CREATING DIGITAL COASTAL WATERSHEDS: THE REMOTE DATA ACQUISITION NETWORK AT BANNOCKBURN PLANTATION, GEORGETOWN COUNTY, SC

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Abstract. Population growth and the resulting land use change required to support this growth is occurring at a tremendous rate along the South Carolina coast. Sustainable technologies and low impact development practices can preserve hydrological and ecological function and protect natural resources; however, baseline hydrology and ecology must be assessed as a benchmark for sustainable development goals over the course of land use change. Short- and long-term impacts from the conversion of forest lands to urban areas must be better understood to minimize negative effects and provide sustainable solutions. Bannockburn Plantation, located in Georgetown County, SC between Hwy. 17 and the Atlantic Ocean, provides a unique opportunity for spatial and temporal research related to coastal hydrology, ecology, and land use change. The 3500-acre site is currently dominated by forested wetlands and upland pine stands. The property is slated for development over the next 10-12 years with the first proposed phase of development to occur within the Upper Debidue Creek watershed.

Bannockburn Plantation is a pilot installation site for a remote data acquisition network and digital watershed project. This network is being deployed for the real-time collection, transmission, storage, and visualization of hydrological and ecological data for coastal headwater streams and forested wetland landscapes. There are five (5) overlapping system levels for the sensor network that are being integrated into a comprehensive monitoring strategy for the property: (1) surface hydrology and water quality; (2) groundwater hydrology and water quality; (3) soil and water carbon dynamics; (4) vegetative ecology, and (5) amphibians and soil moisture. Remotely-accessed environmental sensors can save time and labor while providing real-time data streams for research and computer visualizations for education and outreach. This presentation will provide an overview of the environmental sensor network at Bannockburn Plantation as part of the larger statewide Intelligent River™ project through Clemson University and its Center for Watershed Excellence.

INTRODUCTION

Bannockburn Plantation (33.38° N, 79.17° W), located in Georgetown County on the Waccamaw Neck between Hwy. 17 and the Atlantic Ocean, provides a unique opportunity for spatial and temporal research related to coastal hydrology, ecology, and land use change. The 3500-acre site, typified by low gradient topography and a shallow water table, is currently dominated by forested wetlands and upland pine stands. The property consists of two primary watersheds of interest for monitoring (Figure 1): Upper Debidue Creek and Middleton Creek. The property is slated for development over the next 10-12 years. The first proposed phase of development is to occur within the Upper Debidue Creek watershed.

There are six (6) overlapping system levels for the sensor network that are being integrated into a comprehensive monitoring strategy for the land tract: (1) meteorological data; (2) surface hydrology and water quality; (3) groundwater hydrology; (4) soil and water carbon dynamics; (5) vegetative ecology, and (6) amphibian movement and soil moisture. This monitoring strategy encompasses proposed ideas and contributions from researchers with multi- and interdisciplinary expertise from both the Belle W. Baruch Institute of Coastal Ecology and Forest Science and the Clemson campus, including, but not limited to, representation from the following entities: the Agricultural and Biological Engineering Department, the Center for Watershed Excellence, Clemson Computing and Information Technology (CCIT), the Electrical and Computer Engineering Department, Environmental Engineering and Science, and the Forestry and Natural Resources Department. The project is a component of the state-wide Intelligent River™ initiative and is also associated with Clemson's Program of Integrated Study for Coastal Environmental Sustainability (PISCES).

