

**Florida Water Resources Research Center  
Annual Technical Report  
FY 2012**

# 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 2012) 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 **11 Ph.D., 3 Masters, and 5 undergraduate students** along with 3 post-doctoral associates all focusing on water resources issues during the reporting period (March 2012 to February 2013).

During FY 2012, 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, 8 book chapters, and 11 proceedings and presentations**. 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 and is provided free to the public through the WRRC Digital Library available on the center website (<http://wrrc.essie.ufl.edu/>).

## Research Program Introduction

During FY 2012 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.

### **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. 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 latifolia* (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.

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

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.

The overall goal of this project is to fund an interdisciplinary cohort of 6 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

## Research Program Introduction

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.** Acquisition of hydrologic and hydraulic data is the key component of water resources management in central and south Florida for the South Florida Water Management District (SFWMD). The District is responsible for the collection, validation, and archiving of the District's hydrologic data. The types of data include rainfall, evaporation, water levels (stage), water control structure (gate and pump) operations, and flow. The District requires accurate data collection, processing and archiving of these data for the purposes mentioned above. There is a constant need for good quality rain gage and NEXRAD rainfall data. The project's objective is to develop several qualitative and quantitative indices for evaluation of biases that would ultimately be used to improve the NEXRAD rainfall data. The proposed study would provide a complete assessment of biases at different spatial and temporal resolutions; identify any issues with radar data and issue specific recommendations for improvement of the data in future. This research is highly relevant and critical to SFWMD and all water resources management agencies that use NEXRAD based rainfall data for modeling and management of day-to-day operations of water resources systems.

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

## Basic Information

<b>Title:</b>	Coupled Biological/Chemical Systems for Maximizing Phosphorus Removal from Natural Waters
<b>Project Number:</b>	2011FL267B
<b>Start Date:</b>	3/1/2012
<b>End Date:</b>	2/28/2013
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	6
<b>Research Category:</b>	Engineering
<b>Focus Category:</b>	Nutrients, Surface Water, None
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	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/H<sub>2</sub>O<sub>2</sub>. *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 labile 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.
5. Ged, E.C., Boyer, T.H., 2013. Molecular weight distribution of phosphorus fraction of aquatic dissolved organic matter. *Chemosphere*, 91, 921-927. <http://dx.doi.org/10.1016/j.chemosphere.2013.01.113>
6. Sindelar, H.R., Boyer, T.H., Brown, M.T., 2011. Evaluating advanced oxidations processes for the transformation of organic phosphorus into biologically labile compounds, Abstracts of the 2011 Association of Environmental Engineering and Science Professors Research and Education Conference, University of South Florida, Tampa, Florida, 10-12 July 2011, 1 p.

# WRRC 104B Annual Report for FY2012

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

May 24, 2013

**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 December 2013).

**M.E. Student:** Evan Ged, UF Environmental Engineering Sciences

**B.S. Student:** Jacqueline Cooke, UF Environmental Engineering Sciences

**B.S. Student:** Ashley Walsh, UF Environmental Engineering Sciences

### Project Background

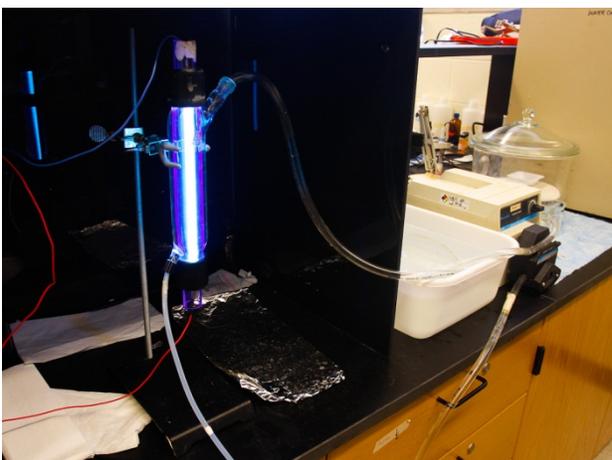
Phosphorus (P) remains a primary pollutant in natural waterways. Phosphorus in agricultural and residential fertilizers, cattle feed, and reclaimed water, eventually finds its way into streams, rivers, and lakes. Excessive P loads can cause eutrophic or hyper-eutrophic conditions in these surface waters, 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 latifolia* (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.

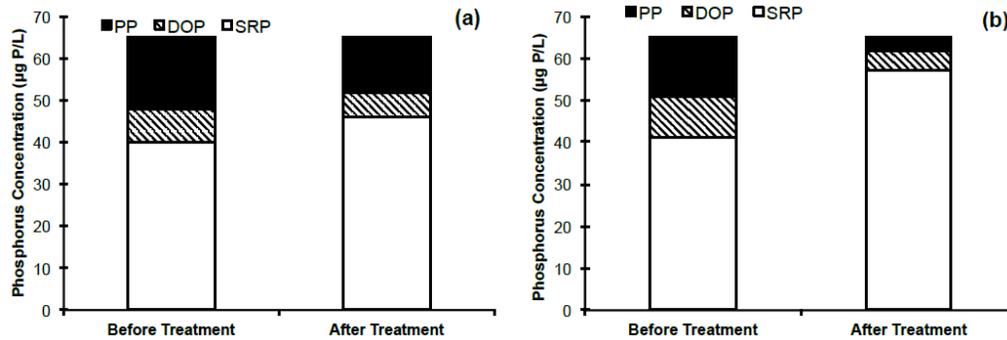
## Project Status

### *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<sub>2</sub>O<sub>2</sub> 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<sub>2</sub>O<sub>2</sub>/L), and oxidant chemical (H<sub>2</sub>O<sub>2</sub> (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<sub>2</sub>O<sub>2</sub> doses of at least 100 mg H<sub>2</sub>O<sub>2</sub>/L (see Figure 2 for example). However, the dynamic nature of most surface waters makes consistent conversion of recalcitrant P to SRP difficult to achieve. Solid forms of H<sub>2</sub>O<sub>2</sub>, sodium percarbonate and sodium perborate, used as substitutes for liquid H<sub>2</sub>O<sub>2</sub> in the UV/H<sub>2</sub>O<sub>2</sub> AOP also had difficulty consistently converting recalcitrant P to SRP, however they both matched the dissolved organic carbon and UV<sub>254</sub> absorbance removal rates of liquid H<sub>2</sub>O<sub>2</sub>. At this time, UV/H<sub>2</sub>O<sub>2</sub> 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 a manuscript in is preparation for submission to an international peer-reviewed journal.



**Figure 1.** UV reactor setup.



**Figure 2.** P profiles before and after treatment of 2× diluted Everglades water from STA-1W treated with: (a) UV exposure time of 10 min and a H<sub>2</sub>O<sub>2</sub> dose of 100 mg H<sub>2</sub>O<sub>2</sub>/L and (b) UV exposure time of 60 min and a H<sub>2</sub>O<sub>2</sub> dose of 100 mg H<sub>2</sub>O<sub>2</sub>/L. An average TP value for all 2× diluted experiments conducted with this batch of Everglades water was used in (a).

### *Molecular weight distribution of dissolved organic phosphorus*

This series of experiments were conducted to gain an improved understanding of the chemistry of dissolved organic phosphorus following from the variability observed in the advanced oxidation experiments. The molecular weight distribution of organic carbon, and to a lesser extent nitrogen, has been characterized in natural waters. There is a lack of data on the molecular weight distribution of organic phosphorus in fresh water. Water samples were collected from the same location in the Everglades as the advanced oxidation experiments. The major result was that organic phosphorus followed a different molecular weight distribution than organic carbon and was most abundant in the low and high molecular weight fractions. Complete discussion of this project can be found in Ged and Boyer (2013).



**Figure 3.** Molecular weight ultrafiltration 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 4 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) is added using peristaltic pumps and concentrated  $\text{CaCl}_2$  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. Nine experiments have been completed to date. Table 1 shows the different operating conditions tested during each experiment.



**Figure 4.** 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)

**Table 1.** Algae scrubber experimental matrix. Flow rate is given in gallons per minute (GPM). Experiments have a constant inflow unless otherwise specified.

Experiment No:	Scrubber 1&2	Scrubber 3&4	Scrubber 5&6
1	1 GPM <sup>a</sup>	2 GPM	2 GPM; Covered
2	1 GPM	2 GPM; Pulsing <sup>a</sup>	2 GPM
3	0.5 GPM	1 GPM; Pulsing <sup>b</sup>	1 GPM
4	0.5 GPM	1 GPM; Pulsing <sup>b</sup>	1 GPM
5	1 GPM	2 GPM; Pulsing <sup>a</sup>	2 GPM
6	1 GPM; Algal Seed <sup>c</sup>	2 GPM; Pulsing <sup>a</sup> ; Algal seed <sup>c</sup>	2 GPM; Algal seed <sup>c</sup>
7	1 GPM; Ca (aq) <sup>d</sup>	1 GPM	2 GPM
8	1 GPM: Ca (aq) <sup>d</sup>	1 GPM: Ca (aq) <sup>d</sup> ; 12 hr <sup>e</sup>	1 GPM
9	1 GPM: Ca (aq) <sup>d</sup> ; Ca (seed) <sup>f</sup>	1 GPM; Ca (seed) <sup>f</sup>	1 GPM

<sup>a</sup>Pulsed inflow with a volume of 4 gal and frequency of once every 2.25 min

<sup>b</sup>Pulsed inflow with a volume of 4 gal and frequency of once every 4.5 min

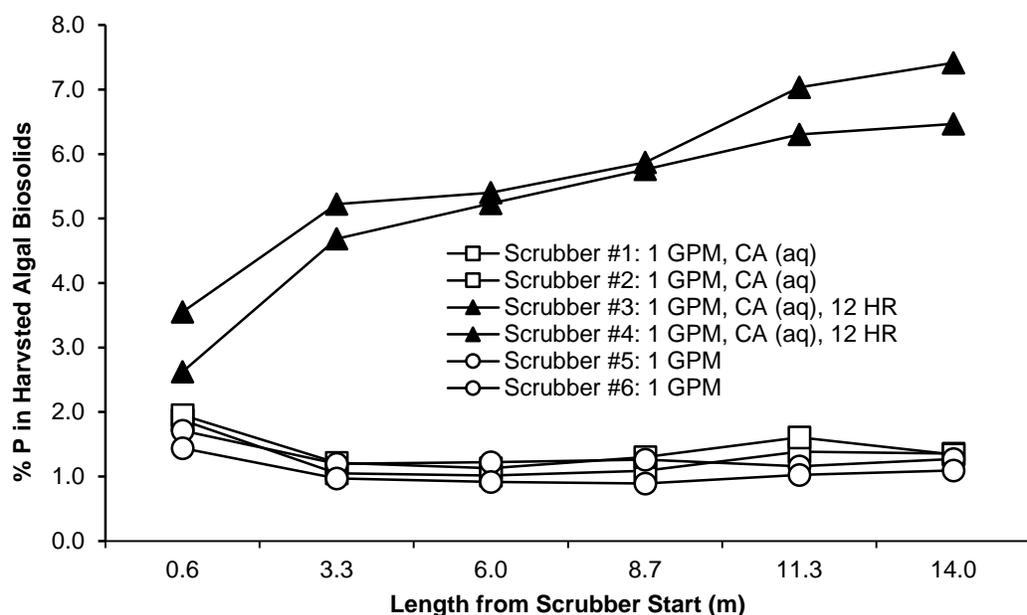
<sup>c</sup>A small amount of algae was left from the previous harvest to seed growth for this experiment

<sup>d</sup>Added 50 mg/L of  $\text{Ca}^{2+}$  using a  $\text{CaCl}_2$  stock solution

<sup>e</sup>Water was pumped to the raceways only during daylight hours

<sup>f</sup>Calcium carbonate ( $\text{CaCO}_3$ ) was added as a seed for calcium-phosphorus co-precipitation

Results from these experiments show that the primary P removal mechanism is algae-mediated co-precipitation of Ca-P. As the algae photosynthesize during the day, the pH rises in the water column. This rise in pH (9–9.5) causes Ca-P to co-precipitate from the water. At night algal photosynthesis stops and the pH decreases back to neutral (7–7.5), leading to the dissolution of some of the Ca-P minerals created during the day. As a result, the best treatment for P uptake in algae scrubbers is 12-hour operation, which stabilizes Ca-P minerals co-precipitated during daylight hours. These results can be seen in Figure 5, which shows the percent P in harvested algal biosolids for experiment 8. During experiment 8, 12-hour operation was used on scrubbers 3 and 4. This increase in percent P in the algal biomass significantly increases P uptake from an average of 24 g P/m<sup>2</sup>/yr for all other experiments to 87 g P/m<sup>2</sup>/yr. This work is nearing completion and the data is being analyzed in preparation for submission to a peer-reviewed journal.



**Figure 5.** Percent P in harvested algal biosolids for experiment 8.

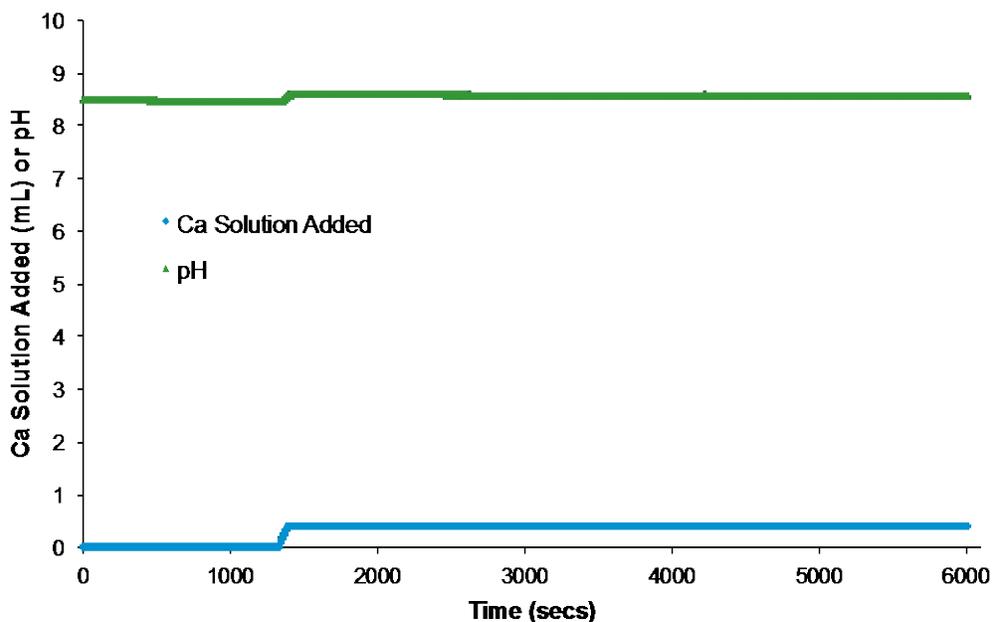
*Co-Precipitation: Phosphorus–calcium–dissolved organic matter system*

Tests are being conducted using a pH-stat system (see Figure 6) 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 model waters containing only Ca, SRP, and DOM. 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.

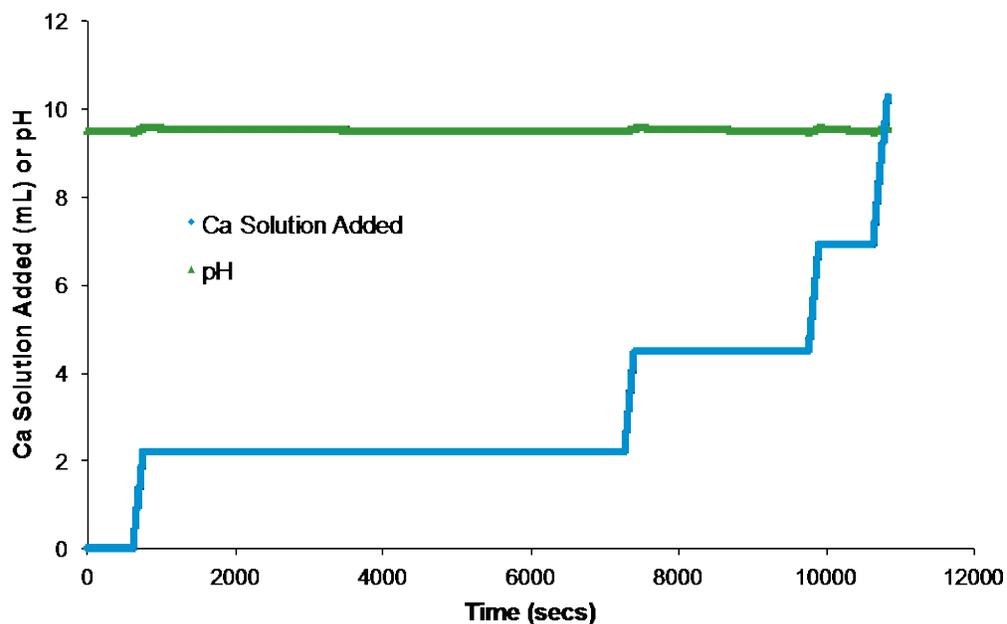
Experiments were conducted at pH 8.5, but there was no significant precipitation of calcite minerals at a DOM concentration of 2.5 mg C/L, as shown in Figure 7. However, when the pH was increased to 9.5, precipitation of calcite minerals occurred in the presence of DOM concentrations as high as 15 mg C/L (see Figure 8). These results suggest that for Ca-P co-precipitation to occur in the presence of DOM, the pH must reach values high enough to overcome the inhibitory effect of DOM. Research has shown that algae create high pH microsites, where pH values can rise as high as 9.5 (Hartley et al. 1998). Our results coupled with this research suggest that algae play a critical role in Ca-P co-precipitation. Algae raise the pH high enough to initiate Ca-P co-precipitation in ecosystems where Ca-P co-precipitation is a primary P removal mechanism. This work is almost complete and the data is being analyzed in preparation for submission to a peer-reviewed journal.



