Journal of South Carolina Water Resources

Volume 1, Issue 1 June 2014

A Publication of the
South Carolina Water Resources Conference
www.scwaterconference.org

Journal of South Carolina Water Resources

Published by:
Institute of Computational Ecology
Clemson University
230 Kappa Street, Clemson, South Carolina 29634-0135
Phone: (864) 656-2618
ice.clemson.edu

EDITOR

EDITORIAL STAFF

EDITORIAL COMMITTEE

ISSN 2334-4962 (online)

Cover photos: (Top L-R) **Virginia Hawkins Falls** in Sunset, S.C. - Courtesy of Cathy Reas Foster, Clemson University Water Resources Agent; **Healing Springs** in Blackville, S.C. - Courtesy of SCDNR. (Bottom L-R) **Bennett's Point** in Green Pond, S.C. - Courtesy of Kim Counts, Clemson University Water Resources Agent; **Congaree National Park** in Hopkins, S.C. - Courtesy of Mary Caflisch, Clemson University Water Resources Agent.

2014
S.C. Water Resources Conference

Informing Strategic Water Planning to Address
Natural Resource, Community, and Economic Challenges

October 15-16 • www.scwaterconference.org
Columbia Metropolitan Convention Center

South Carolina Water Resources Conference (SCWRC)
The purpose of the SCWRC is to provide an integrated forum for discussion of water policies, research projects and water management in order to prepare for and meet the growing challenge of providing water resources to sustain and grow South Carolina's economy, while preserving our natural resources. The conference is a biennial event, held in even-numbered years. (www.scwaterconference.org)

v06262014p

Journal of
South Carolina Water Resources

Volume 1, Issue 1 June 2014

Contents

Introduction
Timothy J. Callahan ... 1

Foreword
Jeffery S. Allen and Lori Dickes ... 2

South Carolina's Climate Report Card: Understanding South Carolina's Climate Trends and Variability
Hope Mizzell, Mark Malsick and Ivetta Abramyan ... 4

Water-Level Trends in Aquifers of South Carolina
Scott V. Harder, Jospeh A. Gellici and Andrew Wachob ... 10

A Case Study in Watershed-Based Plan Development and Implementation for the May River Watershed in Bluffton, South Carolina
Kimberly W. Jones and Ronald Bullman ... 19

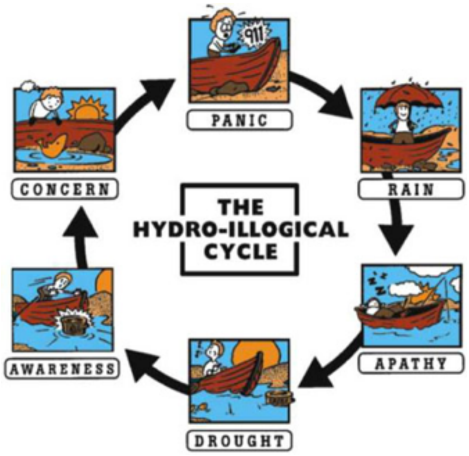
Long Bay Hypoxia Monitoring Consortium
Susan Libes, Michael Trapp, Scott Kindelberger and Danielle Doremus ... 26

Green Infrastructure in Coastal Landscapes: Hydrological Function, Ecological Design and Sustainable Land Use Guidance
Daniel R. Hitchcock, Anand D. Jayakaran and David L. White ... 32

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Issue 1, Page 1, June 2014

Introduction

Timothy J. Callahan, Ph.D.
Journal Editor



© National Drought Mitigation Center

> *"We welcome the first clear day after a rainy spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a little worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows how serious it will be until the last dry day is gone and the rains have come again."*
>
> I.R. Tannehill, *Drought: Its Causes and Effects* (1947)

The "hydro-illogical" cycle; a tongue-in-cheek conceptualization of how people perceive problems for only their near-term impact, but soon forget bad times when resources are plentiful. Drought and flooding are two examples of this. As we write, South Carolina has had above-average winter and spring seasons for river, lake and groundwater levels in most areas. This has been a steady improvement since the most recent drought of 2011-2012. Scientists, managers, and educators involved with water issues think of water cycles; dry-wet-dry conditions that change from summer to winter to subsequent summer, or multi-year shifts in water availability. There are many examples of past societies and their efforts to make use of water resources and improve resiliency: qanats in the Middle East, the Roman aqueducts, large-scale canals for navigation, impoundments for irrigation, and cisterns for harvesting rainwater are just a few examples of the advancements of civilizations dating back millennia. Modern societies still rely on these ancient practices but today advancements in two major areas allow us to be more efficient and forward-thinking: technology to collect data in "real-time" to allow for adaptive management, and a deeper understanding of links between human and ecological needs for water. The aim of the *Journal of South Carolina Water Resources* is to provide a forum for articles about the condition of South Carolina's water resources, with the goals of influencing science-based management decisions and heightening awareness of our water resources. This inaugural issue contains manuscripts from the 2012 South Carolina Water Resources Conference. Henceforth, issues published in odd-numbered years will feature select manuscripts, and in even-numbered years there will be a theme focus to preview the upcoming conference. We encourage authors to consider this forum as an outlet to communicate information and results from their work on advancements in water science, policy, management and law pertaining to South Carolina and the Southeast United States. Basic experimental and discovery science, policy analysis, developments in water and environmental law, management issues, as well as case studies are welcome submissions to be considered for publication in the Journal. We anticipate a wide range of readers across our state and region would like to learn about and engage in water resources matters. South Carolina is a water-rich state, and as our population and economy continue to expand, access to reliable and clean water resources is critically important for the resiliency, health and well-being of South Carolinians. Wider knowledge and awareness of the issues is of utmost importance to protect and make the most of our water resources.

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Issue 1, Pages 2-3, June 2014

Foreword

Jeffery S. Allen, Ph.D. and Lori Dickes, Ph.D.
South Carolina Water Resources Conference Planning Committee Members

> *"It's never enough just to tell people about some new insight. Rather, you have to get them to experience it in a way that evokes its power and possibility. Instead of pouring knowledge into people's heads, you need to help them grind a new set of eyeglasses so they can see the world in a new way."*
>
> John Seely Brown, *Seeing Differently: Insights on Innovation.*

Welcome to the first edition of the *Journal of South Carolina Water Resources*. We are pleased to offer this resource to academics, practitioners and policymakers in South Carolina and the region. The introductory issue of this journal corresponds closely to the October, biennial meeting of the South Carolina Water Resources Conference. The 2014 conference theme is *Informing Strategic Water Planning to Address Natural Resource, Community and Economic Challenges*. With this in mind, the articles chosen for the inaugural edition relate to the critical idea of water planning and management aimed at ensuring the sustainability of this critical natural resource.

While early Americans did not have the technology to map and study watersheds as we do today, early Americans understood the community, economic and natural resource value of these resources. Conservationist John Wesley Powell was an early advocate for watershed planning and policy when in 1878 he called for political jurisdictions in the American West to conform to watershed jurisdictions. This was a radical idea for its time, and Powell arguably lost his job as head of the U.S. Geological Survey over this. However, as early as 1899, with the Rivers and Harbors Act, the United States through the U.S. Army Corps of Engineers (USACE) began to actively engage in water resource policy and planning.

The emphasis on basin wide planning remained as influenced by the actions of the Roosevelt Administration. The Reclamation Act of 1902 established the Bureau of Reclamation and allowed for the Department of the Interior to construct irrigation projects, reservoirs and diversion canals in the western United States and territories. Many of these diversions later became interbasin and interstate transfers. By the 1920s, water resource management and multipurpose planning was in full gear across the United States. The Federal Power Act of 1920 emphasized the river basin as the unit of planning and analysis for the USACE. As well, the River Basin Study (308 Act) of 1925 authorized the USACE to engage in river basin studies across the United States. Until the 1970s this period of water policy and planning largely centered on large federal water projects and comprehensive, basin oriented planning.

By the 1960s and 70s water planning and management began to incorporate issues of environmental degradation and broader quality concerns. Among other things, this demanded identifying pollution sources, prioritizing pollution abatement, ensuring compliance with federal pollution standards, and understanding total maximum daily loads (TMDLs). In addition, the 1970s saw a large increase in federal subsidies for wastewater treatment facilities. This time period saw environmental issues at the forefront of the public consciousness. Given this, public involvement in environmental and natural resource management became more prevalent as federal agencies mandated the inclusion of public involvement into natural resource management issues. In 1996 the National Research Council argued that public participation in natural resource decision making "is critical to ensure that all relevant information is included, that it is synthesized in a way that addresses parties' concern, and that those who may be affected by a risk decision are sufficiently well informed and involved to participate meaningfully in the decision."

By the 1980s there was a substantive policy shift away from comprehensive, interconnected watershed planning. Both Presidents Carter and Reagan were reluctant to fund water projects, and for a time, the movement for holistic, comprehensive water planning and management were on hold. However, by the 1990s there was a resurgence of support for water planning and management, as well as strong evidence and support for the establishment of watershed partnerships across the country. Today, watershed partnerships go by many different names but generally, these are local or regional groups of stakeholders who meet to discuss and collaborate on relevant water policy and management at a watershed (or portion of a watershed) level. The success of these groups working synchronously with policymakers and regulators has led many to argue for these models as the future of water resource planning, management and sustainability.

South Carolina has followed many of these federal trends in water resource planning with the development of USACE reservoirs, establishment of TMDLs, and federal loans for wastewater plants just to name a few. Since the 1970s some of the state of South Carolina's policy efforts have included:

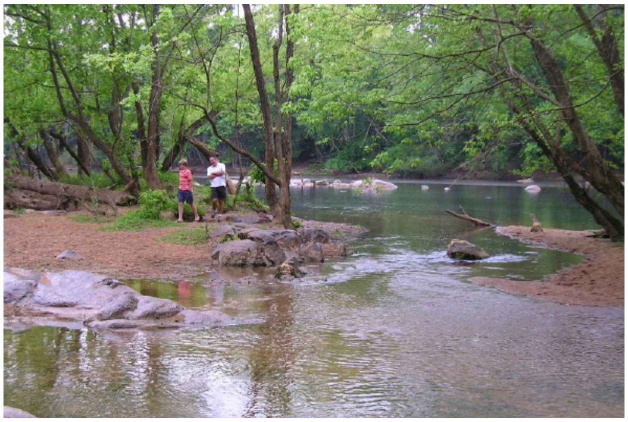
- Water Resources Planning and Coordination Act of 1970
- The 1983 South Carolina State Water Assessment
- The Situation and Outlook for Water Resource Use in South Carolina, 1985-2000
- An Assessment of Issues Affecting the Savannah River Basin
- South Carolina State Water Plan 2004
- Watershed Water Quality Assessment - Savannah River Basin 2010

All of these efforts have been informative and have assisted policymakers in different ways. Recent research from Clemson University reveals that 70% of survey respondents are concerned about the environmental quality of their local streams and waterways. As well, over 65% of respondents are concerned about issues related to water quantity and quality and its impact on our state's economic and community development.

Today, it is recognized that proper water resource management and planning demands following several key principles. First, all water resource planning must take into consideration the interdependent nature of hydrologic systems. Additionally, water resources must be planned and managed in a holistic fashion, acknowledging the multiple demands and needs of this resource. Ideally, water resource planning and management is incorporated into land use and other community and resource planning where critical relationships exist. Finally, planning and management should follow a set of well-established goals and objectives, as well as agreed upon metrics for evaluating and measuring the success of policy measures over time. In the end, we are dependent on this critical resource for food, shelter, industry and recreation; in general our livelihoods and quality of life is dependent on water. Engaging in thoughtful, educational, comprehensive and interdependent water planning and management is critical to the short and long-term sustainability of this life giving resource. Happy reading!

Reedy River (Photo by: Jeffery Allen, Director, Strom Thurmond Institute S.C. Water Resources Center)

Twelve Mile River (Photo by: Jeffery Allen, Director, Strom Thurmond Institute S.C. Water Resources Center)



Broad River (Photo by: Jeffery Allen, Director, Strom Thurmond Institute S.C. Water Resources Center)

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Volume 1, Issue 1, Pages 4-9, June 2014

South Carolina's Climate Report Card: Understanding South Carolina's Climate Trends and Variability

Hope Mizzell, Mark Malsick and Ivetta Abramyan

AUTHORS: S.C. State Climatology Office, S.C. Department of Natural Resources, Columbia, South Carolina, 29209, USA.

REFERENCE: Proceedings of the 2012 South Carolina Water Resources Conference, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. This study provides an overview of South Carolina's climatic trends and variability over the last century. Most studies nationally have focused on large-scale temperature and precipitation trends, but examination of regional and local trends are needed to monitor the significance of the state's climate signal and advance our understanding of the complex physical controls on the region's climate. The behavior of several climatic elements since the 1900s were evaluated for 66 sites in South Carolina and bordering states to determine the variability of the system on annual, seasonal and decadal scales, including the use of threshold approaches to assess climate patterns. Results from the bordering states were not directly discussed, but were included in the study for continuity.

The linear regression model found opposite seasonal trends between minimum temperature and maximum temperature for some stations. The linear trend analysis was more clearly defined for precipitation than for temperature. Most stations experienced a general decreasing trend in summer precipitation totals and an increasing trend in fall precipitation. The 10-year moving averages were able to detect patterns of change over time. The precipitation variables show a decreasing precipitation trend during the 1950s, increasing trend during the 1960s with a decreasing trend over the past decade. The 10-year moving averages for temperature detect a decreasing temperature trend from the late 1950s through the 1960s with a steady temperature increase since the 1970s.

Data on South Carolina tornado occurrences and hurricane landfalls were examined to discern any trends in severe storms. While there does not seem to be an increasing trend in the frequency of tornado occurrences and hurricane landfalls in South Carolina, there is also no evidence that the events are becoming less frequent or less severe.

INTRODUCTION

Climate change has occurred throughout history over timescales that vary from decades to hundreds of thousands of years. Growing questions and concerns over climate change, climate variability and climate extremes have increased the need for research and monitoring activities to better understand the nature of climate fluctuations in South Carolina. The purpose of this study is to examine and document the local climate variability in order to monitor the State's climate signal and better understand the complex controls on the region's climate. Results from the study can help foster better predictions and informed responses to climate variations and extreme events, both on short- and long-term time scales.

PROJECT OBJECTIVES

The objectives for this study are:

1.) Assemble a temporally complete database of climate observations for stations having reliable and lengthy records spatially distributed across South Carolina. Develop a time series for monthly, seasonal, and annual temperature, precipitation and threshold exceedance data for each location.
2.) Assemble a temporally complete database of tornado events and hurricane landfalls in South Carolina. Develop a time series for event occurrence.
3.) Complete linear trend evaluations and 10-year moving averages for each time series.

PROJECT DESCRIPTION

Evaluations of historical precipitation and temperature across the U.S. Southeast reveal much interannual and interdecadal variability (Ingram et al., 2013). Global studies suggest that the U.S. Southeast is one of the few regions that did not experience an overall warming trend in surface temperature during the 20th century (IPCC, 2007). There is also research that suggests that the frequency of extreme temperatures events both warm and cold have declined across much of the Southeast, but with a wide range of decadal and intraregional variability (Kunkel et al., 2013).

The Southeast experiences a wide range of extreme weather and climate events that have resulted in billion-dollar weather disasters over the last three decades (NCDC, 2011). Records of severe events are not as extensive as records of general precipitation and temperature patterns. The best available data on severe thunderstorms, high winds, hail, flooding and tornadoes generally only go back to 1950. Documentation of these occurrences is also highly sensitive to population density limiting the data to recorded events, not necessarily capturing all events.

While there is more extensive data on hurricanes, there are differing perspectives on the trends of Atlantic Basin hurricane and tropical cyclone frequency (Holland et al., 2007; Landsea, 2007; Landsea et al., 2010). Some scholars contend that the record of tropical activity is likely missing storms during the years before satellite detection (prior to late 1960s) and airplane reconnaissance (prior to mid-1940s). Many studies such as this analysis focus on landfalling storms since they would have likely been verified without satellite or reconnaissance coverage.

While some of the research highlighted above includes South Carolina data, the work is broader in scope and not focused on documenting and detecting localized changes. The purpose of this study is to examine South Carolina’s climate variability over the last century by examining seasonal and annual precipitation and temperature records, variations in extreme precipitation and temperature events and the frequency of tornado occurrence and hurricane landfalls. The examination of these trends is needed to monitor the significance of the state’s climate signal and advance our understanding of the complex physical controls on the region’s climate.

METHODOLOGY

Changes in South Carolina’s surface temperature and precipitation over the last 100 years were analyzed using station data from the National Oceanic and Atmospheric Administration U.S. Historical Climate Network (USHCN) and the National Weather Service Cooperative Network (COOP). The USHCN is a dataset that includes adjustments for changes in station location, urbanization and time of observation and the COOP network provided the daily data needed for supplemental threshold approach evaluations. Observations from 66 USHCN stations spanning the period 1901-2010 and 26 COOP stations spanning 60 to 100 years provide adequate spatial coverage for the study area.

Since changing climate extremes may have different and potentially greater impacts than changes in the mean, analyzing climate extremes becomes very important. Monitoring and detection of changes in precipitation and temperature extremes requires daily resolution data which were obtained and analyzed from the COOP network for the period 1938-2010. A threshold exceedance analysis for extreme events was conducted for stations around the State. Several extreme thresholds were examined including, the annual number of days with temperature above 95° F, the Fall-Spring number of days with temperature less than 32° F, and the annual number of days with precipitation greater than 2.00”.

Changes in the frequency of tornado occurrence and hurricane landfalls in South Carolina were also examined. Tornado data is only available starting in 1950 and was retrieved from the NOAA Storm Prediction Center Severe Weather database. There is more extensive data on hurricane landfalls in South Carolina which was retrieved and verified by multiple sources including NOAA’s Atlantic Hurricane Re-analysis Project. Tornadoes and hurricane landfalls provide an objective measure to evaluate trends and variability in event extremes.

RESULTS

Seasonal temperature and precipitation trends based on USHCN data were analyzed using the least squares method. Results showed a general precipitation decrease in the majority of the region for summer rainfall totals (≥1.0” decrease for 55 out of the 66 stations), with 36 out of the 66 stations experiencing a decreasing precipitation trend ≥ 2.50”. The trend analysis for fall rainfall totals was the inverse of summer with all stations across the study area experiencing an increasing precipitation trend (61 stations had an increasing fall precipitation trend ≥1.0”) (Figure 1). The trends for winter precipitation totals show mixed results with a drier trend in the higher elevations and

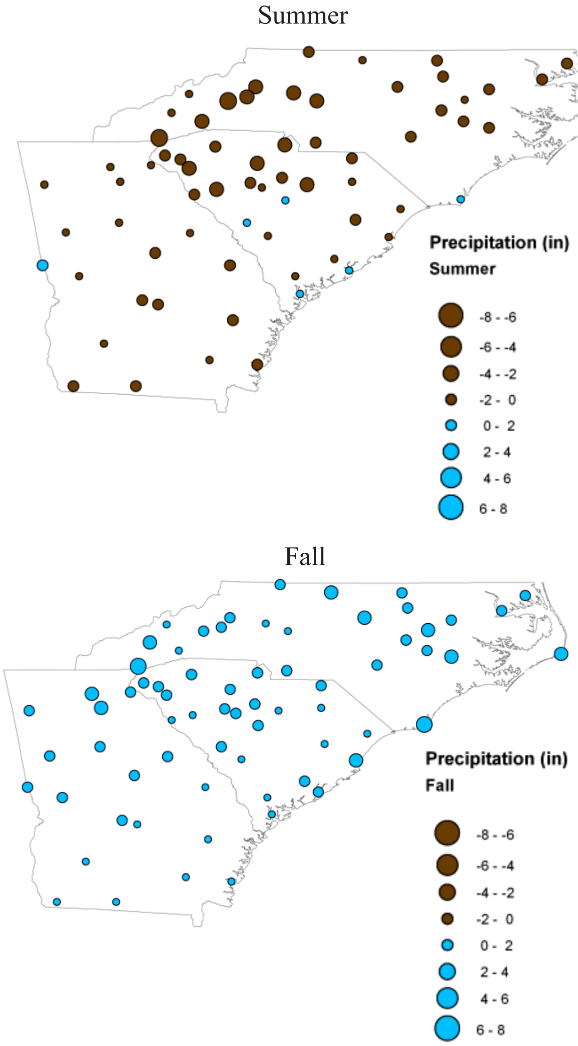


Figure 1. Trends in summer and fall precipitation totals (inches), 1901-2010.

the river headwater regions and a wetter trend from the midlands to the coast. Spring precipitation trends are geographically similar to winter, but with a weaker signal.