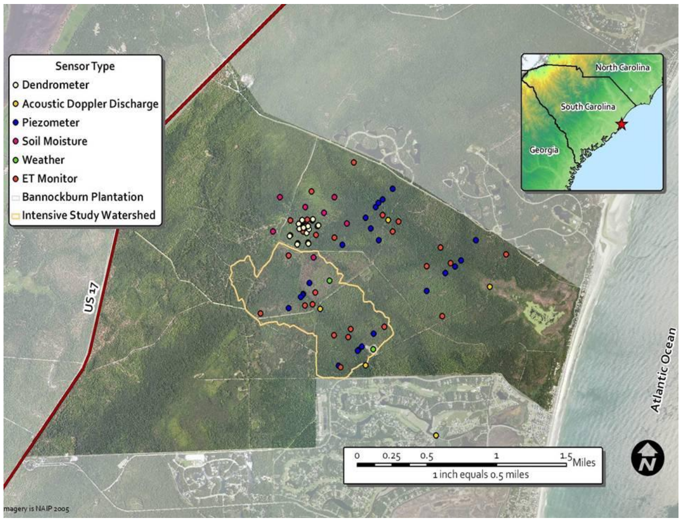

Figure 1. Bannockburn Plantation in coastal Georgetown County, SC, showing sensors for tree growth (white dot), surface flow (yellow), piezometric head (blue), well-rain (orange), soil moisture (red), and weather data (green). Phase I project watershed (Upper Debidue Creek) is outlined in yellow.

METEOROLOGICAL DATA

An array of weather stations and sensors are located in the Phase I Upper Debidue Creek watershed, measuring precipitation, air temperature, relative humidity, wind speed and direction, barometric pressure, and photo-synthetically active radiation (PAR). Some of these data will be used to estimate potential evapotranspiration (PET). Sensor types range from a Rainwise® weather station, Onset® Hobo tipping bucket rain gages, and Campbell-Scientific® data logger with temperature and relative humidity sensors and with a Li-Cor quantum sensor for measuring PAR.

SURFACE HYDROLOGY AND WATER QUALITY

Culvert Monitoring. Existing road culverts at the site are being monitored for water quantity and quality for surface discharge at watershed outlets. These culverts provide suitable locations to monitor flow on the property - initial monitoring is focused on the Upper Debidue Creek watershed (delineated in Figure 1). Sampler assemblies will serve as the flow and water quality parameter data hub for each sample station location. Instrumentation includes ISCO® 6712 samplers configured with ISCO® 750 area velocity flow sensors and In Situ® Troll 9500 sondes with water quality parameter sensors that measure temperature, pH, specific conductance, dissolved oxygen, and oxidation-reduction potential. The ISCO® 6712 is also capable of being programmed to collect water samples for a variety of analytical purposes. For culvert flow monitoring comparisons in the Upper Debidue Creek watershed, stand-alone ISCO® 2150 area velocity flow sensors have also been deployed to test flow sensor utility and accuracy.

Stream Monitoring. In addition to culvert monitoring, stream flow characteristics within watersheds will be monitored using modified Parshall flumes that will be installed in three reaches that have shown reasonable flow magnitudes over recent rainfall events. These flumes have been installed at locations in association with groundwater monitoring transects and culvert monitoring stations. Flumes have been fabricated to specifications dictated by channel morphology and a design storm event. The flumes will be adapted to accurately measure low flow conditions that may not be captured by culvert flow monitoring.

A stage-discharge rating curve will be used to arrive at flow rates passing through the culvert and flume structures, and these data will be monitored in real-time and accessible via the monitoring and sensor network.. Results from both culvert and stream flow monitoring in response to different storm events will be assessed and compared.

Water Quality Monitoring. Water quality parameters that will be monitored at each culvert and flume location include level, temperature, specific conductance, dissolved oxygen, pH, and oxidation-reduction potential (ORP). These data are being collected in real-time and will soon be accessible via the monitoring and sensor network. Surface water samples are also being collected and analyzed for the ionic composition in order to characterize conductivity measurements both during baseflow and storm flow conditions. Currently, automated water sampling is based on various schedules with different timed intervals, but in the future, the sample programs will be configured using a flow-weighted sample compositing strategy. Future research initiatives will provide the opportunity for sample analyses, including those for nitrogen, phosphorus, and sulfur compounds, dissolved organic carbon, total suspended solids, pathogenic bacteria, and other potential constituents of concern. These data, along with flow data from the culverts and flumes, can be used to calculate constituent loads coming from the watersheds.

