Sand River Headwaters Green Infrastructure Project, City of Aiken, South Carolina: A Collaborative Team Approach to Implementing Green Infrastructure Practices

G. W. Eidson[1], C.B. Sawyer[2], D.R. Hitchcock[3], J. Calabria[4], B. Putman[5], V. Chanse[6], C.J. Post[4], J.O. Hallstrom[7], D.L. White[8], S.T. Esswein[2], C. Bellamy[2], R. Shealy[6]

AUTHORS: [1,2] Restoration Institute [2] Center for Watershed Excellence [3] Baruch Institute of Coastal Ecology & Forest Science Clemson [4] Forestry & Natural Resources [5] Civil Engineering [6] Landscape Architecture [7] School of Computing [8] Computing and Information Technology , Clemson University, Clemson, SC 29634, USA
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ABSTRACT. The concepts of green infrastructure and low impact development provide a series of procedures and practices to modify the magnitude, frequency, and duration of stormwater runoff. Projects utilizing low-impact development design attempt to address the hydrologic and hydraulic challenges associated with urban stormwater by mimicing pre-development hydrology to enhance infiltration and treatment functions on site. The City of Aiken's Sand River Headwaters Green Infrastructure Project incorporates sustainable development practices in downtown watersheds with the goal of reducing ongoing impacts to the principal green infrastructure component of the city – Hitchcock Woods. Rain gardens, bioswales, underground cisterns, and pervious pavement provide smart green solutions. These Best Management Practices (BMPs) enhance nature's capacity to absorb stormwater, and provide both economic and environmentally sound approaches to reducing stormwater flows negatively impacting Sand River, Hitchcock Woods, and other downstream impaired waters. This project also enhances the city's environmental health while demonstrating community-based leadership towards sustainability.

INTRODUCTION

Green infrastructure may be defined as management approaches and technologies that mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and reuse (EPA, 2008). An expanded definition may include the interconnected network of green space that conserves natural ecosystem values and functions (Benedict and McMahon, 2002). The Sand River Headwaters Green Infrastructure Project (Project) incorporates both definitions by utilizing green engineering to facilitate restoration of interconnected green space. The project was envisioned during charrettes associated with development of a preferred alternative for the ecological restoration of Sand River, a unique geological formation within Hitchcock Woods. Over the past 15 years, Sand River has been severely eroded by stormwater discharges from downtown Aiken watersheds resulting in formation of an extensive and unstable canyon approximately 70 feet deep (Figure 1). For over a decade, The Hitchcock Woods Foundation and the City of Aiken (City) have been seeking a holistic approach to the restoration of Sand River that balances stormwater management with habitat preservation and restoration. In 2008, the city awarded a grant to Clemson University's Center for Watershed Excellence (Center) to mediate a preferred alternative between affected parties. The Center hosted a series of working meetings and charrettes among key stakeholders, local, state and federal agencies. Working groups were asked to identify ecological stressors, review existing data, identify data needs, evaluate alternatives, and formulate strategies for moving the restoration program for Sand River forward.

Figure 1. Sand River Canyon

Draft goals were established by developing consensus among the working groups and the Center facilitated development of a hybrid remediation plan which was adopted by the parties. Multiple elements of green infrastructure technologies were incorporated into the remediation plan with consensus to focus first on the use of green infrastructure to reduce the volume and flashiness of stormwater entering Hitchcock Woods. Background information, including presentation materials, can be found on the Sand River Ecological Restoration Master Plan web site (http://www.clemson.edu/restoration/focus_areas/restoration_ecology/projects/sand_river/).

In 2009, the City of Aiken, SC applied for and received $3.34 million under the American Recovery and Reinvestment Act (ARRA) to move forward the green infrastructure concepts developed during the Sand River Ecological Restoration Master Plan process. The city awarded a grant funded by ARRA to the Center to assist in design of the project and separately awarded a grant to develop a research and monitoring program for the project that utilizes technologies developed by Clemson's Intelligent River© Research Enterprise.

The project kick-off was in February 2010. The project is being developed within the city's 105 acres of historic parkways and boulevards (Figure 2) which divide city blocks. These green parkways historically played a key role in the management of stormwater but paving and curbing removed numerous parkways from serving as stormwater infiltration zones. Since the 1950s, an extensive stormwater infrastructure has been developed that rapidly shunts most downtown stormwater directly into Hitchcock Woods. Today, downtown stormwaters converge into a 10 foot diameter pipe that discharges into the gabion-basket lined headwater channel of Sand River.