Table 1 displays the seasonal and annual precipitation trend for each station. Aiken was the only station with an increasing precipitation trend greater than 1" for all seasons. Seven stations had a decreasing annual precipitation trend greater than 3" while six stations had an increasing annual precipitation trend greater than 3".

South Carolina temperature patterns are less clearly defined with differential changes in minimum temperature (Tmin) and maximum temperature (Tmax). Winter and spring Tmax generally warmed (Figure 2), but the Tmin during these seasons showed little variation or actually cooled over time. Summer and fall Tmax and Tmin don't consistently demonstrate a uniform trend with some stations warming while others cooled across the region.

Table 1. Seasonal and annual USHCN precipitation trends computed from least squares regression, 1901-2010.

Station	Spring	Summer	Fall	Winter	Annual
Walhalla	-0.3	-2.8	3.4	-2.4	-2.2
Clem Univ	-0.7	-3.3	2.3	-2.9	-4.8
Anderson	-0.7	-4.8	3.9	-1.4	-3.1
Calhoun Falls	-1.3	-2.5	1.9	-1.5	-3.3
Greenwood	-0.5	-5.8	1.4	-2.8	-7.7
Grvl/Spbg	0.1	-2.6	2.3	-2.2	-2.6
Aiken	2.8	1.9	2.8	1.7	9.2
Blackville	0.1	-1.2	0.6	1	0.7
Newberry	-0.3	-2.8	3.8	-1.6	-1
Lil Mtn	0.2	-1.6	2.9	0.4	1.9
Columbia	1.4	0.6	3	2.1	7.2
Santuck	-0.6	-4.7	2.5	-1.8	-4.8
Winnsboro	-0.6	-3.9	2.4	0	-2.1
Camden	-1.3	-4.1	1.4	-1.3	-5.3
Winthrop	-0.9	-4.6	3.1	-1.6	-4.1
Cheraw	-0.8	-3	2.3	-0.4	-1.9
Darlington	-0.2	-0.4	1.5	1.4	2.3
Kingstree	1.7	-3.9	1.8	1.5	1.2
Conway	-0.1	-1.3	1.9	-0.3	0.3
Georgetown	0.2	-1.7	4.5	0.2	3.2
Charleston	0.8	0.9	3.5	0.5	5.8
Summerville	1	-1	3.3	0.5	4
Beaufort	0.9	0.8	3.2	0.1	3.2
Yemassee	0.4	-1.9	1.4	1.6	1.6

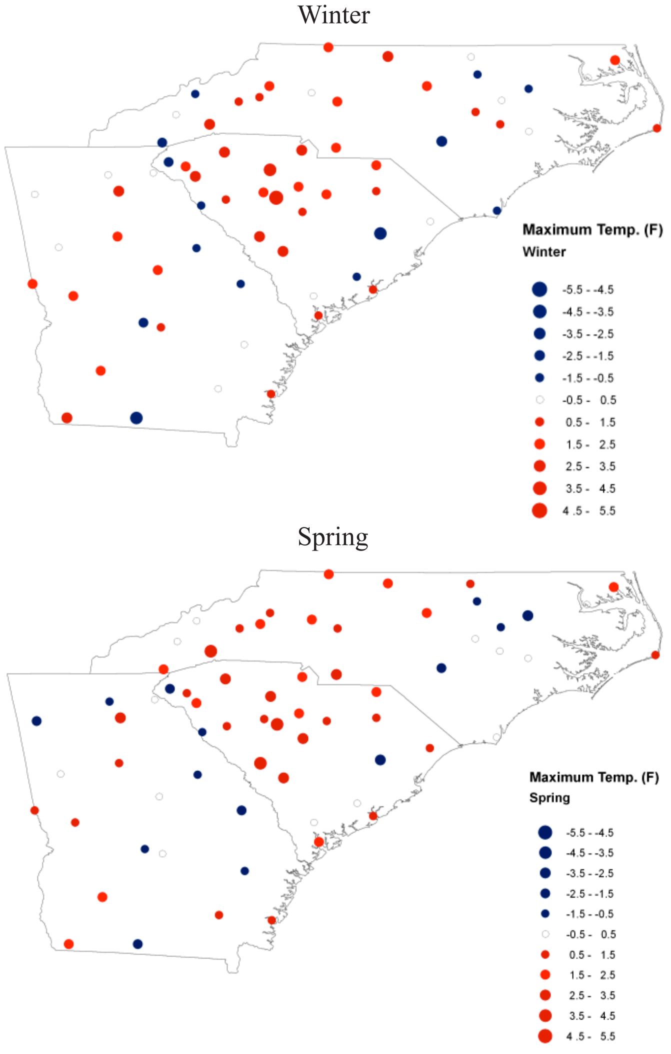


Figure 2. Trends in winter and spring maximum temperature (°F), 1901-2010.

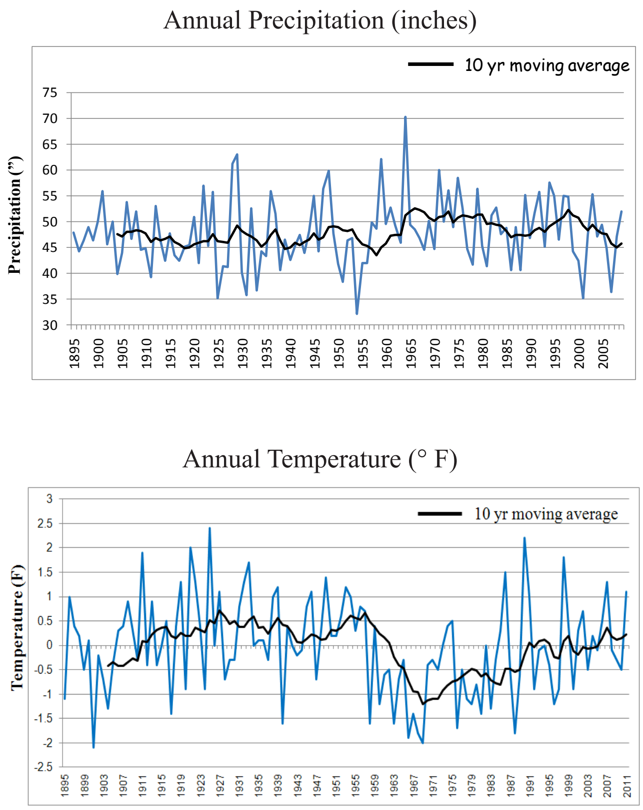


Figure 3. South Carolina annual statewide precipitation (inches) and temperature (°F), 1895-2010.

There are statistical limitations to using a linear trend to analyze climate variability, so moving averages and various threshold approaches were analyzed. The 10-year moving average for statewide annual precipitation shows a decreasing precipitation trend during the 1950s, increasing trend during the 1960s with a decreasing trend over the past decade (Figure 3). The 10-year moving average for statewide temperature shows a decreasing temperature trend from the late 1950s through the 1960s with a steady temperature increase since the 1970s (Figure 3). Future analysis should evaluate potential forcing mechanisms such as the El Nino Southern Oscillation that may contribute to these local variations over time.

Linear trends and 10-year moving average results from the threshold exceedance analysis will be discussed for three South Carolina stations. Walhalla, Saluda, and Charleston were selected from the State's three geographic regions (Upstate, Midlands, Coast) based on length of record (1938-2010) and data quality. The analysis for the annual number of days with temperature ≥ 95° F (Figure 4) reveals a decreasing linear trend for Walhalla (-0.11 days) and Saluda (-0.05 days) and an increasing linear trend for Charleston (+0.05 days). The 10-year moving average pattern for all three stations is consistent with the general temperature signal displayed in Figure 4 with warmer temperatures in the 1950s followed by much cooler temperatures in the 1960s / 1970s and a warming trend from 1980s to present. All three stations had a greater number of days with maximum temperature above 95°F during the 1950s and again from the 1980s to present with a reduced number during the relatively cooler 1960s and 1970s.

Figure 5 displays the September-May number of days with minimum temperature ≤ 32° F for 1938-2010. There is an increasing linear trend for Walhalla (+0.07) and Saluda (+.18) and a decreasing linear trend for Charleston (-0.22). The 10-year moving averages for all three stations show a general trend of increasing number of days below 32°F from the 1950s into the 1960s / 1970s, followed by a decreasing trend through the late 1990s and then an increasing trend through 2010.

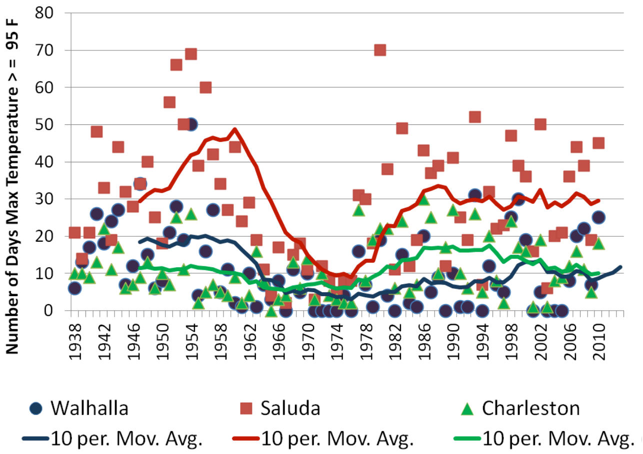


Figure 4. Annual number of days with temperature ≥ 95° F for Walhalla, Saluda, and Charleston, 1938-2010.

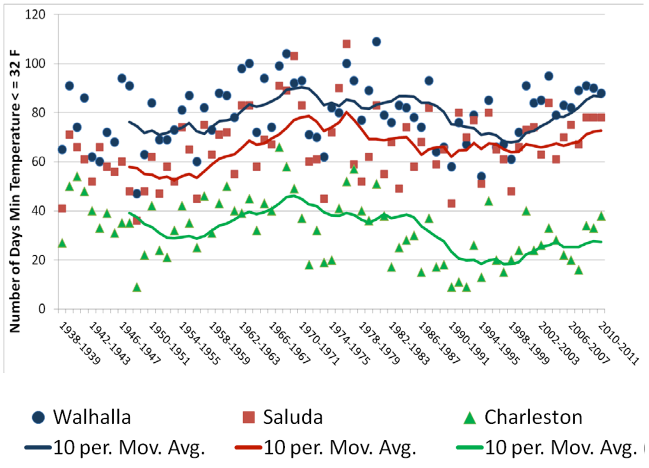


Figure 5. Fall-spring number of days with temperature ≤ 32° F for Walhalla, Saluda, and Charleston, 1938-2010.

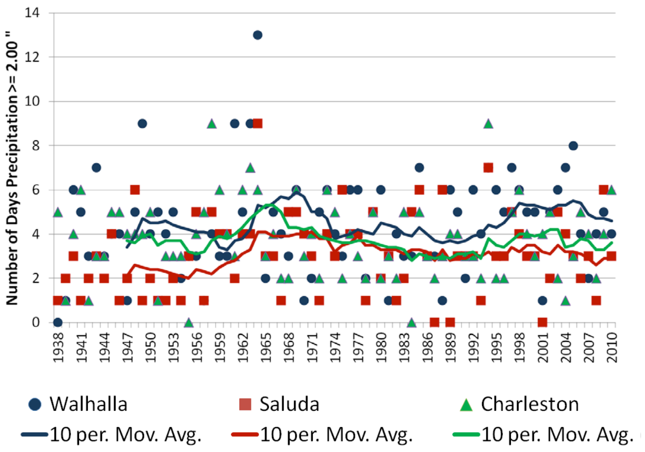


Figure 6. Annual number of days with precipitation ≥ 2.00” for Walhalla, Saluda, and Charleston, 1938-2010.

The evaluation of the days with heavier rainfall totals (precipitation ≥ 2.00”) is displayed in Figure 6. The 10-year moving average for all three stations indicate a higher occurrence of the 2” or greater events during the 1960s which was generally a wetter than normal decade. Even though there is variation from year to year, there is only small fluctuation in the 10-year moving average for Saluda and Charleston from 1970 to present.

The next phase of the project examined the variability of severe weather focusing on tornado occurrence and hurricane landfalls in South Carolina. Tornado data from the period 1950-2010 (Figure 7) demonstrate an increasing trend in these severe storms. This increasing trend is believed to be attributable to increased population levels and the advent of Doppler radar technology in the early 1990s. Figure 7 displays the misleading appearance of an increasing trend in total tornado frequency likely due to observational biases. However, a closer examination of the EF2 and stronger tornado events in South Carolina does not show an increasing trend. The purpose of examining just the stronger tornadoes is based on the premise that these tornadoes would have more likely been reported even during the decades before Doppler radar and hence represents a more reliable way of tracking temporal trends.

There is extensive data on hurricane landfalls dating back to 1878 (Figure 8). Throughout this period South Carolina has experienced two hurricane landfalls in one season only three times (1893, 1959 and 2004). The 10-year moving average suggests an active period during the late 1800s into the early 1900s and also during the 1950s. The longest periods without a landfalling hurricane in SC were 1960-1978 (19 years) and 1990-2003 (14 years).

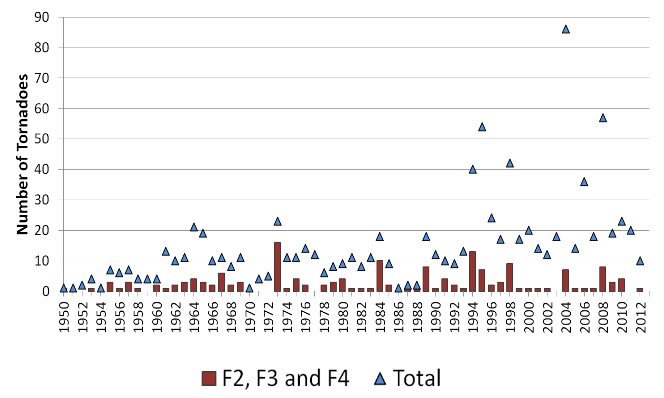


Figure 7. South Carolina annual tornado events (showing stronger events in bars).

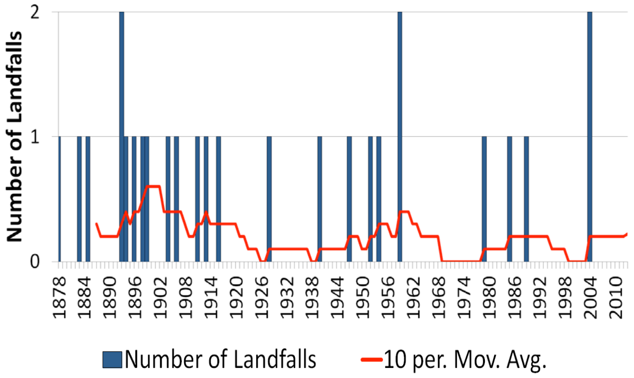


Figure 8. South Carolina hurricane landfalls, 1878-2012.

CONCLUSIONS

The average or mean state of climate, how climate varies over time, and the frequency and persistence of extreme values all influence our lives and well-being. As demonstrated in this study there is a wide range of variability in the climate system. There were years with no hurricanes, but there were years South Carolina experienced two hurricanes in one season. The annual tornado occurrence ranges from one to over eighty. There were years where some stations never reached 95° F while other years the mercury climbed to 95° F or greater on 70 days. The annual data and the 10-year moving averages display large fluctuations for many of the variables over time.

The linear trend analysis for some variables does not show a dominant and consistent change. The only consistent change among all stations was an increasing fall precipitation trend. South Carolina precipitation patterns, however, were more clearly defined than temperature with differential changes between minimum temperature (Tmin) and maximum temperature (Tmax) for some seasons.

While there does not seem to be an increasing trend in the frequency of tornado occurrences and hurricane landfalls in South Carolina there is also no evidence that the events are becoming less frequent or less severe. This report will be updated every 5-years to provide information on the State's climate signal. Future work should expand the analysis to include different climate response variables such as droughts and also include additional statistical evaluations of variance and trends.

LITERATURE CITED

Holland, G.J., and P.J. Webster, 2007. Heightened tropical cyclone activity in the North Atlantic: Natural variability or climate trend? *Philosophical Transactions of the Royal Society-Mathematical, Physics, and Engineering Sciences,* 365 (186): 2695-2716.

Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. *Climate of the Southeast United States: Variability, change, impacts, and vulnerability*. Washington DC, Island Press.

Intergovernmental Panel on Climate Change, 2007. *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S, D. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, New York and United Kingdom.

Kunkel, Kenneth E., T. Karl, H. Brooks, J. Kossin, L. Bosart, and Coauthors, 2013. Monitoring and understanding trends in extreme storms: State of knowledge. *Bulletin of the American Meteorological Society*, 94: 499–514.

Landsea, C.W, 2007. Counting Atlantic tropical cyclones back to 1900. *EOS, Transactions, American Geophysical Union*, 88 (18): 197-208.

Landsea, C.W, 2010. Impact of duration thresholds on Atlantic tropical cyclone counts. *Journal of Climate*, 23: 2508-2518.

National Climatic Data Center (NCDC), 2011. Billon dollar USA Weather/Climate Disasters, http:///www.ncdc.noaa.gov/oa/reports/billionz.html.

NOAA Technical Report, NESDIS 142, 2013. Regional Climate Trends and Scenarios for the U.S., U.S. Department of Commerce, Washington, D.C.

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Volume 1, Issue 1, Pages 10-18, June 2014

Water-Level Trends in Aquifers of South Carolina

Scott V. Harder, Joseph A. Gellici and Andrew Wachob

AUTHORS: South Carolina Department of Natural Resources, Columbia, South Carolina, 29201, USA.

REFERENCE: Proceedings of the 2012 South Carolina Water Resources Conference, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. Groundwater levels are examined to document and evaluate short- and long-term trends observed in each of the major aquifers in the State. Data are compiled from groundwater-monitoring networks maintained by the South Carolina Department of Natural Resources (DNR), the South Carolina Department of Health and Environmental Control (DHEC), and the United States Geological Survey (USGS). The data are used in the support of groundwater management and allocation, assessment of droughts, groundwater-flow modeling, and resource assessment. Hydrographs from approximately 170 wells are reviewed with periods of record ranging from 1 to 56 years.

Water levels across most of the State were affected by droughts occurring from 1998-2002 and from 2007-2008. In the Piedmont, water-level declines varied substantially from 1 to over 10 ft during these drought periods. Though water levels typically returned to baseline levels in many wells, several sites experienced little to no recovery with overall downward trends of 10 to 12 ft from 2000 to 2012.

Middendorf aquifer levels in eastern Berkeley County have declined by approximately 55 ft since the early 1990s. In southern Florence County and southern Lexington County, water levels have declined by approximately 10 ft in the Middendorf aquifer with little to no recovery after the 1998-2002 and 2007-2008 droughts. Similar declines are noted in the Middendorf aquifer in Aiken, Allendale, and Barnwell Counties, where water levels have dropped 3 to 10 ft since the mid-1990s.

In the Black Creek aquifer, water levels in southern Marion County and southern Florence County have declined by 40 ft and 16 ft over their respective periods of record. In Aiken, Allendale, and Barnwell Counties, water levels have dropped 4 to 12 ft in the Black Creek aquifer since the mid-1990s, similar to declines observed in the Middendorf aquifer in these counties.

Water levels in the Tertiary sand aquifer have declined 6 to 15 ft in Allendale and Barnwell Counties since the mid-1990s, similar to patterns observed in the Middendorf and Black Creek aquifers in these counties. This pattern suggests that aquifers have not fully recovered to levels observed before the 1998-2002 drought.

Floridan aquifer water levels have experienced a leveling off or a slight recovery during the past ten years after steady declines throughout the 1970s and 1980s at several wells sites in Beaufort County. Observations in southern Colleton County and southern Charleston County indicate water-level declines in the Floridan aquifer of about 8 and 12 ft, respectively, since 2000. Observations in central Charleston County indicate a decline of about 20 ft since the early 1980s, while observations in northern Colleton County indicate a decline of about 20 ft since the late 1970s.

INTRODUCTION

The South Carolina Department of Natural Resources (DNR) routinely collects groundwater-level data for water-resource assessments and for management and planning purposes. These data are used to identify short- and long-term changes in groundwater levels and storage due to changes in withdrawals, recharge rates, and climatic conditions; to calibrate groundwater-flow models; and to determine regional hydraulic gradients and groundwater-flow rates and directions of the major aquifers. DNR's base groundwater-monitoring network currently includes 122 wells (Figure 1). Water levels of 86 wells are measured hourly with automated data recorders (ADRs); the remaining wells are measured periodically, typically on a bimonthly basis, using an electric measuring tape. Most monitoring wells have been measured since the mid-to-late 1990s, although a number of wells existed before then, one dating back to 1955.