**Figure 6.** pH-stat setup.



**Figure 7.** Calcite precipitation at a pH of 8.5 in model water containing 100  $\mu\text{g}$  P/L and 2.5 mg C/L.



**Figure 8.** Calcite precipitation at a pH of 9.5 in model water containing 100  $\mu\text{g P/L}$  and 15 mg C/L.

### 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 22<sup>nd</sup> 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 3<sup>rd</sup> UF Water Institute Symposium*, University of Florida, Gainesville, Florida, 15–16 February 2012.
- Sindelar, H., Brown, M.T., Boyer, T.H., “Phosphorus removal in natural waters through calcium co-precipitation; effects of natural organic matter,” *Oral presentation at 23<sup>rd</sup> Annual Florida Lake Management Society Conference and Technical Symposium*, Gainesville, Florida, 18–21 June 2012.
- Sindelar, H., Brown, M.T., Boyer, T.H., “Algae scrubbers for phosphorus removal in impaired waters,” *Oral presentation at 24<sup>th</sup> Annual Florida Lake Management Society Conference and Technical Symposium*, Daytona Beach, Florida, 17–20 June 2013.

## References

Adey, W., Lockett, 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.

Hartley, A.M., House, W.A., Leadbeater, B.S.C., Callow, M.E., 1998. The use of microelectrodes to study the precipitation of calcite upon algal biofilms. *Journal of Colloid and Interface Science* 183, 498-505.

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/H<sub>2</sub>O<sub>2</sub>. 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

<b>Title:</b>	Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida
<b>Project Number:</b>	2011FL269B
<b>Start Date:</b>	3/1/2012
<b>End Date:</b>	2/28/2013
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	6
<b>Research Category:</b>	Engineering
<b>Focus Category:</b>	Water Supply, Management and Planning, Models
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	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.
3. 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.
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.
9. Morales, M., Heaney, J., Friedman, K. and J. Martin. 2013. Parcel-level model of water and energy end use. *Jour. American Water Works Assn.*, accepted for publication.
10. Friedman, K., Heaney, J. Morales, M. and J. Palenchar. 2013. Predicting and Managing Residential Potable Irrigation Using Parcel Level Databases. *Jour. American Water Works Assn.*, accepted for publication.
11. Morales, M, Martin, J., Heaney, J. and K. Friedman. 2013. Parcel Level Modeling of Seven End Use Water Demands in 64 Public Supply Land Use Sectors. *Jour. American Water Works Assn.*, accepted for publication.

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

12. Heaney, J., Switt, R., Friedman, K., Morales, M., and K. Riley. 2011. Overview of EZ Guide for Water Conservation Evaluations. *Florida Water Res. Jour.*, Sept.
13. 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.

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](mailto: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 three 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. 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 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 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. 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. These new techniques will be incorporated into EZ Guide software for use by water utilities and other water agencies

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				
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 primary tasks for years 2 and 3 are shown in the above table. The status of these these tasks is described below.

1. Perform water audit and estimate water losses and trends using AMR and other data

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. 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.

The initial water loss evaluation of Sanford revealed significant monthly and annual variation of losses as shown in Figure 1. The rectified billing data provided much more stable estimates of losses compared to using unrectified billing data. This was shown to

be important when evaluating monthly losses. Water loss was calculated by comparing treated supply with billed metered consumption. Systematic data handling error can be added, depending on which billed consumption dataset is being utilized. Next steps include collecting and analyzing data relevant to remaining inputs.

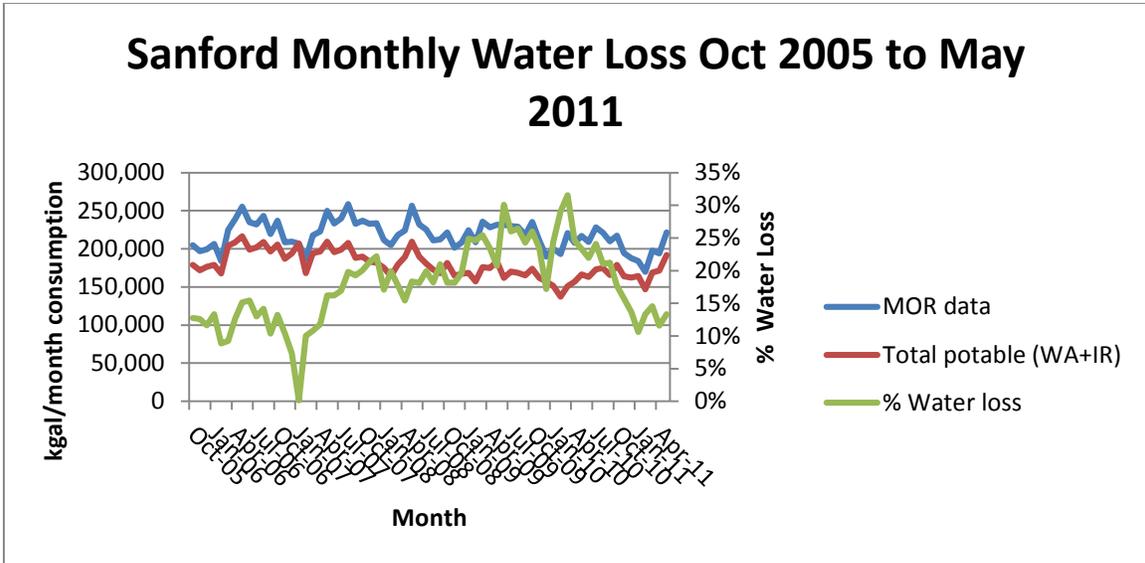


Figure 1. Calculated Sanford monthly water loss from October 2005 to May 2011.

The UF- Sanford parcel customer database contains meter attributes (and associated billing data) from 9/1/2005 through 5/1/2011 for the 19,865 meter locations on 15,103 parcels in the final database after QA/QC. Every meter installed has a unique meter ID, which is associated with a meter location. If a meter at a given location is replaced with another meter at the same location, the meter id will change, but the meter location ID will remain constant. Meter locations were joined to associated parcels using a spatial join assigning meter locations to which parcel boundary it is located in. The data was pivoted to show meter installation dates for all meter locations on a given parcel from 9/1/2005 through 5/1/2011. The most recent meter installation date for each meter location on each parcel was determined from this query. Parcels not displaying a meter installation date between 9/1/2005 through 5/1/2011 are assumed to have a meter which was installed prior to 9/1/2005. A total of 9,364 of 15,103 (62%) parcels in Sanford had at least one meter installed between 9/1/2005 and 5/1/2011 based on the UF-Sanford parcel level database. With the inclusion of the recent meter replacement data from the Sanford conservation tracking workbook, 11,121 of 15,103 (74%) parcels in Sanford had at least one meter installed between 9/1/2005 and 1/4/2012. The remaining 26% are assumed to have meters installed prior to 9/1/2005. The initial evaluation of the expected increase in billed water use because of the new meters was inconclusive and additional evaluations are underway. The accuracy of this meter evaluation is limited by the lack of widespread testing of the old meters that were being replaced.

2. Refined bottom up benefit-cost optimization of water loss, water conservation, and water reuse options using EZ Guide

The primary purpose of creating the detailed Sanford database is to refine initial estimates based on statewide data and default coefficients and evaluate the value added of the additional data. Customer billing data from the Sanford parcel database was used to cluster the 12,566 single family customers based on similarities of peak and average potable water usage into three categories shown in Table 2.

Table 2. Cluster analysis for 12,566 single family homes in Sanford

Cluster	% of accounts	2009 avg. gpad	2009 avg. may peak gpad
1	86.4%	147	161
2	13.5%	449	488
3	0.14%	2,365	6,435
Total or weighted average	100%	221	295

The 13.6% in clusters 2 and 3 are assumed to irrigate from the potable system. In addition, 434 parcels have irrigation meters. These irrigators would not be captured by the cluster analysis since their regular potable water meter would only record indoor usage. Including these customers results in 16% of Sanford SFR customers irrigating from the potable system. This value was then used to override the default assumption that 50% of SFR customers irrigate from the potable system. Changing this assumption alone reduced the overall model error from 31% to 22% reducing outdoor gpcd from an estimated 21 to 10 gpcd based on billing data analysis. This analysis shows that the impact of additional reuse is relatively small.

It is essential to have a hydraulic model of the water distribution system to evaluate flows and pressures throughout the utility. An “all pipe” model is available for Sanford and is being used in this phase of the analysis. Data on pipe leaks and failures are also essential. It was hoped that the recently installed CityWorks data management system would provide this data but it doesn’t appear that this historical information will be available from CityWorks. Thus, we are extracting the available information from paper records.

Methods, procedures, and facilities. The Conserve Florida Water Clearinghouse ([www.conservefloridawater.org](http://www.conservefloridawater.org)) has developed numerous tools for evaluating water loss and water conservation best management practices. Detailed information about these activities is available at our web site. The current staff of the Clearinghouse includes a lead faculty member, one project manager, three PhD students, a systems engineer, and a programmer.

## Publications

Our research results have been published in Florida and national journals as well as in conference proceedings. A complete list of publications is available at the Conserve Florida Water Clearinghouse website ([www.Conservefloridawater.org](http://www.Conservefloridawater.org)). Key relevant recent publications are shown below.

- Morales, M., Heaney, J., Friedman, K. and J. Martin .2013. Parcel-level model of water and energy end use. *Jour. American Water Works Assn.*, accepted for publication.
- Friedman, K., Heaney, J. Morales, M. and J. Palenchar. 2013. Predicting and Managing Residential Potable Irrigation Using Parcel Level Databases. *Jour. American Water Works Assn.*, accepted for publication.
- Morales, M, Martin, J., Heaney, J. and K. Friedman. 2013. Parcel Level Modeling of Seven End Use Water Demands in 64 Public Supply Land Use Sectors. *Jour. American Water Works Assn.*, accepted for publication.
- 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. 8<sup>th</sup> 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 Res. Jour.*, Sept.
- 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

<b>Title:</b>	Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters
<b>Project Number:</b>	2011FL270B
<b>Start Date:</b>	3/1/2012
<b>End Date:</b>	2/28/2013
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	6
<b>Research Category:</b>	Water Quality
<b>Focus Category:</b>	Sediments, Law, Institutions, and Policy, Management and Planning
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	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.
4. Henson W.R., DeRoosij, R., Graham, W.D., Examining the Role of Aquifer Confinement and Model Discretization on Spring Water Discharge and Matrix-Conduit Exchange: Implications for Nutrient Fate and Transport. International Association of Hydrologists Groundwater Quality Conference. Gainesville, FL. April 2013.

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

**PRINCIPAL INVESTIGATOR.**

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

Dr. Tom Frazer, Forest Resources and Conservation – Ecological Consequences of Nutrient Enrichment

Richard Hamann, J.D., College of Law - Environmental Law

**RESEARCH CATEGORY.** Water Quality

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

**ABSTRACT.**

The overall goal of this project is to fund an interdisciplinary cohort of 6 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. Funding for 4 Ph. D. Fellows has been provided by the University of Florida under the Water Institute Graduate Fellows program. **In this proposal, partial funding for 2 additional Ph. D. students is requested from the USGS to add additional expertise in the areas of hydrologic processes and aquatic ecology.** The education and research of each Fellow evolves 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 allows an integrated whole that will reflect disciplinary facets associated with this complex problem. Components currently funded by UF include Paleolimnology, Nutrient Best Management Practices, Riverine Nutrient Processing, and Systems Modeling (Original Proposal PIs Brown, Brenner, Clark, Cohen, Hamann). This proposal will fund additional components in either Hydrologic Processes or Aquatic Ecology (Graham and Frazer, respectively).

**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 links faculty and students from watershed science (Cohen), limnology (Brenner), wetlands and water quality extension (Clark), water law (Hamann), and systems modeling (Brown) to study the scientific basis for, and the design and implementation of numeric nutrient criteria for Florida waters. This proposal seeks funding to further extend 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.

Three primary outcomes of the program include:

- (1) Education and training of 6 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 field campaigns as their research efforts take shape. This will help fellows develop skills in research design, management, and execution.

## **MAJOR FINDINGS AND ACCOMPLISHMENTS SINCE LAST YEAR**

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 4-7<sup>th</sup> 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). One of the candidates has since withdrawn for personal reasons. The 2011 WIGF cohort now 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 Overdeest, Environmental Sociology)

Grant Weinkam (BS Ohio University, MS University of Cincinnati, Advisor Mark Brown, Environmental Engineering Sciences)

*\*partially supported by this grant.*

During the Fall 2011 semester the WIGF faculty and student cohort participated in a 4 day group field trip around the state of Florida focused on visiting Natural and Degraded Systems of Florida and initiated a weekly Socratic Seminar (Fall 2011) to provide a synthetic dialog to refine the cohort's research agenda. The WIGF student cohort also assisted in the planning of the February 2012 Water Institute Symposium.

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 3<sup>rd</sup> Annual University of Florida Water Institute Symposium poster session as well as the 9<sup>th</sup> Annual INTECOL International Wetlands Conference.

During the Spring 2012 semester the weekly Socratic Seminar continued and the WIGF fellows helped host the Water Institute Symposium (Feb 15-16<sup>th</sup>, 2012). A two-day retreat was conducted in May 2012 during which the WIGF faculty and student cohort developed an integrative framework for their proposed individual Ph. D. work on nutrient dynamics, management and policy.

During the Summer 2012 semester the WIGF faculty and student cohort participated in the 5-week UF Law School Costa Rica Study abroad program. The WIGF students, in collaboration with UF Law Students and Costa Rican Law Students, worked on a variety of project, each of which focused on water management issues pertinent to the Tempisque-Bebedero Basin, one of Costa Rica's largest and most water-limited watersheds. The Tempisque-Bebedero Basin and the Pacific Coast of Central America has been characterized as a "climate change hot-spot" due to predicted impacts on water resources, principally drought.

The 2012 projects included an investigation of the legal, socioeconomic, and environmental issues associated with rice production in the buffer zone of Palo Verde National Park; an assessment of the legal

and scientific tools available for improving the health of the impaired wetland at Palo Verde National Park, an internationally recognized wetland; and an analysis of the institutional and legal framework for drought management in the Tempisque Basin. Participants also evaluated new recommendations for establishing minimum environmental flows in the Basin, investigated the environmental and social impacts of a proposed water storage dam in the Basin, and reviewed and critiqued current regulations for nutrient pollution in the Tempisque River. See <http://www.law.ufl.edu/academics/academic-programs/study-abroad/summer-abroad/costa-rica/project-spotlight> for detailed reports on the 2012 projects.

During the Fall 2012 semesters the WIGF students presented and defended their individual Ph. D. research proposals. The following proposals were approved by the students' supervisory committees

**Student:** T. Elliott Arnold, Ph. D. in Geological Science, College of Liberal Arts and Sciences. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Estimating groundwater discharge into lakes via stable isotope and radium mass balance equations: Redefining nutrient budgets and nutrient sources.

**Student:** Wesley Henson, Ph. D. in Agricultural and Biological Engineering, College of Agricultural and Life Sciences and College of Engineering. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Examining the influence of water fluxes, flow paths and age on Nutrient Delivery: Implications for North Florida Springs.

**Student:** Joelle Liang, Ph. D. in Interdisciplinary Ecology, School of Natural Resources and the Environment. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Biogeochemistry and nutrient availability at the sediment-water interface in Florida springs and implications for management.

**Student:** Charles Nealis, Ph. D. in Soil and Water Sciences, College of Agricultural and Life Sciences. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Barriers and motivators to implementation of urban BMPs.

**Student:** Courtney Reijo, Ph. D. in Forest Resources and Conservation, College of Agricultural and Life Sciences. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Eutrophication in flowing waters: Metrics of nutrient limitation and processing in rivers.

