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Proceedings of the Fifth Interagency Conference on Research in the Watersheds

Headwaters to Estuaries: Advances in Watershed Science and Management

March 2-5, 2015, North Charleston, South Carolina

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Edited by Christina E. Stringer, Ken W. Krauss, and James S. Latimer

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Preface

The Fifth Interagency Conference on Research in the Watersheds (ICRW) was held in North Charleston, South Carolina, March 2-5, 2015. The conference theme was selected to recognize the focus of many natural resource agencies and universities in understanding how ecosystems are connected from interior upland habitats to the estuaries, as land use in the upper portion of watersheds often affect hydrological, ecological, and sociological processes downstream. This theme builds on past ICRW programs held in Arizona, North Carolina, Colorado, and Alaska, by delivering a strong southeastern Coastal Plain theme while maintaining a broad national focus that highlights ongoing interagency research and management initiatives.

Human- and climate-mediated impacts to watersheds continue to mount nationally, from the accumulated effects of many small-scale actions (e.g., construction of new roads and neighborhoods) to large-scale development (e.g., port facilities) or climate anomalies affecting critically important watershed processes. While water resource issues are often discussed among western States, this issue came to the forefront in the Southeast during a wide-spread drought of 2005–2007. Residents of Tennessee, Florida, Alabama, and Georgia found themselves coping with water-use restrictions, affecting nearly everything from cropland irrigation and lake recreation to water quality and aquifer recharge. That issue, droughts in other regions, sea level rise, catastrophic wildfire, and severe storm events have lifted watershed science to national importance; studying individual habitats is necessary, but discerning connectivity among multiple individual habitats within a watershed is paramount to water and nutrient management.

The 5th ICRW was structured to focus on key issues faced by managers and scientists throughout the United States, with many of these issues having a strong coastal watershed focus. Thematic areas included managing forested wetlands and agricultural catchments, identifying research advances from experimental watersheds, tracking the fate of contaminants through landscapes, advancing restoration ecology of connected ecosystems, and understanding the role of climatic perturbations (e.g., drought, severe storms) on watersheds. In addition, the role that ecosystems play in water use and management was a focal point, including modeling and measuring evapotranspiration associated with land use change.

The 5th ICRW provided 20 technical sessions and 6 field trips for the 187 participants. The technical program contained talks, poster presentations, and plenary addresses. These proceedings serve as a written transaction for this meeting. The presenters were given the option to contribute an extended abstract or short paper to replace the short abstract that was conveyed in the program. Accordingly, the contributions are identified in three categories: (1) short abstracts, (2) extended abstracts, and (3) papers. The papers contained herein have undergone the requisite review process required by the authors' institution and technical editing to provide a consistent format. My hope is that this proceeding will provide a timely conveyance of the excellent work that was presented at the conference and serve as a useful reference for all.

The presentation of this excellent body of work could not have been possible without the commitment and hard work of the Program Committee, the excellent facilities provided at Trident Technical College, and the support provided by the USDA Forest Service, U.S. Geological Survey, U.S. Environmental Protection Agency, USDA Agricultural Research Service, North Carolina Water Resource Research Institute, and the North Carolina and South Carolina Sea Grant programs. The program for the 5th ICRW is available at: http://www.hydrologicscience.org/icrw5/.

With great appreciation for all those who participated in the 5th ICRW.

Carl C. Trettin, **Conference Chair**
USDA Forest Service

Acknowledgments

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Laurie Alexander, US Environmental Protection Agency

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Lawrence Band, University of North Carolina

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The organizers would like to thank all of the additional individuals not named here, including the conference participants and presenters, for helping to make the 5th ICRW such a success.

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Plenary Session

STRENGTHENING THE SCIENTIFIC FOUNDATION FOR THE CLEAN WATER ACT THROUGH FEDERAL PARTNERSHIP AND TRANSDISCIPLINARY COLLABORATION

Laurie C. Alexander, William G. Kepner, and David C. Goodrich[1]

Abstract—The U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) released a report, titled *Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence*, that summarizes more than 1,200 studies from the peer-reviewed scientific literature on the structural and functional connectivity of streams and wetlands to downstream waters such as rivers, lakes, reservoirs and estuaries (https://www.federalregister.gov/articles/2015/01/15/2015-00339/connectivity-of-streams-and-wetlands-to-downstream-waters-a-review-and-synthesis-of-the-scientific). The evidence reviewed in this report spans many decades of research into aquatic ecosystems and watershed processes. It provides a scientific basis for the Clean Water Rule, which clarifies the definition of "waters of the United States" under the Clean Water Act and went into effect on 28 August 2015. As a technical review, the ORD report does not consider or set forth legal standards for CWA jurisdiction. Rather, it summarizes current scientific understanding of the hydrologic, chemical, and biological connections by which small or temporary streams, nontidal wetlands, and open-waters, singly or in aggregate, affect the integrity of waters protected by the Clean Water Act. It is the result of a multi-year collaboration by scientists working across disciplinary and organizational boundaries to synthesize the best available science in response to evolving policy needs.

INTRODUCTION

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Supreme Court decisions in SWANCC (2001) and Rapanos (2006) raised questions about the scope of the CWA, and motivated new research into the connectivity of waters. In January 2015 the EPA ORD published a report (US EPA, 2015) to inform rulemaking by EPA and the U.S. Army Corps of Engineers on the definition of "waters of the United States" under the Clean Water Act (CWA). As a technical document, this report does not consider or propose legal standards or policy options for CWA jurisdiction. Rather, it evaluates, summarizes, and synthesizes the available peer-reviewed scientific literature to address questions about the physical, chemical, and biological connectivity and downstream effects of three categories of waters: ephemeral, intermittent, and perennial streams; riparian or floodplain wetlands and open waters; and wetlands and open waters in non-floodplain settings.

METHODS

This report is the product of a transdisciplinary collaboration of scientists in the EPA ORD National Center for Environmental Assessment, National Health and Environmental Effects Research Laboratory, National Exposure Research Laboratory, and the United States Department of Agriculture's Agricultural Research Service. The authors reviewed and evaluated a large body of evidence from peer-reviewed sources that were published or in press by December 2014, including original research by scientists in federal agencies. The review synthesizes a total of 1,355 publications, which included 1,150 peer-reviewed journal articles, 120 scientific books or chapters, and 50 Federal reports. Following internal review by EPA and U.S. Army Corps of Engineers operational staff, drafts of the report were externally peer-reviewed by scientists in government, academic, nonprofit, and private industry organizations at three different levels: a peer consultation with 11 topic experts in February 2011, a contractor-led panel review by 11 independent peer reviewers in January 2012, and a review by the EPA Science Advisory Board (SAB), which

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convened public meetings of a 27-member panel in 2013 and 2014. The level of peer review exceeded standards established by OMB (2004). All peer-review panels included Federal partners, who also provided comments during Interagency review. In addition, 133,100 comments from the public were received through the docket (Docket No. EPA-HQ-OA-2013-0582). Comments from all sources were considered and used to improve the clarity and scientific rigor of the document.

CONCLUSIONS

The final report contains five major conclusions, summarized here:

1. The scientific literature unequivocally demonstrates that streams, regardless of their size or frequency of flow, are connected to downstream waters and strongly influence their function.
2. The scientific literature clearly shows that wetlands and open waters in riparian areas (transitional areas between terrestrial and aquatic ecosystems) and floodplains are physically, chemically, and biologically integrated with rivers via functions that improve downstream water quality. These systems act as effective buffers to protect downstream waters from pollution and are essential components of river food webs.
3. There is ample evidence that many wetlands and open waters located outside of riparian areas and floodplains, even when lacking surface water connections, provide physical, chemical, and biological functions that could affect the integrity of downstream waters. Some potential benefits of these wetlands are due to their isolation rather than their connectivity. Evaluations of the connectivity and effects of individual wetlands or groups of wetlands are possible through case-by-case analysis.
4. Variations in the degree of connectivity are determined by the physical, chemical and biological environment, and by human activities. These variations support a range of stream and wetland functions that affect the integrity and sustainability of downstream waters.
5. The literature strongly supports the conclusion that the incremental contributions of individual streams and wetlands are cumulative across entire watersheds, and their effects on downstream waters should be evaluated within the context of other streams and wetlands in that watershed.

ACKNOWLEDGMENTS

This report was funded through the EPA ORD. It has been subjected to Agency review and approved for publication. We are indebted to the report co-authors and the many national experts who reviewed the drafts, provided comments and additions, and helped us in our effort to synthesize the best available science in response to evolving policy needs.

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Managing Forested Wetlands in Coastal Watersheds

OVERVIEW OF FOREST CONDITIONS IN COASTAL COUNTIES

Eunice A. Padley, Sonja N. Oswalt[1]

Forest Inventory and Analysis (FIA) data were summarized for southeastern U.S. counties which had their centroids within coastal watersheds (8-digit HUCs). Coastlines from Texas through North Carolina were included in the analysis, and two time periods were compared (1997-2002 and 2011-2013). Forestland area within the coastal counties totaled 45.3 and 45.9 million acres at the two time periods, but the difference was not statistically significant. Among FIA forest type groups represented in the study area, only loblolly/shortleaf pine showed significant differences. Changes in the extent of wetland forest could not be determined from the FIA dataset.

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REGULATORY OVERVIEW

Robert Huff[1]

Section 404 of the Clean Water Act (CWA) (33 U.S.C. 1344) authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits, after notice and opportunity for public hearing, for the discharge of dredged or fill material into the waters of the United States at specified disposal sites. Under the CWA, it is unlawful to discharge dredged or fill material into waters of the United States without first receiving authorization from the Corps, unless the discharge is covered under an exemption.

The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1977. The amendments included a set of six exemptions from permitting requirements, which can be found under Section 404(f) of the CWA.

One of the six exemptions from permitting requirements listed under Section 404(f) of the CWA is normal farming, silviculture and ranching activities such as plowing, seeding, cultivating, minor drainage and harvesting for the production of food, fiber and forest products. To qualify under this exemption, the activity must be part of an established (i.e. ongoing) farming, silviculture, or ranching operation and not be part of an activity whose purpose is to convert an area of waters of the United States into a use to which it was not previously subject (i.e. change of use, silviculture to farming), and/or the immediate or gradual conversion of a wetland to a non-wetland. If a change of use occurs and the activity impairs the flow or circulation of waters of the U.S., that activity shall be required to have a permit under Section 404(f)(2) of the CWA, commonly referred to as the "recapture provision."

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LOSS OF FORESTED WETLANDS - QUESTIONS, ANSWERS, AND MORE QUESTIONS

Susan-Marie Stedman[1]

The most recent study (2004 – 2009) on the Status and Trends of Wetlands in the Coastal Watersheds of the US indicates a connection between forested wetland loss and areas being used for silviculture. Many questions have been raised about this trend, including how the Status and Tends methodology identifies wetlands and wetland loss, how "minor drainage" is practiced on silvicultural lands, and why only some of the forested wetlands in silviculture become uplands. Watershed-scale pilot studies conducted as part of the National Ocean Policy's Implementation Plan have revealed that local and regional changes in hydrology may play a role in the losses of forested wetlands, and that silviculture may be an intermediate phase in the loss of forested wetlands to development.

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EMERGING ISSUES WITH SILVICULTURE PRACTICES IN WETLANDS

Mike Wylie[1]

Silviculture activities in wetlands involving discharges of dredge and/or fill material have been exempt from Clean Water Act (CWA) permits after the 1975 amendments to the CWA which were phased in by July 1977. However, Congress mandated that all exempt silviculture activities in wetlands maintain wetland hydrology. Congress also allowed minor drainage activities in wetland silviculture sites so landowners could plant, maintain and harvest timber sites. In the southeast there are two predominate wetland, silviculture classes – pine plantations and hardwood forests. Minor drainage to support the management of pine plantations while ensuring CWA wetland status is an emerging silviculture issue in the southeast. Recently, volatile timber prices, rising raw land prices, agricultural conversions and developmental pressure, have led to landowners converting silviculture tracts to other land uses. Typically, the only time federal regulators access a silviculture tract is when a change of land use is contemplated and wetland delineation is requested by the landowner. Many of these silviculture tracts contain wetlands that no longer exhibit wetland hydrology. Moreover, conducting wetland delineations on silviculture sites can be difficult due to: land ownership changes, case law, statute of limitations, drainage conducted before the CWA 1975 statutory changes, drainage ditches, imprecise regulatory definitions, and off-site disturbances.

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EFFECT OF MINOR DRAINAGE ON HYDROLOGY OF FORESTED WETLANDS

Wayne Skaggs, George Chescheir[1]

A simulation study was conducted to determine the impacts of minor drainage for silviculture on wetland hydrology. Long-term DRAINMOD simulations were used to determine the threshold drainage intensity (ditch depth and spacing) that removes wetland hydrology from forested wetlands. Analyses were conducted for 13 soil series and profile combinations at ten locations in the Atlantic and Gulf coastal states. Threshold ditch spacings (LT) were obtained for all combinations of soil profiles and locations. Analysis of the results showed that LT (m) can be approximated as $LT = C\sqrt{T}$, where T ($cm^2\ h^{-1}$) is the horizontal hydraulic transmissivity of the soil profile, and C is a coefficient dependent on ditch depth and geographic location. The threshold spacings can be used as benchmarks to directly evaluate the impact of drainage alternatives on wetland hydrology. Lateral impacts were determined for a 0.9 m (3 feet) deep drainage ditch for all soils and locations considered.

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SOUTH CAROLINA'S BEST MANAGEMENT PRACTICES FOR FORESTY FOR MINOR DRAINAGE

Tonya Smith, Herb Nicholson[1]

Minor drainage is normally used to facilitate regeneration and timber harvesting by temporarily removing surface water from inundated forestland. Specific ditch depth and spacing recommendations are not listed in our manual, as each site is individually evaluated. As with any silvicultural practices conducted in wetlands, it is important to avoid converting a wetland site to an upland site. SC BMPs are designed to avoid this conversion and enable wetlands to remain forested into the future while protecting water quality and the wetland ecosystem.

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Multicollabortive Research on Turkey Creek Watershed and Beyond: 10-Year Accomplishments and New Directions

COASTAL PLAIN SOILS AND GEOMORPHOLOGY: A KEY TO UNDERSTANDING FOREST HYDROLOGY

Thomas M. Williams and Devendra M. Amatya[1]

Abstract—In the 1950s, Coile published a simple classification of southeastern coastal soils using three characteristics: drainage class, sub-soil depth, and sub-soil texture. These ideas were used by Warren Stuck and Bill Smith to produce a matrix of soils with drainage class as one ordinate and subsoil texture as the second for the South Carolina coastal plain. Soils with sandy clay loam sub-soils (the most widely distributed soils on the coastal plain) were further divided by sub-soil depth into three categories: > 40 inches, 20-40 inches, and <20 inches. In 1974 Donald Colquhoun classified geomorphology of the lower SC coastal plain by relationship to seven former marine terraces. Sediments were associated with beach, offshore, or back barrier deposits while river valleys were associated with either fluvial or estuarine deposits. Using GIS, soils in the matrix can be mapped to the geomorphic features revealing a geomorphic explanation for the distribution of soils across the coastal plain. Beach and offshore deposits have sand throughout the soil profile, while back barrier deposits tend to have clay or clay loams. Fluvial terrace deposits have sandy clay loam sub-soils while some estuarine valleys have entirely organic soil profiles. Classification of drainage class is directly related to the average water table depth of soils. Within a single sub-soil type (sands), average water table depth is directly predicted by drainage class. Soil subsurface type also greatly influences drainable porosity (the porosity that is filled or emptied by a small change in water table). Geochemical analysis of flows on sandy subsoil (near Georgetown) and clay sub-soils on Turkey Creek and Watershed 80 (near Charleston) show this difference in drainable porosity and water table fluctuations to be related to the source of storm runoff. Sandy sub-soils have higher drainable porosity, smaller water table fluctuations, and a prevalence of soil water chemistry in runoff. Clay sub-soils have lower drainable porosity, greater water table fluctuation as a response to rainfall and ET, and stream runoff chemistry more similar to that of rainwater.

INTRODUCTION

Forest hydrology has been widely studied in the southeastern Coastal Plain that is typified by watersheds with shallow water table depths due to the mild slopes. Depth of the water table is an important determinant of not only forest productivity but also of the volume of runoff (Elsheman and others 1994, Harder and others 2007, Williams 1979, 2007). The southeastern coastal plain is geologically young and fluvial processes have had little time to develop drainage patterns, resulting in landscapes dominated by older estuarine and marine geomorphic features. Buol (1973) found soils on these old marine features formed catenae (catena being adjacent soil series in the same parent materials that form a soil drainage sequence) with best drained soils near streams and most poorly drained at inter-stream divides opposite of what is expected in areas with mature fluvial geomorphology. Prior to the advent of Light Detection and Ranging (LIDAR) technology, much of the subtle elevation differences in soil setting were not obvious, making interpretation of spatial distribution of soils very difficult.

Soil properties are also a very important aspect of forest productivity. Coile (1952) established that soil texture, depth to a heavy textured layer, and soil drainage (depth to water table) were the main factors that predicted forest growth rates. Using similar principles, Warren Stuck (1976) presented a simple classification chart of South Carolina coastal soil series. All soil series listed on that chart were arranged into six drainage classes and seven subsurface texture/depth classes. The six drainage classes were excessively-well, well, moderately-well, somewhat-poorly, poorly, and very-poorly drained. Texture classes were classified as: sand, 10-18 percent clay, 18-35 percent clay, 35-45 percent clay, and >45 percent clay. Since many coastal sub-soils contained 18-35 percent clay, these were further divided into depth of sub-surface layer of > 40 inches (102 cm), 20-40 inches (51-102 cm), and < 20 inches (51 cm).

South Carolina coastal geomorphology consists of eleven former marine terraces (Cooke 1936, Colquhoun 1974) that represent former stands of sea level. Colquhoun (1974) mapped the eastern most six of these terraces with interpretation of geomorphic features associated with rise or fall of sea level. Terrace features were either offshore

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deposits, beach deposits, or back barrier marsh deposits. Riverine deposits were either floodplain, estuarine, or deltaic deposits.

Current soil surveys and GIS technology allow a qualitative comparison of that simple soil classification to the classes of geomorphic feature, which were mapped for the South Carolina coast. The objective of this paper present the techniques used to make such a comparison and to examine the hydrologic implications of such a soil classification.

PROCEDURES

Soil surveys of the coastal South Carolina counties were obtained from the South Carolina Department of Natural Resources (SCDNR 2013) along with survey maps for each coastal quadrangle. These soil polygons were then merged by series to produce a continuous map of the coastal plain soils within a GIS environment (ARC-GIS 10.1).

GIS was used to create an overlay of the Colquhoun (1974) map to the present soil survey. The original map, 1:1,000,000 scale, was photocopied in page-sized blocks. These blocks were then hand colored, mosaicked, and photographed as a 35 mm slide in 1980. In 2014, the slide was scanned (1200 dpi) and converted to a digital image file. The original map included lines representing major highways present in the 1970s. A current digital road GIS layer (1:24,000) was used to georeference the image of the original map.

Long-term estimates of average water table depth and standard deviations were collected from Williams (2007) for a study site in Hobcaw Barony site near Georgetown and Williams and Amatya (2010)) for the Turkey Creek watershed at the Santee Experimental Forest. These values were placed within the soil classification matrix where the studied soil series occurred. Likewise, drainable porosity values were collected from Williams (1978) and Harder and others (2007) and again placed in the appropriate matrix block.

RESULTS

Soil surveys included a number of soil series not included on the chart presented by Stuck (1976). The original chart was modified in several ways to accommodate the additional soils. The break points in soil texture corresponded to standard soil texture names: sands < 10 percent clay, sandy loam 19-18 percent clay, sandy clay loam 18-35 percent clay, clay loam or sandy clay 35-45 percent clay, and clay > 45 percent. Changing to named categories also revealed a shortcoming of the original in that only clay content was considered. Soils with silt loam or silt sub-soils were undifferentiated from sandy loams. There are 13 current series with such subsoils, requiring an additional subsurface texture class. The original chart had only six drainage classes, yet now there are six series that are classed as somewhat excessively drained, requiring an additional class. Also, the original very poorly drained class included both mineral and organic soils. These were separated by adding an additional very poorly drained organic class. The original chart has been modified to be an 8x8 matrix of drainage class and sub-soil texture (Fig. 1).

The classification in Figure 1 groups 194 separate soil series into 64 categories. Nineteen of those categories are blank since excessive drainage does not occur on soils with more than 18 percent clay in the subsoil, and there are relatively few organic soils or soils with sub-surface clay more than 102 cm deep.

Despite the blank cells, representing the relationships among 194 soils in 45 separate classes on a single map still presents a challenge. The key method to accomplish that was to use systematic color variation among classes. Colors were assigned to cells by hue, saturation, and value (HSV) within a Geographic Information System (GIS) polygon of symbol properties. Drainage class was designated by values with: excessive well (100), somewhat excessively (93), well (85), moderately well (77), somewhat poorly (67), poorly (54), very poorly mineral (24), very poorly organic (0). Subsoil texture was designated by hue with: clay (0)- red, clay loam-sandy clay (28) orange, sand (62)- yellow, sandy loam (68), greenish yellow, sandy clay loam >102 cm – 91-yellowish green, sandy clay loam 51-102cm- 138-green, sandy clay loam <51cm -155-blueish green, silt loam -288-purple.

Despite a large number of highway intersections and a small root mean square error of rectification, the geomorphic overlay could not be evaluated for geospatial accuracy due to the multiple distortions induced by the many manipulations of the image that we performed.

DISCUSSION

Soils and Geomorphology

By refining the drainage and sub-surface texture classification to include an extra drainage class of very poorly drained organic soils and an extra texture class to include subsoils high in silt, all soils mapped on the South Carolina Coastal plain were included in one of the 64 resulting categories (Fig. 1). Additionally, a colorization scheme using the same classification scheme that also included both hue for texture and value for drainage was incorporated in a map of South Carolina coastal plain soils (Fig. 2).

The resulting coastal plain soils map includes a number of prominent features that are similar to features of coastal terrace geomorphology. Colquhoun (1974) revised Cooke's (1936) earlier mapping of coastal terraces into 11 separate terraces (Fig. 3 insert). He also interpreted

Sub surface soil texture

Drainage Class	Sand	Sandy Loam	Sandy Clay Loam >40"	Sandy Clay Loam 20-40"	Sandy Clay Loam <20"	Silt Loam	Clay Loam or Sandy Clay	Clay
Excessively Well	Foxworth Fripp Kershaw Candor Lakeland Chevasse Kureb Newhan Rimini Cainhoy Alpin							
Somewhat Excessively	Wakulla Alga Tarboro Eustis		Pocalla Troup					
Well	Wando	Conetoe Autryville Kennansville Foreston Blanton	Brogden Eddings Fuquay	Suffolk Hockley Ailey Blaney Lucy Wagram	Naboco Cowarts Norfolk Barnwell Orangeburg Dothan Kalamia Red bay Cahaba Altavista Wickham Poindexter Vaucluse	Riverview Nason Congaree Badin Georgeville Hiwassee	Emporia Caroline Faceville Kinston Greenville Neeses Marlboro Varina Nankin Sunsweet	Summerton Clayham
Moderately Well	Seabrook Centenary Echaw Pactolus	Barth Bertie Tomahawk Nansemond Olanta Charleston		Bonneau Chisolm Coosaw	Goldsboro Onslow Clarendon Johns Yauhannah Eunola	Chenneby Craven	Angie Pelion Exum Gilead Duplin Izagora Hornsville	Nemours Persanti Wicksburg Eulonia
Somewhat Poorly	Scranton Chipley Kiawah Sewee Witherbee	Stallings	Albany Ocilla Mirand Edisto	Seagate	Ardilla Quitman Lynchburg Yemassee	Chewacla Jedburg Tawcaw	Augusta Uchee Dunbar Wahee Nahunta	Lenoir Okatee Smithboro
Poorly	Osier Ridgland Leon Baratan St. John's	Bibb Elloree Woodington Plummer		Grifton Pelham Wilbanks	Rains Wehadkee Tomotley Myatt Wadmalaw Ogeechee Youngen Mouzon Lumbee	Leaf	Coxville Gourdin	Bladen Argent Meggett Grady Cantey Chastain Bethera Rembert McColl "Leaf"
Very Poorly	Rutledge Pickney Rossdu Dawhoo Lynnhaven Torhunta	Pocomoke Johnston Paxville Stono		Nakina Portsmouth	Pantego Deloss Hobcaw	Hyde	Santee	Cape Fear Bayboro Brookman Byars Levy(m) Capers (m) Bohicket (m) Hansboro (m)
Very Poorly Organic	Pamlico Dorovan *Hobonny> 90"*					Ponzer		Pungo

Figure 1—South Carolina coastal soils arranged by drainage class, subsoil texture and depth of subsurface. Individual cells are colored with hues that reflect sub-surface texture and values that reflect drainage class.

coastal geomorphic features to reflect features associated with rising or falling sea level. Rising sea level features are common to the present coast of prominent barrier beach deposits, with salt marsh plains landward, and sloping offshore plains seaward. Falling sea level produced mainly erosional reworking of former rising deposits. Riverine deposits included overbank floodplain deposits, estuarine, and deltaic deposits (Fig. 3).

Sandy features are prominent as both riverine dunes (yellow on both maps) and barrier beaches (red in Fig. 3, yellow in Fig. 2). The riverine dunes are one of the few prominent features deposited during low sea level, associated with dry glacial periods (Ivester and Leigh 2003). Barrier beaches of the Talbot and Pamlico terraces are also well defined with sandy soils, although with less excessively well drained soil than the riverine dunes.

Heavy textured subsoils (orange and red in Fig. 2) tend to be associated with former salt marsh plain deposits (brown in Fig. 3) and also estuarine deposits in the inland terraces of the Pee Dee floodplain. On the Santee floodplain, similar terraces are more likely to have silt in the subsoil, although some silt is also found on the more inland Pee Dee floodplain terraces. Marsh plains are widespread in the southern coastal plain while in the northern coastal plain marsh, plains tend to be located just east of many barrier sands, being the farthest western extent of the next lower marine terrace.

Sandy clay loam subsoils tend to be associated with former river deltas (greens on both Fig. 2&3). These are quite extensive on the oldest terraces that Colquhoun (1974) mapped. In Figure 2, these soils are also more prominent on the older terraces located between Wicomico and the sand hills. On the lower coastal plain, the most pronounced delta is south of the Santee River above the Talbot terrace. The Francis Marion National Forest (FMNF) is located on this feature and the marsh plain just to the northwest. The distribution of soils and geomorphology are comparable in the area surrounding the Turkey Creek watershed (Fig. 4).

Soils and Hydrology

The position of the water table has been shown to greatly control the hydrology of coastal forested watersheds (Elsheman and others 1994, Harder and others 2007, Williams 1979, 2007, Amatya and other 1996, Amatya and Skaggs 2001). Forest hydrology research on the lower coastal plain has been the focus of three long-term research areas; the Santee Experimental Forest, the

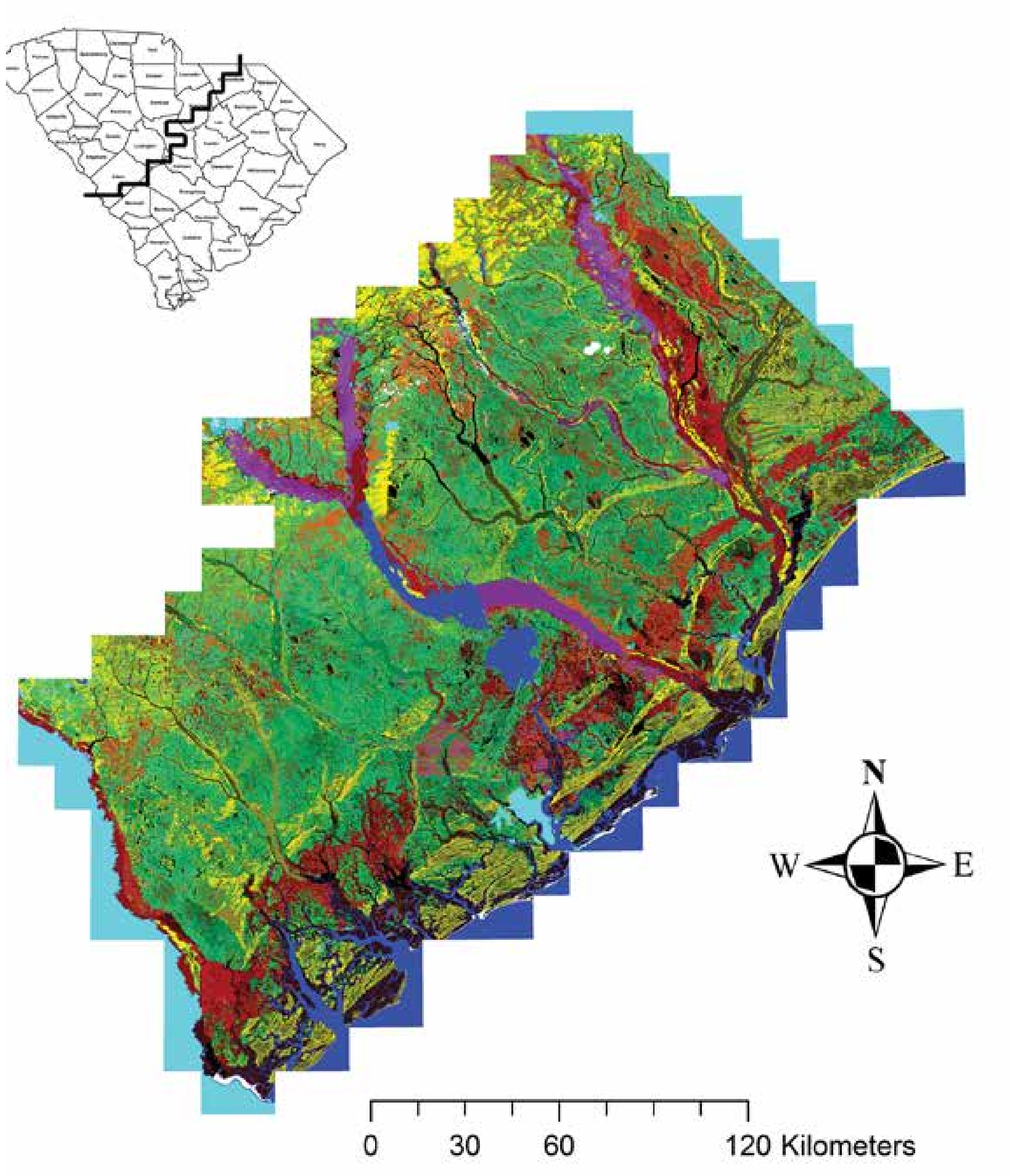

Figure 2—Map of South Carolina Coastal plain soils. Soil classes are colored to match cells in figure using soil series names.

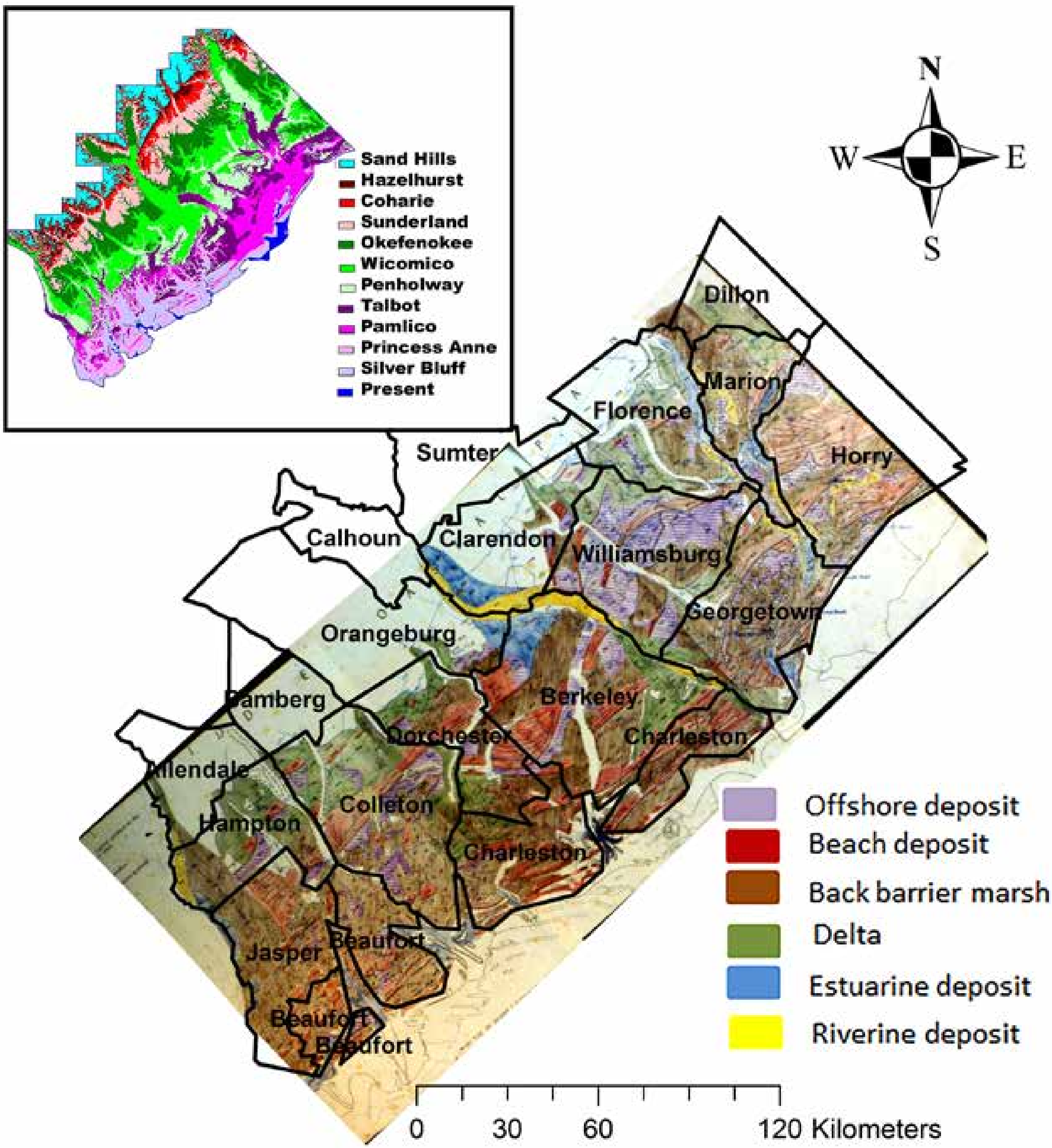

Figure 3—Geomorphic terraces of coastal South Carolina. Inset map shows position of coastal plain terraces from Cooke (1936) and Colquhoun (1974) while map represents individual features of the lower coastal terraces.

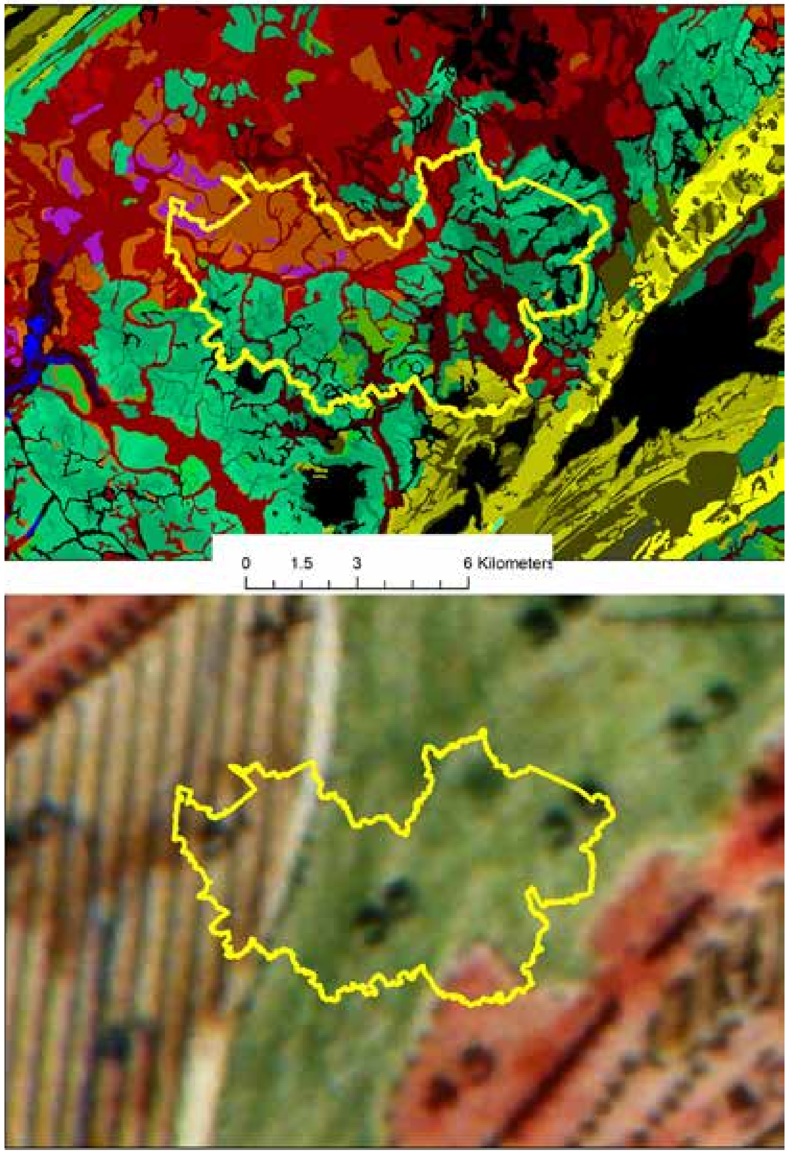

Figure 4—Map of Turkey Creek watershed outline on soils as in Figure 2 and on geomorphic features in Figure 3. Note the higher resolution of the county soil maps compared to the statewide geomorphic map.

Baruch Institute of Coastal Ecology and Forest Science in South Carolina, and the Weyerhaeuser Carteret tract in North Carolina. Long-term water table estimates only a few of the categories in Figure 1 at those sites. Average water table depths and standard deviations are given for those in Figure 5. These data tend to show that drainage class reflects average water table depth quite well, especially for similar subsoil types. Between types, there seems to be a tendency for deeper average water table depths for the same drainage class as the subsoil texture becomes heavier. As subsoil texture becomes heavier, the variance of the water table elevation increases with the coefficient of variation near 100 percent for most of the heavy textured subsoils. Since drainage class includes both average water table and probability a soil will saturate, heavier textured soils with the similar water tables would tend to be in a wetter drainage class due to the increased variability.

Drainable porosity (the portion of soil pore space that drains with a small change in water table depth) has only been determined on five classes (Williams 1978, Harder and others 2007, Amataya and others 1996) but tend to reinforce the tendency seen in variance of the water table depth. Sandy subsoils have porosity values > 0.1 (10 percent), sandy clay loam at 0.09 (9 percent) while clay loam and clay are 0.07 (7 percent) and 0.05 (5 percent), respectively. This implies that 1 mm of rain or drainage on a sandy subsoil will change the water table

Sub surface soil texture

Drainage Class	Sand	Sandy Loam	Sandy Clay Loam >40"	Sandy Clay Loam 20-40"	Sandy Clay Loam <20"	Silt Loam	Clay Loam or Sandy Clay	Clay
Excessively Well	209± 68							
Somewhat Excessively								
Well	93±38							
Moderately Well	90±61			121± 84	120±60 0.093			
Somewhat Poorly	56±39			58± 50			88±88 0.070	34±35
Poorly	58±41 0.105				44±54			0.050
Very Poorly	44± 34 0.113				53±39			
Very Poorly Organic								

Long term depth to water table (cm below surface) and standard deviation
Underlined numbers are soils where drainable porosity were determined.

Figure 5—A reproduction of the cells in Figure 1, with average water table depths of soils that have data for long-term water table averages. Five cells also have data on the value of drainable porosity, that portion of total soil volume that drains with a small change in water table.

7-9 mm while 1 mm on clay subsoil will change the water table 20 mm.

Subsoil texture may also impact the processes by which runoff is produced for coastal plain watersheds. Griffin and others (2014) found runoff from watersheds with heavy textured subsoils (same as Harder and others 2007) had chemistry similar to rainwater (45-67 percent), while watersheds with sandy subsoil produced runoff with chemistry 56-61 percent similar to groundwater. They suggested that the difference was due to a faster saturation of the heavy textured subsoil. Drainable porosity values of 5 percent on the heavy textured soil would suggest less rain would be required to saturate such soils, compared to 10-11 percent for sandy subsoils.

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TEN YEARS OF REAL-TIME STREAMFLOW GAGING OF TURKEY CREEK – WHERE WE HAVE BEEN AND WHERE WE ARE GOING

Paul Conrads, Devendra Amatya[1]

The Turkey Creek watershed is a third-order coastal plain stream system draining an area of approximately 5,240 hectares of the Francis Marion National Forest and located about 37 miles northwest of Charleston near Huger, South Carolina. The U.S. Department of Agriculture (USDA) Forest Service maintained a streamflow gaging station on Turkey Creek from 1964 to 1981. After the substantial impact to the National Forest from Hurricane Hugo in 1989, researchers recognized the importance of re-establishing a streamflow monitoring station on Turkey Creek. The U.S. Geological Survey, in cooperation with the USDA Forest Service and the College of Charleston, established a stream gaging station in Turkey Creek in February 2005 (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035). The gage is located on the downstream side of the U.S. Highway 41N Bridge approximately one-half mile upstream from the discontinued Forest Service gaging station. Since the gage was re-established in 2005, 84 streamflow measurements have been made to establish and confirm the stage-streamflow relation (rating) for the station. Over the ten-year streamflow record, average annual streamflow has varied from a minimum of 1.32 cubic feet per second (ft^3/s) to a maximum of 28.9 ft^3/s. The peak streamflow of 1,470 ft^3/s occurred on October 25, 2008. The long-term streamflow data for Turkey Creek provides a basis for understanding natural variability, reducing uncertainty in model inputs and parameter estimation, and developing new hypotheses about hydrological and ecological functions of coastal plain forested landscapes. Recent research interests in tidal freshwater forested wetlands (TFFW) have included the downstream reaches of the Turkey Creek that transition to TFFW. The extent of tidal effects is temporally variable and results from changing upland streamflow conditions, coastal water levels, and tide cycles. For the TFFW, the riparian water table levels result from precipitation, upland flow, and downstream tidal exchange. The streamflow data from the Turkey Creek gaging station will provide critical data to understanding the dynamic downstream tidal response and its implications to eco-hydrologic functions and processes. The presentation will evaluate the 10 years of streamflow and precipitation data, describe methods of estimating high flood streamflows, compare Turkey Creek to other coastal plain watersheds, and describe the complexity of downstream flows in the riparian areas of TFFW.

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SYNTHESIS OF 10-YEARS OF ECOHYDROLOGIC STUDIES ON TURKEY CREEK WATERSHED

Devendra Amatya, Timothy Callahan, and Carl Trettin[1]

Abstract—Since the establishment of a collaborative study 10 years ago, research on the third-order, 5240 ha forested Turkey Creek watershed in South Carolina's coastal plain has advanced the understanding of rainfall-runoff relationships, stream hydrograph characteristics, and water table dynamics for dominant soil types. Surface water dynamics were shown to be regulated primarily by the water table, which is dependent upon precipitation and evapotranspiration. The baseflow is, however, highly variable, resulting in zero streamflow about one-third of the time, on average. These processes regulate upland freshwater runoff and mediate material export into the tidally influenced larger river downstream. Analysis of pre- and post-Hurricane Hugo streamflow data showed the resiliency of this coastal forest to extreme events. A high-resolution LiDAR-based digital elevation model (DEM) was shown to have increased accuracy in drainage area delineation on this low-gradient coastal plain compared to available topographic maps and DEMs, potentially influencing site hydrology and engineering designs.

INTRODUCTION

Long-term monitoring and datasets from watersheds provide an important opportunity for advancing our understanding of forest ecohydrologic processes, detecting trends, reducing model and parameter uncertainty, and assessing the impacts of climate change and anthropogenic and natural disturbances on water quantity and quality (Algerich and others 2013; Amatya and Skaggs 2011, Furniss and others 2010, Jayakaran and others 2014, Jones and others 2009). Indeed, much of our current understanding about the relationships among forests, climate and climate variability, and streamflow comes from long-term gauged forested watersheds within the Forest Service, U.S. Department of Agriculture's Experimental Forests and Ranges (Vose and others 2014). However, the preponderance of that knowledge and literature is derived from high-energy piedmont and mountain watersheds with different climate and topography (Endale and others 2006, Ford and others 2011, Swank and others 2001, Tajchman and others 1997). The low-gradient coastal watersheds generally have a lower water yield, lower runoff ratio, and higher evapotranspiration (ET) than upland-dominated watersheds (Sun and others 2002). Only a very few observational studies have been conducted on the forested landscapes of the humid semitropical coastal plain in the southeastern U.S., with shallow water table soils potentially controlling the runoff.

Recent population growth, rapid urbanization, and development on the southeastern Atlantic coastal plain have prompted regulators, land managers, and researchers to try to better understand the functional relationships between watershed processes and valued ecosystem services (ESS) and their interactions with climate and forest resources in order to develop sustainable management strategies. To this end, regional stakeholders formed the Turkey Creek Watershed Research Initiative (TCWRI) in late 2004. The main goal of the TCWRI is to identify how land use and climate change could affect water availability, flooding, water table, water quality, and other associated ESS in the Turkey Creek watershed (Amatya and Trettin 2007b). In this way, the TCWRI can serve as reference or representative system within the rapidly urbanizing landscape of the South Carolina lower coastal plain.

Through cooperation with multiple interests, the TCWRI reestablished a real-time stream monitoring gauge on the Turkey Creek watershed (WS 78), headwaters of the East Branch of the Cooper River, on the Santee Experimental Forest (Fig. 1) (Amatya and others 2005). The collaborative approach for conducting ecohydrological studies using the monitoring and modeling framework for the TCWRI was summarized by Amatya and Trettin (2007c).

The objective of this paper is to synthesize the findings of the research since 2005 that have advanced the

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knowledge on ecohydrologic processes, including watershed characteristics, runoff generation, storm event characteristics, water budget, ET, and surface and subsurface flows and their pathways, particularly on Turkey Creek and similar low-gradient coastal watersheds. These include the Hobcaw Barony site maintained by Clemson University in Georgetown and the Dixie Plantation site maintained by the College of Charleston. This approach is based on the early vision of understanding water balance, soil moisture, and precipitation-runoff relationships at varying scales in coastal areas by monitoring experimental watersheds of multiple sizes at the Santee Experimental Forest (USDA FS 1963, Young 1966, 1968). A chronology of studies conducted on the watershed since 2004 is presented in Table 1.

WATERSHED DESCRIPTION

The Turkey Creek watershed (WS 78) is a third-order blackwater stream system draining approximately 5240 ha. It is located about 60 km northwest of Charleston, South Carolina near Huger, in Berkeley County, South Carolina (33° 8' N, 79° 48' W) (Fig. 1). WS 78 was originally gauged in 1963, and it was monitored until 1981. The gauging station was recommissioned in late 2004 with real-time gauges/sensors both for rainfall and flow monitoring (http://waterdata.usgs.gov/sc/nwis/uv?site_no=02172035) (Fig. 1) on SC Highway 41 N near Huger, in cooperation with the United States Geological Survey (USGS), the College of Charleston, and the South Carolina Department of Transportation. The present gauging station is approximately 800 m upstream of the original gauging station. WS 78 was intended to compliment three other lower order watersheds (WS 77, WS 80, and WS 79) within the Santee Experimental Forest (Fig. 1) to provide a basis for large-scale ecohydrological monitoring and modeling (Amatya and Trettin 2007b). Conrads and Amatya (2015) highlighted the statistics of 10 years of streamflow data and emphasized the long-term data as a basis for understanding natural variability, testing models and reducing their uncertainty, and developing new hypotheses.

The elevation of the watershed varies from approximately 2 m above mean sea level at the stream gauging station to 14 m above mean sea level at the headwaters (Haley 2007) (Fig. 1). The subtropical climate is characteristic of the coastal plain, with hot and humid summers and moderate winter seasons. The minimum and maximum air temperatures, based on a 50-year (1951-2000) record at the Santee Experimental Forest, were recorded as –8.5 °C and 37.7 °C, respectively, with an average daily temperature of 18.4 °C. Annual rainfall at the site varied from 830 mm to 1940 mm, with an average of 1370 mm

Table 1—Chronology of studies on the Turkey Creek watershed (WS 78)

Year	Studies/References
2007	Hydrologic Modeling using SWAT—*Haley (2007),* MS Thesis
2007	Forest Hydrologic Research 1) at Santee Experimental Forest—*Amatya and Trettin (2007a)* and 2) Turkey Creek Watershed—*Amatya and Trettin (2007b*)
2007	Estimates of Annual ET—*Amatya and Trettin (2007c)*
2007	Flow Dynamics of Three Coastal Forest Watersheds—*Amatya and Radecki-Pawlik (2007)*
2008	Seasonal Relationships of Rainfall and Runoff—*La Torre Torres (2008)*
2008	Development of a GIS-based Depressional Storage Capacity Model—*Amoah (2008),* PhD Dissertation
2009	Hydrology and Water Quality of Turkey Creek Watershed—*Amatya et al. (2009)*
2010	Outflow Characteristics of Turkey Creek watershed—*Amatya and Trettin (2010)*
2011	Seasonal Rainfall-Runoff Relationships on a Forest Watershed—*La Torre Torres and others (2011)*
2011	Determination of plant characteristics used in discharge capacity—*Miroslaw-Swiatek and Amatya (2011)*
2011	Evaluating SWAT Model for a Low-gradient Forest Watershed—*Amatya and Jha (2011)*
2012	Quantifying Watershed Depression Storage—*Amoah and others (2012)*
2012	Estimating groundwater recharge in lowland watersheds—*Callahan and others (2012)*
2012	Groundwater–surface water interactions in a lowland watershed—*Garrett and others (2012)*
2013	Application of LiDAR data for Hydrologic Assessments—*Amatya and others (2013)*
2014	Storm-event Flow Pathways in Lower Coastal Plain Forested…—*Griffin et al. (2014)*
2014	Hurricane Impacts on a Pair of Coastal Forested Watersheds…—*Jayakaran and others (2014)*
2014	Assessing various potential ET (PET) methods for forest—*Amatya and others (2014)*

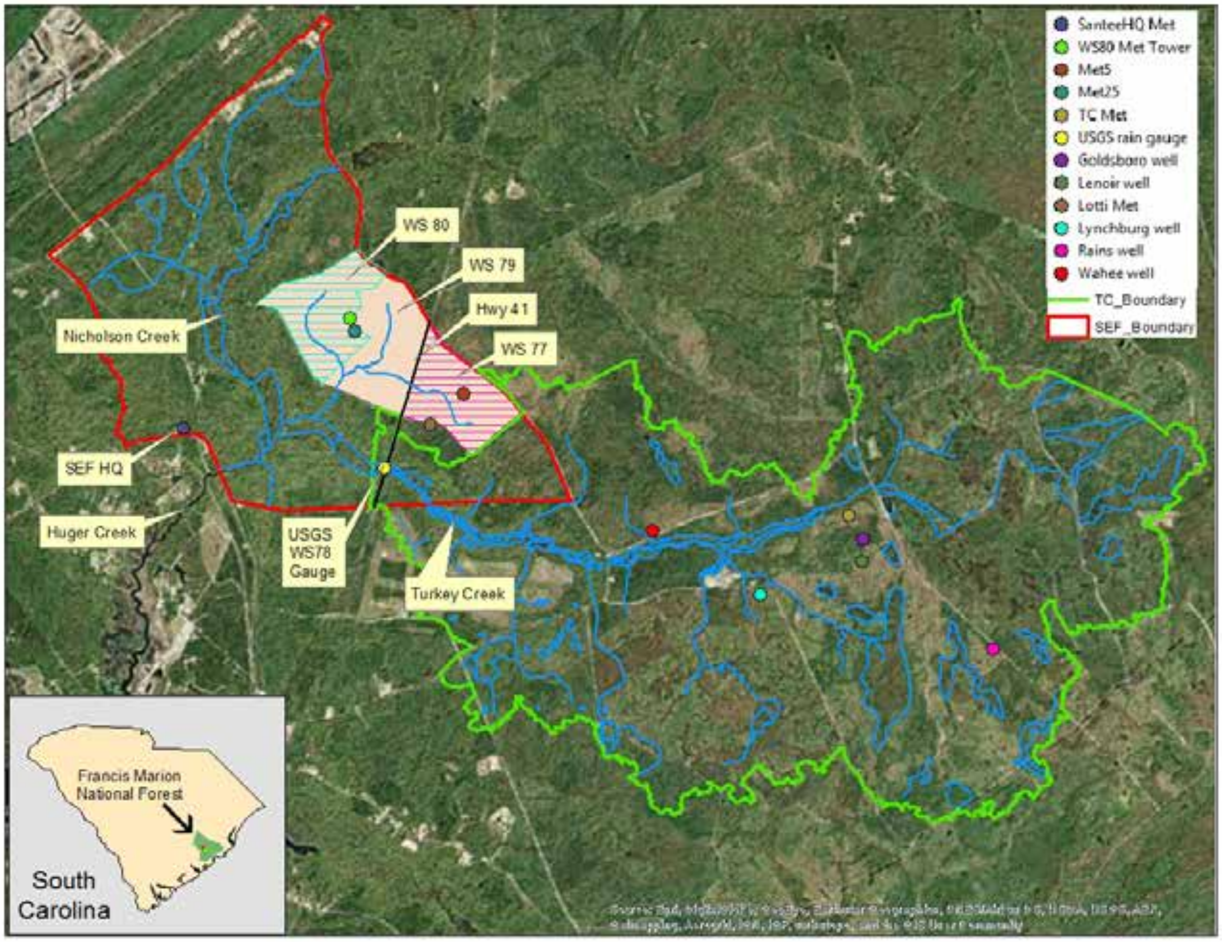

Figure 1—Turkey Creek (TC) watershed (WS 78) in green boundary mapped using high-resolution LiDAR data in 2011 (Table 1). Blue lines are streams and wetlands based on National Hydrography Dataset data. Locations of weather stations, stream gauges, and ground water wells are also shown, including for three other adjacent first- (WS 77 and WS 80) and second- (WS 79) order watersheds within the Santee Experimental Forest (SEF) (red boundary).

based on the 50-year (1951-2000) data (Amatya and others, 2009).

The watershed is underlain by Santee Limestone approximately 20 m below ground surface (bgs) in the western side of the watershed and about 13 m bgs in the eastern area (Williams 2007). Initial groundwater data at the site suggest that the Santee Limestone is overlain by a dense, approximately 10 m-thick semiconsolidated unit (Parkers Ferry Formation). This formation acts as a confining layer to groundwater flow between the shallow surficial sediments and the deeper Santee Limestone only in the watershed's western portion (Williams 2007). The watershed is dominated by poorly drained soils of the Wahee series (clayey, mixed, thermic *Aeric Ochraquults*) mostly on the northern part (or right bank, looking downstream) of the stream and Lenoir series (clayey, mixed, thermic *Aeric Paleaquults*) with shallow argillic horizons with less than 3 m depth (NRCS 1980) mostly on the southern part (left bank) of the stream. Williams and Amatya (2015) presented the soil matrix and classifications relating to drainage for the South Carolina Coastal plain and their implications to shallow water table dynamics that drive the forest hydrology.

Land use within the watershed comprises 44 percent pine forest, mostly loblolly (*Pinus taeda* L.) and longleaf (*Pinus palustris*) pine, 35 percent thinned pine forest, 10 percent forested wetlands, 8 percent mixed forest, and 3 percent agricultural, roads, open areas, and impervious areas (Haley 2007). Most of the current forests on the watershed are a mixture of remnant large trees and natural regeneration that is approximately 25 years old, regenerated since the area was impacted by Hurricane Hugo in 1989 (Hook and others 1991).

Details of the study site and ecohydrologic monitoring procedures are described elsewhere (Amatya and Trettin 2007b, Amatya and others 2009, 2013, Callahan and others 2012, Haley 2007). Table 2 shows the chronology of various monitoring installations on the Turkey Creek watershed.

DISCUSSION OF WATERSHED STUDIES

Watershed Drainage Area

Amatya and others (2013) demonstrated the effects of uncertainty in drainage areas obtained by digital elevation models (DEMs) of varying resolution and delineation method, starting from the historical period to recent use of LiDAR (light detection and ranging), on the average annual runoff coefficient (ROC) for this low-gradient watershed (Table 3). The authors also highlighted the potential effects of lower resolution DEMs on many hydrologic monitoring and modeling studies prior to LiDAR technology.

Using the initial (1964) drainage area of only 3240 ha, the average ROC for the Turkey Creek watershed was estimated to be 0.38 (Table 3). The 2011 drainage area of 5240 ha, obtained using new DEMs based on high-resolution LiDAR data with field verification for culverts and roadbeds, was found to be 27.8 percent smaller (Amatya and others 2013) than the 2008 estimate of 7260 ha obtained by Haley (2007) using 10 m x 10 m interpolated DEMs, but only 6.5 percent larger than the 2004 area of 4920 ha obtained using 30 m x 30 m DEMs (Amatya and Radecki-Pawlik 2007), ultimately affecting the calculated average annual ROCs. Without considering the effects of culverts in 2011 LiDAR-based DEMs, the calculated drainage area was 5880 ha, consistent with the USGS area at its gauge site. Maceyka and Hansen (2015) recently used LiDAR and high-resolution aerial photos of the Francis Marion National Forest containing this watershed and found the largest changes in georeferencing of streams and legacy water management structures, enabling their better mapping. Although the LiDAR-based DEM is presently considered the most accurate for mapping low-gradient coastal plain watersheds with implications for water resources management, some potential limitations of software used in raw data processing and in watershed delineation algorithms should be acknowledged. Furthermore, careful inspection of LiDAR data using manual edits and hand digitizing with field verification is necessary for accurate estimates of drainage areas and stream channels.

Runoff Dynamics

The runoff generation mechanism on the low-gradient coastal watershed is influenced by the position of the spatially distributed shallow water table threshold (Harder and others 2007, Dai and others 2010, Epps and others 2013). Williams and Amatya (2015) reported that the most important aspect of forest hydrology across the coastal plain is the presence of a shallow water table, which influences not only the forest water balance as a source for fulfilling ET demand from vegetation but also as a determinant of the rainfall that becomes streamflow. The author related differences in soil-drainable porosity and water table fluctuations on sandy subsoil (Georgetown, SC) and clay subsoils on Turkey Creek (WS 78) and WS 80 to the source of storm

Table 2—Chronology of monitoring installation and other activities on the Turkey Creek watershed (WS 78)

Year	Month	Activities/Disturbances
1963	November	Gauging station established
1964	January	Rain and streamflow monitoring started
1981	May	Streamflow monitoring discontinued, records mostly by old technology
2004	December	1st Cooperators' meeting to initiate a collaborative research, concurrent with revitalization of the new USGS stream and rainfall gauging station upstream of old Highway 41N bridge
2005	March	New gauge/sensor moved downstream of new Highway 41N bridge
2005	October	Manual monitoring of water physical parameters initiated using Eureka™ Manta sonde
2005	October	Installation of a Campbell Scientific automated weather station
2006	July	Installation of four water table recording wells on Rains, Lenoir, Lynchburg, and Goldsboro soils
2006	June	Installation of a Teledyne Isco, Inc. automatic water sampler
2010	October	Establishing a new Turkey Creek tributary subwatershed streamflow monitoring at Conifer Road
2010	November	Establishing a new subwatershed streamflow monitoring at Eccles Road
2011	January	Establishing a fifth water table recording well on Wahee soil

Table 3—Drainage areas and calculated average annual runoff coefficients (ROC) for Turkey Creek watershed based on map or digital elevation model (DEM) types used during 1964-2011 period (*after Amatya and others 2013*)

Time	Map / DEM Type	Delineation Method	Drainage Area (ha)	ROC
1964	1" = 2 mile Topo	Manual	3240	0.38
1969	1" = 1 mile Topo	Manual	4575	0.27
2004	30 m DEM	ArcHydro	4920	0.25
2005	1:24,000 Topo, 10-foot contours	Manual	5880	0.21
2008	10 m DEM	AV/SWAT	7260	0.17
2010	Partial LiDAR	ArcSWAT	6510	0.19
2011	Full LiDAR	ArcSWAT	5240	0.24

LiDAR = light detection and ranging.
ArcHydro = An Extension with a set of data models and tools that operates within ArcGIS to support geospatial and temporal data analyses.

AV/SWAT = SWAT (Soil and Water Assessment Tool) Hydrologic Model in ESRI ArcView GIS platform;

ArcSWAT = SWAT (Soil and Water Assessment Tool) Hydrologic Model in ESRI ArcGIS platform

runoff. The storm runoff that generally occurs after complete saturation of soils depends also upon the spatial microtopography or effective surface depressional storage as determined by Amoah and others (2012) for this and five other lower coastal plain watersheds using the DEMs with varying grid resolutions, including the LiDAR-based DEM. In comparison to areas with high-gradient topography, the coastal flatwood watersheds are slower in response, with Turkey Creek flow peaking at about 40 to 45 hours, on average, with duration of 12 to 14 days, on average (Amatya and Trettin 2010, La Torre Torres and others 2011; La Torre Torres, 2008).

Using 13 years (1964-76) of previous data, La Torre Torres and others (2011) found a large seasonal variability in storm event ROC, potentially due to differences in forest evapotranspiration that affected seasonal soil moisture conditions. Mean event ROC was higher for wet periods and wet antecedent soil moisture conditions (based on 5-day and 30-day prior antecedent precipitation indices) than for dry periods. The authors suggested that antecedent soil moisture and groundwater table levels are important seasonal runoff generation mechanisms in the coastal soils. The results of storm event hydrograph characteristics using data from 2005-08 by Amatya and Trettin (2010) indicated a hydrologic recovery of forest since its regeneration after Hugo in 1989. The authors also suggested that the runoff and peak flow rates are dependent upon both the rainfall and its intensity, besides the antecedent conditions described better by initial water table positions, as recently demonstrated by Epps and others (2013) for the adjacent watershed (WS 80) and another coastal watershed in Georgetown, SC. The initial water table depth of spatially distributed shallow wells, a surrogate of soil moisture, is dependent upon rainfall and ET, which can be a substantial fraction (as much as 98 percent) of the annual rainfall (Amatya and Trettin 2010, Amatya and others 2009). The annual ROC varied from 0.34 in the wet year of 2005 with 1527 mm of rainfall to as low as just 0.09 for a dry year in 2007 with 994 mm of rainfall. The daily average water table was recorded as low as 2.39 m in late July-early August of 2006 at the well located on well-drained Goldsboro soil. Callahan and others (2012) inspected the water table recession behavior for Goldsboro, Lenoir, and Rains soils using water table hydrograph data. They saw a water table depth for Goldsboro of 2.49 m below ground during the extreme drought of 2007, and also 2.32 m for the Lenoir soil site and 1.8 m for the Rains soil site during the same time (see Figure 2). They also estimated water table recession coefficients of 0.015, 0.035, and 0.030 day^{-1}, respectively.

Stream flow ceased when the water table dropped below 50 cm in all wells. There was negligible stream flow from late March until November in 2007 as a result of dry conditions and high ET demands (Amatya and others 2009). On the other hand, a very large rain event (172 mm) on October 25, 2008 brought the water table to ponding as much as 17 cm above the surface in one of the wells, resulting in an extremely large discharge of 41.6 $m^3 s^{-1}$ (Conrads and Amatya 2015).

A close examination of daily rainfall and flow data on the watershed showed almost no stream response for daily rainfall amounts below 15 mm in the dry summer and about 10 mm in the wet winter, respectively, for a 3-day antecedent dry period for both seasons (Amatya and Trettin 2010). Current daily stream gauging data indicate that this watershed has no stream flow nearly one-third of the time, on average, similar to another 30-

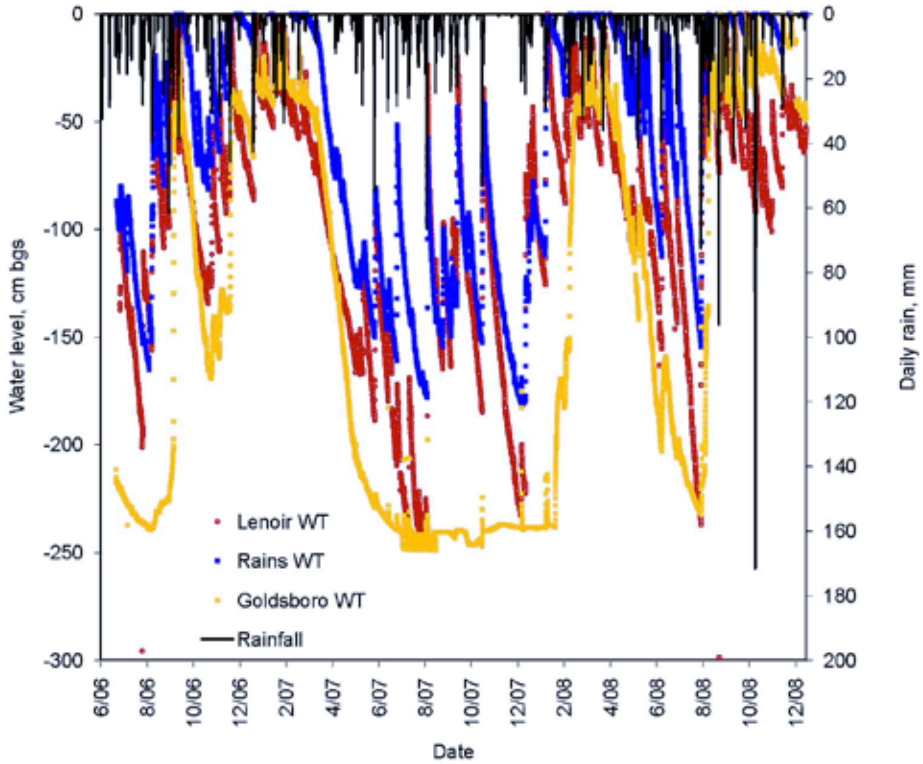

Figure 2—Daily rainfall and water levels in cm below ground surface for water table wells at three locations in the Turkey Creek watershed for the period June 2006 - December 2008 (from Callahan et al., 2012).

km² forest watershed in coastal North Carolina (Amatya and others 2003) but different from the upper coastal plain and upland watersheds of similar or smaller size, where baseflow is a significant component of streamflow (Bosch et al., 2004; Sun and others (2002). This may be due to the large surface and subsurface soil water storage and high growing-season ET demands typical of the forest ecosystems of the low-gradient Coastal Plain, as also shown by Sun and others (2002).

A study of daily stream flow dynamics compared early data from the Turkey Creek watershed (WS 78), which has some open lands, roads and wetlands, with two other adjacent completely forested first- and second-order watersheds on the Santee Experimental Forest. It was hypothesized that somewhat higher annual water yields from the larger (WS 78) compared to the smaller watershed (WS 80) were due to differences in their land use, soils, and topography, as well as increased base flows (Amatya and Radecki-Pawlik 2007) and potential errors in the drainage area calculated for the flow estimate of WS 78, as discussed above (Amatya and others 2013). As expected, the pre-Hugo daily flows persisted for 79 percent of the time with dampened peak flows in the larger WS 78 watershed with a larger storage, compared to only 65 and 60 percent in the second- and first-order watersheds, respectively. The frequency of daily flow occurrence on WS 78 dropped to about 68 percent of the time for the recent 2005-14 period, possibly because of increased ET due to higher temperatures (Dai and others 2013) and growing pine stands following Hugo (Jayakaran and others 2014).

Stormflow and Subsurface Flow

In their study using a simple linear baseflow separation method, La Torre Torres and others (2011) found baseflow contributing up to 56 percent to the total streamflow, with an average of about 28 percent. This is consistent with Amatya and Trettin (2010), who found similar results for recent data using the baseflow separation method by Arnold and Allen (1999) for this watershed. Using the SWAT model (Arnold and others 1998), Amatya and Jha (2011) found that the simulated average annual baseflow contributed 24 percent of streamflow. Recent studies that used end-member mixing analysis by comparing stream flow chemistry to that of precipitation and subsurface water have shown that the base flow contribution to stream flow is about 40 percent, on average, for the upper Turkey Creek system and for the adjacent WS 80 watershed (Garrett and others 2012, Griffin and others 2014). The uncertainty of baseflow separation, including by this chemical hydrograph method, is yet undetermined, but based on a water table fluctuation method, the total groundwater recharge for the watershed ranged widely from 107 ± 39 mm per year (5-10 percent of annual precipitation) for a poorly-drained site (Rains soil) to 1140 ± 230 mm per year (62-94 percent of annual precipitation) for a moderately well-drained site (Goldsboro soil). Analyzing the water budget and range of conditions for vertical hydraulic gradients in the shallow aquifer, we estimated that the average aquifer recharge rate was 114 ± 60 mm per year. Callahan and others (2015) highlighted these studies related to storm runoff behavior in this coastal plain watershed using physical and chemical hydrograph separation techniques.

Evapotranspiration

Using 13 years (1964-76) of data, Amatya and Trettin (2007a) estimated annual ET as a difference between precipitation and streamflow. The 13-year mean annual ET was 983 mm, and the annual ET remained near the potential ET (PET) (>90 percent of average Thornthwaite PET of 1079 mm) for the years exceeding the long-term average rainfall and/or the years with just below the average but with a wet antecedent year. Years with consistently below-average annual rainfall yielded ET equivalent to 80 percent or less of the annual PET. This mean ET estimate was about 11 percent lower than the 1107 mm estimated by Richter (1980) for a 12-year period (1969-80) on the adjacent WS 77 watershed and only 6 lower than the long-term mean reported by Dai and others (2013) for the WS 79 watershed. However, the temporal and spatial ET dynamics of this watershed are still poorly understood. Recently, Amatya and others (2014) showed that the forest-based PET can be substantially higher than the commonly used grass-based PET estimates used in those earlier studies. _

Water Balance

The average annual water balance for this watershed using 13 years (1964-1976) of data yielded 1320 mm of precipitation with 312 mm of streamflow, using recent calculations of watershed area for the old gauge downstream of the current USGS gauge. This yielded a mean ROC of 0.23 with 95 percent confidence interval (CI) of 0.19-0.27 and an average annual ET of 1008 mm with a 95 percent CI of 932-1084 mm, assuming negligible storage and deep seepage. The recent 10 years (2005-2014) of data for this forest regenerated since Hugo in 1989 yielded mean precipitation of 1306 mm and streamflow of only 247 mm, resulting in an ROC of 0.18 and mean annual ET of 1059 mm. The results indicated that although the mean annual post-Hugo flow was lower than the pre-Hugo flow, there was no significant difference in mean annual ET, potentially indicating the return of hydrology to pre-Hugo levels.

Surface Depressional Storage

Amoah (2008) and Amoah and others (2012) quantified representative depressional storage capacity (DSC) of six lower coastal plain watersheds, including Turkey Creek (WS 78), by implementing a lumped DSC model to extract geometric properties of storage elements from DEMs of varying grid resolutions (including the LiDAR-based DEM) and employing a consistency zone criterion. Accordingly, the average DSC was estimated to be 100 mm for WS 78, in contrast with 93 mm and 10 mm for WS 80 and WS 77, respectively, potentially indicating some differences in hydrologic responses based on wetland size and storage as expressed in DSC.

Riparian Vegetation Effects on Discharge

Riparian vegetation type, composition, structure, and abundance on floodplains exert a strong influence on riparian surface and subsurface hydrology and discharges of rivers and streams, especially in low-gradient streams (Benjankar and others 2009, Rood and others 2005). Miroslaw-Swiatek and Amatya (2011) found a close agreement between the modeled stage-discharge relationship using a given stream/floodplain cross-section with friction parameters controlled by various vegetation types and that obtained by the USGS with actual field measurements (Conrads and Amatya 2015). In another study to evaluate the effects of roughness due to assumed shapes of Cypress knees found in the main channel and floodplain on Turkey Creek watershed discharge calculation, Miroslaw-Swiatek and Amatya (*in review*) showed larger calculated friction factors with reduced flow velocities and discharge when a conical knee shape was assumed compared to a cylindrical shape.

Watershed Hydrologic Modeling

A SWAT watershed modeling study conducted by Amatya and Jha (2011), extending the initial works by Haley (2007) on the watershed, found reliable streamflow predictions for the 2005-2010 calibration and validation periods. Although the model *performance was reasonable*, *f*urther model improvements were recommended using more representative LiDAR-based DEMs, field parameters, and testing for internal consistency for its further ecohydrologic applications. Furthermore, since the SWAT model is still unable to predict the daily water table dynamics for wetland hydrology and its functions and biogeochemical processes, efforts are ongoing to develop a simple analytical model to simulate daily water table dynamics on major soil types using the measured daily precipitation, PET, and soil water properties, as described by Amatya and others (2015).

Water Quality

Almost no detailed studies on water quality of this watershed have been conducted, except for the analysis of a 2.5-year (2006-08) data period. This analysis showed measured pollutant concentration values within the ranges for similar land use of the coastal plain, except for NH_4-N, which was slightly higher (Amatya and others 2009).

FUTURE DIRECTIONS AND NEEDS

The long-term studies developed through this collaborative research on the Turkey Creek watershed provide data necessary as "reference" conditions for water resources development and management, wetland restoration and conservation, and also for improving hydrologic assessment tools needed for management decisions on sustaining ecosystem services derived from this rapidly urbanizing landscape. However, some changes in watershed response are expected with time as the forest stands mature and are influenced by management practices and potential climate change. As this watershed is somewhat isolated from population pressure, and development near the coastal waters is expected to continue to increase in the southeastern United States (Hitchcock and others 2015), we recommend the following as topics for future research:

- Monitoring for mercury (Hg) and fecal coliform due to large areas of wet soils and wetlands
- Understanding processes, linkages, and transport mechanisms at the freshwater-tidal interface
- Consideration for monitoring Quinby Creek and others adjacent to Turkey Creek for baseline data needed for near-future developmental impacts
- Developing research techniques for activities that improve forest health and restore ecosystems such as thinning, landscape-scale prescribed fire, and hydrologic restoration
- Developing an accurate quantification of baseflow and storm flow contribution to streamflow
- Developing a quantification of spatial and temporal dynamics of evapotranspiration
- Assessing effects of land use and potential climate change on hydrology, water quality, and vegetation dynamics using validated hydrologic models like SWAT
- Studying watershed responses to wetland and stream restoration efforts such as those that might be considered in implementing the Revised Francis Marion National Forest Plan
- Studying the carbon dynamics and dissolved organic carbon in coastal blackwater streams as a concern for water treatment systems and consumer health

Francis Marion National Forest is in the process of revising the Forest Management Plan (US Forest Service 2015). Turkey Creek is identified as one of the priority watersheds for 1) improving hydrologic functions and watershed health based on past modifications as well as the rehabilitation of existing cross-drainage structures that affect wetland and riparian structure, biota, processes, and functions and 2) restoring longleaf pine ecosystem together with red-cockaded woodpecker (*Picoides borealis*) habitat as an at-risk species (Maceyka and Hansen 2015; Danaher 2015). Accordingly, opportunities may exist in the future for collaborative studies to address relevant issues on this watershed.

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DECIPHERING STORM-EVENT RUNOFF BEHAVIOR IN A COASTAL PLAIN WATERSHED USING CHEMICAL AND PHYSICAL HYDROGRAPH SEPARATION TECHNIQUES

Timothy Callahan, Austin E. Morrison[1]

Interpreting storm-event runoff in coastal plain watersheds is challenging because of the space- and time-variable nature of different sources that contribute to stream flow. These flow vectors and the magnitude of water flux is dependent on the pre-storm soil moisture (as estimated from depth to water table) in the lower coastal plain (LCP) region. For example, sites with typically sandy, well-drained soils can exhibit runoff behavior similar to sites with low-permeability, poorly-drained soils if the pre-storm water table position is close to the surface. Interpreting source contributions to storm runoff include physical (hydrograph separation) and chemical (end member mixing analysis [EMMA]) methods, among others. Our main objective was to reduce uncertainty in calculations of stream flow contribution following storm events by analyzing the water isotope signatures of prospective sources to stream flow. Ratios of the stable isotopes of water (18/16 oxygen, and deuterium/hydrogen) were measured for the different prospective contributing sources and in stream water for storm events; EMMA was performed to characterize the percentage contributions of sources to stream flow. This was compared to physical hydrograph separation techniques that separate quickflow and baseflow components of stream flow response to storms. Chemical and physical hydrograph separation methods can show storm-specific discrepancies raising the question of which method correctly identifies the relative contributions of different sources such as groundwater, soil water, and overland flow to stream flow. The study sites were in the lower Atlantic coastal plain of the Southeast U.S., from the headwaters to the downstream US Geological Survey stream gage (ID 02172035) at Turkey Creek above Huger, South Carolina. The Turkey Creek watershed is a 5,240-hectare, third-order system in the Francis Marion National Forest in Berkeley County and has a confluence with Nicholson Creek, forming Huger Creek which drains to the East Branch of the Cooper River and ultimately to Charleston Harbor. This forested, wetland-rich watershed is an important reference system for the rapidly-developing Charleston metropolitan area and is of interest to watershed managers and stakeholders wishing to understand the hydrological processes influencing storm water dynamics. Our results will illustrate the complexity of runoff production dynamics in LCP watersheds and show that using multiple methods provides a more nuanced understanding of hydrological processes. We will also show that a hydrogeochemical approach to understanding processes on the LCP watersheds is not cost- or time-prohibitive, and can provide critical information to land managers and policymakers who oversee the urbanization of these watersheds.

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DEFINING ECOHYDROLOGICAL FUNCTION TO SUPPORT LOW IMPACT DEVELOPMENT IN COASTAL SOUTH CAROLINA

Daniel Hitchcock, A.D. Jayakaran, T. H. Epps, J. A. Palazzolo, T. M. Williams, D. M. Amatya[1]

In the face of dual pressures in coastal South Carolina - residential and commercial development, along with potential climate change impacts - stakeholders need clear, accurate, relevant, and easily-accessible information for effective decision-making for watershed management and natural resource protection. To fill this need, we focus on defining ecohydrological criteria for sustainable land and water resource guidance, specifically in upland areas that ultimately drain to tidal creeks. Runoff coefficients and derived curve numbers (CNs) – hydrologic metrics that define rainfall-runoff relationships based on watershed and landscape characteristics - have been calculated for first-order watersheds that have low gradient topography and shallow groundwater. Results have implications for watershed planning and site engineering, including storm water management and design. Forested water budgets, including the seasonal influence of evapotranspiration and infiltration on water table elevation as it drives highly variable streamflow, are being refined with the goal of defining pre-development conditions. These results have the potential to not only inform coastal stormwater discharge target criteria, but also to guide the prioritization of conservation and restoration efforts. Stormwater control measures, specifically engineered wetlands and bioretention systems, are being investigated to determine hydraulic and water quality performance considering influence of shallow groundwater. Results will be integrated into an online mapping tool so that site-specific geospatial data -based information can be available to decision-makers. An assessment of existing resources (green infrastructure) and their benefits - via ecosystem services at various scales - can provide guidance toward resource protection with the goal of creating resilient communities - whether by conservation or restoration efforts, or by better site design during land use change.

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ENHANCING HYDROLOGIC MAPPING USING LIDAR AND HIGH RESOLUTION AERIAL PHOTOS ON THE FRANCIS MARION NATIONAL FOREST IN COASTAL SOUTH CAROLINA

Andy Maceyka and William F. Hansen[1]

Abstract—Evaluating hydrology within coastal marine terrace features has always been problematic as watershed boundaries and stream detail are difficult to determine in low gradient terrain with dense bottomland forests. Various studies have improved hydrologic detail using USGS Topographic Contour Maps (Hansen 2001, Eidson and others 2005) or Light Detection and Ranging (LIDAR) in gullied piedmont terrain (James and others 2007), and the Maryland coastal plain (Lang and others 2012). Research within Turkey Creek subwatershed near Huger, SC used LIDAR and field verification to estimate the size of the 52.4 km^2 subwatershed, but the 50-year history had estimates ranging from 32.4 to 72.6 km^2 (Amatya and others 2013).

Turkey Creek was one of 21 subwatersheds evaluated using LIDAR intended for the Plan Revision covering the 1,050 km^2 Francis Marion National Forest (FMNF). LIDAR has proven to be a valuable asset to forest planning by more accurately defining or locating many things including stream networks and watershed boundaries. LIDAR data used to map Turkey Creek were attained in February and March of 2009. Streamflow in Turkey Creek was primarily 0.05-0.28 m^3s^{-1} (somewhat below the 9-year average of 0.39 m^3s^{-1}) so most perennial and intermittent streams should contain water, but small streams and seeps are unlikely to be noticed. High-resolution ortho imagery (ESRI's World Imagery, NAIP 2013 imagery) was also helpful for image interpretation.

The mapping procedure employed both "heads-up digitizing" and DEM-based modeling. It was an iterative process of digitizing and remodeling. Hydrologic barriers were removed from the LIDAR-derived DEM so flow could be modeled. This was accomplished by first, hand digitizing streams that were clearly visible by proxy, based mostly on the linear nature of missing LIDAR ground returns due to the absorption of laser pulses by water. In flat, wet landscapes this valuable information is often lost using current methods to model ground surfaces. LIDAR-derived DEMs can "washout" stream channels in areas due to low topographic relief and/or too few laser returns to properly define ground versus low vegetation or noise returns. The "washout" effect is a result of the alogrithm selecting available stream bank or low vegetation laser returns in areas with no other laser returns (i.e. water). Errors in ground surface are especially problematic in wet areas with low, dense vegetation. When this "washout" occurs it can be difficult to model stream networks using current DEM-based modeling alone. When using current DEM-based methods in these challenging areas, a substantial amount of work is needed to provide a relatively clear path to model streams. Without a "cleared" and defined hydrologic path, the flow accumulation models often get diverted and loose channel contact. Stream paths are "cleared" using digitized line work to keep stream in its main channel. Areas of channel uncertainty, the laser point cloud in planimetric or vertical profile reveals areas with no returns and streams can be recognized if they contain water. Although not as prolific, these flow modeling issues also occur in the piedmont and mountains, and have to be recognized and dealt with. After digitizing the streams and ditches based on recognizable channels or continuous water bearing features, the stream lines were burned into a DEM and remodeled. The flow modeling tools identify only one channel, and the analyst needs to keep it in the main channel. Weighing the imagery and LIDAR derived evidence considering DEM statistics set to refresh with the current display extent (scale), using descrete colors to separate elevation detail and lack of returns from water absorbing the LIDAR pulses are all needed to digitize a refined channel location before burning in the primary channel network. Recognizing characteristic landforms with braided, meandering to linear (ditched) channels

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and their associated hydrology are helpful in making assumptions and interpretations.

Amatya and others (2013) describe improvements in the Turkey Creek boundary as more detail was acquired. This landscape analysis needs work, review, and some field verification. The flow modeling applied the median drainage size for North Carolina (NC) Coastal Flatwoods perennial or intermittent streams was about 16 ha (Russell and others 2008, Russell 2013). The 2005 WBD boundaries used 10-foot contour USGS Topographic Maps and aerial photos to remotely evaluate hydrologic details. Improvements in the National Hydrography (NHD) and Watershed Boundary Datasets (WBD) will undergo more formal review before updating. However, substantial refinement can be made by applying LIDAR detail in georeferencing streams, hydrologic boundaries and identifying modifications (e.g., ditches, dikes).

There are also instances where vegetation is so dense (e.g., pocosins, Carolina bays) that the laser pulse cannot penetrate to water, channel or ground surface and the DEM surface appears elevated. Channel margins with atypical roughness are possible signs of spoil materials from past channelization. Signs of silvicultural bedding, rutting, and wetland drainage are also noticable. Understanding the channel morphology, past activity and vegetation detail helps with interpretation. The extent and separation among perennial, intermittent and ephemeral streams is not well defined in gathering LIDAR data from one flight. However, as more LIDAR flights occur during wet and dry seasons, the successive extent of water could be related to the Turkey Creek flow duration curve and stream permanance separation may improve. Intermittent streams are estimated based on NC information (Russell 2013) using the median16 ha flow accumulation and then removing modeled streams from landscape depressions. However, data collected about flow permanance in the NC coastal plain are variable on drainage size, with 80 percent of ephemeral to intermittent streams ranging from 1.3 to 127 ha, and ephemeral to perennial from 0.1 to 72 ha. With variability likely, median data on NC stream permanence may produce reasonable landscape estimates, but for individual streams, errors of omission and commission are likely without field verification. Differences in estimated watershed size of 21 subwatersheds indicate a standard deviation of 10 percent, while modeled/digitized streams within the FMNF increased stream density averaging 179 percent (Table 1). Figure 1 presents preliminary differences between existing and modeled/digitized streams and boundaries for Turkey Creek subwatershed. Refined coastal watershed boundaries and drainage network may reduce planning errors and improve regulatory, design, mitigation and restoration decisions.

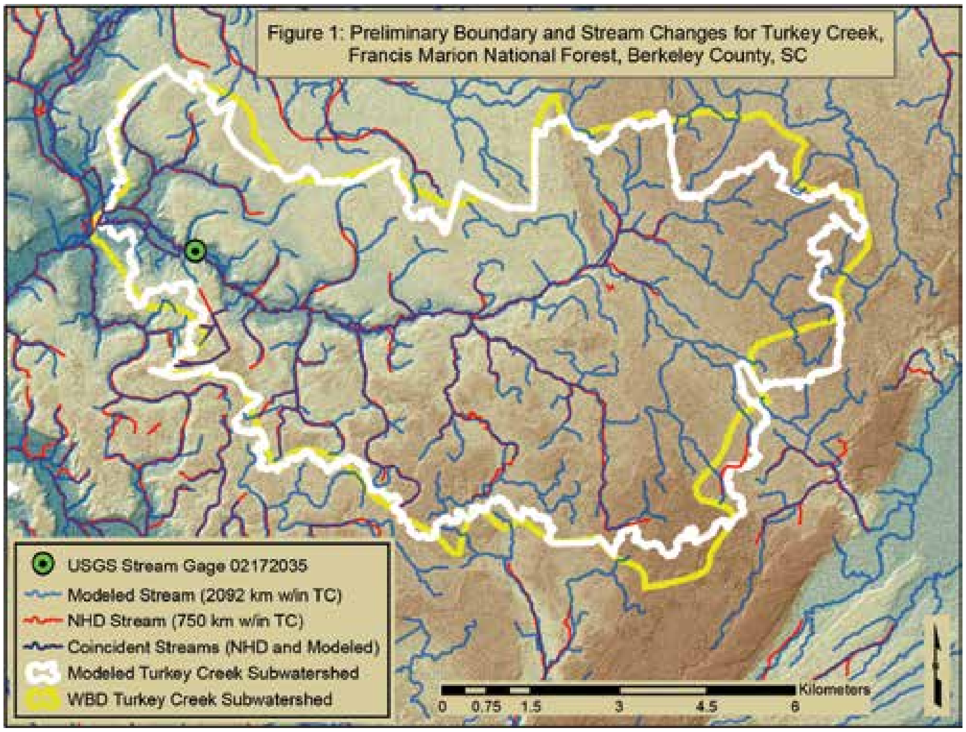

Figure 1—Preliminary boundary and stream changes for Turkey Creek, Francis Marion National Forest, Berkeley County, SC.

