms of P from the water column (Rittmann et al., 2011). As a result, this study evaluated the UV/H_2O_2 advanced oxidation process (AOP) for the breakdown of recalcitrant P to biologically available soluble reactive P (SRP), which could then be removed using available P treatment technologies. This study was accomplished as follows. Test water was collected as grab samples from

Stormwater Treatment Area 1 West (STA-1W) inflow structure at S5A, located on canal C-51. STA-1W is located in Palm Beach County, Florida. STA-1W water was selected because of its P profile. UV oxidation experiments were conducted in a 163 mL re-circulating reactor (see Figure 1). There were three components to each treatment: UV exposure time (min), oxidant dose (mg H_2O_2/L), and oxidant chemical (H_2O_2 (liquid), sodium perborate tetrahydrate (solid), and sodium percarbonate (solid)). Results showed that the breakdown of recalcitrant P to SRP is possible using UV exposure times of at least 10 min and liquid H_2O_2 doses of at least 100 mg H_2O_2/L. However, the dynamic nature of most surface waters makes consistent conversion of recalcitrant P to SRP difficult to achieve. Solid forms of H_2O_2, sodium percarbonate and sodium perborate, used as substitutes for liquid H_2O_2 in the UV/H_2O_2 AOP also had difficulty consistently converting recalcitrant P to SRP, however they both matched the dissolved organic carbon and UV_{254} absorbance removal rates of liquid H_2O_2. At this time, UV/H_2O_2 does not appear feasible for P treatment in Everglades water, however, the technology may hold promise for other water matrices with lower concentration of dissolved organic matter (DOM). This work is complete and has been submitted for publication in the refereed literature (Sindelar et al., Under Review)

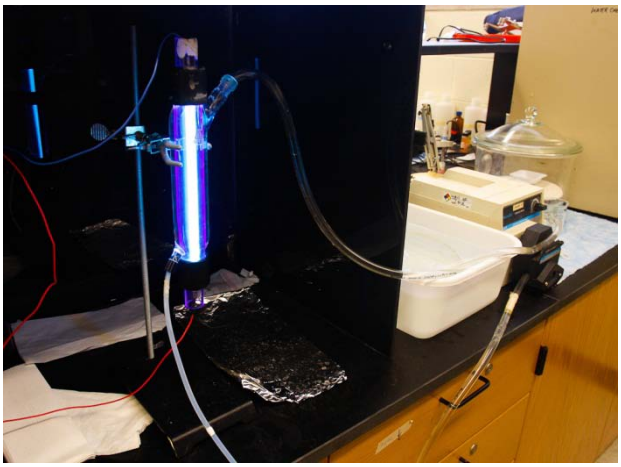

Figure 1. UV reactor setup.

Algae scrubbers

Small-scale algae scrubbers have been constructed at the Main Street Wastewater Treatment Plant in Gainesville, Florida, using aluminum, plastic netting, and PVC liner. Figure 2 shows the design of the algae scrubber system. The water being used is un-chlorinated treated effluent, because chlorine inhibits algae growth. The design incorporates an optional pulse delivery system to create a surge of water for testing pulsed conditions. Calcium (Ca) will be added using peristaltic pumps and concentrated $CaCl_2$ solutions. Six scrubbers are being operated, allowing for three sets of two scrubbers. This replication will permit determination of statistically significant results, which is lacking in the refereed literature. Algae display high turnover rates and can be harvested in as few as eight days (Adey et al. 1993). High algal turnover and use of treated wastewater effluent will allow for short-term testing of many different variables, such as flow rate, Ca addition to the algae scrubbers, and pulsed vs. non-pulsed flow. Detailed analysis of species composition, productivity rates, and P percent in the algae will be conducted to quantify which algae scrubber configuration is best suited for different influent P conditions.

This work is ongoing and is expected to generate at least one publication in the refereed literature.

Figure 2. Algae scrubber photos: (left) all six algae scrubbers being operated at Main St. wastewater treatment plant and (right) an example of algal growth on the scrubbers (the top half of the photo is dark because of the shadow of the raceway side)

Co-Precipitation: Phosphorus–calcium–dissolved organic matter system

Tests will be conducted using a pH-stat system modeled after a system used previously for Ca and DOM experiments (Lin et al. 2005). In earlier work, the pH-stat system used pure Ca precipitation as a reference to determine the inhibitory effect of different water constituents on Ca precipitation. For this work, different Ca and P concentrations will be used to create reference Ca-P co-precipitation rates for Ca-P experiments involving DOM. Experiments will be conducted on both model waters containing only Ca, SRP, and DOM and test waters from select natural systems. Suwannee River DOM will be used in the model waters. The goal is to evaluate the effect of DOM on Ca-P co-precipitation in both model and real waters. This work is expected to start summer 2012 and is expected to generate at least one publication in the refereed literature.

Presentations

- Sindelar, H., Boyer, T.H., and Brown, M.T., "Evaluating advanced oxidation processes for the transformation of organic phosphorus to more biologically labile compounds," *Oral presentation at Florida Lake Management Society 22nd Annual Conference*, St. Augustine, Florida, 13–16 June 2011.
- Sindelar, H., Boyer, T.H., Brown, M.T., "Evaluating advanced oxidations processes for the transformation of organic phosphorus into biologically liable compounds," *Poster presentation at 2011 Association of Environmental Engineering and Science Professors Research and Education Conference*, University of South Florida, Tampa, Florida, 10–12 July 2011.
- Sindelar, H., Boyer, T.H., Brown, M.T., "Evaluating advanced oxidation processes for the transformation of organic phosphorus into biologically labile compounds," *Poster presentation at 3rd UF Water Institute Symposium*, University of Florida, Gainesville, Florida, 15–16 February 2012.

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Adey, W., Luckett, C., Jensen, K., 1993. Phosphorus removal from natural waters using controlled algal production, Restoration Ecology 1, 29-39.

Gao, X., 2006. TMDL Report: Middle St. Johns Basin, Lake Jesup, WBIDs 2981/2981A, Nutrients/Unionized Ammonia. Florida Department of Environmental Protection, Bureau of Watershed Management, Watershed Planning and Coordination Section, Tallahassee, FL.

Lin, Y., Singer, P.C., Aiken, G.R., 2005. Inhibition of calcite precipitation by natural organic material: kinetics, mechanism, and thermodynamics. Environmental Science & Technology, 39(17), 6420-6428.

Rittmann, B.E., Mayer, B., Westerhoff, P., Edwards, M., 2011. Capturing the lost phosphorus. Chemosphere 84, 846-853.

Sindelar, H.R., Boyer, T.H., Brown, M.T., (Under Review). Transformation of recalcitrant phosphorus to biologically labile compounds using UV/H2O2. Submitted to Journal of Hazardous Materials 22 May 2012.

Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida

Basic Information

Title:	Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida
Project Number:	2011FL269B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	6
Research Category:	Engineering
Focus Category:	Water Supply, Management and Planning, Models
Descriptors:	None
Principal Investigators:	James Heaney

Publications

1. Heaney, J. and J. Sansalone. 2012. A Vision for Urban Stormwater Management in 2050. Chapter 17 in Grayman, W. Loucks, D. and L. Saito, Eds. Toward a Sustainable Water Future: Vision for 2050, ASCE Press, Reston, VA.
2. Heaney, J., Friedman, K., and M. Morales. 2011. International Perspective on Urban Water Conservation. Proc. 8th Int. Conf. on Urban Watershed Man., Beijing, China, Sept.
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4. Friedman, K., Heaney, J., Morales, M. and J. Palenchar. 2011. Water Demand Management Optimization Methodology. Jour. American Water Works Assoc., Vol. 103, No. 9.
5. Morales, M., Heaney, J., Friedman, K., and Martin J. 2011. Estimating Commercial, Industrial, and Institutional Water Use on the Basis of Heated Building Area. Jour. American Water Works Assoc., Vol. 103, No. 6.
6. Morales, M., and J. Heaney. 2010. Predominant Commercial Sectors in Florida and their Water Use Patterns. Florida Water Resources Journal, August.
7. Friedman, K. and J. Heaney. 2009. Water Loss Management: Conservation Option in Florida s Urban Water Systems. Florida Water Resources Journal, August, p 24-32. http://www.fwrj.com/techarticles/0809%20FWRJ%20tech1.pdf.
8. Friedman, K. and J. Heaney. 2009.Validity of Water Audit and Water Loss Evaluations for Florida. Proc. Florida Section of AWWA Fall Conference, Orlando, December.

Title. Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida

Principal Investigator. James P. Heaney, Professor, U. of Florida, heaney@ufl.edu, 352-392-7344

Research Category. Engineering

Keywords. Urban water, demand management, water loss control, water use efficiency modeling

Abstract. Continued growth in water demand in many parts of the country including Florida has placed significant stress on traditional groundwater and surface water sources for urban water supply. Regional water supply assessments by the water management districts have shown significant negative impacts of these developments including lowered groundwater tables accompanied by reduced flows in rivers and springs, declining lake levels, and increasing nutrient loads on receiving waters. In response to these problems, water utilities are required to evaluate alternative water supplies and water conservation to meet future water needs. Water losses on the utility side of the customer meters can be as high as 15-20%. A similar loss range exists on the customer side of the meter. Improved methods of water loss control can reduce these losses to 5% or less. The City of Sanford will be used as a case study to evaluate innovative methods of water loss control and the addition of water conservation practices. The EZ Guide 2.0 model will be refined to address these needs to find cost-effective solutions. EZ Guide 2.0 has been developed by the Conserve Florida Water Clearinghouse to find the optimal portfolio of traditional and alternative water supply options and demand management. The work elements for this effort include:

- Evaluate water consumption data using property appraisal attributes and typical water use benchmarks for indoor and outdoor use to determine water saving potential.
- Evaluate commercial, industrial, and institutional water use and water savings potential
- Perform water audit and estimate water losses and trends using automatic meter reading data.
- Inventory water infrastructure, ages, and historical leakage events.
- Develop relationships and refined methods for calculating real and apparent losses from sources to distribution system.
- Apply hydraulic modeling and other analysis to isolate areas of concern and further study.
- Evaluate benefits of master and customer meter change-out program.
- Evaluate effectiveness of other conservation BMPs and compare against new BMPs using the Conserve Florida Water Guide Version 2.0.
- Estimate the economically optimal level of water losses in the treatment and distribution systems.

- Develop trends, criteria and thresholds to establish water-saving goals.

The results will be published in refereed journals as part of doctoral research by two students.

One of the primary water uses in urban areas is irrigation. The increasing use of in-ground irrigation systems has drastically altered the use of water in the urban landscape. Rates of in-ground irrigation system installations have increased exponentially since they became widely available in the 1980s and are approaching saturation in new home construction. This availability of automated irrigation systems has increased the water demand for urban irrigation by allowing for homeowners to easily water their entire yard on the days of their choosing. This use is typically highly seasonal and during the peak irrigation season often exceeds the indoor use, sometimes by several times. Because of the nearly ubiquitous nature of in-ground irrigation systems in new homes and frequent retro-fitting of older homes, larger average and much larger peak demands have been placed on municipal water systems. These demands follow both a seasonal and a diurnal cycle. The irrigation demand has caused an increased pressure on both the treatment systems and distribution systems, as well additional impacts on the environment. To mitigate the impact of additional aquifer withdrawals and to remove users from the potable water systems, many communities, including Sanford, are increasing the use of reclaimed water for irrigation. The use of reclaimed water requires an additional distribution system, but when installed allows irrigation demands to be met by non-potable water on a system that demands less reliability than the potable water system. This removal of irrigation uses can allow municipalities to alter their operation which can have the added benefit of reducing water system losses.

When reclaimed water is available at low or no cost the resource tends to be used at a higher rate than equivalent users on the potable water system. This is not surprising since residential potable water bills can easily be in the hundreds of dollars if large irrigation use is occurring on the potable water system. The City of Sanford is unusual in that a large number of its users (>2,400) have been served by a reclaimed water system for years. Additionally, Sanford meters these customers and charges a small cost for water use on the reclaimed system. This unique dataset provides information on use patterns and trends among reclaimed water users that can be compared against other water users. Sanford also has more than 100 users with irrigation meters. These are users on the potable water system that have a separate meter for their irrigation systems. As with the reclaimed users these users typically have higher water use because the additional cost of a separate meter usually limits this installation to more affluent property owners. This dataset provides for an accurate comparison to be made between reclaimed and potable water irrigation users.

One potential downside of irrigation with reclaimed water is the potential increase in stormwater runoff that over-irrigation can cause. With no- or low-cost reclaimed water, users tend to irrigate more than they might otherwise. This additional application can contribute directly to runoff if irrigation systems apply more water than can infiltrate or have over-spray onto impervious surfaces. Also irrigation systems may not have a

properly installed rain sensor to shut off the system when rainfall occurs. In this scenario irrigation can actually occur during or immediately after rainfall events greatly increasing the potential for runoff. Even when properly installed and set with a functional rain or soil moisture sensor, irrigation systems can still contribute to increased runoff by filling available soil storage and limiting the available capacity in the event of rainfall.

Statement of regional or State water problem. Improved water use efficiency is an integral component of sustainable urban water systems. Some traditional sources of water have been mined beyond their safe yield and have caused problems in terms of reduced surface flows and increased pollutant levels. Utilities in Florida, Georgia, and elsewhere are now required to develop quantifiable water conservation plans that can be part of their portfolio of options to meet future water needs.

Increased water use is placing a growing burden on already strained water resources in the southeast and nationwide. Innovative ideas are being used to combat this problem by increasing the reuse of water that was pumped for potable water use. Reclaimed water systems are increasing in prevalence in Florida to combat additional pumping of aquifers. While reclaimed water use does decrease the required pumping it is important to evaluate whether it can have adverse impacts on other portions of the hydrologic water budget. Stormwater control has been and remains an important component of water resources management in Florida. Reclaimed water users tend to irrigate at a higher rate than potable users due to the low-cost or free water. This water use can cause the unintended consequence of increased runoff.

Statement of results or benefits. Florida may be unique in having a statewide database of attributes of every one of its nine million parcels of land. We are linking this information with customer water use billing records to determine the optimal mix of demand management practices. These new techniques will be incorporated into EZ Guide software for use by water utilities and other water agencies.

Florida may be unique in having a statewide database of attributes of every one of its nine million parcels of land. This parcel data can be combined with billing data to provide a dataset that can be used to estimate water use and water application rates. Sanford is unique in that many users are on metered reuse accounts that allow for irrigation application to be evaluated at the parcel scale. The Seminole County Property Appraiser has developed a GIS dataset for the county that includes the area of each parcel that is covered by impervious surfaces. This data can be used to develop a parcel-level water budget to evaluate the impact of irrigation on runoff.

Nature, scope, and objectives of the project, including a timeline of activities. The three-year schedule of activities is shown below.

ID	Task	Quarter											
		Year 1				Year 2				Year 3			
		1	2	3	4	5	6	7	8	9	10	11	12
1	Initial bottom up evaluation of water loss, water conservation, and water reuse saving potential using EZ Guide	X	X										
2	Perform water audit and estimate water losses and trends using AMR and other data			X	X	X	X	X	X	X			
3	Refined bottom up benefit-cost optimization of water loss, water conservation, and water reuse options using EZ Guide							X	X	X	X		
4	Estimate the economically optimal level of water losses in the treatment and distribution systems.									X	X	X	
5	Develop trends, criteria and thresholds to establish water-saving goals for water loss program										X	X	X
6	Progress Reports	X	X	X	X	X	X	X	X	X	X	X	
7	Final Reports				X				X				X

Major Findings and accomplishments from last year. The two primary tasks for year 1 are shown in the above table. The status of these two tasks is described below.

1. Initial bottom up evaluation of water loss, water conservation, and water reuse saving potential using EZ Guide

Sanford has provided annual information on unaccounted for water (UAW) for fiscal years 2005 to 2010 based on accepted practices for making these estimates. The results, shown in Table 1, illustrate the complexity of the determination of UAW. Annual % UAW varied widely from 13.3% to 27.5% during this six year period. UAW studies in Sanford and other Florida utilities indicate similar wide variability in monthly % UAW. It is important for Sanford to understand the nature of their water use patterns in order to explain the causes of these relatively high annual % UAW and to implement cost-effective changes.

Table 1. Annual trends in unaccounted for water for Sanford

Item	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010
Total Water Production (mil. gallons per year)	2,479	2,641	2,705	2,678	2,669	2,401
Unaccounted for Water (mil. gallons per year)	409	352	432	616	734	539
% Unaccounted For	16.5%	13.3%	16.0%	23.0%	27.5%	22.4%

The results of the initial uncalibrated EZ Guide run for Sanford are shown in Figure 1 and Table 2. Residential water use accounts for 42% of total use. The initial estimate of total

water use for calendar year 2009 is about 8.2% higher than the reported annual use. These initial estimates have been refined to reduce these discrepancies.

Figure 1: 2009 Uncalibrated Water Budget by Sector for Sanford

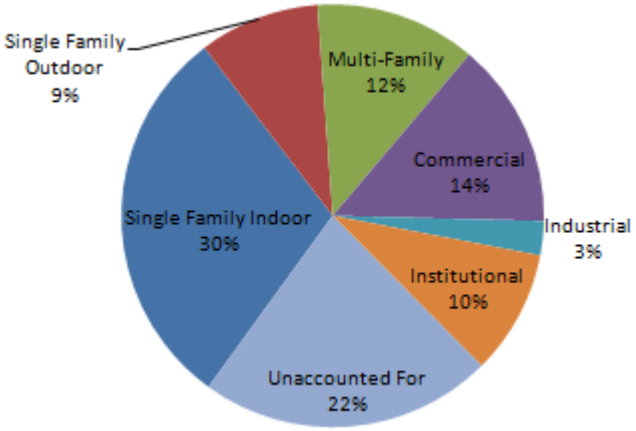

Table 2. Initial Comparison to Reported Data

	FDEP Data	CFWC Estimate	% Difference
Total Number of Accounts	17,729	18,332	3.4%
Population Served	62,052	54,331	-12.4%
Total Water Use (MGY)	2,674.27	2,893.39	8.2%

2. <u>Perform water audit and estimate water losses and trends using Automated Meter Reading and other data.</u>

Initial estimates of Sanford customer water usage were done using Florida statewide databases in the EZ Guide tool. The statewide databases include Florida Department of Revenue (FDOR) parcel property appraisal data, U.S. Census Block data, and Florida Department of Environmental Protection (FDEP) Monthly Operating Reports. This database was queried using a GIS shapefile boundary of Sanford acquired from Saint Johns River Water Management District (SJRWMD). This data was used to generate the initial water usage estimates within EZ Guide.