**Student:** Grant Weinkam, Ph. D. in Environmental Engineering Sciences,. Anticipated graduation date May 2015.

**Proposed Dissertation Title:** Fate and future of phosphorus loading associated with land applied reclaimed water in Florida.

### **TRAINING POTENTIAL.**

Two Ph. D. students (Joelle Liang and Wesley Hanson) are partially funded under this project and will join the UF funded cohort of 4 additional Ph. D. students. Each Ph.D. student has crafted 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.

During the Summer 2012 semester the WIGF faculty and student cohort participated in the 5-week UF Law School Costa Rica Study abroad program. The WIGF students, in collaboration with UF Law Students and Costa Rican Law Students, worked on a variety of project, each of which focused on water

management issues pertinent to the Tempisque-Bebedero Basin, one of Costa Rica's largest and most water-limited watersheds. The Tempisque-Bebedero Basin and the Pacific Coast of Central America has been characterized as a "climate change hot-spot" due to predicted impacts on water resources, principally drought.

The 2012 projects included an investigation of the legal, socioeconomic, and environmental issues associated with rice production in the buffer zone of Palo Verde National Park; an assessment of the legal and scientific tools available for improving the health of the impaired wetland at Palo Verde National Park, an internationally recognized wetland; and an analysis of the institutional and legal framework for drought management in the Tempisque Basin. Participants also evaluated new recommendations for establishing minimum environmental flows in the Basin, investigated the environmental and social impacts of a proposed water storage dam in the Basin, and reviewed and critiqued current regulations for nutrient pollution in the Tempisque River. See <http://www.law.ufl.edu/academics/academic-programs/study-abroad/summer-abroad/costa-rica/project-spotlight> for detailed reports on the 2012 projects.

Joelle Laing: Joelle Laing is conducting her dissertation research on the biogeochemical feedbacks contributing to the growth and success of species of submerged aquatic vegetation. Her research incorporates theory and data from multiple disciplines, including botany, ecology, geochemistry, and hydrology. Currently she is preparing a field study investigating the redox chemistry of sediments underlying different types of vegetation. Since sediment redox chemistry may influence the growth and reproductive success of species of vegetation, she plans to follow her field work with a laboratory experiment on the effects of redox potential on plant growth and reproduction. Her findings will expand theory related to eutrophication responses in lotic systems and will provide insight into the underlying mechanisms which cause nuisance vegetation to dominate in many disturbed lotic systems.

Wes Henson: Over the past year, Wes Henson has focused on developing a broad understanding of how groundwater-surface water science contributes to law and policy making through the University of Costa Rica International Law program. In addition to environmental law courses, he led an interdisciplinary practicum for the summer of 2012. The practicum consisted of international stakeholder and law analysis as well as critical scientific reviews of established environmental flows (minimum flows and levels) for the Tempisque River. For his dissertation, he has been evaluating process-based models to examine methods for representing dual permeability domains in karst aquifers. This summer, his field work is investigating the spatial distribution of denitrification in the upper Floridan Aquifer across a gradient of aquifer confinement, using synoptic geochemical, isotopic, dissolved noble gas and aquifer tests. His future research will focus on how conduit flow processes affect travel time distributions (TTD) and residence times in karst aquifers. These are of great importance for understanding their influence on nutrient transformation and attenuation in the Floridan Aquifer. In addition to his research, Wes participates in several science outreach activities: teaching elementary children about geology, wetlands, and water quality; leading high school 4-H workshops on wetlands and springs; and mentoring an undergraduate student from the Agricultural and Biological Engineering department.



Joelle Laing, Wesley Henson and Water Institute Fellows indicating whether dams are good (thumbs up) or bad (thumbs down), Tempisque River Dam, Costa Rica 2012



Joelle Laing surveying vegetation characteristics at a potential research site, May 2013.



Wesley Henson next to karst swallet in Santa Fe River basin, June 2012.

# Development and Evaluation of Indices for Bias Assessment for Radar-based Rainfall Estimates

## Basic Information

<b>Title:</b>	Development and Evaluation of Indices for Bias Assessment for Radar-based Rainfall Estimates
<b>Project Number:</b>	2012FL301B
<b>Start Date:</b>	3/1/2012
<b>End Date:</b>	2/28/2013
<b>Funding Source:</b>	104B
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<b>Focus Category:</b>	Hydrology, Methods, Models
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Ramesh S Teegavarapu

## Publications

1. Aneesh Goly and Ramesh S. V. Teegavarapu, Selection and Evaluation of Different Spatial Resolutions for Statistical Downscaling of Precipitation, ASCE-EWRI, Environmental and Water Congress, 22 May, 2013, Cincinnati, USA.
2. Aneesh Goly and Ramesh S. V. Teegavarapu, Statistical Characterization and Assessment of Precipitation Extremes during Different Phases of Multi-year and Multi-decadal Climatic Oscillations, ASCE-EWRI, Environmental and Water Congress, 21 May, 2013, Cincinnati, USA.
3. Ramesh S. V. Teegavarapu, Estimation of Missing Precipitation Records using Classifier, Cluster and Proximity Metric-Based Interpolation Schemes, American Geophysical Union (AGU) Fall Meeting, 2012.
4. Extreme Precipitation and Climate Change, IFI, Book Series Meeting, UNESCO, Paris, April 29, 2012.
5. Manual of Standard Practice for Radar Rainfall Data Estimation, Editors: Chandra Pathak and Ramesh Teegavarapu, August 2011, ASCE. Available: April 2012
6. Precipitation, Chapter in ASCE Book on Statistical Distributions in Hydrology: Ramesh Teegavarapu and Chandra Pathak, May 2012, ASCE. Available: May 2013.
7. Ramesh S. V. Teegavarapu, Missing Precipitation Data Estimation using Optimal Proximity Metric-based Imputation, Nearest Neighbor Classification and Cluster-based Interpolation Methods, Hydrological Sciences Journal, 2013. In review.
8. Ramesh S. V. Teegavarapu, Climate Change-Sensitive Hydrologic Design under Uncertain Future Precipitation Extremes, Water Resources Research, 2013. Accepted.
9. Ramesh S. V. Teegavarapu, Statistical Corrections of Spatially Interpolated Precipitation Estimates, Hydrological processes, 2013. In print.
10. Ramesh S. V. Teegavaapu, Aneesh Goly and Jayantha Obeysekera, Influences of Atlantic Multi-Decadal Oscillation on Regional Precipitation Extremes, Journal of Hydrology, 2013. In Print
11. Ramesh S. V. Teegavarapu and Anurag Nayak. Evaluation of Long-term Trends in Extreme Precipitation: Implications of Infilled Historical Data and Temporal-Window based Analysis, Journal of Hydrology, 2013. In review.

## Development and Evaluation of Indices for Bias Assessment for Radar-based Rainfall Estimates

12. Aneesh Goly, Ramesh S. V. Teegavarapu, Arpitha Mondal, Evaluation of Statistical Downscaling Models for Monthly Precipitation in Florida, *Journal of Hydrology*, 2013. In Review.
13. Ramesh S. V. Teegavarapu, Spatial Interpolation using Non-linear Mathematical Programming Models for Estimation of Missing Precipitation Records, *Hydrological Sciences Journal*, 2012.

## **WRRC 104B Project Annual Report**

(Activities during the period March 1, 2012 through February 28, 2013)

Project Title:

# **Development and Evaluation of Indices for Bias Assessment for Radar-based Rainfall Estimates**

Submitted to:

Water Resources Research Center (WRRC)

University of Florida

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Submitted by

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May 24, 2013

## EXECUTIVE SUMMARY

The report provides details of the work and summarizes the analyses completed for the project “Development and Evaluation of Indices for Bias Assessment for Radar-based Rainfall Estimates” supported by USGS 104B Grant and administered by Water Resources Research Center (WRRC), University of Florida. The study was also supported by South Florida Water Management District (SFWMD). Radar data acquired by SFWMD are provided by Vieux and Associates Inc. at different time intervals (near real-time (NRT), end of the day (EOD) and end of the month (EOM)) are used for assessment of bias using two rain gage data sets. The analysis of bias is carried out using an exhaustive framework developed in the current study that relies on visual evaluations, quantitative indices, skill scores and statistical tests. The analysis is conducted at different temporal levels and a seasonal basis (wet, dry and transitional). Radar and rain gage data available from October 2007 to September 2011 are used for the analysis. Data from a total of 189 rain gages is used for the analysis. Results based on completed work suggest that radar data has improved during the period of record. All the indices and skill scores used in the current study suggest that radar data is of good quality at different temporal resolutions and is in agreement with unadjusted rain gage data. However, spatial bias evaluation suggests that radar data consistently underestimates precipitation amounts in northern and southeast areas of the South Florida Water Management District (SFWMD) region. A bias assessment tool (BAT) is developed and all the indices are already incorporated in the tool and was provided to SFWMD.

**Keywords:** Radar (NEXRAD), rain gage, bias analysis, near real-time (NRT), SFWMD, skill scores, contingency tests, Taylor diagram, autocorrelation, statistical hypothesis tests, scalar performance indices, distance metrics.

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## INTRODUCTION

Acquisition of hydrologic and hydraulic data is the key component of water resources management in central and south Florida. The District is responsible for the collection, validation, and archiving of the District's hydrologic data. The types of data include rainfall, evaporation, water levels (stage), water control structure (gate and pump) operations, and flow. The District requires accurate data collection, processing and archiving of these data for the purposes mentioned above. There is a constant need for good quality rain gage and NEXRAD rainfall data. The project's objective is to develop several qualitative and quantitative indices for evaluation of biases that would ultimately be used to improve the NEXRAD rainfall data. The proposed study would provide a complete assessment of biases at different spatial and temporal resolutions; identify any issues with the radar data provided by VAI and issue specific recommendations for improvement of the data in future.

### **Availability of NEXRAD Rainfall Data**

The NEXRAD coverage for the District (Huebner et al., 2003) includes rainfall amounts for 33,773, 2 km by 2 km cells, provided at 15-minute intervals. The current database, at the District, contains values from January 1, 2002, to the present. Each cell has a specific time series of rainfall data.

### **Scope of Work**

The scope of work involved herein includes development of several indices for evaluation of biases using NEXRAD rainfall data provided by VAI and rain gage data. The proposed study derives motivation from the need to assess and evaluate the NEXRAD based precipitation estimates provided by VAI and to assess the quality of the radar data as required by the SFWMD. A comprehensive bias evaluation of NEXRAD data is essential for the District for the assessment of precipitation estimates for years 2007-2011. A bias assessment tool combining several indices if developed would immensely help the District in evaluating radar data in future. The Vieux and Associates Inc. (VAI) provide its rainfall database to the five WMDs and to FSU. Since the algorithm is proprietary, little is known about its characteristics. The final VAI product is placed on a 2x2 km Cartesian grid and the data are provided at 15 min. intervals. The VAI Corporation provides a near real-time product as well as an end-of-the-month product which has undergone further QC. VAI has provided the SFWMD with NEXRAD based precipitation estimates from years 2007 to present data. However, data on a 2 km x 2km Cartesian grid before year 2007 was provided by OneRain Corporation

to SFWMD. The study evaluated the radar data provide by VAI for the period of the record October 2007 – October 2011.

## **BACKGROUND**

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 gages (Hoblit and Curtis, 2000). The best of both measurement techniques is realized by using rain gage data to adjust NEXRAD values. The readers can obtain additional information on this subject from several references (Huebner et al., 2003 and Skinner, 2006). Five NEXRAD sites operated by the National Weather Service (NWS) cover the District: KBYX in Key West, KAMX in Miami, KMLB in Melbourne, KBTW in Tampa and KJAX in Jacksonville. Although data is also available from several private radar installations, the District exclusively uses NWS sites for its NEXRAD rainfall database due to longevity and reliability issues. NEXRAD technology offers the distinct advantage of providing water management officials with a spatial and temporal account of rainfall variability. In July of 2002, the District started acquiring NEXRAD rainfall data. Skinner (2006) provides additional details on the NEXRAD rainfall data and gage-adjustment methodology used in derivation of the data.

Vieux and Associates Inc. (VAI) provides near real-time (NRT), 15-minute rainfall amounts by using the following process:

1. Acquires 15-minute radar rainfall accumulations from the NWS via WSI Corporation, which uses an empirical look-up table to convert reflectivity values to rainfall intensities.
2. Concurrently, 15-minute rainfall accumulation data from several District telemetry rain gage sites are used (via File Transfer Protocol (FTP))
3. Adjusts radar rainfall amounts using gage data algorithms

4. Adjusted radar rainfall depths are placed in a flat file and sent via FTP to the District
5. The District checks the flat file for completeness and loads the data into the Oracle® database

The process outlined above takes between 10 to 20 minutes; thus, the data is referred to as “near real-time.” Each file contains 33,773 values, one value for each of the 2 km x 2 km cells in the grid covering the District. Each 15-minute interval file is 366 kilobytes (kb) in size and is loaded into the Oracle® database in less than 1 minute. The coverage includes a 35-mile area beyond the boundaries of the District. Data for other water management districts is processed concurrently to insure that there are no discontinuities at district boundaries. Near real-time data are verified each month and an end-of-month (EOM) verified set of 15-minute files is produced. The EOM files use additional rain gage data that are not available in real-time and a proprietary algorithm is used to adjust radar rainfall values. Vieux and Associates reviews the results to identify and correct any anomalies or apparent errors. When the EOM files are received by the District, the near real-time data are archived, primarily to preserve the information upon which operational decisions may have been made, and are replaced with the EOM verified data set. The data provided by VAI is bias-corrected gage adjustment methods.

## **PROJECT STATUS**

The project supported by SFWMD and USGS 104B grant is now completed and the final report was provided to SFWMD. Mr. Husayn El Sharif, graduate student in the department of civil engineering, Florida Atlantic University, has graduated in spring 2012. One Ph.D. student, Mr. Aneesh Goly has been involved in this project and helped in the successful completion of the project. Mr. Aneesh Goly is expected to graduate in July, 2013. Two other students, Milla Pierce and Renzo Martinat were also supported by this project.

## **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. Aneesh Goly and Ramesh S. V. Teegavarapu, Selection and Evaluation of Different Spatial Resolutions for Statistical Downscaling of Precipitation, ASCE-EWRI, Environmental and Water Congress, 22 May, 2013, Cincinnati, USA. Poster presentation.

2. Aneesh Goly and Ramesh S. V. Teegavarapu, Statistical Characterization and Assessment of Precipitation Extremes during Different Phases of Multi-year and Multi-decadal Climatic Oscillations, ASCE-EWRI, Environmental and Water Congress, 21 May, 2013, Cincinnati, USA. Poster presentation.
3. Ramesh S. V. Teegavarapu, Estimation of Missing Precipitation Records using Classifier, Cluster and Proximity Metric-Based Interpolation Schemes, American Geophysical Union (AGU) Fall Meeting, 2012.

Several oral presentations were also made.

### **Books**

1. Extreme Precipitation and Climate Change, IFI, Book Series Meeting, UNESCO, Paris, April 29, 2012.
2. Manual of Standard Practice for Radar Rainfall Data Estimation, Editors: Chandra Pathak and Ramesh Teegavarapu, August 2011, ASCE. Available: April 2012

### **Book Chapters**

1. Evaluation and Improvement of Radar-based Rainfall and Design of Monitoring Networks, Manual of Standard Practice for Radar Rainfall Data Estimation, Ramesh Teegavarapu
2. Precipitation Data Augmentation and Analysis of Radar-based Rainfall Data, Manual of Standard Practice for Radar Rainfall Data Estimation, Ramesh Teegavarapu.
3. Precipitation, Chapter in ASCE Book on Statistical Distributions in Hydrology: Ramesh Teegavarapu and Chandra Pathak, May 2012, ASCE. Available: May 2013.

### **Journal Papers**

- 1) Ramesh S. V. Teegavarapu, Missing Precipitation Data Estimation using Optimal Proximity Metric-based Imputation, Nearest Neighbor Classification and Cluster-based Interpolation Methods, Hydrological Sciences Journal, 2013. Under review
- 2) Ramesh S. V. Teegavarapu, Climate Change-Sensitive Hydrologic Design under Uncertain Future Precipitation Extremes, Water Resources Research, 2013. Tentatively Accepted.
- 3) Ramesh S. V. Teegavarapu, Statistical Corrections of Spatially Interpolated Precipitation Estimates, Hydrological processes, 2013. In print
- 4) Ramesh S. V. Teegavaapu, Aneesh Goly and Jayantha Obeysekera, Influences of Atlantic Multi-Decadal Oscillation on Regional Precipitation Extremes, Journal of Hydrology, 2013. In Print

- 5) Ramesh S. V. Teegavarapu and Anurag Nayak. Evaluation of Long-term Trends in Extreme Precipitation: Implications of Infilled Historical Data and Temporal-Window based Analysis, Journal of Hydrology, 2013. (under review).
- 6) Aneesh Goly, Ramesh S. V. Teegavarapu, Arpitha Mondal, Evaluation of Statistical Downscaling Models for Monthly Precipitation in Florida, Journal of Hydrology, 2013. Under Review
- 7) Ramesh S. V. Teegavarapu, Spatial Interpolation using Non-linear Mathematical Programming Models for Estimation of Missing Precipitation Records, Hydrological Sciences Journal, 2012. Published.