Table 1—Francis Marion National Forest - Estimated Change in Watershed Size and Stream Density

Subwatershed (6th Level HUC) (% NF)	WBD_GIS (km^2)	Modeled Boundary GIS (km^2)	Gain/Loss (km^2)	Estimated Boundary Based Change percentage	NHD NF Stream density (km/km^2)	Modeled NF Stream density (km/km^2)	Modeled NF stream increase over NHD (percent)
Awendaw Creek (83%)	103.9	119.6	15.6	15.1%	0.43	2.06	377%
Cane Pond Branch (79%)	43.5	52.3	8.8	20.3%	0.77	2.32	203%
Copahee Sound (0.7%)	127.3	128.5	1.2	1.0%	1.12	4.26	280%
East Branch Cooper River (8%)	75.8	84.4	8.6	11.4%	1.35	2.68	98%
Echaw Creek (72%)	114.9	124.7	9.8	8.5%	0.43	2.05	373%
French Quarter Creek (27%)	78.3	73.3	-5.0	-6.4%	0.71	2.14	202%
Gough Creek (49%)	50.4	46.5	-3.9	-7.7%	1.53	2.79	82%
Guerin Creek (44%)	161.9	157.8	-4.2	-2.6%	0.93	2.52	170%
Headwaters Wambaw Creek (93%)	87.1	80.3	-6.8	-7.8%	0.44	2.01	362%
Lower Wando River (1%)	130.9	135.1	4.2	3.2%	0.05	0.49	920%
Nicholson Creek (96%)	118.3	97.2	-21.2	-17.9%	0.89	1.98	122%
Outlet Wambaw Creek (79%)	99.5	121.1	21.7	21.8%	1.35	2.44	82%
Quinby Creek (62%)	91.8	91.8	-0.0	-0.0%	1.14	2.38	108%

Preliminary comparison of existing watershed boundary data (WBD) and hydrologic modeled boundary data with refined streams.

Preliminary comparison of existing national hydrography data (NHD) and hydrologic modeled and edited streams within the national forest (NF) areas only.

NHD stream extent on NF lands was 750 km, modeled and edited streams was 2092 km, an average increase of 179%.

Subwatersheds with low ownership have had less work and subject to higher error.

Dutart Creek - Savanna River subwatershed had insufficient LIDAR data available and was not evaluated.

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FRANCIS MARION NATIONAL FOREST FOREST PLAN REVISION-ECOSYSTEMS & RESTORATION NEEDS

Mark Danaher[1]

The Forest Service is currently revising the previous 1995 Forest Plan for the Francis Marion National Forest in Coastal South Carolina developed in the wake of Hurricane Hugo which devastated the forest in 1989. Since 1995, the human communities surrounding the Francis Marion National Forest have grown and changed significantly. The revised Francis Marion Forest Plan is being developed under the 2012 Forest Planning Rule. More information concerning the Francis Marion National Forest Plan Revision can be found at: http://www.fs.usda.gov/main/scnfs/landmanagement/planning.

The 2012 Forest Planning Rule adopts a complementary coarse filter "ecosystem" and fine-filter "species" approach to ensure the long-term persistence of native species. The coarse-filter, "ecosystem" approach assures biological diversity. "Ecosystem" forest plan components provide direction to maintain conditions needed for most plant and animal species. As needed, fine-filter "species" direction contributes to the recovery of threatened and endangered species, conserves proposed and candidate species, and maintains a viable population of each species of conservation concern– all collectively referred to as: "At Risk Species". The Forest Plan addresses desired conditions on a forest-wide scale (that is, the desired conditions are applicable across the landscape of the Francis Marion National Forest). Many of the desired conditions are ecosystem based and integrate resource management objectives and resource values. However, where appropriate, conditions are described in relation to specific geographic areas to allow focus on unique or localized circumstances. This presentation will discuss how the 26 subwatersheds (6th level Hydrological Unit Code) on the Francis Marion National Forest will be addressed, along with how they correlate with the coarse and fine filter approaches. Currently, three sub-watersheds including Turkey Creek have been identified as a priority for restoration on the Francis Marion National Forest.

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New Insights into Studies on Long-term Experimental Watersheds to Address Contemporary Emerging Issues

(PART 1)

THE LONG TERM AGROECOSYSTEM RESEARCH NETWORK – SHARED RESEARCH STRATEGY

Jean L. Steiner, Timothy Strickland, Peter J.A. Kleinman, Kris Havstad, Thomas B. Moorman, M. Susan Moran, Phil Heilman, Ray B. Bryant, David Huggins, and Greg McCarty[1]

Abstract—While current weather patterns and rapidly accelerated changes in technology often focus attention on short-term trends in agriculture, the fundamental demands on modern agriculture to meet society food, feed, fuel and fiber production while providing the foundation for a healthy environment requires long-term perspective. The Long-Term Agroecoystem Research Network was established by USDA to ensure sustained crop and livestock production and ecosystem services from agriculture, as well as to forecast and verify the effects of environmental trends, public policies, and emerging technologies. The LTAR Network is comprised of 18 locations across the US, whose shared research strategy is to employ common measurements to advance four areas of foundational science: (1) agro-ecosystem productivity; (2) climate variability and change; (3) conservation and environmental quality; and (4) socio-economic viability and opportunities. Each Network location is engaged in a local adaptation of the "common experiment" which contrasts conventional production systems with innovative systems that optimize services. Protocols and services are being developed for collection, verification, organization, archives, access, and distribution of data associated with Network activities.

INTRODUCTION

Challenges to agriculture have never been greater. The American Society of Agronomy's Grand Challenge for the 21st Century (ASA 2011) is "to double global food, feed, fiber, and fuel production on existing farmland … with production systems that enable food security; use resources more efficiently; enhance soil, water, and air quality, biodiversity, and ecosystem health; and are economically viable and socially responsible." Long-term research is essential to understanding how agriculture has and will adapt to changes in technologies, consumer demands (food, fuel, fiber and other ecosystem services), policy, resource availability and environmental stresses (Walbridge and Shafer 2011). Existing networks, such as the National Ecological Observatory Network (NEON), Long-Term Ecological Research (LTER) network and Smart Forest initiative (U.S. Forest Service) reflect the established recognition of the need for coordination and consistency in land management research programs.

Agriculture faces tremendous challenges in meeting multiple, diverse societal goals, including a safe and plentiful food supply, climate change adaptation/ mitigation, supplying sources of bioenergy, improving water/air/soil quality, and maintaining biodiversity. The Long Term Agroecosystem Research network (LTAR) was developed in 2012 to enable long-term, trans-disciplinary science across farm resource regions to address these challenges (Walbridge and Shafer 2011). The goal of this research network is to ensure sustained crop and livestock production and ecosystem services from agro-ecosystems, and to forecast and verify the effects of environmental trends, public policies, and emerging technologies. The LTAR shared research strategy (SRS) is a living document, founded on the basic goals of the LTAR Network and designed to capitalize on the strengths of the 18 LTAR sites. The LTAR SRS creates common geographically- and temporally-scalable databases that deliver knowledge and applications within priority areas of concern: agro-ecosystem productivity; climate

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variability and change; conservation and environmental quality; and socio-economic viability and opportunities.

SITES

There are eighteen sites representing major agroecoregions of the US in the LTAR network, and flexibility to add additional sites to fill in critical gaps. The first 10 sites were selected in 2012, all from long-term watershed, rangeland, or cropping system locations within the Agricultural Research Service (ARS). In 2014, eight additional sites were selected; some led by ARS, universities and private research foundation. During both selection cycles, sites were evaluated on representation of a major agroecosystem, a history of long-term research and existence of historic data, demonstration of critical mass with strong collaborative partnerships, and a record of scientific leadership and productivity as a team. The diversity of sites is summarized briefly in Table 1.

PROCEDURES

Research Committee

The Shared Research Strategy and implementation for elements within that strategy have been developed and coordinated through the LTAR Research Committee, consisting of a chair from ARS's Office of National Programs and the site leads. Site leaders engage members of their site teams, as needed, to advance LTAR planning and implementation. The work of the Research Committee has been conducted through monthly teleconferences, working groups, and annual meetings.

Working Groups

Following initial teleconference discussions, the Research Committee established a writing team to draft the SRS. The writing team developed a draft and engaged the broader LTAR community, ARS leadership, and an external review panel for feedback and refinement. The first edition of the LTAR-SRS was posted to the LTAR website (Bryant et al. 2013). After addition of 8 sites to the network, another working group was established to update the SRS which is in final review by ARS leadership.

As the work of the SRS writing team progressed additional teams were established to develop a research plan for a Common Experiment. The LTAR Core Measurements and shared protocols are being developed by working groups with expertise in the various areas essential to LTAR research efforts. Additionally, teams are compiling historical data from multiple locations for analysis of precipitation intensity and biomass productivity.

Annual Meetings

Periodic face-to-face meetings have been essential toward building shared understanding across the LTAR network. The first LTAR Annual Meeting was held in conjunction with the 2012 LTER All-Scientists Meeting in Estes Park, Colorado, and the subsequent joint LTAR/NEON workshop at NEON HQ in Boulder, Colorado. Discussions at these meeting focused on the SRS and Core measurements. The next Annual Meeting was retreat style, held at the Central Plains Experimental Range in Nunn, Colorado. A key output of that meeting was development of the concept and basic outline of a Common Experiment that would be implemented at all sites. The team met again in conjunction at the 2014 American Geophysical Union fall meeting where a Union Session was presented on The Long-Term Agro-Ecosystem (LTAR) Network: A New In-Situ Data Network for Agriculture. The LTAR Research Committee met and determined the need for a LTAR Team planning meeting, focused on the LTAR Core Measurements and Shared Protocols, which has been scheduled in Beltsville, Maryland in spring of 2015.

DISCUSSION

The LTAR's SRS is built upon a progressive approach that (1) focuses on priority research questions, (2) reviews measurement variables and protocols used by sites to confirm comparability and identify a core set of variables and protocols for the network to adopt, (3) develops shared data sets from across network sites, (4) initiates new monitoring and experimentation efforts in conjunction with other networks, and (5) conducts retrospective analyses of trends across LTAR sites and modeling studies to generalize locally-derived observations and forecast future outcomes. Successful implementation of LTAR's SRS is based on the commitment to the SRS across all network sites, energetic leadership from each participant in the network, and the engagement of producers, partners and policymakers. The LTAR research is being structured to address four societal concerns: 1) Agroecosystem productivity and sustainability; 2) Climate variability and change; 3) Conservation and environmental quality; and 4) Socio-economic viability and opportunities.

LTAR's Shared Research Principles

Foundational science addresses the key societal concerns through research questions that are targeted toward development of improved understanding, tools, and products that enhance productivity and sustainability of agricultural systems (Fig. 1, Table 2). A key expectation of the LTAR Network is the application of research results to solve critical challenges facing agriculture. Because research based applications and their outcomes

Table 1—Characteristics of the 18 LTAR Network sites selected in 2012 or 2014.

LTAR Site and Location	Estab-lished	Record (years†)	Area (km^2)	Network Affiliations‡	Major crops, land use, and livestock production
R.J. Cook Agronomy Farm, Pullman, WA	1999	14	0.57	LTAP, GRACEnet, REAP, NADP	Wheat, barley, pulses (peas, lentils, chickpeas)
Central Plains Experimental Range, Cheyenne, WY; Nunn, CO	1939	75	865	LTER, NEON, GRACEnet, NADP	Wheat-fallow, rangeland, beef cattle
Gulf Atlantic Coastal Plain, Tifton, Georgia; (Little River Experimental Watershed)	1965	46	334	CEAP, GRACEnet, NADP	Cotton, peanuts, corn, vegetables (~50% irrigated); poultry, beef cattle
Central Mississippi River Basin, Columbia, MO	1971	43	480	CEAP	Grain cropping systems, some pasture, riparian forest
Jornada Experimental Range, Las Cruces, NM	1912	100+	780	CEAP, LTER, NEON, WNBR, UV-B MRP, USCRN, COSMOS	Rangeland, beef cattle, wildlife
Northern Plains, Mandan, ND	1912	100+	9.7	NEON, CEAP, GRACEnet, REAP	Small grains, row crops, beef cattle on grazingland
Southern Plains, El Reno, OK	1948, 1961	53	1,423	CEAP, COSMOS	Beef cattle, winter wheat, pasture, forages, prairie
Upper Chesapeake Bay, University Park, PA	1968	46	1,127	CEAP, GRACEnet	Row crops, dairy, pasture, forest
Upper Mississippi River Basin, Ames, IA	1992	22	6,200	AmeriFlux, CEAP, GRACEnet	Corn-soybean with livestock (swine, beef, dairy)
Walnut Gulch Experimental Watershed, Tucson, AZ	1953	61	150	Ameriflux, CEAP, COSMOS, EOS	Rangeland, beef cattle, wildlife
Lower Chesapeake Bay, Beltsville, MD	1910	21	27	CASTnet, CEAP, COSMOS, EOS, NADP, GRACEnet, SCAN, UV-B MRP	Cropland, poultry, dairy, forages, pasture, horticulture
Archbold Biological Station/ University of Florida, Venus, FL/ Ona, FL	1941	73	102	AmeriFlux, GLEON, NutNet, USCRN	Beef cattle, pasture, rangeland, wildlife
Eastern Corn-Belt, Columbus, OH	1974	Up to 40	N/A	CEAP, GRACEnet,	Cropland, swine, dairy poultry
Great Basin Floristic Province Boise, ID	1961	53	239	CEAP, CZO, NADP, SCAN	Rangeland, beef cattle, wildlife
Kellogg Biological Station Hickory Corners, MI	1987	26	0.42	LTER	Cropland
Lower Mississippi River Basin, Oxford, MS	1981	34	21.3	COSMOS, CEAP, SURFARD, SCAN,	Cotton, corn, soybeans, rice, catfish, sugar cane.
Platte R./High Plains Aquifer, Lincoln, NE	1912	100+	16500	AmeriFlux, GRACEnet, REAP,	Cropland, rangeland, beef cattle, biofuels
Texas Gulf Temple, TX	1937	75	N/A	CEAP, EPA-STN, GRACEnet, NutNet, LTBE, SCAN	Cropland, rangeland, pasture, remnant prairie

† Through 2014

‡ CASTnet: Clean Air Status and Trends Network; CEAP: Conservation Effects Assessment Project; COSMOS: COsmic-ray Soil Moisture Observing System; CZO: Critical Zone Observatory; EOS: Earth Observation System; EPA-STN: USEPA Speciation Trends Network; GLEON: Global Lake Ecological Observatory Network; GRACEnet: Greenhouse gas Reduction through Agricultural Carbon Enhancement Network; LTAP: Long Term Agro-Ecological Pilot; LTBE: Long-Term Biomass Experiment; LTER: Long Term Ecological Research; NADP: National Atmospheric Deposition Program; NEON: National Ecological Observatory Network; NutNet: Nutrient Networt; REAP: Renewable Energy Assessment Project; SCAN: Soil Climate Analysis Network (all sites); SURFARD: NOAA Surface Radiation Network; UV-B MRP: UV-B Monitoring and Research Program; USCRN: US Climate Reference Network; WNBR: World Network of Biosphere Reserves.

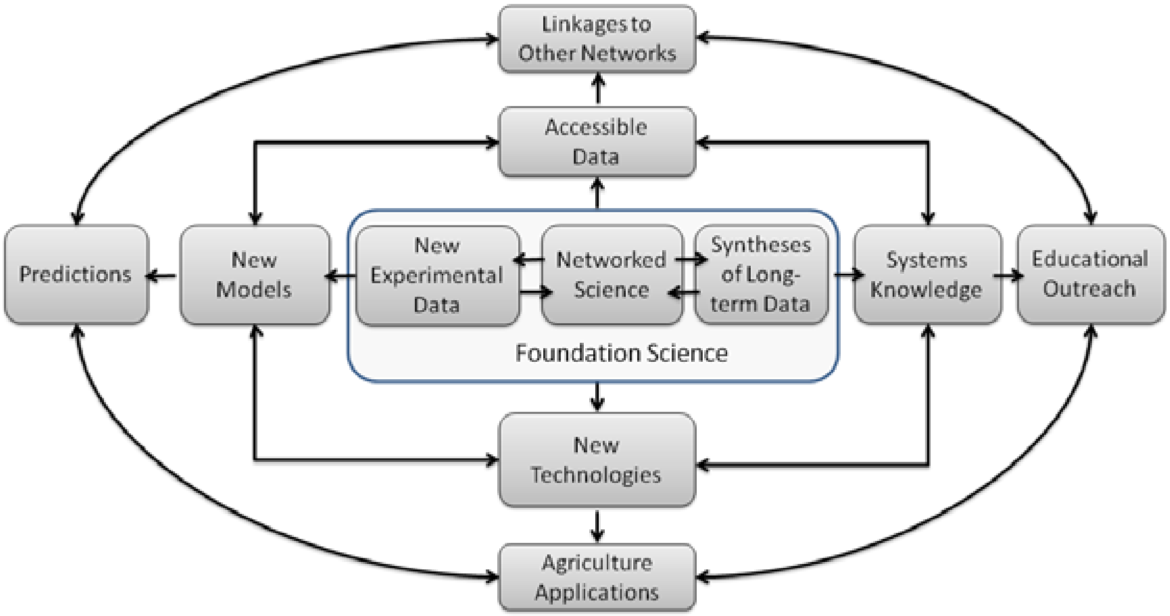

Figure 1—Overview of the foundation science activities of the LTAR network (figure center) resulting in key products (middle rectangle) that lead to an array of outcomes (outer ring).

are impacted by continually-changing trends, demands, and innovations, the LTAR SRS exploits a mixture of data from on-going networked science, new cross-site experiments, and long-term historical measurements. The ongoing integration of foundational science with long-term, multi-location experimental data underpins the provision of four key LTAR products: new knowledge of processes and systems, new technologies and management practices, improved agroecological models, and comprehensive, accessible data.

The LTAR network will provide regional test-beds where the long-term outcomes of agricultural germplasm, technologies, agrochemicals, management strategies, and policies to increase sustainable production systems and environmental protection will be evaluated via retrospective (i.e., historical) and prospective (i.e. predictive) research projects. The research will be conducted across a range of spatial and temporal scales in order to better understand the processes that result in field to landscape scale outcomes (Fig. 2). These results will be accomplished via a hierarchical research strategy (Figure 3) built upon foundation science in four topical areas that yields four key product categories supporting four major outcome areas for US agriculture. This process outline in Figure 1 and Table 2 is driven by societal concerns related to food supply, climate change adaptation/mitigation, bioenergy, water/air/soil quality, biodiversity, and economic sustainability and livelihoods. The foundation science of the LTAR network will be directed toward knowledge gaps and technology needs under four topical areas.

Core Measurements

The shared LTAR research questions will require a set of cross-site measurements related to studies of key agroecosystem processes. Table 3 lists measurements that support the foundation science of the SRS. This list will evolve as measurement technologies improve and additional parameters are identified. Recent trends in ecosystem measurements are to deploy in-situ real-time sensor networks. The LTAR sites will seek opportunities to create networks using common equipment and measurement methodologies to facilitate cross-location comparisons.

Shared Protocols

Efforts toward common methods and data protocols will be driven by 1) the cross-site datasets that are most easily compared and shared; 2) the datasets most needed for ongoing cross-site research projects; 3) new long-term datasets that can be compiled for all sites; 4) the common instrumentation/protocols already in place; and 5) critical new instrumentation and/or measurements, where examples of each are given in Appendix E.

LTAR sites will work to adopt common protocols from the LTAR methods “catalog” as new measurements are added and as old equipment is replaced. In some cases, it will be expedient to initiate new cross-site research at a few select sites, and then validate or expand results to a larger number of sites. An example is constructing a nutrient budget at sites with a full complement of

Table 2—Summary of LTAR Network Shared Research Questions and Expected Outcomes.

<table>
<tr><th>Societal Concerns</th><th></th><th>Foundation Science</th><th></th><th>Research Questions</th><th>Expected Products</th></tr>
<tr><td>Food, fiber and fuel production, resource sustainability and system resilience</td><td>→</td><td>Agroecosystem productivity</td><td>→</td><td>How can production systems be intensified so that inputs decrease and/or outputs increase?</td><td>• New strategies to improve net primary production and crop yields;
• Improved nutrient and water use efficiencies of US food, fiber and bioenergy production systems;
• Quantification of greenhouse gas and water footprints and life cycle analyses of production systems;
• Better methods to evaluate economic value of ecosystem services.</td></tr>
<tr><td>Climate variability and change</td><td>→</td><td rowspan="2">Climate variability and change</td><td rowspan="2">→</td><td rowspan="2">How can agroecosystems increase production with climate change?
What strategies will help mitigate greenhouse gas emissions?
How can agriculture improve water supply and quality in the face of climate change?</td><td rowspan="2">• Improved understanding of recovery processes/lags from drought, floods or other extreme events;
• Carbon or greenhouse gas mitigation credits and markets;
• Monitoring and assessment tools that support adaptive management.</td></tr>
<tr><td rowspan="2">Water supply and quality</td><td>→</td></tr>
<tr><td>→</td><td rowspan="2">Agricultural conservation and environmental quality</td><td rowspan="2">→</td><td rowspan="2">How can production systems be made sustainable for both on and off-site effects?
How can management changes improve resource use efficiency?</td><td rowspan="2">• Indicators of soil quality and function;
• Valuation of ecosystem services;
• Scientific understanding to underpin conservation planning and agricultural land management;
• Monitoring and assessment tools (models) to support adaptive management.</td></tr>
<tr><td>Ecological integrity and ecosystem health</td><td>→</td></tr>
<tr><td>Economic sustainability and livelihoods</td><td>→</td><td>Socio-economic ties to productivity, climate and environment</td><td>→</td><td>How can new or improved commodities be incorporated into agroecosystems to sustain ecological integrity, ecosystem health, and economic opportunity?
How do economic incentives and public policy affect the design and adoption of new production systems?</td><td>• Linkage of georeferenced socioeconomic data bases (US Census, ERS-ARMS, Ag Census) with biophysical modeling;
• Better understanding of motivation, incentives, and barriers to adoption or change;
• Better understanding of interactions between farm structure and supply of agroecosystem goods and services.</td></tr>
</table>

Figure 2—LTAR will examine the temporal dynamics of anthropogenic and environmental impacts across multiple spatial scales.

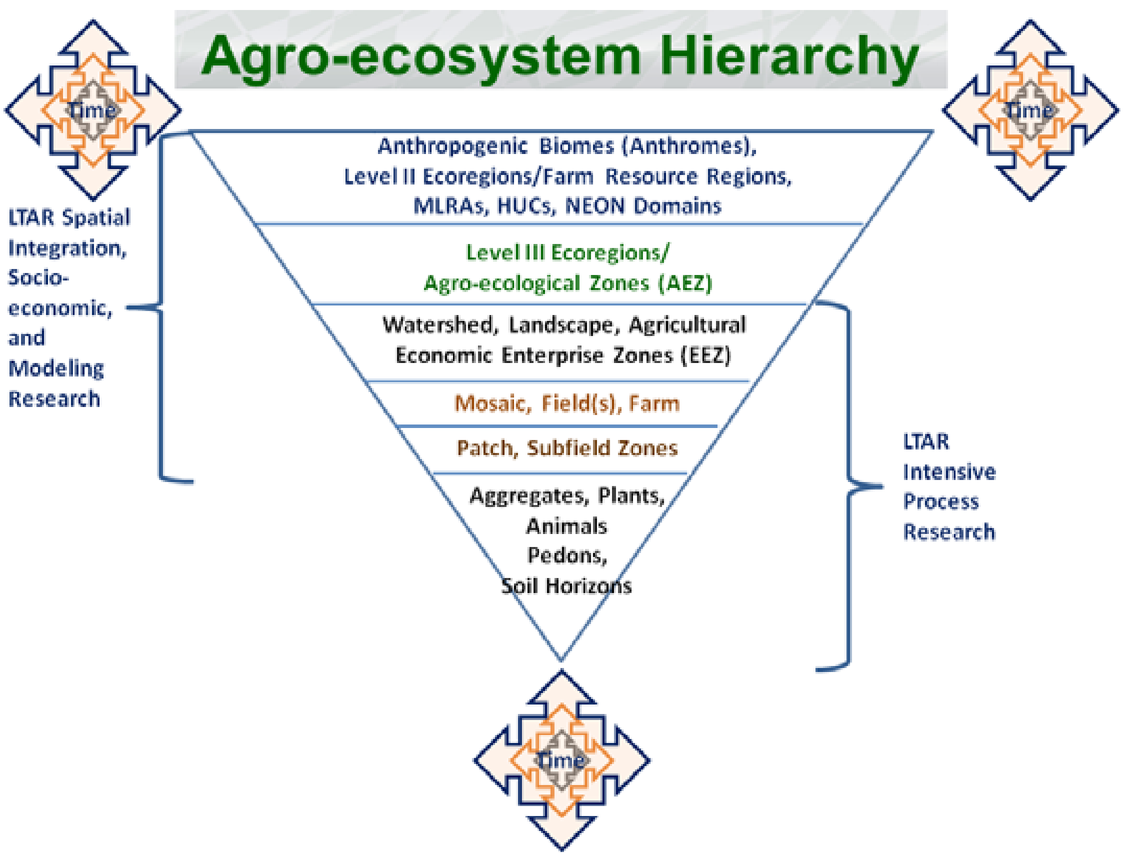

Figure 3—The transfer of matter and energy through agroecosystems is both hierarchical and continuous through space and time (MLRA: Major Land Resource Area, HUC: Hydrologic Unit Code, and NEON: National Ecological Observatory Network).

Table 3—Measurements required for LTAR foundation science and related discussion points.

Type	Measurement	Key Considerations
Plants and Animals	Species composition, biomass growth and development, harvest yield and quality	Sampling strategies, phenomics, community structure
	Plant nutrient concentrations, water and nutrient use efficiencies	Species considered, water and nutrient mass balances, cycles and flows, spatio-temporal scales, measurement technologies
Geography	Digital elevation map and terrain attributes	LiDAR-derived, basis for hydrologic modeling, erosion estimates, hillslope modeling, terrain analysis
	Land cover/use (e.g., forest, range, pasture, cropland, water, urban buildup)	Patch, mosaic structure, spatio-temporal changes in land use/cover
	Remote sensing including multi- and hyper-spectral ground-based or satellite imagery	Linkage to processes, properties and practices including phenomics, water and nutrient stress, biomass accumulation, disease/weeds/pests, surface residue, management practices
Weather	Precipitation, air temperature, solar irradiation, humidity, wind speed and direction, soil microclimate	Measurements required for models and to complement empirical data. Linkage to weather networks (e.g., SCAN), interpolation metrics (e.g., PRISM) and land management decision support (e.g., flex cropping, prescribed burning)
Water	Changes in storage, hydrographs for surface and ground water	Measurements required to characterize base and storm flow, estimate recharge, permitted withdrawals, other
	Evapotranspiration	Water use, evaporation at relevant spatio-temporal scales
	Water quality	Agroecosystem contributions to water at field to watershed scales, such as pH, sediment, pathogens, TOC, DOC, NO_3^-, NH_4^+, P, O_2, temperature, pesticides, and emerging pollutants.
	Stream ecology	Habitat metrics (e.g., bank condition, bed condition, DO, temperature, indicator organisms, shading)
Soil	Soil organic matter (labile, metastable, recalcitrant pools, fluxes), soil respiration, biological species, communities	Measurements required for models and to complement related data. Statistical approaches (e.g., stratified random sampling). Degradation processes (organic matter depletion, decreased biological diversity), sensitivity/resiliency concepts
	Nutrient availability (e.g., N, P, K, S), reaction (pH), toxicity (e.g., Al, Mn, Na), EC, mineralization, CEC, base saturation	N_2 fixation, nutrient supplying power (ion exchange membranes, resins), acidification, salinization, soil resource sensitivity/resiliency concepts
	Soil physical properties (texture, aggregation, bulk density, infiltration, soil rooting depth, water characteristic curves)	Soil degradation processes (e.g., compaction, erosion). Soil process, property characterization at appropriate spatio-temporal scales considering depth increments, terrain, soil classification. Linkage to soil microclimate.
	Soil classification, morphology	NRCS soil survey, higher resolution soil survey, descriptions
Air	Greenhouse gas (GHG) flux	Soil gas exchange (CO_2, N_2O, CH_4) at relevant spatio-temporal scales, GRACEnet and other sites. Eddy covariance flux towers, static chamber measurements, soil oxygen sensors
	Particulate emissions ($PM_{10,}$ $PM_{2.5,}$ TSP), deposition (SO_2, N compounds), organic compounds (e.g., VOC's, agrochemicals)	Linkage to air quality and NADP networks, wind erosion, aerosol formation
Management	Agronomic and livestock management operations (tillage, planting, agrichemical applications), inputs (dates, rates, etc.)	Spatio-temporal scales and linkages to water and nutrient use efficiency, soil health, irrigation management
	Agricultural practice use (conservation farming, precision farming), location and size (CAFOs)	Data availability
Socio-economics	Characterization of markets, farm structure and tenure, demographics, preferences, incentives/barriers to practice adoption	Survey information (USDA census, other), NASS, ownership, rented land, sources of labor

measurements, and augmenting this with partial budgets at other sites. To better understand drought, flood, erosion, vegetation and the impacts of climate change, 16 sites have been instrumented with new sensors to monitor soil moisture at multiple depths and locations in the past two decades. Ideally, shared measurements would be made with protocols common not only to LTAR sites, but also common to LTER, NEON, and other networks.

Since most LTAR sites have valuable continuous data records extending back decades, it may be unrealistic to consider changing all methods to a common protocol. In these cases, we will document that methods are nearly common, and use various QA/QC techniques to validate and compare those methods. Good laboratory practices and chain of custody for samples and data will be documented. Uncertainty introduced by different equipment, sampling and/or analytical methodologies (e.g., differentiating forms of phosphorus), sampling design (e.g., flume geometry), and scale of observation (plot, field, watershed, basin, airshed, etc.) will be documented and acknowledged. Though a common LTAR analytic center is not envisioned, a funded LTAR coordination of methods and protocols is a requirement for LTAR success.

The Common Experiment

The LTAR common experiment will underscore sustainable production systems, practices, and strategies that conserve the nation's natural resources and enhance environmental quality. In combination with the long-term historical data, data from the common experiment will provide a basis for objective evaluation of social, ecological and economic factors affecting the viability of alternative management strategies for US agriculture. A key outcome of this LTAR network common experiment is to develop and disseminate multi-regional, science-based information that will enable implementation of sustainable agriculture production systems that promote food security, environmental values, and climate change mitigation and adaption.

The objectives of the LTAR network common experiment will include:

> Develop and evaluate sustainable, profitable production systems or management strategies that optimize production and/or reduce use of resources while enhancing delivery of ecosystem services through a) altered plant or animal management systems, land use strategies, and production systems, b) adoption of intensified management, and/or c) employing alternative inputs including improved germplasm.

> Develop and employ coordinated, rigorous measurements of indices of productivity; water, nutrient and energy use efficiency; plant productivity; soil erosion; soil health; water and air quality; water availability; and greenhouse gases. Provide regional/national report cards comparing production efficiencies and ecosystem services. Utilize resulting long-term data sets to detect chronic and threshold changes in ecosystem services provided by agricultural ecosystems.

> Identify, quantify, and understand the ecological mechanisms underlying the costs and benefits associated with traditional and alternative food/fuel/fiber production and the provisioning of other ecosystem services from agriculture across the Nation.

> Use long-term measurements and experimental observations to model how ecosystem services from traditional and alternative management scenarios respond to climate projections years into the future and develop management recommendations for adapting to climate variability and change. Provide site-specific calibrations and sensitivity analyses for LTAR core models predicting outcomes.

Multi-Site Analysis of Historic Data

LTAR sites already perform many common measurements, albeit with some differences in specific variables and protocols. Measurements are being made of temporally continuous and spatially extensive meteorological conditions and precipitation events at all 18 sites. There are decadal records of basin-scale vegetation dynamics at 12 sites. Thirteen sites support the high-investment, high-maintenance equipment required to make continuous measurements of runoff, sediment yield and water quality. Analyses are underway or planned in the following areas:

> Agroecosystem productivity and sustainability: The LTAR network includes grassland sites across the southern U.S. During the early 21st century drought, a satellite-based record of above-ground net primary production (ANPP) at all sites could be used to generalize the functional response of grasslands to predicted climate change. Retrospective analysis in a natural setting at the regional scale could play a role in future grassland research, management and policy.

> Climate variability and change: The long-term climate records of LTAR sites permit coordinated quantification of the magnitude of temperature, humidity, and precipitation changes across agricultural regions of North America over at least

four decades. For a multi-decadal analysis period, LTAR sites could be used to establish universal climatic descriptors and response variables (e.g., productivity, watershed runoff/erosion, pest severity). From this continental-scale assessment, we can begin to understand the sensitivity of agricultural systems to changes in the hydro-climatic conditions across the US and North America.

Conservation and environmental quality: Historical advocacy for soil conservation and the evolution of cropping systems, planting technologies, pest control options and tillage practices have produced gradual, but profound, changes in US farming systems. The diverse soil, water, air, pest, and environmental quality data sets of LTAR offer a unique opportunity for retrospective analysis of the beneficial and unintended consequences of conservation practices and programs, from no-till to nutrient and pest management. Ecosystem services can be evaluated as a result of long-term landscape changes, such as, agriculture to urban use, natural ecosystems to agriculture, and restoration of natural ecosystems on former agricultural lands.

Socio-economic viability and opportunities: There is increasing interest in the potential for use of market forces to encourage producers and landowners to adopt new systems or practices to protect water, soil, and atmospheric resources. LTAR data sets can be used to quantify impacts of practices on the desired endpoints and to improve and validate models that are a part of environmental marketing and trading programs in the government or private sector.

LTAR Information Management System (IMS)

The LTAR IMS provides protocol and services for collection, verification, organization, archives, access, bases for analyses, and distribution of data associated with LTAR network activities. Access to all LTAR information will be organized through a web-based LTAR portal (Fig. 4). The goal of information management is to build and maintain an archive of LTAR data files that are fully documented, error free, and organized in useful ways. Our protocol for data collection and processing seeks maximum interaction between researchers and any data users. Development and implementation of the LTAR IMS system will occur under the currently constituted USDA Big Data and Computing Initiative.

Site and data management involvement will begin with the completion of a site-based research metadata survey by researchers; this will alert the LTAR network regarding any specific study and potential LTAR data sets. Once the LTAR IMS is implemented, researchers will then complete the required metadata documentation. All metadata documentation must be provided with any data set made available through our Web-based LTAR data portal. The final responsibility for quality assurance (both in data and documentation content) will rest with the principal investigator who submits the data for inclusion in the LTAR IMS.

CONCLUSIONS

A key expectation of LTAR is application of research results to solve critical challenges facing agriculture. Because research-based applications and their outcomes are impacted by continually-changing trends, demands, and innovations, the LTAR SRS exploits a mixture of data from on-going networked science, new cross-site experiments, and long-term historical measurements. The long-term integration of foundational science with long-term, multi-location experimental data underpins the provision of key LTAR products: new knowledge of processes and systems, new technologies and management practices, improved agro-ecological models, and comprehensive, accessible data. Ultimately, LTAR is expected to provide a wide array of clients, partners, and stakeholders with four basic outcomes: applications of new technologies, predictions of resource responses to system drivers, linkages to other networks, and educational outreach.

This brief overview of the development and content of the LTAR Shared Research Strategy is intended to give conference participants a broad understanding of the scope and direction of the LTAR network. For more detailed discussions, the readers are referred to the full LTAR-SRS document (Bryant et al. 2013).

ACKNOWLEDGMENTS

Numerous scientists from all LTAR sites, as well as anonymous reviewers, have contributed to development of the LTAR Shared Research Strategy. Their contributions are gratefully acknowledged by the authors of this proceedings paper.

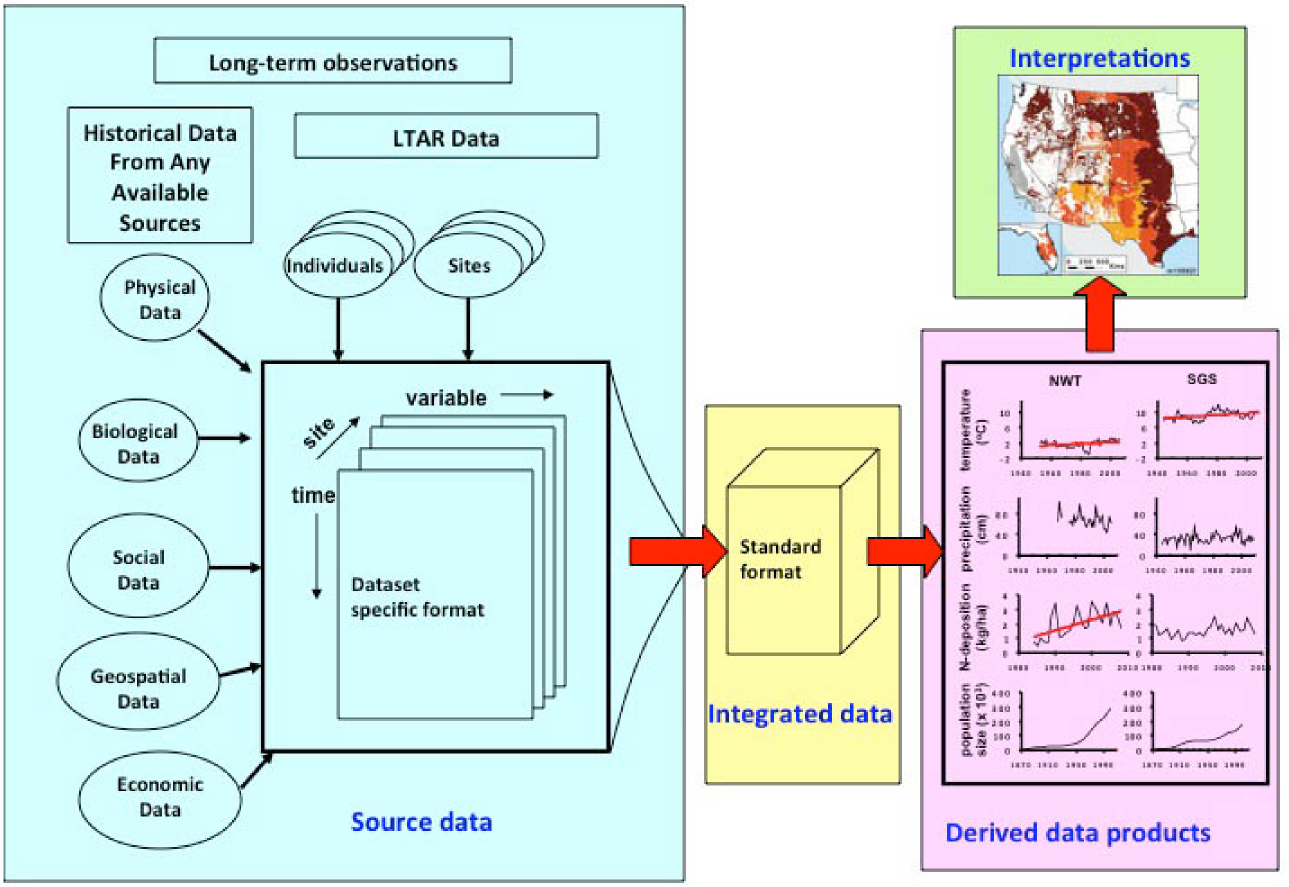

Figure 4—A conceptual model for a data portal framework of LTAR Information Management System providing public access to source data, integrated data, derived data products and data interpretations (adapted from Peters, 2010).

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PERSPECTIVES ON THE DEVELOPING COMMON EXPERIMENT ACROSS THE 18 SITES WITHIN THE LONG TERM AGROECOSYSTEM RESEARCH NETWORK

Kris Havstad[1]

The USDA Agricultural Research Service (ARS) established a Long Term Agroecosystem Research Network (LTAR) across 10 of its research locations, including some of its large watershed facilities, in 2012 and expanded that network to 18 locations in 2014. The LTAR is now designing a common experiment across all 18 locations, which includes 3 non-ARS sites, to be implemented in 2016. Though these 18 sites represent a very diverse array of agricultural systems, from small grains to beef cattle, and a diverse array of production scales, from intensely managed farm fields to extensively managed expansive rangelands, all sites share research objectives and hypotheses. The research plan is now being developed through 2015 for peer review early in 2016. In itself, the development of a common experiment across 18 diverse locations could be viewed as an experiment in coalescing science and scientists. Perspectives on this process, its goals, objectives and hypotheses will be shared by one participant in this ambitious effort.

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STORYTELLING TO SUPPORT WATERSHED RESEARCH ON EMERGING ISSUES

Philip Heilman[1]

Projections of budget deficits by the Congressional Budget Office imply ever-increasing pressure on federal spending for all purposes, including long-term watershed research. This presentation will argue that, since federal funding is ultimately a political decision, those responsible for maintaining long-term watershed research programs should not try to provide rigorous economic justification. Rather, the effort should recognize the natural human tendency to relate to the world through stories, and develop stories so that stakeholders can see their "stake" in supporting both ongoing and emerging watershed research.

The essential elements of storytelling are different than scientific communication and require a different skillset. Effective storytelling is concrete, requires a source of conflict, provides an emotional connection, and focuses on the novel and memorable. In many respects, a compelling story for additional watershed research funding will resemble the "dog and pony show" entrepreneurs tells venture capitalists when asking for the funds to develop a new technology.

Rigor is required in that an experimental watershed seeking expanded funding has to be able to provide new insights related to an emerging issue, the issue has to appeal to stakeholders enough to motivate lobbying, the lobbying efforts have to be persuasive enough to motivate action from a member of Congress, and finally the member has to be capable of providing new funding. If a weak link in that chain makes new funding to address an emerging issue unlikely, perhaps a broader organization could be persuaded to lobby for an emerging issue that could be addressed by a network of research watersheds. Another fallback position could be to remind stakeholders that are dependent on existing products so they lobby to maintain current funding levels, if cuts are threatened. An example story to address emerging issues related to climate resilience in infrastructure and new sources of manageable water for southeastern Arizona using data from the Walnut Gulch Experimental Watershed will illustrate the differences between scientific communication and storytelling.

Scientists would prefer a world in which new funding could be justified on scientific grounds. In this world, we will have to address the need to find new funding by working within the political system, using the language of politics - storytelling, and ensuring that we provide as much tangible value to stakeholders as possible.

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THE USDA-ARS EXPERIMENTAL WATERSHED NETWORK – EVOLUTION, LESSONS LEARNED, AND MOVING FORWARD

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Abstract—The USDA-Agricultural Research Service's Experimental Watershed Network grew from Dust Bowl era efforts of the Soil Conservation Service in the mid 1930's with the establishment of watersheds in three States; one of which is still in operation. In the mid-50's five centers with intensively instrumented watersheds at the scale of 100 to 700 km^2 were established. Primary network research objectives were to quantify the field-scale and downstream effects of conservation practices and develop rainfall-runoff relationships for design of water conservation structures. USDA-ARS has operated over 600 watersheds in its history and continues to operate roughly 120 watersheds, many of which consist of gauged subwatersheds nested within larger gauged watersheds to enable investigation of scaling. With passage of the Clean Water Act in 1972, research objectives have evolved to add a variety of observations relevant to the water quality issues in their respective regions resulting in a more diverse, but less homogeneous network. The core instrumentation and related long record of high-quality observations have led to initiation of a series of multi-location projects to examine trends and directions of these observations across the network. As a result of their long history, intensive monitoring, and well described processes, the USDA-ARS watersheds have been used extensively in the development and validation of numerous watershed models. In addition, they served, and continue to serve as validation sites for aircraft and satellite based remotely sensed instruments. Many of the USDA-ARS Experimental Watersheds have now joined the Long-Term Agro-ecosystem Research Network (LTAR) (Maddox, 2013). This presentation will review major activities and advances derived from the network in addition to discussing some lessons learned in the long-term operation of a national scale network through its evolution from analog to digital instrumentation and internet accessibility.

INTRODUCTION

Much of the following introductory material is derived from Goodrich and others (1993). Depression era efforts by the Civil Conservation Corps (CCC) and the Soil Conservation Service (SCS) were the catalyst for the early USDA-ARS Experimental Watershed Program. The early history of the watershed program as we know it today is described in more detail by Kelly and Glymph (1965). Initial research was motivated by the 1930's conservation motto of "stop the water where it falls." It focused on the merits of upstream watershed conservation to infiltrate precipitation and hold or slow runoff to reduce runoff and erosion. The research was largely concerned with on-site problems at the field scale on watersheds up to roughly 10 hectares. To a large extent the research utilized paired watershed analyses. In 1935 there was an expansion in scope to examine fields and watersheds up to several square kilometers in size with the establishment of major research stations in Coshocton, OH, and Hasting, NE (Harmel and others, 2007). Plot and lysimeter studies were incorporated into the research at these locations in addition to continuing the research on on-site effects of tillage and management practices. The research during this period is largely empirical with emphasis on instrumentation and accurate data collection (Kelly and Glymph, 1965). There was early recognition

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of scaling problems in transferring knowledge from small to larger watersheds (Harrold and Stephens, 1965). As a result, national programs were developed in the 1950's for controlling floodwaters and sediment, as well as assessing downstream effects of conservation practices on watersheds up to 1,000 km^2. The USDA-ARS was created in 1953 and operation and management of many of the experimental watersheds established by USDA's SCS were transferred to USDA-ARS.

A major impetus for expansion of the USDA-ARS experimental watershed program resulted from hearings by the Senate Select Committee on National Water Resources. In 1958 this committee conducted nationwide hearings and a review of US water resources and policy and requested USDA "to make a study of facility needs for research on soil and water problems…" The USDA study resulted in Senate Document 59 (US. Senate, 1959) which identified "Hydrology of Agricultural Watersheds" as high priority. The recommendations in this document mirror more recent calls for improved research and continental-wide observations for water, ecology and soils emanating from the National Ecological Observatory Network (NEON) and Critical Zone Observatories (CZO) (NRC, 2008). Senate Document 59 laid out the following national research objective: "Hydrologic studies are urgently needed on precipitation-runoff relationships and the effect of all types of conservation treatments on runoff … from agricultural watersheds ranging in size from 1 to 400 square miles." Like NEON they recommended core experimental watershed sites with satellite locations ("Experimental watersheds are needed in all 15 major land resource regions…to provide the maximum opportunity for interpolating values between locations with markedly contrasting conditions each should include a number of satellite locations …"). The interdisciplinary nature of the challenge was also recognized as Senate Document 59 stated "...agricultural watershed behavior is a complex problem…research centers must be large enough to represent numerous disciplines." While cyber-infrastructure had not been contemplated in the late 1950's they did recommend measurement of a common set of variables with standard protocols, periodic review of network data, and a central data repository in Beltsville, Maryland.

As a result of Senate Document 59, appropriations were made to establish new watershed research centers in a number of hydroclimatic regions in Chickasha, OK; State College, PA; Boise, ID; Tifton, GA; and Tucson, AZ. In addition, the Columbia, Missouri research unit was directed to become the North Central Hydrologic Laboratory in 1961 as a direct result of Senate Document 59. Analysis of observations from the earlier, smaller watersheds indicated the difficulty in extrapolating hydrologic response characteristics to larger scales. Consequently, the core experimental watersheds established at these new centers were on the order of 100 to 600 km^2, roughly an order of magnitude larger than watersheds established in the 1930-40's. The goal of the watershed research centers was to select a representative core watershed and establish satellites that were less well instrumented. Nested watersheds and unit source areas on major soil types were included in the watershed designs to further investigate scale effects.

A key early challenge in establishing the larger experimental watersheds over a wider range of hydroclimatic regions was development and acquisition of instrumentation and procedures for their installation, operation, and maintenance. A significant, and still valuable, outcome of this work was development and publication of Handbook 224 - Field Manual for Research in Agricultural Hydrology (Brakensiek and others, 1979). Measurement quality control was and still is an important ongoing effort. Johnson et al. (1982) described ARS Experimental Watershed data acquisition programs and an assessment of the quality of collected data at many of the watersheds. Based on data from the Hydrology and Remote Sensing Laboratory in Beltsville, Maryland, by 1990, ARS had operated over 600 watersheds in its history. Of the 600 watersheds, a comprehensive database is available from the Hydrology Laboratory for 333 of these watersheds (www.ars.usda.gov/ba/anri/hrsl/wdchome). This database consists of variable time-series readings for precipitation and runoff from small agricultural watersheds with sufficient detail to reconstruct storm hydrographs and hyetographs with approximately 16,600 station years of data. Records in the Beltsville database run through 1992. Due to budgetary constraints, post 1992 records were maintained at individual watershed centers. DeCoursey (1992) provided an overview of the ARS Experimental Watershed Network in operation at that time including a description of the size distribution, length of record and primary land use of the active watersheds. Approximately 120 ARS watersheds are currently active and collecting a variety of data. The geographic location of active watersheds is illustrated in Figure 1. In many of the locations depicted on this figure, multiple watersheds, many nested, exist or have existed. Table 1 lists the primary ARS Experimental Watersheds and a number of their attributes.

The guidance on instrumentation, installation, calibration, and maintenance described in detail in Handbook 224 led to a relatively uniform national experimental watershed network that focused primarily on observations of weather, climatology, precipitation, and runoff, in addition to detailed characterization of the watersheds. Many lessons were learned during the development of the large USDA-ARS watersheds. An important finding was that meaningful observations were not always possible

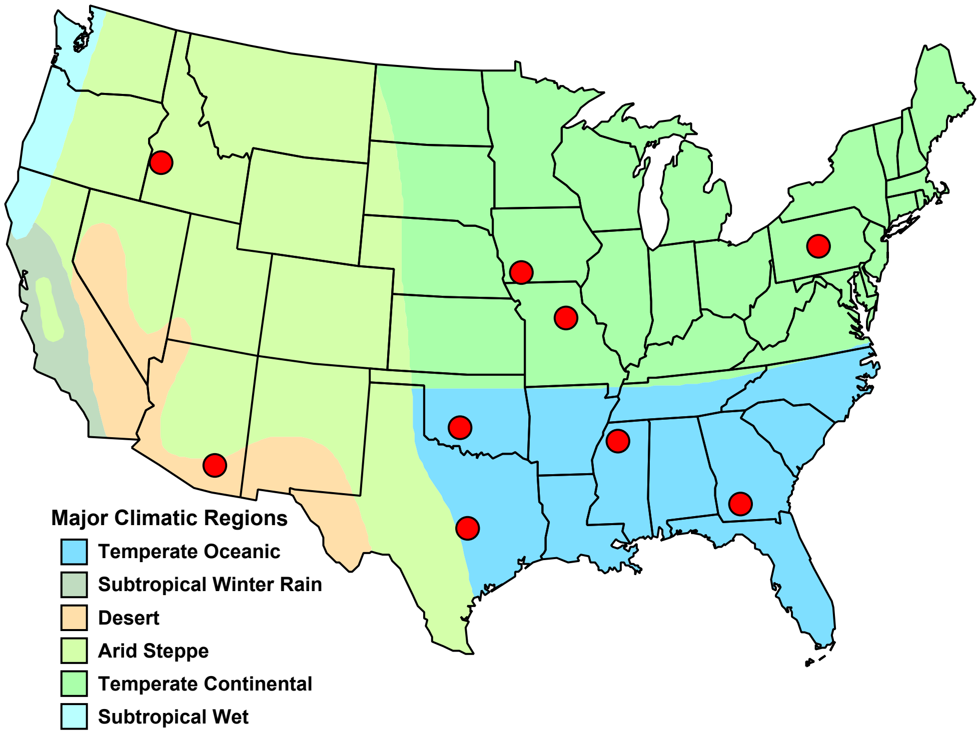

Figure 1—Location of primary ARS Experimental Watersheds.

across the wide range of environments and hydroclimatic conditions. Therefore some specialized instrumentation or installation procedures were developed to collect meaningful data. For example, the snow dominated Reynolds Creek Experimental Watershed in Idaho has two precipitation gauges at each measurement location. One is shielded to reduce wind effects and the second is unshielded. When precipitation is primarily in the form of snow (at temperatures less than –2.2°C) this installation provides more accurate precipitation estimates and also enables the interpretation of unshielded dual gauge measurement locations (Hanson, 1989).

With passage of Clean Water Act (CWA) in 1972 many of the ARS watersheds began collecting water quality data. Due to regional differences in agriculture production and practices, the constituents impacting water quality (sediment, herbicides, pesticides, nutrients, etc.) vary substantially across the network. These differences and budgetary limitations led to a divergence in network data collection. As digital instrumentation and technology advanced the ARS watersheds began the process of converting from analog to digital instrumentation, primarily in the 1990s and 2000s. However, this was done on a location-by-location basis and not uniformly across the network. This is largely the result of the ARS budgetary framework where individual locations are allocated annual budgets. There is not a “network” budget for multi-location purchasing and hiring. The changeover to digital instrumentation was in many cases more about retrofitting existing instrumentation with data loggers and telemetry capabilities so the central core measurements of climate, weather, precipitation and runoff could still maintained. However, a number of new automated sensors became available, such as soil moisture probes. The performance of these sensors tended to vary across soil types and across dry to wet environments. This resulted in location-specific choices of soil probes. However, coordinated efforts for validation of remotely sensed soil moisture products did result in a common soil moisture probes for four of the core experimental watersheds (Jackson and others, 2010). As climate change awareness, increased many locations added energy and carbon flux monitoring and more recently soil respiration and biogeochemistry. As with soil moisture, these additions were done on a location-by-location basis depending on available expertise and research goals.

With improved internet connectivity and lack of a central data repository, many individual locations undertook specific efforts to organize and make their experimental watershed data available in easy to use digital form. These efforts have proven to be expensive and time consuming. Estimated costs of the Data Access Project (DAP) for the Walnut Gulch Experimental Watershed in Arizona were ~$700,000 to put eight data sets up on the web with metadata published in a peer-reviewed journal. Annual maintenance was estimated to be $20,000/year for IT upgrades, basic QA/QC, and maintenance of data loggers and instrumentation (Moran and others, 2009).

Table 1—Selected Attributes of ARS Experimental Watersheds

ARS Experimental Watersheds						Monitoring				
ARS Research Unit	Unit Location	Description	Size	Land Cover/Use	Year Established	Climate	Discharge	Sediment	Water Quality	Other
Southern Plains Range Research Station	Woodward, OK	4 plots	16 ha	Grazing	1977	X	X	X	1	
Southern Piedmont Conservation Research Unit	Watkinsville, GA	7 plots	130 ha	Forest/pasture/ crops	1937	X	X	X	1,3,4	5
Grassland Soil and Water Research Laboratory	Temple, TX	20 plots	350 ha	Mixed cropping/ forage	1937	X	X	X	1,3	5
North Appalachian Experimental Watershed	Coshocton, OH		400 ha	Mixed cropping/ forage	1935	X	X	X	1,3,4	1
Pasture Systems and Watershed management Research Unit	University Park, PA	Watershed WE-38	730 ha	Forest/pasture/ crops	1967	X	X		1	5
National Sedimentation laboratory	Oxford, MS	Goodwin Creek	21.5 km^2	Mixed cropping/ forage	1981	X	X	X		4
Cropping Systems and Water Quality Research Unit	Columbia, MO	Goodwater Creek	73 km^2	Mixed cropping/ forage	1971	X	X	X	1,3	5
Southwest Watershed Research Center	Tucson, AZ	Walnut Gulch	150 km^2	Rangeland	1954	X	X	X		1,3
Northwest Watershed Research Center	Boise, ID	Reynolds Creek	240 km^2	Range/forest/hay	1960	X	X	X	2	2
Southeast Watershed Hydrology Research Center	Tifton, GA	Little River	334 km^2	Mixed cropping	1967	X	X	X	1,3	1,3,5
Grazinglands Research Laboratory	El Reno, OK	Little Washita	610 km^2	Grazing with mixed crops	1936	X	X	X	1	1,3,5

Water Quality: 1 = Nutrient, 2 = Temperature, 3 = Pesticides, 4 = Pathogens I Other: 1 = Flux, Bowen Ratio, 2 = Snow, 3 = Remote Sensing, 4 = Doppler Radar, 5 = Groundwater

As part of these data availability efforts, a number of special journal sections with data and/or research papers were developed. They include Slaughter et al. (2001) for Reynolds Creek, Idaho; Bosch and others (2007) for the Little River, Georgia; Moran and others (2008) for Walnut Gulch, Arizona; Langendoen and others (2009) for Goodwin Creek, Mississippi; Owens and others (2010) for Coshocton, Ohio; Bryant and others (2011) for Mahantango Creek, Pennsylvania; Harmel and others (2014) for Riesel, Texas; and, Sadler and others (2015) for Goodwater Creek, Missouri. While not technically part of the early ARS watershed network, Ames, Iowa (Walnut Creek) and Oxford, Mississippi (Beasley Lake) were established as part of the Management Systems Evaluation Areas (*MSEA*) and Agricultural Systems for Environmental Quality (ASEQ) Projects. Synthesis publications describing these watersheds and related project research are presented by Hatfield and others (1999) and Locke (2004). A broader data services tool integrated with GIS services named STEWARDS (Sustaining the Earth's Watersheds, Agricultural Research Data System) was developed starting in the mid-2000's (Steiner and others, 2008; Sadler and others, 2008). It houses data from a number of the ARS cropland dominated experimental watershed as well as CEAP (Conservation Effects Assessment Project) watersheds.

ACCOMPLISHMENTS

The USDA-ARS Watershed Research program and its experimental watershed network have a lengthy record of high-impact accomplishments. Some of the most significant include:

- Quantifying the effectiveness of conservation practices and BMPs in reducing runoff, erosion, and water quality impacts of agricultural production
- Quantifying the environmental impacts of agricultural fertilizers and chemicals at the watershed scale
- Developing guidelines for reclamation of disturbed lands
- Quantifying the value of riparian ecosystems in improving water quality
- Instrumentation development and hydraulic structure design
- Quantifying the effects of floodwater retarding structures
- Development and validation of numerous remote sensing products
- Improved water supply forecasting
- Development of numerous, widely used, watershed, water quality, and natural resource management models

Through its history the ARS Experimental Watersheds have been able to maintain continuity of core observations (climate, weather, precipitation, runoff) while adapting to meet changing research needs and regional issues.

CURRENT RESEARCH

The rich history of long-term observations within the USDA-ARS Experimental Watershed Network has afforded the ability to conduct multi-location research projects. Current multi-location projects include:

- Indicators of ecosystem services in agricultural watersheds
- Utility of remote sensing for ET and drought monitoring and for assimilation into ARS hydrologic models
- Remotely-derived estimates of net primary production using remotely sensed data across precipitation regimes
- Hydro-climatic trends across North America—a comparative analysis of historical soil water trends in us agricultural lands
- Continental-scale synthesis of high-resolution observations from USDA-ARS and other experimental watersheds and ranges
- Comparison of eddy covariance flux measurements of H_2O vapor and CO_2 in different environments
- Estimating the impacts of projected climate change on regional water availability and quality across diverse physiographic regions of the US

LESSONS LEARNED

A number of important lessons were learned in the initiation, development, maintenance, and evolution of the ARS Experimental Watershed Network that may benefit other national observation based research efforts. Several are offered herein in no particular order of importance. Off-the-shelf instrumentation may not be universally suitable over a diverse set of environments. Some degree of trial and error will be inevitable in developing suitable instruments and siting them to acquire meaningful observations. The time and expense for permitting and acquiring access can be considerable and should not be underestimated. Likewise, the costs of QA/QC for observations, archiving, and data delivery are substantial and should be examined when contemplating adding other core observations to the network. Personnel with good technical, field, and fabrication skills are in short supply, and current hydrology and watershed management degree programs typically do not provide this diverse set of skills. Science and societal challenges will emerge that the network designers did not anticipate, and therefore our observational networks had to adapt. Without a centralized funding model for the entire network, our watersheds have not been able to uniformly integrate these adaptations. In many cases, this makes good economic sense. Collecting and analyzing runoff samples for a suite of nutrients, pesticides, and herbicides is typically of little value in western rangeland where those constituents are not part of common agricultural practices.

MOVING FORWARD AND CONCLUSIONS

Many of the long-term ARS Experimental Watersheds are now part of the Long-Term Agro-ecosystems Research (LTAR) network (Steiner and others, 2015). The vision of the LTAR network is to enable multi-decadal trans-disciplinary and cross-location science to enhance the sustainability of the nation's agro-ecosystems and delivery of goods and ecosystem services. Its primary goal is to sustain a land-based infrastructure for research, environmental management testing, and education that enables understanding and forecasting of the Nation's capacity to provide agricultural commodities and ecosystem services under changing environmental, economic, and societal conditions. Additional details on the LTAR network are reported elsewhere in proceedings of this conference (Steiner and others, 2015). Several efforts are also underway to provide centralized experimental watershed data access. One is through the National Agricultural Library. The other is to utilize community water data services based on the Hydrologic Information System (HIS) developed by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI - https://www.cuahsi.org/wdc). The Reynolds Creek and Walnut Gulch Experimental Watershed Centers have reformatted their core data into the Observations Data Model (ODM) that allows spatial queries for point time series data via WaterOneFlow web services. The companion HydroDesktop (http://hydrodesktop.codeplex.com) is an open source GIS enabled desktop application for searching, downloading, visualizing, and analyzing hydrologic and climate data registered with the Hydrologic Information System.

Moving forward, the USDA-ARS Experimental Watershed Network and LTAR must tackle several challenges to ensure its continued relevancy to the nation's natural resource science and management priorities. What new core observations, beyond the existing observations of weather, climate, precipitation and runoff, should be added to the entire network? Candidates include trace gases, water and wind erosion, ET and CO_2 fluxes, and imaging, among others. In addition to an expanded set of core observations, how will the network evolve to not only incorporate new technology and address new regional issues, but also collect measurements that may be regionally important for a subset of the network and not for other portions of the network? A key point is that these are research networks and not purely data collection observatories. As such, watershed network evolution cannot be solely driven by standardized instrumentation, uniform long-term data collection for all variables, and centralized database management. As a research network it should address common national issues that require region-specific data collection to address region-specific problems, and develop high-impact region-specific solutions. It is the capacity of this unique network to address national issues across the physiographically and environmentally diverse regions of the continent that defines the network, not the assemblage of region-specific data of the various ARS watersheds and rangelands dispersed across the continent.

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This analysis would not have been possible without the many early Soil Conservation Service and ARS scientists and administrators who had the vision and commitment to construct and operate the entire ARS National Experimental Watershed Network for the long-term. In addition we commend and gratefully acknowledge the dedication of ARS staff in maintaining these long-term hydrologic observatories and their diligent long-term collection of high quality watershed data.

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CENTRAL MISSISSIPPI RIVER BASIN LTAR SITE OVERVIEW

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Abstract—The Central Mississippi River Basin (CMRB) member of the Long-Term Agro-ecosystem Research (LTAR) network is representative of the southern Corn Belt, where subsoil clay content makes tile drainage challenging and make surface runoff and associated erosion problematic. Substantial research infrastructure has been in place for more than 40 years, and the recent establishment of the CMRB LTAR site has prompted additional activity. This paper describes a brief history of the research infrastructure, points to resources for further details of documentation and access for research data obtained to date, and describes current plans for expansion.

INTRODUCTION

The Central Mississippi River Basin (CMRB) member of the Long-Term Agro-ecosystem Research (LTAR) network is operated by the USDA-ARS Cropping Systems and Water Quality Research Unit in Columbia, Missouri. The CMRB LTAR represents a runoff-prone (despite gentle slopes) geophysical context with documented erosive soils found in the southern Corn Belt. Land, originally prairie dissected by wooded riparian river corridors, is intensely agricultural. The primary row crops are soybean, corn, and sorghum, and forage is mainly tall fescue. However, row crop production in this region is economically marginal and environmentally risky. In contrast to the rest of the Corn Belt, the CMRB area is not tile drained.

The core research infrastructure is the 73 km^2 Goodwater Creek Experimental Watershed (GCEW). Rain gauge network data have been collected since 1969 and streamflow and sediment load since 1971. In 1991, water quality measurements were added for surface and ground water. Scales studied ranged from plots at 0.0034 km^2, to whole fields at 0.12 to 0.35 km^2, to streams up to 73 km^2. In 2005, 12 larger-scale watersheds (200 to 1200 km^2) within the Salt River basin were instrumented; 8 of these were co-located with USGS flow sites. Since 2010, 3 of the 12 have been retained for a maximum area of 466 km^2. Collateral infrastructure includes cooperator research facilities proximal to and nearly surrounding GCEW.

The 0.34-ha plots are replicated treatment comparisons with summit, backslope, and footslope landscape positions, in place since 1991, with yield measured for the landscape positions. Eighteen of the 30 have been instrumented to measure flow and sample water quality. Adjacent is a 35-ha field (Field 1, or F1) managed conventionally from 1992-2004, and then converted to a "Precision Agriculture System" (PAS). The PAS was developed with input from stakeholders on four criteria (profitability and environmental impact for erosion, surface water quality, and ground water quality). The PAS includes no-till, cover crops, wheat instead of corn where the topsoil was thin, reflectance-based site-specific N applications for wheat and corn, grid-sample-based variable-rate P, K, and lime, and targeting of herbicides. A close parallel treatment to the PAS also exists in the plots. Another plot treatment represents conventional production.

Substantial infrastructure development is underway. A conventional practice field (Field 3, or F3) to serve as Business as Usual (BAU) will be instrumented for surface runoff sampling and measurement and a flux tower. Upgrades to existing flow and sampling equipment are underway, and a historical GCEW stream site at 12 km^2 is being re-installed to help differentiate the urban influence at the headwaters. Radio telemetry has been implemented for the rain gauge network and will extend throughout the 72 km^2 GCEW. Multiple modes

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of telemetry are being implemented in the intensively studied field site that includes the aspirational practice (ASP) and replicated plots of multiple cropping systems, including ASP and BAU. An overview of the physical infrastructure, telecommunications, and vision for the data communications plan is presented below.

PHYSICAL CONTEXT AND HISTORY

At the broad scale, the CMRB comprises a range of ARS and University of Missouri infrastructure (fig. 1) The core, established in 1971, is within GCEW. The ARS Cropland CEAP (Conservation Effects Assessment Project) broadened the scope to the entire Mark Twain Lake, which catches the upper Salt River basin and serves as primary drinking water supply to more than 40,000 residents over much of northeast Missouri. From 2004 to 2011, 12 sites, including GCEW, were sampled on a seasonal basis with automated samplers, and manually on a biweekly basis through the rest of the year where continuous flow from USGS stations existed. Surrounding the Salt River Basin are a number of USDA and University of Missouri Research Centers (RC) that provide controlled space to test hypotheses and provide contexts for comparison and contrasts. These include the Greenley RC, Bradford RC, South Farm RC, Horticulture and Agro-Forestry RC, Tucker Prairie (relic native prairie), Prairie Forks Conservation Area (restored prairie), Baskett Wildlife RC (forested Ameriflux site), and NRCS Plant Introduction Center at Elsberry.

Within the infrastructure shown in figure 1, the Long Branch Watershed remains the focus of current research (fig. 2). At this scale, the riparian forests are clearly visible, and the predominance of cropland in the broad, flat divides between the watersheds is also clear. From the Lower Long Branch USGS flow station, there is a nested flow structure through Young's Creek, then the GCEW itself. From 1971 to ~2000, the GCEW design was a 3-stage nested structure, with 72, 28, and 12 km^2 watersheds up the main stem (on the west). In parallel with Young's Creek is Upper Long Branch. The latter two are natural channels; Lower Long Branch has a low-water crossing as control.

The nested design within GCEW is visible in figure 3, with Weirs 1, 9, and 11 annotated below. In 1990, intensive infrastructure was established at the field and

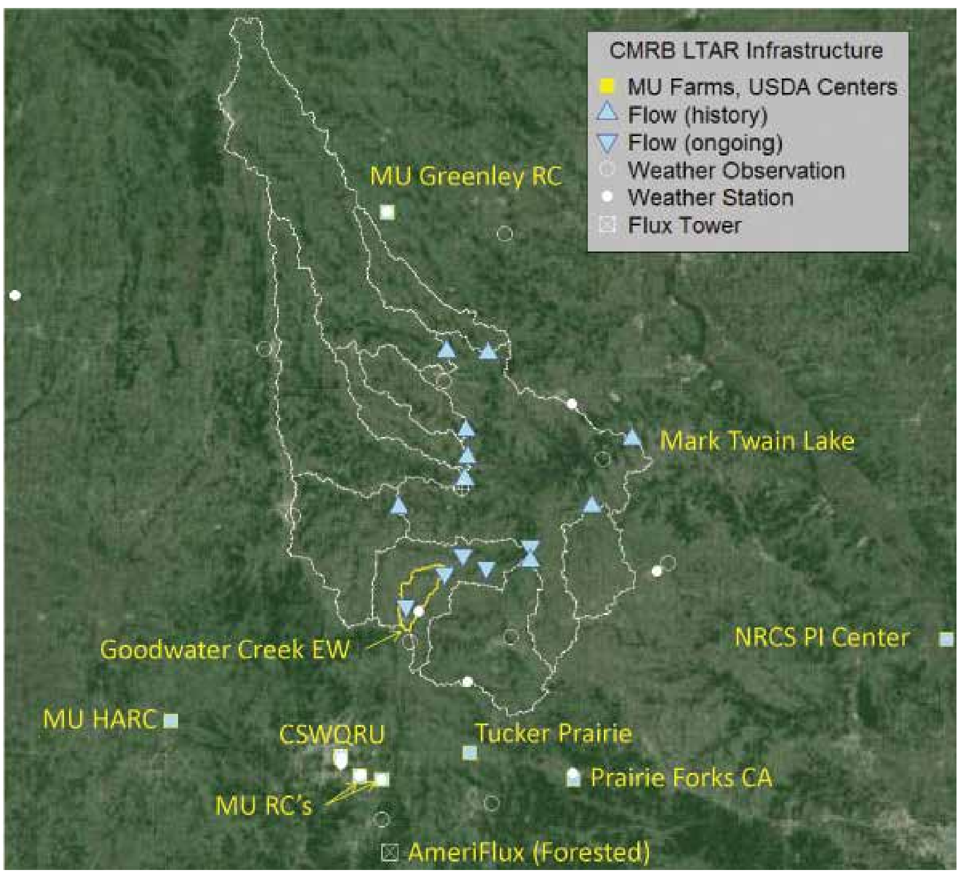

Figure 1—The Central Mississippi River Basin LTAR location and associated research infrastructure. For reference, the gray area at the extreme SE corner is Saint Louis, and the CSWQRU annotation is in Columbia MO.

plot scale. The fields are visible in figure 2, as clusters of well nests that were established in the 1990s, as is the current deployment of weighing rain gauges.

Intensive research infrastructure at the primary field site is shown in figure 4. The right half of the image is a 35-ha field with a weir to gauge runoff and an automated sampler to enable laboratory measurement of sediment, nutrient, and pesticide water quality. The site annotated as weather station includes both an ARS weather station deployed since 1993 and an NRCS SCAN station recently installed (id: CMRB LTAR). To the left are 30 plots of 0.34-ha size, arranged in 3 replications of 10 cropping systems treatments. All are separated by surface berms and in-ground curtains to prevent cross-plot movement of water and soluble constituents. Eighteen of these also have berms at the bottom that route surface runoff through concrete approaches and flumes that are instrumented with automated samplers. These have been constructed with heated stilling wells to enable sampling during periods with temperatures near freezing. They are controlled with separate dataloggers, and stage is measured using a pressure transducer with in-house calibration and temperature compensation algorithms that improve accuracy.

Description of the CMRB/GCEW Database

The data from the CMRB/GCEW was recently documented in a multi-paper special collection in the Journal of Environmental Quality (http://www.ars.usda.gov/Research/Docs.htm?docid=25264). The introduction includes the scientific, physical, and historical context for the research infrastructure (Sadler et al, 2015a). Papers describing data for weather (Sadler et al, 2015b), streamflow (Baffaut and others 2015b), and both herbicide (Lerch and others 2015b) and nutrient (Lerch and others 2015c) water quality follow. The series includes four research papers that address groundwater nutrients (Kitchen and others 2015), stream transport of nutrients (Lerch and others 2015a), and remote sensing of lake water quality (Sudduth and others 2015), plus modeling of the GCEW scale using the SWAT model (Baffaut and others 2015a). The series makes extensive use of supplemental online materials, and potential users of the data are strongly encouraged to examine that. The contents of the papers and the supplemental online materials are also described in more detail through the link. In addition, several additional earlier publications are listed (and linked) that provide critical information regarding sediment (Baffaut and others 2013), hydrologic

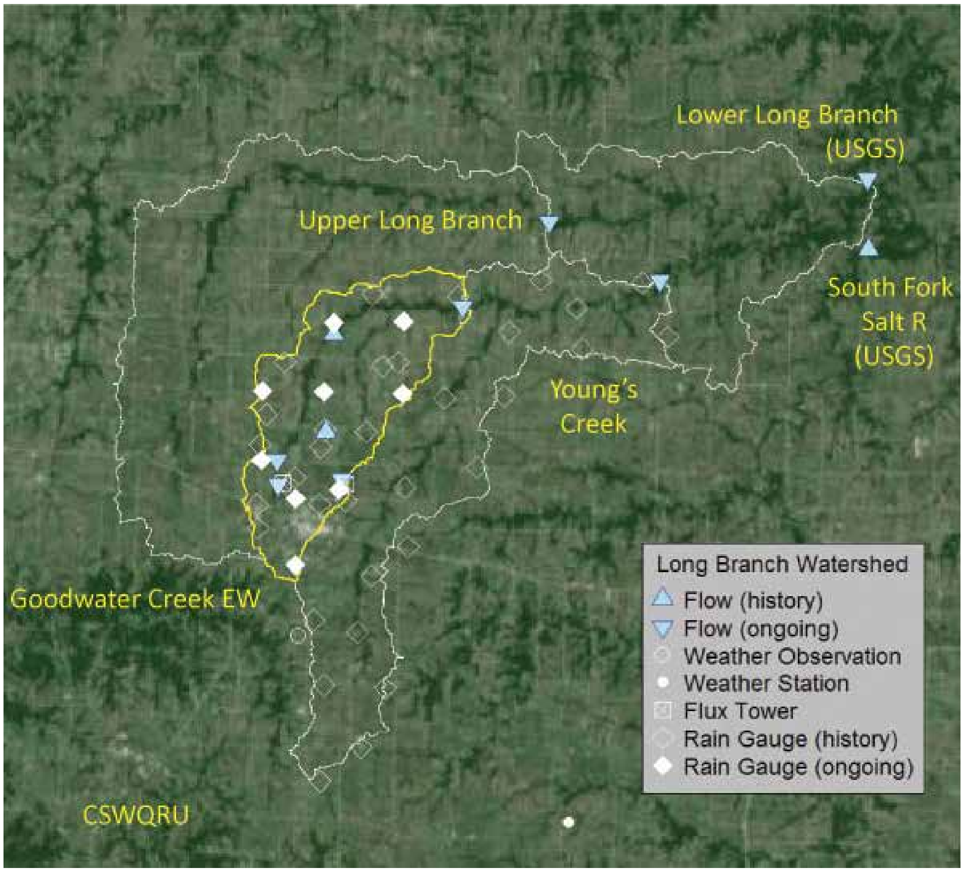

Figure 2—Research infrastructure in the Long Branch watershed of the Salt River.

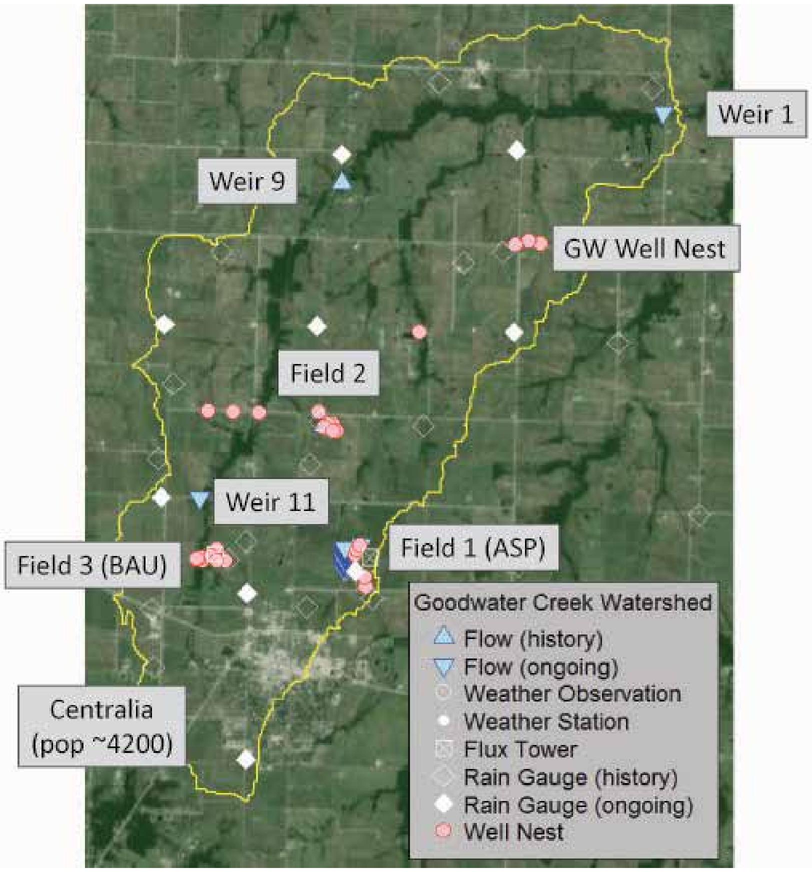

Figure 3—Infrastructure visible at the Goodwater Creek Experimental Watershed scale.

methods (Baffaut and others 2014), and the cropping systems in the research fields and plots (Lerch and others 2005; Kitchen and others 2005, Lerch and others 2008). The data described in this series are available to the public through the STEWARDS database system (Steiner and others 2008a; 2009a, b; Sadler and others 2008).

In addition, extensive soil quality assessments have been conducted at the field and plot scale at the GCEW site (Fig. 4). In 2008, a baseline assessment was initiated on all GCEW management systems, and included a broad range of soil physical, chemical, and biological indicators of soil quality. The soil quality assessments were repeated in 2010 and 2014, and will continue to be periodically done to evaluate the long-term effects of management practices.

Telecommunications development

At this time, the GCEW raingauge network is linked with a radio-frequency telecommunications network to a tower and base station located at the Field 1 weir site. This network is expected to provide the telecommunications backbone for all instruments outside the Field 1 campus, plus the weather station, rain gauge, and planned flux towers within Field 1. Another, lower power, network connects the dataloggers on the plot flumes north of the building and is expected to be able to accept other close-range equipment in that area. Both of these networks will connect to a server in the on-site building. That server will connect through a local ISP to the internet, where servers at the Columbia ARS offices exist. The server also will host WiFi for the field site, providing data access via smartphones and laptops and receiving camera images and video feeds for both security and research purposes.

The server will provide local control and storage, and automatically forward data, as it is received, to the Columbia servers. Scientists will normally access data from the Columbia servers, such that the field server would function as backup. In operation, raw data are not overwritten but rather, edits are added as a separate data product with metadata describing the replacement or transformation. Primary quality assurance (QA) through outlier screening will be performed at dataloggers or the field server, with reports and alerts contingent on those screens. Secondary QA will be performed by technicians and scientists during normal work hours, usually on

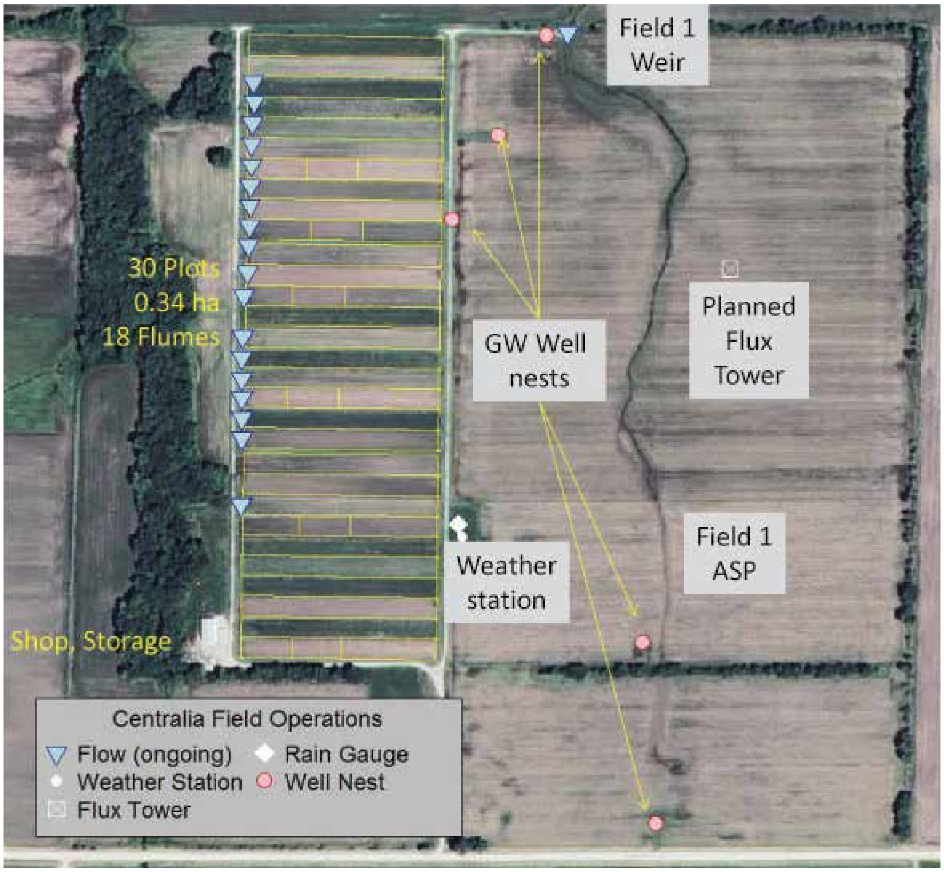

Figure 4—Infrastructure at the Goodwater Creek Experimental Watershed Field 1 site.

a timeframe from daily to monthly, depending on the data stream. This level would involve lab and field standards, cross-site or cross-instrument comparisons, and comparisons with long-term normal data as appropriate. Tertiary QA is done on the annual cycle and involves those and additional comparisons plus statistical comparisons with related or similar instruments. This latter step is required before provisional data is tagged as final.

Planned Research Equipment

Eddy flux towers will be installed in Field 1 as ASP (2015 season) and in Field 3 as BAU (2016) (see fig. 3 for sites). A parallel comparison across two instrument types will be established in Field 1 (2015). Averages at 30-minute intervals will be transmitted and forwarded using on-board post-processing. The high-frequency data will be moved to the server on a weekly basis via storage modules.

The Field 3 BAU site has an existing weir for measuring runoff, but flow measurement and sampling equipment were removed some years ago. Modern versions of that equipment will be installed, and data communication established. Once that is operable, a water sampling protocol for the site will be established and implemented. Similarly, the Weir 11 site was operable from 1971 through 2002, at which time the instrumentation was removed, but the weir remained. Modern equivalents to the instrumentation and sampling equipment will be installed. The Field 3 and Weir 11 sites are high priorities. Upgrading the larger stream sites will involve similar activities – obtaining permissions from right-of-way jurisdictions and landowners, establishing power, building the platform and housing, installing sampling equipment and flow instruments, and establishing communications (cellular modem at those sites). They will be sequenced after the Field 3 and Weir 11 sites.

Historical rainfall data in GCEW was measured with unshielded weighing rain gauges. The SCAN station and other automated stations use unshielded tipping bucket gauges. The LTAR requirement is expected to be a shielded weighing rain gauge. For longitudinal and cross-instrument purposes, statistical descriptions of the relationships among these instruments are required. A 2x2 measurement design will be established at the Field 1 weather station site, exploiting the existing unshielded weighing and tipping bucket gauges and adding the equivalents with double alter shields, all at the same height. This deployment will include air temperature and wind speed at the height of the gauges, as relationships among these gauges is known to depend on wind, and temperature is expected to provide correlation to both seasonal droplet size and rain vs snow relationships.

Similarly, SCAN weather stations use a type of soil moisture measurement that is known to have difficulties in soils with high fractions of 2:1 lattice clays, as exist at this site. An alternative instrument that is expected to perform better in the local soils will be installed in parallel and proximal to the SCAN instruments, and the necessary relationship established. Gravimetric soil moisture and bulk density measurements will be made on a periodic basis for calibration purposes.

The SCAN weather station automatically uploads hourly and daily data to the NRCS weather data server. Software has been developed locally to extract data from the NRCS server. It will be adapted to operate on the native time basis and create a local copy of those data for cross-instrument comparisons and QA purposes. The ARS weather station will be relocated approximately 10 m north to escape the shadow of the SCAN radio antenna during the winter months, and upgraded to current equipment and sensors at that time. Programming to match the 5-minute near real time frequency of the University of Missouri AgEBB weather station mesonet will be implemented at that time. Software to transmit the data to the AgEBB will be implemented as well as storing on the field and office servers. A second AgEBB weather mesonet station will be established near the Paris MO high school, where weekly maintenance will be performed by students as a vocational education activity.

Facilities Plans

The current building on the field site is a 24x12-m metal frame construction, with 1/3 floored and a small area heated and air conditioned. The rest is used for farm equipment storage. A project starting this year will add ~32x12m under roof, with about half farm equipment storage and the rest electronic and hydrologic workshop, multi-purpose space for farm machinery setup, instrumentation, repair, and field day/meeting area, and restroom/shower facilities. Architectural and engineering work will begin in 2015, with construction intended for 2016.

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THE SOUTHERN PLAINS LTAR WATERSHED RESEARCH PROGRAM

Patrick Starks, Jean L. Steiner[1]

Water connects physical, biological, chemical, ecological, and economic forces across the landscape. While hydrologic processes and scientific investigations related to sustainable agricultural systems are based on universal principles, research to understand processes and evaluate management practices is often site-specific in order to achieve a critical mass of expertise and research infrastructure to address spatially, temporally, and ecologically complex systems. The USDA-ARS Grazinglands Research Laboratory (GRL) is host to the Southern Plains Long-term Agricultural Research site (SP-LTAR), and watershed research at the SP-LTAR began in the Upper Washita River basin of Oklahoma in 1961 and continues to present. The two primary research watersheds in this area are the 610 km^2 Little Washita River Research Watershed and the 800 km^2 Fort Cobb Reservoir Experimental Watershed. The size of these watersheds, coupled with the fact that 100 percent of land in both watersheds is privately owned, precludes meaningful manipulative experiments. However, research efforts in these two watersheds have made significant contributions in the areas of development of climate generators, model development and evaluation, remote sensing research, and sediment source tracking. Most of the data sets from these watersheds were highlighted in a special issue of the Journal of Environmental Quality and are publicly available. Eight unit source (1.6 ha) watersheds were established at the GRL in 1979 for the purpose of studying the effects of crop, crop management, grazing, and grazing management on water quality and quantity. Research from these watersheds has contributed greatly to our understanding of the impacts of crop type and crop and animal management on soil erosion and water quality. However, these small watersheds do not completely capture the dynamics and processes unique to agricultural production on larger land units. Thus, ten 16 ha production-level (P-L) watersheds are being established at the GRL to study the impacts of crop and livestock production and conservation practice effects on the local water budget and on water quality. Data from the unit source and P-L watersheds will be used to address issues related to Southern Plains agriculture, help improve field-scale hydrologic models, and address components of both the Pasture and Cropland Conservation Effects Assessment Program.

