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

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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 toward resource protection with the goal of creating resilient communities. These landscape elements are complex within and between varying scales, so stakeholders need clear, relevant, comparable, and easily accessible information for effective decision-making. This presentation will focus on hydrological and ecological metrics that could guide sustainable land use in coastal South Carolina. For example, runoff coefficients have been determined in watersheds challenged by low gradient topography and shallow water table conditions. Forested water budgets for the goal of defining pre-development conditions are being refined, including water table elevation as influenced by stand water use, evaporation, and recession by percolation. Alternative stormwater control measures, such as rain gardens, are also being explored in coastal areas. These monitoring projects are being integrated with an online mapping tool so that geospatial data complement research efforts while providing site-based information to decision-makers. With appropriate hydrological, ecological, and community-based assessments and targets, sustainable land use goals in coastal South Carolina may be better achieved through green infrastructure design.

BACKGROUND AND JUSTIFICATION

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 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., 2012). 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 is 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). The U.S. EPA recognizes green infrastructure as a tool to manage wet weather (U.S. EPA, 2010), and research efforts in this regard are being conducted in coastal South Carolina (Hitchcock et al., 2010). This paper provides specific progress updates and future goals and directions related to these latter efforts.

PROJECT DESCRIPTION AND HIGHLIGHTS

This integrated research and outreach project combines aspects of coastal forested watershed hydrology and ecological engineering with the goal of providing information for decision-makers not only with respect to effective stormwater management but also toward the preservation and restoration of coastal ecohydrological services. An understanding of pre-development hydrology and associated water budgets can guide targeted development strategies and stormwater management practices whether based on evapotranspiration, infiltration, retention, reuse, or a combination of these processes. A landscape-based decision-making approach is complicated by multi-scale dimensions, variables, and associated metrics, models, and tools. These challenges require investigations among several spatial and temporal scales. Spatial management scales include the individual or series ("treatment train") of stormwater control measures (SCM), the development tract, and the watershed or river basin. Temporal scales include daily (storm-event), seasonal and annual (water table fluctuation), and multi-year and decadal (climate variability). How one incorporates information from each of these scales to provide informed and effective land use decision-making is a tremendous challenge for our coastal planners, engineers, and regulators, as well as for researchers and educators involved in this field.

Stormwater Control Measures. Research is being conducted to evaluate the hydraulics and hydrology as well as water quality benefits of rain gardens and bioretention cells in coastal areas where shallow groundwater persist. Figure 1 shows existing rain garden and bioretention system locations. Note the close coastal proximity and thus the potential for shallow groundwater to play a role in system performance. This connection is currently under investigation.

Figure 2 shows a typical water budget for bioretention cells or other SCM. Sampling and monitoring is being conducted to quantify water budget components and assess the role of system location in the landscape on performance based on soils and variable water table position. Real-time data include meteorological parameters, surface water storage, water table position, and soil moisture response (Figure 3).

Inflow, outflow, and groundwater samples are being analyzed for coliform bacteria, nutrients (C, N, P), and suspended solids (TSS) to assess treatment performance. The experimental design includes selected locations that vary by stormwater source(s), surrounding land use and cover, location within the landscape (elevation, soils, and proximity both to surface waters and water table position), as well as specific system design aspects.

Coastal Rainfall – Runoff Relationships. In an effort to better understand seasonally variable watershed discharges as related to groundwater position, recent work has been completed to develop runoff coefficients for coastal areas. Three years of rainfall, flow, and groundwater level data have been evaluated for two first-order lower coastal plain watersheds in SC: Upper Debidue Creek (UDC) near Georgetown and Watershed 80 (WS80) in the Francis Marion National Forest. The resulting direct runoff coefficients (ROCs) – percentage of rainfall conveyed as watershed outflow - ranged from 0 to 32% at UDC and from 0 to 57% at WS80 (Epps, 2012; Epps et al., 2012). Runoff was found to be highly correlated with seasonally variable groundwater elevations. Differences in results between watersheds likely were observed due to different soils typical of each respective location as well as relative water table depth. Modified curve numbers (CN) for watershed outflow prediction as related to water table position and landscape parameters more typical of lower coastal plain have been explored and this work is currently under review (Epps, 2012).