#### **List of students supported by 104B funding last year (March 2012 – February 2013)**

1. Mr. Aneesh Goly, Graduate Student (Ph.D), August 2012-Feb, 2013. Expected graduation, July, 2013.
2. Mr. Renzo Martinat, Undergraduate student, Jan - Feb, 2013.
3. Ms. Milla Pierce, Graduate Student, Jan-Feb, 2013.

#### **Application Software**

Application software, Bias Analysis Tool (BAT) was developed as a part of the project. The tool has undergone a series of tests and is provided to South Florida Water Management District (SFWMD) for real-time and historical radar data analysis. The tool has enormous practical utility and will be extremely useful to several divisions in SFWMD. A user manual for BAT was also developed and provided to SFWMD.

#### **DESCRIPTION OF PROJECT WORK**

The following sections describe the completed project 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.

## ***Tasks***

The primary project tasks and their anticipated order of accomplishment are as follows:

### ***Task 1: Data Collection, Review and Analyses for the Study***

Principal Investigator with the help of the graduate student will collect and analyze a number of data sets, in this Task 1. The time series data sets will include NEXRAD rainfall data and District rain gage data. These data sets will be of a period-of-record as determined appropriate. Where applicable and appropriate, a set of correlation, auto-correlation and covariance analyses of the time series data between and among datasets shall be reviewed. The Principal Investigator shall investigate similar previous works which were performed at the District and others, prior to performing this task.

The following sub-tasks are identified in this task:

- 1.1 Review District's Previous Data Analyses
- 1.2 Obtain and review Vieux and Associates Inc.' s NEXRAD data for the study period Oct 2007 – Oct 2011 including the spatial data files.
- 1.3 Obtain Rain gage data from DBHYDRO or directly from the District.
- 1.4 Review rain gage data.
- 1.5 Conduct spatial analysis using GIS to collocate rain gage and NEXRAD pixels in the region for analysis.

### ***Task 2: Development of indices to evaluate biases***

Several indices are proposed in this study for the evaluation of biases using four categories: 1) time; 2) space; 3) event and 4) point. Specific indices are developed for each category. Some of the categories (other than time) are also analyzed over time even though they are defined for a region, event or a specific location.

## ***Indices***

Three sets of indices are developed which are applicable to each of the categories discussed in the previous section. These three sets of indices are classified as: 1) visual; 2) quantitative and 3) statistical. The indices are shown in Figure 2 and the explanations associated with these indices are provided in the next section.

The following sub-tasks are identified in this task:

- 2.1 Review available methodologies for bias evaluation from literature.
- 2.2 Develop a set of visual, quantitative and statistical bias evaluation indices as discussed in this section.
- 2.3 Develop a technical report providing details of the indices and discuss their use of evaluation

### **Explanations of Proposed Indices**

The proposed indices are developed considering methods used in hydrologic model evaluation and forecast verification of numerical weather prediction models. Evaluation of bias is made by comparing rainfall and radar data by collocating rain gages in the fixed tessellations (i.e., grids) of spatial radar-estimated rainfall surfaces. Pooled and stratified samples will be obtained and they will be evaluated for bias. Pooled sampling involves pooling of sample pairs over specific time or space which is similar to space-based comparison. Stratified version is same as space-based comparison in homogeneous or quasi-homogeneous areas. The comparisons will be made for specific temporal scale, within the SFWMD region or for specific events. Intra-seasonal comparisons will be made at different temporal resolutions (e.g., 15 minutes, hour, day, and month). Seasonal comparison of data is made by grouping of months into different seasons (wet, dry, etc.). Annual evaluations will also be carried out to evaluate changes in the bias values over years. Space-based comparisons are made using mean field bias values for the whole region or specially identified region (e.g., basin, watershed, meteorologically homogenous area) and spatial variation of biases are evaluated. Event-based comparison will involve use of few select storm events based on pre-defined rainfall thresholds and extreme events with high intensity and short duration. Point-based bias evaluation will be addressed by selecting a specific rain gage and cluster of gages. Several indices will be devised to evaluate the biases. Visual indices will involve development of scatter plots to assess evaluation of under or over estimation by radar for select rain gages and regions and for different temporal scales along with box-plots of two data sets (i.e., rain and radar data). Residual (error) plots will be used to assess the error structure, check for any time dependency of errors, autocorrelation aspects and heteroskedasticity. Accumulated rain and radar plots will be used to evaluate deviations (e.g., divergences) and concurrences. Non-parametric distribution procedures (e.g., kernel density estimates) will be used to evaluate the similarity in distributions of rain and radar data. Combined plots of rain and radar data timer series will be used to identify the biases and outliers.

Error performance measures based on rain gage and radar data will need estimation of mean error (ME), mean absolute error (MAE), multiplicative bias (MB), root mean squared error (RMSE), root mean squared factor (RMSF), linear error in probability space (LEPS), correlation coefficient (CC), anomaly correlation (AC), Nash-Sutcliffe efficiency coefficient (NSE) and Heidke skill score (HSS). Contingency measures such as concordance, error rate, specificity and sensitivity will also be used. Bootstrap samples (i.e., sampling with replacement) of radar-rainfall pairs will be used to develop confidence intervals for all the error statistics. Error statistics are calculated for each sample pair. All the error measures may be evaluated by combining them into one score. However, having one combined score may not provide details of individual measures and also there is difficulty in deciding weighting factors for each measure in such a combined score. Combining several measures into one single graph such as Taylor's diagram (Taylor, 2001) will be explored. The use of this diagram will help to evaluate root mean squared error, the correlation coefficient, and the standard deviations based on data sets simultaneously.

Quantitative indices for bias evaluation will involve calculation of summary statistics such as mean, standard deviation, coefficient of variation, skewness and kurtosis and trimmed means and others. Statistical hypothesis tests (e.g., two sample Kolmogorov-Smirnov (KS) test) will be used to compare the distributions of the values from the two data sets. The null hypothesis of two sample KS test indicates that rainfall and radar data are from the same continuous distribution. The alternative hypothesis is that they are from different continuous distributions. Other non-parametric test that will be used is the Wilcoxon rank sum test. This test can help to evaluate if the two data sets (rainfall and radar) are samples from identical continuous distributions with equal medians, against the alternative that they do not have equal medians. Quantile-quantile plot (Q-Q plot) will be used as a graphical procedure to compare two distributions based on rain and radar data sets. A Q-Q plot is essentially a plot of the quantiles of two distributions against each other.

### ***Task 3: Development of Bias Assessment Tool (BAT)***

A bias assessment tool (BAT) will be developed and provided to the District as a part of the deliverable for the project. The tool will be standalone application software that will utilize all the indices used for evaluation and provide graphical results to provide visual assessment of biases. The BAT will be designed to run on a PC. The following are the sub-tasks under Task 3.

3.1 Develop a code to extract collocated rain gage data and NEXRAD (radar) data from Vieux and Associates radar data provided as text file (for 15 min duration).

3.2 Assemble data sets for multiple temporal resolutions.

3.3. Evaluate biases for different categories using the BAT.

3.4 Compile the results for observations and insights and recommendations for improvement

## CRITICAL ISSUES AND ASSUMPTIONS

It is important to recognize several critical issues and limitations associated with the evaluation of radar-based precipitation estimates using several qualitative and quantitative indices briefly discussed earlier in this report. Many indices used in this study are based on measures used in forecast evaluation procedures common in the fields of atmospheric sciences and numerical weather prediction and forecast verification. In the arena of forecast verification, forecasts are considered independent of observations. However, in the current study the radar-based precipitation estimates are considered equivalent to forecasts even though the non-real time radar data are not completely independent from rain gage observations.

The following issues are important considering the analyses reported in this study.

- Radar-based precipitation estimates are adjusted based on rain gage observations. However, radar-based precipitation estimates are not adjusted for each pixel (or spatial grid) in which rain gage is located or the adjustments are not based on one single rain gage. Bias correction procedures are generally applied for post correction of radar-estimated data based on a specific Z-R (reflectivity-rainfall rate) relationship and by using rain gage data from a spatial network of gages.
- Observed precipitation data available from rain gages is not completely error free. However, the data available from the rain gages is assumed to be ground truth and error free without any systematic errors. The rain gage data should be critically evaluated before it can be used for bias analysis. Data cannot be free of random errors.
- Radar-based rainfall estimates are considered as “model estimates” or “forecasts” as these estimates are surrogate measurements of observed rainfall amounts. This assumption also helps in application of forecast verification indices for evaluation of radar-based data.
- Two-sample non-parametric statistical tests are valid if only if the samples from the two data sets are independent. As radar data is adjusted based on rain gage data the assumption of independence is not valid to carry out these tests. However, three non-parametric tests used in this study assume that independent data will be used wherever available.

- Rain gage observations that are not used for adjustment of radar data are ideal for analysis of biases.

Ideally, the indices or measures described in this report are suitable for real-time radar-based precipitation estimates which have not undergone any bias corrections using rain gage data. For the purpose of analysis of radar-based precipitation data in this study, radar data is assumed to be independent of rain gage observations.

## CONTINGENCY TABLES

Measures used for classification of event and nonevent using dichotomous categories to evaluate radar data are developed in the current study. A contingency table using events (non- zero precipitation) and nonevents (no or zero precipitation) based on rain gage and radar data is developed. Four measures (Myatt and Johnson, 2009) such as 1) concordance; 2) error rate; 3) sensitivity and 4) specificity can be obtained from the radar and rain gage data.

The concordance index that is also referred to as proportion correct (PC) gives the fraction of all wet days and dry correctly estimated based on radar-based precipitation data given observed rain gage data. The error rate gives the fraction of all wet and dry events incorrectly estimated based on radar-based precipitation data given observed rain gage data. Sensitivity is also referred to as success rate. It provides information about what fraction of the wet events obtained by radar-based precipitation estimates that were actually observed based on rain gage observations. Specificity provides information about the fraction of dry events obtained by radar-based precipitation estimates that were actually observed as dry events based on rain gage observations. Concordance (accuracy) refers to the accuracy of the radar-based estimation, error rate relates to prediction errors and sensitivity and specificity measures calculate the ability of radar-based rainfall to provide correct states (i.e., rain or no-rain). Accuracy is also referred to as fraction correct and error rate refers to fraction incorrect. Bias score or simply bias gives the ratio of frequency of wet events obtained from radar-based precipitation estimates to the frequency of wet events obtained from rain gage observations.

The probability of detection (POD), also known as the hit rate, measures the fraction of observed wet events by rain gage that was correctly estimated by radar-based estimates. The probability of false detection (POFD) is also known as the false alarm rate, measures the fraction of observed dry events by rain gage to

the dry events that were defined as wet events by radar-based estimates. This measure is also known as false alarm rate (FAR) gives the fraction of wet events based on radar-based precipitation that were observed to be dry events.

## SKILL SCORES

A skill score in forecast verification literature refers to relative measure of quality of a forecasting system compared to some benchmark forecasting system. In the current study, three scores that are relevant to assessment of radar-based rainfall are defined. The terminology that is more closely associated with forecast verification procedures is modified suit to the current study context of bias assessment of radar data. Five skill scores are evaluated in the current study and are based on information obtained from the contingency tables discussed in the previous section. These scores are: (1) Heidke skill score (HSS); (2) critical success index (CSI); (3) Peirce skill score (PSS); (4) Gilbert skill score (GSS) and (5) Odd's ratio.

The HSS calculated based on counts from the contingency table that evaluates the data considering proportion correct (PC) considering the number of hits due to chance. Critical success index (CSI) provides information about how well the wet events obtained by radar-based precipitation data correspond to rain gage observed wet events. The Peirce skill score answers the question: What was the accuracy of the radar-based rainfall estimate in predicting the correct category, relative to that of random chance? The GSS referred to as equitable threat score answers the questions: How well did the wet events estimated by radar-based rainfall estimates correspond to the observed wet events (accounting for hits due to chance)?

The odd's ratio score answers the question: What is the ratio of the odds of a wet event indicated by rain gage observation being correct based on radar-based estimation, to the odds of a wet event estimated by radar data being wrong? The score measures the ratio of the odds of making a hit to the odds of making a false alarm. Linear error in probability space (LEPS) score (Wilks, 2011; Jolliffe and Stephenson, 2012) is defined as the mean absolute difference between cumulative probability based on the radar and the cumulative frequency of the rain gage data.

## TRANSITION PROBABILITIES OF DRY AND WET SPELLS

Transition probabilities associated with dry and wet spells are calculated. These probabilities are referred to as two-state first order Markov chain probabilities. The variable  $P_{11}$  refers to probability of occurrence of positive precipitation in time interval  $i + 1$  given the occurrence of positive precipitation in the previous interval,  $i$ . The variable  $P_{10}$  refers to probability of no precipitation in time interval  $i + 1$  given the occurrence of positive precipitation in the previous interval,  $i$ . The variable  $P_{01}$  refers to probability of occurrence of precipitation in time interval  $i + 1$  given no precipitation in the previous interval,  $i$ . The variable  $P_{00}$  refers to probability of no precipitation in time interval  $i + 1$  given no precipitation in the previous interval,  $i$ . A comparison of these probabilities based on rain and radar data should reveal the discrepancies in persistence of wet and dry spells. Probabilities obtained by good quality radar-based data and rain gage observations should be similar in values.

## QUANTITATIVE INDICES

Several error measures and association measures are used in the current study to evaluate the radar data as this is considered as estimate compared to observed rainfall data from rain gage.

The mean error (ME) measures the average magnitude of error. This error is calculated as difference between radar-based rainfall estimate and rain gage observation. One limitation of this error is that the negative and positive errors will cancel out leading to over or underestimation of overall error. The mean error is a measure of overall reliability. The mean absolute error (MAE) measures the average magnitude of absolute error. The absolute sign eliminates the possibility of positive and negative residuals cancelling out. The measure is not sensitive to outliers and eliminates the limitation associated with ME. The MAE is a measure of overall accuracy. This measure provides the mean of squared residuals and is sensitive to outliers. Atypical events, outliers will magnify the errors due to squaring of the residuals. Root mean squared error is based on MSE and is a minor variant of MSE. The unit of this measure is same as the unit for the observation or estimation. The *RMSF* is the exponent of the root mean square error of the logarithm of the data. The logarithmic transformation is mainly performed to smooth the data, reduce the discontinuities, and make the data more robust (CAWCR, 2012). An RMSE can be interpreted as giving a scale to the additive error; the RMSF can be interpreted as giving a scale to the multiplicative error (CAWCR, 2012).

Nash–Sutcliffe model efficiency coefficient (NSEC) is generally used in hydrological modeling for assessment of hydrological models. In the current study, the NSEC is used to assess the quality of radar-based rainfall estimates compared to the rain gage observations. Measures of association between two data sets (i.e., radar and rain gage) can be evaluated using Pearson (ordinary) correlation coefficient, Spearman rank correlation and Kendall's  $\tau$ . Measure of linear association between radar and rain gage data can be obtained by traditional Pearson (ordinary) correlation coefficient. The spearman rank correlation ( $\rho_{rank}$ ) is calculated based on ranked or ordered observations of rain gage and radar observations. This correlation measure provides a robust measure of linear association that is resistance to outliers. Kendall's  $\tau$  is another alternative robust and resistant measure of correlation. This measure is used in the current study in addition to traditional measures such as Pearson correlation coefficient and Spearman rank correlation.

#### **TAYLOR DIAGRAM: A MULTI DATA ASSESSMENT TOOL**

Taylor diagram (Taylor, 2001) is used to summarize three different performance measures in one diagram based on the radar and rain gage data. The diagram provides a concise statistical summary of how well patterns match (two or more) each other in terms of their correlation, their root-mean-square difference and the ratio of their variances. Taylor diagram combines statistical measures such as standard deviations, centered root mean squared deviations or errors (RMS) and correlations based on multi-model estimations in one graph. In the current study, Taylor diagram is used to assess NRT (near real-time), EOD (end of the day) and EOM (end of the month) data sets.