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Mercury Fate, Transport, and Bioaccumulation in Wetland Influenced Ecosystems: Field Studies and Modeling

IMPACT OF BASIN SCALE AND TIME-WEIGHTED MERCURY METRICS ON INTRA-/INTER-BASIN MERCURY COMPARISONS

Paul Bradley, Mark E. Brigham[1]

Understanding anthropogenic and environmental controls on fluvial Mercury (Hg) bioaccumulation over global and national gradients can be challenging due to the need to integrate discrete-sample results from numerous small scale investigations. Two fundamental issues for such integrative Hg assessments are the wide range of basin scales for included studies and how well discrete samples capture the characteristically high temporal variability of fluvial biogeochemistry, seasonally and over shorter time spans.

To assess inter-comparability of fluvial Hg observations at substantially different scales, Hg concentrations, yields, and bivariate-relations were evaluated at nested-basin locations in the Edisto River, South Carolina and Hudson River, New York. Differences between scales were observed for filtered methylmercury (FMeHg) in the Edisto (attributed to wetland coverage differences) but not in the Hudson. Total mercury (THg) concentrations and bivariate-relationships did not vary substantially with scale in either basin. Results indicated that small (<80 km^2) basin studies provide a reasonable foundation for development of orders of magnitude up-scaled conceptual or numerical models for application at large-basin and regional scales with comparable landscape characteristics. Combined with the lack of significant correlation between study basin size and estimates of mean annual FMeHg concentration across a national gradient, these results indicate that differences in basin scale as such are not a primary concern when integrating individual study results over global and national gradients if geospatial measures of wetland coverage and stream connectivity are included.

The inability to use automated sampling procedures for ultra-clean MeHg sampling and the cost of MeHg analyses preclude continuous or near-continuous MeHg sampling and substantially limit the number of collected discrete MeHg water samples. Thus, the representativeness of discrete sampling regimes is a fundamental concern in fluvial environments, which typically exhibit much more spatial and temporal variability in Hg concentrations than do lacustrine systems. Consistent with numerous previous studies, fish Hg correlated strongly with sampled water FMeHg concentration ($\rho = 0.78$; $p = 0.003$). However, improved correlation ($\rho = 0.88$; $p < 0.0001$) was achieved with time-weighted mean annual FMeHg concentrations estimated from basin-specific LOADEST models and daily streamflow. The results of this study illustrated that continued optimization of numerical tools to interpolate Hg concentrations over select life-cycle time periods will improve our understanding of the linkages between fluvial Hg concentrations and bioaccumulation.

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WATERSHED CYCLING OF MERCURY AND CONTROLS ON METHYLMERCURY PRODUCTION IN NORTHERN MINNESOTA LANDSCAPES

Randy Kolka, Carl Mitchell, Ed Nater[1]

Mercury is the number one contaminant in surface waters of the U.S. because of health concerns for both humans and other animals when they consume fish. The form of mercury that bioaccumulates in the food chain is an organically complexed form known as methylmercury. Over the past 20 years we have conducted research to understand the mercury cycle in Northern Minnesota landscapes. Notable studies have characterized how both total mercury and methyl mercury cycles in peatland watersheds, the controls on the production of methylmercury, the effect of increasing sulfate deposition on mercury fluxes in both water and biota, and the influence of forest fire on mercury cycles. We will discuss these studies and summarize the current state of knowledge on mercury cycling in these landscapes.

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SENSITIVITY OF STREAM METHYL HG CONCENTRATIONS TO ENVIRONMENTAL CHANGE IN THE ADIRONDACK MOUNTAINS OF NEW YORK, USA

Doug Burns, Karen Riva Murray, Elizabeth A. Nystrom, David M. Wolock, Geofrey Millard, Charles T. Driscoll[1]

The Adirondacks of New York have high levels of mercury (Hg) bioaccumulation as demonstrated by a region-wide fish consumption advisory for children and women who may become pregnant. The source of this Hg is atmospheric deposition that originates from regional, continental, and global emissions. Soils in the region have large Hg stores equivalent to several decades of atmospheric deposition suggesting that the processes controlling Hg transport from soils to surface waters may greatly affect Hg concentrations and loads in surface waters. Furthermore, Hg can be converted to its neuro-toxic methyl form (MeHg), particularly in riparian and wetland soils where biogeochemical conditions favor net methylation. We measured MeHg concentrations during 33 months at Fishing Brook, a 65 km^2 catchment in the upper Hudson River basin in the Adirondacks. Seasonal variation in stream MeHg concentrations was more than tenfold, consistent with temperature-driven variation in net methylation rates in soils and sediment. These data also indicate greater than twofold annual variation in stream MeHg concentrations among the three monitored growing seasons. The driest growing season had the lowest MeHg concentrations, and these values were greater during the two wetter growing seasons. We hypothesize that contact of the riparian water table with abundant organic matter and MeHg stored in the shallowest soil horizons is a dominant control on MeHg transport to the stream. An empirical model was developed that accounted for 81 percent of the variation in stream MeHg concentrations. Water temperature and the length of time the simulated riparian water table remained in the shallow soil were key predictive variables, highlighting the sensitivity of MeHg to climatic variation. Future changes in other factors such as Hg emissions and deposition and acid deposition will likely also influence stream MeHg concentrations and loads. For example, lime application to an Adirondack stream to increase pH and enhance ecosystem recovery from acidification has increased MeHg concentrations, which may be associated with parallel increases in dissolved organic carbon concentrations. Future changes in the Hg cycle of this region will likely be complex, reflecting changes in climatic drivers and emissions of Hg and other air pollutants.

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OPTIMIZING FISH AND STREAM-WATER MERCURY METRICS FOR CALCULATION OF FISH BIOACCUMULATION FACTORS

Paul Bradley, Karen Riva Murray, Barbara C. Scudder Eikenberry, Christopher D. Knightes, Celeste A. Journey, Mark A. Brigham[1]

Mercury (Hg) bioaccumulation factors (BAFs; ratios of Hg in fish [Hgfish] and water [Hgwater]) are used to develop Total Maximum Daily Load and water quality criteria for Hg-impaired waters. Protection of wildlife and human health depends directly on the accuracy of site-specific estimates of Hgfish and Hgwater and the predictability of the relation between these parameters. BAF variability can be viewed as resulting from two conceptual drivers: 1) ecological variability (signal) due to ecosystem-specific differences in Hg uptake and accumulation and 2) methodological variability (noise). Thus, minimizing methodological variability in Hgfish (numerator) and Hgwater (denominator) estimates is critical to BAF-based Hg risk management.

Data collected by fixed protocol from 11 streams in 5 states distributed across the US were used to assess the effects of Hgfish normalization/standardization methods and fish sample numbers on BAF numerator estimates. Fish length, followed by weight, was most correlated to adult top-predator Hgfish. Site-specific BAFs based on length-normalized and standardized Hgfish estimates demonstrated up to 50 percent less variability than those based on non-normalized Hgfish. Permutation analysis indicated that length-normalized and standardized Hgfish estimates based on at least 8 trout or 5 bass resulted in mean Hgfish coefficients of variation less than 20 percent.

The influences of water sample timing, filtration, and mercury species on the modeled relation between game fish and water mercury concentrations were evaluated across the same 11 sites, in order to identify optimum Hgwater sampling approaches for BAF denominator estimation. Each model included fish trophic position, to account for a wide range of species collected among sites, and flow-weighted Hgwater estimates. Models based on methylmercury (filtered [FMeHg] or unfiltered) performed better than total mercury models. Models including mean annual FMeHg were superior to those with mean FMeHg calculated over shorter time periods throughout the year. FMeHg models including metrics of high concentrations (80th percentile and above) observed during the year performed better, in general. These higher concentrations occurred most often during the growing season at all sites.

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SIMULATING MERCURY AND METHYL MERCURY STREAM CONCENTRATIONS AT MULTIPLE SCALES IN A WETLAND INFLUENCED COASTAL PLAIN WATERSHED (McTIER CREEK, SC, USA)

Chris Knightes, G.M. Davis, H.E. Golden, P.A. Conrads, P.M. Bradley, C.A. Journey[1]

Mercury (Hg) is the toxicant responsible for the most fish advisories across the United States, with 1.1 million river miles under advisory. The processes governing fate, transport, and transformation of mercury in streams and rivers are not well understood, in large part, because these systems are intimately linked with their surrounding watersheds and are often highly spatially variable. In this study, we apply a linked watershed hydrology and biogeochemical cycling (N, C, and Hg) model (VELMA, Visualizing Ecosystems for Land Management Assessment) to simulate daily flow, fluxes, and soil and stream concentrations of total mercury (THg) and methyl mercury (MeHg) at multiple spatial scales in McTier Creek within the Edisto River basin. The Edisto River basin is in the Coastal Plain of South Carolina, USA, and is characterized by low stream-gradients and extensive riparian wetlands with some of the highest top predator fish tissue Hg concentrations in the USA. By linking hydrology with N, C, and Hg cycling, the VELMA model can capture the importance of hydrology in linking watershed and wetland Hg to the stream Hg concentrations as well as the importance of dissolved organic carbon in transport. In this study, we (1) used field study data to calibrate and simulate Hg fate and transport processes at a reach scale (0.1 km^2), (2) applied this calibrated parameter set at larger watershed scales including two headwater sub-watersheds (28 km^2 and 25 km^2) nested within the McTier Creek watershed (79 km^2), and (3) evaluated how accurate the reach-scale parameters and processes are when scaled up to larger scales. The results of the VELMA multi-scale simulations suggest that water column stream THg concentration predictions matched observations reasonably well at different scales using reach-scale calibrations, but the model simulations of MeHg stream concentrations at reach, sub-watershed, and watershed pour points are out-of-phase with observed MeHg concentrations. This result suggests that processes governing MeHg loading to the main channel may not be fully represented in the current model structure and underscores the complexity of simulating MeHg dynamics in watershed models as well as the need for a better understanding of processes governing methylation and MeHg transport. This work demonstrates the importance of hydrology in understanding Hg fate in watersheds and streams and the influence of out-of-channel versus in-channel processes.

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SCALING UP WATERSHED MODEL PARAMETERS—FLOW AND LOAD SIMULATIONS OF THE EDISTO RIVER BASIN

Toby Feaster, Stephen Benedict, Jimmy Clark, Paul Bradley, Paul Conrads[1]

The Edisto River is the longest and largest river system completely contained in South Carolina and is one of the longest free flowing blackwater rivers in the United States. The Edisto River basin also has fish-tissue mercury concentrations that are among the highest recorded in the United States. As part of an ongoing effort by the U.S. Geological Survey to expand the understanding of relations among hydrologic, geochemical, and ecological processes that affect fish-tissue mercury concentrations within the Edisto River basin, analyses and simulations of the hydrology of the Edisto River basin were made using the topography-based hydrological model (TOPMODEL). The potential for scaling up a previous application of TOPMODEL for the McTier Creek watershed, which is a small headwater catchment to the Edisto River basin, was assessed. Scaling up was done in a step-wise process beginning with applying the calibration parameters, meteorological data, and topographic wetness index data from the McTier Creek TOPMODEL to the Edisto River TOPMODEL. Additional changes were made with subsequent simulations culminating in the best simulation, which included meteorological and topographic wetness index data from the Edisto River basin and updated calibration parameters for some of the TOPMODEL calibration parameters. Comparison of goodness-of-fit statistics between measured and simulated daily mean streamflow for the two models showed that with calibration, the Edisto River TOPMODEL produced slightly better results than the McTier Creek model, despite the significant difference in the drainage-area size at the outlet locations for the two models (30.7 and 2,725 square miles, respectively). Along with the TOPMODEL hydrologic simulations, a visualization tool (the Edisto River Data Viewer) was developed to help assess trends and influencing variables in the stream ecosystem. Incorporated into the visualization tool were the water-quality load models TOPLOAD, TOPLOAD-H, and LOADEST. Because the focus of this investigation was on scaling up the models from McTier Creek, water-quality concentrations that were previously collected in the McTier Creek basin were used in the water-quality load models.

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EVALUATION OF MERCURY LOADS FROM CLIMATE CHANGE PROJECTIONS

Paul Conrads, Paul M. Bradley, Stephen T. Benedict, Toby D. Feaster[1]

McTier Creek is a small coastal plain watershed located in Aiken County, South Carolina. McTier Creek forms part of the headwaters for the Edisto River basin, which is noted for having some of the highest recorded fish-tissue mercury concentrations in the United States. A simple water-quality load model, TOPLOAD, which was developed for McTier Creek, utilizes a mass balance equation in conjunction with hydrologic simulations from the topography-based hydrological model - TOPMODEL. TOPLOAD is an effective tool for analyzing the relative flux contribution of the simulated surface and groundwater flow paths in TOPMODEL. Climate models for the Southeastern United States project increased temperatures across the region but also project differing precipitation results with some models indicating an increase in precipitation and some, a decrease. Climate models for the Southeast generally agree that the frequency and durations of droughts are likely to increase due to the higher temperature and resulting increases in evapotranspiration. To evaluate effect of projected climate change on flow paths for McTier Creek due to changes in hydrology, downscaled data from two global circulation models (GCM) for one emission scenario were used as inputs to TOPLOAD. One GCM, the Community Climate System Model (CCSM), projects an increase in total precipitation whereas the other GCM, ECHO (a hybrid of the European Center atmospheric GCM [ECHAM] and the Hamburg Primitive equation ocean GCM [HOPE]), projects no significant change in total precipitation. Both models project changes in precipitation intensity and duration. The relative changes in the total mercury flux contributions for the flow paths in TOPLOAD for each GCM and the management implications will be given in this presentation.

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CLIMATE CHANGE AND WATERSHED MERCURY EXPORT IN A COASTAL PLAIN WATERSHED

Heather Golden, Christopher D. Knightes, Paul A. Conrads, Toby D. Feaster, Gary M. Davis, Stephen T. Benedict, Paul M. Bradley[1]

Future changes in climatic conditions may affect variations in watershed processes (e.g., hydrological, biogeochemical) and surface water quality across a wide range of physiographic provinces, ecosystems, and spatial scales. How such climatic shifts will impact watershed mercury (Hg) dynamics and hydrologically-driven Hg transport is a significant concern. We apply an ensemble of watershed models to simulate watershed hydrological and total Hg (HgT) fluxes from the landscape to the watershed outlet (i.e., HgT export) and water column HgT concentrations in response to a set of statistically-downscaled climate change projections in a Coastal Plain watershed. Three watershed models are used to quantify and bracket potential changes in hydrologic and HgT export, including the Visualizing Ecosystems for Land Management Assessment Model for Hg (VELMA-Hg), the Grid Based Mercury Model (GBMM), and TOPLOAD, a water quality constituent model linked to TOPMODEL hydrological simulations. Based on downscaled estimates from two global circulation models (i.e., ECHO, which represents dry future conditions for the region, and CCSM3, which reflects wet future conditions) we estimate a 19 percent decrease in average annual watershed HgT export in response to climate change using the ECHO projections and a 5 percent increase with the CCSM3 projections in the study watershed. Average monthly watershed HgT export increases using both climate change projections in the late spring (March through May), when HgT concentrations and streamflow are high. Results suggest that hydrological transport associated with changes in precipitation and temperature is the primary mechanism driving HgT export response to climate change. Our ensemble watershed model approach highlights the uncertainty associated with projecting climate change responses – both hydrologically and biogeochemically – and the use of such projections in future watershed management and planning efforts.

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Water Quality

(PART 1)

THE USE OF ACOUSTIC DOPPLER METERS TO ESTIMATE SEDIMENT AND NUTRIENT CONCENTRATIONS IN FRESHWATER INFLOWS TO TEXAS COASTAL ECOSYSTEMS

Zulimar Lucena, Michael Lee[1]

Excessive sediment and nutrient loading are among the leading causes of impairment in water bodies of the United States due to their effect on biologic productivity, water quality, and aquatic food webs. Understanding the nutrient and suspended sediment loads affecting estuarine waters is fundamental to the assessment of the physical, chemical, and biological processes governing the aquatic system and essential for establishing watershed management strategies. The need to effectively estimate sediment and nutrient loads into coastal ecosystems and reservoirs highlights the importance of developing methods for monitoring these constituents. One technique to determine suspended sediment concentrations involves the use of acoustic Doppler meters. The acoustic Doppler meters are primarily used to measure water velocity using the Doppler principle, but also output a return pulse strength indicator called backscatter. These backscatter data can serve as an explanatory variable for developing regression model estimates of sediment and nutrients when related to discrete measurements of these constituents collected over the discharge range of the river. In this manner, the backscatter signal from these instruments may serve as a surrogate for these constituents in some environments and provide a continuous estimate of in situ concentrations. In Texas, the U.S. Geologic Survey, in cooperation with the Texas Water Development Board and the Galveston Bay Estuary Program, have installed acoustic Doppler meters on the lower reaches of the Trinity River going into Trinity Bay, on the Guadalupe River going into San Antonio Bay, and the Colorado River going into Matagorda Bay. Surrogate models between backscatter and nutrient and suspended sediment concentrations are being evaluated in these systems. The Surrogate Analysis and Index Developer Tool (SAID), developed by the USGS, is being used to process acoustic parameters as predictor variables of sediment and nutrient concentrations and assist in the creation of regression models while providing visual and quantitative diagnostics. These models can enhance our limited understanding of inflow contributions to the coastal waters of Texas, particularly during high flow periods when substantial pulses of sediment and nutrients have the potential of affecting the aquatic ecosystem. Improved methods for determining freshwater inflow contributions of discharge, sediment, and nutrients may be useful for inclusion in hydrodynamic and water quality models and may help fill a data gap of the volume of freshwater inflow entering Texas coastal ecosystems.

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FUSING LONG-TERM, HISTORICAL, AND HIGH-RESOLUTION DATA TO INFORM ESTIMATES OF WATERSHED-SCALE NITROGEN RETENTION

Jonathan Duncan, Lawrence Band[1]

Closing watershed nitrogen budgets is difficult because inputs typically far exceed outputs. A leading hypothesis to explain this discrepancy is that retention is poorly constrained because a disproportionate amount of denitrification occurs in small portions of the landscape (hot spots) during brief hydrologic conditions (hot moments). Many measurement and modeling frameworks under-sample denitrification and transport associated with these hot spots and hot moments. Significant progress in closing a watershed nitrogen budget requires combining a suite of sensors to capture spatial and temporal heterogeneity of nitrogen dynamics. Long-term weekly sampling of stream chemistry at Pond Branch, MD USA, a 37 ha forested watershed in the Piedmont physiographic province, has revealed recurrent summer peaks in nitrate concentrations and loads. A high-frequency in-stream in situ nitrate sensor has revealed that concentration-discharge dynamics of diel and storm events are different from those calculated using weekly data. Statistical calculations of nitrogen export and concentration-discharge analyses yield important insights into biological vs. hydrologic mechanisms of retention. Resolving denitrification in soils requires mapping spatial heterogeneity with high-resolution topographic data derived from LiDAR. A combination of soil oxygen probes and soil core measurements is required to estimate denitrification from watershed soils. Riparian microtopography in Pond Branch has been shown to be an important control in watershed scale denitrification. Enhanced consideration of the hydrogeomorphic template of watersheds to predict the location and importance of biogeochemical hotspots ultimately requires understanding their genesis. In Pond Branch, a fuller understanding of historical land use change and the corresponding geomorphic changes is important to help constrain our interpretation of landscape form and biogeochemical function. Fusing long-term, historical, and spatiotemporal sensor data is required for moving towards closing the watershed nitrogen budget.

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COMPARING NUTRIENT EXPORT FROM FIRST, SECOND, AND THIRD ORDER WATERSHEDS IN THE SOUTH CAROLINA ATLANTIC COASTAL PLAIN

Augustine Muwamba, Devendra M. Amatya, Carl C. Trettin, and James B. Glover[1]

Abstract—Monitoring of stream water chemistry in forested watersheds provides information to environmental scientists that relate management operations to hydrologic and biogeochemical processes. We used data for the first order watershed, WS80, and second order watershed, WS79, at Santee Experimental Forest. We also used data from a third order watershed, WS78, to identify the differences in temporal changes of stream water chemistry from 2006 to 2012. Phosphate concentrations for WS80 and WS79 decreased from 2006 to 2012. Most of the nitrogen (N) component was dominated by organic N and the watershed that registered highest organic N also registered highest total N concentration. Phosphate and N concentrations for all watersheds varied with rainfall received in the area. The annual mean pH of all watersheds significantly increased with stream conductivity ($p < 0.05$). The differences in fluctuations of observed annual stream water nutrient concentrations for all watersheds may provide a basis for nutrient availability for aquatic responses.

INTRODUCTION

The stream water chemistry at Santee Experimental Forest in South Carolina is routinely monitored for environmental assessment records, and data can be used by researchers to identify potential impacts of burning, land uses, and weather changes on water quality. Richter and others (1983) reported that most of the nitrogen (N) for Santee Forest is in organic form and that phosphate and potassium (K) concentrations were mostly from soil derived particulates for data collected from 1976 to 1979. Wilson and others (2006) also reported higher organic N than inorganic N when analyzing data for the periods of 1976-1981 and 1989-1994. The organic N concentration contributed most to total nitrogen (TN) of Turkey Creek (third order watershed) for 2006-2008 (Amatya and others 2009). Amatya and others (2009) also reported an inverse relationship between dissolved oxygen and stream temperature for Turkey Creek. Ammonium nitrogen and phosphate concentrations decreased with flow and the greatest portion of stream water TN concentration was organic N for the two first order watersheds in Coastal North Carolina (Amatya and others 2006, 2007). Lu and others (2005) also documented that variation in flow and rainfall lead to variation in stream nutrient concentrations. Other factors that can lead to variation in stream water chemistry of watersheds are seasonal temperature variation, spatial and temporal variations of land use, vegetation cover and silivicultural management practices (Lu and others 2005). The fact that fertilizers are not applied to Santee Experimental Forest, nutrient concentrations are hypothesized to decrease with plant age due to increasing plant uptake and fluctuate with flow. Therefore, studying the temporal changes of N components (NH_4-N, NO_3-N, TKN, organic N, and inorganic N) and phosphorus (P) within each watershed and among watersheds is very important for nutrient availability and stream water quality assessment.

The data reported were collected from three watersheds: a first order watershed (WS 80), a second order watershed (WS79), and a third order watershed (WS78) of drainage areas of 160 ha, 500 ha, and 5,240 ha, respectively. WS79 is comprised of two first order watersheds, the relatively undisturbed (WS80) as a control and a treatment (WS77) that is subjected to prescribed burning, and a small area in between. The objective was to compare N and P concentrations among the first order (WS80), second order (WS79), and third order (WS78) watersheds for a period of 2006-2012. Other physical and chemical parameters compared were stream temperature, pH, specific conductance, and dissolved oxygen (DO) concentration.

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MATERIALS AND METHODS

First (WS80), Second (WS79), and Third (WS78) Order Watersheds

The site for the watersheds is located in the South Carolina coastal plain (33.15° N and 79.8° W). Established in 1968, WS80 is a mosaic of upland (70 percent) and wetland (30 percent) forests with an area of 160 ha and drains the first order streams to Turkey Creek. Soils for WS80 are classified as somewhat poorly to poorly drained (SCS 1980). Loblolly pine and hardwoods currently predominate WS 80. The elevations range from 4 to 6 m with 0 to 3 percent slope for WS80. The weather parameters reported by Harder and others (2007) included a mean annual temperature of 18.3^{0}C and average annual precipitation of 1370 mm. Other authors have documented the site's hydrologic changes and water quality (Sun and others 2000, Amatya and others 2003, 2006, 2007). WS79 (mosaic upland (75 percent) and wetland (25 percent) forests) is a second order watershed with a drainage area of 500 ha formed by streams from two first order watersheds, WS80 (160 ha) and WS77 (155 ha). WS77 is dominated by loblolly pine and subjected to prescribed burning. The third order watershed, WS78 is a mosaic upland (90 percent) and wetland (10 percent) forest, and has a drainage area of 5240 ha. The elevation of WS78 ranges from 3.6 m at the stream gauging station to 14 m above mean sea level. WS78 soils consist of poorly drained soils of Wahee (clayey, mixed, thermic *Aeric Ochraquults*) and Lenoir (clayey, mixed, *Thermic Aeric Paleaquults*) series (SCS 1980) and small areas of somewhat poorly and moderately well drained sandy and loamy soils. The greatest land use within the watershed is loblolly pine (*Pinus taeda* L.) and long leaf pine (*Pinus palustris*) forest. Other land uses of WS78 include forested wetland and hardwood and crop lands, roads and open areas (Amatya and others 2009). Details, uses and weather parameters measured at WS78 were documented by Amatya and others (2009). Figure 1 shows the location map for WS80, WS79, and WS78. Other details of the watersheds are posted on the website, http://cybergis.uncc.edu/santee/waterQualityPage.php.

Water Quality Monitoring and Analysis

Grab samples were collected weekly, or more frequently depending upon the storm size, and analyzed for N (NH_4-N, NO_3-N, and total N) and P (in the form of phosphate) from 2006 to 2012. Amatya and others (2007) described the details of water quality monitoring and analysis. Bottles with samples preserved were frozen until the sample analysis at the Soil Chemistry Laboratory in Charleston, South Carolina. The parameters of stream temperature, pH, specific conductance, and dissolved oxygen (DO) concentration were also determined as a function of time. Water samples at the watershed outlets were collected using an ISCO 3700 sampler. Ammonium nitrogen in water was analyzed by QuikChem© Method, Flow Injection Analysis Calorimetry. Nitrate-nitrite was determined by the QuikChem© Method 10-107-04-1, Flow Injection Analysis. Total N was determined by

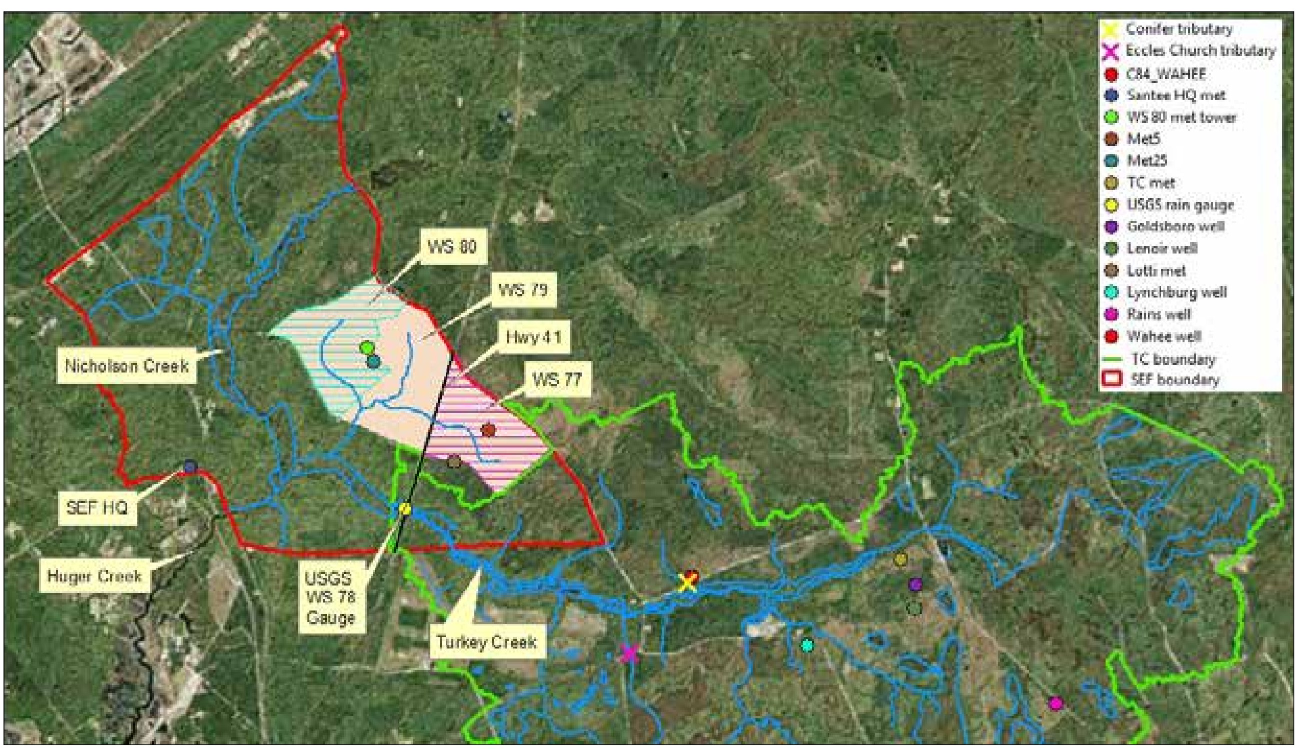

Figure 1—Location map of watersheds WS80, WS79, and WS78 (from Amatya and others 2015).

QuikChem© Method 10-107-04-3-B, In-Line Digestion Followed by Flow Injection Analysis). The detection limits for NH_4-N, NO_3-N, and total N were all 0.01 mg L^{-1}. Dissolved inorganic nitrogen (DIN) was calculated as a sum of NH_4-N and NO_3-N, and DON was calculated as total N minus DIN. Phosphate was determined by Micro-membrane Suppressed Ion Chromatography. Details of water quality monitoring and analysis are also posted on the website, http://cybergis.uncc.edu/santee/waterQualityPage.php, under metadata.

RESULTS AND DISCUSSION

Temporal Changes of pH, Stream Conductivity, Dissolved Oxygen, and Temperature

Table 1 shows the annual mean and ranges for pH, stream conductivity, dissolved oxygen, and temperature. The annual mean pH followed the trend WS80>WS78>WS79 except for 2008 and 2010. WS80 registered the highest conductivity compared to WS79 and WS78 from 2006 to 2012. WS78 recorded the highest DO concentration from 2006-2012; the DO concentration trend was WS78 > WS80 > WS79. There were no significant differences in stream temperatures between watersheds ($p > 0.05$). A positive correlation between annual mean pH and stream conductivity ($p < 0.05$) for all watersheds was recorded. Annual mean stream conductivity of WS79 and WS78 significantly increased with stream temperature ($p < 0.05$). Annual mean dissolved oxygen significantly increased with a decrease in temperature for WS78 ($p < 0.05$).

We found an inverse relationship of DO concentrations with the water temperature for 2006 to 2008, with high values during the cold winter (maximum of 14.3 mg L^{-1} in January 2007) and lower values (lowest of 1.36 mg L^{-1} in June 2006) during the hot summer months, with an average of 6.1 mg L^{-1} for WS78 (Amatya and others 2009). The pH levels and DO concentrations for watersheds were partly attributed to natural conditions and swamp conditions by Lebo and others (2000). The interactions of parameters could be attributed to varying sizes of the watersheds, seasonal variations in flows and rainfall, variation in land uses, and vegetation growth patterns (Lu and others 2005).

Temporal Changes of Nitrogen and Phosphorus

Figures 2 to 7 show changes of annual mean N and phosphate concentrations from 2006 to 2012 for all watersheds. The decreasing concentration trend with increased rain was more pronounced with phosphate than N. The annual rain received in the area was 1264, 1041, 1521, 1458, 1380, 959, and 1117 mm in 2006, 2007, 2008, 2009, 2010, 2011, and 2012, respectively. For all watersheds, organic N was higher than inorganic N (Fig. 4 and 5). The watersheds that registered highest organic N also registered highest total N (Fig. 5 and 6). Except for 2006 and 2010, total N was highest for WS80 than WS78 and WS79. Watersheds 80 and WS78 registered a systematic decrease in phosphate concentrations from 2008 to 2012 unlike WS79. Ammonium nitrogen concentrations for WS78 were higher than NO_3-N from 2006 to 2012. Ammonium nitrogen, NO_3-N, total N, and phosphate maximum concentrations (mg L^{-1}) for WS80 were 1.07, 0.16, 2.05, and 0.58, respectively for the period 2006 to 2012. For WS79, the maximum NH_4-N, NO_3-N, total N, and phosphate concentrations (mg L^{-1}) recorded were 1.47, 0.05, 2.80, and 0.07, respectively. The maximum NH_4-N, NO_3-N, total N, and phosphate concentrations (mg L^{-1}) recorded for WS78 were 0.33, 0.23, 1.93, and 0.30,

Table 1—Annual mean of physical and chemical parameters for WS80, WS79, and WS78 with ranges in parentheses

		2006	2007	2008	2009	2010	2011	2012
pH	WS80	6.7(5.8-8.8)	7.8(6.9-8.4)	8.5(8.1-9.5)	6.0(5.5-6.3)	6.4(5.9-7.2)	6.0(5.3-6.2)	5.9(4.8-6.4)
	WS79	6.4(5.5-7.5)	7.5(6.1-8.3)	8.0(7.4-8.6)	NA	6.2(5.6-7.1)	5.7(5.5-6.2)	5.7(4.9-6.2)
	WS78	6.6(5.8-7.3)	7.6(5.7-8.8)	6.9(5.4-8.7)	NA	6.0(5.0-7.7)	5.9(4.9-6.4)	5.8(4.9-6.6)
Conduct. (microS/cm)	WS80	0.2(0.1-0.5)	0.3(0.1-0.5)	0.2(0. 1-0.4)	0.1(0.07-0.2)	0.10(0.06-0.2)	0.1(0.06-0.2)	0.12(0.07-0.2)
	WS79	0.2(0.1-0.3)	0.2(0.1-0.3)	0.16(0.1-0.2)	NA	0.08(0.06-0.1)	0.08(0.06-0.1)	0.07(0.06-0.1)
	WS78	0.2(0.1-0.4)	0.2(0.1-0.3)	0.1(0.01-0.3)	NA	0.05(0.01-0.1)	0.08(0.05-0.1)	0.08(0.07-0.1)
DO (mg L^{-1})	WS80	3.3(0.4-8.8)	4.4(1.6-11.2)	4.5(2.0-7.8)	3.5(0.8-8.1)	4.6(2.0-8.8)	3.2(1.2-6.3)	4.2(1.4-7.9)
	WS79	2.9(0.3-8.8)	3.9(0.9-12.4)	5.8(1.7-10.0)	NA	4.6(1.4-10.2)	2.5(0.7-7.7)	2.8 (1.0-5.9)
	WS78	5.1(1.4-11)	5.7(1.4-14.3)	6.7(1.6-12.0)	NA	7.5(1.6-12.9)	4.5(0.9-8.8)	4.9(0.9-11.2)
Temp. (^{0}C)	WS80	20(6.4-29)	18.4(5.8-30.2)	13.4(6.0-21.0)	11.7(7.4-14.3)	13.7(4.4-27.2)	18.6(8.1-27.7)	17.0(4.7-26.1)
	WS79	20(6.6-27)	18(5.6-29.7)	12.9(4.8-20.5)	NA	13.6(4.8-26.7)	16.8(5.5-27.3)	16.6(5.1-25.7)
	WS78	20(6.8-28)	18.6(5.6-29.6)	17.8(4.6-26.2)	NA	12.3(3.7-27.3)	19.5(8.8-27.7)	16.7(4.4-26.8)

DO = Dissolved oxygen, Conduct. = Stream conductivity, Temp. = Temperature, NA = Data not available respectively. The NO_3-N concentrations for all watersheds from 2006 to 2012 did not exceed drinking water standard value, 10 mg L^{-1}, reported by USEPA (2000).

Nitrogen and phosphate concentrations varied with rain received with years receiving highest rainfall registering lower concentrations, and this was attributed to dilution effects. The dilution effects due to increasing flow volumes on nutrients have been reported by Lynch and Corbett (1990). Differences in flush effects after dry periods of the year could also lead to variability within and between annual mean nutrient concentrations. Elevated nutrient concentrations soon after long dry periods were associated with flush effects (Amatya and others 1998, 2009). The systematic decrease in inorganic N and phosphate from 2006 to 2012 for WS80 was attributed to increased uptake since the site was undisturbed. The annual mean phosphate concentrations for WS80 were greater than WS79 concentrations probably due to lower flow for WS80 than WS79. Since WS77 and WS80 drain to form WS79, and WS77 has been reported to register higher flow than WS80 (Amatya and others 2006, 2007) due to greater slope and periodic prescribed burning that reduces vegetation cover on WS77, greater organic N and phosphate concentrations were recorded for WS80. Plants might have preferred inorganic N than organic N and since no inorganic fertilizers were applied to WS80, greater organic N than inorganic N was recorded for the watersheds. Amatya and others (2009) also reported higher NH_4-N concentration than NO_3-N for WS78 when analyzing data for the period, 2006 to 2008. Wilson and others (2006) also reported

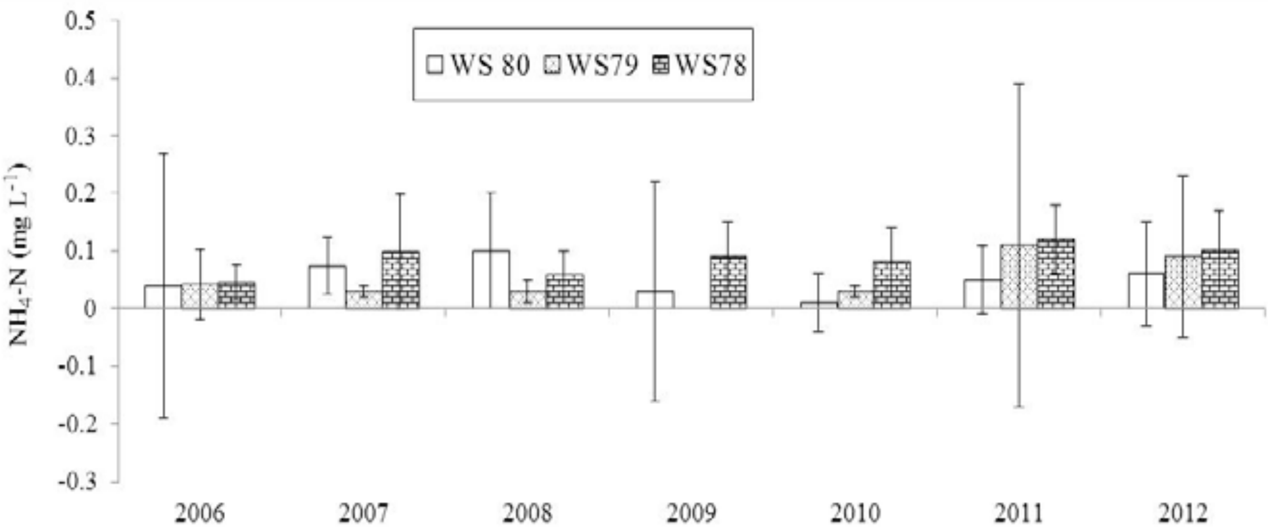

Figure 2—Annual mean ammonium nitrogen concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78). Bars represent standard deviations of the mean.

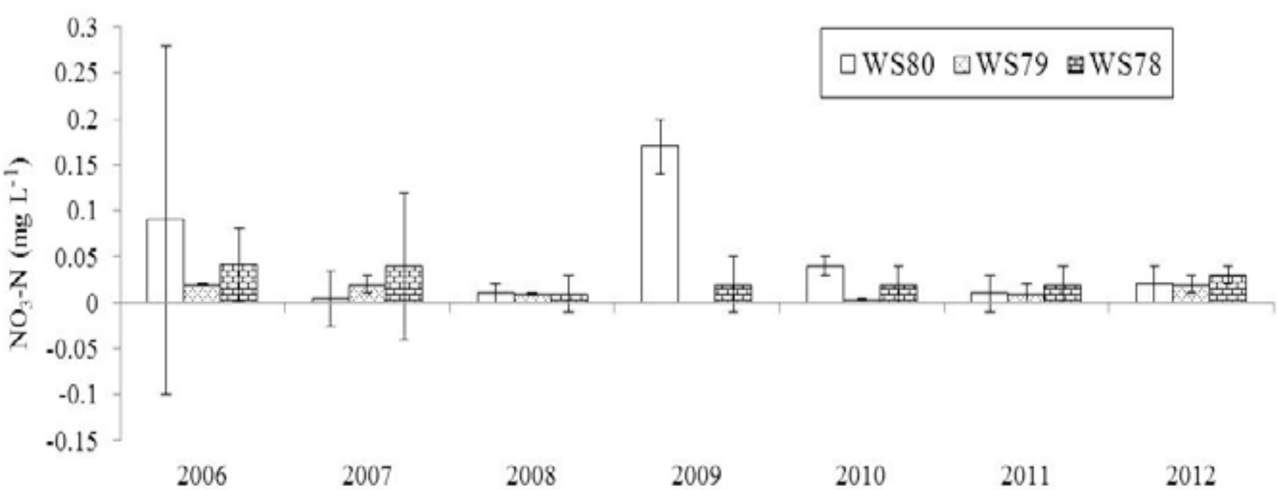

Figure 3—Annual mean nitrate nitrogen concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78). Bars represent standard deviations of the mean.

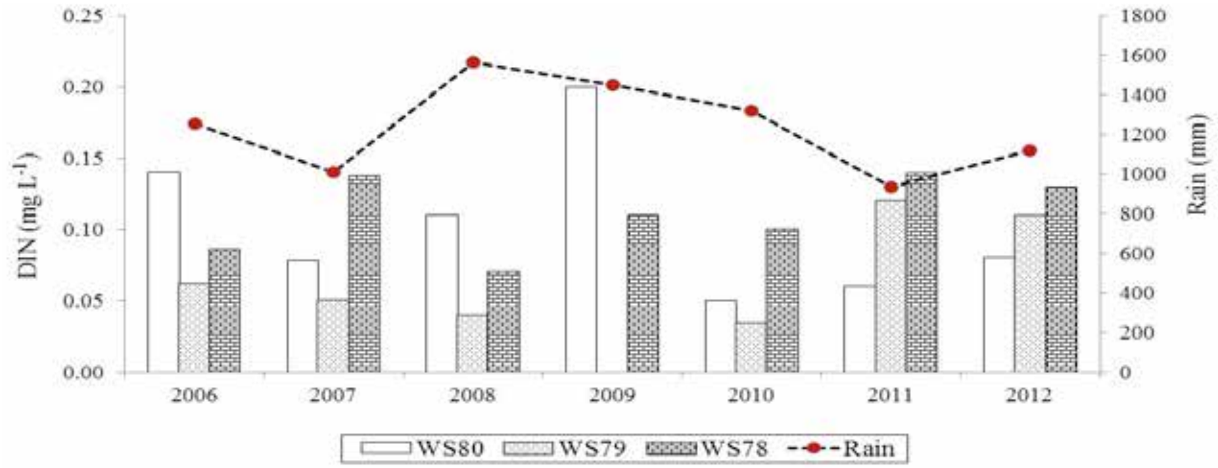

Figure 4—Annual mean dissolved inorganic nitrogen concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78).

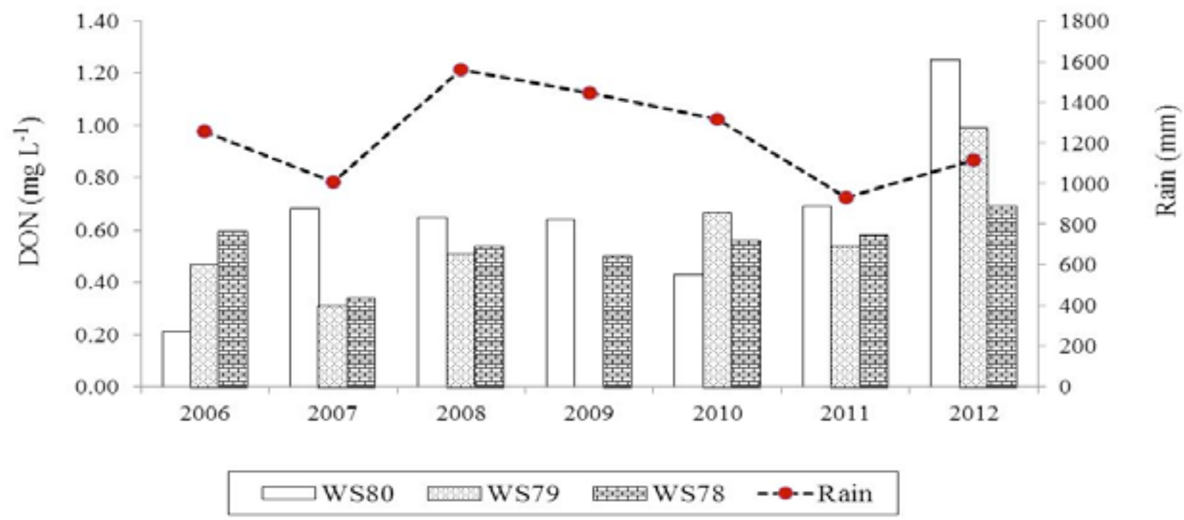

Figure 5—Annual mean dissolved organic nitrogen concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78)

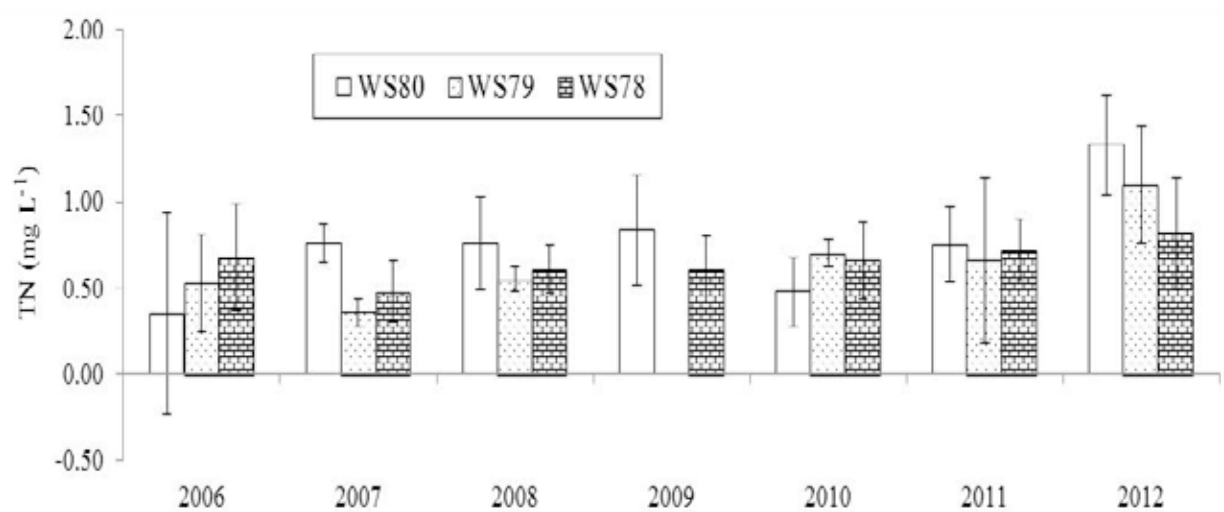

Figure 6—Annual mean total nitrogen concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78). Bars represent standard deviations of the mean.

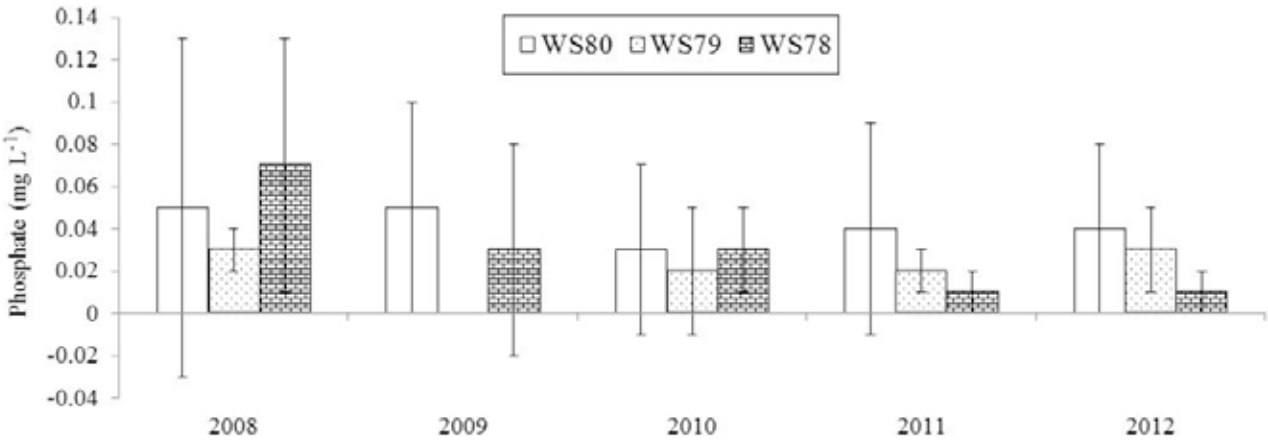

Figure 7—Annual mean phosphate concentration as a function of time for a first order (WS80), second order (WS79), and third order watershed (WS78). Bars represent standard deviations of the mean.

greater organic N than inorganic N with historical data. Other probable reasons for variabilities in nutrient concentrations among watersheds could be differences in watershed drainage areas, land uses, vegetation types, and plant uptake. For example, Lu and others (2005) reported that small scale watersheds have greater heterogeneity than large scale watersheds.

CONCLUSIONS

Variations in N and P concentrations and pH, DO, conductivity, and stream temperature from 2006 to 2012 for all watersheds were likely influenced by rainfall received, differences in plant nutrient uptake, constituents (vegetation type and cover), differences in land uses, and watershed areas. The dominant N component for all watersheds was organic N and the watershed that had the highest DON also registered the highest total N. Phosphate concentration showed a systematic decreasing trend from 2006 to 2012 for WS80 and WS78.

ACKNOWLEDGMENTS

We extend our appreciation to USDA Forest Service Southern Research Station for providing data and funds that facilitated the project.

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QUANTIFYING IN-STREAM NITRATE REACTION RATES USING CONTINUOUSLY-COLLECTED WATER QUALITY DATA

Matthew Miller, Anthony Tesoriero, Paul Capel[1]

High frequency in situ nitrate data from three streams of varying hydrologic condition, land use, and watershed size were used to quantify the mass loading of nitrate to streams from two sources – groundwater discharge and event flow – at a daily time step for one year. These estimated loadings were used to quantify temporally-variable in-stream nitrate processing rates. Nitrate in groundwater discharge was identified as contributing approximately 70 percent of the total nitrate load to a large river and small agricultural stream, compared with 45 percent to a small urban stream. The greatest in-stream losses of nitrate occurred during the summer and fall months, with net in-stream losses of up to 70 percent of total nitrate load in the large river, 60 percent in the agricultural stream, and 50 percent in the urban stream. Stream discharge and nitrate concentrations were inversely correlated with nitrate loss rates; whereas temperature and photosynthetically active radiation were positively correlated with loss. This study demonstrates a new approach for interpreting high frequency nitrate data that may be applied in other stream ecosystems to quantify temporal variability in nitrate source loading and rates of in-stream processing. These source and rate estimates can in turn be used to improve predictive models of nitrate transport and potentially inform efforts to reduce nutrient loads to streams and coastal environments.

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A WATERSHED-SCALE CHARACTERIZATION OF DISSOLVED ORGANIC CARBON AND NUTRIENTS ON THE SOUTH CAROLINA COASTAL PLAIN

Daniel Tufford, Setsen Altan-Ochir[1]

Dissolved organic matter (DOM) is recognized as a major component in the global carbon cycle and is an important driver of numerous biogeochemical processes in aquatic ecosystems, both in-stream and downstream in estuaries. This study sought to characterize chromophoric DOM (CDOM), dissolved organic carbon (DOC), and dissolved nutrients in major rivers and their tributaries of the South Carolina Coastal Plain to assess the impact of land cover, soils, and other factors on water quality. During eight trips from June 11 to July 9 of 2014 throughout the South Carolina Coastal Plain, we visited 54 sites, where we measured field parameters (temperature, dissolved oxygen, pH, and specific conductance) and collected water samples for laboratory analysis of DOM ultraviolet absorbance and concentrations of DOC and dissolved nutrient. Sample sites included headwater wetlands and springs, streams and rivers, and water table monitoring wells. Spectral analysis of the filtered water samples was done from 200-800 nm using a Shimadzu UV-1700 spectrophotometer. We calculated absorption coefficients, spectral slope coefficients, and related metrics to facilitate broad characterizations of the nature of the CDOM in the water based on source and other landscape factors. We performed principle components analysis (PCA) to further understand variability in the data from a landscape perspective. The highest concentrations of CDOM occurred in black waters and in smaller streams and rivers. There were significant differences in spectral ratios, DOC concentration, and pH among the different water types and stream orders. PCA showed that DOC in black water is strongly associated with the occurrence of wetlands. Land cover associations were more variable in brown and clear water. DOC concentration in blackwater streams was higher in the lower Coastal Plain than in the upper Coastal Plain. This presentation will discuss these and other results of dissolved nutrient analysis and the context within the understanding of Coastal Plain ecological linkages with coastal estuaries.

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Water Responses to Management and Restoration

EVALUATING HYDROLOGICAL RESPONSE OF FUTURE LAND COVER CHANGE SCENARIOS IN THE SAN PEDRO RIVER (U.S./MEXICO) WITH THE AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT (AGWA) TOOL

William G. Kepner, I. Shea Burns, David C. Goodrich, D. Phillip Guertin, Gabriel S. Sidman, Lainie R. Levick, Wilson W.S. Yee, Melissa M.A. Scianni, Clifton S. Meek, Jared B. Vollmer[1]

Abstract—Long-term land-use and land cover change and their associated impacts pose critical challenges to sustaining vital hydrological ecosystem services for future generations. In this study, a methodology was developed to characterize potential hydrologic impacts from future urban growth through time. Future growth is represented by housing density maps generated in decadal intervals from 2010 to 2100, produced by the U.S. Environmental Protection Agency (EPA) Integrated Climate and Land-Use Scenarios (ICLUS) database. ICLUS developed future housing density maps by adapting the Intergovernmental Panel on Climate Change (IPCC) social, economic, and demographic storylines to the conterminous United States. To characterize hydrologic impacts from future growth, the housing density maps were reclassified to National Land Cover Database 2006 land cover classes and used to parameterize the Soil and Water Assessment Tool (SWAT) using the Automated Geospatial Watershed Assessment (AGWA) modeling system.

INTRODUCTION

Scenario analysis provides the capability to explore pathways of change that diverge from baseline conditions and lead to plausible future states or events. Scenario analysis has been used in studies related to environmental decision support to assist in evaluating policy or management options, such as in the Colorado River Basin (USDI 2012). Most approaches are designed to analyze alternative futures related to decision options, potential impacts and benefits, long-term risks, and management opportunities (Steinitz and others 2003, Kepner and others 2012, March and others 2012). The technique provides a dynamic and flexible way to evaluate policy or management options and is frequently combined with process modeling intended to bridge the gap between science and decision making across a broad range of spatial and temporal scales (Liu and others 2008a and 2008b, Mahmoud and others 2009).

The objective of this study is to develop and demonstrate a methodology to integrate a widely used watershed modeling tool with an internally consistent national database of alternative futures which can then be scaled to regional watershed applications. The focus of the study is to explore cumulative impacts of housing densities parsed out at decadal intervals to the year 2100 on a hydrological ecosystem consisting primarily of ephemeral and intermittent waters.

Ephemeral waters are extremely important in the arid west as a key source of groundwater recharge (Goodrich and others 2004). They provide important near channel alluvial aquifer recharge to support aquatic ecosystems in downstream perennial and intermittent streams (Baille and others 2007) and also provide critical ecosystem services (Levick and others 2008). Based on the National Hydrography Dataset; 94, 89, 88, and 79 percent of the

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streams in Arizona, Nevada, New Mexico, and Utah, respectively, are intermittent or ephemeral (Alexander and others 2015).

For the purpose of this study, the results are restricted to the San Pedro River, U.S./Mexico (Fig. 1). The intent is to quantitatively evaluate hydrologic impacts of future developments at the basin scale, which intrinsically addresses the cumulative impact of multiple housing development projects. The study area encompasses the Arizona portion of the watershed (9,800 km^2). The San Pedro River flows 230 km from its headwaters in Sonora, Mexico to its confluence with the Gila River near the stream gage (USGS 09473500) at Winkelman, AZ. It is nationally known as one of the last free-flowing rivers in the Southwest. It has significant ecological value, supporting one of the highest numbers of mammal species in the world and providing crucial habitat and a migration corridor to several hundred bird species. Vegetation ranges from primarily semi-desert grassland and Chihuahuan desert scrub in the Upper San Pedro to primarily Sonoran desert scrub and semi-desert grassland in the Lower San Pedro. The Upper San Pedro is home to the San Pedro Riparian National Conservation Area (SPRNCA). It was designated as the first National Conservation Area for riparian protection by Congress in 1988. The SPRNCA protects approximately 64 km of river and is administered by the U.S. Department of the Interior, Bureau of Land Management (Kepner and others 2004, Bagstad and others 2012).

METHODS

The Automated Geospatial Watershed Assessment (AGWA; Miller and others 2007; http://www2.epa.gov/water-research/automated-geospatial-watershed-assessment-tool and http://www.tucson.ars.ag.gov/agwa) tool is the key hydrological modeling system utilized in this study to identify areas that are most sensitive to environmental degradation as well as areas of potential

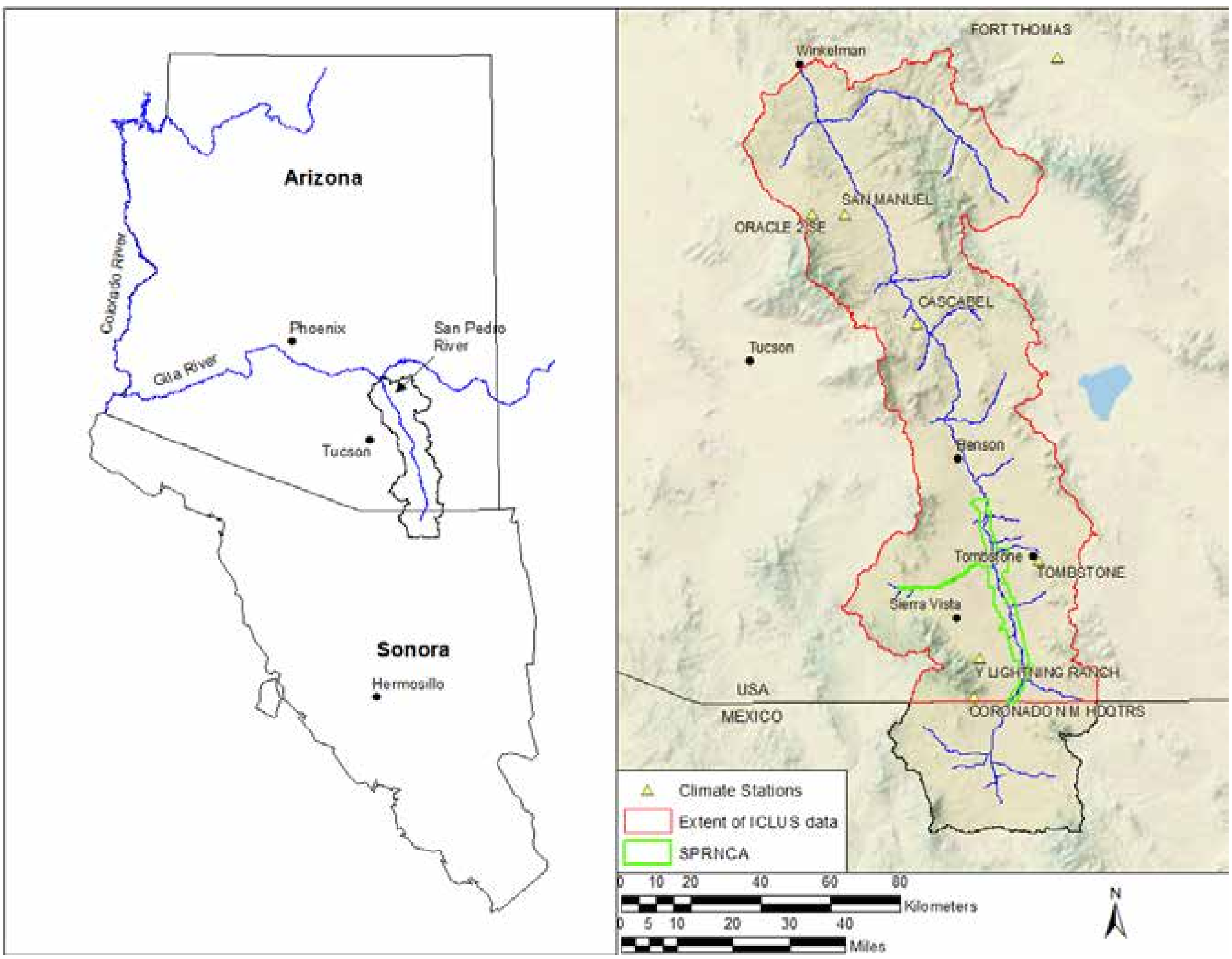

Figure 1—Location Map of the Study Area Contrasting the Extent of the ICLUS Data Used in the Future Scenarios to the San Pedro Watershed.

mitigation or enhancement opportunities, and thus inform restoration, permitting, and water management strategies. AGWA is recognized as one of the world's primary watershed modeling systems (Daniel and others 2011) providing the utility to generate hydrologic responses at the subwatershed scale and spatially visualize results for qualitative comparisons.

The AGWA tool was used to model the San Pedro Watershed with the SWAT model. The AGWA tool is a user interface and framework that couples two watershed-scale hydrologic models, the KINematic Runoff and EROSion model (KINEROS2; Semmens and others 2008) and the Soil and Water Assessment Tool (Arnold and others 1994), within a geographic information system (GIS). The coupling of hydrologic models and GIS within the AGWA tool performs model parameterization, execution, and watershed assessment at multiple temporal and spatial scales, and visualization of model simulation results. Current outputs generated through use of the AGWA tool are runoff (volumes and peaks) and sediment yield, plus nitrogen and phosphorus with the SWAT model. Simulations were parameterized using a 10m digital elevation model (DEM) and derived flow direction and accumulation, modified State Soil Geographic (STATSGO) soils, seven precipitation stations, and the 10 land cover datasets produced by combining the National Land Cover Database/North American Landscape Characterization Project (NLCD/NALC) digital land cover datasets with the decadal ICLUS datasets.

The approach is a multi-step process. First, the watershed border is defined to ensure that data are obtained for the entire study area. Digital land cover data is converted into a format compatible with AGWA and reflecting the available scenario options into the future. Next, soils and precipitation data for the study area are located and extracted. Finally, AGWA is used to delineate subwatersheds as comparative units and parameterize and run the Soil and Water Assessment Tool (Neitsch and others 2002; Srinivasan and Arnold 1994) for the baseline condition and future land cover/use scenarios. The Integrated Climate and Land-Use Scenarios (ICLUS; Bierwagen and others 2010; EPA, 2009; EPA, 2010) project data were identified as an ideal dataset for projecting basin-wide development into the future. The ICLUS national-scale housing-density (HD) scenarios are consistent with the Intergovernmental Panel on Climate Change (IPCC 2001) Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000) greenhouse gas emissions storylines and they are available in 10-year increments until 2100.

To define the project extent, the project watershed is delineated in AGWA and given a buffer distance of 500 meters. The watershed is delineated using a 10-meter DEM that has been hydrologically corrected to ensure proper surface water drainage. In the United States (and for basins extending into Mexico), the U.S. Geological Survey's (USGS) The National Map Viewer and Download Platform (http://nationalmap.gov) provides the National Elevation Dataset (NED; http://ned.usgs.gov/) source data. The digital land cover available for this study is derived from two sources. The National Land Cover Database 2006 (Fry and others 2011) was used in combination with the North American Landscape Characterization Project (EPA, 1993) to capture classified digital land cover of known accuracy (Kepner and others 2000, Kepner and others 2003, Skirvin and others 2004).

Because the 2006 NLCD and 1992 NALC datasets have different classifications, the NALC land cover was reclassified to match the NLCD land cover. The reclassified NALC dataset of Mexico is then combined with the 2006 NLCD dataset of the U.S. resulting in a derived NLCD dataset that covers the entire project extent. The ICLUS HD data is combined with the NLCD/NALC data to project future development by decade to 2100. The ICLUS data have five categories of housing density representing rural, exurban, suburban, urban, and commercial/industrial.

The ICLUS database produced 5 seamless, national-scale change scenarios for urban and residential development. The A2 Scenario is characterized by a high fertility rate (average number of children that would be born to a woman over her lifetime) and low net international migration; it represents the highest U.S. population scenario gain (690 million people by 2100). The Base Case (BC) and Scenario B2 are the middle scenarios, with a medium fertility rate and medium to low international migration. Differences between BC and B2, as well as A1 and B1, reflect how housing is allocated – sprawl vs. compact growth patterns. As a result of this distinction, the county populations in urban and suburban areas generally grow faster than in rural areas in the base case, but the experiences of individual counties vary. A1 and B1, with low fertility rates and high international migration are the lowest of the population scenarios. The primary difference between these scenarios occurs at the domestic migration level, with an assumption of high domestic migration under A1 and low domestic migration under B1. The effect of different migration assumptions becomes evident in the spatial model when the population is allocated into housing units across the landscape. The national Baseline forecast for 2100 is 450M people and B1 could be lower at 380M people. The A2 Scenario results in the largest changes in urban and suburban housing density classes and greater conversion of natural land-cover classes into new population centers, or urban sprawl. The largest shift from suburban densities to urban occurs in 2050 – 2100 for the A-family scenarios (Bierwagen and others 2010). The ICLUS scenarios were developed using a demographic model to estimate future populations through the year 2100 and then allocated to 1-hectare pixels by county for the conterminous U.S. (EPA 2009, EPA 2010). The final data sets provide decadal projections of both housing density and impervious surface cover from the 2000 baseline year projected out to the year 2100.

The NLCD data has different land cover classes, a different projection, and is at a different resolution (30m) than the ICLUS data (100m); therefore the ICLUS data were pre-processed for use in this project. Preprocessing includes clipping the ICLUS data to the boundary of Arizona, projecting the ICLUS data to UTM Zone 12 NAD83, reclassifying the ICLUS data to NLCD classes and resampling the ICLUS data from 100m to 30m. The resulting dataset was then merged with the NLCD dataset so the ICLUS data replaced the NLCD data if there was a change in land cover. The reclassification scheme was determined based on housing density definitions, which were different between the two datasets. As a result the "Rural" land cover type in the ICLUS data was defaulted to the NLCD class present at that location. This methodology was incorporated into a tool in ArcToolbox in ArcGIS for easy conversion of the ICLUS datasets.

In this example, only Scenario A2 (corresponding to storyline A2 in the SRES) of the ICLUS data was used for example analysis, however all five ICLUS scenarios (A1, A2, B1, B2, and BC) were used in the final analysis (Burns and others 2013). Ten land cover datasets per scenario (50 total) are produced from the combination of the NLCD/NALC datasets and the ICLUS datasets, representing the change in landscape attributed to population and development changes by decade from 2010 to 2100. For each scenario, the dataset from 2010 is used as the project baseline to which the successive decadal datasets are compared. Soils data for the U.S. were obtained from the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center's (NCGC) State Soil Geographic (STATSGO; USDA-NRCS 1994) database. Soils data for Mexico were obtained from the San Pedro Data Browser (Kepner and others 2003, Boykin and others 2012). The soil types were matched and redefined to equivalent STATSGO soil types. Precipitation data obtained from the National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov/) were used to drive the SWAT model in AGWA. Climate stations within or near the San Pedro Watershed were reviewed for periods of record and completeness of the dataset. The review produced a total of seven climate stations in Arizona with the recorded precipitation needed for the SWAT model (Fig. 1). The period of record is from 1971-2001.

RESULTS

All scenarios resulted in an increase to the Human Use Index (HUI) metric averaged over the entire watershed. HUI (adapted from Ebert and Wade, 2004) is the percent area in use by humans. It includes NLCD land cover classes "Developed, Open Space"; "Developed, Low Intensity"; "Developed, Medium Intensity"; "Developed, High Intensity"; "Pasture/Hay"; and "Cultivated Crops". The ICLUS A2 Scenario resulted in the largest increase of the HUI, 2.21percent in year 2100 for the entire watershed (Fig. 2 and Table 1).

Similarly to the increases in HUI over the entire watershed, both simulated runoff and sediment yield increased at the watershed outlet over time for all scenarios; Scenario A2 experienced the largest percent change in surface runoff and sediment yield, 1.04 and 1.19 percent, respectively (Figures 3 and 4; Tables 2 and 3). Percent change was calculated using the following equation:

$$\frac{([decade_i]\text{-}[base_i])}{[base_i]} \text{ x } 100 \qquad (1)$$

where $[decade_i]$ represents simulation results for a decade from 2020 through 2100 for a given scenario (i) and $[base_i]$ represents the baseline 2010 decade for the same scenario.

Figure 5 depicts the percent change of HUI, channel sediment yield, and subwatershed surface runoff from 2010 to 2100 for Scenario A2. The changes in HUI relate well to the changes in sediment yield and surface runoff. The figures show the impact of growth locally on one level with the subwatersheds and in greater detail with the explicit percent change in the growth areas.

DISCUSSION

Hydrologic impacts of future growth through time were evaluated by using reclassified ICLUS housing density data by decade from 2010 to 2100 to represent land cover in AGWA. AGWA is a GIS tool initially developed to investigate the impacts of land cover change to hydrologic response at the watershed scale to help identify vulnerable regions and evaluate the impacts of management. AGWA allows for assessment of basin-wide changes and cumulative effects at the watershed outlet as well as more localized changes at the subwatershed level.

ICLUS datasets were used for a number of reasons including their availability (http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305). Reclassification was necessary to convert from housing density classes

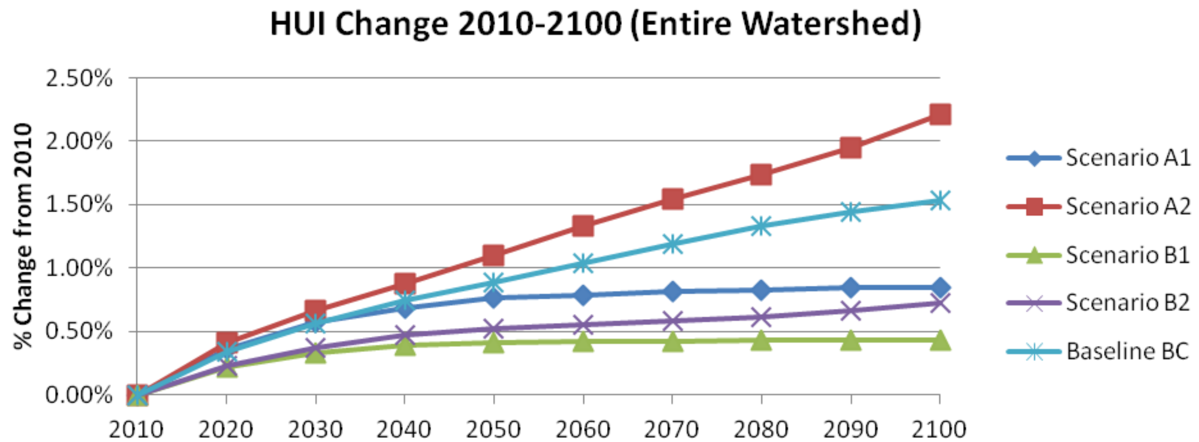

Figure 2—Watershed Average Human Use Index (HUI) for All Scenarios.

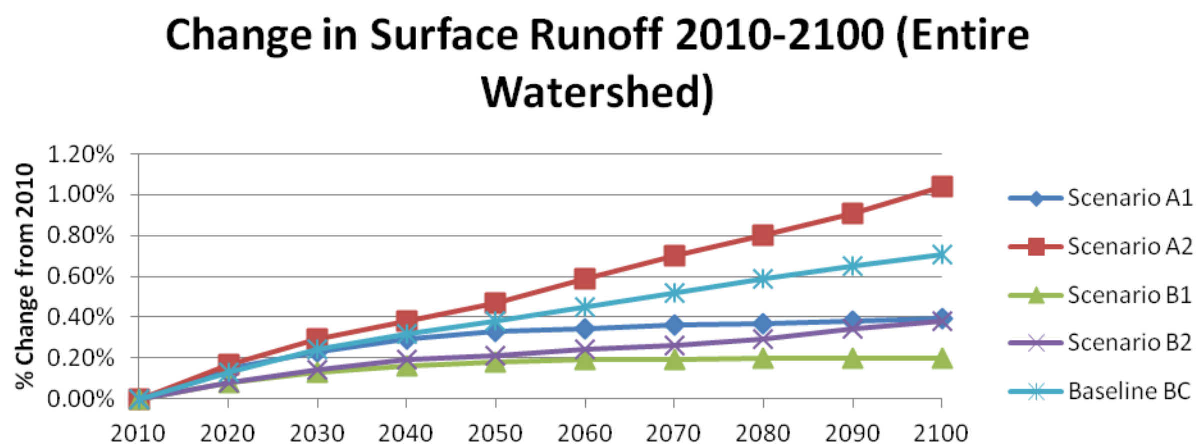

Figure 3—Watershed Average Percent Change in Surface Runoff for All Scenarios.

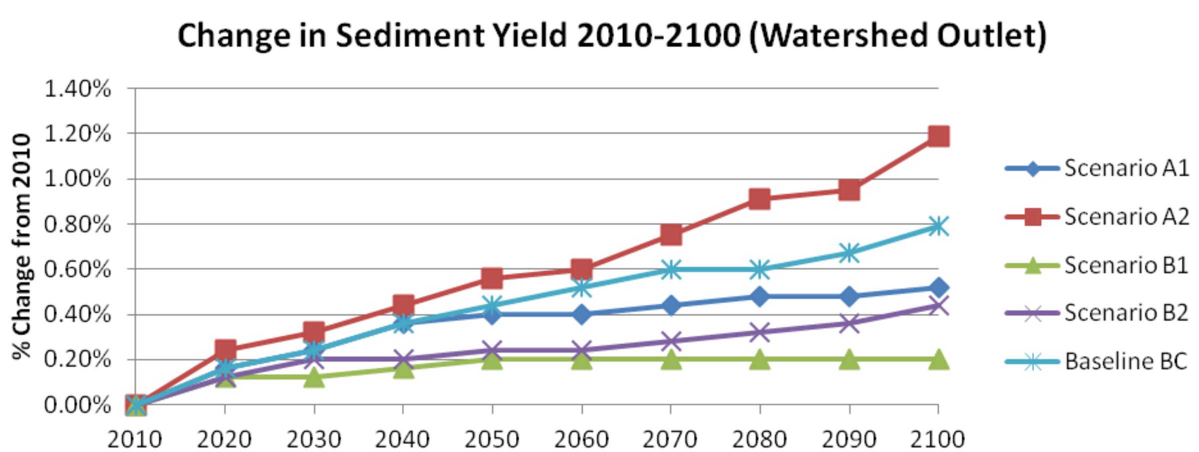

Figure 4—Watershed Average Percent Change in Sediment Yield for All Scenarios.

Table 1—Change in Human Use Index for All Scenarios (2010 - 2100)

	HUI Base	Change in Human Use Index from base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario A1	5.23%	0.36%	0.57%	0.69%	0.76%	0.79%	0.81%	0.83%	0.84%	0.85%
Scenario A2	5.09%	0.41%	0.66%	0.88%	1.10%	1.33%	1.54%	1.73%	1.95%	2.21%
Scenario B1	5.15%	0.22%	0.33%	0.39%	0.41%	0.42%	0.43%	0.43%	0.43%	0.43%
Scenario B2	5.09%	0.23%	0.37%	0.47%	0.52%	0.55%	0.58%	0.61%	0.66%	0.73%
Baseline BC	5.12%	0.34%	0.57%	0.74%	0.89%	1.04%	1.19%	1.33%	1.44%	1.54%

Table 2—Change in Surface Runoff for All Scenarios (2010 - 2100).

	Surface Runoff Base	Percent Change in Surface Runoff from Base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario A1	42.98 mm	0.15%	0.23%	0.29%	0.33%	0.34%	0.36%	0.37%	0.38%	0.39%
Scenario A2	42.95 mm	0.17%	0.29%	0.38%	0.47%	0.59%	0.70%	0.80%	0.91%	1.04%
Scenario B1	42.96 mm	0.08%	0.13%	0.16%	0.18%	0.19%	0.19%	0.20%	0.20%	0.20%
Scenario B2	42.96 mm	0.08%	0.14%	0.19%	0.21%	0.24%	0.26%	0.29%	0.34%	0.38%
Baseline BC	42.96 mm	0.13%	0.24%	0.32%	0.38%	0.45%	0.52%	0.59%	0.65%	0.71%

Table 3—Change in Channel Sediment Yield for All Scenarios (2010 - 2100).

	Sediment Yield Base	Percent Change in Sediment Yield from Base								
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Scenario A1	25220 t	0.16%	0.24%	0.36%	0.40%	0.40%	0.44%	0.48%	0.48%	0.52%
Scenario A2	25200 t	0.24%	0.32%	0.44%	0.56%	0.60%	0.75%	0.91%	0.95%	1.19%
Scenario B1	25210 t	0.12%	0.12%	0.16%	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%
Scenario B2	25200 t	0.12%	0.20%	0.20%	0.24%	0.24%	0.28%	0.32%	0.36%	0.44%
Baseline BC	25200 t	0.16%	0.24%	0.36%	0.44%	0.52%	0.60%	0.60%	0.67%	0.79%

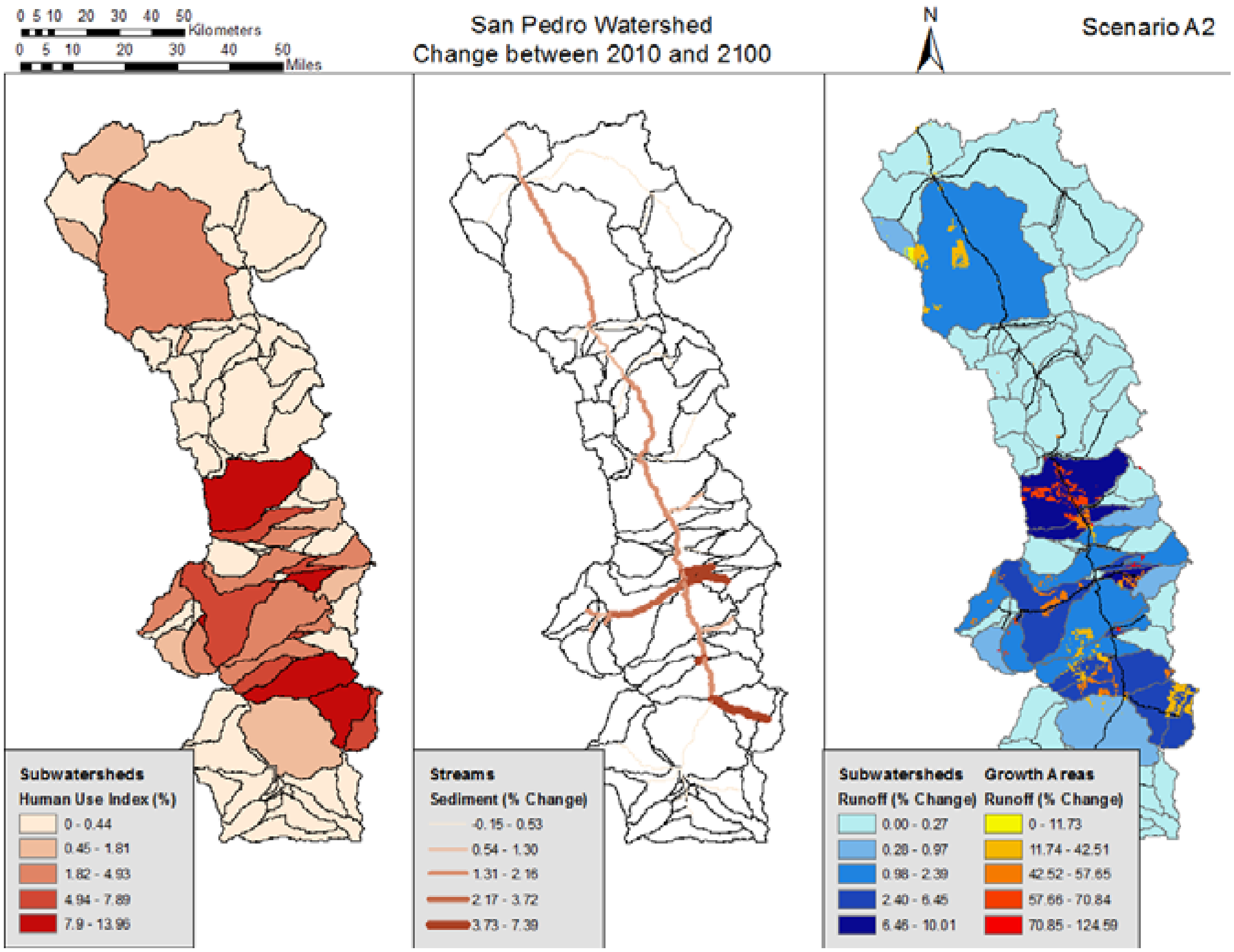

Figure 5—Change in Human Use Index (HUI), Sediment Yield, and Surface Runoff (both Average and Explicit) in Percent from 2010 to 2100 for Scenario A2.

to "developed" type classes in the 2006 National Land Cover Database. All land cover classes of the NLCD are supported in AGWA via look-up tables which allow for translation of land cover classes into hydrologic parameters necessary to parameterize the hydrologic models.

The results produced by the AGWA-SWAT modeling represent a qualitative assessment of anticipated hydrologic change resulting from the ICLUS A1, A2, B1, B2, and BC scenarios. Historic rainfall and climate data are used to drive the SWAT model, so anticipated climate change is not accounted for in the results, although climate change may amplify or reduce the results presented here. Quantitative assessments of anticipated hydrologic impacts resulting from the ICLUS scenarios would require calibration for the baseline (2010) for each scenario and additional information to parameterize future decades, including but not limited to the design and placement of flood mitigation measures (detention basins, riparian buffers, water harvesting, recharge wells, open space infiltration galleries, etc.) that would be a required component of any future development.

The methodology presented herein uses HUI as an easily quantifiable metric for land cover change resulting from urban growth; however it does not distinguish between different types of human use. Different types of human use, ranging from "Developed, Open Space" to "Developed, High Intensity" to "Cultivated Crops" have different hydrologic properties associated with them, so despite the observed relationship between increasing HUI and increasing surface runoff and sediment yield in the results, HUI cannot be used as a surrogate for actual hydrologic modeling, which more closely captures the actual land cover properties and the complex interactions and feedbacks that occur across a watershed.

The greatest changes in surface runoff occur in subwatersheds where the change in HUI was also greatest; accordingly, the smallest changes in surface runoff occur in areas where the change in HUI was smallest. Sediment yield in the channels is largely driven by surface runoff, so channels immediately downstream of subwatersheds with high changes in HUI and surface runoff experience the largest changes in sediment yield. The results emphasize the importance of investigating localized impacts to natural resources at appropriate scales as the impacts at the subwatershed scale and below can be much greater than at the basin scale. They also highlight the effective modulation of local changes by large undevelopable areas. At the subwatershed scale, unacceptable hydrologic impacts may be observed that would not otherwise be captured at the basin scale if development was occurring basin-wide. Instead, basin-wide impacts are effectively averaged out by undevelopable lands. Thus any interests in cumulative effect should be addressed at the subwatershed versus basin scale for this western watershed or others like it which contain large tracts of land in the public domain, and are therefore not subject to direct urbanization impacts.

CONCLUSIONS

Changes in land cover/use under the A2 Scenario result in the greatest hydrologic impacts due to a higher population growth rate and a larger natural land cover conversion rate. The results of the analyses for all scenarios over the 2010 – 2100 year period (Tables 2 and 3) indicate changes in the range of 0.2 percent (B1 Scenario) to 1.04 percent (A2 Scenario) on average surface runoff across the watershed, and changes in the range of 0.2 percent (B1 Scenario) to 1.19 percent (A2 Scenario) on sediment yield at the watershed outlet.

Local changes to hydrology and sediment delivery at the subwatershed level and below are relevant because at those scales the impacts tend to be much more significant. Additionally, since the hydrologic impacts are tied to changes in land cover, and because the San Pedro Watershed has large amounts of land that cannot be developed, the hydrologic impacts at a watershed scale are expected to be limited. The localized impact of development found in this study may be representative for much of the western arid and semi-arid U.S., where 47.3 percent of the 11 coterminous western states (AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, and WY) is managed as federal public lands by the Bureau of Land Management, Fish and Wildlife Service, National Park Service, U.S. Forest Service and the Department of Defense (Gorte and others 2012). Despite the constraints that limit developable areas, hydrologic changes at the watershed scale are still expected to occur.

Simulated increases in percent change of surface runoff and sediment yield closely tracked increases in the HUI metric; consequently growth and development should be moderated to prevent large increases in surface runoff and sediment yield, which could degrade water quality from sediment and pollutant transport, erode and alter the stream channel, degrade or destroy habitat, decrease biological diversity, and increase flooding. The effects of growth may be magnified or mitigated by climate change, though this is not accounted for in this analysis.

Scenario analysis is an important framework to help understand and predict potential impacts caused by decisions regarding conservation and development. For the EPA and other stakeholders, hydrologic modeling systems (e.g. AGWA) integrated with internally-consistent national scenario spatial data (i.e. ICLUS) provide an important set of tools that can help inform land use planning and permitting, mitigation, restoration, and water management strategies.

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ECOHYDROLOGY OF A FLOODPLAIN FOREST: RELATIONSHIPS BETWEEN VEGETATION AND GROUNDWATER RESOURCES AT CONGAREE NATIONAL PARK, SOUTH CAROLINA USA

Timothy Callahan, Lauren Senn[1]

The goal of this project was to investigate the relationship between the shallow, unconfined aquifer and woody vegetation at eight sites of the Congaree Observation Well Network at Congaree National Park near Hopkins, South Carolina. Eight piezometers with screens of 1.5-m length (top-of-screen depths ranging from 3.0 to 5.0 m below ground surface) along a 1.8-km cross-valley transect from the foot of a fluvial terrace and terminating near Cedar Creek in the national park. Time series data of groundwater level and temperature have been collected with automated data loggers in the piezometers since 2009. Groundwater response to storm event data from a nearby weather station was used to approximate specific yield of the sub-soils and sediments of the aquifer. White's Method was used to analyze diurnal ET signals for select periods during 2009-2012. Vegetation surveys focused on woody shrub and canopy species growing within a 400 m^2 plot centered on each well. Metrics included basal area index (BAI), biodiversity, and relative abundance. Gross ET estimates ranged from 0.2 to 10 mm per day, depending on season. Vegetation composition was typical of floodplain forest associations as previously described for the site; however, ET and BAI were not correlated. Alternative explanations include the following: 1) local topographic changes in the form of hummocks and hollows may influence groundwater flow; 2) hydrostratigraphic variation may influence the ET signal more than the local vegetation; 3) the effects of local vegetation can only be measured with larger plots. Qualitative analysis of LIDAR elevation data collected along the piezometer transect suggest there may be some relation between hummocks (small hills) and vegetation, but more refined data are needed to quantify this association. We will present extrapolated estimates of ET across the entire floodplain portion of the park and discuss the uncertainties of such data. The details of groundwater dynamics are not well understood in the Congaree River Valley, and neither are the relative scale of evapotranspiration (ET) in the water budget and our intention is provide baseline data for future research, along with information that could help develop management guides for flood control and predictions in these types of watersheds.