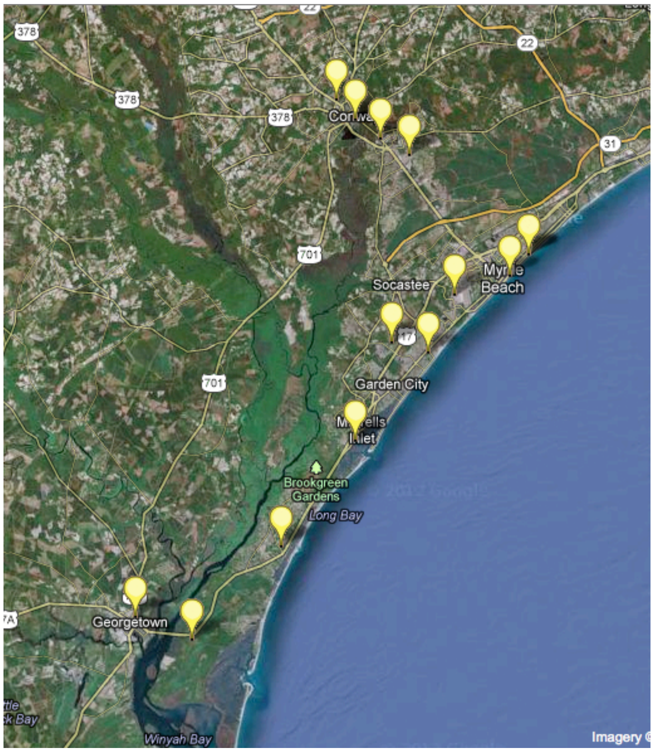


Figure 1. Prevalence of rain garden and bioretention locations for coastal Horry and Georgetown Counties indicated by yellow markers (from the SC LID Atlas and the National NEMO Network - not all are included – visit http://www.clemson.edu/public/carolinaclear/lidmap/ for more information).

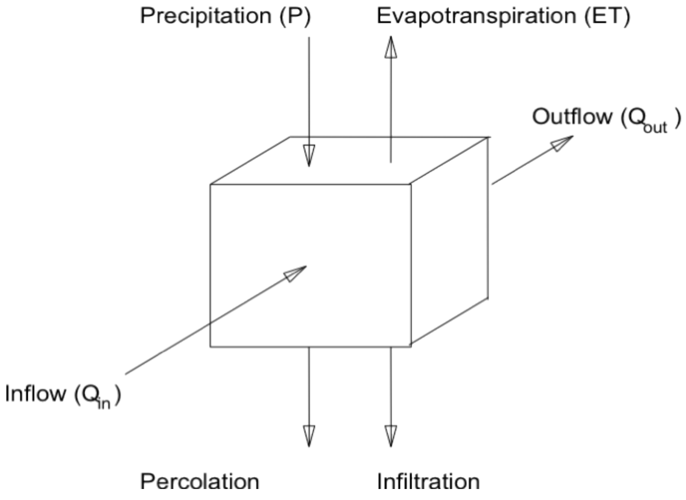
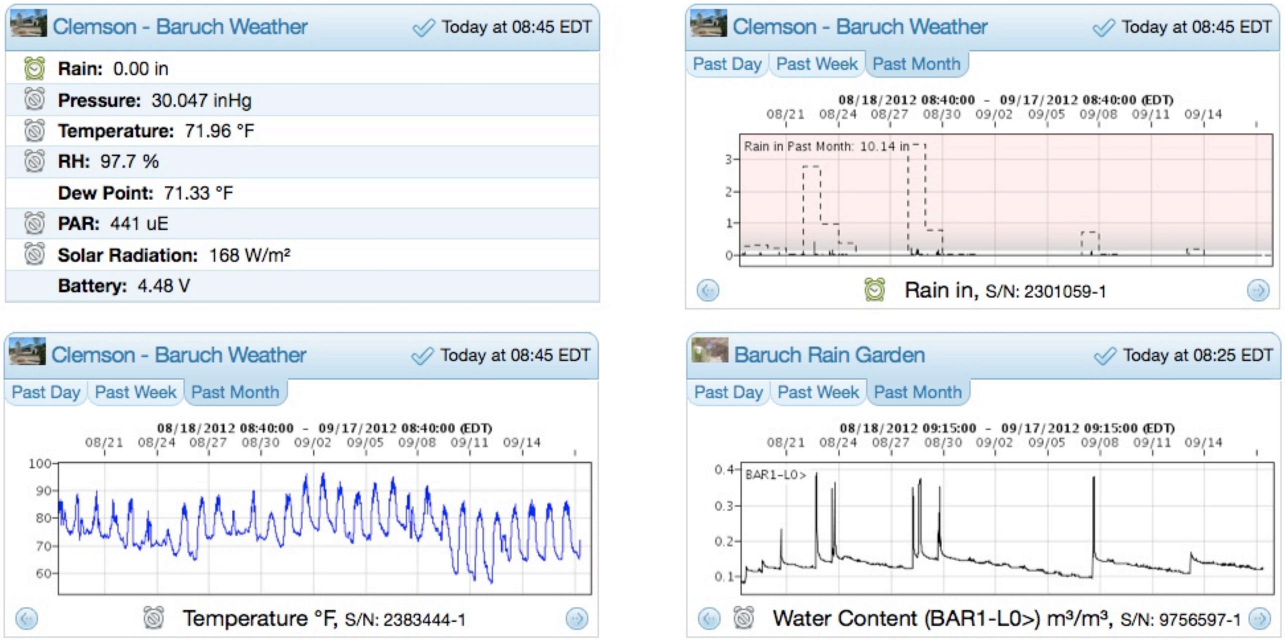
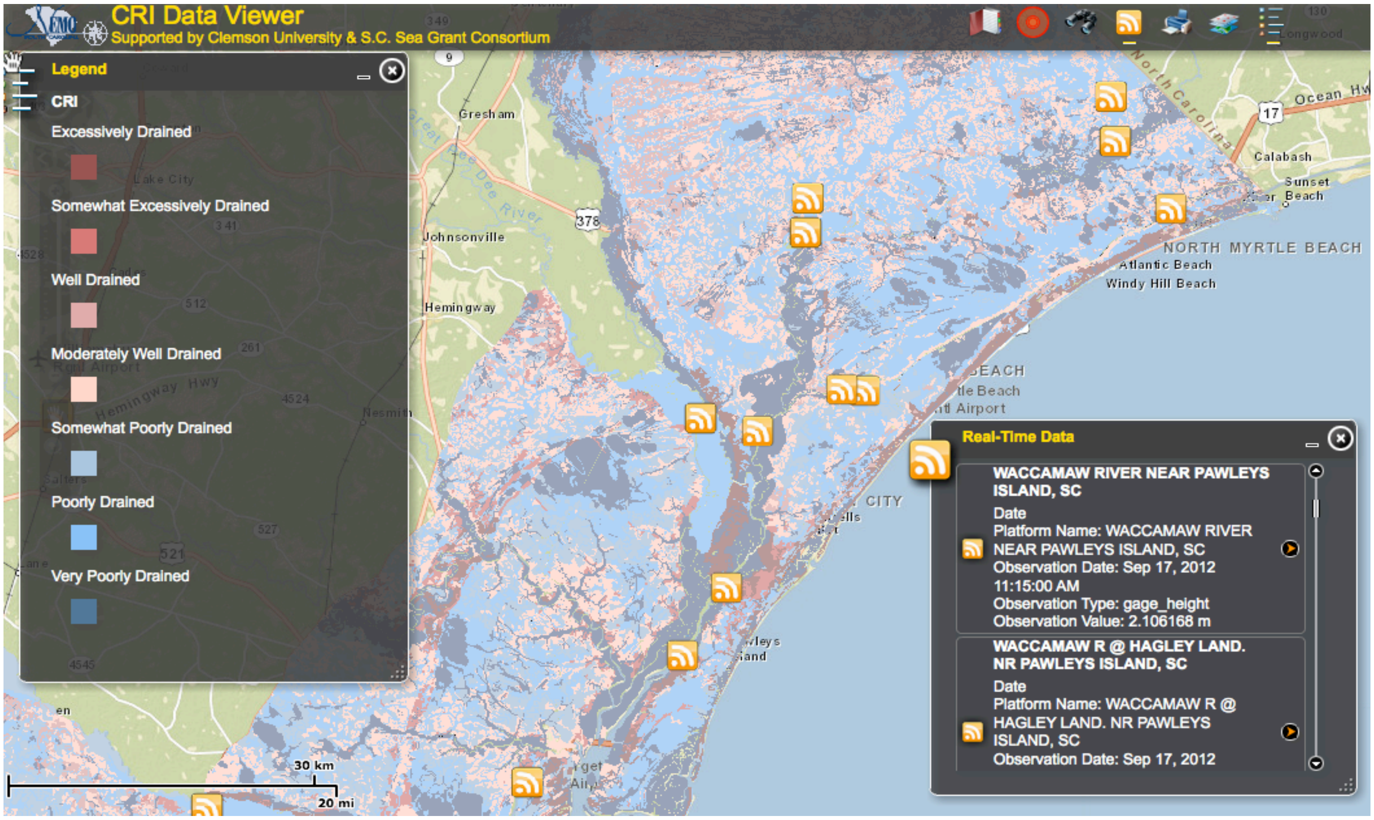


Figure 2. Water budget for stormwater systems such as constructed bioretention and wetland cells. (Storage = P + Q_{in} – ET – Q_{out}). Percolation and infiltration processes vary by system design depending on existence of liner or underdrains (exfiltration), so both are included here.



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/baruch/rain_gardens). A subset of all data including real-time weather parameters (top left), and the past month of ambient air temperature (bottom left), rainfall (top right) along with surface soil moisture content (bottom right) are shown respectively.



WACCAMAW RIVER NEAR PAWLEYS ISLAND, SC
Date
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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 data viewing capabilities using RSS feeds for coastal Horry and Georgetown Counties (http://www.cri-sc.org).

Geospatial Information and Data Viewing. The online Community Resource Inventory (CRI) (Figure 4) has been piloted in Georgetown County with some expanded information for Horry County (http://www.cri-sc.org). 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.

FUTURE GOALS AND DIRECTIONS

The integration of multi-scale information will be accomplished as follows: (1) introduce SCM monitoring data into the CRI tool as RSS feeds (initially rain gardens with other systems to be added in the future); (2) extrapolate rainfall-runoff-water table relationships for a larger geospatial area; (3) develop criteria for SCM suitability based on geospatial data, specifically soils and topography, as well as groundwater elevation data; (4) incorporate SCM suitability into mapping layers for CRI tool; and (5) assess longer term implications as related to climate variability, sea level rise, higher water table elevations, and more extreme precipitation regimes. It is anticipated that these additions and upgrades to existing tools will aid in effective future land use planning and stormwater infrastructure decision-making over multiple spatial and temporal scales in coastal South Carolina.

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