#### **STATISTICAL ASSESSMENT AND TESTS**

Initially basic summary statistics are evaluated and compared for radar and rain gage data using measures of central tendency, dispersion or spread and shape. Several summary statistics are used to describe different measures of: 1) central tendency; 2) dispersion and 3) shape for rain and radar data sets for comparative purposes. These statistics are conceptually simple and are evaluated to gain basic understanding of the radar and rain gage data sets. Evaluation of central tendency can be carried out using mean, trimmed mean and others. Some of these standard measures may not provide accurate information for positively skewed precipitation datasets. Interquartile range (IQR) refers to the difference between 75<sup>th</sup>

and 25<sup>th</sup> percentiles of a variable. The interquartile range is an alternative to the standard deviation and is less affected by extremes than the standard deviation. The range ( $R$ ) provides information about the difference between the maximum and the minimum of a sample dataset.

The mean absolute deviation (MAD) is the mean of deviations of observations from mean of sample dataset. Radar and rain gage data sets are used to calculate the mean absolute deviations and are compared. The mean absolute deviation can also be calculated using the mean of deviation observations from a median value of the sample dataset. Measures of shape are evaluated using skewness coefficient and kurtosis parameters of the dataset. The parameters are estimated for rain and radar data sets and are compared.

## TESTS FOR DISTRIBUTIONS OF DATA

Comparative analysis of distributions of radar and rain gage data can be carried out using non-parametric statistical hypothetical tests and they include: 1) Kolmogorov-Smirnov (KS) two sample test; 2) Ansari-Bradley test and 3) Wilcoxon Rank Sum test. The KS test can be used for testing differences in mean, variance, or both. The test is ideal for evaluating overall differences in the two samples. Ansari-Bradley test is ideal for testing differences in variance with the assumption that the two samples have identical means. The Wilcoxon Rank Sum test evaluates the differences in medians, with the assumption of identical variances.

Two sample Kolmogorov-Smirnov (KS) test can be used to compare the distributions of the values in the two datasets (i.e., radar and rain gage). The null hypothesis ( $H_0$ ) is that rain gage observations and radar-based precipitation estimates are from the same continuous distribution. The alternative hypothesis ( $H_a$ ) is that these two data sets are from different continuous distributions. The hypothesis test is carried out at a specific statistical significance level (e.g., 5%).

The Ansari-Bradley (AB) test is used in the current study to evaluate the hypothesis that two independent samples of rain and radar data come from the same distribution (null hypothesis:  $H_0$ ), against the alternative (alternative hypothesis:  $H_a$ ) that they come from distributions that have the same median and shape but different dispersions (e.g. variances). The test is conducted at a 5% significance level. The rank sum test can be used to evaluate the null hypothesis that data from radar and rain gage are independent

samples from identical continuous distributions with equal medians, against the alternative that they do not have equal medians. The radar and rain gage data can be of different lengths. The test is equivalent to a Mann-Whitney  $U$ -test. The three statistical tests discussed previously are based on the assumption that the two data sets (i.e. rain gage and radar) are independent. The Wilcoxon rank sum test is a non-parametric equivalent of t-test.

## **SERIAL AUTOCORRELATION**

The radar or rain gage measurements at different time intervals can be assessed for serial autocorrelation using the two series independently. The autocorrelation coefficient is also referred to as serial correlation coefficient. Autocorrelation diagrams referred to as autocorrelograms are developed for rain and radar data sets. An autocorrelogram is a plot of lagged time interval values and autocorrelation values at these intervals.

## **QUANTILE-QUANTILE PLOTS**

A quantile-quantile plot (Wilks, 2011) which is also referred to as q-q plots is a visual way for comparing the marginal cumulative probability distributions of radar and rain gage data. In this plot a comparison is made by using quantiles of both the data sets. A q-q plot will be linear if rain and radar data samples come from the same distribution.

## **CONFIDENCE INTERVALS FOR BIAS INDICES**

Bootstrap samples can be generated to evaluate the performance of different methods. The samples are observed rain gage and estimated radar-based rainfall data pairs and they are drawn randomly with replacement. The performance measures or indices are calculated for each bootstrap sample for evaluation of radar-based precipitation data. Confidence intervals (CIs) can be developed for the error performance measures. The intervals can be developed using one of the four methods: 1) basic percentile; 2) bias corrected; 3) bias corrected and accelerated and 4) studentized. The development of confidence intervals will help in assessing the differences between model performances statistically.

## SIMILARITY OF PROBABILITY DENSITY FUNCTIONS OF RAIN AND RADAR DATA

Similarity of two probability density functions (PDFs) can be established using metrics that compare the distances between these two functions. Distance measures used for comparison of PDFs in the current study are briefly discussed in the next section. PDFs can be developed using parametric and non-parametric models using one of the standard distributions or kernel density estimates. However, histograms using constant bins (i.e., class intervals) can be used for comparison. Typically, relative frequency histograms of rainfall and radar data are generally positively skewed.

### DISTANCE MEASURES FOR COMPARISON

Several distance measures are used in this study to assess the similarity of histograms of rain and radar data. The measures are calculated based on the relative frequency values obtained based histograms of radar and rain gage data with exactly same bin sizes. Ideal value of distance between two histograms for exact match or similarity is zero. The distance metrics calculated over different temporal horizons (e.g., water year) will provide an assessment of similarities in histograms of radar and rain gage data. Evaluation of distances will provide an assessment of improvement or worsening of radar data over time.

### VARIOGRAM ANALYSIS: EVALUATION OF SPATIAL DEPENDENCE

A variogram cloud is developed using observations (i.e. rain gage and radar) at different sites and is evaluated for spatial dependence. A variogram cloud is a plot of distances and variance or semi-variance values. Distance in this context refers to Euclidean distance between any two observation sites. The average variance values are obtained for rain gage and radar-based rainfall data and are compared.

### REPLACEMENT TESTS

Replacement tests are proposed to check the validity of radar data when missing rain gage values are replaced in three possible configurations in this study. These configurations are: 1) systematic, 2) random and 3) systematic and random replacement. Once the replacement of data is completed, the data sets can

be tested for homogeneity using different homogeneity tests such as Pettitt's test (Pettitt, 1979), Buishand's test (Buishand, 1982), Alexandersson's standard normal homogeneity test (SNHT) (Alexandersson, 1986) and Von Neumann ratio test (Von Neumann, 1941).

## **EVALUATION OF RESIDUALS**

Residuals based on radar and rain gage data are estimated for each time interval and they are evaluated for any systematic bias, time dependent bias, any signs of heteroskedasticity and normality of residuals. A residual is calculated for each time interval. In calculating the residuals, radar data are considered as estimated values and rain gage data as observed values. Visual evaluation will reveal many of the issues associated with residuals. Probability plots of residuals using can be evaluated for normality.

## **CUMULATIVE PLOTS**

Comparison of cumulative plots of radar-based precipitation and rain gage observations can provide assessment of time consistent accumulations of these two data sets. A cumulative plot is a variant of a double mass curve. The rain gage and radar data sets when plotted together show how cumulative totals vary over time.

## **KERNEL DENSITY ESTIMATES**

Kernel density estimation (KDE) is a non-parametric technique to characterize the data. In comparison to parametric estimators the parameters to be estimated from data, non-parametric estimators have no fixed structure and depend on all the data points to reach an estimate. Adoption of smooth kernel function can overcome the limitations of the histograms. KDE is used in the current study as histograms do not provide a smooth representation of the data. In the current study a Gaussian kernel is used for developing KDE for rain gage and radar-based data.

## **SUMMARY OF ASSESSMENT INDICES AND PERFORMANCE MEASURES**

This section briefly discusses the use of different measures and indices for operations, modeling and short-term planning. The utility of the indices, measures and tests are described in Table 1. While a specific index or performance measures is attached to one of the categories, the end-user can use the indices in any way appropriate for decision making.

Table 1 Measures and their utility for operations, modeling and short-term planning.

Measures, Indices and Evaluation Tests and Methods	Utility for Operations [O], Modeling [M] and Short-term Planning [S]
Contingency Measures	Operations/short-term Decision Making and Evaluation [O, S]
Skill Scores	Short term Planning and Improvement [S]
Performance Measures (Error Measures)	Modeling, long-term assessment [M]
Transitional Probabilities	Short-term Evaluation & Modeling [S, M]
Association Measures and Plots	Operations, Short-term evaluation, modeling [O, S, M]
Taylor Diagram	Modeling and Long-term Assessment [M]
Summary Statistical Measures	Short term planning and Improvement and Modeling [S, M]
Data Distribution Analysis	Modeling [M]
Serial Autocorrelation	Modeling and long-term evaluation [M]
Quantile Plots	Modeling [M]
Variograms	Modeling [M]
Bootstrap Sampling based Confidence Intervals	Modeling [M]
Infilling or Replacement Tests	Operations, Short-term Planning [O, S]
Evaluation of Residuals	Long-term Assessment, modeling [M]
Cumulative Plots	Modeling [M]
Kernel Density Estimates	Modeling [M]
Statistical Hypothesis tests	Short-term evaluation, modeling [S, M]

## RAIN AND RADAR DATA SETS

Two rain gage and three data sets are analyzed in this study. Details of these data sets are provided in the Table 2.

Table 2 List of radar and rain gage data sources used for the study.

Data Source	Temporal Resolution	Missing data	Period of Record	Comments
<b>Rain Gage Data</b>				
CR10	15 minute data	Yes	Oct 2007 – Sept 2011	Missing Data is flagged (Tag: M)
NRG	15 minute data	Yes (May 2008)	Oct 2007- Sept, 2011	Missing Data is augmented and also filled with radar data (Tag: R)
<b>Radar Data (NEXRAD)</b>				
NRT	15 minute data	Yes	Oct 2007- Sept 2011	Near Real-Time Data
EOD	15 minute data	No	Oct 2007 – Sept 2011	Adjusted End of the day (EOD)
EOM	15 minute data	No	Oct 2007 – Sept 2011	Adjusted End of the Month (EOM)

The locations of rain gages are shown in Figure 1.

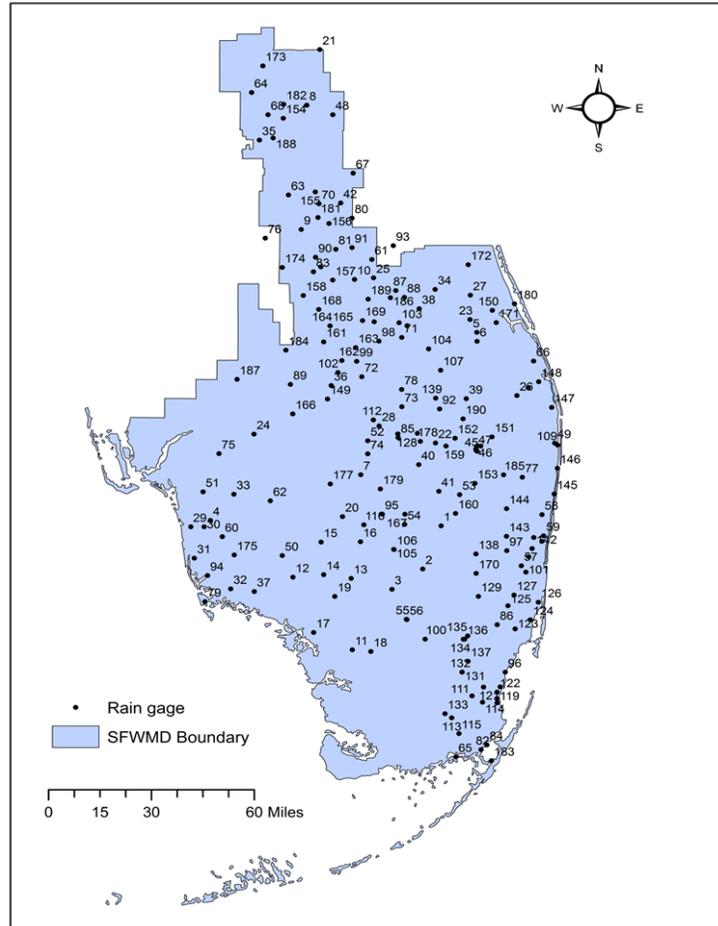


Figure 1 Location of rain gage sites (site numbers are provided for reference) in the SFWMD region used for the current study.

#### DATASET COMBINATIONS FOR ANALYSIS

This section reports preliminary results obtained based on analysis completed with different rain gage and radar data sets. Analysis using CR10 rain gage data and NRT (near real-time) and EOM (end of the month) radar data are provided in this section. Different combinations of rain gage-radar data sets are used in this study and these combinations are shown in the Figure 2.

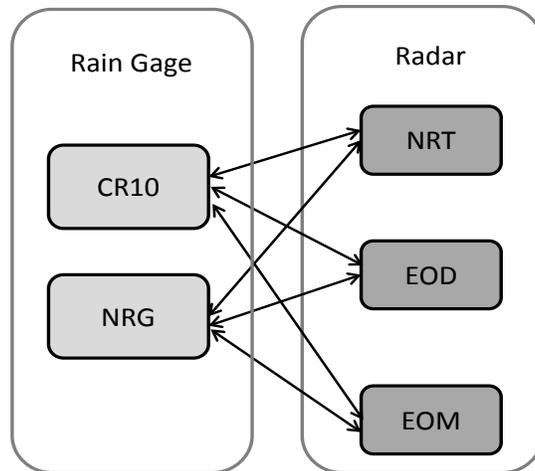


Figure 2 Combinations of rain gage and radar data sets used for analysis.

NRG rain gage data refers to CR10 rain gage data augmented by radar data. The CR10 rain gage data is the observed rainfall data with missing records. Results and analysis for different data sets are presented in the appendices A, B, C, D and E.

### BIAS ASSESSMENT TOOL (BAT)

A bias assessment tool (BAT) is being developed as one of the tasks of the current study. The tool incorporates several assessment indices and skill scores discussed earlier in this report. An initial screen shot of the BAT is provided in Figure 3. There are several modules that are accessible through menu choices that can be used for preparation of data, evaluation of data along with visual, quantitative and statistical indices or skill scores.



Figure 3 Initial Screenshot of the Bias Assessment Tool (BAT).

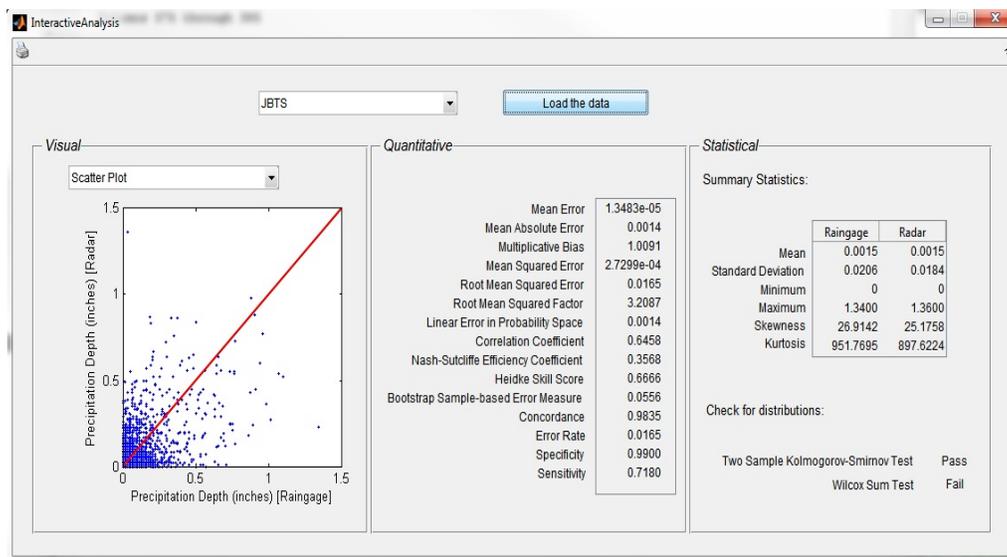


Figure 4 Interactive analysis module of Bias Assessment Tool (BAT).

Figure 4 shows the interactive analysis module of BAT. The users can interactively evaluate visual, quantitative and statistical indices for each station independently or for the whole region.

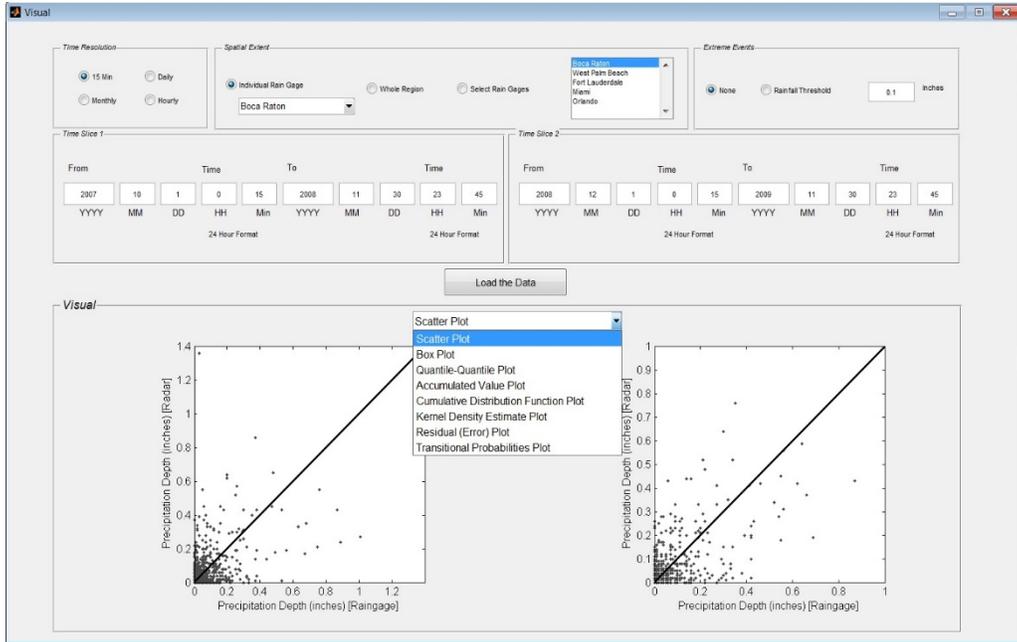


Figure 5 Comparative analysis module of Bias Assessment Tool (BAT).

Figure 5 shows the comparative analysis module that will help the user to analyze two data sets from different temporal windows at the same time.

## RESULTS AND ANALYSIS

This section presents results and analysis based on NEXRAD near real-time (NRT) data and CR10 rain gage data. Results related to other data sets are provided and discussed in appendices. Near real-time data represents data sets with minimal bias corrections by the vendor and therefore are the best data sets compared to EOD and EOM data sets for bias analysis.

### Analysis with NRT (near real-time) Data

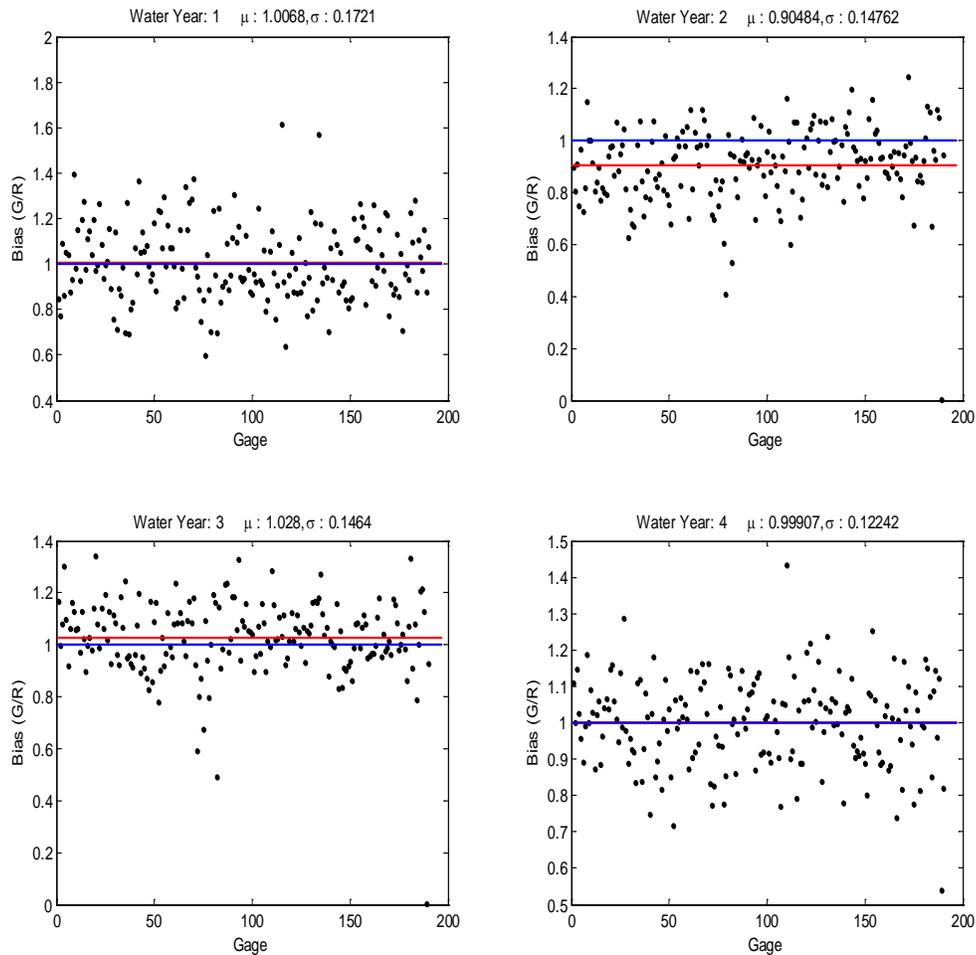


Figure 6 Bias values for annual totals at different gages in different water years (blue line: bias equal to 1 and red line: average bias).

Bias plots for four years are shown in the Figure 6. These plots are constructed based on annual totals. In general the bias values fluctuate between 0.6 to 1.4 and there is improvement in the bias when most recent data is considered.

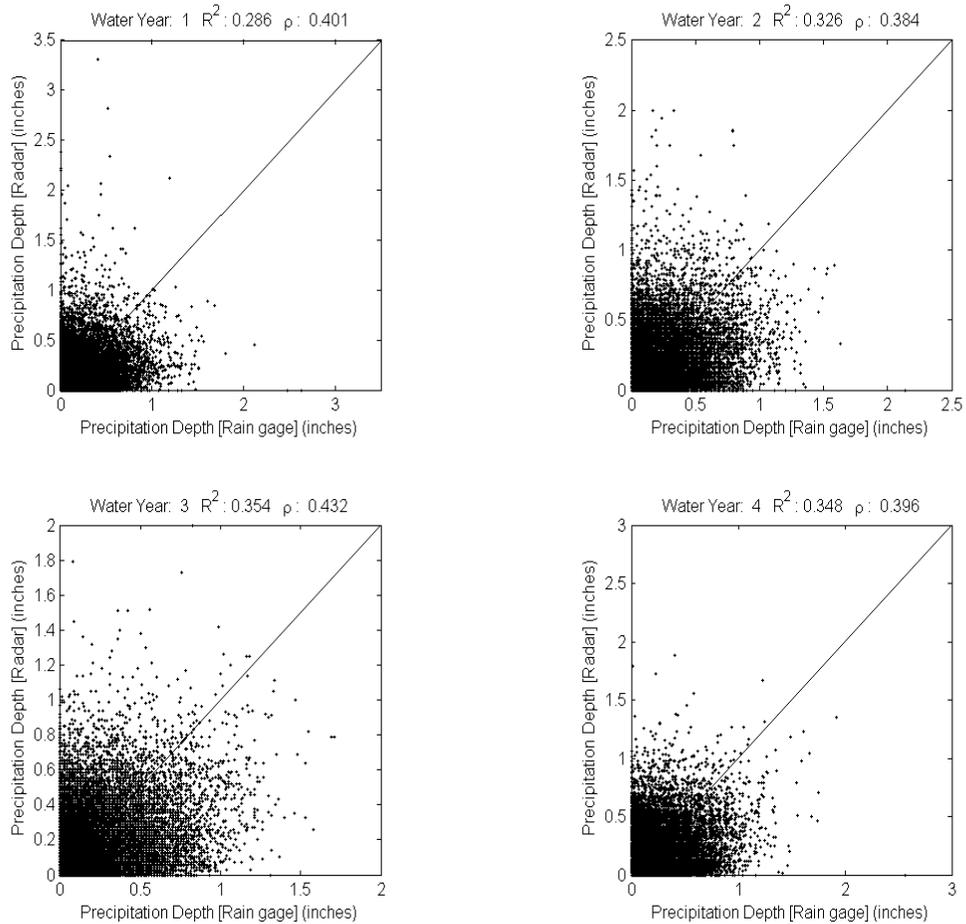


Figure 7 Rain gage data and radar data for 15 minute data at all 189 sites for different water years.

Scatter plots (as shown in Figure 7) suggest good agreement between radar and rain gage with improvement in the coefficient of determination and correlation coefficient over the years.

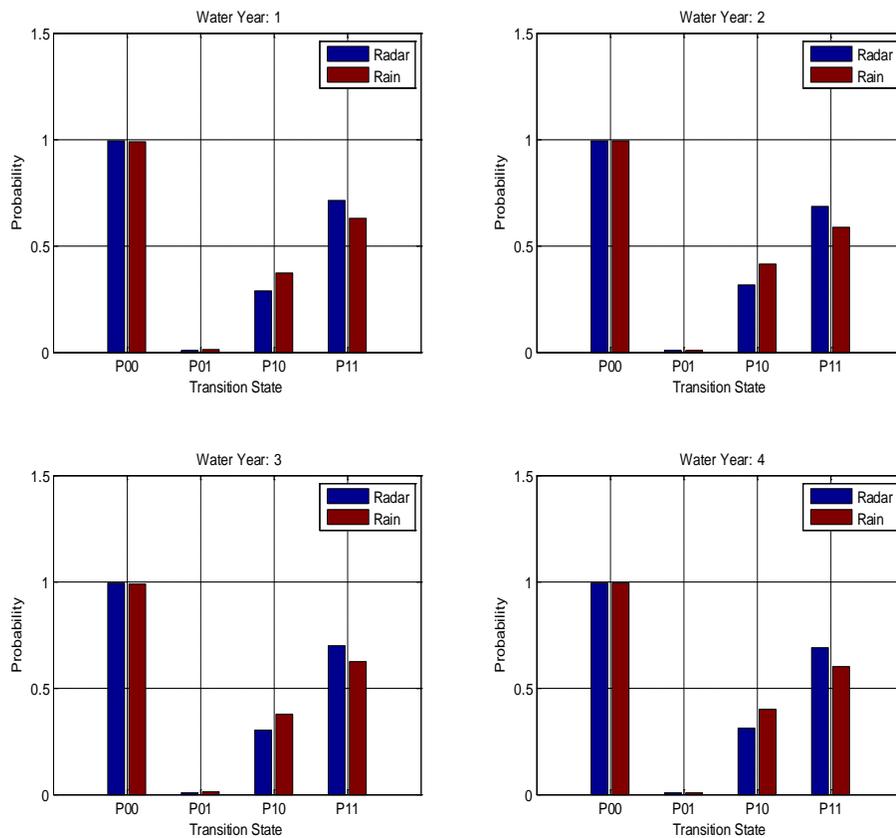


Figure 8 Average transition state probabilities based on rain gage data and radar data at all sites for different water years.

The transition probabilities shown in Figure 8 are based on average values obtained from all the stations. The radar data seems to be consistently overestimating the wet-wet transition ( $P_{11}$ ) and underestimating wet-to-dry ( $P_{10}$ ) transition probabilities. This is true for all the years of analysis.

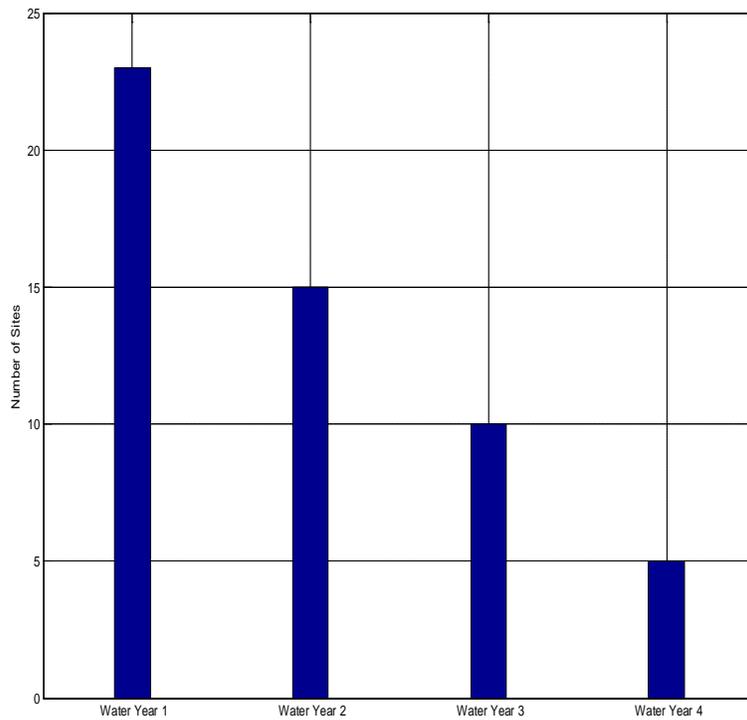


Figure 9 Number of sites failing two-sample Kolmogorov-Smirnov (KS) test in different water years.

The number of sites (refer to Figure 9) failing two sample Kolmogorov-Smirnov (KS) is decreasing over the years suggesting the data distributions of radar and rain gage are similar.

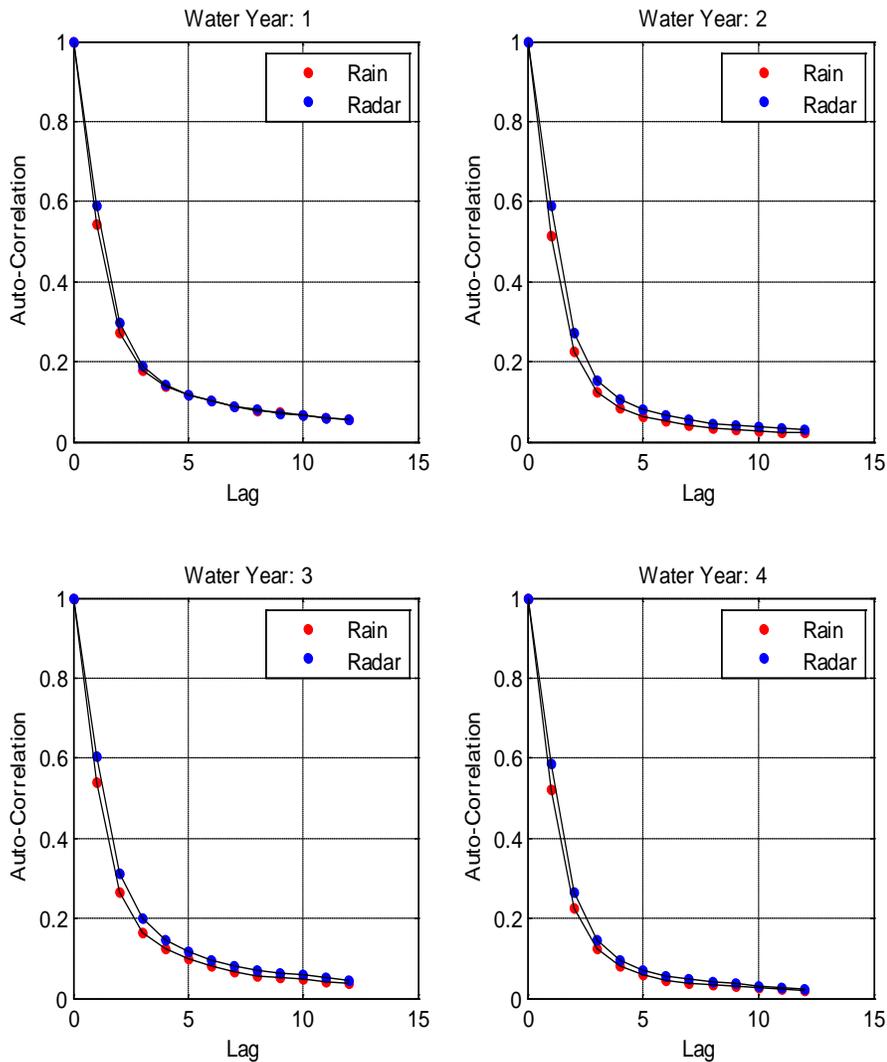


Figure 10 Autocorrelation values at different lags in different water years.

The average values of serial autocorrelation at different temporal lags calculated based on rain and radar data at all sites in different water years are shown in Figure 10. A consistent overestimation of autocorrelation (i.e., persistence) is shown by radar in all the water years except in water year 1. Autocorrelation plots of residuals are shown in Figure 11.