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RELATIONSHIPS BETWEEN WILDLAND FIRES AND WATERSHED HYDROLOGY ACROSS THE CONTIGUOUS U.S.

Dennis W. Hallema, Ge Sun, Peter V. Caldwell, Steven P. Norman, Erika C. Cohen, Yongqiang Liu, Steven G. McNulty[1]

Wildland fires contribute to the natural succession in forested watersheds by stimulating growth and biodiversity. Notwithstanding, these fires present an increasing hazard at the wildland-urban interface, and cover large areas as a result of the high fire severity associated with forest densification. Fire severity and intensity determine to a large degree the total burnt area and loss of leaf area (LAI), however our knowledge of the impact on hydrology is far from complete. Loss of LAI and interception can increase runoff and sediment loads threefold or more, and is considered a first-order effect of fire. A study involving an Arizona ponderosa pine forest shows that infiltration rates decrease by up to 62 percent on a severely burnt soil, and may cause higher peak flow (e.g. 201-290 percent) and accelerated erosion as a result of reduced soil wettability. Simulations with the WaSSI water balance model suggest that a reduction of LAI by 50 percent can lead to a significant increase in water yield (e.g. >17-93 mm/yr, or 7-21 percent in wet regions with annual precipitation >800 mm and 3-32 mm/yr, or 10-20 percent in regions with 300-800 mm of precipitation). Forested watersheds are important sources of water supply, and stakeholders are becoming increasingly aware of the potential effects of wildland fire on these water supplies and the occurrence of flash floods causing severe damage to property and infrastructure. Nevertheless, there are many ways to mitigate excessive runoff due to fire, such as pre-fire management, Burned Area Emergency Response, and recent studies recommend a total ground cover of at least 60 percent with straw mulch, which reduces runoff and sediment yields during at least one year following a wildland fire, however the effect of combinations of fuel management at different scales (local, regional) remains uncertain. In this contribution we present an overview of the advances in scientific literature on the relationship between wildland fires and watershed hydrology across the contiguous United States, and aim to identify new avenues for research that can enhance the resilience of forest ecosystems and assist decision making with regard to prescribed fuel treatments. This research was supported in part by an appointment to the USFS. Research Participation Program administered by the ORISE through an interagency agreement between DOE and the USFS. All opinions expressed in this work are the author's and do not necessarily reflect the policies and views of USDA, DOE, or ORAU/ORISE.

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RIPARIAN AREA HARVESTING IMPACTS ON VEGETATION COMPOSITION AND DIVERSITY

Katherine Elliot, James M. Vose[1]

In the southern Appalachians USA, the boundaries of riparian areas are often hard to define. Vegetation is often used as a riparian indicator and plays a key role in protecting water resources, but adequate knowledge of floristic responses to riparian disturbances is lacking. Our objective was to quantify floristic composition and diversity of the riparian communities before (2004) and one, two, and seven years after harvest treatments with varying buffer widths. The treatments were harvest distances of 0 m, 10 m, and 30 m away from the stream edge. Sites were harvested between 2005 and 2006. The harvest method for all treatments was a heavy selection cut followed by a highlead, cable-yarding leaving a low residual basal area (ca. 5.0 m^2/ha) within the harvested zone. We examined: (1) differences among sites using a mixed linear model with repeated measures (SAS 9.4); (2) multivariate relationships among ground-layer species composition and environmental variables (soil water content, light transmittance, tree basal area, shrub density, and distance from stream) using nonmetric multidimensional scaling (NMS); and (3) species composition among sample years using a multiresponse permutation procedure (MRPP) in PC-ORD version 5. The first year after harvest, overstory density and basal area were reduced by 83 percent and 65 percent, respectively, for the 0-m buffer site; reduced by 50 percent and 74 percent for the 10-m buffer site; and reduced by 45 percent and 29 percent for the 30-m buffer site. After 7 years, however, both the 0-m and 10-m buffer sites had nearly three times greater density than before the harvest treatments, whereas density in the 30-m buffer site was similar to its pretreatment condition. Basal area remained significantly lower on all harvested sites over time compared to the reference. Ground-layer species composition differed significantly overtime for the 0-m buffer (MRPP; $T = -5.709$, $A = 0.044$, $P < 0.0001$) and 10-m buffer (MRPP; $T = -5.485$, $A = 0.041$, $P < 0.0001$), but the 30-m buffer (MRPP; $T = -1.021$, $A = 0.008$, $P = 0.1510$) and reference (MRPP; $T = 1.242$, $A = -0.009$, $P = 0.9141$) sites did not change after harvest treatments. Average Sørensen distance increased after 7 years, indicating greater within-group heterogeneity (species diversity) after harvesting. These vegetation recovery patterns provide critical information for evaluating management options in riparian zones in the southern Appalachians.

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ADVANCING STREAM RESTORATION DESIGN: A SCIENCE-BASED APPROACH USING DATA AND METHODOLOGIES FROM THE AGENCIES

Jessica Palazzolo, Joshua Robinson, Philip Ellis[1]

Ecosystem restoration design is a relatively new field of work that requires multi-disciplinary expertise in the natural sciences. Although the field is new, federal agencies and public institutions have spent several decades and millions of dollars researching the sciences and methods that underly restoration activities. However, many restoration practitioners are either unaware of this vast body of knowledge or simply do not know how to apply it to these new project types.

This presentation will outline a science-based approach to project assessment, design, and construction using publicly-available data and methods from the USGS, USDA-NRCS, USACOE, FWS, EPA, FHWA, USBR, FEMA, interagency working groups, and peer-reviewed scientific publications. Project examples located in various regions of North and South Carolina will be presented, including urban stream daylighting, physical restoration of mountainous step-pool channels, and hydrologic restoration of bidirectionally-flowing floodplain streams. The examples will cover information from the disciplines of hydrology, hydraulics, ecology, geomorphology, and civil engineering. The presentation will introduce various publicly-available resources, and will outline a robust framework for assessing and designing creek restoration projects.

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Watershed Assessment-Tools and Data

MANAGING THE SPACE-TIME-LOAD CONTINUUM IN TMDL PLANNING: A CASE STUDY FOR UNDERSTANDING GROUNDWATER LOADS THROUGH ADVANCED MAPPING TECHNIQUES

Phillip Harte, Marcel Belaval, Andrea Traviglia[1]

The lag time between groundwater recharge and discharge in a watershed and the potential groundwater load to streams is an important factor in forecasting responses to future land use practices. We call this concept managing the "space-time-load continuum." It's understood that in any given watershed, the response function (the load at any given time) will differ for surface runoff and groundwater discharge. The mean age of surface runoff may be days whereas for groundwater it could be many decades. Surface runoff reflects contemporaneous land use practices and relatively quick reactions whereas groundwater load reflects past land use practices and attenuation mechanisms in the aquifer and ephemeral zone around streams. The total load combines both response functions and understanding the makeup of the two responses can improve forecasting of future loads.

We used advanced mapping techniques to quantify potential groundwater loads of chloride to a small watershed in southern New Hampshire. The small watershed is adjacent to a major highway corridor and the use of salt as a road deicing agent has caused increases in chloride concentrations in nearby Policy Brook, the subject of a chloride TMDL. Specific conductance in Policy Brook showed high levels (1300 $\mu S\ cm^{-1}$), about five times background, during periods of baseflow indicating a groundwater pathway for road salt.

Electromagnetic (EM) terrain induction conductivity surveys were conducted along Policy Brook to map road-salt contaminated groundwater discharge. Three different EM tools were used that probed slightly different depths of investigation (ranging from 0 to 12 feet below the streambed). Electromagnetic surveys identified several reaches of high conductivity groundwater. Based on the delineation of reaches, seven streambed piezometers were installed to sample for shallow groundwater. Correlation of shallow groundwater conductivity with EM allowed for the calculation of a spatially continuous mass load of chloride. Given the depth of EM surveys, the shallow groundwater represents a near term (months to years) potential groundwater load. The potential groundwater load was found to be 50 percent greater than the instantaneous load calculated from increases in chloride along Policy Brook during a baseflow period. Over the next few years, we surmise that the seasonal variability in chloride in Policy Brook will increase in response to the inherent seasonal variability in groundwater discharge and the growing divergence of surface and groundwater loads; the divergence being fueled by current improved practices to reduce road salt as reflected in surface runoff, and past practices as reflected in groundwater loads.

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THE ROLE OF WATERSHED CHARACTERISTICS IN ESTUARINE CONDITION: AN EMPIRICAL APPROACH

James Latimer, Melissa Hughes, Michael Charpentier, Christine Tilburg[1]

Estuarine condition is a function of the nature of the estuary, ocean, and atmospheric systems, and the upstream watershed. To fully understand and predict how an estuary will respond to drivers and pressures, each compartment must be characterized. For example, eutrophication effects on estuarine condition are generally well known; less understood is how the attributes of estuarine watersheds, and their spatial distributions, relate to estuarine condition. The Gulf of Maine Council's Ecosystem Indicator Partnership (ESIP) and the Environmental Protection Agency's (EPA) Office of Research and Development have joined for a project designed to link watersheds to estuarine conditions. Specifically, the goal of this research is to develop methods and indicators for mapping watershed integrity and aquatic condition in order to predict estuarine condition. The analysis uses a common set of watershed spatial indicators and estuarine state/impact indicators. The study builds on past work in southern New England using relationships between land use characteristics and aquatic habitat extent metrics (e.g., eelgrass) and on ESIP's work in northern New England, which has assembled a large database of watershed, contaminants, climate change, aquaculture, and eutrophication variables. The aquatic condition data are comprised of regional data sets, including EPA's National Coastal Assessment. Watersheds are being characterized using multiple indicators such as land use magnitude and proximity, percent impervious cover, landscape development indexes, and measures of terrestrial and hydrological fragmentation and connectivity. Preliminary results are consistent with the hypothesis that land use magnitude and proximity affect downstream estuarine status and impacts. The research will develop methods, models, and data on estuarine condition and watershed characteristics, which in turn can help justify and prioritize watershed protection across the United States and Canada.

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WETLAND EXTENT AND PLANT COMMUNITY COMPOSITION VULNERABILITY TO CLIMATE CHANGE

Michael Nassry, Denice H. Wardrop, Anna T. Hamilton, Christopher J. Duffy, Jordan M. West[1]

The potential impact of climate change on wetland-provided ecosystem services has been largely unspecified because of the difficulty in predicting changing hydrologic conditions, which are a major driver of structure and function in these ecosystems. The Penn State Integrated Hydrologic Model (PIHM), constructed and calibrated using nationally available data sets (e.g., soils, topography, national wetlands inventory (NWI) wetlands, USGS stream gages), was used to generate groundwater depth conditions for multiple hydrogeomorphic (HGM) wetland types (depression, slope, riverine), across a range of ecoregions in Pennsylvania, under historical and future climate scenarios. The vulnerability of wetland extent to climate change was assessed based on changes in groundwater depth and changes in the percent of time groundwater was present in the rooting zone (upper 30 cm). These estimates of extent vulnerability were calculated at annual, seasonal, and growing season scales as well as at ecoregion, watershed, and HGM-specific spatial scales. Such scale-specific vulnerability assessments provide insight into the complexity of wetland sensitivities to changes in the hydrologic drivers of wetland structure and function and offer a surrogate for the estimation of which wetland-provided ecosystem services will be the most vulnerable to future climate change. Wetland plant community composition can also be a measure of wetland vulnerability and may be both more sensitive and an earlier indicator of climate change induced stress than wetland extent. To test this, an existing database of metrics characterizing the floral community (e.g., percent invasives, percent annual, floristic quality assessment index) and long-term hydrologic monitoring was used to develop relationships linking hydrology, anthropogenic disturbance, and community composition. Using the effects of disturbance on hydrology as a proxy for climate change, the hydrology and plant community relationships were extended to the modeled future hydrology scenarios to provide estimates of wetland plant community composition responses to climate change.

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LAND COVER CHANGE IN COASTAL WATERSHEDS 1996 TO 2010

Nate Herold[1]

Land use and land cover play a significant role as drivers of environmental change. Information on what is changing and where those changes are occurring is essential if we are to improve our understanding of past management practices or policies and effectively respond now and in the future. Through its Coastal Change Analysis Program (C-CAP), the National Oceanic and Atmospheric Administration (NOAA) produces nationally standardized land cover and change information for the coastal regions of the U.S. These products provide inventories of coastal intertidal areas, wetlands, and adjacent uplands (using documented, repeatable procedures), with the goal of monitoring these habitats every five years. This program has been in existence since the mid-1990s and features multiple dates of information available for most coastal areas of the U.S. This presentation will summarize the availability of this land cover and change data, how it can be accessed via NOAA's Digital Coast, recent improvements to wetland mapping accuracies, summarize changes observed regionally, what change information is available on a watershed basis, how C-CAP can be used to inform management decisions or drive more detailed mapping efforts, and how this data is being used to model potential future impacts from sea level rise.

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MAPPING VARIABLE WIDTH RIPARIAN BUFFERS

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Riparian buffers are dynamic, transitional ecosystems between aquatic and terrestrial ecosystems with well-defined vegetation and soil characteristics. Previous approaches to riparian buffer delineation have primarily utilized fixed-width buffers. However, these methodologies only take the watercourse into consideration and ignore critical geomorphology, associated vegetation and soil characteristics. Utilizing spatial data readily available from government agencies and geospatial clearinghouses, such as digital elevation models (DEM) and the National Hydrography Dataset, the Riparian Buffer Delineation Model (RBDM) offers advantages by harnessing the geospatial modeling capabilities of ArcMap GIS, incorporating a statistically valid sampling technique along the watercourse to accurately map the critical 50-year plain, and delineating a variable width riparian buffer. Options within the model allow incorporation of National Wetlands Inventory (NWI), Soil Survey Data (SSURGO), National Land Cover Data (NLCD) and/or Cropland Data Layer (CDL) to improve the accuracy and utility of the riparian buffers. This approach recognizes the dynamic and transitional natures of riparian buffers by accounting for hydrologic, geomorphic and vegetation data as inputs into the delineation process. By allowing the incorporation of land cover data, decision makers acquire a useful tool to assist in managing riparian buffers. The model is formatted as an ArcMap toolbox for easy installation and does require a Spatial Analyst license.

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Watershed Assessments at Multiple Scales

PAIRED FORESTED WATERSHED EXPERIMENTS IN THE PIEDMONT OF NORTH CAROLINA

Johnny Boggs, Ge Sun, Steven McNulty[1]

Understanding how regional-specific water resources respond to disturbances can serve as useful information to land managers as they aim to set flow targets needed to maintain ecological integrity in surface waters or to design riparian buffers for water quality protection. There are three distinct land provinces across North Carolina: the Mountains, Piedmont, and Coastal Plain. Population density, topography, and distribution of major forest landscapes are unique to each region, resulting in a range of different water resource needs and responses to land management practices. Experimental forests in the Mountain and Coastal regions of North Carolina offer a long history of watershed hydrology and water quality data related to sustainability of forest and water resources following silvicultural activities. Little data is available for the Piedmont portion of the state. This study addressed this spatial knowledge gap through a series of paired watershed studies in the Piedmont at Hill Demonstration Forest: control watersheds (HF2 and HFW2) and treatment watersheds (HF1 and HFW1) and Umstead Research Farm control watershed (UF2) and treatment watershed (UF1). We quantified changes in discharge, water quality, riparian buffer stand dynamics, and buffer tree water use after a clear-cut harvest where best management practices (BMPs) were installed to protect water quality. We found that discharge in treatment watersheds increased dramatically, averaging 240 percent in HF1 and 200 percent in UF1, and 40 percent in HFW1 during the postharvest period, 2011-2013. Total suspended sediment export in the treatment watersheds also increased significantly after harvest due to the increase of discharge quantity and movement of in-channel legacy sediment. Stormflow peak nitrate reached its maximum concentration during the first two years after harvest in treatment watersheds then declined due to nitrate uptake by the rapid regrowth of woody and herbaceous plants. We found that 36 percent of the UF1 streambank trees were blown down due to opening of the canopy during harvest, but caused no measurable increase in mean daily stormflow sediment concentration. HF1 residual trees in the buffer used 43 percent more water in growing season postharvest (314 mm) than growing preharvest (220 mm) period. This resulted in an 8 percent change in stream discharge due to an increase in buffer stand transpiration. Our results align with forest management studies in the Mountains and Coastal Plain where temporary increases in discharge were accompanied by increased in-channel sediment transport and nutrient exports but were not sufficiently disruptive to impact aquatic life and ecological integrity. However, percent change in discharge and peak nitrate concentrations tended to be higher in the Piedmont when compared to the Mountain and Coastal Plain regions.

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VERIFICATION OF HYDROLOGIC LANDSCAPE DERIVED BASIN-SCALE CLASSIFICATIONS IN THE PACIFIC NORTHWEST

Keith Sawicz[1]

The interaction between the physical and climatic attributes of a basin (form) control how water is partitioned, stored, and conveyed through a catchment (function). Hydrologic Landscapes (HLs) were previously developed across Oregon and are comprised of components describing climate, seasonality, aquifer permeability, terrain, and soil permeability for over 5,000 assessment units; they therefore represent hydrologic form throughout Oregon. This approach was then extended to the three Pacific Northwest (PNW) states of Washington, Oregon and Idaho to over 10,000 assessment units. The PNW assessment units were developed using the National Hydrography Dataset Plus V2 catchment boundaries. Hydrologic landscapes have the advantage of describing how water should flow through and out of each HL in continuous space. However, HLs are unable to be verified without stream flow information. Hydrologic function was investigated through the extraction of characteristics of the long-term climatic and streamflow signals (hydrologic signatures) for 199 basins in the PNW. Hydrologic signatures include Runoff Ratio, Baseflow Index, Snow Ratio, and Recession Coefficients. To compare the PNW HL classification to hydrologic signatures, we developed 5 methodologies to aggregate and interpret information provided by HLs to the basin scale. These methodologies use the areal fraction of HL composition within each basin to cluster basins together into similar classes with respect to both the underlying HL composition and hydrologic signature values. For HL aggregation to be considered successful, it must show similarity in hydrologic signatures within basin clusters and distinctness between basin clusters. We hypothesize that we will find: 1) a way to aggregate HLs that form homogeneous and distinct classes 2) strong relationships between HL derived basin clusters and hydrologic signatures; 3) signatures related to water balance are explained by climatic conditions; and 4) signatures describing flow paths are predicted by terrain, soil, and aquifer permeability. Preliminary findings suggest that basins clustered using HLs that contribute most to moisture excess and deficit provide basin classes that best separate combined hydrologic signature properties.

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WATERSHED AND LONGITUDINAL MONITORING EVENTS

Harold Harbert, Steven Blackburn[1]

Georgia Adopt-A-Stream partners annually with many organizations, universities and watershed groups to conduct sampling events with volunteers at a watershed level. These monitoring events range from one-day snapshots to week-long paddle trips. One-day sampling events, also called "Blitzs," River Adventures and River Rendezvous, generally target 20-50 sites within a watershed. The multi-day events involve sampling anywhere from 10 to 20 sites per day, 70-120 sites per event, and are usually part of a larger activity called "Paddle Georgia." The multi-day events are located on a different Georgia river each year and bring along hundreds of citizens on the adventure. Partners for these events include local governments, watershed organizations, Adopt-A-Stream groups and many other entities which provide sampling equipment, technical support and sponsorship. Depending on the objectives of the event, data can be collected on many parameters including water quality chemistry, bacteria, macroinvertebrates and physical characteristics. Data is posted on our website/database and is available for citizens and partners to view in graphs and basic GIS or download for analysis. In addition to collecting and sharing the data, small reports are written and shared with the community, and the information has been used at the local, state and federal level. During this presentation we will discuss Georgia's volunteer water quality monitoring program and how we've used watershed-wide sampling events to connect with a larger audience, collect and share quality assurance water data, and lessons learned.

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A VALIDATION STUDY OF A RAPID FIELD-BASED RATING SYSTEM FOR DISCRIMINATING AMONG FLOW PERMANENCE CLASSES OF HEADWATER STREAMS IN SOUTH CAROLINA

William Wenerick, Ken M. Fritz, Mitchell S. Kostich[1]

Classifying streams according to permanence is important in determining regulatory jurisdiction and in implementing pollution control programs. Administrators of these programs need rapid methods for making timely and defensible decisions. A rapid, field-based stream classification method developed in North Carolina compares the overall sum of ordinal scores based on observation of 26 geomorphology, hydrology, and biology attributes to numeric thresholds in order to preliminarily classify a stream reach as ephemeral, intermittent or perennial. Our study was among the first to evaluate the method and directly compare classifications based on scores to continuous hydrologic data from electrical resistance sensors and from direct observations of instream conditions during discrete wet and dry season visits. Ephemeral reaches scored lower than intermittent and perennial, but scores were not significantly different between intermittent and perennial reaches. Scores were seasonally stable and related to measures of duration, but not frequency. Geomorphology attributes were not important in a random forest model. Scores of the presence of baseflow in the dry season were more important than those from the wet season. Other important attributes and parameters were macrobenthos, rooted upland plants, bankfull width, drainage area, and ecoregion. Continuous hydrologic data and statistical analysis can be used to calibrate and fine-tune similar tools in other regions.

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QUANTIFYING VARIABILITY: PATTERNS IN WATER QUALITY AND BIOTA FROM A LONG-TERM, MULTI-STREAM DATASET

Camille Flinders, Douglas McLaughlin[1]

Effective water resources assessment and management requires quantitative information on the variability of ambient and biological conditions in aquatic communities. Although it is understood that natural systems are variable, robust estimates of variation in water quality and biotic endpoints (e.g. community-based structure and function metrics) are rare in US waters; due, in large part, to the need for, but paucity of, consistent, long-term studies. A key objective of National Council for Air and Stream Improvement (NCASI) Aquatic Biology Program is to guide and inform facilities, researchers, and regulators by conducting research that increases the understanding of biota and receiving water responses to effluent exposure. Laboratory studies evaluate biological responses to effluent and effluent constituents while field studies place potential lower-level effects into the context of higher-level, in-stream patterns, and utilizes effluent-biota relationships to develop tools or models that address effluent effect concerns applicable to different mills and/or receiving water scenarios. A cornerstone of this program is the Long-term Receiving Water Study (LTRWS), which is a multi-faceted field and laboratory study designed to evaluate effluent-related responses in short- and long-term laboratory bioassays, in-stream water and habitat quality, and the structure of fish, macroinvertebrates, and periphyton communities. Initiated in 1998 in four pulp and paper mill effluent receiving streams (Codorus Creek, PA; Leaf River, MS; McKenzie and Willamette Rivers, OR), water quality and biota are assessed seasonally at multiple sites upstream and downstream of the discharge to differentiate point source stressor responses from variation that occurs naturally over a stream continuum and to evaluate patterns in the context of seasonal and long term annual variability. Assessment of water quality in key tributary streams provides additional information in explaining main channel water quality patterns. We used this multi-year (n=15), seasonally sampled dataset of water quality and biota from multiple sites (n=5-7) to examine spatial and temporal variation in select endpoints (basic WQ variables, nutrient concentrations; select fish and macroinvertebrate metrics, chlorophyll a). Probability distributions and confidence intervals were used to quantify variation across sites and seasons within streams, and as a basis for exploring how variability estimates are affected by sample size. A subset of endpoints will be presented and differences in patterns across endpoints and streams will be discussed. Study results will help guide the design of monitoring studies in terms of number and frequency of sampling and study duration.

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WATERSHEDS, ECOREGIONS AND HYDROLOGIC UNITS: THE APPROPRIATE USE OF EACH FOR RESEARCH AND ENVIRONMENTAL MANAGEMENT DECISIONS

James Glover, James Omernik, Robert Hughes, Glenn Griffith, Marc Weber[1]

It has long been recognized that conditions at a point on a stream are highly dependent on conditions upgradient within the topographic watershed. The hydrologic unit (HU) system has provided a useful set of nationally consistent, hydrologically based polygons that has allowed for the generalization and tabulation of various conditions within the stream and its valley. However, environmental managers and researchers sometimes treat all hydrologic units as true topographic watersheds, resulting in an exclusion of many data upgradient of the sample point, or giving a misleading illustration of watershed conditions. Using ambient water quality data collected throughout South Carolina, we tabulated data at the 12 digit HU, 10 digit HU, 8 digit HU, and true topographic watershed scale for each sample point. For both the watershed, which we delineated by clipping, merging and/or dissolving hydrologic units, and the unaltered hydrologic units, total and percent area were computed for landcover and the level III ecoregion that made up each polygon. For each sample point along the stream, descriptive statistics were computed for common water quality parameters. For a given ecoregion, water quality parameters in tributary streams were more similar to each other than they were to measures taken from the main stem river into which they flowed. While this was not unexpected, we show how the common practice of extrapolating to the HU scale, in lieu of the topographic watershed, can mask spatial patterns and can potentially result in spurious conclusions. These results demonstrate the importance of integrating ecoregion and true topographic watersheds for the generalization of surface water data. This integration can lead to a better understanding of the natural world, which in turn can result in better management decisions.

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Environmental History of Lowcountry Rice Culture: A Current Study of Interdisciplinary Investigations

ENVIRONMENTAL RELATIONS BETWEEN INLAND RICE CULTURE AND THE COOPER AND WANDO RIVER WATERSHEDS, SOUTH CAROLINA

Hayden R. Smith[1]

Abstract—This study explains the geographical importance of the Cooper and Wando River watersheds, located east of Charleston (SC), in relation to inland rice cultivation during the colonial and antebellum periods. By focusing on the geological formation of this watershed, this paper will explain the connection between this plantation enterprise and the natural environment. The central South Carolina coastal plain physiography consists of a series of soil deposits during the Pleistocene. This topography provided a foundation for which free and enslaved rice cultivators lived and worked. By examining the spatial patterns of these actors in relation to the topography, this paper intends to show another chapter where the natural environment influences human action. Inland rice cultivation provided a foundation for the South Carolina colonial plantation complex and enabled planters' participation in the Atlantic economy, dependence on enslaved labor, and dramatic alteration of the natural landscape. Also, the growing population of enslaved Africans led to a diversely acculturated landscape unique to the Southeastern Coastal Plain. Unlike previous historical interpretations, which generalize inland rice cultivation in a universal and simplistic manner, this study discusses how agricultural systems varied from plantation to plantation. By explaining the importance of planters' and slaves' creative alterations of the inland topography, this interpretation will emphasize agricultural modes of production as ecological phenomena.

INTRODUCTION

Reservoir irrigated rice cultivation provided the first successful plantation enterprise in South Carolina. Despite this agriculture mode of production serving as the foundation for the South Carolina colonial economy, Lowcountry inland rice cultivation has had an elusive history. Unlike the visible tidal rice embankments still existing along South Carolina tidal rivers, remnant inland fields are harder to find and many presently lie in overgrown wooded watersheds. Lack of cultivation has transformed the once carefully managed fields into second or third growth forests and wetlands. Few colonial documents remain that describe the cultivation technology. Nineteenth century narratives often confuse the more visible tidal method of producing rice with the earlier inland method. Relating to these incongruities is the understanding that inland, not tidal, rice cultivation initially drove rigorous importation of enslaved Africans to such an extent that South Carolina became a "black majority" by 1739 (Smith 2012).

This paper explains how planters both adapted to and altered the environment by planting rice in inland swamps during the colonial and early antebellum periods. By explaining the importance of planters' and slaves' creative alteration of the inland topography, this interpretation explains how attention to the environment can present a more accurate understanding of the close relationship between Lowcountry cultivators and the land. By examining environmental relationships, this study can contribute to the broader understanding of African and European technology transfer in the New World and the use of multidisciplinary sources to help answer questions previously unattainable through traditional methods.

INLAND RICE CULTIVATION

Inland cultivation began as a simple process for growing rice by controlling irrigation schedules on accessible sites. But as demand for the crop and land value increased, planters spent more energy expanding old inland fields and creating new inland rice environments. Planters had to creatively adapt a general cultivation model to the diverse landscape of the South Carolina Coastal Plain. This adaptation to the terrain forced planters to make each plantation unique to the environment in an effort to maximize available land for efficient rice cultivation. Also, cultivators had to work within the limitations of this environment by effectively managing water flow and lessening the impact of natural disasters. Reacting to the opportunities of the global economy, inland planters used enslaved labor to clear more land and maximize the crop's output. This practice encouraged the ever-expanding slave trade in South Carolina and diaspora of Africans through the New World.

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The basic inland rice field consisted of two earthen dams enclosing a low-lying area bordered by subtle ridges. Enslaved people built up the embankments with available fill from adjoining drainage trenches. The dam on higher elevation contained stream or spring fed water to form a reservoir, or a "reserve," that would provide a water supply to the lower rice fields (Fig. 1). Once cultivators released water from the reservoir, a second dam retained this resource to nourish rice fields. Located between these two earthen structures was a series of smaller embankments and ditches to hold and drain water effectively during the cultivation process (Hilliard 1975).

Inland rice cultivation depended upon the simple flow of water from high to low ground, as water distributed from rainstorms and springs flowed down hill while watersheds pulled this resource into creeks and streams. Land level enough for rice cultivation, yet with sufficient angle to allow proper drainage, took shape throughout the South Carolina Coastal Plain. Terrain in this region provided ideal situations for inland rice cultivation, for the Atlantic Ocean's rise and fall during the Pleistocene (~2 million to ~ten thousand years ago) created fingers of small streams and creeks that spanned out from higher elevations, and merged into larger rivers flowing into the nearby ocean (Colquhoun 1969).

As the Atlantic Ocean's shoreline slowly encroached and retreated, barrier island chains and corresponding tidal flats formed over the millennia to create scarps and terraces. Prehistoric terraces consisted of sand and shells, while the backside of these ridgelines consisted of clay loam from former tidal marshes and lagoons. Scarps serve as physical lines of demarcation between the terraces, forming from either erosion of the receding coastline or during the depositional stage of former barrier islands. Water's movement through these facies coincidentally shaped the land, forming knolls, ridges, and troughs,

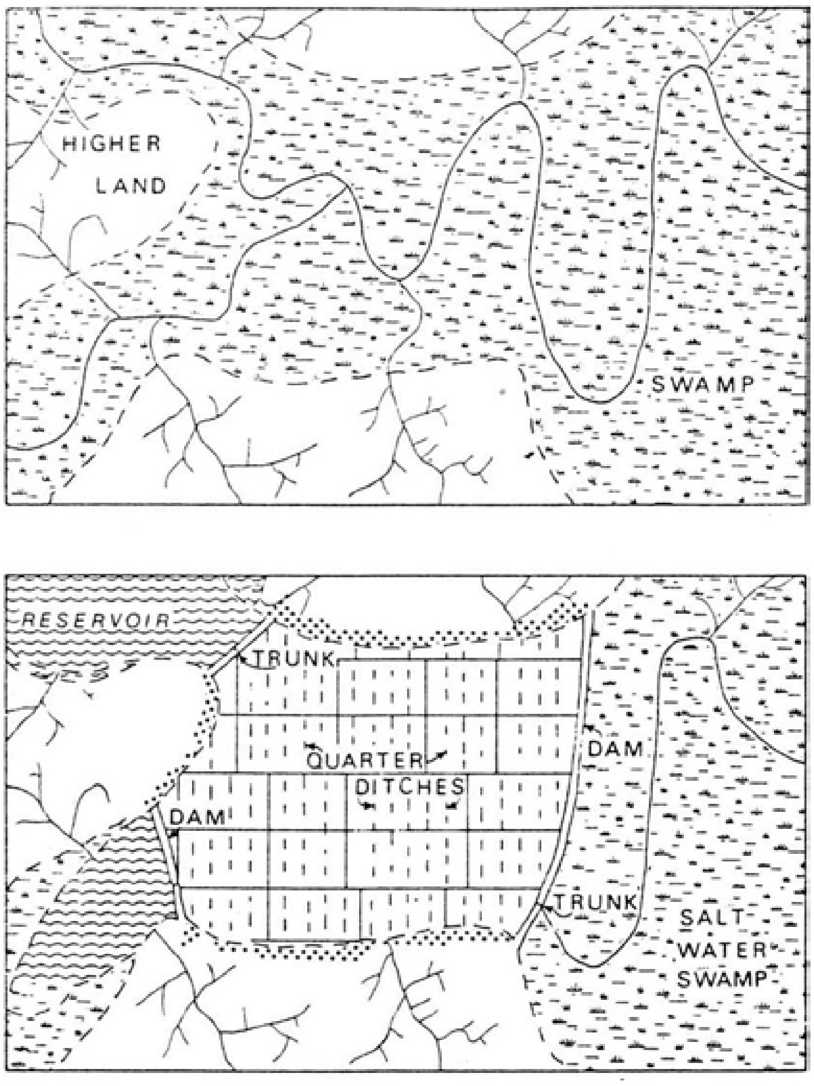

Figure 1—Basic inland rice field

which became critical features to rice plantations and the people who lived on them. Islands of high pine-lands lying within and around the plantations' swamps enabled planters to establish buildings and grazing fields on *terra firma* while creeks flowing around these landforms provided the water source and floodplain needed for inland rice cultivation. The early agricultural practices were necessarily ecologically diverse, as planters had to adapt their economic activities with the various microenvironments located on their property (Kovacik and Winberry 1989).

By focusing on specific examples located in the Cooper and Wando River watersheds, this paper will discuss how topography helped define irrigation patterns, field design, and settlement patterns. This spatial setting consists of the Eastern and Western branches of the Cooper River, converging with the Wando River to form the eastern half of the Charleston Harbor. Both rivers originate in the Lower Coastal Plain and flow relatively short distance compared to the neighboring Santee River, where headwaters begin approximately four hundred forty miles away from the coast. Including land covered by a 20th century hydro-electric dam project, the Cooper River flows approximately sixty miles and traverses four of the five Lower Coastal Plain terraces. The Wando River flows approximately twenty miles through just one terrace. Establishing inland rice cultivation systems in these terraces, planters and their enslaved laborers worked within the boundaries of these landscapes to create agricultural modes of production. At the same time, these topographical boundaries influenced settlement patterns and provided a pallet for inhabitants to construct a unique cultural identity.

Enslaved Africans' close connection to Lowcountry wetlands and small-stream floodplains provided access for individuals to express their cultural identity through subsistence agriculture. The close proximity of plantation settlement highlands and low-lying wetlands enabled seventeenth century slaves to construct nearby rice fields "on the plantation periphery" (Carney and Rosomoff 2009, Price 1991). Early plantation settlement patterns consisted of the plantation owner and enslaved houses within close proximity on highland knolls or ridgelines. The Lowcountry topography's highland swells caused by Pleistocene deposits and resulting erosion, created a landscape surrounded by bays, streams, creeks, and rivers. Slaves' necessity to grow crops for survival challenged them to use available land. For select West Africans transplanted in this New World environment, nearby wetlands provided similar spatial zones for growing rice. Relying on cultural memory, these enslaved cultivators constructed embankments for where they could grow patches of rice in similar fashion to their homeland. Also enslaved laborers' presence cutting cypress or herding cattle in swamps enabled them to become more familiar with wetland hydrology. As Peter Wood (1974) notes, these "black pioneers" were a mobile population that negotiated through Euro-American void swamps by tending to their enslaved duties. As part of the "numerous aspects of their varied African experience" that took place in the Lowcountry, rice became one of many subsistence crops grown upon the unwanted land.

Early eighteenth century planters relied on small tributaries' definable floodplains to experiment with modes of irrigation control found in dams, embankments, ditches, and drains. By 1716, René Ravenel used a limestone spring, formed from a downdip in the Floridian aquifer system, to irrigate his Pooshee Plantation rice fields. Occurring more frequently in the Penholoway Terrace, these artesian springs, or fountains by the local residents, provided consistent water flow for rice plantations throughout the Biggin Swamp community. Pooshee Springs was one of six notable fountains bordering the basin that established this area as one of the central rice zones in colonial South Carolina (Smith 2012). In turn, as Max Edelson described, enslaved labor "made comparatively simple alterations to the land that took advantage of the existing contours of its topography" (Edelson 2006). Slaves dug into Pooshee's gray, sticky sandy clay loam and threw a dam between the higher fine sandy loam to form a reservoir. Up to seventeen slaves then constructed a second dam to impound spring fed water and maintained the modest twelve-acre enclave.

Towards the coast, the Princess Anne Terrace's brackish tidal rivers presented new challenges for early rice cultivators. Because the terrace complex's close proximity to the ocean, Princess Anne began at sea level with a gently inclined slope up to twenty feet (Willoughby and Doar 2006). The ocean's incoming tide pushed a salt wedge of brackish water against the downward flowing rivers. While freshwater hydrology became a critical component for tidal irrigation on the Cooper River, the Wando River's limited watershed did not generate enough flow to initiate this hydraulic machine. Millennia of the Wando's ebb and flow through the maritime floodplains created an interwoven chain of creeks and tributaries. To utilize this environment, planters had to construct earthen barriers to prevent the brackish tidewater from flowing into these low-lying watercourses.

Richard Beresford's use of a circumventer shaped network of tidal creeks on Charleywood Plantation represents how planters initially attempted to cultivate this environment. Charleywood rice fields contained the basic structure as discussed at Pooshee, yet the lack of elevation change on the Wando River floodplains created different aesthetic. Whereas Pooshee Swamp consisted of a relatively straight watercourse from the spring, Charleywood's tidal creeks came from multiple directions, wrapping around subtle highland knolls, and converging in Guerin Creek. Pooshee's rice field consisted of a single system of two dams bordering the rice. Charleywood, however, relied on dams to partition seventy-five acres into seven field divisions that allowed improved irrigation control compared to flooding a single unit. Five divisions average five acres apiece, while the remaining two garaged twenty-five acres apiece. Because early inland fields were limited to narrow watercourses, their acreage did not compare to later tidal systems sprawling across broad floodplains. However, early inland cultivators still had to pay attention to subtleties of the land, realizing when an impounded field was too big to effectively draw water on and off the fields. By subdividing the fields, even in situations where water directly flowed from one field to the next, cultivators could manage the amount of water volume on individual plots flooding the entire crop more consistently in shorter distances with a low elevation run compared to one elongated field with a greater elevation change. However, irrigation problems resulted from people having to flood each division in order from the lowest elevation to the highest elevation. This process offered little flexibility in flooding individual sections as lower fields had to rely on water impounded upstream (Smith 2012).

By the mid-1700s, planters and their enslaved laborers began settling into new inland environments and expanding previously unaltered terrain. New agricultural methods emphasized that rice cultivators take command of water to secure flooding and draining of fields. Planters sought solutions to pressure of freshets breaching reservoir dams, plus enable systematic flooding and draining of fields. Flanking canals, dredged waterways that abutted exterior field embankments, optimistically provided an answer to this problem. These canals allowed cultivators to irrigate fields unilaterally through trunks without having to flow each division. Planters' ability to control water was essential when rice fields were on different cultivation schedules, either by a few days to over a month. Also, trunk minders could add or remove water as they saw fit without having to disrupt flood stages on adjoining fields. Staggering flood schedules avoided possible depletion of impounded water, as springs and creeks could recharge the reservoirs before the next flood cycle. During freshets, trunk minders could release excess water through the flanking canals, bypassing the rice fields, and relieving pressure on the back dam.

Planters understanding of water control coinciding with their motivation to increase rice acreage let to new methods to drawing water onto and off the rice fields. Windsor Plantation represented how flanking canals took shape. Windsor's fields fit within the tight boundary of the Nicholson Creek floodplain. The elevation difference between pineland communities and the cypress hardwood forest varied between thirty to forty feet within one thousand feet, as the Bethera Scarp's geological "unconformities" allowed Nicholson Creek to gorge out steeper "landscape gradients" compared to the Penholoway and Queen Anne Terraces. (Colquhoun 1965) The watershed's has a dramatic elevation change compared to the five to ten foot elevation decline in the same one thousand foot increment along the Cooper River tidal floodplains. Through the eighteenth century the Roches optimistically surveyed four divisions within the confines of the scarp to the northwest and the Talbot plain's highlands to the southeast. Yet they has one division of forty-five acres developed for rice cultivation with twenty-four "mostly country born" people under their control. (Anon. 1784) The Roches relied on the predominant knoll forming Nicholson Creek's southern boundary to contain the inland rice fields. Forming a crescent shape around a forty-foot bluff, Nicholson Creek connected with Turkey Creek to form the Huger Creek and serve as the headwaters of the Eastern Branch of the Cooper River. This bluff served as an optimal site for the Windsor house, slave settlement, and outbuildings.

By 1725, Patrick Roche of Windsor Plantation ordered twelve enslaved labors to sculpt fields out of the Nicholson Creek cypress bottomlands. Fishbrook Field, named after the neighboring plantation on Turkey Creek, was the result of cutting trees, removing cypress stumps, and shaping forty-five acres of land. Nicholson Creek's meandering channel passed the Fishbrook Field's western border, separated by an earthen embankment. The Roches then diverted the creek away from the middle of the floodplain by embanking a fifty-five acre division and channeling water into a flanking canal (Fig. 2). Unlike Fishbrook Field, the second field division impeded the natural watercourse with an earthen dam and then redirected the creek around the western perimeter (Windsor Plantation [Plat]. 1790). A variation of this system consisted of two canals flanking the fields on each side. Duel canals increased efficiency of moving water around fields during freshets and also providing additional flexibility flooding and draining individual divisions. Slightly higher elevation enabled planters to cultivated corn, peas, and indigo at additional provisional an economic crops.

As the mid-century Lowcountry plantation enterprise became firmly entrenched with Atlantic markets, inland planters began to initiate more aggressive irrigation practices from a combination from increased enslaved labor, acquired agricultural knowledge, improved canal networks, and suitable cultivated landscapes. As a result, developing inland field systems took on a new aesthetic moving away from small acreage with naturally fluid boundaries to larger field divisions with geometrically

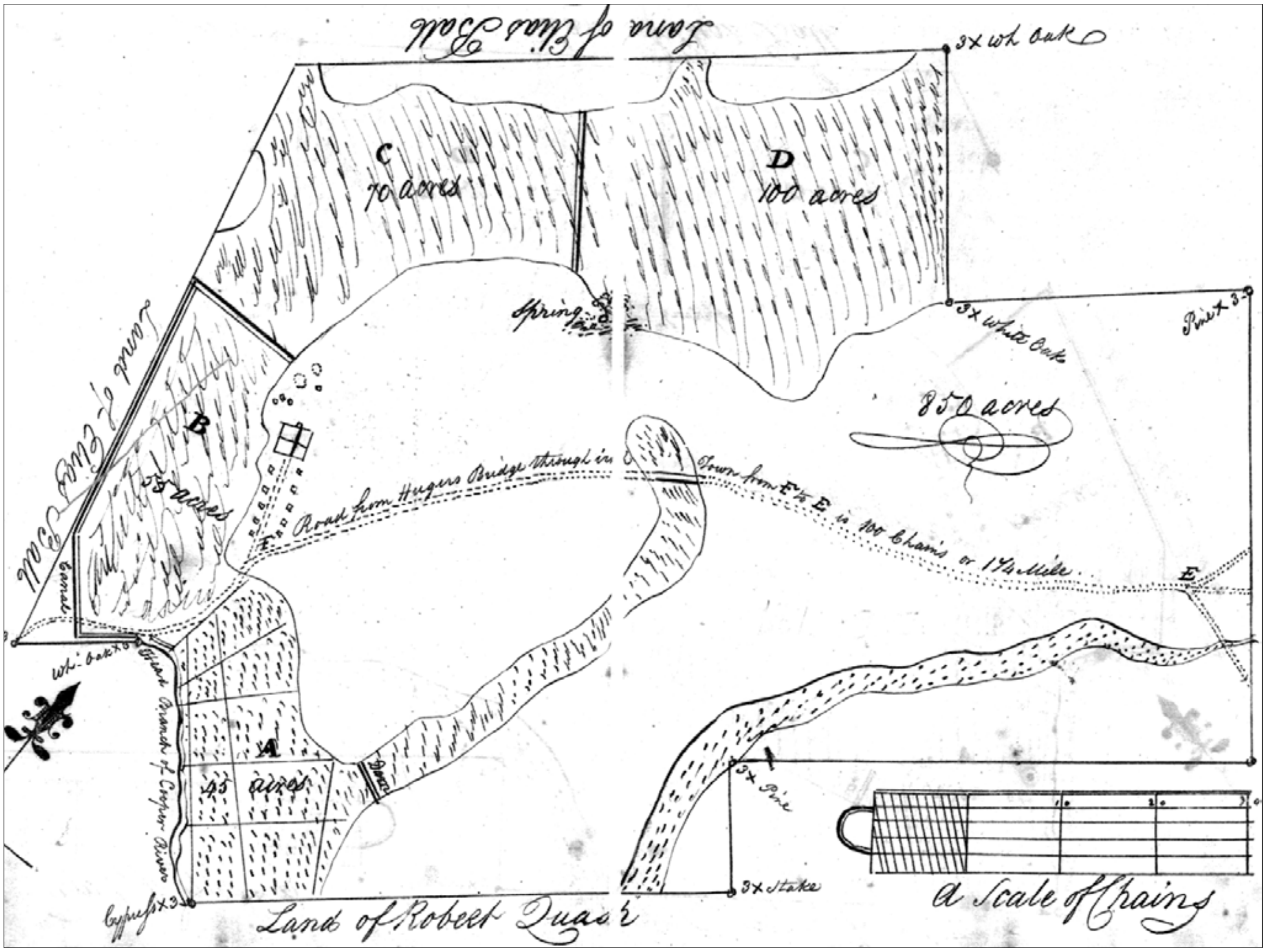

Figure 2—Windsor Plantation, with rice fields in division "A" and flanking canal wrapping around division "B"

rigid embankments. The changing aesthetic correlated with emerging tidal irrigation. By the latter half of the eighteenth century, Richard Beresford, Jr. depended upon upwards of two hundred fifty-three enslaved laborers to expand his Charleywood Plantation fields.

Beresford's massive enslaved labor force carved an intricate grid-like formation of canals, ditches, embankments, and dikes over three hundred fifty acres, forming twenty-three field divisions that averaged fifteen acres apiece (Fig. 3). The new field system was built on older Pleistocene deposits, which consisted of more clay and shell to retain water compared to the plantation's lower sandy loam field system. To irrigate Charleywood's larger rice fields, enslaved cultivators relied on two reservoirs located on the Cainhoy Scarp. With a larger watershed of scale compared to earlier examples, the reservoirs impounded over forty acres of water flowing from meandering creeks and bays common to the Lower Coastal Plain's scarps, where canals channeled the water in a linear downward motion.

Charleywood spatial patterns also shifted in relation to the plantation's rice cultivation. Early Charleywood inhabitants lived on slightly elevated land located approximately one-tenth mile west and only four to five feet above the original rice fields, however the settlement was abandoned by 1772. According to one eighteenth century resident, planters built their homes on the "Edge of Swamps, in a damp moist Situation" because they wanted "to view from their Rooms, their Negroes at Work in the Rice Fields." By overlooking developed agricultural spaces, planters' views of progress, order, and labor management reflected the romantic perception of the inland landscape. However, early eighteenth century colonists did not understand the connections between malaria-carrying anopheles mosquitoes and low-lying habitats. What resulted from this ill perceived settlement pattern resulted in significant mortality rates. Approximately thirty-seven percent of white males and forty-five percent of white females born between 1721 and 1760 and surviving into adulthood in St. John's Parish died before their fiftieth birthday. Charleywood's

Figure 3—Charleywood Plantation, with new rice fields on top and old rice fields on bottom

Christ Church Parish offered more dire statistics, where eighty-five percent of all white males born between 1721 and 1760 and surviving into adulthood died before their fiftieth birthday (Merrens and Terry 1984).

By the 1770s, two new settlements appeared on the Charleywood landscape. The upper settlement, built in the Cainhoy Scarp's sandy pine flatwoods community, was more than likely relocated for healthier living conditions. Because Beresford was an absentee planter, the upper Charleywood settlement housed the plantation overseer and slaves. The other half of Charleywood's enslaved population also had to endure exposed and sickly conditions at the second settlement located in the middle of the new rice fields. The centrally located Bay Hill settlement consisted of four houses, a corn house, a mite pen, and a sick house. Bay Hill residents lived on an isolated stretch of high land approximately one hundred feet wide and four hundred sixty feet wide nestled between the Fairlawn Canal and surrounding rice fields.

CONCLUSION

Combining increasing water control projects and ever-expanding enslaved labor population with an established Lowcountry rice market economy and emerging tidal irrigation technology, inland rice field practices changed dramatically by the antebellum period. Where planters in these environments were limited by water control on and off their fields, the increasing network of canals and drains made expanding field divisions more economically accessible. Yet enslaved African-Americans were forced to dam more streams for reserve water, dig up soil for earthen embankments, and cultivate more acres of rice. Studying places like Pooshee, Windsor, and Charleywood reveal the ecological complexity of these plantation systems. This form of rice cultivation not only required that cultivators maintain a critical understanding of how to grow rice, but also how to utilize the surrounding landscape to the best of their ability. Planters and slaves had to control water through floodplains, yet not fall victim to natural disasters, such as freshets or droughts. To see how these people dealt with water control provides a broader picture in understanding specific cultivation methods. This story moves beyond how people planted the crop, but also how they shaped the land within geographical limitations to effectively irrigate rice and develop settlement patterns. By connecting the larger environment with these specific micro-topographies, one may further understand how the Lowcountry topography played a role in shaping culture and society as a whole.

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CLAY IS EVERYTHING: ARCHAEOLOGICAL ANALYSES OF COLONIAL PERIOD INLAND SWAMP RICE EMBANKMENTS

Andrew Agha[1]

Rice became the market export crop in the early eighteenth century that made South Carolina become an economic and agricultural powerhouse after many exotic tropical cultivars failed (Carney and Porcher 1993, Carney 1996, 2001, Littlefield 1981, Fields-Black 2008). In the late 1990s, scholars had laid out a line of evidence that reveals the roles enslaved West Africans played in the Carolina Lowcountry in regards to rice: the methods of planting, the technology needed to make it grow in flooded conditions and the methods required to prepare it for market (Carney 2001). Once the African element was realized, studies of Carolina's rice culture leaned more towards unlocking the ethnic components of rice cultivation; or, put more bluntly, who was responsible for what components of rice technology and agriculture (Alpern 2013).

Fueled by cues from major scholars (Carney 1996, Ferguson 1992, Joyner 1984, Littlefield 1981, Wood 1974), I set out to employ historical archaeology on a, at the time, presumed inland swamp rice field embankment that I believed was used for water control (Agha 1999, 2001). This embankment sits along the line separating higher dry ground from lowland hardwood swamp near Willtown Bluff, South Carolina, located on the South Edisto River. My excavations in this embankment yielded intact soils that revealed the processes involved in its construction. My 7x3 foot cross sections also recovered datable ceramics and artifacts that allowed me to interpret who the original embankment and rice field builder was (John Smelie, years of tenure: 1719-1727), and these artifacts also helped me identify a later repair episode to the bank sometime in the 1750s or early 1760s (James Stobo, years of tenure: 1740-1767) (Agha 1999, 2001, Agha and Philips 2009).

The sequence for the construction steps for this embankment are not simple ditch digging and piling of earth in a line haphazardly, as it would appear from simple outside observation. The soil profile instead shows a complex configuration of soil types and textures that allowed this earthwork to remain intact and unharmed by nature's reclamation of the old plantation lands since roughly 1800. First, the enslaved West Africans, probably already familiar in some ways with rice cultivation, approached this virgin piece of landscape and started digging two ditches parallel to each other with a 10 foot space between. The humus was piled on top of the original ground surface in between the ditches. When the enslaved started to dig into the subsoil, here a silty sand followed by a clayey sand, they piled that up along the man-made ridge next. Figure 1 displays the cross section profile and photo, showing these events. The artifacts that show the repair episode lie between the subsoil core and the topmost darker fill. This particular embankment is roughly 2,000 feet long and is in a perfect line with no angle changes or turns.

This embankment was needed to drain an adjacent work area to the north, and its ditches also served as transport for water to drain from the uplands down towards the river swamp where I identified a fresh water reservoir for formal inland rice fields. Ten years after conducting these first excavations I had the opportunity to dig a cross section in a bank within identified inland rice fields. This bank lies at the headwaters of the Bluehouse Swamp

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near Ladson, South Carolina, and belonged to a plantation that likely started rice agriculture before 1740 (Agha and others 2010). This bank has a parallel twin, and together these banks support a major ditch or minor canal. Water has flowed between these berms since the late eighteenth century. While similar to the Willtown example – water transport – the methods of construction are very different.

The enslaved first excavated a wide swath of humus that included the space for the ditch and both embankments. Once they reached subsoil clay, they then excavated the ditch deeper (refer to bottom of Fig. 1). The clay quarried out of the ditch was then piled carefully on

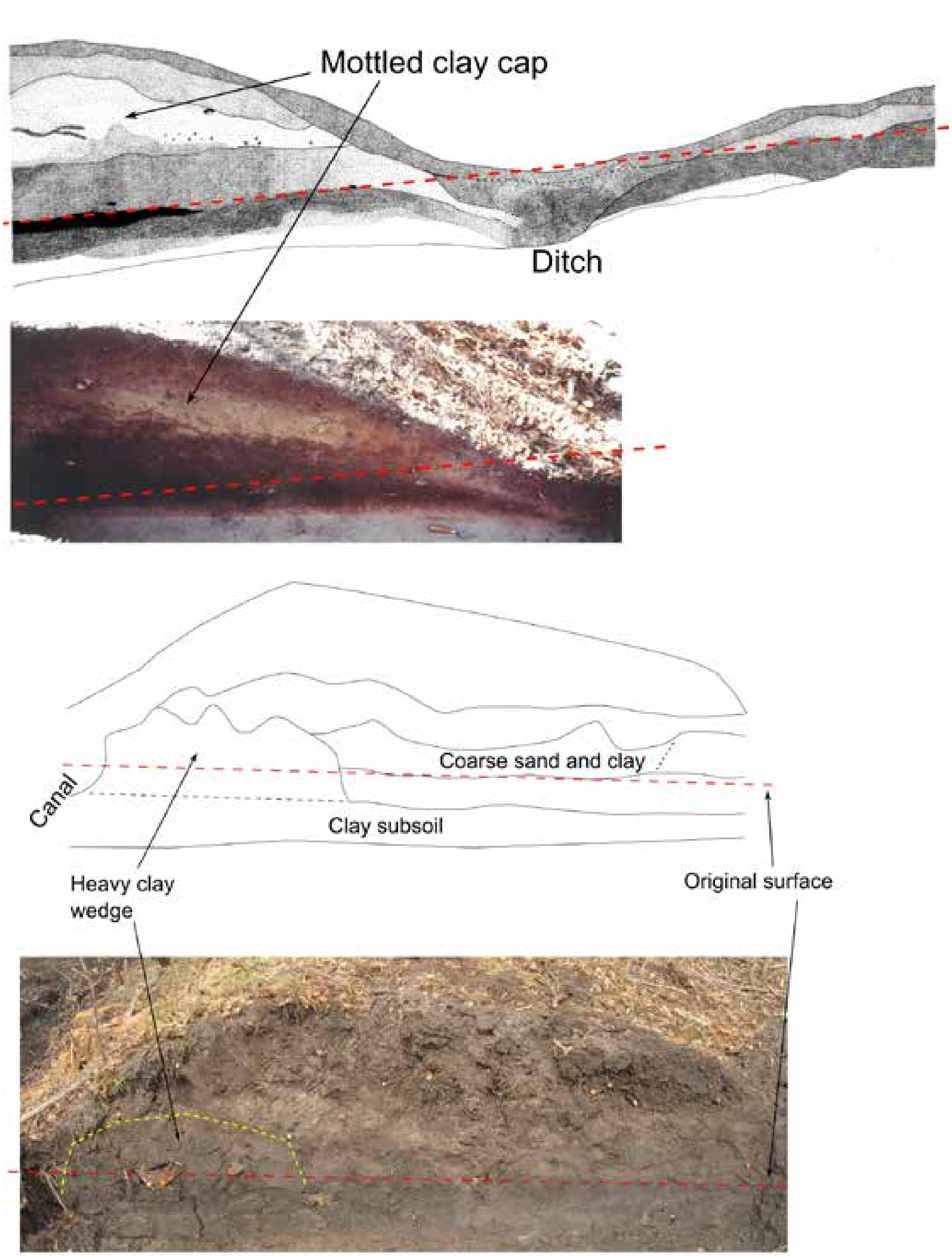

Figure 1—Profile drawing and photo of embankment excavation at Willtown (top), profile drawing and photo of embankment at Bluehouse Swamp (bottom).

either side of the cut, so that two linear mounds or "walls" were constructed on either side of the ditch. Then, coarse sand from a foreign location was piled up next to the clay ridge opposite the ditch. The enslaved Africans then mixed large lumps of clay the size of softballs into the piled sand. Overlying this clay ridge and coarse sand is a homogenous silty loam and clay mixture, followed by a homogenous clayey loam to cap the bank and create the surface. The coarse sand does not occur naturally in either the swamp or terrestrial landscape; its origination, function and purpose are unknown. It may have facilitated stability or drainage within the bank. Besides the presence of this sand, the use of clay here is a revelation.

West Africans have constructed buildings out of clay and earth for centuries. They have made pottery for almost 8,000 years (Clark 1970). As slaves, they had an ancestral knowledge of clay that far surpassed the personal experience of their British owners. The enslaved married the clay fill to the intact surface of the clay subsoil so perfectly I was unable to discern a line separating the two. In essence, these banks create a "clay pipe" for major water transport, and exhibit a foresight not seen in any of the seven embankments I have excavated in both swamp and upland settings. Clay cores have been identified in several upland examples, but the use of clay in this fashion shows a technology that has not been identified in the Carolina Lowcountry before. The two embankments I present here are similar in function but different in scope. Rice field construction was not simple "ditch-digging" by mindless workers beaten by the Middle Passage and their planter-owners. It was instead a hydrological engineering marvel concocted through cultural interaction and expertise. Future studies of banks throughout the Lowcountry could reveal correlates between England's drained fens and West Africa's mangrove rice fields. Regardless of their roots, inland rice embankments are the largest surviving architecture made by not only African hands, but possibly of African minds.

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ADVANCED GEOSPATIAL TECHNIQUES AND ARCHAEOLOGICAL METHODS TO INVESTIGATE HISTORICAL RICE CULTIVATION AT WORMSLOE HISTORIC SITE

Alessandro Pasqua[1]

Despite much of the environmental history of Wormsloe State Historic Site on the Isle of Hope, Georgia having previously been documented and described, there are still some aspects that require deeper investigation. For example, whether rice cultivation was ever performed at Wormsloe is a question which does not have a definitive answer. The primary goal of this study, therefore, is the investigation of the Isle of Hope landscape through remote sensing techniques such as terrestrial laser scanning (TLS) and unmanned aerial systems (UAS) to identify archaeological evidence related to historical rice cultivation. Terrestrial laser scanning will be employed to create an accurate and high resolution 3D bare earth digital elevation model (DEM) of the areas under investigation in order to analyze present-day microtopographic features that may be indicative of old rice fields such as ditches, dikes, and embankments. Furthermore, the use of UASs will provide a detailed aerial view of the study areas that can be used to generate a geovisualization of the historical topography and landscape potentially present during the late 18th century and throughout the 19th century. The collection of multiple images of the terrain from different angles will allow the employment of an emerging technique in photogrammetry known as Structure from Motion (SfM) to create 3D models of the areas under investigation. This study also employs archaeological methods such as phytolith analysis to determine the presence of rice plant deposits in the areas where historical rice cultivation is suggested. The results of this study will improve the current understanding of Wormsloe's historical land use and development, as well as its archaeological and historical significance.

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Coastal Drought

DROUGHT AND COASTAL ECOSYSTEMS: AN ASSESSMENT OF DECISION MAKER NEEDS FOR INFORMATION

Kirsten Lackstrom, Amanda Brennan, Kirstin Dow[1]

The National Integrated Drought Information System (NIDIS) is in the process of developing drought early warning systems in areas of the U.S. where the development and coordination of drought information is needed. In summer 2012, NIDIS launched a pilot program in North and South Carolina, addressing the uniqueness of drought impacts on coastal ecosystems. The monitoring and management of drought in coastal regions presents several challenges. While commonly used drought indices incorporate data such as rainfall, streamflow, soil moisture, groundwater levels, and snow pack, such indices were developed for upland areas and may not be appropriate indices for characterizing coastal drought. Furthermore, current systems of drought management focus primarily on agricultural impacts, fire risks, and maintaining water supplies for municipal and industrial use, energy production, and navigation. Understanding of drought impacts on other interests and sectors (e.g. environmental resources, public health, and water quality) remains limited. In addition, these impacts are currently not well integrated into existing planning and response processes at national, regional, state, and local levels.

This paper introduces the NIDIS-Carolinas program and provides information about one of the pilot projects. Interviews with fishermen, outdoor recreation business owners, and land managers in the Beaufort County (SC) and Carteret County (NC) areas were conducted to document and assess local-level experiences with drought and decision makers' needs for drought information and resources in the coastal Carolinas. Their concerns center on water quality conditions, particularly salinity levels and fluctuations, and the availability of freshwater to meet the needs of coastal animals, plants, and habitats. Fluctuating salinity levels affect the movement, location, and abundance of many aquatic species, thereby affecting their accessibility to fishers. On managed lands, drought conditions increase fire risks and make impoundments unsuitable for waterfowl and fish, thereby affecting conservation objectives and limiting recreational use of those areas. Interviewees do not regularly use formal sources of drought information but consider a range of locale-specific information related to weather (precipitation, temperature), salinity, wind, tides, and other environmental conditions in making decisions. Interviewees indicated interest in baseline data regarding "normal" and extreme hydroclimate conditions and integration of drought information with other coastal and ecological monitoring efforts. Findings from this project will help inform other components of the program, including the development of a drought index for coastal regions based on USGS real-time salinity measurements, the identification of ecological thresholds, and testing of ecological indicators of drought for coastal ecosystems.

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DEVELOPMENT OF A COASTAL DROUGHT INDEX USING SALINITY DATA

Paul Conrads, Lisa Darby[1]

The location of the freshwater-saltwater interface in surface-water bodies is an important factor in the ecological and socio-economic dynamics of coastal communities. It influences community composition in freshwater and saltwater ecosystems, determines fisheries spawning habitat, and controls freshwater availability for municipal and industrial water intakes. These dynamics may be affected by coastal drought through changes in Vibrio bacteria impacts on shellfish harvesting and occurrence of wound infection, fish kills, harmful algal blooms, hypoxia, and beach closures.

Many definitions of drought have been proposed, with most describing a decline in precipitation having negative impacts on water supply and agriculture. Four general types of drought are recognized: hydrological, agricultural, meteorological, and socio-economic. Indices have been developed for these drought types incorporating data such as rainfall, streamflow, soil moisture, groundwater levels, and snow pack. However, these drought indices were developed for upland areas and may not be appropriate indices for characterizing drought in coastal areas. Because of the uniqueness of drought impacts on coastal ecosystems, a need exists to develop a coastal drought index. The availability of many real-time and historical salinity datasets provides an opportunity to develop a salinity-based coastal drought index.

The challenge of characterizing salinity dynamics in response to drought is excluding responses attributable to occasional saltwater intrusion events. We applied various statistical and numerical techniques to evaluate the most appropriate approach to develop salinity drought indices. An approach similar to the Standardized Precipitation Index was modified and applied to salinity data obtained from sites in South Carolina and Georgia, USA. Coastal drought indices characterizing 1-, 3-, 6-, 9-, and 12 month drought conditions were developed. Evaluation of the coastal drought index indicates that the index can be used for different estuary types (for example, brackish, olioghaline, or mesohaline estuaries), for regional comparison between estuaries, and as an index for wet conditions (high freshwater inflow) in addition to drought conditions. The development of the various drought characteristic intervals (1-, 3-, 6-, 9-, and 12 month) allow for the coastal drought index to be correlated with environmental response variables that occur on different time intervals.

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A WATERSHED-SCALE CHARACTERIZATION OF DISSOLVED ORGANIC CARBON AND NUTRIENTS ON THE SOUTH CAROLINA COASTAL PLAIN

Daniel L. Tufford, Setsen Altan-Ochir, Warren Hankinson[1]

Dissolved organic matter (DOM) is recognized as a major component in the global carbon cycle and is an important driver of numerous biogeochemical processes in aquatic ecosystems, both in-stream and downstream in estuaries. This study sought to characterize chromophoric DOM (CDOM), dissolved organic carbon (DOC), and dissolved nutrients in major rivers and their tributaries of the South Carolina Coastal Plain as a screening assessment of the impact of land cover, soils, stream order, and other factors on DOC characteristics and water quality. During eight trips from June 11 to July 9, 2014 throughout the South Carolina Coastal Plain, we visited 54 sites and collected water samples for laboratory analysis of DOM ultraviolet absorbance and concentrations of DOC, dissolved organic nitrogen (DON), and dissolved inorganic nitrogen (DIN). Sample sites included headwater wetlands and springs, streams and rivers, and water table monitoring wells. Spectral analysis of the filtered water samples was done from 200-800 nm using a Shimadzu UV-1700 spectrophotometer. We calculated the spectral ratio (SR, the ratio of slope coefficients at 275-295 nm: 350-400 nm) to facilitate broad characterizations of the nature of the CDOM in the water based on stream order, water type (black, brown, clear), and physiography (lower Coastal Plain (LCP), upper Coastal Plain (UCP)). We performed analysis of variance (ANOVA) to test for significant differences ($p<.05$) in measured values and interaction and multiple regression to determine dominant influences of land cover and soils. Dependent variables were DOC, SR, DON, and DIN. Independent variables were proportions of land cover types and soil order. ANOVA showed the largest concentrations of DOC occurred in black water and in low order streams. The DOC concentration was larger in black water on the LCP than the UCP. There were significant differences in SR (lowest in LCP and low order streams), DON concentration (largest on LCP), and DIN (largest in clear water on the UCP). Regression analysis indicated that most of the variability in DOC concentration was explained by amount of forested wetlands and soil type (mostly Spodosols) in the watershed. Most of the variability for both DON and DIN was explained by the amount of agricultural land cover although for DON some soil orders were dominant on the LCP and in low order streams. There were few significant regression models for SR and no clear patterns. Our results indicate that low order streams on the Coastal Plain are important channels for delivery of high molecular weight organic carbon to coastal estuaries.

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THE EXTENT OF TIDAL INFLUENCE IN THE WACCAMAW RIVER, SOUTH CAROLINA

Benjamin Thepaut, John Shelton, Susan Libes, Paul Conrads, Robert Sheehan[1]

The Waccamaw River Basin is located in the coastal plain and meanders from North Carolina to South Carolina. This tidal black-water river flows parallel to the coast past the cities of Conway and Georgetown, terminating in Winyah Bay. The river is hydrologically connected to the Atlantic Intracoastal Waterway (AIW) and experiences semi-diurnal tides with a range classified as micro-tidal (< 6.5 feet). The semi-diurnal tidal amplitude in the Waccamaw River declines with increasing distance upstream from Winyah Bay and the AIW. Temporal variations in the longitudinal tidal gradient of Winyah Bay, AIW, and the Waccamaw River reflect varying effects of astronomical tides, weather, and streamflow.

Streamflow data collected at Reaves Ferry at river mile 63.0 showed that when water levels receded in early September 2013, a semi-diurnal tidal amplitude of 0.4 to 1.0 feet was recorded in addition to reversing stream velocity. Improved understanding of the hydrology at these tidal freshwater reaches would provide valuable information for water-resource and land-use planning and management.

In order to explain the temporal difference in variance a time series model, Auto Regressive Integrative Moving Average (ARIMA) was used in the analysis of the tidal reach based upon hourly averaged observations from 06/21/2013 to 09/12/2014. The upstream, local, and downstream data were hourly averaged and analyzed with a multiple regression and ARIMA. A multiple regression model was used to systematically show that all the predictors were significant (r^2=0.921, <0.03 at p=0.05) in describing variance of water level at Reaves Ferry. Results from the ARIMA show that all tidal reach predictors were significant (<0.00 at p=0.05) in describing water level at Reaves Ferry.

The low gradient of the coastal plain and low river flow allow for significant tidal influence along the Waccamaw River. The ARIMA time-series model was successfully able to delineate the hydrograph at Reaves Ferry of tidal and non-tidal scenarios. At the monthly-scale, there are clear patterns between downstream and upstream predictors, which are shown or are evident in the Reaves Ferry hydrograph. The frequency and duration of flooding in tidal freshwater forested wetlands is highly variable based on these predictors in the Waccamaw River. Future study plans aim to examine the distribution of TFFW and analyze water-quality events in conjunction with tidal processes. This information aims to benefit local scientists and highlight the importance of USGS long-term gaging stations.

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New Insights into Studies on Long-term Experimental Watersheds to Address Contemporary Emerging Issues

(PART 2)

HYDROLOGIC CHANGE IN A COAST REDWOOD FOREST, CASPAR CREEK EXPERIMENTAL WATERSHEDS: IMPLICATIONS FOR SALMONID SURVIVAL

Elizabeth Keppeler[1]

Abstract—The 52-year record of streamflow from the Caspar Creek Experimental Watersheds shows a trend toward decreasing rainfall and streamflow during the fall season when coho salmon *(Oncorhynchus kisutch)* migrate upstream to spawn. Rainfall records show a slight declining trend in fall totals and a slight increasing trend in spring totals since 1962, but only November shows a significant decrease in rainfall with year. Mean daily flows between late-October and mid-December declined by about one third. "Fish-passage" flows became less frequent in November. These flows were correlated with adult coho abundance estimates. The first-of-season peak flow, needed to breach the seasonally-formed sandbar at the Caspar Creek estuary and open access to upstream spawning habitat, occurred later. Results were similar on the South Fork (logged 1967-1973) and North Fork (logged 1985-92).

INTRODUCTION

During the fall and winter of 2013-14, coho salmon (*Oncorhynchus kisutch*) were thwarted from making their annual migration from the ocean to their native streams along much of California's coast because of persistent drought and lack of streamflow. These anadromous fish are acutely dependent on fall freshets, which ordinarily breach seasonally-formed sandbars at river mouths and open access to the spawning habitat of north and central coast streams. Although numerous factors affect salmonid survival and productivity, climatic variation (including severe storms, drought, El Niño-Southern Oscillation (ENSO), and hydrologic regime shifts) can alter both marine and freshwater habitat conditions and impact salmonid abundance. The marked decline of California's coho populations triggered federal listing in 1996 and 1997 under the Endangered Species Act, as well as state listing in 2005. Maintaining and increasing the number of spawning adults is a key goal for coho recovery (CDFG 2004, NMFS 2012). Adequate flows for fall spawning, spring out-migration, and summer rearing conditions are essential to species survival along the California coast south of Punta Gorda.

Climatic change is affecting background environmental conditions and may result in altered timing, magnitudes, and frequencies of hydrologic processes. Shifts in runoff have been documented in mountainous, snowmelt-dominated watersheds of the western U.S. (Safeeq and others 2014, Peterson and others 2008, Stewart and others 2004). Null and others (2010) reported changes in centroid timing (CT) of runoff in high elevation west-slope Sierra Nevada watersheds, but found little change in runoff timing in low elevation watersheds that did not reach the Sierra Nevada Crest. In north coastal California, Madej (2011) examined long-term climate data and runoff records from 19 gauged watersheds and found no trends in annual rainfall other than a decrease in September. No change in the CT was detected in these lower elevation coastal streams. Summer low-flow (defined as 7-day minimum) decreased at 10 of the sites, including North Fork Caspar Creek. Burt and others (2014) examined the impacts of extreme climatic variability on post-logging streamflow response at the H.J. Andrews Experimental Forest, Oregon. Because interannual variability is high relative to long-term climate trends (Abatzoglou and others 2014), data sets spanning multiple decades are essential for analyzing the hydrologic response to climatic variation and forest management.

For this analysis, 52-year rainfall and streamflow records from the Caspar Creek Experimental Watersheds were used to explore trends in the seasonal distribution of precipitation and runoff with particular emphasis on the critical fall period when coho migrate to the headwaters of Caspar Creek. Understanding these trends is essential if strategies are to be developed for effectively managing water resources and mitigating potential harm to endangered salmonid populations resulting from altered hydrologic regimes.

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STUDY AREA

Caspar Creek is a perennial fifth order coastal stream draining 21.7 km^2 of largely forested topography in the Coast Range of northern California. At its headwaters, 10 km from the Mendocino coast, elevations attain 322 m and hillslopes can be as steep as 60° (Fig. 1). The forest, composed primarily of coast redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*), was first logged from the 1860's to 1904 and continues to be managed for research and timber production in the modern era.

Two experimental watersheds, the 473-ha North Fork (NF) and the 424-ha South Fork (SF), occupy the Caspar Creek headwaters in the Jackson Demonstration State Forest. Within the experimental watersheds, rainfall, streamflow, and sediment yields have been measured continuously since 1962 as part of a long-term partnership between the California Department of Forestry and Fire Protection and the U.S. Forest Service. Road construction and harvests of second-growth timber were carried out in 1967, 1971-1973 (SF) and in 1985-1986, 1989-1992 (NF). Beginning in 1962, NF and SF streamflow has been

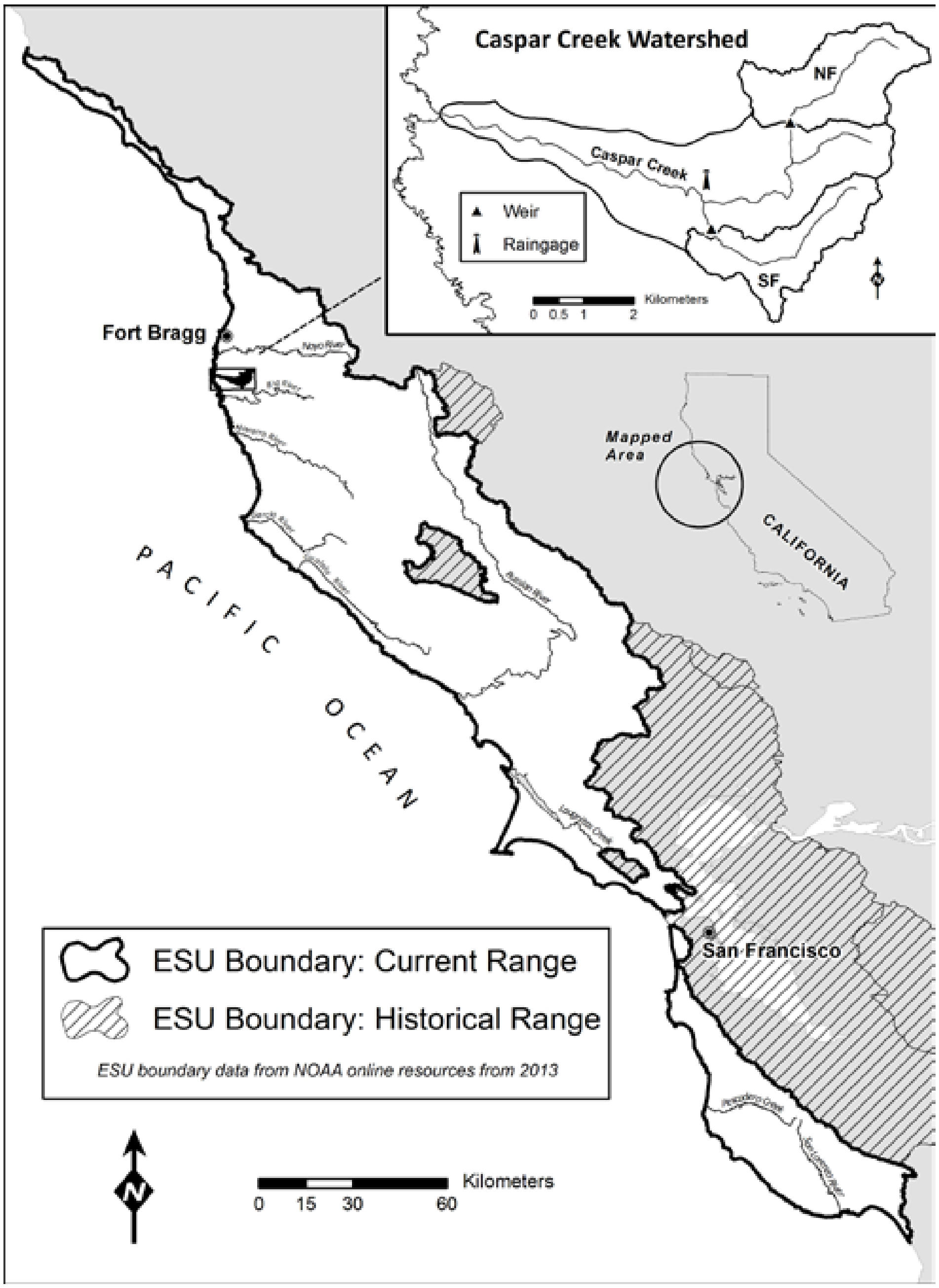

Figure 1—Central California Coast Coho Salmon Evolutionarily Significant Unit and Caspar Creek Watersheds.

measured at sharp-crested compound weirs, and recording rain gauges have been in operation at multiple elevations (Henry 1998).

Annual precipitation averaged nearly 1150 mm and varied from 305 mm to 2202 mm over the 52 year record at the S620 rain gauge (Fig. 1). Snowfall is rare and hydrologically insignificant. Roughly 95 percent of annual rainfall occurs between October and April, with the centroid of annual precipitation occurring in mid-January. Night and morning fog occurs frequently during summer months. Temperatures are mild, with mean monthly temperatures ranging between 7°C and 15°C. Stream temperatures measured above the NF weir are considered to be within the desirable range for native fish, with weekly averages peaking during August-September at 13 to 15.5°C and dropping to winter minimums of 5 to 7°C.

Caspar Creek lies within the Central California Coast Coho Salmon Evolutionarily Significant Unit (CCC-ESU) and supports anadromous coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) along 14 km of channel. Coho travel upstream in mid-November through early January to spawn. Eggs hatch after five to seven weeks, and fry emerge from stream gravels during March through May or later. As the summer progresses, juveniles move to deeper pools to feed and grow. Coho typically emigrate to the ocean as yearlings from April through June, and then return to their native streams to spawn after two years in the ocean (CDFG 2004). Both spawning and out-migration are triggered by short-term increases in discharge and changes in stream temperature. Estimates of "escapement," the number of adult salmon surviving the marine environment to return to spawn, are used to monitor current abundances and predict future populations. These data demonstrate high interannual variability and declining regional abundance (Gallagher and others 2014) despite the implementation of fishing restrictions, increasingly stringent habitat protection measures, and major restoration efforts in recent decades.

METHODS

Daily precipitation totals measured near the confluence of the SF with mainstem Caspar were used in this analysis. Trends in monthly and seasonal precipitation were examined using linear regression with water year (here considered to begin on August 1st) as the independent variable. In addition, because fall rainfall accumulations must increase discharges enough to erode the sandbar that forms at the mouth of Caspar Creek before coho can return to spawn, exceedance dates for seasonal thresholds of 300 mm and 500 mm were calculated for each year. Field experience suggests that 300 mm of cumulative precipitation is necessary to diminish the soil moisture deficit sufficiently to generate a storm flow, and 500 mm is needed to wet up the soil profile to groundwater depth.

NF and SF ten-minute discharges, mean daily flow (MDF), and instantaneous peak flows were examined. Flow data for hydrologic year (HY) 1977 and early HY63 were unavailable. Several approaches were used to evaluate changes in seasonal flow over the 52-year record. Analysis was first performed graphically to visually compare streamflow patterns by decade. The mean and median MDF by date were calculated for each decade, and 30-day averages were computed to smooth the resulting flow index. This visual analysis revealed a fairly distinct divergence in the later two decades relative to the first three, and the data were consolidated accordingly into two groups: HY63-92 and HY93-12. The difference in average MDF between the two groups was then assessed to provide a measure of change in the seasonal runoff patterns. Additionally, the data were divided into two groups of equal years for T-test comparisons of mean MDF in the earlier versus later streamflow record.

Next, flow durations for fall "fish-passage flows" were tallied from 10-minute discharge records. Passage flows for adult anadromous salmonids encompass a range of 85 to 1331 L s^{-1} according to NOAA Fisheries and California Department of Fish and Wildlife design guidelines for the Caspar Creek fish ladders (Winzler & Kelly and others 2006). For each water year, instantaneous discharges within this range were tallied by month for the November to January spawning season, omitting HY63 and HY77 where the records were incomplete. These flow durations, expressed as cumulative days, were regressed against water year to evaluate trends. Caspar escapement estimates were regressed against seasonal passage flow durations to determine if coho returns were correlated to these flows. Escapement estimates were only available for 2000-2014 (Gallagher and others 2014).

Lastly, the seasonal distribution of storm peaks was explored. NF instantaneous peak flows greater than 680 L s^{-1} were tallied by date. Although the threshold is arbitrary biologically, this magnitude of peak flow (0.15-year recurrence interval at the NF weir) is used to define storms for many of the flow and sediment yield analyses performed on the Caspar Creek data set. Caspar Creek flows of this magnitude are sufficiently powerful to erode the sandbar at the mouth and typically result in elevated discharges of sufficient duration for coho migration to occur. The date of the first fall peak, the last spring peak, and the length of the storm season (expressed as the number of days between the two) were calculated for each water year. Regression analysis was used to evaluate trends.

RESULTS

Most indices of fall rainfall and streamflow showed declining trends with time, but few were statistically significant. In contrast, spring trends were weakly positive, but none were statistically significant ($p=0.10$).

Rainfall

Caspar Creek rainfall records suggest a slight declining trend in fall totals and a slight increase in spring totals since 1962, but only November shows a significant decrease (*p=0.05*) in rainfall with year. Regression results indicate that the date on which cumulative precipitation exceeded 300 mm has shifted to occur later in the season (*p=0.093*), resulting in a predicted delay of 22 days in attaining this seasonal threshold (Dec04 in 1963 versus Dec26 in 2014). A similar trend observed in the 500 mm exceedance date was also significant (*p=0.092*) (Fig. 2).

Streamflow

Streamflow response reflects not only rainfall inputs, but is also influenced by soils, topography, vegetation, and antecedent moisture conditions. The comparison of 30-day average MDF for 1963-1992 with that since 1992 shows reduced fall flows in recent decades relative to the earlier data (Fig. 3). On the NF, MDF between October 24th and December 14th averaged 86 L s^{-1} for the first three decades of record versus 59 L s^{-1} for the most recent two decades – a decline of 31 percent. The largest differences were observed in late November. When these data were divided into two sets of 24 years (HY64-88 and HY89-12), the mean of the more recent data was significantly lower (*p=0.021*) than that of the earlier time period. For the remainder of the year, average MDF was slightly higher in the two most recent decades. SF results were similar to NF, showing a decline of one third (89 versus 59 L s^{-1}) for October 24th and December 14th and slightly elevated flows during late-spring. These similarities suggest that logging was not an influential factor in this result.

Of greater biological significance is the timing and duration of fish-passage flows (85 to 1331 L s^{-1}). About 18 percent of Caspar Creek weir flows fall within this range. No significant trends in annual frequencies of these flows were detected. Passage flows for November-December showed decreasing, but statistically insignificant, trends with year. Only November passage flows exhibited a significant decreasing trend over the length of record (*p=0.013* NF, *p=0.017* SF). Mean frequency of these flows during the November-January spawning season is 27 days. Although November accounts for only 15 percent of these flows, November streamflow exceeded the minimum fish-passage flow during 20 (NF) and 18 (SF) of the 25 years between 1964 and 1989, while November flows allowed fish passage during only 12 (NF) and 10 (SF) of the last 25 years (Fig. 4).

Further evidence of a possible hydrologic regime shift was observed in the seasonal distribution of NF storm peaks greater than 680 L s^{-1}. Fall storms (October-December) have not occurred during 18 of 52 water years, with 13 stormless falls occurring since 1989. Although the declining trend was not statistically significant, stormless falls were twice as frequent during the second half of the 52-year record. Mean fall storm count for 1989-2014 was significantly lower than for 1963-1988 (*p=0.081*). The apparent increasing trend in spring storm counts was not significant. Similarly, examination of the date of the first and last storm of the season showed a significant delay in the arrival of the first storm (*p=0.013*), while the delay

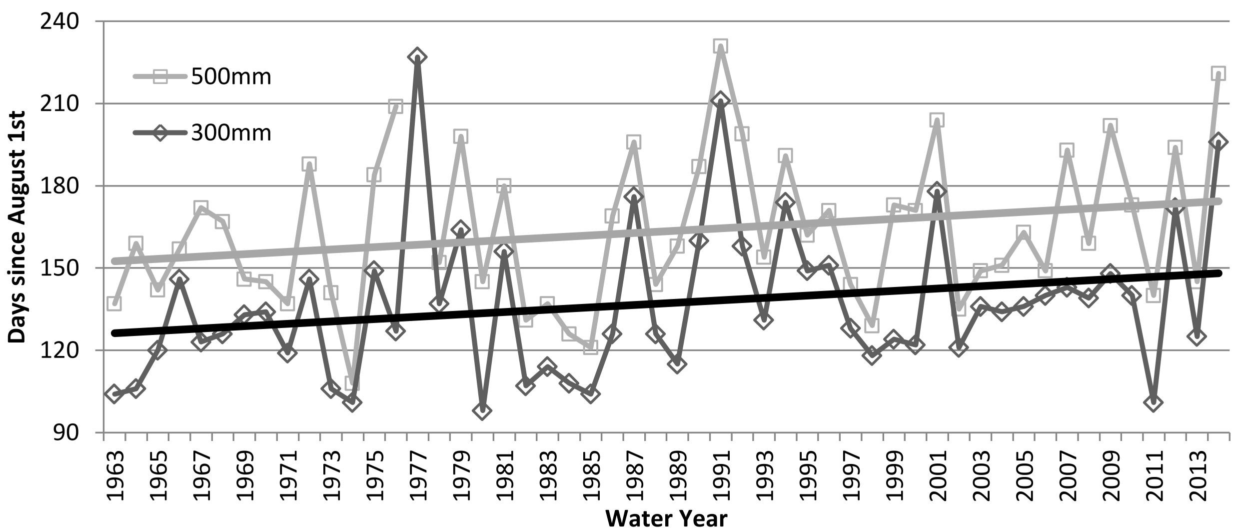

Figure 2—Seasonal rainfall threshold exceedance dates. Both 300 mm and 500 mm trends significant (p=0.093, 0.092). Median date for 300 mm is December 11th (day 133) and for 500 mm is January 5th (day 170). (Less than 500 mm precipitation recorded during HY77).