SUBSURFACE AND GROUNDWATER HYDROLOGY

Three primary methods have been employed for subsurface hydrological monitoring: (1) transects of multilevel piezometers; (2) combinations of understory rain gauges, soil moisture sensors, and water table wells, and (3) multiple soil moisture probes. Each method addresses the movement of groundwater, its relation the measured water table, and impacts on vegetation growth or evapotranspiration (ET) limitation. Within the Upper Debidue Creek watershed, sensor deployment is as follows (Figure 1):

Groundwater Input to Stream Flow. Two (2) transects of five (5) piezometers have been placed in each of the two watersheds (Figure 1) near where streamflow measurements are being proposed as previously described. Each transect will have three (3) levels of piezometric potential at the watershed divide, at the transition from pine to hardwood, and at bottom of the stream. By collecting real time data on piezometric potential, stream level, and flow, we will be able to examine the importance of groundwater as a source of quick flow after the rain. These hydrology data will allow construction of a point wise water balance model to be applied to the entire property in the undeveloped state. The groundwater and surface hydrology measures can then be used to test such a model and make inference as to the adequacy of the hypothetical basis of the model. The model can be calibrated and used empirically to examine impact of development. Groundwater samples will also be collected from piezometers and analyzed for the ionic composition in order to characterize conductivity measurements.

Rain-well-soil Moisture Sites. Ten (10) locations per watershed have been instrumented with fully screened wells to measure the water table, a soil moisture probe at the top of the B horizon, and a tipping bucket rain gauge below the canopy. The wells are 5 cm diameter by 3.3 m long with a pressure transducer in the bottom. Two of these sites are in plots where sap flow is being monitored.

Soil Moisture Only. These sensor arrays provide information regarding the spatial extent and temporal controls of ephemeral wetlands (or depressional storage) on these flat watersheds. The design uses low-cost Decagon® soil moisture probes to determine spatial distribution of moisture and saturation. A spiral arrangement of 19 nodes is being placed to allow data collection at lag distance from 5- 500m (Figure 1). Each node includes five (5) soil moisture probes to examine short distance correlations. The spiral includes six (6) well-rain nodes as described above. The purpose of these will be to examine spatial distribution of rainfall and water table within the same area to estimate water table position at each of the soil moisture nodes. The placement of the spiral allows the examination of lag distances of 500-1500m from the well-rain network nodes in described above.

The soil moisture probe network has been related to LIDAR elevation data and 2006 1m resolution ortho-aerial photography. The spatial distribution of elevation and tree crowns can be determined from these data. These data can then be correlated to 30cm LIDAR-derived contour and vegetation survey data across the entire Bannockburn property.

SOIL AND WATER CARBON FLUX

The Bannockburn Plantation property provides a unique opportunity to study the relation between soil and water organic and inorganic carbon flux. A sensor pack that will automatically quantify stream organic and inorganic carbon, using an infrared gas analyzer to measure CO2, pH sensors and a CDOM sensor to measure dissolved organic matter will be integrated into the existing environmental sensor and data network.

A key component of this study is to develop interpolated spatial data layers and pool estimates of existing soil carbon, by analyzing the soil samples that are currently being collected as wells are being installed. This ties the planned hydrologic sensor network (both soil and trees) to carbon cycle research. Soil samples are being analyzed for total carbon using stable isotope mass spectroscopy, to both quantify carbon pools and potentially track carbon pools from the soil to the stream. Cores for bulk density determination are required to develop soil carbon pool estimates. Available models for carbon and water flux would be calibrated and validated using sensor network data.

VEGETATIVE ECOLOGY

Current tree growth patterns are being monitored through monthly or annual measurements of diameters, while the proposed sensor network allows for realtime continuous measurements. Continuous sap flow measurements are being incorporated into the sensor network and will provide a link with hydrological monitoring through ET estimates and water table measurements. Productivity and nutrient cycling are being monitored through litterfall and decomposition studies. These measurements provide data to better understand the capacity of the different habitat types to act as filters for nutrients and sediments coming into the watersheds. Soil analyses and carbon flux dynamics, as previously described, will be quantified to determine effects on belowground root growth and decomposition on carbon storage and burial. Growth functions and carbon relations based on species type as well as by site will be established to upgrade existing forest simulation models to predict present and future habitat quality.