2014 South Carolina Water Resources Conference

Informing Strategic Water Planning to Address
Natural Resource, Community and Economic Challenges

October 15-16, 2014
Columbia Metropolitan Convention Center
www.scwaterconference.org

2014 Conference Planning Committee

Co-Chairs:

Gene W. Eidson, Clemson University Institute of Computational Ecology
Calvin B. Sawyer, Clemson University Center for Watershed Excellence

Conference Coordinator:

Dawn Anticole White, Clemson University Institute of Computational Ecology

Committee Members:

Black & Veatch, Robert Osborne
Clemson University Center for Watershed Excellence, Katie Giacalone
Clemson University Strom Thurmond Institute, Jeffery S. Allen, Lori Dickes, Robert T. Carey
Coastal Carolina University, Susan Libes
College of Charleston, Timothy J. Callahan
NOAA Coastal Services Center, Chris Ellis
Santee Cooper, Mike Harrelson
Savannah River National Laboratory, John J. Mayer
SCANA, Darrell Shier, Brandon G. Stutts
SCDHEC - Bureau of Water, David Graves, Heather Preston
SCDHEC - Ocean and Coastal Resource Management, Rheta Geddings DiNovo
S.C. Sea Grant Consortium, M. Richard DeVoe, Susannah Sheldon
University of South Carolina, Gwendelyn Geidel
USDA Forest Service, Devendra Amatya
U.S. Army Corps of Engineers, Colton Bowles
U.S. Geological Survey, Noel Hurley, Eric Strom

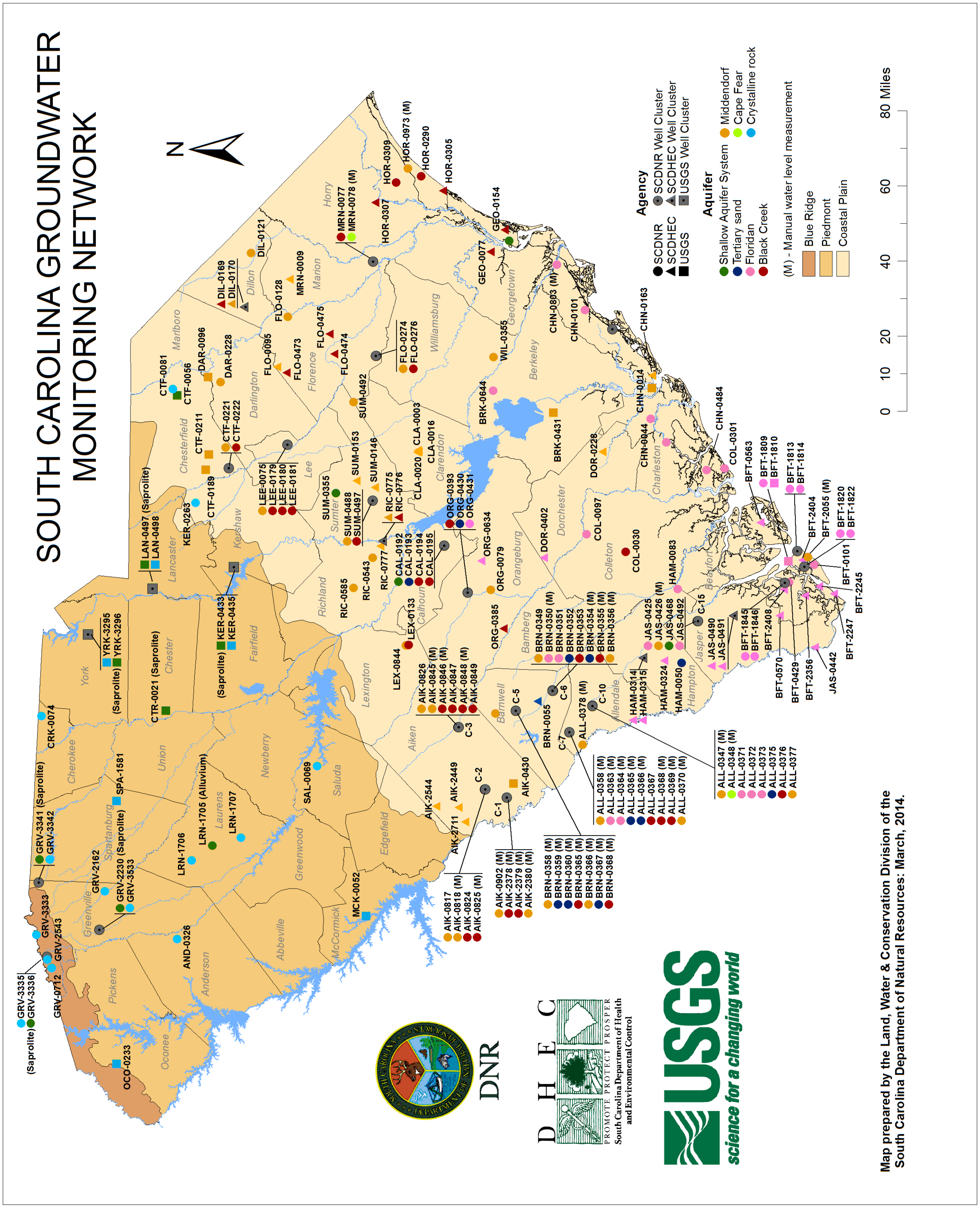


Figure 1. South Carolina groundwater monitoring network.

Reported groundwater use for the State as a whole has shown no noticeable trend from 2002 to 2012, and exhibits annual fluctuations indicative of climate conditions. Reported irrigation on a statewide basis has increased noticeably over the same period, while reported industrial use has declined. Reported groundwater use for water supply has also shown little no noticeable trend from 2002 to 2012. However, the potential for significant increases in groundwater use for agricultural and golf course irrigation, industry, energy production, and public water supply over the next several decades stresses the need for long-term groundwater-level monitoring. In addition, recent multi-year droughts from 1998-2002 and 2007-2008 have highlighted the importance of long-term groundwater-level data in the assessment of ground water resources.

The DNR well network is part of a collaborative monitoring effort with the Department of Health and Environmental Control (DHEC) and the United States Geological Survey (USGS). The goal of this cooperative effort is to develop and maintain a statewide groundwater-monitoring network that provides scientifically defensible information for use in planning, managing, and developing South Carolina's groundwater resources in a responsible and sustainable manner for all current and future users. DHEC currently maintains 41 continuous groundwater level monitoring sites, while USGS maintains 18 sites.

The background and methods described in this study are for the DNR monitoring network. Groundwater level trends are discussed mainly for those wells in the DNR network; however, several USGS sites are referenced as well. Periods of record for wells in the DHEC network only range from 1 to 6 years, and hence, are too short to adequately evaluate trends. Wells sites for all three agencies are illustrated in Figure 1.

RELATED WORK

DNR has published a series of reports documenting groundwater-level data collected from the DNR monitoring network. Harwell and others (2004) documents water-level data collected from 56 wells during the period from 2000 through 2001. Agerton and others (2007) contains water-level data collected from 69 wells during the period from 2000 through 2005. Other groundwater-level compilations include intermittent and periodic water-level measurements of 16 Piedmont province wells and 266 Coastal Plain province wells by Waters (2003). That report represents 282 hydrographs and is the most extensive compilation of historical South Carolina groundwater-level data to date. Hydrograph records range from 6 to 50 years, and about one-third of the record sets span periods greater than 20 years. Gellici and others (2004) published selected groundwater data illustrating the effects of the 1998-2002 drought. More recently, Harder and others (2012) published groundwater-level data for 109 wells for the period from 2006 through 2010 and also reviewed groundwater-level trends for the all the major aquifers in the state.

METHODS

Well Numbering Systems and Hydrogeologic Framework

Wells are identified by a county well number. The county well number consists of a county-name abbreviation (Table 1) and a sequential number that is assigned by the DNR in coordination with USGS. For example, SAL-0069 represents the sixty-ninth well inventoried by the DNR in Saluda County.

Table 1. County-name abbreviations for monitoring network.

County	Abbreviation	County	Abbreviation
Abbeville	ABB	Greenwood	GNW
Aiken	AIK	Hampton	HAM
Allendale	ALL	Horry	HOR
Anderson	AND	Jasper	JAS
Bamberg	BAM	Kershaw	KER
Barnwell	BRN	Lancaster	LAN
Beaufort	BFT	Laurens	LRN
Berkeley	BRK	Lee	LEE
Calhoun	CAL	Lexington	LEX
Charleston	CHN	Marion	MRN
Cherokee	CRK	Marlboro	MLB
Chester	CTR	McCormick	MCK
Chesterfield	CTF	Newberry	NEW
Clarendon	CLA	Oconee	OCO
Colleton	COL	Orangeburg	ORG
Darlington	DAR	Pickens	PCK
Dillon	DIL	Richland	RIC
Dorchester	DOR	Saluda	SAL
Edgefield	EDG	Spartanburg	SPA
Fairfield	FAR	Sumter	SUM
Florence	FLO	Union	UNI
Georgetown	GEO	Williamsburg	WIL
Greenville	GRV	York	YRK

The hydrogeologic framework used in this report is that of Aucott and others (1987). Aucott divided the Coastal Plain sedimentary sequence into six aquifers, which in ascending order are: Cape Fear, Middendorf, Black Creek, Tertiary sand, Floridan, and shallow aquifer system (surficial). In 1995, Aadland and others presented a detailed hydrogeologic characterization of the Coastal Plain sequence at the Savannah River Site (SRS) and surrounding area that resulted in a revised hydrogeologic framework and a new hydrostratigraphic nomenclature for west-central South Carolina (Aadland and others, 1995). Aquifers and confining units were named after local geographic features near type-well localities and the previous aquifer names, which were based on geologic formations, were abandoned at SRS. This revised framework and new nomenclature were extended across the rest of the Coastal Plain in the report *Groundwater Availability in the Atlantic Coastal Plain of North and South Carolina* in the chapter entitled “Hydrogeologic Framework of the Atlantic Coastal Plain, North and South Carolina “(Gellici and Lautier, 2010). For this report, the names and framework of Aucott and others (1987) continue to be used, but wells are also assigned to aquifers using the new framework and nomenclature described by Gellici and Lautier as well. The three hydrogeologic frameworks are summarized in Figure 2.

Aquifers in the Piedmont and Blue Ridge provinces of the state are classified as crystalline rock or shallow aquifer system. The shallow aquifer system is further differentiated as saprolite or alluvium.

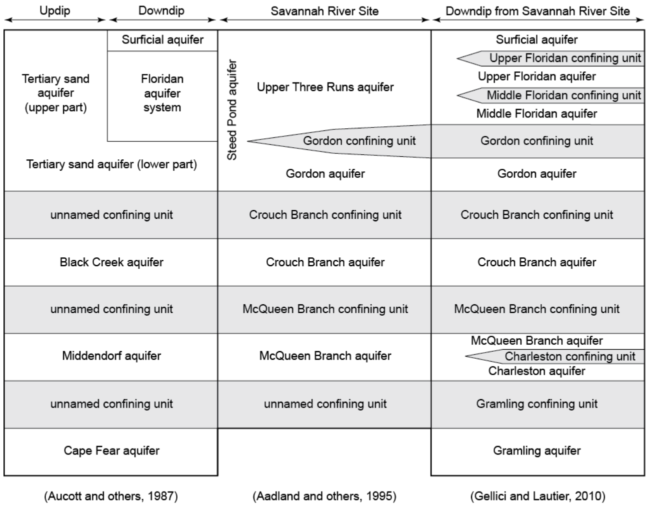


Figure 2. Three hydrogeologic frameworks for South Carolina. “Updip” refers to sediments in the upper Coastal Plain; “downdip” refers to sediments in the lower Coastal Plain.

Data Collection

Groundwater-level data are presented in feet above or below land surface and measurements and sensor settings are made relative to a specified measurement point. Some of the land-surface and measuring-point elevations were surveyed from USGS or South Carolina Geodetic Survey benchmarks and are reported to the nearest tenth or hundredth of a foot using the National Geodetic Vertical Datum of 1929 (NGVD29). Elevations at other sites were taken from USGS topographic maps and estimated to the nearest foot, and are considered accurate to one-half the map contour interval. Well locations were determined with the Global Positioning System (GPS) using the North American Datum of 1983 (NAD83).

Manual measurements typically are made with electric tapes, which are capable of an accuracy of 0.01 ft (feet). However, visibility, thermal expansion and contraction, and tape sinuosity diminish measurement accuracy in field conditions, and accuracies, therefore, are assumed to be no better than 0.05 ft in practice. Flowing artesian wells are manually measured with 0–30, 0–60, or 0–100 psi (pounds per square inch) range Bourdon-type test gages. The gages are calibrated annually by a commercial testing laboratory and are rated to 0.25 percent of their respective measurement ranges.

Water-level sensors used for automated monitoring stations include shaft encoders and pressure transducers whose readings are calibrated to manual measurements. Shaft encoders measure depth to water and have a rated accuracy and resolution of 0.01 ft. The sensor reading is set in reference to a manual tape measurement; however, well plumb, casing joints, and cable disturbances can affect subsequent readings. Measurements within 0.10 ft of a concurrent manual measurement are accepted, along with the corresponding records. Pressure transducers measure the height of water above the sensor. The sums of the transducer measurement (depth above probe) and corresponding taped measurement (depth to water) recorded at each site visit have been compared to determine transducer performance. Where the sum of measurements was found to differ by 0.2 ft from previous measurements, a potential instrument fault may have existed, but no record correction was applied. Where the specifications were exceeded repeatedly, either instruments were recalibrated or instrument failure was confirmed. If failure was confirmed, the transducer was replaced and the associated records were excluded from the hydrograph.

Logged measurements are stored in both raw-data and processed-data tables. The raw-data table contains uncorrected hourly measurements and reflects the readings and the performance of various sensors as they were originally stored in data loggers. Raw data are stored mainly "as is" and are archived at DNR for insight into hardware conditions and for quality assurance. Processed-data tables are corrected for barometric pressure, where appropriate, and are winnowed of measurement anomalies and hardware failures. Average daily water level is calculated for each day having 17 or more hourly measurements.

Groundwater data presented in this report are daily averaged and/or manual values. Groundwater data and statistics are available on the DNR website at http://www.dnr.sc.gov/water/hydro/groundwater/index.html. Additional information on the groundwater monitoring network can be found in Harder and others (2012).

RESULTS

Hydrographs are presented for the crystalline rock aquifer system in the Piedmont and Blue Ridge Provinces and for the four main aquifers of the Coastal Plain (Middendorf, Black Creek, Tertiary sand, and Floridan). The caption for each hydrograph includes the open or screened interval for the well, and in cases where the interval is unknown, the total depth of the well below land surface is listed instead. Wells constructed in crystalline rock or limestone are not generally screened and remain as an open hole, while wells constructed in unconsolidated sand sediments generally have screened casings in the aquifer(s) of interest. Nomenclatures used by both Aucott and others (1987) and Gellici and Lautier (2010) for the hydrogeologic framework are included in the figure caption for wells in the Coastal Plain.

Crystalline Rock Aquifer

Hydrographs for most wells in the Crystalline Rock aquifer show noticeable seasonal fluctuations, which can range from 1 ft in AND-0326 (Figure 3) to 16 ft in SAL-0069 (Figure 4). Significant declines in water levels due to the multi-year droughts of 1998-2002 and 2007-2008 are observed in some wells such as CRK-0074 (Figure 5), GRV-3342, and LRN-1706, but declines are less severe in other wells such as GRV-2543 (Figure 6), GRV-3335, and AND-0326 (Figure 3). Most sites in the DNR network have recovered from the effects of these droughts and little to no long-term declines are observed; however, MCK-0052 and SPA-1585, both maintained by the USGS, have experienced long-term declines of over 10 ft and 15 ft, respectively, over their 18-year periods of record.

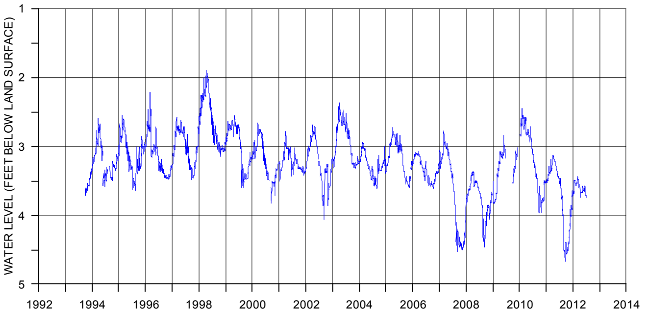


Figure 3. Daily average water levels for AND-0326 (Crystalline Rock aquifer; open hole interval 75-398 ft).

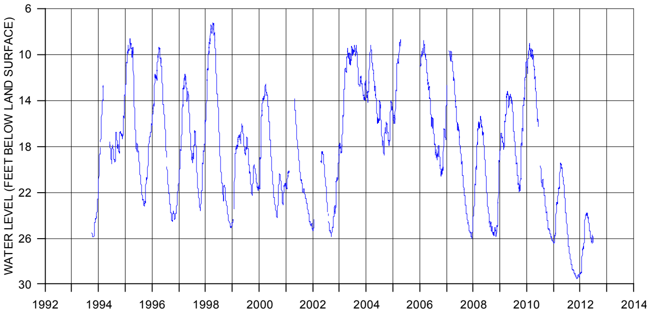


Figure 4. Daily average water levels for SAL-0069 (Crystalline Rock aquifer; open hole interval 92-480 ft).

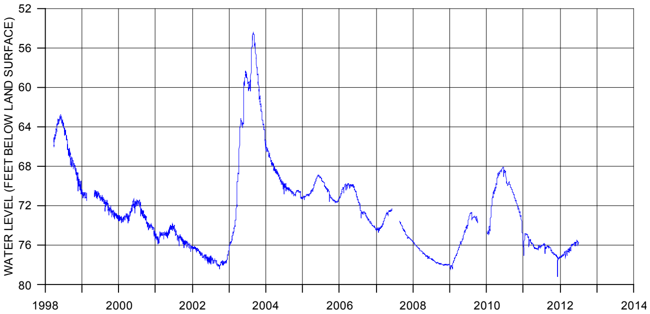


Figure 5. Daily average water levels for CRK-0074 (Crystalline Rock aquifer; open hole interval 99-265 ft).

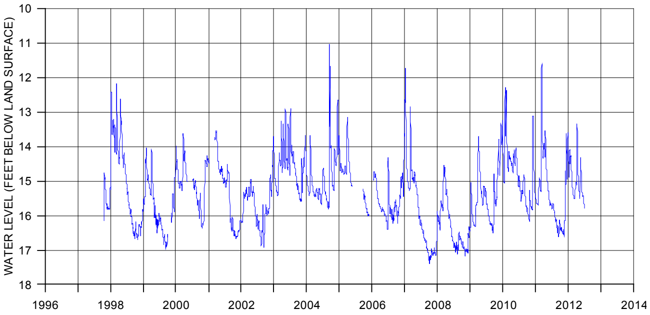


Figure 6. Daily average water levels for GRV-2543 (Crystalline Rock aquifer; total depth 50 ft).

Middendorf

In southern Florence County, the water level in the Middendorf aquifer has steadily dropped about 10 ft over the past ten years at well FLO-0274 (Figure 7) in Lake City. In southern Lexington County at well LEX-0844, the water level in the Middendorf declined about 10 ft during the 1998-2002 drought, leveled off after the drought, and has yet to fully recover to pre-drought levels (Figure 8). Similar declines are noted in the Middendorf aquifer in Aiken, Allendale, and Barnwell Counties, where water levels have dropped 3 to 10 ft since the mid-1990s (AIK-0845, ALL-0347 and BRN-0349, for example).

Well BFT-2055, at Hilton Head Island, is screened in both the Cape Fear and Middendorf aquifers; measurements therefore reflect composite water levels. They are presumed to more closely reflect Middendorf water levels, owing to that system's greater thickness and hydraulic conductivity. Consequently, BFT-2055 measurements are presented with Middendorf aquifer data. Water levels in wells BFT-2055 (Figure 9) and JAS-0426 have been declining over the past 10 years, by 28 ft in BFT-2055 and by about 12 ft in JAS-0426. BRK-0431, a well maintained by the USGS, has experienced a decline of approximately 55 ft since 1990.

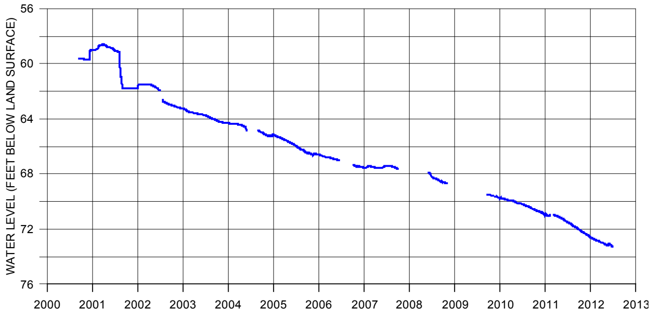


Figure 7. Daily average water levels for FLO-0274 (Middendorf/ McQueen Branch aquifer; screened interval 540-560 ft).