This project reconnects stormwater flow into a subset of parkways. A dozen parkways in downtown Aiken are being reconfigured with bioretention areas to capture and treat stormwater while adjacent streets and parking lots are being reconstructed with pervious concrete, asphalt, and pavers which will absorb larger amounts of rainfall.

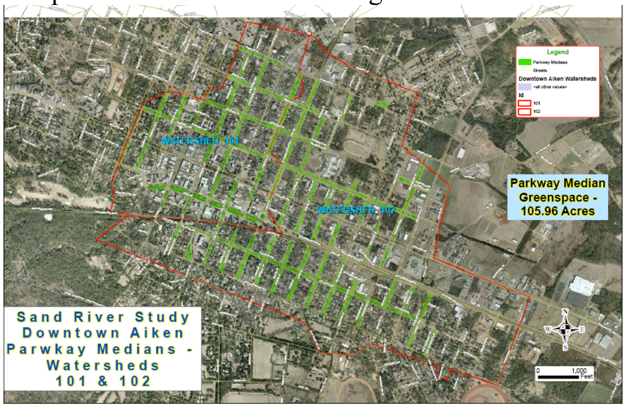

Figure 2. City of Aiken, SC Downtown Parkway Grid with Project Construction Area Outlined in Red.

PROJECT OBJECTIVES

The project objectives are outlined below.

1. Quantify hydrologic flows, pollutant concentration and loading of representative BMPs in response to storm events.
2. Assess Green Infrastructure BMP design, installation, and maintenance to develop cost-effectiveness profiles.
3. Optimize site-level remote data acquisition capabilities and integrate associated collection, transmission, display, and archival facilities into the *Intelligent River*™ network.
4. Address environmental stakeholder concerns related to project construction and implementation.
5. Evaluate stormwater management associated with the green infrastructure project.
6. Disseminate results to the general public, as well as regional design engineers, site developers, municipal and county stormwater staff, state environmental agencies, landscape architecture academics and professionals, planning agencies, and peer-reviewed journals.

PROJECT DESCRIPTION

The project is divided into three primary components: 1) Stormwater Monitoring System and Infiltration Optimization 2) Intelligent River™ Integration and 3) Landscape Architecture Designs. These elements are discussed below.

1. Stormwater Monitoring System and Infiltration Optimization

Until recently, standard site development practices included conveying untreated stormwater runoff away from developed areas into an underground drainage network, which negatively affected water quality in receiving waters and increased the intensity and volume of peak discharges. In order to address the hydrologic and hydraulic challenges associated with urban stormwater, the concepts of green infrastructure and low impact development provide a series of procedures and practices to modify the magnitude, frequency, and duration of stormwater runoff. The overall goal is to recreate a hydrologically functional landscape through low-impact development design that opens parkways to receive stormwater flows and mimics pre-development hydrology by enhancing infiltration and treatment functions in place.

Methods

To determine the effectiveness of green infrastructure elements in retaining stormwater and removing associated pollutants, representative installations of each are being evaluated. Storms are being monitored during each phase of the study. During and after each storm event, collected data includes weather parameters, inflows and outflows, soil moisture content and storage within the BMP soil profile, and groundwater level via wells installed within and below the invert elevations. Surface and groundwater samples are being collected and analyzed for pollutant concentrations. Baseline flow data are being collected at selected trunk lines flowing into the 10-foot diameter pipe that discharges stormwater from downtown Aiken watersheds into the Sand River.

A Campbell Scientific, Inc. weather has been installed within the project zone to record solar radiation, wind speed and direction, relative humidity, temperature, barometric pressure, and rainfall. The rainfall measurement provides data for calculating the volume of water that falls directly onto the infiltration BMPs. Storm depth and duration, as well as peak and average intensity, are determined. Solar radiation, wind speed, humidity, and temperature data are being used to estimate evapotranspiration.

Surface pollutant concentrations and loading rates are determined by sampling surface water during storm events at inflows and outflows, as well as within groundwater wells. Water budgets for bioswales are also being calculated. Pollutant removal efficiencies are calculated by comparing inflows and outflows as percent concentration differences and as mass load reductions. When possible, automated flow-based sampling is being utilized, where the sample volume collected is proportional to the flow rate obtained by a flow sensor. Initial flow monitoring is providing baseline flow-to-volume proportions to refine the sample composite strategy to be used in sampler programming. The sampling strategy has been developed to ensure fine-grained (i.e., temporally dense) sampling during the first flush of a given storm event, with continued composite sampling over as much of the duration of the storm hydrograph as possible. Collection and handling of samples are conducted according to established regulatory protocols. Water quality parameters, including temperature, specific conductance, and pH, are continuously monitored at discharges where accessible.

Surface flows, which represent a significant proportion of the inflow to BMPs present measurement challenges due to extensive modifications to the original design specifications. For flow measurement and sample collection, weir boxes for outlet control of BMP discharge were installed as part of the BMP design. In order to monitor groundwater levels and infiltration rates, at least 2 wells per infiltration BMP have been installed. Water level recorders continuously record data in each of the wells. Water level data from these wells are being used for hydraulic gradient determination and infiltration rates. Soil moisture content is being monitored throughout the soil profile of relevant BMPs to assess plant-available water and infiltration. This is being accomplished by the use of a vertical series of soil moisture sensors installed within each bioswale. Infiltration capacity with respect to the wetting front that results from stormwater inflow is being estimated.

Groundwater sampling at each well is being performed manually at the initiation of, during, and after selected storm events at appropriate intervals for as long as percolate is determined. Sampling intervals and frequency are being determined in the initial phase of the project through the interpretation of soil moisture and groundwater level data. These samples are being used to determine pollutant concentration differences and to calculate mass fluxes through the soil profile and below each bioswale. Laboratory analyses are being performed on selected samples to optimize treatment design. Initial screening may rule out some analytes over time if concentrations are below parameter detection limits for first flush samples. Pollutant concentration data collected through sampling will be converted to mass loads with respect to flow data associated with individual and total inflows and outflows.

On-site infiltration BMP performance is being assessed in several ways. Outflow-to-inflow peak and time-to-peak ratios are being determined and the exceedence probability method is being used to determine performance based on water quantity by interpretation of data across multiple storms. Laboratory and/or field studies may allow for the determination of hydraulic conductivities of various soil media, including those associated with the bioretention, stormwater wetland, and subgrade material for permeable parking. Pollutant removal efficiencies are being calculated by comparing influent and effluent mass loadings as a percent change. Where possible, BMP performance is also being expressed in terms of event mean effluent concentrations (EMCs) and pollutant load reductions in order to compare these results with related studies.

Multiple porous pavement types are being evaluated including pervious concrete, porous asphalt, and permeable interlocking concrete pavers. These three types of porous paving materials have shown to be effective in reducing stormwater runoff and improving stormwater quality while providing a structurally sound pavement surface. Preliminary investigation of the subgrade soil properties at the site of the porous pavement installation involved analysis of core samples to characterize and determine soil type, permeability, and moisture/density relationships. Laboratory investigations were conducted on the local materials utilized to construct the porous pavement structures. These investigations involved the evaluation of local aggregates used for the porous aggregate base, pervious concrete, and porous asphalt. Physical properties of the aggregates were also measured using standard test procedures. Full-depth pavement cross-sections have been constructed in the lab and the systems were tested to measure the permeability/infiltration rate and the contaminant filtration capabilities. Design variables included porous aggregate base gradation, pervious concrete mix design, porous asphalt mix design, and permeable interlocking concrete paver type, joint material, and bedding material. Extensive photo and video documentation of the construction process is archived at: http://www.clemson.edu/restoration/focus_areas/restoration_ecology/projects/watershed_center/aiken_green/onsite.html.

2. Intelligent River© Integration

A baseline understanding of the City's downtown watersheds was developed prior to BMP installation using commercial measurement instruments as outlined above. However, while necessary, the approach is insufficient by itself to address the city's *long-term* stormwater management goals. The size, power, and expense of commercial instruments preclude the possibility of high-volume installations, limiting the spatial density of collected datasets. These data are essential to developing a precise understanding of the water quantity and quality impacts of individual BMPs and the treatment train as a whole. Further, the long-term sustainability of the treatment train requires continuous monitoring to ensure the integrity of the installations and to signal the need for BMP maintenance.