Site specific water use data is needed to improve upon initial estimates. The initial estimates provide a reasonable breakdown of demand patterns. However, case study utilities with additional data such as customer water billing and county property appraisal data are used to provide default estimates of parameters such as customers irrigating from the potable system, and Commercial, Institutional, and Industrial (CII) water use coefficients. UF worked closely with a consulting firm and Sanford to compile a detailed parcel level database consisting of customer billing data, Seminole County property appraisal data, and Sanford business data. This database was used to improve water use estimates within EZ Guide by replacing default coefficients with calculated values directly from the database.

After combining all of these datasets, the final Sanford flat file contains 15,102 parcels 40 FDOR parcel and U.S. Census attributes, 29 Seminole County attributes, 9 Reference USA business data attributes, 176 attributes relating to meter attributes including customer change dates, meter change dates, rate structures, and meter sizes, and 64 months of customer water usage from 19,297 meter locations from 10/2005 through 5/2011 for each of the four services (i.e. potable, irrigation, reclaimed, or cooling tower meter). Data from roughly 1,000 meters was not carried through to the final dataset as a result of the QA/QC process.

Kenneth Friedman, a doctoral student, is continuing work on developing a methodology for evaluating water use in Sanford. This effort is utilizing the EZ Guide 2.0, parcel data, and billing data to develop study areas that can be evaluated for water loss. During this process, additional interest has focused on analyzing the unique reclaimed water use dataset. Reclaimed water is being widely used in Florida to avoid additional potable water use; however not much research has been done to evaluate usage patterns and the impact of reclaimed water on the urban water budget.

Scott Knight, a doctoral student, has started to evaluate the impact of reclaimed water on the urban water budget. This research is focused on development of a model to evaluate a water budget at the parcel-scale with the use of billing and parcel data. High frequency meteorological data is being employed with the water use data to evaluate the impact of reclaimed water on increased stormwater runoff. Data from the City of Sanford for 2,422 reclaimed water accounts and 145 irrigation accounts is being used to develop model parameters for irrigation application rate for both types of parcels. These application rates are used to evaluate the impact of irrigation on runoff at the parcel-scale. The development of this model (based on the STORM - Storage, Treatment, Overflow, Runoff Model) includes the addition of irrigation, soil storage, and an adjustable time step. The model includes continuous simulation with the ability to easily adjust variables to allow for “what-if” simulations.

Initial data analysis shows that users of reclaimed water apply approximately 60% more water than customers with irrigation meters. This increased application rate contributes to stormwater runoff by decreasing available soil storage before and/or during rainfall events and increasing runoff following rainfall events. Initial model results show that with no irrigation on a parcel the difference in runoff can be 20% or more dependent upon irrigation practices. In the case of reclaimed water users this amount could be much higher because of the more frequent application and/or increased application rate.

Publications

Our research results have been published in Florida and national journals as well as in conference proceedings. It is anticipated that the reclaimed irrigation water use will be developed into a paper for submission to a journal by the end of August 2012 and will be presented at a conference by the end of 2012. A complete list of publications is available at the Conserve Florida Water Clearinghouse website (Conservefloridawater.org). Key relevant recent publications are shown below.

Heaney, J. and J. Sansalone. 2012. A Vision for Urban Stormwater Management in 2050. Chapter 17 in Grayman, W. Loucks, D. and L. Saito, Eds. Toward a Sustainable Water Future: Vision for 2050, ASCE Press, Reston, VA.

Heaney, J., Friedman, K., and M. Morales. 2011. International Perspective on Urban Water Conservation. Proc. 8th Int. Conf. on Urban Watershed Man., Beijing, China, Sept.

Heaney, J., Switt, R., Friedman, K., Morales, M., and K. Riley. 2011. Overview of EZ Guide for Water Conservation Evaluations. *Florida Water Resources Journal*, September.

Friedman, K., Heaney, J., Morales, M. and J. Palenchar. 2011. Water Demand Management Optimization Methodology. *Jour. American Water Works Assoc.*, Vol. 103, No. 9.

Morales, M., Heaney, J., Friedman, K., and Martin J. 2011. "Estimating Commercial, Industrial, and Institutional Water Use on the Basis of Heated Building Area." *Jour. American Water Works Assoc.*, Vol. 103, No. 6.

Morales, M., and J. Heaney. 2010. Predominant Commercial Sectors in Florida and their Water Use Patterns. *Florida Water Resources Journal*, August.

Friedman, K. and J. Heaney. 2009. Water Loss Management: Conservation Option in Florida's Urban Water Systems. *Florida Water Resources Journal*, August, p 24-32. http://www.fwrj.com/techarticles/0809%20FWRJ%20tech1.pdf.

Friedman, K. and J. Heaney. 2009.Validity of Water Audit and Water Loss Evaluations for Florida. *Proc. Florida Section of AWWA Fall Conference*, Orlando, December.

Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters

Basic Information

Title:	Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters
Project Number:	2011FL270B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	6
Research Category:	Water Quality
Focus Category:	Sediments, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Wendy D Graham

Publications

1. Reijo, C.; Arnold, T.E.; Burkett, V.; Henson, W.R.; Laing, J.M.; Weinkam, G. 2012. Characterization of Nutrient Uptake Kinetics in a Spring-fed North Florida Stream. Poster presented at the 3rd Annual University of Florida Water Institute Symposium: Nutrient Dynamics, Policy, and Management in Watersheds. Gainesville, FL, Feb. 2012.
2. Henson, W.R. and Niswonger, R.G, Evaluating the Effects of Horizontal Spatial Discretization on Interflow in the Soil Zone Using the Richards and Groundwater Flow Equations, poster Presented at the Fall AGU Conference, San Francisco, CA, Dec. 2011.
3. Cohen, M.C., Henson W.R., Petitt, C. Burkett, V., Weinkam, G., Laing, J.M. Reijo, C. and Arnold, T. E. Nutrient Spiraling in a Bottomland Sub-Tropical Stream. 9th INTECOL International Wetlands Conference, Orlando FL, June 2012.

TITLE. Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters

PRINCIPAL INVESTIGATORS.
Dr. Tom Frazer, Forest Resources and Conservation – Ecological Consequences of Nutrient Enrichment
Dr. Wendy Graham, Agricultural and Biological Engineering - Hydrologic Processes

COOPERATORS:
Dr. Mark Brenner, Geological Sciences - Paleolimnology
Dr. Mark Brown, Environmental Engineering Sciences – Systems Modeling
Dr. Mark Clark, Soil and Water Science - Nutrient Best Management Practices
Dr. Matt Cohen, Forest Resources and Conservation – Riverine Nutrient Dynamics
Richard Hamann, J.D., College of Law - Environmental Law
Dr. Christine Overdevest, Sociology, Criminology and Law - Environmental Policy and Governance

RESEARCH CATEGORY. Water Quality

KEYWORDS. Numeric Nutrient Criteria, Paleolimnology, Best Management Practices, Hydrologic Processes, Riverine Nutrient Dynamics, Aquatic Ecology, Environmental Policy, Systems Modeling

ABSTRACT.
The overall goal of this project is to fund an interdisciplinary cohort of 7 Ph. D. Fellows to develop the new knowledge, and creative engineering, management and policy solutions needed to establish and achieve numeric nutrient criteria (NNC) for Florida's waters. The education and research of each Fellow will evolve from specific problems and research questions related to management of Florida's water and watersheds under NNC. The unique cross-disciplinary environment of our program will allow an integrated whole that will reflect disciplinary facets associated with this complex problem.

STATEMENT OF REGIONAL OR STATE WATER PROBLEM.
In January 2010 the US Environmental Protection Agency embarked on a new approach to regulate nutrient pollution in aquatic ecosystems. Previously, nutrients were managed according to narrative criteria that categorized water bodies as impaired using observed biological responses, specifically an imbalance in the native flora and fauna of the aquatic ecosystem. Now, rather than waiting for biological impairment to become apparent before implementing ecologically protective nutrient levels, EPA will regulate nutrients according to now finalized numeric criteria (http://water.epa.gov/lawsregs/rulesregs/upload/floridaprepub.pdf). Under this plan, concentration thresholds will be established for each water body type (i.e., lakes, wetlands, rivers/streams, springs, estuaries, and canals) and enforced uniformly statewide.

This new approach constitutes a paradigm shift that has generated significant controversy. On one hand, it offers a simple metric for the regulatory process, and which may accelerate the timeline for listing and restoring degraded water bodies. It is also pre-emptive, reducing the risk of tipping water bodies into a degraded state that is often irreversible. On the other hand, it ignores the site-specificity that was an important component of narrative standards. Each river, lake and estuary is different, and adoption of a single standard is therefore "under-protective" of some systems and "over-protective" of others. The basis for setting such thresholds is fraught with uncertainty. Although development of alternative site-specific criteria can be petitioned, the cost and time associated with gathering such additional data to modify numeric values for a particular water body will be considerable. Therefore, the proposed approach, while conferring simplicity and predictability will also create rigidity that precludes adaptation and optimization.

Adoption of numeric standards is intended to be a national endeavor, enacted on a state-by-state basis. In Florida, adoption of numeric criteria is contentious, in large part because of the number and wide diversity of water bodies in the state. The process unfolding now in Florida will undoubtedly influence how other states manage their surface water resources. This developing environmental management strategy provides an opportunity to provide guidance and rigorous oversight of the process. Graduate students trained in the crucible of this controversy, and engaged in the dialog it has engendered, will be well equipped to solve the trans-disciplinary problems associated with water resource conflict all over the world.

The currently funded Water Institute Graduate Fellows (WIGF) program will link faculty and students from watershed science (Cohen), limnology (Brenner), wetlands and water quality extension (Clark), water law (Hamann), environmental governance (Overdevest), and systems modeling (Brown) to study the scientific basis for, and the design and implementation of numeric nutrient criteria for Florida waters. The 104B funding for this project extends these links to include hydrologic science (Graham),and aquatic ecology (Frazer), facets that obviously impact the design and implementation of numeric nutrient criteria.

STATEMENT OF RESULTS OR BENEFITS.

The WIGF program will provide a greater understanding and framework to address issues of water and watersheds and the interplay of policy and science required to manage them. The program will build a firm disciplinary base (each student's major), overlay coursework in complementary disciplines, and incorporate interdisciplinary training and research experiences. Specifically, this program will:

(1) Use a synthetic approach to understanding watershed-scale nutrient dynamics through the application of models, field measurements, and data mining.
(2) Explore effectiveness of best management practices for reducing nutrient loads.
(3) Explore the local-scale couplings and feedbacks among climate, land-use, water use, and nutrient cycling in watersheds, and how these relationships scale-up to affect nutrient fluxes to springs, lakes, wetlands and estuaries.
(4) Understand the effects of increased nutrient delivery on key biogeochemical and ecological processes that, in turn, influence the structure and function of aquatic ecosystems.
(5) Quantify nutrient uptake and recycling kinetics in streams and rivers to provide a needed quantitative foundation for establishment of downstream protective values (DPVs).
(6) Combine paleolimnological techniques with modeling approaches to develop reference (pre-disturbance) conditions for lakes.
(7) Evaluate the regulatory and policy implications of numeric nutrient criteria and their acceptance of criteria as a means to protect certain water resource values.

Three primary outcomes of the program include:

(1) Education and training of 7 Ph .D. scientists and engineers to prepare them for the challenges of managing water and watersheds.
(2) Increased scientific understanding of the relationships between and uncertainty associated with watershed nutrient dynamics and ecological conditions in Florida waters.
(3) Provision of biophysical, social science and policy perspectives grounded in Florida water law toward a national effort to apply numeric nutrient criteria to surface waters.

Other features include institutionalization of cross-disciplinary research and education, internationalization of student perspectives, blending of disciplines in doctoral training, and dissemination of results within and outside traditional academic circles.

NATURE, SCOPE, AND OBJECTIVES OF THE PROJECT, INCLUDING A TIMELINE OF ACTIVITIES.

Our broadest goal is to develop a graduate program that stresses integration of engineering, biophysical, and social sciences and addresses issues related to management of water and watersheds through field-based teaching and research. The program consists of three elements:

Education - The educational experience fostered by this program will complement the disciplinary focus of each student's own research. The program will blend experiential learning and academic course work. A core set of interdisciplinary courses (some developed by the former UF NSF-funded IGERT in Adaptive Management) will be required of each student, regardless of discipline or major. A weekly seminar involving both faculty and students will focus on combining social, ethical and scientific domains as they relate to the program's focus using a Socratic format of inquiry and debate between participants to stimulate critical thinking and to illuminate ideas.

Research - We have identified a significant water management issue, numeric nutrient criteria (NNC), as the central topic around which our program will be constructed. The education and research experience of each student will evolve from and be shaped by specific problems and research questions related to adaptive management of Florida's water and watersheds under NNC. During the 1st fall semester we will devote our weekly Socratic seminar to identifying study watersheds and developing a scope of work addressing the research approach. The product of this will be a multi-authored "research report" that outlines the major watershed issues. Each student will draw from this experience in formulating his/her research topic.

Service - We will foster a component of ethical responsibility and civic involvement, which will be reinforced in core coursework and our continuing biweekly seminar that integrates ethics, communication, and leadership skills with research methods, scientific inquiry, and engineering practice. We anticipate involving undergraduates in studios, research, and special programs (including field trips) under mentorship of our graduate students. Finally, we will encourage students to get involved in community projects and education initiatives (e.g. watershed working groups) related to program objectives on a volunteer basis.

Project Timeline-

Student Recruitment (December, 2010 – February, 2011) – Each faculty member will be responsible for recruiting within his or her discipline. We will develop a brochure and web ad that showcases our WIGF Program for placement on various academic and professional web sites. In addition, we will advertise on the IGERT web site. We anticipate inviting students to UF campus in mid-February to mid-March. (All faculty members will participate)

Cohort Building Exercise I (August 2011) – Natural and Degraded Systems of Florida.
Similar to the "Everglades course" developed for the UF-IGERT, we will develop a 2-week course that will show case natural and degraded watersheds in north and central Florida. (All faculty members will participate)

Socratic Seminar (Fall 2011 and Spring 2012) - This weekly 3 hour seminar is required each semester. In the first year, we will focus on a synthetic dialog related to the cohort's research agenda that will ultimately lead to development of a large integrative proposal. In later years the seminar will be used to focus student research questions. (All faculty members will participate)

Cohort Building Exercise II (Feb 2012) – Water Institute Symposium. Students will work with Water Institute staff in planning and developing a two-day Symposium at UF that will bring together scientists, managers, and policy experts to discuss watershed management and NNC.

Watershed Management & Restoration course (Summer 2012) – Modeled after the Watersheds course developed for the UF-IGERT, this required course will be team taught by WIGF Program faculty. (All faculty members will participate)

Cohort Building Exercise III (July-August 2012) –Writeshop. This writing workshop will be conducted following Summer 2012 as the culmination of the Socratic seminar; students and faculty will cloister at a location and write a major integrative proposal for submission in Fall 2012 to one of the following NSF programs: NSF-Biocomplexity, NSF-IGERT, NSF-WSC, NSF- CNH, NSF-Environmental Engineering, NSF- Hydrologic Sciences. (All faculty members will participate)

METHODS, PROCEDURES, AND FACILITIES.

The research theme addresses complex and emerging issues related to the management, protection, and regulation of nutrients in Florida watersheds. The US-EPA's proposed Numeric Nutrient Criteria (NNC) will have significant impacts on all sectors of Florida's economy including, industries discharging pollutants to lakes and flowing waters, publicly owned water treatment facilities, public and private storm water management agencies, and agriculture. It will require rethinking the way in which point source and non-point source discharges are dealt with as well as the institutional frameworks of governance and regulation that manage them. Real, cost-effective solutions, and public willingness to address the issue, will require not only the talent and efforts of Florida planners, designers, engineers and scientists, but an adaptive approach to implementation that adequately addresses scientific uncertainty and adapts to complex local conditions. Our research theme will address both the biophysical science and social policy dimensions of watershed research related to NNC.

We will use an experiential, multidisciplinary field-based program of research to study watersheds comparing nutrient dynamics, land use impacts, and management alternatives. Our goal is to provide quantitative science in support of flexible NNCs. There are already research programs underway at UF, with others proposed, and this WIGF Program will build on these existing initiatives. The watersheds will be identified in the first weeks of the program. The final decision will take into consideration the potential for synergistic activities with proposed and ongoing research initiatives at, for instance, the Santa Fe River basin, Newnans Lake, Lake Apopka, and Lake Alice. A key feature that ties our research theme to our educational/training program is integration of experiential, field-based research, whereby all students and faculty members on the team participate in field data collection, public management meetings (e.g., basin working groups, NNC public meetings) and weekly core seminars. Thus, we ensure integration across disciplines and a holistic perspective by each member of the team.

Field Campaigns - Our field research efforts will be organized into field campaigns in which all members of the program team participate. Campaigns will include such activities as water quality sampling, lake sediment coring, diurnal productivity measurements, administering stakeholder questionnaires, stormwater sampling, etc. Each campaign will be designed to collect data that will be used by one or more graduate students in their research projects. Each fellow/faculty team will be responsible for organizing filed campaigns as their research efforts take shape. This will help fellows develop skills in research design, management, and execution.

Individual Research Efforts

The UF funded effort consists of 7 Ph. D. Fellows. Each Fellow will has a biophysical and social/policy facet to their research. Students in the biophysical sciences focus primarily on that area, with a secondary focus in policy/social and systems sciences, while students in the policy/social and systems sciences will

adopt the reverse strategy. For details on the proposed research efforts for the 7 fellows see http://waterinstitute.ufl.edu/WIGF/ParticipatingFaculty.html

MAJOR FINDINGS AND ACCOMPLISHMENTS FOR 2011

A national recruiting effort for the Water Institute Graduate Fellow (WIGF) cohort was conducted from December 2010 to February 2011. A total of 133 candidates applied for these fellowships, and the faculty team identified 17 excellent candidates from the pool. Eight of these candidates were invited to Gainesville during March 4-7th 2011 to participate in a recruitment weekend. Offers were made to 7 of these candidates and all accepted and enrolled in UF. The GPAs of the enrolled fellows ranged from 3.8 to 4.0 (mean 3.91) and the GREs ranged from 1100 to 1400 (mean 1270). The 2011 WIGF cohort includes:

Tom Arnold (BS Penn State, MS UF, Advisor Mark Brenner, Geological Sciences)
Resources and Conservation)
Wesley Henson (BS/MS University of Nevada Reno, Advisor Wendy Graham, Agricultural and Biological Engineering)*
Joelle Liang (BS Berry College, MS North Carolina State University, Advisor Tom Frazer, Interdisciplinary Ecology)*
Charlie Nealis (BS/MS UF, Advisor Mark Clark, Soil and Water Sciences)
Courtney Riejo (BS Carroll University, MS Virginia Tech, Advisor Matt Cohen, Forest
Chris Pettit (BS New College, JD UF, Advisor Christine Overdevest, Environmental Sociology)
Grant Weinkam (BS Ohio University, MS University of Cincinnati, Advisor Mark Brown, Environmental Engineering Sciences)

*partially supported by 104B grant.