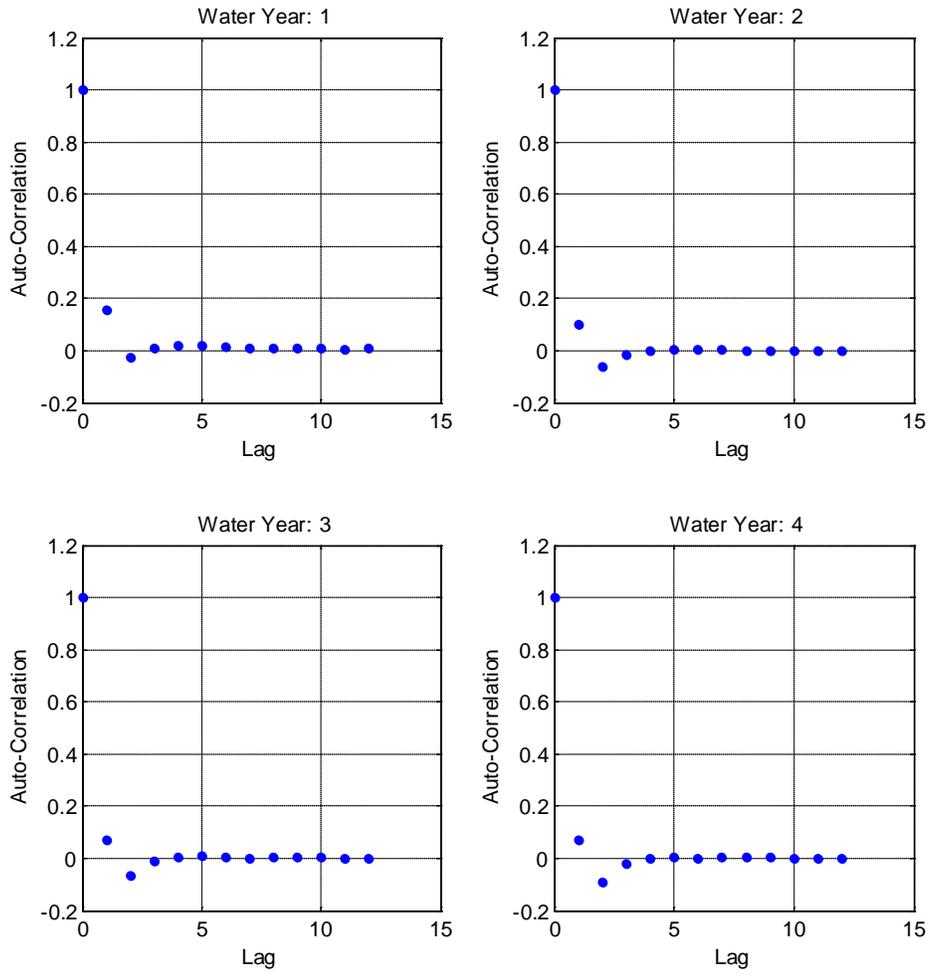


Figure 11 Autocorrelation plots of residuals in different water years.

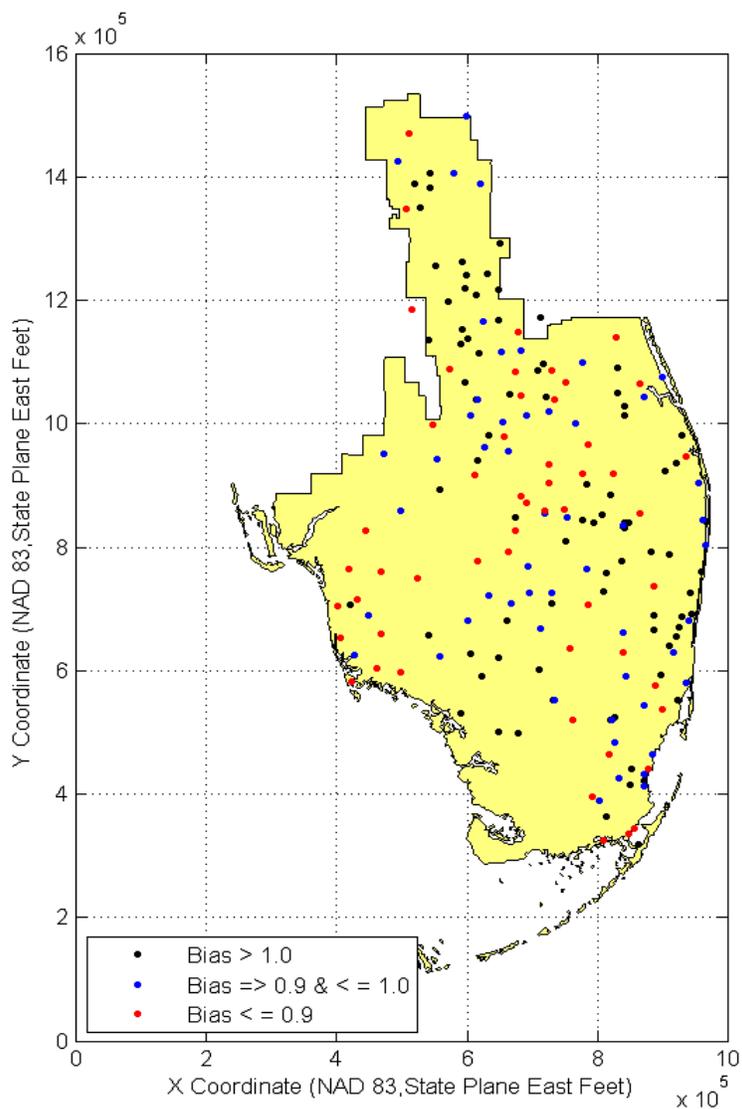


Figure 12 Spatial variation of bias at 189 sites in water year 1.

Spatial variation of bias is explained in the Figure 12 for water year 1. Underestimation of rainfall values based on G/R ratio is seen at several areas which require implementation of improved bias adjustment procedures from data provider to address these biases.

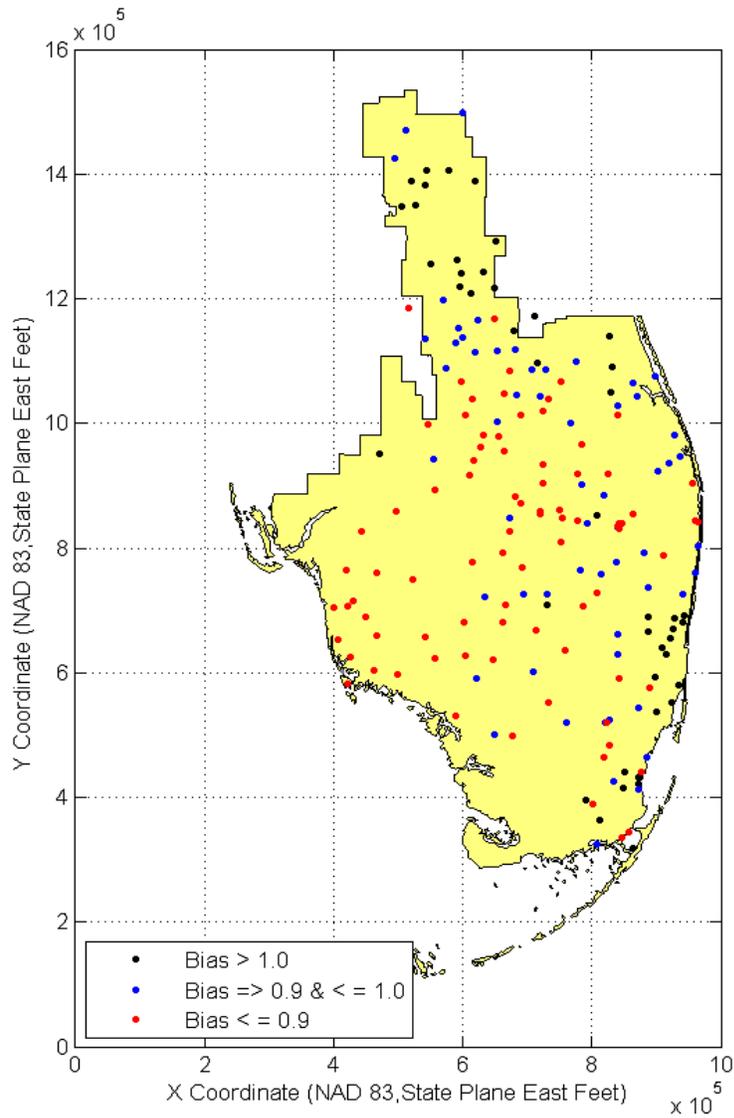


Figure 13 Spatial variation of bias at 189 sites in water year 2.

Patterns similar to spatial variations of bias shown in Figure 13 are evident for water year 2. Underestimation of rainfall values based on G/R ratio is seen at several areas which require implementation of bias adjustment procedures from data vendor to address these biases.

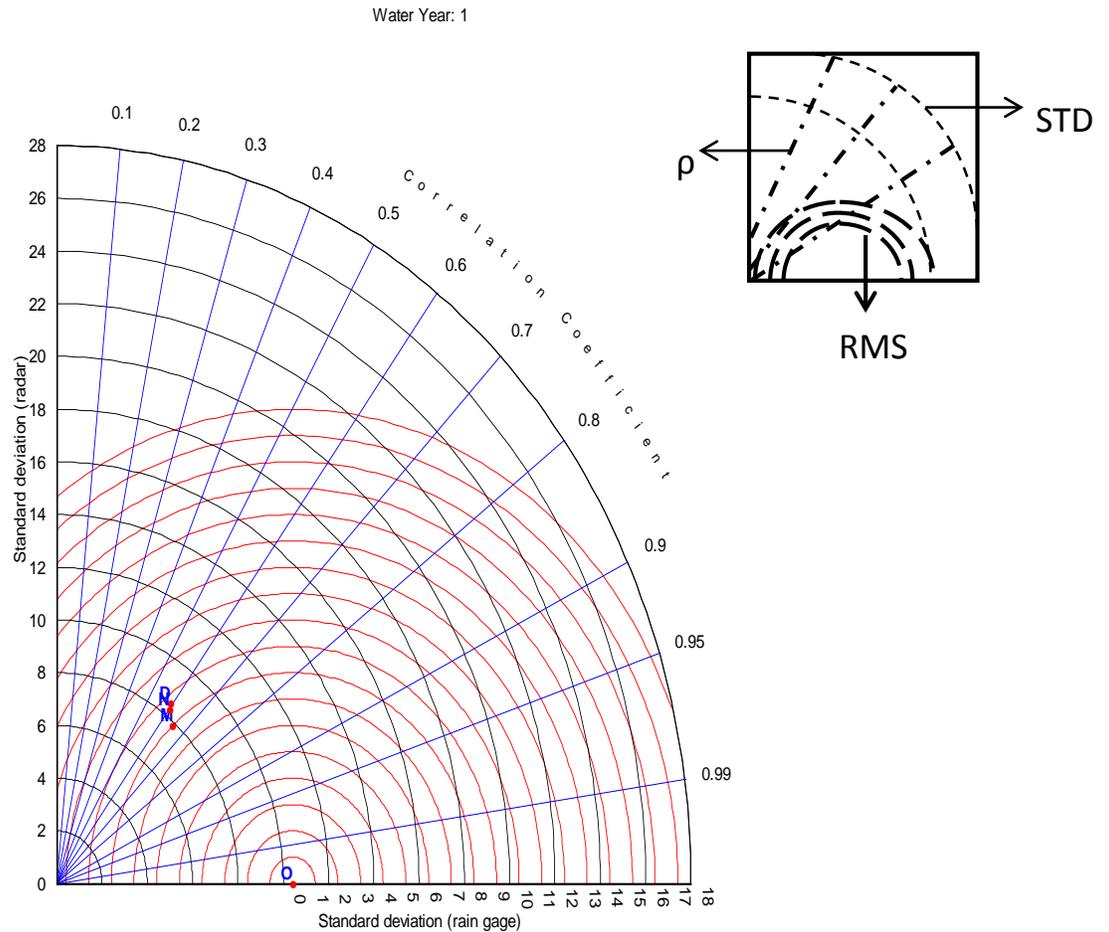


Figure 14 Taylor diagram for comparative assessment of NRT (N), EOD (D), EOM (M) radar data and observed (O) rain gage (CR10) observations on an annual basis at 189 sites for water year 1.

Comparative assessment of near-real-time data (NRT), end of the day (EOD) and end of the month (EOM) are carried out using Taylor diagrams for different water years. One such comparison is shown in Figure 14. Results suggest that radar data progressive improved as the time resolution increased with EOM providing the best results for two performance measures. Taylor diagrams that support these conclusions for water years 1, 2, 3 and 4 respectively. A variogram cloud is used to evaluate the spatial dependence and variability based on distance between any two observations sites (for rain gage) and grids (for radar data). A variogram cloud for water year 2 using 15 minute data sets is shown in Figure 15. It is evident from the figure that radar data is underestimating the spatial dependence.

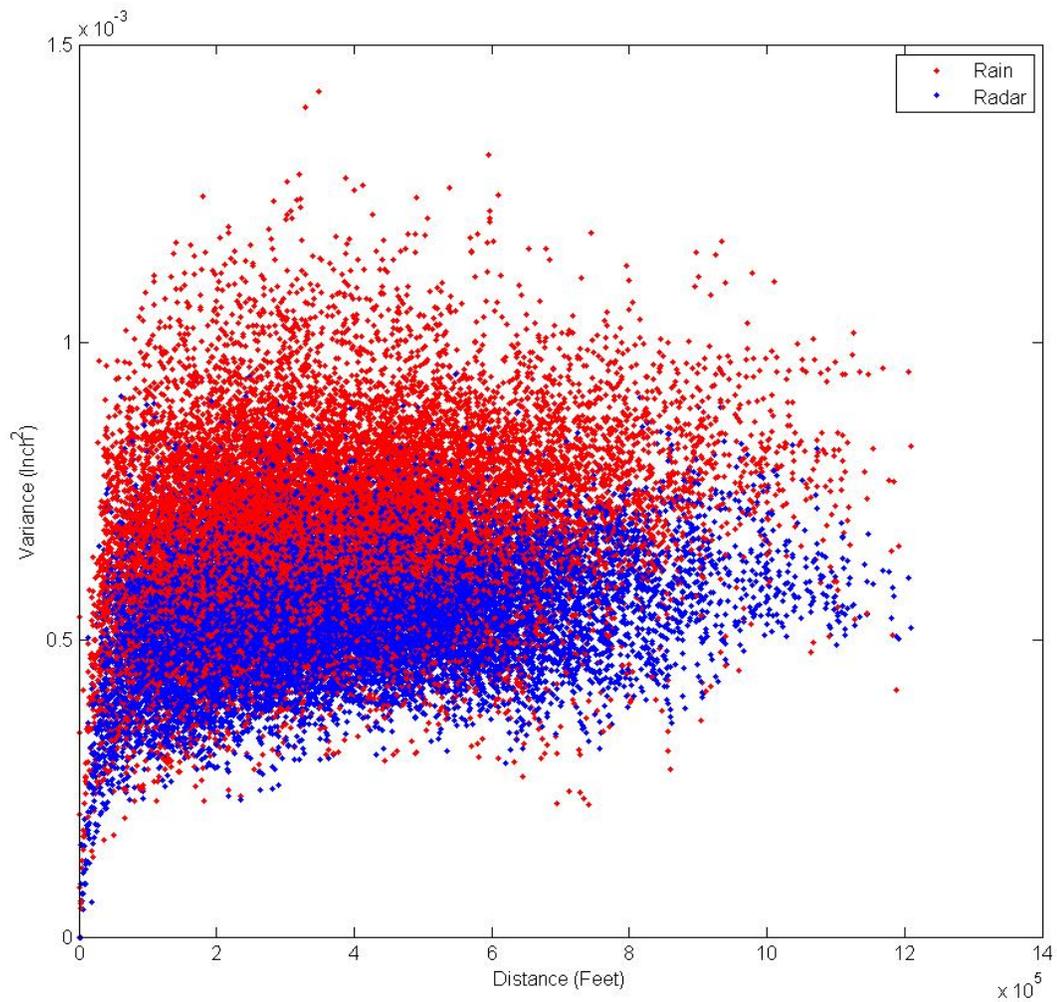


Figure 15 Variogram cloud based on rain gage and radar data (15 min) for water year 2.

### SCALAR PERFORMANCE MEASURES

Exhaustive details related to performance measures based on different indices and skill scores and confidence intervals based on bootstrap sampling are provided in report submitted to SFWMD. Few results based on these measures are provided in this section. Table 3 provides details of the performance measures and skill scores for near-real-time radar data set.

Table 3 Performance measures and skill scores based on CR10 (rain gage) and NRT (radar) data sets at a temporal resolution of 15 minutes.