Methods

To address long-term monitoring requirements, the team is adapting and extending components of the *Intelligent River*© infrastructure for use in the City's stormwater management program. The Intelligent River© (Eidson et al., 2010) implements a distributed sensing fabric that spans a large geographical area. The back-end dissemination system relays collected data to end-user applications and long-term storage repositories in real-time. It is, in effect, a high-fidelity *macroscope* that provides unprecedented visibility into watershed dynamics. It is an ideal instrument for the Aiken program.

Adapting the *Intelligent River*© for BMP monitoring required both hardware and software development spanning multiple network tiers. An overview of the work being performed is outlined below.

Platform Development: As part of our prior work, we developed a low-cost, low-power sensor platform for long-term in situ deployments. The basic hardware configuration supports most major sensor interconnect standards, includes a programmable processor, wireless transmitter, and high-capacity data storage (*microSD*) card. The device measures approximately 2.1”x2.1”x3.1” and operates for 8 - 12 months on a single 9v battery. All supporting software libraries have been field-tested to ensure correctness.

Adapting the sensor platform for use in the Aiken program required two hardware revisions, implemented as “daughter boards” to the basic platform. First, a radio board was developed to provide cellular connectivity at each BMP for exfiltrating collected data samples in real-time. The board provides link redundancy (in addition to the existing WiFi network), improving the reliability of the collection system. Second, the team developed a digital bridge board to provide connectivity to high-end commercial sensing instruments. While the board has broad applicability, the design is tailored for use in integrating automated samplers with the back-end collection and dissemination system.

Portal Development: The Intelligent River© portal (www.intelligentriver.org) serves to meet local and regional data visualization and access needs. Users can visualize real-time observation data using both web-based tools and specialized data visualization applications. Spatial representation is achieved using *Google Maps* that supports advanced data displays and dynamic content adjustments that include an interactive charting system. Data is accessed by project but can also be unified with other data providers including NWS, USGS and USACE. By unifying providers under a common interface, the Intelligent River™ serves as a “one stop shop” for water resources data. In addition, a *Flash*-based desktop tool is available for querying, monitoring, and downloading real-time data, with support for accessing QA/QC flags.

3. Landscape Architecture Site Selection and Design

The landscape architecture aspect of this project is focused on site-specific design elements associated with stormwater infiltration and detention throughout the project site. These elements include 1) design at multiple scales of green infrastructure; 2) community-based green infrastructure approaches, plans, and designs; and 3) assessment of human dimensions of green infrastructure and stormwater using multi-methods design and social science methods. The project was developed with a goal of being selected as a SITES™ registered pilot project for the Sustainable Sites Initiative™.

Methods

To develop green infrastructure concepts and designs that will include stormwater infiltration and detention, community design, and other green infrastructure approaches, at least one graduate student designer/researcher under faculty guidance is exploring design and assessing functionality of a spectrum of green infrastructure designs and plans at the regional, city, neighborhood and site scales.

Explaining community involvement at the city, neighborhood, and site levels requires comprehending physical, spatial, and social insights and methods. Participatory action research, archival research, and interviews are being used to assess levels of community involvement and community-based planning to green infrastructure and stormwater management in Aiken. Examining factors such as demographics, environmental attitudes, and mapping social, cultural, and ecological aspects, i.e., the social and the physical, provides the institutional and planning context for understanding Aiken's emerging approaches to stormwater management through community-based green infrastructure design.

Sustainable Sites Initiative™

The team was notified in June 2010 that the project was chosen as a pilot project for the Sustainable Sites Initiative™, a new program testing the nation's first rating system for green landscape design, construction and maintenance. The project will join 174 other pilot projects from 34 states, Canada, Iceland and Spain as part of an international pilot program to evaluate the new SITES™ rating system for sustainable landscapes. SITES™ is a partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin and the United States Botanic Garden. Like the other pilot projects, the site will test a system for achieving different levels of site sustainability on a 250-point scale and the performance benchmarks associated with the Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009. The organization will use feedback from the projects during the pilot phase, which runs through June 2012, to revise the final rating system and reference guide by early 2013. The Sustainable Sites Initiative™ is an interdisciplinary partnership to transform land-development and management practices with the nation's first voluntary rating system for sustainable landscapes.

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