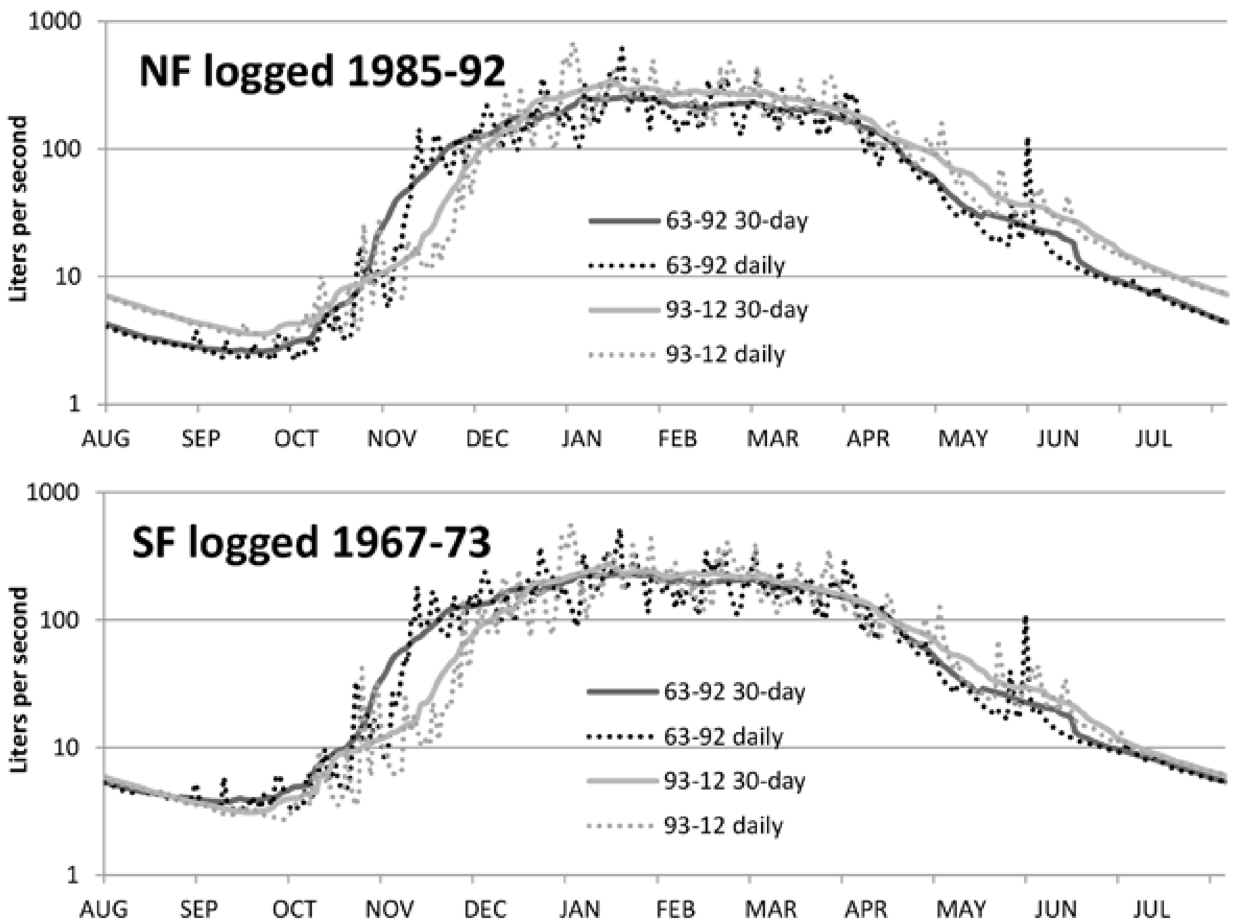

Figure 3—Mean daily flow 1963-1992 and 1993-2012, mean daily average and 30-day running average.

in arrival of the final storm of the extended winter season was not significant. This pattern might appear to indicate a shortened high flow season; however that trend was also not significant (Fig. 5).

DISCUSSION

While interannual variability is large relative to trends observed here, evidence of a possible hydrologic regime shift is present for both NF and SF, suggesting that timber harvest history was not a strong influence on the overall trend. Fall season rainfall, fish-passage flows, and first-of-season storm peaks all show signs of delayed occurrence across the span of the 52-year Caspar Creek data set. The consequence of this delay is less evident. Botkin and others (1994) reported that minimum flows in November, were strongly correlated with the abundance of spring Chinook salmon adults returning to spawn on Oregon's Rogue River three years later. Others have correlated fall flows with coho abundance in the nearby Noyo River, noting a weak positive relationship between juvenile abundance and mean monthly flows for the time period between the preceding November 15th and January 15th (Stillwater Sciences, 2008). When Caspar coho escapement estimates for 2000-2014 were regressed against fish-passage flows for November through January, the relationship was significant (*p= 0.028*) only when an exceptionally high 2005 abundance estimate was omitted. This anomaly may be explained by the exceptional 2002 return and subsequent favorable ocean conditions during the two-year marine life stage of this three-year cohort. Gallagher and others (2012) found that marine survival was more important to total survival than freshwater survival. Brood cycle population dynamics, ocean conditions, and freshwater (particularly winter) habitat qualities all influence coho abundance. Nonetheless, the prospect of delayed onset of fall rains and reduced fall flows into the future suggests that coho spawning migrations may be increasingly impeded.

Recent reports detail the formation and persistence of a stagnant weather pattern along the west coast during the past three winters, including 2014-15. A persistent region of atmospheric high pressure nicknamed the "ridiculously resistant ridge" has been blamed for the recent California drought, leading to forecasts of continued abnormally dry weather. Temperatures are warming faster in the Arctic than anywhere else in the world. This arctic amplification

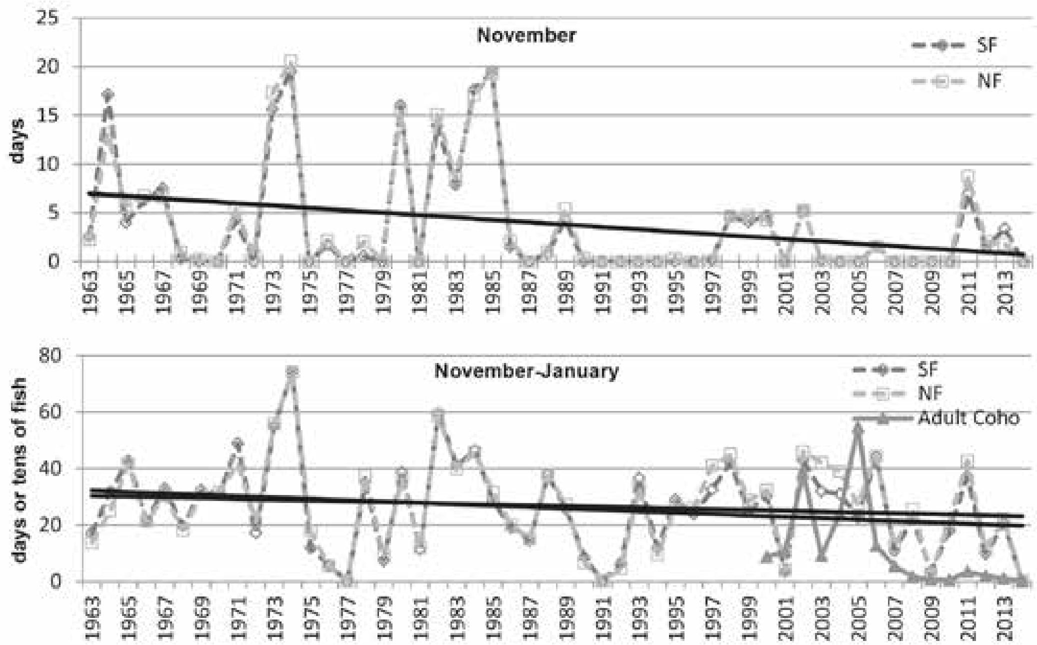

Figure 4—Duration of fish-passage flows (85 to 1331 L s[-1]) expressed as days within flow range for North Fork and South Fork and adult coho abundance estimate expressed as tens of fish. Only November trends significant (p=0.017 SF, 0.013 NF).

has spurred climate scientists to investigate the pathways by which arctic changes can influence mid-latitude weather and extreme events (Cohen and others 2014). Possible linkages include changes in storm paths and altered jet stream characteristics, both of which are key drivers of mid-latitude weather along the west coast. Temporal concentration (intensification) of precipitation brought about by altered atmospheric circulation is cause for concern not only because extreme events trigger high winter flows that negatively impact over-winter salmonid survival (Gallagher and others 2012), but also because the lack of sufficient fall rainfall may leave adult coho unable to enter their natal streams to spawn. Greater understanding of these linkages and their effects on coastal streams and anadromous fisheries is needed.

FUTURE DIRECTIONS

Caspar Creek is one of several long-term research sites providing data for the understanding forest ecosystems and management impacts. Because of the length of record, consistency of measurements, and use of established controls, data from research watersheds are invaluable for addressing complex issues of climate and hydrology. Reid and Lewis (2011) developed an antecedent precipitation model to calculate expected flows from the NF in the absence of logging to model the effects of altered rainfall and harvest in the Caspar Creek watersheds. This approach may prove useful to further explore the consequences of hydrologic regime shift in this watershed. In addition, it may be useful to examine potential water quality and stream temperature effects brought about by reduced or delayed fall flows using an interdisciplinary approach. Fisheries biologists can provide additional insights into the effects of a compressed or delayed migration season on coho recovery and restoration planning. Other kinds of climatic change (for example, temperature increases and altered fog frequency) will also influence streamflow and freshwater habitat conditions.

The observational study discussed herein does not demonstrate a causal link between global climatic trends and patterns observed at Caspar Creek. Cause and effect may be established only through further monitoring and climate modelling advances. Meanwhile, it remains critically important to pursue applied and process-based research that enhances our understanding of ecosystem function and resilience. Forest management and timber harvest activities will continue across the forested landscapes of the western U.S. Maintaining natural processes while utilizing forest products, managing to reduce wildfire severity, and ensuring adequate water supplies will require strategic thinking, interdisciplinary research, and adaptive management.

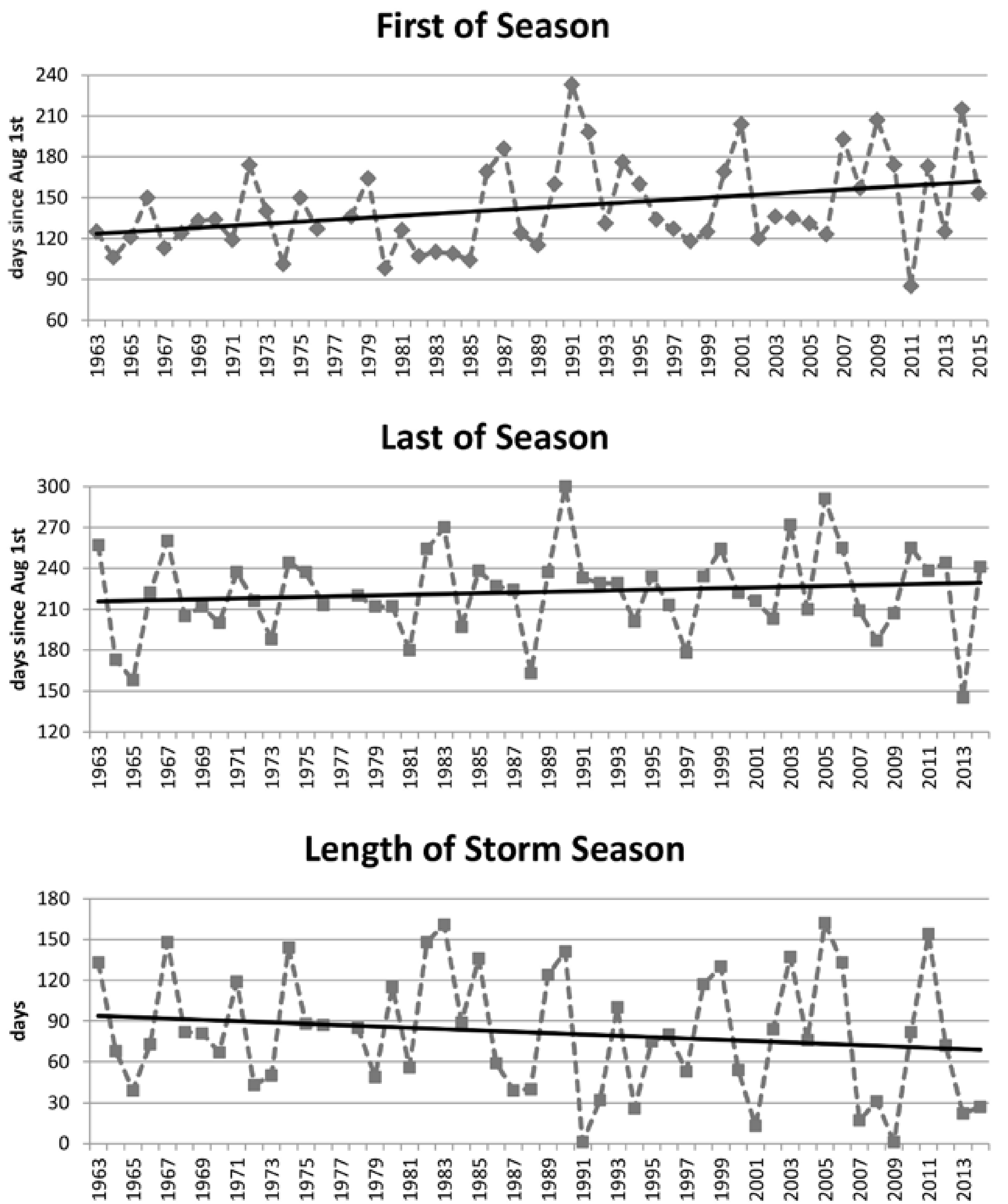

Figure 5—First fall peak flow, last spring peak flow, and length of storm season by hydrologic year. Only first-of-season trend significant *(p=0.013)*.

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IMPACT OF SOIL MOISTURE DEFICIT ON ECOSYSTEM FUNCTION ACROSS THE UNITED STATES

Susan Moran, Morgan Ross, Mallory Burns[1]

The cumulative effect of recent prolonged warm drought on regional ecosystem function is still uncertain. Large regions of the United States are experiencing new hydroclimatic conditions with extreme variability in climate drivers such as total precipitation, precipitation patterns (e.g., storm size, intensity and frequency), and seasonal temperatures. In turn, some regions are experiencing prolonged soil moisture deficit, when the average monthly soil moisture drops below the record-long mean for an unprecedented number of consecutive months. These new conditions are eliciting a variety of short- and long-term responses in ecosystem productivity, and thus, generalizations across space and time are rare. Through a series of studies using long-term records of USDA experimental watersheds, ranges and forests, some cross-biome conclusions have been reached, leading to several consistent predictions about ecosystem resilience. A key finding was that soil moisture deficit is a more consistent predictor of ecosystem productivity than climate drivers such as precipitation and temperature. In fact, ecosystems facing prolonged soil moisture deficit were found to reach a threshold associated with recent reports of regional grassland and forest mortality. Such thresholds, driven by the recent extended drought, were observed for both water- and light-limited grasslands in the southern United States. This presentation presents a synthesis of the role that soil moisture measurements play in understanding and predicting the functional response of ecosystems to climate change. Results are based on multi-location analysis of decade-long hydroecological measurements at experimental sites across the United States during the early 21st century drought. These results advance our understanding of ecosystem responses to complex climate variability, and demonstrate the value of new global observations of surface soil moisture with orbiting missions.

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TESTING RESILIENCY OF HYDROLOGIC DYNAMICS OF A PAIRED FORESTED WATERSHED AFTER A HURRICANE IN ATLANTIC COASTAL PLAIN USING LONG-TERM DATA

Devendra Amatya, Herbert Ssegane, Charles Andy Harrison, Carl Trettin[1]

Hurricanes are infrequent but influential disruptors of ecosystem processes, including streamflow and evapotranspiration dynamics in the southeastern Atlantic and Gulf coasts. However, literature on hurricane effects on long-term streamflow dynamics is lacking in this highly urbanizing region characterized by a poorly drained low-gradient forested landscape. Furthermore, the validity of paired watershed approach, often used for quantifying effects of land management and land use change on streamflow dynamics, is still poorly understood for systems dramatically impacted by the hurricanes. In this long-term study on a paired 1st order forested watershed system within the Santee Experimental Forest, South Carolina impacted by Hurricane Hugo in 1989, we used streamflow data from10 year (1969-1978) for a pre-hurricane (pre-Hugo) period and the most recent 10 years after forest regeneration (2004-2013) (post-Hugo period) to examine the effects of the hurricane on paired relationships of streamflow dynamics using hydrograph characteristics and the flow frequency duration patterns for extreme high and low flows. We tested the hypothesis that the post-Hugo paired watershed relationships between the treatment and the control (both with regenerated forests since Hugo) for mean storm event hydrograph characteristics (i.e. stormflow volume, peak flow rate, time to peak, and runoff coefficients) are not significantly different from the pre-Hugo ones, indicating both the resiliency of these coastal forests to the extreme hurricane events and the paired approach. We also examined the relationships of the same hydrograph characteristics between the control and treatment watersheds observed during the pre-hurricane annual partial prescribed burning treatment period (1976-81) and the post-Hugo treatments of whole tree thinning and burning conducted during 2006-11 for difference in the treatment effects. These results have strong implications in using long-term data as a baseline reference as well as for applications of the paired watershed approach on this and similar other coastal forest systems for assessing land use/land cover change and management impacts.

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HYDROLOGICAL EFFECTS OF TROPICAL LAND USE MANAGEMENT INCENTIVES: PANAMA CANAL WATERSHED

Fred Ogden, Jefferson S. Hall, Holly Barnard, Robert F. Stallard, Eli Fenichel, Vic Adamowicz, Brent Ewers, Ed Kempema, Julian Zhu[1]

Panama lies in the seasonal tropics and over 85 percent of annual precipitation falls during the May-December wet season. Extreme rainfall events near the end of the wet season can produce flooding that impact Panama Canal operations. During the December-April dry season, occasional water shortages limit the draft of ships passing through the Panama Canal, as well as hydropower production. The Smithsonian Tropical Research Institute (STRI) Panama Canal Watershed Experiment- Agua Salud Project (ASP) broadly aims to improve our predictive understanding of the effects of land-use, land-cover, and land management decisions on the provisioning of ecosystem services in the Panama Canal Watershed (PCW) and in similar tropical landscapes with saprolitic soils. The hydrological component of the STRI-ASP is focused on runoff generation, flow paths, and residence times as affected by land-cover and land-use history. We have instrumented 10 watersheds that range in size from 7 ha to 178 ha, from which we collect high-frequency rainfall, meteorological, runoff, water quality, isotopic, and groundwater level data. Our study watersheds have similar topography, soil types, and rainfall; the dominant difference between them is land-cover and land-use history. Observed effects of land-use/cover and land management include differences in event-scale runoff volumes and peak flow rates, both of which affect flooding, water quality and erosion. Over seasonal time scales, we observe that land-use and land-cover also affect base flow discharges- an important dry-season ecosystem service. Ultimately, we aim to improve the ability of physics-based hydrological models to predict the influence of land-use and land-cover on hydrological response in tropical watersheds with saprolitic soils, which represent about 70 percent of the tropics. We share data with the Panama Canal Authority to test the scalability of our hydrological observations in larger watersheds. While this presentation focuses on hydrological processes and observations, our team includes socio-economists working to better understand the effectiveness of land-use incentives provided by the Panama Canal Authority in the PCW, and ecologists studying a wide-range of other land-cover related ecosystem service provisioning including timber production, habitat, and species diversity.

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IDENTIFICATION OF TEMPORAL PATTERNS OF LONG-TERM HYDROLOGICAL SIGNALS IN LOWER MISSISSIPPI RIVER BASIN USING WAVELET ANALYSIS

Ying Ouyang[1]

Estimates of surface hydrological characteristics in watershed ecosystems are essential to climate change assessment, water supply planning, water quality protection, ecological restoration, and water resources management. Wavelet analysis is one of the major data analysis methods developed during the last couple decades and has been proved to be a very successful technique for signal process, meteorology, oceanography, and water quality assessment. Using wavelet analysis, we analyzed the temporal patterns of hydrological signals, including precipitation, stream flow, and air temperature, in the Lower Mississippi River Basin (LMRB). The long-term (> 60 years) measured hydrological data used in the study were obtained from USGS surface water monitoring stations located in the headwater upstream areas (or quasi-pristine areas) within the LMRB. Our specific objectives were to: (1) identify the decadal temporal patterns of precipitation, stream flow, and air temperature in conjunction with the past climate change impacts in the LMRB; and (2) estimate the annual and seasonal temporal patterns of stream flow associated with recurrence intervals of low flow in the LMRB. Results and conclusions from this study will be presented.

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Assessments for Watershed Management

INTEGRATING TIDAL AND NONTIDAL ECOLOGICAL ASSESSMENTS

Mark Southerland and Roberto Llansó[1]

The Maryland Department of Natural Resources (DNR) has a long history of conducting rigorous assessments of ecological conditions in both tidal and nontidal waters. The Long-Term Benthic (LTB) Monitoring Program and the Maryland Biological Stream Survey (MBSS) both use reference-based indicators of benthic invertebrate communities to provide areawide estimates of condition status and trends. While these programs are comparable in approach, their assessments have remained independent. The management goals for state agencies, U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and other agencies are increasingly watershed based and would benefit from an integration of tidal and nontidal assessments. Small-scale studies have demonstrated that upstream land uses can have profound effects on both nontidal and tidal waters downstream, but the prevalence of these effects over large areas have not been effectively studied. We analyzed two decades' worth of synoptic data on the condition of Maryland tidal and nontidal waters to determine the range of concurrence in condition assessments between upstream and downstream waters. The results indicate that a consistent report card of ecological condition across tidal and nontidal waters is practicable, and has implications for improving our understanding of the dynamics of freshwater tidal and nearshore ecosystems.

As an example, we present an assessment of the Upper Eastern Shore of the Chesapeake Bay in Maryland. The Upper Eastern Shore is predominantly agricultural. Forested areas account for 31 percent of land cover, 8 percent of the basin is comprised of urban lands, and development is low intensity. As of 2000, agricultural sources contributed 72 percent to the basin's total nitrogen load, and 67 percent to the phosphorus load. Agriculture was also the largest source of sediment, contributing 88 percent of the basin's sediment load. The first 2 rounds of the MBSS (1995-1997, 2000-2004) showed stream benthic condition failing over 50 percent of the upper Chester River primary sampling unit (salmon shade), whereas a majority of the basin area had moderately good stream benthic condition (light green shade) (Fig. 1). The Upper Chester River exhibited the worst water quality in the region. An increasing trend in total nitrogen concentration was detected in the Upper Chester River and poor status was observed for chlorophyll *a*, total suspended solids, total nitrogen, total phosphorus, and Secchi depth. Over the same time period, benthic community condition was worst in the upper tidal fresh portion of the Chester River (100 percent fail), moderately good in the middle oligohaline portion (33 percent fail), and degraded in the lower mesohaline portion (60 percent fail). Except for the Northeast River, the other major basin tributaries had good to moderately good tidal benthic community condition (Fig.1).

The results of LTB agree well with those of the MBSS, and can be used to identify areas impacted by high nutrient and sediment runoff. Additionally, LTB shows the influence of the Chesapeake Bay mainstem. Low dissolved oxygen events are common and severe in the Maryland mainstem. Anoxia is a common feature of the mid-bay deep channel, and hypoxia typically affects benthic communities in mainstem waters. Eastern Bay and the Lower Chester River reflect benthic community condition influenced by mainstem hypoxia and, therefore, provide contrast to MBSS results (Fig. 1). While nontidal waters are affected by stressors in the watershed, tidal waters show upstream and downstream sources of stress. The integration of tidal and nontidal assessments thus provides a holistic picture of ecosystem condition.

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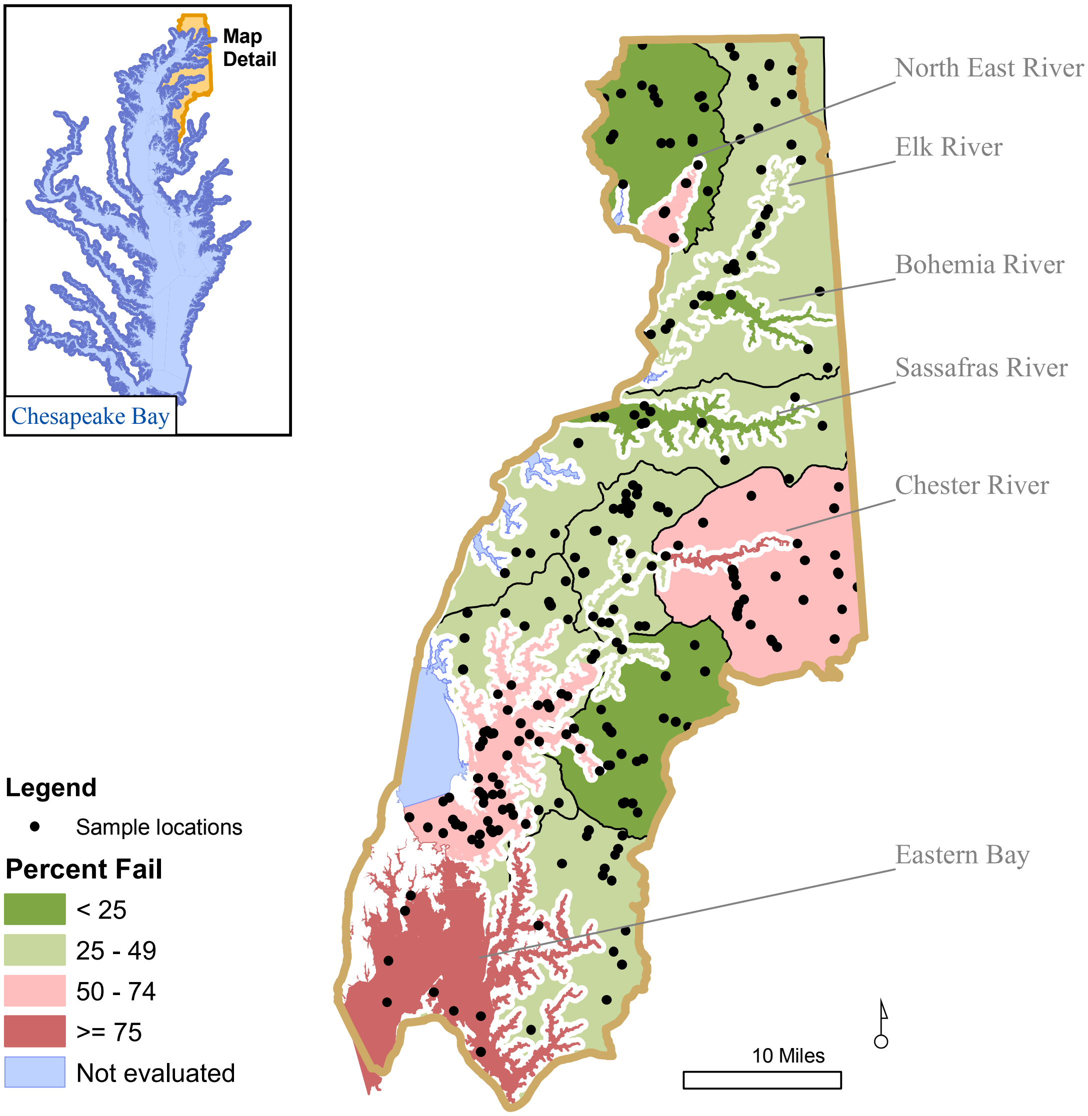

Figure 1—Maryland Upper Eastern Shore Basin tidal (rivers and bays) and nontidal (primary MBSS sampling units) assessment of benthic invertebrate condition. Shown is the percent area failing the LTB or MBSS benthic index of biotic integrity, 1995-1997 and 2000-2004.

DEVELOPMENT OF AN INTEGRATED ECOSYSTEM MODEL TO DETERMINE EFFECTIVENESS OF POTENTIAL WATERSHED MANAGEMENT PROJECTS ON IMPROVING OLD TAMPA BAY

Edward T. Sherwood, Holly Greening, Lizanne Garcia, Kris Kaufman, Tony Janicki, Ray Pribble, Brett Cunningham, Steve Peene, Jim Fitzpatrick, Kellie Dixon, and Mike Wessel[1]

Abstract—The Tampa Bay estuary has undergone a remarkable ecosystem recovery since the 1980s despite continued population growth within the region. However during this time, the Old Tampa Bay (OTB) segment has lagged behind the rest of the Bay's recovery relative to improvements in overall water quality and seagrass coverage. In 2011, the Tampa Bay Estuary Program, in partnership with the Southwest Florida Water Management District, began development of an integrated set of numerical and empirical modeling approaches to evaluate management actions to improve the ecology of the OTB estuarine segment. The goal was to integrate watershed, hydrodynamic, water/sediment quality, and ecological models (light and biota) to simulate changes in OTB ecology in response to the future implementation of large-scale management actions. The potential management actions evaluated: 1) completely diverting stormwater/freshwater input from a portion of the subwatershed that historically drained to the Gulf of Mexico, 2) diverting 100 percent of the directly discharged advanced wastewater treatment effluent to OTB from the subwatershed, 3) physically altering causeways along road expanses that intersect OTB, 4) reducing stormwater nutrient loads by 25 percent throughout the subwatershed, and 5) various combinations of these actions, as well as, other secondary management actions. The integrated set of models were used to evaluate the net environmental benefits to OTB's water quality (light environment and dissolved oxygen conditions), sediment quality (reduced accumulation of organic-rich sediments), potential expansion of seagrasses, and benthos/nekton habitat suitability. Based upon this evaluation, management actions that produced the greatest simulated improvements relative to costs are being considered for further evaluation in the OTB segment and subwatershed.

INTRODUCTION

The Tampa Bay estuary has been recognized as one of the few national and worldwide examples of a coastal ecosystem in recovery despite continued urbanization and population growth within its watershed (Greening et al. 2014). Baywide seagrass coverage continues to expand and now has approached levels commensurate to the extent last observed in the 1950s, a recovery goal set by the community through the Tampa Bay Estuary Program's (TBEP) Comprehensive Conservation and Management Plan (TBEP 2006). However, periodic setbacks have been observed in some of the Bay's extent, particularly in the Old Tampa Bay (OTB) management segment (Figure 1).

Compared to other areas of the Bay, OTB's recovery has lagged. The primary ecological issues of concern in OTB leading up to the development of this project included:

- organic sediment (muck) accumulation in the upper portions of OTB,
- limited seagrass expansion in distinct, poor circulation areas of OTB,
- alteration of freshwater inflows from managed channels discharging to OTB, and
- the periodic occurrence of nuisance algal blooms (*Pyrodinium bahamense*).

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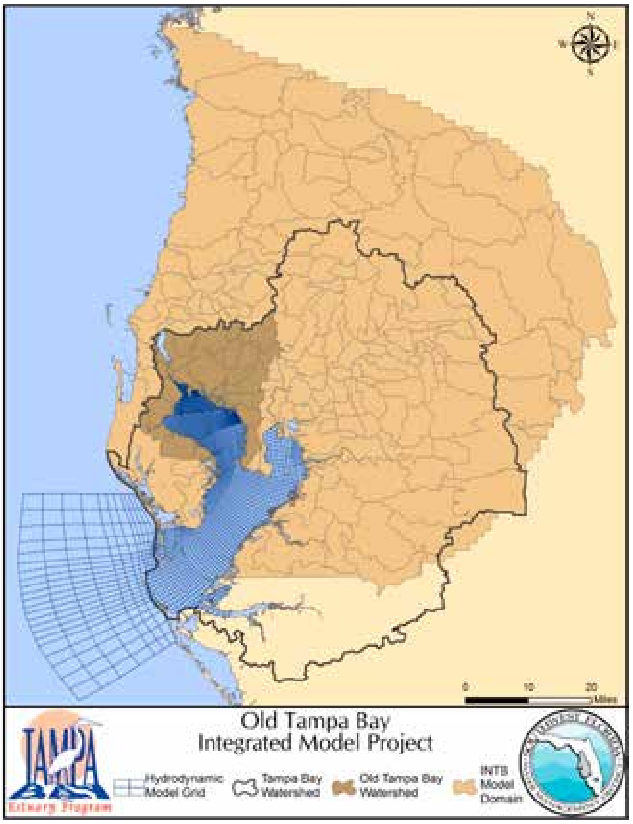

Figure 1—Overview map highlighting the Tampa Bay watershed, Old Tampa Bay watershed, watershed model domain (INTB), and hydrodynamic/water quality model domains.

In response, the TBEP, in partnership with the Southwest Florida Water Management District (SWFWMD), sought to develop an integrated ecosystem model to determine potential management actions that could further enhance OTB's recovery and address the primary issues outlined above. The integrated model envisioned, included the development of a linked watershed, bay hydrodynamic, water/sediment quality, and set of ecological models (biota and seagrass suitability). This new tool would then be used to simulate the net environmental benefits of potential, large-scale management actions relative to baseline conditions in OTB. Because much has been done in the Tampa Bay region to kick-start the Bay's recovery (e.g., wastewater treatment plant upgrades, enhanced stormwater regulations, residential fertilizer use ordinances, etc.), the models were intended to simulate actions that would require significant investment and buy-in from the region in order to implement. Such actions as bridge/causeway infrastructure modifications, modifying managed freshwater inflows, and continued wastewater/stormwater infrastructure improvements were considered.

METHODS

The overall project was broken into five discrete, serial tasks. Task 1 included the development of 10 management actions that were hypothesized to potentially improve OTB's condition. Development of the management actions enlisted support and feedback from the Tampa Bay resource management community through a series of stakeholder meetings conducted in 2011-2012. Task 2 included the assimilation of available data sources for development of an integrated set of models and identification of potential data gaps that would be needed to be filled to fully develop the modeling system. Task 3 involved generation of a Model Development Plan and a US Environmental Protection Agency (USEPA) approved quality assurance project plan (QAPP). Task 4 included the actual development, calibration and validation of the integrated model system over a 2000-2009 baseline period relative to available monitoring datasets. Task 5 simulated the net environmental benefits of the 10 identified management actions from Task 1 under the integrated set of models relative to baseline (2000-2009) conditions in OTB. This last task further prioritized the 10 potential management actions relative to their overall, anticipated implementation costs. Descriptions of each of the modeling components selected for use under this project follows.

Watershed Model

The Integrated Northern Tampa Bay (INTB) Model was deemed best suited for the watershed modeling component of the OTB integrated model system. INTB couples HSPF and MODFLOW, simulating surface water-ground water processes and their interactions for uplands and water bodies (Geurink and Basso, 2013). The INTB is used by Tampa Bay Water and SWFWMD for water supply planning in the region.

Bay Hydrodynamic Model

ECOMSED was selected as the hydrodynamic model, as there was an existing ECOMSED model application for the entire spatial domain of Tampa Bay. While the grid resolution and focus on OTB was not sufficient for this project, the experience and knowledge gained from previous studies aided in the development of the OTB application of ECOMSED. Another key factor in this selection was the existing model code that directly linked ECOMSED to the chosen bay water quality model (RCA).

Bay Water Quality Model

This component of the integrated model system was to be used to assess the effectiveness of management actions towards improving water quality, water clarity, and the potential for expanding seagrass coverage. Given the factors that influence seagrass growth and survival, the resultant bay water quality model was required to relate nutrients, suspended solids, and color to phytoplankton biomass and available light, utilizing advective and tidal linkages through the chosen hydrodynamic model. The RCA model code was selected. Familiarity with the model code was important to allow modifications or enhancements as necessary (i.e., the addition of CDOM, groundwater loadings, and benthic algae dynamics) and so that model calibration/verification could be performed more efficiently. The RCA model has been in existence for more than 20 years, has a proven track record, and has pre- and post-processing tools applicable under this project.

Ecological Model Components

An Optical Model component was used to predict water clarity from RCA outputs at suitable spatial and temporal scales with respect to seagrasses. The capability of modeling the spectral characteristics of light, rather than just as percent photosynthetically active radiation (percent PAR), allowed additional assessments for determining potential areas where seagrass coverage could increase/decrease as a result of management alternatives being implemented. The ability to model spectral distributions of light was key to the evaluation. The recommended Optical Model for the OTB integrated model system was the empirical optical model originally developed by Kirk (1981).

A secondary ecological model was also developed. The Environmental Favorability Function (EFF: Real et al., 2006), a derivative of logistic regression, was selected to quantify the effects of changes in water quality on fishes and benthic macroinvertebrates in OTB. The advantages of using the EFF model over standard logistic regression includes reducing prediction bias due to differences in taxa prevalence and the ability to directly compare taxa with different presence/absence ratios. The goal of using the EFF model was to describe changes in environmental favorability under a set of environmental conditions as predicted by the ECOMSED and RCA models.

Net Environmental Benefit (NEB) Analysis

The predicted results from each management action simulation using the integrated model (a model run) were compared to the baseline period (i.e., 2000-2009) for various, a priori key ecological attribute (KEA) outputs from each of the model components. For each management scenario, a 10-year mean KEA was compared to the 10-year mean KEA over the Baseline, and a score was calculated. The score for each KEA has been defined such that a positive score represents a potential benefit (a desirable outcome) and a negative score indicates a potential decline (an undesirable outcome) relative to the Baseline condition for each KEA. The NEB scores for each KEA were calculated and summarized at several spatial scales including three subareas that related to the original issues of concern in OTB.

RESULTS & DISCUSSION

Model Calibration and Skill Assessments

Following initial construction of each of the model components, all models were calibrated to the observed conditions during the 2000-2009 period. Model calibration refers to the adjustment of model coefficients and model resolution in order to minimize the overall error in simulating the variables of interest over the full range of hydrologic and meteorological conditions that occurred during the 2000-2009 period. The effectiveness of the model calibration was then assessed using various skill assessments and diagnostics. The goal was to minimize the overall model error for the full simulation period, with specific focus on OTB. A full description of the model calibration and skill assessment can be found in Janicki Environmental, Inc. (2014). Model skill assessment included comparisons error of variables of interest with a set of predefined values (i.e., skill assessment criteria). Model skill assessment included both qualitative evaluations (i.e., time series plots, contour plots, etc.) and quantitative evaluations using metrics (e.g., relative error, root mean square error, correlation coefficients) of model output in comparison to observed conditions.

The following skill assessment results were obtained for each of the modeling components under this project:

- Watershed Model – all seven (7) of the criteria were met;
- Bay Hydrodynamic Model – eighteen (18) of the twenty-four (24) criteria were met;
- Bay Water Quality Model – thirty-two (32) of the forty-eight (48) criteria were met;
- Optical Model – seven (7) of the eight (8) criteria were met;
- EFF Models – benthos – six (6) of the eight (8) criteria were met; fish – nine (9) of the eleven (11) criteria were met.

Net Environmental Benefit Analysis

Muck accumulation in upper OTB--Outputs from the Bay hydrodynamic and water quality models from the upper portions of OTB were used to assess potential changes in sediment muck accumulation. The KEAs that are most relevant to muck accumulation included: salinity and water age (ECOMSED outputs); organic carbon content in the sediments (RCA output); chlorophyll-a, total nitrogen, and dissolved inorganic nitrogen in the water column (RCA output).The management scenario that resulted in the highest NEB score relative to the muck accumulation issue was Scenario 9 – the combined nonpoint (25 percent) and point source (100 percent) reduction management action. Other positive scores were found for those scenarios that included either reduced flows from Lake Tarpon or other nutrient load reductions. The nonpoint source reduction scenario (2) and the combined 100 percent Lake Tarpon Outfall Reduction and causeway alterations scenario (10) also resulted in relatively high NEB scores.

In addition to the net environmental benefit analysis, the rate of organic carbon deposition was also examined. Reducing the rate of deposition is necessary to achieve any reduction in the amount of muck as the amount of muck at any point in time is a function of the rate of deposition and the rate of decomposition of the deposited organic carbon.

Table 1 presents a comparison of the total mass of organic carbon (tons) deposited in upper OTB over the 10-year model period (2000-2009) under the Baseline condition and each of the management action scenarios examined. Scenarios 1 and 10 (100 percent Lake Tarpon discharge diversion scenarios) resulted in large reductions in organic carbon deposition. The combined nonpoint and point source reductions (Scenario 9) also resulted in relatively high reductions in organic carbon deposition in that portion of OTB.

***Limited Seagrass Recovery*—**Limited seagrass expansion has occurred in several areas of OTB; however, results presented here are summarized for the entirety of OTB. The KEAs used to calculate these NEB scores were: percent PAR (Optical Model output), colored dissolved organic material (CDOM, RCA output), chlorophyll-a (RCA output), total suspended solids (RCA output), and area with adequate light (Optical Model output).

The highest NEB score was recorded for the combined nonpoint and point source reduction management action (Scenario 9) (Fig. 2). The nonpoint source reduction management action (Scenario 2), the point source load reduction management action (Scenario 3), and the combined 100 percent Lake Tarpon Outfall Reduction and causeway alterations management action (Scenario 10) also resulted in relatively high NEB scores.

Table 2 presents comparisons of the area with adequate light to support seagrass between the Baseline and each management action scenario. The values presented are the resulting adequate light acreages in Year 10 of the 10-year modeling period (2000-2009). Therefore, these values reflect the response to the cumulative changes in the nutrient loading and other management actions over that 10-year period.

***Nuisance Algal Blooms*—**The project team determined that the issue of concern relating to the occurrence of nuisance algal blooms in OTB could not be adequately addressed using the existing model outputs. Additional data collection efforts were recommended to better understand the life history, bloom initiation and distributions of the primary (*Pyrodinium bahamense*) alga of concern in this region. The TBEP is considering additional studies to address these information gaps on the alga species.

Table 1—Total mass of organic carbon deposition to upper Old Tampa Bay (OTB) over the 10-year model period relative to the Baseline and each scenario run with gross and percent differences between these mass estimates. Positive differences indicate improvements in potential muck accumulation in this focus area.

Management Action Scenario	Baseline (tons)	Scenario (tons)	Difference (tons)	Difference (%)
1-100% diversion of Lake Tarpon inflow	1,516,342	1,308,844	207,498	13.7
2-Gross 25% reduction in OTB nonpoint source loads	1,516,342	1,405,782	110,560	7.3
3-100% reduction in point source discharges to OTB	1,516,342	1,401,651	114,691	7.6
4-Alterations to Courtney Campbell Causeway	1,516,342	1,509,742	6,600	0.4
6-Alterations to Howard Frankland Bridge & Causeway	1,516,342	1,518,492	-2,150	-0.1
7-50% diversion of Lake Tarpon inflow	1,516,342	1,440,301	76,041	5.0
8-Combined Scenarios 6 & 7	1,516,342	1,440,360	75,982	5.0
9-Combined Scenarios 2 & 3	1,516,342	1,322,157	194,184	12.8
10-Combined Scenarios 1, 4 & 6	1,516,342	1,306,755	209,586	13.8

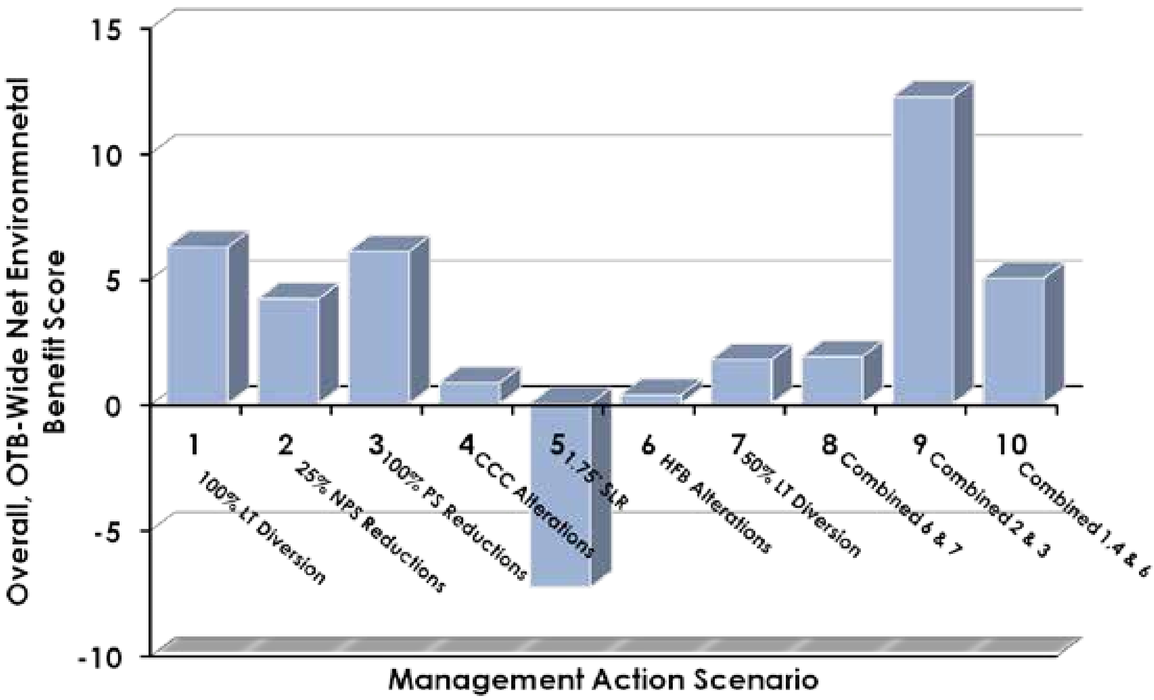

Figure 2—Overall results of combined net environmental benefit (NEB) analyses across the entirety of OTB relative to the 10 management action scenarios simulated under this project. Positive and negative scores relate to positive and negative benefits, respectively.

Table 2—Comparison of the number of acres with adequate light to support seagrass after a 10-year model run period (2000-2009) under the Baseline and each scenario with gross and percent differences between these areal estimates. Positive differences indicate improvements in the areal light conditions supportive of seagrass growth throughout Old Tampa Bay (OTB).

Management Action Scenario	Baseline (acres)	Scenario (acres)	Difference (acres)	Difference (%)
1-100% diversion of Lake Tarpon inflow	10,558	11,101	543	5.1
2-Gross 25% reduction in OTB nonpoint source loads	10,558	10,791	233	2.2
3-100% reduction in point source discharges to OTB	10,558	10,774	216	2.0
4-Alterations to Courtney Campbell Causeway	10,558	10,497	-61	-0.6
6-Alterations to Howard Frankland Bridge & Causeway	10,558	10,543	-15	-0.1
7-50% diversion of Lake Tarpon inflow	10,558	10,706	148	1.4
8-Combined Scenarios 6 & 7	10,558	10,728	170	1.6
9-Combined Scenarios 2 & 3	10,558	11,491	933	8.8
10-Combined Scenarios 1, 4 & 6	10,558	11,191	633	6.0

Figure 3—Comparison of pertinent net environmental benefit (NEB) scores for each management action scenarios (#) relative to potential implementation cost rankings for the muck accumulation issue in upper Old Tampa Bay (OTB).

Implementation Cost Considerations

Muck accumulation in upper OTB—For each priority issue, a comparison of the NEB scores relative to the costs to potentially implement the management actions was made. Figure 3 displays the NEB ranking for each of the scenarios along the y-axis (higher is better), and the relative cost ranking along the x-axis, for the issue of muck accumulation in Safety Harbor. Data points also indicate the relative permitting constraints: High (H); Medium (M); and Low (L).

Scenario 9, the combined nonpoint (25 percent) and point source (100 percent) reduction management action, resulted in the highest NEB with a modest permitting constraint, although at the highest implementation cost. The nonpoint source reduction scenario (2) also returned a high NEB ranking with a modest permitting constraint at a somewhat lower cost.

Limited Seagrass Recovery—Figure 4 displays the NEB ranking for each of the scenarios along the y-axis, and the relative cost ranking along the x-axis for the priority issue of limited seagrass expansion in two problematic areas in Old Tampa Bay (Feather Sound region and northwest Hillsborough County drainage areas).

As was observed with the muck accumulation issue, Scenario 9, the combined nonpoint (25 percent) and point source (100 percent) reduction management action, resulted in the highest NEB with a modest permitting constraint, although at the highest implementation cost for promoting more seagrass expansion in select areas of OTB. The nonpoint source reduction scenario (2) also returned a high NEB ranking with a modest permitting constraint at a somewhat lower cost, and the point source load reduction scenario (3) resulted in the same NEB ranking at an even lower cost.

CONCLUSIONS

An integrated set of watershed, bay hydrodynamic, bay water quality, and bay ecological models was developed under this project. The resulting KEA outputs from each of the modeling components were individually assessed to determine a NEB score, and pertinent scores were summarized according to priority issues and areas in OTB. The resulting NEB analyses indicated that combined efforts to reduce point source (primarily domestic wastewater treatment plants) and nonpoint source (primarily urban/suburban stormwater inputs) nutrient inputs to OTB's watershed and embayment would have the greatest overall benefit to ecology, however

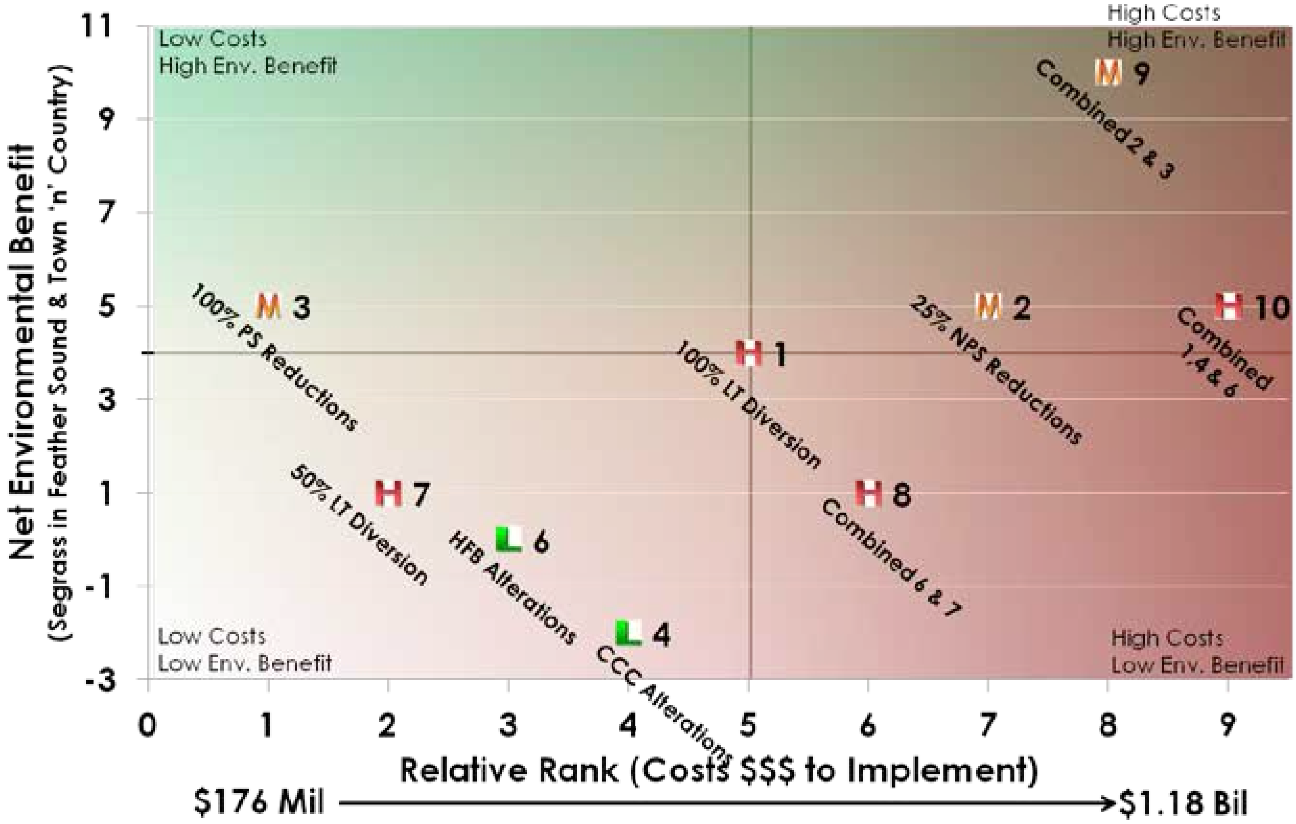

Figure 4—Comparison of pertinent net environmental benefit (NEB) scores for each management action scenarios (#) relative to potential implementation cost rankings for seagrass recovery in two areas of Old Tampa Bay (OTB), Feather Sound region and northwest Hillsborough drainage areas.

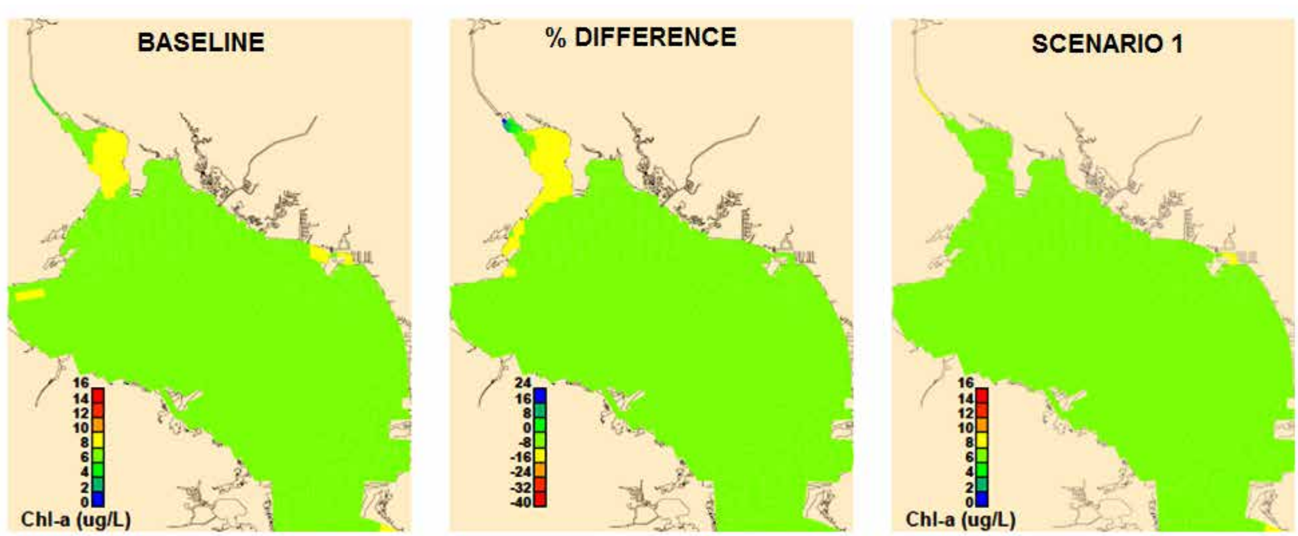

Figure 5—Localized differences (scenario - baseline as a percentage, middle panel) in chlorophyll-a (µg/L) conditions in OTB simulated from the 100% Lake Tarpon Outfall diversion scenario (1, right panel) relative to the calibrated, baseline condition (left panel) averaged over the 2000-2009 period.

at an extremely high implementation cost. Localized issues (e.g., muck accumulation in upper OTB) would also benefit from localized management actions (e.g., reductions in Lake Tarpon outfall discharges, Figure 5) at lower costs; however, overall benefits to OTB's entire ecology were less prominent. Physical alterations (e.g., causeway modifications) also showed similar localized benefits to specific issues; however causeway modifications appeared to have minor or negligable ecological benefits in OTB. In addition, causeway modification benefits also appeared to be better enhanced when combined with other actions (e.g. reducing Lake Tarpon outfall discharges, point source/nonpoint source reductions), adding to potential implementation costs. As resource managers in the region begin to plan for further ecosystem recovery in OTB, the modeling results from this assessment and further application of the integrated model system can be used to weigh benefits to the environment versus costs to implement actions in order to promote the most cost-effective solutions to improve OTB's ecology.

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WATERSHED PLANNING, IMPLEMENTATION AND ASSESSMENT: THE MAY RIVER WATERSHED ACTION PLAN CASE STUDY

Kimberly W. Jones, Christopher L. Ellis, Jeremy S. Ritchie[1]

Abstract—Prior to exponential growth in the early to mid-2000s, the Town of Bluffton, SC was one square mile; as of 2015, it is approximately 55 square miles. Associated with this growth was a shellfish harvesting closure for nearly one-third of the May River in 2009. The Town and its partners developed and began to implement the May River Watershed Action Plan in 2011. The plan is a "living document" allowing for the incorporation of new information and technology as well as modifications based upon its impact on water quality. The continuous evaluation of the success of any watershed management plan is crucial to keeping a plan relevant. Utilizing an adaptive management logic model strategy provides managers a tool to effectively assess and modify their watershed management plan in response to ever-changing environmental conditions, an increasing technical knowledge base, increasing implementation costs, and decreasing resources, in the face of a constant demand for action and favorable results. This case study provides an example of utilizing an adaptive management logic model to initially evaluate a watershed plan.

INTRODUCTION

The May River (HUC 3060110-03) is a tidal embayment located in southern Beaufort County, SC. The Town of Bluffton (Town), sitting alongside the river, has had strong ties to it since its establishment in 1825. Commercial shellfish harvesting has historically been, and still remains, a significant component of the economy, tradition and community character of the Town. Additionally, the aesthetics and views of the May River increase the popularity of Bluffton for residential, commercial, and tourist visitation growth, tying the Town's economic conditions directly and indirectly to the river. For these reasons, the May River has been designated an Outstanding Resource Water (ORW) by the South Carolina Department of Health and Environmental Control (SCDHEC 2012).

Rising popularity of the area resulted in the Town's incorporated limits expanding from one square mile in 1987 to approximately 55 square miles today. Between 2000 and 2010 the Town's population increased by 883 percent from 1,275 to 12,530. The number of housing units rose from 501 to 5,393 during the same time, an increase of 976 percent (U.S. Census Bureau 2000 and 2010).

With the rapid increase in population and development came rising fecal coliform levels in the May River's environmentally sensitive headwaters, resulting in nearly one-third of the river being closed to shellfish harvesting in 2009. Today, the May River is included in the approximately 1,100 Total Impairments listed among 920 Impaired Sites within the state of South Carolina's Clean Water Act Section 303(d) listed waterbodies (SCDHEC 2014). Thus, the following case study of the development, implementation and initial evaluation of the May River Watershed Action Plan is pertinent for both coastal and interior water resource managers whose goal is to develop a comprehensive approach to prevent, respond to, or to evaluate the impacts of their plans on water quality impairments.

Program Background

The May River is located within the jurisdictions of the Town of Bluffton and Beaufort County, where it bisects the Town's jurisdiction (Fig. 1). With annexation and substantial residential development, land use was converted from mostly pine crops to residential subdivisions and an associated increase in impervious surface and stormwater runoff. In 2007, SCDHEC reported to the Town that fecal coliform levels in the headwaters of the May River were increasing. In 2008, in response to this increase, the Environmental Protection Agency (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

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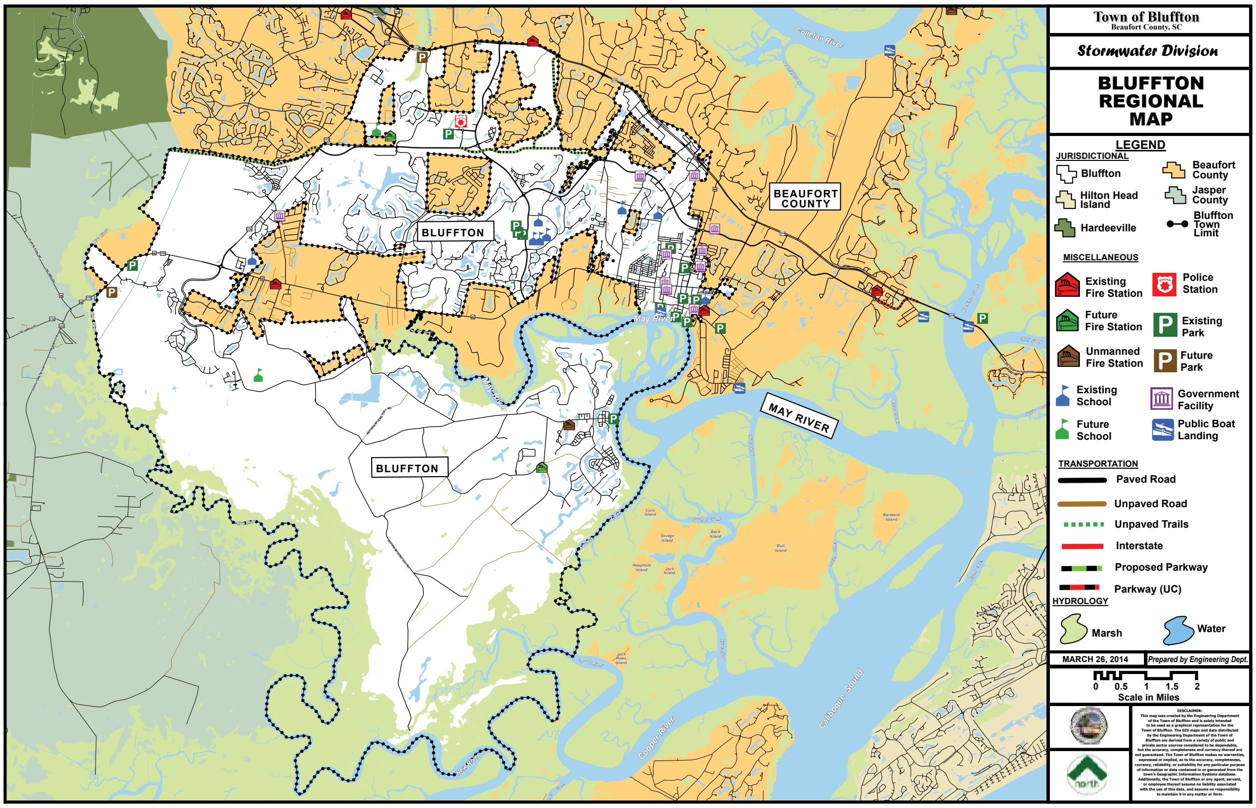

Figure 1—Bluffton region and May River location.

plan which was awarded an EPA 319 grant by SCDHEC for implementation to reduce the fecal coliform levels. Despite initial implementation of that plan, 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.

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 voluntarily committed to take action to augment the existing 319-funded watershed plan to create an updated, comprehensive May River Watershed Action Plan (Action Plan).

The goal of the Action Plan is to create a program which includes both structural and nonstructural Best Management Practices (BMPs) projects to restore shellfish harvesting within the headwaters of the May River and to protect the river from future degradation. Adapting the guidelines found in the "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" (EPA 2008), Town staff worked for nearly a year with consultants, Beaufort County, and local stakeholders to develop the Action Plan (AMEC 2011). The Bluffton Town Council adopted the May River Watershed Action Plan by Resolution in November 2011 as a program for stormwater management and May River watershed restoration and protection.

With the Action Plan program providing direction to the Town's stormwater management and water quality improvement projects for nearly three years, a number of the program's projects have been implemented or are on-going. Currently, a simultaneous effort is being made to continue with project implementation while objectively evaluating the impact of these projects on improving water quality. As a result of this evaluation, Town staff can make adjustments to the Action Plan program as needed and re-evaluate its impact at regular intervals in the future.

This iterative approach is known as adaptive management (EPA 2008) and is depicted in Figure 2. Implementing an adaptive management strategy provides managers a tool to effectively assess and modify their watershed management plans in response to ever-changing environmental conditions, an increasing technical knowledge base, increasing implementation costs, and decreasing funding sources, while under a constant demand for action and positive results.

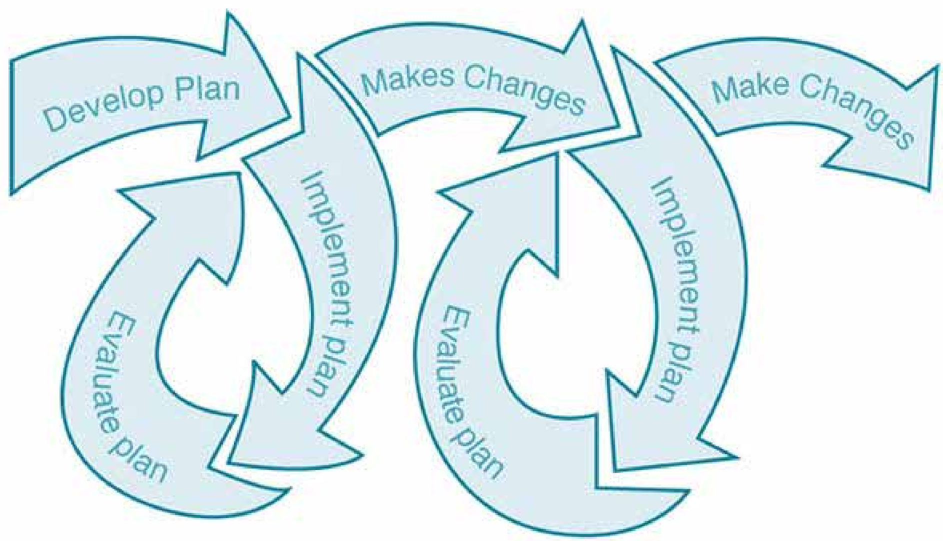

Figure 2—Iterative process of adaptive management.

PROGRAM DESIGN AND IMPLEMENTATION

Program Design

The Town's detailed process to develop and initially implement the Action Plan has been previously documented (Jones and Bullman 2014). By adapting the EPA (2008) guidelines, the Town and its partners worked through each of the following steps. While listed chronologically, many steps occurred simultaneously and are on-going:

Conducted a Social Inventory – identified the stakeholders and built partnerships.

Conducted an Environmental Inventory – coalesced existing data to determine past and present conditions and identify where there were gaps in the data so that they could be acquired.

Set Goal and Initial Objectives – the project team and decision makers (Town Council) determined what "success" would look like and reached consensus to identify the goal.

Designed and Created the Watershed Action Plan – as the plan was under development, short-, mid-, and long-term outcomes which supported the goal were developed.

Implemented the Watershed Action Plan – initial activities and outputs were implemented to show progress and build excitement and momentum toward the desired long-term outcomes.

Measure Progress and Make Adjustments – this is the initial evaluation of the Action Plan utilizing the adaptive management plan logic model strategy to determine program effectiveness and is described in greater detail below.

Program Implementation

To date under the Action Plan program, nineteen projects have produced or are producing on-going outputs for evaluation (Table 1). These diverse projects have vastly differing approaches as a possible means to improve water quality, and include a $480,000 Capital Improvement Program (CIP) project, nonstructural BMPs such as public outreach and engagement via meetings, events and social media, policies in the form of ordinance changes, as well as small-scale BMPs intended for individual home sites such as rain barrels, rain gardens and bird roosting deterrent systems for docks. Thus, evaluating the projects over time for efficiencies and effectiveness in attaining the Action Plan's goal to improve water quality and protect it into the future will allow Town management to decide which projects warrant receiving continued, but limited resources (both financial and staff time) and which ones should be modified or discontinued.

PROGRAM EVALUATION METHODS

The Town conducted an initial evaluation of the Action Plan utilizing the adaptive management logic model (Fig. 3) strategy. The ultimate criterion utilized to gauge success of the Action Plan is a decrease in fecal coliform concentration numbers at SCDHEC shellfish monitoring stations, resulting in a re-opening of the closed shellfish

Table 1—May River Watershed Action Plan outputs, outcomes and evaluation

	ACTION PLAN CURRENT INITIATIVES	OUTPUTS	OUTCOMES	MEETING GOAL		CONT.?
		2011 - 2014		YES	NO	
1	Fecal Coliform “Hot Spot” Monitoring	~1,000 samples collected annually	Provides data to assess project efficacy and environmental indicator for program successes; Provides input for future project retrofit areas.	x		YES
2	May River Watershed Action Plan Advisory Committee	Committee formed and meets quarterly to review project progress and performance measures.	Provides public forum to gather input into project, programs & initiatives; Provides process for quarterly assessment of data and adaptive management of Action Plan.	x		YES
3	Neighbors for Clean Water - Facebook, Twitter, Website	Brand created; Social media sites launched and continued; 3 watershed entry signs installed.	Continued opportunities to reach a broad audience via social media and traditional media venues.	x		YES
4	Community Clean-Ups	Annually - 2 events; with 250 volunteers; 2 tons collected total	Community clean-ups will continue and staff will increase participation levels by broadening the scope of the events to be more festival-like.	x		YES
5	Outreach/Education Events & Participant #s	Annually 40 events; reach of 2,000	Continued outreach & engagement is necessary for success, however improved performance metrics need to be investigated and adopted.	x		YES
6	Unified Development Ordinance Based on Watershed Principles- Growth Framework Map	Map directs future growth to desired areas to protect headwaters.	Uncertain what impact the Growth Framework Map has had on development patterns on the whole.	?	?	?
7	Unified Development Ordinance Based on Watershed Principles- Low Impact Development Incentives	Incentives are identified and available.	Uncertain what impact the incentives have had on development designs; requires better promotion of availability and tracking in the development process.	?	?	?
8	Unified Development Ordinance Based on Watershed Principles- Stormwater Volume Control	Requires post-construction stormwater run-off volumes to equal pre-construction levels.	Uncertain what impact the volume requirment has had for protecting receiving waterbodies; requires calculation of percentage of stormwater volume decrease compared to previous design requirements.	?	?	?
9	Unified Development Ordinance Based on Watershed Principles- Transfer of Development Rights	1,300 units transferred; prevents 146 acres impervious surface in headwaters.	While this program was effective in this single case, it needs to be more broadly promoted and applied.	?	?	?
10	Rain Barrel (55-gallon)	175 installed	Increased awareness and engagement for 150 homeowners (several sites received multiple barrels); prevented additional run-off from home sites.	x		YES
11	Rain Garden (~70 sq. ft. each)	13 installed	Not the most effective stormwater BMP due to cost & maintenance needs making homeowners reluctant to participate.		x	NO
12	Doggie Dooley Pet Septic Installation	5 installed in support of “scoop the poop” pledge campaign; 30 pledges signed	While this small-scale program was used as an incentive to have pet owners sign a “scoop the poop” pledge to be eligible to win a Doggie Dooley, only 30 pledges were made.		x	NO
13	Manure Management Plan & Riparian Buffer Garden	250 sq. ft. garden installed	This particular project stabilized the soil and provided filtration of runoff. Wide-spread application of this BMP would be time consuming and costly.	?	?	?
14	Bird Roosting Deterrent for Docks	40 deterrents obtained; 10 installed	Homeowners were reluctant to deploy a roosting deterrent due to their appearances.		x	NO
15	Septic System Maintenance Assistance	Annually - 56 service requests	Until sanitary sewer service is extended to most residents, this program is necessary for environmental and health/ safety/welfare of the public.	x		YES
16	New Riverside BMP Pilot Project	1.25 acre lagoon created to treat a 300 acre sub-basin; one year of monitoring data shows 70% reduction in fecal coliform conc.	The long-term efficacy of a pond to reduce fecal coliform loading from an undeveloped drainage area is currently being investigated via the monitoring data.	?	?	?
17	Animal Waste Ordinance Completed	Adopted; 1 ticket written and dismissed by judge	Widespread education in support of this ordinance needs to be conducted for police officers, judges and general public to increase its effectiveness as a BMP for fecal coliform reduction.		x	YES
18	Trash Can Installation in Old Town	6 cans installed	Trash cans are emptied weekly and more frequently after festivals, thus preventing debris from entering the river. Quantification of amounts needed to determine impact.	x		YES
19	Construction Site Sediment & Erosion Control Inspections	Annually - 1,050 inspections	Sediment and erosion control inspections are effective to prevent sediment transport of pollutants to receiving waterbodies.	x		YES

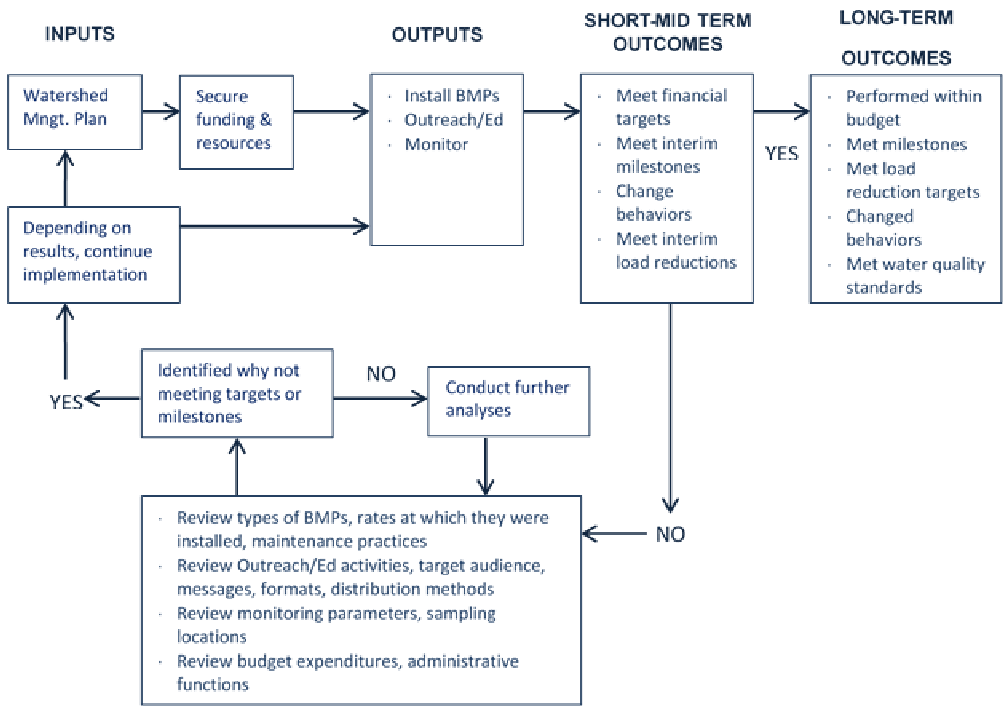

Figure 3—EPA example of an adaptive management logic model for a watershed management plan assessment.

harvesting beds, thus attaining the goal of the Action Plan. This long-term outcome is an indication of holistic watershed health. However, the success of each individual project and its outputs which contribute to that goal were assessed to determine if short-, and mid-term outcome performance measures, previously identified during each project's design, are being achieved.

Town staff, with the input of the six public members of the May River Watershed Action Plan Advisory Committee (WAPAC), review the status of project completion and overall program implementation on a quarterly basis. Together, the WAPAC and staff decide when evaluation of a project should be conducted at meaningful time intervals. If the intended performance measures are not being met, further investigation will occur as to why.

Based upon the information, the Action Plan projects, performance measures or resources will be adjusted as necessary with the input of the WAPAC and other stakeholders previously identified during the Action Plan planning process. This iterative process will continue until the shellfish beds are re-classified as open for harvesting. From that point, the Action Plan will continue to be assessed using the adaptive management logic model approach to ensure future protection of the May River and its watershed.

RESULTS

The results of the adaptive management logic model evaluation for the Action Plan projects from the last three (3) years are presented in Tables 1 and 2. Programs and projects that were part of the Town's first EPA Clean Water Act Section 319 Grant, as awarded by SCDHEC, are fully summarized in the final report to SCDHEC (Jones 2014).

Evaluating the nineteen Action Plan projects indicates that, to date, nine projects resulted in outcomes considered to be positive improvements for water quality. The outcomes of four projects are not considered to be meeting the goal of improving water quality, and six projects require modification and re-assessment to determine if their outcomes are contributing to water quality improvement.

Sixteen projects are considered worth continuing, though seven of those require modifications either in design or performance metrics to be fully re-evaluated as they are currently not meeting or are uncertain of meeting the desired outcomes. Three initiatives – rain gardens, Doogie Dooley pet septic installation, and bird roosting deterrents – were not considered worth continuation due to poor public response or participation, as well as limited water quality improvements in spite of high staff effort or monetary requirements.

Table 2—Results of the May River Watershed Action Plan evaluation

	# of Projects	# of Projects to Continue	# of Projects to Modify	# of Projects to Discontinue
Meeting Outcomes	9	9	0	0
Not Meeting Outcomes	4	0	1	3
Uncertain of Meeting Outcomes	6	0	6	0
Totals	**19**	**9**	**7**	**3**

Of the seven projects determined to require modification, only one is a structural BMP, while the remaining six are policies. The recently completed CIP stormwater BMP, the New Riverside Pilot Project Pond, has a year of monitoring data collected. Initial indications are that the pond is reducing fecal coliform concentrations by 80 percent. Despite this, the long-term outcome of this project is unclear as not enough data have been collected yet to fully understand the system.

The six policy-related projects are either not meeting, as is the case with the Pet Waste Ordinance, or are unclear as to their contribution to the long-term desired outcomes and goal of the Action Plan. The metrics of these projects must be reassessed, as well as the overall project design, to better quantify their contribution to the desired outcomes.

DISCUSSION

The benefits of the adaptive management strategy and several case studies are summarized by the EPA (2013) in its "A Quick Guide to Developing Watershed Plans to Restore and Protect Our Waters." The routine and intensive evaluation and analyses of pre-determined performance measure data are crucial to the success of any watershed management plan as these ensure the plan is current with industry standards and technical knowledge as well as adapting to a variable physical environment. Additionally, these periodic "check-ups" of a plan ensure that tangible steps toward water quality improvements are being made to meet not only local expectations, but possibly regulatory requirements as well if the waterbody in question is subject to a Total Maximum Daily Load (TMDL).

The benefits of utilizing the adaptive management logic model to assess the Action Plan are evident in the results. The evaluation of the projects in the Action Plan indicates that approximately half of the initiatives are resulting in outcomes considered positive for water quality improvement. What is striking is that 38 percent (7 of the 19 projects) are believed to be producing positive results, but require modification of design, performance measures or data acquisition to re-evaluate and fully support this assumption. Notably, the projects which are unclear as to their success are all policies, with the exception of the stormwater BMP which, as previously stated, requires more time and data to allow a full evaluation. This observation points out the need for the Town, and others who may adopt a policy as a BMP, to clearly define performance measures which can be obtained following policy implementation. Additionally, all of the initiatives require a quantitative assessment of contributions to fecal coliform load reduction.

Applying the adaptive management approach also provided insight to the Town into which efforts are worth continuing. Sixteen percent (3 of the 19 projects) are not currently considered worthy for continuation based upon poor return on staff investment of time and resources, thus allowing those resources to be dedicated toward the other projects which require modification. Alternatively, if more resources (staff and funding) become available, these projects may be revised based on the input received to improve their reception and implementation by the public.

While applying the adaptive management strategy logic model may seem complex, it actually helps to clarify a watershed management program's or individual project's path forward by elucidating where efforts are paying off, where they are not, and where it's unclear. In the era of doing "more with less," while still expected to make progress by citizens and regulators, this strategy helps to justify managerial decisions aimed at maximizing the return on resources expended toward a common goal.

ACKNOWLEDGMENTS

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 members including Mayor Lisa Sulka and Mayor Pro Tempore Ted Huffman, Karen Lavery, Fred Hamilton, Larry Toomer, Oliver Brown, Allyne Mitchell, and Charlie Wetmore. Numerous technical partners have included USEPA, NOAA-Office for Coastal Management, NOAA-CSC Human Dimensions Program, NOAA-NCCOS, USGS, SCDNR, SCDHEC nonpoint source program, SCDHEC-Shellfish Program, SCDHEC-OCRM, Clemson University, University of South Carolina, University of South Carolina-Beaufort, the Lowcountry Institute and the managers of the Beaufort County Stormwater Utility. Community partners have included members of the May River Waterbody Management Plan Implementation Committee and May River Watershed Action Plan Advisory Committee. I would like to thank the following Town staff for their continued support of and contributions to implementing the May River Watershed Action Plan – current and past Town Managers Marc Orlando and Anthony Barrett, respectively; and the dedicated and talented staff especially Jeremy Ritchie, Carl Norris, Alex Leinbach, Bill Baugher, Beth Lewis, Sam Connor, Ron Bullman, James Ayers, Frank Hodge and Shawn Leininger; as well as the Bluffton community.

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THE 2014 ASSESSMENT OF STREAM QUALITY IN THE PIEDMONT AND SOUTHERN APPALACHIAN MOUNTAIN REGION OF SOUTHEASTERN UNITED STATES

Celeste Journey, Paul M. Bradley, Peter Van Metre[1]

During the spring and summer of 2014, the U.S. Geological Survey (USGS) National Water-Quality Assessment Program (NAWQA) assessed stream quality across the Piedmont and southern Appalachian Mountain region in the southeastern United States. The goal of the Southeast Stream Quality Assessment (SESQA) is to characterize multiple water-quality factors that are stressors to aquatic life – contaminants, nutrients, sediment, and streamflow alteration – and the relation of these stressors to ecological conditions in streams throughout the region. Two of the most important anthropogenic factors affecting water quality in the region are urbanization and streamflow alteration; therefor, these factors were targeted in the assessment. Findings from the assessment will provide communities and policymakers with information about what human and environmental factors are the most critical in controlling stream quality, which will provide insight about possible approaches to protect and improve stream quality. The targeted design of the assessment used streamflow and land-use data to identify and select sites that reflected a range in the amount of urbanization and streamflow alteration. One hundred twenty-one sites were selected and sampled across the region for as many as 10 weeks during April, May, and June 2014 for contaminants, nutrients, and sediment. This water-quality "index" period culminated with an ecological survey of habitat, periphyton, benthic macroinvertebrates, and fish at all sites. Sediment was collected during the ecological survey for analysis of sediment chemistry and toxicity testing. Of the 121 sites, 59 were on streams in watersheds with varying degrees of urban land use, 5 were on streams with numerous confined feeding operations (CAFOs), and 13 were reference sites with little or no development in their watersheds. The remaining 44 "hydro" sites were on streams in watersheds with relatively little agricultural or urban development but with hydrologic alteration, such as a dam or reservoir. This presentation will provide a detailed description of and preliminary findings from the specific study components of the SESQA that included surveys of ecological conditions, routine water sampling, deployment of passive polar organic compound integrative samplers (POCIS) of pesticides and contaminants of emerging concern, and synoptic sediment sampling and toxicity testing at all urban, CAFO, and reference sites. At a subset of urban sites, continuous water-quality monitoring and daily pesticide sampling also were conducted and will be described. Hydro sites had a reduced scope for its assessment that included synoptic surveys of ecology, sediment chemistry, and water chemistry.

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CEAP WATERSHED ASSESSMENTS: ACCOMPLISHMENTS AND OPPORTUNITIES FOR NEW ADVANCES

Lisa Duriancik, Mark Walbridge, Deanna Osmond, Roberta Parry[1]

The Conservation Effects Assessment Project (CEAP) was established in 2003 to document the effects and benefits of conservation practices. CEAP conducts assessments at multiple scales – national, regional, and watershed scale – on croplands, grazing lands and wetlands, and to address wildlife concerns. A major part of CEAP since its inception included a collection of 42 small Watershed Assessment Studies, involving 3 USDA agencies along with numerous other Federal and university partners. These long term studies have documented cases of water quality improvements at the watershed and other scales in some circumstances and all have been key in identifying existing challenges to measuring the water resource outcomes of conservation implementation at the scale of a watershed. Recent accomplishments will be reviewed. Future opportunities will be discussed including continued assessment of conservation effects within watersheds, particularly in conjunction with targeted conservation implementation. Looming water and soil resource challenges and conditions will be considered and to better inform conservation treatment needs.

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USDA'S NATIONAL INSTITUTE OF FOOD AND AGRICULTURE (NIFA): ENGAGING KNOWLEDGE AND TECHNOLOGY, INCENTIVES AND POLICIES TO PROMOTE APPROPRIATE DECISION MAKING IN THE MANAGEMENT OF WATER AND WATERSHEDS

James Dobrowolski[1]

Agriculture, across the value chain, is the greatest consumptive user of water resources in the United States and around the world. Perhaps the greatest challenge facing agricultural producers will be increased agricultural production to meet rising demand in the face of limited water resources. This will require producers to adapt water management strategies to an increasingly variable climate, extreme weather conditions, and frequent occurrence of droughts. The development of new science and technologies focused on widening the array of choices for the efficient use of water, sustaining water quality and managing watersheds at multiple scales and for multiple purposes is needed. USDA National Institute of Food and Agriculture's (NIFA) water and watersheds science, education and extension/outreach (REE) portfolio engages knowledge and technology, incentives, and policies to promote appropriate decision making. Water and watersheds address critical water resources issues such as drought, excess soil moisture, flooding, availability (quality + quantity) in an agricultural context. Ongoing drought conditions in the western and southwestern U.S. as well as drought and excess moisture conditions in the southern and eastern U.S. make continued activity and support for water and watersheds REE a critical focus of NIFA's funding portfolio. Significant variations from the historical rate of water supply, demand and quality are projected to have major impacts on rural, urbanizing and peri-urban agricultural, horticultural, forest, and rangeland production systems. NIFA's water and watersheds program focuses on developing solutions for water management that form a nexus across food, water, climate, energy, human health and the environment. Funding will continue to be used to develop technologies and tools for a broad group of stakeholders to sustain and improve water availability. We propose to present NIFA's systems approach to public funding that links social, economic and behavioral sciences with biophysical sciences and engineering to address water and watershed issues.

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Water Quality

(PART 2)

SOIL AND STREAM CHEMISTRY RELATIONSHIPS IN HIGH ELEVATION WATERS

Jennifer Knoepp, Katherine J. Elliott, William A. Jackson, James M. Vose, Chelcy Ford Miniat, Stanley J. Zarnoch[1]

High elevation watersheds in the southern Appalachian Mountains have unique soils and vegetation communities. They also receive greater inputs of acidic deposition as a result of increased precipitation compared to lower elevation sites. Since the implementation of the Clean Air Act Amendment in 1990, concentrations of acidic anions in rainfall have been declining; however, some high elevation watersheds continue to show signs of chronic or episodic acidity. In three large watersheds, North River in Cherokee National Forest, Santeetlah Creek in Nantahala National Forest, and North Fork of the French Broad in Pisgah National Forest, we selected five catchments within each to represent the range in elevation. We collected stream and organic and mineral soil samples seasonally, and measured soil chemistry, mineral soil lime requirement, overstory composition and qualitative site characteristics in each catchment. Watersheds differed in stream acid neutralizing capacity (ANC) and soil chemistry; catchments within watersheds differed in overstory vegetation composition. We used a mixed model statistical approach to determine soil chemical, vegetation, and site characteristic variables that best explained variation in stream ANC. Stream ANC values averaged 42 μeq L^{-1} for North River, 24 μeq L^{-1} for Santeetlah Creek and 19 μeq L^{-1} for North Fork; and ANC was related to soil exchangeable and total cation concentrations and vegetation characteristics such as overstory species composition and total basal area. Our analyses suggest that vegetation characteristics as well as organic and mineral soil cation and total carbon concentrations are indicators of stream ANC and thus, may be useful in identifying sites for which lime application could be used to restore streams from the impacts of acid deposition.