Performance Measure	Year 1	Year 2	Year 3	Year 4
Mean Error (ME)	-1.4E-06	0.000143	-3.7E-05	2.18E-06
Mean Absolute Error (MABE)	0.001572	0.001439	0.001459	0.001153
Multiplicative Bias (MB)	0.999026	1.110222	0.97553	1.001932
Mean Squared Error (MSQE)	0.000306	0.000293	0.00028	0.00024
Root Mean Squared Error (RMSE)	0.017488	0.017105	0.01672	0.015508
Root Mean Squared Factor (RMSF)	3.430207	3.564883	3.240621	3.403268
Linear Error in Probability Space (LEPS)	0.001573	0.001292	0.001478	0.001087
Correlation Coefficient (CORR)	0.535448	0.571098	0.595425	0.590233
Nash-Sutcliffe Efficiency Coefficient (NSEC)	0.169788	0.176609	0.282813	0.260504
Heidke Skill Score (HSS)	0.627252	0.613199	0.651726	0.625337
Contingency Measure: Concordance (CMC)	0.979108	0.981838	0.981181	0.985235
Contingency Measure: Error Rate (CMER)	0.020892	0.018162	0.018819	0.014765
Contingency Measure: Specificity (CMSP)	0.987822	0.988922	0.989443	0.991787
Contingency Measure: Sensitivity (CMSE)	0.670451	0.671277	0.682613	0.654693
Pierce Skill Score (PSS)	0.599183	0.572724	0.632659	0.605587
Gilbert's Skill Score (GSS)	0.456932	0.442168	0.483378	0.454902
Odd's Ratio (OR)	165.0287	182.299	201.5682	228.9617
Bias Score (BS)	1.101785	1.156875	1.064161	1.068989
Probability of Detection (POD)	0.670451	0.671277	0.682613	0.654693
False Alarm Ratio (FAR)	0.391486	0.41975	0.358544	0.387559
Critical Success Index (CSI)	0.46841	0.451857	0.494093	0.462911
Boot Strap CI (L)	0.054714	0.062625	0.053676	0.060738
Boot Strap CI (U)	0.056091	0.063829	0.054876	0.061933

It can be observed from the Table 3 that improvements can be seen in the radar data based all the indices and skill scores over time. Performance measures based on different skill scores and indices for different data sets (NRT, EOD and EOM) are provided in Table 4. These measures suggest that marginal improvements are seen from EOD to EOM data sets. Since NRT data sets are essential for operations in real-time, EOD data sets may be not be required for hydrologic modeling purposes when EOM data sets are available.

Table 4 Performance measures and skill scores based on CR10 (rain gage) and NRT (radar), EOD and EOM data sets at a temporal resolution of 15 minutes for water year 4.

Performance Measure	NRT	EOD	EOM
Mean Error (ME)	2.18E-06	5.91E-05	1.54E-05
Mean Absolute Error (MABE)	0.001153	0.001132	0.0011
Multiplicative Bias (MB)	1.001932	1.052694	1.013753
Mean Squared Error (MSQE)	0.00024	0.000222	0.000216
Root Mean Squared Error (RMSE)	0.015508	0.014884	0.014713
Root Mean Squared Factor (RMSF)	3.403268	3.385519	3.346904
Linear Error in Probability Space (LEPS)	0.001087	0.00104	0.001034
Correlation Coefficient (CORR)	0.590233	0.623374	0.627232
Nash-Sutcliffe Efficiency Coefficient (NSEC)	0.260504	0.313891	0.32954
Heidke Skill Score (HSS)	0.625337	0.62975	0.646592
Contingency Measure: Concordance (CMC)	0.985235	0.985011	0.986353
Contingency Measure: Error Rate (CMER)	0.014765	0.014989	0.013647
Contingency Measure: Specificity (CMSP)	0.991787	0.990965	0.992641
Contingency Measure: Sensitivity (CMSE)	0.654693	0.682465	0.666884
Pierce Skill Score (PSS)	0.605587	0.591597	0.634177
Gilbert's Skill Score (GSS)	0.454902	0.459588	0.477751
Odd's Ratio (OR)	228.9617	235.7411	270.0263
Bias Score (BS)	1.068989	1.141505	1.040806
Probability of Detection (POD)	0.654693	0.682465	0.666884
False Alarm Ratio (FAR)	0.387559	0.402136	0.359262
Critical Success Index (CSI)	0.462911	0.467749	0.485387
Boot Strap CI (L)	0.060738	0.057405	0.057584
Boot Strap CI (U)	0.061933	0.059022	0.058958

## MAIN INSIGHTS FROM RESULTS AND ANALYSIS

Results and analysis are provided in several appendices for different temporal resolutions. Only main insights from the results are provided in this section of this main report. The main insights are:

- The radar data is in good agreement with rain gage data at different temporal scales (i.e., 15 minute, hour, day, month and year). This is evident from scatter plots and cumulative density function plots of annual totals. Annual bias plots for different water years based on all rain gages show the average bias values close to 1. Scalar performance measures and skill scores calculated based on near real-time, end of the day and end of the month radar data sets and CR10 rain gage data indicate good agreement of radar data with rain gage data.
- As expected the performance of radar data sets based on all indices and skill scores progressively improved as temporal scale of radar data adjustment for analysis is changed from near real-time to end of the month. The skill scores based on radar data compared with rain gage data also improved over different years and best performance is seen in the last water year.
- Visual and statistical tests also suggest that radar data at all levels (near real-time, end of the day and end of the month) are in good agreement with ground truth (i.e. rain gage data). In general the errors computed based on radar and rain gage data show no evidences of temporal dependence, major heteroskedasticity, non-normality of errors (residuals) and statistically significant autocorrelation at different lags. Plots of residuals show random variations with no increase or decrease over time. The autocorrelations are close to zero as evident from autocorrelograms.
- Replacements tests indicate that radar data can be used for augmenting rain gage data or infilling missing data in different modes: 1) systematic; 2) random and 3) systematic and random replacement. Homogeneity tests need to be used to confirm that rain gage data is homogeneous after infilling. Spatial evaluation of bias indicates significant and consistent under estimation of precipitation by radar data in two areas of the SFWMD region.

Underestimation is evident by gage to radar precipitation ratios (G/R) higher than 1. The ratios

are calculated using annual precipitation totals. These areas are generally located in the North and Southeast corners of the SFWMD region.

- Parametric and non-parametric tests used for evaluating similarity of distributions characterizing radar and rain gage data sets provided mixed results. The two sample Kolmogorov-Smirnov (KS), Ansari-Bradley and Wilcoxon Sum tests indicate that alternate hypothesis being true for observations at several sites. However, the number of sites at which the alternate hypothesis being true reduced over time (when water year time window is considered).
- Distribution similarity is evaluated using twelve proximity-based measures (i.e. distances). The distances have reduced over time suggesting improvement in the similarity. Transition probabilities  $P_{10}$  (probability of transition from wet to dry) and  $P_{11}$  (probability of transition from wet to wet) are underestimated and overestimated respectively by radar data when compared to rain gage data for temporal scale of comparison of 15 minutes. However, a different picture of probabilities evolves when the temporal scale is increased from 15 minutes to an hour or a day.
- Serial autocorrelation of rain gage and radar data are evaluated at different lags. Radar data seems to consistently overestimate the autocorrelation at first two to three temporal lags. Accumulated radar and rain gage data plots show no significant deviation of radar from rain gage data for most of the gages in all the water years.
- Spatial variogram analysis of data revealed spatial dependence (inter station relationship) being underestimated by radar data when compared to the same by rain gage data. This issue needs to be addressed by the data vendor in future and apply appropriate spatial bias corrections. Only marginal improvements are seen from the near-real-time (NRT) data to end of the day (EOD) data when all the bias indices are considered.

## CONCLUSIONS

This report provides details of the work completed for the project dealing with assessment of NEXRAD-based rainfall estimates provided by the vendor Vieux and Associates Inc. All the indices and skill scores used in the current study point to good and robust quality of NEXRAD (radar) data

provided by the vendor that can be used for operational purposes as well as hydrological modeling tasks. However, the data vendor needs to address few issues related to spatial biases evident and indices that point to potential improvements. The quality of radar data sets and their agreement with rain gage data sets is evaluated by several indices and scores that are primarily used in forecast verification process. The skill scores are improvised to adapt them to the analysis reported in this study. The results presented in this report are based on bias analysis at different time horizons (i.e., 15 minutes, hour, day, month and year). A bias assessment tool (BAT) is also completed as a part of this study. The tool can be used by the District for evaluation of radar-rain gage data sets for bias. A demonstration of the tool to the District team involved in the project along with the help documentation for the tool was completed.

## REFERENCES/BIBLIOGRAPHY

1. Alexandersson, H. (1986). A homogeneity test applied to precipitation data. *Journal of Climatology*. 6:661–675.
2. Buishand, T. A. (1982). Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology*, 58, 11-27.
3. Durbin, J., and G. S. Watson. *Testing for Serial Correlation in Least Squares Regression I*. Biometrika 37, pp. 409–428, 1950.
4. IPCC, 2001: Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp. ([http://www.grida.no/climate/ipcc\\_tar/wg1/317.htm#fig84](http://www.grida.no/climate/ipcc_tar/wg1/317.htm#fig84)).
5. Joliffe, I. T., D. B. Stephenson. 2012. *Forecast Verification: A Practitioner’s Guide in Atmospheric Science*, Wiley-Blackwell.
6. Martiniatis, S. M., H. E. Fuelberg, J. L. Sullivan, C. S. Pathak, A intercomparison of precipitation values from the OneRain Corporation Algorithm and Natioal Weather Service Procedure, ASCE, EWRI Conference, May, 2007.
7. Myatt, G. J., Johnson, W. P. (2009). *Making Sense of Data II: A Practical Guide to Data Visualization, Advanced Data Mining Methods, and Applications*

8. Pettitt, A. N. (1979). A non-parametric approach to the change-point problem. *Applied Statistics*, 28(2):126-135.
9. Skinner, C. 2006. Developing A Relationship Between NEXRAD Generated Rainfall Values and Rain Gage in South Florida. Master's Thesis. Department of Civil Engineering, Florida Atlantic University, Boca Raton, Florida.
10. Taylor, K.E.: Summarizing multiple aspects of model performance in a single diagram. *J. Geophys. Res.*, 106, 7183-7192, 2001
11. Von Neumann, J. (1941). Distribution of the ratio of the mean square successive difference to the variance. *Annals of Mathematical Statistics*, 12:367–395.
12. Wilks, D. S. (2011). *Statistical methods in Atmospheric sciences*, Academic press.

#### **SOUTH FLORIDA WATER MANAGEMENT DISTRICT - REFERENCES**

1. Anagnostou, E.N. 2006. A Comparison of FSU and OneRain Rainfall Data. Report - September 24, 2006. St. Johns River Water Management District and South Florida Water Management District, West Palm Beach, Florida.
2. Huebner, R.S., C.S. Pathak and B.C. Hoblit. 2003. Development and Use of a NEXRAD Database for Water Management in South Florida. ASCE World Water & Environmental Resources Congress, June 2003, Philadelphia, Pennsylvania.
3. Pathak, C.S., R.S. Huebner and E.P. Swartz. 2005. Rainfall Monitoring Using NEXRAD Data for Water Management in South Florida. First Florida Radar Rainfall User Workshop, November 15, 2005. University of Central Florida, Orlando, Florida.
4. Pathak, C.S. and S. Palermo. 2006. Rainfall Based Management Plan for Water Conservation Area 3A in Florida Everglades. ASCE/EWRI World Water & Environmental Congress, Annual Conference, May 21-25. Omaha, Nebraska. Proceeding.
5. Pathak, C. S. (Ed.). 2006. Hydrologic Monitoring Network of South Florida Water Management District – Draft Report. South Florida Water Management District, West Palm Beach, FL.

## **Information Transfer Program Introduction**

During the review period, 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.

# Florida Water Resources Information Transfer

## Basic Information

<b>Title:</b>	Florida Water Resources Information Transfer
<b>Project Number:</b>	2012FL302B
<b>Start Date:</b>	3/1/2012
<b>End Date:</b>	2/28/2013
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	6
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	None, None, None
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Kirk Hatfield, Mark Newman

## Publications

1. Klammler, H., K. Hatfield, M.M. Mohamed, I.V. Perminova, M. Perlmutter. 2013. Capture and release zones of permeable reactive barriers under the influence of advective-dispersive transport in the aquifer, *Advances in Water Resources*. (In Review).
2. Shcherbina, N. S., S.S. Kalmykov, S. A. Ponomarenko, K. Hatfield, R. Haire, and Perminova, I. V. 2013. Partitioning of Waterborne Plutonium Partitioning to Immobile and Mobile Humic Materials in the Binary and Ternary Systems, *Environmental Science & Technologies*. (In Review).
3. Acar, Ö, H. Klammler, K. Hatfield, M. A. Newman, M. Annable, J. Cho, B. Parker, J. Cherry, P. Pehme, P. Quinn, and R. Kroeker. 2013. A stochastic model for estimating groundwater and contaminant discharges from fractured rock passive flux meter measurements. *Water Resour. Res.* VOL. 49, 1 15, doi:10.1002/wrcr.20109.
4. Karpiouk, L.A., S.A. Ponomarenko, A.I. Konstatinov, N. Hertkorn, A.M. Muzafarov, K. Hatfield, I.V. Perminova. 2012. Controlling Aqueous Sorption of Humic Substances on Silica Gel by Directed Alkoxysilyl-Derivatization of Their Functionalities, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol 396, 224-232, DOI: 10.1016/j.colsurfa.2011.12.068.
5. Klammler H., K. Hatfield, J.A.G. Luz, M.D. Annable, M. Newman, J. Cho, A. Peacock, V. Stucker, J. Ranville, S. Cabaniss, and P. S. Rao. 2012. Contaminant Discharge and Uncertainty Estimates from Passive Flux Meter Measurements, *Water Resour. Res.* 48, W02512, DOI: 10.1029/2011WR010535.
6. Karpiouk, L.A., S.A. Ponomarenko, A. Mourran, D. Bochkariov, A. M. Muzafarov, K. Hatfield and I.V. Perminova. 2012. Self-assembly of alkoxysilanized humic substances into multidomain adlayers at the water-solid interface: linking surface morphology to molecular structures of adsorbate, *Soft Matter*, 8 (8), 2452 2459. DOI: 10.1039/C2SM06582G.
7. Inglett, K.S., H.S. Bae, H.C. Aldrich, K. Hatfield, A.V. Ogram. 2011. *Clostridium chromiireducens* sp. nov., isolated from Cr(VI)-contaminated soil, *International journal of systematic and evolutionary microbiology*, 61 (11), 2626-31. DOI: 10.1099/ijs.0.024554-0.
8. Perminova, I.V., S. N. Kalmykov, N. S. Shcherbina, S. A. Ponomarenko, V. A. Kholodov, A. P. Novikov, R. G. Haire, K. Hatfield. 2013. Humic functional derivatives and nanocoatings for remediation of actinide contaminated environments, *Nanomaterials for Environmental Protection*, Edited by B. I. Kharisov, O. V. Kharissova, and H. V. R. Dias. ISBN 0-471-9781118496978 Copyright © 2000 Wiley, Inc. (In review).
9. Klammler, H., K. Hatfield, J. Luz, M. Annable, M. Newman, J. Cho, A. Peacock, V. Stucker, J. Ranville & C. Clark. 2012. Water and contaminant flux estimation from multi-layer passive flux

## Florida Water Resources Information Transfer

meter measurements, *Advances in Fluid Mechanics*, WIT Transactions on Engineering Sciences, Vol 74, pp 301-313.

10. Hatfield, K., H. Klammler, M. Annable, M. Newman, J. Cho, J. Jawitz and P.S.C. Rao. Monitoring Water and Contaminant Fluxes in Aquifers, Streams, and Hyporheic Zones. Proceedings of the National Ground Water Summit. Garden Grove, CA. May 6-10, 2012.
11. Hatfield, K., H. Klammler, M.D. Annable, M.A. Newman, J. Cho, B.L. Parker, and J.A. Cherry. PFM Concepts for Measuring Fluxes, Gradients and Conductivities in the Hyporheic Zone. Proceedings of the Fall Focus Conference of the University Research Consortium for Field Focused Groundwater Contamination Research. Denver, CO. November, 2012.
12. M.D. Annable, K. Hatfield, H.R. Klammler, Newman, M.A., J. Cho, B.L. Parker, J.A. Cherry. Update on Development of the fractured rock borehole flux meter. University Consortium for Field-Focused Groundwater Contaminant Research Annual Meeting, June 12-14, 2012. University of Guelph. Guelph, Ontario.

## **Information Transfer Program FY 2012**

During the review period, 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, 8 book chapters, and 11 proceedings and presentations.

WRRC Website: The Center maintains a website (<http://wrrc.essie.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 and is provided free to the public through the WRRC Digital Library which is housed on the center website <http://wrrc.essie.ufl.edu/reports/>.

# USGS Summer Intern Program

None.

<b>Student Support</b>					
<b>Category</b>	<b>Section 104 Base Grant</b>	<b>Section 104 NCGP Award</b>	<b>NIWR-USGS Internship</b>	<b>Supplemental Awards</b>	<b>Total</b>
<b>Undergraduate</b>	5	0	0	0	5
<b>Masters</b>	3	0	0	0	3
<b>Ph.D.</b>	11	0	0	0	11
<b>Post-Doc.</b>	3	0	0	0	3
<b>Total</b>	22	0	0	0	22

## 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 2012:

**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 Gowdich 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 11 Ph.D., 3 Masters, and 5 undergraduate students along with 3 post-doctoral associates all focusing on water resources issues during Fiscal Year 2012.

**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.