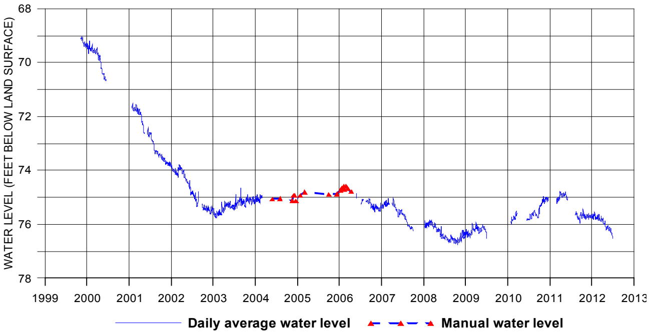


Figure 8. Daily average and manual water levels for LEX-0844 (Middendorf/McQueen Branch aquifer; screened interval 392-502 ft).

In well FLO-0128, the water level has been recovering since August 1999 when it hit an all-time low of 92.1 ft below land surface (Figure 10). By 2010, the water level recovered to 41.2 ft bls, as the City of Florence continues to supplement its groundwater supply with surface water from the Pee Dee River.

In contrast to the larger declines observed in the western and southern Coastal Plain, water levels in Darlington, Lee, and Richland Counties (DAR-0228, LEE-0075, RIC-0543, and RIC-0585) have experienced little to no long-term decline over the past 10 to 15 years (Figure 11). Seasonal fluctuations are observed in the data from wells in these counties and have been more pronounced over the last 5 years. Drawdowns from the severe droughts from 1998-2002 and from 2007-2008 are observed as well; however, water levels typically returned to baseline levels after each of these two droughts.

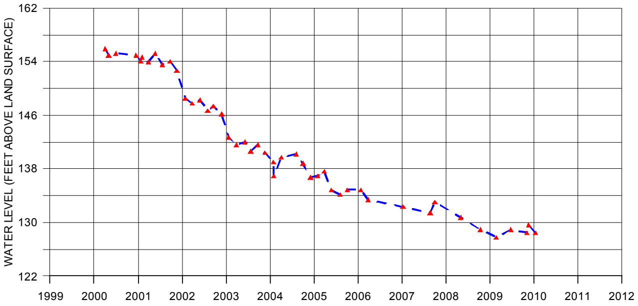


Figure 9. Manual water levels for BFT-2055 (Middendorf/ Gramling aquifer; screened interval 2,782-3,688 ft). Middendorf water levels rise above land surface at this site.

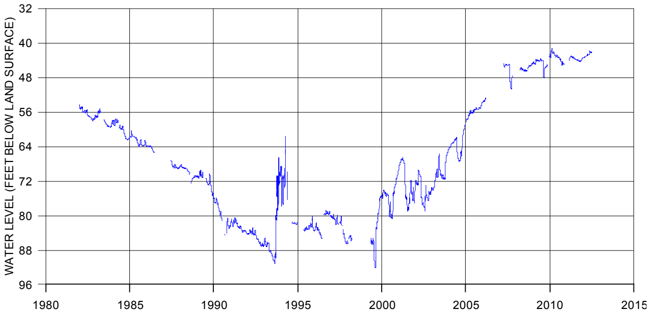


Figure 10. Daily average water levels for FLO-0128 (Middendorf/ McQueen Branch aquifer; screened interval 265-690 ft).

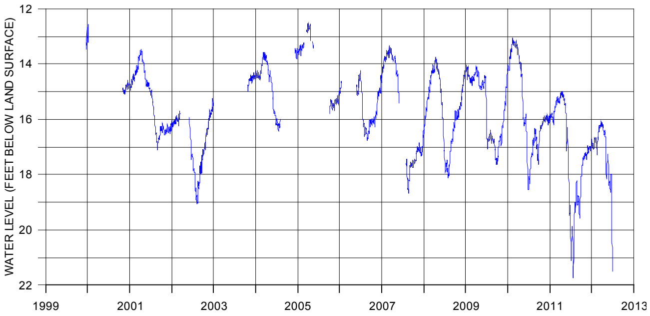


Figure 11. Daily average water levels for LEE-0075 (Middendorf / McQueen Branch aquifer; screened interval 306-356 ft).

Black Creek

The water level in well MRN-0077 (Figure 12), located at Britton's Neck, steadily declined about 40 ft from 1993 to 2010. Well FLO-0276 (Figure 13), in Lake City, has seen its water level drop 16 ft from 2001 to 2010. In Aiken, Allendale, and Barnwell Counties, water levels have dropped 4 to 12 ft in the Black Creek aquifer since the mid-1990s (AIK-0847, ALL-0367 and BRN-0355, for example), similar to declines observed in the Middendorf aquifer in these counties (Figure 14).

Water levels in COL-0030 have experienced declines of approximately 4 ft from 1996 to 2010, while maintaining noticeable seasonal fluctuations (Figure 15). Water levels at ORG-0393 have seen long-term declines of only 1 to 2 ft since 2001, but the water levels exhibit strong seasonal fluctuations ranging from 8 to 20 ft (Figure 16).

Tertiary Sand

Water levels in the Tertiary sand aquifer have declined about 6 to 15 ft in Allendale (ALL-0375; Figure 17) and Barnwell Counties (BRN-0352; Figure 18) since the mid-1990s, similar to patterns observed in the Middendorf and Black Creek aquifers in these counties. This pattern suggests that aquifers have not fully recovered to levels observed before the 1998-2002 drought. Water levels at ORG-0430 have had smaller overall declines of 4 to 5 ft since 2001 while maintaining strong seasonal fluctuations on the order of 8 to 10 ft (Figure 19).

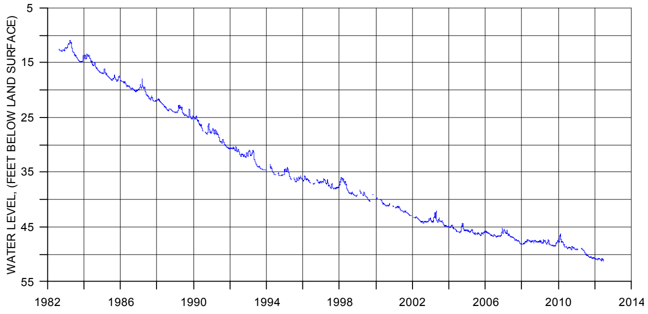


Figure 12. Daily average water levels for MRN-0077 (Black Creek/Crouch Branch aquifer; 325-355 ft).

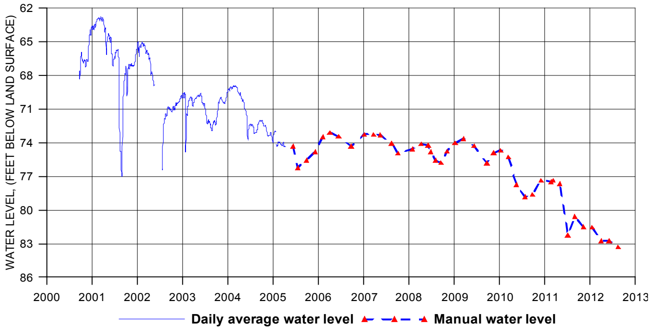


Figure 13. Daily average and manual water levels for FLO-0276 (Black Creek/Crouch Branch aquifer; screened interval 230-250 ft).

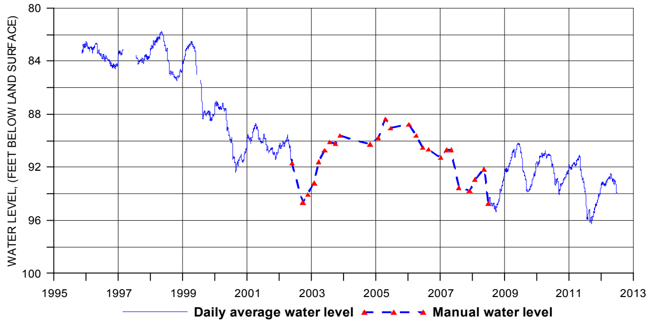


Figure 14. Daily average and manual water levels for ALL-0367 (Black Creek/Crouch Branch aquifer; screened interval 551-561 ft).

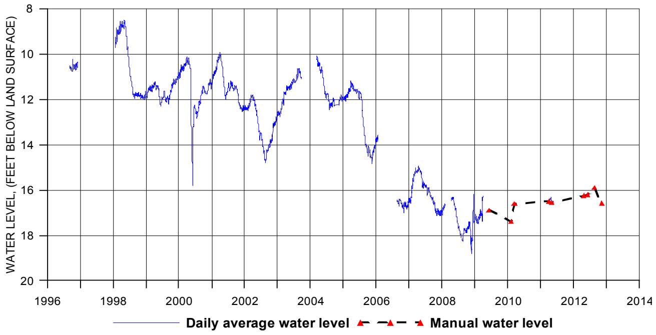


Figure 15. Daily average and manual water levels for COL-0030 (Black Creek/Crouch Branch aquifer; total depth 1,340 ft).

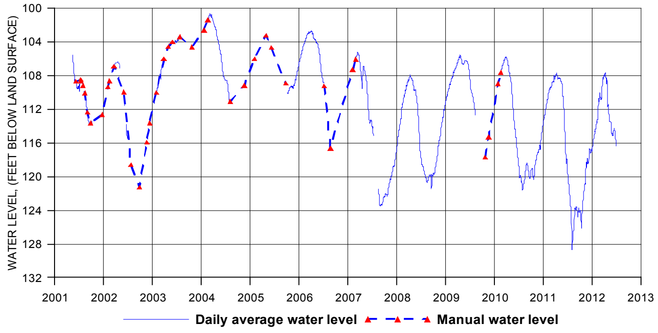


Figure 16. Daily average and manual water levels for ORG-0393 (Black Creek/Crouch Branch aquifer; screened interval 423-463 ft).

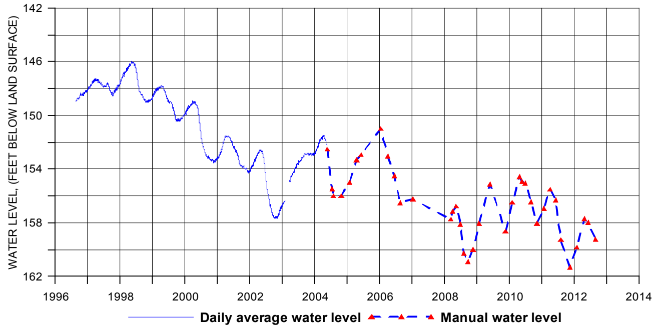


Figure 17. Daily average and manual water levels for ALL-0375 (Tertiary sand/Gordon aquifer; screened interval 453-578 ft).

Floridan

Water levels in BFT-0101 (Figure 20) have shown a slight recovery during the past ten years after a steady decline throughout the 1970s and 1980s; however, seasonal fluctuations have increased from 1 to 2 ft to 4 to 9 ft during the same period. Note the longer time scale in Figure 20.

Well BFT-0429 has seen overall water levels remain steady after a decline of approximately 5 ft during the 1970s and 1980s. Similar to BFT-0101, the magnitude of seasonal fluctuations in this well has increased from 1 to 2 ft to 5 to 7 ft during the past several decades.

Wells COL-0301 (Figure 21) and CHN-0484 (Figure 22), both located near Edisto Beach, have seen water-level declines of about 8 and 12 ft, respectively, since 2000. Both of these wells also exhibit strong seasonal fluctuations. The water level in well CHN-0044 (Figure 23) has declined about 20 ft since the early 1980s, and well COL-0097 (Figure 24) has seen a decline of about 20 ft since the late 1970s.

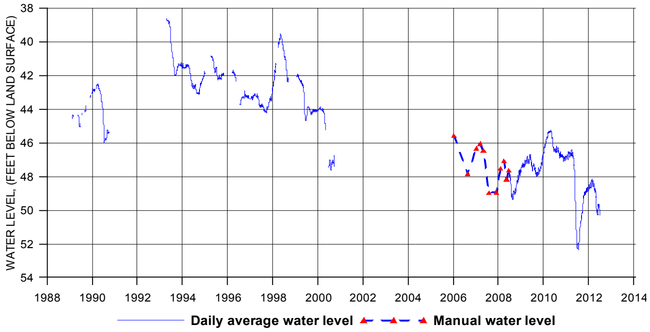


Figure 18. Daily average and manual water levels for BRN-0352 (Tertiary sand/Gordon aquifer; screened interval 278-288 ft).

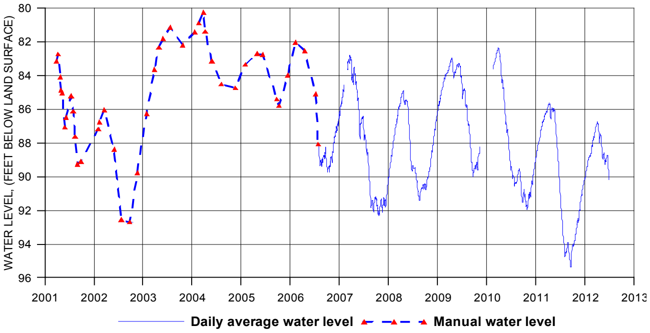


Figure 19. Daily average and manual water levels for ORG-0430 (Tertiary sand/Gordon aquifer; screened interval 205-265 ft).

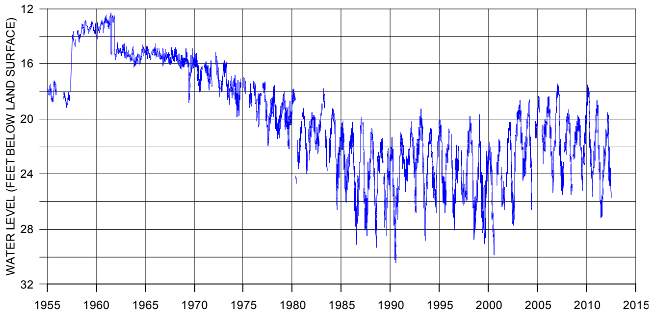


Figure 20. Daily average water levels for BFT-0101 (Floridan/ Upper Floridan aquifer; open hole interval 129-442 ft).

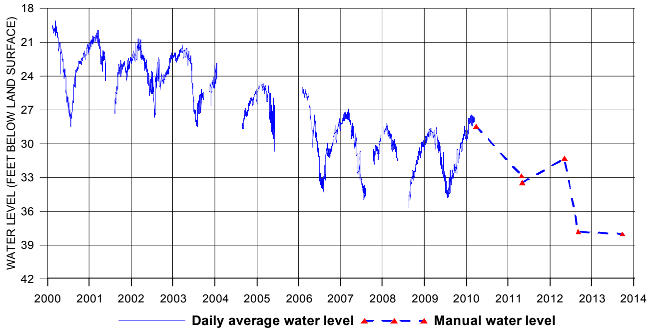


Figure 21. Daily average and manual water levels for COL-0301 (Floridan/aquifer zone within Gordon confining unit; open hole interval 516-545 ft).

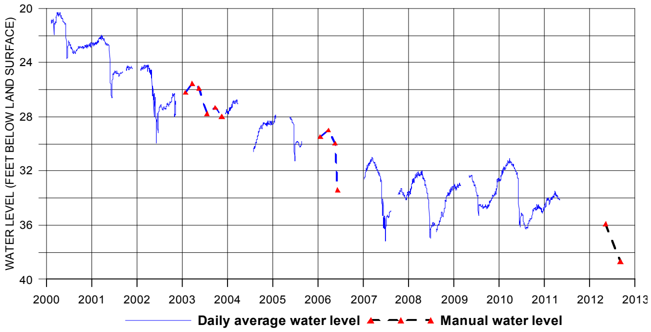


Figure 22. Daily average and manual water levels for CHN-0484 (Floridan/aquifer zone within Gordon confining unit; open hole interval 280-560 ft).

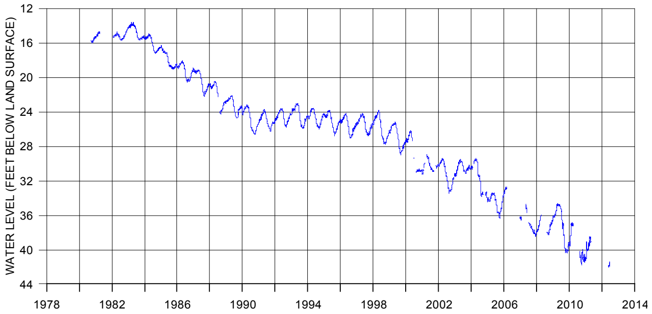


Figure 23. Daily average water levels for CHN-0044 (Floridan and Tertiary sand/Middle Floridan and Gordon aquifer; open hole interval 180-434 ft).

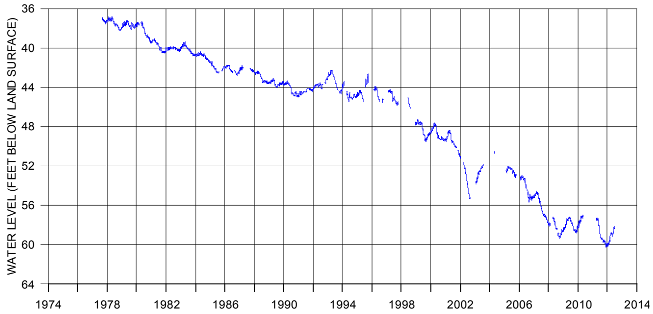


Figure 24. Daily average water levels for COL-0097 (Floridan/ Middle Floridan aquifer; open hole interval 132-342 ft).

DISCUSSION

Long-term groundwater-level declines have been observed in each of the major aquifers in the state. These declines are likely a result of both drought and groundwater pumping. Many well sites experienced a strong response to the multi-year droughts of 1998-2002 and 2007-2008. However, while some wells experienced a recovery after these droughts, other well sites did not.

Seasonal fluctuations are evident at many wells owing to higher recharge rates in winter as compared to summer. In Colleton and Charleston Counties, as well as in Beaufort County, the larger fluctuations observed over the past several decades are likely the result of natural seasonal variations coupled with increasing rates of irrigation.

There are many challenges for the State's water managers in the interpretation of groundwater-level data throughout the state. First, water-level declines can be caused by drought and/or localized pumping for water supply and irrigation as well as from the cumulative effects of pumping over broader regions. In addition, uncertainties in recharge areas and recharge rates for the State's aquifers add to the complexity of understanding groundwater level behavior. Many of the wells in the network have only been monitored for 10 to 15 years and, hence, may lack a sufficient period of record from which to adequately evaluate trends. Lastly, despite having over 170 continuously monitored wells by DNR, DHEC, and the USGS, large areas of the state, particularly the middle coastal plain, currently have little to no continuous monitoring.

These challenges make it difficult to evaluate the significance of these observed water-level declines; however, these trends highlight the importance of maintaining a state groundwater-monitoring network and the establishment of long-term groundwater datasets. Future work should include adding wells in those aquifers and areas of the State where current monitoring is poor or nonexistent. In addition, a more detailed study on groundwater-level trends should be completed that takes into account climate variability and local/regional groundwater use. Such a study is needed to differentiate the effects of drought and groundwater pumping on water level behavior.

LITERATURE CITED

Aadland, R.K., Gellici, J.A., and Thayer, P.A., 1995, Hydrogeologic framework of west-central South Carolina: *South Carolina Department of Natural Resources, Water Resources Division Report 5*, 200 p.

Agerton, K.E., Park, A.D., Gawne, C.E., and Wachob, A., 2007, Water resources data for South Carolina, 2000-2005: *South Carolina Department of Natural Resources, Water Resources Report 41*, 91 p.

Aucott, W.R., Davis, M.E., and Speiran, G.K., 1987, Geohydrologic framework of the Coastal Plain aquifers of South Carolina: *U.S. Geological Survey Water-Resources Investigation Report 85-4271*, 7 sheets.

Gellici, J.A., Kiuchi, M., Harwell, S.L., and Badr, A.W., 2004, Hydrologic effects of the June 1998-August 2002 drought in South Carolina: *South Carolina Department of Natural Resources, Water Resources Report 34*, 49 p.

Gellici, J.A., and Lautier, J.C., 2010, Hydrogeologic framework of the Atlantic Coastal Plain, North and South Carolina, in Campbell, B.G., and Coes, A.L., eds., Groundwater availability in the Atlantic Coastal Plain of North and South Carolina: *U.S. Geological Survey Professional Paper 1773*, p. 49-162.