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SOIL AND SALINITY MOBILIZATION AND TRANSPORT IN THE COLORADO RIVER BASIN

Cole Green Rossi, Mark A. Weltz, Kossi Nouwakpo, Ken McGwire[1]

Federally, the evaluated potential of soil loss risk in national reports in the past and ways to adapt to be proactive in preventing accelerated soil loss on rangelands has been incomplete. The areas where it is difficult to measure due to the complexities of multiple interactions (splash, sheet and rill formation, landscape dominated by wind and water processes, presence of iron oxide nodes, etc.) is only a small fraction. Rangeland soils are generally consolidated, uncultivated, and have lower organic matter content than cropland soils. These soils can have various slopes and debris such as rock, gravel, plant litter, woody debris and biological soil crusts. The vegetation is irregular and patchy with varied heights and varieties. Our approach takes all of this into consideration by triplicating rainfall simulations at four rates on natural soils (hoofprints). The rainfall simulator conducts 2, 10, 25, and 50-year return period rainfall events on 10 different plots in triplicate. Runoff water was collected to measure salinity and sediment that could eventually reach the Colorado River. Rainfall intensity and the log of sampling time were the two most sensitive variables when modeling the data. A rainfall simulator with cameras and sensors run by a computer versus LIDAR were used per plot to eventually compare photographic evidence and expense to determine if this new method is a more cost effective and wiser choice to use on rangelands. Ultimately, the Rangeland Hydrologic Ecosystem Model (RHEM), which has now been integrated into APEX will capture the vegetation and small measures of what is being captured within the 6 m x 2 m plot, the model will be adjusted for salts and for effervescence (once the soil is dry, the salt resurfaces and attaches itself to plant roots). This also extends the plant.dat database in APEX and RHEM related parameters. We have been successful at two sites in Utah and are arranging for additional sites in Utah as well as Colorado, New Mexico and other areas residing within the Colorado River Basin initially due to the geology and the focus on the Colorado River. Having all of the data will take a minimum of three additional years to be able to compare sites and run model simulations and compare LIDAR results to the unique rainfall simulator camera and sensor data for surface runoff, sediment, and salinity.

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NUTRIENT AND SALT MASS BALANCE ON THE LOWER ARKANSAS RIVER AND A CONTRIBUTING TRIBUTARY IN AN IRRIGATED AGRICULTURAL SETTING

Alexander Huizenga, Ryan T. Bailey, Timothy K. Gates[1]

The Lower Arkansas River Basin is an irrigated, agricultural valley suffering from high concentrations of nutrients and salts in the coupled groundwater-surface water system. The majority of water quality data collection and associated spatial analysis of concentrations and mass loadings from the aquifer to the stream network has been performed at the regional scale (> 500 km^2). This study attempts to monitor and quantify hydro-chemical processes on a small spatial and temporal scale in specific locations in the region. Using a suite of in-stream instruments and observation piezometers along the stream corridor, a 4.7 km reach of the Arkansas River, as well as a 2 km reach of a contributing tributary, Timpas Creek, were monitored in order to quatify mass inputs and outputs of nutrients (N, P). Monitoring included growing season length water quality sampling, as well as two high-intensity monitoring events. Using this monitoring data, a mass-balance approach was used to quantify groundwater-surface interactions and exchanges for nitrate loadings in the Arkansas River. Results suggest that significant in-stream processing of nitrate occurs in the Arkansas River during low discharges and that nitrate degredation through denitrification and vegetative uptake occurs in the riparian zones of the river and creek. The information and data gathered from this research will clarify the needs for future data gathering efforts in the region and provide a database from which to draw for future small-scale groundwater-surface water modelling efforts in the Lower Arkansas River Valley.

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EVALUATING THE EFFECTS OF WOODY BIOMASS PRODUCTION FOR BIOENERGY ON WATER QUALITY AND HYDROLOGY IN THE SOUTHEASTERN UNITED STATES

Natalie Griffiths, C. Rhett Jackson, Menberu Bitew, Enhao Du, Kellie Vaché, Jeffrey J. McDonnell, Julian Klaus, and Benjamin M. Rau[1]

Forestry is a dominant industry in the southeastern United States, and there is interest in sustainably growing woody feedstocks for bioenergy in this region. Our project is evaluating the environmental sustainability (water quality, quantity) of growing and managing short-rotation (10-12 yrs) loblolly pine for bioenergy using watershed-scale experimental and modeling approaches. The 3 study watersheds (R: 45 ha; B: 169 ha; C: 117 ha) are located in the Upper Coastal Plain of South Carolina, with characteristics typical of the landscape including low-relief topography and low- to moderate-quality sandy soils overlaying a clayey argillic horizon. In 2010, the watersheds were instrumented and hydrologic and water quality (nitrogen, phosphorus, dissolved organic carbon, herbicides) measurements began in streams, riparian and deep groundwater, interflow, precipitation, and throughfall. After 2 years of baseline monitoring (2010-2012), approximately 40 percent of the 2 treatment watersheds (B, C) were harvested (2012) and planted with loblolly pine seedlings (spring 2013) with the third watershed (R) serving as an unmanipulated reference. Fertilizers and herbicides were applied yearly following planting to achieve high yields. All silvicultural activities followed South Carolina Best Management Practices (BMPs), and thus our project will also evaluate whether typical BMPs are adequate to protect water resources under short-rotation woody crop production for bioenergy feedstocks.

Overland flow has not been observed in these low-relief watersheds, and while seeps appear during wet climate periods in newly planted areas, water reinfiltrates within the first few meters of the riparian zone. Interflow (water flowing through soils) occurs on and within the clay layer following precipitation events, but a combination of shallow topography and anomalies in the clay result in short interflow distances (tens of meters). Therefore, the hillslopes where pine is planted are largely hydrologically disconnected from the streams, except in steeper-sloped areas near the riparian zone. A combination of runoff ratios, temporal groundwater elevation profiles, and water and nitrate stable isotopes suggest that groundwater is the dominant flowpath in these watersheds. Thus excess fertilizers or herbicides will likely first enter groundwater and then stream water following a several year lag. The post-treatment water quality data support this hypothesis. There have been no appreciable increases in stream water ammonium, nitrate, or soluble reactive phosphorus concentrations in the treatment watersheds (B, C) compared to the control (R) watershed. However, the post-treatment groundwater nitrate concentrations are increasing (<2 mg N/L in 2014). Measurements are planned to occur until canopy closure (2018).

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UNDERWATER AERATION AND ARTIFICIAL FLOATING WETLANDS TO TREAT WATER QUALITY NUTRIENT ISSUES IN PONDS

Mike Haberland, Craig McGee[1]

Hopkins Pond, New Jersey, experiences cyanobacteria blooms due to thermal stratification, and eutrophication caused by excessive phosphorous levels. In 2013, a diffused aeration system was installed in the pond designed to maximize water lift rate and transfer rate of dissolved oxygen by the release of extremely fine air bubbles along the pond bottom. The rising bubbles draw bottom water along with them to the surface creating an artificial circulation. This circulation mixes water that otherwise would thermally stratify, and increases the dissolved oxygen content throughout the water column. Oxygenating deeper waters near the pond bottom also results in a decrease in the release of phosphorous from the sediment. In addition to the aeration system, as a demonstration project, we designed and installed 350 square feet of artificial floating wetlands (AFWs) using a biological filter substrate and wetland plants for nutrient removal. AFWs reduce nitrogen and phosphorous in a water body using natural microbial action in the filter substrate and uptake by obligate aquatic vegetation. Microbiological activity plays a major role in nutrient removal in wetland systems and the large surface area of the woven floating wetland material provides a tremendous amount of substrate for the growth of bacteria. The AFWs are anchored offshore in water depths that exceed the normal habitat requirements for the plant material and yet are able to continue to provide the same water treatment ecosystem services as their land based counterparts. Since installation of these treatment devices phosphorous levels dropped from 0.126 mg/L down to 0.08 mg/L.

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Monitoring and Management

REGIONAL EFFECTS OF AGRICULTURAL CONSERVATION PRACTICES ON NUTRIENT TRANSPORT

Anna Maria Garcia, Richard B. Alexander, Jeffrey G. Arnold, Lee Norfleet, Mike White, Dale M. Robertson, Gregory Schwarz[1]

The Conservation Effects Assessment Program (CEAP), initiated by USDA Natural Resources Conservation Service (NRCS), has the goal of quantifying the environmental benefits of agricultural conservation practices. As part of this effort, detailed farmer surveys were compiled to document the adoption of conservation practices. Survey data showed that up to 38 percent of cropland in the Upper Mississippi River basin is managed to reduce sediment, nutrient and pesticide loads from agricultural activities. The broader effects of these practices on downstream water quality are challenging to quantify. The USDA-NRCS recently reported results of a study that combined farmer surveys with process-based models to deduce the effect of conservation practices on sediment and chemical loads in farm runoff and downstream waters. As a follow-up collaboration, USGS and USDA scientists conducted a semi-empirical assessment of the same suite of practices using the USGS SPARROW (SPAtially Referenced Regression On Watershed attributes) modeling framework. SPARROW is a hybrid statistical and mechanistic stream water quality model of annual conditions that has been used extensively in studies of nutrient sources and delivery. In this assessment, the USDA simulations of the effects of conservation practices on loads in farm runoff were used as an explanatory variable (i.e., change in farm loads per unit area) in a component of an existing a SPARROW model of the Upper Midwest. The model was then re-calibrated and tested to determine whether the USDA estimate of conservation adoption intensity explained a statistically significant proportion of the spatial variability in stream nutrient loads in the Upper Mississippi River basin. The results showed that the suite of conservation practices that NRCS has catalogued are a statistically significant feature in the Midwestern landscape associated with nitrogen runoff and delivery to downstream waters. Estimates of the magnitude of this effect using SPARROW indicated that conservation practices have played a significant role in reducing nutrient pollution from agricultural activities to downstream receiving water bodies.

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ASSESSMENT OF FORESTRY BEST MANAGEMENT PRACTICES, I: STREAM WATER CHEMISTRY NATURAL VARIABILITY AND FERTILIZATION INFLUENCES

Erik Schilling, Daniel McLaughlin, Matt Cohen, Larry Korhnak, Paul Decker, Camille Flinders[1]

Nutrient pollution can be a leading cause of impairment to some U.S. waters. As a result, state and federal agencies are actively engaged in designing management programs and numeric nutrient criteria (NNC) to address nutrient impairments. Following implementation of the Clean Water Act, Florida, like other timber producing states, developed, tested and implemented best management practices (BMPs) to reduce potential impacts to water resources resulting from forest management activities. While decades of research have continually documented the effectiveness of forestry BMPs, questions remain about their effectiveness, particularly for nutrients. Concerns about nutrient responses to forest activities are particularly important in Florida, one of the first states to develop NNC for springs, lakes and other flowing waters. Therefore, assessing the effectiveness of forestry nutrient BMPs on established NNC endpoints is a crucial exercise. To that end, the Florida Fertilization Study is designed to evaluate the response of the State's forestry BMPs to protect water resources and aquatic ecosystems during fertilization operations. In this paired watershed study, we employed a novel suite of in situ sensors in coastal blackwater streams to collect high resolution data (sub-hourly to sub-daily) on flow, nitrate, soluble reactive phosphorus (SRP), colored dissolved organic matter (CDOM), turbidity, dissolved oxygen (DO), pH, and specific conductance. Such sensors provide new tools to enumerate seasonal to sub-daily variation in water chemistry and flow, improving inferences of controls acting at different scales. Data will be used to compare baseline and post-fertilization conditions and to isolate fertilization effects from natural variation. First year pre-fertilization data clearly demonstrate large solute and flow variation in response to rainfall and day-night cycles. These latter diurnal patterns are evident in several analytes (flow, CDOM, DO), suggesting both watershed (transpiration) and instream (metabolism) influences. Flow variation has significant water quality effects, including enrichment of organic nitrogen and dilution of SRP. These data allow us to quantify natural variation in multiple parameters at the temporal scales at which they actually vary, and thus provide a much richer and more precise approach to elucidating the effects of forest fertilization and BMP effectiveness.

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ASSESSMENT OF FORESTRY BEST MANAGEMENT PRACTICES, II: PATTERNS IN STREAM BIOLOGICAL ENDPOINTS IN TERMS OF NATURAL VARIABILITY AND FERTILIZATION

Camille Flinders, Daniel L McLaughlin, Larry Korhnak, William J Arthurs, Joan Ikoma, Matthew J Cohen, Erik B Schilling[1]

Watersheds dominated by forest cover typically have high quality water. In managed forests, fertilizers may be periodically applied during the growing period. The Florida Forest Service has developed Best Management Practices (BMPs) for managed forests to minimize the potential impacts of forestry operations, including fertilization, to forest streams and maintain water quality. However, a comprehensive study evaluating stream condition (i.e. water quality and biota) prior to, during, and following fertilization in the context of BMPs and natural variability has not been conducted. In 2012 we undertook a 5 year study to characterize stream condition prior to, during, and following fertilizer application in two managed forests in central Florida. In conjunction with extensive hydrological and water quality monitoring, we evaluated physical and biological benchmarks associated with Florida's Department of Environmental Protection (FDEP) numeric nutrient criteria. Three sites on two managed forest streams in north Florida were evaluated for phytoplankton chlorophyll a (chl a), aquatic vegetation and periphyton biomass (Linear Vegetation and Rapid Periphyton Surveys), habitat condition, and benthic invertebrate assemblages (Stream Condition Index, SCI). Macroinvertebrate assemblages on Hester-Dendy multiplate samplers were also collected to evaluate temporal variability. Samples are collected at least twice per year for some endpoints (SCI) and up to 8 times per year for others (artificial substrates). To date and in both streams, phytoplankton chl a, aquatic vegetation, and periphyton biomass values are attaining FDEP's nutrient thresholds. Macroinvertebrate SCI scores classified both stream as "healthy" and/or "exceptional" in the first year of the study. Macroinvertebrate data from artificial substrates showed distinct assemblages for each site even within a stream, with some site-specific seasonal variation. Detailed study findings to date will be discussed in the context of forest BMPs and temporal variability.

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CONTINUOUS WATER-QUALITY MONITORING TO IMPROVE LAKE MANAGEMENT AT LAKE MATTAMUSKEET NATIONAL WILDLIFE REFUGE

Michelle Moorman, Tom Augspurger[1]

The U.S. Fish and Wildlife Service has partnered with U.S. Geological Survey to establish 2 continuous water-quality monitoring stations at Lake Mattamuskeet. Stations on the east and west side of the lake measure water level, clarity, dissolved oxygen, pH, temperature, salinity, and conductivity. The west side is classified as hyper-eutrophic and is dominated by cyanobacteria, while the east side is classified as eutrophic and has a declining population of submerged vegetation. The lake is an important wintering habitat for migratory waterfowl on the Atlantic flyway. Managers are concerned about submerged vegetation declines due to poor water quality. Project objectives include collecting continuous-monitoring data, assisting with a cooperative assessment of the lake by collecting monthly water-quality samples, and providing input on the development of a comprehensive lake monitoring plan. Lake Mattamuskeet provides one example of how multiple agencies can work in partnership to improve understanding of the lake's water-quality dynamics.

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MANAGING WATERSHEDS TO CHANGE WATER QUALITY: LESSONS LEARNED FROM THE NIFA-CEAP WATERSHED STUDIES

Deanna Osmond, M. Arabi, D. Hoag, G. Jennings, D. Line, A. Luloff, M. McFarland, D. Meals, A. Sharpley[1]

The Conservation Effects Assessment Project (CEAP) is an USDA initiative that involves the Agricultural Research Service, the National Institute for Food and Agriculture (NIFA), and the Natural Resources Conservation Service. The overall goal of CEAP is to provide scientifically credible estimates of the environmental benefits obtained from USDA conservation programs. One of the CEAP projects was to determine the effectiveness of water quality change at the watershed scale. Funding for these watershed studies were provided by USDA-NIFA and -NRCS. The 13 watersheds selected for this protocol had minimally five years of water quality and land use data, and a modeling and socioeconomic component. As the 13 NIFA-CEAP watershed studies were finishing, a team led by NC State University began the task of synthesizing lessons learned about managing agricultural landscapes to meet physical, biological, and chemical water quality goals. The NC State team reviewed project documents and conducted site visits and key informant interviews at all 13 NIFA-CEAP watersheds. The objective of the key informant interviews was to ascertain community values relative to water quality and conservation practice adoption. By using all sources of information, lessons learned were synthesized into general categories – water quality, land treatment, modeling, socio-economic, education, and project management. The information was then crystalized into the most critical 15 lessons learned and these will be presented and discussed.

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Linking Terrestrial and Marine Ecosystems

THE PHYSICAL AND GEOCHEMICAL INTERACTION BETWEEN A TIDALLY-DOMINATED ESTUARY SYSTEM (WASSAW SOUND, GA) AND A RIVER-DOMINATED ESTUARY (SAVANNAH RIVER, GA) THROUGH SALINITY AND INORGANIC CARBON

Mike Scaboo, Christopher Hintz[1]

The Wilmington, Bull, and Savannah Rivers are interconnected waterways that flow through adjacent Savannah and Wassaw Sound Estuaries. These systems are linked by the upper reaches of the Wilmington River maintained as part of the Intracoastal Waterway. Significant changes to the Savannah River began in December 2014 with the initiation of the Savannah Harbor Expansion Project. The purpose of this study was to determine the extent of interaction between the Wilmington and Savannah Rivers using a suite of physical and chemical parameters. Samples were collected 1 m above the benthos and 1 m below the surface. Sampling occurred in the summer 2012-2014 during high and low tides on the same days, on spring and neap tides in the same month, extending into the fall in 2014. Drought, flood, and average rainfall years were captured. Samples were analyzed for temperature, salinity, carbonate chemistry, dissolved oxygen and stable carbon isotope along the river transects. DIC ranged from 875 µmol kg^{-1} to 2250 µmol kg^{-1} and pH ranged from 7.11 to 7.79. The flooding of the Savannah River in 2013 saw salinities in the Wilmington River as low as 7 ppt while during the drought and average years salinities between 13 and 17 ppt were observed. The only freshwater input for the Wilmington River is from the Savannah River and can be detected on the surface through half of the Wilmington River. There is negligible detection of Savannah River water in the Bull River. The Bull and Wilmington rivers connect through the narrow St. Augustine Creek. Water from the Wilmington River may be blocked by a sill formed at the entrance to Bull River. Estuarine pH was lower during low tide in the rivers with CO_2 input from respiration in the high marsh during high tide. The pH was also lower overall between 2012 and 2014, likely due to the difference in a drought and average rainfall year. The deepening of the Savannah River will allow more salt water moving up river, which may redirect more surface water into the Wilmington River increasing the freshwater influence to the ecosystem.

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WATER SOURCES IN MANGROVES IN FOUR HYDROGEOMORPHIC SETTINGS IN FLORIDA AND MEXICO

Christina Stringer, Mark Rains[1]

Mangroves are transitional environments, where fresh water from the terrestrial environments mix with seawater from the marine environment. The relative contributions of these sources vary and play a role in controlling the physical and chemical hydrological characteristics of mangroves and facilitate the exchange of mass, energy, and organisms between mangroves and the surrounding hydrological landscape. Therefore, understanding the water sources in mangroves is a critical first step in developing sound management strategies. We examined the hydrogeochemistry of four mangrove communities in distinct hydrogeomorphic settings along the Costalegre on the central Pacific coast of Mexico and along the Indian River Lagoon, east-central Florida. Salinities varied, with values ~9 psu in a basin mangrove, ~17 psu in a riverine mangrove, ~33 psu in a fringe mangrove, and a range of ~30-75 psu in a carbonate barrier island mangrove. Salinity, cation and anion concentrations, and isotopic signatures were used as tracers in mass-balance mixing models to quantify estimates of relative fresh-water and seawater contributions to each mangrove. The basin mangrove had mean fresh-water contribution estimates of 63-84 percent; the riverine mangrove had fresh-water estimates of 39-51 percent; and the fringe mangrove had fresh-water contributions of 0-5 percent. In contrast, waters in the carbonate barrier island mangrove exhibited no characteristics indicative of any fresh-water contribution. These results illustrate the varying role that groundwater plays in mangrove hydrodynamics, and the potential role that hydrogeomorphic classification can play in helping to make first-order estimates to mangroves in different hydrogeomorphic settings.

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DESIGNING A MANGROVE RESEARCH AND DEMONSTRATION FOREST IN THE RUFIJI DELTA, TANZANIA

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Despite the growing body of literature on science and management of mangroves, there is a considerable knowledge gap and uncertainty at local levels regarding the carbon pool size, variability of carbon sequestration and carbon stocks within mangrove forests, mechanisms that control carbon emissions from degradation of mangrove forests, impacts of conversion to other land uses, challenges and opportunities associated with restoration practices and sustainability of ecosystem services. These concerns are valid globally, but they are particularly important in Africa due to limited research that has been conducted in the continent. The USDA Forest Service (USFS) and the Center for International Forest Research (CIFOR) have completed comprehensive studies on mangrove carbon in the South East Asia (SEA) and the Oceania (Donato and others 2011, Kauffman and others 2011) with financial support from the United States Agency for International Development (USAID) as part of its Sustainable Wetlands Adaptation and Mitigation Program (SWAMP). By drawing from the reported findings, lessons and experiences from SWAMP, inter-agency consortiums of academic and research institutions and conservation non-governmental organizations in Tanzania and Mozambique, with technical support from the USFS Center for Forested Wetlands Research and financial assistance of the USAID Africa Bureau, are developing the East Africa Mangrove Carbon Project (EAMCP). This initiative intends to support capacity development, advance scientific knowledge, and improve data collection in the areas of measurement and monitoring of carbon stocks and the impact of utilization and degradation in mangrove forests. Ultimately, EAMCP aims to provide scientific information and capacity to inform effective policy and management actions for the secured future of mangroves in East Africa. The consortium in Tanzania is utilizing the EAMCP opportunity to establish a mangrove research and demonstration forest in the Rufiji Delta (MRDF). This facility will be officially designated and sanctioned within the administering government agency, the Tanzania Forestry Service (TFS). The designation will entail recognition of the site as a special use area, where activities are aimed at research, demonstration, and training for capacity development of academic and scientific community, practitioners and managers, and communities.

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The Rufiji Delta, which is located about 150 km South of Dar es Salaam, contains the largest continuous mangrove forest in Tanzania and the region, comprising approximately 53,000 ha (Semesi 1992). Eight of the 10 mangrove species occurring in Tanzania are found in the Delta (Wagner and Sallema-Mtui 2010). Over 150,000 people inhabit the Rufiji Delta and its floodplain, the majority of who subsist on traditional fishing, cultivation, and extraction of mangrove wood products. Most of the mangrove logging that feeds other part of Tanzania as far as the islands of Zanzibar is done within the Rufiji Delta. The Delta is characterized by traditional shifting cultivation of rice that involves clearance of mangrove areas in the upper reaches where freshwater flooding prevails. The delta supports the most important fishery in Tanzania's coastline, accounting for about 80 percent of all wild-shrimp catches in the country (Masalu 2003). As one of the largest deltas containing the largest mangrove forest in East Africa, the Rufiji Delta offers an excellent site for research activities, allowing for ground-truthing of methodologies and management practices. The Delta provides a mangrove forest that is representative of the scale of a delta landscape, providing sufficient area for current and future uses, including long-term and large-scale experiments. The proposed area of about 9,200 ha of a single tract of mangrove forest is favorable for easy management and monitoring. The site includes the present main distributary of the Rufiji River, and other smaller branches and creeks, provide the capability to consider mangroves in a variety of both geomorphic and hydrologic settings. As the majority of mangrove species known to occur in Tanzania are found in the Delta, the area provides the opportunity to study each of the species, individually and in association with the other species. The site incorporates both a salinity and geomorphic gradient from the ocean front to freshwater floodplain margin. Freshwater areas are those where mangrove conversion to agricultural use is practiced. As such, it offers the possibility to address issues across a full environmental gradient, including agricultural

Figure 1— Approximate delineation of the MRDF in the north Rufiji Delta.

impacts and mangrove management demonstrations like site restoration of abandoned and existing agricultural lands, as well as feasibility considerations of limited use. The proposed site includes harvesting disturbance that could be used for research. The presence of wood cutters provides an opportunity to engage them to develop and test sustainable management practices like comparing the impacts of selective and clear cutting. The proposed site is readily accessible, and is adjacent to an existing field station at Nyamisati Village that will facilitate operational logistics related to research and training, including availability of office space, stores, boats and local laborers, and lodging accommodations. The field station has a great potential of being elevated to a regional mangrove information center.

The MRDF has three core objectives: 1) To improve, share and apply scientific knowledge on assessment of carbon stocks, restoration and sustainable use to support the conservation of mangrove ecosystems; 2) To strengthen and build capacity for integrated mangrove management institutions and strategies, and empower dependent local communities to engage in decision-making and management that conserves, restores and sustainably uses mangrove ecosystems; and 3) To enhance mangrove forest resource governance by encouraging integrated management programs and conservation investments that are ecologically and socio-economically sound. The general approach for the MRDF is to develop mangrove assessment and monitoring capabilities, implement experiments and develop tools to address utilization and management issues. Presently, research on mangrove ecosystems is derived from individual studies, usually conducted on independent sites. Accordingly, there is no basis for accumulating information from individual studies on a given forest site. When studies are conducted on the same forest area there is greater efficiency in the work and investigators are able to address more complex questions because of the linkages to other studies on the same site. A common research area also provides an excellent basis for management demonstrations (e.g. silvicultural practices) and training activities because of the well-established interdisciplinary data sets that can be made available. Establishment of this research forest has a high-likelihood for persistence after the initial project; properly implemented, the facility will leverage additional projects.

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WATERSHED MANAGEMENT TO SUPPORT CORAL REEF RECOVERY AND RESILIENCY

Lisa Vandiver, Tom Moore, Sean Griffin, Michael Nemeth, Rob Ferguson[1]

Coral reef habitats in the Caribbean region have experienced significant reductions in abundance over the past several decades. These declines are due to both global stressors, such as increases in sea surface temperatures and ocean acidification, and localized stressors, such as land-based sources of pollution (LBSPs). Climate change has led to increased occurrence and extent of coral bleaching events, tropical storms and hurricanes, and coral disease. Management of these global threats is difficult; however, studies have shown that coral reef recovery and resilience can be enhanced by managing local nutrient and sediment stressors. Over the past decade, NOAA has taken a leading role in the abatement LBSPs to support recovery, enhancement, and resiliency of coral habitats in the Caribbean.

This presentation will provide an overview of the watershed management techniques that NOAA's Restoration Center and NOAA's Coral Conservation Program have utilized to combat LBSPs to protect and restore the seagrass and coral habitats in a priority region in the Caribbean: Culebra, Puerto Rico. Culebra is a small island, approximately 11.6 square miles, off the northeast coast of Puerto Rico. This island is surrounded by relatively healthy coral and seagrass habitats; however in the past decade scientists have reported a 20 to 40 percent decline in live coral cover in certain portions of the island that are suspected to be linked to LBSPs. In 2010, a group of regional experts identified Culebra as a priority for coral reef conservation. Since then NOAA has partnered with federal agencies, jurisdictional agencies, and local stakeholders to develop a watershed management plan to identify sources of pollution and prioritize LBSP management actions for the island. This plan has served as a means of prioritizing the implementation of LBSP management actions on Culebra. In addition, this summer studies were initiated to establish baselines for nearshore water quality and seagrass and coral health. This information, combined with research of the management practices themselves, will provide resource managers the information needed to evaluate the performance of the LBSP management actions and inform adaptive management strategies.

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WATERSHED PROCESSES FROM RIDGE TO REEF: CONSEQUENCES OF FERAL UNGULATES FOR CORAL REEF AND EFFECTS OF WATERSHED MANAGEMENT

Gordon Tribble, Jonathan Stock, Jim Jacobi[1]

Molokai's south shore has some of Hawaii's most extensive and best-developed coral reefs. Historic terrigenous sedimentation appears to have impacted coral growth along several miles of fringing reef. The land upslope of the reef consists of small watersheds with streams that flow intermittently to the ocean. A USGS gage at the outlet of one of the most impacted watersheds (Kawela) recorded an average suspended sediment discharge of 1350 tons per square mile between 2006 and 2011. Approximately one-half of the total annual suspended sediment was delivered during one day per year. Once delivered to coastal waters, the sediment persists for many years and is re-suspended approximately 300 days per year. Geomorphic mapping, high resolution photography, and field surveys were used to map vegetation and erosive processes throughout the Kawela watershed. The surveys revealed denuded areas at mid-elevations in the watershed eroding at rates approaching 16 mm/year. This denudation and subsequent erosion is attributed to large recent populations of feral goats and previously by cattle. In 2006, a rapidly-eroding site was selected to monitor rainfall, runoff, erosion and vegetative cover. Intensive culling of goats by land managers began three years later (2009). From 2009 to 2014 a marked increase in vegetation was observed. Dry-season vegetation cover increased approximately from 3 percent to 15 percent and wet-season cover increased approximately from 28 percent to 68 percent. In addition, the nature of the vegetation changed from heavily grazed grasses and stunted shrubs to a much lusher foliage with an increase in native shrubs. During that same time period, the rate of erosion at the site decreased from about 16mm/year to less than 5 mm/year. The results indicate that ungulate removal allowed rapid vegetation recovery and subsequent reduction of erosion. Continued ungulate control may reduce sediment loads to coastal waters and lead to a gradual improvement in water quality and coral cover.

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Hydrology and Water Quality Modeling

LINKING STATISTICALLY- AND PHYSICALLY-BASED MODELS FOR IMPROVED STREAMFLOW SIMULATION IN GAGED AND UNGAGED WATERSHEDS

Jacob LaFontaine, Lauren Hay, Stacey Archfield, William Farmer, Julie Kiang[1]

The U.S. Geological Survey (USGS) has developed a National Hydrologic Model (NHM) to support coordinated, comprehensive and consistent hydrologic model development, and facilitate the application of hydrologic simulations within the continental US. The portion of the NHM located within the Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (GCPO LCC) is being used to test the feasibility of improving streamflow simulations in gaged and ungaged watersheds by linking statistically- and physically-based hydrologic models. The GCPO LCC covers part or all of 12 states and 5 sub-geographies, totaling approximately 726,000 km^2, and is centered on the lower Mississippi Alluvial Valley. A total of 346 USGS streamgages in the GCPO LCC region were selected to evaluate the performance of this new calibration methodology for the period 1980 to 2013. Initially, the physically-based models are calibrated to measured streamflow data to provide a baseline for comparison. An enhanced calibration procedure then is used to calibrate the physically-based models in the gaged and ungaged areas of the GCPO LCC using statistically-based estimates of streamflow. For this application, the calibration procedure is adjusted to address the limitations of the statistically generated time series to reproduce measured streamflow in gaged basins, primarily by incorporating error and bias estimates. As part of this effort, estimates of uncertainty in the model simulations are also computed for the gaged and ungaged watersheds.

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BLIZZARDS TO HURRICANES: COMPUTER MODELING OF HYDROLOGY, WEATHERING, AND ISOTOPIC FRACTIONATION ACROSS HYDROCLIMATIC REGIONS

Richard MT Webb, David L Parkhurst[1]

The U.S. Geological Survey's (USGS) Water, Energy, and Biogeochemical Model (WEBMOD) was used to simulate hydrology, weathering, and isotopic fractionation in the Andrews Creek watershed in Rocky Mountain National Park, Colorado and the Icacos River watershed in the Luquillo Experimental Forest, Puerto Rico. WEBMOD includes hydrologic modules derived from the USGS Precipitation Runoff Modeling System, the National Weather Service Hydro-17 snow model, and TOPMODEL. PHREEQC, a geochemical reaction model, is coupled with the hydrologic model to simulate the geochemical evolution of waters as they evaporate, mix, and react within the landscape. The two watersheds are at opposite ends of the hydroclimatic spectrum. Andrews Creek, with an average temperature near 1°C and average runoff of 90 cm/yr, drains water and snowmelt from the flank of the North American Continental Divide, whereas the Icacos River, with an average temperature exceeding 20°C and average runoff of 400 cm/yr, drains a tropical rain forest. And although the igneous intrusive rocks underlying the two watersheds are similar, the weathering rates are not. Hikers near Andrews Creek will often walk on bare granite, while those hiking through the Icacos watershed will be separated from the bedrock by several meters of heavily weathered saprolite. Variations in the stable isotopes of water measured in precipitation are also not similar. The $\delta^{18}O$ values of rain falling on the continental divide are near -8 permil while the snow dumped by blizzards onto smiling skiers has $\delta^{18}O$ values near -20 permil. In contrast, afternoon showers in Puerto Rico have $\delta^{18}O$ near 0 permil while drenching rains during the passage of tropical depressions can have $\delta^{18}O$ values less than -5 permil. WEBMOD succeeds at simulating observed variations in major ions and stable isotopes measured in surface water as a mixture of waters, gases, and ions exchanged between atmosphere and soils as they mix along various flowpaths on their way to the outlet. The model is a valuable tool for simulating variations in the quantity and quality of water in watersheds with diverse geology, climate, and ecology, and for investigating the response of watersheds to climate change, acid mine drainage, acid rain, biological transformations, and other chemical reactions.

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A WATERSHED-BASED SPATIALLY-EXPLICIT DEMONSTRATION OF AN INTEGRATED ENVIRONMENTAL MODELING FRAMEWORK FOR ECOSYSTEM SERVICES IN THE COAL RIVER BASIN (WV, USA)

John M. Johnston, Mahlon C. Barber, Kurt Wolfe, Mike Galvin, Mike Cyterski, Rajbir Parmar, Luis Suárez[1]

We demonstrate a spatially-explicit regional assessment of current condition of aquatic ecoservices in the Coal River Basin (CRB), with limited sensitivity analysis for the atmospheric contaminant mercury. The integrated modeling framework (IMF) forecasts water quality and quantity, habitat suitability for aquatic biota, fish biomasses, population densities, productivities, and contamination by methylmercury in headwater watersheds. The CRB is an 8-digit hydrologic unit watershed facing widespread land use change, and the IMF simulates a network of 97 stream segments using the SWAT watershed model, a watershed mercury loading model, the WASP fate and transport model, the PisCES fish community model, a fish habitat suitability model, the BASS fish community and bioaccumulation model, and an ecoservices post-processer. The application of these models was facilitated by the automated data retrieval and model setup tool D4EM and updated model wrappers and interfaces for data transfers between these models. Results for each stream segment demonstrate three distinct groupings for flow. Baseline IMF predictions for all ecoservices are provided for 1990–2010 across all segments, with summary statistics compared to independent models and field data for the period 2001-2010 after model spin-up. Spin-up of the IMF is also addressed to reach dynamic steady state, corresponding to the age of the longest lived fish in the drainage.

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WATERSHED MODELING AND DEVELOPMENT OF ECOLOGICAL FLOWS IN THE APALACHICOLA-CHATTAHOOCHEE-FLINT RIVER BASIN, ALABAMA, FLORIDA, AND GEORGIA

William Hughes, Mary Freeman, Elliott Jones, John Jones, Jacob Lafontaine, Jaime Painter, Lynn Torak, Steve Walsh[1]

In Grant Parish, LA, increases in overstory basal area, canopy cover, and development of understory woody plants reduce over the last 50 years, the Apalachicola-Chattahoochee-Flint (ACF) Basin in Alabama, Florida, and Georgia has undergone extensive development of water resources for municipal and industrial supplies, power generation, and agriculture. Concurrent with this development, there has been increasing conflict over the use of water in the ACF system, resulting in legal battles over the rights to this valuable resource. The U.S. Geological Survey (USGS) is studying the ACF basin as part of the Department of Interior's initiative titled "Water: Sustain and Manage America's Resources for Tomorrow" (WaterSMART) that will provide improved water-availability information and develop new tools to support water management decisions. This federally funded, four-year study has three major components that build on USGS data collection and modeling capabilities: estimating water use, modeling surface and groundwater flow, and modeling ecological flow relations. The water use component will develop a site-specific database of water use for the ACF Basin, develop new methods for estimating agricultural withdrawals, and compile available water-use projections. Calculations of net water use will be improved by obtaining information on interbasin transfers, determining septic-tank return flows, and estimating consumptive use by thermoelectric plants. The hydrologic modeling component will consist of a surface-water model for the entire ACF Basin using the USGS Precipitation-Runoff Modeling System (PRMS) and a MODFLOW groundwater model for the lower Chattahoochee and Flint River Basins. These models will be linked to provide improved simulation of groundwater/surface-water interactions in the lower part of the Basin. The ecological flows component will use multi-state, multi-season ecological models to predict changes in fish and mussel species occupancy based on variations in flow conditions associated with climate change, land-use change, and changes in water withdrawals or discharges.

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INTERANNUAL VARIABILITY IN THE EXTENT OF WETLAND-STREAM CONNECTIVITY WITHIN THE PRAIRIE POTHOLE REGION

Melanie Vanderhoof, Laurie Alexander[1]

The degree of hydrological connectivity between wetland systems and downstream receiving waters can be expected to influence the volume and variability of stream discharge. The Prairie Pothole Region contains a high density of depressional wetland features, a consequence of glacial retreat. Spatial variability in wetland density, drainage evolution, and precipitation patterns as well as interannual and interdecadal variability in climate can be expected to result in variable degrees of wetland-stream connectivity within the region. Although numerous studies have examined how interannual variation in wetland water level influence available waterfowl habitat within this region, very few studies have explicitly examined how this variability in water level might influence the degree of surface water connectivity between wetlands or between wetlands and streams within this region. This study utilized a time series analysis of Landsat images (1990-2011) to map interannual variability in patterns of inundations and wetland-stream connectivity by fusing static data sources (e.g. NWI, NHD) with dynamic data sources (e.g. Landsat). Changes in the degree of wetland-stream connectivity were related to temporal variability in wetness conditions using drought indices and stream gauge data, as well as spatial variability in geology, as characterized by the U.S. EPA ecoregions, which influence wetland and stream density. We found that both the area of inundation and the degree of wetland-stream connectivity was correlated with climate conditions, and that the degree of wetland-stream connectivity varied between ecoregions. An improved understanding of wetland-stream connectivity within landscapes that contain a high density of depressional wetlands is critical to improve our predictions of stream flow and our understanding of how water moves through watersheds. Disclaimer: authors views expressed here do not necessarily reflect views or policies of USEPA.

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Tidal Freshwater Rivers and Creeks -
Do They Influence Terrestrial Ecosystem Functions

UNDERSTANDING THE LINKAGES BETWEEN A TIDAL FRESHWATER FORESTED WETLAND AND AN ADJOINING BOTTOMLAND HARDWOOD FOREST

Brooke Czwartacki, Carl C. Trettin, Timothy J. Callahan[1]

The low-gradient coastal topography of the southeastern Atlantic Coastal Plain, coupled with large oceanic tidal amplitudes cause rivers that discharge to the coast to exhibit tidal influence of tides far inland. In those reaches, tidal-freshwater forested wetlands (TFFW) occupy floodplains which eventually transition to non-tidal, bottomland hardwood-forested ecosystems. Hydrodynamic studies have not adequately addressed the upland boundary of TFFWs, where the hydrologic regime shifts from tidal-to fluvial-dominated processes as a result of a deceasing tidal gradient. Understanding how the tide influences those upper reaches is fundamental to understanding how rising sea-level may influence wetland dynamics. In this study, we investigated the following questions: (i) how, and to what extent, does the tidal-freshwater stream influence the shallow groundwater in the riparian zone; and (ii) how does the vegetation community differ in riparian zones of tidal-freshwater streams as compared to adjacent non-tidal systems. To address these questions, we collected hydrology and vegetation information in a fourth order stream, Huger Creek and its non-tidal tributary, Turkey Creek (USGS gage ID 02172035), in the Santee Experimental Forest near Cordesville, South Carolina. These streams form the headwaters of the East Branch of the Cooper River, which flows into the Charleston Harbor estuary. Information was collected over an eighteen-month period from monitoring gages in Huger and Turkey Creeks, from water-table wells in the riparian wetlands, and from vegetation surveys in riparian zone plots. Our analysis indicates: (i) that the water-table gradient is "upstream" and the tidal pulse affects the shallow ground water table, and (ii) that the forest-community structure showed no significant relationship to tidal vs. non-tidal hydrodynamics in the riparian zones. These results emphasize the need to assess ecology and hydrology characteristics of tidal-freshwater forested wetland systems separately from non-tidal systems because of the tidal regulation of the water budget. Considering that rising sea level will affect large areas of the coast with low topographic gradients, existing TFFW systems should be inundated. As a result, upstream non-tidal zones will soon be affected by tides due to rising seas. Improved understanding of the linkages across the interface of tidal and non-tidal terrestrial ecosystems will provide valuable information to decision makers and is needed to anticipate long-term ecological resiliency during higher sea levels.

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BIOGEOCHEMICAL AND SURFACE ELEVATION CONTROLS OVER TIDALLY INFLUENCED FRESHWATER FORESTED WETLANDS AS THEY TRANSITION TO MARSH

William Conner, Ken W. Krauss, Gregory B. Noe, Jamie A. Duberstein, Nicole Cormier, Camille L. Stagg[1]

Many coastal ecosystems along the south Atlantic are transitioning from forested wetlands to marsh due to increasing tidal inundation and saltwater intrusion primarily attributed to global climate change processes. In 2004, we established long-term research sites in Georgia, South Carolina, and Louisiana to understand how climate factors (temperature, precipitation, streamflow, sea-level rise, droughts, and hurricanes) interact to elevate soil salinities and flooding that collectively foster forest dieback and habitat conversion in tidal freshwater forested wetlands of the Southeast. We have documented changes in forest structure and growth of trees in swamps of South Carolina, Georgia, and Louisiana from 1988-2014 subjects to a variety of flooding regimes. We found that as estuarine influence shifts inland with sea-level rise, forest growth becomes linked to salinity and salinity-induced changes in nutrient availability. While litterfall estimates seem to be well defined with 3–5 years of data, stem growth across hydrological gradients in some areas are still not clear even with 10 years of data. We found that salinity, soil total nitrogen, flood duration, and flood frequency affect forest diameter increment, litterfall, and basal area the greatest, and in predictable ways. Even small concentrations of salinity (e.g., < 2 g/L) can drastically decrease basal area increment growth rates and litterfall production, lead to increased nitrogen mineralization, and reduce surface elevation in these intertidal forests with inherently low sedimentation rates and thereby exacerbate encroachment of marsh vegetation. Conversion to oligohaline marsh is associated with increased sediment nutrient inputs that may then increase herbaceous productivity, further increase sediment trapping, and enhance the resilience of tidal wetland surface elevation to sea-level rise. These changes in soil nutrients can be slow to affect the ecosystem, but have long-lasting effects on productivity and permanent changes in the composition of forest stands. Based on long-term data, we will describe processes as determined from two primary river systems in the Southeast, and describe a way forward in understanding whether other river systems transition similarly with increasing salinity.

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TRACKING SALINITY INTRUSIONS IN A COASTAL FORESTED FRESHWATER WETLAND SYSTEM

Anand D. Jayakaran, Thomas M. Williams, and William H. Conner[1]

Coastal forested freshwater wetlands are sentinel sites for salinity intrusions associated with large, tidally influenced, storm-driven or drought-induced incursions of estuarine waters into freshwater ecosystems. These incursions may also be exacerbated by rising sea levels associated with climate change. A coastal forested freshwater wetland in South Carolina - Strawberry Swamp - has experienced dieback of freshwater forested wetland trees due to increased salinity levels within the wetland (Williams et al. 2012). Strawberry Swamp comprises a drainage area of 236 hectares at its outlet into the tidal creek. Ground elevations in the watershed range from mean sea level (MSL) at its outlet to 1.5 m above MSL at the watershed boundary. Historical aerial images of the swamp show considerable changes to forest structure vegetation through the last few decades (Williams et al. 2012, Jayakaran et al. 2014). Vegetation in the wetland is transitioning from a closed canopy of common freshwater tree species such as bald cypress, water tupelo and swamp tupelo at its upper reaches to a more open canopy due to the establishment of salt tolerant grasses closer to the outlet. The wetland is prime habitat for several wildlife species and amphibians as evidenced by game cameras. The wetland drains into a tidal creek at its outlet through a pipe culvert; the tidal creek is connected to Winyah Bay which receives freshwater from the third largest watershed on the eastern coast ultimately discharging into the Atlantic Ocean. Tidal dynamics influence the wetland outlet, while at its upper sections, the water flows are driven by rainfall and topographical slope. Backwater effects from Winyah Bay also appear to impact flow dynamics at the wetland outlet when large river flows discharging into Winyah Bay force freshwater into tributary tidal creeks and swamps. A corollary to the phenomenon of high flows in the rivers is the influence of drought or low flow conditions in the rivers that results in the movement of the salt-freshwater wedge landward, causing increased salinity in the Bay and its tributary systems (tidal creeks and connected wetlands). In June 2013, water level, temperature, and conductivity sensors were installed along the salinity gradient to measure temporal variations in hydrologic conditions within the swamp. Microclimatic conditions were also measured and water flux at the tidally influenced watershed outlet was logged using an acoustic Doppler flow velocity sensor installed within the pipe culvert to measure bi-directional flows. At the upper extent of the watershed, a groundwater well was installed and instrumented with a depth, temperature conductivity sensor to characterize groundwater position and groundwater salinity. A conductivity temperature depth (CTD) sensor was also deployed within the tidal creek to measure water level and salinity changes in that section of the system. For the purposes of this extended abstract, data measured between June 2013 and January 2015 will be reported and discussed.

Results from 16 months of monitoring salinity in Strawberry Swamp show a pronounced salinity gradient between the upper reaches of the swamp and its lowest tidally influenced section at the outlet with the highest salinities measured at the swamp outlet. The upper reaches of the swamp were influenced primarily by incident rainfall within the watershed, with salinity levels in the two healthy zones ranging from 0.2 to 1.5 PSU, while at the mid-

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stressed zone, salinity ranged from 1.6 to 3.6 PSU. At the zone that is currently experiencing the most dieback of trees (stressed zone), salinity ranged from 3.3 to 7.0 PSU. At the outlet there appears to be a complex dynamic driven by tides, local rainfall, and estuarine backwater effects. Salinity ranged from 0.3 to 15.6 PSU over the period of record. The data show that average salinity in the outflow is marginally higher than the average inflow salinities. Flow measurements at the outlet suggest that the wetland exports that represents 7.9 percent of rainfall incident on the watershed (Table 1). Tidal flows at the outlet summed over a daily time step showed that there were consecutive days of net flow into the swamp (inflows) between

Table 1—Total inflows and outflows measured at Strawberry Swamp outlet between June 2013 and January 2015.

	Volume of water (m^3)	Volume expressed as depth per unit watershed area (mm)	Total Rainfall (mm) (10/2013 and 1/2015)	Rainfall runoff ratio (%)
Inflow	-285,981	-122	1,602	7.9
Outlow	583,435	249		
Net flow	297,454	127		

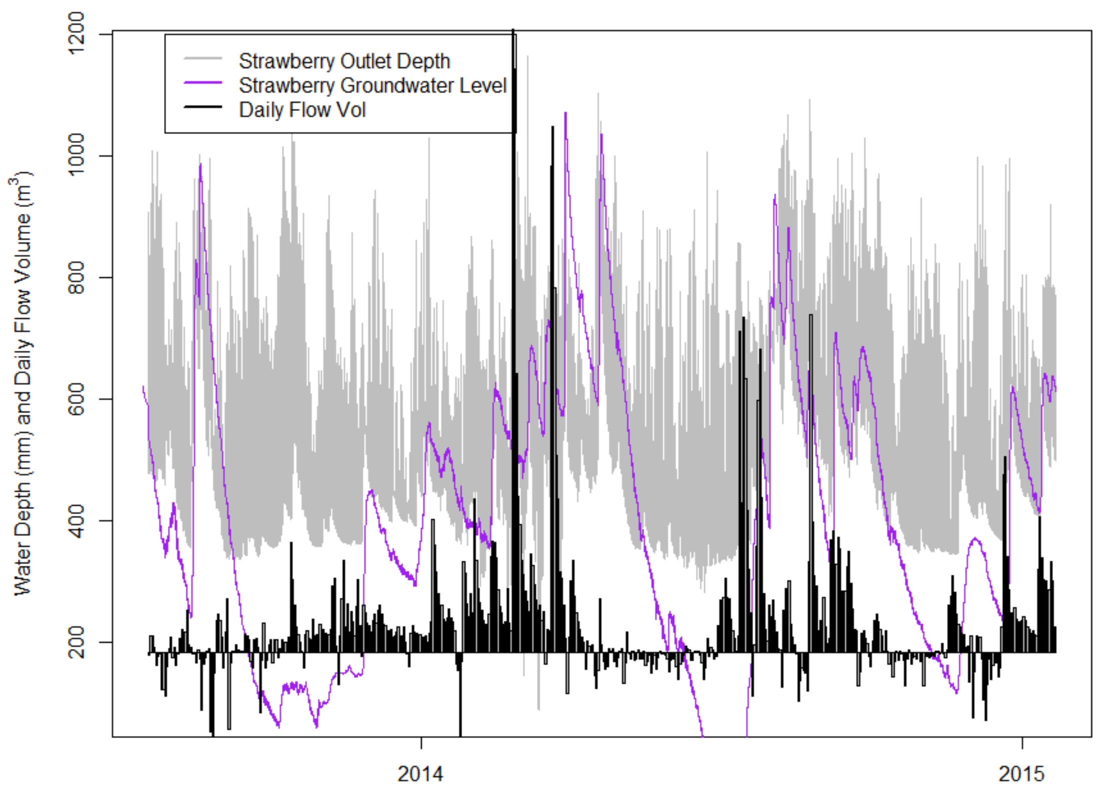

Figure 1—Net daily flow volumes measured at Strawberry Swamp outlet between June 2013 and January 2015 represented as vertical bars. Water level at the wetland outlet is depicted as a gray line and show the influence of tidal, backwater, and upland flow dynamics. Groundwater level measured at an upland location is shown with a purple line and represent water elevations above a datum that is 3.3m below the ground surface.

May and July 2014 as well as in November and December 2014 (Fig. 1). These periods appear to coincide with low groundwater levels in the watershed. However, this net inflow of water into the swamp does not appear to be repeated during another period of low groundwater elevation during November 2013. Data collection is ongoing and we hope to develop a clearer picture of flow and salinity fluxes in Strawberry Swamp.

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LINKING FRESHWATER TIDAL HYDROLOGY TO CARBON CYCLING IN BOTTOMLAND HARDWOOD WETLANDS

Carl C. Trettin, Brooke J. Czwartacki, Craig J. Allan, Devendra M. Amatya[1]

Abstract—Hydrology is recognized as one of the principal factors regulating soil biogeochemical processes in forested wetlands. However, the consequences of tidally mediated hydrology are seldom considered within forested wetlands that occur along tidal water bodies. These tidal water bodies may be either fresh or brackish, and the tidal streams function as a reservoir to sustain a shallow water table depth as compared to nontidal stream reaches. Accordingly, both the hydrology and water chemistry are expected to affect the forest carbon cycle; however, there are few studies to support this assertion. Hypotheses that are suggested by this hydrogeomorphic setting include greater net primary productivity and greenhouse gas emissions. However, given the persistent and dynamic high water table, it is important to consider micro-topography in quantifying greenhouse gas emissions, a functionality similar to boreal peatlands. A major constraint to assessing carbon cycle dynamics in tidally influenced forested wetlands is the lack of an accepted classification system and reliable spatial data base to indicate their spatial extent; this is particularly important for the upper tidal reaches where there is not a threat of changes in salinity associated with sea level rise. Advancing research to address this important part of the landscape is fundamental to addressing issues associated with sea level rise and the interaction of coastal development on estuaries.

INTRODUCTION

Tidal freshwater forested wetlands exist at the interface between marine and terrestrial ecosystems. Until recently, they have been overlooked by wetland scientists, perhaps because they have a hydrologic regime that is characterized by both marine and terrestrial influences. The American Geophysical Union (AGU) Chapman Conference–Hydrogeomorphic Feedbacks and Sea Level Rise in Tidal Freshwater River Ecosystems, held in Reston, VA, 13-16 November, 2012, highlighted the importance of these wetland ecosystems and the considerable uncertainties about their ecological functions, as well as the potential effects associated with sea level rise and climate change. The objective of this paper is to provide context for needed research on the carbon cycle in tidal freshwater forested wetlands because they are at the outlets of terrestrial watersheds that are inextricably linked to estuaries, and it is a landscape that is experiencing sustained development pressures.

Tidal Freshwater Forested Wetlands

Tidal freshwater forested wetlands (TFFW) occur in floodplains situated near the coastal zone along freshwater rivers that are subject to tides. While water table depth and duration of inundation are the primary factors controlling vegetation patterns in wetlands (Rheinhardt and Hershner 1992) along tidally influenced rivers and streams, salinity concentration intercedes and regulates vegetation zonation (Odum 1988). Salt marsh communities dominated by smooth cordgrass (*Spartina alternafloras*) and black needlerush (*Juncus roemarianus*) occur in estuarine riparian zones where salinity levels range from 5 to >30 ppt. In the oligohaline (brackish) marsh (0.5–5 ppt) zone, smooth cordgrass and black needlerush are common, but big cordgrass (*Spartina cynosuroides*) is typically prominent and is often mixed with bulrush (*Scirpus americana*) and pickerelweed (*Pontederia cordata*) (Wiegert and Freeman 1990). The most significant shift in vegetative community composition occurs where salinity concentration is below 0.5 ppt; here, freshwater marsh vegetation includes spatterdock (*Nuphar lutem*), giant cutgrass (*Zizaniopsis miliaceaes*), wild rice (*Zizania aquatica*), smartweed (*Polygonums* spp.), cattail (*Typha* spp.), and rose mallow (*Hibiscus moscheutos*) (Odum and others 1984).

Tidal freshwater forested wetlands exist in a narrow margin between the head of tide and freshwater marsh, and they are distinguished from nontidal forests by the presence of tide in the adjoining stream or river. Tidal freshwater forested wetlands support a broad range of bottomland hardwood communities ranging from bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa*

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aquatic) stands in floodplains that are regularly flooded and maintain nearly constant soil saturation, to oak (*Quercus* spp.) and gum (*Nyssa sylvatica)* stands that are seasonally flooded, closely resembling the nontidal bottomland hardwood communities further upstream (Conner and others 2007, Kroes and others 2007, Light and others 2002).

Distribution and Classification

The presence of salt-tolerant vegetation assists in defining the boundaries between saltwater, brackish, and freshwater vegetative communities, but locating the forested edge of the tidal zone is difficult due to the uninterrupted forest cover within the tidal/nontidal convergence zone (Day and others 2007). This uncertainty arises from multiple sources, including the lack of a well-defined classification system, inconsistent terminology, and lack of data on the head-of-tide. The current estimates of land area occupied by TFFW are based on a coastal county survey conducted by the National Oceanic and Atmospheric Administration (NOAA), which delineated tidal freshwater forests and marshes based on National Wetland Inventory (NWI) data (Field and others 1991). Thus, the estimate is likely conservative due to reliance solely on vegetative data in a system that is hydrologically complex (Doyle and others 2007).

The most commonly used wetland classification system is the U.S. Fish and Wildlife Service's Wetland and Deepwater Habitat Classification System, developed by NWI, which uses vegetative cover to distinguish between wetland types and classes (Cowardin and others 1979). Tidal freshwater forested wetlands are categorized as either riverine (in-channel) or palustrine, which are denoted tidal by a water regime modifier. Tidal freshwater swamps are defined as separate from the adjacent estuary system by a salinity threshold of less than 0.5 ppt, and their proximity to the open ocean. Estuarine wetlands are mostly open or only partially closed off to the ocean, where salinities can range from polyhaline (18–30 ppt) closest to the ocean, to mesohaline (5.0–18 ppt) further up the estuary (Cowardin and others 1979). The riverine classification relates primarily to the area between the banks of a stream channel and describes both in-channel and forested cover. Palustrine forested wetlands include wetlands dominated by trees. Riverine and palustrine classifications also apply to nontidal wetlands; therefore, a water regime modifier is used to denote wetlands subjected to a freshwater tide. In the tidal system, three main types of flooding regimes exist: subtidal, regularly flooded, and irregularly flooded. To avoid confusion with saline environments, the nontidal water regime modifiers are used with the addition of the word "tidal" to differentiate these systems from palustrine or riverine nontidal systems. The modifiers indicate wetland surface tidal inundation patterns and include permanently flooded-tidal (the land surface is exposed less than once daily), regularly flooded-tidal (land surface is exposed at least one time daily), and seasonally flooded-tidal (land surface is flooded less than daily) (Cowardin and others 1979).

The tidal freshwater forested wetlands are most prominent along the Southeastern Atlantic lower Coastal Plain, where it is estimated that over 200,000 ha exist (Field and others 1991). However, considerable uncertainty exists in the estimates of TFFW area, in large part because of the inconsistent use of the tidal modifiers within the NWI. The majority of TFFW are concentrated along the coasts of the South Carolina, Georgia, Florida, Virginia, and Maryland, with smaller areas along the Gulf Coast and upper portions of the Atlantic Coastal Plain. South Carolina has the largest TFFW land area (estimated at over 40,000 ha) as a result of the relatively large tide range and low topographic gradient in the lower Coastal Plain.

DISCUSSION

Hydrology of Tidal Freshwater Forested Wetlands

Riparian wetlands exist at the interface of aquatic and terrestrial ecosystems, which are distinguished functionally by gradients of biophysical conditions, ecological functions, and biological communities (Batzer and Sharitz 2006). Their landscape position provides a hydrologic connection between water bodies and uplands due to proximity to rivers, streams, lakes, and estuary or marine environments. The main sources of water are precipitation, groundwater discharge, overland flow, interflow, and surface runoff from the adjacent water body (Batzer and Sharitz 2006). Riparian wetlands that occupy the freshwater (salinity <0.5 ppt) intertidal zone between nontidal forested riparian zones and freshwater marsh have a hydrologic regime that is subject to both tidal and fluvial influences. Accordingly, the water table in TFFW is affected by the adjoining tidal stream or river and is typically much wetter than upland riparian zones (Hackney and others 2007).

Studying a TFFW riparian zone in the lower Coastal Plain of South Carolina, Czwartacki (2013) showed that the tidal freshwater stream functioned as a reservoir to sustain a higher mean water table within the tidally influenced riparian zone as compared to the nontidal bottomland hardwood wetland (table 1). Accordingly, the tidal stream reach sustains the water table, and during periods of low flow from the uplands (e.g., during summer and fall), the hydraulic gradient can be upstream (fig. 1). In addition to maintaining a higher water table, the hydroperiod within the tidal riparian zone responds to the tidally mediated stream stage, especially within 30–50 m of the stream. Therefore, soil in tidal freshwater bottomland hardwood wetland may be characterized as being much wetter than a nontidal wetland, which suggests that the carbon dynamics would also be affected.

Micro-topography

Micro-topography is the undulating relief that is common to most forests, but particularly pronounced in wetlands, where it is typically described as hummocks and hollows. Hummocks are elevated areas (averaging +15 cm above base soil elevation). In contrast, hollows are bowl-shaped depressions below the average wetland surface elevation, characterized by long periods of saturation that restrict plant growth (Courtwright and Findlay 2011, Duberstein and Conner 2009). Micro-topography affects the available soil volume above the water table (fig. 2). Hollows are thought to increase flood duration and soil moisture through depression storage and affect the frequency and depth of flooding (Courtwright and Findlay 2011). Duberstein and Conner (2009) identified semi-diurnal tide signatures in groundwater hydrographs in old slough channels and found persistently saturated soil conditions despite drought conditions. Rheinhardt

Table 1—Mean water table depth in the tidal transition zone and nontidal bottomland hardwood wetland over a 16-month period in 2011-2013 (from Czwartacki 2013). Sites are arranged on a tidal gradient, with the far left being the lowest tidal site (LLT) and the far right being the nontidal site (NT-1).

Zone	Mean water table depth below surface (cm)
Lower tidal	45
Mid-tidal	108
Upper Tidal	154
Nontidal	154

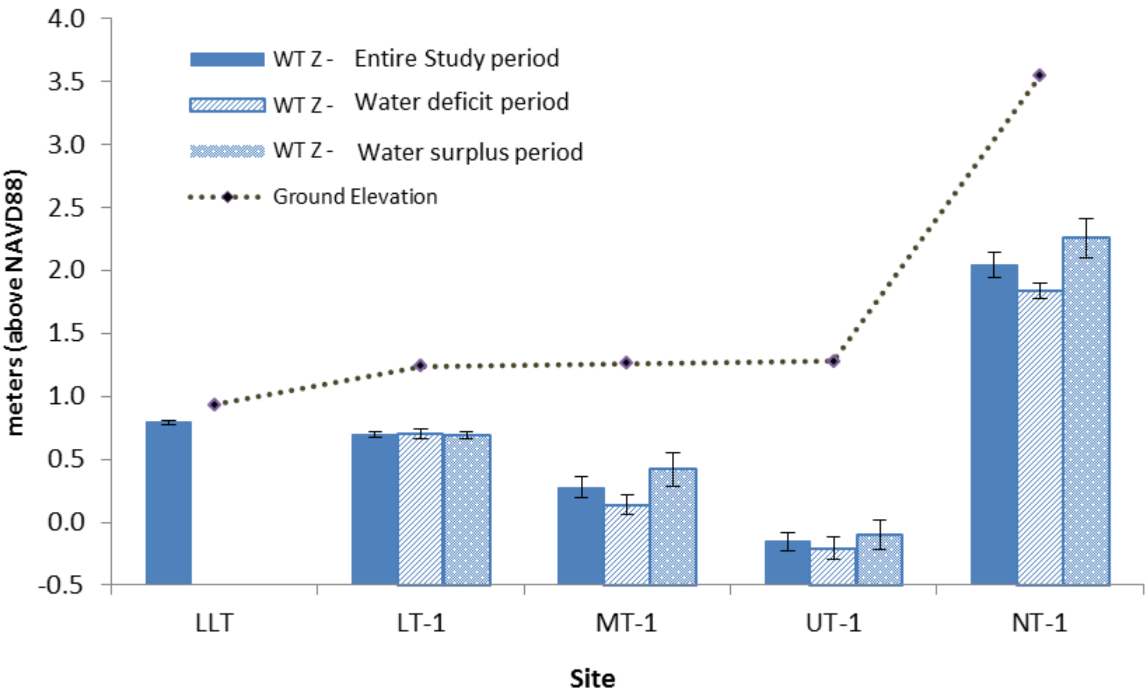

Figure 1—Water table characterization in a tidal to nontidal stream reach, based on results presented by Czwartacki (2013) for Huger Creek, South Carolina.

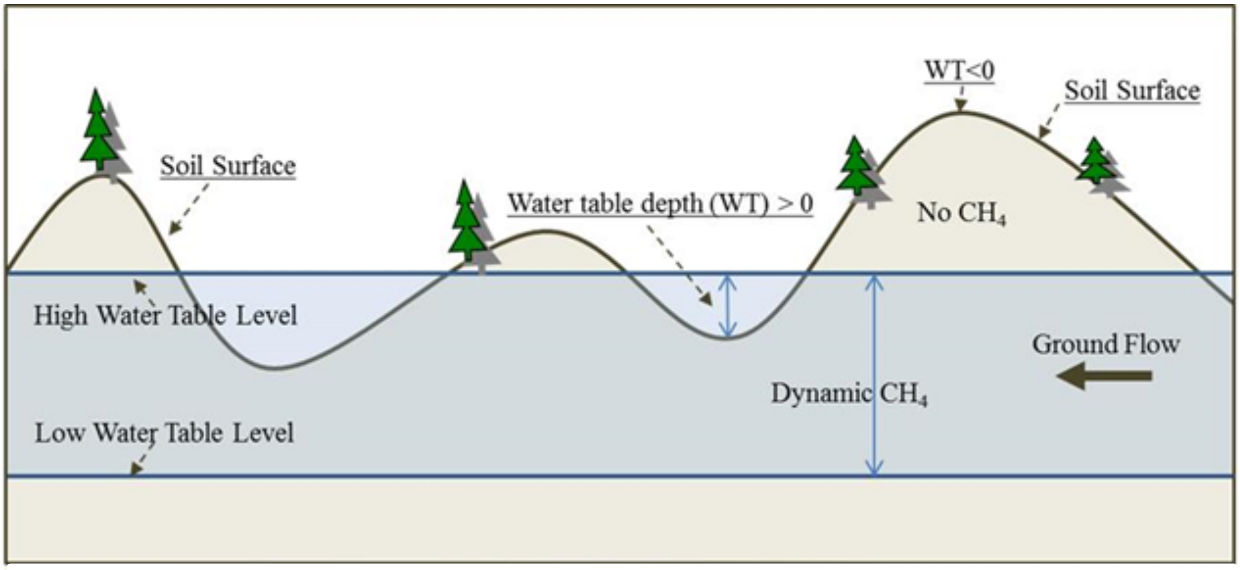

Figure 2—Effect of micro-topography on soil volume.

and Hershner (1992) also reported that the tidal stream hydroperiod influenced the water regime in tidal-swamp hollows along the Pamunkey River, Virginia. In forested peatlands, micro-topography is recognized to affect carbon dynamics and greenhouse gas emissions (Trettin and others 2006). Taking into account that soil water regime is similarly influenced in the mineral soil of tidally influenced swamps, the expectation is that they will also exhibit a spatially complex soil gas emission pattern that is regulated by the distribution of the micro-topography and proximity to the tidal creek.

Carbon Dynamics in Tidal Freshwater Forested Wetlands

Carbon dynamics—and especially greenhouse gas emissions—in forested wetlands are strongly influenced by water table position (Trettin and Jurgensen 2003). Consequently, the contrasting hydrologic setting within tidal and nontidal freshwater riparian zones may be expected to alter carbon sequestration and fluxes (fig. 3). Wetland-dominated riparian zones have long been recognized as a primary source of carbon in waterborne fluxes of carbon in receiving streams (e.g., Doskey and Berch 1994, Harvey and Odum 1990, Harvey and others 1995). Although riparian soils are assumed to be the primary source of dissolved carbon compounds in adjacent receiving waters, more recent studies indicate that "fresh" vegetation decomposition products can make up the majority of dissolved organic carbon compounds found in tidally influenced stream channels (Engelhaupt and others 2001). Waterborne carbon transport and atmospheric losses in wetland-dominated riverine systems have been found to be dominated by dissolved inorganic carbon (DIC) transport and subsequent atmospheric loss through abiotic and/or microbial mediated processes (Elder and others 2000, Richey and others 2002.)

The freshwater tidal stream functions as a reservoir of water that oscillates on a semidiurnal tidal cycle. During each semidiurnal tidal cycle, channels and rivulets within the riparian zone are inundated and subsequently drained, with the tidal stream being the source of the flood water and the receiving stream for the draining water. Correspondingly, there is a direct exchange of pore water in sediments within 2–3 m of the tidal stream (Nuttle and Hemond 1988), suggesting that dissolved constituents, including dissolved carbon and gases, and inorganic constituents are also exchanged. In many estuarine systems, there can be large changes in flow and water level on the tidal time scale (<13 hours); but, on extended time scales (day to weeks), there may be only small changes in net (tidally averaged) flow and water level during periods of low runoff from the uplands. In tidal creeks, like Huger Creek where there is seasonal freshwater flow from the uplands, the streamflow can be dominated by tidal inflows on the flood (incoming) and ebb (outgoing) tides during periods of low flow from the uplands. However, during periods of high flow from the uplands, flow from within the watershed may dominate the stream discharge. During low- or no-flow upland conditions, net flows will be negative (inland) with downstream source water, with a different water-quality signature, slowly moving upstream and exchanging with the upland water in the channel and riparian pore water. The residence time of downstream source water in these upper tidal reaches can last for long periods of time during drought periods, with high freshwater outflows required to flush the system to a more riverine-type condition.

In nontidal wetlands, methane (CH_4) efflux is regulated by the water table relative to the soil surface (Trettin and others 2006), with hummock positons having significantly lower emission rates than hollows (Bubier and others 1993). Studying a bottomland tidal swamp in North Carolina, Megonigal and Schlesinger (2002) showed that tidal forcing on the riparian zone water table can regulate CH_4 efflux from hollows. Accordingly, the net flux across an area of tidal riparian zone is likely an interaction among micro-topography and tidal forcing.

PERSPECTIVE

As a result of the high evapotranspiration demands of coastal forests (Amatya and Skaggs 2011, Domec and others 2012, Gholz and Clark 2002, Marion and others 2013), many headwater watersheds exhibit ephemeral flow, being dry during the most of the growing season and having runoff in the fall or winter. Thus, the hydrologic flux from these upland watersheds and their associated riparian zones occurs in pulses during precipitation-driven flow events (Dai and others 2011, 2013; Epps and others 2013). In contrast, the tidal riparian reaches that occur lower in the landscape experience daily pulses of flooding and ebbing (rising and draining) waters, which can effectively import carbon and other constituents, as well as export materials from these riparian zones. The fluxes and associated mass balance of carbon within these forested wetlands that interface uplands and estuaries have not been measured. We hypothesize that carbon sequestration is higher in TFFWs as compared to an upstream nontidal forested wetland, and that carbon export is also larger (fig. 4). In tidally influenced riparian zones, available water should not limit productivity as compared to nontidal riparian zones that exhibit wide fluctuations in water table depth; correspondingly, export of organic matter will be facilitated by the daily inundations from the tidal stream.

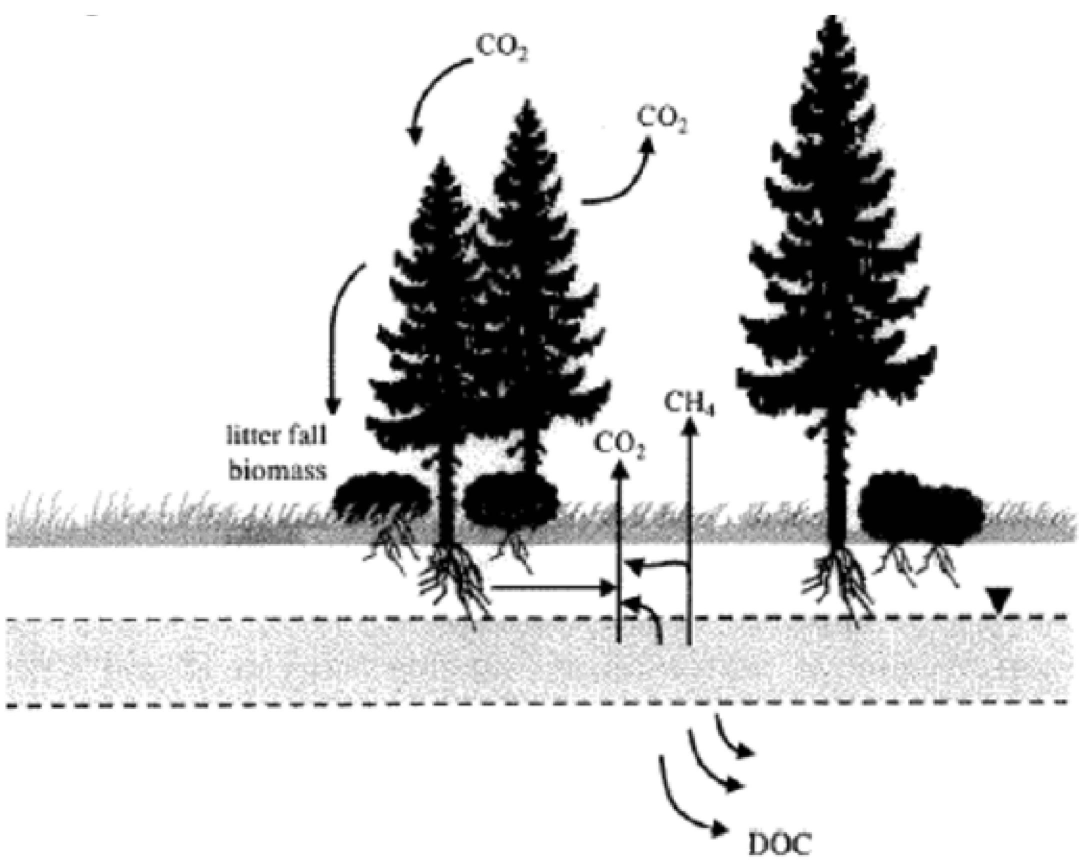

Figure 3—Carbon cycle forested wetlands (adapted from Trettin and Jurgensen 2003) reflecting a nontidal and tidal hydrologic regime.

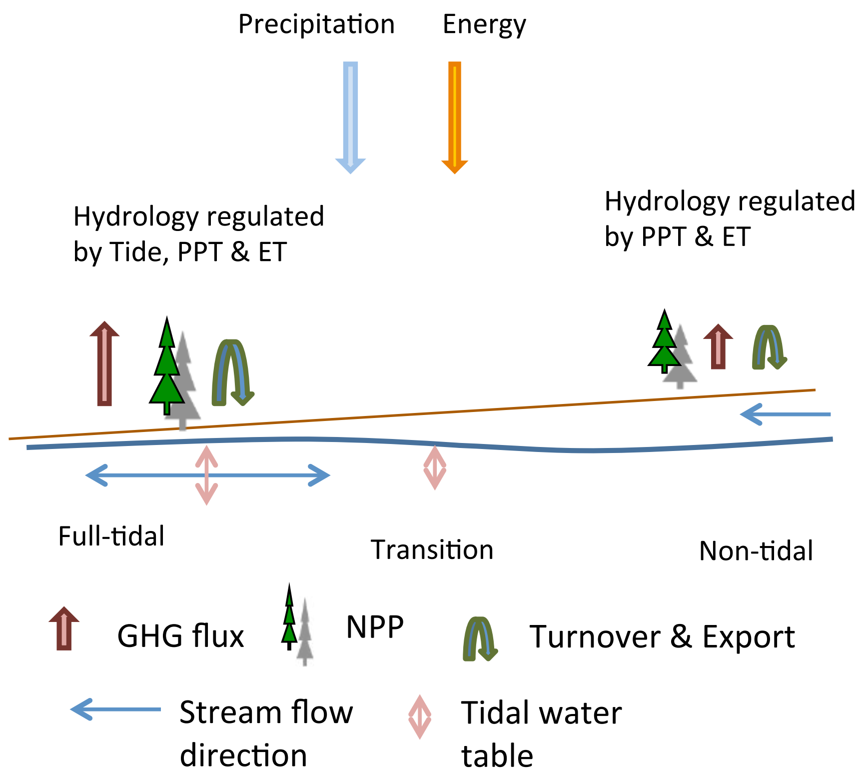

Figure 4—Depiction of the effects of the tidally imposed hydrologic regime on carbon cycling. Sequestration, turnover and greenhouse gas emissions are expected to be greater in the tidal freshwater forested wetland as compared to the upstream nontidal wetland principally due to the persistent high water table.

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DETERMINING VOLUME SENSITIVE WATERS IN BEAUFORT COUNTY, SC TIDAL CREEKS

Andrew Tweel, Denise Sanger, Anne Blair, John Leffler[1]

Non-point source pollution from stormwater runoff associated with large-scale land use changes threatens the integrity of ecologically and economically valuable estuarine ecosystems. Beaufort County, SC implemented volume-based stormwater regulations on the rationale that if volume discharge is controlled, contaminant loading will also be controlled. The County seeks to identify which of their tidal creeks and rivers and what portions of these waters are most sensitive to stormwater runoff. Through an ongoing collaborative process with county officials and concerned citizens, four watersheds of critical interest were instrumented with rain gauges and salinity sensor arrays to monitor the movement of freshwater down these systems from volume “sensitive” headwaters to volume “insensitive” downstream waters. The change in salinity was measured as the primary indicator of the volume of stormwater entering the estuarine ecosystem. Runoff analyses were complicated somewhat by significant tidal exchanges that alter estuarine salinities twice daily. Thirteen and twenty-five hour filters were applied to the salinity time series to isolate the stormwater impacts from tidal effects. Watersheds and sub-watersheds were ranked with regard to their relative stormwater volume sensitivity by comparing several salinity response parameters derived from the time series data. Stormwater runoff is also being modeled with the Stormwater Runoff Modeling System (SWARM) to estimate the expected runoff based on watershed area, land cover, soils, and slope. If the empirical and modeling approaches correlate well, SWARM will be used to model stormwater volume sensitivity in additional estuarine watersheds, as well as to project impacts of climate change and engineered stormwater retrofits on tidal creeks. This information will permit Beaufort County to focus policy and stormwater management actions on those portions of tidal creeks that are most sensitive to stormwater inputs.

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STORMWATER RUNOFF IN WATERSHEDS: A SYSTEM FOR PREDICTING IMPACTS OF DEVELOPMENT AND CLIMATE CHANGE

Ann Blair, Denise Sanger, Susan Lovelace[1]

The Stormwater Runoff Modeling System (SWARM) enhances understanding of impacts of land-use and climate change on stormwater runoff in watersheds. We developed this single-event system based on US Department of Agriculture, Natural Resources Conservation Service curve number and unit hydrograph methods. We tested SWARM using US Geological Survey discharge and rain data. Multi-site validations conducted for both undeveloped and developed watersheds support the robustness of our system in quantifying and simulating runoff: rainfall to runoff differences between measured and modeled volumes ranged from 3 to 11 percent; r^2 for hydrograph curves ranged from 0.82 to 0.98. Key applications of SWARM are: (1) comparing runoff among watersheds representing different environmental settings (e.g., levels of development, soil types, a range of sizes, topography); (2) evaluating and illustrating (singularly or in combination) effects of primary drivers of runoff amount and flashiness including development level, soil type, antecedent runoff conditions, rainfall amount; (3) predicting runoff under a range of development scenarios within a watershed; and (4) integrating effects of urbanization and projected climate change scenarios. User-friendly templates make SWARM a good tool for scientific research, for resource management and decision making, and for community science education. The modeling system supports investigations of social and economic impacts to communities as they plan for increased development and climate change. SWARM currently is used in several research projects including one led by South Carolina Department of Natural Resources / ACE Basin NERR to identify estuarine waterways sensitive to stormwater runoff volume in Beaufort County, SC. Although we calibrated SWARM specifically to the southeast coastal plain, it can be applied to other regions by recalibrating parameters and modifying calculation templates.

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Interdisciplinary Research in the Watersheds: A Forum for Team Players

SPATIO-TEMPORAL VARIATION IN DISTRIBUTION OF AQUATIC SPECIES AND THEIR HABITATS IN A RESERVOIR TRANSITION ZONE

Andrew Dolloff, Craig Roghair, Colin Krause, John Moran, Allison Cochran, Mel Warren, Susie Adams, Wendell Haag[1]

Dams convert riverine habitat to a series of reaches or zones where differences in flow, habitat, and biota, both downstream and in reservoirs, are obvious and well described. At the upstream extent of a reservoir, however, is a transitional reach or zone that contains characteristics of riverine habitat both in the upper reservoir and in tributaries connected to the reservoir. The total amount and quality of habitat within the transition zone depends on characteristics that vary greatly both seasonally and on shorter, often unpredictable time scales depending on dam operation and a combination of weather and climate. Relatively little is known about the persistence and resilience of biological communities in the transition zone. The Lewis Smith development impounds several major headwater tributaries in the Black Warrior River watershed, including two large tributaries flowing through the Bankhead National Forest in north Central Alabama: Sipsey Fork and Brushy Creek. Water levels upstream of the Lewis Smith development fluctuate seasonally up to 6 m and are highest in early spring and lowest in late fall or early winter. The watershed upstream of the Lewis Smith development is home to extremely diverse biological communities with at least 69 fish, 18 mussel, and 6 crayfish species, counting native, introduced, and exotic species, several of which are restricted to the Black Warrior River drainage or are species of conservation concern. Beginning in 2012, we partnered in a multi-year effort to describe habitat conditions and biological communities within transitional habitats in the Sipsey Fork and Brushy Creek watersheds. Overall project objectives are to: 1) delineate the extent and physical characteristics (structure, sediment, etc.) of transition zone and sub-zone habitats during both full and minimum pond levels, 2) describe the distribution of fish, crayfish and mussel species with an emphasis on Federal and State Threatened and Endangered species, and 3) assess the role of tributaries as refuge habitats. Fish, mussel, and crayfish distributions in Sipsey Fork and Brushy Creek appear to be related to habitat zones (impounded, transition, stream) and subzones (stream-run, run-impounded). In general, the transition zone functions as an ecotone, with the highest overall species diversity. Within the transition zone we collected species associated with river, stream, and headwater habitats more frequently from the stream-run subzone than the run-impounded subzone. Impounded and transitional habitats also function as pathways for upstream invasion by non-native fish, mussel, and crayfish species introduced into Lewis Smith reservoir.

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ENVIRONMENTAL SUSTAINABILITY OF INTERCROPPING SWITCHGRASS IN A LOBLOLLY PINE FOREST

George Chescheir, François Birgand, Mohamed Youssef, Jami Nettles, Devendra Amatya[1]

A multi-institutional watershed study has been conducted since 2010 to quantify the environmental sustainability of planting switchgrass (*Panicum virgatum* L.) between wide rows of loblolly pine (*Pinus taeda* L.). The hypothesized advantage of this intercropping system is the production of biofuel feedstock to provide additional revenue in forested lands and to utilize land areas that could not otherwise be used for food production. Three paired watershed scale (8 to 27 ha) studies are being performed at three locations: Carteret County, NC, Greene County, AL and Calhoun County, MS. An additional study is being performed at the plot scale (0.8 ha plots) in Lenoir County, NC. Treatments on these studies are: 1) Young trees (1 – 6 yr) with standard forestry practice, 2) Young trees with switchgrass planted between rows, 3) switchgrass planted with no trees, and 4) mid-rotation (15 to 18 yr) trees with standard forestry practice. Each watershed is instrumented to automatically measure and record flow at the outlet, water table depths and soil moisture in the fields, and weather data. Flow proportional composite samples are collected at the watershed outlets and shallow groundwater samples are collected in the fields. Water quality samples are analyzed for nitrate (NO_3^--N), ammonium (NO_4^+-N), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), total phosphorous (TP), and dissolved organic carbon (DOC). Reference evapotranspiration (REF-ET) and actual ET for each vegetation type is being estimated using remote-sensing satellite images and meteorological data. Models have been developed to predict ET and ET related parameters (temperature, stomatal conductance) using LandSat data. Field and watershed scale models have been modified to better simulate the hydrology, and nutrient and sediment loss from the different land-uses on the watersheds. DRAINMOD based models have been used for simulating the flat poorly-drained watersheds in NC and APEX and SWAT models have been used for simulating the upland watersheds (MS and AL). Other sustainability parameters (wildlife, stream biota, plant biodiversity, soil carbon, biomass crop productivity and operational safety) are also being measured and analyzed in the watershed and plot studies. The information and models resulting from this multi-disciplinary study will be used to develop best management practices to sustainably produce biofuel feedstock in a forestry setting.

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PREDICTING FISH POPULATION DYNAMICS WITH SPATIALLY EXPLICIT, INDIVIDUAL-BASED MODELS: INTEGRATION OF ECOLOGY, HYDROLOGY, GEOMORPHOLOGY AND MORE

Bret Harvey, Steve Railsback[1]

Many important watershed science and management problems involve interactions among biological and physical factors. For example, the persistence and productivity of highly valued stream fish populations are commonly influenced by interactions among hydrologic and thermal regimes, sediment routing, the effects of predators and competitors, and food availability. Human influences such as water diversions, restoration projects, introduced species and climate change commonly further influence and complicate watershed management questions. Spatially explicit, individual-based models have the potential to address this complexity by simulating the environment down to spatial scales relevant to individual animals, while incorporating influential temporal variation in key physical factors. In STREAM and in SALMO are individual-based models of trout and salmon that simulate networks of stream reaches using habitat cells on the scale of a few square meters and information on streamflow, water temperature and turbidity at daily or sub-daily time steps. These models have been applied at ~40 sites for purposes such as understanding effects of habitat variables and physical regimes, evaluating flow and temperature management alternatives, and assessing/forecasting effects of restoration projects. The development and application of such models requires expertise in ecology, behavior, hydrology, geomorphology, engineering, and software development, and the ability to quantify biological and physical variables at high frequency over long time periods. Because these models integrate the effects of many watershed processes on important biological resources, they can provide a clear framework for interdisciplinary research and focusing it on important management questions.

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MANAGEMENT OF RIPARIAN AND AQUATIC ECOSYSTEMS USING VARIABLE-WIDTH BUFFERS

Brian Pickard, Gordon H. Reeves, K. Norman Johnson[1]

Management of aquatic and riparian ecosystems is constrained because of the reliance on "off-the-shelf" and one-size-fits-all concepts and designs, rather than considering specific features and capabilities of the location of interest. As a result, use of fixed- width buffers that generally depend on stream size is the most common approach. This is easy to administer and apply, and along with lack of guidance for developing buffers and uncertainty about results of using variable-width buffers, development and application of a variable approach to management of riparian and aquatic ecosystems has been limited. However, new analysis tools, such as NetMap, and practices, such as tree tipping, and a growing understanding of how key ecological processes occur within a watershed allows for development of viable and practical alternative approaches to the fixed-width approach that are ecologically beneficial and cost-effective while providing potential opportunities for other management objectives. We developed an approach that recognizes the inherent variation in where ecological processes occur within a watershed as well as the capacity to provide productive habitat to establish the size of riparian buffers and the type, extent, and objectives of management activities at a particular location. More productive and ecologically important locations receive the largest buffer in which management is directed to solely achieving ecological goals. Locations that are less productive and more immune to management impacts have less area devoted to solely achieving ecological goals and more area for managing for ecological and other goals. We provide an example of the application of this approach on federally managed lands in western Oregon.

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WILD SALMON RESPONSE TO NATURAL DISTURBANCE PROCESSES

Russell F. Thurow, John M. Buffington[1]

Dynamic landscapes are shaped by a variety of natural processes and disturbances operating across multiple temporal and spatial scales. Persistence of species in these dynamic environments is also a matter of scale: how do species dispersal and reproductive rates merge with the scales of disturbance? Across the Pacific Northwest, salmon populations have evolved with a complex set of natural disturbance patterns and processes creating and altering their essential habitats. In most watersheds, human activities have changed the disturbance regimes and compromised our ability to examine both the natural processes and salmon population responses. In this study, we evaluated wild Chinook salmon responses to natural disturbance processes in the Middle Fork Salmon River (MFSR), Idaho. The MFSR is a large wilderness basin where natural processes function relatively unimpeded by human activities. During the last 20 years, a series of fires have burned large portions of the MFSR basin. Those fires, followed by intense thunderstorms over some burned areas, have resulted in large debris flows that have altered salmon habitats within both the mainstem MFSR and several major tributaries. Over this same 20 year period, we have annually surveyed and geo-referenced the location of all Chinook salmon redds (spawning nests) across the entire MFSR basin. In this paper, we describe the mechanisms of debris flow creation and sediment routing, illustrate temporal and spatial responses of spawning Chinook salmon to natural patterns of habitat disturbance in the basin, assess the importance of salmon dispersal and habitat connectivity, and addresses how a changing climate may alter natural landscape dynamics. In particular, warming temperatures are expected to increase fire frequency and subsequent debris flows in the basin, while increased rain-on-snow events may cause more frequent avalanches, both of which input wood and sediment to the stream network. Field observations are coupled with sediment routing models to explore the consequences of these dynamic processes on salmon habitat over space and time. Inspection of larger-scale stream and basin morphology shows that these processes have been acting on this landscape for millennia and have had long-term effects on channel gradient, stream width, and associated salmon habitats. Consequently, the disturbance processes are not new, geomorphically or biologically, but rather their frequency and spatial extent are being altered by climate change. Although salmon have evolved with these disturbance processes, a key question is whether adaptation of native species can keep pace with rates of climate change and associated disturbance regimes.

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AN ECOLOGICAL ASSESSMENT OF LAND USE IMPACTS IN SMALL WATERSHEDS OF THE CHESAPEAKE BAY

Andrew Leight, John Jacobs, Lonnie Gonsalves, Gretchen Messick, Shawn McLaughlin, Jay Lewis, Julianna Brush, Eric Daniels, Matthew Rhodes, Lewis Collier, Robert Wood[1]

The Chesapeake Bay, the nation's largest estuary, remains in relatively poor condition despite intensive public and scientific attention. In order to better understand the stressors and impacts occurring in the Bay as a result of land management decisions we conducted an assessment of both habitat condition and organismal response in three small watersheds of the upper Bay. We selected watersheds with different types of land use (agricultural, suburban, mixed-use). We collected samples in Spring, Summer, and Fall over three years, including measurements of organism health over a wide range of biological organization – from molecular to community level. Some responses followed predictable trends, such as poor benthic community condition in the highly urbanized watershed. Less obvious were findings that indicated there may be tradeoffs in the response of some organisms to stressors. For example, fish abundance and fish health were inversely related, with high abundances and poor condition in the agriculturally dominated watershed and the opposite occurring in the highly developed watershed. Our findings also agree with other studies that have discovered greater impacts to habitat condition in small, headwater tributaries close to land-based sources than in the mainstem. We subsequently extended the study to three other watersheds in the Chesapeake Bay in order to examine the same suite of stressors and responses in lower salinity rivers and to increase our understanding of land use effects on estuarine conditions. We collaborated with various stakeholders to conduct the study and are engaged with them to discuss application of the findings.

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New Insights into Studies on Long Term Experimental Watersheds to Address Contemporary Emerging Issues

(PART 3)

INSIGHTS FROM LONG-TERM RESEARCH ON THE FERNOW EXPERIMENTAL FOREST

Mary Beth Adams[1]

In 1951, five weirs were constructed in the mixed hardwood forests of the Fernow Experimental Forest and watershed research began. Specializing in long-term watershed scale manipulations, researchers at the Fernow have evaluated effects of various silvicultural practices on water yield, seasonal flow patterns, water quality and on ecosystem processes and ecosystem services. Experiments with fairly narrow initial hypotheses have attracted researchers from around the world to address issues far removed from timber harvesting and forest management. Considerable research has been dedicated to understanding the effects of air pollution, particularly acidic deposition, on forest ecosystems. This research has led to detailed studies on biogeochemical cycling in mixed species forests. New issues which have arisen and been added to the research portfolio are soil acidification, nitrogen saturation, base cation depletion, climate change, and severe storm effects. The Fernow is unusual because of the variability in nitrogen retention among its gaged watersheds. In particular, research on cycling of nitrogen in forested watersheds has been ongoing for many years at the Fernow. In the early years (1970s and early 1980s), fertilization studies suggested that nitrogen was limiting tree growth. Later watershed research documented that nitrogen appeared to be available in excess of biotic demand, suggesting that some stands on the Fernow were nitrogen-saturated. Long-term documentation of high rates of nitrogen (and sulfur) deposition, along with parallel monitoring of stream water chemistry from several gauged headwater streams, has revealed high rates of nitrate export, along with some of the lowest rates of nitrogen retention in the eastern U.S. The Fernow Watershed Acidification Study and the Fork Mountain Long Term Productivity Study have both evaluated the effects of elevated nitrogen additions on nutrient cycling, tree growth, soil chemistry, and a variety of other parameters. Still, there are interesting gaps in our understanding of ecosystem processes, such as nutrient cycling, that suggest additional research topics.

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LONG-TERM HYDROLOGIC RESEARCH ON THE SAN DIMAS EXPERIMENTAL FOREST, SOUTHERN CALIFORNIA: LESSONS LEARNED AND FUTURE DIRECTIONS

Peter M. Wohlgemuth[1]

Abstract—The San Dimas Experimental Forest (SDEF) is located in the San Gabriel Mountains, about 45 km northeast of Los Angeles, California. The SDEF was originally established in 1934 to document and quantify the hydrologic cycle in semiarid uplands with intermittent headwater streams. New and innovative equipment was necessary to measure rainfall and streamflow in this mountainous terrain. Long-term monitoring has revealed a number of hydrologic patterns following land use change and wildfire. Water quality monitoring shows that the SDEF has had very high levels of nitrate due to its proximity to the heavily polluted Los Angeles Basin. These nitrate levels, which approach federal standards, are exacerbated by land use change and fire. In the future, evaluating the hydrologic response from climate change models and testing specific climate change predictions for southern California may be possible using the 80-year record of temperature, rainfall, and streamflow from the San Dimas Experimental Forest.

INTRODUCTION

The San Dimas Experimental Forest (SDEF) is a nearly 7000 ha research preserve administered by the USDA Forest Service, Pacific Southwest Research Station, and has been the site of extensive hydrologic monitoring for over 80 years (Dunn and others 1988). Established in 1934, the original mission of the SDEF was to quantify the water cycle in semiarid upland terrain and to determine if any extra water could be harvested to support agriculture and domestic water supply in the valleys below (Robinson 1980). With its headquarters at Tanbark Flat (34° 12' N latitude, 117° 46' W longitude), the SDEF is located in the San Gabriel Mountains, about 45 km northeast of Los Angeles, California (fig. 1).

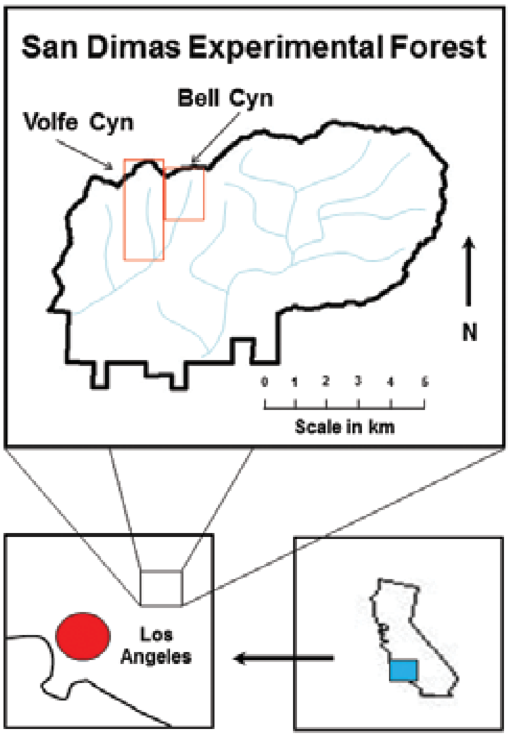

Figure 1—Location map of the San Dimas Experimental Forest.

The Experimental Forest and Range network can be considered a cornerstone of USDA Forest Service Research due primarily to the long-term datasets acquired from these reserves. Long-term observations and monitoring can document subtle ecological shifts that are harbingers of environmental change not readily apparent from studies of only a few years duration. Furthermore, the effects of complex environmental processes or the response to land use changes or to management manipulations can only be fully appreciated over time.

In the early 1930s, the hydrologic cycle was fairly well understood in the humid eastern section of the United

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States where water was abundant. However, in the arid and semiarid West, water was scarce and watershed management was in its infant stages (Leopold and others 1964). Headwater streams were intermittent and rainfall-runoff relationships were virtually unknown. Long periods of drought were punctuated by large floods which destroyed property while millions of cubic meters of potentially usable water escaped to the sea. Because of the general scarcity and variability in water supply, wise watershed management depended on a better understanding of the water cycle in semiarid uplands. This prompted the establishment of the SDEF.

STUDY AREA

Elevations in the SDEF study area range from 450 to 1675 m and topography consists of a highly dissected mountain block with steep hillside slopes and steep channel gradients. Bedrock geology is dominated by Precambrian metamorphics and Mesozoic granitics that produce shallow, azonal, coarse-textured soils (Dunn and others 1988). The region experiences a Mediterranean-type climate, characterized by hot, dry summers and cool, wet winters. Temperatures range from -8^{o} C to 40^{o} C. Mean annual precipitation, falling almost exclusively as rain, is 715 mm in the SDEF (80-year record), but rain during individual years can range from 252 to 1848 mm.

Native vegetation in the SDEF consists primarily of mixed chaparral, a dense shrubland of drought-tolerant plants 3-5 m in height. Plant cover on south-facing slopes ranges from closed stands of chamise (*Adenostoma fasciculatum*) and ceanothus (*Ceanothus* spp.) to more open stands of chamise and black sage (*Salvia mellifera*). North-facing hillsides are dominated by scrub oak (*Quercus berberidifolia*) and ceanothus, with occasional hardwood trees – coast live oak (*Quercus agrifolia*) and California laurel (*Umbellularia californica*) – occurring on moister shaded slopes and along the riparian corridors (Wohlgemuth 2006). Some pine-oak forest occurs in the higher elevations, especially on north-facing aspects, including canyon live oak (*Quercus chrysolepis*), big-cone Douglas-fir (*Pseudotsuga macrocarpa*), sugar pine (*Pinus lambertiana*), and a remnant grove of ponderosa pine (*Pinus ponderosa*).

Fire has been a part of the southern California landscape since before recorded history and is the disturbance event which drives much of the local environmental response (Sugihara and Barbour 2006). Fire alters the physical and chemical properties of the soil – bulk density and water repellency – promoting overland flow on the hillsides at the expense of infiltration (DeBano 1981). This water is quickly conveyed to the adjacent stream channels and flooding is a common post-fire hydrologic response (Krammes and Rice 1963). Stand-replacing wildfires occurred on the SDEF in 1919, 1960, and 2002.

One of the management treatments following the wildfire in 1960 was the type-conversion of the native chaparral vegetation in some watersheds to a mixture of perennial grasses. It was thought that type-conversion would aid in future fire control and would enhance water yield by replacing deep-rooted shrubs with shallow-rooted grasses (Rice and others 1965). These perennials included a variety of wheatgrass species (*Agropyron* spp.), Harding grass (*Phalaris tuberosa* var. *stenoptera*), big bluegrass (*Poa ampla*), smilo grass (*Piptatherum miliaceum*), and Blando brome (*Bromus hordaceous*) (Corbett and Green 1965). Over time, many of the seeded grass species have disappeared from the sites and substantial amounts of buckwheat (*Eriogonum fasciculatum*) and black sage have established on the type-converted watersheds.

METHODS

The hydrologic monitoring for this study was conducted in Volfe and Bell Canyons (fig. 1). Volfe Canyon watershed is 300 ha in size and covered with native chaparral vegetation. Volfe Canyon is a long-term reference watershed managed for minimal human disturbance. Bell Canyon consists of multiple headwater basins ranging in size from 25 to 40 ha. Originally covered with native chaparral vegetation, Bell2 was type-converted to perennial grasses in 1958 and Bell1 was similarly converted in 1960 (Dunn and others 1988). Bell3 remains in chaparral.

Rainfall on the SDEF has been measured continuously since 1934 in a network of weighing raingages (Dunn and others 1988). Total annual rain for individual study areas was computed as the area-weighted average of the nearest stations measured in millimeters. Rainfall was assumed to be spatially uniform across the catchments and was also calculated as cubic meters based on watershed area.

Streamflow has been measured in Volfe and Bell Canyons since 1938 (Dunn and others 1988). Stream discharge was measured in weirs for low flows (<50 L/s) and flumes for high flows. Stage heights were read from float-driven stream charts at 6 hour intervals and at inflection points during storm events. Discharge was computed from stage height using rating curves developed for each instrument and summed over the time intervals to get an annual water yield in cubic meters.

Water quality has been measured in Volfe and Bell Canyons since 1986. Pumping samplers draw aliquots of stream water every 6 hours while the creeks are flowing. Samples are analyzed in the laboratory using an ion chromatograph with detection limits of 0.01 ppm. Nitrate (NO_3) is the primary analyte.

RESULTS AND DISCUSSION

Equipment Development

During the 1930s and 1940s, much time and effort were spent developing equipment to measure the various hydrologic components at SDEF. On mountainous terrain, a more accurate measurement of rainfall was realized if the gage was tilted perpendicular to the hillside slope rather than set in a vertical orientation (Hamilton 1954). Streamflow was intermittent, flashy, and often heavily bulked with sediment. Several tiers of weirs and flumes were necessary to accurately measure the range of expected discharges from the larger watersheds: a 90° weir in the throat of a 0.91 m (three-foot) flume nested in a 2.44 m (eight-foot) flume. Moreover, a supercritical flume was developed – the San Dimas flume – capable of measuring flows containing considerable sediment and debris (Wilm and others 1938). A large lysimeter complex was built to quantify soil moisture, percolation, and evapotranspiration (Patric 1961), although this apparatus suffered from significant design flaws and was subsequently abandoned.

Fire Response

Post-fire flooding has long been documented in southern California (Kraebel 1934). Using the rainfall and runoff records from SDEF, this post-burn hydrologic response can be quantified and compared to pre-fire values. Storm rainfall, peak flows, and resulting flow volumes for Volfe Canyon watershed are shown in table 1. Prior to the 1960 wildfire, the response to these early season moderate rainfall events is modest. However, the first four storms following the wildfire shows a spectacular contrast. Both peak flows and flow volumes increase by four orders of magnitude compared to pre-fire levels from similar storms (table 1). From these before and after hydrologic findings from the SDEF, the downstream damage to human communities by flooding following a wildfire in southern California can be easily explained.

Type-Conversion

Runoff records from the multiple small watersheds in Bell Canyon were used to assess the effects of type-conversion. None of the immediate post-fire years (1961-1964) were used in this analysis, eliminating the fire effects mentioned above. A test of normalcy using the Bell3 control watershed indicates a different runoff response trajectory between the pre- and post-conversion time periods (fig. 2). To account for this response difference, the runoff ratios (RO), the percentage of rainfall that leaves the watershed as streamflow (Ratzlaff 1994), were calculated and the type-converted catchments were compared to the control. Bell1 watershed, which produced more runoff than Bell3 even prior to the vegetation change, increased its water yield by a factor of three following type-conversion (fig. 3). Bell2 had a similar response (fig. 4). Thus, type-conversion does appear to increase runoff and water yield from southern California chaparral watersheds. However, apart from the wholesale ecosystem changes and effects on native fauna, subsequent studies have shown that there are serious environmental consequences of type conversion, including increased erosion in the form of soil slips and slope failures (Rice and others 1969) and degraded water quality (Riggan and others 1985).

Table 1—Rainfall, peak flows, and flow volumes from the Volfe Canyon watershed for similar storms before and after a wildfire of July 1960.

Storm Dates	Rainfall	Peak flow	Flow volume
	mm	L/s	m^3
Dec. 3-4, 1955	34.3	0.157	14
Oct. 19-21, 1958	27.4	0.116	2
Nov. 2-5, 1958	41.4	0.300	1
Jan. 11-12, 1960	36.1	0.068	2
Wildfire – July 1960			
Oct. 9-10, 1960	21.3	3351	37,455
Nov. 3, 1960	36.8	370	48,060
Nov. 5-6, 1960	39.6	5538	55,258
Nov. 12, 1960	32.5	9347	412,037

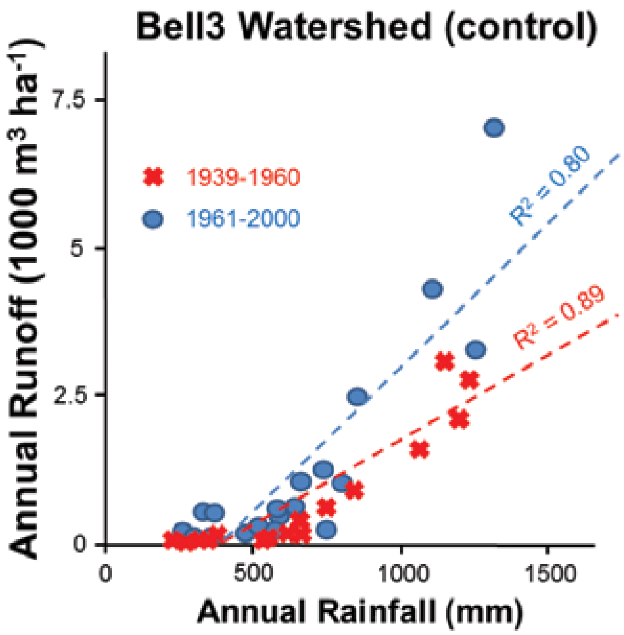

Figure 2—Rainfall-runoff relationships in Bell3 watershed during the pre- and post-type-conversion time periods of Bell1 and Bell2 watersheds. The immediate post-fire years of 1961-1964 have been omitted from this analysis.

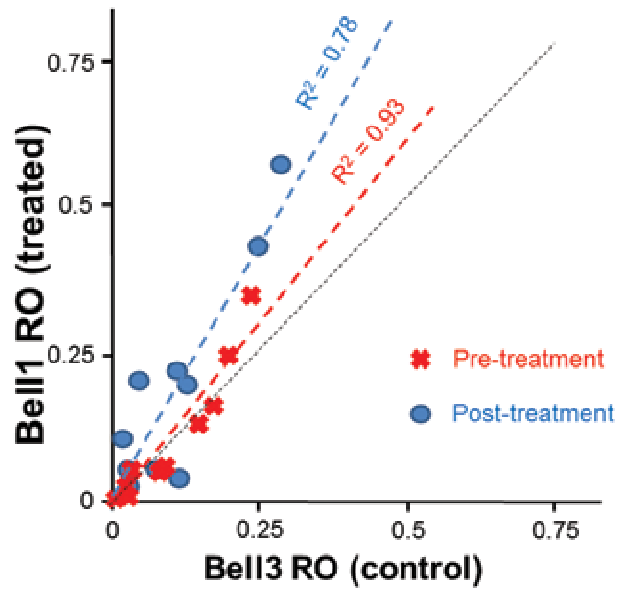

Figure 3—Runoff ratios (RO), the percentage of rainfall that leaves the watershed as streamflow, from Bell1 pre- and post-conversion compared with RO from Bell3. Black dotted line is the line of one-to-one correspondence.

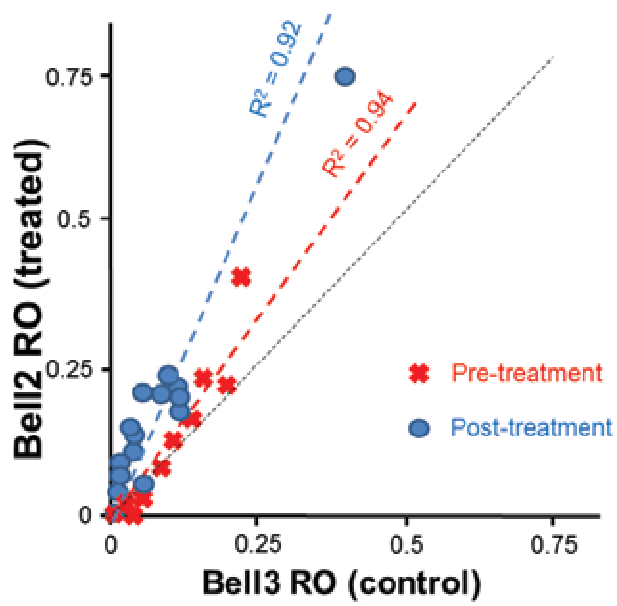

Figure 4—Runoff ratios (RO), the percentage of rainfall that leaves the watershed as streamflow, from Bell2 pre- and post-conversion compared with RO from Bell3. Black dotted line is the line of one-to-one correspondence.

Water Quality

Water quality sampling began sporadically in the early 1980s and became a programmatic feature of SDEF monitoring in 1986. High rates of atmospheric N deposition are produced in southern California by chronic air pollution, primarily from automobile exhaust from the Los Angeles Basin. These pollutants become trapped in an inversion layer that gets pushed up against the inland mountains by daily onshore air flows from the Pacific Ocean. This deposition in the headwater mountains, including the SDEF, has led to measured surface water levels of nitrate that approach the Federal EPA standard of 10.0 mg L^{-1} for nitrate-N (Fenn and others 2003). Substantial amounts of nitrate are washed off shrub surfaces during the summer and autumn, when small storms are interspersed with pollution episodes. Measured stream water nitrate concentrations in the SDEF have been as high as 7.0 mg of nitrate-N L^{-1} in undisturbed native vegetation. These values are some of the highest measured rates in the United States and up to 1000 times greater than more pristine areas in southern California (Riggan and others 1985). Although there has been a slight decline in N deposition over the last twenty years with more stringent pollution control requirements, nitrate levels in SDEF stream water remain high (Meixner and others 2006). Fire can further increase nitrate levels in SDEF stream water. Initial data following a prescribed fire showed that nitrate-N concentrations in streams could be as much as 15.7 mg L^{-1}, 1.5 times the Federal standard (Riggan and others 1985). Greater concentrations and yields of nitrate were also measured in watersheds that were type-converted to grasslands. Possibly, the greater nitrate levels reflected greater subsurface soil exposure caused by the landsliding in these altered landscapes coupled with the more rapid water flux through the shallow-rooted grasses. Maximum measured yield was 19.4 Kg of N $ha^{-1}yr^{-1}$ in grass vegetation compared to 10.0 Kg N $ha^{-1}yr^{-1}$ in chaparral (Riggan and others 1985).

INTO THE FUTURE

If the model projections are correct, climate change will profoundly affect global weather patterns. Although there is considerable variability among the many models, the general consensus is that temperatures will increase and precipitation will decrease in most continental areas (Cayan et al. 2008). This will alter the local hydrologic cycle (the disposition of rain and snow, evaporation, transpiration, the timing of snowmelt, water storage) that will in turn affect water supplies. In southern California, the Mediterranean pattern of wet winters and dry summers is projected to continue. However, some models predict that the area could experience periods of up to 30 years where annual rainfall is more than 10 percent below historical levels (Cayan et al. 2008), and the annual precipitation could decrease by 20 to 40 percent by the year 2100 (EPA 2013). One possible benefit of the long-term weather, rainfall, and stream runoff records at SDEF may be the ability to estimate the hydrologic response to expected climate change. Because of the natural variability inherent in any long-term dataset (e.g. figure 2), surrogates for climate change scenarios may already exist in the SDEF archives. Thus, realistic estimates of hydrologic response could be used for planning purposes as well as to validate the output of climate change models.

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To the visionaries who established the San Dimas Experiment Forest and to the dedicated cadre of scientists and technicians who stayed the course, thank you.

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WATER-LIMITING CONDITIONS BASED ON MONTHLY WATER BALANCES AND POTENTIAL EVAPOTRANSPIRATION AT PANOLA MOUNTAIN RESEARCH WATERSHED, GEORGIA, U.S.A.

Brent Aulenbach, Norman E. Peters, James Freer[1]

Drought and resulting water-limiting conditions can result in negative ecological impacts such as reduced plant growth and increased stress that can make plants more vulnerable to threats such as insect infestations. The long-term dataset at Panola Mountain Research Watershed, a small 0.41-hectare forested watershed near Atlanta, Georgia, U.S.A., was used to better quantify the important factors leading to water-limiting conditions. Actual evapotranspiration (ET) relative to potential ET (PET) was used as an indicator of water limiting conditions as PET represents the potential maximum ET, assuming no water limitations. Actual and potential ETs were compiled on a monthly basis for the period 1985 through 2011, which contains multiple drought periods. Potential ET was calculated from air temperature and solar radiation using the Priestley–Taylor equation. Actual ET was determined using the watershed water budget, and was calculated as the difference between monthly precipitation, runoff, and changes in water storage within the watershed. Water storage was determined using a water storage-baseflow relation developed for this watershed.

Annual water yields, the proportion of precipitation that occurs as runoff each year, varied greatly, ranging from 9.7 to 46 percent. The magnitude of water yields were largely dependent on the annual precipitation and whether the majority of precipitation occurred during the dormant season, resulting in more runoff, versus the growing season, resulting in more ET. Actual ET averaged about 40 millimeters per month (mm/month) during the dormant season and 88 mm/month during the growing season and peaked with an average of 123 mm/month in July. Actual ET averaged about 89 percent of PET during the dormant season and 70 percent of PET during the growing season. For this analysis, we defined months with water-limiting conditions as those where actual ET was <60 percent of PET. Months with water-limiting conditions were observed during the growing season when monthly precipitation was low (defined as <50 mm) and was irrespective of watershed storage condition. This result may indicate that storage available in shallow soils derived from recent precipitation is a more important control on actual ET than overall watershed storage, with plant transpiration as the driver. The results of this analysis should assist in assessing the effects of future changes in seasonal and long-term climate patterns in precipitation on components of the water budget along with changes in the severity and duration of water-limiting conditions.

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CHANGES IN BASEFLOW CONDITIONS OVER A 42 YEAR OBSERVATION PERIOD FOR THE LITTLE RIVER EXPERIMENTAL WATERSHED IN SOUTH GEORGIA

David D. Bosch, Randall G. Williams, Timothy C. Strickland, Jeff G. Arnold and Peter G. Allen[1]

Hydrology is the driving force of sediment, nutrient, and pesticide movement. Separation of streamflow hydrographs into rapid surface runoff and baseflow can vastly improve our understanding of chemical transport. In addition, characterizing these two components of streamflow can also greatly improve overall watershed hydrologic budgets which are critical for accurate evapotranspiration estimation. For validation of hydrology in model simulations, direct runoff and baseflow components of the streamflow hydrographs typically need to be separated. Incorrect representation of baseflow patterns can lead to erroneous results in watershed analysis.

Here we examine annual and seasonal variations in baseflow within the Little River Experimental Watershed (LREW) from 1972 to 2013. The LREW is located near Tifton, Georgia, in the South Atlantic Coastal Plain of the U.S.A. (N31°26'13", W83°35'17"). The LREW is part of the Gulf Atlantic Coastal Plain LTAR (Maddox 2013). The hydrology, precipitation, and water quality of the LREW have been monitored by the Southeast Watershed Research Laboratory (SEWRL) since 1967 (Bosch and others 2007). The climate is humid subtropical with a long growing season. Annual precipitation averages 1192 mm yr^{-1}. Mean annual temperature is around 18.7°C, with the coldest month of the year being January with an average temperature of 10.6°C and the warmest being July with an average temperature of 26.8°C.

Streamflow during the months of December through April in watersheds throughout the Southeastern Coastal Plain is typically much greater than during the months of May through November. Greater precipitation and lower evapotranspiration rates during the winter and spring months create higher soil-moisture and greater aquifer recharge, increasing surface runoff responses and groundwater contributions to streamflow. Baseflow, the portion of streamflow coming from vadose zone and groundwater sources, makes up a large fraction of the streamflow during the winter and spring periods. Thus, baseflow is extremely important to sustaining streamflow throughout the Southeastern Coastal Plain. Increasing demands on groundwater, changes in land-use, and changes in precipitation patterns due to climate change are all expected to impact baseflow conditions and streamflow volume.

Historical precipitation and streamflow data were obtained from the SEWRL database (Bosch and others 2007). The period of record examined was from 1972 to 2013. This analysis was limited to examination of data from the largest watershed, Watershed B, a 334 km^2 drainage area. Daily precipitation and streamflow data extrapolated from the subdaily data were examined. Data were partitioned into annual and seasonal periods for hydrograph

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Table 1—Results of annual and seasonal baseflow analysis for Little River Station B, 1972-2013.

Period	Winter	Spring	Summer	Fall	Yearly
Baseflow Index	0.55	0.57	0.42	0.47	0.54
Standard Deviation	0.07	0.09	0.09	0.13	0.04

analysis. The seasonal periods selected, based upon prior research, were December through February (winter), March through May (spring), June through August (summer), and September through November (fall). The digital filter method used for separation of high and low frequency signals was used for separation of baseflow (Lim and others 2005). The two parameter Eckhart digital filter was used with a maximum baseflow index (BFImax) of 0.80 and an alpha value of 0.98. The baseflow index is the ratio of baseflow to total streamflow.

Examination of the 42 years of annual flow data produced an average baseflow index of 0.54 (Table 1). Average seasonal baseflow indexes varied from 0.57 for the spring to 0.42 for the summer (Table 1). Variability of the annual data was low as were the variability of the winter, spring, and summer seasons. Variability of the fall was higher.

Baseflow was found to decrease as a function of increasing rainfall (Fig. 1). This is attributed to the saturated conditions which accompany high precipitation, subsequently leading to rapid surface runoff. Trends in baseflow were examined for both the annual and seasonal data. Annual baseflow was found to be decreasing over the 42 year period. Analysis of precipitation data indicated annual precipitation over the 42 year period was also decreasing (α=0.05). Since higher annual precipitation appears related to lower baseflow, a decreasing annual precipitation would be expected to yield lower baseflow conditions, conflicting observed long-term baseflow trends. Examination of seasonal precipitation patterns indicated decreasing long-term trends for the winter and spring precipitation and increasing trends for the summer

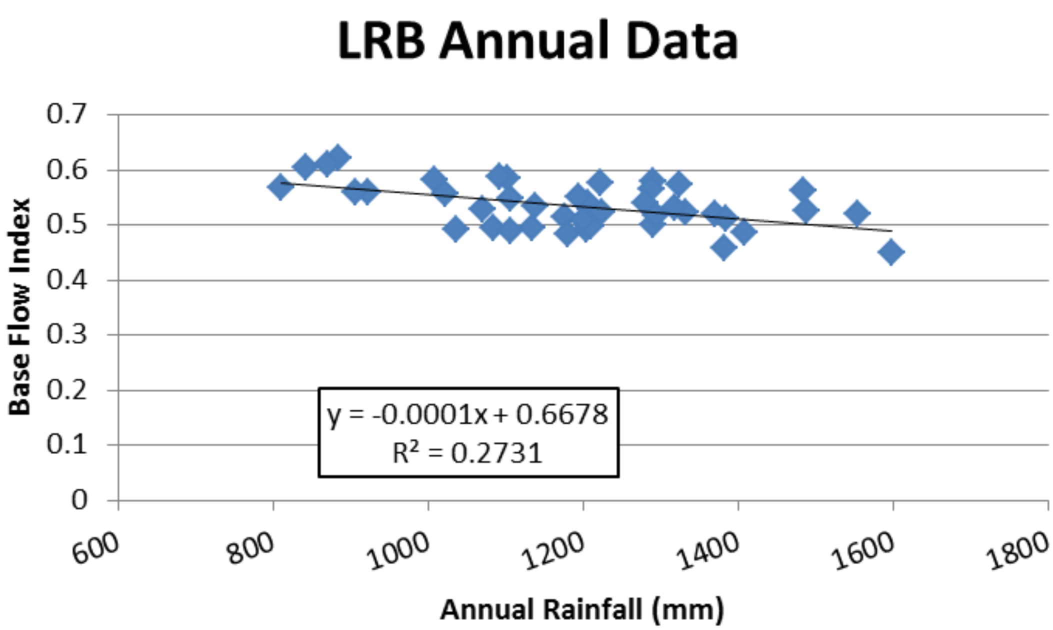

Figure 1—Baseflow index as a function of annual rainfall illustrating a decreasing trend in baseflow as a function of increasing annual rainfall (significant at α=0.05).

and fall precipitation. This shift in seasonal precipitation patterns would explain the long-term decrease in baseflow.

Overall, baseflow was found to produce 54 percent of annual streamflow, 13 percent less than prior published results. Baseflow was the largest during the months from December through May (55-57 percent) and the least during the months from June through November (42-47 percent). Annual baseflow was found to decrease with increasing annual precipitation. Data indicated a decreasing long-term trend in annual precipitation, decreasing baseflow, and increasing variability. Data also indicate a shift in seasonal precipitation from the winter and spring to the summer and fall which is believed to contribute to reduced baseflow in the watershed.

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THIRTY-YEAR RESULTS FROM A PAIRED-CATCHMENT STUDY OF UPLAND FLOWPATH RESPONSES TO FOREST COVER CONVERSION IN NORTHERN MINNESOTA

Stephen Sebestyen, Randy Kolka[1]

Long-term studies on paired-research catchments have often showed periods of changes to water yields and peak stormflow after forest harvesting. Most studies have focused on whole-catchment or downstream responses. In contrast, few studies have ever been established to measure and investigate specific pathways of water routing through catchment soils or how sub-catchment hydrological flowpaths respond to experimental vegetation manipulations, as well as common metrics of annual water yields and stormflow magnitudes. At the Marcell Experimental Forest (MEF) in northern Minnesota, subsurface and surface runoff collectors were operated in a paired-catchment study of forest conversion to conifer (spruce/pine) cover after clearcutting of deciduous (aspen/birch) trees on upland mineral soils. The runoff collectors measured amounts of flow from mineral soils on hillslope plots. Upland runoff data were collected from both north- and south-facing slopes in a reference and an experimental catchment. In the MEF landscape, which includes northern peatlands, the hillsllope flowpaths drain to central peatlands. As such, we distinguish between sources of water in upland and peatland soils, as well as apportion flow along the two different upland flowpaths. Herein, we report on the timing and magnitude of forest-conversion effects on the routing of water along surface and subsurface runoff pathways. Annual water yields increased during the first post-harvest decade and returned to pre-harvest levels from 10-20 years after harvest/conversion. During the third post-harvest decade, annual water yields continued to decrease and water yields were about 50 percent lower relative to the pre-harvest period. Since the upland clearcut in 1980, total annual surface and subsurface runoff amounts from the converted forest have decreased to a trivial annual amount, while streamflow and upland runoff amounts in the reference catchment showed no trends. To elucidate reasons why these changes occurred, we initiated a study of transpiration. Together, these studies suggested that forest conversion in post-glaciated catchments with northern peatlands may lead to fundamental changes in catchment hydrology. The uplands now yield practically no water and the coniferous forest transpires most of the available water, which means that runoff from a peatland is the primary source of streamflow. These findings have important implications for the management of forested landscapes and the practice of restoring conifer cover to forests of northern Minnesota, which is the headwater of several major rivers.

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LONG TERM RECORDS PROVIDE INSIGHTS ON THE RELATIVE INFLUENCE OF CLIMATE AND FOREST COMMUNITY STRUCTURE ON WATER YIELD IN THE SOUTHERN APPALACHIANS

Peter Caldwell, Chelcy Ford Miniat, Steven Brantley, Katherine Elliott, Stephanie Laseter, Wayne Swank[1]

In forested watersheds, changes in climate and forest structure or age can affect water yield; yet few long-term observational records from such watersheds exist that allow an assessment of these impacts over time. In this study, we used long-term (~80 yrs) observational records of climate and water yield in six reference watersheds at the Coweeta Hydrologic Laboratory in the southern Appalachian mountains of North Carolina to determine whether water yield has changed over time, and examine and attribute the causal mechanisms of change. These six reference watersheds are unmanaged with only successional dynamics and natural disturbances altering the forest structure since the 1920s. AutoRegressive, Integrated Moving-Average (ARIMA) time series modeling revealed significant ($p<0.05$) decreases in annual water yield (Q) and runoff ratio (Q/precipitation (P)) for lower elevation watersheds beginning in 1973; but no significant change in P was identified. These results suggest that water loss to evapotranspiration (ET) has been increasing since this time. Further, departures in cumulative water yield from that expected given data prior to 1973 could not be explained by P alone in low elevation watersheds, providing additional evidence of a change in ET. A monthly timestep water balance model, WaSSI, along with our long-term climate record, was used to estimate the impact of changes in other climatic variables on water yield. This approach allowed us to separate the influence of climate from that of changes in forest structure and composition. These simulations revealed that changes in water yield in some watersheds could not be explained by climate alone, suggesting that vegetation dynamics have also contributed to the changes in ET. Lastly, we combined species composition, stem diameter and stem density data from long term permanent plot surveys with tree water use by species and diameter derived from sap flux measurements. With these data, we estimated changes in ecosystem water use that corroborate the changes in ET and Q not explained by climate alone for the six reference watersheds. Our results suggest that natural disturbances and successional vegetation dynamics can induce significant changes in water yield even in unmanaged forested watersheds, a conclusion only made possible because long-term records were valued and maintained over 80 years. Our results could have significant implications for water supply in the region and may inform forest management strategies to mitigate climate change impacts on water resources, as well as emphasize the importance of maintaining long term monitoring networks.

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EVALUATING BIOLOGICAL AND PHYSICAL DRIVERS OF EVAPOTRANSPIRATION TRENDS AT NORTHEASTERN US WATERSHEDS

John L. Campbell, Matthew A. Vadeboncoeur, Heidi Asbjornsen, Mark B. Green, Mary Beth Adams, and Elizabeth W. Boyer[1]

Despite a general consensus that the Earth's hydrologic cycle is intensifying as a result of anthropogenic climate forcing (e.g. Huntington 2006), there remains substantial uncertainty over the consequences of this intensification for terrestrial evapotranspiration (ET; e.g., Hobbins and others 2004, Walter and others 2004, van Heerwaarden and others 2010). Most models indicate that climate change will cause an increase in ET, but evidence from field observations has been inconsistent. Unidirectional changes in ET could profoundly alter local water balances and streamflow dynamics, having important implications for water supply and associated services, including drinking water, irrigation, recreation, wastewater assimilation, and power generation.

We evaluated long-term trends in ET at three small (39 to 123 ha), gauged reference watersheds in the northeastern U.S. with the longest combined records of precipitation and streamflow: Fernow Experimental Forest, West Virginia (FEF); Hubbard Brook Experimental Forest, New Hampshire (HBEF); and Leading Ridge, Pennsylvania (LR). Although these measurements are collected at other small watersheds in the region, the selected watersheds have records that are 25 to 45 years longer than any other comparable watersheds. We estimated ET with the water balance approach (ET=precipitation-streamflow), which assumes that changes in groundwater storage are minimal on an annual basis and seepage loss is negligible. Long-term trends were evaluated with the Mann-Kendall test, which is a non-parametric test that is commonly applied to analyses of long-term hydrometeorological time series data (Helsel and Hirsch 1992). The slope for each trend was calculated as the median of all possible pair-wise slopes (Sen 1968). Reported p values were considered significant at the $\alpha = 0.05$ level.

When all the years of available data were considered, time series analyses showed significant declines in ET at FEF and HBEF and no significant change at LR (Fig. 1). When a common time frame was used (i.e., 1959-2011), the ET trend at FEF remained negative, but was not significant (slope=-0.682 mm yr^{-1}, p=0.101). Use of a common time frame had little effect on the slope and p-value for HBEF because only one year was eliminated from the analysis (i.e. 1958). The lack of consistent trends in ET among watersheds suggests that local influences may override potential broader regional drivers of ET. In addition to significant declines in ET, HBEF also had significant increasing trends in precipitation (slope=5.6 mm yr^{-1}; p=0.002) and stream water (slope=6.9 mm yr^{-1}; p=0.001), whereas the other two watersheds showed no significant trends. Evapotranspiration at the HBEF differs from the other watersheds, in that a smaller fraction of the precipitation entering the watershed is transpired/evaporated (36 percent) compared to FEF (56 percent) and LR (59 percent). This difference is likely due to the longer growing season at the more southerly sites, which provides more opportunity for transpiration.

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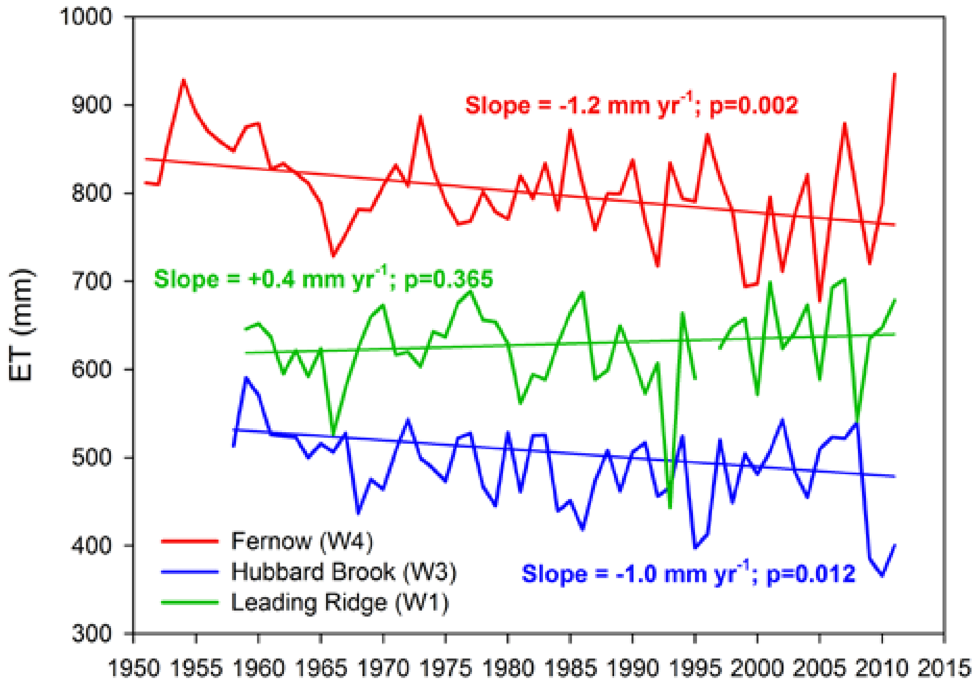

Figure 1—Long-term trends in evapotranspiration (ET) calculated using the water balance approach for gaged watersheds at the Fernow Experimental Forest, West Virginia; Hubbard Brook Experimental Forest, New Hampshire; and Leading Ridge, Pennsylvania.

Hydrometeorological data from each site was used to explore some of the potential underlying climatic mechanisms that could explain the variability in ET. Stepwise multiple linear regression (backwards elimination) was used to identify the most important climatic factors that affect ET. We considered several potential drivers including summer (June, July, August) minimum and maximum air temperature, vapor pressure deficit (VPD) at 1400 EDT (www.ncdc.noaa.gov), Palmer Drought Severity Index (http://www.ncdc.noaa.gov/cag), and annual and growing season precipitation. At LR, the only significant term was growing season precipitation, which showed a significant positive effect (R^2=0.18). At FEF, a more complex model explained more of the variability in ET (R^2=0.61) with annual precipitation, growing season VPD and maximum air temperature showing significant positive effects, and summer minimum air temperature showing a negative effect. At HBEF, the best model included only summer precipitation, which interestingly, showed a significant negative relationship with ET (R^2= 0.10) and was counter to our expectations. Including year as a covariate improved the model at HBEF (R^2=0.16), but had no effect at LR and only slightly improved the model at FEF (R^2=0.67). The positive relationship between summer precipitation and ET at FEF and LR indicates that ET is sometimes limited by water availability at these watersheds. It is unclear what is driving the negative relationship between ET and summer precipitation at HBEF, but may be related to factors that were not quantified, such as cloudiness or soil moisture-temperature interactions. Nevertheless, the negative relationship suggests that water availability is not limiting ET at HBEF and that it is more likely limited by energy at this cooler site.

To further evaluate controls on ET, we analyzed tree ring chronologies collected from 5 individuals (3 cores per tree) of three dominant tree species at each of the three study watersheds. Ring widths were measured to the nearest 0.01 mm (Velmex Measuring System and measureJ2X software) and cross-dated (verified with the COFECHA program, Holmes 1983). Autoregressive standardization (ARS) was used to convert raw ring-width series into growth indices that contain detrended patterns in variation that are representative of the stand. Pearson correlation coefficients (Table 1) indicated that ARS chronologies were correlated with ET at FEF (except sugar maple) and LR, but not at HBEF. At FEF and LR, trees tended to grow better during wet summers (low VPD, high precipitation, high PDSI), and less during warm summers (high max temp, high VPD). These patterns are consistent with the hydrometeorological-ET relationships and indicate that water stress plays a role in limiting ET at these sites. At HBEF, there were no significant relationships between climate variables and ARS chronologies, though notably the relationships were opposite of the other two watersheds, trending towards less growth in wet summers, and more growth with higher maximum temperatures.

Future work will involve analyses of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes in tree rings to further elucidate ET patterns. Tree ring $\delta^{13}C$ can be used to identify changes in water use efficiency, and $\delta^{18}O$ assists in determining whether those changes in water use efficiency are due to changes in photosynthetic rate (e.g., because of changes in nutrient supplies or environmental stressors such as acid deposition) or stomatal conductance (e.g., in response to changes in VPD). These advances are providing critical insight into patterns of ET within the Northeast region, enabling a better understanding of the relative importance of site-specific and regional drivers of ET.

Table 1—Pearson correlation coefficients of ARS tree ring chronologies and climatic variables for watersheds at the Fernow Experimental Forest, West Virginia; Hubbard Brook Experimental Forest, New Hampshire; and Leading Ridge, Pennsylvania.

	ET	Temperature		Water stress		Precipitation	
		Summer Tmin	Summer Tmax	Summer VPD	Summer PDSI	Annual	Summer
Fernow							
Sugar maple	0.072	0.046	-0.133	-0.274*	0.086	0.092	0.331*
Red oak	0.246*	0.146	-0.176	-0.291*	0.403*	0.265*	0.419*
Tulip poplar	0.307*	0.100	-0.315*	-0.282*	0.435*	0.373*	0.311*
Leading Ridge							
Sugar maple	0.332*	-0.033	-0.281*	-0.451*	0.094	0.215	0.408*
Red oak	0.367*	0.104	-0.337*	-0.243	-0.030	0.310*	0.258
White pine	0.307*	-0.012	-0.300*	-0.035	-0.206	0.105	0.172
Hubbard Brook							
Sugar Maple	-0.141	-0.082	0.058	0.180	-0.207	-0.116	-0.014
American Beech	-0.125	-0.223	0.040	-0.044	-0.121	-0.249	-0.079
Red spruce	0.051	-0.021	-0.129	0.220	0.101	-0.095	-0.002

* Indicates statistical significance at the α=0.05 level.

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Advances in Evapotranspiration and Modeling on Multiple Land Uses

UNDERSTANDING AND MANAGING THE WATER USE OF PLANTED FORESTS IN A CHANGING ENVIRONMENT

Jami Nettles[1]

Forest productivity will only become more important in the future, not just for carbon sequestration and renewable energy but for wood products and economic security for an increasing population. However, the threat of increasing drought and resource scarcity means a need for more explicit characterization of the water use of planted forests and the understanding of productivity trade-offs necessary to reduce water use. This requires prediction of species-specific water use under different soil, topographic, climate, and planting conditions and a mechanism to account for trade-offs in ecosystem services that cannot always be directly compared. High quality site-specific research has been conducted and synthesized globally to illustrate general principles: in an energy limited setting, trees use more water than grass in a ratio that increases with water availability. Plant physiology studies have given an understanding of water use (evapotranspiration (ET)) response to soil and atmospheric conditions, somewhat extractable to various tree species. But knowledge bridging the scale from landscape to plant for a given site is still limited. Several strategies for accounting for and reducing the water use of planted forests have been suggested, including fees for additional water consumption over a baseline and site-specific management techniques such as thinning, understory suppression, and site layout in the landscape and within the management tract; however, there is limited research linking these to operational forestry. This presentation uses ET data from silvicultural and biofuel feedstock research and industrial ownership patterns in the southeastern US to evaluate proposed water management strategies and estimate water yield, productivity, and economic outcomes. New ET assessment methods will allow not only scientists, but planners and forest managers the opportunity to quantify the water use of plantation forests. Management techniques, however, must be developed along with the data. We must not just use an objective function that maximizes runoff and favors low productivity settings, but consider the effect of water for ecological requirements and forest productivity and develop workable forest management strategies that optimize benefits.

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COMPARATIVE ANALYSES OF MEASURED EVAPOTRANSPIRATION FOR VARIOUS LAND SURFACES

Suat Irmak[1]

There is a significant lack of continuously measured ET data for multiple land surfaces in the same area to be able to make comparisons of water use rates of different agro-ecosystems. This research presentation will provide continuous evapotranspiration and other surface energy balance variables measured above multiple land use and management practices. The presentation is a part of a large surface energy balance and associated variables measurement network [Nebraska Water and Energy Flux Measurement, Modeling, and Research Network (NEBFLUX)]. NEBFLUX is a statewide network that is designed to measure evapotranspiration, microclimatic and climatic variables, plant physiological parameters (yield, biomass production, plant height, leaf area index, leaf stomatal functions, leaf temperature, etc.), soil water content (every 0.30 m down to 1.8 m from soil surface on an hourly basis throughout the year), and other surface characteristics for various vegetation surfaces under different tillage, irrigation and rainfed management settings. It is a network of micrometeorological tower sites that mainly uses advanced instrumentation such as Bowen ratio energy balance systems (BREBS) and Eddy Covariance System to measure surface water and energy fluxes between terrestrial agro-ecosystems and microclimate.Vegetation surfaces include center pivot-irrigated maize and soybean rotation under disk-till, no-till, and ridge-till, rainfed winter wheat, subsurface drip-irrigated winter wheat, subsurface and center pivot-irrigated continuous maize, center pivot-irrigated seed maize/cover crop rotation, irrigated continuous soybean;center pivot-irrigated grassland; rainfed grassland; alfalfa, rainfed switchgrass, riparian vegetation comprised of Phragmites (*Phragmites australis*)-dominated cottonwood (*Populus deltiodes var. occidentalis*) and peach-leaf willow (*Willow salix*) plant communities.

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URBAN EVAPOTRANSPIRATION IN A HUMID ENVIRONMENT - ORLANDO, FLORIDA, USA

David M. Sumner, Cor M. J. Jacobs[1]

An areally-integrated assessment of ET flux was obtained using eddy covariance methods over an urban/suburban landscape in the humid sub-tropical environment of Orlando, Florida, USA. Mean annual ET during the 3.5-year study period was 921 mm. On average, ET returned a large fraction of rainfall to the atmosphere (72 percent). But annual rainfall varied much more on a year-to-year basis (922 to 1,746 mm) than did urban ET (843 to 974 mm). Interestingly, 12-month periods of relatively high ET occurred during drier periods and 12-month periods of relatively low ET occurred during wetter periods. These results may be related to the generally drier atmosphere and less cloud cover that occur during lower rainfall periods. In addition, this largely urban environment is not subject to large soil moisture limitations because of the prevalence of lawn irrigation and lakes. Corroboration of the ET measurements was provided by independent water budgets for two watersheds that make up much of the source area for the ET measurements. An urban analogue to the "crop coefficient" concept was derived for the studied landscape. This metric was combined with an available satellite-based, State of Florida reference ET product (http://fl.water.usgs.gov/et/) to provide a method for transferring the results of this study to similar landscapes for other time periods and geographic areas. The results of this investigation in a humid, sub-tropical urban setting are compared and contrasted with urban ET estimates for other environments.

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OPERATIONAL ET REMOTE SENSING (RS) PROGRAM FOR IRRIGATION SCHEDULING AND MANAGEMENT: CHALLENGES AND OPPORTUNITIES

Prasanna Gowda[1]

Evapotranspiration (ET) is an essential component of the water balance and a major consumptive use of irrigation water and precipitation on cropland. Any attempt to improve water use efficiency must be based on reliable estimates of ET for irrigation scheduling purposes. In the Texas High Plains, irrigation scheduling is implemented using lysimeter-based crop coefficients and reference ET data from the Texas High Plains ET Network.This presentation will discuss the current state of irrigation management in the Texas High Plains, knowledge gaps, ongoing developments, and the role of remote sensing based regional ET mapping algorithms with respect to irrigated agriculture in the Texas High Plains. Also, ongoing multi-institution research effort to enhance ET and irrigation algorithms in crop and hydrological models will be highlighted.

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ADVANCED IMAGE PROCESSING APPROACH FOR ET ESTIMATION WITH REMOTE SENSING DATA OF VARYING SPECTRAL, SPATIAL AND TEMPORAL RESOLUTIONS

Sudhanshu Panda, Devendra Amatya, Young Kim, Ge Sun[1]

Evapotranspiration (ET) is one of the most important hydrologic parameters for vegetation growth, carbon sequestration, and other associated biodiversity study and analysis. Plant stomatal conductance, leaf area index, canopy temperature, soil moisture, and wind speed values generally correlate well with ET. It is difficult to estimate these hydrologic parameters of vast forest cover through in-situ measurements. But remote sensing has the proven ability for estimating some of those hydrologic and crop growth parameters in a rapid, accurate, and cost-effective manner. Since forest land cover may not be always homogeneous it is more difficult to use remote sensing products to model these ET related hydrologic parameters. The goal of this study is to develop advance image processing approach for developing ET parameter estimation model for different cover conditions like homogenous pine, homogenous switch grass, pine and understory, pine and switch grass multi-cropping, and unmanaged pine forest. The image data produced by different remote sensors on satellite systems have unique characteristics- spatial, spectral, radiometric, and temporal. Image spatial resolution varies with sensors like Landsat 7/8 (30 m), SPOT MSS (10 m) and Panchromatic (5 m), NAIP imagery (1 m) and CIR orthoimageries (0.15 m). Spectral resolution differs with different spectral bands, i.e., Landsat 7 ETM+ with 8 bands, Landsat 8 with 11 bands, SPOT with 5 bands, and aerial sensors with 4 bands. Individual spectral bands has the ability to correctly determine (in our case) different ET parameters more efficiently and accurately. Radiometric resolution refers to the data depth indicative of the sensitivity of the sensor to incoming energy. Temporal resolution refers to the revisit frequency/time of the sensor to a specific location on earth surface, e.g., Landsat revisit time is 16 days over a specific geographic location on Earth. This helps in our ET parameter study better as the changes in ET parameters over time during growth period(s) can be ascertained from remotely sensed Digital Number values and modelled. This study encompasses different study sites such as Parker Tract, Carteret, and Lenoir, NC, Green County, AL, and Calhoun County, MS with different vegetation cover types. The study distinguishes different imagery usage based on their sensor characteristics as discussed with scientific deliberations to develop ET and ET parameter prediction models of the vegetation types. In the process, advanced image analysis protocols are developed for efficient and accurate ET and ET parameter prediction model development.

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ESTIMATING WATERSHED EVAPOTRANSPIRATION ACROSS THE UNITED STATES USING MULTIPLE METHODS

Ge Sun, Shanlei Sun, Jingfeng Xiao, Peter Caldwell, Devendra Amatya, Suat Irmak, Prasanna H. Gowda, Sudhanshu Panda, Steve McNulty, Yang Zhang[1]

Evapotranspiration (ET) is the largest watershed water balance component only next to precipitation in the United States. ET is closely coupled with ecosystem carbon and energy fluxes, affects flooding or drought magnitude, and is also a good predictor for biodiversity at a regional scale.Thus, accurately estimating ET is of paramount importance to quantify the effects of land use change and climate change on watershed ecosystem services in water supply, water resources management, carbon sequestration, and biodiversity conservation. However, ET remains to be an imprecise science and difficult to quantify at the watershed level.This study compared ET estimates for over 400 watersheds with size ranging 40-25751 km^2 using multiple independent methods including watershed water balance (Precipitation – Streamflow or P-Q method), eddy covariance net work (AmeriFlux, NEBFLUX) approach by up-scaling eddy flux measurement using the regression tree method (EC-MOD), MODIS based remote sensing approach, and watershed hydrologic modeling (e.g., WaSSI, SWAT). Our preliminary analysis found that there were large discrepancies in the computed watershed ET estimates among the selected methods due to different assumptions and limitations among the ET methods. In particular, ET estimated by the eddy covariance method or MODIS products were 25-40 percent lower than the estimates by the P-Q method. The WaSSI model generally over-estimated ET by 20 percent when compared to the P-Q (534±196 vs 487±263 mm/yr) method.We discuss the potential causes of the discrepancies found in this study and methods to improve ET estimates at a watershed scale.

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Poster Session

LONG-TERM TRENDS IN CLIMATE AND HYDROLOGY IN AN AGRICULTURAL HEADWATER WATERSHED OF CENTRAL PENNSYLVANIA, USA

Ray B. Bryant, Haiming Lu, Kyle R. Elkin, Anthony R. Buda, Amy S. Collick, Gordon J. Folmar, and Peter J. Kleinman[1]

Abstract—Climate change has emerged as a key issue facing agriculture and water resources in the US. Long-term (1968-2012) temperature, precipitation and streamflow data from a small (7.3 km^2) watershed in east-central Pennsylvania was used to examine climatic and hydrologic trends in the context of recent climate change. Annual mean temperatures increased 0.38°C per decade, which led to an expansion of the growing season, and increased evapotranspiration (+37.1 mm per decade). Additionally, mean annual precipitation also increased while the overall change in streamflow decreased. In general, the findings suggest some challenges for producers and water resource managers with regards to increased rainfall and runoff. However, some changes such as an enhanced growing season can be viewed as a positive effect.

INTRODUCTION

In the humid northeastern USA, climate change concerns revolve around increases in annual and seasonal temperatures, changes in seasons and greater variability in weather patterns that adversely impact agriculture. The length of the growing season in the northeast has been increasing in response to the increase in minimum temperature throughout the northeast United States. Past climate change has also altered precipitation patterns and watershed hydrology, especially with regard to extreme events (Walsh and others 2014). On an annual basis, the total precipitation has risen at a rate of 9 mm per decade since 1900.

To date, much of the research on past climate change on agriculture and water resources has focused on a regional or national scale assessment (Horton and others 2014, Walsh and others 2014). While these assessments are important, they tend to average the effects of changing conditions over a large spatiotemporal scale and ignore specific impacts at local scales. Here, we present a holistic, long-term (1968-2012) analysis of climate and hydrologic trends (annual, seasonal, monthly and daily), in the WE-38 watershed, a long-term intensively monitored upland basin in the Appalachian mountain region of east-central Pennsylvania.

SITE

The WE-38 watershed is a 7.3 km^2 subcatchment of the Mahantango Creek watershed (420 km^2) located in the Ridge and Valley physiographic region of east-central Pennsylvania. The climate of WE-38 is temperate and humid, with a mean annual temperature of 10.1°C, annual precipitation averaging 1080 mm, and streamflow representing about 46 percent of total precipitation (Bryant and others 2011). Land use and geology in WE-38 ranges from mature forest cover on sandstone ridges (350-510 m elevation) to mixed cropland and pasture in valleys on shale and siltstone (125-300 m in elevation). The upland hillsides and ridges feature residual soils derived from sandstones and shales that are well drained and possess high infiltration capacities. In contrast, soils in the lower landscapes and valley bottoms are typically derived from colluvial deposits and are characterized by poor drainage, perched water tables, and frequent runoff generation by saturation excess (Buda and others 2009, Gburek and others 2006).

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PROCEDURES

Precipitation, temperature and streamflow data were complied using data sets that included a minimum value data point of at least once per day. In all three cases, automated data collection systems were installed between 1996 and 1997 to monitor their respective parameters at 5 minute intervals.

For portions of data that were missing, standard data augmentation techniques were used to infill occasional data gaps that resulted from site damage, equipment failure, routine maintenance or extreme events (Buda and others 2011a, Buda and others 2011b). To replace daily missing values for precipitation, simple averaging methods were used (McCuen 1998, Dingman 2002). A series of linear regressions using predictive equations related several water measuring stations were used to fill in missing streamflow data. Data gaps in temperature less than 5 hours were replaced by linear interpolation while data gaps greater than 5 hours were not replaced.

In order to relate the data from WE-38, other climatic and hydrologic records from other measurement stations in the area were examined to determine an understanding of longer-term regional trends (i.e. those that extend prior to 1968). In total, four stations were used which gave temperature, precipitation and stream-flow. Using these data, a number of different temperature, precipitation and streamflow indices were calculated in order to describe how the climate and hydrology of WE-38 changed during the 45 year study period. The indices used in the study fell into three basic categories: measures of extreme values (maxima and minima) and central tendency (means), which describe, for example, the maximum or minimum daily temperature or the annual mean precipitation; threshold tendencies, which tally the number of days or identify the specific date when a fixed temperature or precipitation threshold is exceeded, for instance, growing season or last freezing date; and percentile-based threshold indices, which describe the excellence rates (number of days) above or below a certain threshold (consecutive days with streamflow less than the 10th percentile of the distribution).

In addition to the indices described above, we also sought to assess long-term changes in watershed evapotranspiration in WE-38 as inferred by the water balance equation. All water balance equations were done on a calendar year basis to be consistent with the assessment of trends in precipitation and temperature.

Prior to conducting formal statistical analysis of the long-term trends, all of the climate and hydrologic data, as well as the indices derived from these data were organized into four temporal scales: daily, monthly, seasonal (summer, autumn, growing, etc.) and annual. Additionally, we also assessed climatic and hydrologic trends over the fixed-length growing (15 April - 15 October) and non-growing (16 October - 14 April) seasons based on average conditions in the region.

Trends in climate and hydrology for each of the four temporal scales discussed above were evaluated using the rank-based Mann-Kendall test (Hirsch and others 1982). The rate of change for each time series was determined using the Theil-Sen slope method (Theil 1950, Sen 1968), which calculated the median slope of all possible pairs of points in the data set. For graphical representation, LOWESS regression lines were plotted, as well as an 11-yr moving average (Cleveland 1979, Matonse and Frei 2013). The Mann-Kendall tests and Theil-Sen slope calculations were completed using the water quality package in the R software environment, while Origin software was used to plot the LOWESS regression lines and moving average trends.

RESULTS AND DISCUSSION

Temperature

Temperature patterns in the WE-38 watershed were generally consistent with those observed in the northeastern US, as well as nationally. Mean temperatures in the watershed exhibited significant increasing trends at annual, seasonal and monthly time scales from 1978 to 2012. Annual mean temperatures in WE-38 showed a smooth, steadily increasing trend (0.38° C per decade) during the 35 year temperature monitoring period (fig. 1a).

The mean minimum temperatures also increased throughout the WE-38 watershed from 1978-2012. On an annual basis, mean minimum temperatures showed a smooth upward trend (0.43°C per decade) during the study period (fig. 1b), increasing at a rate faster than that of the annual mean temperatures. Increases in the mean minimum temperatures were evident for all three-month seasons, both growing and non-growing seasons, and annually.

Annual mean maximum temperatures in WE-38 increased along with annual mean and annual mean minimum temperatures, albeit at generally slower rates for the time scales of the period studied. Annual mean maximum temperatures rose steadily during the study period (fig. 1c), increasing at a rate of 0.35°C per decade. Significant increases in monthly mean maximum temperatures occurred in the months of January, March, April and September, and during the spring and autumn seasons. All of these months and seasons also had significant increases in mean minimum temperatures as previously discussed. However, there were no increases in

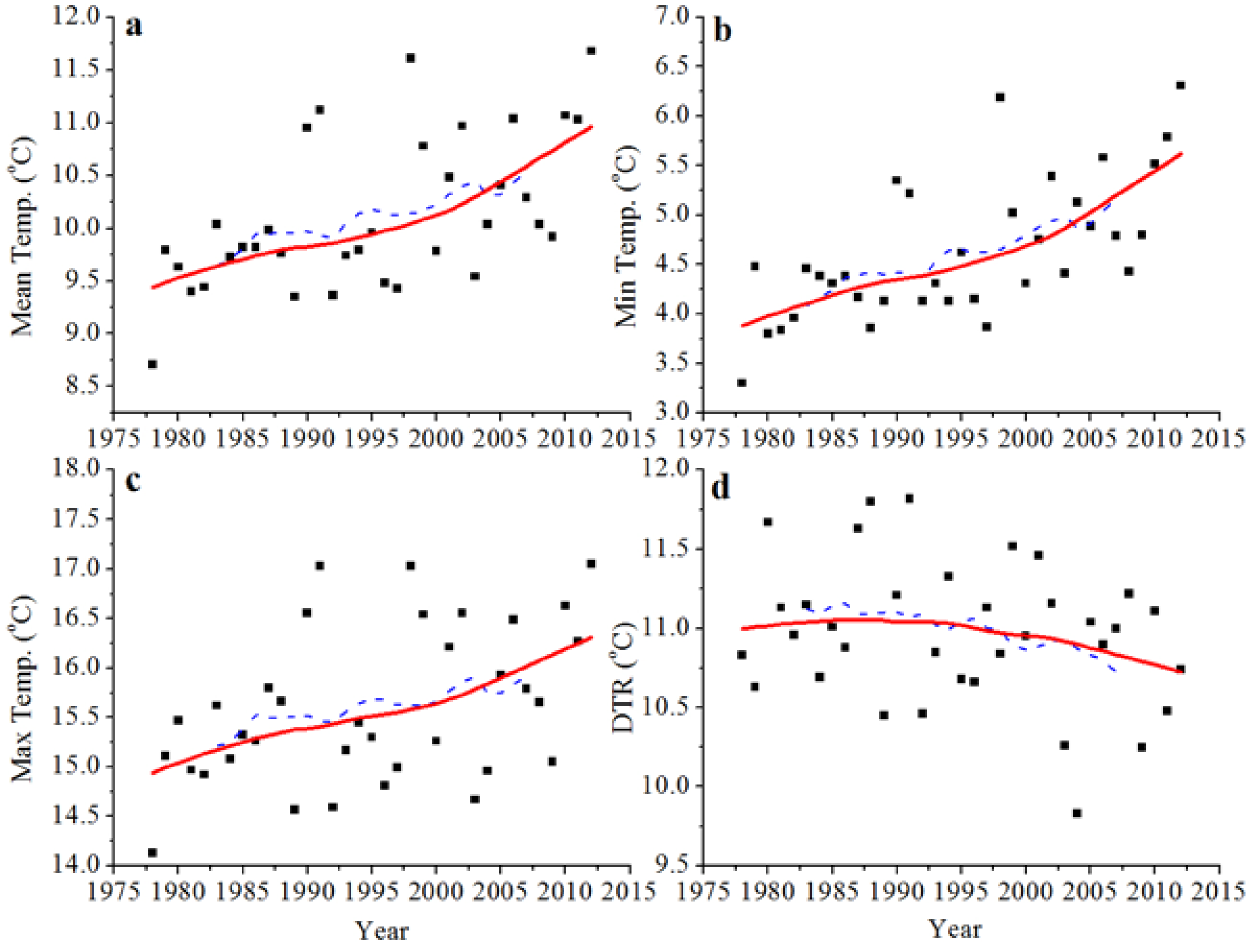

Figure 1—Long-term trends for the WE-38 watershed (1978 to 2012) in (a) annual mean temperature; (b) annual mean minimum temperature; (c) annual mean maximum temperature; and (d) diurnal temperature range (DTR). Solid lines represent LOWESS regression trends and dashed lines indicate 11-year centered moving average trends.

the mean maximum temperatures in June, July and August or in the summer season, all of which did show increases in mean minimum temperatures.

Disproportionate changes in maximum and minimum temperatures, as described above, resulted in a general declining trend in the diurnal temperature range over the extent of the watershed (fig. 1d). Diurnal temperature range decreased significantly in June and August as a result of increases in mean and minimum temperatures in the absence of increases in mean maximum temperatures. There was also a significant decrease in diurnal air temperature range during the summer season and the growing season at rates of -0.37 and -0.20 °C per decade, respectively. Notably, diurnal temperatures range increased in March and April as a result of greater increases in mean maximum temperatures relative to mean minimum temperatures.

Seasonal Changes and Core Indices

Indices of warm weather all increased in duration during the 1978 to 2012 study period. The lengths of warm season, growing season and summer season increased by 2.82, 2.83 and 4.00 days per decade, respectively, over the study period. The changes however, were not uniform over time. On average the summer season extended from early June to mid-September, but the start and end dates varied by one month. The length of the summer season (mean daily temperature over 13°C) increased continuously, but at a slightly accelerated rate after 1995 (fig. 2a). In addition, summer days (annual count of days with maximum temperature above 25°C) increased by 4.17 days per decade and tropical nights (annual count of days with minimum temperature greater than 20°C) increased 0.83 days per decade.

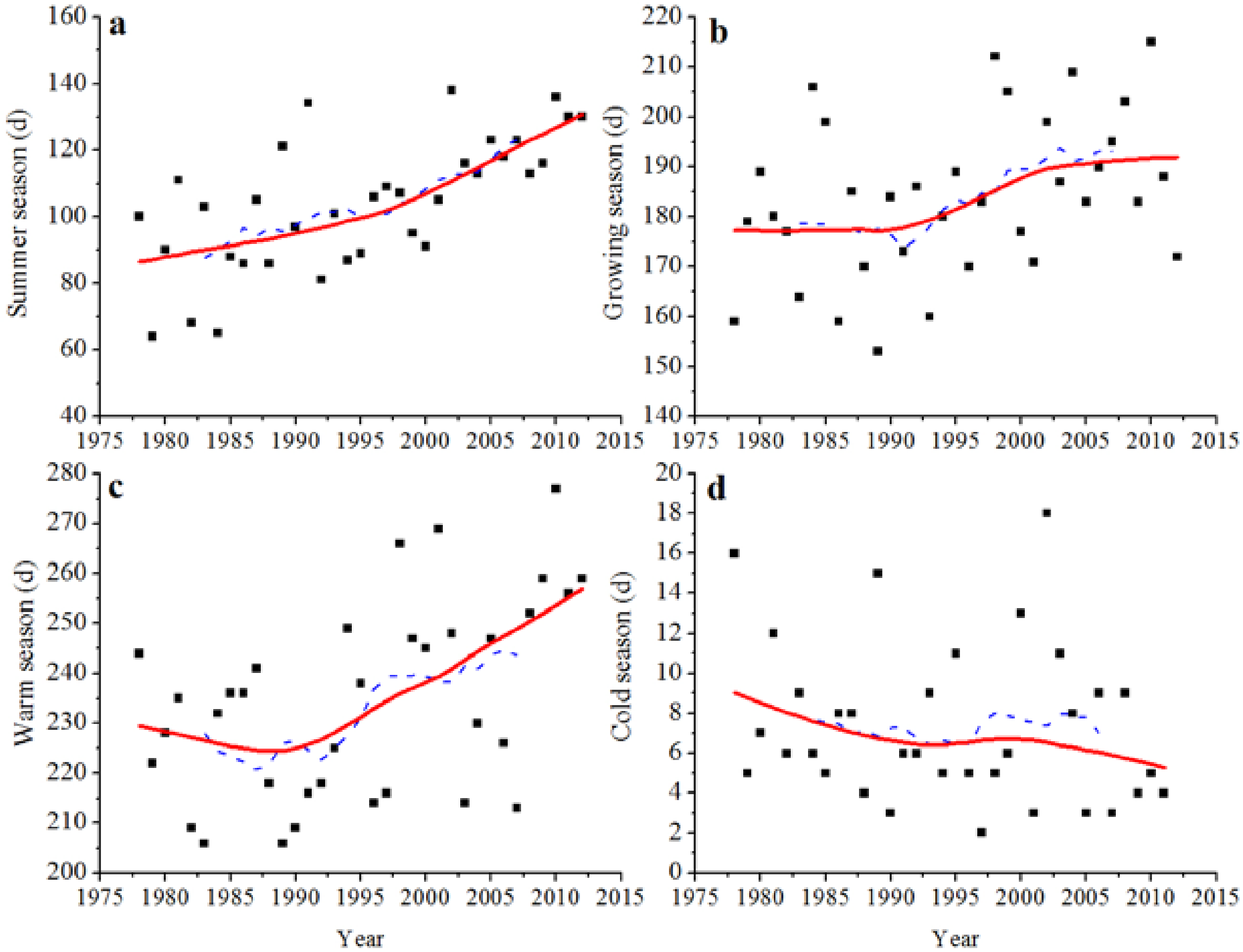

Figure 2—Long-term trends in temperature threshold indices in the WE-38 watershed (1978 to 2012) for (a) summer season; (b) growing season; (c) warm season; and (d) cold season. Solid lines represent LOWESS regression trends and dashed lines indicate 11-year centered moving average trends.

The growing season (number of consecutive days with daily mean temperature above 5°C) generally extended from mid-April to mid-October but dates ranged by three weeks. The length of the growing season increased rapidly between 1990 and 2002, but changes prior to and after this period were minor (fig. 2b). On average, the late March to mid-November warm season (consecutive days with mean daily temperature above 0°C) showed a flat or slightly decreasing trend prior to 1990, then increased steadily (fig. 2c). During the 1978 to 2012 period, the warm season began as early as late February and ended as late as mid-November.

In contrast, the duration of the cold weather periods in WE-38 trended shorter from 1978-2012. The average length of the cold season (consecutive days with daily temperatures below -5°C) ranged from starting as early as mid-December and ending as late as mid-February. The length of the cold season decreased at a fairly uniform rate (fig. 2d) of -0.74 days per decade, and the number of frost days also decreased at a rate of -3.64 days per decade.

The last freezing date in spring retreated at an average rate of -5.5 days per decade and at a uniform rate over the study period (fig. 3). Over the same period, the first freezing date in autumn occurred later at an average rate of 4.00 days per decade, and the rate of increase was greater after 1995 (fig. 3).

Precipitation

Total precipitation in WE-38 displayed inter-annual and seasonal variability over the 45 year study period. Annual total precipitation ranged from 710.3 mm to 1905.4 mm, with a mean of 1097.8 mm. Seasonally, total precipitation during the growing season (mid-April to mid-October) was 34 percent higher than during the non-growing season

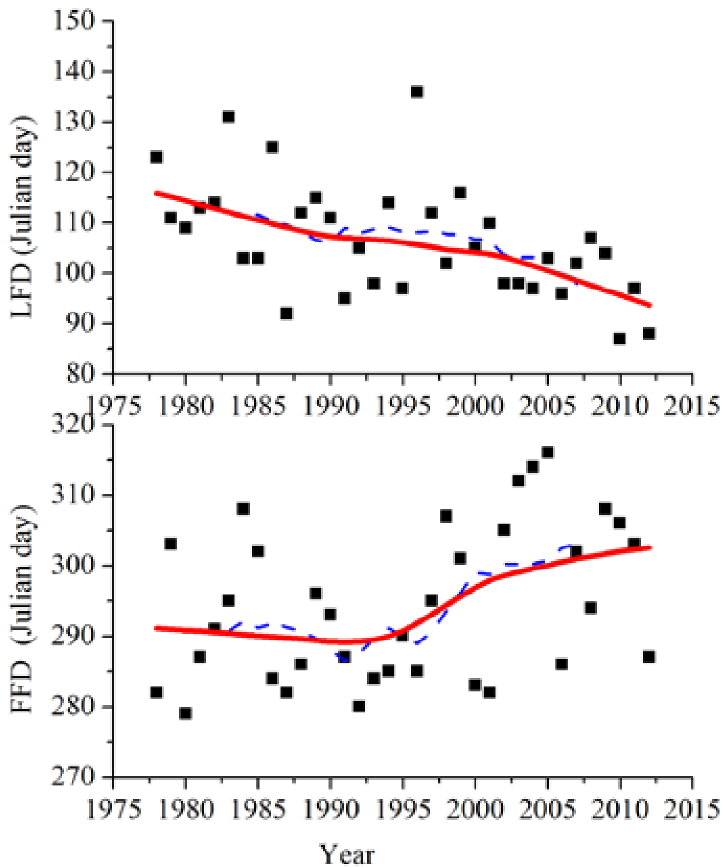

Figure 3—Long-term trends in the Julian day for last freezing date (LFD, top) and first freezing date (FFD, bottom) for the WE-38 watershed (1978 to 2012). Solid lines represent LOWESS regression trends and dashed lines indicate 11-year centered moving average trends.

with June being the wettest and February being the driest months (Table 1).

Total precipitation generally increased in the watershed with the most significant trends occurring at seasonal and monthly time scales. Annual total precipitation increased at a rate of 21.89 mm per decade, however, the trend was not significant. Monthly total precipitation increased significantly in October and January at rates of 8.18 and 6.71 mm per decade, respectively. Notably, none of the four seasons showed significant changes in total precipitation.

Trends in intensity of precipitation at daily (d^{-1}) and hourly (h^{-1}) time scales were variable, with significant increasing trends mostly during the non-growing season. Maximum daily precipitation increased in September and January at rates of 3.99 mm d^{-1} per decade and 2.23 mm d^{-1} per decade, respectively. There was a significant increasing trend in maximum daily precipitation at a rate of 5.30 mm d^{-1} per decade for the autumn season. Maximum daily precipitation in the non-growing season also increased at a rate of 2.24 mm d^{-1} per decade, but there was no significant change during the growing season. The hourly intensity of precipitation in the non-growing season increased in December and January at rates of 0.61 mm h^{-1} per decade and 5.27 mm h^{-1} per decade, respectively (Table 1). Seasonal trends showed increasing hourly intensities of storm events in autumn, winter and spring, but no change in the summer. The hourly intensity of precipitation also increased during the non-growing season, but not during the growing season.

While the intensity of precipitation events clearly increased during the non-growing season, the number of days with intense rainfall remained largely unchanged during the 1968 to 2012 study period. Moderately heavy precipitation events became less frequent compared to days and event with heavier precipitation. Furthermore, days with trace and light precipitation showed opposing

Table 1—Trends in precipitation at various temporal scales in the WE-38 watershed (1968-2012). Slopes are expressed as a rate of change per decade. Slopes in red show trends with statistical significance at p<0.1.

Period		Mean precip., mm	Total precip., mm		PM1d, mm d-1		PM1h, mm hr-1	
			slope	p-value	slope	p-value	slope	p-value
Spring	Mar	83.13	2.3	0.27	-0.01	0.44	-0.08	0.3
	Apr	87.85	3.99	0.2	0.87	0.32	0	0.47
	May	104.46	1.48	0.33	-0.34	0.33	0.87	0.18
Summer	Jun	122.64	-9.49	0.23	-0.79	0.33	-0.34	0.37
	Jul	97.94	1.46	0.36	0.55	0.35	0.69	0.23
	Aug	98.08	5.52	0.22	-0.3	0.41	-0.7	0.17
Fall	Sep	118.83	6.35	0.19	**3.99**	**0.04**	0.83	0.19
	Oct	90.48	**8.18**	**0.05**	1.35	0.19	0	0.38
	Nov	86.45	-4.23	0.11	-0.14	0.44	0.29	0.23
Winter	Dec	78.49	2.61	0.28	0.32	0.41	**0.61**	**0.04**
	Jan	70.91	**6.71**	**0.08**	**2.23**	**0.04**	**5.27**	**0.07**
	Feb	58.07	-0.61	0.42	-0.29	0.37	-0.06	0.26
Spring		275.45	4.31	0.31	0.21	0.36	**1.23**	**0.07**
Summer		317.68	-0.32	0.48	0	0.47	-0.39	0.38
Fall		297.64	7.49	0.21	**5.3**	**0.01**	**1.35**	**0.09**
Winter		208.5	4.22	0.31	0.15	0.11	**0.62**	**0.01**
Average growing season		629.11	5.2	0.4	0.7	0.37	0	0.48
Average non-growing season		470.51	2.52	0.42	**2.24**	**0.07**	**0.79**	**0.03**
Annual		1097.79	21.89	0.14	1.99	0.11	1.03	0.21

trends during the study period with the number of days having trace precipitation increased at a rate of 0.354 days per decade. In contrast, to trace precipitation, the number of days having light precipitation (2.5 to 12.7 mm) decreased at a rate of -0.467 days per decade and the percentage of precipitation that fell as light precipitation also declined. Light precipitation accounted for about 30 percent of the total.

Streamflow

Streamflow in the watershed varied seasonally and annually over the 45 year monitoring period (Table 2). Mean monthly streamflow showed strong seasonal variations typical for watersheds in the northeast US, with the lowest flows occurring in August (12.40 mm) and the highest flows occurring in March (77.83 mm). These streamflow variations reflected seasonal patterns in temperature and evapotranspiration, which were highest in summer and lowest in winter. On an annual basis, streamflow depth averaged 509.2 mm (46 percent of annual precipitation) from 1968 to 2012, with inter-annual variability largely driven by annual precipitation. The lowest streamflow depth occurred in 2001 (207.4 mm), which was the drought of the study period. In contrast, 2011 saw the highest stream flow depth (1199.9 mm), which coincided with the wettest year in the study.

Total streamflow depth in WE-38 largely declined over the 45 year period (Table 2), with most of the significant reductions occurring at monthly and seasonal time scales. Annual total streamflow depth decreased by -16.9 mm per decade, although the trend was not statistically significant. On a monthly basis, streamflow depth decreased most strongly during the month of February (-7.49 mm per decade). Significant decreases in streamflow depth also occurred in July and during the summer season at rates of -1.24 mm and -5.12 mm per decade respectively. Notably, streamflow depth increased markedly in October at a rate of 4.95 mm per decade, reflecting the strong increase in monthly total precipitation observed.

Of the 45 year study period, 30 years had flood events with peak streamflow exceeding the 2.33 year return period. Each of these 30 flood events was either caused by a precipitation event that also exceeded the 2.33 year

Table 2—Trends in streamflow depth in the WE-38 watershed (1968 to 2012). Slopes are expressed as a rate of change per decade. Slopes in red show trends with statistical significance at p<0.1.

Period		Mean streamflow depth	Streamflow depth	
			Slope	p-value
		mm	mm	
Spring	Mar	77.83	-0.45	0.48
	Apr	62.69	-1.94	0.34
	May	47.26	-3.68	0.11
Summer	Jun	34.92	-1.86	0.16
	Jul	14.19	**-1.24**	**0.06**
	Aug	12.4	-0.74	0.17
Fall	Sep	28.32	-0.25	0.43
	Oct	30.84	**4.95**	**0.01**
	Nov	39.1	-0.23	0.5
Winter	Dec	56.49	1.78	0.3
	Jan	53.79	2.29	0.3
	Feb	52.34	**-7.49**	**0.02**
Spring		187.78	-8.24	0.21
Summer		61.49	**-5.12**	**0.08**
Fall		97.56	3.44	0.28
Winter		163.44	-8.01	0.24
Average growing season		178.38	**-11.19**	**0.08**
Average non-growing season		332.54	-5.54	0.22
Annual		509.2	-16.9	0.28

return period, or a rain-on-snow event. Notably, one of the largest floods in WE-38 occurred on January 19, 1996, and was due to rapid snowmelt induced by heavy rain. However, there does not appear to be any trend associated with the number of flood events that occur in the warm season and are not affected by snowmelt. Furthermore, the number of flood events that occur during the cold season when runoff is affected by snowmelt appears to be declining.

In WE-38, the average length of periods of low streamflow, represented by the maximum consecutive days during which mean streamflow was lower than the 10th percentile, was 16 days and ranged from 0 to 70 days (fig. 4). These low streamflow periods increased at an average rate of 1.9 days per decade over the study period. Annual evapotranspiration strongly increased in the watershed at a rate of 37 mm per decade (fig. 5).

CONCLUSIONS

The implications of climate change trends for agricultural production in WE-38 can be viewed as a net positive for the kind of row crop agriculture that is typical for the study area, at least in the near term. Warmer temperatures, driven primarily by increasing minimum temperatures, lead to longer growing seasons and more growing degree days. While warmer annual mean temperatures will result in greater evapotranspiration, monthly precipitation totals are also increasing, except for the wettest month of June.

Decreases in light precipitation events are welcome as they are less effective at supplying crop needs and with the total increase in precipitation, should be interpreted as an increase in more effective precipitation. Significantly wetter Octobers may complicate harvests, but the trend of the arrival of the first autumn freeze to occur later should mitigate this complication. The increase in intense

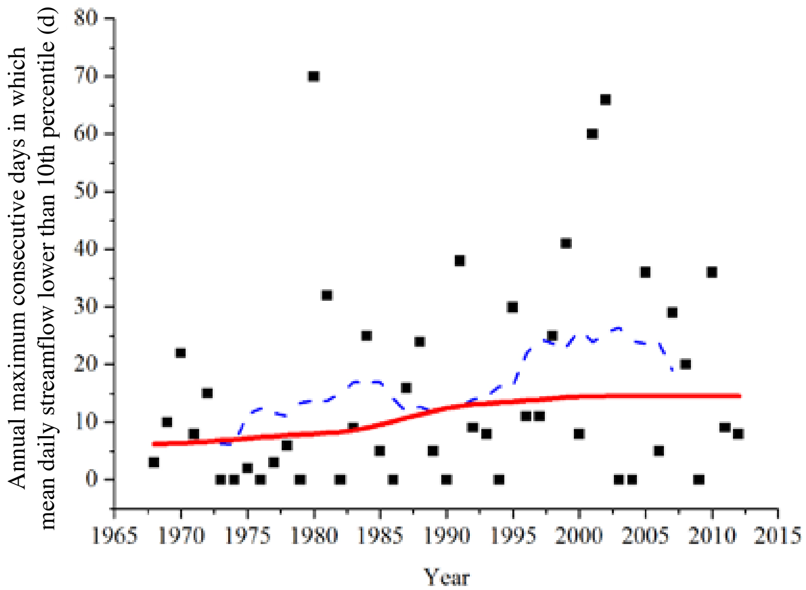

Figure 4—Long-term trends in the maximum annual consecutive number of days during which daily mean streamflow in the WE-38 watershed was lower than the 10th percentile (1968 to 2012). Solid lines represent LOWESS regression trends and dashed lines indicate 11-year centered moving average trends.

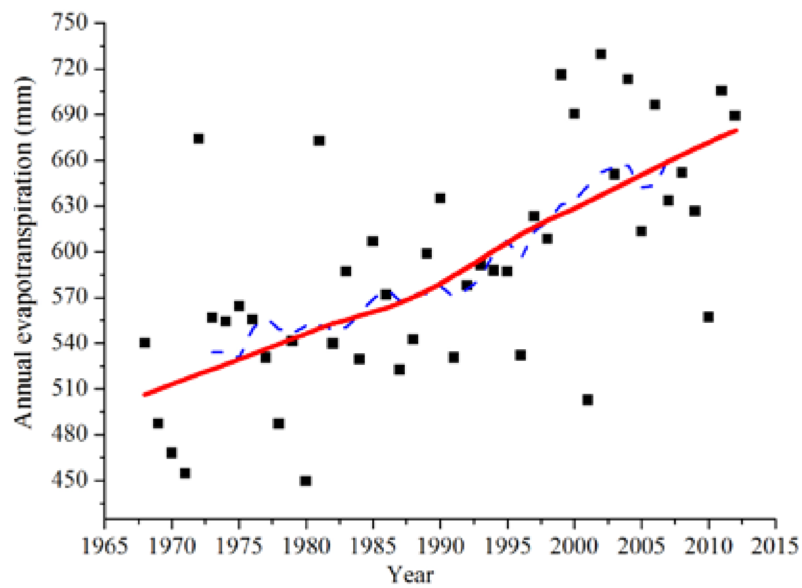

Figure 5—Long-term trends in annual actual evapotranspiration for the WE-38 watershed (1968 to 2012). Solid lines represent LOWESS regression trends and dashed lines indicate 11-year centered moving average trends.

precipitation events is indicative of a greater risk of crop damage, but is of limited geographical extent. However, the need for cost of crop insurance may become greater in response to this trend.

With respect to the conservation of the Chesapeake Bay, nutrients and sediment are the major pollutants that derive from agricultural watersheds in the Susquehanna River Watershed. Under current Pennsylvania regulations winter spreading of manure is allowed, but producers are discouraged against this. However, the decreasing snow accumulation that is being seen offer increased opportunities to spread manure during low runoff risk times.

In conclusion, the present and near term effects of climate change do not appear to present great challenges for agricultural production, water resources or the Chesapeake Bay conservation efforts, but that does not mean that the effects of these changes will not worsen in the future. Additionally, the rate of change generally appears to be much greater than what has been observed in other studies of other geographical areas, and it appears to be increasing. Whereas that rate of change is not expected to reverse itself, the potentially negative, longer term effects of climate change will be realized sooner.

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THE WALNUT GULCH LTAR

Phillip Heilman, Susan Moran, Mark Nearing, Mary Nichols, Russ Scott, David Goodrich[1]

The Walnut Gulch LTAR builds on and advances 60 years of research on the USDA-ARS Walnut Gulch Experimental Watershed surrounding the town of Tombstone in southeast Arizona. Instrumentation on the watershed was initiated in 1953 and currently approximately 149 square kilometers of semiarid rangeland are monitored and serve as an outdoor laboratory. The watershed is a tributary to the upper San Pedro Basin that drains northward spanning the Mexico-U.S. border. Satellite watersheds associated with the WG-LTAR include 8 small watersheds located in the Santa Rita Experimental Range (SRER) operated by the Univ. of Arizona that are located roughly 75 km WNW of Tombstone and 40 km south of Tucson. These watersheds are representative of approximately 60 million hectares of brush and grass covered rangeland found throughout the semi-arid Southwest in the transition zone between the Chihuahuan and Sonoran Deserts. Elevation of the watersheds ranges from ~900 m to 1585 m MSL. In this region, cattle grazing is the primary land use with mining, limited urbanization, and recreation making up the remaining uses. All the instrumented watersheds are drained by ephemeral channels that are dry about 99 percentof the time. The "Business as Usual" agricultural practice consists of continuous and rotational pasture grazing. Brush management is a relatively common practice to increase forage production, improve vegetative cover, and reduce surface soil erosion. It has increased in recent years in Texas through New Mexico and into southeastern Arizona due the availability of Natural Resource Conservation Service Environmental Quality Incentive Program (EQIP) funding. The 8 WG-LTAR Santa Rita watersheds have a 40-year set of baseline observations of rainfall, runoff and sediment delivery comparing the two different grazing practices with and without mesquite *(Prosopis velutina)*. Our proposed alternatively managed production system (AM) will involve removing mesquite on two of the Santa Rita watersheds to evaluate the impacts on a number of ecosystem services compared with the prior record and the other six untreated watersheds. An overview of key historical research results as well as the existing and planned infrastructure and experimental design will be presented in this poster.

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LONG TERM AGROECOSYSTEM RESEARCH IN THE SOUTHERN PLAINS

Jean L. Steiner, Patrick J. Starks, Jurgen Garbrecht, Daniel Moriasi, Paul Bartholomew, Jim Neel, Kenneth E. Turner, and Brian Northup[1]

The Southern Plains (SP) site of the Long Term Agroecosystem Research (LTAR) network is headquartered at the USDA-ARS Grazinglands Research Laboratory (GRL) in El Reno, Oklahoma. The GRL was established in 1948. A long-term watershed and climate research program was established in the Little Washita River Experimental Watershed (LWREW) in 1961 and in the Fort Cobb Reservoir Experimental Watershed (FCREW) in 2004 (Steiner and others 2014). The GRL mission is to develop technologies, management strategies, and tools to evaluate and manage risks and tradeoffs for integrated crop, forage, and livestock systems under variable climate, energy and market conditions.

Research is conducted at: 1) the 27 km^2 GRL which is comprised of tall grass prairie, pastures, and annual crops and forages that support beef cattle herds, 2) the 610 km^2 LWREW watershed which was established to study hydrologic impacts of USDA-funded flood retarding structures, and 3) the 786 km^2 FCREW watershed that was established to quantify interactive effects of climate, land use, and agricultural conservation practices on environmental outcomes. The climate is continental with about 210 days in the growing season. Mean annual temperature is 15.5 ^oC and mean annual precipitation is about 850 mm with a gradient across the region. The research sites are within the Southern Plains NEON domain; Red-Arkansas HUC 11 watershed; Prairie Gateway farm resource region. Climate variability and gradients characterize the Great Plains and are a primary driver of agro-ecosystem processes in the region (Garbrecht and others 2014).

The SP LTAR addresses a spectrum of cropland, pastureland, and grazed prairie characteristic of SP landscapes. Extreme climate variability in space and time make it essential to identify sustainable and resilient forage-based production systems that are adaptable across enterprise types. Developing knowledge and tools to support diverse agricultural systems in the face of complex interactive ecological, climate, policy, and economics drivers requires transdisciplinary science conducted over decades to provide understanding that is scalable in time and space. Anticipated outcomes include production systems that support vibrant rural economies, promote biological diversity (soil, plant, and animal), and reduce greenhouse gas emissions, with positive impacts on carbon sequestration, water and air quality, and agricultural sustainability.

Research is affiliated with four of the USDA-ARS National Programs: Water Availability and Watershed Management; Forage, Pasture, and Rangeland Systems, Food Animal Production; and Global Change, Emissions, and Soils. Major collaborations (Table 1) include the Grazing CAP coalition: Oklahoma State University, Kansas State University, University of Oklahoma, Tarleton State University, The Samuel Roberts Noble Foundation, and USDA-ARS-Bushland, supported by USDA-NIFA-AFRI. The long-term watershed research includes numerous key partners, including Oklahoma State University, the Oklahoma Mesonet, Oklahoma Water Resources Board (OWRB),

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Table 1—Key Partners and Collaborators of the Southern Plains LTAR

Oklahoma State University	Tarleton State University - TIAER
University of Oklahoma	Samuel Roberts Noble Foundation
Oklahoma Mesonet	Oklahoma Conservation Commission
Grazing CAP	Oklahoma Water Resources Board
Southern Plains Climate Hub	USGS
Kansas State University	USDA-NRCS, other federal agencies
South Central Climate Science Center	Numerous ARS locations
RISA-SCIPP	Numerous international universities
Langston University	

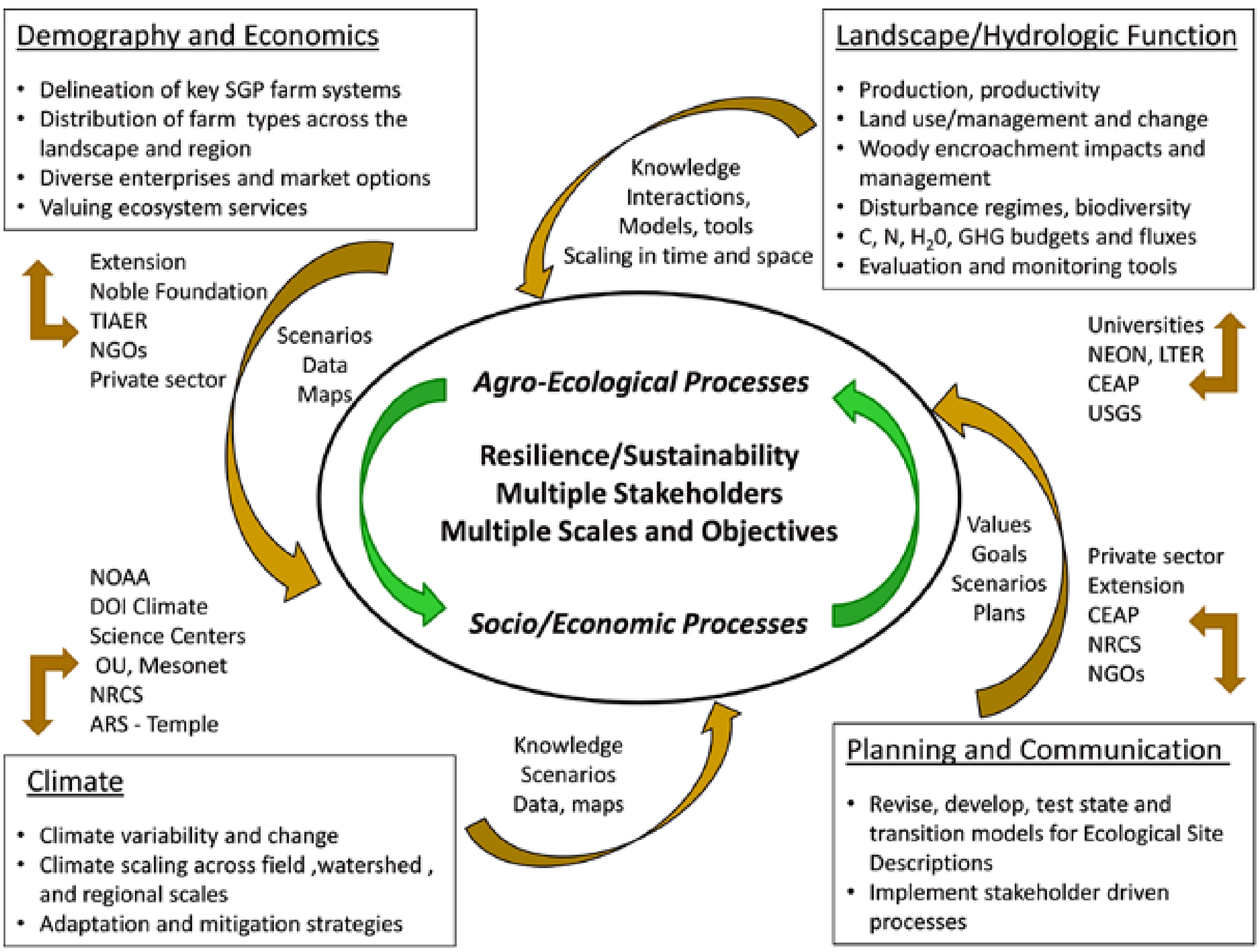

Figure 1—Schematic of the LTAR-SP research.

USGS, Oklahoma Conservation Commission, USDA-NRCS, EPA, US Bureau of Reclamation, and landholders in the watershed. Many other aspects of the research involve partnerships with additional universities, including Texas AgriLife, University of Oklahoma, Beijing Normal University, Universidad Autónoma de Zacatecas, Jomo Kenyatta University, DOI South Central Climate Science Center, International Center for Agroforestry.

The broad research emphasis spans productivity and resilience of forage-grazing systems, multiple marketing options, agro-ecosystem impacts of climate variability and change at multiple scales, and environmental impacts of conservation practices (fig. 1). All of these issues are of global relevance. Improved understanding within this regional research program will be linked with other long-term research efforts to advance our understanding of processes that transcend regions.

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This work is supported in part by USDA to Project No. 2012-02355 through the National Institute for Food and Agriculture's Agriculture and Food Research Initiative, Regional Approaches for Adaptation to and Mitigation of Climate Variability and Change. The project, "Resilience and Vulnerability of Beef Cattle Production in the Southern Great Plains under Changing Climate Land Use and Markets (Grazing CAP)", is a regional, integrated project comprising six institutions including Oklahoma State University, Kansas State University, Oklahoma University, Tarleton State University, the Samuel Roberts Noble Foundation, and USDA-ARS laboratories at El Reno, Oklahoma and Bushland, Texas. Project Web site: greatplainsgrazing.org.

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GULF ATLANTIC COASTAL PLAIN LONG TERM AGROECOSYSTEM RESEARCH SITE, TIFTON, GA

Timothy Strickland, David D. Bosch, Dinku M. Endale, Thomas L. Potter[1]

The Gulf-Atlantic Coastal Plain (GACP) physiographic region is an important agricultural production area within the southeastern U.S. that extends from Delaware in the Northeast to the Gulf Coast of Texas. The region consists mainly of low-elevation flat to rolling terrain with numerous streams, abundant rainfall, a complex coastline, and many wetlands. The GACP Long Term Agroecosystem Research (LTAR) site is representative of the Tifton-Vidalia Upland (TVU) physiographic subprovince which has relatively homogeneous geology, soils, parent materials, land use, agricultural management, and economic and social patterns. Total row crop land in the TVU is about 18 percent of the land area. The remaining land in farms is primarily in woodland or pastureland. The 65 percent of the TVU that is not in farms is primarily privately owned forest land with about 5 percent of the TVU in urban, suburban, rural housing, or transportation uses. Research efforts at the GACP LTAR encompass broad subject areas that are critical to agricultural systems in the Southeastern Coastal Plain and are designed to develop ecologically-based, whole-farm and area-wide approaches that rely on the inherent strengths of our agricultural production systems. Principal crops in descending order of acreage are cotton, peanut, corn, soybean, and wheat. GACP LTAR sustainable scenario development is focused on sustainable intensification of crop production in the face of increased water demand, periodic drought cycles, heavy pest and weed pressure, and expectations of increased biofuel feedstock production in the Southeastern U.S.

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REYNOLDS CREEK LONG-TERM AGRICULTURAL RESEARCH

Mark Seyfried, Fred Pierson, Tony Svjecar, Kathleen Lohse[1]

The Reynolds Creek Experimental Watershed (RCEW) was established by the Agricultural Research Service (ARS) in 1960 to investigate rangeland hydrology issues in the northwestern USA. The site, which is administered by the Northwest Watershed Research Center (NWRC) in Boise, Idaho, is representative of much of the region, with a 1000 m elevation range and associated climate and vegetation range. Precipitation is mostly rain at low elevations and averages about 250 mm per y and is mostly snow at higher elevations averaging about 900 mm per y. Hydrometeorological and stream flow data collection started shortly after 1960 and the network has been expanded to include 8 weirs and 30 meteorological sites. In addition, detailed snow and soil water and temperature data are part of the network. Data have been available over the internet via ftp since 2000.These data have been used to document climate trends over the past 50 years and its impacts on stream flow and soil water dynamics with estimated effects on vegetation production. In addition, these data have been part of a major model development and testing program, and NWRC snow and soil models are in widespread use. The watershed has also been the site of a number of experimental studies investigating management effects, especially due to prescribed fire, on overland flow and erosion. Current emphasis is on linking hydrological expertise from the ARS with biogeochemical and ecological research based at Idaho State University and Boise State University. The RCEW has been designated a Critical Zone Observatory (National Science Foundation) and is related, along with ARS unit in Burns, Oregon (Range and Meadow Forage Management Research Unit), as part of a new Long Term Agricultural Research (LTAR) site. These are separate projects with overlapping objectives. The primary objectives of the CZO are to: (i) measure carbon and water fluxes in a variety of vegetation and climatic conditions, (this includes net flux using eddy covariance as well as individual components of the carbon balance such as forage production), (ii) quantify the spatial distribution of soil and vegetative carbon across the entire landscape using a combination of soil mapping and verified remote sensing, and (iii) simulate water and carbon fluxes and plant production across the landscape using models verified models. For the LTAR, data collection is similar with the emphasis on the long-term effects of vegetation change. Work will extend beyond the RCEW to relatively degraded, slightly drier location north of the RCEW.

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AN INTERACTIVE TOOL FOR PROCESSING SAP FLUX DATA FROM THERMAL DISSIPATION PROBES

A. Christopher Oishi, Chelcy F. Miniat[1]

Sap flux sensors are an important tool for estimating tree-level transpiration in forested and urban ecosystems around the world. Thermal dissipation (TD) or Granier-type sap flux probes are among the most commonly used due to their reliability, simplicity, and low cost. However, the accuracy of TD sensors depends upon the correct processing of the raw data. Improper signal processing can lead to over- or under-estimation of sap flux and may ignore the contribution of nocturnal water through the trunk. In an effort to improve and standardize the approach of TD probe data processing, we developed a MATLAB-based software script that combines automated signal processing with an interactive QA/QC interface. We show results from a variety of tree species and climates.

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THE CONEWAGO CREEK INITIATIVE: A MODEL FOR COMMUNITY WATERSHED ENGAGEMENT AND RESTORATION

Matt Royer, Kristen Kyler, Jennifer Fetter[1]

Over the last several years, a partnership of over thirty organizations called the Conewago Creek Initiative has been working cooperatively in a small watershed to increase community engagement and work with farmers and landowners to adopt land management practices to improve water quality. The partnership is facilitated by the Penn State Agriculture and Environment Center, a research, extension and engagement center of the College of Agricultural Sciences. The concept of the Initiative is to establish a "shared discovery" watershed where the value of community based private/public partnerships to address nonpoint source pollution challenges can be demonstrated. The Initiative was supported by a grant from the National Fish and Wildlife Foundation. Further support was provided by the U.S. Department of Agriculture's designation of the Conewago as a Chesapeake Bay "Showcase Watershed" and the Pennsylvania Department of Environmental Protection through the Section 319 nonpoint source pollution control program. The Initiative's work has resulted in increased citizen engagement and outreach, an increase in adoption of best management practices, and positive water quality improvement trends in the watershed. The Initiative provides a model for local watershed community based engagement. It demonstrates a preferred approach to address local, upstream water quality problems in order to meet priority restoration goals for larger estuarine water bodies, (i.e., the Chesapeake Bay).

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CONEWAGO STREAM TEAMS – INCLUDING YOUTH IN WATERSHED RESTORATION CREATES LOCAL WATERSHED CONNECTIONS, PROMPTS COMMUNITY SERVICE, AND INCREASES WATER LITERACY IN YOUTH

Jennifer Fetter, Sanford Smith, Matt Royer[1]

Youth in Pennsylvania's Dauphin, Lebanon, and Lancaster Counties were invited to be part of a unique opportunity: a chance to learn, hands-on, about the water in their own community and how their daily lives impact that water. This is the mission of the 4-H Stream Teams program, which was piloted within the Conewago Creek Watershed and surrounding communities in 2010-2013. This small, 53 square mile watershed is the focus of much attention, as partners from a wide-variety of government agencies, universities, and non-government organizations come together to see what a fully collaborative effort (in this case the Conewago Creek Collaborative Conservation Initiative) can do to restore a small watershed and ultimately improve the quality of water entering the Chesapeake Bay. Thanks to the efforts of Penn State Extension Educators and to funding from a USDA-NIFA Integrated Water Quality Program Grant, youth had the opportunity to be included in this collaborative effort. The three major components of the 4-H Stream Team concept are 1) provide a hands-on water-education curriculum that teaches youth about water conservation, water science, and water quality issues 2) focus youth learning experiences on small watersheds where their daily lives have the greatest impact and 3) promote community service and outreach projects that youth take ownership of in their own small watersheds. With the help of 159 dedicated volunteers, over 3,340 youth have been reached through 4-H Stream Team activities. For those youth who completed 4-H Stream Teams activities and participated in evaluations, there has been demonstrated knowledge gained in water topics, increased knowledge of youth's own local watershed boundaries, and participation in community service and outreach projects that directly benefited the local watersheds in and around the Conewago Creek pilot program.

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CHANGES IN SEDIMENT YIELD AND STREAM MORPHOLOGY IN AN ACTIVELY MANAGED FORESTED WATERSHED DUE TO UPSTREAM DISTURBANCES

Ilkim Cavus, Latif Kalin, Ferhat Kara[1]

Attaining high quality water has always been a big concern for humankind. Forested watersheds are known to provide the cleanest form of water. However, conversion of forested lands to agricultural and/or urban use, as well as disturbances created in forested watersheds lead to degradation and deterioration of our water resources. To minimize the disturbance impacts on water quality various best management practices (BMPs) such as streamside management zones (SMZs) are implemented in managed forested watersheds. On the contrary, any upstream urban and agricultural activities where BMPs are not present or are inadequate can negatively impact downstream water quality regardless of the presence of downstream BMPs. In a recent study two small paired watersheds located near Auburn, Alabama were examined for streamflow and sediment yield in 2009 and 2010 to evaluate the efficacy of SMZs at trapping sediment yield from a clearcut area. Recent urban activities upstream of the study watersheds and poorly designed BMPs around these activities provided us an opportunity to observe and document the impacts of upstream disturbances on downstream stream water quality and morphology. Six monitoring stations were established to observe flow and sediment yield. Sediment data collection began in January 2014, and will proceed until June 2015. In addition to sediment concentration measurements, cross-sections of the channels have also being surveyed at several locations across the streams, following each significant storm events in order to assess the effects on channel morphology. Although a full spectrum of data are not ready to reach to an overarching conclusion, data collected so far show substantial increase in sediment load. Sediment concentrations are up to two orders of magnitude higher compared to the levels from the previous study where sediment concentrations were monitored following a clearcutting. Furthermore, channel morphology is altered visibly following almost every significant rain event (>1 inch). Preliminary data suggest that assessment of watersheds as a whole is needed in order to define the origin of problems and mitigate them more effectively.

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REAL TIME MONITORING OF NITROGEN, CARBON, AND SUSPENDED SEDIMENT FLUX IN TWO SUBBASINS OF THE CHOPTANK RIVER WATERSHED

Gregory McCarty, Megan Lang[1]

Intensive water quality monitoring of agricultural watersheds can provide important information on the effects of land cover and effectiveness of conservation practices designed to mitigate water quality concerns associated with agricultural production. For this study, robust water quality monitoring systems designed to measure nitrate, organic carbon and sediment concentrations using in situ UV-Vis spectrometer probes were deployed in two tributaries of the Choptank Watershed, Maryland. For accurate flux measurements, each monitoring system was co-located at USGS gage stations (USGS 01491000 and 01491500) defining what we have termed as the Greensboro and Tuckahoe sub-basins, respectively, within the headwater region of the Choptank River Watershed. These sub-basins have similar amounts of cropland but Greensboro has considerably more wetland area and greater percentage of cropland on hydric soil. Comparison of nitrate and carbon fluxes from these sub-basins will improve understanding of current and historical wetland function in agricultural landscapes and impacts of wetland drainage and restoration on nutrient export from watersheds. We hypothesize that carbon fluxes provide good indication of wetland connectivity to the stream network and can thereby provide information on important ecosystem services provided by wetlands within agricultural settings.

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ALBEMARLE SOUND DEMONSTRATION STUDY OF THE NATIONAL MONITORING NETWORK FOR U.S. COASTAL WATERS AND THEIR TRIBUTARIES

Michelle Moorman, Sharon Fitzgerald, Keith Loftin, and Elizabeth Fensin[1]

The U.S. Geological Survey's (USGS) is implementing a demonstration project in the Albemarle Sound for the National Monitoring Network for U.S. coastal waters and their tributaries. The goal of the National Monitoring Network is to provide information about the health of our oceans and coastal ecosystems and inland influences on coastal waters for improved resource management. The network integrates biological, chemical, and physical features and links uplands to the coastal ocean. The purpose of the Albemarle Sound pilot study is to: 1) Inventory current monitoring programs in the Albemarle Sound, 2) Conduct a gap analysis to determine current monitoring needs, 3) Implement a monitoring program to address data gaps, and 4) Create a web-based map portal of monitoring activities. As part of the project, the USGS worked with stakeholders to inventory current programs and design a monitoring program. Results after 3 years of implementation will be discussed.

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PUBLICALLY ACCESSIBLE DECISION SUPPORT SYSTEM OF THE SPATIALLY REFERENCED REGRESSIONS ON WATERSHED ATTRIBUTES (SPARROW) MODEL AND MODEL ENHANCEMENTS IN SOUTH CAROLINA

Celeste Journey, Anne B. Hoos, David E. Ladd, John W. Brakebill, Richard A. Smith[1]

The U.S. Geological Survey (USGS) National Water Quality Assessment program has developed a web-based decision support system (DSS) to provide free public access to the steady-state SPAtially Referenced Regressions On Watershed attributes (SPARROW) model simulation results on nutrient conditions in streams and rivers and to offer scenario testing capabilities for research and water-quality planning. Access to the decision support system is through a graphical user interface available online at http://cida.usgs.gov/sparrow. Nationally, the SPARROW models are based on the modified digital versions of the 1:500,000-scale River Reach File and 1:100,000-scale National Hydrography Dataset stream networks.

For South Carolina, the DSS has total nitrogen and total phosphorus models for the South Atlantic-Gulf and Tennessee Region based on the Enhanced River Reach File 2.0. The system can be used to estimate nutrient conditions in unmonitored streams in South Carolina and to produce estimates of yield, flow-weighted concentration, or load of nutrients in water under various land-use conditions, changes, or resource management scenarios. This model divides larger river basins into multiple stream catchments and models nutrient contributions by source inputs and land use within each of those catchments. The model information, reported by stream reach and catchment, provides contrasting views of the spatial patterns of nutrient source contributions, including those from urban (wastewater effluent and diffuse runoff from developed land), agricultural (farm fertilizers and animal manure), and specific background sources (atmospheric nitrogen deposition, soil phosphorus, forest nitrogen fixation, and channel erosion). However, the large scale and static nature of the model (modeled only for the 2002 water year) have produced some limitations on the application of the decision support system on the state level.

To address those limitations, the USGS is working cooperatively with the Resources For the Future program to adapt the steady-state model for South Carolina to a dynamic model that will simulate seasonal-average loads, yields, and concentrations during the period 2001-2003. Temperature and an Enhanced Vegetation Index from Moderate Resolution Imaging Spectroradiometer (MODIS), a National Aeronautics and Space Administration Terra-satellite-borne sensor, will be used as input to the dynamic model to characterize seasonal uptake and release of nitrogen during land-to-water transport.

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THE MID-ATLANTIC REGIONAL WETLAND CONSERVATION EFFECTS ASSESSMENT PROJECT

Megan Lang, Greg McCarty, Mark Walbridge, Patrick Hunt, Tom Ducey, Clinton Church, Jarrod Miller, Laurel Kluber, Ali Sadeghi, Martin Rabenhorst, Amir Sharifi, In-Young Yeo, Andrew Baldwin, Margaret Palmer, Tom Fisher, Dan Fenstermacher, Sanchul Lee, Owen McDonough, Metthea Yepsen, Liza McFarland, Anne Gustafson, Rebecca Fox, Chris Palardy, William Effland, Mari-Vaughn Johnson, Judy Denver, Scott Ator, Joseph Mitchell, Dennis Whigham[1]

Wetlands impart many important ecosystem services, including maintenance of water quality, regulation of the climate and hydrological flows, and enhancement of biodiversity through the provision of food and habitat. The conversion of natural lands to agriculture has led to broad scale historic wetland loss, but current US Department of Agriculture conservation programs and practices seek to replace or ameliorate the ecosystem services lost to agricultural conversion. Wetland restoration can enhance watershed resiliency in the face of land use and climate change, and provide critical ecosystem services that enhance the condition of downstream waters. In addition, restored wetlands can directly influence climate change through the regulation of greenhouse gases and carbon sequestration. In order for the USDA to best allocate funds to improve environmental outcomes, a better understanding of the effects of wetland restoration practices is needed. The Mid-Atlantic Regional (MIAR) Wetland Conservation Effects Assessment Project (Wetland-CEAP) is a regional component of the national Wetland-CEAP which was initiated by the Natural Resources Conservation Service (NRCS) to develop a broad collaborative wetland science foundation that facilitates the production and delivery of scientific results. The MIAR is an interdisciplinary study which brings together scientists from multiple federal agencies and the University of Maryland to study non-tidal palustrine wetlands in the MIAR Coastal Plain, including prior converted croplands (historic wetlands) and natural and restored wetlands. The results and implications of an initial ground based study will be discussed and current efforts to extrapolate this information to a broader spatial and temporal scale via remote sensing and modeling will be described. Project findings are being used to assess and improve the effectiveness of conservation practices and Farm Bill programs affecting wetlands and associated lands in the Mid-Atlantic Coastal Plain. This project encourages future inter-agency cooperation and is an important step towards producing a national model that can be used to support the adaptive management of wetland restoration and enhancement programs.

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GUAM PAGO WATERSHED CONSERVATION

Maria Lynn Cruz, Laura F. Biggs[1]

The purpose of this research is to explore water science methodologies in determining the source of sedimentation in the Guam Pago Watershed. Watersheds provide drinking water, an agricultural water source, and forms of recreation. However, from years of soil erosion and several factors occurring inland, the mouth of Pago River has widened allowing a larger amount of sediment and nutrient rich water onto a greater area of coral. With the use of water science equipment such as the Manta turbidity logger and rain gauges, initial monitoring will focus on narrowing down the causes of sedimentation. In order to distinguish inland factors from coastal factors, loggers will be launched at an upstream point where the Sigua and Lonfit rivers converge, and at a point near the opening of Pago Bay. As a relatively small island, research and education are key in achieving and maintaining a sustainable environment. In order to encourage an action for improvement or mitigation to target behaviors within the target audience, this study is intended to increase scientific and community understanding of the effects of land usage on Pago Bay.

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HAS THE PROMISE OF DNA BARCODING BEEN ACHIEVED? A CRITICAL LOOK AT THE APPLICATION OF EDNA BARCODING TO BIOMONITORING

Carolina Penalva-Arana, Erik Pilgrim, John Martinson[1]

Biological monitoring programs aim to assess the health of waters and determine the direct impact anthropogenic activities are having on the ecosystems. There is a need for the development of accurate and reproducible methods that can assess biodiversity rapidly and in a cost-effective manner. A system for tracking water quality changes brought on by such things as climate change, invasive species, nutrients, or pollution is imperative as these disturbances are occurring more often and in more places. A highly touted new strategy for evaluating biodiversity is the application of high throughput next generation sequencing to environmental DNA (eDNA), whereby the sequence of one or more specific genes can be used to distinguish between a wide range of species. This comprehensive view of an ecosystem can shed light on the health of an ecosystem by revealing the presence/absence of microbes to macroinvertebrates in a sample. In collaboration with Ohio EPA (OEPA) we aim to validate, in a field context, the efficacy of eDNA sequencing using multiple barcodes (eDNA barcoding) to identify species, and compare the species found by this method against those identified through standard morphological-based methods. Our results show little overlap between the 115 macroinvertebrate species identified by OEPA and the eDNA method, with only 15 species shared between samples. However, the eDNA barcoding approach identified a larger number of taxa that were not identified by OEPA taxonomist, demonstrating a potential underestimation of biodiversity and information relevant to water quality within this ecosystem. In addition, eDNA data is explored to identify microbes of interest to human and potentially indicative of ecosystem health. However, the question remains: Is the eDNA barcoding method, which can identify more taxa with less effort that current methodologies, a viable new tool for determining ecosystem health?

Disclaimer: The views expressed are those of the authors and do not necessarily reflect the views or policies of the US EPA.

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ASSESSING THE RELATIONSHIP BETWEEN FORESTS AND WATER IN THE HIGH ROCK LAKE WATERSHED OF NORTH CAROLINA

Tom A. Gerow, Jr., David G. Jones, and Wenwu Tang[1]

Forests are recognized as a priority source of relatively high quality and reliable water, be it for human use or ecological function. The High Rock Lake watershed straddles the piedmont and foothill regions of North Carolina, and a Total Maximum Daily Load (TMDL) restoration plan is being developed for the reservoir. The findings of the study should add to the body of knowledge regarding how forests can be a solution for protecting water resources, and may help to reduce the costs of treating public water supplies. Seventy-one datasets obtained over five years of benthic macroinvertebrates sampling within the watershed were analyzed, and used as a proxy for determining overall water quality. Estimates of the costs to treat water, and water quality grab sample data from thirteen public water systems in the watershed were also obtained and analyzed. Finally, a method was developed for conducting a GIS-based stream buffer land cover assessment, in an effort to localize the findings of the study and identify potential land parcels where forestry-related conservation practices may improve watershed health, function, or quality. This study identified a correlation between the extent of forest cover, and effects of other land cover types, with the quality of water for ecological function as well as the relative cost to treat public water supplies. When evaluating aquatic life Biotic Index and EPT Taxa Richness, better results were observed in those subwatersheds where the forest cover was approximately 37 to 48 percent (or more) of the land use/land cover; and where natural cover was approximately 50 percent (or more) of the land use/land cover. Conversely, when urbanized or developed land cover exceeded approximately 20 percent, the measures for aquatic life worsened. These overall trends identified that the percent forest or natural cover can be a corollary indicator of the general quality of water, and that in this study area, better water quality was associated with those subwatersheds that were predominantly forested. Another aspect of this study examined the quality of water samples taken at multiple water supply intakes and associated cost estimates for treating the water for human use. A general trend was observed that indicated costs to treat the water were lower when the contributing watershed consisted of approximately 70 percent (or more) forest cover. Alternatively, higher costs to treat water occurred with increased turbidity, and turbidity was found to be higher when the amount of forest cover fell below 60 to 70 percent of the watershed's total land cover. An analysis was conducted of land cover / land use for each of the 127 subwatersheds (12-digit HUC) within the High Rock Lake watershed, to categorize each subwatershed in accordance with the identified "Forest Cover Model" thresholds related to forest cover and water quality, (i.e., forest cover is below 37 percent; or forest cover is between 37 and 48 percent; or forest cover exceeds 48 percent.) The map generated from this analysis quickly identifies forest cover in relative terms, which can also be used to correlate the anticipated quality of water originating from each subwatershed. With this information, end users can quickly identify where in the watershed different approaches in deploying forest and land management best management practices (BMPs) may be appropriate, to sustain quality water resources, given the relative amount of forest cover in the subwatershed. In addition, a closer examination was made to evaluate the stream buffer structure and land cover within select subwatersheds to identify streams that could potentially benefit from forestry related conservation measures, with the presumption that improvements to its riparian buffer should translate to improvements to the stream itself. This High Rock Lake watershed assessment study was conducted by faculty, staff, and students of the Center for Applied GIS Science at the University of North Carolina at Charlotte, with funding and project oversight provided by staff of the North Carolina Forest Service, via grants from the USDA Forest Service and the USEPA.

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INTEGRATED RESEARCH – WATER QUALITY, SOCIOLOGICAL, ECONOMIC, AND MODELING – IN A REGULATED WATERSHED: JORDAN LAKE, NC

Deanna Osmond, Mazdak Arabi, Caela O'Connell, Dana Hoag, Dan Line, Marzieh Motallebi, Ali Tasdighi[1]

Jordan Lake watershed is regulated by state rules in order to reduce nutrient loading from point and both agricultural and urban nonpoint sources. The agricultural community is expected to reduce nutrient loading by specific amounts that range from 35 - 0 percent nitrogen, and 5 - 0 percent phosphorus. In addition, trading is allowed and the development community is anxious to purchase credits within the agricultural community in the form of buffers. This multidisciplinary research project has explored different facets of agricultural nonpoint source abatement in Jordan Lake watershed. Two paired watershed experiments have detailed nutrient reductions through conservation systems on pasture or cropland. A detailed key-informant survey of farmer beliefs relative to conservation practice adoption and trading has documented that views about conservation practice adoption are complex and vary based on farmers' experiences, social-networks, and personal beliefs about each practices' utility, impact and outcomes. Socioeconomic analysis indicates that despite general support for water quality improvements, the majority of farmers were disinterested in participating in the trading program for financial, environmental, and pragmatic reasons related to the specifics of the trading program. Water quality modeling suggests that nutrient loads are reduced in agricultural areas relative to urban areas. Furthermore many agricultural fields have no nitrogen credits to trade and those that can trade have only a small amount. Lastly, economic analysis indicates that the price of nutrients available for trades likely will be too high for trades to occur, especially when the costs of trading are considered. Supply of credits is very low, which significantly increases transaction costs. In addition, a survey of local farmers showed that they would require a significant financial premium above the cost of conservation practices to adopt them since they are unfamiliar with the conservation practices and lack trust about how the program would work. Financial compensation from developers increases the likelihood of participation, but will likely be insufficient to initiate trades in this region.

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WATER USE EFFICIENCY AT BASIN AND FARM SCALES

Ehsan Goodarzi, Lotfollah Ziaei, Saeid Eslamian[1]

The available water resources in basins are becoming scarce while demands for water are considerably increasing among various sectors due to economic and population growths. Water deficiency is becoming a main constraint for sustainable regional development and it is the primary motivation in creating water to supply user requirements in particular for agricultural demands within a basin. As agriculture is the largest water user at the global level, the general focus has been on getting higher efficiency by changing irrigation system or improving irrigation scheduling to reduce the water shortage effects. In addition, significant efforts are being placed to improve water usages efficiency and optimize water consumptions by developing systematic and implementable plans. One way to preserve existing natural water resources is using recycled water. For instance in the case of farm lands irrigation, water is almost never wholly finished since the amount of that drains away in the forms of surface runoff and deep percolation can be returned into the system. In other words, the only real loss in the basin scale is evaporation. Based on the classical concepts of water efficiency, all of the wasted water including evaporation, surface runoff and deep percolation are lost, whereas both surface runoff and deep percolation can be reentered into the system and added to the surface or ground water bodies to be used again by downstream users. Considering the return flows as part of available water resources and reuse it is known as multiplier effect of water recycling. To better understand the potential impacts of irrigation interferences at a water basin scale, the multiplier effect of water recycling from an irrigation perspective is studied in the Zayandeh Rud basin located in the central part of Iran. This study is developed in a general manner to describe how the efficiency of system can be different from farm to basin scales.

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GROUNDWATER AVAILABILITY IN THE CROUCH BRANCH AND MCQUEEN BRANCH AQUIFERS, CHESTERFIELD COUNTY, SOUTH CAROLINA, 1900–2012

Bruce Campbell, James E. Landmeyer[1]

Chesterfield County is located in the northeastern part of South Carolina along the southern border of North Carolina and is primarily underlain by unconsolidated sediments of Late Cretaceous age and younger of the Atlantic Coastal Plain. Approximately 20 percent of Chesterfield County is in the Piedmont Physiographic Province, and this area of the county is not included in this study. These Atlantic Coastal Plain sediments compose two productive aquifers: the Crouch Branch aquifer that is present at land surface across most of the county and the deeper, semi-confined McQueen Branch aquifer. Most of the potable water supplied to residents of Chesterfield County is produced from the Crouch Branch and McQueen Branch aquifers by a well field located near McBee, South Carolina, in the southwestern part of the county.

The primary purpose of this study was to determine groundwater-flow rates, flow directions, and changes in water budgets over time for the Crouch Branch and McQueen Branch aquifers in the Chesterfield County area. This goal was accomplished by using the U.S. Geological Survey finite-difference MODFLOW groundwater-flow code to construct and calibrate a groundwater-flow model of the Atlantic Coastal Plain of Chesterfield County. The model was created with a uniform grid size of 300 by 300 feet to facilitate a more accurate simulation of groundwater-surface-water interactions.

The calibrated groundwater-flow model was then used to calculate groundwater budgets for the entire study area and for two sub-areas. The sub-areas are the Alligator Rural Water and Sewer Company well field near McBee, South Carolina, and the Carolina Sandhills National Wildlife Refuge acquisition boundary area. For the overall model area, recharge rates vary from 56 to 1,679 million gallons per day (Mgal/d) with a mean of 737 Mgal/d over the simulation period (1900-2012). The simulated water budget for the streams and rivers varies from 653 to 1,127 Mgal/d with a mean of 944 Mgal/d. The simulated "storage-in term" ranges from 0 to 565 Mgal/d with a mean of 276 Mgal/d. The simulated "storage-out term" has a range of 0 to 552 Mgal/d with a mean of 77 Mgal/d. Groundwater budgets for the McBee, South Carolina, area and the Carolina Sandhills National Wildlife Refuge acquisition area had similar results.

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DEVELOPING A DROUGHT EARLY WARNING INFORMATION SYSTEM FOR COASTAL ECOSYSTEMS IN THE CAROLINAS

Kirsten Lackstrom, Amanda Brennan, Paul Conrads, Lisa Darby, Kristin Dow, Daniel Tufford[1]

The National Integrated Drought Information System (NIDIS) and the Carolinas Integrated Sciences and Assessments (CISA), a National Oceanic and Atmospheric Administration (NOAA)-funded Regional Integrated Sciences and Assessments (RISA) program, are partnering to develop and support a Carolinas Drought Early Warning System pilot program. Research and projects focus on the unique coastal ecosystems in North and South Carolina. In the Carolinas, drought effects on environmental resources, particularly in coastal areas, are not as well-understood, or as well-integrated into existing drought planning and response processes, as other impacts and resources (such as, agriculture, surface water supplies).

Key concerns related to drought and coastal ecosystems focus on impacts to water quality and quantity, habitats, species, and estuarine processes.

- Drought contributes to increased salinity and saltwater intrusion, reduced flushing and assimilation of pollutants, and overall water quality changes.
- Ecosystem impact concerns center on habitat loss or conversion and consequent effects on recruitment, distribution, and migration patterns as well as on primary and secondary production.
- Saltwater intrusion, low stream flows, and low water levels contribute to impacts and are attributed to both drought and human actions (e.g. changes in dam releases due to drought).

This poster will highlight current activities to develop a drought early warning information system in the Carolinas:

- Development of a coastal drought index based on U.S. Geological Survey (USGS) real-time salinity data
- Assessment of ecological indicators of drought in southeastern coastal ecosystems
- Development of an 'Atlas of Hydroclimate Extremes' for the Carolinas
- Assessment of drought indicators for coastal zone fire risk
- Forecasting the SC blue crab fishery using real-time freshwater flow data
- Increasing coastal observations of drought through citizen science and the Community Collaborative Rain, Hail, & Snow Network (CoCoRaHS)

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PRECIPITATION PARTITIONING IN SHORT ROTATION BIOENERGY CROPS: IMPLICATIONS FOR DOWNSTREAM WATER AVAILABILITY

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The southern United States is a potential leader in producing biofuels from intensively managed, short rotation (8–12 years) woody crops such as southern pines, and native and non-native hardwoods. However, their accelerated development under intensive management has raised concerns that fast-growing bioenergy crops could reduce recharge to stream flows and groundwater, relative to other land cover types or less intensively managed woody crops. In this study, we characterize and compare the partitioning of precipitation into interception, transpiration, throughfall, infiltration, and soil evaporation for 12-year-old, intensively managed loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*) stands at the Department of Energy Savannah River Site in New Ellenton, South Carolina. Three replicate plots of each species were instrumented with sap flow probes, box lysimeters, integrated temperature and soil moisture probes, precipitation gauges, and throughfall gauges to allow estimation of the components of the total water balance and to parameterize process-based models. Preliminary soil moisture measurements show that annual Relative Extractable Water (REW) is similar between sweetgum and loblolly pine plots (0.43); however, REW was significantly lower in sweetgum compared to loblolly plots in the summer (0.41 vs. 0.53), but higher in early spring months (0.63 vs. 0.58). These results suggest comparable annual water use by sweetgum and loblolly pine, but higher water use by sweetgum than pine during the growing season, and higher water use by loblolly pine than sweetgum during the dormant season. This work will provide key insights on the implications of bioenergy crop expansion in the South for loblolly and sweetgum.

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VARIATIONS IN CANOPY AND LITTER INTERCEPTION ACROSS A FOREST CHRONOSEQUENCE IN THE SOUTHERN APPALACHIAN MOUNTAINS

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Variations in evapotranspiration (ET) have been well documented across a variety of forest types and climates in recent decades; however, most of these data have focused on mature, second-growth stands. Here we present data on two important fluxes of water, canopy interception (Ic) and forest floor litter interception (Iff), across a chronosequence of forest age in the southern Appalachian Mountains. We used climate stations and throughfall collectors to measure gross rainfall and estimate Ic at each site and used a non-linear mixed model to determine the effects of forest age and precipitation on stand Ic. We also collected forest floor biomass monthly at each site and used these data in a model of litter wetting and drying to determine the quantity of water lost to Iff. Precipitation varied from 1679 to 2095 mm yr^{-1} across sites and across years (2011–2013). Canopy interception increased rapidly with forest age and then leveled off to a maximum of ~11percent in an old-growth mixed hardwood site. Despite differences in forest structure, forest floor biomass did not vary with age, suggesting either lower decomposition rates in younger sites, or likely high decomposition rates across all sites. Unlike Ic, modeled estimates of interannual variation in Iff were insensitive to annual rainfall amount and were dependent primarily on forest floor biomass. At all sites, Iff accounted for 4–6 percent of total precipitation and varied primarily due to differences in rainfall among sites with a higher percentage of Iff in sites with lower rainfall. Additional measurements are currently underway to validate the litter interception model using litter moisture probes and forest floor wet and dry weights. Improved estimates of interception will contribute to our understanding of how forest structure and climate variability affect forest water use and help improve models of rainfall partitioning across the broader matrix of forest age classes.

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RESTORATION OF SOUTHERN APPALACHIAN RIPARIAN FORESTS AFFECTED BY EASTERN HEMLOCK MORTALITY

Katherine Elliott, Chelcy F. Miniat, Jennifer Knoepp, Michael A. Crump, C. Rhett Jackson[1]

Widespread mortality of eastern hemlock (*Tsuga canadensis*) through hemlock woolly adelgid (HWA) infestation has altered riparian forest structure and function throughout the southern Appalachians. Eastern hemlock and Rhododendron maximum often co-occur in these riparian forests, where the latter species is highly shade tolerant, forms a dense shrub layer that strongly attenuates light incident on the forest floor, has little to no herbaceous cover below its canopy, negatively affects tree seedling recruitment, and decreases nitrogen availability in the soil and litter layer to non-ericaceous species. In these forests, post-mortality successional dynamics may well be dominated by rhododendron. We hypothesize that removal of rhododendron will improve these degraded forests by restoring structure and function: allowing recruitment of trees and herbs; increasing forest floor decomposition rates; increasing soil pH, nutrient availability and nutrient cycling rates; and, subsequently, raising stream pH and acid neutralizing capacity (ANC).

Here we report on a study in which we are conducting rhododendron and forest floor removal experiments in riparian corridors once dominated by eastern hemlock at two spatial scales: intensive plot scale, and un-replicated stream reach scale. For the former, sixteen 20 x 20 m replicate plots comprise a fully factorial experiment wherein aboveground rhododendron biomass removal, and O-horizon removal has two levels (removal or not). For each treatment, we are measuring microenvironment changes, the rate of recovery in vegetation dynamics (growth and recruitment), and nutrient pools and fluxes, and on the reach scale plots we are also measuring stream water quality, and in-stream processes. Pre-treatment measurements are ongoing and reported here. We will impose the rhododendron and O-horizon removal treatments in Mar-May 2015. Active and adaptive management strategies will be required to transform degraded riparian systems into more desirable states. Land managers need science-based restoration methods to aid recovery of forest structure and function after widespread loss of an important species.

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PHYSIOLOGICAL RESPONSES OF EASTERN HEMLOCK *(TSUGA CANADENSIS)* TO BIOLOGICAL CONTROL AND SILVICULTURAL RELEASE: IMPLICATIONS FOR HEMLOCK RESTORATION

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The rapid loss of eastern hemlock (*Tsuga canadensis*) from riparian zones in the southern Appalachian Mountains due to Hemlock Woolly Adelgid (*Adelgis tsugae*, HWA) infestation has resulted in changes to watershed structure and function. Several restoration strategies have been proposed, including silvicultural treatments that increase incident light in forest understories, and the introduction of predator beetles to control populations of HWA. We conducted separate nursery and field experiments to investigate the physiological effects of releasing eastern hemlock from light limitation. We hypothesized that higher light levels and reduced infestation from biological control would improve tree carbon balance. The nursery experiment exposed HWA-infested seedlings to five different incident light levels (from 0–90 percent shade). The field experiment was conducted in mixed hardwood stands with eastern hemlock in the understory that were either uninfested or infested with HWA, and either with or without predator beetles (*Sasajiscymnus tsugae*) present (Control, Infested, Infested+Predator). In the field experiment, in each stand (C, I, I+P), we targeted half of the eastern hemlock trees to have 0.125 ha gaps created around them. In both experiments we compared short- and long-term indices of physiological stress (leaf net photosynthesis, or Anet; leaf fluorescence, or Fv/Fm; and total non-structural carbohydrate content, or TNC) to test for improvements in hemlock leaf physiology and carbon balance in response to these treatments. In the nursery experiment, there was no variation in Fv/Fm among treatments and Anet was inversely related to light availability; however, TNC increased with increasing light exposure. In the forest gaps, Fv/Fm showed that trees were stressed immediately after gap creation, but started to acclimate to increased light within a few weeks. Trees in gaps had higher Anet and TNC than non-gap trees. TNC was highest in uninfested trees, followed by infested trees with predator beetles, and then infested trees with no predator beetles. Our results indicate that combining biological control with silvicultural treatments may improve long-term survival of infested trees and be an effective restoration treatment.

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REGIONAL EFFORTS TO PROMOTE FORESTRY BEST MANAGEMENT PRACTICES: A SOUTHERN SUCCESS STORY

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The Southern Group of State Foresters has a long history of water resource protection efforts, providing leadership in BMP development, improvement, and implementation, enhancing state BMP programs, establishing effective partnerships, and standardizing an approach to consistently monitor implementation across the region.

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WATER USE ASSESSMENTS SUPPORTING COMPANY-SPECIFIC GROWTH AND SUSTAINABILITY GOALS

John Beebe[1]

Abstract—In areas with increasing demand for water, addressing water use objectives has long been a primary environmental objective and key concern among industrial water users including paper mills and other forest product companies. However, in recent years, water use metrics and related information (including population change, climate information, and land use characterization) have gained considerable importance to companies for addressing longer-term goals pertaining to growth and sustainability when it comes to water availability. One effort underway, lead by the National Council for Air & Steam Improvement, Inc. (NCASI), has compiled water metrics and related watershed information as a means for better understanding and projecting the demands for water in various parts of the country. This paper provides details on specific components of the effort to document water-related information on a case-by-case basis, as well as provide summary information and key findings culminating from this assessment.

INTRODUCTION

Many industries rely on access to natural water resources for use in the manufacturing of consumer goods and materials. With an increasing overall population, relocation of inhabitants away from rural areas, as well as the recurrence of droughts in certain parts of the country, forest products companies are more cognizant of information that is vital to supporting their long-term, sustainable water use goals. These goals extend to: a) overall water resources/availability, b) water stewardship, c) protecting against environmental degradation, and d) environmental sustainability in general.

With a greater understanding of the factors and constraints on water resources, companies can be better positioned to interact with other water stakeholders and make better long-term decisions for their facilities and the surrounding environment. Representing pulp and paper manufacturers as well as the wood products industry and forest landowners, NCASI has developed a comprehensive database of water use metrics and watershed-related information for their member companies. This database for water resource managers and ensuing watershed reports for NCASI members offer a means for companies to be helpful water stewards and creates an information resource that is unlike that of any other industry.

Detailed reports for each company (see fig. 1) include available water source and water withdrawal information, population metrics, data on public water needs (including municipal water supplies), water intakes and discharge information for each facility, local climate information (e.g., subbasin precipitation averages), various watershed characteristics, and upstream/downstream water use information (by use category). Each report generated as part of this effort relied on the compilation and/or assessment of demographic information and various environmental metrics into a database and corresponding GIS (fig. 2). Other components of the database and associated reports include land use composition, change in river flow (near each facility), influent & effluent ratios (i.e., relative to receiving stream & surface water flows), cooling water vs. process flow volumes, as well as a recent addition of information on the presence of threatened and endangered aquatic species (or their critical habitat designations) in mill receiving waters.

DATA SOURCES

The principal data sources for these assessments include the NCASI Environmental Data Resource & Receiving Water Database, Fisher International's global mill database, the National Land Cover Database (NLCD), county population statistics from the U.S. Census Bureau (USCB),[2] the USGS National Water-Use Information Program,[3] EPA's PCS & ICIS databases,[4] as well as the

[2] U.S. Department of Commerce - Census Bureau (www.census.gov)

[3] U.S. Geological Survey National Water-Use Information Program (water.usgs.gov/watuse/wunwup.html)

[4] EPA Permit Compliance & Integrated Compliance Information Systems (www.epa.gov/enviro/pcs-icis-overview)

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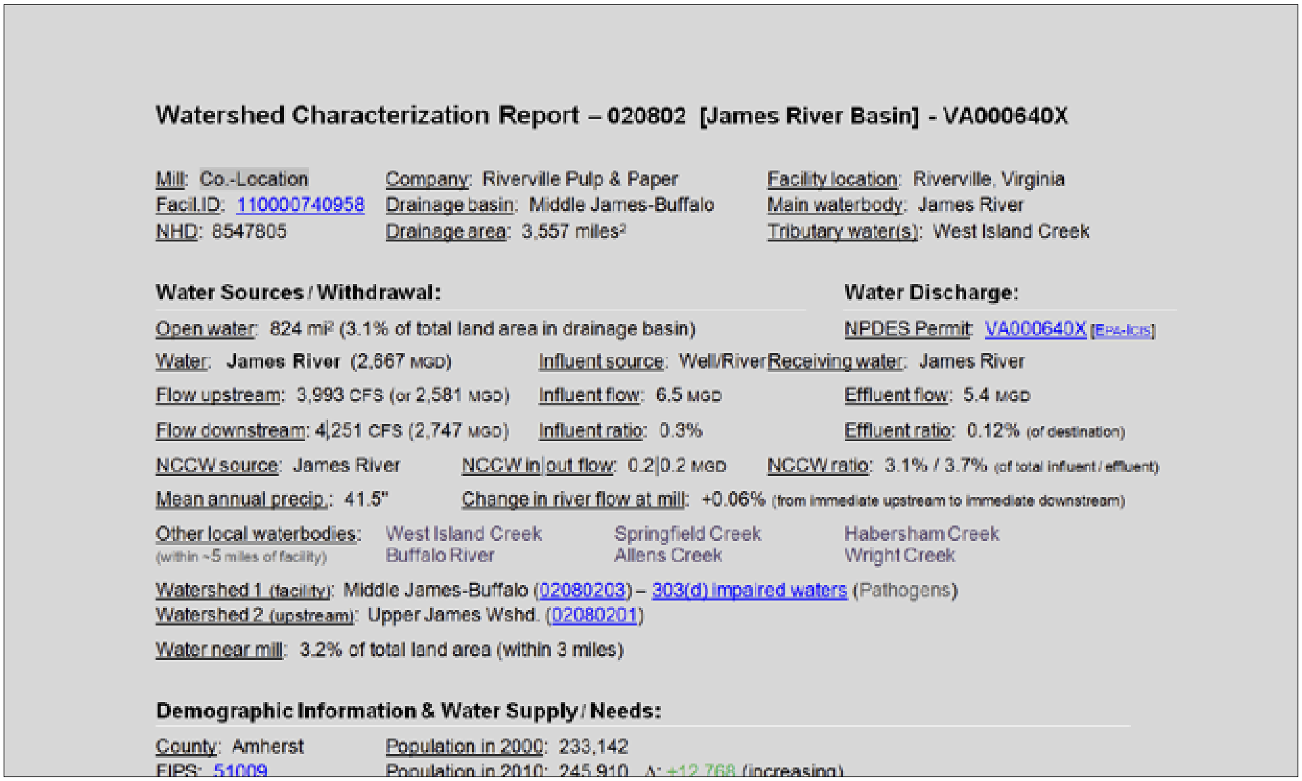

Watershed Characterization Report – 020802 [James River Basin] - VA000640X

Mill: Co.-Location | Company: Riverville Pulp & Paper | Facility location: Riverville, Virginia
Facil.ID: 110000740958 | Drainage basin: Middle James-Buffalo | Main waterbody: James River
NHD: 8547805 | Drainage area: 3,557 miles² | Tributary water(s): West Island Creek

Water Sources / Withdrawal:

Open water: 824 mi² (3.1% of total land area in drainage basin)
Water: James River (2,667 MGD)
Influent source: Well/River
Flow upstream: 3,993 CFS (or 2,581 MGD)
Influent flow: 6.5 MGD
Flow downstream: 4,251 CFS (2,747 MGD)
Influent ratio: 0.3%
NCCW source: James River
NCCW in|out flow: 0.2|0.2 MGD
NCCW ratio: 3.1% / 3.7% (of total influent / effluent)
Mean annual precip.: 41.5"
Change in river flow at mill: +0.06% (from immediate upstream to immediate downstream)

Water Discharge:

NPDES Permit: VA000640X [EPA-ICIS]
Receiving water: James River
Effluent flow: 5.4 MGD
Effluent ratio: 0.12% (of destination)

Other local waterbodies: (within ~5 miles of facility) West Island Creek, Buffalo River, Springfield Creek, Allens Creek, Habersham Creek, Wright Creek

Watershed 1 (facility): Middle James-Buffalo (02080203) – 303(d) impaired waters (Pathogens)
Watershed 2 (upstream): Upper James Wshd. (02080201)

Water near mill: 3.2% of total land area (within 3 miles)

Demographic Information & Water Supply / Needs:

County: Amherst | Population in 2000: 233,142
FIPS: 51009 | Population in 2010: 245,910 Δ: +12,768 (increasing)

Figure 1—Top portion of combined water use/watershed characterization report for an example (i.e., hypothetical) facility scenario.

EPA WATERS database[5] for CWA §303(d) impairment data. Additional demographic information for this summary was provided by the U.S. Census Bureau (USCB 2012) and obtained from EPA-ECHO[6] Detailed Facility Reports.

PROCEDURES

Reports were generated to summarize data on industry facilities and their environment, as well as provide references to data sources corresponding to each reporting element. Source references in their electronic form, shown as blue hyperlinks on each report (fig. 1 & 2), provide access to supplementary information, and each batch of reports generated for NCASI member companies is accompanied by a definitions sheet providing detailed descriptions of each piece of information including corresponding data sources.

Each facility water-use/watershed characterization report also contains standard watershed metrics including waterbody identifier (i.e., NHD ComID#), surface water name and type (i.e., river/stream), stream order, a description of average flow conditions, relative location of the immediate receiving water reach within the watershed, cumulative drainage area, stream network density/ bifurcation, etc,.

Watershed information assembled as part of this effort is designed to not only generate facility-specific information useful to companies that comprise the forest products industry, but also to produce a database of water-related and other environmental metrics that can be used as a research tool to analyze information for the industry on a national or regional basis, as well as look for trends in mill demographic and other data over time.

RESULTS AND DISCUSSION

In terms of water sources, one component of the reports is the amount of potentially accessible surface water (or "open water") nearby, expressed as a percentage of total land area within a set radius from each mill. While this metric may not be specific to the corresponding watershed for some facilities, it provides a crucial piece of water resource information for companies and the industry as whole. Overall, the amount of nearby open water around pulp and paper facilities in the U.S. averages 8.1 percent

[5] EPA Watershed Assessment, Tracking & Environmental Results System (www.epa.gov/waters)

[6] EPA Enforcement & Compliance History Online (www.epa-echo.gov)

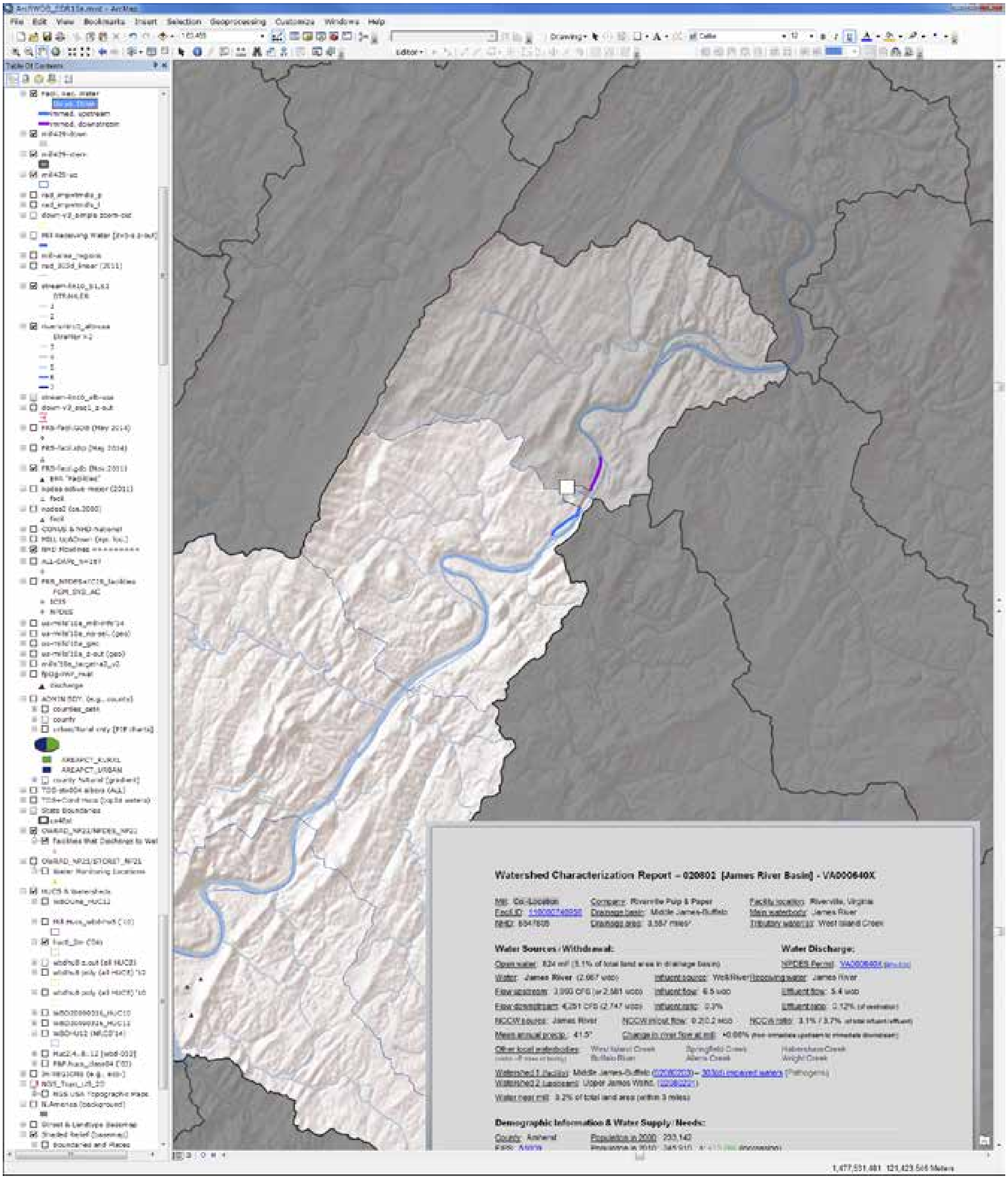

Figure 2—Example facility scenario and lower portion of corresponding mill watershed with upstream area shown (highlighted), downstream area (shaded light gray), surrounding subwatersheds (shaded gray), and example watershed characterization report (embedded graphic).

of the total land area. And, while slightly more than 10 percent of all industry facilities are located in areas in which the surrounding land mass contained greater than 20 percent open water (e.g., large lakes and rivers), the amount of available water is less than 10 percent for about three quarters of all U.S. facilities. It was also noted that about five percent of this industry's mills across the country have less than 1 percent open water nearby.

The surrounding land uses of the watershed also provided important information for individual facilities and, using the database corresponding to this report, can be summarized for broader areas involving multiple facilities or for groups of facilities owned by the same company for making water use decisions. At the national level we found that the area upstream of all facilities currently averages about 58 percent forestland (compared to 51 percent downstream), and approximately 21 percent is classified as agricultural land (compared to 27 percent downstream). Wetlands also comprise a significant area of the industry's watersheds, averaging 7.5 percent of the upstream drainage area (compared to 9.0 percent downstream), whereas grassland and other/mixed land classifications average 6.3 percent upstream (versus only 2.4 percent downstream). Collectively, urban areas comprise only 3.1 percent of upstream drainage areas (and nearly double that amount with 6.1 percent of downstream areas).

Since the composition of urban and agricultural/rural land in the vicinity of a mill can have a dramatic effect on local water availability, we also compiled similar land classification percentages for the urban areas and rural lands around each facility (similar to the metric for water availability) as well as on a per-county basis. Facilities areas were characterized further by population density using Census data and found that the large majority of mill locations are in predominantly rural areas, with an average of 92.5 percent rural (per USDA-ERS definition) across all facilities, and about half (or 51 percent) of facilities with greater than 95 percent rural land. Less than 5 percent of facilities are located in or near cities with greater than 90 percent urban land. On a county-by-county basis, more than half of all U.S. pulp & paper mills are located in counties that are greater than 95 percent rural and more than 75 percent of all facilities are located in counties that are greater than 80 percent rural (Figure 3). While mills located in the same watersheds as metropolitan areas or associated reservoirs potentially face critical water shortages, the large percentage of mills located in rural areas suggests agricultural water use may be of greater importance than city or overall water use.

Demographically, among the more than 200 mills in the U.S., the industry facility associated with the fastest growing population is located near Boston, MA (with a population increase in the associated county of nearly 19,000 persons over a recent 2-year period), followed by facility locations in counties near Portland, OR (increasing 7,750 over the same 2-year period), near Newark, NJ (increasing 7,650), and near Charleston, SC (increasing by 7,380 persons). It is also worth noting that mills with the highest population densities in the immediate vicinity (i.e., within a 3-mile radius) include a mill located in Tacoma, WA mill with greater than 3,500 inhabitants per square mile (IPSM), followed by two facilities in Green Bay, WI with about 3,200 IPSM. By comparison, and providing a more general characterization of population sparseness for the industry, the average population density for the remaining mills is less than 450 IPSM. Census data also indicated that the trend in population for people living near most facilities increased slightly over a recent 10-year period, but from the most recent comprehensive Census information (USCB 2012), the population at the county level corresponding to mill locations shows a decrease in population for nearly half (i.e., about 46 percent) of our industry's mills.

The NCASI database also contains information on the surface waters utilized by the industry and the corresponding influent (intake) volumes, as well as detailed information on individual facility receiving waters and their corresponding effluent (i.e., discharge) quantities. In terms of average river flow for facilities that discharge to U.S. surface waters, receiving waters across the forest products industry collectively average about 22,000 million gallons per day (MMGD) or about 34,000 cubic feet per second (CFS), and the difference in flow from immediately upstream of the facilities to immediately downstream (while accounting for flow generated from point source discharges) varied from as little as 3 CFS in smaller headwater systems to 15,000 CFS or more in larger river systems. This same metric averages 1,380 CFS across all mill receiving waters. Increases in flow were also documented and expressed as a percentage, which in the U.S. averages a 19 percent increase downstream compared to the corresponding upstream flow for all facilities. As for quantifying influents and effluents relative to total surface water volumes, the proportion of water brought into facilities currently averages 2.1 percent of the corresponding waterbodies throughout the industry, and the percentage of mill effluent discharge volumes to receiving water flow in the immediate reach of the corresponding rivers and streams averages about the same, just 2.0 percent.

Facility water use, including both mill process water and non-contact cooling water, across the country averages about 6.25 MMGD (or 9.7 CFS) per mill. By comparison, total water withdrawals from surface waters from all sources (including for agriculture, other industries, and

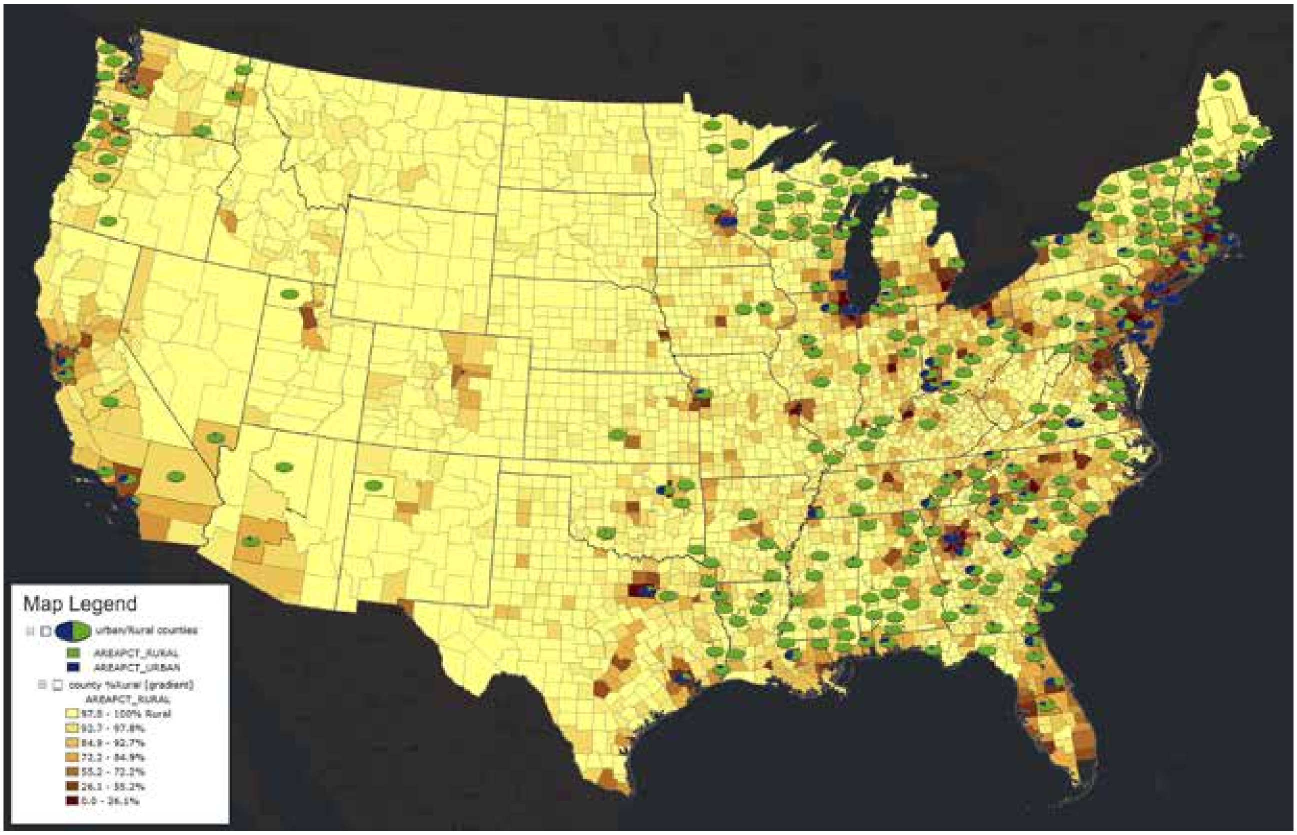

Figure 3—Facility locations showing predominantly rural land settings except for counties located in and around U.S. metropolitan areas.

domestic uses) exceeds 1,000 MMGD in a few industry counties. The average across all counties in which mills operate is 168 MMGD, which represents an average increase of 8 percent (from 154 MMGD) over a recent 10-year period (i.e., 2000 to 2010). In terms of total water use in these counties by category, the vast majority was withdrawn by hydroelectric facilities (70 percent), followed by industrial sources (14 percent), agriculture/irrigation (7 percent), domestic water use (6 percent), as well as mining and other sources (3 percent).

CONCLUSION

Reports generated from this effort summarize data on industry facilities and their environment, and provide detailed characterization reports containing standard watershed metrics, descriptions of average flow conditions and nearby water sources, as well as water use information for this industry and other industrial/non-industrial (e.g., domestic) uses. Assembling this information not only generated facility-specific information useful to NCASI member companies, but also generated a database of water/environment-related metrics that can be used to analyze information at various scales, as well as look for trends in data over time. Data from these assessments can also be overlapped with water quality assessment information (e.g., EPA CWA §303(d) impairments) to help anticipate which facilities with certain watershed characteristics are more likely to be involved in a water quality improvement (e.g., TMDL) effort. In addition, more recent information on threatened and endangered species in mill receiving waters is helping to identify which industry facilities may require additional considerations for the volumes of water intake and/or discharge flows to not negatively impact aquatic ESA species and/or their critical habitat. Other demographic information used (but not described herein) may also be useful to specific companies or facilities in their water use decisions and related environmental sustainability goals.

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INCREASING ALUMINIUM LEVELS IN NOVA SCOTIA, CANADA

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Global acidification of water catchments has resulted in increased mortality of aquatic organisms and the release of toxic metals from surrounding geology. In regions where recovery has not been observed, the mobility of aluminium is possible in the low pH values, and has been associated with the deaths of *Salmo salar*. We investigate the long-term trends of aluminium, ionic aluminium and other stream ions in Mersey River, Nova Scotia, Canada to determine whether aluminium should be considered a threat to local *S. salar* populations. Data has been obtained from 1980 to 2014 from Environment Canada, and interpolated for weekly averages. A modified empirical formula is used to estimate ionic aluminium. Total aluminium and ionic aluminium show increases since 1980, with changes of 2.2 $\mu g\ L^{-1}\ yr^{-1}$ and 0.1 $\mu g\ L^{-1}\ yr^{-1}$ respectively. The ionic aluminium exceeds the toxic threshold of 15 $\mu g\ L^{-1}$ for salmon more frequently in the 2000s. There is no sign of recovery or leveling off of aluminium in the near future, which threatens the livelihood of *S. salar* in Nova Scotia rivers. More research is required to uncover the source of the increasing aluminium, and to refine the ionic aluminium empirical equation for a better understanding of the long-term trends. Aluminium can no longer be considered a minor problem in Nova Scotia rivers, and should be addressed before total extirpation of *S. salar* populations.

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PRIORITIZING CATCHMENTS FOR TERRESTRIAL LIMING IN NOVA SCOTIA

Marley Geddes, Shannon Sterling[1]

Chronic acidification of freshwater systems is a major issue in South Western Nova Scotia (SWNS), Canada. Despite reductions in sulphur emissions, water quality has not improved and is not predicted to improve naturally for another 60 years. This is concerning because acidification is a limiting factor for the Southern Upland (SU) Atlantic salmon (*Salmo salar*) which were evaluated as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2010. Population modelling for two of the largest populations within the SU designatable unit (LaHave and St. Mary's rivers) indicate a high probability of extirpation (87 percent and 73 percent, respectively) in 50 years if conditions remain unchanged. More positively, models for the LaHave River show that a 20 percent increase in habitat quality can reverse the risk of extirpation risk from 87 percent in 50 years to 21 percent. Liming, the addition of buffering materials to a freshwater system, is a common method of increasing pH of acidified streams. Similarly, terrestrial liming is the addition of buffering materials to the catchments, or drainage basins, of the acidified river. The advantages of terrestrial liming is that it addresses the problem directly and can have a long term effect after a small number of applications, if done correctly. The effectiveness of terrestrial liming in SWNS is currently being researched and may be a promising method to improve water quality in the area. The decision on where to lime and how much to lime is crucial to the success of terrestrial liming in increasing pH and helping support the SU Atlantic salmon. When selecting sites to lime considerations need to be made for attributes supporting an increasing in pH as well as the ability for a site to support a self-sustaining SU population. There is a need for a comprehensive study identifying candidate terrestrial liming sites in SWNS. My research will meet this need through a comprehensive Geographic Information System (GIS) analysis of potential sites and the prioritization of these sites using a decision-based model and site scoring methods.

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DEVELOPMENT OF A MERCURY LOAD MODEL USING TOPMODEL FLOW SIMULATIONS AT McTIER CREEK, SOUTH CAROLINA

Stephen T. Benedict, Paul A. Conrads, Toby D. Feaster, Celeste A. Journey, Heather E. Golden, Christopher D. Knightes, Gary M. Davis, Paul M. Bradley[1]

McTier Creek is a small watershed located in Aiken County, South Carolina and forms part of the headwaters for the Edisto River basin. The Edisto River basin is noted for having some of the highest measured fish-tissue mercury concentrations in the United States. In an attempt to improve the understanding of the factors causing these high mercury levels, the National Water-Quality Assessment Program of the U.S. Geological Survey conducted an extensive field investigation of mercury in the McTier Creek ecosystem. This investigation included the collection of hydrologic, biologic, and water-quality data as well as the development of a number of hydrologic and water-quality models. One modeling effort involved the development of a simple water-quality load model that utilized a mass-balance equation in conjunction with hydrologic simulations from the topography-based hydrological model (TOPMODEL). Several variants of this load model were developed including one, called TOPLOAD, which utilized the simulated surface and subsurface flow components taken directly from TOPMODEL. A second variant, TOPLOAD-H, added a groundwater partitioning algorithm to TOPMODEL, thereby providing for multiple groundwater flow components. A brief description of the development of these simple mercury load models and results of the simulation in the McTier Creek basin will be presented.

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SIMULATION OF STREAMFLOW IN THE McTIER CREEK WATERSHED, SOUTH CAROLINA

Toby D. Feaster, Heather E. Golden, Paul A. Conrads, Paul M. Bradley[1]

The McTier Creek watershed is located in the Sand Hills ecoregion of South Carolina and is a small catchment within the Edisto River basin. Two watershed hydrology models were applied to the McTier Creek watershed as part of a larger scientific investigation to expand the understanding of relations among hydrologic, geochemical, and ecological processes that affect fish-tissue mercury concentrations within the Edisto River basin. The two models are the topography-based hydrological model (TOPMODEL) and the grid-based mercury model (GBMM). TOPMODEL uses the variable-source area concept for simulating streamflow, and GBMM uses a spatially explicit modified curve-number approach for simulating streamflow. The hydrologic output from TOPMODEL can be used explicitly to simulate the transport of mercury in separate applications, whereas the hydrology output from GBMM is used implicitly in the simulation of mercury fate and transport in GBMM. The modeling efforts were a collaboration between the U.S. Geological Survey and the U.S. Environmental Protection Agency, National Exposure Research Laboratory.

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DEVELOPING THE U.S. GEOLOGICAL SURVEY STREAMSTATS WEB APPLICATION FOR SOUTH CAROLINA

Toby D. Feaster, Jimmy M. Clark[1]

Government agencies, engineers, scientists, water-resources managers, and others use streamflow statistics for the purposes of water management, permitting, and infrastructure design. Examples of such streamflow statistics are the 1-percent chance flood (also referred to as the 100-year flood), the mean annual flow, and the annual minimum 7-day average streamflow with a 10-year recurrence interval. These statistics can be computed for locations where streamflow data are collected, such as at U.S. Geological Survey (USGS) streamgages. However, financial and human-resource limitations make it impossible to collect data everywhere streamflow statistics may be needed, which are often are ungaged locations where no streamflow data are available.

To address the needs of entities requiring streamflow information, the USGS, in cooperation with Environmental Systems Research Institute, Inc., developed a web-based application called StreamStats that serves published streamflow statistics to the public and facilitates the estimation of streamflow statistics for ungaged sites on streams (http://water.usgs.gov/osw/streamstats/index.html). StreamStats is an integrated web-based geographic information system (GIS) application that makes the process of computing streamflow statistics for ungaged sites faster, more accurate, and more consistent than previous methods.

StreamStats allows a user to select any point on a stream through a web-based interactive map and delineate the contributing drainage area to that point. Once the user confirms the basin boundary, StreamStats identifies any regional USGS equations that are available for the basin, computes the required basin characteristics, and uses them in the equations needed to compute the streamflow statistics. Additionally, a report containing the computed basin-characteristic values and streamflow statistics is generated. StreamStats also provides an option to download a shapefile of the drainage boundary that can be imported into a local GIS. The shapefile includes the computed basin characteristics and streamflow statistics as attributes.

In October 2014, the USGS, in cooperation with the South Carolina Department of Transportation, began an investigation to develop and implement the StreamStats web application in South Carolina. When completed, the application will include regression equations to estimate flood-frequency flows at rural and urban ungaged locations along with the basin characteristics needed to compute those estimates. The StreamStats database also will include low-flow frequency statistics published by the USGS. Additionally, field measurements of historic bridge scour in South Carolina and USGS historic indirect flow measurements will be incorporated into the South Carolina StreamStats application. It is anticipated that the project will be completed by April 2018.

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USE OF BENEFICIAL BACTERIA TO TREAT NUTRIENTS IN POND WATER

Mike Haberland, Salvatore Mangiafico, Debra Haberland[1]

Agriculture and urban ponds often suffer impaired water quality from high levels of nitrogen and/or phosphorous that typically triggers excessive "blooms" of algae or cyanobacteria. These blooms can lead to extremely low dissolved oxygen levels leading to fish kills, fouling of irrigation equipment, smothering of native vegetation, health and odor nuisance from rotting organic matter, loss of recreational or commercial value and general unsightliness. Bacteria are known to breakdown nitrogen and phosphorous and ammonia in controlled wastewater treatment plant processes. Based on this information, commercial enterprises market beneficial bacteria products scaled for application to reduce nutrient levels in eutrophic ponds. This project tested a beneficial bacteria product to determine its effectiveness to reduce high phosphorous levels in a controlled pond water experiment. The bacteria in the tested product were: 2-*Bacillus subtilis*, 2-*B. amyloliquefaciens*, *B. pumilis*, *B. licheniformis*, and *B. megatarium*. We compared three treatments of pond water, versus three treatments of pond water with beneficial bacteria added. All treatment water was filtered to 5 µm. All treatments were supplied with air to keep the water aerated, mixed, and to encourage microbiological activity. Samples were collected weekly for three weeks. A second set of treatments was also compared, but no supplemental air was added. Sample parameters included DO, temperature, pH, conductivity, and orthophosphate (soluble phosphorous). The orthophosphorous values were analyzed using a LaMotte Smart3 Colorimeter. All the 190 L treatment containers were maintained at ambient pond water temperature and light conditions by floating them in the pond. A raw pond water sample was collected each week and compared to the treatments. Results showed no significant difference in orthophosphorous reduction across all treatments with the addition of the beneficial bacteria.

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INVESTIGATION OF CO_2 AND CH_4 EMISSIONS FROM TIDAL FRESHWATER AND NON-TIDAL BOTTOMLAND FOREST RIPARIAN ZONES

Bryan Farley, Carl Trettin, Craig Allan[1]

Tidal bottomland hardwood forests and wetlands are found throughout the Southeastern Atlantic Lower Coastal Plain due to its low topographic gradient and is characterized by a complex network of drainage systems that intertwine with mesotidal estuaries and freshwater tidal systems. Wetlands are an important source of greenhouse gases including CO_2 and CH_4 and need to be considered in any future climate-modeling scenarios. The production of CH_4 and CO_2 in wetlands is the result of a complex suite of microbial activities that include interactions that both enhance and inhibit competition for key organic substrates. The Santee Experimental Forest is a 6,100 acre-research facility located within the Francis Marion National Forest, SC and is situated within the Huger Creek watershed in the headwaters of the East Branch of the Cooper River. Historical rice cultivation in the Santee Experimental Forest has resulted in a series of relic berms and drainage ditches that are superimposed on a complex microtopography consisting of natural hummocks and hollows. This project seeks to determine whether tidal bottomland hardwood forests are functionally different from non-tidal bottomland hardwood forests. The project will investigate environmental variables such as water table position and periodicity, soil temperature, soil moisture level, soil redox conditions, decomposition rates, organic matter content, grain size, porosity, and density in both tidal and non-tidal sites. Additionally, the project will investigate how the wetland hydroperiodicity and complex microtopography affects CO_2 and CH_4 emissions. The seasonal CO_2 and CH_4 emissions from tidal, transitional, and non-tidal bottomland hardwood forests will be measured with a monthly sampling regime to determine if there are differences in the emission rates along the longitudinal tidal to non-tidal gradient. A spatially and temporally extensive series of measurements will be taken in the dormant and growing seasons to measure spatial differences in emission rates across the floodplain and temporal differences over a series of complete diurnal cycles.

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IMPACT OF OFF-HIGHWAY VEHICULAR TRAIL SYSTEM ON WATER QUALITY

Stephanie Laseter, Chelcy Miniat, Randy Fowler, Dick Rightmyer, Ed Hunter[1]

To quantify the impact of an off-highway vehicle (OHV) trail system on water quality we used a paired-watershed approach to compare a treatment site (watershed containing OHV trail system) to a reference watershed with similar area, topography, elevation, land cover, management history and slope. The Locust Stake OHV trail system is located in Habersham County, GA on the North Fork of the Broad River (managed by the USDA Forest Serivice Chattooga River Ranger District). The trail system encompasses 11 sections which were designated for OHV use in the mid-80s and were operational until January 2012. The system was closed in 2012 and a trail assessment was completed. Following the Assessment, the USFS installed a series of silt fences to limit erosion and barriers to prevent further use of individual trail sections. One trail was closed permanently. We deployed automated water samplers (Sigma,Inc) in treatment and reference watersheds to collect flow proportional samples. Samplers were programmed to collect water samples during heavy rain events when expected sediment transport rates to be at their maximum. Sites were also instrumented with an ISCO sonde to measure turbidity in-stream at the same location. Water samples were analyzed for total suspended solids (TSS) at the Coweeta Hydrologic Lab. Concurrent observations between the reference and treatment watersheds were modeled over time, with intervention terms to designate levels of OHV use. We report the results of weekly TSS, turbidity, streamflow and trail use since late 2013. Land managers need science-based information on the impact that OHV trail use has on stream water quality to make decisions on managing forests for recreation.

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THE AGRICULTURAL CONSERVATION PLANNING FRAMEWORK: A GIS-BASED TOOLBOX TO FACILITATE WATERSHED PLANNING AT THE HUC12 SCALE

M.D. Tomer, S.A. Porter, D.E. James, and K.J. Cole[1]

Investments in agricultural conservation are most effective if practices are located where measurable improvements in water quality are likely to result. Methods are available to map where some conservation practices should effectively improve water quality, but these methods have not yet been brought into a common framework to assist watershed planning. The Agricultural Conservation Planning Framework (ACPF) has been developed to apply precision conservation techniques in HUC12 watersheds, emphasizing practices suited to Midwestern agriculture and application of terrain analysis to high-resolution digital elevation models derived from LiDAR (Light Detection And Ranging) survey data. We have combined a suite of analyses that identify where a variety of conservation practices can be placed to intercept and treat water where it moves and accumulates on the landscape into an ArcGIS toolbox. The approach classifies practices by their relative placement (i.e., in-field, below-field, or riparian zone) and flow pathway addressed (surface runoff or subsurface tile drainage). Utilities are included to identify fields most prone to deliver runoff to streams, and a riparian classification scheme provides a simple but functional method to map buffer opportunities throughout the stream corridor. The framework can be applied to provide multiple scenarios with combinations of practices that can be evaluated using stakeholder feedback. A spreadsheet tool to compare planning scenarios in terms of potential nutrient reduction and land area required for implementation has also been developed. A key advantage of this approach is that it provides a non-prescriptive but landscape-specific resource for local communities to engage in watershed planning at the HUC12 scale. Required input data are widely available, enabling application in many watersheds at relatively little cost.

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CULVERT DESIGN AND TIDAL MARSH HEALTH

Jaclyn Daly-Fuchs, Clayton Willis, Pace Wilber[1]

Roads constructed through salt marsh can restrict tidal flow and fish passage if culverts are not adequately sized, designed, and maintained. The implications for restricted marsh hydrology include degraded water quality, nekton use, and vegetation growth. Numerous roadways throughout the Charleston area bisect tidal marshes. We examined 18 marsh sites where culverts were embedded into the roadway to determine if hydrology, vegetation, and fish passage were impaired. We then compared culvert size, shape, and elevation to tidal features such as wetland and creek width to develop guidance on culvert design standards for restoration or new roadway projects.

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These proceedings contain the abstracts, manuscripts, and posters of presentations given at the Fifth Interagency Conference on Research in the Watersheds—Headwaters to estuaries: advances in watershed science and management, held at the Trident Technical College Conference Center in North Charleston, South Carolina, March 3-5, 2015. The conference was hosted by the USDA Forest Service, Southern Research Station, Center for Forested Wetlands Research.

The conference theme was selected to recognize the focus of many natural resource agencies and universities in understanding how ecosystems are connected from interior upland habitats to the estuaries, as land use in the upper portion of watersheds often affect hydrological, ecological, and sociological processes downstream. This theme builds on past ICRW programs held in Arizona, North Carolina, Colorado, and Alaska by delivering a strong southeastern coastal plain theme while maintaining a broad national focus that highlights ongoing interagency research and management initiatives.

The conference was structured to focus on key issues faced by managers and scientists throughout the US, with many of these issues having a strong coastal watershed focus. Thematic areas included managing forested wetlands and agricultural catchments, identifying research advances from experimental watersheds, tracking the fate of contaminants through landscapes, advancing restoration ecology of connected ecosystems, and understanding the role of climatic perturbations (e.g., drought, severe storms) on watersheds. In addition, the role that ecosystems play in water use and management was a focal point, including modeling and measuring evapotranspiration associated with land use change.

Keywords: Coastal plain, forest hydrology, land use, watershed science.