The WIGF students have explored multiple interdisciplinary water quality issues in Florida through site visits, field experiments, conferences and symposia, interdisciplinary coursework, and biweekly integrated seminar discussions. During Fall 2011 and Spring 2012 the students conducted a Tracer Additions for Spiraling Curve Characterization (TASCC) experiment (Covino et al. (2010)) to a low relief, spring-fed stream in Florida. Previously, the method has been tested only in mountain streams in the western United States. Using this robust methodology, the students successfully characterized the saturation kinetic curve of nitrogen through stream dosing experiments and presented research results at the 3rd Annual University of Florida Water Institute Symposium poster session as well as the 9th Annual INTECOL International Wetlands Conference.

A two-day retreat is planned for the end of May 2012 during which the WIGF faculty and student cohort will develop the framework for a major integrative proposal on nutrient dynamics, management and policy for submission to one of the following NSF programs: NSF-SEES, NSF-WSC, NSF- CNH, NSF-Environmental Engineering, NSF- Hydrologic Sciences. At the conclusion of the summer it is anticipated that each of the WIGF students will have details of their individual research proposals within this proposal identified and developed.

TRAINING

Two Ph. D. students are partially funded under this project and will join the UF funded cohort of 5 additional Ph. D. students. Each Ph.D. student will craft a dissertation around a topic and disciplinary facet of interest to them while contributing to the team's overall research theme of watershed management and policy in the face of Numeric Nutrient Criteria.

Student: Joelle Liang, Ph. D. in Interdisciplinary Ecology, School of Natural Resources and the Environment
Proposed Dissertation Title: Biogeochemical factors contributing to *Lyngbya* spp persistence in freshwater and estuarine systems and implications for species richness.

Student: Wesley Henson, Ph. D. in Agricultural and Biological Engineering, College of Agricultural and Life Sciences and College of Engineering
Proposed Dissertation Title The role of Groundwater-Surface Water Interactions in Nutrient Transport from the field to basin scale in Springs and Streams in Northern Florida.

Joelle Laing and Wesley Henson Lake Okeechobee Field Trip August 2011

Wesley Henson, Dr. Matt Cohen, and Valerie Burkett after weir Installation at TASCC field site spring 2012

Wesley Henson next to karst swallet in Santa Fe River basin Spring 2012

Reference:

Covino, T. P., McGlynn, B. L., & McNamara, R. A. 2010. Tracer additions for spiraling curve characterization (TASCC): Quantifying stream nutrient uptake kinetics from ambient to saturation. *Lim. & Ocean.* 8: 484-498.

In-Filling Missing Daily Rain Gauge Data Using Radar Rainfall Data: Influence of Homogeneous Rain Areas

Basic Information

Title:	In-Filling Missing Daily Rain Gauge Data Using Radar Rainfall Data: Influence of Homogeneous Rain Areas
Project Number:	2011FL273B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	19
Research Category:	Engineering
Focus Category:	Hydrology, Methods, Models
Descriptors:	None
Principal Investigators:	Ramesh S Teegavarapu

Publications

1. Ramesh S. V. Teegavarapu, and Chandra Pathak, Development of Optimal Forms of Z-R relationships, Weather Radar and Hydrology Symposium, Exeter, England, April 2011, 6 pages.
2. Extreme Precipitation and Climate Change, IFI, Book Series Meeting, UNESCO, Paris, April 29, 2010.
3. Husayn El Sharif and Ramesh S.V. Teegavarapu, Spatial Statistics Preserving Methods for Estimation of Missing Precipitation Data Involving a Single Best Estimator, FAU Research Day, March 30, 2012. Research Poster Award Winner.
4. Husayn El. Sharif, Ramesh S. V. Teegavarapu, Spatial Statistics Preserving Interpolation Methods for Estimation of Missing Precipitation Data, AGU Fall Meeting, 2011.
5. Ramesh S. V. Teegavarapu, Chandramouli Viswanathan, Ravi Chittamuru, Examining climate change indices using Indiana rainfall data, KWRRI Annual Symposium, 2012.
6. Ramesh S. V. Teegavarapu, Chandramouli Viswanathan, Pradeep Behera, Variability of Precipitation Extremes and Climate Change: Evaluation using Descriptive Indices, AGU Fall Meeting, 2011.
7. Ramesh S. V. Teegavarapu, Spatial Interpolation for Missing Precipitation Data: Use of Proximity Metrics, Nearest Neighbor Classifiers and Clusters, paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012.
8. Husayn El. Sharif and Ramesh S. V. Teegavarapu, Evaluation of Spatial Interpolation Methods for Missing Precipitation Data: Preservation of Spatial Statistics. Paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012.
9. Ramesh S. V. Teegavarapu, Aneesh Goly, Chandramouli Viswanathan, Pradeep Behera, Precipitation Extremes and Climate Change: Evaluation using Descriptive WMO Indices. paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012.
10. Teegavarapu, R.V.S. 2012. Spatial interpolation using nonlinear mathematical programming models for estimation of missing precipitation records. Hydrological Sciences Journal.(In Press)
11. Ramesh S. V. Teegavarapu, Singaiah Chinatalapudi, Chandra Pathak, Ricardo Brown. 2012.Optimal Spatial Interpolation and Data-Driven Methods for Infilling Missing Rain Gage Records using Radar (NEXRAD) based Precipitation Data. Journal of Hydrologic Engineering, ASCE (In Review).

12. Ramesh S. V. Teegavarapu, Kandarp Pattani, Chandra Pathak. 2012. Optimized Reflectivity (Z)-Rainfall Rate (R) Relationships for Improved Radar-based Precipitation Estimates. Journal of Hydrologic Engineering, ASCE. (In Review).
13. Teegavarapu, R. S. V, 2012. Missing Precipitation Data Estimation using Optimal Proximity Metric-based Imputation, Nearest Neighbor Classification and Cluster-dependent Interpolation Methods. Hydrological Sciences Journal. (In Review).

WRRC 104B Project Annual Report

(Activities during the period March 1, 2011 through February 28, 2012)

Project Title:

In-Filling Missing Daily Rain Gauge Data Using Radar Rainfall Data: Influence of Homogeneous Rain Areas

Submitted to:

Water Resources Research Center (WRRC)

University of Florida

P.O. Box 116580, Gainesville, Florida

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May 24, 2012

EXECUTIVE SUMMARY

This report summarizes the work completed for the second phase of the project, “In-Filling Missing Daily Rain Gauge Data Using Radar Rainfall Data: Influence of Homogeneous Rain Areas” supported by supported by USGS 104B Grant administered by Water Resources Research Center (WRRC), University of Florida, and matching funds from South Florida Water Management District (SFWMD). The report also discusses the methodologies, application of models and results based on the work completed under this project. The studies investigated the use of optimal power function relationship in estimating missing data using radar and evaluate the variations in functional coefficients and exponents in different homogeneous areas. Mathematical programming models are developed to optimize the exponents and coefficients of the power function. The best model based on performance evaluations can be used for infilling the missing rain gage data at several rain gages in the South Florida Water Management District (SFWMD).

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2
LIST OF FIGURES 4
LIST OF TABLES 5
INTRODUCTION AND BACKGROUND 6
PROJECT STATUS 7
Publications 7
Conference Publications/Presentations 7
List of students supported by 104B funding last year (March 2011 – February 2012) 8
DESCRIPTION OF PROJECT WORK 8
LITERATURE REVIEW: ESTIMATION OF MISSING PRECIPITATION DATA 9
PROJECT TASKS 12
INFILLING OF RAIN GAGE RECORDS USING RADAR (NEXRAD) DATA 13
NEXRAD DATA 13
DATA COLLECTION EFFORT 14
RAIN AREAS 23
INFILLING OF MISSING DATA: WEIGHT VARIATIONS IN HOMOGENOUS RAIN AREAS 23
COEFFICIENTS AND EXPONENTS FOR THE POWER MODEL $Y = AX^B$ 26
SPATIAL VARIATION OF COEFFICIENTS AND EXPONENTS 26
SPATIAL VARIATION 26
SPATIAL VARIATION OF MEAN VALUES 27
EXTREME EVENTS 27
VARIATION OF POWER MODEL: INFLUENCE OF DISTANCE BETWEEN RAIN GAUGE AND THE RADAR 27
RESULTS AND ANALYSIS 28
PERIOD OF RECORDS (POR) COEFFICIENTS AND EXPONENTS 28
INSIGHTS FROM RESULTS AND OBSERVATIONS 34
CONCLUSIONS 35
REFERENCES 36

LIST OF FIGURES

Figure 1 Designation of NEXRAD grids surround a rain gage. 23
Figure 2 Location of selected NEXRAD grids (of 9 pixels each) and the rain areas in different locations of South Florida. 24
Figure 3. Scatter plot for Coefficients throughout the POR and Rain Areas 30
Figure 4. Scatter plot for Exponents throughout the POR and Rain Areas. 30
Figure 15. Frequency Distribution of Coefficient and Exponent values throughout the POR and 163 Rain Gauges 31
Figure 6. Wet Season Scatter plot for Coefficients throughout the POR and Rain Areas. 32
Figure 7. Wet Season Scatter plot for Exponents throughout the POR and Rain Areas. 32
Figure 8. Spatial Distribution of Coefficients for the entire Period of Records obtained by using the Inverse Distance Weighted Interpolation Method. 33
Figure 9. Spatial Distribution of Exponents for the entire Period of Records obtained by using the Inverse Distance Weighted Interpolation Method. 34

LIST OF TABLES

Table 1 List of stations based on recorder type 1 14
Table 2 List of stations based on recorder type 2 16
Table 3 List of stations based on recorder type 2 16
Table 4 List of stations based on recorder type 3 18
Table 5 List of stations based on recorder type 3 19
Table 6 List of stations based on recorder type 4 20
Table 7 List of stations based on recorder type 4 21
Table 8 List of stations based on recorder type 4 22
Table 9 Weights obtained from mathematical programming formulations for different clusters .. 25
Table 10 Performance of models for in-filling of precipitation data 25
Table 11. Comparison of RMSE values obtained by using power model ($0.9\ x^{0.9}$) model and model using optimal coefficient and exponents for homogeneous area 1. 28
Table 12. Period of Records Coefficient, Exponent and RMSE values for Area 1. 29
Table 13. Period of Records Coefficient, Exponent and RMSE values for Area 2. 29

INTRODUCTION AND BACKGROUND

The use of NEXRAD rainfall data for providing information about the extreme rainfall amounts resulting from storms, hurricanes and tropical depressions is common today. Often corrections are applied to this rainfall data-based on what was actually measured on the ground by rain gages (generally referred to as "ground truth"). Understanding and modeling the relationships between NEXRAD and rain gage data are essential tasks to confirm the accuracy and reliability of the former surrogate method of rainfall measurement. Traditional non-linear regression models in many situations are found to be incapable of capturing these highly variant non-linear spatial and temporal relationships. This study proposes to investigate the use of emerging computational data modeling techniques and assess these functional approximation methods for this purpose.
The project's objective is to develop a method that would be used to in-fill the historical daily missing rain gauge data. The proposed method would use NEXRAD rainfall data, for this purpose, and it will be applied to the existing available data and its performance would be evaluated and assessed. Upon successful development and verification of the model, the model will be used in filling the missing daily rain data for rain gauge stations. This project involves developing methodology for filling of the missing historical daily rain data from rain gauge stations. The daily rain gage data from 368 Districts' rain gages are also available for spatial and temporal analysis. For SFWMD, the rainfall data are available in DBHYDRO for downloading. The period-of-record (POR) for these stations varies. The POR for this study will be from January 1, 2002 to December 31, 2007.

In addition, the daily radar rainfall (NEXRAD rainfall) data coverage for each of the District rain gauge stations are also available and include radar rainfall amounts for 2 km by 2 km cells. Each cell has a specific time series of rainfall data. The SFWMD has database that contains values from January 1, 2002 to the present. The mean monthly precipitation data for all the NOAA rain gages that included the in-filling of the missing data were made available from Dr. Christopher Daly of the Spatial Climate Analysis Services at the Oregon State University. Theses datasets are known as Parameter-elevation Regression on Independent Slopes Model (PRISM) datasets. It is believed that these datasets may not be of reasonable data quality for the central and south Florida due to relatively flat topography of the region. In addition, Dr. Jennifer Adam of Department of Civil and Environmental Engineering from University of Washington reported that they have developed daily rainfall data for the continental USA from 1950 to 1999 at 1/8 th degree grid (from NCDC station data) that were scaled to match PRISM datasets. These available data sets are currently being evaluated for their suitability to the project.

PROJECT STATUS

The final phase of the project is now completed. The second phase of the project was supported by 104B Grant for the period (March 2010 – February 2011). The final phase dealing with infilling precipitation data in homogeneous areas. Mr. Ricardo Brown, graduate student in the department of civil engineering, Florida Atlantic University, has graduated in Spring 2012. Two other graduate students, Mr. Aneesh Goly and Mr. Husayn El Sharif have been involved in this project and helped in the successful completion of the project. Currently Mr. Aneesh Goly and Mr. Husain El Sharif are working on extensions of the study.

Publications

Journal publications have submitted and several papers have been published in prestigious international conferences. The following is the list of papers presented and published.

Conference Publications/Presentations

1. Ramesh S. V. Teegavarapu, and Chandra Pathak, Development of Optimal Forms of Z-R relationships, Weather Radar and Hydrology Symposium, Exeter, England, April 2011, 6 pages.

2. Extreme Precipitation and Climate Change, IFI, Book Series Meeting, UNESCO, Paris, April 29, 2010.

3. Husayn El Sharif and Ramesh S.V. Teegavarapu , Spatial Statistics Preserving Methods for Estimation of Missing Precipitation Data *Involving a Single Best Estimator, FAU Research Day, March 30, 2012.* ***Research Poster Award Winner****.*

4. Husayn El. Sharif, Ramesh S. V. Teegavarapu, Spatial Statistics Preserving Interpolation Methods for Estimation of Missing Precipitation Data, AGU Fall Meeting, 2011.

5. Ramesh S. V. Teegavarapu, Chandramouli Viswanathan, Ravi Chittamuru, Examining climate change indices using Indiana rainfall data, KWRRI Annual Symposium, 2012.

6. Ramesh S. V. Teegavarapu, Chandramouli Viswanathan, Pradeep Behera, Variability of Precipitation Extremes and Climate Change: Evaluation using Descriptive Indices, AGU Fall Meeting, 2011.

7. Ramesh S. V. Teegavarapu, Spatial Interpolation for Missing Precipitation Data: Use of Proximity Metrics, Nearest Neighbor Classifiers and Clusters, paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012. (paper submitted Jan 2012)

8. Husayn El. Sharif and Ramesh S. V. Teegavarapu, Evaluation of Spatial Interpolation Methods for Missing Precipitation Data: Preservation of Spatial Statistics. Paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012. (paper submitted Jan 2012)

9. Ramesh S. V. Teegavarapu, Aneesh Goly, Chandramouli Viswanathan, Pradeep Behera, Precipitation Extremes and Climate Change: Evaluation using Descriptive WMO Indices. paper submitted to EWRI, 2012, ASCE, New Mexico, May, 2012. (paper submitted Jan 2012)

Journal Papers

1. Optimal Spatial Interpolation and Data-Driven Methods for Infilling Missing Rain Gage Records using Radar (NEXRAD) based Precipitation Data, Ramesh S. V. Teegavarapu, Singaiah Chinatalapudi, Chandra Pathak, Ricardo Brown' 2012. Submitted to Journal of Hydrologic Engineering, ASCE. Revised paper to be submitted.

2. Optimized Reflectivity (Z)-Rainfall Rate (R) Relationships for Improved Radar-based Precipitation Estimates, Ramesh S. V. Teegavarapu, Kandarp Pattani, Chandra Pathak, Submited to Journal of Hydrologic Engineering, 2012, ASCE.

3. Teegavarapu, R V.. S. 2012. Spatial interpolation using nonlinear mathematical programming models for estimation of missing precipitation records, Hydrological Sciences Journal.(in press)
4. Teegavarapu, R. S. V, 2012. Missing Precipitation Data Estimation using Optimal Proximity Metric-based Imputation, Nearest Neighbor Classification and Cluster-dependent Interpolation Methods, under review , Hydrological Sciences Journal.

List of students supported by 104B funding last year (March 2011 – February 2012)

1. Mr. Ricardo Brown, Graduate student, expected graduation, Spring, 2012
2. Mr. Aneesh Goly, Graduate Student (Ph.D), expected graduation, December 2012.
3. Mr. Husain El Sharif, Undergraduate student, July, 2012.
4. Lin Huang, Graduate Student, Sept-Dec, 2012.

DESCRIPTION OF PROJECT WORK

The following sections describe the completed work along with methodologies and results. The work described is already published in ASCE international conference proceedings. The work has been submitted for peer-reviewed international journals.