Harder, S.V., Gellici, J.A., Gawne, C.E., and Wachob, A., 2012, Groundwater levels in South Carolina, 2006-2010: *South Carolina Department of Natural Resources, Water Resources Report 50*, 154 p.

Harwell, S.L., Park, A.D., Hockensmith, B.L., and Gawne, C.E., 2004, Water resources data for South Carolina 2000-2001: *South Carolina Department of Natural Resources, Water Resources Report 31*, 86 p.

Waters, K.E., 2003, Water levels in South Carolina-A compilation of historical water-level data: *South Carolina Department of Natural Resources, Land, Water and Conservation Division Report 26*, 300 p.

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Volume 1, Issue 1, Pages 19-25, June 2014

A Case Study in Watershed-Based Plan Development and Implementation for the May River Watershed in Bluffton, South Carolina

Kimberly W. Jones[1] and Ronald Bullman[2]

AUTHORS: [1]Director, Stormwater Management Division, Town of Bluffton, P.O. Box 386, 20 Bridge Street, Bluffton, South Carolina 29910. [2]Land Development Manager, Ryland Homes, 216 Seven Farms Drive, Suite 200, Charleston, South Carolina 29492.

REFERENCE: Proceedings of the 2012 South Carolina Water Resources Conference, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. The Town of Bluffton, South Carolina was a one square mile coastal village until it experienced exponential growth in the early 2000s, and today is approximately 54 square miles. Until this recent growth, few sources of possible impairments to water quality were recognized within the watershed, and even fewer within close proximity to the river itself. In 2007, the Town was told by the S.C. Department of Health and Environmental Control (SCDHEC) that fecal coliform levels in the May River headwaters were increasing and in 2009 the river received a shellfish harvesting classification down-grade. In response to this down-grade, the Town of Bluffton, with Beaufort County and stakeholders, committed to take action to restore shellfish harvesting in the river and to prevent further degradation to the river. Following the U.S. EPA (EPA) guidelines for developing watershed plans, Town staff worked for nearly a year with consultants, Beaufort County, topic experts and local residents to develop the May River Watershed Action Plan which was adopted by Town Council in November 2011. The May River Watershed Action Plan:

- provides a strategy for assessing problems and implementing solutions to restore shellfish harvesting in the May River;
- provides a strategy for assessing and implementing preventative measures to protect the May River from future degradation; and
- identifies opportunities for land purchase, conservation easement purchase, and public, private and public/private opportunities for retrofit projects.

This case study outlines how the Town implemented the EPA's planning process; the lessons learned during the development of the May River Watershed Action Plan for use by other communities faced with a similar need; the immediate results of implementing the plan; and a number of short-term results that have been achieved.

INTRODUCTION

This case study documents the development, initial implementation and results of a watershed-based plan for the May River Watershed (HUC 3060110-03) in response to rising fecal coliform levels. It serves as a real-world example of the EPA approach to develop a restorative watershed plan (EPA, 2008). This process and the lessons learned are pertinent for both coastal and interior water resource managers whose goal is to develop a comprehensive approach to either prevent, or respond to, a Clean Water Act Section 303(d) listed waterbody. In South Carolina alone, SCDHEC states that there are 1,108 Total Impairments among 920 Impaired Sites within the state's waterways (draft SCDHEC, 2014).

BACKGROUND

The Town of Bluffton, located in southern Beaufort County, South Carolina, is a coastal community with strong ties to its local waterbody, the May River. The May River is a regionally significant waterbody for a number of reasons. First, the river contains numerous

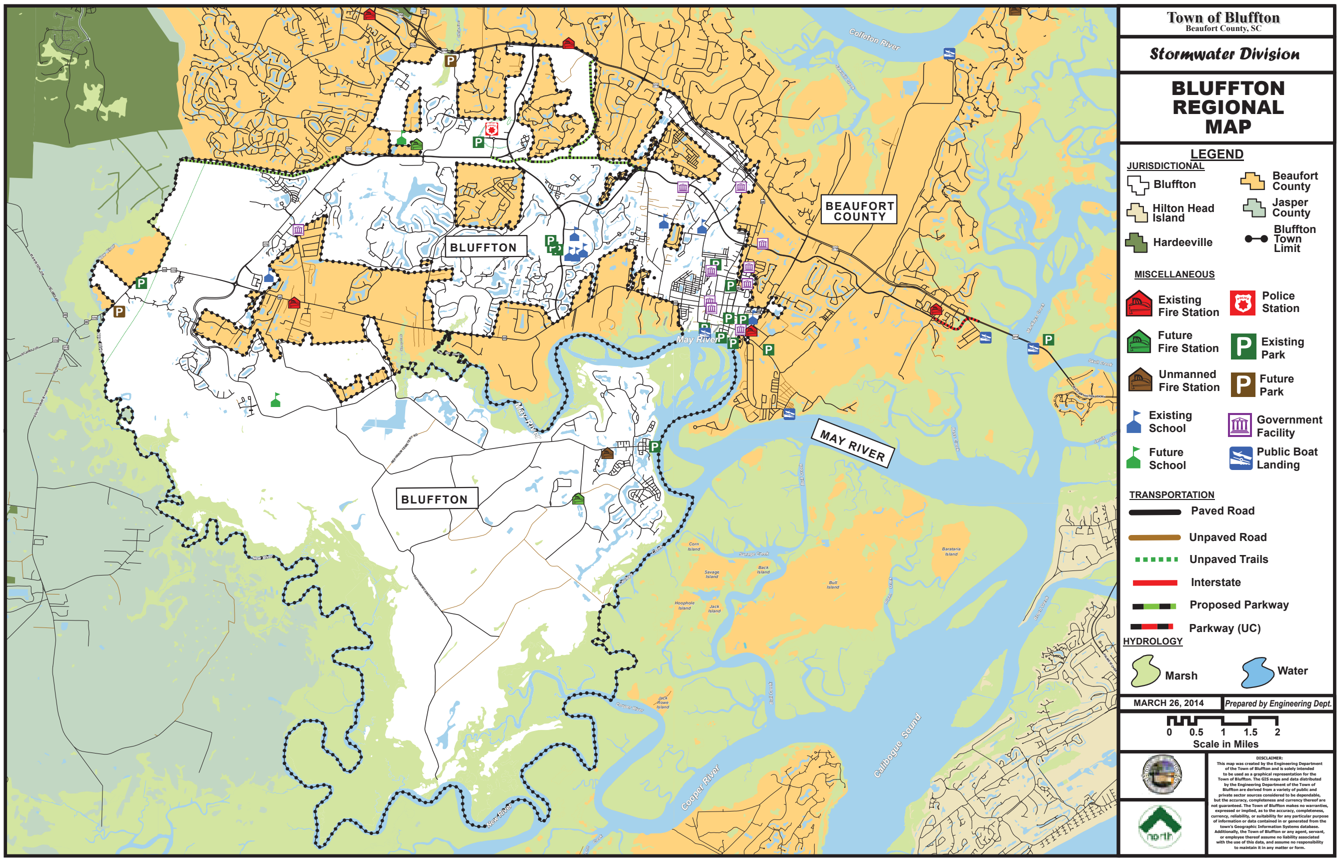


Figure 1. Bluffton region and May River location.

natural resource populations that are directly harvested and utilized by local and regional residents. Second, the aesthetics and views of the May River waterbody increase the popularity of the area for continued commercial, residential, and tourist visitation and growth, thus tying the Town's economic conditions directly and indirectly to the river. Finally, the river provides a sense of community character and pride that is locally and regionally recognized.

The May River watershed is located within the jurisdictions of the Town of Bluffton and Beaufort County, where it bisects the Town's jurisdiction (Figure 1). The Town of Bluffton was one square mile for over 130 years until 1987 when the Town annexed additional parcels into its jurisdiction. Today Bluffton is approximately 54 square miles and one of the largest municipalities in South Carolina. However the majority of this growth occurred within the first decade of 2000. The annexations resulted in substantial residential development, resulting in land use being converted from substantial acreage of pine crops to residential subdivisions with increased impervious surface and associated stormwater runoff.

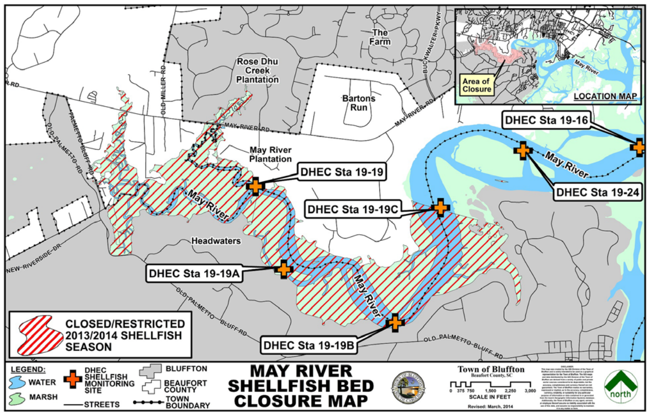


Figure 2. Shellfish bed closure in the May River.

In 2007, SCDHEC told the Town that fecal coliform levels in the headwaters of the May River were increasing. In 2008, in response to this increase, the EPA and SCDHEC designated the May River as a priority and threatened watershed, thus making it eligible for EPA Clean Water Act Section 319 grant funding. In 2009 the Town developed an initial watershed plan which was awarded an EPA 319 grant by SCDHEC for implementation to reduce the fecal coliform levels. Despite initial implementation, in the fall of 2009 the river received its first-ever shellfish harvesting classification down-grade in the headwaters due to high fecal coliform levels (Figure 2).

While recreational contact is still permissible, rising fecal coliform levels can be an indicator of the deterioration of the overall health of a watershed since an increase in this pollutant is often associated with an increase in other pollutants including sediments, nutrients, and potentially viruses. In response to this degradation of water quality, the Town of Bluffton, in conjunction with Beaufort County and local citizens, voluntarily committed to take action to augment the existing 319-funded watershed plan to develop an updated, comprehensive May River Watershed Action Plan. This expanded plan would include both structural and nonstructural Best Management Practices (BMPs) to restore shellfish harvesting in the river, as well as include measures to prevent further degradation in the May River. Adapting the EPA guidelines for watershed plan development (EPA, 2008), Town staff worked for nearly a year with consultants, Beaufort County, and local residents to develop the May River Watershed Action Plan (AMEC, 2011). Town Council adopted the May River Watershed Action Plan (Action Plan) by Resolution in November 2011.

PROJECT GOAL AND OBJECTIVES

Clearly the immediate goal of the planning process was to develop a comprehensive watershed management plan. However, as the Town and consultants worked through the EPA watershed management plan development steps, detailed below in "Methods," identifying and keeping the ultimate goal of the Action Plan in mind was instrumental in guiding document development.

The goal of the May River Watershed Action Plan is to restore shellfish harvesting within the headwaters of the May River and protect the river from future degradation. To achieve the goal the objectives for the Action Plan include:

- providing a strategy for assessing problems and implementing solutions to restore shellfish harvesting in the May River;
- providing a strategy for assessing and implementing preventative measures to protect the May River from future degradation;.
- identifying opportunities for land purchase, conservation easement purchase, and public, private, and public/private opportunities for retrofit projects;
- establishing priorities, identifying funding opportunities, coordinating specific partners and policies (i.e. ordinance changes), and establishing timelines such that the Town can use this information as a business plan to be implemented with other Town annual Capital Improvement and Budgeting programs; and
- serving as a template for other area watershed action plans within the Town's jurisdiction.

The Action Plan utilizes the significant amount of available information, gathered previously over many years, regarding the watershed and the May River itself. It also incorporates lessons learned from previously implemented actions and Best Management Practices within this watershed and similar watersheds to develop a strategy with specific short-, medium-, and long-term actions for measurable water quality improvement. The May River Watershed Action Plan allows the Town of Bluffton to have earlier implementation of projects for short term results and develop community-supported long-term strategies to return the May River Watershed to full shellfish harvesting status.

METHODS

Adapting the guidelines set out by the EPA for developing watershed plans, the Town worked through each of the following steps detailed further below:

Set Goal and Initial Objectives

The ultimate goal of the May River Watershed Action Plan is to restore shellfish harvesting throughout the May River and to protect the river from future degradation. However, identifying measurable objectives across various time frames is an important component in the Action Plan's development. One of the biggest threats the Town recognized to any watershed improvement or protection plan is taking early meaningful steps. Often the full list of projects needed to completely restore and protect a watershed can overwhelm the decision-making process and prevent any improvement from taking place.

Therefore, the Action Plan priority projects have been identified with respect not only to their anticipated performance, but also to their rate of implementation. The rate of implementation becomes an important factor as the cumulative loading reductions will be higher due to earlier implementation of projects. A timeline for all Action Plan projects and programs has been identified and allows for the proper policies, partnerships and funding mechanisms to be developed for successful implementation.

Environmental Inventory

Conducting an environmental inventory of the watershed is an integral step in the planning process. Many historical and current data sets may be available and a thorough literature search including water quality sampling reports, land use data, and wetland coverage can provide key information.

A wealth of previous and current environmental data for the May River watershed exists from a number of independently-conducted, and town-sponsored, monitoring programs and studies. These monitoring programs and studies include the SCDHEC - Shellfish Management Area 19 monitoring data (Monday, 2007-2012), the SC Estuarine and Coastal Habitats Assessment Program (Van Dolah, et. al., 2006), May River Baseline Assessment (Van Dolah, et.al., 2004), May River Waterbody Management Plan (Kiernan, 2008), Water Quality Concerns in the May River (Bergquist, 2010), as well as an on-going, weekly, water quality monitoring program for fecal coliform "hot spot" identification. This program was initiated by the Town in 2008 in partnership with the University of South Carolina Beaufort - Gateway Campus and Beaufort County.

These data and reports characterize the watershed and its changes over time, thus identifying potential areas to implement structural and non-structural BMP retrofits and preventative measures.

One of the most striking occurrences noted is that stormwater lagoon discharges as a whole are low in fecal coliform concentrations. However, when these discharges leave the outfall structures and enter the stormwater outfall ditches, the fecal coliform concentrations can increase by ten-fold (Ahern et. al., 2012). While the mechanism by which this phenomenon occurs is still not completely understood, the results have been documented in both the Ahern, et. al. (2012) study as well as within the Town's on-going weekly water quality monitoring program.

Social Inventory

Equal in importance to conducting an environmental inventory is conducting a social inventory of stakeholders. This group should include representatives of a variety of perspectives to develop community involvement and buy-in to the plan.

This broad-spectrum approach for the Town included representatives from the general public, community leaders, developers and subject-matter experts (both public and private sector). After these individuals were identified, the Town engaged them in various activities including committees, workshops, and advisory groups, ensuring community engagement in the process of the Action Plan's development.

Additionally, when a draft of the document was completed, an evening public meeting was held to garner wide public review and comments. This draft was also vetted by the Town's Water Quality Technical Advisory Committee comprised of water quality experts from NOAA, EPA, USGS, USACOE and state university representatives. Comments from both meetings were documented and utilized to refine the final version.

Design an Implementation Program

To show activity and dedication to improving water quality conditions, the Town developed an initial watershed plan directed at reducing fecal coliform sources. The initial plan was submitted to SCDHEC in response to a Request for Proposals (RFP) for a U.S. EPA 319 grant. In 2009, SCDHEC awarded the Town a 319 grant which included over a dozen projects. Several of these projects were chosen based upon their common use by other communities. These 319-funded immediate actions included:

- rain barrel/rain garden program,
- septic system inspections/pump outs,
- pet waste stations,
- social marketing campaign,
- unified development ordinance overhaul based on watershed management principles,
- bird roosting deterrents, and
- stormwater BMP pilot project retrofit.

Again, these projects were implemented to not only improve water quality within the May River and its watershed immediately, but to also show action, raise community awareness to the problem, and involve the community in several of the solutions.

Develop Watershed Action Plan

With the assistance of previously identified stakeholders, consultants, governmental and non-governmental partners, the available information and recommendations from the multiple studies previously conducted were synthesized into the May River Watershed Action Plan from December 2010 to November 2011. The final document incorporates structural and non-structural BMPs, as well as restorative and preventative measures. Town Council adopted by Resolution the May River Watershed

Action Plan in November 2011 and formed a permanent Advisory Committee in June 2012. The Committee is tasked with advising and guiding the Town on future and existing projects and strategies aimed at restoring shellfish harvesting in the May River. Their responsibilities include the following:

- reviewing and evaluating actions based on policy changes presented by Town staff;
- reviewing and evaluating actions based on targeted or proposed projects presented by Town staff;
- reviewing and evaluating actions based on partnership opportunities presented by Town staff;
- reviewing and evaluating actions based on funding opportunities presented by Town staff;
- offering experience, knowledge, expertise and guidance advancing the overall goals of the Action Plan; and
- any other applicable items deemed necessary.

Implement the Watershed Action Plan

With short-term, mid-term and long-term projects identified in the Action Plan, implementation began immediately with the smaller projects included in the 319 grant. These accomplishments are summarized in the "Results" section.

Simultaneously, based on prioritization procedures developed in the Action Plan, four initial restorative BMP projects have been identified. These projects were identified as priorities based upon weekly fecal coliform "hot spot" monitoring results, potential fecal coliform loading reduction after a BMP retrofit, available funding and land access.

Measure Progress and Make Adjustments

The Action Plan is a living document and is expected to be updated periodically by staff as the identified strategies and tactics become implemented and further developed. It should be noted that as this document is updated, additional studies and other work products are expected. These work products will be added as appendices or may be included as references to external sources (e.g. monitoring databases, websites). This ensures that future work products will be incorporated in this Action Plan and can be properly utilized, that interested parties can see the technical basis for the recommended strategies and tactics, and will prevent the document from becoming overly cumbersome to the point that it is no longer easy to use.

RESULTS

The results of the process are varied and on-going. Most notably, the Action Plan itself was developed with community input, adopted by Town Council as a guiding document, and is currently being utilized by the Town to guide both structural and non-structural BMP implementation. The document and its supporting appendices may be found at: http://www.townofbluffton.sc.gov/government/Pages/ordinances.aspx.

To date a number of activities, projects and programs have been completed and are on-going throughout the watershed including:

- 175 (55-gallon size) rain barrels installed;
- 16 rain gardens installed;
- 98 septic system maintenance/repair service calls;
- 10 pet waste stations installed in public areas;
- 6 trash cans in Old Town historic district installed;
- 5 Doggie Dooley pet septic systems installed;
- 1 manure management plan and riparian buffer garden installed;
- RV/campground waste management plan developed;
- unified development ordinance overhaul based on watershed management principles adopted, including a stormwater volume control requirement;
- animal waste ordinance completed;
- social marketing campaign completed including development of "Neighbors for Clean Water" brand, website and Facebook page;
- on-going construction site sediment and erosion control inspection program;
- on-going ditch maintenance and enhancement program;
- on-going easement acquisitions and negotiations for access to properties;
- on-going water quality monitoring program funded by the Town via stormwater utility fees;
- transfer of a minimum of 1,300 residential units, which prevents an additional 146 acres of impervious surface, out of the May River headwaters region via the Transfer of Development Rights Ordinance; and
- installation of 1.25 acre stormwater lagoon to reduce fecal coliform concentrations at an identified "hot spot."

DISCUSSION

Several of these accomplishments warrant further discussion. The Unified Development Ordinance (UDO) revision based upon watershed principles adopted a Growth Framework map which illustrates the Town's desired growth areas that coincide with regions best suited to accommodate growth within the watershed. The areas outside of the growth nodes are the ones most important for the siting of the preventative measures identified in the Action Plan. These measures may include fee simple purchase of land, conservation easements, purchase of development rights or the transfer of development rights.

The ability to transfer development rights within its jurisdiction provided the mechanism for the Town to allow the transfer of the 1,300 residential units out of the headwaters into a reserve "bank" for allocation elsewhere within the Town. This action prevented an additional 146 acres of impervious area in the headwaters of the May River. Another preventative measure is the encouragement of Low Impact Development designs using incentives such as reduced application fees and review times.

Based upon the results of the on-going weekly sampling program and an aquifer storage and recovery well discharge study (Ahern, et. al., 2012), a technical change in the UDO was made in the stormwater chapter. Currently, the Town and Beaufort County require stormwater volume control for all new development to be equal to pre-development conditions through on-lot controls. This approach helps to reduce pollutant loads by reducing runoff volume. The Town's stormwater ordinance may be found at: http://www.townofbluffton.sc.gov/Documents/izone.pdf in Article 5.10 (Town of Bluffton, 2011).

Currently the Town is negotiating an access easement with a residential subdivision to implement a second SCDHEC-awarded 319 grant. This retrofit project is aimed at reducing stormwater volume by using existing stormwater lagoons for irrigation in common-area property. Thus, the storage capacity within the lagoons is increased.