Plot Establishment. Along the hydrology well arrays, paired plots of 20-m x 25-m dimensions have been established in each stand providing a 0.1 ha sampling area per stand at each elevation (dry, transition, wet). In each plot, all trees > 10cm diameter at breast height (DBH) are being tagged, identified by species, and measured for diameter. For each stem tagged, a viability status (dead, healthy, partial defoliation, dying branches) is being recorded. Standing dead trees are also being measured for size and assessed a condition code to describe the possible fate (intact, snapped, toppled, etc.) and level of deterioration (crown, bole, and bark integrity). Shrubs and saplings (stems >2.5cm DBH and <10 cm DBH) are being inventoried by recording species and dbh in an interior 5-m x 5-m plot. Canopy leaf density and cover is approximated based on light attenuation collected with a LAI-2000 Plant Canopy Analyzer at peak foliage and leaf-off stages relative to simultaneous ambient open-canopy readings. Forest age estimates will be derived based on stem size and ring counts. Plot data will be used to calculate size class distributions, density, and basal area (BA) of each species in each area. Relative density and relative dominance will be calculated for each species within each wetland, and importance values for each species calculated.

Dendrometer Bands. Typically, seasonal growth patterns of trees and annual stem production are measured with stainless steel dendrometer bands installed on 10 trees (>10-cm DBH) in each plot. Dendrometer bands have proven a cost effective way to make short-term repeated measurements of tree-stem growth and expansion. Plans are for a subset of banded trees to be fitted with devices that measure continuous growth changes as part of the remote data system. This automated version of the dendrometer band will be able to track tree-stem growth using a strain gauge sensor.

Sap Flow Measurements. There is a critical need in forest science to begin linking our research to the stand and landscape levels. Sap flow investigations can be expanded to quantify water flow at multiple depths into the tree; not all sapwood is as effective as the outer portions at conducting water. Once absolute rates of sap flow are determined and depth profiles are constructed, stand water use can be calculated as a function of species distribution; tree diameter distribution; environmental stress regime (e.g., flooded versus drained); and daily, monthly, and annual meteorological state (e.g., vapor pressure deficit, light regime).

Litterfall Measurements. Monitoring litterfall is critical to understanding nutrient dynamics and plant productivity in forested ecosystems. Litterfall is being collected in each plot using five randomly placed 0.25 m^2 littertraps with 1 mm mesh fiberglass screen bottoms. The traps are elevated to prevent inundation and will emptied monthly or every two weeks depending upon season (peak litterfall occurs from late September to December). Leaves, reproductive parts, and small branches will be separated, dried, and weighed after each litter collection period. Total annual litterfall will represent leaf biomass production.

Field transects. Thirteen transects, 100 m apart, with plots spaced at 50 m (total 150) were used to examine the ecosystem level integration of water table measurements with vegetation. At each plot GPS location, water table level, and species, height, and diameter of 12 trees were recorded. Water table depths at these plots will be related to the ten continuous recording wells.

All vegetation measurements will be applied to nutrient budgets, productivity estimates, ecological models and visualization applications (Figure 2) for forests on the Bannockburn property.

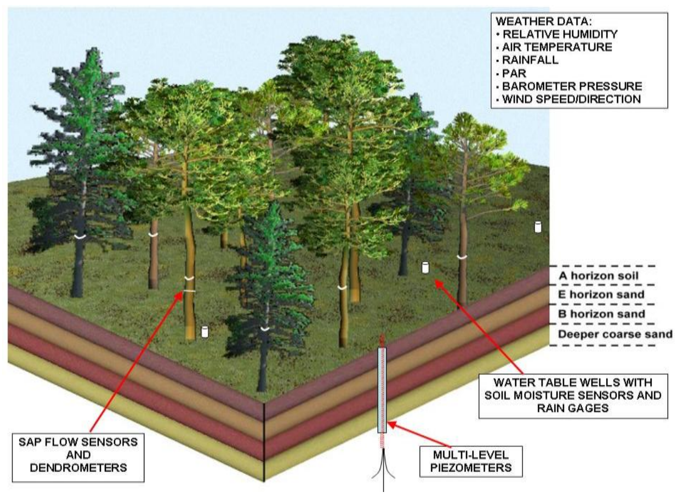

Figure 2. Forest visualization that includes tree canopy, understory, and soil horizons with some of the related instrumentation for the hydrologic and ecological sensor network.