LITERATURE REVIEW: ESTIMATION OF MISSING PRECIPITATION DATA

Rainfall amounts vary geographically within central and south Florida. For example, rainfall characteristics and patterns on land surrounding Lake Okeechobee and ocean are different from that of central overland mass. In addition, spatial variation in rainfall amounts for shorter durations, such as one-, three-, and five- day, is significantly greater than monthly, seasonal and annual rainfall. Therefore, in this study, spatially varying rainfall should be considered based on varying meteorologically/climatological conditions during dry and wet periods. Rainfall is a multi-dimensional process occurring in space and time. For a selected rainfall event, various possible realizations could be formulated that are occurring along the time scale. Mean rainfall value over an area of all possible realizations of that event could be considered for the analysis. Spatial interpolation of precipitation data for imputation of missing records is an essential and crucial step in the development of continuous precipitation data without any gaps needed for hydrologic frequency analysis, modeling and design. Often precipitation data gaps of different length are unavoidable due to random and systematic errors. Incorrect recording and transcription of precipitation data creates gaps in the data to be filled and casts doubt on the reliability of data for statistical analysis (Hosking and Wallis, 1998; Wallis et al., 1991). Precipitation as a vital input for many hydrological modeling studies has a direct bearing on the hydrological modeling and water resources management at different spatial and temporal scales. The importance of rainfall as being the most sensitive input in hydrologic simulation models is stressed by many researchers in their studies (e.g., Larson and Peck, 1974; Vieux, 2001; Xu and Singh, 1998). Xu and Singh (1998) indicate that the accuracy of a streamflow simulation model primarily depends on how well the variability of the rainfall can be defined. Spatial interpolation methods ranging from conceptually simple weighting techniques to methods using stochastic variance dependent techniques are now available for estimation or imputation of missing precipitation data (Teegavarapu, 2008). In many precipitation studies, gaps are attributed to be as data missing completely at random (MCAR) as defined by Little and Rubin (1987). In the current study missing rainfall data and techniques for its estimation or imputation methods are of interest. The main limitations of some of the available deterministic interpolation methods is the lack of objectivity in the selection of weighting parameters, number of neighbors and functional forms that account for spatio-temporal correlations among observations. In the current study optimal proximity-based imputation, nearest neighbor classification and cluster-based methods are proposed and developed for estimation of missing precipitation data at a single site.

Weighting methods (Smith, 1993), reciprocal distance based methods (Simanton and Osborn, 1980; Wei and McGuiness, 1973), nonlinear deterministic and stochastic variance dependent interpolation methods (e.g. kriging) (Teegavarapu, 2007; Zimmerman et al., 1999), and regression and time series analysis methods (Salas, 1993) are among the most commonly used

methods for estimating missing precipitation records. Comparative studies of rainfall estimation using these methods can be found in Singh and Chowdhury (1986), Tabios and Salas (1985) and Tung (1983). Variants of local regression models incorporating meteorological and variables that change in spatial domain (i.e., elevation) were proposed by Daly et al. (1994) and Daly et al. (2002). PRISM (precipitation-elevation regression on independent slopes model) (Daly et al., 1994) is one of such variants. Models incorporating locally weighted polynomials (Loader, 1999; Regonda et al. 2006) are conceptual improvements over traditional weighting methods in which the number of neighbors and polynomial functions are objectively chosen. The coefficient of correlation weighting method (CCWM) proposed by Teegavarapu and Chandramouli (2005) was adopted in several recent studies (e.g., Kim et al., 2008; Westerberg, et al., 2009).

Inverse distance weighting method (IDWM) or reciprocal distance weighting method recommended by the Handbook of Hydrology (ASCE, 2001) is the most commonly used method for estimating missing data in the fields of Hydrology and Geosciences. Teegavarapu and Chandramouli (2005) and Tomczak (1998) provided several improved variants of IDWM for estimating missing precipitation data. Lu and Wong (2008) modified IDWM weights by distance based decay parameters to adjust the diminishing strength in relationships with increasing distances. Teegavarapu (2009) used an association rule mining (ARM) approach to improve estimates of missing precipitation data. Global interpolation methods that use trend surface analysis with polynomial equations of spatial coordinates (Wang, 2006) are equally applicable for spatial interpolation of precipitation data. However, selection of the appropriate functional form to model the trend poses a major problem due to large number of possible candidate functions (Sullivan and Unwin, 2010). Xia et al. (1999) used inverse distance, normal ratio, single best estimator, multiple regression methods for estimation of missing climatological data. Regression was proved to be the best among all the methods investigated in their study. Xia et al. (2001) also reported the use of thin-splines, closest station, multiple linear regression techniques and Shepards' method (Shepard, 1968) for estimation of daily climatalogical data. They indicated that thin-splines method was the best among all the methods investigated. While thin-plate spline methods have several advantages over others, however they tend to generate steep gradients in data-poor areas leading to compounded errors in the estimation process (Chang, 2004). Improvements in interpolations are possible using thin-spline with tension method. Ramos-Calzado et al. (2008) proposed a new approach for estimating missing precipitation data considering the rainfall measurement uncertainty. Improvements were achieved in the estimation of precipitation data when the stations with lowest measurement uncertainty were selected in the interpolation process.

Stochastic surface interpolation methods, belonging to the general family of Kriging have been applied to hydrological spatial interpolation problems (Vieux, 2001; Grayson and Bloschl, 2001).

Conceptual variants of Kriging have been used in the past to estimate missing precipitation data as well as to interpolate precipitation from point measurements (Dingman, 2002; Vieux, 2001, Ashraf et al., 1997). Co-kriging of radar and rain gage data has been employed by Krajewski (1987) to estimate mean areal precipitation. Seo et al. (1990a, 1990b) and Seo (1996) described the use of co-kriging and indicator kriging for interpolating rainfall data. Seo and Smith (1993) employed a Bayesian approach for short-term rainfall prediction using radar data in conjunction with rain gage data. Real-time estimation of rainfall fields using radar and rain gage data was discussed by Seo (1998). The use of ordinary kriging along with universal function approximation for estimating missing daily precipitation data was recently reported by Teegavarapu (2007). Kriging in its various forms by far dominates any study involving precipitation interpolation and estimation.

Regression and time series models belong to class of inductive modeling approaches with functional forms of the relationships defined a priori are useful for estimation of missing data (Dingman, 2009). Empirical models derived using evolutionary and biological principles, namely, Genetic algorithms (Goldberg, 1989), artificial neural networks ((Zurada, 1992), and genetic programming (Koza, 1992) have found numerous applications in the development and application of inductive models in the field of hydrologic forecasting. Applications of artificial neural networks (ANNs) in the fields of hydrology and water resources (ASCE, 2001a; 2001b; French et al., 1992; Govindaraju and Rao, 2000; Teegavarapu and Chandramouli, 2005; Kuligowski and Barros, 1998) are not new. The universal functional approximation abilities of ANNs were already confirmed independently by Cybenko (1989) and Hornik et al. (1989). Teegavarapu (2007) demonstrated the use of universal functional approximation within a stochastic variance dependent interpolation technique for estimation of missing precipitation data. Genetic programming (GP) can be used to create models with the help of mathematical operations and variables for function approximation (Giustolisi and Savic, 2004). Recent work of Teegavarapu et al. (2009) focused on the development of optimal functional forms using genetic algorithms and mathematical operators for estimating missing precipitation data. The functional forms provided better estimates compared to those by traditional geographical distance-based methods. In spite of several improvements in traditional methods, limitations of spatial interpolation methods continue to exist. Veiux (2001), Grayson and Bloschl (2001), Sullivan, and Unwin, (2010), Teegavarapu (2007, 2008, 2009), Teegavarapu et al. (2009) and Brimicombe (2003) discussed numerous limitations of the inverse distance weighting method (IDWM) and other spatial interpolation methods. Eischeid et al. (2000) report similar limitations of interpolation methods used for estimation of missing daily temperature and precipitation records. The success of inverse distance weighting method and many other interpolation methods depend primarily on the existence of positive spatial autocorrelation (Griffith, 1987; Vasiliev, 1996, Sullivan and Unwin, 2010). Reciprocal distances as weights in IDWM may not serve as surrogate measures to

quantify spatial autocorrelations. In some instances the existence of negative autocorrelation may be become a major limitation in the application of IDWM. Another important issue relevant to many spatial interpolation approaches is the selection of neighborhood points of observations for estimation of missing data at a point of interest. The arbitrariness in the choice of weighting parameter and the definition of the neighborhood are two major limitations of weight based interpolation methods. The limitations are common to deterministic and stochastic interpolation methods except locally weighted polynomial based methods. The methods proposed and investigated in the current study are aimed at developing data-dependent objective weighting schemes using proximity measures common in numerical taxonomy and new variants of k-nearest neighbor classification and clustering techniques. Variants of few traditional spatial interpolation methods are also investigated in the current study.

The functional relationships that link point rain gage and grid-based radar observations are generally nonlinear (Teegavarapu et al., 2008; Skinner et al., 2009). Skinner et al. (2009) indicated that a power functional form can characterize the rain and radar data relationship and was appropriate for a region in South Florida. The main motivation of the study reported in this paper is to assess different grid-based linear optimal weighting methods in estimation of missing data at rain gage. Radar data available as gridded data can be used for estimation of missing precipitation data at a rain gage using local filters (Lloyd, 2006) with focal functions to derive the value of a cell using values from a group of cells. Moving window approach is adopted in this study in which pixels (grids) with radar-based precipitation estimates surrounding a rain gage are used to estimate missing data at that gage. Spatial domain filters (Mather, 2004) are common in the remotely sensed image processing studies which use moving average windows to reduce the variability of image. These spatial filters are forms of focal operators (Lloyd, 2005; 2007) where values of any given cell (grid, or pixel) are a function of values from the surrounding pixels. However, no optimization methods are generally involved. The optimization methods used in the current study can be referred to as geographically weighted optimization (GWO) methods. The current study evaluates the use of local along with moving window optimization and data-driven methods for estimation of missing precipitation data at gage using grid-based radar data. The influence of spatial and temporal variability of rainfall processes on the performance of spatial interpolation algorithms. Seasonal variation of rainfall, rainfall areas that are delineated based on physical processes affecting the genesis and morphology of rainfall processes, and other factors may affect the performance of infilling methods.

PROJECT TASKS

The following three major tasks and related sub-tasks were completed as a part of this study. Initially a technical approach that would be used to in-fill the historical daily missing rainfall data for rain gauges was developed. The data collection effort was taken u. NEXRAD and rain gage data was collected from SFWMD and was analyzed. The time series data sets included daily District rain gage and NEXRAD rainfall data. These data sets have a period-of-record from January 1, 2002 to December 31, 2007. Methodologies to fill the daily missing rainfall data to obtain the best quality rainfall estimates was investigated and several optimization and data-driven models were formulated and developed for evaluation on a pre-selected set of rain gage stations. Several performance measures were evaluated before selecting the best model for infilling the missing rainfall data. The best model from the set of models investigated in the current study will be finally used for infilling missing rain gage data at 268 rain gage stations in the District.

INFILLING OF RAIN GAGE RECORDS USING RADAR (NEXRAD) DATA

Deterministic and stochastic weighting methods are the most frequently used methods for infilling rainfall values at a gage based on values recorded at all other available recording gages or other sources. Radar (NEXRAD) data is also commonly used for infilling of rainfall data. Several issues that affect the infilling methods include: the historical rain gage and radar data, spatial and temporal variability of rainfall, radar-rain gage relationships, selection of spatial extent of radar data. The current study evaluates the influence of spatial and temporal variability of rainfall processes on the performance of spatial interpolation algorithms. Seasonal variation of rainfall, rainfall areas that are delineated based on physical processes affecting the genesis and morphology of rainfall processes, and other factors may affect the performance of infilling methods. All these issues are important for south Florida which experiences wide variability in rainfall in space and time. In the current study, data from five rain gages and radar (NEXRAD) data in the south Florida region are used to evaluate the influence of spatial and temporal variability of rainfall processes on the performance of methods used for infilling rain gage data.

NEXRAD DATA

Next Generation Radar (NEXRAD) or Weather Surveillance Radar 88 Doppler (WSR-88D) data provide complete spatial coverage of rainfall amounts using a predetermined grid resolution (usually 2 km by 2 km or 4 km by 4 km). The NEXRAD rainfall data is limited by relying on the measurement of raindrop reflectivity, which can be affected by factors such as raindrop size and

signal reflection by other objects. Because the reflected signal measured by the radar is proportional to the sum of the sixth power of the diameter of the raindrops in a given volume of atmosphere, small changes in the size of raindrops can have a dramatic effect on the radar's estimate of the rainfall. For this reason, the radar is generally scaled to match volume measured at the rain gauges (Hoblit and Curtis, 2000). The best of both measurement techniques is realized by using rain gauge data to adjust NEXRAD values.

Weather data acquired from radar (NEXRAD) is generally used by the water management agencies in making decisions for operational purposes. However, the use has been largely limited to visual interpretation of data as opposed to quantitative analysis. Data derived from radar based precipitation estimates (i.e. NEXRAD data) can be used to estimate the missing precipitation values. However, the reliability of radar-based precipitation measurements is a contentious issue (Young et. al, 1999; Adler et al., 2001). Radar rainfall estimates derived from conversion of reflectivity measurements are known to contain systematic errors, or bias, and other random errors or artifacts that limit the utility of radar rainfall. Quality control and enhancement of radar rainfall estimates may be accomplished through gauge-adjustment procedures.

DATA COLLECTION EFFORT

Precipitation data sets for rain gage and NEXRAD (2km x 2km grid) were collected and analyzed. Data from a total of 268 rain gages depending on the type of recorder were collected from DBHYDRO database. The NEXRAD data developed by OneRain Corporation was also obtained from SFWMD. The rain gages are classified depending on four recording types and they are: 1) manual; 2) operational maintenance with multiple sources; 3) telemetry (radio network) and 4) CR10 (Campbell Scientific). Details of these rain gages are provided in Tables 1 – 8.

Table 1 List of stations based on recorder type 1

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
S20_R	05817	5/24/1968	3/17/2008	Belfort Rain Gage	25.36713319250	-80.37650645290
CLEW.FS_R	06220	11/13/1968	6/30/2008	Unknown (Manual)	26.73506462710	-80.89533872850
LWD.E1.3_R	06290	9/1/1955	6/30/2008	Unknown (Manual)	26.61228952610	-80.20504346010
LWD.E2.2_R	06321	8/31/1955	6/30/2008	Unknown (Manual)	26.45451731600	-80.17115411390
LWD.E2_R	06299	8/31/1955	6/30/2008	Unknown (Manual)	26.52840351420	-80.17032044000
LWD.GA_R	06276	8/31/1955	6/30/2008	Unknown (Manual)	26.61895580360	-80.12643009120
LWD.HQ_R	06306	8/31/1955	6/30/2008	Unknown (Manual)	26.48312720700	-80.12309703790
LWD.L28_R	06302	8/31/1955	6/30/2008	Unknown (Manual)	26.49562700240	-80.20282144950
LWD.L32_R	06322	8/31/1955	6/30/2008	Unknown (Manual)	26.47062794220	-80.20504387860
LWD.L38M_R	05892	9/30/1974	6/30/2008	Unknown (Manual)	26.42396271900	-80.12226398170
LWD.L39R_R	05893	9/30/1974	6/30/2008	Unknown (Manual)	26.41674105870	-80.20393304930
LWD.MIL_R	06298	8/31/1955	6/30/2008	Unknown (Manual)	26.52090364120	-80.12393025800
LWD.POWE_R	05793	8/31/1955	6/30/2008	Unknown (Manual)	26.36896486970	-80.15393185950
LWD.RANG_R	05792	8/31/1955	6/30/2008	Unknown (Manual)	26.38757548200	-80.20476657570
PRATT AN_R	06122	4/17/1957	6/30/2008	Unknown (Manual)	26.90450120580	-80.30393445760
S133_R	05845	6/23/1970	6/30/2008	Unknown (Manual)	27.20615719420	-80.80089003390
S4_R	05879	7/31/1974	6/30/2008	Unknown (Manual)	26.78984374420	-80.96171320990
BCBNAPLE_R	LX271	1/1/1995	6/27/2008	Unknown (Manual)	26.22536622760	-81.80813990820
EAST BEA_R	05962	5/31/1980	5/31/2008	Unknown (Manual)	26.79811626870	-80.69505581240
EAST SHO_R	05835	12/31/1969	5/31/2008	Unknown (Manual)	26.74895131520	-80.68366680650
PAHOKEE1_R	05838	3/4/1957	5/31/2008	Unknown (Manual)	26.81311461900	-80.56366393060
PAHOKEE2_R	05839	3/1/1957	5/31/2008	Unknown (Manual)	26.78394849770	-80.52532984090
PEL LAK1_R	05837	3/4/1957	5/31/2008	Unknown (Manual)	26.85172484670	-80.61338714730
PEL LAK2_R	06125	3/4/1957	5/31/2008	Unknown (Manual)	26.84200287330	-80.60227581550
S65C_R	06024	5/31/1966	5/31/2008	Unknown (Manual)	27.40101995520	-81.11511274760
SFCD_R	05965	5/31/1980	5/31/2008	Unknown (Manual)	26.72812018080	-80.85339321730
FT. LAUD_R	05850	9/30/1971	5/30/2008	Unknown (Manual)	26.06369922170	-80.25949193900
S61_R	05868	2/20/1965	5/7/2008	Unknown (Manual)	28.14033177710	-81.35205653780
S65A_R	05981	6/17/1965	5/7/2008	Unknown (Manual)	27.65805333240	-81.13421222380
DEVILS_R	05953	3/31/1980	4/30/2008	Unknown (Manual)	26.60284840610	-81.12839985080
LABELLE_R	05952	4/1/1980	4/30/2008	Unknown (Manual)	26.75312137980	-81.43868324770
S65_R	05940	3/5/1965	4/30/2008	Unknown (Manual)	27.80305527700	-81.19827915820
GILL REA_R	05807	3/31/1957	1/31/2008	Unknown (Manual)	26.06036587640	-80.23171337540
CORK.HQ_R	05916	11/1/1959	3/31/2007	Unknown (Manual)	26.38369256900	-81.58313292100
CHAPMAN_R	05902	11/7/1968	2/1/2007	Unknown (Manual)	28.00168484850	-81.19367405160

Table 2 List of stations based on recorder type 2

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
ARCHBO 2_R	16604	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.18171543690	-81.43395921230
BELLE GL_R	16595	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.65701023360	-80.62977679680
C18W_R	16603	1/9/1992	7/29/2008	Operational/Maintanence with Multiple Sources	26.87200259590	-80.24504400220
CANAL PT_R	16702	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.86700212790	-80.61644272350
CLEW.FS_R	16696	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.73506462710	-80.89533872850
CORK.HQ_E	16597	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.38369256900	-81.58313292100
CV5_R	16668	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.91951116130	-81.12177060320
FT. LAUD_R	16698	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.06369922170	-80.25949193900
G136_R	16598	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.66767299440	-80.94929719470
G56_R	16611	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.32785518660	-80.13087583980
HOLLYWOOD	16614	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.04842121550	-80.12754354350
HOMES.FS_R	16700	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.47761090670	-80.44838992620
IMMOKA 3_R	16602	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.46146625970	-81.43729565500
KISS.FS2_R	16617	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	28.29056448340	-81.44840001330
L005	16694	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.95673552340	-80.97238091610
L006	16695	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.82175691440	-80.78341609010
LZ40	16631	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.90174235290	-80.78924581950
MC COY	16634	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	28.45166974010	-81.31117586730
MIAMI 2_R	16632	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	25.78370841210	-80.13310014790
MIAMI.AP_R	16615	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.81704171550	-80.28310513320
MIAMI.FS_R	16609	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.82704166310	-80.34421775230
NNRC.SFS	DJ194	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.48479540320	-80.65311091750
OKEE F 2_R	16697	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.25393424370	-80.78727725720
PERRINE_R	16596	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	25.60038324170	-80.34977549610
POF-13	16590	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.94307539510	-81.35478842700
RACOON PT	16708	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	25.96704105610	-81.31646270150
S123	16577	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.61038253610	-80.30782996690
S124_R	16578	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.12925845240	-80.36569899830
S127_R	16573	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.12220559120	-80.89597346510
S129_R	16574	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.02977494840	-81.00145085910
S131_R	16575	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.97922185420	-81.09006411970
S133_R	16576	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.20615719420	-80.80089003390
S135_R	16580	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.08663792270	-80.66134976970
S13_R	16579	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.06612697290	-80.20884162700
S140_R	16581	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.17203010210	-80.82728352480
S153_R	16582	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.98894245310	-80.60449761730
S155_R	16583	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.64478812140	-80.05503909450
S174_R	16584	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.48372268290	-80.56339249030
S177_R	16585	3/18/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.40276844940	-80.55836621430
S18C_R	16659	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.33067259440	-80.52505968200

Table 3 List of stations based on recorder type 2

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
S191_R	16669	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.19193140100	-80.76244819580
S20F_R	16692	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.46288829260	-80.34755450890
S20G_R	16691	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.48947858110	-80.34689773060
S21A_R	16690	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.51935140640	-80.34633569430
S21_R	16689	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.54318716570	-80.33093596130
S26_R	16686	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.80743259430	-80.26049889760
S27_R	16628	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.85097909480	-80.18821674860
S28Z_R	16684	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.91342716010	-80.29310473710
S29Z_R	16685	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.96203641470	-80.26449256950
S29_R	16629	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.92905816090	-80.15147509110
S2_R	16647	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.70034251190	-80.71616761950
S308_R	16588	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.98467999800	-80.62115000130
S30_R	16608	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.95675937980	-80.43144128040
S331_R	16662	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.61093971470	-80.50977915970
S338_R	16661	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	25.66092660440	-80.48123240950
S33_R	16682	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.13584751210	-80.19449168390
S34_R	16683	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.15036304890	-80.44227385790
S352_R	16693	9/23/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.86394676820	-80.63199864290
S36_R	16681	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.17341676180	-80.17837797320
S37A_R	16680	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.20610898220	-80.13165307250
S37B_R	16612	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.22377325970	-80.17046897650
S38_R	16679	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.22980397370	-80.29838110870
S39_R	16677	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.35595086450	-80.29758714300
S3_R	16648	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.69895434790	-80.80728098650
S40_R	16676	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.42157807760	-80.07249941910
S41_R	16675	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.53118087710	-80.05920617790
S44_R	16674	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.81722044730	-80.08056784770
S46_R	16673	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	26.93422309810	-80.14170754690
S49_R	16589	4/25/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.26146340870	-80.35934580270
S5A_R	16645	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.68450861050	-80.36754787070
S65A_R	16572	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.65805333240	-81.13421222380
S65C_R	16657	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.40101995520	-81.11511274760
S65E_R	16621	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.22532322760	-80.96256031810
S65_R	16571	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.80305527700	-81.19827915820
S68_R	16654	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.32990717940	-81.25232899820
S6_R	16651	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.47229533120	-80.44560570210
S70_R	16664	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.11866113410	-81.15728707770
S71_R	16667	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.03386100600	-81.07089528330
S72_R	16666	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.09154318100	-81.00670841770
S77_R	16624	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.83931757220	-81.08534198390
S78_R	16625	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.78978607860	-81.30284709440
S79_R	16587	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.72242197930	-81.69305568760
S7_R	16652	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.33591180850	-80.53671975120
S80_R	16618	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.11116047130	-80.28476725620
S82_R	16655	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.27282194760	-81.20200942260
S83_R	16656	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.26687747970	-81.18100296280
S84	16599	10/21/1993	7/29/2008	Operational/Maintanence with Multiple Sources	27.21615690220	-80.97339393710
S8_R	16606	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.33230148990	-80.77422576490
S97_R	16627	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.20551102140	-80.34071111310
S99_R	16672	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	27.47059184340	-80.47171593760
TAMI AIR_R	16593	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	25.64121571430	-80.42672138340
WPB AIRP_R	16610	1/8/1991	7/29/2008	Operational/Maintanence with Multiple Sources	26.67812039630	-80.10976280090
S5AY_R	16643	1/8/1991	4/1/2008	Operational/Maintanence with Multiple Sources	26.76700429090	-80.49977377570
S65D_R	16658	1/8/1991	3/12/2008	Operational/Maintanence with Multiple Sources	27.31448693740	-81.02283905000
S75_R	16663	10/21/1993	3/12/2008	Operational/Maintanence with Multiple Sources	27.19183183350	-81.12719237920
FORTMYERWS	16594	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	26.58368622070	-81.86647136080
FTL	16613	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	26.09286445990	-80.20643469540
IMMOKALE_R	16601	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	26.39313535540	-81.40701773450
NAPLES_R	16633	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	26.16814625220	-81.78980644300
S332_R	16660	10/21/1993	3/1/2008	Operational/Maintanence with Multiple Sources	25.42178071880	-80.58978260900
S4_R	16650	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	26.78984374420	-80.96171320990
S61_R	16570	1/8/1991	3/1/2008	Operational/Maintanence with Multiple Sources	28.14033177710	-81.35205653780
S9_R	16607	1/8/1991	11/13/2007	Operational/Maintanence with Multiple Sources	26.06160206170	-80.44375240950
FTP FS_R	16591	1/8/1991	9/13/2007	Operational/Maintanence with Multiple Sources	27.36698472550	-80.51421704280

Table 4 List of stations based on recorder type 3

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
S190_R	15988	3/18/1997	7/28/2008	Telemetry (Radio Network)	26.28410586260	-80.96773573990
S21_R	K8670	3/18/1997	7/28/2008	Telemetry (Radio Network)	25.54318716570	-80.33093596130
CV5_R	K7776	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.91951116130	-81.12177060320
HGS5X_R	12737	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.86394676820	-80.63199864290
NNRC.SFS	UJ622	1/1/1999	7/27/2008	Telemetry (Radio Network)	26.48479540320	-80.65311091750
S127_R	K8632	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.12220559120	-80.89597346510
S129_R	K8633	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.02977494840	-81.00145085910
S131_R	K8635	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.97922185420	-81.09006411970
S135_R	K8637	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.08663792270	-80.66134976970
S140_R	K8640	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.17203010210	-80.82728352480
S169_R	K8653	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.76228693620	-80.92311706060
S2_R	K8665	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.70034251190	-80.71616761950
S334_R	K8651	3/18/1997	7/27/2008	Telemetry (Radio Network)	25.76176723770	-80.50227787720
S335_R	K8652	3/18/1997	7/27/2008	Telemetry (Radio Network)	25.77608375960	-80.48294263280
S34_R	K8658	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.15036304890	-80.44227385790
S38_R	K8669	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.22980397370	-80.29838110870
S39_R	K8674	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.35595086450	-80.29758714300
S3_R	K8622	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.69895434790	-80.80728098650
S5A_R	K8682	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.68450861050	-80.36754787070
S68_R	K8686	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.32990717940	-81.25232899820
S6_R	K8685	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.47229533120	-80.44560570210
S70_R	K8689	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.11866113410	-81.15728707770
S71_R	K8690	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.03386100600	-81.07089528330
S72_R	K8691	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.09154318100	-81.00670841770
S7_R	K8688	3/18/1997	7/27/2008	Telemetry (Radio Network)	26.33591180850	-80.53671975120
S82_R	K8694	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.27282194760	-81.20200942260
S83_R	K8695	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.26687747970	-81.18100296280
S97_R	K8698	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.20551102140	-80.34071111310
S99_R	K8699	3/18/1997	7/27/2008	Telemetry (Radio Network)	27.47059184340	-80.47171593760
S133_R	K8636	3/18/1997	7/24/2008	Telemetry (Radio Network)	27.20615719420	-80.80089003390
S177_R	K8656	3/18/1997	7/24/2008	Telemetry (Radio Network)	25.40276844940	-80.55836621430
G136_R	K8623	3/18/1997	7/23/2008	Telemetry (Radio Network)	26.66767299440	-80.94929719470
G57_R	K8628	3/18/1997	7/23/2008	Telemetry (Radio Network)	26.23119207380	-80.12420944350
S13_R	K8634	3/18/1997	7/23/2008	Telemetry (Radio Network)	26.06612697290	-80.20884162700
S167_R	K8647	3/18/1997	7/23/2008	Telemetry (Radio Network)	25.50284287930	-80.46505606120
S37B_R	K8667	3/18/1997	7/23/2008	Telemetry (Radio Network)	26.22377325970	-80.17046897650
S84_R	K8696	3/18/1997	7/23/2008	Telemetry (Radio Network)	27.21615690220	-80.97339393710
C18W_R	K7774	3/18/1997	7/22/2008	Telemetry (Radio Network)	26.87200259590	-80.24504400220
G56_R	K8627	3/19/1997	7/22/2008	Telemetry (Radio Network)	26.32785518660	-80.13087583980
S332_R	K8650	3/18/1997	7/22/2008	Telemetry (Radio Network)	25.42178071880	-80.58978260900
S338_R	K8654	3/18/1997	7/22/2008	Telemetry (Radio Network)	25.66092660440	-80.48123240950

Table 5 List of stations based on recorder type 3

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
S36_R	K8663	3/18/1997	7/22/2008	Telemetry (Radio Network)	26.17341676180	-80.17837797320
S37A_R	K8664	3/18/1997	7/22/2008	Telemetry (Radio Network)	26.20610898220	-80.13165307250
S44_R	K8678	3/18/1997	7/22/2008	Telemetry (Radio Network)	26.81722044730	-80.08056784770
S8_R	K8693	3/18/1997	7/22/2008	Telemetry (Radio Network)	26.33230148990	-80.77422576490
G200_R	K8701	3/18/1997	7/21/2008	Telemetry (Radio Network)	26.41702056990	-80.78311452430
S123	K8630	3/18/1997	7/21/2008	Telemetry (Radio Network)	25.61038253610	-80.30782996690
S27_R	K8673	3/18/1997	7/21/2008	Telemetry (Radio Network)	25.85097909480	-80.18821674860
S28Z_R	K8619	3/18/1997	7/21/2008	Telemetry (Radio Network)	25.91342716010	-80.29310473710
S40_R	K8675	3/18/1997	7/21/2008	Telemetry (Radio Network)	26.42157807760	-80.07249941910
S41_R	K8677	3/18/1997	7/21/2008	Telemetry (Radio Network)	26.53118087710	-80.05920617790
S47B_R	K8680	3/18/1997	7/21/2008	Telemetry (Radio Network)	26.85811606170	-81.13895464840
S153_R	K8643	3/18/1997	7/20/2008	Telemetry (Radio Network)	26.98894245310	-80.60449761730
S18C_R	K8660	3/18/1997	7/20/2008	Telemetry (Radio Network)	25.33067259440	-80.52505968200
S20F_R	K8666	3/18/1997	7/20/2008	Telemetry (Radio Network)	25.46288829260	-80.34755450890
S30_R	K8638	3/18/1997	7/20/2008	Telemetry (Radio Network)	25.95675937980	-80.43144128040
S331_R	P6930	3/7/2003	7/20/2008	Telemetry (Radio Network)	25.61093971470	-80.50977915970
S46_R	K8679	3/18/1997	7/20/2008	Telemetry (Radio Network)	26.93422309810	-80.14170754690
S49_R	K8681	3/18/1997	7/20/2008	Telemetry (Radio Network)	27.26146340870	-80.35934580270
S75_R	K8692	3/18/1997	7/20/2008	Telemetry (Radio Network)	27.19183183350	-81.12719237920
G331D_R	PT420	8/3/2005	7/17/2008	Telemetry (Radio Network)	26.42065363030	-80.51756069300
G54_R	K8626	3/18/1997	7/17/2008	Telemetry (Radio Network)	26.09488054070	-80.22984429440
S125_R	MJ469	1/1/1999	7/17/2008	Telemetry (Radio Network)	26.16425096980	-80.29754802710
S124_R	K8631	3/18/1997	7/16/2008	Telemetry (Radio Network)	26.12925845240	-80.36569899830
S179_R	K8657	3/18/1997	7/16/2008	Telemetry (Radio Network)	25.47372183880	-80.41450033290
S155_R	K8645	3/18/1997	7/15/2008	Telemetry (Radio Network)	26.64478812140	-80.05503909450
S174_R	V7571	7/24/2007	7/14/2008	Telemetry (Radio Network)	25.48372268290	-80.56339249030
S20G_R	K8668	3/18/1997	7/14/2008	Telemetry (Radio Network)	25.48947858110	-80.34689773060
S21A_R	K8671	3/18/1997	7/14/2008	Telemetry (Radio Network)	25.51935140640	-80.34633569430
S9_R	UJ621	5/8/2001	7/14/2008	Telemetry (Radio Network)	26.06160206170	-80.44375240950
S165_R	K8646	3/18/1997	7/13/2008	Telemetry (Radio Network)	25.54260809750	-80.40949962740
S26_R	K8672	3/18/1997	7/13/2008	Telemetry (Radio Network)	25.80743259430	-80.26049889760
S29Z_R	K8621	3/18/1997	7/13/2008	Telemetry (Radio Network)	25.96203641470	-80.26449256950
S29_R	K8620	3/18/1997	7/13/2008	Telemetry (Radio Network)	25.92905816090	-80.15147509110
S33_R	K8648	3/18/1997	7/13/2008	Telemetry (Radio Network)	26.13584751210	-80.19449168390
S154_R	K8644	3/18/1997	7/9/2008	Telemetry (Radio Network)	27.21060152810	-80.91839270130
S191_R	K8662	3/18/1997	7/8/2008	Telemetry (Radio Network)	27.19193140100	-80.76244819580
S174_R	K8655	3/18/1997	7/23/2007	Telemetry (Radio Network)	25.48372268290	-80.56339249030

Table 6 List of stations based on recorder type 4

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
ROTNWX	GE354	12/23/1997	7/29/2008	CR10 (Campbell Scientific Inc.)	26.33200839000	-80.87998992340
3AS3WX	LA375	3/5/2007	7/28/2008	CR10 (Campbell Scientific Inc.)	25.85172632830	-80.76626186310
FHCHSX	V2458	5/17/2007	7/28/2008	CR10 (Campbell Scientific Inc.)	26.65404504380	-80.06824918940
S12D_R	LS269	7/18/2000	7/28/2008	CR10 (Campbell Scientific Inc.)	25.76195478130	-80.68191499340
S59_R	16567	12/26/1995	7/28/2008	CR10 (Campbell Scientific Inc.)	28.26550006170	-81.31113514810
SEBRNG_R	TA405	11/30/2004	7/28/2008	CR10 (Campbell Scientific Inc.)	27.45831450680	-81.35429261520
ACRAWX	UA568	5/26/2006	7/27/2008	CR10 (Campbell Scientific Inc.)	27.12024402140	-80.43211364170
CFSW	15517	10/21/1992	7/27/2008	CR10 (Campbell Scientific Inc.)	26.73506462710	-80.89533872850
DANHP_R	DU537	5/7/1996	7/27/2008	CR10 (Campbell Scientific Inc.)	25.97870843360	-81.48091068880
MIAMI LO_R	16068	12/19/1994	7/27/2008	CR10 (Campbell Scientific Inc.)	26.68201054840	-80.80616988760
MIAMI.FS_R	DU524	4/23/1996	7/27/2008	CR10 (Campbell Scientific Inc.)	25.82704166310	-80.34421775230
S75WX	RQ467	12/29/2003	7/27/2008	CR10 (Campbell Scientific Inc.)	27.19187861030	-81.12800805840
AVEMARIA	VW740	5/21/2008	7/24/2008	CR10 (Campbell Scientific Inc.)	26.30169313440	-81.43136219060
JDWX	G0859	9/12/1997	7/24/2008	CR10 (Campbell Scientific Inc.)	27.02866361290	-80.16532114080
MAXCEY N_R	UA631	6/20/2006	7/24/2008	CR10 (Campbell Scientific Inc.)	27.68364077380	-81.02367105310
S65CW	15473	10/20/1992	7/24/2008	CR10 (Campbell Scientific Inc.)	27.40142848030	-81.11478499350
S65DWX	LJ290	2/23/2000	7/24/2008	CR10 (Campbell Scientific Inc.)	27.31425088980	-81.02215006610
SGGEWX	OR084	9/18/2002	7/24/2008	CR10 (Campbell Scientific Inc.)	26.14537083250	-81.57564333540
SVWX	FI273	5/14/1997	7/24/2008	CR10 (Campbell Scientific Inc.)	27.29031988730	-80.25365730040
3A-NE_R	LX283	8/2/2000	7/23/2008	CR10 (Campbell Scientific Inc.)	26.27876393400	-80.60501990560
ALL2R	HA469	2/19/1998	7/23/2008	CR10 (Campbell Scientific Inc.)	28.19863748040	-81.23990520050
BRYGR	OU142	10/11/2002	7/23/2008	CR10 (Campbell Scientific Inc.)	26.69709360880	-81.48511250160
COLGOV_R	DU536	4/30/1996	7/23/2008	CR10 (Campbell Scientific Inc.)	26.12981437350	-81.76258370660
COLLISEM	DU533	1/30/1996	7/23/2008	CR10 (Campbell Scientific Inc.)	25.99065284550	-81.59146894920
CREEK_R	P2035	12/12/2002	7/23/2008	CR10 (Campbell Scientific Inc.)	28.03882455540	-81.46506388860
ENR101_R	15851	2/11/1994	7/23/2008	CR10 (Campbell Scientific Inc.)	26.64228796930	-80.41754927240
ENR106_R	DU515	5/24/1995	7/23/2008	CR10 (Campbell Scientific Inc.)	26.64923559970	-80.41866081930
ENR203_R	15874	9/29/1993	7/23/2008	CR10 (Campbell Scientific Inc.)	26.64339897830	-80.43338303730
ENR301_R	15877	3/22/1994	7/23/2008	CR10 (Campbell Scientific Inc.)	26.62089997990	-80.43366082090
ENR401_R	15862	8/26/1993	7/23/2008	CR10 (Campbell Scientific Inc.)	26.63006622100	-80.43977210080
EXOTR	HA471	2/11/1998	7/23/2008	CR10 (Campbell Scientific Inc.)	28.15575779650	-81.11506802680
G600_R	G6530	10/20/1997	7/23/2008	CR10 (Campbell Scientific Inc.)	26.36059772120	-80.90566380100
GRIFFITH_R	SO643	7/8/2004	7/23/2008	CR10 (Campbell Scientific Inc.)	27.49475923010	-80.92950299180
IMMOKALE_R	DU523	7/30/1996	7/23/2008	CR10 (Campbell Scientific Inc.)	26.39313535540	-81.40701773450
INDIAN L_R	P6922	1/25/2003	7/23/2008	CR10 (Campbell Scientific Inc.)	27.78780280050	-81.32673259890
KISSFS_R	OU252	7/4/2002	7/23/2008	CR10 (Campbell Scientific Inc.)	28.29056448340	-81.44840001330
L2GW_R	SN311	6/24/2004	7/23/2008	CR10 (Campbell Scientific Inc.)	26.60800282500	-80.94937187600
PC61_R	OH522	4/17/2002	7/23/2008	CR10 (Campbell Scientific Inc.)	27.50484967680	-81.19614740640
S336_R	16713	10/12/1995	7/23/2008	CR10 (Campbell Scientific Inc.)	25.76148944540	-80.49672218270
S65_R	RQ463	2/4/2003	7/23/2008	CR10 (Campbell Scientific Inc.)	27.80305527700	-81.19827915820
S7WX	GG630	1/11/1998	7/23/2008	CR10 (Campbell Scientific Inc.)	26.33591180850	-80.53671975120
WSTWPB_R	UP592	7/28/2006	7/23/2008	CR10 (Campbell Scientific Inc.)	26.68861087370	-80.18805584490
WSTWPB_R	UP594	7/28/2006	7/23/2008	CR10 (Campbell Scientific Inc.)	26.68861087370	-80.18805584490
3A-NW_R	LA365	5/24/2000	7/22/2008	CR10 (Campbell Scientific Inc.)	26.26648313780	-80.77950022500
3A-S_R	HC941	4/8/1998	7/22/2008	CR10 (Campbell Scientific Inc.)	26.08209260090	-80.69154218030
AVON P_R	T0917	7/2/2004	7/22/2008	CR10 (Campbell Scientific Inc.)	27.63169738540	-81.26478729140
BCA17	PT542	6/11/2002	7/22/2008	CR10 (Campbell Scientific Inc.)	26.20494722240	-81.16846111140

Table 7 List of stations based on recorder type 4

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
KRBNR	FZ609	5/15/1997	7/22/2008	CR10 (Campbell Scientific Inc.)	27.46131020260	-81.17114896670
KREFR	FI286	5/16/1997	7/22/2008	CR10 (Campbell Scientific Inc.)	27.50253533050	-81.19533847400
L006	12524	1/27/1989	7/22/2008	CR10 (Campbell Scientific Inc.)	26.82175691440	-80.78341609010
LZ40	13081	4/25/1990	7/22/2008	CR10 (Campbell Scientific Inc.)	26.90174235290	-80.78924581950
OPAL_R	15580	10/23/1992	7/22/2008	CR10 (Campbell Scientific Inc.)	27.32198698100	-80.77533346850
S5AX_R	LS350	4/29/2000	7/22/2008	CR10 (Campbell Scientific Inc.)	26.67895293910	-80.53783021290
S6Z_R	JG018	5/4/1999	7/22/2008	CR10 (Campbell Scientific Inc.)	26.64284381930	-80.58088676830
WPBC_R	TS282	3/24/2006	7/22/2008	CR10 (Campbell Scientific Inc.)	26.76478214230	-80.49866264180
BCA10_R	V2489	6/19/2007	7/21/2008	CR10 (Campbell Scientific Inc.)	25.71399407870	-81.02173609220
BCA14_R	V2491	4/26/2007	7/21/2008	CR10 (Campbell Scientific Inc.)	26.04453762040	-81.29979518060
BCA15	PT536	6/13/2002	7/21/2008	CR10 (Campbell Scientific Inc.)	26.03959500080	-81.02711777630
BCA16	PT539	6/11/2002	7/21/2008	CR10 (Campbell Scientific Inc.)	26.05657500080	-81.15595000100
BCA18	PT545	6/11/2002	7/21/2008	CR10 (Campbell Scientific Inc.)	26.20656805490	-80.98360722140
BCA19	PT548	6/13/2002	7/21/2008	CR10 (Campbell Scientific Inc.)	25.79277777700	-81.20249999860
BCA20	PT551	6/13/2002	7/21/2008	CR10 (Campbell Scientific Inc.)	25.70611111160	-80.93499999980
BCNPA4_R	TA451	3/16/2005	7/21/2008	CR10 (Campbell Scientific Inc.)	25.95759563330	-81.10368020540
BCNPA9_R	TB034	9/27/2005	7/21/2008	CR10 (Campbell Scientific Inc.)	25.77871280920	-80.91201051970
BEELINE_R	TY244	4/12/2006	7/21/2008	CR10 (Campbell Scientific Inc.)	28.45278015240	-81.17811741850
BIG CY SIR	15685	10/21/1992	7/21/2008	CR10 (Campbell Scientific Inc.)	26.32146984830	-81.06784423780
C24SE	JI170	11/29/1998	7/21/2008	CR10 (Campbell Scientific Inc.)	27.33107876940	-80.46293761480
ENR308_R	15888	4/13/1994	7/21/2008	CR10 (Campbell Scientific Inc.)	26.62256656060	-80.43893874330
L001	16021	8/4/1994	7/21/2008	CR10 (Campbell Scientific Inc.)	27.13962310720	-80.78902942170
L005	12515	10/26/1988	7/21/2008	CR10 (Campbell Scientific Inc.)	26.95673552340	-80.97238091610
LOTELA_R	TA345	12/2/2004	7/21/2008	CR10 (Campbell Scientific Inc.)	27.59142168280	-81.43534645320
LOXWS	DU551	12/31/1995	7/21/2008	CR10 (Campbell Scientific Inc.)	26.49896027460	-80.22226642280
MCARTH_R	UA643	5/26/2006	7/21/2008	CR10 (Campbell Scientific Inc.)	27.43864928780	-81.20645336930
OKALN_R	RS692	12/18/2003	7/21/2008	CR10 (Campbell Scientific Inc.)	26.63355959910	-81.35678072390
OKALS_R	RS696	12/19/2003	7/21/2008	CR10 (Campbell Scientific Inc.)	26.52669097470	-81.32225125690
SIX L 3_R	16278	3/20/1995	7/21/2008	CR10 (Campbell Scientific Inc.)	26.23091792380	-81.13034598320
WCA1ME	DU517	2/12/1996	7/21/2008	CR10 (Campbell Scientific Inc.)	26.51062677460	-80.31032429240
BELLE GL	DO532	4/17/1996	7/20/2008	CR10 (Campbell Scientific Inc.)	26.65684143180	-80.63002468820
EAA2	15182	10/31/1991	7/20/2008	CR10 (Campbell Scientific Inc.)	26.55840372090	-80.70922327930
EAA5	15184	11/5/1991	7/20/2008	CR10 (Campbell Scientific Inc.)	26.43646379120	-80.61505461230
FKSTRN_R	SG918	6/10/2004	7/20/2008	CR10 (Campbell Scientific Inc.)	26.14338492680	-81.35041628810
KIRCOF_R	M1208	8/9/2000	7/20/2008	CR10 (Campbell Scientific Inc.)	28.15494443980	-81.42433333820
S140W	15506	10/21/1992	7/20/2008	CR10 (Campbell Scientific Inc.)	26.17129276450	-80.82598904860
S65AMW_R	V8859	6/26/2007	7/20/2008	CR10 (Campbell Scientific Inc.)	27.65937716250	-81.13295352620
SHING.RG	15323	3/12/1992	7/20/2008	CR10 (Campbell Scientific Inc.)	28.37750498870	-81.45034496380
SNIVELY_R	T0933	7/14/2004	7/20/2008	CR10 (Campbell Scientific Inc.)	27.97168553430	-81.41756730960
TICK ISL_R	MX236	1/16/2001	7/20/2008	CR10 (Campbell Scientific Inc.)	27.68586217170	-81.18645218360
WRWX	FF846	4/16/1997	7/20/2008	CR10 (Campbell Scientific Inc.)	28.04834922240	-81.39950674190
ACRA2_R	SX445	7/27/2004	7/19/2008	CR10 (Campbell Scientific Inc.)	27.16140610350	-80.43261225030

Table 8 List of stations based on recorder type 4

Station Name	DBKEY	Start Date	End Date	Recorder Type	Latitude	Longitude
ALICO_R	16224	3/20/1995	7/18/2008	CR10 (Campbell Scientific Inc.)	26.51285130910	-80.98200817380
ELMAX_R	UA602	8/8/2006	7/17/2008	CR10 (Campbell Scientific Inc.)	27.75280461660	-81.07728305050
FPWX	FZ598	9/3/1997	7/17/2008	CR10 (Campbell Scientific Inc.)	26.43258016290	-81.72340781170
GOLDFS2	DU525	7/9/1996	7/17/2008	CR10 (Campbell Scientific Inc.)	26.22842077180	-81.63202434990
ROCK K_R	QS268	11/23/2003	7/17/2008	CR10 (Campbell Scientific Inc.)	27.55788639030	-80.82736972340
SOUTH BA_R	15971	9/15/1994	7/17/2008	CR10 (Campbell Scientific Inc.)	26.66506602450	-80.70116734010
3A-SW_R	JA344	2/19/1999	7/16/2008	CR10 (Campbell Scientific Inc.)	25.98981505800	-80.83617370160
BLUEGOOS_R	HD301	5/3/1998	7/16/2008	CR10 (Campbell Scientific Inc.)	27.21979509420	-80.46506032500
S61W	15484	10/20/1992	7/16/2008	CR10 (Campbell Scientific Inc.)	28.14033177710	-81.35205653780
S78W	15495	10/21/1992	7/16/2008	CR10 (Campbell Scientific Inc.)	26.78978607860	-81.30284709440
SIRG	15730	10/28/1993	7/16/2008	CR10 (Campbell Scientific Inc.)	26.90727933530	-80.19170904610
FTP FS_R	HD299	5/1/1998	7/15/2008	CR10 (Campbell Scientific Inc.)	27.36698472550	-80.51421704280
KENANS1_R	T0958	12/14/2004	7/15/2008	CR10 (Campbell Scientific Inc.)	27.88891159950	-81.01811486110
MAXCEY S_R	UA598	8/4/2006	7/15/2008	CR10 (Campbell Scientific Inc.)	27.54142356860	-81.10033975750
OKEE F 2_R	16285	2/24/1995	7/15/2008	CR10 (Campbell Scientific Inc.)	27.25393424370	-80.78727725720
STA5WX	RQ470	11/30/2003	7/15/2008	CR10 (Campbell Scientific Inc.)	26.44752083220	-80.89019389010
TOHO10_R	JW234	6/24/1999	7/15/2008	CR10 (Campbell Scientific Inc.)	28.20249071900	-81.35043850240
3AS3W3_R	M6888	5/9/2000	7/14/2008	CR10 (Campbell Scientific Inc.)	25.85324262410	-80.76910772670
TMCWX	VM872	2/5/2008	7/14/2008	CR10 (Campbell Scientific Inc.)	27.39694441140	-80.42510915530
BASING_R	QS264	11/20/2003	7/13/2008	CR10 (Campbell Scientific Inc.)	27.40365070900	-81.01144957990
PEAVINE_R	T0919	7/5/2004	7/13/2008	CR10 (Campbell Scientific Inc.)	27.54947906850	-81.02339371530
MARCO_R	PT097	5/14/2003	7/10/2008	CR10 (Campbell Scientific Inc.)	25.93194372470	-81.71197818580
ROOK_R	PT099	5/3/2003	7/10/2008	CR10 (Campbell Scientific Inc.)	26.05083432310	-81.70045998040
ARS B0_R	15582	10/6/1992	7/9/2008	CR10 (Campbell Scientific Inc.)	27.32032027310	-80.84144608330
NAPCON_R	OU145	2/4/2002	7/9/2008	CR10 (Campbell Scientific Inc.)	26.16718701850	-81.78777343220
S331W	16261	7/20/1994	7/9/2008	CR10 (Campbell Scientific Inc.)	25.61093971470	-80.50977915970
BASSETT_R	15577	6/30/1992	7/8/2008	CR10 (Campbell Scientific Inc.)	27.41142848690	-80.92116978350
COCO1_R	DO535	4/19/1996	7/8/2008	CR10 (Campbell Scientific Inc.)	26.27286429930	-81.77980544530
COCO3_R	PT615	4/8/2003	7/8/2008	CR10 (Campbell Scientific Inc.)	26.27320632730	-81.71724567280
CORK_R	DO541	5/30/1996	7/8/2008	CR10 (Campbell Scientific Inc.)	26.42230208320	-81.57868797810
DAVIE2_R	16192	10/31/1991	7/8/2008	CR10 (Campbell Scientific Inc.)	27.26976621510	-80.70533214380
DUP3_R	DO542	8/15/1996	7/8/2008	CR10 (Campbell Scientific Inc.)	26.85894620190	-80.48421744080
INRCTY_R	PS983	3/5/2003	7/8/2008	CR10 (Campbell Scientific Inc.)	28.25593444360	-81.50379305440
VENUS_R	TF254	11/8/2005	7/8/2008	CR10 (Campbell Scientific Inc.)	27.08058777730	-81.33631100360
951EXT_R	DO534	6/19/1996	7/7/2008	CR10 (Campbell Scientific Inc.)	26.30258498560	-81.68841396600
S5A_R	16176	1/26/1995	7/7/2008	CR10 (Campbell Scientific Inc.)	26.68450861050	-80.36754787070
WPBFS_R	GA832	5/21/1997	7/7/2008	CR10 (Campbell Scientific Inc.)	26.68962009050	-80.18482048580
DCRK_R	PT427	8/3/2003	7/2/2008	CR10 (Campbell Scientific Inc.)	26.81622220180	-81.84472222330
GTRSLU_R	PT429	4/20/2004	7/2/2008	CR10 (Campbell Scientific Inc.)	26.80772999610	-81.88323001260
LEHIGH W_R	15464	11/10/1992	7/2/2008	CR10 (Campbell Scientific Inc.)	26.60729522980	-81.64979939860
MBTS	DO555	5/31/1996	7/2/2008	CR10 (Campbell Scientific Inc.)	25.25734134420	-80.42228006540
MDTS	15662	10/11/1991	7/2/2008	CR10 (Campbell Scientific Inc.)	25.27872923380	-80.39505700870
PALMDALE_R	15786	4/16/1992	7/2/2008	CR10 (Campbell Scientific Inc.)	26.92450289550	-81.31395792750
POPASH_R	PT425	9/10/2003	7/2/2008	CR10 (Campbell Scientific Inc.)	26.81457997720	-81.80601076410
TPTS	15658	10/11/1991	7/2/2008	CR10 (Campbell Scientific Inc.)	25.20650998550	-80.37477901510
WHIDDEN3_R	15465	11/9/1992	7/2/2008	CR10 (Campbell Scientific Inc.)	26.94672517380	-81.56618515210
COW CREE_R	JG320	11/21/1998	7/1/2008	CR10 (Campbell Scientific Inc.)	27.35781887530	-80.62977487590
FLYING G_R	7507	3/13/1988	7/1/2008	CR10 (Campbell Scientific Inc.)	27.31393144090	-80.94700406180
JBTS	15083	5/23/1991	7/1/2008	CR10 (Campbell Scientific Inc.)	25.22456572800	-80.54006104190
PEL 23_R	16191	1/30/1995	7/1/2008	CR10 (Campbell Scientific Inc.)	26.81228169810	-80.61005386460
S65E_R	16280	2/23/1995	7/1/2008	CR10 (Campbell Scientific Inc.)	27.22532322760	-80.96256031810
S70_R	16279	3/20/1995	7/1/2008	CR10 (Campbell Scientific Inc.)	27.11866113410	-81.15728707770
MOBLEY_R	15583	9/3/1992	6/3/2008	CR10 (Campbell Scientific Inc.)	27.35337491530	-80.81616762630
PINE ISL_R	T0929	7/21/2004	5/27/2008	CR10 (Campbell Scientific Inc.)	28.11612579730	-81.12645026820
SILVER	MX237	12/6/2000	5/20/2008	CR10 (Campbell Scientific Inc.)	26.30169313440	-81.43136219060
PAIGE_R	16204	1/30/1995	5/5/2008	CR10 (Campbell Scientific Inc.)	26.60562541680	-80.94950710870
SCOTTO	HD784	5/2/1998	4/14/2008	CR10 (Campbell Scientific Inc.)	27.37431852710	-80.45085698010
MICCO_R	LX296	9/1/2000	1/4/2008	CR10 (Campbell Scientific Inc.)	27.47253708580	-81.14395198500
SLT09_R	VG437	12/3/2004	12/31/2007	CR10 (Campbell Scientific Inc.)	27.18319137960	-80.30880305530
SLT26_R	VG446	11/13/2004	12/31/2007	CR10 (Campbell Scientific Inc.)	27.30399969960	-80.30700027630
SLT36_R	VG451	12/3/2004	12/31/2007	CR10 (Campbell Scientific Inc.)	27.14099971740	-80.18800029080
SLT40_R	VG456	11/12/2004	12/31/2007	CR10 (Campbell Scientific Inc.)	27.13800527200	-80.24838639290

RAIN AREAS

Rainfall areas (or rain areas) are defined to represent the physical processes responsible for, or affecting, the genesis and morphology of rainfall processes near the coast and inland. The delineation of these areas in south Florida is recently discussed in a study by Vieux (2006). The rainfall patterns are complex because they are influenced by local convergence zones and sea breeze effects near the coast that enhance precipitation, by inland gradients, and large water bodies such as Lake Okeechobee (in south Florida) that tends to suppress rainfall processes. Another factor affecting the rainfall patterns come from both frontal boundaries and hurricanes, which can produce rainfall gradients that vary in a north-south direction depending on path and location of stalled fronts and storms (Vieux, 2006). It would be interesting to investigate how the rain areas will affect the in-filling processes, both spatially and temporally. The main objective of the study is to in-fill rainfall records based on NEXRAD data using a mathematical programming model to identify clusters of NEXRAD grids surrounding a rain gage. Investigation of spatial and temporal variability of clusters (identified by weights) is also carried out as a part of this study.

INFILLING OF MISSING DATA: WEIGHT VARIATIONS IN HOMOGENOUS RAIN AREAS

RESULTS AND ANALYSIS

The mathematical programming model, Model 16 was applied for in-filling rain gage values. Data at the rain gage station are assumed to be missing for the purpose of testing the cluster based in-filling method proposed in this study. In order to understand the distribution of weights in the NEXRAD grid surrounding a gage, the cluster of nine cells are designated in alphabetical order as shown in Figure 1.

A	B	C
D	E	F
G	H	I

Figure 1 Designation of NEXRAD grids surround a rain gage.

It is important to note that all the NEXRAD data used in the current study are gage adjusted. In addition to Model 16, another model, referred to as Model 6 is defined for evaluation of results. In case of Model 6, the missing rain gage values are in-filled using the values of NEXRAD grid (i.e. cell E shown in Figure 21) in which the rain gage is located.

The weights obtained by solution of Model 16 for different clusters are shown in Table 17. It is evident from the results, that the weights assigned to the cell (i.e. grid) in which the rain gage is located either zero or not necessarily highest as generally expected. The number of cells participating in the optimal weighting scheme ranges from 1 to 8. The upper bound on the number of cells is fixed at nine. Five stations (referred to as station #1, 2, 3, 4 and 5) are used for the current study and these are: 1) station # 1(station: Avon Park, location: latitude:27 35 28; longitude: 81 31 07); 2) station # 2 (station: Palmdale, location: latitude: 26 55 28; longitude: 81 18 50); 3) station # 3 (station: S99, location: latitude:27 28 14; longitude: 80 28 18), station # 4 (location: WPB Airport, latitude:26 40 41; longitude: 80 06 35) and station # 5 (location: CV5 latitude:26 55 10; longitude: 81 07 18). The location of these five stations along with surrounding cluster of 9 cells (pixels) and rain areas are shown in Figure 2.

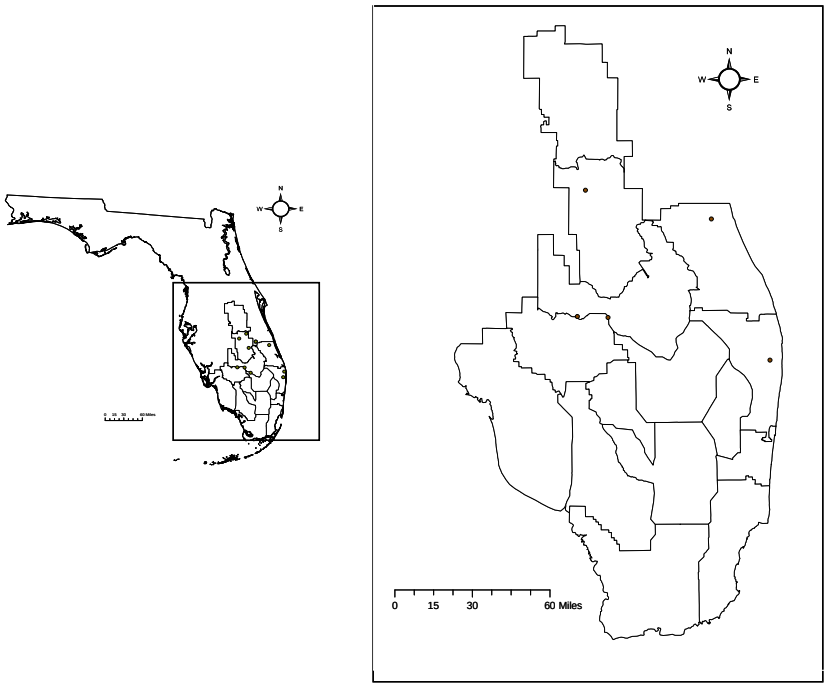

Figure 2 Location of selected NEXRAD grids (of 9 pixels each) and the rain areas in different locations of South Florida.

Table 9 Weights obtained from mathematical programming formulations for different clusters

Cells Cluster	A	B	C	D	E	F	G	H	I
1	0.020	0.253	**0.727**	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.020	**0.489**	0.020	0.391	0.020	0.020	0.020	0.020
3	0.000	0.081	**0.572**	0.000	0.347	0.000	0.000	0.000	0.000
4	**0.878**	0.000	0.000	0.020	0.000	0.000	0.000	0.102	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	**1.000**	0.000	0.000

Models based on optimal weighting and simple methods (referred to as Model 16 and model 6 from the previous report) were applied for in-filling precipitation data. Results related to the performance of these models are shown in the Table 18. Two performance measures, namely, mean absolute error (MAE) and correlation coefficient (ρ) are used for evaluation of the models.

Table 10 Performance of models for in-filling of precipitation data

Cluster		Performance Measure MAE	 (ρ)
1	Model 16	17.520	0.910
	Model 6	20.510	0.885
2	Model 16	19.500	0.885
	Model 6	19.300	0.875
3	Model 16	52.080	0.528
	Model 6	61.948	0.488
4	Model 16	18.546	0.939
	Model 6	20.710	0.932
5	Model 16	16.060	0.415
	Model 6	25.630	0.379

Evaluation of the two performance measures from Table 10 suggests that Model 16 is consistently performing better than Model 6. The mean absolute error values in case of cluster 2 are almost equal.

In order to evaluate the temporal variability of weights, only wet season (i.e., May – October) data are used to train and test the models. In case of cluster #1, for wet season, the weights for A, B,

C,….I are 0.023, 0.299, 0.678, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000 respectively. These weights are marginally different from those reported for station # 1 for the wet and dry seasons combined (shown in Table 9).When only dry season data is used for station #1, the weights were different. The weights for A, B, C,… I., are 0.141, 0.000, 0.839, 0.000, 0.020, 0.000, 0.000, 0.000, 0.000 respectively. Further studies need to be conducted to assess the temporal variability. The limited number of experiments completed in the study may not completely reveal the spatial and temporal patterns and the variations of weights for in-filling purposes in rain areas.

COEFFICIENTS AND EXPONENTS FOR THE POWER MODEL $Y = AX^B$

One of the objectives of this work stated earlier is trying to improve the power model $Y = 0.9\ X^{0.9}$ proposed by Skinner (2006). Optimal values of exponents and coefficients in the model were obtained using a nonlinear optimization solver. A total of fourteen stations were used in this preliminary analysis. The RMSE values generated by the resulting coefficients from using the solver tool were compared to those found by using the $Y = 0.9\ X^{0.9}$ power function. The optimization formulation was evaluated for all 163 stations and the analysis was carried out for the whole period of record from year 2002 to 2007.

SPATIAL VARIATION OF COEFFICIENTS AND EXPONENTS

Once all coefficients and exponents were computed by using nonlinear optimization solver and in order to determine any pattern in their spatial variation, their values were ranked and color coded to then be overlaid on the rain areas by using a GIS platform. Several sets of maps were created by first using the individual values for coefficient and exponents, as well as the Root Mean Square Errors; and then by using the Inverse Distance Weighted as an interpolation method to generate contour areas of similar values. These maps were developed for the whole Period of Records, as well as the Dry and Wet seasons.

SPATIAL VARIATION

To test the effect of removing a number of stations on the overall spatial variation of the coefficients and Root Mean Square Error values, fourteen stations (one from each Rain Area) were selected to be removed from the analysis and then interpolation maps were created and compared with the original ones. The stations were selected according to their central location

within the Rain Area and also considering the fact that there were neighboring stations around them. Starting from Area 1 and going down to Area 14, the selected stations are: TOHO10, KRBN, S131, BLUEGOOS, S78W0 CORK, S6Z, WPBFS, BIGCYPSIR, BCA16, S38, 3AS, S33, and S167.

SPATIAL VARIATION OF MEAN VALUES

Mean values for each rain area were computed for coefficients, exponents, and Root Mean Square Errors. These computations were obtained for the entire period of records and the dry and wet seasons. Maps were created by grouping the resulting values into four classes and color coding all rain areas with similar results.

EXTREME EVENTS

In order to determine how extreme events affect the values for coefficient and exponents and the RMSE, an analysis was conducted for all rain events considered extreme by registering two inches of more of precipitation at the rain gauge. All those extreme values were selected for each one of the fourteen Rain Areas and the values for coefficients, exponents, and RMSE were computed. Furthermore, values for the coefficients, exponents, and RMSE were computed considering all 163 stations regardless of the Rain Area they were located. These values were found for the entire Period of Records first and then for the dry and wet seasons.

VARIATION OF POWER MODEL: INFLUENCE OF DISTANCE BETWEEN RAIN GAUGE AND THE RADAR

To investigate the hypothesis that the location of the Radar with respect to the Rain Gauge location has a direct effect on the values observed for the computed coefficients, exponents, and RMSE, the rain events for the entire Period of Records, and the Dry and Wet seasons were evaluated and the Coefficients, Exponents, and RMSE values computed and plotted for their visual analysis.

RESULTS AND ANALYSIS

Brief summary of results using comparative analysis using power model (Skinner, 2009) and optimized power model for different homogeneous areas.

Table 11. Comparison of RMSE values obtained by using power model ($0.9\ x^{0.9}$) model and model using optimal coefficient and exponents for homogeneous area 1.

RAIN			SOLVER		RMSE		
AREA	STATION	N	a	b	Skinner's	SOLVER	% gain
1	ALL	266	0.927	0.823	0.22	0.21	4.55
2	FLYGW	200	0.943	0.715	0.30	0.26	13.33
3	DAV2	295	0.811	0.697	0.42	0.32	23.81
4	BLUEGOOS	327	0.815	0.805	0.34	0.30	11.76
5	CV5	311	1.003	0.830	0.26	0.24	7.69
6	951EXT	340	0.858	0.709	0.41	0.36	12.20
7	BELLGL	359	0.860	0.707	0.31	0.28	9.68
8	C18W	324	0.847	0.696	0.28	0.24	14.29
9	ALICO	324	0.880	0.737	0.31	0.30	3.23
10	BCA15	371	0.776	0.780	0.35	0.31	11.43
11	3A-36	350	0.802	0.774	0.31	0.28	9.68
12	3A-NE	376	0.897	0.681	0.33	0.31	6.06
13	G54	355	0.917	0.818	0.27	0.27	0.00
14	HOMEFS	247	0.941	0.789	0.42	0.40	4.76
	Min	200	0.776	0.681	0.22	0.21	0.00
	Max	376	1.003	0.830	0.42	0.4	23.81
	Mean	317.5	0.877	0.754	0.32	0.29	9.46

PERIOD OF RECORDS (POR) COEFFICIENTS AND EXPONENTS

The computed coefficient values for all rain areas as well as sample sizes (N), and Root Mean Squared Errors for the entire Period of records are presented in Table 12 and Table 13.

Table 12. Period of Records Coefficient, Exponent and RMSE values for Area 1.

Area 1 POR				
Station	a	b	N	RMSE
ALL2	0.949	0.823	474	0.229
EXOT	0.924	0.930	564	0.372
KIRCKOF	0.823	0.828	534	0.280
KISSFS2	0.912	0.799	494	0.257
S59	0.909	0.767	534	0.299
S61W	0.954	0.798	510	0.313
SGRG	0.975	0.780	542	0.314
TOHO2	0.945	0.830	483	0.293
TOHO10	0.856	0.782	562	0.268
TOHO15	0.897	0.841	553	0.271
WRWX	0.871	0.843	524	0.278
Mean	0.911	0.820	524.909	0.289
Std Deviation	0.046	0.045	31.108	0.037
C.V.	0.051	0.054	0.059	0.128
Minimum	0.823	0.767	474	0.229
Maximum	0.975	0.930	564	0.372

Table 13. Period of Records Coefficient, Exponent and RMSE values for Area 2.

Area 2 POR				
Station	a	b	N	RMSE
FLYINGG	0.936	0.709	516	0.286
KRBN	0.895	0.887	490	0.221
KREF	0.922	0.759	552	0.296
MICCO	0.826	0.765	535	0.312
PC61	0.866	0.830	498	0.243
S65CW	0.865	0.760	464	0.252
S65DWX	0.865	0.711	480	0.242
S65E	0.893	0.677	478	0.263
S68	1.005	0.764	479	0.269
S70	1.082	0.760	486	0.278
S71	0.882	0.687	442	0.315
S75	1.032	0.735	497	0.250
S82	1.067	0.748	472	0.285
S83	1.110	0.766	474	0.359
S84	0.973	0.757	474	0.229
S154	0.972	0.802	501	0.234
TICK	0.961	0.712	488	0.326
Mean	0.950	0.755	489.765	0.274
Std Deviation	0.085	0.052	26.195	0.038
C.V.	0.090	0.068	0.053	0.140
Minimum	0.826	0.677	442	0.221
Maximum	1.110	0.887	552	0.359

Following there is a series of graphs that compile the information resulting from computing all coefficient, exponent and RMSE values for 163 stations reporting rain events during the 2002-

2007 period of records throughout the fourteen District's rain Areas. The graphs (Figure 3 and Figure 4) at first show individual representations for coefficients, exponents, as well as the RMSE values. Then a combined series analysis and a frequency distribution histogram for coefficient and exponent values are presented.

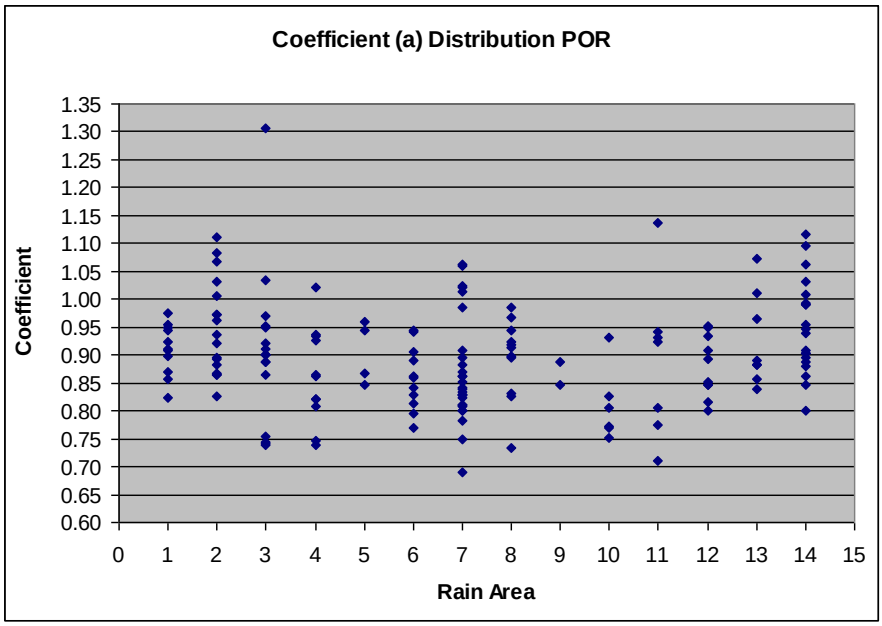

Figure 3. Scatter plot for Coefficients throughout the POR and Rain Areas

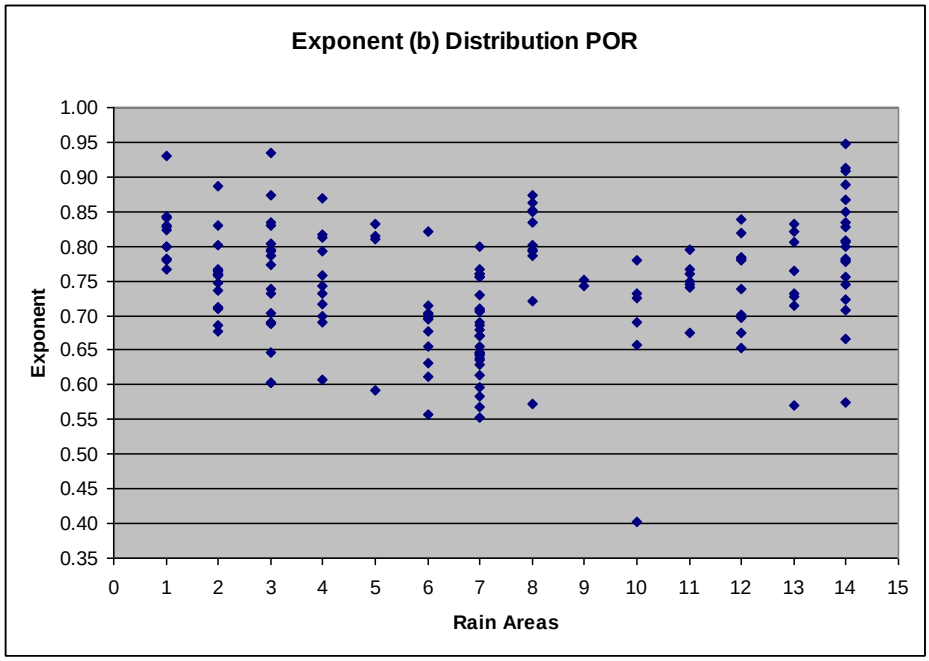

Figure 4. Scatter plot for Exponents throughout the POR and Rain Areas.

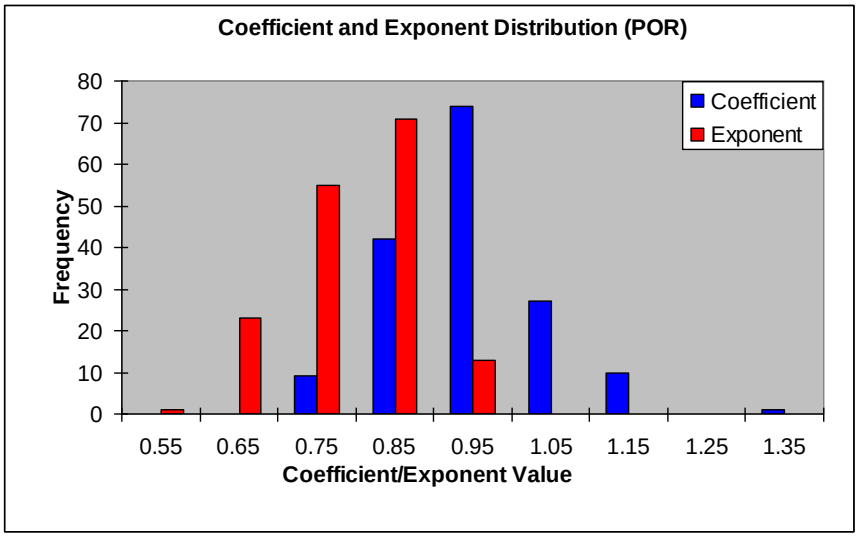

Figure 5. Frequency Distribution of Coefficient and Exponent values throughout the POR and 163 Rain Gauges

Based on the results observed for the analyzed data, it can be determined that the Coefficient values tend to be in the range of 0.69 to 1.31 with an overall mean value of 0.90. The highest value correspond to the one computed for station S191 in Rain Area 3. The exponent values ranged from 0.40 to 0.94 with a mean of 0.74. The lowest Exponent was found for station SIXL3 in Area 10. The root mean squared errors showed values from 0.22 to 0.54 with a mean of 0.30. The highest RMSE value was computed for station SIXL3 in Area 10. In general, the coefficient values generated by SOLVER by using Excel® are higher than the exponents and their frequency distributions are positive and negatively skewed respectively. It can also be observed that there is a slight tendency of coefficient and exponent values to be higher for stations closer to the location of the reporting RADAR (Melbourne or Miami). Not so for the RMSE values. This premise will be explored in later sections.

Following there is a series of graphs that compile the information resulting from computing all coefficient, exponent and RMSE values for 163 stations reporting rain events during the wet season for the period of records 2002-2007 throughout the fourteen District's rain Areas. The graphs at first show individual representations for coefficients, exponents, as well as the RMSE values; and then a combined series analysis and a frequency distribution histogram for coefficient and exponent values.

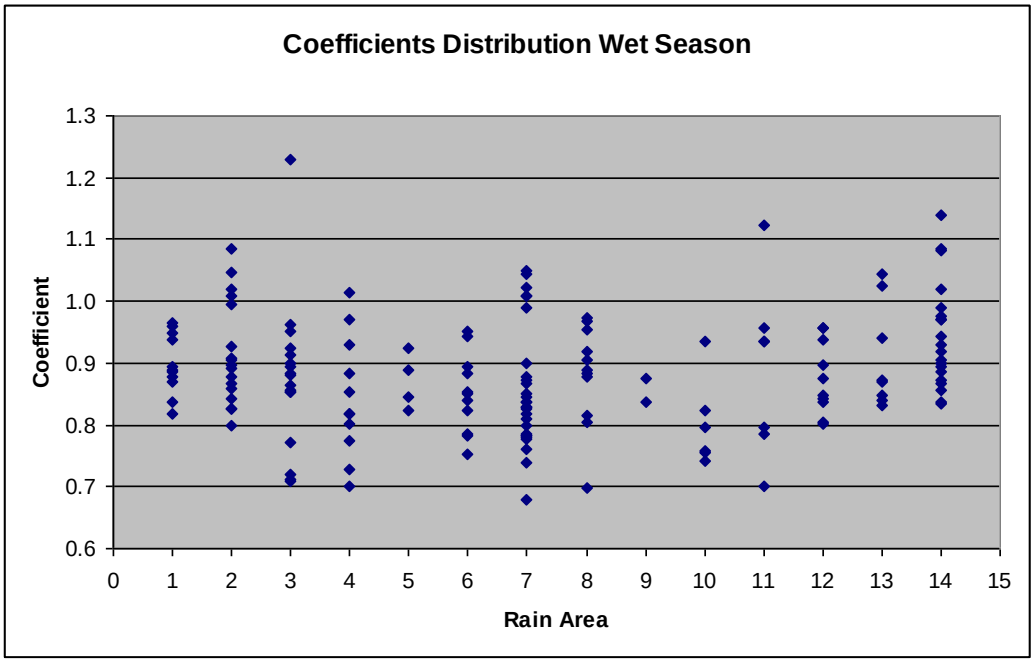

Figure 6. Wet Season Scatter plot for Coefficients throughout the POR and Rain Areas.

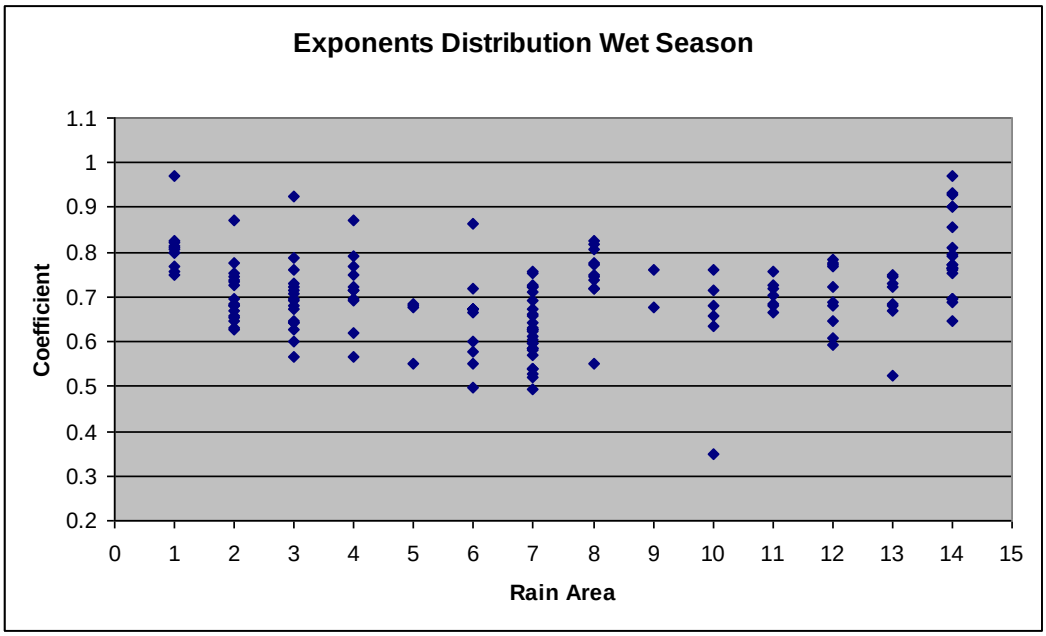

Figure 7. Wet Season Scatter plot for Exponents throughout the POR and Rain Areas.

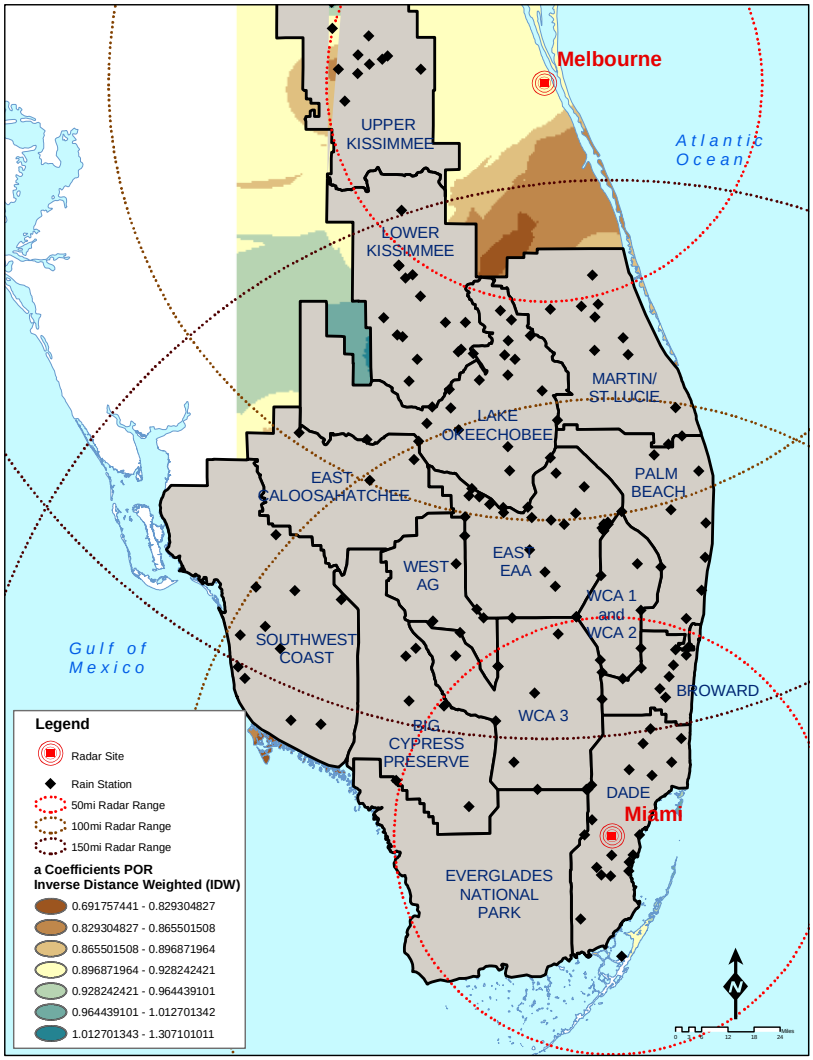

Figure 8. Spatial Distribution of Coefficients for the entire Period of Records obtained by using the Inverse Distance Weighted Interpolation Method.

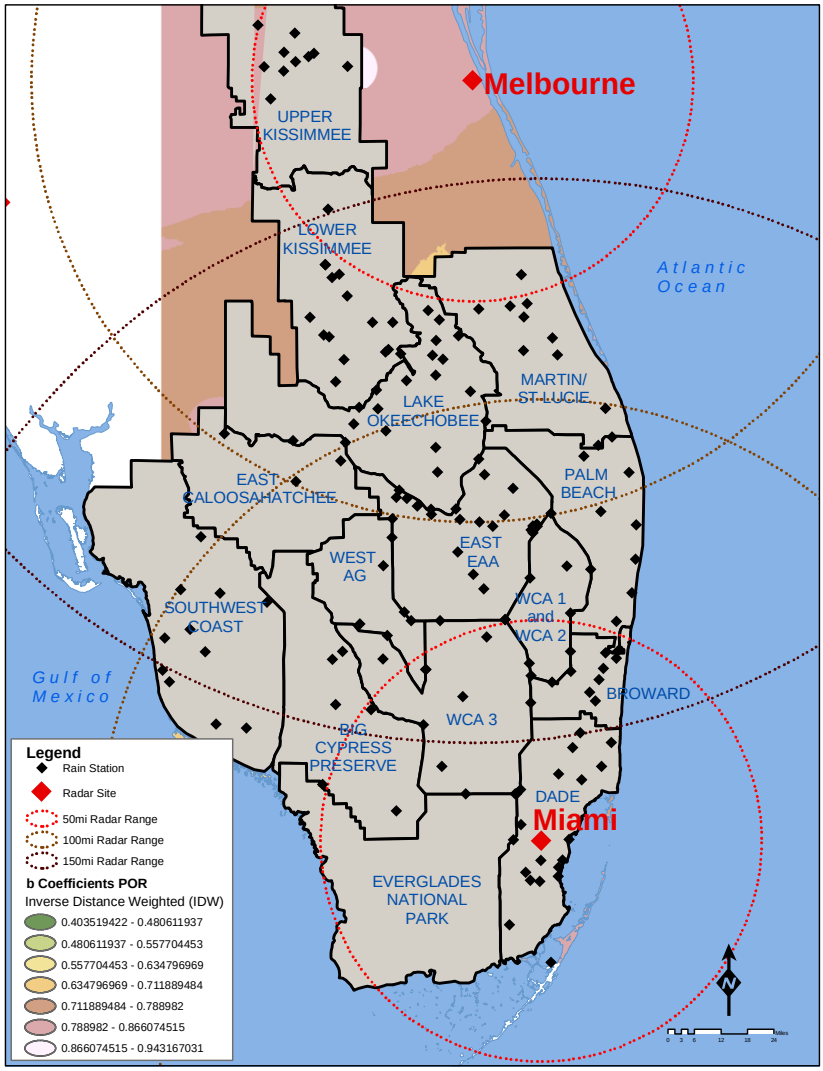

Figure 9. Spatial Distribution of Exponents for the entire Period of Records obtained by using the Inverse Distance Weighted Interpolation Method.

INSIGHTS FROM RESULTS AND OBSERVATIONS

The development of optimized power relationships between rain gage and radar estimates, generated coefficient and exponent values that significantly reduced the root mean squared error (RMSE) values. Just in the preliminary analysis including fourteen stations, the percent gain in the RMSE value reduction was reported to be up to 24%. This is indicative that the use of optimized power relations is needed instead of having a single model applied across the District's area. Values for the coefficient (a) derived for the entire period of records are within 0.69 and 0.86 and they are mostly distributed for the study area in a diagonal fashion extending from the northeast and southwest areas. This section of the terrain is entirely within the 50 mile and the 100 mile radius from the Miami radar. Similarly, the exponent (b) show the same pattern and their

values are in the range of 0.55 to 0.71. Therefore, it can be claimed that the radar distance to the gauging stations has a significant influence on the coefficient and exponent spatial distribution when the whole period of records is analyzed.

The dry season rain events generated coefficient and exponent values with a spatial distribution similar to one observed for the entire period of records, and their values ranged from 0.81 to 0.92 for the coefficient and from 0.74 to 0.82 for the exponent. Once again the vicinity of the gauging station to the Miami radar plays an important role in the final results. When all rain gauge and NEXRAD rainfall records for the wet season were analyzed, the coefficient (a) values ranging from 0.84 to 0.99 cover most of the area of study, just leaving isolated areas in the northeast and southwest where the values are within 0.68 to 0.83. The spatial variability for exponent (b) for the same period of records is that most of the values are between 0.61 and 0.70 and occurred in the central and western parts of the study area and then values from 0.71 to 0.79 extend along the east coast of Florida. In our case study when the data for one station in each rain area was removed from the analysis, the resulting spatial variability for the coefficient and exponent values was not significantly affected. This methodology can be used to estimate missing rain gauge rainfall data or even to determine the optimal number of rain gauges needed in a particular area.

The coefficient and exponent values derived for extreme events greatly differ from those computed for all events extreme or not. This finding endorses the need for using specific coefficient and exponent values for rain events reporting more than two inches of precipitation at the rain gauge. At this time, and based on the results from the case study, it is recommended that the inverse distance weighed (or any other) interpolation method be used to conduct a more detailed analysis on the spatial variation of the coefficients and exponents when rain gauge data from selected stations are removed from the analysis.

CONCLUSIONS

The study reports development, implementation and evaluation of optimization of power function for infilling of missing rain gage data using radar data. Optimal coefficient and exponents are obtained for the entire region and also for different homogeneous areas in the SFWMD region. This study completes final phase of evaluation of infilling using radar data. Several optimization methods were developed as a part of the second phase of the infilling precipitation data study. The infilling of missing data was initially based on data from rain gages. Upon successful evaluation of the methods, they will be extended to NEXRAD data for grid-based estimation of missing precipitation data. Of all the methods developed, the best method based on the

evaluation of several performance measures will be selected to obtain NEXRAD grid based data for infilling missing rain gage records.

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Information Transfer Program Introduction

During the review period (FY2011), the Florida WRRC actively supported the transfer of water resources research findings and results to the scientific and technical community that addresses Florida's water resource problems. The Center provided support for preparation and presentation of 26 peer-reviewed journal articles, 1 book chapter, 19 proceedings and presentations, and 3 PhD dissertations.

Florida Water Resources Information Transfer

Basic Information

Title:	Florida Water Resources Information Transfer
Project Number:	2011FL271B
Start Date:	3/1/2011
End Date:	2/28/2012
Funding Source:	104B
Congressional District:	6
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Kirk Hatfield, Mark Newman

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Information Transfer Program FY 2011

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WRRC Website: The Center maintains a website (http://wrrc.ce.ufl.edu/) which is used to provide timely information regarding applied water resources research within the state of Florida. The Center website provides information regarding ongoing research supported by the WRRC, lists research reports and publications that are available, and provides links to other water-resources organizations and agencies, including the five water management districts in Florida and the USGS.

WRRC Digital Library: The Center maintains a library of technical reports that have been published as a result of past research efforts (Dating back to 1966). Several of these publications are widely used resources for water policy and applied water resources research in the state of Florida and are frequently requested by others within the United States. As part of the WRRC information and technology transfer mission, the library was converted to digital form in 2010 and is provided free to the public through the WRRC Digital Library which is housed on the center website http://wrrc.ce.ufl.edu/reports.html.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	0	4
Masters	2	0	0	2	4
Ph.D.	9	0	0	3	12
Post-Doc.	0	0	0	3	3
Total	15	0	0	8	23

Notable Awards and Achievements

The WRRC continues efforts to maximize the level graduate student funding available to the state of Florida under the provisions of section 104 of the Water Resources Research Act. Listed below are some of the Center's notable achievements for FY 2011:

Nationally recognized Best Ph.D. Dissertation Award. Joshua Dickenson, a Ph.D. graduate from the University of Florida Environmental Engineering Sciences Department received national recognition and was awarded First Place for the 2012 UCOWR (Universities Council on Water Resources) Best Dissertation Award, for his dissertation entitled, "Urban Stormwater Particle and Disinfection Modeling." Joshua's Ph.D. supervisory committee chair was Dr. John Sansalone. This makes four times in the past 5 years in which a Florida WRRC nominated student dissertation has either won (Joshua Dickenson, 2012 and Heather Byrne, 2009) or received honorable mention (Victoria Keener, 2010 and Leslie Gowdish 2007) for the national dissertation award demonstrating the quality of student research performed at the University of Florida.

Research with immediate impact: A previous 104B student-lead seed project (Stuart Norton, 2011) was extended to a multi-year project with cooperating state agencies (Southwest Florida Water Management District and St. Johns River Water Management District) and local municipalities (City of Bradenton) to pilot test and apply methods developed at the University of Florida to mitigate arsenic mobilization during aquifer storage recovery (ASR). With the topic of alternative water supply becoming a critical issue within the state and nation, the outcome of this work will provide immediate impact to the field of water supply within Florida and throughout the nation. The project has and will continue to generate multiple peer reviewed publications, has received recognition as the best student research project at the 2010 UF Water Institute Symposium, and was nominated for consideration in the National Institutes for Water Resources (NIWR) IMPACT awards.

STEM Education: Recognizing the importance of STEM (Science, Technology, Engineering, and Mathematics) Education initiatives, the Florida Water Resources Research Center is very proud to have supported the research efforts of 12 Ph.D., 4 Masters, and 4 undergraduate students along with 3 post doctoral associates all focusing on water resources issues during Fiscal Year 2011.

Support for Junior Faculty: WRRC supported faculty member Treavor Boyer (WRRC project 2011FL267B) was awarded an NSF CAREER award which focuses on his vision for water treatment through innovative techniques of wastewater management and water recycling strategies.

Support for established Faculty: James Heaney (WRRC 2011FL269B) has been awarded with the American Society of Civil Engineers Julian Hinds Award.