The Town is also negotiating a wetlands restoration/ditch modification project with another private landowner. This project will be the first of several to improve water quality in receiving waters by modifying the ditched channels through wetlands. Data from the weekly monitoring program suggest that the wetland ditches (conveyances) are themselves the sources of fecal coliform, instead of serving as a treatment for reduction (Ahern, et. al., 2012). Additionally, the ditches bypass the infiltration and evapotranspiration benefits offered by wetlands. Reconnecting the flood plains of these ditches is considered to be another mechanism for stormwater volume reduction.

The two-pronged approach of the Action Plan to be both restorative and preventative is encapsulated in each of these projects and policies.

CONCLUSION

Throughout the process of developing the May River Watershed Action Plan, there have been a number of lessons learned which are of use to others who are about to embark on a similar project. These include:

- The EPA Watershed Planning Guidelines are just that – guidelines. Adapt the process to work for your situation and community.
- Do not underestimate the power of stakeholders in the process. Identify and engage them early.
- Technical expertise is invaluable, but plain communication (education) is key.
- Involve all pertinent internal departments (public works, planning, engineering, stormwater, etc.) and other jurisdictions.
- Show early action for credibility.
- Identify potential funding sources (establishing a Stormwater Utility, grants, etc.).
- Be patient. This detailed Plan took one year to develop after over 4 years of studies, activities and a more generic, initial watershed plan.

ACKNOWLEDGEMENTS

Numerous individuals and organizations contributed to this process. However, no action would have been possible without the support of our current and past Town Council including Mayor Lisa Sulka, Mayor Pro Tempore Oliver Brown, Mike Raymond, Ted Huffman, Karen Lavery, Fred Hamilton, Allyne Mitchell, Charlie Wetmore and Town Manager Anthony Barrett. Numerous technical partners have included EPA, NOAA, USGS, SCDNR, SCDHEC nonpoint source program, SCDHEC-Shellfish Program, SCDHEC-OCRM, Clemson University, University of South Carolina, University of South Carolina-Beaufort and Lowcountry Institute. Community partners include members of the May River Waterbody Management Plan Implementation Committee and May River Watershed Action Plan Advisory Committee.

LITERATURE CITED

Ahern, D., C. Sexton, D. Warren, and K. Jones. 2012. Water Volume Causes Generation of Bacteria Loads from Wetland Systems. *Proceedings of the 2012 Southeast Stormwater Association Conference*, held October 17-19, 2012, in Chattanooga, T.N.

AMEC, Center for Watershed Protection, Thomas & Hutton, and Ward Edwards. 2011. May River Watershed Action Plan. Final Report. Prepared for the Town of Bluffton. 126 pp.

Bergquist, D.C., R.F. Van Dolah, J. Felber, and C. Keppler. 2010. Water Quality Concerns in the May River: Analysis of Monitoring Data Collected by the Town of Bluffton and Palmetto Bluff Development. Final Report. Prepared for the Town of Bluffton and Palmetto Bluff Development. 77 pp.

BP Barber. 2007. Town of Bluffton May River Monitoring Program: Stormwater Sampling Study. Prepared for Town of Bluffton, Bluffton, S.C. Project No. 05405.

BP Barber. 2008. Town of Bluffton May River Watershed Monitoring Program. Prepared for Town of Bluffton, Bluffton, S.C. File No. 05405.

BP Barber. 2009. Town of Bluffton May River Watershed Monitoring Year 2008-2009. Prepared for Town of Bluffton, Bluffton, S.C. File No. 05405

Kiernan, S. 2008. Waterbody Management Plan for the May River. Final Report to the Town of Bluffton, S.C. Submitted by S.C. Department of Health and Environmental Control, Ocean and Coastal Resource Management, Charleston, S.C.

Monday, M. 2007. Shellfish Management Area 19 - 2007 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C.

Monday, M. 2008. Shellfish Management Area 19 - 2008 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C.

Monday, M. 2009. Shellfish Management Area 19 - 2009 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C.

Monday, M. 2010. Shellfish Management Area 19 - 2010 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C.

Monday, M. 2011. Shellfish Management Area 19 - 2011 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C..

Monday, M. 2012. Shellfish Management Area 19 - 2012 Annual Update. Submitted by the Shellfish Sanitation Section, Water Monitoring, Assessment and Protection Division, Environmental Quality Control - Bureau of Water, South Carolina Department of Health and Environmental Control, Columbia, S.C.

South Carolina Department of Health and Environmental Control. 2014. DRAFT State of South Carolina Integrated Report for 2014 Part I: Section 303(d) List of Impaired Waters. South Carolina Department of Health and Environmental Control, Columbia, S.C.

Town of Bluffton. 2011. Town of Bluffton Unified Development Ordinance. Bluffton, S.C.

U.S. EPA. 2008. *Handbook for Developing Watershed Plans to Restore and Protect Our Waters, EPA 841-B-08- 002.*

Van Dolah, R.F., D.C. Bergquist, G.H.M. Riekerk, M.V. Levisen, S.E. Crowe, S.B. Wilde, D.E. Chestnut, W. McDermott, M.H. Fulton, E. Wirth, and J. Harvey. 2006. *The Condition of South Carolina's Estuarine and Coastal Habitats During 2003-2004: Technical Report.* Charleston, S.C.: South Carolina Marine Resources Division. Technical Report No. 101. 70 pp.

Van Dolah, R.F., D.M. Sanger, and A.B. Filipowicz (eds). 2004. A baseline assessment of environmental and biological conditions in the May River, Beaufort County, South Carolina. Final Report to the Town of Bluffton, S.C. Submitted by the Marine Resources Division, South Carolina Department of Natural Resources, Charleston, S.C.; the U.S. Geological Survey, South Carolina District, Columbia S.C.; and the Center of Coastal Environmental Health and Biomolecular Research, National Ocean Service, NOAA, Charleston S.C.

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Volume 1, Issue 1, Pages 26-31, June 2014

Long Bay Hypoxia Monitoring Consortium

Susan Libes[1], J. Michael Trapp[2], Scott Kindelberger[3] and Danielle Doremus[3]

AUTHORS: [1]Director, Waccamaw Watershed Academy, Burroughs & Chapin Center for Marine and Wetland Studies, Coastal Carolina University, P.O. Box 261954, Conway, South Carolina 29528-6054. [2]Project Manager and Environmental Laboratory Director, Michael Baker International, 14725 Alton Parkway, Irvine, California 92618-2027. [3]Research Grant Specialist, Environmental Quality Laboratory, Burroughs & Chapin Center for Marine and Wetland Studies, Coastal Carolina University, P.O. Box 261954, Conway, South Carolina 29528-6054.

REFERENCE: Proceedings of the 2012 South Carolina Water Resources Conference, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. In October 2011, the coastal municipalities of North Myrtle Beach, Myrtle Beach, Surfside, and Horry County signed a resolution, under the aegis of their Coastal Alliance of mayors, to develop and implement the Long Bay Hypoxia Monitoring Consortium. The goal of this consortium is to support monitoring and studies that further characterize hypoxia and its causes in Long Bay. The baseline data will enable assessments of water quality management efforts. Monitoring stations are to be maintained at three piers, Cherry Grove (NMB), Apache (Horry County), and Second Ave N. Pier (Myrtle Beach). Turbidity and chlorophyll sensors will be deployed at two piers and radon detectors at three piers. All piers will have weather stations. Data will be accessible via a real-time public website. Biological responses to low dissolved oxygen (DO) will be assessed via monitoring of larval recruitment and net plankton. The S.C. Department of Natural Resources (SCDNR) is also conducting creel surveys at the piers. These efforts are being coordinated with a marine education outreach campaign that includes signage at the piers, presentations at pier events, and web-based content.

INTRODUCTION

During mid-July of 2004, fishermen along the coastal region of Long Bay began reporting unusually prolific flounder catches. Water quality surveys conducted during the following week documented hypoxic conditions in the nearshore bottom waters. The unusual flounder behavior was subsequently attributed to these low dissolved oxygen levels (Sanger et al. 2010).

Long Bay is a partially-enclosed coastal embayment that borders the sandy beaches of the Grand Strand in northeastern South Carolina (Figure 1). This area is a focal point for beach-based tourism, hosting 15 million visitors a year. Hypoxic conditions in Long Bay were unexpected given the shallow water depths, partial enclosure, and lack of nearby rivers and marshes. Since no routine dissolved oxygen (DO) concentration measurements had ever been made in Long Bay, several state agencies partnered to establish continuous water quality monitoring platforms on the seaward ends of two fishing piers in water depths that range from 5 to 7 m depending on the tides. These sites (Apache and Springmaid Piers) were operational by 2006 and featured measurements of salinity, DO and temperature, collected every 15 minutes in the surface and bottom waters using YSI and Hydrolab datasondes. Data access was provided through public websites. These data were used to support research

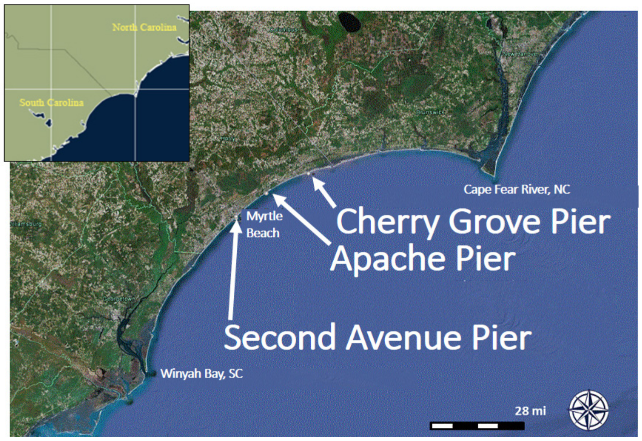


Figure 1. Long Bay, South Carolina. Green circles mark the positions of the pier monitoring stations.

efforts investigating the causes of low DO in Long Bay and for educational outreach targeted at reducing nonpoint source pollution into these coastal waters. Some of these research efforts are described in McCoy et al. (2011) and Sanger et al. (2012). The educational outreach has been conducted under the aegis of the Coastal Waccamaw Stormwater Education Consortium (CWSEC) (http://cwsec-sc.org/).

PROJECT OBJECTIVES

In recognition of a likely linkage between low DO and terrestrial inputs of oxygen-demanding substances, the municipalities of the Grand Strand agreed in August 2011 to form a monitoring consortium. The mission of the Long Bay Hypoxia Monitoring Consortium is two-fold: (1) to collaboratively support water quality monitoring that will help determine the causes and effects of low DO, and (2) to help identify and implement management activities that will mitigate undesirable impacts to water quality. Continued monitoring will be performed to help evaluate the effectiveness of these management interventions.

PROJECT DESCRIPTION

Background and Related Work

Since 2006, low DO has been observed primarily during June through September. In 2009, severely hypoxic conditions were documented during several days in August and September. Related field work suggests that low DO is restricted to a narrow band paralleling the shoreline (Koepfler et al. 2010 and Sanger et al. 2012). The origin of the low DO during the summer is thought to arise from a physical constraint on mixing caused by the combined effects of solar heating and southwesterly winds. The resulting frontal conditions keep nearshore waters close to the coastline. This constrained mixing is most pronounced at the maximum concavity of Long Bay, which is the location of the urbanized center of the Grand Strand.

Scientists agree that polluted stormwater runoff is one potential contributor of oxygen-demanding materials to Long Bay, suggesting management actions can be undertaken to prevent further degradation and to remediate if necessary.

The nearshore waters of Long Bay are also prone to contraventions of water quality standards for fecal indicator bacteria. This has given rise to numerous 303(d) listings for recreational impairments requiring development of Total Maximum Daily Loads (TMDLs). Hence generalized concern exists over managing terrestrial flows into Long Bay, with monitoring needed to help develop and evaluate the success of these strategies.

Although water quality monitoring at the Springmaid Pier ended in 2007 due to lack of continued funding, observations were continued and enhanced at Apache Pier with short-term financial support from several state agencies, i.e. S.C. Department of Natural Resources (SCDNR), S.C. Department of Health and Environmental Control - Ocean and Coastal Resource Management (SCDHEC OCRM), S.C. Sea Grant Consortium, and the S.C. Chapter of the Coastal Conservation Association. All but the latter of these groups have also provided funding to support research into the causes of low DO in Long Bay.

By the summer of 2011, grant funds for monitoring had been exhausted. State and federal agencies that traditionally engage in long-term water quality monitoring in South Carolina did not have the capacity to expand their networks. Unless another funding approach was developed, continuous DO monitoring would have had to been terminated. This was especially problematic as the local municipalities of the Grand Strand had recently been required under the federal Clean Water Act's National Pollution Discharge Elimination System (NPDES) program to protect local water quality through development and implementation of local stormwater management programs. Water quality monitoring information will be required to demonstrate improvements to impaired waters.

Experimental Design

The Long Bay Hypoxia Monitoring Consortium was established by a resolution of the Coastal Alliance signed in August 2011. The Coastal Alliance is comprised of the mayors from the coastal municipalities of the Grand Strand, including the cities of Myrtle Beach and North Myrtle Beach, the towns of Surfside Beach and Atlantic Beach, and the unincorporated areas of Horry County. The Long Bay Hypoxia Monitoring Consortium is now supporting water quality and biological monitoring at three fishing piers on the Grand Strand.

Funding for the monitoring at the Apache Family Campground and Pier, the Second Avenue Pier and the Cherry Grove Pier is being provided by Horry County, and the cities of Myrtle Beach and North Myrtle Beach, respectively. The pier owners and operators are providing essential support services. The National Oceanic and Atmospheric Administration maintains a federally funded weather and tide station at Springmaid Pier. An effort to instrument a fourth pier in Surfside Beach was not realized due to logistic and funding limitations.

Coastal Carolina University's Environmental Quality Lab, under the aegis of the Burroughs & Chapin Center for Marine and Wetland Studies, is responsible for equipment installation, maintenance, and data management. This was the group who made the initial discovery of low DO in July 2004, while performing unrelated field work at Springmaid Pier.

The new installations at the Cherry Grove and Second Ave. piers provide information on water quality at the northern end of Long Bay and at a site near its maximum concavity, respectively. These monitoring stations, along with Apache Pier, have sondes that are collecting turbidity and chlorophyll data to provide more information on the causes of low DO, i.e. the relative abundance of particulate matter and phytoplankton. pH is being measured to obtain insight into another stressor, ocean acidification, which should be intensified under hypoxic conditions as carbonic acid is a byproduct of the aerobic respiration of organic matter. Bottom-water radon (Rn-222) detectors have been deployed to characterize constrained mixing and groundwater inputs to Long Bay. Funding has also been provided for a larval recruitment study to document effects of low DO on local biota.

METHODS

Water Quality and Meteorology

At the seaward end of each pier, just beyond the surf zone, YSI sondes are deployed in the surface and bottom waters on stainless steel ziplines held in place by a concrete anchor fabricated to keep the ziplines separated. This approach minimizes sampling artifacts associated with standpipes, but requires a robust design to withstand high-energy conditions characteristic of the nearshore environment. The surface sondes are maintained ~1m below the sea surface using an innovative counterweighting system shown in Figure 2. The bottom sonde is stationed ~1m above the seafloor in water depths that range from 5 to 7 meters depending on the tides.

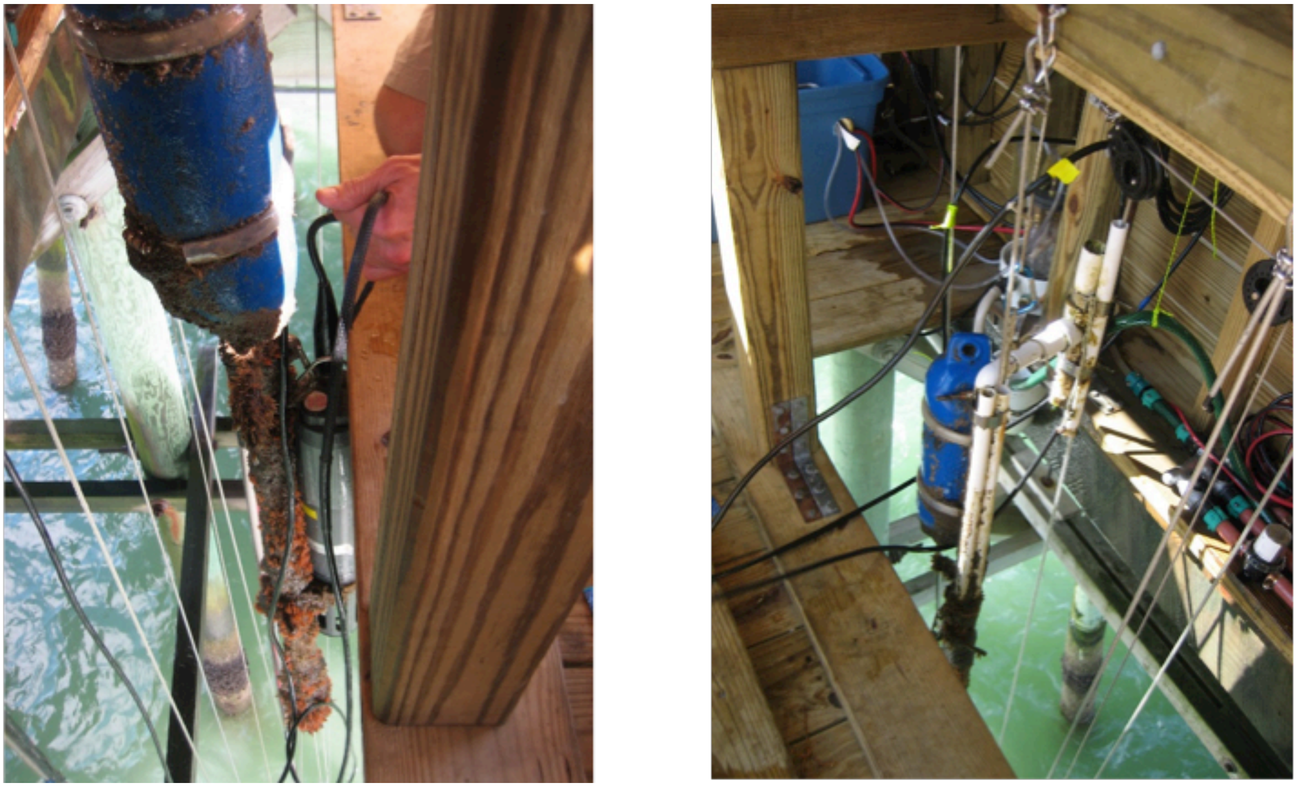


Figure 2. Pier monitoring station at the Second Ave. Pier showing ziplines and counterweighting. (a) Left photograph shows the surface sonde strapped to a PVC "sled" that slides vertically on two stainless-steel ziplines. The blue buoy is flotation that maintains the surface sonde ~1 m below the sea surface. (b) Right-hand photograph shows the zipline and PVC sled. To reduce biofouling, the sled is now fabricated from copper pipe. The blue box in the upper left corner houses the RAD-7 radon detector. Red hoses in the lower right-hand corner are part of a filter manifold that prevents particles from clogging the detector.

At the Apache pier, a YSI 600 OMS sonde is deployed in the surface water with optical DO, temperature, conductivity and depth sensor. YSI 6600 EDS sondes are being used in the bottom water at Apache and in the surface and bottom at the other two piers with additional sensors for turbidity, chlorophyll, and pH. Meterological observations are provided by a Vaisala WXT520 weather station mounted ~10m above sea level. These units measure air temperature, barometric pressure, relative humidity, precipitation, wind direction and speed.

The sensors report every 15 min via a dedicated cell modem to a server maintained by YSI Econet, Inc. The data are relayed in real-time to a public web portal: http://www.ysieconet.com/public/WebUI/Default.aspx?hidCustomerID=131. This site also provides an option to download all data to a .csv file within a user-selectable data range. Various entities, such as Southeastern Coastal Ocean Observing Regional Association (SECOORA), are streaming the pier data in real-time. The SECOORA data stream at http://secoora.org/maps/ is part of the national Integrated Ocean Observing System (IOOS).

The sondes are equipped with all available antifouling accessories. Nevertheless, manual cleaning is required at least three times a week during warm weather. During these visits, secchi depths are measured. Field quality control (QC) activities includes pre and post deployment comparison with a manually deployed sonde. Chlorophyll results are ground truthed against acetone-extracted measurements on grab samples collected at least weekly from each site and depth. In-situ accuracy is + 0.4 mg/L for DO, + 0.1 C for temperature and +0.25 psu for salinity. Efforts are underway to characterize true in-situ accuracy of the pH, chlorophyll, and turbidity sensors. Data QC records are created using Aquarius software from Aquatic Informatics, Inc.