SOIL MOISTURE NETWORK FOR WETLAND/AMPHIBIAN MONITORING

In South Carolina, as many as 27 species of amphibian breed in ephemeral wetlands (Semlitsch et al. 1996)– a class of wetlands experiencing disproportionate habitat losses (Semlitsch and Bodie 1998). Amphibians as a group are a sensitive indicator of environmental change and those that breed in ephemeral wetlands are especially responsive to shifts in climate, upland habitat degradation, and changes in water chemistry. Drought cycles have enormous impacts on amphibians breeding in Carolina Bays and similar wetlands (Pechmann et al. 1989; Semlitsch et al. 1996). Likewise, cumulative impacts of roads and housing development are the primary cause of amphibian and reptile population declines in urbanizing areas, due to direct mortality, genetic isolation, surface water pollution, and other impacts (Windmiller and Calhoun 2008). As losses of ephemeral wetland function accumulate at the region scale, ecosystem-wide effects, including loss of flood storage and biodiversity effects are predicted.

The primary goal of this research at the Bannockburn site has been to assess the distribution and abundance of amphibians and reptiles in relation to landscape-scale fluctuations in surface water and soil moisture. Because amphibians are known to rapidly respond to rain events and synchronize breeding to surface water peaks, it is important to understand the spatial extent and patterns that typify the Bannockburn amphibian and reptile communities before, during, and after such events.

Preliminary data on the distribution and activity of amphibians and reptiles were collected during the summer of 2008. Nightly surveys were conducted around each of the soil moisture sites. Surveys were conducted between June 21 and August 1. All habitat types within a 50m radius of the sampling site were systematically searched with headlamp (a visual encounter survey). Likewise, all species calling, and their breeding habitats were noted. GPS locations of sighted individuals were recorded and uploaded to a GIS of the site.

Long-term study design will incorporate remote monitoring of amphibians using sound detection (e.g., breeding calls), and also intensive capture-recapture monitoring around specific wells. Movements of focal species will be analyzed as well, using radiotelemetry.

While much of this effort is focused on amphibians, due to the close functional relationship between surface water and soil moisture conditions and their activity, it is important to remember the role of reptiles, as well. Reptiles often respond to the same environmental cues as amphibians, largely because many depend on stream networks and ephemeral wetlands for food. Thus, our research has and will continue to take a community-level approach. At the Bannockburn study site, we have the opportunity to integrate surface and groundwater monitoring to study the interplay among hydrological dynamics, land use change, and wildlife populations. Hydrology and soil moisture sensors will not only create the ability to monitor spatial and temporal aspects of water retention and movement at the landscape level, but also provide a mechanism to link climate, hydrology, and land use change to wildlife habitats, specifically those that support amphibian populations.

SUMMARY

This coastal component of the Intelligent River™ project demonstrates an integrated approach to monitoring complex environmental systems. The development of the environmental sensor network at Bannockburn Plantation has relied on the syntheses of research expertise and technological development related to hydrology and ecology in coastal landscapes. This project will not only provide real-time data for a variety of users but will also allow for establishment of a benchmark for sustainable development and serve as a long-term mechanism for monitoring land use change as it takes place.

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REFERENCES

Pechmann, J.H.K., Scott, D.E., Gibbons, J.W., Semlitsch, R.D., 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetlands Ecology and Management 1, 3-11.

Semlitsch, R.D., Bodie, J.R., 1998. Are small, isolated wetlands expendable? Conservation Biology 12, 1129-1133.

Semlitsch, R.D., Scott, D.E., Pechmann, J.H.K., Gibbons, J.W., 1996. Structure and dynamics of an amphibian community: evidence from a 16-year study of a natural pond, In Long-Term Studies of Vertebrate Communities. eds M.L. Cody, J.A. Smallwood, pp. 217-248. Academic Press, San Diego, CA.

Windmiller, B.S., Calhoun, A.J.K., 2008. Conserving vernal pool wildlife in urbanizing landscapes, In Science and Conservation of Vernal Pools in Northeastern North America. eds A.J.K. Calhoun, P.G. deMaynadier, pp. 233-252. CRC Press, Boca Raton, FL.