Shore power is required to support data relay and the radon pump. Lightning protection features an extensive set of grounding wires and pom-pom diffusers. YSI Econet maintains a back-up system for their servers. In the event of a long-term power or communication failure, the sondes are programmed to log sensor data with a capacity to store several weeks.

Radon

Radon-222 is a naturally occurring radionuclide that is released into groundwaters from the decay of radium, a common component of sedimentary rocks such as limestone. As a result, this radionuclide is released into nearshore waters as a natural component of submarine groundwater discharge. Radon-222 decays rapidly, so measurement of concentrations in the nearshore waters provides a quantitative estimate of groundwater inputs and nearshore mixing constraints. This had been demonstrated for Long Bay by McCoy et al. 2011 and by a short-term deployment during 2011 at Apache Pier. In both cases, a highly significant inverse correlation of Radon-222 with DO was observed, suggesting that this natural tracer can serve as a low-cost approach to documenting the physical conditions that promote the development of low DO.

Each pier has been outfitted with a RAD-7 (Durridge Co.) radon dectector which is located on the pier deck (Figure 2) and continuously fed bottom water via a submersible pump. Alpha decay counts are integrated for reporting on 30-minute intervals. A filter manifold is required to prevent introduction of particles from the highly turbid bottom waters. Data are manually downloaded and returned to the lab for processing.

Larval recruitment

A low-cost approach to documenting the impact of low DO on native marine life is being conducted biweekly year-round by monitoring larval recruitment onto a hard substrate.

Many marine invertebrates live as epifauna attached to hard substrates including piers, jetties, and natural hard bottom features. These animals occupy intermediate positions in food webs and can be very abundant. They serve as indicator species that record the ecological effects of abnormal events, such as low DO.

The epifaunal monitoring involves identification of common taxa (presence/absence), characterization of these taxa as live or dead, estimation of density (number per unit area) and community composition. These data are being used to relate seasonal and interannual patterns of abundance to ambient water quality.

Recruitment substrates are deployed at two depths (mid-and surface) at each pier. Two replicate strings (1 string = 4 PVC tiles, 8 settlement surfaces) are deployed and retrieved biweekly. Substrates are examined immediately to characterize epifauna as alive or dead, and to identify the more delicate taxa. Substrates are then preserved by freezing to enable later counting and faunal identification work.

Educational Outreach

Educational outreach is being conducted as part of the activities of the Coastal Stormwater Education Consortium (CWSEC) due to the relationship of nearshore water quality with transport of pollutants

We care about our
LOCAL WATER QUALITY

Water quality monitoring equipment is installed at this pier.

Fishermen, boaters and swimmers may find the real-time data gathered by this equipment useful. Visit the online data page to find information on:

- Air & Water Temperature
- Wind Direction & Speed
- Salinity
- Water Depth
- Dissolved Oxygen
- Relative Humidity
- Air Pressure
- Rainfall
- Turbidity
- Chlorophyll & pH

Go to www.ysieconet.com and click on
Long Bay Hypoxia Monitoring, SC

Figure 3. Educational signage posted at pier monitoring stations.

via stormwater runoff. The stormwater managers of each coastal municipality are engaged in this outreach education as it is a required component of their NPDES Phase II stormwater program permit.

The YSI Econet portal web pages include extensive information on the reason for the monitoring and the meaning of each water quality parameter. Educational signage has been posted at each pier (Figure 3). At the Apache and Second Ave. piers, a plasma screen is mounted in the bait shop to present the real-time data. Other outreach efforts include press conferences and participation in pier activities, such as Local's Appreciation days. A business-style card has been developed as a handout to spread information on the website location.

RESULTS AND DISCUSSION

Diaz and Rosenberg (2008) have included Long Bay in their inventory of the world ocean's hypoxia zones. With this dubious distinction has come the realization that more careful stewardship is required to protect and enhance water quality in Long Bay, especially since the ocean is the base of the Grand Strand's tourist-driven economy.

The formation of the Long Bay Hypoxia Monitoring Consortium is one step along a path towards better stewardship that began with a pro bono response by various state agencies and universities to a singular event, discovery of hypoxic conditions in Long Bay in July 2004. The collaborative nature by which this response initially evolved is described by Sanger et al. (2010).

The timing of these science-based stewardship efforts has been fortuitous; occurring during the period when local municipalities are developing their federally mandated stormwater programs, whose goal is reduction of polluted runoff. A major management approach has been relocation of runoff from hundreds of pipes that discharge on the beach face to a few ocean outfalls. The latter discharge onto the seafloor at the water depths where hypoxia is observed to occur. Water quality treatment practices have been installed upstream of most of these outfalls. Installation of the pier monitoring stations provides a resource to help assess the efficacy of these practices.

A major unknown is the source of the oxygen-demanding substances responsible for sustaining low DO in Long Bay. Various efforts have been undertaken to identify the dominant sources, including a NOAA-funded study that is quantifying the export of nutrients and organic matter from local tidal creeks, called "swashes", into Long Bay. This project was funded in recognition of strong community support, as evidenced by actions such as local funding of pier monitoring. The local stormwater managers were involved in the selection of swash study sites and data interpretation.

Ancillary benefits provided by the pier monitoring program include: (1) Meteorology information that is of general interest to tourists and locals; (2) Depth data that provide tidal elevation information; and (3) Information on sea state that can be inferred from the surface sonde's depth sensor as it is neutrally buoyant ~1 m below the sea surface.

Other synergistic activities include coordination with a SCDNR fish survey (creel and catch effort) being conducted collaboratively with CCU's marine science undergraduate students. Undergraduate students are also engaged in plankton monitoring at the fishing piers in a program modeled after NOAA's Plankton Monitoring Network. The focus of this effort is on identification of harmful algal blooms (HABs).

ACKNOWLEDGEMENTS

Drs. Rick Peterson and Juli Harding of Coastal Carolina University are leading the radon and larval recruitment components of this monitoring program. Funding has been provided by the City of Myrtle Beach, North Myrtle Beach, and Horry County. The Horry County Legislative Delegation has approved use of SCDNR funds for short-term operational support at Apache Pier. We are deeply grateful to the owners and operators at the Apache, Cherry Grove, and Second Avenue piers.

Prior to the formation of the Long Bay Hypoxia monitoring consortium, financial support was provided by SCDHEC-OCRM, the S.C. Sea Grant Consortium, SECOORA, SCDNR and the S.C. Chapter of the Coastal Conservation Association.

LITERATURE CITED

Diaz, R.J. and R. Rosenberg, 2008. Spreading dead zones and consequences for marine ecosystems. *Science*, 321: 926-929.

Federal Geographic Data Committee. 2012. Coastal and Marine Ecological Classification Standard. Publication #FGDC-STD-018-2012.

Koepfler, E., S. Lake, E.M. Smith, J. Bennett, S. Libes. 2007. Examination of Inner Shelf Water Quality in Long Bay, South Carolina, using Dataflow. Estuarine Research Federation Providence Rhode Island Meeting, November 2007, abstract.

McCoy, C., R. Viso, R. Peterson, S. Libes, B. Lewis, J. Ledoux, G. Voulgaris, E. Smith and D. Sanger (2011) Radon as an indicator of limited cross-shelf mixing and submarine groundwater discharge in a coastal embayment along the South Atlantic Bight. *Continental Shelf Research*, 31: 1306-1317.

Sanger, D., E. Smith, G. Voulgaris, E. Koepfler, S. Libes, G. Riekerk, D. Bergquist, D. Greenfield, P. A. Wren, C. McCoy, R. Viso, R. Peterson, and D. Whitaker (2012) Constrained Enrichment and Hypoxia Formation in Long Bay, South Carolina (USA), an Open Water Urbanized Coastline, Marine Ecology Progress Series, 461:15-30.

Sanger, D., D. Hernandez, S. Libes, G. Voulgaris, B. Van Dolah, G. Reikerk, B. Davis, E. Smith, R. Shuford, D. Porter, E. Koepfler, and J. Bennett (2010) A Case History of the Science and management Collaboration in Understanding Hypoxia Events in Long Bay, South Carolina, USA. *Environmental Management*, 46: 340-350.

South Carolina Water Resources Conference
Journal of South Carolina Water Resources
Volume 1, Issue 1, Pages 32-38, June 2014

Green Infrastructure in Coastal Landscapes: Hydrological Function, Ecological Design and Sustainable Land Use Guidance

Daniel R. Hitchcock[1], Anand D. Jayakaran[1] and David L. White[2]

AUTHORS: [1]School of Agricultural Forest & Environmental Sciences, Clemson University, Baruch Institute of Coastal Ecology and Forest Science, PO Box 596, Georgetown, South Carolina 29442. [2]Clemson Computing and Information Technology (CCIT), Clemson, South Carolina 29634.

REFERENCE: Proceedings of the 2012 South Carolina Water Resources Conference, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. Coastal landscape modification, specifically the conversion of forests to residential and commercial development, coupled with potential climate change impacts, could lead to irretrievable natural resource impairment. An assessment of existing resources (green infrastructure) and their benefits via ecosystem services provides useful guidance for resource protection to enhance community resilience. These landscape elements are complex within and between varying scales; therefore stakeholders need clear, relevant, comparable, and easily accessible information for effective decision-making.

In this paper, we discuss hydrological and ecological parameters that could guide sustainable land use in coastal South Carolina. Analyses have been conducted in watersheds with low gradient topography and shallow water table conditions to define pre-development conditions. We also investigate hydrologic and hydraulic performance of vegetated stormwater control measures - specifically infiltration-based bioretention systems - in these coastal areas with frequently limited infiltration capacity. Results from these analyses are being integrated into an online mapping tool so that geospatial data variability complement research efforts, and vice versa, while also providing site-specific information to land and water resource decision-makers.

BACKGROUND AND RELATED WORK

In South Carolina, low gradient coastal watersheds with shallow water tables are often prone to flooding and water quality impairments, especially where urbanization has occurred (Tufford et al., 2003; Holland et al., 2004). Seasonally variable groundwater position (Figure 1) plays a substantial role in the ratio of rainfall to discharge and runoff volume (Sun et al., 2002; Amatya et al., 2006; Harder et al., 2007; La Torre Torres et al., 2011; Epps 2012; Epps et al., 2013a; Epps et al., 2013b). The mechanism by which runoff is generated can and should dictate what stormwater control measures (SCMs) are implemented and how they are designed, specifically toward the goals of reductions in both peak flow rate and total discharge volume.

Green infrastructure has been defined as "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife". (Benedict and McMahon, 2006). Recent focus on green infrastructure by the U.S. EPA as a measure for "managing wet weather" includes a subset of technologies known as Low Impact Development (LID). EPA-recommended site-scale practices include rainwater harvesting, downspout disconnection, rain gardens, permeable pavements, vegetated swales, green roofs, and brownfield and infill redevelopment. Neighborhood-scale approaches include "green" parking, streets, and highways; pocket wetlands, and urban forestry strategies. Watershed scale strategies include riparian buffers (U.S. EPA, 2010a). Many of these strategies are further explored in a sustainable design and green building toolkit for local governments (U.S. EPA, 2010b). From a stormwater regulatory standpoint, anticipated changes to the NPDES permit requirements both nationwide and within South Carolina are moving toward volume- and infiltration-based strategies in contrast to the current requirements

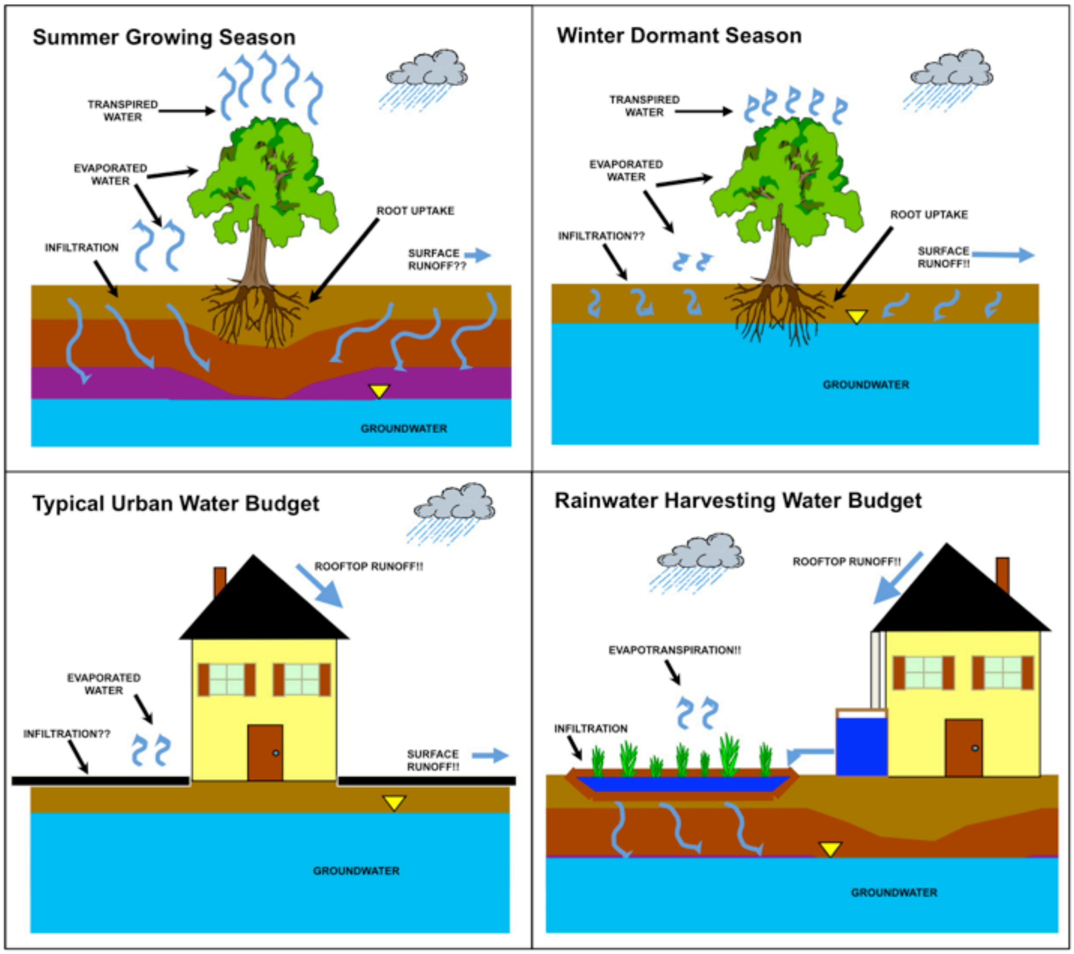


Figure 1. Conceptual water budgets for forested versus urban systems, including seasonally variable groundwater elevations (top panels) for pre-development conditions, and an impervious surface scenario compared to a rainwater harvesting system (bottom panels) based on green infrastructure design principles.

where post-development peak flows must at least equal those of pre-development. As these mandates move forward, local and regional decision-makers and land use practitioners need science-based tools to inform the design process.

From a larger conceptual view of green infrastructure, we can summarize landscape design goals as follows:

- retain the natural landscape and hydrology;
- promote open space, corridor, and habitat preservation;
- encourage riparian and floodplain protection;
- reduce and disconnect impervious surfaces; and
- provide on-site stormwater management and water re-use.

Potential short- and long-term adverse impacts from coastal land use change can be reduced by informed decision-making at various scales, especially if targets for sustainable solutions are well defined. Whether the effort is one of preservation or restoration (or both), the integrated yet often highly variable system components of water, soils, and vegetation - as well as respective processes within the landscape - must be incorporated into the strategy. The preservation and/or enhancement of ecosystem services should optimize sustainable land use and water resource protection strategies. This work will identify sustainable land use practices and natural resource preservation strategies given available landscape information based on a natural resource inventory. The project also seeks to develop science-based tools to inform the decision-making process related to green infrastructure.

PROJECT DESIGN

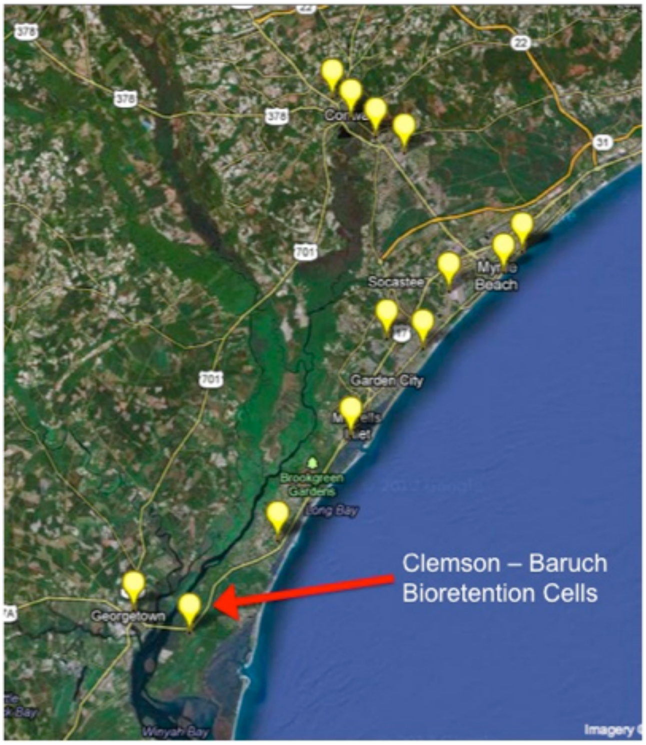
We utilize a growing understanding of coastal forested hydrologic processes and ecological engineering design principles to provide information to land and water resource decision-makers, not only with respect to effective stormwater management, but also toward the preservation and restoration of coastal ecohydrological services. Achieving pre-development flows under the post-construction scenario is a regulatory requirement, but this is usually accomplished with a hydrographic assessment typically conducted by watershed modeling (curve number based TR-55) (Epps et al., 2013b). However, an understanding of associated water budgets (Figure 1) that represents seasonal variability would better guide targeted site-specific development strategies. Proper stormwater management practice selection, siting, and sizing depends on whether the practice functions primarily via evapotranspiration, infiltration, retention, reuse, or a combination of these processes.

A landscape-based decision making approach can be complicated by multi-scale factors, creating a need for process-based information among varying spatial and temporal scales. Spatial scales can include the individual or series ("treatment train") of SCMs, the development tract, and the watershed or river basin scale. Temporal scales include daily (storm-event), seasonal and annual (water table fluctuation), multi-year and even decadal (climate variability). Planners, engineers, and regulators need to incorporate spatial and temporal scale information into effective land use decision-making.

Coastal Stormwater Control Measures

Infiltration-based rain garden and bioretention systems are gaining popularity for use in coastal locations (Figure 2). However, due to shallow groundwater influence and thus frequent wet conditions - especially in winter months - many of these systems are hydrologically and ecologically converting into retention-based wetland systems, performing differently than originally intended. Coastal proximity and thus the potential for shallow groundwater can play a significant role in system performance.

Ongoing investigations seek to better understand the connection between surface and groundwater quantity and quality associated with these vegetated SCMs (bioretention and wetlands), as well as the interaction of these processes under varying landscape parameters (sandy versus clayey soils, SCM elevation, depth to seasonally high water table, proximity to tidal surfaces waters) and drainage area features (impervious surface percentages, slope, time to concentration, etc.). An example is the Clemson - Baruch bioretention demonstration site (Figure 2) where rooftop runoff is being collected and managed. This site exhibits the other end of the hydrologic spectrum compared to the bioretention-conversion-to-wetland scenario previously described. The bioretention system was installed in 2009 on Lakeland soil (excessively well-drained sand). Parameters being monitored include rainfall, ambient air temperature, relative humidity, solar radiation, and water table position, as well as soil moisture (as volumetric water content) within a vertical profile below the bioretention cell bottom. The seasonally high water table depth is at approximately 1.0 m below ground surface (bgs). A snapshot of data is provided in Figure 3 illustrating the response of groundwater elevation to rain events. The quick response of soil moisture reflects a water flux characterized by extremely rapid infiltration rates as well as a rapid decline in available soil water. Further analyses of these data and water quality data for the Clemson-Baruch bioretention cells and others in coastal South Carolina are currently underway.

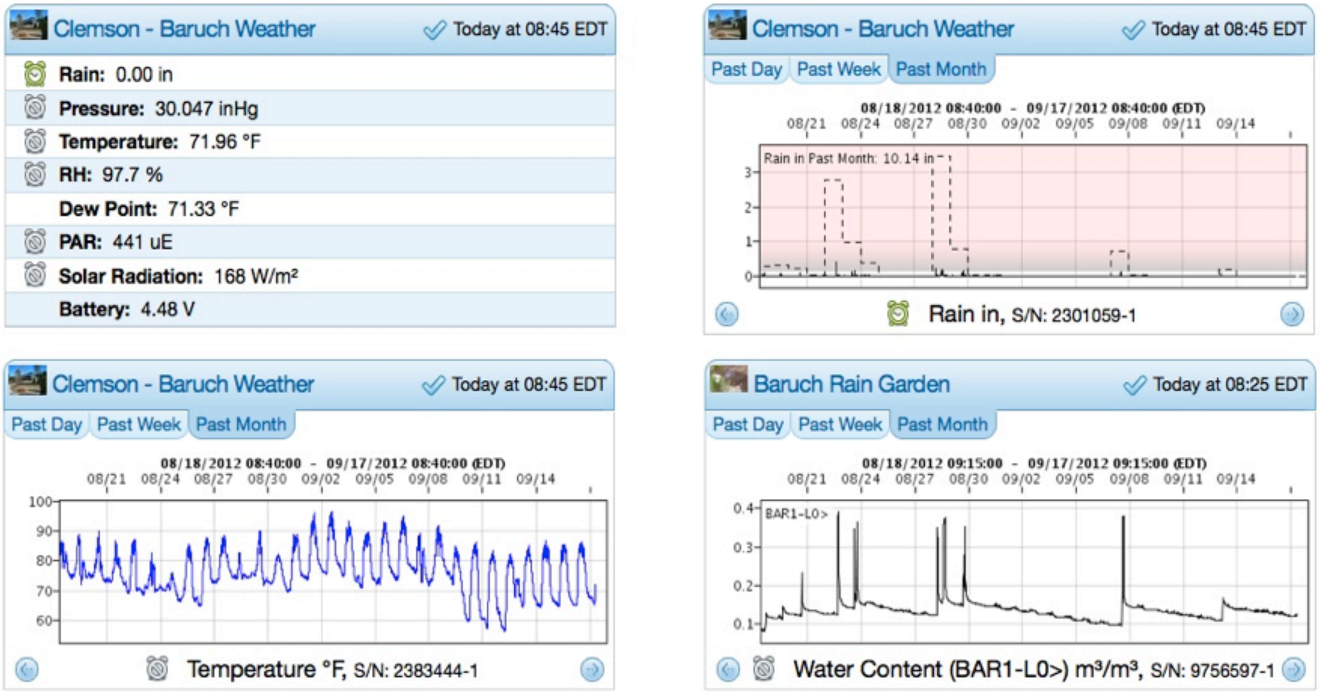


Clemson – Baruch Bioretention Cells

Figure 2. Locations of rain garden and bioretention in coastal Horry and Georgetown Counties indicated by yellow markers (from the SC LID Atlas and the National NEMO Network - not all are included - visit http://www.clemson.edu/public/carolinaclear/lidmap/ for more information). The location of the Clemson-Baruch Institute bioretention demonstration site is highlighted.

Geospatial Reference, Variability and Assessment

An online Community Resource Inventory (CRI) (screen grab shown in Figure 4) has been piloted by the S.C. Sea Grant Extension Program and Clemson University in lower coastal plain of Georgetown County, South Carolina, with some expanded information for Horry County (http://maps.clemson.edu/cri/index.html) (including the greater urbanized area of Myrtle Beach).



Clemson - Baruch Weather ✓ Today at 08:45 EDT

Rain: 0.00 in

Pressure: 30.047 inHg

Temperature: 71.96 °F

RH: 97.7 %

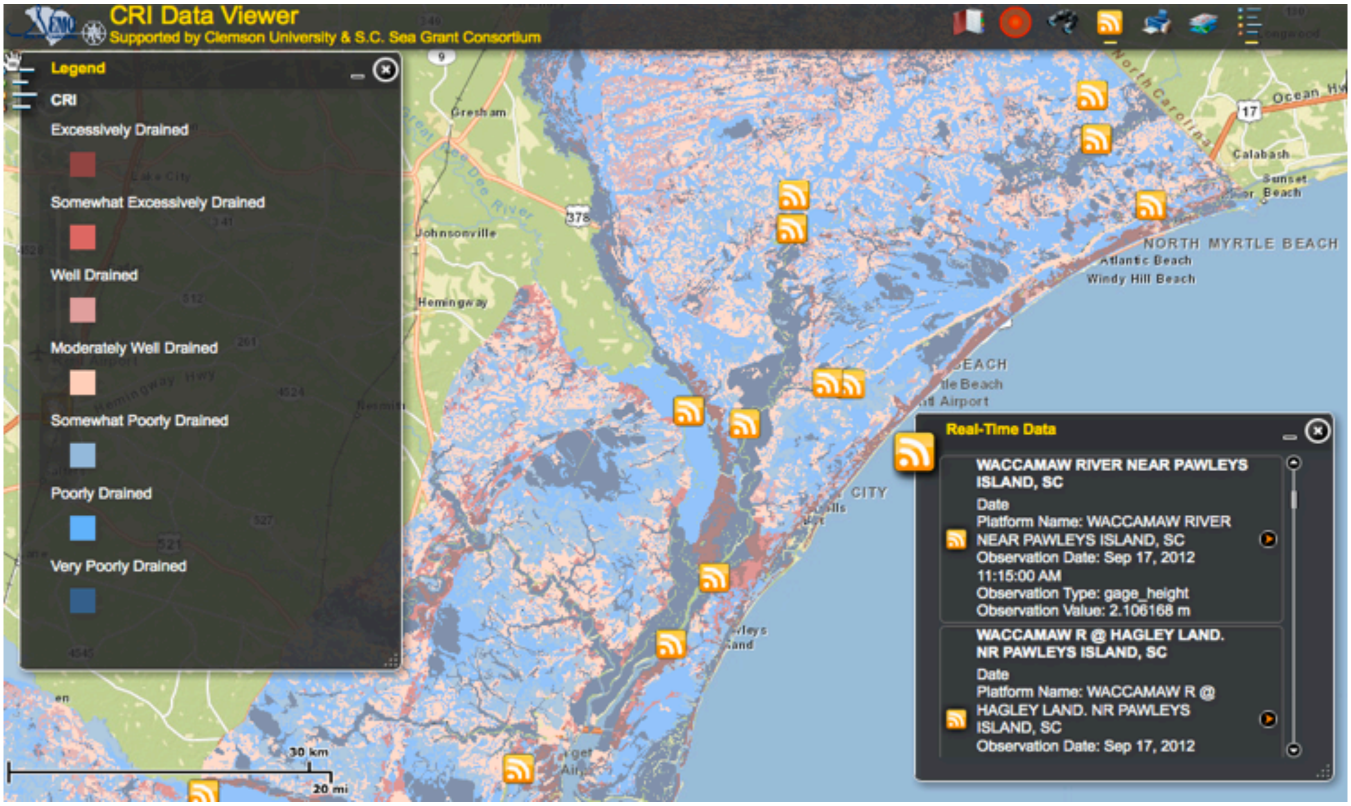
Dew Point: 71.33 °F

PAR: 441 uE

Solar Radiation: 168 W/m²

Battery: 4.48 V

Figure 3. Sample screenshot of meteorological and hydrographic data from the Clemson-Baruch rain gardens (http://www.clemson.edu/public/rec/baruch/rain_gardens.html). A subset of all data including real-time weather parameters (top left), ambient air temperature (bottom left), rainfall (top right) and surface soil moisture content (bottom right) are shown respectively.



Legend

CRI

Excessively Drained

Somewhat Excessively Drained

Well Drained

Moderately Well Drained

Somewhat Poorly Drained

Poorly Drained

Very Poorly Drained

Real-Time Data

WACCAMAW RIVER NEAR PAWLEYS ISLAND, SC

Date

Platform Name: WACCAMAW RIVER NEAR PAWLEYS ISLAND, SC

Observation Date: Sep 17, 2012 11:15:00 AM

Observation Type: gage_height

Observation Value: 2.106168 m

WACCAMAW R @ HAGLEY LAND. NR PAWLEYS ISLAND, SC

Date

Platform Name: WACCAMAW R @ HAGLEY LAND. NR PAWLEYS ISLAND, SC

Observation Date: Sep 17, 2012

Figure 4. Online Community Resource Inventory (CRI) depicting soil drainage classes (with legend) and real-time access to USGS water resources data for coastal Horry and Georgetown Counties (http://www.cri-sc.org).

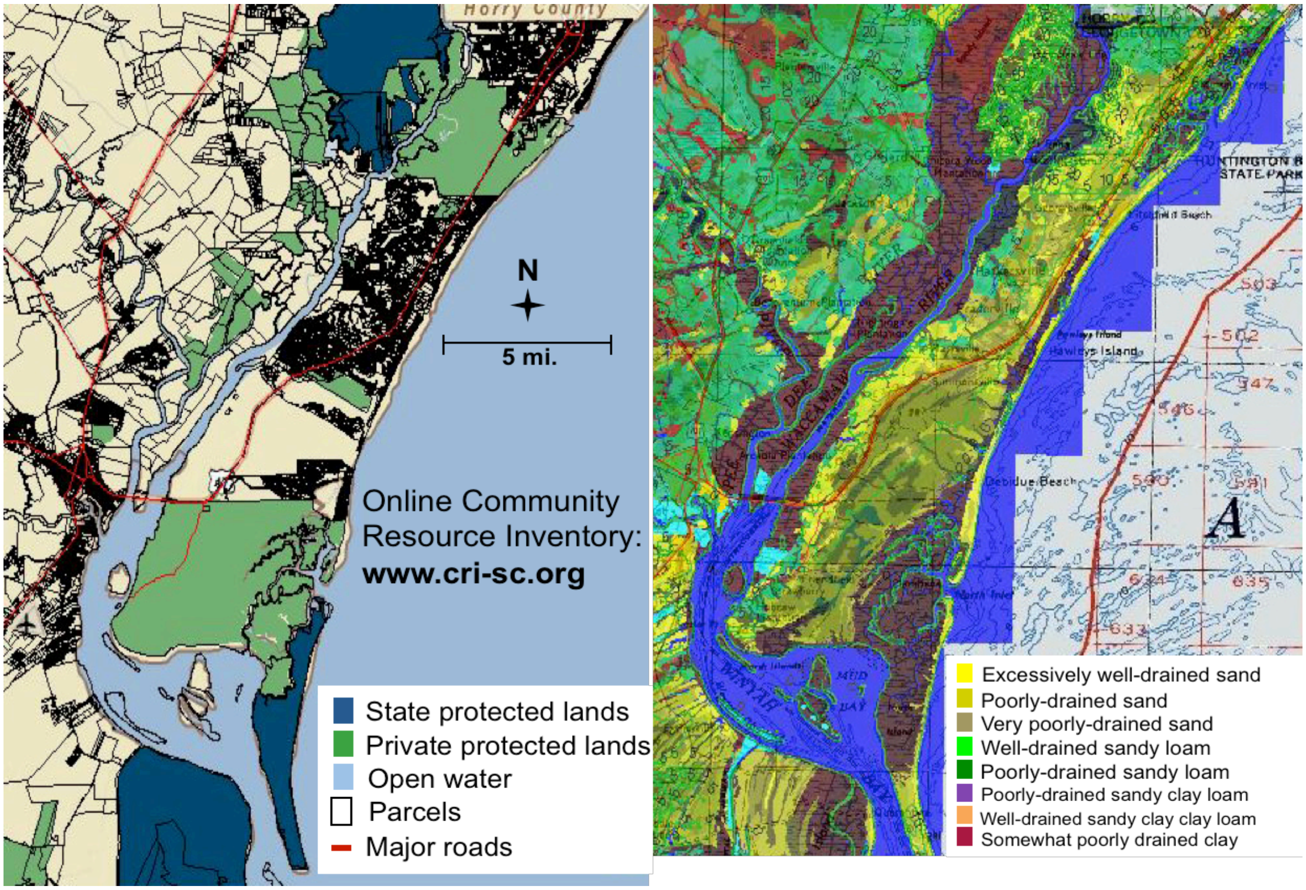


Figure 5. Map outputs from the Online Community Resource Inventory (CRI) for Georgetown County, SC, focusing on the Waccamaw Neck. Property ownership (parcels and protected lands) information overlays a street map for natural resource planning and zoning (left) and soil drainage class information overlays a USGS topo map to be used for stormwater management plan reviews and decision-making (right).

Data layers can be viewed over street maps, aerial imagery, or topographic maps, and include elevation, soils, land use/land cover, impervious surfaces, parcels, zoning, protected lands, watersheds, impaired waters, and flood zones, among others (Hitchcock et al., 2010). Real-time data can be viewed as RSS feed portals in the mapping tool. Currently only USGS data links are available online, but efforts are underway to populate the tool with data collected from SCM investigations

Figure 5 shows a sample view of the CRI for coastal Georgetown County (image modified by addition of legends). The tool provides multiple data layers that can be useful to site design professionals and stormwater plan reviewers, among others. As Low Impact Development (LID) practices based on green infrastructure are becoming more popular, the geospatial tool can aid users by providing SCM practice information, including site parameters and landscape features. The tool is being modified to include a SCM suitability and feasibility layer based on geospatial landscape and hydrologic data. An extended use of the tool may include the capability to inform planning and zoning processes with parcel information, impervious surface areas, public and protected land areas, land use/land cover data, and habitat designations.

In Figure 6, water quality impairments can be identified using the mapping tool, in this case showing fecal coliform impairments from the 2010 SCDHEC 303(d) list, including shellfish monitoring locations as well as TMDL status for coastal waters of Georgetown County and southern Horry County. Land cover data are also shown. Such geospatial information can be useful for the prioritization of stormwater management efforts, as well as sustainable land use and decision-making for improved water resource protection. As the tool continues to be improved, the geospatial and real-time hydrologic data along with water quality impairment information may have the capacity to guide future conservation and restoration activities.

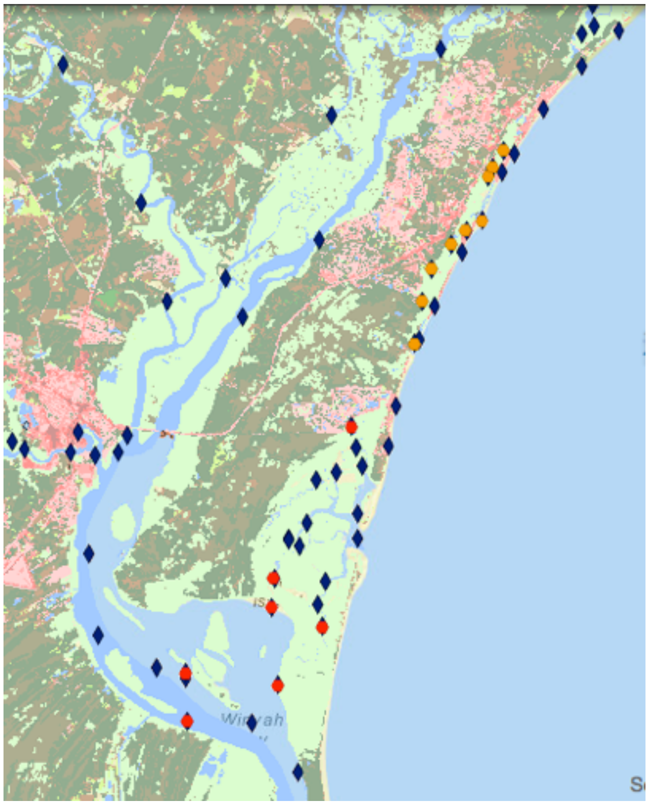


Figure 6. SCDHEC 303(d)-listed water quality impairment sites (2010) (blue diamonds = all coastal monitoring stations, red diamonds = impaired fecal shellfish sites, orange diamonds = impaired fecal shellfish sites with TMDL) and National Land Cover Database (2006) data (light green = emergent wetlands, dark green = forests, light pink = low density developed lands and dark pink = medium density developed lands).

FUTURE GOALS AND DIRECTIONS

Geospatially referenced data, including a reliable inventory of site-specific conditions, are pertinent to performance-based selection and/or enhancement of SCMs for effective stormwater management, especially those measures that rely on existing or newly installed green infrastructure. Increased utility of geospatial information for resource inventory and better understanding of relationships to ecosystem services - here specifically stormwater quality and quantity management - will be accomplished as follows via the online CRI tool: (1) extrapolate rainfall-runoff-water table relationships and curve numbers (Epps et al., 2013a; Epps et al., 2013b) for a larger geospatial area; (2) introduce SCM (bioretention and wetland) monitoring data into the CRI tool as RSS feeds; (3) develop criteria for SCM suitability and feasibility based on geospatial data, specifically soils and topography, as well as groundwater elevation data and existing land use/cover; (4) incorporate SCM suitability and feasibility indices into mapping layers for increased function of the CRI tool; and (5) assess longer term implications as related to climate variability, sea level rise, higher water table elevations, and more extreme temperature and precipitation regimes.

As investigations into the role of green infrastructure in sustainable land use and water resource protection continues, the resulting science-based information will be relevant, accessible, and meaningful for effective land use planning and stormwater infrastructure decision-making over multiple spatial and temporal scales in coastal South Carolina.

ACKNOWLEDGEMENTS

Very special thanks to Samantha Bruce and April Turner (S.C. Sea Grant Consortium), Jeff Vernon (Clemson-Baruch Institute), and Dawn White (Clemson University Center for Watershed Excellence, Institute of Computational Ecology) for their continued assistance with online CRI development. This work was sponsored by the S.C. Sea Grant Consortium with NOAA financial assistance awards No. NA06OAR4170015 and NA10OAR4I70073. The online CRI was sponsored by a cooperative agreement between the University of Connecticut and the S.C. Sea Grant Consortium. This work was partially supported by Clemson University's Public Service Activities (PSA). Other support was provided by the Carolina Clear program and the Center for Watershed Excellence, both administered through Clemson University and the Clemson Experiment Station.

REFERENCES

Amatya, D.M., M. Miwa, C.A. Harrison, C.C. Trettin and G. Sun, 2006. *Hydrology and water quality of two first order forested watersheds in coastal South Carolina*. ASABE Paper no: 062182, St. Joseph, Mich.:ASABE, 22 pp.

Benedict, M. A., and E. T. McMahon. 2006. *Green Infrastructure: Linking Landscapes and Communities*. Island Press, 299 pp.

Epps, T. H. 2012. *Assessment of the rainfall response of headwater streams in lower coastal plain South Carolina*. Masters thesis, Biosystems Engineering program, Clemson University. May, 2012.

Epps, T. H., D. R. Hitchcock, A. D. Jayakaran, D. R. Loflin, T. M. Williams, and D. M. Amatya. 2013a. Characterization of storm flow dynamics

S.C. Water Resources Conference

2012 Contributors

Clemson University
Restoration
Institute

DUKE
ENERGY®

santee cooper®

Charleston
Water System

Greenville
Water

SC ENERGY OFFICE
B&CB
SC BUDGET AND CONTROL BOARD

YSI®
a xylem brand

of headwater streams in the South Carolina lower coastal plain. *Journal of the American Water Resources Association* 49(1):76-89.

Epps, T. H., D. R. Hitchcock, A. D. Jayakaran, D. R. Loflin, T. M. Williams, and D. M. Amatya, 2013b. Curve number method assessment for two headwater streams in lower coastal plain South Carolina, USA. *Journal of American Water Resources Association*, 49(6):1284-1295.

Harder, S., D. Amatya, T. Callahan, C. Trettin, and J. Hakkila, 2007. Hydrology and water budget for a forested Atlantic coastal plain watershed, South Carolina. *Journal of the American Water Resources Association* 43(3):563-575.

Hitchcock, D.R., D.L. White, A.D. Jayakaran, T.M. Williams, K. Giacalone, J. Calabria, C.B. Sawyer, and G.W. Eidson. 2010. Green infrastructure assessment tools for varying scales in coastal South Carolina. In: Eidson, G.W. and Sawyer, C.B., eds., *Proceedings of the 2010 South Carolina Water Resources Conference*, October 13-14, Columbia, SC.

Holland, A.F., D. Sanger, C. Gawle, S. Lerberg, M. Santiago, G. Riekerk, L. Zimmerman, and G. Scott. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. *Journal of Experimental Marine Biology and Ecology* 298(2):151-178.

La Torre Torres, I.B., D.M. Amatya, G. Sun, and T.J. Callahan. 2011. Seasonal rainfall–runoff relationships in a lowland forested watershed in the southeastern USA. *Hydrological Processes* 25:2032-2045.

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift, J.P. Shepard, and H. Riekerk, 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the southern US. *Journal of Hydrology* 263:92-104.

Tufford, D.L., C.L. Samarghitan, H.N. McKellar Jr., D.E. Porter, J.R. Hussey. 2003. Impacts of urbanization on nutrient concentrations in small southeastern coastal streams. *Journal of the American Water Resources Association* 39(2):301-312.

U.S. EPA. 2010. Managing Wet Weather with Green Infrastructure. Accessed Sept. 17, 2012. http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm.