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Proceedings of the Sixth Interagency Conference on Research in the Watersheds

Working Watersheds and Coastal Systems: Research and Management for a Changing Future

July 23–26, 2018, Shepherdstown, WV

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Edited by:

James S. Latimer, Carl C. Trettin, David Bosch, and Charles R. Lane

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Abstract

These proceedings contain the full-length papers, extended abstracts, and research abstracts of oral presentations and posters given at the Sixth Interagency Conference on Research in the Watersheds (ICRW)—Working Watersheds and Coastal Systems: Research and Management for a Changing Future, held at the National Conservation Training Center, Shepherdstown, WV, July 23-26, 2018.

The Sixth ICRW focused on "working watersheds." These so-called watersheds and coastal systems provide a wide array of useful economic goods and services (e.g., agricultural products, urban development, recreation, etc.). However, maintaining aquatic condition and functional integrity while balancing issues arising in working watersheds such as nutrient loading, landscape disturbance, and invasive species requires creative scientific approaches and adaptive management. The conference was structured to present and address key research and management issues faced by watershed managers and scientists throughout the United States. Research was presented by Federal, State, and local scientists, academics, and non-governmental organizations focusing on managing the complex watershed systems and watershed components (e.g., streams, rivers, lakes, estuaries, etc.). Thematic areas included watershed monitoring and management, hydrologic modeling, restoration, remote sensing research, climate change, extreme climatic events, and focal research areas (e.g., Appalachian watersheds, trans-boundary systems, evapotranspiration), as well as ecosystem-specific themes such as wetlands.

The conference was hosted by the U.S. Environmental Protection Agency, Office of Research and Development, with material and in-kind support from the following organizations: Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), the U.S. Department of Agriculture (USDA) Forest Service, the USDA Agricultural Research Service, the U.S. Geological Survey, the Bureau of Land Management, and the U.S. Fish and Wildlife Service. The Sixth ICRW was built on the foundation laid by the previous lead and hosting organizations: USDA Agricultural Research Service (2003), USDA Forest Service (2006 and 2015), U.S. Geological Survey and CUAHSI (2009), and the Bureau of Land Management and National Park Service (2011). The Seventh ICRW will be hosted by the USDA Agricultural Research Service in Tifton, GA, March 2020.

Keywords: Appalachian watersheds, coastal habitats, coastal wetlands, extreme climatic events, evapotranspiration, hydrologic modeling, land use, monitoring, stream and river networks, transboundary waters, watershed management, watershed science.

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Session Moderators

- **Coastal Habitats and Resources: Management, Protection, and Restoration**
  Chair: Lisa Vandiver (NOAA)
- **Managing and Characterizing Complex Aquatic Systems across Different Land Uses and Spatial Scales**
  Chairs: Ana Garcia and Jennifer Keisman (USGS)
- **Monitoring Aquatic Systems from Daily to Decadal Scales: Advances and Applications**
  Chairs: James Latimer (US EPA) and Rick Webb (USGS)
- **Novel Approaches and Applications in Hydrologic Modeling for Watershed Research**
  Chairs: David Bosch (USDA-ARS) and Bill Kepner (US EPA)
- **Using Long-term Data on Assessing Extreme Climatic Events Effects on Watershed Processes, Functions, and Management Practices**
  Chairs: Jami Nettles (Weyerhaeuser) and Tae Hee Hwang (USDA-FS)
- **Water Quality Research in the Appalachia Region**
  Chair: Jason Hubbart (West Virginia University)
- **Waters at the Border—Science, Management, and Policy Challenges for Transboundary Watersheds**
  Chairs: Jana Compton (US EPA), Jiajia Lin (US EPA/National Research Council, and Jill Baron (USGS)
- **Watershed Evapotranspiration in a Changing Environment**
  Chair: Ge Sun (USDA-FS)
- **Watershed Research and Management in a Changing Climate**
  Chair: Tanya Spero (US EPA)
- **Wetland Trends in Coastal Watersheds: Drivers, Effects, and Adaptive Management**
  Chair: Megan Lang (US FWS)

Field Tour Facilitators

Fish and Fruit—Tim Leeds, Kathryn Root, and staff (USDA-ARS; National Center for Cool and Cold Water Aquaculture); Tracy Leskey, Breyn Evans, Wojciech Janisiewicz, Teresa Mersing, Teresa Silveous, and staff (USDA-ARS Appalachian Fruit Research Station)

Antietam National Battlefield— National Park Service staff

Rafting the Shenandoah—River & Trail Outfitters

Regional Karst Landscapes—Daniel Doctor (USGS)

Conference Venue

National Conservation Training Center, Shepherdstown, WV (US FWS)

The organizers would like to thank all the additional unnamed individuals, including the conference participants and presenters, for helping to make the Sixth ICRW such a success.

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SECTION 1

Coastal Habitats and Resources

THE TAMPA BAY STORY: FOSTERING COLLABORATIVE PARTNERSHIPS TO RESTORE AN URBAN ESTUARY

Gary E. Raulerson, Edward T. Sherwood, Maya C. Burke, Holly S. Greening and Anthony J. Janicki

Abstract—An adaptive nutrient management plan for the Tampa Bay watershed evolved over the past 30+ years largely through efforts implemented by the Tampa Bay Nitrogen Management Consortium (NMC), which has been coordinated by the Tampa Bay Estuary Program (TBEP) since 1996. The NMC consists of approximately 45 stakeholders that work cooperatively to help support efforts to recover seagrass in Tampa Bay through implementation of total nitrogen (TN) load reduction projects. To date the NMC partners have invested >$2.47B in various nutrient load reduction, educational, and land preservation projects in Tampa Bay, FL. These investments have resulted in the reduction or preclusion of approximately 530 tons of TN loadings to the estuary since the early 1990s. As a result, the Tampa Bay community's seagrass recovery goal to restore acreages to near 1950s levels has been recently achieved and exceeded. However, population expansion and anticipated introduction of new sources of TN loads to the Bay's watershed will create future challenges. Therefore, the NMC continues to implement new load reduction projects in a collaborative and consensus-driven process.

INTRODUCTION

Tampa Bay, located on the eastern side of the Gulf of Mexico, is the largest open-water estuary in the State of Florida (1,063 km^2, fig.1). A population of over 3 million people resides in its 5,698 km^2 watershed. Land use within the basin is mixed, including 32 percent in undeveloped, 20 percent in agricultural, 43 percent in residential (urban and suburban), and 5 percent in mining (primarily phosphate on the eastern side of the bay). Prominent natural habitats include mangroves, salt marshes, and seagrasses, while habitats with smaller footprints include salt barrens, oysters, and hard bottom.

Similar to many coastal watersheds around the world, environmental degradation as a result of urbanization and development peaked from the 1960s-70s in Tampa Bay. Among other abuses, poorly treated domestic wastewater was discharged into the bay from the large urban centers (cities of Tampa and St. Petersburg), small package plants and aging septic systems were abundant throughout the urbanizing watershed, and little treatment was generally required for stormwater runoff or other industrial dischargers to the Bay. As a result, water quality became extremely poor within the system, leading to the formation of algal blooms and mats in the upper bay segments adjacent to the urban centers and expanding developed areas (Old Tampa Bay and Hillsborough Bay). Consequently, approximately 44 percent of seagrass coverage was lost in the bay between 1950 and 1981 (Lewis and others 1998) primarily from light limitation caused by excessive phytoplankton production and secondarily from direct burial through dredge and fill activities. Several news outlets, including local newspapers and the nationally syndicated TV show "60 Minutes," ran pieces about the problems facing Tampa Bay. Most declared Tampa Bay as "dead" at that time.

In recognition of these issues, local citizens initially motivated government to take action to restore Tampa Bay. In 1967 the Florida State legislature created the Environmental Protection Commission of Hillsborough County (EPCHC), which initiated a routine, ambient water quality monitoring program in the early 1970s within Tampa Bay. Their monthly water quality data collection continues to this day (over 45 years at time of publication). The Wilson-Grizzle Act of 1972 required Advanced Wastewater Treatment for all municipal sewage plants discharging to the Tampa and Sarasota Bay watersheds. During the 1980s, the State of Florida enacted a series of stormwater regulations that resulted in enhanced stormwater controls that further reduced nitrogen loading from nonpoint sources. During the 1987 update to the Federal Clean Water Act, the National Estuary Program was created, and soon after (1990), Tampa Bay was designated as an "Estuary of National Significance."

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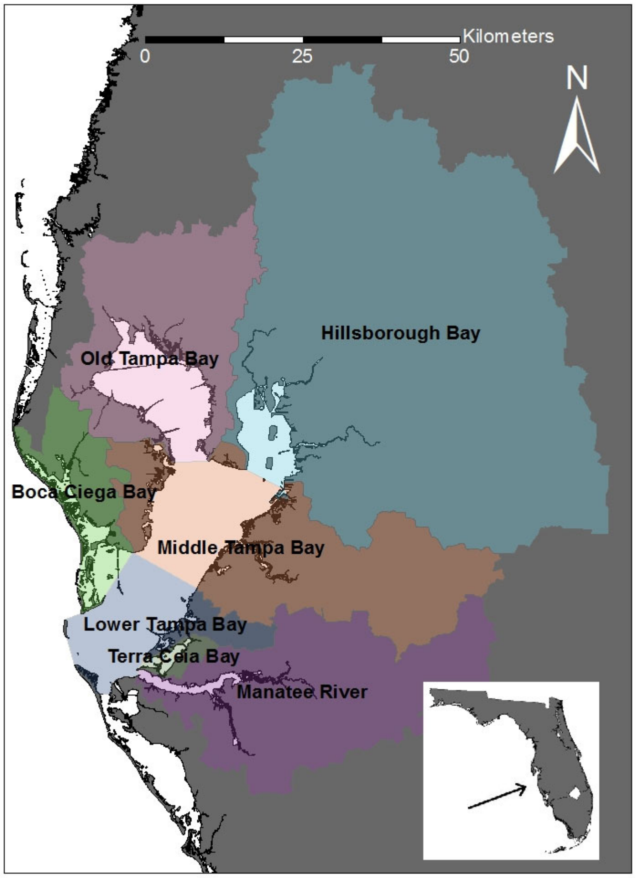

Figure 1—Location and map for the Tampa Bay estuary.

SCIENTIFIC RATIONALE FOR THE SEAGRASS PARADIGM

The formation of the Tampa Bay Estuary Program (TBEP) in the early 1990s further spearheaded the development of a nitrogen management paradigm for the benefit of restoring seagrass resources to the Tampa Bay estuary (fig. 2). The TBEP established the restoration of seagrass in the bay to levels estimated in the 1950's as a primary goal for overall bay restoration in 1995. In establishing and addressing this goal, a conceptual paradigm was developed to identify the primary, manageable factors thought to influence the recovery and sustainability of seagrass resources within the bay (fig. 2). As depicted in the TBEP's nitrogen management paradigm (fig. 2), reduced water clarity resulting from excessive nitrogen loads to the bay through increased light attenuation by phytoplankton responding to these loadings were the key water quality indicators by which seagrass recovery could be managed. Research in the 1990s clearly established that nitrogen loads were the limiting nutrient in the Tampa Bay estuary and that phosphorus loadings to the bay from an enriched "Bone Valley region" within the watershed were not controlling estuarine production.

Efforts to relate nitrogen loading to algal response in the bay (via chlorophyll-a measurements) and the resulting reduction in light availability due to increases in chlorophyll-a levels were subsequently undertaken. Both empirical (Janicki and Wade 1996) and mechanistic (Wang and others 1999) models were used to relate nitrogen loads to chlorophyll-a concentrations within the four major bay segments of Tampa Bay. Results from each modeling approach tended to agree with one another (Morrison and others 1996), and the TBEP adaptive nutrient management strategy was further developed through the application of the empirical models initially established by Janicki and Wade (1996).

Janicki and Wade (1996) used a two-stage empirical modeling approach to define the relationships between: (1) total nitrogen (TN) loads and chlorophyll-a concentrations and (2) chlorophyll-a concentrations and light attenuation in each of the major bay segments. The TN load-chlorophyll-a model accounts for the hydrologic exchange and the nonconservative properties of nitrogen within the estuary through various least-square regression approaches. Furthermore, the external TN loads utilized in this model have been derived from either best estimates of local data sources and/or measured inputs to the Tampa Bay estuary from seven source categories (Janicki Environmental 2008, Poe and others 2005, Pribble and others 2001, Zarbock and others 1996). Application of this model reinforced the TBEP adaptive nutrient management strategy to "hold the line" on nitrogen loadings to the bay at annual average levels estimated during the 1992-1994 period (Greening and Janicki 2006, Greening and others 2014).

Appropriate bay segment-specific chlorophyll-a concentrations (table 1) were derived from the second stage of the Janicki and Wade (1996) empirical modeling approach. Chlorophyll-a levels were related to light attenuation (via estimates derived from secchi disk depths) using a functional form of Beers' law in a linear regression and served as a proxy for light availability to seagrass in the bay. Concomitant to these modeling approaches, Dixon (1999) determined that 20.5 percent of incident light was required to maintain *Thalassia testudinum* (turtle grass) shoot density and biomass at the deepest edge of seagrass beds in Lower Tampa Bay.

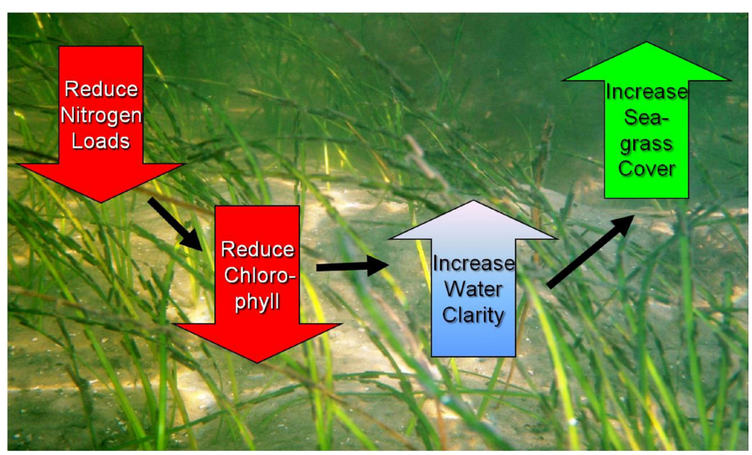

Figure 2—Seagrass paradigm for Tampa Bay, illustrating linkages between nitrogen loading, phytoplankton, water clarity, and seagrass growth.

Table 1—Chlorophyll-a and light penetration targets and current (2017-2021) nitrogen loading allocations established for Tampa Bay

Major Bay segments	Chlorophyll-a (ug/L)	Light Penetration (m^{-1})	2017-2021 allocated total nitrogen loads (tons/year)
Old Tampa Bay	8.5	0.83	486
Hillsborough Bay	13.2	1.58	1451
Middle Tampa Bay	7.4	0.83	799
Lower Tampa Bay	4.6	0.63	349

Given this minimum light requirement, predictions of chlorophyll-a levels and secchi disk depths (light penetration) necessary to restore seagrass to average depths observed in each of the major bay segments during the 1950's (1.0 m in Hillsborough Bay to 2.5 m in Lower Tampa Bay) were used to assess the development of annual targets for these parameters (Greening and Janicki 2006, Janicki and Wade 1996).

Based on improving seagrass coverage and water quality seen over the 1990-1996 period, secondary targets were developed from the average annual chlorophyll-a levels seen during 1992-1994 (a period of time with high and low rainfall during which seagrass was expanding). The ultimate selection of bay segment-specific chlorophyll-a and water clarity targets were conservatively established as the average annual levels developed from the empirical model predictions (Janicki and Wade 1996) or the 1992-1994 average annual levels—whichever were lower (table 1) (TBEP 1996, 2001). During this same time, the 1992-1994 average annual total nitrogen loads were established as the appropriate nitrogen load management targets by TBEP partners to support the maintenance of the chlorophyll-a and light attenuation targets developed for each of Tampa Bay's major bay segments.

Since 1996, periodic re-evaluation of the chlorophyll-a and light attenuation targets developed as part of the adaptive nutrient management strategy for Tampa Bay has occurred (Janicki and others 2001, Janicki Environmental 2001). Also during this time, annual assessments of the agreed upon bay segment specific chlorophyll-a and light attenuation targets (developed from secchi disk depths) have been used by bay managers to guide decisions related to nitrogen management in each of the four major bay segments (Janicki and others 2000). These assessments, termed the annual "decision matrix," have shown that the bay segment water clarity targets developed by the TBEP have been largely met and that a general improvement in annual water clarity conditions in the bay has been seen since the early 1990s (Sherwood and Raulerson 2018). Consequently, seagrass coverage in Tampa Bay continues to increase over time and now exceeds the restoration goal and 1950s historic estimate.

THE NITROGEN MANAGEMENT CONSORTIUM

Development and Organization

In the mid-1990s, it was recognized that continued development, if left unaddressed, had the potential to increase nitrogen loads to the Bay and threaten the "hold the line" strategy. The Nitrogen Management Consortium (NMC), as organized by TBEP, was formed in 1996 to support and encourage voluntary interactions between various public and private entities (table 2) to encourage and promote projects that would maintain nitrogen loading at the "hold the line" targets. Local, State, and Federal public partners worked in cooperation with diverse private entities (including electric utilities, phosphate mining companies, and shipping industry interests) to meet nitrogen loading offsets anticipated from future growth in the watershed. Created as an open forum for discussion between and among regulated and regulatory entities with impacts to or responsibilities for Tampa Bay, the NMC fosters ongoing discussion regarding the creation of nitrogen reduction projects and partnerships to implement the necessary projects to "hold the line" on TN loadings. Regular meetings (up to six times per year as needed) provide opportunities to foster relationships, build trust, and identify areas with additional project (current or future) needs. Additionally, TBEP staff and contractors are in regular contact with NMC members to discuss ongoing issues and obtain current loading estimates.

The approach advocated by the NMC stresses cooperative solutions and flexible strategies to meet nitrogen management goals. For example, the TBEP Comprehensive Conservation and Management Plan (TBEP 2017) includes language supporting implementation of the nitrogen management strategy but does not identify individual projects. Additionally, Consortium partners are encouraged to identify and implement cost-effective partnership projects that collectively achieve the nitrogen management goals. This work has also been recognized by both the Florida Department of Environmental Protection (FDEP) and the Environmental Protection Agency (EPA) as demonstrating sufficient progress towards meeting the federally-recognized Total Maximum Daily Load (TMDL) for nutrients in Tampa Bay.

Table 2—Nitrogen Management Consortium (NMC) members from 1998-2017

NMC public partners	1998	2002	2007/9	2012	2017
Agricultural Economic Development Council of Hillsborough County			x	x	x
City of Bradenton			x	x	x
City of Clearwater[a]	x	x	x	x	x
City of Gulfport			x	x	x
City of Lakeland			x	x	x
City of Largo			x	x	x
City of Mulberry			x	x	x
City of Oldsmar			x	x	x
City of Palmetto			x	x	x
City of Plant City			x	x	x
City of Safety Harbor				x	x
City of St. Petersburg[a]	x	x	x	x	x
City of Tampa[a]	x	x	x	x	x
Environmental Protection Commission of Hillsborough County	x	x	x	x	x
Florida Department of Agriculture & Consumer Services		x	x	x	x
Florida Department of Environmental Protection[a]	x	x	x	x	x
Florida Department of Transportation			x	x	x
Florida Fish and Wildlife Commission/FWRI	x	x	x		
Hillsborough County[a]	x	x	x	x	x
MacDill Air Force Base			x	x	x
Manatee County[a]	x	x	x	x	x
Manatee County Agricultural Extension Service	x	x			
Pasco County[a]				x	x
Pinellas County[a]	x	x		x	x
Polk County			x	x	x
Sarasota County				x	x
Southwest Florida Water Management District[a]	x	x	x	x	x
Tampa Bay Estuary Program	x	x	x	x	x
Tampa Bay Regional Planning Council	x	x	x	x	x
Tampa Bay Water			x	x	x
Tampa Port Authority	x	x	x	x	x
U.S. Army Corps of Engineers	x	x			
U.S. Environmental Protection Agency (non-voting member of the TBEP Policy Board)[a]	x	x	x	x	x

continued

The initial "Partnership for Progress" document (TBEP 1998) included a resolution signed by the original partners (table 2) that both adopted the plan and committed to its implementation. The NMC membership has increased from 25 in 1998 to 45 in 2017, including local, State, and Federal agencies as well as multiple private partners, a demonstration of the commitment of multiple entities within the region to the restoration and conservation of Tampa Bay's natural resources. As part of a 5-year, Florida State Reasonable Assurance reporting period, each organization contributes to ongoing water quality, loading and seagrass coverage assessments. All entities with averaged allocations < 1 ton TN per year are requested to contribute a recommended one-time nominal amount ($500), and all other sources are requested to contribute a one-time recommended amount of $6,000 during a 5-year reporting cycle. The per-entity contribution is reduced accordingly, if more than 25 members contribute. The funds are expended in the production of technical analyses and a 5-year Reasonable Assurance Update report; support and organization of meetings with individual Consortium entities and agencies; analyzing issues and options to support the Consortium in the development of guiding principles; facilitation of Consortium meetings and Implementation Group meetings and workshops; support and documentation for draft and final bay-segment allocations; support and documentation for assessing compliance with facility-specific allocations; and full documentation of analyses and processes.

Table 2 (continued)—Nitrogen Management Consortium (NMC) members from 1998-2017

NMC Private Partners	1998	2002	2007/9	2012	2017
Alafia Preserve, LLC			x	x	x
Busch Gardens Tampa Bay					x
Cargill Fertilizer, Inc.	x	x			
CF Industries, Inc.	x	x	x	x	
CSX Transportation	x	x	x	x	x
Duke Energy Corporation (formerly Progress Energy)			x	x	x
Eagle Ridge, LLC				x	x
Eastern Associated Terminals Company	x	x	x	x	
Florida Phosphate Council	x	x			
Florida Power & Light Company	x	x	x		
Florida Strawberry Growers Association	x	x		x	
HRK Holdings, Inc.					x
IMC-Phosphate Company	x	x			
Kerry I&F Contracting				x	x
Kinder Morgan Bulk Terminals, Inc. (was Pakhoed Dry Bulk)	x	x	x	x	x
LDC Donaldson Knoll Investments, LLC			x	x	x
Lowry Park Zoo					x
Mosaic Company			x	x	x
Tampa Electric Company		x	x	x	x
Tampa Port Services, LLC					x
Trademark Nitrogen			x	x	x
Tropicana Products, Inc.			x	x	x
Yara North America			x	x	x

[a]Current (2018) members of the Tampa Bay Estuary Program (TBEP) Policy Board.

Note: Acquisitions and mergers of private partners have resulted in some changes of member names.

Documenting Progress and Reasonable Assurance

During modeling efforts in the 1990s (Greening and Janicki 2006), it was estimated that to maintain the "hold the line" targets, a cumulative 85 tons of nitrogen per year would need to be offset by the year 2000 (TBEP 1998). To help achieve that goal, the NMC created an initial action plan "Partnership for Progress" (TBEP 1998) that identified more than 100 implemented or planned projects which collectively reduced or prevented an estimated 134 tons of nitrogen per year from entering Tampa Bay. The existing loads and load reductions expected from nitrogen removal projects were usually calculated by the implementing parties based on best available science of treatment efficiencies. A 1998 Interlocal Agreement signed by the Policy Board for the TBEP (table 2) formally institutionalized the goals of the NMC and committed the membership to implementation of the TBEP Comprehensive Conservation and Management Plan (CCMP) goals and actions, including nitrogen load reduction projects, appropriate to their respective governmental units.

In 2002, the TBEP and NMC provided initial Reasonable Assurance (RA) documentation (TBEP 2002) to the FDEP summarizing actions of the partners within the NMC that would result in the attainment of State water quality nutrient criteria for Tampa Bay. The document was formatted to facilitate its use in demonstrating reasonable assurance that designated uses of waterbody segments within the Tampa Bay basin, which were designated as potentially impaired for nutrients pursuant to §62-303, F.A.C., will be maintained or restored. The document also provided a basis for designation of alternative site-specific thresholds for each bay segment that more accurately reflected conditions beyond which an imbalance of flora and fauna would occur. Significant findings within the 2002 RA included a demonstration that ongoing efforts to reduce nitrogen loadings were resulting in adequate water quality to support seagrass coverage increases. Also, an annual decision matrix (fig. 3) and stoplight graphic (fig. 4) were created to aid in the analysis of both seagrass coverage and water quality improvements that would trigger management activities if standards were not met during this

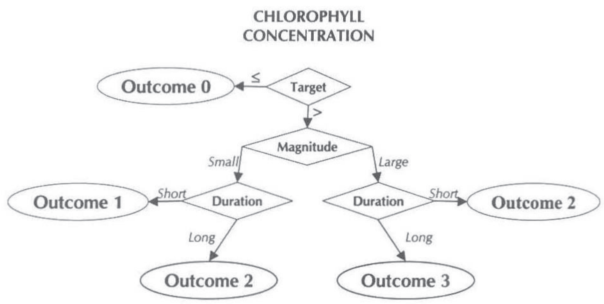

Figure 3—Decision matrix used for seagrass, water clarity, and chlorophyll-a.

time (Janicki and others 2000). Data collected by the EPCHC beginning in 1974 was used in the "decision matrix" to observe trends starting before implementation of significant management activities (e.g., advanced wastewater treatment). In recognition of the ongoing, yet significant progress made by the TBEP and NMC, the FDEP concluded in 2002 that "the nitrogen management plan developed by the TBEP for Tampa Bay provides reasonable assurance that impairment of designated uses related to nutrients in Tampa Bay will be adequately addressed."

Currently, the TBEP and the NMC provide a comprehensive update to the original 2002 RA document every 5 years with additional annual status and trends reports submitted in the interim years. In general, the comprehensive updates provide a synthesis on project implementation, bay water quality and seagrass restoration progress, and updated TN loading information by bay segment, source categories, individual facilities, and permitted entities.

A 2007 Reasonable Assurance Update (TBEP; Janicki Environmental 2007) and 2009 Addendum (TBEP; Janicki Environmental 2009) were developed by the TBEP and NMC to: (1) provide an update on implementation of the Tampa Bay Nitrogen Management Strategy to FDEP for the 2003-2007 period; (2) provide adequate documentation to allow FDEP a finding of Reasonable Progress pursuant to §62-303.600, F.A.C., for the 2002-2006 period; and (3) provide total nitrogen loading allocations to categories of nitrogen sources by major bay segment, and facility-specific and MS4 specific allocations within each major bay segment, to support any FDEP water quality based effluent limitation, FDEP Reasonable Assurance determination, and to comply with the federally-recognized TMDL for Tampa Bay. The development and identification of specific loading allocations for individual sources was requested by FDEP in 2007 to help ensure that State water quality requirements would continue to be met for the entire bay and each bay segment. During the 2002-2006 reporting timeframe, a Microsoft® Access® database was created and populated with projects submitted by the TBEP and Nitrogen Management Consortium partners. The TBEP "Action Plan Database" was later developed into an online reporting system for use by the TBEP, the NMC,

Year	Old TB	Hills. Bay	Middle TB	Lower TB
1975	Red	Red	Red	Green
1976	Red	Red	Red	Yellow
1977	Red	Red	Red	Red
1978	Red	Red	Red	Yellow
1979	Red	Red	Red	Red
1980	Red	Red	Red	Red
1981	Red	Red	Red	Red
1982	Red	Red	Red	Red
1983	Red	Yellow	Red	Red
1984	Red	Green	Red	Yellow
1985	Red	Red	Red	Yellow
1986	Red	Yellow	Red	Green
1987	Red	Yellow	Red	Green
1988	Yellow	Green	Yellow	Green
1989	Red	Yellow	Red	Yellow
1990	Red	Green	Red	Yellow
1991	Green	Yellow	Yellow	Yellow
1992	Yellow	Green	Yellow	Yellow
1993	Yellow	Green	Yellow	Yellow
1994	Yellow	Yellow	Red	Red
1995	Red	Yellow	Red	Yellow
1996	Yellow	Green	Yellow	Green
1997	Yellow	Green	Red	Yellow
1998	Red	Red	Red	Red
1999	Yellow	Green	Yellow	Yellow
2000	Green	Green	Yellow	Yellow
2001	Yellow	Green	Yellow	Yellow
2002	Yellow	Green	Green	Green
2003	Red	Yellow	Green	Yellow
2004	Red	Green	Green	Yellow
2005	Green	Green	Yellow	Yellow
2006	Green	Green	Green	Green
2007	Green	Green	Green	Green
2008	Yellow	Green	Green	Yellow
2009	Yellow	Yellow	Green	Green
2010	Green	Green	Green	Green
2011	Red	Green	Yellow	Green
2012	Green	Green	Green	Green
2013	Green	Green	Green	Green
2014	Green	Green	Green	Green
2015	Yellow	Green	Yellow	Green
2016	Yellow	Green	Green	Green
2017	Yellow	Green	Green	Green

Figure 4—Stoplight graphic showing comparison of annual mean chlorophyll-a concentrations to regulatory targets from 1975-2017.

and regulators (http://apdb.tbeptech.org). A notable highlight for the period was the determination that in 2006, both chlorophyll-a and light attenuation targets were met in all four bay segments for the first time since records began in 1974. These submittals extended the State RA determination through 2012.

The 2012 RA Update (covering the years 2007-2011) showed that, with the exception of the Old Tampa Bay segment in 2009 and 2011, FDEP-adopted chlorophyll-a thresholds were being met in all four major bay segments over the reporting period (TBEP; Janicki Environmental 2012). As part of the compliance assessment protocol established in the 2009 Reasonable Assurance Addendum, a response to these exceedances was not necessary since they did not occur in 2 concurrent years. Nevertheless, the TBEP and NMC initiated actions to address the exceedances observed in the Old Tampa Bay segment. Based on projects implemented over the 2007-2011 period, it was estimated that cumulatively an additional 98.1 tons per year of TN was precluded from entering Tampa Bay. Future projects by Consortium participants (with completion dates after 2011) were estimated to preclude an additional 62 tons per year of TN. Seagrass coverage in Tampa Bay observed in 2008 and 2010 continued to show increasing acreage on a baywide basis, and the seagrass extent in Tampa Bay in 2010 (13,313 ha) was the highest recorded since the 1950s. During the 2007-2011 reporting timeframe, it was recognized that nitrogen load allocations were completely distributed to existing sources summing to the federally-recognized TMDL, requiring new or expanding TN loading sources to develop load reduction actions, projects, or transfers as offsets. The Consortium developed a process to assign allocations to new, missed, or expanding sources in the future that was formally accepted by the FDEP in 2012. This submittal resulted in an extension of the State RA determination through 2017.

The 2017 RA Update (TBEP; Janicki 2017) covered the 2012-2016 time period. Several important benchmarks and findings resulted from this update. During this timeframe, estimates of seagrass coverage for 2014 and 2016 exceeded estimates from the 1950s and the original seagrass restoration goals established by the TBEP and its partners in 1995. Another finding during this period was that hydrologically-normalized total loads to Tampa Bay were at the lowest levels since initially estimated (1985), despite an ever-increasing population in the Tampa Bay metropolitan area. However, chlorophyll-a issues within Old Tampa Bay continued to be reported and the NMC began discussions on potential management activities to address water quality issues in this bay segment. Projects conducted baywide within this reporting period provided an estimated TN load reduction of 147.3 tons/year, while future projects were estimated to preclude an additional 482.8 tons/year of TN. The continued progress towards improving water quality and achieving seagrass restoration goals, as well as commitments for multiple partners to continue collaborative efforts to maintain water quality at current levels (table 1), resulted in an FDEP decision to place all Tampa Bay segments into EPA Assessment category 2 for TN—effectively delisting the segments as impaired for nutrients and acknowledging that the segments are attaining all designated uses.

PROJECT EXAMPLES

Over 500 nutrient load reduction projects with a total cost of more than $710 million ($2.47 billion including land acquisition) have been implemented within the Tampa Bay watershed (TBEP; Janicki 2017). These projects have been conducted at multiple scales (from individual homeowners' yards to the entire watershed/airshed) and have targeted a wide variety of sources (from residential stormwater to atmospheric deposition). For example, reductions of atmospheric emissions from coal-fired electric generating plants between 1995 and 1997 resulted in estimated reductions of NOx emissions of 11,700 - 20,000 tons. Micro-irrigation of row crops provided an estimated 25-percent decrease in fertilizer applied to agricultural lands within the watershed and a reduction of 6.4 tons TN per year. Upgrades in fertilizer material handling systems by the phosphate and port shipping industries were estimated to provide a reduction of approximately 10 tons TN per year to control fertilizer product loss during shipment. A stormwater diversion project from approximately 620 acres through a reconfigured borrow pit system provided treatment prior to discharge back into a Hillsborough Bay tributary resulting in an estimated 1.0 ton TN per year load reduction. The Florida Yards and Neighborhoods Program, a long-term outreach and educational program encouraging residential landscaping practices such as "right plant, right place," minimal irrigation, and minimal fertilizer use, provided an estimated minimum of 845 pounds of TN removal per year in Manatee County. Funds for project implementation have come from a wide variety of sources, including general local revenue, ad valorum taxes, grants, and general operating expenses incurred by private entities.

MAINTAINING SCIENTIFIC RIGOR

Documenting the recovery of Tampa Bay has relied on consistent and quality-assured monitoring efforts. Tampa Bay's regional monitoring programs have been recently highlighted among other nationally-recognized, long-term programs in the nation (Schiff and others 2015). Existing water quality monitoring programs include ambient programs conducted by the EPCHC, Manatee County, and Pinellas County. Water quality samples from over 100 stations baywide are collected and analyzed on a monthly basis through the collective efforts of these monitoring programs. All county monitoring programs and their laboratories have State-approved Quality Assurance Plans on file, and comply with FDEP's QA rule, § 62-160, F.A.C., including FDEP approved Standard Operating Procedures. All participating county laboratories are National Environmental Laboratory Accreditation Conference (NELAC) certified. Quarterly round-robin exchanges for statistically-rigorous, inter-laboratory comparisons are conducted by the Southwest

Florida Regional Ambient Monitoring Program participants (http://www.tbeptech.org/committees/swfl-ramp). Nonpoint source estimates of nutrient loadings to Tampa Bay since 1985 rely heavily on these data collection efforts. Additional source estimates for domestic and industrial point sources, fertilizer losses at port facilities, direct atmospheric deposition, groundwater discharges, and spring inputs follow a similar rigor and are described more completely in Greening and others (2014). Lastly, the Southwest Florida Water Management District continues to assess seagrass coverage through a multistep geospatial analysis of aerial photography including field verification on approximately a biennial basis since 1988 (Kaufman 2017, Sherwood and others 2017, Tomasko and others 2005).

CONCLUSION: DEMONSTRATED SUCCESS AND FUTURE ISSUES

As a result of efforts conducted by numerous partners throughout the Tampa Bay watershed, and as led by the TBEP and NMC, estimates for average annual total nitrogen loadings to Tampa Bay for the 2010-2016 period are approximately 1/3 of those estimated in 1976 despite a continued increase in population and associated pressure on nitrogen loading (fig. 5) (TBEP; Janicki Environmental 2017). This significant load reduction, as predicted within the nitrogen management paradigm, has resulted in decreases in baywide chlorophyll-a concentrations and increases in water clarity to the extent that seagrass coverage exceeds 1950s estimates (fig. 6). Additionally, potential positive feedback processes have been observed between the increasing expansion of seagrass and continued baywide water quality improvements (Greening and others 2016, Sherwood and others 2015). Consequently, positive recognition by regulatory, public, and policy communities within the region and nationally have been garnered by the TBEP and NMC for its pragmatic nitrogen management strategy.

However, there is still work to be done in Tampa Bay. Although Old Tampa Bay seagrass conditions still show increasing acreage trends, there are concerns regarding recurring chlorophyll-a exceedences (that do not necessarily trigger management response requirements, as of yet). Bay managers continue to explore the feasibility and implementation of management actions that could improve this bay segment's overall ecological condition and water quality. Several recent TBEP initiatives have directed more focused research and restoration efforts towards this bay segment and its watershed. For example, preliminary research has indicated that severe blooms of *Pyrodinium bahamense* result from a combination of stormwater events and physical water quality conditions in Old Tampa Bay, and additional work investing potential bioremediation of *P. bahamense* blooms by shellfish is ongoing. Furthermore, TBEP and NMC partners continue to implement stormwater infrastructure and point source improvement projects throughout the Tampa Bay watershed that cumulatively contribute to the Bay's overall ecological improvement.

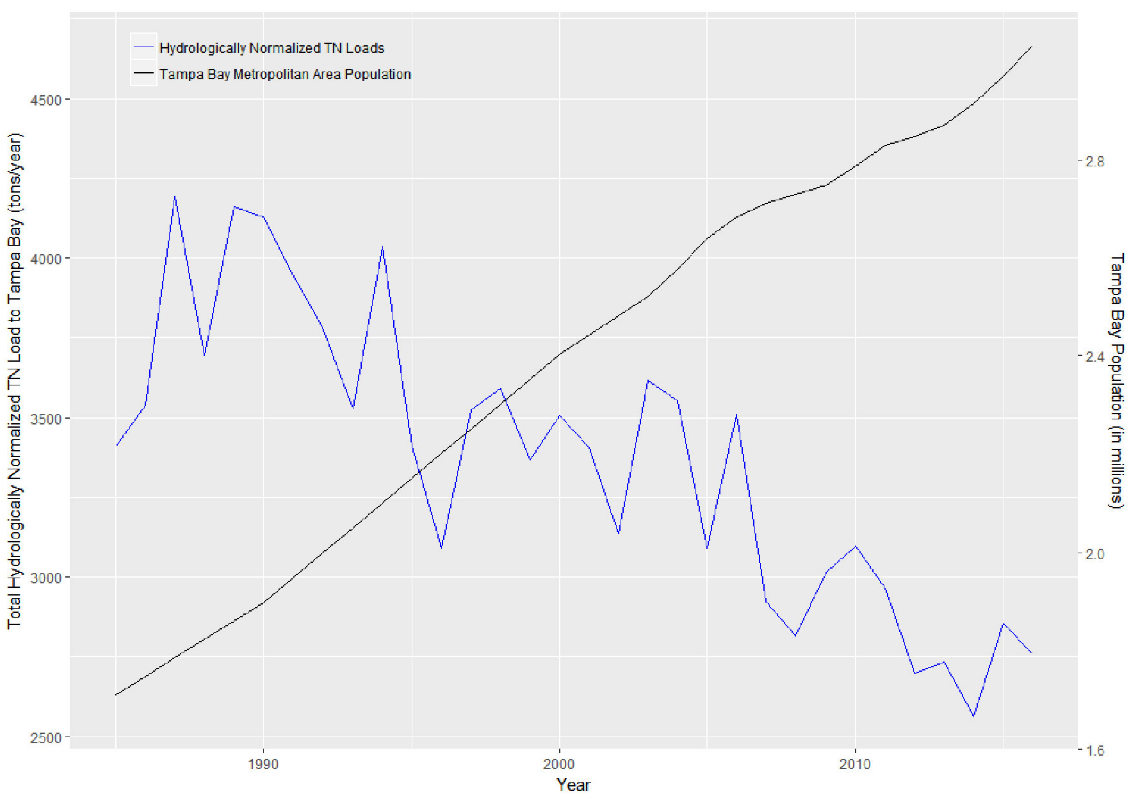

Figure 5—Nitrogen loading and population for Tampa Bay from 1985 to present.

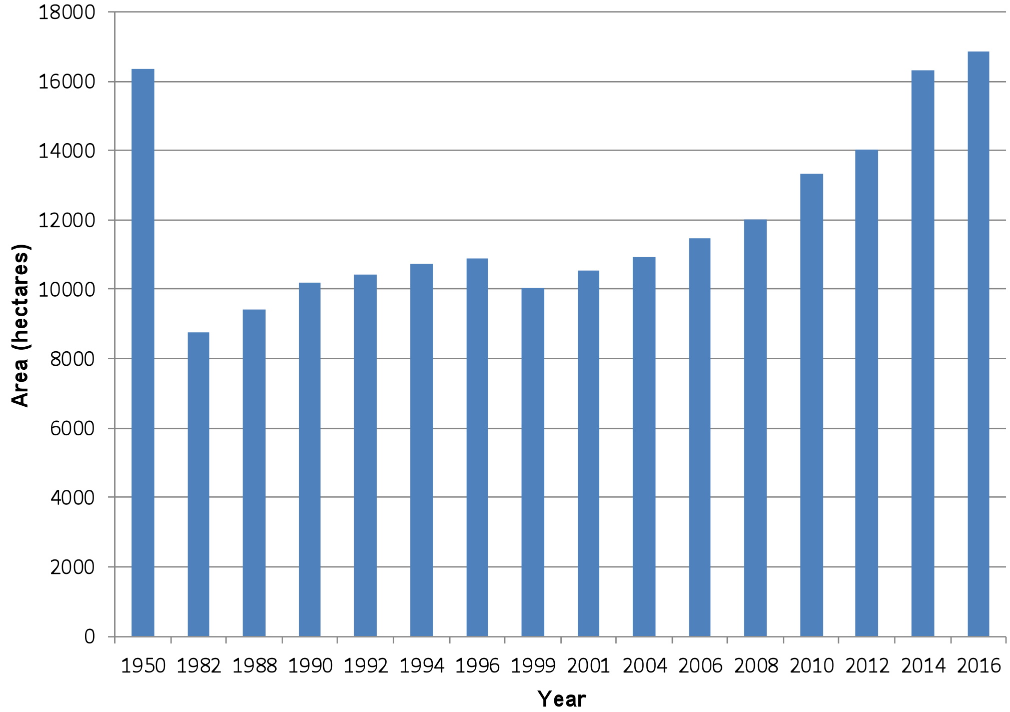

Figure 6—Seagrass coverage in Tampa Bay (data courtesy of Southwest Florida Water Management District).

The TBEP and NMC, as well as multiple agencies and communities within the region, continue to address future challenges anticipated within the Tampa Bay system. The primary concern continues to be coastal population growth and development within the region, and the additional TN loadings that the continued urbanization of the watershed might engender. In contrast, aging infrastructure issues are also presenting themselves as a challenge to the region. TBEP partners are attempting to encourage the repair or replacement of failing private sewer laterals that are recognized to be an important factor contributing to recent, unanticipated sanitary sewer overflows. The partnerships developed through the TBEP and NMC will continue to convene on a regular basis to address these recognized issues, and any potential new issues that may arise in the future. These partnerships have solidified the commitments of individual entities, encouraged additional development of potential TN load reduction projects, and are helping to secure the funding sources necessary for their potential TN load reduction projects and are helping to secure the funding sources necessary for their implementation for the collective community benefit of improving Tampa Bay water quality and its seagrass resources.

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The authors express appreciation for the considerable efforts of the TBEP, its Management and Policy Board members, the Nitrogen Management Consortium, and numerous other partners throughout the region involved in continuing efforts to create useful science-management links towards Tampa Bay's restoration. This project was partially funded through EPA Section 320 Grant Funds and local government (Hillsborough, Manatee, Pasco and Pinellas Counties; the Cities of Clearwater, St. Petersburg, and Tampa; Tampa Bay Water; and the Southwest Florida Water Management District) contributions to the TBEP's operating budget.

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A BRIEF HISTORY OF THE CHESAPEAKE BAY PROGRAM AND HOW IT'S FACILITATING THE RECOVERY OF ONE OF THE BAY'S MOST IMPORTANT HABITATS: SUBMERGED AQUATIC VEGETATION

Brooke Landry, Jennifer Keisman, Bill Dennison, Bob Orth, and Jonathon Lefcheck

Abstract—In the 1970's, a period ripe with environmentalism, U.S. Senator Charles Mathias (R-MD) called for and appropriated Congressional funding for a study to analyze the degradation of the Chesapeake Bay ecosystem. The study determined that excess nutrient pollution from the Bay's watershed was the primary culprit for the Bay's degrading water quality and loss of aquatic life, including a catastrophic loss of submerged aquatic vegetation (SAV)—one of the Bay's most important habitats. Soon thereafter, in 1983, the Chesapeake Bay Program was formed and charged with the ambitious task of restoring the iconic estuary. Fast forward 35 years and the Bay Program has evolved into one of the most successful models of Federal, State, and local partnership in the world. Through a series of landmark agreements, the Program and its partners have successfully implemented adaptive management strategies and actions, including the Chesapeake Bay Total Maximum Daily Load (TMDL), that have reduced water column nitrogen concentrations in the Bay by 23 percent and phosphorus concentrations by 8 percent, on average. Though seemingly modest, the reductions have been directly linked to a resurgence of SAV over the same time period. In 1984, results of the baywide SAV aerial survey indicated that there were < 39,000 acres of SAV remaining in the Bay's shallow waters. In 2016, 97,668 acres were mapped, exceeding the Bay Program's 2017 SAV restoration goal of 90,000 acres for the second year in a row. This achievement validates the Chesapeake Bay Program's sustained efforts to restore the Bay and shows that the 2025 SAV restoration target of 130,000 acres is within reach.

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RIDGE TO REEF INTEGRATED TERRESTRIAL AND MARINE MONITORING TO ASSESS THE IMPACT OF WATERSHED RESTORATION ON MARINE SEDIMENT DYNAMICS AND CORAL REEF SEDIMENTATION IN ST. JOHN, U.S. VIRGIN ISLANDS

Sarah Gray, Carlos Ramos-Scharrón, Julia Royster, and Lisa Vandiver

Abstract—Terrigenous sediment derived from unpaved roads is a significant stressor to coral reefs in the high-relief island of St. John, U.S. Virgin Islands. The 10.7 km^2 Coral Bay watershed was the focus of a NOAA-ARRA watershed restoration program completed in 2011, which included: sediment retention structures, road drainage improvements, and limited road paving. A 7-year terrestrial-marine monitoring program to assess the effectiveness of this restoration at multiple spatiotemporal scales measured: (a) terrestrial erosion and runoff-sediment yields; (b) time integrated (sediment traps) and high resolution (nephelometers) marine terrigenous sedimentation and turbidity at shoreline and coral reef sites; and (c) sediment "residence time" using short-lived radioisotopes (SLR) in developed/restored and minimally developed sites.

Watershed erosion, sediment yields, terrigenous sedimentation, and coral exposure to sedimentation stress were significantly greater below developed compared to minimally developed watersheds. Restoration program paving reduced road-segment-scale erosion rates to 4-29 percent of pre-paving rates, but watershed modeling showed that ~90 percent of the ~110 Mg per year reductions were due to sediment retention ponds. In the marine environment, resuspension contributed more to turbidity and deposition than shorter lived (hours) runoff plumes, and limited the ability to resolve changes post-restoration in the potential exposure of corals to sedimentation stress.

Due to resuspension, statistically significant pre- vs. post- restoration reductions in marine sedimentation were not measured. However, significant decreases in % clay and terrigenous sediment were found below the restored watersheds post restoration. These data suggest that % clay (rather than reduced total sedimentation) may be a more sensitive tracer of effective restoration, which targets sediment input from unpaved roads.

Lessons learned from the Coral Bay watershed restoration and monitoring program may serve to inform the development of effective management and monitoring strategies that may be applied to other areas with similar ephemeral hydrologic behavior. Long term (several seasons) integrated terrestrial- marine monitoring is essential to quantify the habitat impact of watershed restoration and must include regular coordination and data sharing between a multidisciplinary team of scientists, community members, and the sponsors.

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DIARY OF A PACIFIC ISLAND STREAM MONITOR

Kathryn Graziano, Anne Kitchell, Malcolm Johnson, Autumn Poisson, Max Muña, James Manglona, and Michelle West

Abstract—This talk describes the methodology, challenges, and results of multi-year stream monitoring to quantify reductions in soil loss due to extensive badland revegetation efforts in the Talakhaya watershed. The area studied encompassed over 1,000 acres of steep terrain and the only perennial streams on the southwestern side of Rota, CNMI. A two-phased stream monitoring study between 2012-2017 by the University of Guam, NOAA, and territorial agencies involved measuring flow, suspended sediment, and turbidity at multiples sites in five subwatersheds with varying degrees of vegetative cover. Researchers hypothesized that total suspended solids (TSS) and turbidity in streams would be higher in subwatersheds with bare soils than in more vegetated areas, and that sediment loads would decrease over time in replanted subwatersheds. It was hoped that linking watershed monitoring with a coastal water quality sampling program would show a direct relationship between watershed restoration and nearshore health.

Day 1: Restarting the sampling protocol after a 15-month hiatus seemed reasonable, until we discovered that the control subwatershed (barren) had been replanted. We added a new control to the study, which required the installation of pressure transducers at two new, questionably-accessible stations.

Day 30: Upon further investigation, it turns out that those anomalies in the precipitation data were caused by shotgun pellets, ants in the tipping bucket, and rain gauge abduction by aliens. On another note, Cape Air successfully delivered water quality samples to Saipan for analysis.

Day 60: Contrary to popular belief, it doesn't have to rain during the rainy season. We are getting baseflow samples at some stations (I didn't know "perennial" streams could dry up), but the sediment concentrations are highest in the forested subwatershed. That might have something to do with the Japanese diversion structure and the cows.

Day 120: Good news, we found the flow meter. Bad news, I'm not sure we have enough measurements to confidently establish stage-discharge relationships. P.S. We have no flow information for the new control subwatershed.

Day 160: Despite all the blood, sweat, and tears contributed to this effort, results are inconclusive. It's clear we need more data. Perhaps an alternative monitoring approach is warranted.

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UNDERSTANDING AND MEASURING CHANGES IN COASTAL RESILIENCE: LESSONS FROM THE DOI HURRICANE SANDY RESPONSE PROGRAM

Peter Murdoch, Richard O. Bennett, Susan M. Taylor, Kim M. Penn, and Bhaskar Subramanian

Abstract—Hurricane Sandy made landfall in the Northeastern United States on October 29, 2012, wreaking havoc on communities in 12 states and the District of Columbia. In the aftermath of that destruction, the Department of the Interior (DOI) funded 162 restoration, mitigation, and research projects to develop and implement best practices for enhancing coastal resilience of communities, ecosystems, and infrastructure to sea level rise, storm surge, and wave erosion. Since then, Federal, State, and nongovernmental (NGO) partners have been developing recommendations for a small set of core environmental and socio-economic measurements to assess project performance and overall coastal resilience at multiple temporal and spatial scales. These measurements are being assessed for their ability to identify vulnerability, detect disturbance, and track recovery. Leveraging of existing data and measurement capabilities, and nesting research watersheds and coastlines within baseline surveys of regional environmental condition, will be essential to enable cost-effective resilience management of coastal regions and help define best-resilience practices before more costly mitigation or restoration efforts are required. The conceptual model, science updates, lessons learned from the DOI Sandy program, and opportunities for collaboration in building a research and monitoring program in the northeast coastal regions and beyond will be presented.

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MAKING OUR SCIENCE ACCESSIBLE: ENGAGING STAKEHOLDERS TO PARTICIPATE IN COASTAL WETLAND RESTORATION DECISIONS USING WEB MAPPING APPLICATIONS

Justin Saarinen, Kurt Kowalski, and Blake Draper

Abstract—With multiple benefits served to aquatic ecosystems, widespread restoration of the services provided by coastal wetlands is one of the highest priorities of the congressionally supported Great Lakes Restoration Initiative (GLRI). This is a complex challenge, as some former functional Great Lakes coastal wetland areas are more conducive to restoration than others given their relative locations on the landscape, the specific services they provide and the land-use history. Furthermore, stakeholders find the data and decision tools necessary to remotely identify and evaluate those areas are disparate, while also technically inaccessible for their optimal use. Therefore, we developed a suite of web-based mapping applications designed to foster participation by regional stakeholders engaging in restoration decisions. These applications provide ready access to a spatially explicit and scalable (parcel to region) composite index model for restoration to support the identification and prioritization of potentially restorable coastal wetlands (i.e., areas that could return to coastal wetland status if hydrologically reconnected to the Great Lakes). This model was created using a geodesign framework that included expert formulation of six primary geospatial data layers (water surface/land elevation, hydric soils, flow lines, conservation and recreation lands, impervious surfaces, undeveloped lands). Users can query the dataset to summarize model results and produce outputs that support prioritization and selection of restoration sites. A geonarrative application (https://glcwra.wim.usgs.gov/) was developed to link the individual restoration assessments through a larger story and streamline access to the mapping applications. This work (1) promotes multi-scale (site to landscape) assessment of the restoration potential, function, and ecosystem services of coastal wetlands; (2) encourages regional participation in the process; and (3) leverages GLRI restoration investments.

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BENTHIC HABITAT METRICS AS INDICATORS FOR LINKING WATERSHED RESTORATION TO CORAL REEF HABITATS

Lisa Vandiver

Abstract—National Oceanic and Atmospheric Administration (NOAA)'s Coral Reef Conservation Program and NOAA's Restoration Center utilize watershed restoration as a technique to reduce the threat of land-based sources of pollution (LBSP) to benefit coral reef habitats. However, there has been little success in translating watershed restoration into a quantifiable impact to coral reef habitats. Here we propose and evaluate a simplified monitoring protocol that would use benthic habitat metrics (i.e., seagrass and macroalgal cover) as a means of quantifying the coastal habitat impact of watershed restoration in NOAA's Caribbean coral reef jurisdictions. Preliminary results suggest that monthly measurements of water clarity, turbidity, and total chlorophyll a are strongly correlated to the degree of LBSP threats. Specific habitat metrics (e.g., *Thalassia testudinum* Density, Percent macroalgal cover, Epiphyte index, and maximum depth of seagrass growth) are also strongly correlated to LBSP threats. Furthermore, these habitat metrics can be used to inform the development of initial water quality thresholds to identify nearshore water quality targets for restoration. Although this is certainly a simplified approach to evaluating a very complicated problem, it is potentially a way to develop meaningful water quality thresholds and coastal habitat restoration targets for watershed restoration.

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WATER CLARITY CRITERIA FOR SEAGRASS PROTECTION IN SARASOTA BAY, FL: AN OPTICAL MODEL AND ASSESSMENT TOOL

L.K. Dixon, Michael R. Wessel, and Emily R. Hall

Abstract—Seagrass is a key ecological indicator and a cornerstone of the Sarasota Bay Estuary Program's conservation and management plan for Sarasota Bay, FL. The amount of light reaching the seagrass is an important water quality indicator but the attenuation of photosynthetically active light through the water column (KdPAR) is difficult to accurately measure in this shallow water estuary. Accordingly, a spectrally explicit optical model was developed and parameterized as a function routinely measured water quality constituents including color, chlorophyll and turbidity and successfully calibrated and validated against known quality observed (KdPAR) data. Segment-specific seagrass depth targets ranging between 1.5 and 3.1 m were identified based on the 95th percentile of the depth distribution during a benchmark period when seagrass acreages (and water clarity) were stable. Quantile regression was used to relate the distribution of modeled KdPAR between biennial aerial seagrass mapping events to the seagrass depth distribution at the closest subsequent event and indicated that the duration of high clarity conditions over two or more successive growing seasons may be the most critical for seagrass depth changes in most segments. A water clarity reporting tool was developed to score the results of annual optical model water clarity predictions relative to benchmarks (i.e., the 20th and 40th percentiles) established for the reference period. A color coded table presented the results as "Stable", "Caution", or "Declining" (Green, Yellow and Red, respectively). Trends in annual scores, averaged over 2 or 3 years, were generally consistent with observed changes in seagrass depths and support the utility of the method. The spectrally explicit optical model allows for the reliable estimation of water clarity using routinely collected water quality data and the Water Clarity Reporting Tool provides a straightforward method of disseminating complex light attenuation processes to both managers and the public.

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SEAGRASS AMELIORATES CORAL PHYSIOLOGICAL PERFORMANCE UNDER OCEAN ACIDIFICATION (OA) CONDITIONS

Emily Hall, Cinzia Alessi, Sean Fitzpatrick, Zhazira Irgebay, and Lindsay Arick

Abstract—Coral reefs are the most biologically diverse and economically important ecosystem on the planet; however they are sensitive to impacts from human activities like ocean acidification (OA). Ocean acidification lowers the saturation state of calcium carbonate utilized by calcifying organisms, potentially leading to dissolution of skeletons and reduced ability to form new calcium carbonate structures, as well as impacting general health and physiology. Seagrass meadows, sometimes found adjacent to coral reefs in the Florida Keys, are mostly net autotrophic as a carbon sink and use the excess bicarbonate for growth. This presents the possibility of locally mediating OA effects on corals downstream of seagrass meadows. We performed a land-based study as well as an in situ study to understand if seagrass could ameliorate coral physiological performance under OA conditions. We tested the impacts of the presence of seagrass (*Halodule wrightii* and *Syringodium filiforme*) on carbonate chemistry and coral health (*Acropora cervicornis*, *Porites porites*, and *Porites astreoides*) in OA scenarios expected to occur in this century and present day conditions in land-based experimental settings as well as physiological performance of *A. cervicornis* within and outside of a natural seagrass bed. Physiological and functional responses measured include chlorophyll a, total protein, zooxanthellae counts, photosynthesis, respiration, and net calcification. Physiological responses were variable among species; however, growth and rates of photosynthesis were generally higher in the presence of seagrass. Results presented here describe the potential for seagrass to buffer against negative effects from OA.

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POLLUTANT INPUTS TO COASTAL ENVIRONMENTS AND THEIR REGULATION FROM AN ENDANGERED SPECIES ACT PERSPECTIVE

Pat Shaw-Allen

Abstract—The Endangered Species Act requires Federal agencies to consult with the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) to ensure that the activities they authorize, fund, or carry out are not likely to jeopardize the continued existence of endangered or threatened species or adversely modify or destroy their designated critical habitat. This includes implementation of the Clean Water Act by the U.S. Environmental Protection Agency (EPA). While EPA approves water quality criteria proposed by the States for use in regulating discharges, permitting authority has been delegated to most States and tribes. This presentation summarizes the EPA authorizations NMFS has consulted on and places these consultations in context of current permitted discharges to coastal waters and their constituent pollutants.

INTRODUCTION

Adequate regulatory protections are among the threat-based recovery criteria identified in the 2015 recovery plan for elkhorn and staghorn coral, listed as threatened under the Endangered Species Act (ESA). Since issuing the recovery plan, the Acropora Recovery Implementation Team has convened an Ecotoxicology Workgroup to assess the current state of knowledge on the effects of toxic chemicals on coral and to prioritize the work needed to fill gaps in current knowledge. Prioritization requires identifying those pollutants that are most likely to be discharged to coral reefs. Permitting and monitoring required under the Clean Water Act (CWA) is one source of information. The following paragraphs focus on the interface between the ESA and the CWA. After providing an overview of these acts, this text describes how and where the ESA intersects with the CWA, with particular focus on toxic pollutant discharges to waters where ESA-protected corals occur.

THE GOALS OF THE CLEAN WATER ACT AND THE ENDANGERED SPECIES ACT

The primary goal of the CWA is to restore and maintain the integrity of the Nation's waters to achieve water quality that provides for the protection and propagation of fish, shellfish, and wildlife; and provide for recreation in and on the water. To this end, the CWA requires each State, tribe, and territory to adopt water quality standards, which include limits for pollutant concentrations in water. Standards are used in regulating pollutant discharges under the National Pollutant Discharge Elimination System [NPDES, section 402], monitoring water quality [section 305(b)] identifying impaired waters, and in limiting pollutant discharges to impaired waters as Total Maximum Daily Loads [TMDLs, section 303(d)]. The discharge of dredged or fill material into waters of the United States is regulated under section 404 of the CWA. Dredged materials must be tested for pollutant load and toxicity before placement.

The goal of the ESA is to protect and recover species that are endangered or threatened to the point where protection under the ESA is no longer necessary. This requires the removal or reduction of threats to the species and the ecosystems on which they depend. To this end, the ESA prohibits "take" of ESA protected resources by any individual, organization, or agency subject to United States jurisdiction, including the EPA. The definition of "take" includes: wound, harm, or kill. Harm is further defined to include significant habitat modification or degradation that results in death or injury to ESA-listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. There are two mechanisms in the ESA where take may be exempted or authorized. Under section 10 of the ESA, take permits may be sought by a non-federal entity for take resulting incidental to, but not the purpose of, carrying out the covered activity or for directed take in those cases where interaction with a protected species is intentional (e.g., research, rescue, filming). Take resulting from actions that are authorized, funded, or undertaken by a Federal agency such as EPA may be exempted through consultation under section 7 of the ESA and is specified in the incidental take statement of the resulting biological opinion.

The ESA is implemented by the USFWS and NMFS, taken together, the Services. Generally, National Marine Fisheries Service (NMFS) is responsible for marine species and certain fish species that use both marine and freshwaters and the U.S. Fish and Wildlife Service (USFWS) is responsible

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ESA-protected terrestrial and freshwater species. Given the migratory nature of many ESA-listed marine species, all coastal waters of the United States and its territories include the range or designated critical habitat of ESA-protected species under NMFS' jurisdiction.

HOW DOES THE CLEAN WATER ACT AFFECT THREATENED AND ENDANGERED SPECIES?

It would appear that implementation of the CWA would remove or reduce threats to aquatic ESA-protected species and the ecosystems on which they depend. Removal of threats would require that water quality standards established under the CWA not result in pollutant discharges that cause adverse effects to ESA-protected species and habitats. However, while aquatic species benefit from the CWA, the objective of setting water quality standards is to protect most aquatic ecosystems under most, but not all, circumstances. This is expressed in EPA's guidance for developing recommended limits for pollutant concentrations in water (Stephen and others 1985). The guidance states:

"Because aquatic ecosystems can tolerate some stress and occasional adverse effects, protection of all species at all times and places it is not deemed necessary for the derivation of a standard ...[given adequate data]... a reasonable level of protection will probably be provided if all except a small fraction of the taxa are protected, unless a commercially or recreationally important species is very sensitive."

The EPA water quality guidelines and their application in protecting or restoring water quality cannot be assumed to result in pollutant exposures that do not cause adverse effects in threatened and endangered species. Studies comparing the sensitivity of threatened and endangered species relative to species commonly used in laboratory toxicity tests suggest multiplying EPA water quality guidelines by a generic adjustment factor of about 0.5 to obtain a limit that would protect ESA-listed species (Besser and others 2005, Dwyer and others 2005, Sappington and others 2001). However, this adjustment only addresses differences in physiological sensitivity to a toxic pollutant for bony fish. This factor may not be appropriate for corals, abalone, or cartilaginous species (i.e., smalltooth sawfish, giant manta). In addition, when assessing risk to an ESA-protected species, the vulnerability of an imperiled population of that species to the loss of an individual, or key individuals, amplifies the fundamental threat posed by a toxic pollutant.

It follows that take may occur as a result of EPA authorizing the adoption of water quality standards by States, tribes, and territories or as a result of authorizing discharges under EPA-administered NPDES permits that apply these standards. This is why, even though the CWA is intended to protect water quality, the EPA will request consultation with the Services when it authorizes actions implementing the CWA.

CONSULTATION

Under ESA section 7, if EPA determines that their action will have no effect on any potentially exposed ESA-protected species or designated critical habitat, then EPA is expected to document the rationale behind the determination(s) and is encouraged, but not required, to inform the Services of no effect determinations. If EPA determines that the action may affect, but is "not likely to adversely affect" any ESA-protected resources, EPA is required to request concurrence from the Services. If the Services agree with EPA's "not likely to adversely affect" determination(s), the Services provide EPA with a letter of concurrence. This interaction is an "informal consultation." Finally, if EPA determines its action may affect or may adversely affect ESA-listed species, or if the Services disagree with an agency's "not likely to adversely affect" determination, the agency must request formal consultation.

The goal of formal consultation is to help a Federal Agency ensure that adverse effects resulting from their proposed action is not likely to jeopardize the continued existence of endangered or threatened species or adversely modify or destroy designated critical habitat. The Services analyze the effects of anticipated take and prescribe Reasonable and Prudent Alternatives, where necessary, to avoid jeopardy or adverse modification or destruction of designated critical habitat may occur and, where appropriate, Reasonable and Prudent Measures to reduce take caused by the action. These prescriptions are mandatory if the action is to proceed in compliance with the ESA. A Biological Opinion issued on completion of formal consultation documents the analysis, the prescriptions, and an incidental take statement specifying the amount of take authorized for the action, provided the prescriptions are implemented.

Approval of Water Quality Standards Affecting Coastal Environments

The CWA requires that States and territories periodically reevaluate the water quality standards that are applied to water quality monitoring and discharge permitting. Since EPA must approve these revised standards before they can be applied, NMFS has consulted or is currently consulting on water quality standards for a variety of pollutants affecting coastal waters of Oregon, California, Florida, Puerto Rico, the Virgin Islands, North Carolina, Delaware, Washington, DC, New Jersey, Delaware, and Maine. The absence of consultations on the water quality standards for every triennial review and every coastal State and territory suggests that EPA determined those standards would have no effects on ESA-protected species and habitats. These determinations may or may not have incorporated technical assistance from NMFS, so the accuracy of these no effect determinations cannot be certain and consultation on effects to species under NMFS jurisdiction may not always occur when it is needed.

When consultation does occur, the scarcity of saltwater toxicity test data to assess pollutants in marine environments is often of concern to NMFS. Toxicity tests do not commonly expose ESA-protected species, so data from closely related surrogate species, preferably within the same family, are used to infer effects on ESA-protected species. Due to abundant data gaps, it is often necessary to use data from more taxonomically distant species. Assessing effects on protected marine mammals and sea turtles is particularly difficult since their exposures to aquatic pollutants are through the food web and suitable data for inferring effects, even from taxonomically distant species, are not available.

The ECOTOXicology knowledgebase (ECOTOX) contains the data used to derive water quality guidelines. The data in ECOTOX are predominantly for fish (46 percent) and arthropods (26 percent). Only about 75,000, or 20 percent of these studies, are saltwater exposures (table 1). As a result, species like corals and elasmobranchs (sharks, rays, and sawfish) are poorly represented in the derivation of most water quality standards. In addition, not all the data reported in these studies are for responses that are readily relatable to survival and fitness (e.g., growth, brood size, etc., table 1). There are gaps for important pollutants that are released into coastal waters (table 1). For example, there are no data for selenium among the 54 toxicity tests reporting effects on survival and fitness in ESA-listed coral families, and selenium is a pollutant discharged by the older exhaust gas scrubbers used to remove sulfur oxides from a ship's engine and boiler exhaust gases. Another consideration for evaluating water quality standards is that pollutant discharges are rarely composed of a single pollutant. They are mixtures which, taken together, may result in additive, more than additive, or less than additive effects. Among those NPDES permits with discharge monitoring limits, nearly 70 percent require monitoring of five or more constituents (chemicals) and/or characteristics (pH, toxicity, oxygen demand). It would seem that the assessment of specific discharges in specific locations is a more germane evaluation for effects on ESA-protected species and habitats, but these assessments still need to begin by considering water quality standards representing "safe levels" and the underlying data used to derive them.

Pollutant Discharge Permits Affecting Coastal Environments

Based on data from EPA's Enforcement and Compliance History Online database (ECHO), at the time of this writing there are just over 42,000 active NPDES permits for

Table 1—Number of toxicity tests within Endangered Species Act (ESA)-listed and other species groups

Species groups	Number of tests	Tests reporting survival and fitness effects	Toxicants tested for survival and fitness
ESA-listed Marine plant			
Johnson's seagrass family	66	14	6
Other seagrasses	319	65	13
ESA-listed Marine Invertebrates			
Abalone family	375	235	48
ESA-listed coral families	331	232	54
Other stony corals	112	84	12
ESA-listed Marine and Anadromous Fish exposed in salt water			
Sturgeon family	2		
Rockfish family	43	37	10
Eulachon family	7	4	2
Grouper family	80	29	14
Salmon, trout family	586	381	89
Other Sharks, rays, and sawfish (no family data)	271	35	24
Other Marine Species			
Invertebrates	44,277	32,576	1,846
Fish	16,788	11,260	1,104
Other Freshwater Exposures (excluding amphibians and reptiles)			
Plants	44,281	29,480	2,427
Invertebrates	97,762	87,005	4,201
Fish	106,566	75,642	4,674

discharging into waters of the Coastal Management Zone of the United States and coastal subbasins of Alaska. The EPA is the permitting authority for about 3 percent of these permits. The EPA uses separate databases to track an additional 6,000 discharges potentially affecting coastal waters from pesticide applications and vessel operation. These are the only NPDES discharges that are, or have been subject, to ESA consultation and any resulting prescriptions for the protection of ESA-protected species and habitat. Information about the number of active dredge and fill permits under section 404 of the CWA is not readily available. Over the past year, NMFS has addressed just over 300 dredge and fill actions.

About 90 percent of the discharges authorized by EPA are authorized under general permits for multiple dischargers having similar operations and types of discharges. EPA general permits cover stormwater discharges from municipal separate storm sewer systems, industrial sites, construction sites, residue from pesticide applications, and discharges from vessels. Municipal stormwater typically contains a mixture of metals, oil, and grease from motor vehicles, fertilizers, pesticides, sediment, and plant material from landscaping. Stormwater from industrial sites reflects the types of activities occurring at, and materials stored on, an industrial property. These range from bark and sawdust from lumber yards to heavy metals and solvents from metallurgical operations. Discharges from construction sites include sediments, flocculants used to reduce suspended sediment, fertilizer from revegetation areas, and oil, grease, and metals from construction equipment. The types of pollutants discharged under the pesticides general permit are mixtures of active pesticide ingredients and any synergists or additives used to improve pest targeting or mixture dispersal. Finally, pollutants from vessels include metals and oil and grease, trash, antifouling agents, and non-native aquatic organisms transported on hulls or discharged in ballast water.

Dischargers wishing to be covered under a general permit submit notices of intent (NOI) to discharge as a discharger's certification that they will comply with requirements under that general permit, including the requirement to comply with applicable federal laws like the ESA. NMFS consults or provides technical assistance for most of the EPA-issued municipal stormwater general permits and consults on all of EPA's other general permits. When EPA consults with NMFS on its general permits, the permits are evaluated as programs, assessing the pollutant limits and requirements within the permit along with design and implementation of the authorization and compliance process. The prescriptions resulting from these consultations typically require compliance verification, program data review, outreach, and notification of incidents affecting ESA-protected species and habitats. In addition, individual NOI submitted under general permits are subject to NMFS review if discharging to areas where ESA-listed species under NMFS' jurisdiction occur.

WHAT ABOUT DISCHARGES AUTHORIZED BY STATES, TRIBES, AND TERRITORIES?

States, tribes, and territories with permitting authority also issue individual and general permits, and their general permits typically mirror the general permits developed by EPA, including requirements to comply with the ESA. The Services sometimes provide technical assistance to the States in their standard and general permit development and provide recommendations on limiting take to help dischargers avoid liability or enforcement under the ESA. For example, the State of Florida has sought technical assistance from NMFS on its development of water quality standards for turbidity. However, not all State programs contact NMFS for technical assistance or notify NMFS when new permits or standards are under development.

HOW ARE ESA-LISTED CORALS PROTECTED UNDER THIS REGULATORY PATCHWORK?

Pollutant discharges potentially affecting ESA-listed corals are regulated by EPA, State, and territory authorities. Within the range of ESA-listed corals, Florida, the Virgin Islands, and Texas issue NPDES permits under programs they manage. While EPA periodically reviews these NPDES programs through a "Permit and Program Quality Review" procedure, these reviews focus on requirements under the CWA. EPA does not evaluate compliance with the ESA and there is no role for Services in these program reviews. NMFS does consult on the EPA-issued permits for Puerto Rico, American Samoa, Guam, Johnston Atoll, Midway Island, Northern Mariana Islands, and Wake Island.

While NMFS' prescriptions for the protection of ESA-listed corals are not applied universally, discharges authorized through State and EPA permitting are tracked in EPA's compliance and discharge monitoring databases. Current compliance information indicates that > 90 percent of discharges to waters that may affect ESA-protected corals are in compliance with their permits. Most violations are for failure to submit discharge monitoring reports. However, only 7 percent of the approximately 3,000 NPDES permits in water affecting ESA-listed coral species are required to submit discharge monitoring reports. Few violations are for exceeding permit pollutant limits. As discussed previously, the limits are based on toxicity data and water quality criteria that may result in adverse effects to ESA-listed coral, so compliance with permits does not necessarily mean that adverse effects are not occurring in this species group.

The discharge monitoring reports submitted in 2017 provide insight into authorized pollutant discharges to waters where ESA-listed corals occur. This information is useful in prioritizing the work needed to fill information gaps in our current state of knowledge on the effects of toxic chemicals on coral. These reports identify discharges of 24 effluent constituents in the Caribbean and 34 constituents discharged from permits issued in Guam, American Samoa, and the Northern Mariana Islands. The top five pollutants based on Toxic Weighted Pound Equivalents for NPDES discharges to these waters are listed in table 2. Copper occurs most frequently among the top five pollutants, followed by ammonia and zinc. The highest rates of discharges occur to the waters of Florida and Guam.

There are, of course, legacy pollutants, unmonitored non-point discharges, and illicit discharges affecting coastal waters. The CWA requires that States monitor water quality and identify impaired waters for restoration. The results of these assessments provide further insight into pollutants potentially affecting coral. Aquatic life impairments of Florida's coastal shoreline are related to organic enrichment. Organic enrichment and turbidity dominate aquatic life impairments of the coastal waters of Puerto Rico and the Virgin Islands. For American Samoa, Guam, and the Northern Mariana's, pathogens are consistently a major cause for impairment.

CONCLUSION

While EPA approves water quality criteria proposed by the States for use in regulating discharges, permitting authority has been delegated to most States and tribes. As a result, there are relatively few opportunities for NMFS to influence the actual discharges occurring in coastal waters where ESA-listed species occur through consultation. Consultation on EPA approval of State water quality standards may not always occur when it is needed. When consultation does occur, the relative scarcity of data available for developing water quality standards for marine environments is often a challenge. Another consideration for evaluating water quality standards is that pollutant discharges are rarely composed of a single pollutant. Assessment of specific discharges in specific locations is a more germane evaluation for effects on ESA-protected species and habitats. As stated previously, there are relatively few opportunities for NMFS to influence the actual discharges occurring in coastal waters where ESA-listed species occur. In addition, given the abundance of aquatic impairments related to organic enrichment and turbidity, not all aquatic pollutant sources affecting ESA-listed coral appear to be adequately regulated.

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Table 2—Top five pollutants, based on Toxic Weighted Pound Equivalents discharged to coastal waters where Endangered Species Act (ESA)-listed corals occur

Florida	Caribbean	American Samoa (4)	Guam	Northern Marianas
Chlorine/TRC Copper Hydrogen sulfide Fluoride Ammonia	Sulfide Chlorine Copper Zinc Mercury	Mercury Zinc Copper Ammonia	Dioxin Copper Fluoride Chromium Ammonia	Copper Nitrate Zinc Lead Ammonia

USING ENDANGERED SPECIES ACT CONSULTATIONS AS A TOOL TO IMPROVE WATER QUALITY AND MONITORING IN CORAL REEF ECOSYSTEMS

Lisamarie Currubba

Abstract—The NOAA Coral Reef Conservation Program has been investing in watershed restoration projects in jurisdictions with coral resources for a number of years, often in partnership with the U.S. Environmental Protection Agency (EPA). Two Atlantic/Caribbean coral species, elkhorn and staghorn, were listed as threatened under the Endangered Species Act (ESA) in 2006 and five more, lobed star, boulder star, mountainous star, pillar, and rough cactus corals were listed in 2014. Fifteen Indo-Pacific corals were also listed as threatened in 2014. Because of this, NOAA Fisheries collaborates with EPA through ESA section 7 consultations for the development of water quality standards and EPA permit requirements that are protective of corals. Here we present two examples of this collaboration through section 7 consultations, one in the U.S. Virgin Islands (USVI) and one in Puerto Rico. The USVI example demonstrates how water quality standards can be developed along with monitoring to track the effectiveness of setting numeric limits on things like turbidity and nutrients on improving coral health. The Puerto Rico example demonstrates how collaboration with EPA and permit applicants under programmatic consultations for general permits can be used to ensure stormwater management is designed in a site specific way to minimize potential impacts of land-based pollutant transport to nearshore waters during construction of projects in the coastal zone.

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SECTION 2

Managing and Characterizing Complex Aquatic Systems I

LANDSCAPE FEATURES AND PROCESSES AFFECT AQUATIC NUTRIENT DYNAMICS IN A REGIONAL-SCALE RIVER BASIN

Samson Mengistu, Heather E. Golden, Charles R. Lane, Scott G. Leibowitz, Jay R. Christensen, Jana E. Compton, Ellen D'Amico, Amy Prues, Marc H. Weber, and Ryan A. Hill

Abstract—Surface depressions on landscapes create "hotspots" for biogeochemical processing, which play a role in a watershed's surface water quality. However, despite recent expansions in the availability of high resolution spatial datasets and capabilities to analyze them, limited progress has been made in using these data to investigate the extent to which surface depressions have water quality consequences, particularly in large regional river basins. This study investigates the link between surface depressions and nitrogen and phosphorus dynamics across the 490,000 km^2 Upper Mississippi River Basin (UMRB). An initial 10-year dataset from nearly 330 Federal, State, and local gages throughout the UMRB with total nitrogen (TN) and total phosphorus (TP) records were acquired and summarized for seasonal and annual analyses. We used nationally available high resolution spatial data to delineate the UMRB sub-watersheds draining to the selected gages and build new datasets to help explain surficial hydrologic transport. We delineated the sub-watersheds using the National Hydrography Dataset (1:24K) and a 10-m digital elevation model obtained from U.S. Geological Survey's 3D elevation program. We calculated spatial predictors describing depressional areas and other landscape characteristics using a crop data layer, point-source data, and ancillary nationally available datasets. Preliminary analyses between the response variables (i.e., seasonal and annual TN and TP concentrations) and spatial predictors suggest depressional areas in the landscape have a statistically significant relationship with downstream TN and TP concentrations. However, these preliminary results also indicate that predictor-response variable relationships may be seasonal. Outcomes from this study will improve our understanding of landscape-scale controls on in-stream nutrient concentrations across the UMRB and subsequent receiving waters such as the Gulf of Mexico.

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POOLED MONITORING—A NOVEL APPROACH THAT POOLS FUNDING TO SUPPORT RESEARCH TO ANSWER KEY RESTORATION QUESTIONS VS. SITE/PROJECT SPECIFIC MONITORING IN THE CHESAPEAKE BAY

Sadie Drescher and Jana Davis

Abstract—Efforts to restore the Chesapeake Bay and its tributaries call for a significant increase in the number of watershed restoration projects intended to improve both water quality and habitat. Questions about the performance and function of some of these practices persist in the regulatory and practitioner community that prevent more rapid implementation. As a result, a new initiative called the Pooled Monitoring Program has been designed to connect key stormwater and stream restoration questions posed by the regulatory and practitioner communities with researchers in the scientific community.

Pressing questions about the practices have been articulated over the last several years with input from the regulators and practitioners. Examples include questions about cumulative impacts of restoration practices at a watershed scale, differences in efficacy of different stream restoration techniques, trade-offs among different resources impacted positively and negatively by restoration activities (e.g., trees removed during stream restoration), how and if iron flocculate is associated with stream restoration techniques and whether it is "bad," and how to predict or model structural stability of stream restoration. The Initiative articulates the "burning" restoration questions that regulators and practitioners need to make decisions. The novelty of the initiative is derived from identifying funds used for other types of monitoring that have more power in a pool.

Results of the research are communicated back to the regulators and practitioners in a way that maximizes their ability to inform work in those realms. The Pooled Monitoring Program aims to answer these questions to ultimately increase confidence in proposed restoration project outcomes, clarify the optimal site conditions in which to apply particular restoration techniques, provide information useful to regulatory agencies in project permitting, and provide information that will help guide monitoring programs. Finally, new key restoration questions are added each year ensuring that the top restoration questions continue to be answered with robust research using the Pooled Monitoring Program. For more information see our Web site at https://cbtrust.org/restoration-research/.

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DRIVERS OF ORTHOPHOSPHATE TRENDS IN TRIBUTARIES TO CHESAPEAKE BAY

Rosemary Fanelli, Joel Blomquist, and Robert Hirsch

Abstract—Orthophosphate (PO_4) is the most bioavailable form of phosphorus (P) in aqueous systems, and excess PO_4 may cause harmful algal blooms in lake and estuary ecosystems. A major restoration effort is underway for Chesapeake Bay (CB), with the goal of reducing P, nitrogen, and sediment loading from the watershed. However, spatial patterns in PO_4 fluxes and trends in those fluxes over time remain poorly understood, because most of the scientific attention has been focused on total phosphorus to date. To address this research gap, we analyzed PO_4 fluxes and trends over a 9-year period at 53 monitoring stations across the CB watershed to: (1) characterize the importance of PO_4 to TP fluxes and trends; (2) describe spatial and temporal patterns of PO_4 concentrations across seasons and stream flow; and (3) explore factors that may explain these patterns across time and space. Agricultural watersheds exported the most TP in the CB watershed, with PO_4 comprising up to 50 percent of those exports. Although PO_4 exports are declining at many sites, some agricultural regions are experiencing increasing trends at a rate sufficient to drive increases in TP. Regression modeling suggests that point source declines are likely responsible for the decreases observed in many of the watersheds, and that declining point sources may reduce concentrations at both low and high flows. Watersheds with higher enrollment in the Conservation Reserve Program had lower summer PO_4 concentrations, highlighting the potential of that practice for mitigating the effects of agriculture on PO_4 in streams. Manure inputs were a strong predictor of PO_4 concentrations at high flows, and increasing manure applications may be contributing to increasing PO_4 concentrations. Conservation tillage was also correlated with changes in PO_4 concentrations at high flow, suggesting that this practice could contribute to increasing PO_4 concentrations as well. Overall, this study highlights the success of point source reductions for reducing PO_4 exports in many CB tributaries. These results also underscore the need for phosphorus management strategies to target dissolved PO_4 and sediment-associated phosphorus in soils and biomass, particularly in regions with high manure inputs.

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EXPLORING DRIVERS OF REGIONAL WATER-QUALITY TRENDS USING DIFFERENTIAL SPATIALLY REFERENCED REGRESSION—A PILOT STUDY IN THE CHESAPEAKE BAY WATERSHED

Jeffrey Chanat and Guoxiang Yang

Abstract—An understanding of riverine water-quality dynamics in regional mixed-land-use watersheds is the foundation for advances in landscape biogeochemistry and informed land management. A "differential" implementation of a well-established statistical/process-based model is proposed to empirically relate a regional pattern of changes in constituent flux, over a multi-year period, to spatially referenced changes in explanatory variables over the same period. Interpretation is based on conceptualizing change in flow-normalized flux, traceable to a shift in the concentration-discharge relation, as a transition between "quasi-steady-state" conditions. A pilot implementation explores factors influencing changes in flow-normalized flux of total nitrogen over the period 1990-2010 at 43 sites in the non-tidal Chesapeake Bay watershed. A cross-validated 7-parameter model explains 80 percent of the transformed variability in flux changes, estimated independently using monitoring data. Combined, five time-varying sources, point, agricultural fertilizer, manure, atmospheric, and urban land, contribute between 1/4 to 1/2 of the model's explanatory power. The remainder is accounted for by localized changes in two variables governing land-to-water transport: air temperature and precipitation. Although qualified by constraints on explanatory data availability at the time of formulation, the pilot suggests limits on allowable model complexity, places practical bounds on the efficacy of management actions targeting nitrogen, and indicates that climatic variability should be taken into account when interpreting any outcome at this time scale. Overall, the study suggests that differential spatially referenced regression is a promising approach for broadening the scientific understanding of factors driving regional water-quality trends, and for supporting evidence-based land-management decisions.

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DELINEATION OF WETLAND HYDROLOGIC HOT-SPOTS USING LARGE-SCALE MODELS

Adnan Rajib, Heather Golden, Charles Lane, and Ellen D'Amico

Abstract—Wetlands are hot spots of hydrological activity in watersheds. However, most hydrological models do not produce fine-resolution spatial characterizations of watershed locations where wetlands have the greatest impact on downstream hydrology. This is particularly true for large river basins. In response to this limitation, we initiated a large-scale modeling study to enable wetland hydrological hot spot delineation across the ~0.45 million km^2 Upper Mississippi River Basin (UMRB). Using the Soil and Water Assessment Tool (SWAT), we developed a high-spatial resolution hydrologic model for UMRB with ~20,000 National Hydrography Dataset stream segments. We included a spatially explicit 100-year floodplain in SWAT, and further modified the model to incorporate floodplain hydraulic geometry and roughness parameters that vary both spatially and temporally with normal and flood conditions. The areal extent and water-storage capacity of ~0.9 million wetlands in the UMRB were determined from the National Wetland Inventory and 10-m National Elevation Dataset and incorporated into the SWAT model as Hydrologically Equivalent Wetlands (HEWs). With aggregated wetland storage-discharge functions at sub-basin level, the use of HEWs allows quantification of wetland hydrologic contributions to downstream flow over the ~0.45 million km^2 domain. A 5-year hydrologic simulation using the modified UMRB SWAT model enabled spatially explicit delineation of wetland hydrologic hotspots across the basin. The results highlight specific zones of wetland influence, identifying areas for targeted wetland management and restoration.

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THE CONSERVATION EFFECTS ASSESSMENT PROJECT (CEAP) WATERSHED ASSESSMENTS: A SYNTHESIS OF MEASURING AND UNDERSTANDING THE EFFECTS OF CONSERVATION PRACTICES WITHIN WATERSHEDS

Lisa Duriancik, Daniel Moriasi, John Sadler, Teferi Tsegaye, Jean L. Steiner, Martin A. Locke, Tim C. Strickland, and Deanna L. Osmond

Abstract—Under the Farm Bill, the USDA spends about $5 billion per year on agricultural conservation programs supporting technical and financial assistance for implementation of conservation practices (CPs) and systems on private agricultural lands. In 2003, the USDA Natural Resources Conservation Service entered into partnership with USDA Agricultural Research Service and many other partners to create the Conservation Effects Assessment Project (CEAP). The objective of CEAP is to quantify the environmental effects of CPs and develop the science base for managing the agricultural landscape for environmental quality. Over the last 15 years, research and assessment has been conducted to test the effectiveness of CPs at various spatial scales using combined monitoring and modeling approaches in a national coordinated network of small CEAP Watershed Assessment Studies. Documenting conservation effects in watersheds on water quality, availability, and soils is a substantial technical challenge, yet remains an area of significant interest to stakeholders, policymakers, agricultural land managers and agencies alike. Major findings of 15 years of work in the ARS CEAP Benchmark Watershed Assessment Studies and other CEAP watersheds is being synthesized. Findings will focus on highlighting the measured effects of conservation at different scales, with a particular interest in watershed or sub-watershed effects, but to include Edge-of-Field (EOF) effects. Where measured effects are challenging to document because of the influence of numerous complex drivers, particularly at larger scales, modeled results will also be reviewed. Application of data and findings from CEAP to inform development and delivery of USDA conservation programs and initiatives such as the National Water Quality Initiative, Mississippi River Basin Initiative, Great Lakes Restoration Initiative, Chesapeake Bay Watershed and Regional Conservation Partnership Program, will be discussed in the context of adaptive management. Lastly, potential future directions will be presented.

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STRENGTHENING RESILIENCY IN COASTAL WATERSHEDS: A WEB-BASED GIS MAP VIEWER DECISION SUPPORT SYSTEM

Anne Kuhn and Jane Copeland

Abstract—To promote and strengthen the resiliency of coastal watersheds in the face of climate change and development, ecological outcomes as well as socioeconomic issues need to be considered. An integrated assessment framework is being developed to help watershed managers, coastal communities, and other stakeholders strengthen coastal resiliency by identifying and prioritizing conservation and restoration efforts within coastal watersheds. This framework is linked to a desktop and web-based decision support system (DSS) incorporating ecological integrity principles with ecosystem services (ES). The DSS tools operate within a geospatial platform, allowing for spatially-explicit analysis of individual ecological units and their associated ESs at multiple scales, and provides web-based and mobile applications (tablets and smart phones) developed for a range of users from technical users/stakeholders to the general public. The DSS tools allow for the evaluation of both ecological integrity and ESs of key functional processes, components and elements of watershed integrity relative to the location within the watershed (e.g., headwater streams, flood plains, riparian condition, coastal wetlands). The web-based map viewer DSS enables stakeholders to integrate a watershed perspective into their decisionmaking at multiple scales. This coastal watershed resiliency DSS can be used to make decisions for: (1) prioritizing protection and restoration of upland and riparian habitat for water quality and mitigating non-point source stressors; (2) reducing flooding risks by identifying opportunities to restore flood plains and riparian zones increasing aquatic connectivity for habitat and flood resilience; (3) planning for sea level rise adaptation, marsh migration, and marsh hydrology restoration; and (4) optimizing green infrastructure to reduce nutrients and non-point source pollutants. These DSS tools are unique in that they integrate ecosystem services and ecological integrity with science-based decisionmaking, allowing managers to consider ecological outcomes as well as economic and social issues when making important decisions within their watershed.

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STRATEGIES TO ADDRESS ENDOCRINE DISRUPTION IN FISH AND WILDLIFE IN THE CHESAPEAKE BAY WATERSHED

Kelly Smalling

Abstract—U.S. Geological Survey (USGS) scientists have established a national framework to evaluate endocrine disrupting chemicals (EDCs) and their effects on fish and wildlife. The four strategic goals for EDCs outlined by the framework were to (1) identify and quantify sources, fate, transport, distribution and exposure; (2) evaluate their effects on fish and wildlife; (3) determine their mechanism(s) and thresholds for adverse effects, and (4) develop appropriate assessment tools and models to evaluate risk. The framework and strategic goals were applied directly to ongoing research in the Chesapeake Bay watershed to assess the exposure and potential effects of EDCs on fish and wildlife. The Chesapeake Bay is the largest estuary in the United States, and provides critical resources to fish, wildlife and people that use the 64,000 square mile watershed. For more than a decade, adverse effects associated with exposure to EDCs have been observed including intersex (testicular oocytes) in bass and plasma vitellogenin in male fishes (bass and sucker species). Skin lesions and mortalities of both adult and young-of-year bass have also been observed in fish from the same locations where the prevalence of intersex was high. Currently, emphasis is being placed on aquatic ecosystems with a focus on the identification of relevant EDCs, how they enter waterbodies, and how they affect aquatic organisms. Studies are investigating key pathways of EDC transport and exposure including the mechanisms and chemical thresholds associated with observed effects. Controlled laboratory and environmental field sampling approaches are being applied in tandem at six integrator sites that are dominated by agricultural land use. EDC research in the Chesapeake Bay Watershed was designed as a coordinated and collaborative effort between Federal, State and academic research partners to fill data gaps and synthesize findings. This study will provide a scientific basis for resource managers to consider strategies to reduce the occurrence of EDCs and their effects on fish and wildlife in this, and other, valuable ecosystems.

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WHERE THE MAP MEETS THE MUD: WATERSHED ASSESSMENT

Matt Royer, Kristen Kyler, Jenn Fetter, and Sarah Xenophon

Abstract—As limited resources continue to curb regional pollution reductions, a great need has emerged to prioritize project implementation across watershed regions. To overcome this challenge, Penn State's Agriculture and Environment Center has developed a comprehensive watershed assessment method supporting municipalities, landowners, and scientists in prioritizing implementation of best management practices. This assessment can be replicated in a variety of regions at varying scales and for a broad range of uses. Additionally, it requires minimal training and low capital investment, making this strategic method widely accessible and cost effective. By integrating commonly available tools and models, while approaching assessment with scientific accuracy and practical application, the Center has created a process to prioritize projects for long-term planning, implementation, and monitoring. This presentation outlines the methods and explores the detailed steps of our watershed assessment process, while providing the audience with the tools to apply this systematic approach to their own regions. We will also discuss our "lessons learned" from method development and how completed assessments are currently being used to support implementation. The tools that are presented in our discussion can be adapted, mastered, and replicated by a wide range of audience members, not only for use in this assessment method, but also for use in additional professional capacities.

Our discussion begins with the methods of our assessment process, prefaced by setting goals and objectives while facilitating local partnerships. The process transitions into an innovative watershed assessment using aerial imagery, followed by windshield surveys conducted to confirm current conditions. Once projects are confirmed, a quantitative analysis takes place after which, projects are run through commonly available watershed models. Throughout our presentation, we will also demonstrate how our staff completed each step and what resources were required for successful assessments.

This cost-effective, yet thorough assessment method ultimately aids land managers, large or small, in reducing non-point source pollution in the pursuit of clean water and effective watershed management. By streamlining the decision-making process for community leaders, we can effectively prioritize the use of limited resources and produce the most pollution reduction for the least cost during implementation.

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ASSESSING THE IMPACT OF WILDLAND FIRE ON RUNOFF AND EROSION USING THE AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT TOOL

D. Phillip Guertin, David C. Goodrich, I. Shea Burns, B. Scott Sheppard, Jane Barlow Patel, T.J. Clifford, Carl Unkrich, William G. Kepner, and Lainie Levick

Abstract—Functionality has been incorporated into the Automated Geospatial Watershed Assessment Tool (AGWA) to assess the impacts of wildland fire on runoff and erosion. AGWA (https://www.epa.gov/water-research/automated-geospatial-watershed-assessment-agwa-tool-hydrologic-modeling-and-watershed or www.tucson.ars.ag.gov/agwa) is a GIS interface jointly developed by the USDA-Agricultural Research Service, the U.S. Environmental Protection Agency, the University of Arizona, and the University of Wyoming to automate the parameterization and execution of the hydrologic and erosion models RHEM, KINEROS2, and SWAT. Through an intuitive interface, the user selects an outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM). The watershed model elements are then intersected with terrain, soils, and land cover data layers to derive the model input parameters. Based on a small sample of pre- and post-fire rainfall-runoff data, a method was developed to adjust model parameters for vegetation cover and burn severity maps. AGWA was used on over 50 wildland fires by the U.S. DOI Interagency Burned Area Emergency Response teams to assess fire impacts on runoff and erosion and support development of Burned Area Assessment Reports, and to assess runoff and erosion impacts of wildland fire before and after forest health treatments.

INTRODUCTION

Wildland fires in the western U.S. are increasing in frequency and size (Westerling and others 2006). From a watershed perspective this increase in fire activity results in more watershed area being disturbed by fire over time, which will cause increases in water yield, peak flows, hillslope erosion, sediment yield, and mass soil movement (Ice and others 2004, Shakesby and Doerr 2006). The potential impacts are regulated by the degree of disturbance within the watershed, which is a factor of the severity of the fire and its effects on vegetation and soils (Moody and others 2008). Assessing the potential onsite and downstream risks resulting from a wildland fire is an important component in the post-fire planning and mitigation process. This paper will review the design and development of the Post-Fire Assessment Toolkit (PFA) for the Automated Geospatial Watershed Assessment Tool (AGWA) (Goodrich and others 2012, Miller and others 2007). The PFA was designed to predict fire impacts on downstream flooding and hillslope erosion which are used to identify locations at risk.

METHODS

AGWA Overview

AGWA (Goodrich and others 2012, Miller and others 2007) is a Geographic Information System (GIS) based watershed modeling tool. The guiding principles for the development of AGWA were that it: (1) provides simple, direct, transparent, and repeatable parameterization routines through an automated, intuitive interface; (2) is applicable to ungauged watersheds at multiple scales; (3) evaluates the impacts of management and is useful for scenario development; and (4) uses free and commonly available GIS data layers.

The models currently incorporated in AGWA are KINEROS2 (K2 – KINematic runoff and EROsion model) (Goodrich and others 2012, Smith and others 1995) Rangeland Hydrology and Erosion Model (RHEM) (Hernandez and others 2017) and Soil and Water Assessment Tool version 2000 and version 2005 (SWAT) (Arnold and Fohrer 2005). AGWA supports modeling along a continuum of spatial and temporal scales, ranging from hillslopes (~hectares) to large watersheds

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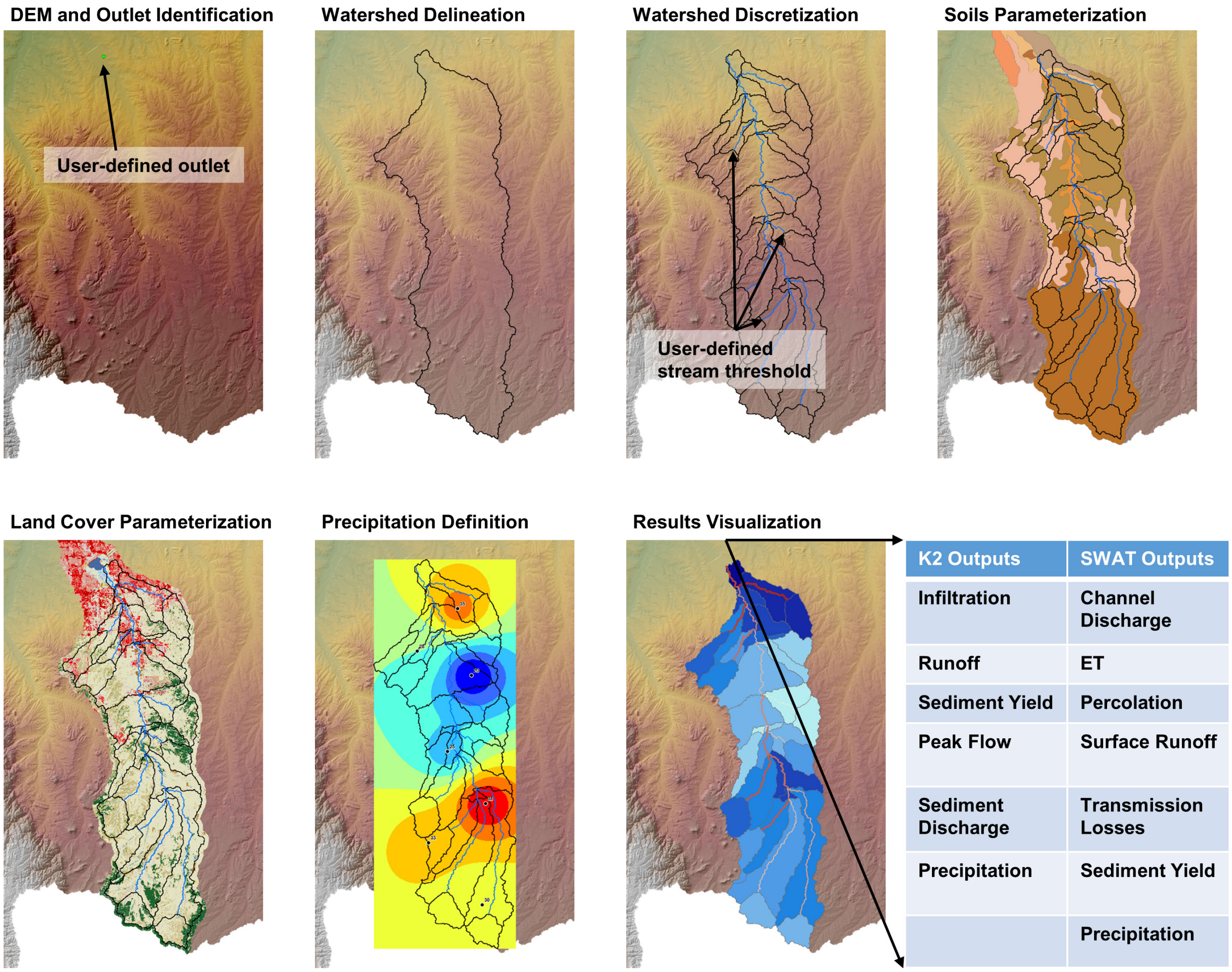
(>1000 km^2) and from individual storm events (minute time steps) to continuous simulation (daily time steps over multiple years). AGWA supports the parameterization and execution of hydrologic models for watershed modeling efforts by performing the following tasks: watershed delineation; watershed discretization into discrete model elements; watershed parameterization; precipitation definition; simulation creation; simulation execution; and simulation results visualization (fig. 1). Various data are required to support this functionality, including: a raster-based DEM (digital elevation model); a polygon soil map (NRCS SSURGO, NRCS STATSGO, or FAO soil maps); and a classified, raster-based land cover (NLCD, NALC, and GAP/LANDFIRE datasets are supported via provided look-up tables; however, other datasets may also be used if accompanied with a related look-up table). AGWA does not require observed precipitation or runoff to drive the models when used for relative assessment/differencing between scenarios. For precipitation input, AGWA can use user-defined depths and durations, user-defined hyetographs, or design storms to drive K2, and included weather station-based generated, daily precipitation (U.S. only) to drive SWAT. However, high-quality rainfall-runoff observations are required for calibration and confidence in quantitative model predictions (Goodrich and others 2012).

K2 is the primary model used for post-fire assessments. K2 predicts the runoff volume, peak flow, and sediment yield from individual hillslope elements to medium size watersheds. K2 is an event-oriented, physically-based model describing the processes of interception, infiltration, surface runoff, and erosion. In this model, watersheds are represented by subdividing contributing areas into a cascade of one-dimensional overland flow and channel elements using topography. Infiltration-excess overland flow processes are used to compute excess rainfall for surface runoff. A watershed is represented as a series of overland flow model elements (curvilinear or planar) and channels in a cascade,



K2 Outputs	SWAT Outputs
Infiltration	Channel Discharge
Runoff	ET
Sediment Yield	Percolation
Peak Flow	Surface Runoff
Sediment Discharge	Transmission Losses
Precipitation	Sediment Yield
	Precipitation

Figure 1—The required steps in AGWA to perform a watershed assessment. A DEM is used to delineate the watershed and subdivide it into model elements (i.e. hillslopes and channels for K2 and subwatersheds and channels for SWAT). The model elements are parameterized based on the DEM, soils, and land cover layers. The precipitation input is then selected from various sources. After the model is executed, the results are imported and visualized in the GIS.

on which the processes of infiltration, interception, retention, erosion, sediment detachment, transport and deposition are all explicitly treated. Partial differential equations are used to describe these processes and are solved by finite difference techniques. Runoff is routed using the kinematic wave equations for overland and channel flow. These equations, and those for erosion and sediment transport, are solved using a four-point implicit finite difference method (Smith and others 1995). Two important model parameters related to representing the impact of wildland fire are the soil saturated hydraulic conductivity (Ks) used in the Smith-Parlange infiltration equation and the Manning's n roughness factor (n) for overland flow (Semmens and others 2008).

Post-Fire Assessment Tool

Wildland fire can affect both the volume and peak flow of runoff resulting from a rain event. Studies have found that the impact on runoff volumes is much less than the impact on peak flows (Campbell and others 1977, Canfield and others 2005, Ice and others 2004, Moody and Martin 2001, Neary and others 2003, Shakesby and Doerr 2006, Springer and Hawkins 2005). Figure 2 shows the pre- and post-fire streamflow response for a small watershed in the Santa Catalina Mountains in southeastern Arizona, USA (Canfield and others 2005). Although the post-fire (right) rainfall event was smaller (44 mm vs. 54 mm, but similar pattern) and had a small runoff volume (4.6 mm vs. 10 mm) it had significantly higher peak runoff (4.32 mm/hr vs. 0.16 mm/hr). Note that the post-fire event had duration in minutes (~ 4 hours) compared to the pre-fire event where the duration is in days (~ 11 days). The research results clearly indicate that the biggest impact of fire is on the rate of flow, not the volume of flow.

Parameterization

Parameterization procedures were developed to capture the effects of wildland fire on two important hydrologic parameters: Soil Saturated Hydraulic Conductivity (Ks) and the Overland Flow Manning's n roughness value (n), where Ks primarily influences the volume of flow and n primarily influences the rate of flow. The procedures for post-fire Ks adjustments are relatively conservative compared to the post-fire adjustments of Manning's n.

The soils database provides a texture-based estimate (Rawls and others 1982) of saturated hydraulic conductivity (Ks), and the land cover layer provides information associated with land cover types, such as percent cover, interception, and hydraulic roughness (Manning's n). Ks is then adjusted for percent cover using equation 1 developed by Stone and others (1992):

$$Ks = Ks_{Soil} * e^{0.0105*CC} \quad (1)$$

where

Ks = the saturated hydraulic conductivity (mm/hr)

Ks_{Soil} = the saturated hydraulic conductivity obtained from soil texture (mm/hr)

CC= the canopy cover in percent.

Pre-fire CC values are set to nominal conditions for the NLCD cover class based on NLCD descriptions and CC values for the general classes found in the literature.

Using a Burn Area Reflectance Classification (BARC) that preferably has been field-verified to reflect the soil burn severity, the pre-fire land cover layer is reclassified to reflect the effect of burn severity. Based on the burn severity (High, Moderate, and Low), the percent canopy cover and Manning's n values are changed (see table 1; Canfield and others 2005). The reduction in canopy cover for NLCD classes, as a function of burn severity, was obtained via personal communication. (Personal communication. 2004. P. Robichaud U.S. Forest Service, Rocky Mountain Research Station, 1221 South Main Street, Moscow, ID 83843). Percent canopy cover is not part of the NLCD national data layers that are updated roughly every 5 years. The LANDFIRE program, initiated in 2009 by the U.S. Department of the Interior and

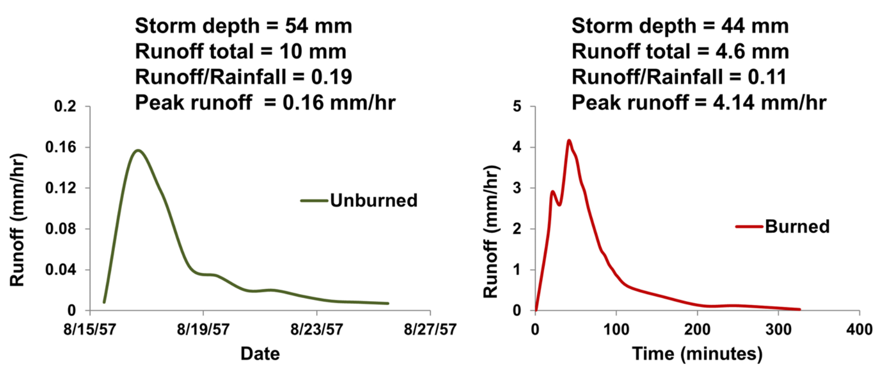


Figure 2—Pre-fire and Post-fire hydrographs recorded at Marshall Gulch, AZ. This figure illustrates the difference in storm response for unburned and burned conditions (from Canfield and others 2005, Sheppard 2016).

Table 1—Canopy cover and Manning's n for unburned and low, moderate, and high severity burns as assigned by AGWA

Change from Unburned Condition				
Percent Cover				
NLCD Land Cover Class	Unburned	Low Severity	Moderate Severity	High Severity
Deciduous Forest	50	43	34	25
Evergreen Forest	50	43	34	25
Mixed Forest	50	43	34	25
Scrub	25	21	17	12
Grasslands/Herbaceous	25	21	17	12
Manning's n				
	Unburned	Low Severity	Moderate Severity	High Severity
Deciduous Forest	0.4	0.199	0.06	0.017
Evergreen Forest	0.8	0.199	0.058	0.017
Mixed Forest	0.6	0.199	0.058	0.017
Scrub	0.055	0.01	0.005	0.003
Grasslands/Herbaceous	0.13	0.024	0.012	0.007

Sources: Burns and others (2013), Canfield and others (2005).

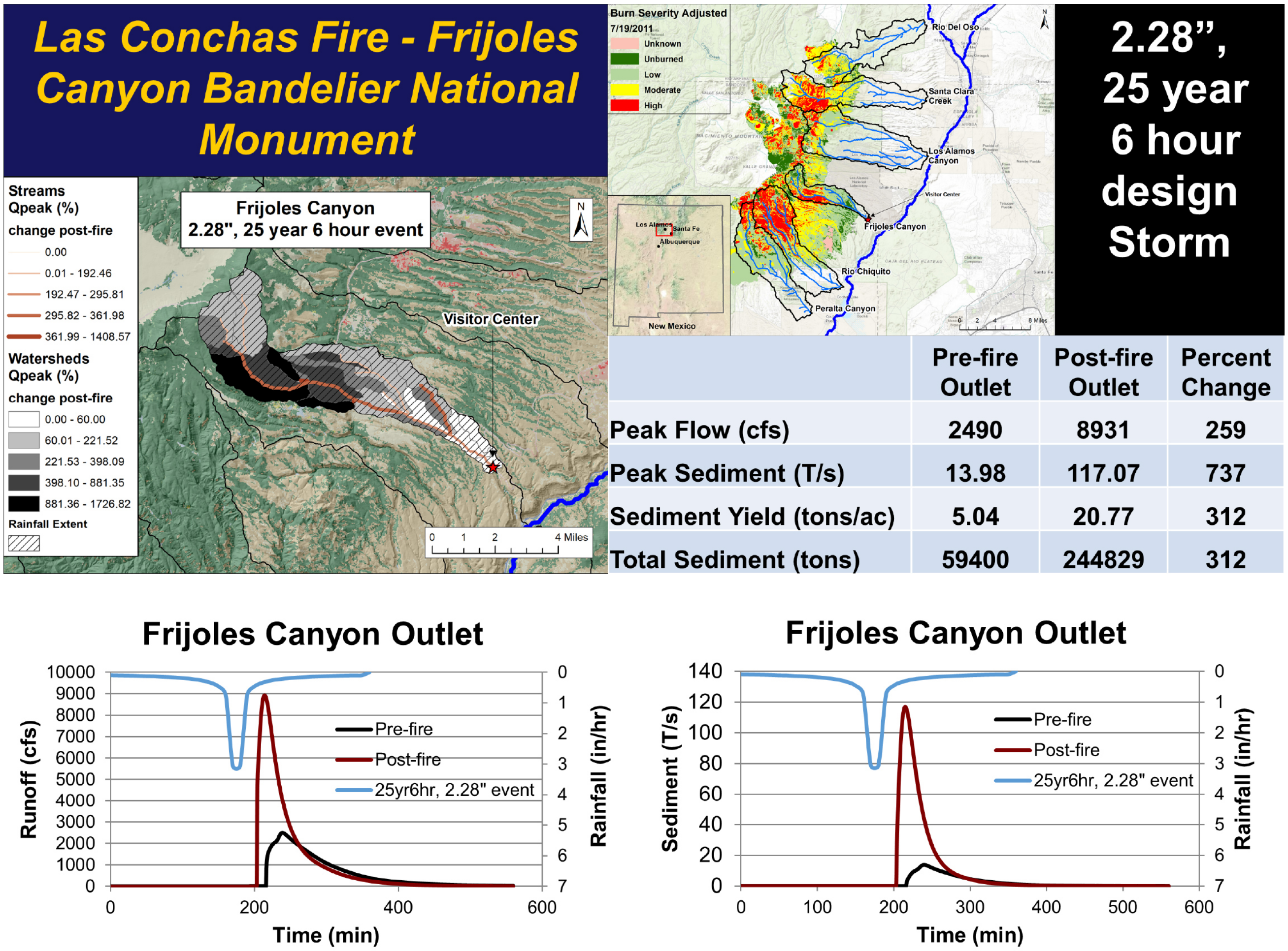
U.S. Forest Service (https://www.landfire.gov/) is providing a variety of land cover, land use, and change-over-time geospatial products nationally. LANDFIRE products include a larger number of land classes than NLCD, include canopy cover for those classes, and are updated on a 2-year basis. The AGWA team is in the process of updating AGWA tools to utilize LANDFIRE geospatial products. This will provide better pre-fire vegetation and canopy cover conditions. Ks is recomputed using the new land cover value for the burnt area. The final result will be a mosaic of unburned areas and areas with different burn severity which are used to assign the parameters for each modeling element based on an area-weighted average.

Conceptually, K2 represents a watershed as a series of hillslope elements and channel reaches. Each hillslope element has its own set of parameters. Runoff and erosion are simulated for each hillslope element and routed to the channel reach. The channel reaches are linked together and route the runoff and sediment to the watershed outlet. This distributed structure allows the modeling results to be mapped so areas at risk can be assessed (see fig. 3).

Validation

Chen and others (2013) evaluated the Rule of Thumb method, Modified Rational Method (MODRAT), HEC-HMS Curve Number model, and KINEROS2 model for assessing the impacts of wildland fires. In their investigation, all models were applied to paired burned and unburned watersheds, as well as unburned and burned conditions in a watershed that had both pre-fire and post-fire observed rainfall and runoff events. These watersheds were located in the San Dimas National Forest in southern California. The unburned watershed was 5.54 km^2 and the burned watershed was 6.16 km^2. The burned watershed was 31.6 percent burned in the 1953 Barrett fire, including 18.2 percent severely burned and 13.4 percent partially burned areas. The burn occurred in the upper portion of the watershed. The vegetation in these watersheds was composed of chaparral, semi-barren areas, and woodland consisting of oak, maple, and big cone Douglas fir. Data was recorded at several rain gages within the watersheds, including intensity recording gages. Stream flow measurements were taken at the outlet of each watershed. The HEC-HMS CN approach and the KINEROS2 model both create complete hydrographs and were investigated more thoroughly by the authors. It was found that the pre-fire storms were better simulated by the HEC-HMS model and that the post-fire storms were better predicted by the KINEROS2 model. Chen and others (2013) postulate that this had to do with how surface runoff is generated in each model. KINEROS2 treats surface runoff generation as infiltration excess whereas the Curve Number method employed in HEC-HMS is more consistent with saturation excess runoff generation.

Sheppard (2016) also found that the current parameterization scheme in AGWA provides reasonable post-fire estimates for relative change risk assessments. Sheppard (2016) calibrated K2/AGWA for five small burnt watersheds in Arizona, Colorado, and New Mexico. Sheppard (2016) found a high degree of variability in the calibration results for Ks and Manning's n across watersheds and determined that the AGWA parameterization process provided results that fit within the range of calibrated values. Sheppard (2016) found that adjusting Ks based on rainfall intensity significantly improved the modeling results and suggested that adding this adjustment procedure would improve the K2/AGWA results more than modifying the current parametrization procedures.



	Pre-fire Outlet	Post-fire Outlet	Percent Change
Peak Flow (cfs)	2490	8931	259
Peak Sediment (T/s)	13.98	117.07	737
Sediment Yield (tons/ac)	5.04	20.77	312
Total Sediment (tons)	59400	244829	312

Figure 3—Typical post-fire assessment results produced by AGWA. For this example, the Value-At-Risk (VAR) was the Bandelier National Monument Visitor Center.

The Natural Resources Conservation Service (2016) evaluated AGWA for predicting bulking and peak discharge on the Dump Fire in Saratoga Springs, UT and found it worked reasonably well although it tended to underestimate sediment yield. Herbst and others (2013) evaluated AGWA's ability to estimate sediment loads (megagrams per year) for the Sierra Nevada and Central Coast regions in California. With no calibration AGWA overestimated sediment load by 72 percent in the Sierra Nevada region and by 77 percent in the Central Coast region. The authors noted that with local adjustments the AGWA sediment predictions were improved.

Sidman and others (2016a) examined how rainfall representation, the most sensitive input parameters in hydrologic modeling, affected the estimates of peak flow and the identification of at-risk locations within a watershed. The study used K2/AGWA to compare several spatial and temporal rainfall representations. The representations include: (1) Constant intensity applied in a spatially uniform patterns over the entire watershed; (2) Soil Conservation Service Type II hyetographs with rain applied uniformly over the entire watershed; (3) SCS-Type II hyetographs uniformly applied over only the burned area; and (4) space-time variable National Weather Service DHR radar data. The total rainfall depth for representations 1-3 was the watershed average rainfall depth based on the DHR radar data. In this analysis, K2 was parameterized using AGWA procedures without calibration.

Two large return period events were modeled by Sidman and others (2016a): North Creek at Zion National Park, Utah on August 21, 2007 after the Kolob Fire, and Frijoles Canyon at Bandelier National Monument, New Mexico on August 21, 2011 after the Las Conchas Fire. Figure 4 illustrates the effect of precipitation representation on estimating peak flow. In both cases the DHR radar observations, the best representation of rainfall temporal and spatial distribution available, provided the best results. It is worth noting that K2 with AGWA default parameters also estimated the peak flow well in both cases. In North Creek, DHR radar-rainfall inputs under-predicted peak flow by 18 percent and at Frijoles Canyon it over-predicted peak flow by 17 percent. This reinforces the importance of rainfall representation in model performance. K2/AGWA was not calibrated for either watershed and still showed peak flows within 20 percent of the U.S. Geological Survey peak flow estimates.

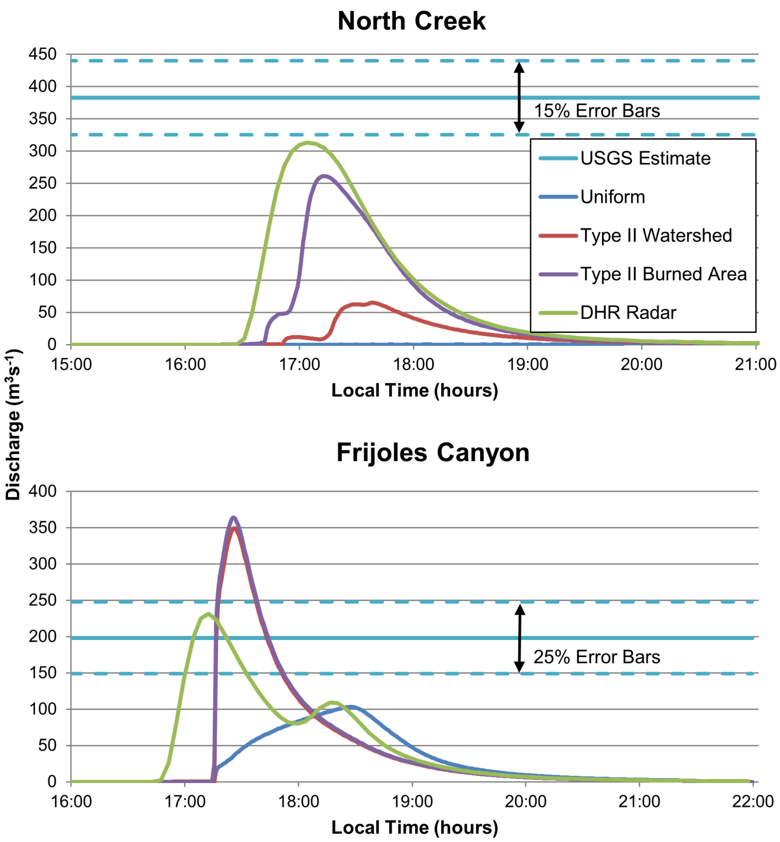


Figure 4—Hydrographs for modelled storms for North Creek, Zion National Park, and Frijoles Canyon, Bandelier National Monument. "Uniform" represents uniform rainfall intensity over the entire watershed, "Type II Watershed" is a Soil Conservation Service (SCS 1972) Type II distribution over the entire watershed, "Type II Burned Area" is a SCS Type II distribution over just the burned area, "DHR" is Digital Hybrid Reflectivity radar data from the National Weather Service for the actual storm event (August 1, 2007 at Zion and August 21, 2011 at Bandelier). The U.S. Geological Survey (USGS) peak flow and uncertainty estimates are based on post-flood indirect measurements and analysis (Sidman and others 2016a).

In post-fire assessments, when a rainfall-runoff event has not yet occurred, an assumed rainfall distribution must be used for modeling, leading to the question of how rainfall representation affects the identification of at-risk locations within a watershed. The relative impact of the fire on peak flow for individual stream reaches and sediment yield from hillslope elements was evaluated using rainfall representations 1-3 noted previously, plus the 2-year, 30-minute design storm for southern Utah. Within the burned area, the stream reaches and hillslope model elements were sorted from high to low, with the largest value (i.e., peak flow or sediment yield) given the rank of 1, the second largest given the rank of 2, and so on. The ranks for the different rainfall representations were then compared using the Spearman's rank correlation coefficient (McBean and Rovers 1998). In general, the Spearman's correlation coefficients were high, pointing to agreement in rankings across the different representations. At North Creek, the average coefficient for stream reaches was 0.72, and the average for hillslopes was 0.94. At Frijoles Canyon, the average coefficient for stream reaches was 0.82, and the average for hillslopes was 0.78. These high correlation coefficients suggest that K2/AGWA is not sensitive to changes in rainfall representation when predicting areas with high relative change pre- and post-fire. The fact that rainfall representation does not greatly affect prediction of high-risk areas is important during a rapid post-fire assessment when future storm characteristics are not known.

RESULTS

Application

AGWA has been adopted by the U.S. Department of the Interior National Burned Area Emergency Response (BAER) teams for rapid post-fire watershed assessments. AGWA has been used on over 50 fires since 2011. Figure 3 illustrates the typical products (including the use of English units) created by AGWA for BAER teams for their assessment report. AGWA uses a burn severity map to modify land cover conditions to represent post-fire conditions. The BAER team, in cooperation with local land managers and emergency officials, also creates a list of locations associated with Values-At-Risk (VAR) that includes life and property, natural resources, archeology sites, etc. that managers are interested in protecting or restoring. AGWA is used to model post-fire watershed response to these specific point locations providing the information presented in figure 3. In figure 3, the Bandelier National Monument Visitor Center is a VAR from the Las Conchas Fire, which started in June 2011 and burned more than 60,000 hectares. Typically, a 10 or 25-year return period rainfall event (NOAA Atlas 14, http://www.nws.noaa.gov/oh/hdsc/) is used to assess risk. The simulations are for a 25 year, 6 hour return period rainfall event. A Soil Conservation Service Type II hyetograph was used for the rainfall representation. For this watershed, the high burn severity areas were in the southwest portion of the watershed where the change in peak flows from the hillslope elements were > 1,700 percent, resulting in a 259 percent increase in peak flow at the visitor center. Given that high-quality rainfall-runoff data were not available for model calibration, a design storm was used to drive the simulations. The content of figure 3 is typical for reports generated for BAER assessments, and is supported by Sidman and others (2016a), noted above, who found that greater attention is given to the percent changes in peak runoff rate and erosion/sediment related predictions by the BAER teams in prioritizing treatment and mitigation measures.

BAER teams use initial AGWA results derived from the preliminary BARC map to locate and prioritize areas to validate their development of the final soil burn severity map. The final AGWA simulations using the field validated soil burn severity map are used to determine risk to life and property, assess potential risk of structural failure (e.g. culverts, bridges, and dams), and identify areas with high erosion that could be evaluated for hillslope treatments such as mulch and reseeding treatments that mitigate downstream impacts. For example, AGWA was used on the Elk Wildfire Complex that burned over 52,000 hectares east of Boise, ID in August of 2013. Initially, the U.S. DOI BAER team identified about 6,475 treatable hectares within the burned watersheds that consisted of high burn severity and steep slopes. AGWA was used to simulate the watershed response for pre-fire and post-fire conditions to identify areas of high-risk for runoff and erosion. The interdisciplinary BAER team used spatially explicit AGWA results in an interactive process to locate polygons across the burned area that posed the greatest threat to downstream Values-at-Risk. The group combined the treatable area, field observations, professional judgment, and AGWA output to target seed and mulch treatments that most effectively reduced the threat. Using this process, the BAER team reduced the treatable hectares from the original 6,475 hectares to between 800 and 1,600 hectares depending on the selected alternative. The final awarded contract for post-fire mulch treatments cost roughly $1,500/ha; therefore, BAER/AGWA targeted treatment applications resulted in a total savings of ~$7.2 to $8.4 million by only treating the areas most effective in reducing the threat to downstream values (reduced acreage).

Barlow (2017) recently developed a tool for AGWA to quickly map inundated areas adjacent to stream channels with relatively simple geometry and downstream conditions (without major constriction and backwater). The tool uses algorithms from the U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-2 model (CEIWR-HEC 1990). The tool will allow resource managers to quickly determine if a VAR is at risk for flooding after a fire. AGWA also has the ability to assess common post-fire treatments, such as the application of straw mulch.

DISCUSSION

The AGWA tool with the K2 model has proven to be a valuable tool for performing post-fire assessments and has been formally adopted by the U.S. DOI National BAER teams for initial determination of risk to downstream values. Testing has shown that K2 captures post-fire peak floods well using the parameterization procedures in AGWA if rainfall data are available to represent the temporal and spatial pattern of rainfall. The relative change results can also be used to identify areas at risk. AGWA has also been used to assess the hydrologic and erosion impacts of fire prevention treatments (Sidman and others 2016b). Research is needed to improve the ability of K2 to model pre-fire conditions in some vegetation types, especially forests with heavy duff layers and limited occurrences of infiltration excess runoff.

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QUANTIFYING THE BENEFITS OF LAND CONSERVATION ON WATER SUPPLY IN THE CATAWBA-WATEREE WATERSHED

Michele Eddy, Katie van Werkhoven, Ben Lord, Jake Serago, and Samuel Kovach

Abstract—The Catawba-Wateree watershed in North Carolina and South Carolina is faced with a number of pressing water resource management challenges. Key among these challenges are the needs of 18 drinking water utilities to (1) meet long-term and often competing water demands from a growing population, and (2) protect water quality in their rivers, streams, and reservoirs from the effects of continuing growth and development. Changes in land use and land cover that will accompany population growth could impact water availability within the watershed in multiple ways, including reduced reliability of baseflow, increased sediment load, and changes in evapotranspiration. The impacts of land use change may be exacerbated by increased water withdrawals and a warming climate. In combination, these changes could generate a situation in which there is a steadily growing imbalance between water demand and available water supply within the watershed. This study aimed to determine if deterioration in water availability and water quality due to land use change can be cost-effectively mitigated by focusing conservation efforts on identified geographic "hot spots" within a watershed. A spatially explicit hydrologic model was used to simulate streamflow under current and likely future land use, climate, and water use conditions for NHDPlus catchments across the watershed. Changes in flow characteristics and sediment load were compared to baseline/current conditions for each catchment under each future scenario. Catchments (or groups of hydrologically connected catchments) were ranked by the magnitude of the predicted changes in these variables in each scenario to reveal defined geographic areas (i.e., hot spots) that contribute disproportionately to the deterioration of water availability and quality within the watershed under the assessed conditions. The identified hot spots are locations where concentrated management options, such as land conservation, could be instituted to prevent losses to drinking water utilities in terms of availability and quality of supplies. In combination with an economic cost-benefit analysis, the study results offer guidance for the set-up of a "water fund" for the watershed, which could be used to pay for economically beneficial upstream land conservation activities.

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SECTION 3

Monitoring Aquatic Systems

SEASONAL DISCONNECT BETWEEN HYDROLOGY AND RETENTION DRIVES RIVERINE N EXPORT IN WESTERN OREGON

Jana E. Compton, Kara E. Goodwin, Daniel J. Sobota, and Jiajia Lin

Abstract—Watershed nutrient balance studies traditionally focus on annual timescales to examine factors controlling landscape level nutrient inputs, processing, and export. In areas with strongly seasonal precipitation, leaching losses may be greater during wet seasons when hydrologic forcing overwhelms retention and removal mechanisms. Information describing seasonal nitrogen (N) fluxes can provide insights on how N supply, landscape retention mechanisms, and hydrologic processes interact to shape the amount and timing of riverine N export, and can provide guidance for nutrient management. In Oregon's Willamette River Basin (WRB), a large watershed with pronounced dry summers and wet winters, we examined how the spatial distribution of farmland, cities, and forests influence N inputs and interact with hydrology to affect riverine N export. Nitrogen loads affect surface water functions and also groundwater quality in this area. Locally-derived data on N inputs coupled with streamflow and chemistry were compiled to calculate N balances for 25 WRB sub-watersheds for the mid-2000s. For the entire WRB, 80 percent of the nitrogen inputs came from agricultural activities, largely from synthetic N fertilizer (71 percent). The second largest input to the WRB was atmospheric N deposition (10 percent). Fractional riverine N export (annual riverine N export/annual watershed N input) averaged 20 percent of total N inputs; but ranged widely from 8 to 66 percent across the watersheds. Watersheds with the highest fractional export had very high rates of N input, or contained large proportions of urban land. Fall and winter seasons together accounted for 60-90 percent of the riverine N export across all watersheds. Summer export was generally quite low, but was highest in the watersheds that receive summer snowmelt. Fractional N export in the WRB watersheds is relatively high relative to other areas of the United States. The fate of N, whether it is retained in the soils and groundwater or exported downstream or to the coast, is important for considering the net effects of N. Our analysis indicates that the wet winter season drives the high proportion of N inputs exported to rivers during winter in this strong seasonal climate.

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USING NITROGEN ISOTOPES OF CHIRONOMIDAE AS AN INDEX OF NITROGEN SOURCES AND PROCESSING WITHIN WATERSHEDS AS PART OF EPA'S NATIONAL AQUATIC RESOURCE SURVEYS

J. Renée Brooks, Jana Compton, Alan Herlihy, Dan Sobota, Amanda Nahlik, and Marc Weber

Abstract—Nitrogen (N) removal in watersheds is an important regulating ecosystem service that can help reduce N pollution in the nation's waterways. However, processes that remove N such as denitrification occur at defined points in space and time. Measures that integrate N processing within watersheds over time would be particularly useful for assessing the degree of this vital service. Because most N removal processes isotopically enrich the remaining N, $\delta^{15}N$ from basal food-chain organisms in aquatic ecosystems can provide information on watershed N processing. As part of EPA's National Aquatic Resource Surveys (NARS), we measured $\delta^{15}N$ of Chironomidae collected from thousands of lotic and lentic ecosystems across the continental United States; these larval aquatic insects were found in abundance in almost every lake, river, and stream surveyed. Using information on N loading to the watershed and summer total N concentrations in the water column, we assessed where elevated chironomid $\delta^{15}N$ would indicate N removal rather than possible enriched sources of N. Chironomid $\delta^{15}N$ values ranged from -4 to +20 ‰, and were higher in rivers and streams than in lakes (median = 7.6 ‰ vs. 4.8 ‰, respectively), indicating that lotic chironomids acquired N that was processed to a greater degree than lentic chironomids. For both lotic and lentic chironomids, $\delta^{15}N$ increased with watershed-level agricultural land cover and N loading, and decreased as precipitation increased. In rivers and streams with high synthetic fertilizer N loading, we found lower N concentrations in streams with higher chironomid $\delta^{15}N$ values, suggesting high rates of N removal. At low levels of synthetic fertilizer N loading, the pattern reversed; streams with enriched chironomid $\delta^{15}N$ had higher N concentrations, suggesting enriched sources such as manure or sewage. Our results indicate that chironomid $\delta^{15}N$ values can integrate watershed-level N sources, input rates, and processing for water quality monitoring and assessment at large scales.

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NUTRIENT EXPORT FROM HIGHLY MANAGED COASTAL WATERSHEDS: LESSONS LEARNED FROM LONG-TERM MONITORING DATA

Yongshan Wan

Abstract—The health of estuarine ecosystems is often influenced by hydraulic and nutrient loading from upstream watersheds. This study analyzed a long-term (1979~2014) water quality and discharge dataset collected from four adjacent coastal watersheds in south Florida where land and water resources are highly managed through an intricate canal network. The objective was to determine the temporal and spatial changes in nutrient concentrations and export behavior in relation to watershed hydrology and resources management. While close associations of nutrient concentrations with land management and storm-water retention were identified across watersheds, long-term trends in nutrient concentrations were intervened by short-term highs driven by high discharges and lows associated with regional droughts. Nutrient export exhibited a chemostatic behavior for total nitrogen for all the watersheds, largely due to the biogenic nature of organic nitrogen associated with the ubiquity of organic materials in the managed canal network. Varying degrees of chemodynamic export was present for total phosphorus, reflecting complex biogeochemical responses to the legacy of long-term fertilization, low soil phosphorus sorption, and intensive stormwater management. The anthropogenic and hydro-climatic influences on nutrient concentrations and export behavior had great implications in nutrient management programs for restoration of the downstream estuarine ecosystem.

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ASSESSING PHYSIOCHEMICAL AND BIOLOGICAL CONDITION OF RIVERS AND STREAMS WITHIN THE MISSISSIPPI RIVER BASIN AND SUB-BASINS

Richard Mitchell, Susan Holdsworth, and Michelle Maier

Abstract—The National Rivers and Streams Assessment (NRSA) is a partnership between U.S. Environmental Protection Agency, States and Tribes, with the purpose of providing estimates of river and stream conditions at national and large regional scales. NRSA uses a randomized, unequally weighted probability survey design that provides an unbiased assessment of condition for these core indicators. Due to the geographic scale of the Mississippi River basin, NRSA is able provide an adequate sample size to report on the condition of rivers and streams for the entire Mississippi River basin, as well as major sub-basins such as the Ohio River basin. For this study the Mississippi River basin was divided into six sub-basins to ensure sufficient sampled sized for condition estimate (Upper Missouri, Lower Missouri, Arkansas-White-Red river basin, Ohio-Tennessee). To ensure comparability of results, NRSA utilizes standard sampling protocols across all sites. NRSA utilizes regionally developed thresholds for assigning condition classification (good, fair, poor) based regional reference condition. NRSA started in 2008/2009, with the second survey occurring in 2013/2014. Approximately 900 sites were sampled within the Mississippi River basin during each survey, with approximately 50 percent of sites re-sampled between surveys. Results from NRSA 2013/2014 showed substantial nutrient degradation throughout the Mississippi basin, with five out of the six sub-basins having at least 50 percent of river and stream miles in poor condition for phosphorus. Biological condition (benthic macroinvertebrates) was much more variable throughout the basin, with the percentage of river and stream miles in poor condition ranging from a low of 32 percent in the Upper Missouri to a high of 80 percent in the Lower Mississippi. Changes in phosphorus condition occurred between 2008/2009 and 2013/2014, with five of the six sub-basins showing a significant decrease in river and stream miles from 2008/2009 to 2013/2014. The basin wide increases of river and stream miles in poor condition for phosphorus were not seen for either nitrogen or biological condition, but there were some significant changes for a few of the sub-basins for both nitrogen and biological condition. As NRSA continues, future results will provide important data for assessing both nutrient and biological trends within the Mississippi basin.

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RELATING WATERSHED LAND USE TO BENTHIC INVERTEBRATE CONDITION IN THE VIRGINIAN BIOGEOGRAPHIC PROVINCE, USA

Marguerite C. Pelletier, Arthur J. Gold, Jane Copeland, Liliana Gonzalez, and Peter V. August

Abstract—Estuaries are dynamic transition zones linking freshwater and oceanic habitats. These productive ecosystems are threatened by a variety of stressors including human modification of coastal watersheds. In this study, we examined potential linkages between estuarine condition and the watershed by landscape condition attributes and benthic invertebrate communities. We sought to determine if the spatial arrangement of watershed attributes was important in predicting benthic invertebrate condition. We examined attributes at the watershed scale as well as those associated with riparian areas. We also examined whether attributes closer to the estuary were more strongly related to benthic invertebrate condition. Since riparian and watershed variables were highly correlated at this scale, either riparian or watershed variables were adequate for assessing estuarine invertebrate condition. Modeling estuarine condition indicated that inherent landscape structure (e.g., estuarine area and watershed area) is important to predicting benthic invertebrate condition and needs to be considered in the context of watershed/estuary planning and restoration. As shown in other studies, anthropogenic geospatial attributes (development, agriculture) are associated with adverse impacts. Previous studies demonstrated the importance of land use closer to the estuary, but this relationship was not observed in this study, perhaps due to the watershed heterogeneity in our study area.

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THE NATIONAL ECOLOGICAL OBSERVATORY NETWORK AQUATIC SAMPLING: DISSOLVED GAS CONCENTRATIONS, STRATIFICATION CONDITIONS IN LAKES, AND REAERATION RATES IN STREAMS

Kaelin Cawley and Keli Goodman

Abstract—The National Ecological Observatory Network (NEON) is deploying instrumentation and collecting samples on a continental scale for 30 years, beginning in 2018. There are five components of NEON: Airborne Observation Platform (AOP), Terrestrial Instrument System (TIS), Terrestrial Observation System (TOS), Aquatic Instrument System (AIS), and Aquatic Observation System (AOS). Collocation of measurements associated with each of these components will allow for linkage and comparison of data related to physical, chemical, and biological parameters. The NEON Aquatic subsystem, comprised of AOS and AIS, will quantify the impacts of climate change, land use, and biological invasions on freshwater populations and processes. NEON will collect observational samples to evaluate stream geomorphology and lake bathymetry, organismal community composition, surface and groundwater chemistry, and habitat structure, in addition to deploying instrumentation in and around water bodies. Additionally, data processing of NEON measurements is standardized, and these quality-controlled data products are freely available through a publicly accessible online data portal (data.neonscience.org).

Some of the data that will be collected, processed, and published by NEON are particularly relevant to discovering connections between air, land and associated freshwaters, which drive the dynamics of carbon in inland waters. As part of the AOS sub-system, samples are being collected biweekly from 24 streams and 3 rivers, and samples are collected monthly from 7 lakes for analysis of greenhouse gas (GHG) concentrations (CO_2, N_2O, and CH_4). At the same time, depth profiles for temperature, conductivity, and dissolved oxygen will be collected in the lake and river sites. From these depth profiles, stratification conditions can be discerned. At stream sites, reaeration tracer experiments (simultaneous conservative and gas tracer injection) are performed about 6 times per year. The stream reaeration rates will be related to stream discharge values to develop a rating curve from which temporally interpolated reaeration rates can be derived from high frequency discharge data. Dissolved gas concentrations and physical parameters derived from the NEON dataset will make up a component of GHG flux estimates at these sites, which will be useful for elucidating the relationship between GHG fluxes and physical characteristics of inland waters.

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HOW BEST TO ADDRESS THE CHALLENGE OF GEOLOGY ALONG AN AGRICULTURAL REACH OF THE ARKANSAS RIVER IN COLORADO?

Carleton Bern, Michael Holmberg, and Zachery Kisfalusi

Abstract—The Arkansas River and the irrigation water it provides are the foundation for rural economies and communities in southeast Colorado. Water quality for agriculture, wildlife, and drinking water supplies in the region face complex but interrelated challenges from high concentrations of uranium, selenium, and salinity. Uranium concentrations in the river and groundwater sometimes exceed drinking water standards and uranium accumulates in downstream irrigated soils. Selenium concentrations in the river and some tributaries exceed the chronic exposure threshold for aquatic life in much of the region. Salinity accumulates in soils and decreases irrigated crop yields. The ultimate sources of these constituents are Cretaceous marine rocks present throughout the region, but canal diversions, reservoir storage, and irrigation are among the many anthropogenic influences that also affect their concentrations.

A wicked problem can be so named because of contradictory requirements, and the water quality challenges in the Arkansas River qualify. Deep percolation and subsequent return flow to the river from irrigation and water management structures contribute to greater mobilization of uranium, selenium, and salinity, but irrigators and other water users struggle with resulting poor water quality. Further, efforts to reduce deep percolation through increased irrigation efficiency can be at odds with requirements that return flows be maintained in line with the Kansas-Colorado Arkansas River Compact. Finally, some amount of irrigation-induced, deep percolation is required to prevent salinity buildup in irrigated fields.

Strategies to improve water quality in the Arkansas River in southeast Colorado have been suggested through previous reach-scale modeling efforts. The work presented here seeks to test assumptions about the drivers of uranium, selenium, and salinity concentrations, which include evaporation, transpiration, mobilization from geologic sources, and biogeochemical sequestration. Each driver imparts a fingerprint on the chemistry or isotopic composition of water they influence. Using chemistry and isotopes as tracers, the relative magnitude of each driver's influence can potentially be traced, as well as how it varies spatially and seasonally. The resulting understanding can point towards management strategies likely to have the greatest positive influence on water quality, while not impacting water usage from the Arkansas River.

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HYDROGEOCHEMICAL CHANGES AND WATERSHED DEGRADATION INDUCED BY HEMLOCK LOSS IN NORTHEASTERN RIPARIAN FORESTS

Kanishka Singh, Todd Walter, and Mark Whitmore

Abstract—Eastern hemlock (*Tsuga canadensis*) is a keystone coniferous tree species found across eastern North America that performs a variety of crucial ecosystem functions. Riparian forests and aquatic habitats dependent on hemlock-induced conditions are threatened by the hemlock woolly adelgid (*Adelgestsugae annand*), an invasive species of insect that infests and precludes the tree from producing new foliage, causing rapid mortality. Hemlock decline is expected to initiate a cascade of ecosystem dynamics and attendant biogeochemical fluxes with the potential to precipitate severe water quality degradation through elevated nitrate loading into neighboring watersheds. Further, as climate change facilitates adelgid range expansion and increases the frequency of large precipitation and soil runoff events, the negative repercussions of hemlock loss pose greater future complications for watershed management.

Extant literature investigating such dynamics illuminates a number of relevant terrestrial factors, such as forest succession, temperature, the frequency of freeze-thaw events, soil frost, snow-bank depth, antecedent moisture, and soil profile, but remains divided on their ultimate consequences for water quality.

This present research project, based in Catskill State Park (NY), examines some of these factors and their relationship with hydrogeochemical changes and water quality, in the context of hemlock decline and deciduous succession in northeastern riparian forests.

Plots with critical infestation neighboring streams are identified with red and near- infrared spectrum imaging characterized as normalized difference vegetation index data. Satellite information is verified through in-situ light measurements of photosynthetically active radiation. Fluxes in nitrogen pools, nitrification and mineralization rates in soil, as well as dissolved oxygen and aqueous nitrate concentrations in streams are measured and analyzed, and if significant changes are recorded, hydrologic modeling will be carried out to determine downstream effects. Findings may help natural resource managers understand what levels of hemlock decline contribute to critical changes in riparian stream chemistry and water resource quality.

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ADVANCING CONTINUOUS STREAMFLOW AND WATER QUALITY MONITORING NETWORKS IN THE COASTAL PLAIN, WACCAMAW RIVER WATERSHED, SOUTH CAROLINA

Benjamin Thepaut

Abstract—The U.S. Geological Survey (USGS), South Atlantic Water Science Center, Conway Field Office is located in Horry County near the northeastern coast of South Carolina and maintains 29 stations at various waterbodies in the Santee and Pee Dee River basins. The stations are located in diverse hydrologic environments unique to the southeastern Coastal Plain such as fresh, black water rivers that are also tidally affected. These stations are equipped with instrumentation which records various parameters, including water level, velocity, precipitation, water temperature, specific conductance, pH, dissolved oxygen, and turbidity . Data are typically recorded at 15-minute intervals and transmitted hourly, via satellite, to the USGS NWISWeb, publicly accessible webpage (http://waterdata.usgs.gov/sc/nwis/rt). NWISWeb users also have the ability to query conditions in real-time and establish thresholds for automatic data delivery via email or text message using the USGS WaterAlert and WaterNow applications.

In addition to routine parameters, USGS stations have the ability to incorporate a suite of other monitoring instrumentation at any time. This ability to incorporate additional parameters is timely and beneficial as the South Carolina Department of Health and Environmental Control is currently developing nutrient concentration criteria for estuaries, rivers, and streams. In June, 2016, equipment was added to monitor nitrate (as NO_3^-) at an existing stream gage on the Waccamaw River near Longs, SC (USGS station 02110500). Data collected is post-processed using discrete samples to calibrate the equipment and develop a relationship between the recorded values and sample data. Project objectives include the validation of equipment and deployment strategies, determining baseline nitrate concentrations, and assess sources and sinks of nitrate. This presentation will focus on the advancement of monitoring stations in South Carolina, collection of continuous streamflow and water quality data, and highlight provisional nitrate data.

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TEMPORAL DISTURBANCE AT THE MICRO SCALE: NATURAL AND ANTHROPOGENIC IMPACTS ON SEEPAGE ACROSS THE SEDIMENT-WATER INTERFACE

Don Rosenberry

Abstract—The volume within several cm of the sediment-water interface is a dynamic ecotone where large gradients in physical, chemical, and biological processes and concentrations exist. Disturbances can disrupt flows of water, chemicals, and organisms across the interface and alter conditions both within and beyond this transitional volume. Simple and common anthropogenic influences can greatly disrupt this interface and may have unintended or unanticipated consequences. Boat wakes, for example, can create orders-of-magnitude increases in rates of flow across the sediment-water interface. Seepage at an estuary in New York City changed from upward flow at 1 cm/d to downward flow at more than 200 cm/d as a barge approached and then back to upward seepage, but at more than 100 cm/d as the barge moved away from the measurement location. One-minute averages of seepage in 10 m water depth at a lake in central Minnesota increased from 0.2 to 0.6 cm/d as a large boat wake passed the measurement location. The standard deviation for that 1-minute interval increased from 1 to 9 cm/d, indicating the seconds-long disruption at 10-m depth was much larger during actual passage of the wave. Upward seepage at the shoreline of a large lake in California reversed and became downward when calm conditions transitioned to 15-cm-amplitude small waves, potentially flushing nutrients into the lake from the near-shore margin. These processes, although short in duration, represent large disturbances that have rarely been considered in studies of processes at and near the sediment-water interface. Biological and geochemical consequences of these disturbances thus far are largely unknown and may warrant additional investigation.

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SECTION 4

Novel Approaches and Applications

CHARACTERIZING DEPRESSIONAL WETLAND STORAGE IN A WATERSHED: LINKING REMOTE SENSING AND HYDROLOGIC MODELING APPROACHES

J. Christensen, G. Evenson, M. Vanderhoof, Q. Wu, H. Golden, C. Lane, and L. Alexander

Abstract—Wetlands in the 700,000 km^2 Prairie Pothole Region of North America (PPR) can store large amounts of water on the landscape. Some wetlands fill and spill to other aquatic systems while others fill and merge within larger wetland depressions. Wetland storage and spillage varies both spatially and temporally in PPR watersheds and these variable dynamics influence hydrologic and biogeochemical landscape processes. To explore how to best characterize spatial and temporal variability of this wetland storage, we compared three approaches, (1) hydrological modeling alone, (2) remotely-sensed data alone, and (3) integrating remotely-sensed data into a hydrological model. These approaches were tested in the Pipestem Creek Watershed, North Dakota across a drought to deluge cycle (1990-2011). A Soil and Water Assessment Tool (SWAT) model was modified to include the water storage capacity of individual wetlands on the landscape identified in the National Wetland Inventory (NWI) dataset. The SWAT-NWI model simulated the water balance, storage and spillage of each wetland during the 21-year study period. However, SWAT-NWI only accounted for fill-spill, and did not allow for the expansion and merging of wetlands situated within larger depressions. The SWAT-NWI model was then modified to use LiDAR-derived depressions that account for the potential maximum depression extent, including the merging of smaller wetlands. Alternatively, we assessed the occurrence of fill-merge mechanisms using Landsat-derived inundation maps on 19 cloud-free days during the 21 years. During deluge, fill-merge mechanisms were prevalent across the Pipestem watershed and storage volume was dominated by large merging depressions. The inundation maps were used to evaluate the ability of the SWAT-depression model to simulate fill-merge dynamics in addition to fill-spill dynamics. Ultimately, using remote sensing to inform and validate process-based modeling allows us to assess both the spatial and temporal continuum of storage across a watershed, identify approach limitations, and improve efforts to study and map wetland storage dynamics in the PPR and beyond.

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CONTRASTING SWAT PREDICTIONS OF WATERSHED-LEVEL STREAMFLOW AND NUTRIENT LOSS RESULTING FROM STATIC VERSUS DYNAMIC ATMOSPHERIC CO_2 INPUTS

Kpoti Gunn, Tamie Veith, and Anthony Buda

Abstract—Past climate observations have indicated a rapid increase in global atmospheric CO_2 concentration during late 20th century (13 ppm/decade), and models project further rise throughout the 21st century (24 ppm/decade and 69 ppm/decade in the best and worst case scenario, respectively). We modified SWAT2012, a watershed-level, semi-distributed hydrologic and water quality simulation model, to incorporate dynamic atmospheric CO_2 concentrations and account for the mechanistic effects of CO_2 concentrations on vegetative transpiration by plant species. Using downscaled predictions from nine climate models for 1960-2100, we investigated the effects of static versus dynamic CO_2 inputs on simulated streamflow and nutrient concentrations in an agricultural watershed that drains to the Chesapeake Bay. Preliminary results under current agricultural management indicated that rising CO_2 levels through the 1900s were minimal enough to not impact streamflow and water quality, but that additional increases in CO_2 will have an impact and must be considered as we move further into the 21st century. In particular, predicted streamflow levels decrease, presumably in response to increased plant evapotranspiration as CO_2 concentrations continue to rise. We will compare the predicted streamflow and evapotranspiration between the static and the dynamic CO_2 status, and explore the implications of these changes on nutrient concentrations and fluxes.

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MODELING VIOLATIONS OF THE NITRATE STANDARD FOR PUBLIC DRINKING WATER ACROSS THE CONTERMINOUS UNITED STATES

Michael Pennino, Scott G. Leibowitz, and Jana E. Compton

Abstract—Excess nitrate in drinking water is a human health concern, especially for young children. As a result, when a public drinking water system exceeds the 10 mg nitrate-N L^{-1} maximum contaminant level (MCL) standard, that system is reported as having a violation in the U.S. Environmental Protection Agency's (EPA) Safe Drinking Water Information System. We used random forest classification (RFC) and RF regression (RFR) modeling to predict nitrate violations across the conterminous United States, to determine where systems are most likely to exceed the nitrate MCL. For RFC, we assigned stream catchments in the national hydrography dataset that have had a violation any time between 2013 and 2017 as a one and catchments without violations as a zero. For RFR, we calculated the mean annual percent of public drinking water systems in violation for each catchment. As explanatory variables, we used EPA's StreamCat variables, including land cover, nitrogen inputs from fertilizer, precipitation, and soil characteristics. We also calculated other metrics: agricultural drainage, nitrogen surplus, aquifer type, water inputs and withdrawals, density of septic systems and wastewater treatment plants for each catchment. For groundwater systems, the RFC model was able to correctly classify 79.9 percent of catchments with or without systems, whereas the RFR model explained 26.6 percent of the variation. The variables consistently most important in both models for predicting groundwater system violations were percent cropland, temperature, soil permeability, fertilizer inputs, water table depth, and precipitation. For surface water systems, the RFC model was able to correctly classify 83 percent of catchments with or without systems, however, the RFR model explained <0 percent of the variation. The variables most important for both models were percent cropland, runoff, baseflow, percent forest, and organic matter content. Regions predicted to have the highest probability of violations were central California, areas in Texas, Oklahoma, and Kansas that are above the Ogallala aquifer, the Upper Midwest (Minnesota, Wisconsin, and Michigan), and southeast Pennsylvania and Delaware. Understanding where violations are most prevalent and the causes of violations will help inform future management decisions on how treatment, source water protection, and other management options could best protect drinking water from nitrate contamination.

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APPLICATION OF REGRESSION-BASED RAINFALL-RUNOFF MODELING FOR IMPROVING THE QUALITY OF DATA FOR THE SEMI-ARID WALNUT GULCH LTAR EXPERIMENTAL WATERSHED

Menberu M. Bitew, David Goodrich, Eleonora Demaria, Philip Heilman, Lainie Levick, Carl Unkrich, Mark Kautz, and Mary Nichols

INTRODUCTION

The Walnut Gulch Experimental Watershed (WGEW) is a semi-arid experimental watershed and Long Term Agro-ecosystem Research site (LTAR) (https://www.tucson.ars.ag.gov/ltar/) managed by the USDA-ARS Southwest Watershed Research Center for which high-resolution, long-term hydro-climatic data are available across its 149 km^2 drainage area. The WGEW has been instrumented since 1953 to quantify hydro-climatic variables and improve our understanding of semiarid hydrology. We present the analysis of 50 years of hourly summer rainfall and runoff data to develop criteria for assessing data quality. A total of 88 weighing-type recording rain gauges with a precision of 0.25 mm and 1-minute time step are distributed within the watershed (Goodrich and others 2008). The dense network of sensors paired with nested, gauged subwatersheds, captures the spatial structure of both rainfall and watershed runoff responses. With the objective of evaluating the consistency of hydro-climatic observations, data curation, and sharing legacy data, we developed a multi-parameter regression model that can be used to detect suspect observations with a goal to improve data quality. A total of 22 predictors related to precipitation and watershed properties, antecedent conditions, and the temporal information of rainfall events from 12 nested sub-watersheds ranging in area from 0.002 – 94 km^2 were used for model development.

DATA

The rainfall event properties included (1) conditional mean of hourly rainfall, (2) the maximum 15-minute intensity, (3) conditional mean of rainfall durations, (4) location of the center of the storm with respect to the sub-watershed outlet, and (5) the storm size as a fraction of watershed area. Watershed properties included physiographic variables such as area, shape, slope, flow length, stream density, stream order, sizes of stock ponds contributing area, channel bed area, saturated hydraulic conductivity, hydrologic soil group, and land cover properties. We also evaluated the interaction between rainfall and runoff through antecedent moisture condition (AMC) (SCS 1972), and antecedent runoff condition (ARC). The temporal properties include time of rainfall occurrence such as season, month, and hour of occurrence. Table 1 contains the complete list of the predictors.

METHOD

We implemented a three-step approach to develop an optimal multi-parameter regression model using 85 percent of the dataset while the remaining 15 percent was used to evaluate the predictive accuracy of the model. First, F-tests were conducted to identify the parameters that best fit the population from which the data were sampled using least squares. All significant parameters and their interaction terms with p-values <0.05 were used as regression predictors. In this step, the objective functions were to minimize the deviation of individual values from the distribution through the sum of squared deviates as a standard error and the residual of the sum of squares (RSS) to maximize the adjusted R-squared. Secondly, we evaluated the sets of selected potential models for their predictive accuracy for the application of QA/QC. Finally, we further assessed the models using a multimodel inference approach that used the Akaike Information Criteria (AIC) (Akaike 1973). Here the objective was to determine if those predictors can lead to parameter overfitting which F-tests do not usually reveal. The multimodel inference approach compares the relative quality of models through estimation of information that would be lost if a particular model consisting of the subset of the predictors was used.

MODEL PERFORMANCE

The optimal regression model was developed based on 18 predictors (given in bold in table 1) selected using a combination of the AIC and F-test analyses. The evaluation of the model using basic and categorical statistics showed a good correlation, explaining 63 percent of the variance. The model predictive accuracy was assessed using the 15 percent independent validation data, which showed correlation coefficients ranging from 0.4-0.94, and Nash efficiency

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Table 1—Types of potential parameters related to rainfall runoff response in Walnut Gulch nested watersheds[a]

Group/class	Variable type	Units	Definition
Precipitation properties	**Event rainfall depth**	mm/hr	Conditional hourly mean rainfall accumulation of 3 hours preceding and 1 hour succeeding event runoff in the watershed.
	Maximum rainfall intensity	mm/min	Average of a conditional maximum 15 minute intensity of 3 hours preceding and 1 hour succeeding an event.
	Duration	Min	Total duration of rainfall 1 hour succeeding and 3 hours preceding event.
	Storm size	m^2/m^2	Areal extent of rainfall event using Theissen polygons normalized by the watershed area.
	Storm distance	m/m	The ratio of flow path from the storm center to the maximum watershed flow path length
Antecedent condition	5 days antecedent moisture	–	Prior moisture condition in the contributing area based on accumulation of rainfall over 5 days. Dry ("< 2.1"), wet ("> 4.1") or else average (SCS 1972)
	2 days antecedent moisture	–	
	5 days antecedent runoff	–	Prior moisture condition in the channels based on accumulation of rainfall over 5/3 days before the event. Dry (<0.001mm), wet (>1mm) or else average
	3 days antecedent runoff	–	
Watershed properties	**Area**	km^2	Watershed contributing area.
	Shape	m/m	The ratio of watershed width (in the direction of main channel flow) to length of watershed.
	Slope	%	Average slope in percent.
	Length	km	The longest flow path based on D8-algorithm
	Stock pond area	km^2/km^2	Contributing areas of the detention stock ponds in some of the sub-watersheds
	Area of channel bottom	km^2	Miller and others. 1996 measured the channel bottom area of Walnut Gulch channels to estimate transmission loss.
	Stream density	m/m^2	The ratio of total length of NHD high resolution stream networks to watershed area.
	Stream order ratio	m/m	The ratio of length of first order stream network to the total length of stream orders 2 and above.
	Hydraulic conductivity	mm/hr	Average watershed scale surface layer property for soil water movement from SSURGO database.
	Hydrologic soil group[a]	–	Average soil group showing infiltration ability of the watershed.
	Average land productivity	–	Normal year rangeland production in pounds/ acre/year normalized by average production in Walnut Gulch.
	Event month	12-Jan	Rainfall distribution varies significantly within the summer months.
	Rainfall hours	0 - 23	Hours representing the rainfall event time showing the diurnal effects.

[a] Hydrologic soil groups A, B, C, and D were assigned numeric values 1 to 4, respectively.

Note: A total of 20 parameters were identified and used as predictors for runoff estimation; the significant parameters of the optimal regression equation are indicated in bold.

coefficients up to 0.76 for the different size sub-watersheds. The model predicted 92 percent of runoff events and 86 percent of no-runoff events across all the sub-watersheds considered in the study.

APPLICATION OF THE REGRESSION MODEL FOR ASSESSING MEASUREMENTS

The regression model was used to evaluate and flag questionable precipitation or runoff events by providing a unique method for ensuring that rainfall and runoff data in the WGEW database are consistent and contain minimal error. We applied the regression model to watersheds 63.004 (2.26 km^2) and 63.006 (93.3 km^2) to demonstrate and present QA/QC potential of the regression model. Using the predicted runoff obtained from the regression equation, the observed runoff, and the depth of precipitation events, we identified 25 questionable rainfall and/or runoff events in both 63.004 and 63.006 sub-watersheds. Figure 1 shows examples of those flagged events. The graphs on the left hand (fig. 1) show the rainfall on the receding side of the hydrograph, and the graphs on the right (fig. 1) show no rainfall associated with runoff within a reasonable time window.

CONCLUSION

In the development of the multi-parameter regression model, in addition to the combination of F-tests and the exhaustive search approach, careful evaluation of the application of the regression model is needed to select an optimal model. The exercise demonstrated that the regression model could complement existing QA/QC procedures to identify suspect observations requiring further checking and thus improve the quality of rainfall and runoff data in the Walnut Gulch Experimental Watershed. The model also has the potential for making runoff predictions in similar hydro-climatic environments where high-resolution ground-based radar-rainfall estimates are available.

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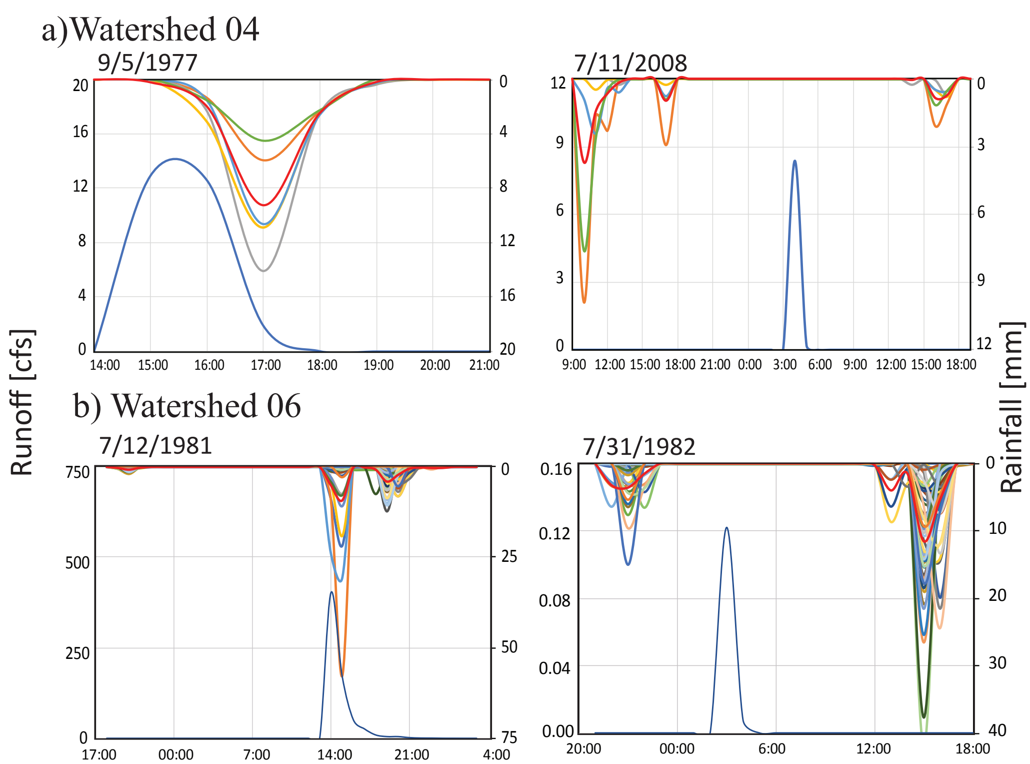

Figure 1—Selected suspect flagged events for runoff (blue) and rainfall (red line represents conditional mean of the rain gauges) observations from 25 flagged events in watershed 63.004 (top 2 panels) and watershed 63.006 (bottom 2 panels).

MODELING IMPACTS OF INTER-BASIN TRANSFERS ON WATER SUPPLY DISTRIBUTION FOR NATIONAL FOREST LANDS AND THE CONTERMINOUS UNITED STATES

Kai Duan, Peter V. Caldwell, Chelcy F. Miniat, Ge Sun, and Paul V. Bolstad

Abstract—The 170 National Forests and Grasslands (NFs) in the conterminous United States occupy 8.8 percent of the land area yet provide 14 percent of the freshwater supply. Regional availability of water supply from these NFs, as well as State and private forests and non-forested areas, varies spatially depending on local water yield and streamflow accumulated from upstream watersheds. Several previous studies have addressed water yield from NF lands under natural conditions without human impacts. However, redistribution of water from NF lands through human water management such as inter-basin water transfers (IBTs) is largely unstudied due to the lack of data. Using monthly outputs from the Water Supply Stress Index model for the time period of 1961-2015, geospatial attributes of streams from the National Hydrography Dataset, and a modified dataset of 228 IBTs from U.S. Geological Survey reports, we established an inventory of sources of renewable freshwater for the 82,773 12-digit Hydrologic Unit Code (HUC-12) watersheds. Specifically, the footprint of water originating from NFs was tracked and compared under two scenarios with or without the impact of IBTs. Results suggest that these IBTs have played a notable role in re-distributing water from the NFs to densely populated areas. For example, the 8.1 billion m^3 water transferred through five IBTs from the Sierra Nevada and the Colorado River to southern California has been a major source of freshwater for cities including Los Angeles, and water originated from NF lands accounts for 66 percent (5.3 out of 8.1 billion) of the water transferred. Across the HUC-12 watersheds, IBTs caused changes in the contribution of NF lands to regional streamflow in 2,249 watersheds, varying between a decrease of 11 percent in the proportion of water from NFs to an increase of 60 percent. Over 1,000 watersheds, mostly located in the drainage basins of South Atlantic-Gulf, Missouri, Arkansas-White-Red, and Rio Grande, have benefited from additional water from NFs delivered by the IBTs. These results provide insights into the natural and anthropogenic water nexus among watersheds, and can support water management at various levels when linked to national water use census data.

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RANGELAND WATERSHED RESEARCH FOR THE WEST

Philip Heilman, Guillermo E. Ponce-Campos, Fred B. Pierson, and David C. Goodrich

Abstract—There is a significant national interest in land management in the West, with widespread federal ownership. Public land management agencies and grassroots watershed groups need a concerted regional effort to quantify watershed processes and improve watershed management for the sustainable provision of ecosystem services across the rangeland of the West. We used Google Earth Engine to reclassify the 2011 USGS GAP-Landfire National Terrestrial Ecosystems dataset in the 17 western States into the area that could be considered rangeland. This area, which excludes cities, mines, open water, rainfed or irrigated cropland, and mesic or wet forests, covers roughly 3 million km^2. Within that rangeland area, we were able to identify 27 experimental watersheds, forests and ranges with long-term measurements of streamflow, including active and inactive sites. A further 26 sites perform long-term ecological research on rangelands. Perhaps the greatest constraint on the systematic application of improved understanding to management is the relative immaturity and limited mapped extent of ecological sites, the accepted interagency conceptual model for managing rangelands within their vegetative potential.

INTRODUCTION

"Approximately half a million square miles [1.3 million km^2] in the Southwestern United States are in the arid and semiarid climatic zones. The principal use of this vast area is for livestock grazing." This first short paragraph of the first paper published about the Walnut Gulch Experimental Watershed (Keppel and Fletcher 1959) describes the area that Walnut Gulch represents with its climate and land use. Although no map was provided, the area described presumably included Arizona, New Mexico, Utah, and Colorado, plus parts of California, Nevada, and Texas, minus cities, irrigated agriculture, and the high elevation areas in those States with more mesic or wet climates. Today, although it is much easier to map areas with defined characteristics, we generally expect a more nuanced description of the physical, chemical, biological, or management-affected processes to extrapolate before identifying, for a given experimental watershed, the larger area where similar processes are expected to dominate. Even then, extrapolation is typically done with a simulation model to adjust for important characteristics that necessarily differ between the intensively studied watersheds and the larger representative area.

Today, investments in spatial datasets and expanded technical capabilities allow the western watershed community to begin to address the region as a whole rather than in smaller, fragmented, representative areas around individual research sites. Most of the land across the West is typically described as "rangeland," which is defined in the glossary of the Society for Range Management (SRM 2018) as "Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem." The glossary further defines range itself as "grassland, grazable forestland, shrubland and pastureland." In addition to grazing, western rangeland managers face a suite of challenges related to invasive species including woody plant encroachment, fire, climate change, and degradation/desertification (Wilcox 2010). Important characteristics of rangeland are that it is extensive, water-limited, heterogeneous, has limited management information or control over ecological processes compared to other land uses, and often is in the public domain.

The challenge in western rangelands is to manage ecologically rather than agronomically, with the goal of either maintaining a certain perennial plant community or shifting toward a community deemed more desirable. A subdiscipline of hydrology known as "ecohydrology" has recently emerged to address the interrelated issues of ecology and hydrology, with a focus on climate-soil-vegetation dynamics (Rodriguez Iturbe 2000). Newman and others (2006) argue for an interdisciplinary approach to the ecohydrology of water-limited environments. As precipitation in the West is both low in average magnitude and highly variable in space and time, long-term research is particularly important to understand watershed and ecological processes, especially in plant communities that involve long-lived shrubs and trees.

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Ultimately, the key questions in western watershed management are: What plant communities exist across the landscape? What other plant communities are possible? How can we value the flows of ecosystem services, such as providing forage, appropriate soil and water relationships, open space and recreational opportunities, habitat for wildlife, etc., from those plant communities we could manage for? And if we can identify a more desirable plant community than the one present, how do we economically and adaptively manage for that community? All of these issues impact rangeland watersheds at the scales of rangeland management including the hillslope, low-order channel, and headwater watershed. The challenge for public land managers is to develop a management plan that can withstand public scrutiny. For example, an upland erosion prediction tool could be run with parameters based on current vegetation, and if the estimated erosion rate is deemed too high, alternative vegetation communities could be assessed and a decision made about whether or not vegetation or land management could achieve an acceptable amount of erosion. Similarly, flow estimates could be assessed at any point on a channel for a storm of given return period to assess channel erosion, design transportation infrastructure, calculate flooding risk, assess water quality, or address other watershed management needs. Increasingly, public land managers will also be expected to address such issues given the much more complicated assumption of a non-stationarity climate.

The purpose of this paper is to identify and characterize the area in the West that can be considered rangeland. With that area defined, we will make a preliminary inventory of the long-term watershed and ecology research sites, landownership, watershed features and ecological sites descriptions on rangeland across the West. We assume that the rangeland West is static, but the area may be expanding. The 100th meridian had been considered the dividing line between the more arid West and the humid East. Recently, however, Seager and others (2018) argued that the eastern boundary of the West, defined by an aridity index as the ratio of precipitation to potential evapotranspiration equal to unity, is shifting to the east. Ideally, a long-term collaboration between research and action agencies will develop with specialized functions to allow increased specialization and a division of labor to stretch constrained State and Federal budgets to improve the art and science of western watershed management.

METHOD

Here, we focus on the 17 westernmost States and base our effort to define western rangeland on the GAP/LandFire (GLF) National Terrestrial Ecosystems 2011 version 3 (see fig. 1). This dataset is distributed as a gridded file at 30m x 30m cell-resolution and is based on Landsat and the National Vegetation Classification (NVC) system with the highest level

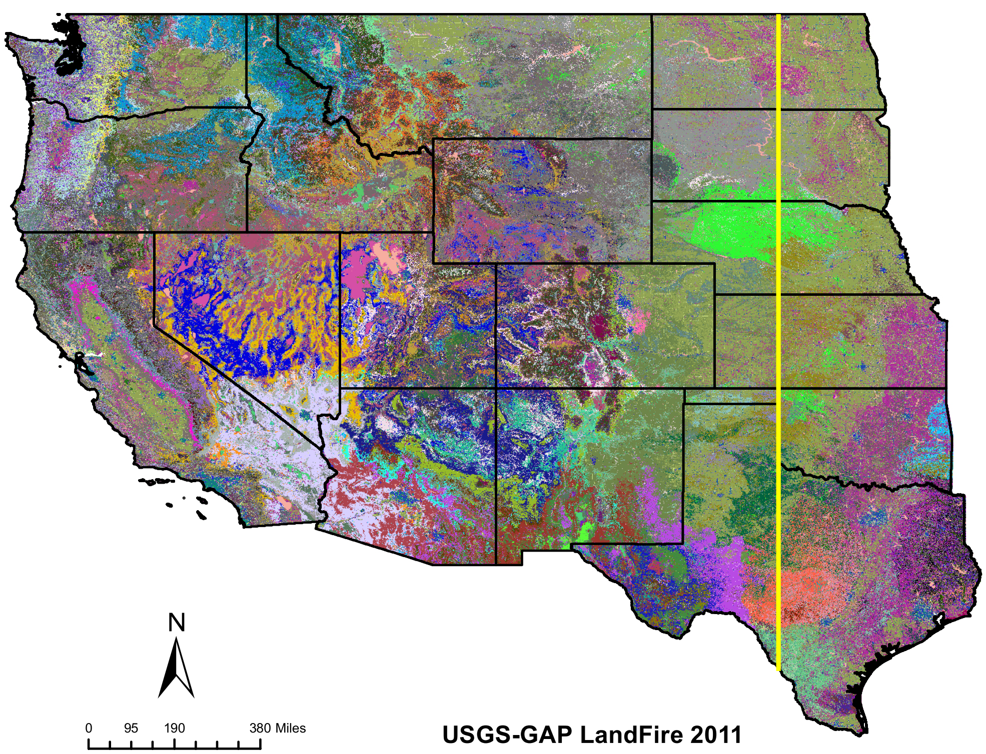

Figure 1—USGS GAP-Landfire map showing vegetation within the 585 total classes of the National Vegetation Classification (NVC) system across the 17 western States.

of detail available in a gridded format. The NVC system uses classes (e.g., Forest & Woodland) based on the dominant growth form. It also includes information about Division, Formation, Group, Macrogroup, and Subclass. The GLF layer, along with other datasets, were uploaded into Google Earth Engine (GEE) to operate in a single platform designed for very large raster datasets.

Filtering the GAP-LandFire Dataset

As an initial step, we selected all pixels from the NVC classes Shrub & Herbaceous (SH) and Desert and Semi-desert (DS) as rangeland pixels and excluded developed areas, dryland and irrigated cropland, bodies of water, and mines. The Forest & Woodland (FW) class had to be split into the drier subclasses that could be grazed and so considered rangeland while excluding the more mesic and wet forests with thick duff layers that promote shallow surface or subsurface flow and which rarely erode unless disturbed. For example, for "47 - Forest & Woodland - Madrean Pinyon-Juniper Woodland", 47 is the class code, along with the NVC-Class joined to the subclass with a hyphen. Using this association, we created maps in GEE for the iterative visual inspection/selection of those classes considered rangeland. The drier forest and woodland areas considered rangeland were identified by comparison with Forest Service, U.S. Department of Agriculture and other grazing allotment boundaries, State maps of rangeland, a Koppen climate map, and coauthor knowledge (fig. 2). A more definitive refinement of the western rangeland area based on the yet-to-be released 2016 GAP-Landfire National Terrestrial Ecosystems Dataset confirmed by experts within each State is a desirable next step.

Long-Term Rangeland Hydrology and Ecology Research Sites

We grouped the Shrub & Herbaceous, Desert and Semi-desert, and the Forest & Woodland pixels considered to be rangeland into a single rangeland class. To identify the potential long-term watershed and ecological research sites we overlaid the rangeland area with the location of research networks and instrumentation in the fields of hydrology and ecology. For hydrology, we considered the Long-Term Agroecosystem Research (LTAR) network. We added the long-term USDA sites including experimental forests and ranges identified in Moran and others (2008) as having more than 20 years of observational record, provided the individual research site indicated a stream gauging program on their website, even though some of the sites are no longer collecting streamflow data. In addition, the Kings River Experimental Forest has since collected a long term dataset, and the Loch Vale U.S. Geological Survey experimental watershed is included as an example of a low vegetation watershed. We also included the Department of Energy's East River Watershed in the Upper Colorado River Basin because of the depth and breadth of

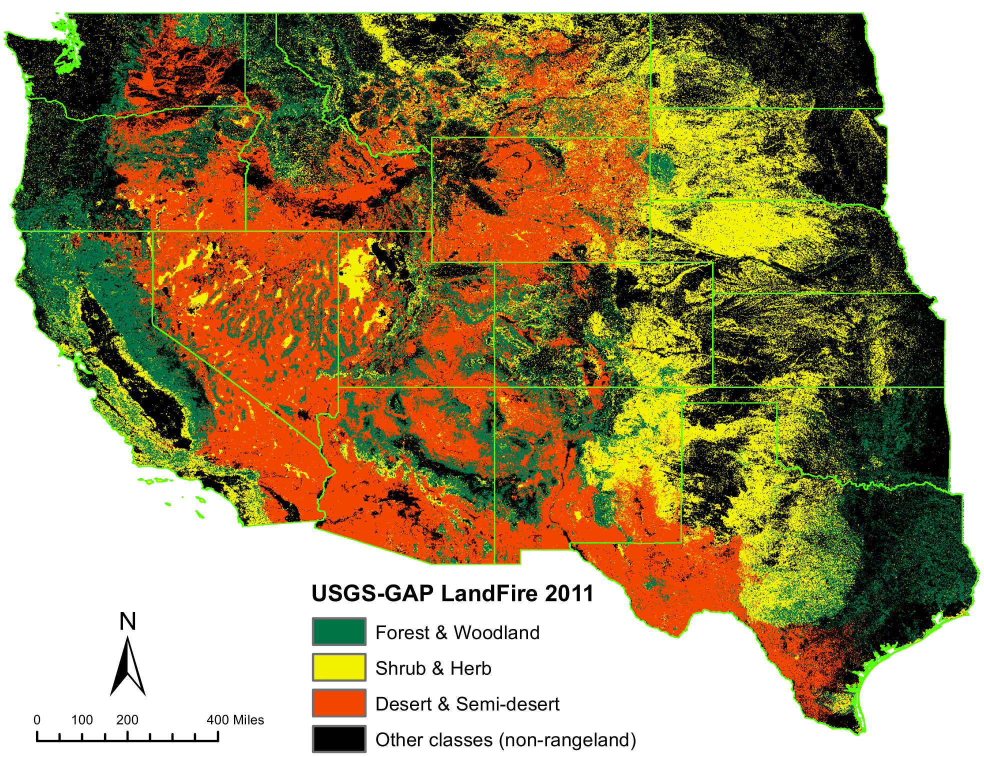

Figure 2—USGS GAP-Landfire classes reclassified to group plant community types and exclude non-rangeland areas.

observations. The Watershed Boundaries Dataset–Hydrologic Unit Code-12 (HUC) system was used to identify what are often nominally considered watersheds with more than 50 percent of rangeland area coverage. Then, within those watersheds, the NHD-Streams layer was used to calculate the stream lengths of ephemeral and intermittent streams in each one. Finally, the National Hydrography Dataset-Point location of gaging stations (code=36701) is another critical dataset, although less information about the determinants of runoff is available than at the experimental watersheds.

For ecological research sites, we focused on the national networks, namely the Long-Term Agroecosystem Research (LTAR) network, the Long-Term Ecological Research (LTER) network, and the National Ecological Observatory Network (NEON). Lastly, the ESRI USGS Federal Lands map service was used to estimate the area in federal land, by considering land owned by the Bureau of Land Management, Forest Service, Fish and Wildlife Service, Bureau of Reclamation, Department of Defense, and National Park Service. We did not do a complete inventory of the other lands such as land held in trust by the Bureau of Indian Affairs or owned by States to provide income for public education.

RESULTS AND DISCUSSION

The area of the 17 western States totals almost 5M km². Of that, western rangeland totals just over 3M km^2 or 63 percent of the total land surface (table 1). In other words, the total rangeland area is roughly the size of the 11 westernmost States. Roughly a third of the area of the 17 westernmost States is public land. There are around 33,000 HUC12s in the West that are at least half rangeland. And there are more than 4 million km of ephemeral and intermittent streams in watersheds that are at least 50 percent rangeland across the West.

Rangeland Hydrologic Datasets

The locations of 27 research watersheds across the West with long-term streamflow data are shown in figure 3. Unfortunately, in a number of the sites the records are dated, and it is unclear how much concurrent precipitation, soil, topography, and watershed cover data are available to develop and test simulation models. Other experimental watersheds will undoubtedly be found, although they probably have shorter-term records and less data about characteristics on the interior of those watersheds. In addition, there are thousands of USGS stream gauges, primarily on the perennial streams.

Table 1—Summary statistics by western State of rangeland area and hydrologic features

Western States	Total area	Rangeland area	Rangeland area	Public land area	Public land area	Rangeland HUC12s	Ephemeral and Inter. streams
	km^2	*km^2*	*% of total*	*km^2*	*% of total*	*number*	*km*
Arizona	295,293	260,221	88	123,541	42	3,044	446,480
California	423,794	310,976	73	231,117	55	3,698	522,390
Colorado	269,382	159,854	59	103,910	39	1,978	234,400
Idaho	215,994	131,221	61	138,749	64	1,748	124,697
Kansas	212,948	61,854	29	2,430	1	386	52,364
Montana	379,807	232,689	61	118,071	31	2,801	378,772
Nebraska	200,046	107,344	54	3,375	2	1,059	61,555
Nevada	286,118	270,756	95	242,048	85	2,537	467579
New Mexico	314,988	278,492	88	106,966	86	3,001	323,888
North Dakota	182,600	45,662	25	11,629	6	395	43,791
Oklahoma	181,027	56,993	31	4,822	3	443	41,606
Oregon	254,297	150,465	59	136,073	54	1,863	208,452
South Dakota	199,312	103,011	52	15,095	8	1,389	158,723
Texas	696,240	403,181	58	18,481	3	3,588	442,638
Utah	219,687	180,562	82	143,196	65	2,322	236,781
Washington	184,158	60,595	33	55,562	30	664	78,412
Wyoming	252,883	204,228	81	125,153	49	1,975	334,299
Total or average	4,768,574	3,018,104	63	1,580,218	33	32,891	4,156,827

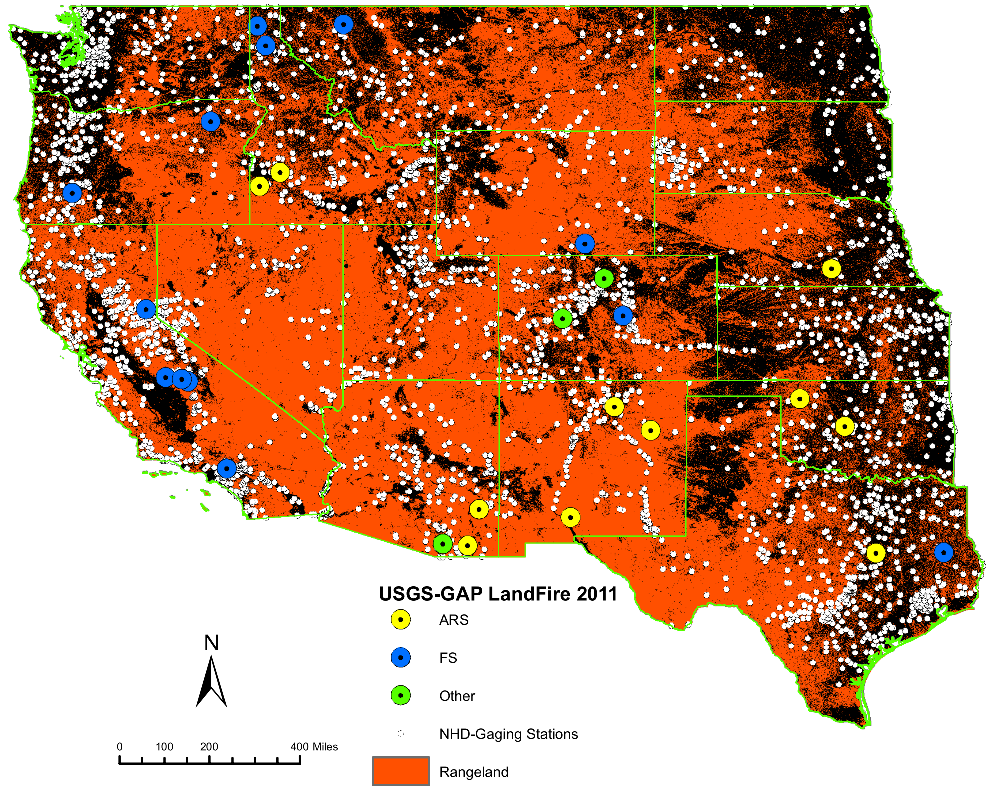

Figure 3—Experimental watersheds and National Hydrography Dataset (NHD) stream gages on western rangelands.

Rangeland Ecologic Datasets

A 2005 Memorandum of Understanding between the Natural Resources Conservation Service, Forest Service, and Bureau of Land Management established ecological sites as the standard interagency tool for rangeland management. Ecological sites describe the kinds, amounts, and proportions of plants a given site is capable of producing. While desirable as a conceptual foundation, ecological sites currently are not consistently mapped. Ecological sites are mapped for conservation planning on individual ranches, and more could be done to map ecological sites when correlated to individual soil series, which are mapped as part of Order 3 soil surveys. In these surveys one cannot directly map ecological sites based on the corresponding soil series, as there would be significant error: many map units contain substantial inclusions (soil series other than those that officially form the map unit) and typically map units will list three different soil series that could each be correlated to different ecological sites. The various soil series are often distributed within map units, not as associations in a regular pattern on the landscape, but as complexes without a regular pattern. A further complication is that even where ecological sites are mapped, typically the vegetation communities, or States, are not mapped. In part that is because State and transition models are neither mature nor easy to map. An obvious next step would be to map sites and States across long-term hydrologic and ecologic research sites. Table 2 summarizes the published information on Ecological Site Descriptions from the Ecological Site Information System (ESIS). A new website to document ecological sites, the Ecosystem Dynamics Interpretive Tool (EDIT), is under development. Figure 4 shows 26 ecological research sites distributed across the West, some of which participate in more than one research network.

Future Directions for Improved Modeling of Western Watersheds

It would be naive to believe that understanding the hydrology and ecology of western watersheds by simply collecting existing long-term datasets across the West would be straightforward, given that the datasets were originally collected for local, site-specific purposes, often without standardized instrumentation. Also, for decades, watershed models applied in the West were developed originally for cropland, such as the Soil and Water Assessment Tool, or SWAT. These models are based primarily on older subsystem models such as the curve number for runoff and the USLE or its variants developed for cropland systems.

Soon, new technologies to characterize model inputs will allow the development and application of a new generation of simulation models for western watersheds that are less empirically- and more physically-based. Given the ongoing improvements in remote sensing of precipitation, we can expect much better characterization of this most important

Table 2—Ecological site descriptions in the Ecological Site Information System (ESIS) database by western States

Western States	Approved rangeland site descriptions	Provisional rangeland site descriptions	Approved forest land site descriptions	Provisional forest land site descriptions	Certified reference sheets
			number		
Arizona	0	420	0	0	166
California	14	181	20	47	1
Colorado	4	63	0	0	66
Idaho	0	1	0	0	1
Kansas	34	47	0	0	30
Montana	0	175	0	0	22
Nebraska	7	90	0	0	69
Nevada	0	157	0	13	38
New Mexico	0	280	0	41	9
North Dakota	0	72	0	0	66
Oklahoma	0	46	0	0	28
Oregon	2	321	0	18	245
South Dakota	2	196	0	0	176
Texas	0	318	0	34	237
Utah	0	334	0	2	269
Washington	0	13	0	17	0
Wyoming	7	277	0	0	274
Total	70	2,991	20	172	1,697

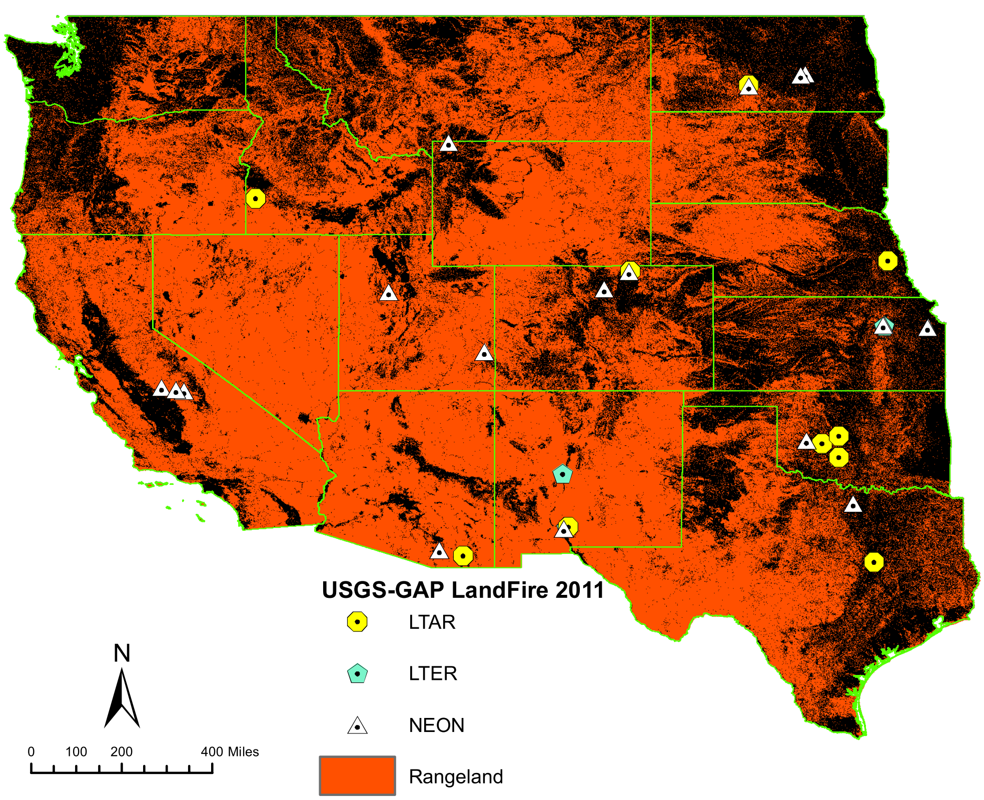

Figure 4—Western rangeland ecological research locations.

model input, the quantitative precipitation estimate, or QPE, based a fusion of information in NOAA's Multi-Radar Multi-Sensor (MRMS) from the new generation of dual-pol NEXRAD sensor, the new geostationary GOES 16, 17, T and U satellites, rain gages, lightning maps, etc. We can expect a much better understanding of vegetation structure, if not composition, from the long-term Landsat dataset, the Sentinel 2 sensor, the National Aerial Imagery Program (NAIP), a host of high resolution private earth observing satellites, point clouds from aerial lidar over large areas and Structure from Motion (SfM) point clouds based on drone photography over smaller areas. The same lidar collections will also characterize topography at very high resolution in association with the USGS 3D Elevation Program (3DEP), potentially leading to a 1 meter Digital Elevation Model across the West, a two order of magnitude improvement over the current 10 meter standard. Digital soil maps will undoubtedly improve over time, but it is unclear if current investments in rangeland soil mapping will lead to a consistent, up-to-date, West-wide soil map anytime in the near future. Similarly, detailed maps of the potential plant communities, ecological sites, will probably be available only on localized areas, although national scale estimates of vegetation characteristics such as production by Robinson and others (2018) are now possible. A combination of very detailed datasets, such as will be available from the NEON Airborne Observation Program (AOP) and less detailed, but spatially referenced vegetation datasets such as SageSTEP (Sagebrush Steppe Treatment Evaluation Project), the National Resource Inventory (NRI) of the NRCS and the Assessment, Inventory, and Monitoring (AIM) program of the BLM could define current vegetation, if not potential alternative States.

SUMMARY

In general terms, the 3 million km^2 western rangeland area identified in this preliminary study is slightly larger than the combined areas of the 11 westernmost States. As western watersheds are increasingly under stresses such as increasing populations and fires, as well as decreasing water supplies and public land management personnel, interagency cooperation based on a common scientific understanding will be required. This paper presents a small step toward more coordinated management of western watersheds by identifying the rangeland area and providing an inventory of the locations with longer-term measurements of watershed and ecological relationships. There are many more sites with useful hydrologic or ecologic observations, such as USGS stream gauging stations or vegetation monitoring plots, but the systematic interpretation of those shorter-term and less-complete datasets will require significant future efforts. Coordination of research and model development and validation with a watershed focus could better meet needs for rangeland watershed decisionmaking with limited budgets. A measure of success will be the extent to which research and action agencies share data, develop more coordinated efforts to collect and apply watershed-scale data, and ultimately develop a more specialized institutional framework to understand and manage western watersheds.

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COMPARISON OF THE CRITICAL-DEPTH METHOD WITH CONVENTIONAL INDIRECT METHODS OF COMPUTING PEAK DISCHARGE IN MOUNTAIN STREAMS AND AN EVALUATION OF THE 2013 RAINSTORM AND FLOOD IN THE COLORADO FRONT RANGE

Robert D. Jarrett

INTRODUCTION

This presentation provides a brief overview of the September 2013 Colorado Front Range rainstorm and flooding, an assessment of the NOAA Atlas 14 (which is derived from an analyses of point rainfall data obtained at precipitation gages), and a comparison of peak discharges computed with the critical-depth method as compared to standard, indirect-measurement methods. A critical component of flood science, watershed restoration, and watershed management is rapid and reliable data collection for subsequent water-resources investigations. In September 2013, up to about 510 mm of rainfall over 7 days produced record flooding over much of the Front Range. According to NOAA Atlas 14 (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html), the rainfall recurrence interval at many locations was at least 1,000 years. Though the storm was unique given the amount, footprint, and duration, many such rainfall amounts have occurred in eastern Colorado, which motivated this comprehensive rainstorm analysis. Since NOAA Atlas 14 became available in the past decade, there has been an increase in the number of reported 1,000-year storms in the United States (e.g., 2017 Harvey in Houston, TX, and two 1,000-year storms in 2 years in Ellicott City, MD; 2018 Flagstaff, AZ). Certainly, some 1,000-year storms are to be expected each year in the United States, but the rate of increase in such reports is questionable. This apparent increase in more 1,000-year storms has been part of the discussion of the effects of global climate change.

METHODS

NOAA Atlas 14 was used to estimate rainfall frequency of point rainfall values for extreme storms compiled in Eastern Colorado through 1997 (McKee and Doesken 1997) with the September 2013 Storm added. Most of these extreme storm data were from rainfall bucket surveys at ungaged sites. The analysis indicates more than a dozen storms exceeded not only the 1,000-year recurrence interval, but many storms exceeded 10,000 to 100,000-year recurrence intervals (fig. 1). The 2013 storm of 510 mm in about four days has about a 100,000-year recurrence interval. For comparison, the July 1976 Big Thompson Canyon storm, the deadliest flood in Colorado, had a point rainfall of about 355 mm in 4 hours; the associated recurrence interval far exceeds one million years. These results shown in figure 1 are implausible and strongly suggests NOAA Atlas 14 overestimates storm frequency for rare events in Colorado.

Estimating the magnitude and frequency of regional flooding first requires substantial peak-discharge documentation. One hundred-fifty indirect measurements were obtained using the critical-depth method where channel slope exceeds about 0.01 m/m at a cost-effective $250 per measurement vs. at least $10,000 for standard indirect-flood methods. Because of the extreme nature of flow hydraulics and sediment transport, the 2013 flood measurements were assigned an estimated uncertainty of ±20 percent. The September 2013 rainstorm produced widespread flooding typically with recurrence intervals of up to about 700 years in the areas of maximum rainfall (CH2MHILL 2014).

RESULTS AND DISCUSSION

Fifty-seven of the critical-depth indirect measurements were made at or near sites where standard indirect methods of computing peak discharge (slope-area, bridge contractions, 2-D hydraulic models, etc.) were made by five other flood teams. Although the true discharge often is unknown, the critical-depth method has been validated for mountain streams (slope ≥ 0.01 m/m) to be within about ±15 percent (Jarrett and England 2002); thus, the critical-depth method results was used as the basis of the comparison. Unfortunately, and unexpectedly, three estimates of flood discharge differed by more than about 200 percent and should be considered outliers (fig. 2). Most of the larger differences (> about 20 percent) were for smaller streams with discharges generally less than about 160 m^3/s in smaller, higher gradient channels where estimating Manning's n values is difficult, and the potential effects of channel erosion and deposition on flood discharges are the greatest. In addition, the largest differences were associated with one investigator having the least flood hydraulic experience.

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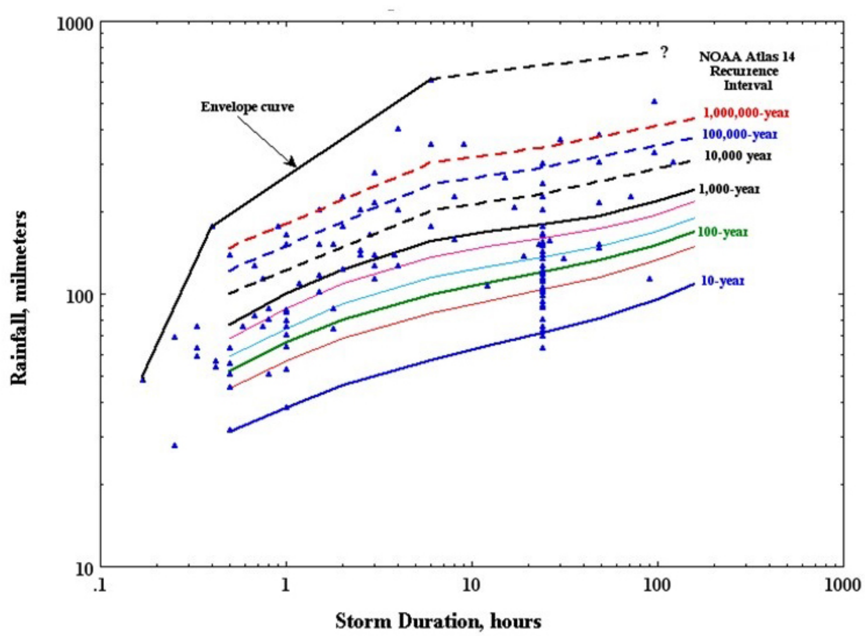

Figure 1—Rainfall frequency data compiled for eastern Colorado through 1997 and the September 2013 storm with NOAA Atlas 14 rainfall recurrence information; dashed lines are extrapolations. An envelope curve of maximum rainfall and storm duration in eastern Colorado also is provided, which shows an upper bound of extreme point rainfall amounts.

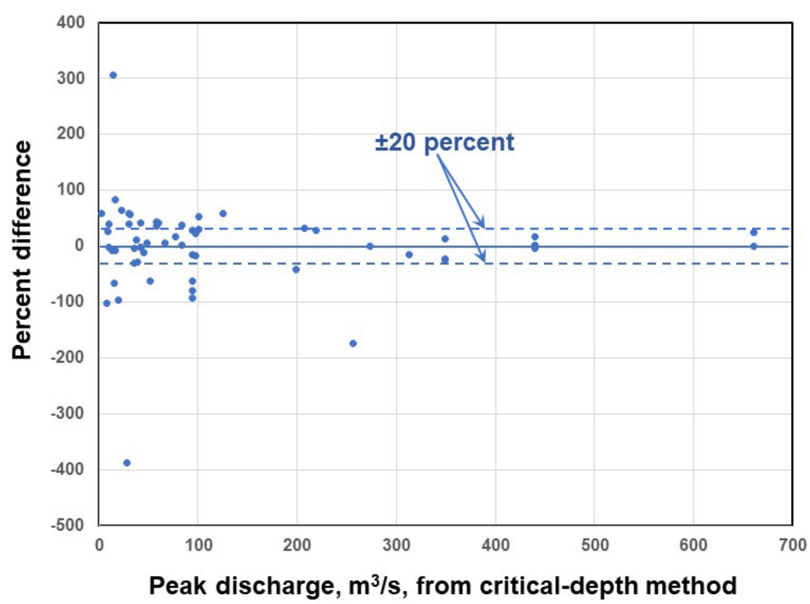

Figure 2—Difference in flood discharges using the critical-depth method and other standard indirect methods for estimating flood discharge in mountain rivers.

Scientists, engineers, and planners were provided these peak-discharge data and technical assistance to better understand the nature of the September 2013 flooding to help the region recover more effectively from flooding, for floodplain management, and design of new infrastructure located in the floodplain. The overarching goal of this presentation is a cost-effective method to document flood discharges and subsequent analyses provide better clarity of an extreme event's frequency than NOAA Atlas 14. The over-estimation of rainstorm recurrence interval is, in part, identified by the extreme discrepancy with the associated frequency for the 2013 Colorado flood. The most likely explanation is that NOAA Atlas 14 is only based on analysis of data at gaged sites. Improvements to NOAA Atlas 14 would benefit from use of thousands of point rainfall data at ungaged sites in the United States (e.g., bucket rainfall data as well as validated NEXRAD rainfall estimates). Additional assessments of NOAA Atlas 14 for estimating infrequent rainstorms appear warranted given the results in figure 1 to provide more realistic rainfall frequencies.

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MODELING URBAN HYDROLOGY AND GREEN INFRASTRUCTURE USING THE AGWA URBAN TOOL AND THE KINEROS2 MODEL

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Abstract—The Automated Geospatial Watershed Assessment (AGWA) Urban tool was developed to support the design and placement of a suite of Green Infrastructure (GI) practices, singularly or in combination, in order to simulate urban hydrology with and without GI features at the household and neighborhood scale. The AGWA Urban tool takes advantage of the advanced, physically based infiltration algorithms and geometric flexibility of the Kinematic Runoff and Erosion (KINEROS2) watershed model. The resulting software provides an up-to-date GIS Urban - GI assessment framework that automatically derives model parameters from widely available spatial data. The new tool was used to assess a variety of GI designs across a subdivision in Sierra Vista, AZ for design objectives to: (1) Maximize stormwater capture, (2) Maximize water augmentation, and (3) Maximize ecosystem services.

INTRODUCTION

In arid and semi-arid regions, green infrastructure (GI) can address several issues facing urban environments, including augmenting water supply, mitigating flooding, decreasing pollutant loads, and promoting greenness in the built environment. An optimal design captures stormwater, addressing flooding and water quality issues, in a way that increases water availability to support natural vegetation communities and landscaping in the built environment.

Some of the commonly applied GI practices include rain gardens, bioretention cells or basins, permeable pavements, green roofs, swales, infiltration trenches, roof runoff harvesting, and impervious disconnection (Dietz 2007).

Various urban hydrological models have successfully represented and simulated urban hydrology and GI practices (Elliot and Trowsdale 2007, Jayasooriya and Ng 2014, Zoppou 2001), and give a better understanding of physical hydrological processes within urban areas to analyze and mitigate urban water quality and quantity, along with the role of GI practices. Geographic Information Systems (GIS) provide various techniques to visualize, analyze, and interpret patterns, trends, and relationships in data (Goodchild and others 2005). Hydrology, with its geographic and spatial nature, is an ideal candidate for use in GIS (DeVantier and Feldman 1993, Stuart and Stocks 1993, Sui and Maggio 1999, Vieux 2001). Numerous hydrological models have been coupled with GIS to facilitate parameter extraction from spatial data and visualization of modeling results (Bhaduri and others 2000, Chen and others 2009, Lee and others 2012, Miller and others 2007, Srinivasan and Arnold 1994).

This study presents a GIS approach to simulating urban hydrology and GI using the Kinematic Runoff and Erosion (KINEROS2) model, and its integration with the Automated Geospatial Watershed Assessment (AGWA) tool. The objective of this study is to analyze the quantity of water from street runoff, and the potential of mitigating this rainfall excess using GI practices to maximize stormwater capture, water augmentation, and ecosystem services.

KINEROS2 MODEL

The KINEROS2 model was developed by the U.S. Department of Agriculture's (USDA) Agricultural Research Service (ARS). KINEROS2 is a spatially distributed, physically based, event driven model that simulates runoff and erosion for small watersheds (Goodrich and others 2012, Smith and others 1995). Overland flow is simulated using kinematic wave equations over rectangular elements with linear or curvilinear hillslopes, and through channelized flow in trapezoidal channels. Infiltration is simulated using a modified Smith-Parlange infiltration model (Parlange and others 1982).

KINEROS2 contains a rectangular urban element that consists of up to nine overland flow areas (fig. 1) that contribute to one-half of a paved, crowned street. These nine overland flow

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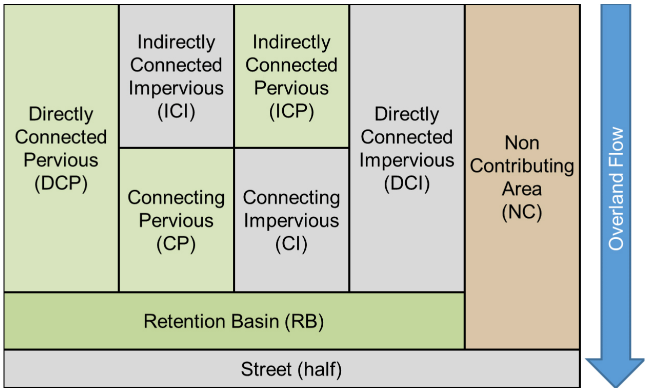

Figure 1—Overland flow areas available in the urban element of the KINEROS2 model.

areas include: (1) directly connected pervious (DCP) area, (2) directly connected impervious (DCI) area, (3) indirectly connected impervious (ICI) area, (4) indirectly connected pervious (ICP) area, (5) connecting pervious (CP) area, (6) connecting impervious (CI) area, (7) non-contributing (NC) area, (8) an infiltrating retention basin (RB) area, and (9) street half on to which the aforementioned overland flow areas contribute runoff. The urban element in KINEROS2 can be used to represent a single housing parcel or a number of parcels in an urban development (Kennedy and others 2013). The ICI can be used to represent roofs, DCI for driveways, CP for front yards and DCP for all other yards, NC for swimming pools or walled areas, and RB for retention basins or rain gardens on the parcels. A typical urban watershed can be represented as a series of urban elements with the assumption that runoff flows from each element into a street or alley half and follows the path along the street to the watershed outlet.

The capabilities of KINEROS2 to model urban hydrology in detail forms the basis of this study by representing each parcel in the watershed using the urban element.

AGWA TOOL

The AGWA tool was jointly developed by the USDA-ARS, the University of Arizona, and the U.S. Environmental Protection Agency, Office of Research and Development (EPA/ORD) (Goodrich and other 2012, Miller and others 2007). AGWA is a GIS-based tool that uses existing spatial datasets in the form of digital elevation models (DEM), land cover maps, soil maps, and weather data to prepare parameters for hydrological models. Currently, AGWA supports the Soil and Water Assessment Tool (SWAT) (Arnold and others 1998), the KINEROS2 model, and the Rangeland and Hillslope Erosion model (RHEM) (Nearing and others 2011). AGWA supplies the parameters to these models, executes the models, and imports the results back in the GIS for visualization and analysis. AGWA is designed to provide qualitative estimates of runoff and erosion relative to landscape change. It, like virtually all watershed models, cannot provide quantitative estimates without careful calibration using high quality rainfall-runoff observations.

The AGWA Urban tool utilizes the urban component in KINEROS2 to simulate urban hydrology with and without GI practices. Input parameters are generated from parcel, street, land cover, soils, and precipitation datasets. Additionally, inputs in the form of overland flow paths, and GI designs and locations can be manually provided. The AGWA Urban tool supports retention basins (e.g., bioretention cells, infiltration strips, infiltration basins), permeable driveways or walkways, disconnection, and rainwater harvesting cisterns as GI practices. Each parcel is represented as a KINEROS2 urban element. The AGWA Urban tool executes the KINEROS2 model based on these input parameters. Runoff and infiltration results are visualized as maps and peak flow results are displayed as hydrographs. Runoff and infiltration volumes can be visualized for each individual parcel and accumulated runoff volumes can be visualized along the streets as stormwater flows towards the outlet. Absolute and percent change comparisons are also available for runoff and infiltration volumes.

STUDY AREA

The La Terraza subdivision in Sierra Vista, AZ (fig. 2) was selected as the study area based on Kennedy's (2013) study, the availability of input datasets, and high-quality observations of rainfall and runoff. Sierra Vista is located in Cochise County in southeastern Arizona, at an elevation of approximately 1300 m, with an annual average precipitation

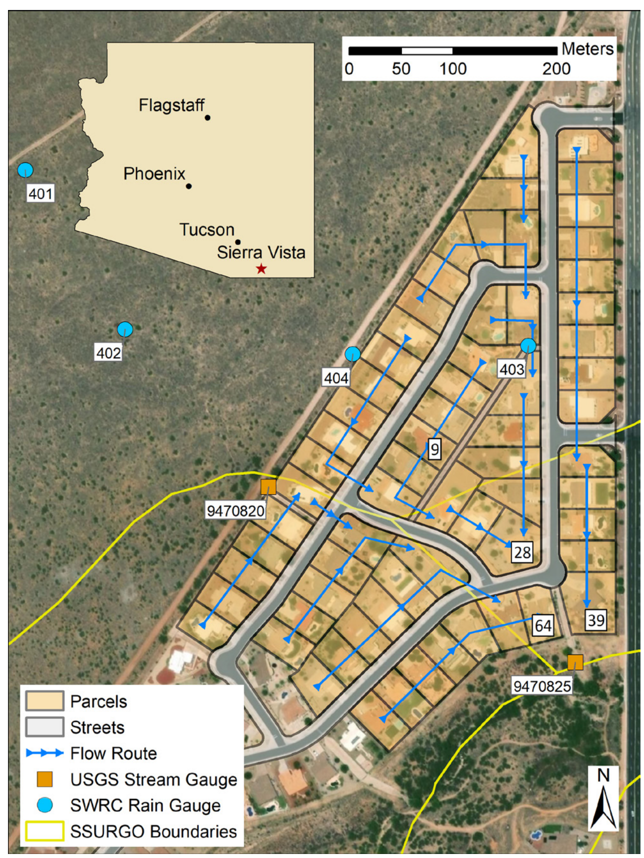

Figure 2—The La Terraza urban watershed in Sierra Vista, AZ.

of 360 mm and annual mean temperature of 17.4 ºC based on records over the period 1981-2000. The La Terraza subdivision is a residential development spanning 14 hectares located in the western part of the city. This study focused on an urban watershed consisting of 66 housing lots with an average parcel size of 1780 m^2, average house area of 380 m^2, average driveway area of 108 m^2, and 7.3 m wide asphalt streets within the La Terraza subdivision. The total impervious area in the watershed amounts to 5.48 hectares (39 percent of total watershed area), with street impervious area equal to 2.27 hectares (16 percent of total watershed area).

METHODS

The AGWA Urban tool was used to setup the input parameters for the model. Parcel and street files were obtained from the Cochise County' Information Technology department. The AGWA Urban tool accepts these files as inputs, and extracts parcel dimensions and street widths from them. Base map imagery, available in ArcMap, was used to determine the house and driveway areas on each parcel manually. Every parcel was assumed to have a front yard area and a noncontributing area equal to 10 percent of the total lot area. Values for slope, and land cover parameters were obtained from Kennedy and others (2013). Soil parameters were obtained using the USDA Soil Survey Geographic Database (SSURGO), with three different soil map units within the La Terraza urban watershed. Each parcel was assigned a specific set of soils parameters based on the soil map unit it intersected. Flow paths were drawn to represent the actual overland stormwater route converging towards three parcels (IDs 28, 39, 64) towards the southern part of the urban watershed (fig. 2). The output from these three parcels were combined to represent a single outlet. Stormwater was assumed to flow off the lots into the streets and along the streets to the outlet. This model representation was calibrated and validated by Korgaonkar and others (2014). Parcel ID 9 (fig. 2) and its representation using the urban element with and without GI practices, based on fractional areas of roofs, driveways, and yards is displayed in figure 3. ICI is used to represent roofs, DCI for driveways, CP for front yards, and NC for water sinks in yards. DCP is used to represent all remaining areas in the lot.

Five scenarios (table 1) were designed to assess the impact of roads on runoff and effect of GI in reducing runoff volumes and peak flows. Scenario 1 (S1) is considered as the base scenario, where the model (calibrated and validated by Korgaonkar and others 2014) was simulated over the analysis period of 10 years without any GI practices. In scenario 2 (S2), a retention basin was installed in each parcel. The retention basin was designed with a surface area equal to 10 percent of the total parcel area, a basin depth of 0.3 m, and a hydraulic conductivity of 8.3 mm/hr. The retention basin was assumed empty at the start of each rainfall event. Note that runoff from driveways represented by DCI is captured by the retention basins to simulate all runoff retention on the parcel itself. Scenario 3 (S3) converted all driveways to permeable driveways with a hydraulic conductivity of 8.3 mm/hr. In scenario 4 (S4), each parcel was installed with a 3.78 m^3 (1,000 gallon) cistern to simulate rainwater harvesting off the roofs. The cistern was assumed empty at the start of each rainfall event. For scenario 5 (S5), GI designs from S2, S3, and S4 were all installed on each parcel. Rainfall data was extracted from SWRC Gauge 403 (https://www.tucson.ars.

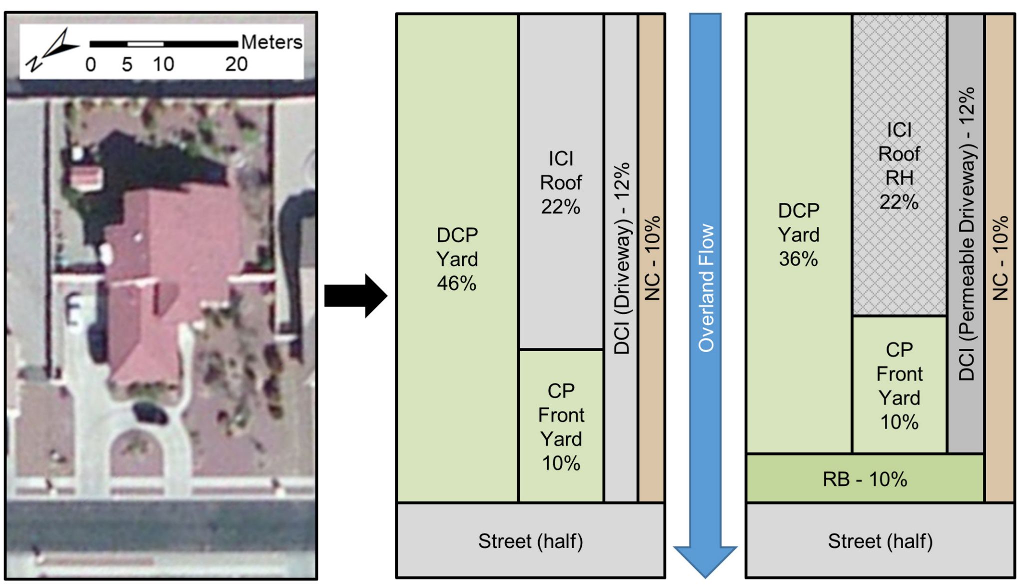

Figure 3—Parcel ID 9 in the La Terraza urban watershed (left), KINEROS2 representation without GI (center), and with retention basin (RB), permeable driveway and rainwater (RH) harvesting GI practices (right). Percent values of each of the overland flow areas are indicative of the percent of the total parcel area.

Table 1—Description of the five case study scenarios

Scenario	GI practice	Description
S1	Base - No GI practices	Validated model without any GI practices
S2	Retention Basin (RB)	S1 with retention basin on all 66 parcels. Retention basin area equals 10 percent of the parcel area, depth equals 0.3 m, and hydraulic conductivity of 8.3 mm/hr. Average retention basin capacity equals 53.41 m^3.
S3	Permeable Driveways (PD)	S1 with all 66 driveways considered permeable with a hydraulic conductivity of 8.3 mm/hr
S4	Rainwater Harvesting (RH)	S1 with a 3.78 m^3 cistern on each of the 66 parcels capturing roof runoff
S5	All GI practices	S1 with GI designs from S2, S3, and S4 in combination on each of the 66 parcels

ag.gov/dap/) for the period ranging from January 2006 to December 2015, comprising 787 rainfall events. Initial soil saturation was assumed 0.20 for all events. The analysis was run with a 1-minute time step for each of the rainfall events in the 10-year period.

RESULTS AND DISCUSSION

Figure 4 shows the monthly rainfall volumes, averaged over a period of 10 years. The months of June, July, August, and September represent the monsoon season with high rainfall volumes, characterized by short duration, high intensity thunderstorms caused by convective lifting. In the winter months, rainfall volumes are low and caused by long duration, low intensity frontal storms (Brooks and others 2003, Sheppard and others 2002).

Figure 5 and table 2 summarize the average monthly runoff volumes at the watershed outlet for the five scenarios described in table 1. From simulation results, S2 (retention basins), and S5 (a combination of all GI practices) have the highest reduction in runoff volumes at the outlet, followed by S3 (permeable driveways), and S4 (rainwater harvesting), respectively. Scenarios S2, S4, and S5 have a larger impact during the monsoon months due to larger rainfall excess volumes captured by the GI practices. However, for the smaller events during the rest of the year, permeable driveways perform similar to the other GI practices. It should be noted that these results are dependent on viably selected GI designs based on the parcel dimensions and configurations. Any change in these design parameters can consequently result in changes in infiltration and runoff volumes.

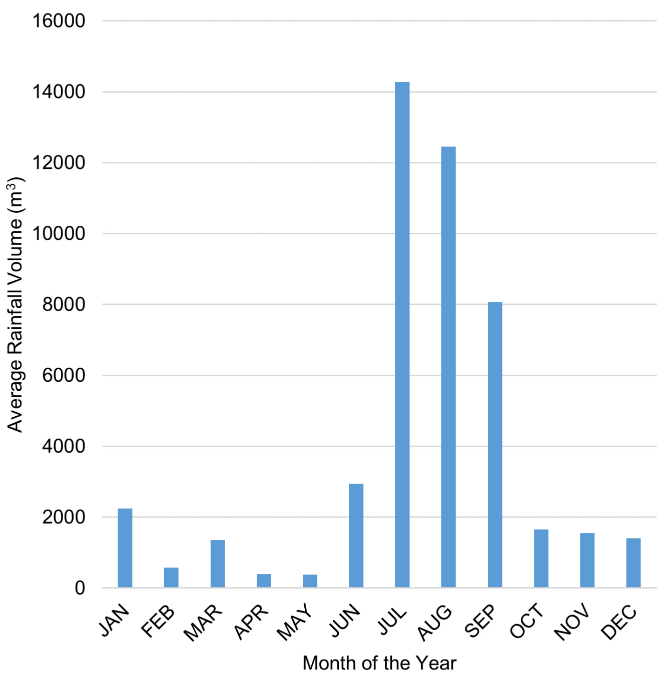

Figure 4—Rainfall volumes averaged over a period of 10 years (January 2006 to December 2015).

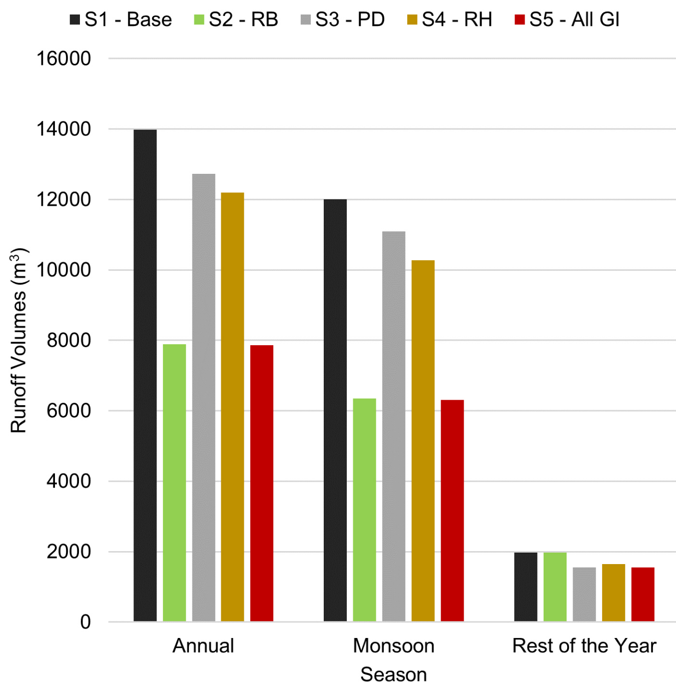

Figure 5—Runoff volumes (averaged over a simulation period of 10 years) for the five case study scenarios. (RB–with retention basin, PD–with permeable driveways, RH–with rainwater harvesting) summarized based on seasons.

Table 2—Monthly runoff volumes at the watershed outlet for the five case study scenarios averaged over a period of 10 years (January 2006 to December 2015) and percent reduction in monthly runoff volumes for the scenarios as compared to S1 for the same period

Month	Rainfall Volume (m^3)	Runoff volumes at watershed outlet (m^3) andvolume reduction compared to S1 (%)								
		S1 - Base No GI	S2 - RB		S3 - PD		S4 - RH		S5 - All GI	
			m^3	%	m^3	%	m^3	%	m^3	%
January	2245	479	363	24	390	19	470	2	363	24
February	571	106	92	13	93	13	106	< 1	92	13
March	1349	271	218	20	229	16	264	3	218	20
April	392	77	63	18	64	17	77	1	63	18
May	383	79	62	21	63	20	78	1	62	21
June	2944	1057	476	55	993	6	953	10	476	55
July	14274	4706	2552	46	4368	7	4013	15	2519	46
August	12448	3958	2013	49	3669	7	3344	16	2013	49
September	8064	2287	1304	43	2058	10	1968	14	1304	43
October	1659	361	268	26	307	15	333	8	268	26
November	1552	325	251	23	269	17	318	2	251	23
December	1399	277	226	18	231	16	273	1	226	18

Additionally, the assumption of empty retention basins and cisterns before each event is representative of best-case scenarios, or ideal conditions. This may not be practical, and the actual effectiveness of these practices will reduce.

In the case of S1, the base scenario, street runoff and parcel runoff are approximately equal for the monsoon months (fig. 6). This can be attributed to larger rainfall volumes in the monsoons, which generate larger runoff from the parcels as compared to the rest of the year when the streets account for 75 percent or more of the total runoff volume at the outlet. Streets account for about 50 percent of the total impervious area in the urban watershed but generate higher runoff due to higher connectedness. There is potential to capture this runoff by either introducing breaks in the hydrological connectedness of the street network and diverting runoff into GI practices along the streets, or by converting parts of impervious streets into pervious areas. A viable option would be to introduce infiltration practices like rain gardens, galleries, basins or swales along the streets that can capture runoff as it flows down the street. These practices can not only provide flood mitigation, but also support native vegetation and landscaping to improve the neighborhood aesthetics.

CONCLUSIONS

The AGWA Urban tool provides a user-friendly interface to parameterize and run the KINEROS2 model for urban hydrology and GI analysis. It uses commonly available parcel, street, soil, and precipitation datasets to extract parameters for each individual parcel in an urban watershed. The KINEROS2 model provides nine overland flow areas (fig. 1) to simulate run-on and runoff overland flow-processes for different areas within a parcel. This representation allows for simulation at a small scale, to understand the different hydrological processes occurring on each parcel. The AGWA tool is also capable of displaying results in the form of infiltration and runoff volumes, and hydrographs.

Five scenarios (table 1) were simulated to analyze the impact and effectiveness of retention basins, permeable driveways and rainwater harvesting on flood mitigation. These scenarios were designed to help understand the effects of streets on overall runoff volumes at the watershed outlet. Simulations were carried out over a period of 10 years (January 2006 to December 2015) with 787 rainfall events. Simulation results indicated that retention basin installations in each parcel were able to reduce the total runoff at the outlet by up to 55 percent, with a higher reduction during the monsoon months of June, July, August, and September (fig. 5). Behind retention basins, rainwater harvesting off roofs had the second highest reduction in terms of total runoff volumes, followed by permeable driveway installations. It should be noted that for the smaller events during the rest of the year, permeable driveways were able to capture more rainfall excess as compared to the other GI practices, thereby reducing overall runoff volume due to their connectedness to streets. For S2 and S5, runoff from the parcels was zero and simulated runoff at the watershed outlet; all generated from the streets. This is evident from equal runoff volumes for both scenarios (table 2).

At the individual parcel scale, GI practices can help reduce runoff, foster infiltration, and supplement outdoor water use via roof runoff capture. At the neighborhood scale, street generated runoff can be a potential candidate for capture via GI practices. In the La Terraza subdivision, streets accounted for nearly 50 percent of the total impervious area and contributed the same percentage (and more for smaller events) of runoff volumes. This shows the potential to route this water into basins that can support native vegetation and increase the greenness for a neighborhood. The trees that would grow from these installations would provide shade and help in reducing the heat island effect in these areas. Although our focus has been GI practices at the parcel level, there is potential for runoff capture from streets, with numerous benefits at the neighborhood scale.

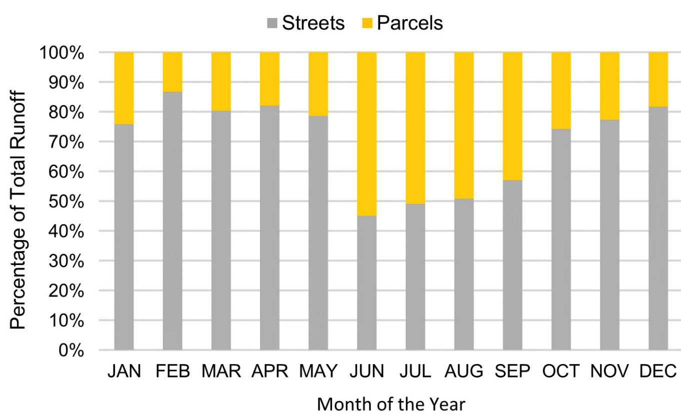

Figure 6—Percentage of monthly runoff volumes (averaged over a simulation period of 10 years) generated by streets and parcels for the S1–Base scenario.

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MAPPING STREAM AND FLOODPLAIN GEOMORPHIC CHARACTERISTICS WITH THE FLOODPLAIN AND CHANNEL EVALUATION TOOLKIT (FACET)

Marina Metes, Kristina Hopkins, Gregory Noe, and Samuel Lamont

Abstract—The Floodplain and Channel Evaluation Toolkit (FACET) was developed as an open source tool to calculate a suite of geomorphic metrics describing channel and floodplain geometry from high-resolution digital elevation models (DEMs), providing estimates of channel width, bank height, cross-sectional area, and active floodplain extent. Field data from sites in the Chesapeake Bay and Delaware River watersheds were used to calibrate and validate FACET within four physiographic provinces: (1) Coastal Plain, (2) Piedmont, (3) Valley and Ridge, and (4) Appalachian Plateau. FACET has built-in pre-processing steps to hydrologically condition DEMs using open-source tools (Whitebox GAT, TauDEM) and the stream network is delineated using the initiation points of an existing stream layer such as the High Resolution National Hydrography Dataset. Stream banks are identified using two methods: (1) by applying a slope-threshold method at cross-sections which are automatically generated at a user-defined interval along the delineated stream network, and (2) by applying a curvature-threshold method for grid cells within a buffered distance from the stream network. The active floodplain is identified using a height above nearest drainage (HAND) grid and empirical regression models built for each physiographic province relating the HAND threshold to drainage area. Channel and floodplain metrics are extracted from each method. Other user-defined input parameters control the sensitivity of calculations to sinuosity, relief, and channel/floodplain width, allowing for the ability to optimize FACET at multiple scales and/or regions if field survey data are available for calibration. The increasing availability of high-resolution elevation data provides the ability to scale up field-based measurements to the watershed scale. Geomorphic metrics derived from FACET can be related to field measurements of bank erosion and floodplain deposition rates to predict fluxes at unmeasured reaches and improve the development of watershed sediment and pollutant budgets. Geomorphic metrics also can improve regional-to-national scale hydrologic and water quality models and support land and water resource management decisionmaking.

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INTEGRATING LIDAR DATA AND GOOGLE EARTH ENGINE FOR MAPPING WATERSHED-SCALE WETLAND HYDROLOGICAL DYNAMICS

Qiusheng Wu and Charles Lane

Abstract—The Prairie Pothole Region of North America is characterized by millions of depressional wetlands, which provide critical habitats for globally significant populations of migratory waterfowl and other wildlife species. Due to their relatively small size and shallow depth, these wetlands are highly sensitive to climate variability and anthropogenic changes, exhibiting inter- and intra-annual inundation dynamics. The National Wetlands Inventory (NWI) for this region was developed decades ago through manual interpretation of black-and-white aerial photographs acquired in the 1980s, which is static and out of date. Traditional medium-resolution satellite imagery (e.g., Landsat, MODIS) do not effectively delineate these small depressional wetlands. By integrating high-resolution Light Detection and Ranging (LiDAR) data, time-series aerial photographs from the National Agriculture Imagery Program (NAIP), and Google Earth Engine, we developed a workflow for mapping wetlands and analyzing their hydrological dynamics at watershed scales. Machine learning algorithms were used to classify aerial imagery with additional spectral indices to extract wetland inundation areas, which were further refined using LiDAR-derived landform depressions. The wetland delineation results were then compared to the NWI dataset to evaluate the performance of the proposed method. We tested the workflow on the 2270-km^2 Pipestem Creek subbasin in North Dakota (2009 - 2015). The results showed that the proposed method can not only delineate the most up-to-date wetland inundation status but also demonstrate wetland hydrological dynamics, such as wetland coalescence through the fill-spill hydrological processes. Our workflow provides a scalable framework readily available to be adapted to delineate wetlands at regional and national scales.

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SECTION 5

Watershed Research and Management

PROJECTING REGIONAL CLIMATE CHANGE FOR AIR QUALITY AND WATER QUALITY APPLICATIONS

Tanya Spero, Jared Bowden, Megan Mallard, and Chris Nolte

Abstract—This presentation will provide an overview of methods to downscale future global climate projections to characterize climate change at regional and local scales. Changes in weather patterns and extreme events have implications for air quality, water quantity, and water quality that can inform decisions related to watershed management. Although both statistical and dynamical downscaling techniques will be discussed, the focus will be on the more resource intensive dynamical downscaling. Examples will be shown from dynamical downscaling fields developed by the U.S. Environmental Protection Agency and their research partners. In addition, several of the nuances and limitations of each approach will be presented.

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DEVELOPING INTENSITY-DURATION-FREQUENCY (IDF) CURVES FROM MODELED METEOROLOGICAL FIELDS TO INFORM STORM WATER MANAGEMENT UNDER FUTURE SCENARIOS

Anna M. Jalowska and Tanya L. Spero

Abstract—Extreme precipitation has important implications for watershed management, agriculture, urban and rural development, public infrastructure, and human health. Based on 30-year flood loss averages, flooding associated with extreme precipitation causes 82 casualties and about 7.96 billion dollars in damages across the United States each year. Intensity-Duration-Frequency (IDF) curves are a common tool used to account for extreme precipitation events in urban and environmental planning. The IDF curves estimate a frequency of occurrence of extreme rain events (rainfall amount within a given period of time) based on frequency analyses of the available historical observational data. Often the data for frequency analyses are not available. This study develops a methodology to produce IDF curves for three cities in the Southeastern United States for a 23-year historical period (1988–2010), using a 36-km dynamically downscaled Weather Research and Forecasting (WRF) model simulation. The results are verified against historical observational data. This study applies the IDF curve methodology to project future extreme precipitation probabilities for 75 years (2025-2100) by dynamically downscaling future climate projected by the Community Earth System Model (CESM) under Representative Concentration Pathway 8.5 (RCP 8.5) to 36 km. U.S. historical climate records since 1950s indicate an increase in frequency and intensity of extreme precipitation in the Eastern United States. Recent climate research suggests that the frequency and magnitude of extreme precipitation in the U.S. will continue to increase throughout the 21st century. Preliminary data from the CESM-WRF RCP 8.5 future scenario, indicate ~30 percent increase in annual precipitation from 2025 to 2100. The 100-year recurrence interval precipitation amounts exhibit a median increase of ~6 percent with the highest change in the 1-h (~11-percent increase) and 24-h (~16-percent increase) return periods. The 2-year recurrence interval precipitation amounts demonstrated highest median increase of 12 percent, with most significant change in the 12-h (~17-percent increase) and 24-h (~16-percent increase) return periods. The methodology presented in this study will be used to develop a database for the EPA's National Risk Management Research Laboratory (NRMRL) Storm Water Management Model (SWMM).

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SOIL MOISTURE SCALING FUNCTION DEVELOPMENT FOR THE LITTLE RIVER EXPERIMENTAL WATERSHED

M. H. Cosh, D. D. Bosch, A. Coffin, T. J. Jackson, A. Colliander, S. Chan, R. Bindlish, W. Crow, and S. Yueh

Abstract—Soil moisture remote sensing scales are on the order of 3–36 km with the advent of the Soil Moisture Active Passive Mission (SMAP). In situ networks that are used to calibrate and validate these remote sensing products also exist in this range of scales, but there are challenges to be met in estimating the soil moisture across an entire region with a network of sensors. Scaling functions have been developed to estimate large scale soil moisture from these sensor networks in the most accurate means possible. For example, the Little River Experimental Watershed near Tifton, GA, is a SMAP Core Validation Site and while it had a low error (< 0.03 m^3/m^3) when compared to the SMAP data product for the region, there was a considerable bias (~0.10 m^3/m^3) present. A field experiment was developed to update the scaling function used for the Little River region by deploying a temporary network across a greater selection of land covers than were previously covered by the permanent soil moisture network. After 6 months of deployment it was possible to create a new function which decreased the bias of the network to approximately 0.045 m^3/m^3, a significant improvement.

Author information: M. H. Cosh, D. D. Bosch, A. Coffin, T. J. Jackson, A. Colliander, S. Chan, R. Bindlish, W. Crow, and S. Yueh of the U.S. Department of Agriculture, Agricultural Research Service.

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IMPACTS OF POTENTIAL CHANGES OF LAND USE, CLIMATE, AND WATER USE FOR WATER AVAILABILITY, COASTAL CAROLINAS

Ana Maria Garcia and Laura Gurley

Abstract—Sustainable growth in coastal areas with rapidly increasing populations, such as the coastal regions of North and South Carolina, relies on an understanding of the current state of coastal natural resources coupled with modeling future impacts of changing coastal communities and resources. Changes in climate, water use, population, and further urbanization will place additional stress on societal and ecological systems that are already competing for water resources. The potential effects of these stressors on water availability are not fully known, and future management of water resources and planning efforts to meet societal and ecological needs requires estimates of likely changes in population growth, land-use, and climate.

Two Soil and Water Assessment (SWAT) models were built to help address the challenges that water managers face in the Carolinas: the (1) Cape Fear and (2) Pee Dee drainage basins. SWAT is a basin-scale, process-based watershed model with the capability of simulating water-management scenarios. Model areas were divided into 2 square mile subbasins to evaluate ecological response at headwater streams. Subbasins were subsequently divided into smaller, discrete hydrologic response units based on land use, slope, and soil type. Data compiled on water-use from 2000-2014 were included. These water-users included public water supply, industrial water use, irrigation needs, and golf courses. Potential future streamflow values were also estimated based on a suite of scenarios that coupled land use change projections, climate projections, and water use forecasts. The approaches and new techniques developed as part of this project can be transferred to other growing coastal areas that face similar water availability conflicts.

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QSWAT MODELING FOR FORECASTING HYDROLOGIC BEHAVIOR IN A COASTAL FORESTED WATERSHED IN THE GLOBAL CLIMATE CHANGE SETUP

Sudhanshu Panda, Devendra M. Amatya, and Ge Sun

Abstract—Understanding the potential impacts of climate change and associated stresses on water resources is key to develop overall adaptation responses to minimize negative consequences at the local level. Streamflow and depth to water table within the forest landscape of the lower coastal plain along the Southeastern Atlantic Ocean is heavily dependent on precipitation and evapotranspiration. The main goal of this study is to set up and apply a distributed watershed-scale model for Turkey Creek water, a typical forest watershed within the U.S. Department of Agriculture Forest Service Francis Marion National Forest in coastal South Carolina to forecast hydrologic effects of future climate change. We used the QSWAT (QGIS based Soil and Water Assessment Tool) model to assess the impacts of climate change on the water balance, water yield, flooding, and droughts on the low-gradient coastal forested watershed. High-resolution LiDAR data was used to develop the DEM for delineating watershed boundary and hydrologic modeling along with classified landuse data using 1m resolution NAIP imagery, SSURGO and the National Forest soils database. Precipitation and weather data from stations within the site were used as model input along with other default QSWAT database as primary model inputs. Model calibration and validation for the baseline watershed condition was conducted using the 10-year (2005–2014) streamflow data. The validated SWAT model is further applied to analyze the hydrologic effects of potential climate change using two contrasting scenarios of future climate from the regional climate models for 2015 to 2050. The QSWAT simulation model used multivariate Adaptive Constructed Analogs (MACA) daily weather data (precipitation, air temperature, humidity, wind speed, and solar radiation) obtained from five CMIP models. They are: Beijing Climate Center Climate System Model (BCC_CSM1.1), Canadian Centre for Climate Modeling and Analysis (CanESM2) model, National Center of Atmospheric Research, USA (CCSM4) model, NOAA Geophysical Fluid Dynamics Laboratory, USA (GFDL-ESM2G) model, and the Met Office Hadley Center, UK (HadGEM2-CC) model. Simulation results of water yield and evapotranspiration for these scenarios are analyzed for understanding the hydrologic response to climate change. Information gained from this study should serve for management decision support in the low-gradient forested watersheds in the region.

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CAN MOUNTAINOUS TERRAIN WITHIN PUERTO RICO BUFFER THE PROJECTED SUBTROPICAL PRECIPITATION DECLINE?

Jared Bowden, Adam J. Terando, and Tanya L. Spero

Abstract—A robust response of global climate models (GCMs) in the coming decades to increasing greenhouse gases is a global decline in subtropical precipitation, particularly over the oceans. This is a concerning result for small island nations, especially those within the Caribbean, as the exposure to long-term drying will likely create significant stresses to already vulnerable ecosystems and water resources. However, climate change projections from GCMs cannot resolve the terrain and land use/land cover that interact with the prevailing trade winds to create sharp precipitation gradients over short distances (< 10km), which promote a rich mosaic of habitats in this "Ridge-to-Reef" system. High resolution regional climate models (RCMs) can better resolve the mountainous terrain and associated microclimates, such as those within Puerto Rico which sits in the heart of the large-scale precipitation decline in the Atlantic Ocean.

To illustrate the effects of the terrain on the climate and precipitation regime of Puerto Rico, two different GCMs are dynamically downscaled using a RCM to a 2-km horizontal resolution centered on mid-century, 2040–2060, for a business as usual (RCP 8.5) greenhouse gas scenario. Results from these climate change realizations suggest that higher elevations within Puerto Rico may buffer the large projected subtropical precipitation decline. This presentation will discuss the robustness of these results and compare them to a statistical downscaling method that depicts more drying at higher elevations in the future. We highlight the implications for both water resource and natural resource management in Puerto Rico and similar areas around the world.

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THE VALUE OF LONG-TERM RESEARCH AT U.S. GEOLOGICAL SURVEY RESEARCH WATERSHEDS

James Shanley, Mike McHale, and Pete Murdoch

Abstract—Long-term research catchments are sentinel sites for detecting, documenting, and understanding environmental change. The small watershed approach fosters advances in understanding fundamental hydrological, biogeochemical, and ecological processes, while a collective network of catchment observatories offers a broader context to synthesize understanding across a range of climates and landscapes. We report here on the value and successes of small watershed programs of the U.S. Geological Survey, with examples from the Water, Energy, and Biogeochemical Budgets (WEBB) program, and small watershed studies in the Catskill and Adirondack Mountains in New York. We also nest those watersheds in the context of regional small watershed networks such as the National Network of Reference Watersheds. Long-term datasets are vital to understanding trends and effects of changing climate and atmospheric deposition. Institutional support for long-term monitoring provides infrastructure and context that foster academic partnerships for focused shorter term grants. Research watersheds are test sites for new methods and technologies, allow iterative hypothesis testing, and are training grounds for the next generation of scientists. In the current era of de-emphasis of field observations and declining budgets for science, it is especially important to sustain research watershed programs for their scientific value and societal benefits.

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TRENDS IN WATER YIELD UNDER CLIMATE CHANGE AND URBANIZATION IN THE U.S. MID-ATLANTIC REGION

Glenn Moglen, S. Kumar, A. Godrej, H. Post, and T. Grizzard

Abstract—Changes in climate and land use are two primary drivers of hydrologic adjustment. This study analyzes 40 years of water resources data for 10 watersheds in the Washington, DC, metropolitan area to quantify the impact of climate change and urbanization on water yield. The watersheds investigated have experienced varying degrees of land use change, from relatively little change to rapid and extensive urbanization. Comparing the data trends for different watersheds allows the separation of effects due largely to climate from those due to land use change. Predominantly rural watersheds show a steady decline in annual water yield while predominantly urban watersheds do not show any similar trend with time. Separating the year into growing versus non-growing seasons reveals that limited evapotranspiration from urban surfaces during the growing season or the general effects of a leaking water distribution network may mask the reductions in water yield in urban watersheds from changing climate. These analyses provide hydrological evidence for generally enhanced evapotranspiration and complex interactions between concurrent climate change and urbanization within the study area.

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IMPLICATIONS OF CLIMATE AND EMISSIONS CHANGES ON ATMOSPHERIC NITROGEN DEPOSITION TO THE CHESAPEAKE BAY WATERSHED

Patrick Campbell, Jesse O. Bash, Chris Nolte, Tanya Spero, Ellen J. Cooter, Kyle Hinson, and Lewis Linker

Abstract—Atmospheric deposition remains one of the largest loadings of nutrients to the Chesapeake Bay Watershed (CBW). The interplay between future climate and emission changes, however, will cause shifts in the future nutrient deposition abundance and regime [e.g., oxidized vs. reduced nitrogen (N)]. In this work we use a Representative Concentration Pathway 4.5 W m^{-2} (RCP4.5) scenario-driven Community Earth System Model version 1.0, and dynamically downscale an offline WRF version 3.8.1 and CMAQ version 5.2 model system coupled to the agro-economic Environmental Policy Integrated Climate (EPIC) model. We use the model system to explore the relative impacts of emission and climate changes on atmospheric nutrient deposition to the CBW for a current (CURR: 1995–2004) and a future period (FUT: 2045–2054). The regional emission projections in CMAQ are based on Federal and State regulations promulgated in 2015, which use baseline and projected emission years 2011 and 2040, respectively. Evaluation of the downscaled WRF/CMAQ CURR simulations in the CBW show a good agreement in average 2-meter temperature (CBW average mean bias ~ +1.5 K) and precipitation (CBW average mean bias ~ +12.4 mm) compared to reanalysis datasets, with a warmer (CBW relative change ~ +14 percent) and wetter (CBW relative change ~ +4 percent) FUT period under RCP4.5. An approximate WRF/CMAQ CURR comparison against surface observations of wet deposition (WDEP) of inorganic PM2.5 species also shows good agreement, except for larger underpredictions in WDEP of PM2.5 nitrate. Climate and deposition changes impact the EPIC agroecosystem changes, leading to increases in FUT ammonia (NH_3) fertilizer application and crop soil content, which in turn affects the CMAQ bi-directional NH_3 surface exchange in the CBW. These changes along with widespread decreases anthropogenic nitrogen oxides (NO_x) emissions (U.S. average ~ -51 percent), but increases in agricultural NH_3 emissions (U.S. average ~ + 2 percent) projected in the FUT period leads to a shift towards relative decreases in total oxidized N deposition (CBW seasonal average ~ -40 to -50 percent), along with increases in total reduced N deposition (CBW seasonal average up to ~ +20 percent) that are dominated by NH_3 dry deposition changes.

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SEASONALITY OF ORTHOPHOSPHATE IN THREE FRESHWATER TRIBUTARIES TO THE CHESAPEAKE BAY

Karen C. Rice, Aaron L. Mills, Rosemary Fanelli, and Alexander M. Soroka

Abstract—Thirty years (1985-2014) of dissolved inorganic phosphate, orthophosphate (OP), data were analyzed in three tributaries to the Chesapeake Bay, the Choptank, Patuxent, and Rappahannock Rivers. OP concentrations and fluxes varied with respect to each watershed's response to climate, land use, and streamflow. Cumulative fluxes of OP in the Rappahannock River were greater in the cool season than the warm season, due to greater streamflow. The Patuxent River exported more OP in the warm season, and the Choptank River exported OP nearly equally in the two seasons. The OP response in the Patuxent River was dominated by land use and modified by streamflow. The Choptank River exports OP that is unable to be stored in the watershed because the sorption sites may be filled; some of the OP release may be temperature facilitated. The differences among the watersheds' responses to climate, land use, and streamflow indicate that management strategies need to address the dominant factors controlling transport of OP, so that it may be managed with maximum efficacy.

INTRODUCTION

In fresh water, inorganic phosphorus (P) is the critical element controlling eutrophication (e.g., Upreti and others 2015). Orthophosphate (PO_4^{3-}, abbreviated as OP) is the dissolved form (water sample was passed through a 0.45-µm pore-diameter filter) of inorganic P. OP, also termed soluble reactive inorganic P, is readily bioavailable. Concentrations of OP are always lower than sorbed or complexed P, and OP may comprise as much as 20 percent of the total inorganic P. Most P is sorbed to or complexed with some solid phase material at all pH values.

Land cover and anthropogenic land use exert controls on stream-water chemistry. Wastewater-treatment plant effluent, failing septic systems, feedlot runoff, and excess fertilizers applied to agricultural fields all can lead to elevated concentrations of P in groundwater, surface water, and other downstream receiving waters. Non-point-source inputs of P to watersheds include farm and urban/suburban fertilizers and animal manures. Additionally, OP can be derived from manure stockpiles where leaching waters reach preferential flow paths (i.e., macropores) in the subsurface, allowing passage to groundwater or surface water with minimal contact with soil particles (Wyngaard and others 2011). In contrast, runoff from agricultural fields carries P bound to suspended particulates (around 90 percent) (Weil and Brady 2016). Point-source inputs of P include industrial and municipal effluents and combined-sewer overflow (CSO), where storm drainage is added to domestic waste in sanitary sewerage systems. In general, P from wastewater-treatment plants and failing septic systems is OP (e.g., Millier and Hooda 2011).

River discharge also can influence water chemistry by affecting the loading of P. For example, a melting snowpack or large rain event over saturated soils can result in overland runoff during which the discharging water never contacts mineral surfaces to which P is sorbed. In such cases, concentration of OP in the river water may be decreased by dilution with the overland runoff, but fluxes might remain the same due to the increased overall discharge.

Water temperature (WT) also exerts control on stream-water chemistry. Changes in WT can cause physiochemical and/or biogeochemical changes to affect water quality. The majority of P sorption to sediment is thought to be irreversible under oxidized conditions (Sharpley and others 1993). Under some conditions, however, P may desorb from particulates, increasing OP concentrations in pore waters and ultimately the overlying water column, particularly in lakes (Correll 1998). In a laboratory study, Duan and Kaushal (2013) reported that as WT increased, OP was released from sediments by microbiologically mediated degradation of the organic material to which the P was sorbed. Similarly, Upreti and others (2015) conducted field and laboratory analyses in a stream in the Chesapeake Bay (CB) watershed and observed release of P as a result of changes in pH, increases in WT, and especially as a result of increases in microbial activity. In contrast, in rice paddy fields, Sugiyama and Hama (2013) observed that sorption of P was enhanced by increased temperatures. However, they noted that when OP concentrations in water overlying sediments were very low with respect to the concentration of bound P, the sediments acted as a source of P to the overlying water, even when the WT was high.

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Despite the importance of OP in eutrophication of fresh waters (e.g., Correll 1998; Jarvie and others 2017), and despite a few essential works (e.g., Boynton and others 1995; Sharpley 2000; Zhang 2018), OP sources, dynamics, and fate in the CB watershed still are not well understood. The CB watershed lacks a multi-year, multi-watershed analysis of OP. To address that void, we examined 30 years (1985-2014) of OP data for three major CB rivers. We focused on processes within the rivers that could affect their freshwater portions, rather than the effect of those processes and fluxes on the estuarine environment far downstream. Our objective was to examine 30 years of OP dynamics and seasonality to identify the major controls on OP mobility to the downstream environment.

Study Area

The 166,319-square kilometer (km^2) CB watershed extends from southern New York to southern Virginia, and includes parts of six States as well as the District of Columbia (fig. 1). The U.S. Geological Survey (USGS) and partner agencies have monitored the nutrient and sediment input in nine of the CB watershed's large tributaries for more than 30 years (Moyer and others 2017). The monitoring stations are gaged and sampled upstream of the extent of tidal influence. In this paper, we focused on OP data collected at three of the stations: (1) Choptank River; (2) Patuxent River; and (3) Rappahannock River (fig. 1). The watersheds were chosen on the basis of their relatively small sizes and the range in land use among the three stations.

The three watersheds are distinguished by some important physical characteristics (fig. 1; table 1). The Choptank River flows entirely across the Coastal Plain Physiographic Province, which has minimal topography (watershed slope of 0.1 percent) and is composed predominately of unconsolidated sand. The Choptank River watershed is the smallest of the three and has the highest percentage of agricultural land, which includes intensive poultry production (Falcone 2017). The Patuxent River originates in the Piedmont Physiographic Province and extends into the Coastal Plain Physiographic Province. The Patuxent River watershed has by far the highest human population density, the highest percentage of developed land, and the highest wastewater-treatment plant density (Falcone 2017). The Rappahannock River watershed, the largest of the three, drains only the Piedmont Physiographic Province. The Piedmont was formed by the weathering of ancient igneous and metamorphic rocks, resulting in a thick residuum of

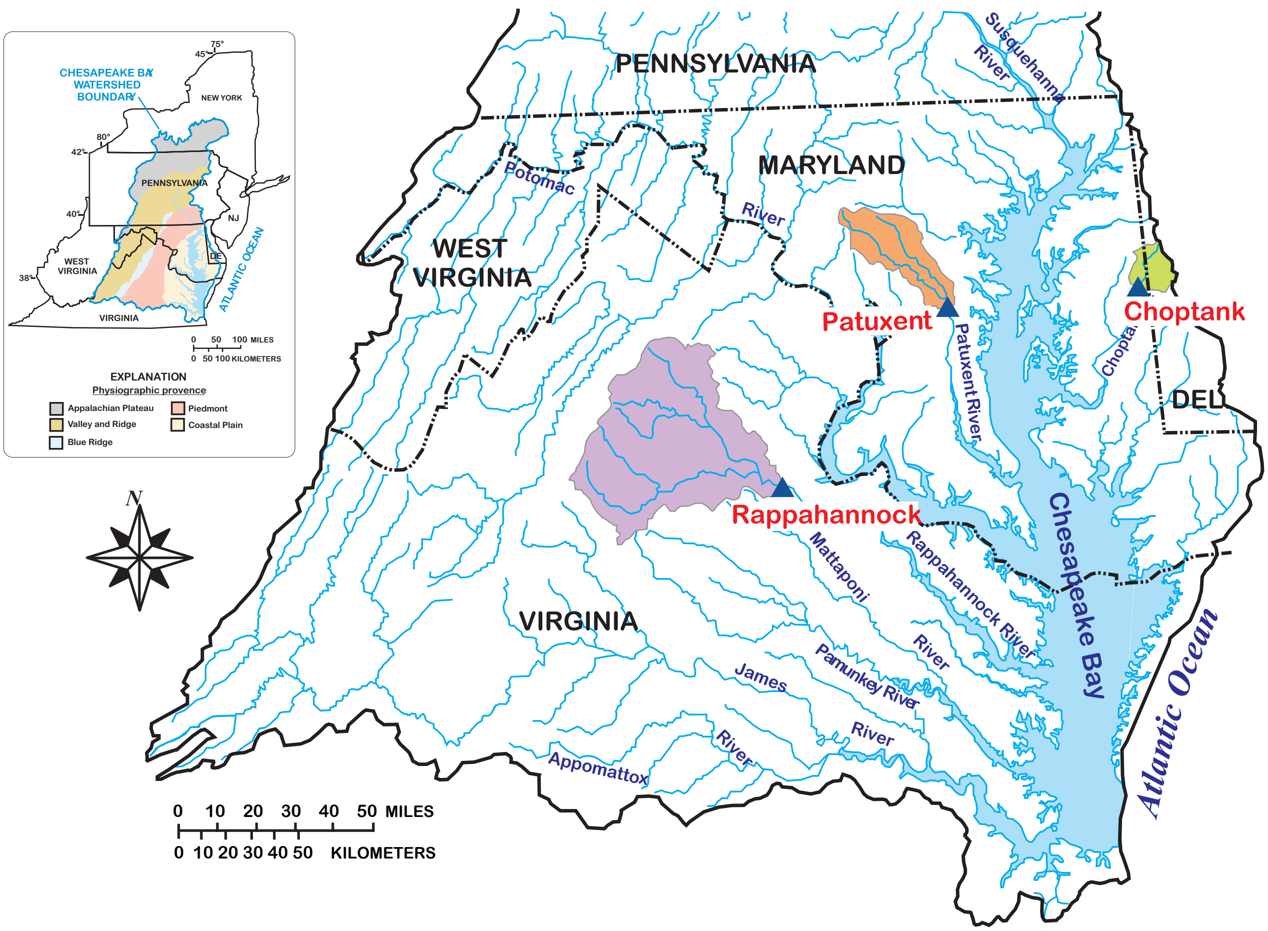

Figure 1—Location of the study watersheds within the Chesapeake Bay watershed. Locations of the sampling sites (triangles) are given in table 1. Map modified from Moyer and others (2012).

Table 1—Properties of the three stations and 30-year average percent contribution of water and orthophosphate (OP) to the Chesapeake Bay

Physical characteristics	Station: Choptank River near Greensboro, MD	Station: Patuxent River near Bowie, MD	Station: Rappahannock River near Fredericksburg, VA
Station Abbreviation	CHOP	PATX	RAPP
USGS Gaging Station Identification Number	01491000	01594440	01668000
Station Location			
North Latitude	38.997	38.956	38.308
West Longitude	-75.786	-76.694	-77.529
Drainage Area (km^2)	293	901	4,131
Population Density, 2010 (persons km^{-2})	16.2	169	13.7
% Water Contribution to Chesapeake Bay	0.23	0.60	2.7
% OP Contribution to Chesapeake Bay	0.37	1.0	2.8
Land Use in 2012 (%)			
Agricultural	51	27	38
Developed	10	53	12
Undeveloped	21	15	50
Change in Land Use from 1985-2012 (%)			
Agricultural	-1	-8	0
Developed	6	12	7
Undeveloped	-4	-5	-7
River Discharge (m^3sec^{-1})			
Cool Season			
Range	0.365 – 106	3.09 – 180	3.77 – 1,254
Median	5.17	14.0	69.9
Warm Season			
Range	0.068 – 159	1.58 – 331	0.261 – 1,546
Median	1.74	8.24	28.1
OP Concentration (mg P L^{-1})			
Cool Season			
Range	0.001 – 0.091	0.003 – 0.55	0.002 – 0.08
Median	0.017	0.02	0.011
Warm Season			
Range	0.001 – 0.179	0.004-0.88	0.002 – 0.07
Median	0.03	0.039	0.011
Water Temperature (°C)			
Cool Season			
Range	0 - 21	0 – 25	0 – 23
Median	8.0	8.0	7.5
Warm Season			
Range	8.5 – 30	2.1 – 28	9.6 – 32
Median	21	21	22
Slope of Regression Line of Water Temperature Trend (°C yr^{-1})	0.0234	-0.0002	0.0594
P-value of regression line (α=0.05)	0.0432	0.9883	0.0004

highly weathered saprolite and soil. The weathered materials are rich in residual iron, which makes them strong sorbers of OP. In contrast, the Coastal Plain was largely formed from beach sands deposited during periods of higher sea level. Unlike the clay-rich Piedmont soils, Coastal Plain soils are mostly quartz sand and, except where there are coatings of iron or organic matter, have little sorptive capacity.

Data Sources

River water at the monitoring stations has been sampled at least monthly for 30 years, across a wide range of flow conditions, and the USGS has compiled a database of water-quality data collected at each station (Moyer and others 2012). We analyzed data for water years 1985 through 2014 (i.e., October 1984 through September 2014), the period in which data across all stations were most consistently collected.

Land-use data for the watersheds, including population density, wastewater-treatment plant density, percentages of agriculture, developed, and undeveloped land in each watershed, and watershed slope were obtained from Falcone (2017). Small changes in land use in each of the watersheds occurred during the study period (table 1).

DATA ANALYSIS

Monthly OP fluxes were calculated using the Weighted Regressions on Time, Discharge, and Season (WRTDS) model (Hirsch and others 2010), which outperforms historically used regression-based approaches (Chanat and others 2015; Moyer and others 2012). WRTDS uses a sparse set of discrete water-quality observations combined with a continuous daily stream-discharge record to estimate concentration on days for which no water-quality data are available. Daily concentration and flux estimates are aggregated to monthly and annual time scales, to which an algorithm is applied to estimate the trend in "flow-normalized flux" by integrating out the year-to-year variability in streamflow.

WT was measured at each station when stream-discharge measurements were made. WT is a composite of the water derived from the watershed and is affected by air temperature, groundwater inputs, and land cover along the length of the river, but especially immediately upstream from the sampling point. Therefore, the WT measurement may not represent conditions throughout the watershed, especially in the larger drainage areas. Simple linear regression was used to establish trends in WT, following methods of Rice and Jastram (2015).

Seasonal patterns in monthly flow-normalized fluxes and concentrations were analyzed to identify any linkages between changing WT and its impacts on OP dynamics. The year was divided into two seasons based on WT. The cool season was defined as November-April, and the warm season was defined as May-October. Monthly fluxes of OP were accumulated within the two seasons for the 30 years of data. Linear regressions of the cumulative flux data for the two seasons were calculated at each station to determine relative average rates of OP export for the entire period. For all statistical analyses, significance was determined at a = 0.05. Concentration-discharge (c-Q) relations, expressed as plots of OP concentration as a function of streamflow, were created for all sites by season. To examine changes over time, c-Q plots by decade were examined.

RESULTS

The median OP concentration during the cool season was approximately 0.02 mg P L^{-1} at the Choptank and Patuxent Rivers, but it was lower (0.011 mg P L^{-1}) in the Rappahannock River. Similarly, during the warm season, the median OP concentration was higher in the Choptank and Patuxent Rivers (0.03 and 0.039 mg P L^{-1}, respectively) and lower in the Rappahannock River (0.011 mg P L^{-1}).

Significant seasonal differences in WT in the Choptank and Patuxent Rivers were observed (t-test, $p < 0.0001$). For the three sites, WT for the 30-year period for the cool season ranged from 0 to 25° C, with a median of 8.0° C. For the warm season, WT ranged from 2 to 32° C, with a median of 21° C. Thirty years of WT data indicated that the Choptank and Rappahannock Rivers had statistically significant increasing trends, with the rate in the Rappahannock over twice that in the Choptank (table 1). The WT data indicated no trend in the Patuxent River (table 1).

When monthly flow-normalized concentrations of OP were segregated into cool and warm seasons, concentrations were higher in the warm than the cool season (fig. 2). In contrast, segregation of fluxes of OP in the same way showed that

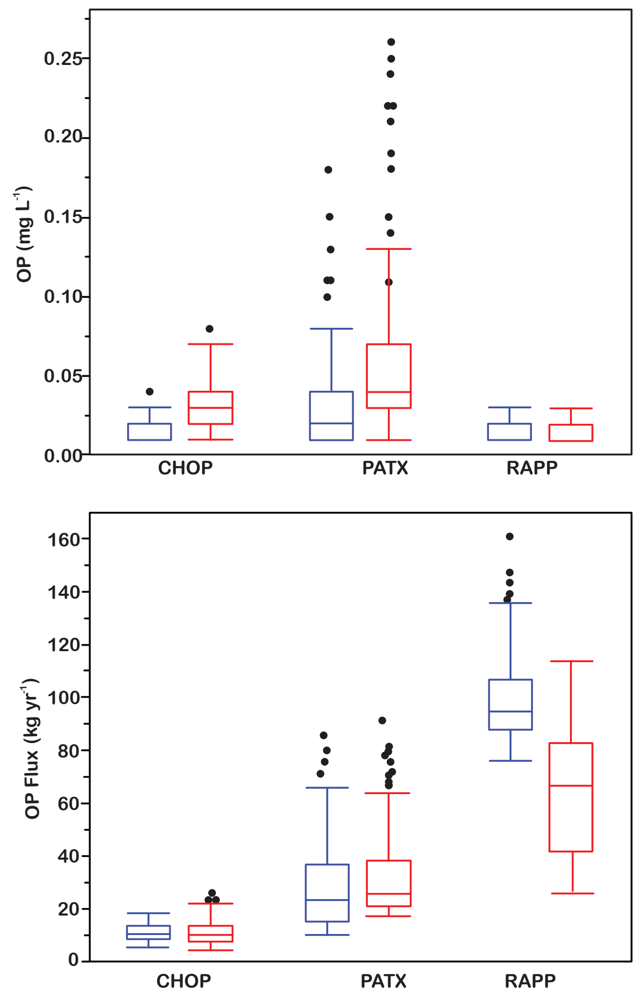

Figure 2—Box plots showing (A) monthly concentrations of OP (in milligrams P per liter); and (B) flow-normalized monthly fluxes of OP (in kilograms per year). The 30 years of data were divided into two seasons: cool, November-April (blue boxes); and warm, May-October (red boxes). Horizontal line inside the box is the median concentration; top and bottom of the box is the 75th and 25th quantiles, respectively; top and bottom of whiskers are the 75th quantile + 1.5 times the interquartile range and the 25th quantile – 1.5 times the interquartile range, respectively; dots are outliers.

fluxes in the warm season were lower than in the cool season (fig. 2). A t-test (modified by a Bonferroni adjustment for multiple comparisons) indicated the mean OP concentration in the Choptank and Patuxent Rivers was statistically different in the two seasons ($p < 0.0001$). The Rappahannock River was the exception, with no significant difference in the mean OP concentration between the two seasons.

Cumulative fluxes of OP were greater in the cool season than the warm season in the Choptank and Rappahannock Rivers but were greater in the warm season in the Patuxent River (table 2). These ratios indicate that the Choptank and Patuxent Rivers exported OP at nearly equal rates in both seasons, and the Rappahannock exported more OP in the cool than the warm season (table 2).

C-Q relations at each station were variable (fig. 3). Changes in the seasonal OP c-Q relations over the decades were more apparent at some of the stations (fig. 4).

DISCUSSION

A major scientific challenge to unraveling biogeochemical cycles in the environment is presented by the occurrence of simultaneous changes in multiple variables. For example, isolating the effects of changing streamflow, land use, and climate on stream-water chemistry is particularly difficult. Multiple competing and overlapping factors could be affecting the 30-year record of observed seasonal OP behavior (fig. 2). Although we are considering occurrence of simultaneous changes in multiple variables, it is difficult to understand the relations among those variables without an understanding of how each variable behaves independently. We focused on three variables (streamflow, land use, and WT) that could affect the observed OP patterns.

With respect to streamflow, the median discharge during the cool season was significantly greater than during the warm season at all the sites. Because river discharge is higher during the cool season than the warm season, the seasonal OP concentration patterns could be explained by simple dilution. For example, if the mass of OP passing the streamgage is similar year round, higher streamflow during the cool season would dilute the concentration of OP. C-Q plots of the Patuxent River showed clear dilution of OP by streamflow during both seasons (fig. 3). In contrast, the Rappahannock and Choptank Rivers showed higher concentrations of OP with higher streamflow during both seasons (fig. 3), suggesting mobilization of OP rather than dilution at these sites.

The patterns in the c-Q relations could reflect the different sources of OP in the watersheds, which often coincide with different land uses. Land use for each watershed varied spatially and temporally (table 1). With agriculture as the dominant land use in the Choptank River watershed, fertilizer and manure is a major source of P (Ator and others 2011). Agricultural sources could explain the positive c-Q relation (fig. 3), whereby OP may be transported via surface or subsurface flow from actively farmed fields. The timing of the application of manure also may facilitate transport of OP. Van Es and others (2004) found that the greatest P leaching rates occurred with late fall manure applications, compared to early- or late-spring applications, and the observation may be partially due to the lower biological uptake in P during the cool season. The timing of applications with respect to rainfall patterns also can affect transport of P to rivers. Kleinman and Sharpley (2003) found the highest concentrations of P in runoff from manure applied 3 days prior to rainfall, compared to applications occurring 10 or 24 days prior to simulated rainfall. Although we do not have detailed application information for these watersheds, the seasonal increases in OP concentrations in the agricultural-dominated watersheds could be linked to spring-time applications of manure and fertilizer on agricultural fields. Changes in land use may cause changes in these sources, which may shift the c-Q relation over time. Thus, management activities on agricultural lands within the watersheds could influence seasonal patterns in OP concentrations.

The seasonal OP patterns could be explained by physiochemical and biogeochemical processes in the watersheds related to WT. Three processes that could explain

Table 2—Slopes of linear regressions of cumulative flow-normalized orthophosphate (OP) fluxes and yields by cool and warm seasons, 1985–2014

	Slope of the regression line				
Site	Cool season		Warm season		Cool:Warm
	kg P	*kg P km*$^{-2}$	*kg P*	*kg P km*$^{-2}$	
CHOP	70	0.5293	60	0.4485	1.18
PATX	151	0.3693	171	0.4190	0.88
RAPP	577	0.3080	382	0.2039	1.51

Note: The ratios of the slopes in the cool season to those of the warm season are shown. Every regression was significant ($p < 0.0001$). Kg P per season and per season per area are shown.

CHOP=Choptank River; PATX=Patuxent River; RAPP=Rappahannock River.

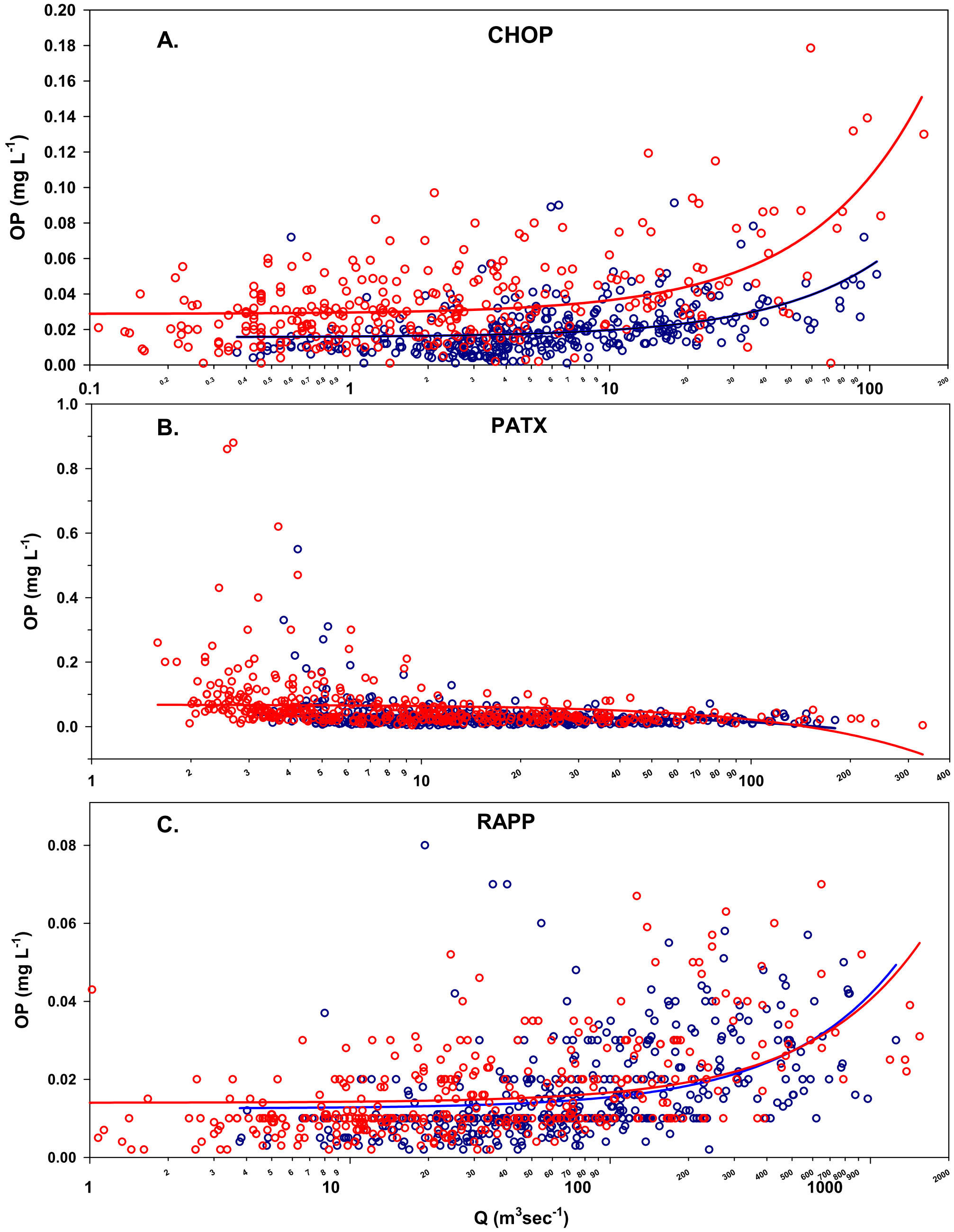

Figure 3—Seasonal c-Q (concentration-river discharge) plots of OP (in milligrams P per liter) at Choptank (A); Patuxent (B); and Rappahannock (C) River stations. Red symbols, warm season; blue symbols, cool season. Lines are simple linear regressions of the seasonal data on a semi-log scale.

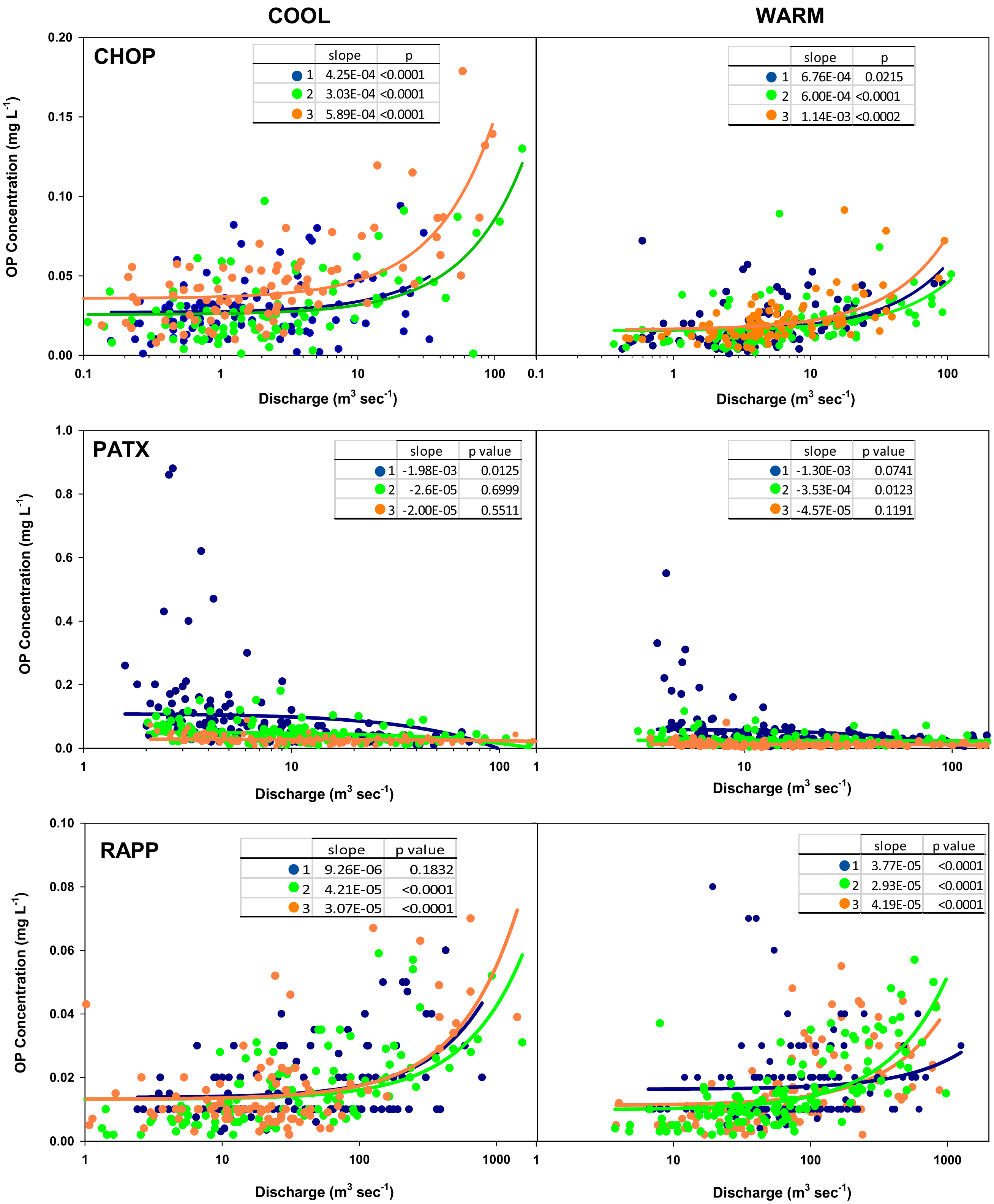

Figure 4—Decadal c-Q (concentration-river discharge) plots of OP (in milligrams P per liter) at the Choptank (A), Patuxent (B), and Rappahannock (C) River stations. Decade 1, water years 1985-1994, blue symbols; decade 2, water years 1995-2004, green symbols; decade 3, water years 2005-2014, orange symbols. Slopes of regression line and p-values given for each set of data.

the higher OP concentrations during the warm season are: (1) chemical equilibria may favor a release of P from the exchange sites during the warm season in response to increased WT, i.e., P bound to sediment in the water column or to bed sediment may desorb to become dissolved OP (Sugiyama and Hama 2013); (2) release of P from organic sediments to the water column because of increased degradation of organic matter during the warm season (e.g., Duan and Kaushal 2013; Upreti and others 2015); and (3) P that was complexed with iron oxyhydroxides released because of anaerobic reducing conditions, anoxia, and the concomitant reduction of Fe(III) to Fe(II) during the warm season. Similar to method (3) of P release, direct reduction of Fe(III) to Fe(II) by iron-reducing bacteria and subsequent dissolution of the Fe-containing particles also would release P to the dissolved fraction.

Given the multivariate combinations of the parameters, OP dynamics in the watersheds were different, depending on which parameter dominated. The cumulative OP fluxes in the Choptank River were nearly equal during both seasons (table 2). The watershed differs from the others with respect to land use; more than 50 percent of the watershed was in agricultural land use, much of which was dedicated to feed production (corn, grain, and soybeans) for the regional poultry industry. While the percentage of agricultural land changed only slightly from 1985-2012 (table 1), the footprint of poultry houses increased drastically, from 58,000 to 497,000 m^2 (Soroka 2018). Area covered by poultry houses is important, as Taylor and Pionke (2000) found manure generally is applied near its source. Further, de Guzman and others (2012) observed Choptank River subwatersheds with poultry houses had higher concentrations of particulate-bound P, a potential source for OP. Grain producers within the Choptank River watershed routinely apply P-rich poultry manure as a fertilizer due to its low cost, local availability, and its ability to increase soil productivity. The sandy soils and aquifer materials of the Choptank River watershed provide notably fewer P sorption sites than do the clay-rich materials found in the Piedmont Physiographic Province. Low sorption capacity for P in this watershed, combined with long-term manure applications, suggests that the degree of P saturation may be nearing a maximum. Soil tests indicate high levels of P in Coastal Plain soils (Sallade and Sims 1997; Sims 2000). As a watershed approaches P saturation, the soil pool of soluble P increases, retention of OP decreases, and thus the potential for OP transport increases, resulting in leakage of OP (Vadas and Sims 1998; Vadas and others 2007). Leakage of OP due to lack of sorption capacity, however, would not display a seasonal pattern. When the Choptank River data were examined by decade, the slope of the positive c-Q relation increased with time, particularly during the warm season (table 3), suggesting that the watershed may have become increasingly saturated with P over the three decades of monitoring.

In the Choptank River watershed, an additional layer of complexity to the pattern is the possibility of temperature-facilitated P desorption. WT in the Choptank River station increased at a rate of 0.023° C y^{-1} (table 1). Seasonal desorption at the Choptank River station is supported by higher median OP concentrations in the warm (0.03 mg P L^{-1}) than the cool season (0.02 mg P L^{-1}). Upreti and others (2015) observed a positive relation between WT and desorption of P from sediment of another Coastal Plain stream. Upreti and others (2015) observed greater OP concentration increases with WT increases in headwater areas, closer to P sources. An increase of P sources in headwater areas indicates a greater propensity for P loading and thus, OP desorption.

The Patuxent River exported OP at a cumulative rate slightly higher in the warm than the cool season (table 2). The watershed had the highest wastewater-treatment plant density and the highest percentage of developed land, likely explaining why it had the highest minimum, median, mean, and maximum OP concentrations (0.003; 0.029; 0.046; and 0.880 mg P L^{-1}, respectively) of the stations. Point sources are the dominant source of P in the Patuxent River watershed (Ator and others 2011). The effect of point sources is apparent in the OP c-Q relation, whereby concentrations are diluted by increased streamflow (fig. 3). The median OP concentrations during both seasons decreased were examined by the three decades, median OP concentrations decreased during both seasons: the cool season median decreased from 0.044 to 0.021 to 0.01 mg P L^{-1}, while the warm season median decreased from 0.09 to 0.04 to 0.02 mg P L^{-1}. There was no clear pattern in the slopes of the c-Q relations for either season (table 3). The seasonal OP patterns appear to be a case of concentrations that are diluted during the cool season by higher streamflow. These observations suggest that both land use and streamflow exert control over the OP concentrations at this station, with land use the dominant factor (supply of P, which decreased over time) and streamflow the moderating factor (dilution of P).

The Rappahannock River watershed ranks second to the Choptank River in agricultural land use (table 1), and like the Choptank River, it displays higher OP concentrations at higher discharge (fig. 3). There is a geologic source of P in the watershed (Terziotti and others 2010), and a mass-wasting event occurred in 1995 (Morgan 1997), potentially exposing the geologic source. In contrast to the Choptank River, where the median seasonal OP concentrations differed, the median OP concentration in the Rappahannock River during the two seasons was the same (0.011 mg P L^{-1}). Increases in median OP concentrations were not observed (0.01 mg P L^{-1} every decade), despite: (1) an agricultural source; (2) a potential geologic source; (3) WT increasing at a rate of 0.0594° C y^{-1} (table 1); and (4) the slope of the c-Q relation during the warm season increasing over the decades (table 3). The Piedmont physiographic province, which underlies the Rappahannock River watershed, produces heavily weathered bedrock and soils that offer abundant clay minerals for P sorption sites. Compared to the Choptank River, the Rappahannock River watershed may have not only more sorption sites, but also the interaction between P and the mineral surface may be stronger. During both seasons, the slope of the c-Q relation was the highest in the 2000s, perhaps reflecting P release during the mass-wasting event of 1995.

Algal blooms have been observed in the Choptank (Glibert and others 2001), Patuxent (http://eyesonthebay.dnr.maryland.gov/eyesonthebay/stories2/bloom.html), and Rappahannock (http://www.vdh.virginia.gov/environmental-epidemiology/harmful-algal-blooms-habs/algal-bloom-surveillance-map/Rivers) Rivers. Of the three mechanisms that can cause desorption of P from sediment or particulates, increased WT, as has been observed in the CB region (Rice and Jastram 2015), will accelerate that desorption. It is possible that these WT-dependent mechanisms operated simultaneously to increase OP concentrations in the warm season at the three sites, but the effect was masked by the influence of land use, streamflow, and geology. Should stream waters continue to warm, the processes through which OP can be released from sediments likely will amplify, causing increased concentrations of OP during the warm season. Higher concentrations of OP would spur seasonal eutrophication, leading to anoxic conditions, leading to reduction of iron oxides, causing additional release of OP. Higher WT also would increase microbial degradation of organic matter on sediments, releasing more P (Duan and Kaushal 2013; Upreti and others 2015). The increased OP in the water column would fuel more eutrophication and the cycle would continue in a positive—but environmentally detrimental—feedback loop. In other words, increasing WT would serve as a facilitator to the processes leading to eutrophication in the freshwater tributaries to the bay.

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CLIMATE CHANGE IN WEST VIRGINIA AND IMPLICATIONS FOR APPALACHIAN FOOD DESERTS

Evan Kutta, Jason Hubbart, and Elliot Kellner

Abstract—Increasing variability in temperature and precipitation patterns are reducing the security of natural resources including food, water, and energy in many locations globally. These climate changes are particularly relevant to the agricultural sector, particularly given increasing demand for food, less predictable water supplies, and more expensive energy. Among these challenges however, opportunities may be emerging in previously less productive areas such as West Virginia with implications for the entire Appalachian region often typified by food deserts. To focus the current work, observed datasets of daily maximum temperature, minimum temperature, and precipitation for 18 individual observation sites in West Virginia dating back to at least 1930 were used. Daily data were averaged annually and spatially (all 18 sites) and the Mann-Kendall trend test and Sen's slope estimator were used to assess statistically significant ($\alpha = 0.05$) trends in temperature and precipitation. Maximum temperatures were shown to decrease significantly over the entire period of record (1900–2016), minimum temperatures were found to increase significantly during all three periods of record, and precipitation was found to increase significantly over the second half (1959–2016). Observed climate trends indicate that West Virginia may be becoming wetter and more temperate and thus potentially more supportive of a broader range of crops and a longer and more productive growing season. Therefore, this work suggests the food desert crisis impacting the Appalachian region could be alleviated by restoring the regions' agricultural sector, which could simultaneously improve human health and socioeconomic well-being.

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WHY IS THERE SO MUCH MERCURY IN PERMAFROST? WHEN AND WHERE WILL IT GO IF IT THAWS?

Paul Schuster, Kevin Schaefer, Ron Antweiler, Rob Striegl, Kim Wickland, Dave Krabbenhoft, John Dewild, Nicole Herman-Mercer, and Gustaf Hugelius

Abstract—Warming of northern regions is causing permafrost to thaw with major implications for the global mercury (Hg) cycle. Mercury was estimated in permafrost regions based on in situ measurements of sediment total mercury (STHg), soil organic carbon (SOC), and the Hg to carbon ratio (RHgC) combined with maps of soil carbon. We measured a median STHg of 43 ± 30 nanograms of Hg per gram of soil and a median RHgC of 1.6 ± 0.9 nanograms of Hg per gram of carbon, consistent with published results of STHg for tundra soils and 11,000 measurements from 4,926 temperate, non-permafrost sites in North America and Eurasia. We estimate that the Northern Hemisphere permafrost regions contain 1,656 ± 962 gigagrams of Hg, of which 793 ± 461 gigagrams is frozen in permafrost. This store is nearly twice as much Hg as all other soils, the ocean, and the atmosphere combined. As warming continues over the next century, this Hg may be released to streams and groundwater. Existing estimates greatly underestimate Hg in permafrost soils, indicating a need to reevaluate the role of Arctic regions in the global Hg cycle. Further research is under way to expand the current dataset through the inclusion of soils from several other circumpolar permafrost regions (Norway, Russia, Siberia, Canada, and Antarctica). This additional data will create a more robust dataset and greatly improve the performance of models used to predict the rate of potential Hg release on a timeframe up to the next century.

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SECTION 6

Wetland Trends

CALCULATING THE ECONOMIC BENEFITS OF COASTAL WETLANDS

Susan-Marie Stedman

Abstract—Coastal wetlands (wetlands in coastal watersheds) provide a wide range of economic benefits. They include use values, both direct (fish, timber) and indirect (shoreline stabilization, flood control) as well as non-use values (biodiversity). Use values are the easiest to quantify, especially direct use values tied to human markets. For example, the value of timber from pine plantations in wetlands can be calculated based on market prices and typical timber yield. The value of commercial fish associated with wetlands can be estimated using data on the use of wetlands by various life stages of commercial fish and the typical dockside prices for those fish. Indirect use values require more creative economic analyses. For example, a recent study of the effects of Superstorm Sandy on the northeast United States used high-resolution flood and loss models to calculate the averted losses associated with wetlands. This presentation will review methods used to calculate the economic value of coastal wetlands, the results of those calculations, and considerations for incorporating economic analyses into decisionmaking.

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COASTAL WETLAND RESOURCE CHANGE AND DRIVERS AS QUANTIFIED BY THE NATIONAL WETLANDS INVENTORY WETLANDS STATUS AND TRENDS PROJECT

Megan Lang, Susan-Marie Stedman, and Rusty Griffin

Abstract—The U.S. Fish and Wildlife Service (USFWS) is congressionally mandated to produce decadal reports on the status and trends of wetlands within the United States. To date, the USFWS National Wetlands Inventory (NWI) program has produced six national and eight regional Wetlands Status and Trends reports. Regional reports often provide a more in-depth exploration of areas experiencing heightened wetland alteration. A recent regional Wetlands Status and Trends report, co-authored by the USFWS and the National Oceanic and Atmospheric Administration, focused on wetland trends within U.S. coastal watersheds (8 digit hydrologic unit code watersheds that contain tidal water bodies or drain to the Great Lakes) between 2004 and 2009. This region contains a diversity of wetland types, including both fresh and saltwater wetlands. Wetlands in this low-lying region have historically been abundant and provide a wealth of ecosystem services that support human health, safety, and livelihoods, as well as critical habitat for migratory birds and other wildlife. These same areas have experienced land cover conversion, as well as degradation, due to their suitability for commercial industry, including agriculture, and are under increasing pressure due to population growth. The report found that nearly 40 percent of wetlands in the conterminous U.S. are found in coastal watersheds, but that they are being lost at a greater rate relative to other areas of the U.S. Wetlands in coastal watersheds were lost at an average rate of 324.4 km^2 per year, an increase of 25 percent in loss rate between the periods of 1998 through 2004 and 2004 through 2009. Emergent and forested/shrub wetland losses were highest for salt water wetlands, while forested wetland losses were greatest for freshwater wetlands. A marked gain was observed in pond habitats. Wetland change was highest in the Atlantic and Gulf of Mexico coastal watersheds, when compared to other coastal regions. Drivers of wetland change (loss and state conversion) within this region are complex, and include development, intensive forest management, and coastal processes. This presentation will provide a brief description of Status and Trends protocols and historic findings for coastal watersheds with an emphasis on policy and management relevant trends.

Author information: Megan Lang, Susan-Marie Stedman, and Rusty Griffin of the U.S. Fish and Wildlife Service.

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THE INTERAGENCY COASTAL WETLANDS WORKGROUP: EXPLORING CHALLENGES AND OPPORTUNITIES IN COASTAL WETLAND MANAGEMENT

Jennifer Linn and Dominic MacCormack

Abstract—In response to concerns about the rate of wetlands loss in coastal watersheds, the Interagency Coastal Wetlands Workgroup (ICWWG) was formed to help identify the causes of these losses as well as identify strategies to address them. The ICWWG consists of representatives from the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, U.S. Geological Survey, Natural Resources Conservation Service, and Federal Highway Administration.

The ICWWG held seven regional workshops involving local, State and Federal stakeholders to gather input about factors driving wetland loss in coastal watersheds, successful approaches for addressing this loss, and remaining information needs. Findings were released in 2013. The ICWWG subsequently completed a series of four coastal wetland loss pilot studies to assess watershed-specific data to help identify actions federal agencies can take in coordination with state, tribal, regional, and local agencies to improve management of coastal wetlands and reduce losses nationwide. A Summary Findings of these four pilot studies was released in July, 2017.

This session will detail trends observed in the pilot studies and discuss opportunities for coastal wetland resource management. Emphasis will be placed on the strategies available to Federal, State, and local agencies in cooperative contexts.

Author information: Jennifer Linn and Dominic MacCormack of the U.S. Environmental Protection Agency.

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INCREASED HYDROLOGIC CONNECTIVITY: CONSEQUENCES OF REDUCED WATER STORAGE CAPACITY IN THE DELMARVA PENINSULA (U.S.)

Daniel McLaughlin, C. Nathan Jones, Grey Evenson, and Megan Lang

Abstract—Across the Delmarva Peninsula, depressional wetlands (i.e., Delmarva bays) are common features that store water and provide associated landscape functions (e.g., floodwater attenuation, nutrient retention, and habitat). However, pervasive ditching has increased surface water connectivity and thus decreased wetland water storage capacity at local to landscape scales. Here, we utilized both geospatial analysis and hydrologic modeling to explore drivers and consequences of this modified surface water connectivity. Our geospatial analysis quantified both historical and contemporary wetland storage capacity across the region, and suggests that over 70 percent of historical storage capacity has been lost due to ditching. Building upon this analysis, we applied a catchment-scale model to simulate implications of reduced storage capacity on catchment-scale hydrology. In short, increased connectivity (and concomitantly reduced wetland water storage capacity) decreases catchment inundation extent and spatial heterogeneity, shortens cumulative residence times, and increases downstream flow variation with evident effects on peak and baseflow dynamics. As such, alterations in connectivity have implications for hydrologically mediated functions in catchments (e.g., nutrient removal) and downstream systems (e.g., maintenance of flow for aquatic habitat). Our work elucidates such consequences in the Delmarva Peninsula while also providing new tools for broad application to target wetland restoration and conservation. Views expressed are those of the authors and do not necessarily reflect policies of the U.S. Environmental Protection Agency or U.S. Fish and Wildlife Service.

Author information: Daniel McLaughlin, C. Nathan Jones, Grey Evenson, and Megan Lang of Virginia Polytechnic Institute and State University.

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ASSESSMENT OF WETLAND CONSERVATION PROGRAM EFFECTIVENESS IN THE MID-ATLANTIC LOWER COASTAL PLAIN REGION OF THE UNITED STATES

Greg McCarty, Megan Lang, Sangchul Lee, Amir Sharifi, Ali Sadeghi, and William R. Effland

Abstract—The U.S. Department of Agriculture (USDA) Mid-Atlantic Regional (MIAR) Wetland Conservation Effects Assessment Project (CEAP-Wetland) study covers an area of ~58,000 km^2 in the Eastern United States, including areas of the Atlantic Coastal Plain physiographic province located in five States (North Carolina, Virginia, Maryland, Delaware, and New Jersey). To support assessment of current wetland restoration practices, 48 primary study sites were selected (18 restored, 16 prior converted cropland, and 14 natural) and ecosystem service provision was evaluated using both remote sensing and *in situ* measurements. The services evaluated include: climate regulation, pollution mitigation, water storage and biodiversity. Study results support the following recommendations: (1) Longer easement/contract periods should be promoted to allow time for slower environmental processes to occur; (2) Soil compaction should be minimized to encourage root growth and enhance movement of nitrate rich groundwater into wetland soils capable of nutrient removal; (3) Either a greater number of restored wetland cells and/or larger wetland cells can better support the regulation of hydrologic flows and groundwater levels, and the mitigation of natural hazards, such as flooding; (4) Natural wetlands should be conserved, not only due to the high level of ecosystem services they provide, but also because they directly enhance provision of ecosystem services from restored wetlands and prior converted croplands; (5) Greater effort should be made to restore wetlands in locations that are low elevation relative to broader-scale topographic gradients which are more likely to intercept up gradient groundwater containing agricultural contaminants and sediments; (6) Wetland basins should be shallow with gentle slopes, such that they support hydroperiods and water depths characteristic of natural wetlands to encourage colonization and growth of vegetation that are representative of more natural conditions; (7) Intra-regional variations in physical and biological parameters should be considered when targeting, implementing, and managing wetland conservation practices; and (8) Increased applications of geospatial datasets and techniques within precision conservation practice strategies can enhance not only ecosystem service provision but also the determination of derived benefits at landscape and watershed scales. Findings are being used to support enhanced implementation of wetland conservation practices.

Author information: Greg McCarty, Megan Lang, Sangchul Lee, Amir Sharifi, Ali Sadeghi, and William R. Effland of the U.S. Department of Agriculture, Agricultural Research Service, Hydrology and Remote Sensing Laboratory.

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EFFECTS OF CLIMATE CHANGE ON COASTAL WETLANDS: ADAPTIVE MANAGEMENT CASE STUDIES FROM THE NATIONAL WILDLIFE REFUGE SYSTEM

Scott Covington and Kurt Johnson

Abstract—The U.S. Fish and Wildlife Service (FWS) has more than 185 coastal National Wildlife Refuges (NWR or refuge), most of which are being impacted by relative sea level rise (RSLR) and associated impacts of storms and the surges they produce. Habitat loss and infrastructure damage and/or loss are the key impacts. For example, surveys by the National Wetlands Inventory report that the United States lost over 34,000 ha of salt marsh habitats from 2004-09, the most recent statistic available. Although not all these losses are on refuges, the statistic illustrates the profound changes occurring in coastal habitat primarily as a result of RSLR coupled with storm surges. In addition, the costs associated with hurricane damage to coastal infrastructure alone exceeds $28 billion a year, according to the Congressional Budget Office (2016). We evaluated RSLR and storm surge impacts for seven coastal refuges, each of which faces unique challenges and has developed a management program tailored to respond to these threats. We surveyed climate change related impacts from the past decade at these coastal refuges, and summarized how the refuges are addressing those impacts, as well as how they are monitoring their management progress. At Alligator River NWR in North Carolina, wind fetch from Pamlico Sound causes more damage than RSLR, because it batters the eastern refuge shore causing massive erosion of the peat soils and forces salt water from the bay upstream into low lying tributaries, killing salt-intolerant vegetation. When "Superstorm Sandy" hit Prime Hook NWR in Delaware, it ripped huge inlets in the coastal barrier island, spilling saltwater into a freshwater marsh, killing that vegetation. RSLR is causing inundation of the low-lying salt marsh at Blackwater NWR in Maryland, and is also impacting submerged aquatic vegetation along the refuge's shore. Shoreline erosion of up to 10 feet per year in some places within Anahuac NWR in Texas resulted in extreme losses of valuable land and habitat. RSLR and limited sediment accretion contribute to the complete inundation of the Pacific cordgrass at Seal Beach NWR in California. Tidal marsh restorations in Bandon Marsh NWR in Oregon and Billy Frank Jr. Nisqually NWR in Washington have returned tidal flows to drained and diked areas with the intention of restoring habitat and building greater system resilience to sea level rise and climate change.

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DYNAMIC SURFACE WATER EXTENT (DSWE): AN OPERATIONAL SATELLITE-BASED PRODUCT FOR THE SYNOPTIC ASSESSMENT OF MORE THAN 30 YEARS OF INTRA-ANNUAL VARIATIONS IN WATERSHED AND WETLAND INUNDATION

John Jones

Abstract—The U.S. Geological Survey (USGS) is generating a new data product named Dynamic Surface Water Extent (DSWE) that can contribute to our understanding of variations in the areal extent of inundation through time and enable synoptic watershed and wetland monitoring. DSWE uses the extensive Landsat Archive for the United States as well as data from on-going, moderate resolution satellite systems such as Landsat Enhanced Thematic Mapper and the Operational Land Imager as input, yielding intra-annual records on inland and coastal wetland inundation for more than a 30-year period. A collaborative, multi-tiered evaluation strategy documents DSWE uncertainty and demonstrates its utility for water and wetland resource management. Vegetated wetland environments are particularly challenging for both DSWE inundation detection and DSWE uncertainty assessment. Analyses of *in situ* data on inundation and water stage collected by the USGS and other DSWE project collaborators at key U.S. wetland areas have identified DSWE strengths and weaknesses as well as facilitate DSWE use in science and resource management. Examples drawn from this experience illustrate DSWE uses for watershed hydrologic modeling and coastal wetland monitoring.

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EVALUATING RECENT LANDSAT-BASED MAP PRODUCTS FOR SURFACE WATER AND WETLAND INFORMATION

Zhiliang Zhu

Abstract—Recently, continuous research and data refinements have led to at least three independently developed, continental-scale map products that are based on Landsat and are highly relevant to information needs for surface water and wetlands. The three map products are: the European Union Joint Research Center (JRC) Global Surface Water Explorer (GSWE), the U.S. Geological Survey (USGS) Dynamic Surface Water Extent (DSWE) product, and the USGS Land Cover Monitoring, Analysis, and Projection (LCMAP) system. All three products have 30-m resolution, cover a common time-window from mid-1980 to present, are temporally resolved annually and seasonally, and are developed using time-series remote sensing methods. The JRC's GSWE and USGS DSWE products are aimed at water-specific policy and science applications, whereas LCMAP is developed as a general-purpose, multi-category product meeting needs for a variety of applications. With the National Hydrological Dataset (NHD) as a standard, we conducted a preliminary comparison of surface water extent from the three map products plus the traditional National Land Cover Database (NLCD). We also compared wetland extent from LCMAP and NLCD with the National Wetland Inventory data. The comparisons were conducted for Chesapeake Bay Watershed. This presentation will show results of the two comparison exercises for their accuracy, extent, and abilities to capture seasonal and inter-annual variabilities.

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QUANTIFYING WETLAND INUNDATION DYNAMICS IN COASTAL WATERSHEDS USING VIRTUAL CONSTELLATIONS OF OPTICAL AND RADAR EARTH OBSERVATION SATELLITES

Ben DeVries, Chengquan Huang, Wenli Huang, Megan W. Lang, John W. Jones, Irena F. Creed, and Mark L. Carroll

Abstract—Inundation dynamics in wetlands constitute a key variable in the study of the hydrologic cycle in coastal watersheds. While hydrologic models are indispensable in the study of coastal watershed hydrology, satellite data play an increasingly important role in these studies. The opening of many satellite data records and advances in cloud computing technologies have combined to allow the production of continental to global scale land cover change products, including products aimed at quantifying surface water changes at high spatial and temporal resolution. Despite these advances, wetland inundation dynamics are particularly difficult to monitor, given the ephemeral nature of many water bodies, especially among coastal watersheds. Data products based on optical satellite data, such as those from the Landsat constellation, often fail to capture dynamics in surface water extent due to frequent cloud cover and resulting gaps in the time series, a limitation that can be overcome through the use of radar observations. The Sentinel-1 constellation of Synthetic Aperture Radar (SAR) satellites, managed by the European Space Agency's (ESA) Copernicus program, is the first global, open-access SAR data source, and represents an important step forward in the ability to comprehensively map inundation dynamics from space. Importantly, the fusion of Sentinel-1 SAR data with optical data from Landsat and ESA's Sentinel-2 constellation of optical sensors will enable monitoring of inundation dynamics at nearly daily temporal resolution. Here we present first results of a very high temporal resolution surface water product for the Atlantic Coastal Plain physiographic region based on Sentinel-1 SAR and Landsat and Sentinel-2 optical data. We show that both optical and radar satellite data sources are required to adequately track changes in wetland inundation in these dynamic regions, especially in response to extreme hydrologic events like floods. These results represent a step forward in the fusion of data from virtual constellations of optical and SAR Earth observation satellites to characterize wetland inundation dynamics in coastal watersheds. Leveraging "next-generation" satellite constellations like the follow-on Landsat and NASA-ISRO SAR (NISAR) missions to better understand wetland hydrologic dynamics will require improved data fusion approaches such as those described in this study.

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SECTION 7

Using Long-Term Data

WARMING TEMPERATURE HOMOGENIZES LANDSCAPE VEGETATION PATTERNS AT THE CATCHMENT SCALE

Taehee Hwang, Lawrence E. Band, Chelcy F. Miniat, James M. Vose, Conghe Song, and Paul V. Bolstad

Abstract—Hydroclimate change is expected to bring warmer temperatures and increased hydrologic extremes, including more intense precipitation and longer inter-storm periods. In mountainous headwater catchments, downslope flow could mitigate the impact of dry periods in convergent topographic areas, buffering vegetation species from soil moisture stress during drought. Here we investigate changes in catchment-scale vegetation patterns in six forested headwater catchments in the Coweeta Hydrologic Laboratory in the southern Appalachian Mountains. We use a 30-year Landsat Thematic Mapper (TM) image record, spanning a period of recorded warming from the mid-1980s to present, and relate these long-term vegetation dynamics to seasonal water balance and low flow dynamics. Contrary to expectation, upslope vegetation showed a greater response to warming, compared downslope, also supported by long-term tree and litterfall data in one of the reference watersheds (20 years). This indicates that vegetation density (leaf area) patterns paths have been homogenized along hydrologic flow over time. In contrast to our expectations, the vegetation downslope may be experiencing lower growth with increased drought conditions than upslope vegetation, due to their strong dependency on upslope water subsidy. This suggests that vegetation downslope may experience more dramatic changes in hydroclimate condition with more frequent droughts due to their strong dependency on upslope subsidies. This study also highlights the need to understand underlying hydrologic balance along hillslope gradient and topographic redistribution of soil moisture to predict forested ecosystem response to climate change.

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"THE STORM WAS DOWNRIGHT WEIRD:" UNDERSTANDING THE DECEMBER 2007 STORM IN SOUTHWEST WASHINGTON USING SHORT- AND LONG-TERM HYDRO-CLIMATIC DATA

Maryanne Reiter and Jami Nettles

Abstract—From December 1–4, 2007 an unusual and powerful storm struck northwest Oregon and southwest Washington with hurricane-force winds and extreme magnitude precipitation. The windstorm, dubbed "the Great Coastal Gale" had high wind speeds (>50 knots) for 2 days, far exceeding the duration of other historic regional windstorms. The duration of high winds led to extensive damage to coastal structures and surrounding forests. The intense rainfall most heavily affected areas on the eastside of the north Oregon Coast Range, the Willapa Hills of southwest Washington and the eastern Olympic Peninsula. The greatest recorded storm rainfall was 499 mm (19.6 inches) with a 24-hour rainfall maximum of 364 mm (14.35 inches) for a station in the Willapa Hills. Snowmelt generally contributed only a small amount of runoff compared to rainfall. Ten rivers in Washington exceeded their flood of record. In the Chehalis River basin, five all-time high records were broken. In the upper Chehalis River, flood peaks were twice the previous flood of record and estimated to have a recurrence interval of 500 years. The extreme magnitude precipitation in that area also resulted in a large number of landslides, but where rainfall totals were closer to the 100-year storm, very few landslides occurred. The greatest impact of rainfall, flooding and landslides occurred in an area of the State that is sparsely populated and where, until recently, there was no weather radar and few climate stations. Because of the more localized nature of the storm and the lack of publicly available climate data, the storm was initially classified as a moderate event. Accessing all available stream gage and climate station data were critical in interpreting the magnitude of this event in order to put the damage in context. Equally as important for interpreting the storm were our company climate stations that we had previously located in areas where no public stations existed. This storm and its aftermath illustrated the importance of access to long-term public data as well as maintaining a robust monitoring network in areas where public data is lacking.

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HYDROLOGIC IMPACTS OF EXTREME PRECIPITATION EVENTS ON A LOW GRADIENT COASTAL PLAIN WATERSHED

David Bosch

Abstract—Extreme climatic events, particularly those involving extreme precipitation, can have dramatic effects on the landscape. These effects can be buffered or enhanced by the characteristics of the landscape. The Little River Watershed (LRW) at the headwaters of the Suwannee Basin in south central Georgia of the United States has been studied by the Southeast Watershed Research Lab of the USDA Agricultural Research Service since 1968. Data are collected on the LRW to quantify the long-term relationships between precipitation and streamflow. Watersheds in this region are characterized by low-gradient stream channels with wide and heavily vegetated floodplains. The long-term nature of the dataset provide an opportunity to characterize the impact of extreme precipitation events in particular on this unique landscape. The characteristics of these coastal plain watersheds can buffer the impacts of extreme events during dry seasons of the year but offer less buffering during wet seasons. Observed precipitation and streamflow were analyzed to develop probability distribution curves for each. Extreme rainfall and streamflow events were then related back to seasonal patterns to separate the effects of large springtime events from summer hurricane related events. Lastly, a comparison was made between the impacts of the extreme events on a primarily agricultural watershed to those observed in an urban watershed.

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POTENTIAL IMPACTS OF EXTREME PRECIPITATION EVENTS ON PEAK DISCHARGES AT USDA FOREST SERVICE LONG-TERM EXPERIMENTAL WATERSHEDS

S. Tian, D.M. Amatya, D.A. Marion, P. Caldwell, S. Panda, S. Laseter, G.M. Chescheir, J.M. Grace, C. Roghair, M.A. Youssef, G. Sun, J.M. Vose, Y. Ouyang, and A. Dolloff

Abstract—Increased peak-flow magnitudes resulting from growing extreme precipitation events might have adverse effects on the existing stormwater management, drainage, culverts, bridges, and other applications. Engineers and hydrologists often use precipitation intensity-duration-frequency (PIDF) curves published by National Oceanic and Atmospheric Administration (NOAA) for design of such infrastructure. However, it is unknown how the PIDF has changed over time for specific sites and applications. In this paper, we derived PIDF curves using a Generalized Extreme Value Distribution (GEV) approach with 1976–2015 hourly precipitation data from rain gauges at two USDA Forest Service research sites instead of using corresponding NOAA estimates. Coweeta Hydrologic Laboratory (CHL), NC, and Santee Experimental forest (SEF), SC representing a mountain and a coastal type site, respectively. The study objectives were to (1) examine the trend of annual maximum rainfall intensity, and (2) compare the derived design PIDFs for 2-, 5-, 10-, 25, -50-, 100-, and 200-year return periods for durations ranging from 1-hour to 72-hours to NOAA estimates. Preliminary results showed no trend in rainfall intensities at the coastal SEF site. However, increasing trends were found at the mountainous CHL site for all durations especially since after 2000, although significant trends were only detected for durations of 24-hours ($p=0.04$) and 2-day ($p=0.03$). Compared to our results using on-site data, published NOAA predictions underestimate rainfall intensities for durations of 1-hour and 2-hours for frequencies > 25-years and overestimated for longer durations with frequencies > 50-years. This finding may be significant as shorter duration intensities are critical for infrastructure design on flashy high-gradient sites with shorter time of concentration (Tc), especially if a design frequency of > 25 years is used for road infrastructure. However, at the coastal SEF site with longer Tc, both the NOAA and our results yielded similar results for 1-hr duration for up to 50-year frequency after which NOAA slightly exceeded our value. For all other durations, our results were higher than those from the NOAA estimates for all frequencies > 5-years, indicating NOAA-based estimates may lead to underestimating design rainfall intensities for sizing road infrastructure at the coastal SEF site.

Author information: S. Tian, D.M. Amatya, D.A. Marion, P. Caldwell, S. Panda, S. Laseter, G.M. Chescheir, J.M. Grace, C. Roghair, M.A. Youssef, G. Sun, J.M. Vose, Y. Ouyang, and A. Dolloff of North Carolina State University.

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THE ROLE OF DROUGHT IN THE HYDROLOGIC RESPONSE OF A MANAGED COAST REDWOOD WATERSHED

Elizabeth Keppeler and Joseph Wagenbrenner

In California, projections of intensifying wet-dry extremes and shifts in precipitation seasonality suggest that hydrologic droughts may become more frequent in the coast redwood region. An increase in hydrologic drought frequency may be particularly problematic for aquatic species that rely on flow in headwater streams during the region's June-October dry season.

We used a 55-year record of precipitation and streamflow to explore the relationship between meteorological drought and hydrologic drought in the Caspar Creek Experimental Watersheds in north coastal California. The 4.24-km^2 South Fork (SF) and 4.73-km^2 North Fork (NF) watersheds are managed for research and timber production. Originally clearcut and burned prior to 1904, second-cycle selection-harvest occurred on the SF from 1967 to 1973 and partial-clearcutting on the NF from 1985 to 1992.

The only significant trend in annual precipitation and precipitation-adjusted runoff over the period of record was for SF runoff ($p=0.02$). It is not yet clear whether the decline in SF runoff is a response to forest regrowth, climatic variation, or a combination of both.

Time series of the standardized precipitation index (SPI) (McKee and others 1993), the standardized runoff index (SRI) (Shukla and Wood 2008), and monthly anomalies of precipitation and streamflow were derived from long-term monthly precipitation and runoff records. Using the 12- and 24- month SPI time series, we defined severe drought as a period of negative SPI where the drought index value was less than -1.5 for 12 months or more. Two severe drought events were identified: 1976-1978 (D77) and 2013-2014 (D14). For each drought, we calculated the drought duration as the number of consecutive months with SPI less than zero, severity as the cumulative SPI for that duration, and intensity as the mean SPI for that duration (Mishra and Singh 2010). We defined the extreme as the minimum SPI for the duration and persistence as the length of time the SRI remained less than the SPI following the end of drought.

For both droughts, the maximum cumulative precipitation deficit exceeded mean annual precipitation and required more than 5 years of rainfall surpluses to be ameliorated. SPI values declined to more than two standard deviations below the mean, indicating "extreme" drought conditions during each event. Although the two droughts were meteorologically comparable, D14 was more severe and more persistent than D77. Accumulated monthly runoff anomalies, as percent of annual mean, were larger than those of precipitation and larger in D14 than D77 (table 1). We identified an apparent lag in baseflow recovery of < 2 years following the cessation of meteorological drought (fig. 1). Also, we found that hydrologic drought developed in the absence of severe meteorological drought as a result of an 8-year period of below-normal rainfall suggesting even mild multi-year precipitation deficits may propagate to amplify hydrologic extremes.

Our analyses suggest timber harvest may have ameliorated the hydrologic drought in the first 5 years after the SF selection harvest, but, four decades later, intensified the second hydrologic drought during subsequent forest regeneration and expected increased transpiration. The largest increases in post-harvest streamflows were observed on the SF in 1978 as D77 ended. In contrast, D14 occurred during a period of regrowth and recovering transpiration rates after the NF had been partially-clearcut and broadcast burned (1985-1992), and pre-commercially thinned (1993-2001). Thus, this hydrologic drought was more severe on both recovering watersheds.

These droughts produced variations in the magnitude and timing of fall flows that may have impacted the spawning success of the State- and federally-listed coho salmon (*Oncorhynchus kisutch*). Multiple regression analyses using the prior water year's SPI suggest that antecedent conditions from the previous 1 to 2 years influenced early-season runoff response (expressed as the initial 10 percent exceedance flow of the season, Q10, an approximation of the lower flow threshold for salmonid passage). For water years preceded by relatively dry conditions a mean of 327 mm was required to generate the Q10. When prior year conditions were wetter, Q10 was generally exceeded with significantly less rainfall. Harvest intensity and age were also

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significant factors (*p=0.05*). In 1978, the NF reference watershed did not attain Q10 until cumulative rainfall reached 484 mm, while the recently logged SF watershed attained Q10 after just 170 mm of precipitation. In 2014, it was not until March, after 444 mm of precipitation had occurred, that this threshold was exceeded—too late in the year for the fall-run coho to spawn in this coastal stream.

These results suggest that forest management treatments and climatic variations interact to influence hydrologic responses to meteorological droughts. Questions remain regarding the relative importance of various mechanisms.

Research at the Caspar Creek Experimental Watersheds is funded by the U.S. Department of Agriculture Forest Service and the California Department of Forestry and Fire Protection.

Table 1—Drought characteristics of the 1977 and 2014 droughts: 12-month and 24-month Standardized Precipitation Index (SPI12, SPI24) and Standardized Runoff Index for North Fork Caspar Creek (SRI12NF and SRI24NF) and South Fork Caspar Creek (SRI12SF and SRI24SF), the accumulated monthly anomaly of precipitation and North and South Fork streamflow (percent of mean annual) and the month and year the maximum anomaly occurred for each variable and drought

A	1977 Drought: JAN. 1976-JAN. 1978			2014 Drought: JAN. 2013-NOV. 2014		
Index	SPI12	SRI12NF	SRI12SF	SPI12	SRI12NF	SRI12SF
Duration, months	25	24	23	23	38	38
Severity	-45.3	-45.0	-35.4	-32.2	-44.0	-47.0
Intensity	-1.8	-1.9	-1.5	-1.4	-1.2	-1.2
Extreme	-3.19	-3.38	-2.83	-3.54	-3.22	-3.46
Persistence, months		10	0		19	19
B	1977 Drought: MAR76-JAN79			2014 Drought: SEP12-DEC15		
Index	SPI24	SRI24NF	SRI24SF	SPI24	SRI24NF	SRI24SF
Duration, months	35	43	25	40	50	57
Severity	-47.1	-41.6	-26.3	-51.9	-56.6	-63.3
Intensity	-1.3	-1.0	-1.1	-1.3	-1.1	-1.1
Extreme	-2.72	-2.38	-1.99	-2.17	-2.22	-2.26
Persistence, months		7	0		21	21
C	Precipitation	NF	SF	Precipitation	NF	SF
Accumulated Monthly Anomaly, %	-102	-173	-149	-113	-206	-211
month-yr	Nov-1977	Dec-1977	Nov-1977	Nov-2015	Nov-2015	Nov-2015

NF=North Fork; SF=South Fork.

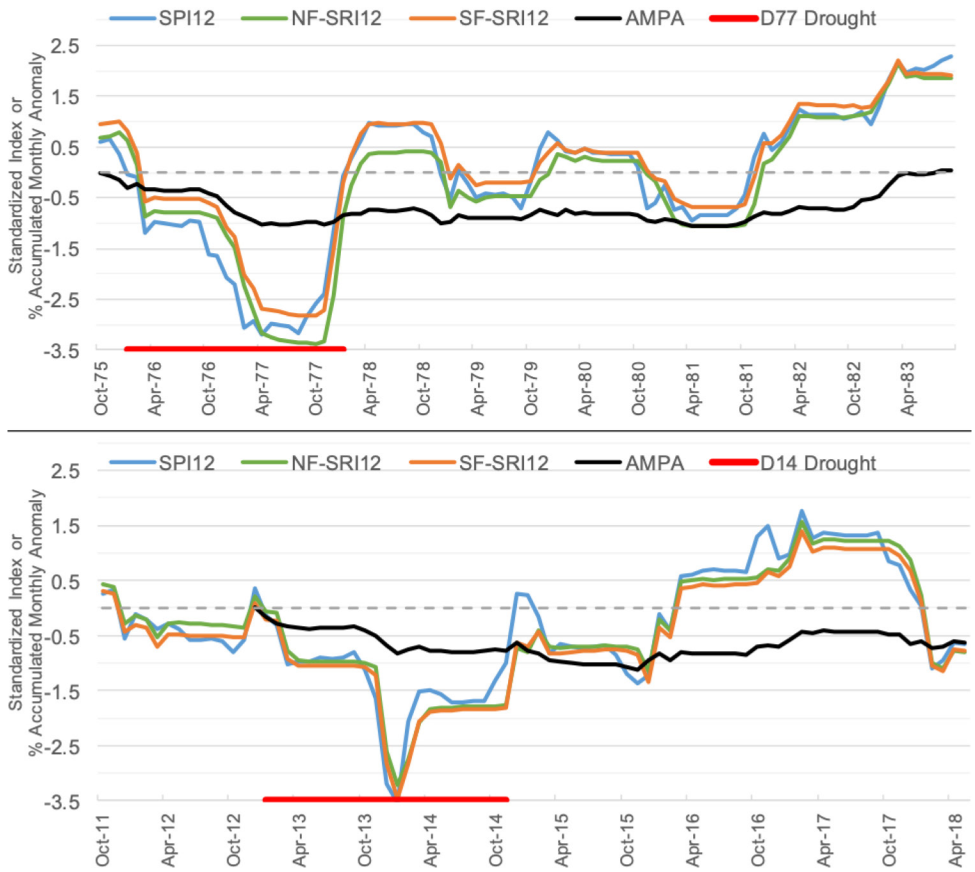

Figure 1—Variations in drought indices for precipitation (SPI12) and runoff (NF-SRI12 and SF-SRI12) and accumulated monthly precipitation anomaly (AMPA, percent of monthly mean) during two droughts: D77 and D14.

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AUTOMATED GEOSPATIAL MODEL BASED ASSESSMENT OF EROSION VULNERABILITY AT FOREST ROAD/STREAM CROSSINGS UNDER EXTREME PRECIPITATION INTENSITIES SCENARIO

Sudhanshu Panda, Devendra M. Amatya, Johnny Grace, Pete Caldwell, and Dan Marion

Abstract—Forest road/stream crossing drainage structures (culverts/bridges) are vulnerable to erosion due to high gradient topography and climate change related extreme precipitation events. Therefore, the goal of this study is to develop automated geospatial models to identify erosion hazards and vulnerability risks to these structures through amounting the sediment erosion passing through them during extreme precipitation events. This study is completed in three environmentally differing watersheds: (1) Coastal Turkey Creek watershed in South Carolina, (2) Mountainous Coweeta watershed in North Carolina, and (3) Alum Creek watershed in central Arkansas. Two modeling approaches were used in this study: (1) a streambank erosion spatial vulnerability assessment (SBEVA) model, and (2) Revised Universal Soil Loss Equation (RUSLE) model for erosion potential estimation. SBEVA model was developed in ArcGIS ModelBuilder using geospatial data like landuse, digital elevation models (DEM), various soil characteristics, and design flood discharges calculated using 100-year recurrence interval 24-hour partial duration series storm data obtained from National Oceanic & Atmospheric Administration (NOAA). All these spatial environmental variable rasters were reclassified with their vulnerability probability scale developed through the Delphi method of weighted scale determination. The combined parameters overlayed model provided the qualitative scale vulnerability results of all the forest streams. RUSLE model was developed in ArcGIS ModelBuilder to estimate pixel based erosion amount and a cumulative erosion at each road/stream crossings. The model uses the proven empirical equations using factors: rainfall erosivity, soil erodibility, slope length and gradient, crop/vegetation management, and support practice for erosion prediction. NOAA 100-year, 30-minute partial duration series storm intensity raster was used to develop the latest Isoerodent map (R-factor). The K, L, and S-factor rasters were developed from gSSURGO data. OBIA-based classified ultra-high resolution orthoimageries provided accurate and timely C-factor and P-factor rasters. Both SBEVA and RUSLE model resultant rasters were spatially combined to establish the most vulnerable culverts/bridges in the three forested watersheds. In addition, to confirm and identify through our study, GNSS instruments were used to groundtruth the culverts for erosion vulnerability in extreme weather condition. Moreover, this study would provide proactive decision support to USDA Forest Service or any other agencies responsible for safeguarding these structures.

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SIERRA NEVADA STREAMFLOW RESPONSE TO FOREST FUELS TREATMENTS DURING THE CALIFORNIA DROUGHT

Ryan Bart, Mohammad Safeeq, Joseph Wagenbrenner, and Carolyn Hunsaker

Abstract—Forest fuel treatments (e.g., thinning, prescribed fire) are used in the Sierra Nevada to minimize forest fire risks and in some cases have been shown to affect the amount and timing of water contributing to streamflow. This effect, however, is variable, with the amount of post-treatment streamflow change affected by differences in treatment locations and post-treatment meteorological conditions. In this study, we examined the effect of fuel treatments on Sierra streamflow in two sets of paired-watershed experiments. The first set of watersheds, Providence, was located at the rain-snow transition zone and consisted of treatments that included thinning, prescribed fire, and thinning followed by prescribed fire. The second set of watersheds, Bull, was located above the rain-snow transition zone and had an identical treatment design. The treatment events happen to coincide with one of the most severe droughts in California history (2012-2016). As such, the overarching research question for this analysis was how do fuel treatments affect streamflow during drought conditions? Results from the paired-watershed experiments showed no discernible change in post-treatment annual streamflow, seasonal streamflow or low flows at either of the study locations. To explore the physical mechanisms for why no streamflow change was observed during the drought, we used an ecohydrology model, The Regional Hydro-Ecologic Simulation System (RHESSys), to model the effect of fuel treatments on streamflow under different levels of post-treatment precipitation. The modeling results indicated that streamflow change during drought conditions should be minimal at the levels of basal area removed that occurred with the treatments, confirming the paired-watershed results. This study contributes to the growing body of knowledge demonstrating when and where forest fuel treatments may affect streamflow.

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SECTION 8

Managing and Characterizing Complex Aquatic Systems II

ENVIRONMENTAL PROTECTION AGENCY ECOSERVICE MODELS LIBRARY (ESML): A NEW TOOL FOR QUANTIFYING AND VALUING ECOSYSTEM SERVICES

Tammy Newcomer-Johnson, Randy Bruins, Gregg Lomnicky, John Wilson, and Ted DeWitt

Abstract—A challenge in quantifying and valuing ecosystem services is finding ecological models with endpoints that align with ecosystem services. U.S. Environmental Protection Agency (EPA)'s EcoService Models Library (ESML) is a readily available tool that addresses this challenge. ESML is a website and database for finding, examining, and comparing ecological models that may be useful for estimating ecosystem goods and services. This new EPA tool released in 2018, describes >125 ecological models. ESML shows how ecological models align with ecosystem services under two classification systems: (1) U.S. EPA's National Ecosystem Services Classification System, and (2) the European Environment Agency's Common International Classification of Ecosystem Services. This presentation discusses which classes of ecosystem services are covered by this population of ecological models, and the implications for quantifying and valuing ecosystem services.

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QUANTIFYING FLOODPLAIN ECOSYSTEM SERVICES

Kristina Hopkins, Gregory Noe, Samuel Lamont, Peter Claggett, Dianna Hogan, and Emily Pindilli

Abstract—Retention of sediments and nutrients in floodplain areas provides critical ecosystem services to downstream communities. Lidar mapping, field data collection, and modeling were integrated to quantify the ecosystem service of sediment and nutrient retention that floodplains provide in the Delaware River watershed. The mapping component of this project resulted in the development of the Floodplain and Channel Evaluation Toolkit (FACET) to identify features and calculate key metrics describing channel and floodplain geometry from high-resolution bare-earth elevation data in the Delaware River watershed. Field data collection employed dendrogeomorphic techniques to estimate rates of stream bank erosion and floodplain sediment deposition at 15 sites in the watershed. These two datasets were combined to develop predictive models estimating sediment trapping and export for each stream reach within the non-tidal portion of the Delaware River watershed. This assessment of floodplain net sediment flux and associated ecosystem services will help identify areas for targeted management to maintain areas with high ecosystem service values, and to restore areas that could provide the most ecosystem service benefits.

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ENVIRONMENTAL PROTECTION AGENCY ENVIROATLAS: INDICATORS FOR WORKING WATERSHEDS

Anne Neale

Abstract—Over recent decades, the Government has made a wealth of information publicly available as part of the Federal Open Data Policy. The EnviroAtlas provides a wealth of geospatial data and other resources to decisionmakers, educators, and researchers. EnviroAtlas resources are organized according to the benefits we receive from ecosystems (i.e., ecosystem goods and services) with one of the major categories being Clean and Plentiful Water. Much of the information contained within EnviroAtlas may be of particular interest to stakeholders engaged in the research, maintenance, protection, and improvement of aquatic condition and functional integrity within watersheds. This presentation will provide a brief overview of EnviroAtlas resources and will include data related to water use, potential wetland restoration, potential evapotranspiration now and in the future, floodplain delineation, water quality trading, aquatic invasiveness, overland flow, and pollutant loads.

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LOOKING FOR SOLUTIONS TO WATER QUALITY PROBLEMS IN THE CHESAPEAKE BAY WATERSHED: WHAT DOES WATER QUALITY TRADING HAVE TO OFFER?

Patricia Gleason

Abstract—The Unites States Environmental Protection Agency (EPA) believes that market-based approaches such as water quality trading provide greater flexibility and have the potential to achieve water quality and environmental benefits greater than would otherwise be achieved under more traditional regulatory approaches. Water quality trading is an approach that offers greater efficiency in achieving water quality goals on a watershed basis. It allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution control costs differentials among and between sources. Six case studies will be presented from across the Chesapeake Bay Watershed that illustrate different water quality trading approaches.

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THE URBAN WATERS PROGRAM: A PLATFORM FOR ACTIONABLE SCIENCE TO IMPROVE CITIES AND THEIR WATERWAYS

Morgan Grove, Bob Shedlock, Mike Galvin, Sarah Hines, and Steve Terracciano

Abstract—The Urban Waters program involves 14 Federal agencies working together and with State and local partners to improve cities and their waterways in 19 locations across the United States. While a major focus of Urban Waters is on specific projects and their implementation, many of the agencies have the capacity to conduct research and provide technical assistance. Thus, Urban Waters offers a novel forum for coordination, collaboration, and synthesis of federal research assets for local decisionmakers to use.

In this presentation, we use the Baltimore, Maryland Urban Waters project to discuss the structure, topics, and lessons learned for interactions among federal agencies and local decisionmakers and some of the novel outcomes of this partnership. Some of the key federal "research" agencies involved include U.S. Department of Agriculture, U.S. Geological Service, Environmental Protection Agency, National Science Foundation, and National Aeronautics Space and Administration. Baltimore Urban Waters' structures facilitate the co-design and co-production of research, as well as sharing of data, findings, and research products. Topics range from vary specific issues, such as polychlorinated biphenyl (PCB)s in aquatic systems to the social, economic, and ecological benefits or urban land reclamation in disadvantaged neighborhoods. Lessons are diverse, including how to engage and retain interest of scientists and decisionmakers over the long term, to how to leverage and integrate existing data with new data needs. While not an initial focus of the Urban Waters program, the capacity for actionable science has played an increasing role in the success of the program.

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SCALING GREEN INFRASTRUCTURE TO WATERSHEDS: CURRENT INSIGHTS AND FUTURE DIRECTIONS

Heather Golden, Nahal Hoghooghi, and Brian Bledsoe

Abstract—Urbanization modifies watershed hydrological processes, such as evapotranspiration, soil water storage, and runoff, and therefore requires deliberate, targeted stormwater management. Green infrastructure (GI) is a decentralized approach to stormwater management that uses plants, soils, and landscape design, and is promoted as a sustainable method for attenuating the adverse water quality and quantity (e.g., flooding) effects from urbanizing systems. However, evidence on the efficacy of GI is primarily based on local-scale studies, such as plots and small homogeneous patches of landscapes—not watersheds, the widely established scale of water resources management. Here we present considerations and approaches for scaling local-scale water quantity and quality responses to GI to watersheds. We discuss important concepts emerging from GI research at the local scale, methods for scaling this research to watersheds, recent advances in scaling the effects of GI practices on water quality and quantity at watershed scales, and the use of combined novel measurements and models for these scaling efforts. We highlight these ideas with a case study that uses model simulations to assess how various types and configurations of GI practices affect watershed hydrology in a mixed land cover watershed. Our synthesis of recent research suggests that advances are being made to scale results from GI studies to watersheds, but we are still at the vanguard of what may become an expansive area of research.

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TRACKING FLOWS OF WATER THROUGH A COMPLEX URBAN SYSTEM: CHICAGO

Laura Erban, Stephen Balogh, Henry Walker, and Daniel Campbell

Abstract—Urban water systems are complex and tightly coupled. In Chicago, the third largest U.S. city, wastewater treatment plant (WWTP) effluent comprises up to 70 percent of streamflow, more than half of which is withdrawn for thermoelectric power generation (PG). Despite the interdependence of users and mass conservative behavior of water flows, monitoring and management efforts are highly fragmented. Here we comprehensively analyze the urban water system in greater Chicago during water years 2001-2010 and examine longer trends in coupled flows. Our study area is defined by the seven counties that are served by the Chicago Metropolitan Agency for Planning (CMAP). We use a reproducible workflow codified in our newly developed R package CityWaterBalance to automate data retrieval and quantify the relative magnitudes of measured and unmeasured flows through the CMAP region. Among other insights, our system-level assessment reveals the comparable long-term (10-year) average magnitudes between (a) Lake Michigan withdrawals and river inflow, (b) total effluent (WWTP and PG) and river outflow, and (c) sewer infiltration and combined sewer overflow. Finer scale examination of temporal trends reveals significant reductions in potable water use and sewer overflows, and steady wastewater effluent volumes despite increased precipitation in recent years. Although a wealth of open data is available to study this region, discrepancies in spatial and temporal resolution preclude finer analysis of all system components at a scale relevant to CMAP. However, the increasing availability of web-served data will improve our ability to assess and compare urban water flows and to inform management decisions.

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SECTION 9

Water Quality in Appalachia

THE EXPERIMENTAL WATERSHED STUDY APPROACH TO MONITORING AND MANAGING CONTEMPORARY MIXED-LAND-USE WATERSHEDS

Jason Hubbart and Elliott Kellner

Abstract—Advancements in contemporary watershed management are both a major challenge, and urgent need of this century. The experimental watershed study (EWS) approach was used in forested wildland watersheds over a century ago to quantitatively characterize basic landscape alterations (e.g., forest harvest, road building) on water quality and various ecosystem responses. In recent years, EWS is being repurposed for contemporary multiple-land-use watershed monitoring and management practices. Contemporary watersheds comprise a mosaic of land use practices including (but not limited to) urbanizing centers, industry, agriculture, and rural development. The EWS method provides scalable and transferrable results that address the uncertainties of development, and outcomes of mitigation practices, while providing a scientific basis for total maximum daily load (TMDL) targets. This is critical considering increasing numbers of Clean Water Act 303(d) listed waters nation-wide. Collaborative adaptive management (CAM) programs, designed to consider the needs of many stakeholders, can also benefit from EWS-generated information, which can be used for best decisionmaking, and serve as a guidance tool throughout the CAM program duration. Of similar importance, long-term EWS monitoring programs create a model system to show stakeholders how investing in rigorous scientific research initiatives improves decision-making and reduces long-term costs, thereby improving management decisions, increasing management efficiencies, and sustaining natural resources through more focused investments. The evolution from classic wildland EWS designs to contemporary EWS designs in multiple-land-use watersheds will be presented while illustrating how such an approach can encourage innovation, cooperation, and trust among watershed stakeholders working towards a common goal of improving and sustaining hydrologic regimes and water quality.

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U.S. ENVIRONMENTAL PROTECTION AGENCY'S OPENTERRAWORKS SOFTWARE SYSTEM—AN OPEN-SOURCE 2D/3D LANDSCAPE DESIGN GIS TOOL

Justin Babendreier

Abstract—Human activities involving significant terrain alteration (e.g., earthworks operations associated with mines, urban development, landslides) can lead to wide-ranging changes in the surrounding terrestrial and aquatic environments. Potential aesthetic impacts can be associated with modified relief, soils, or change in land cover. Additionally, changes can be seen in spatiotemporal rates of surface runoff and erosion; rerouted flow paths; impacts to water quantity and quality; and species and ecosystem composition. Readily-accessible GIS-based landscape design tools available to the environmental community are lacking. Often modelers lack tools to create the detailed views of the land needed to model environmental changes before they happen. The OpenTERRAworks Software System (OTW) is an open-source Geographical Information System (GIS) that expands the capacity of U.S. Environmental Protection Agency to predict hillslope- to watershed-scale effects of proposed, alternative, and legacy landscape designs involving significant terrain modification terrain (3D) and/or surface (2D) modification. Users can readily access web-served landscape datasets and modify acquired data to represent changes in terrain elevations, soils, land use/land cover, and hydrography. OTW represents a "substitution" pattern for consuming landscape data that capture many key features of the environment needed to understand and predict future watershed conditions at multiple scales. OTW is not a model, but instead helps generate modified data in formats that many hydrology models and other analytical frameworks already consume. OTW provides a set of site-level, value-added "design operations" (e.g., cut, fill) for defining landscape change within the conterminous United States. OTW tracks design branches and phases at and across sites. OTW's geologic erosion routine and a companion dataset of coal seam data (West Virginia only) allows users to construct resource layers they can employ for design cuts. Typical intended consumers of OTW output files are analytical tools or models that already consume HUC8-scale geospatial datasets in standard formats. Typical uses include producing modified datasets, allowing users to analyze "futures" and/or conduct comparative analysis of baseline vs. future landscapes. OTW's newest Model Mode facilitates customized extensions that let model developers and users automate production of input data that can be consumed directly by their modeling system (e.g., add new map layers and web-services as needed).

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CUMULATIVE EFFECTS OF UNCONVENTIONAL OIL AND GAS DEVELOPMENT ON THE CHEMISTRY OF HEADWATERS WITHIN WEST VIRGINIA

Kevin Eliason, Todd Petty, and Eric Merriam

Abstract—We assessed the effects of unconventional oil and gas (UOG) development on headwater stream chemistry and biological condition within the Monongahela River watershed, West Virginia. We selected 53 study sites differing with respect to their individual and combined influence from UOG, conventional oil and gas (COG), coal mining, and residential development. Principal components analysis identified three dominant (~60 percent cumulative variance explained) dimensions of variation in water chemistry. Principal component (PC) 1 (~31 percent variance explained) was associated with dominant ions (Ca, Mg, K, Na, and SO_4^{-2}), as well as Sr and Br. Multiple regression analysis suggested mining and residential development were the dominant contributors to altered chemistry as characterized by PC 1. Using elevated Br/Cl as a tracer of oil and gas impact suggested greater chemical degradation with increased oil and gas intensity in impacted sites; however only 15 sites had elevated Br/Cl. Our results suggest UOG development is having a significant but inconsistent effect on surface water chemistry, with overall chemical degradation being dominated by mining and development. Additional sampling is needed to improve our ability to characterize and predict chemical degradation associated with UOG, as well as consider potential combined effects of UOG and other pre-existing land use stressors on aquatic communities.

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THE EFFECTS OF OFF-HIGHWAY VEHICLES ON STREAM WATER QUALITY IN THE NORTH FORK OF THE BROAD RIVER

Chelcy Miniat, P.P. Clinton, S.H. Laseter, and L.K. Everage

Abstract—Managing forests for recreational benefits, such as off-highway vehicle (OHV) use, as well as other ecosystem services such as clean and abundant water, can often present challenges for land managers when one ecosystem service conflicts with another. We conducted research in the Chattahoochee National Forest to assess whether the presence of OHV trails, and trail use, were associated with higher total suspended solid (TSS) concentration, TSS export, and turbidity in streams during 25 individual storms in 2015–2016. We used a paired watershed approach, with a treatment watershed containing the Locust Stake OHV trail system on the North Fork of the Broad River, paired with a reference watershed similar in all respects except for the trail system. Prior to the trails being re-opened following a period of closure, the OHV treatment watershed had TSS concentration 4.4 times greater for any given flow than the reference watershed (14.2 vs. 3.2 mg/L/cfs). After trail opening, the OHV treatment watershed had TSS concentration 7.3 fold greater for any give flow than the reference (63.7 vs. 8.7 mg/L/cfs). TSS concentration in the OHV treatment watershed 4.5 times higher when trails were open compared to when trails were closed, 14.2 vs. 63.6 mg/L/cfs; and while TSS concentration also increased in the reference watershed for these storm events, it was not significant. Our results suggest that the Locust Stake OHV trail system is associated with poorer water quality, but that water quality is improved with trail closure. Future management actions could focus on a spectrum of reducing hotspots of erosion to permanent trail closure and remediation.

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HUMAN DIMENSIONS OF WATER QUALITY: A WEST VIRGINIAN CASE STUDY

Jonas Levêque and Robert C. Burns

Abstract—Water quality issues in the Appalachia region are great and require further understanding of the chemical, biological, physical aspects of water quality and the human dimensions associated with it. With past and current human activities that have influenced water quality, and different sectors of activity competing for natural resources in the Appalachia, research on water quality is essential for this region. This study aims at understanding the social aspects related to water quality in Appalachia and more precisely on West Virginia, as a case study. While water provides different ecosystem services to the general public, this study has aimed at understanding the public perceptions of water quality, for drinking purposes but also from a recreational standpoint. For instance, one of the goals of this study was to understand how water quality perceptions affect intentions to recreate in West Virginia. Another goal was to understand how drinking behaviors (using bottled water, using a filter, treating the tap water) are related to the health risks perceptions when drinking from the tap. Other factors were also considered to explain these behaviors and intentions. Specifically, variables such as trust in governments and agencies, concern for the environment, and demographics variables. This study was operationalized during the Spring 2017, using an online survey. A total of 724 randomly selected rural West Virginia residents, and 4,188 West Virginia University students received an invitation via e-mail and completed the survey. As data is currently analyzed, we hypothesized several relationships among the diverse variables. Particularly, we hypothesized that higher risk perceptions of water quality would decrease recreation intention in West Virginia and increase the use of bottled water instead of tap water. Multiple linear regression using IBM SPSS software is used to test these hypotheses. The implications of these results in terms of management will be discussed for the case of West Virginia and the Appalachia region.

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CHARACTERIZATION OF SUB-WATERSHED-SCALE STREAM CHEMISTRY REGIMES IN AN APPALACHIAN MIXED-LAND-USE WATERSHED

Elliott Kellner, Jason Hubbart, Kirsten Stephan, Ember Morrissey, Zachary Freedman, Evan Kutta, and Charlene Kelly

Abstract—An exploratory study was conducted in an urbanizing, mixed-land-use Appalachian watershed. Six study sites, characterized by contrasting land use/land cover, were instrumented to continuously monitor stream stage. Weekly grab samples were collected from each site and analyzed for elemental composition via spectrometric and spectrophotometric methods. Additional physico-chemical parameters were measured in situ. Data were analyzed using a suite of statistical methods, including hypothesis testing, correlation analysis, and Principle Components Analysis (PCA). Significant differences ($p < 0.05$) between study sites were identified for every measured parameter except Cu concentration. However, different parameters showed significant differences ($p < 0.05$) between site pairings. PCA results highlight consistent spatial differences between elemental composition and physico-chemical characteristics of streamwater samples. Results from correlation analyses indicated varying significant ($p< 0.05$) relationships between chemical parameters and hydroclimate metrics, with certain elements (e.g., Ca, Sr) and physico-chemical parameters (e.g., specific conductance) displaying greater sensitivity to hydroclimate at sites mixed-land-use sites, as compared to predominately urban, agricultural, or forest sites. Given the geological, topographical, and climatological similarities between the sites, and their close proximity, it was concluded that land use characteristics and associated hydrologic regime contrasts were the primary factors contributing to the observed results. Results comprise valuable information for land and water managers seeking to mitigate the impacts of land use practices on water resources and aquatic ecosystem health. The applied methodology can be used to more effectively target sub-watershed-scale remediation/restoration efforts within mixed-use watersheds, thereby improving the ultimate efficacy of management practices.

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SECTION 10

Waters at the Border

EUTROPHICATION MANAGEMENT IN THE BALTIC SEA — A PARTIAL SUCCESS?

Michelle McCrackin

Abstract—Eutrophication is a major stressor in the Baltic Sea, which is home to the world's largest anthropogenic "dead zone." Environmental management is politically complicated because there are 14 countries in the drainage basin. The causes and consequences of eutrophication are well documented and a number of national and international policies have been implemented to address external nutrient loads. Nutrient reduction targets have been established through close collaboration between scientists and the Helsinki Commission (intergovernmental organization established in 1974 to protect the sea's environment). Since the 1980s, nutrient loads have nearly halved due largely to improved sewage treatment capabilities. Meeting environmental targets will require addressing diffuse agricultural sources. More recently, the long response time of the sea has led to "fatigue" and further nutrient reductions are seen as burdening the agricultural sector. Concern that slow recovery from eutrophication will weaken political support has led to discussions of geo-engineering measures to remove accumulated nutrients from the sea. To better disseminate scientific knowledge to policy- and decision-makers, Stockholm University partnered with a private foundation in 2014 to create Baltic Eye, a boundary organization composed of scientists, professional communicators, and policy analysts. I will share Baltic Eye's progress in engaging with eutrophication-related policies in the Baltic Sea region.

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P-OPTIMAL WETLANDS: ASSESSING THE CAPACITY OF WETLANDS TO IMPROVE WATER QUALITY IN GREAT LAKES AGRICULTURAL WATERSHEDS

Scott Bell, Jacob Berkowitz, Derek Schlea, Anthony Friona, and Michael Voorhees

Abstract—The reduction of harmful algal blooms (HABs) linked with nonpoint source phosphorus runoff remains a key priority of the Great Lakes Restoration Initiative (GLRI). In response, innovative solutions to watershed scale nutrient management are needed in both United States and Canadian watersheds. Numerous studies evaluate nutrient dynamics and removal in wetlands, indicating a wide range of phosphorus reduction capacity based on various factors including location, design and edaphic conditions. While many wetlands function as effective nutrient sinks (providing improved water quality), others operate as net nutrient sources (impairing downstream waters). Current work, supported by U.S. Environmental Protection Agency (USEPA) with GLRI funds and implemented through the U.S. Army Corps of Engineers (USACE) Environmental Research and Development Center (ERDC) and USACE Buffalo District, seeks to optimize phosphorus removal in wetlands through appropriate siting, design, and management. Such wetlands are herein referred to as P-optimal wetlands. The development of P-optimal wetland demonstration projects provides a template to employ nature-based nutrient pollution solutions across watersheds of concern, thus addressing regional (and international) excess nutrient loading and associated HAB scenarios. The optimization approach focuses on three main objectives: (1) restoring/creating wetlands in locations contributing to excess phosphorus loads; (2) designing wetlands to achieve maximum phosphorus removal through soil sorption and plant uptake, and (3) insuring that wetlands exhibit sufficient soil phosphorus sorption capacity (SPSC). Measured SPSC, a characteristic related to soil composition and landuse history, will help determine the end-state (i.e., nutrient sink or source) and sustainability of wetland features on the landscape. In total, the optimization process promotes the most effective application of limited resources across a watershed or region. The presentation will discuss how potential P-optimal wetland locations are being identified, report preliminary SPSC results from constructed wetlands in agricultural watersheds, and identify challenges to the development of regional nutrient reduction strategies utilizing natural and nature based features including P-optimized wetlands.

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NITROGEN INVENTORIES IN THE NOOKSACK-FRASER TRANSBOUNDARY WATERSHED: NORTH AMERICAN DEMONSTRATION FOR THE INTERNATIONAL NITROGEN MANAGEMENT SYSTEM

Jiajia Lin, Jana Compton, Jill Baron, Donna Schwede, Shabtai Bittman, David Hooper, Chris Clark, Peter Kiffney, Nichole Embertson, Barb Carey, Heather MacKay, Robert Black, and Gary Bahr

Abstract—Excessive nitrogen (N) loading can lead to eutrophication in coastal and fresh waters, air quality issues, and nitrate contamination of groundwater. The Nooksack-Fraser Transboundary-Nitrogen (NFT-N) project was developed to explore ways to work with a community to balance the beneficial and harmful aspects of nitrogen management. The NFT area (2639 km^2) is home to communities dependent on farming, fisheries, and outdoor recreation. Our first goal was to determine sources and fates of N in the watershed in 2014 using data on energy use, transportation, fertilization, wastewater treatment plants, livestock operations, wildlife, and more. This project brings together stakeholders, agencies, tribes, and scientists from the United States and Canada to characterize this transboundary N inventory.A comprehensive N assessment can benefit decisionmaking by providing key information on sources, transformations, and effects. This effort builds upon an existing Canadian N inventory for the Lower Fraser Valley, and currently is focusing on N sources on the United States side. The N needed for crops was estimated using local-specific data collected in 2014, while evaluating different fertilizer and manure application rates with various management intensities. Preliminary result found that to meet crop N demand on the United States side, about 2947-3526 metric tons (MT) of N had to be applied. Because only about 50 percent of applied manure N is available to crops after denitrification, mineralization, and volatilization loss, substituting manure for inorganic fertilizer would require 5937-7103 MT manure N. The combined septic and sewage input of N ranged between 71 and 84 MT per year, while atmospheric deposition contributed 527 MT N per year. Preliminary results demonstrate the importance of N inputs from agriculture. Future efforts will include updating agricultural data and Canadian budget information, and improving understanding of N fate and transport in ground and surface water in order to examine the impacts of N policy and management across the boundary (United States-Canada), and to support the development of sustainable N management plans in the region.

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USING MULTI-MEDIA MODELING TO INVESTIGATE CONDITIONS LEADING TO HARMFUL ALGAL BLOOMS

Valerie Garcia, Catherine Nowakowski, Marina Astitha, Penny Vlahos, Ellen Cooter, and Chunling Tang

Abstract—Lake Erie is the 12th largest lake in the world and provides drinking water to over 11 million people in the United States. Twenty-two thousand seven hundred and twenty square miles of varying landcover (e.g., urban, agriculture) drain directly into Lake Erie. Harmful algal blooms (HABs) have historically been an issue in Lake Erie, with events peaking in the late 1960's to early 1970's. Several studies have shown that these events were the result of excess phosphorus draining predominantly into the western portion of the lake from agricultural practices occurring in the surrounding watersheds. Phosphorus controls led to recovery of the lake by 1990, but since the mid-1990s, there has been a resurgence of HAB events, with the largest event on record occurring in 2015. We used linked and coupled physical models to examine relationships among environmental variables across multiple sources and pathways. Because these models link emission sources with meteorology and the pollutant concentrations found in the environment, they shed new light on the complex interactions of these chemicals and chemical mixtures. We used the broad range of variables available from these models, representing meteorology, hydrology, atmospheric processes, landscape characteristics, and agriculture management practices to examine relationships with available dissolved oxygen and chlorophyll α concentrations measured in Lake Erie. We found that inorganic nitrogen (N) fertilizer applied to crops and atmospheric N deposition were the strongest nutrient loading predictors of dissolved oxygen and chlorophyll α concentrations measured in Lake Erie. Further, we were able to examine the relationships of oxidized and reduced forms of N deposition, and dry and wet N deposition. The results of this analysis will be presented at the conference.

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SECTION 11

Watershed Evapotranspiration

EVAPORATIVE DEMAND: DYNAMICS AND OPPORTUNITIES IN DROUGHT EARLY WARNING, MONITORING, AND VULNERABILITY ASSESSMENT

M.T. Hobbins, C.F. Dewes, J.L. Huntington, D.J. McEvoy, I. Rangwala, S. Shukla, and H.M. Yocum

Abstract—Atmospheric evaporative demand (E_0)—the "thirst of the atmosphere"—plays a central role in determining and signaling watershed-scale hydroclimatic states, but until now it has remained poorly understood, modeled, and appreciated. Recent developments of accurate, long-term, fine-resolution land surface/atmosphere reanalyses have allowed those interested in changing hydroclimatic regimes and their extreme anomalies—notably drought—to exploit this flux. To this end, the National Oceanic and Atmospheric Administration (NOAA) is developing a reference evapotranspiration (ET_0) reanalysis as an accurate metric of E_0, and from this developing a drought index that represents drought's demand perspective. This index permits early warning and attribution of agricultural flash drought and hydrologic drought, and analysis of fire weather risk. NOAA is also collaborating with various partners in forecasting E_0 at subseasonal-to-seasonal and climate timescales.

To fully represent drought dynamics, one must address both the supply and demand sides of the surface hydrologic imbalance. Traditionally, the supply of moisture to the surface has been estimated using precipitation, data for which are widely available. However, the demand side has long been poorly represented—generally by a temperature-based E_0. Temperature-based E_0 cannot adequately replicate observed trends in drought-relevant fluxes/states of E_0, actual evapotranspiration (ET), or soil moisture (Hobbins and others 2008), or their variability (Hobbins 2016). Even though physically based E_0 estimators have been available for decades—e.g., the Penman-Montieth equation (Montieth 1965)—the further radiation, humidity, and wind-speed data required to generate fully physical estimates over space-time scales useful for drought monitoring have only recently become available with the advent of land surface/atmosphere reanalyses.

The basic principles behind E_0 and drought require a nuanced understanding of the drought-related interactions between E_0 and ET—both complementary and parallel—as shown in figure 1. Under water-limited conditions or starting from a dry state (as in ongoing drought), the complementary relationship dominates (Bouchet 1963). Here, decreasing moisture availability decreases ET, releasing this energy instead as sensible heat, thereby increasing temperature (as a first-order effect), vapor pressure deficit, and thus E_0. In this paradigm, so long as the hydroclimate remains water-limited, ET and E_0 respond in opposite directions. Under energy-limited conditions (or starting from a wet state, as in a drought starting in humid hydroclimates), both ET and E_0 move in parallel, with ET responding to variations in E_0 until such point that water availability becomes limiting; ET then starts to decline and the complementary dynamics dominate. Most importantly, E_0 rises in all drought cases, often before ET declines and certainly before vegetative stress is observable from in-situ or remote-sensing measurements. This makes E_0 a robust, and often leading, indicator of drought (Hobbins and others 2016).

NOAA is exploiting the opportunities presented by E_0 by developing a new, demand-side understanding and approach to drought at operational, secular, and climate timescales. Thus far, this work has primarily revolved around the new Evaporative Demand Drought Index (EDDI; https://www.esrl.noaa.gov/psd/eddi/), a standardized drought index that expresses as a percentile the anomaly in E_0 relative to its long-term climatology at various time-scales (Hobbins and others 2016; McEvoy and others 2016). EDDI has demonstrated early warning of agricultural and hydrologic drought, incipient fire danger, and particularly conditions leading to flash drought. The E_0 used in EDDI is ET_0 derived from the American Society of Civil Engineers Standardized Reference ET equation (ASCE-EWRI 2005) forced by North American Land Data Assimilation System phase-2 drivers (NLDAS-2; https://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php) and is publicly available (ftp://ftp.cdc.noaa.gov/Projects/RefET/). It also permits explicit attribution of the demand side of drought into its meteorological and radiative drivers. This work is being extended globally for food-security monitoring under the aegis of the Famine Early Warning System Network (FEWS NET; http://fews.net/).

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Looking forward, opportunities in forecasting E_0 at daily to climate timescales abound. NOAA has developed a short-term (daily to weekly) forecast ET_0 product (https://digital.weather.gov/), while McEvoy and others (2016) and Shukla and others (2017) have demonstrated the efficacy of subseasonal-to-seasonal E_0 forecasts across CONUS and Africa, respectively; across CONUS the E_0-forecast skill is higher than for precipitation. At climate timescales, Dewes and others (2017) showed that projected mid 21st-century drought risk varies significantly with the physical representativeness of the E_0 parameterization, GCM forcing data selection, and drought index used, but there are significant conceptual and biophysical questions to be addressed before successful implementation of climate-scale E_0 projections in drought and climate-vulnerability assessments.

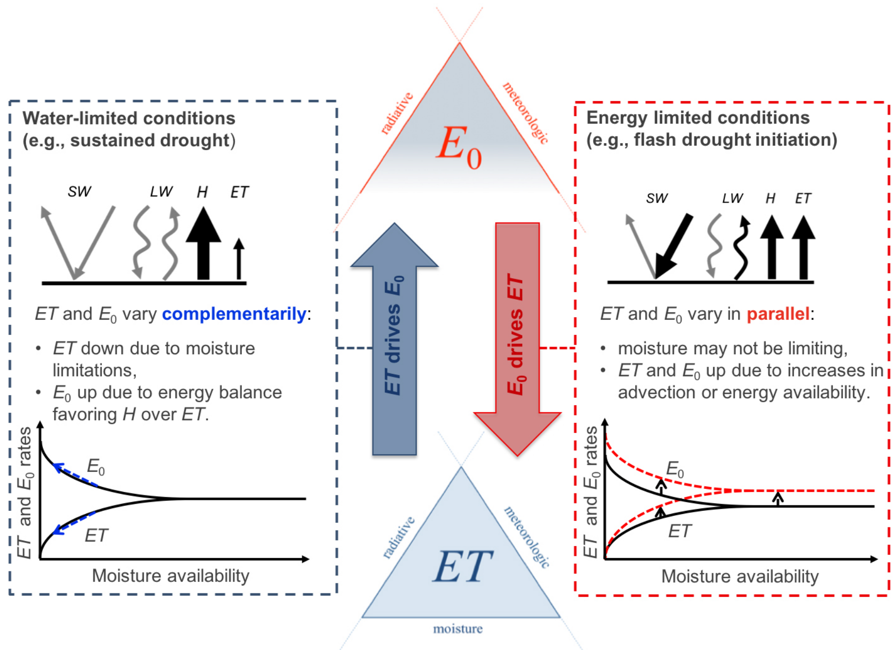

Figure 1—Land surface-atmosphere interactions under drought, demonstrating the constraints on ET and E_0 and their drought-related physical interactions at either end of the hydroclimatic spectrum: the water-limited conditions of sustained drought (dashed blue box at left) and the energy-limited conditions of flash drought initiation in humid hydroclimates (dashed red box at right). The energy balances show sensible heat (H), latent heat flux (ET), and the shortwave and longwave radiation balances (SW and LW, respectively).

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IS POTENTIAL EVAPOTRANSPIRATION INCREASING? A COMPARISON OF ESTIMATION METHODS TO LONG-TERM MEASUREMENTS

Peter Caldwell, K. Duan, and C.F. Miniat

Abstract—Potential evapotranspiration (PET), a measure of evapotranspiration (ET) when water is not limiting, is often used in hydrologic models to examine potential changes in watershed yield (Q) under climate change scenarios. These studies estimate PET using microclimatic variables and one of a number of equations ranging from complex (e.g., Penman-Monteith) to simple (e.g., Hamon) depending on climate data availability. PET can also be estimated from direct measurements with open evaporation pans, or in energy-limited regions, annual watershed ET (precipitation – Q) can approximate annual PET. Many studies have examined biases in PET estimates using prediction equations relative to direct measurements over short time periods but few evaluate predictions of how PET has changed over the long-term in response to climate change. In this study, we examined differences in the magnitude and timing of changes in predicted PET from 1961-2015 at the U.S. Department of Agriculture Forest Service Coweeta Hydrologic Laboratory using the Penman, Priestley-Taylor, and Hamon methods. We then compared these predictions of changes in PET over time to pan evaporation measurements and reference watershed ET. Preliminary results indicate that mean PET predicted with all equations using standard adjustments was consistent with pan evaporation and watershed ET, highlighting the fact that over the long-term ET is energy rather than water limited at this site. All PET estimation methods, pan evaporation, and watershed ET showed that annual PET has increased over time, however the magnitude and timing of change over the period of record varied across methods. The magnitude of predicted increases in PET over the period of record ranged from 10 percent (Hamon method) to 17 percent (Priestley-Taylor method) while pan evaporation and watershed ET increased 8 percent and 13 percent, respectively. The timing of changes in PET ranged from increases from 1961 to 1988 and constant since that time (Priestley-Taylor), to constant from 1961 to 1977 then increasing to the present (Hamon). These results suggest that predictions of the magnitude and timing of changes in PET can vary widely among estimation methods and in relation to direct measures, thus projections of future changes in Q under climate change scenarios could be highly dependent on PET estimation method used.

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EFFECTS OF FOREST COMPOSITION ON COMPONENTS OF EVAPOTRANSPIRATION IN A MATURE, SOUTHERN APPALACHIAN FOREST

A. Christopher Oishi, Chelcy Miniat, Steven Brantley, Kimberly Novick, Paul Bolstad, James Vose, Peter Caldwell, and Kai Duan

Abstract—Mature, temperate forests have often demonstrated relatively low interannual variability in evapotranspiration (ET), compared to variability in precipitation. However, warming temperatures have the potential to increase forest ET by increasing the atmospheric demand for water (i.e., vapor pressure deficit) and extending the growing season length. Whether increases in potential ET translate to actual ET will depend on local conditions, including seasonal soil water availability and stand characteristics. The effect of warmer temperatures on actual ET is particularly uncertain in forests with a diversity of leaf habits (e.g., evergreen and deciduous), plant hydraulic strategies (e.g., isohydric and anisohydric), and drought tolerance characteristics (e.g., rooting depth) since interactions among species may amplify or mute the overall response. We examine 7 years of data (2011-2017) from the Coweeta Hydrologic Laboratory in the Southern Appalachian mountains of North Carolina, including meteorological, eddy covariance, sap flux and streamflow measurements. Despite high interannual variability in precipitation (1315 to 2384 mm y^{-1}; coefficient of variation (CV) = 20 percent) and in pan evaporation (701 to 1071 mm y^{-1}; CV = 15 percent), eddy covariance-based ET was much less variable (813 to 905 mm y^{-1}; CV = 4 percent). Variation in the timing of leaf expansion in the deciduous canopy did not affect springtime transpiration, due to the contribution of transpiration from the evergreen understory. Although no growing season drought conditions occurred during the study period, we found some evidence that moderately low soil moisture may affect ET when it occurs late in the growing season. These results will improve our understanding of how predicted changes in species composition through management practices, changing disturbance regimes, or successional change (e.g., mesophication) are likely to affect forest water use and water yield.

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INVESTIGATING IMPACTS OF DROUGHT AND DISTURBANCE ON LANDSCAPE EVAPOTRANSPIRATION USING HIGH SPATIOTEMPORAL RESOLUTION DATA

Yun Yang, Martha Anderson, Feng Gao, Christopher Hain, Asko Noormets, Ge Sun, Randolph Wynne, and Valerie Thomas

Abstract—Forest ecosystem services such as clean water and timber supplies are increasingly threatened by drought and disturbances (e.g., harvesting, fires, and conversion to other uses) that can have great impacts on the hydrologic cycle of forests. Hence, improved understanding of the hydrologic response to drought and disturbance at a high spatiotemporal resolution is important for effective forest management at landscape scale to maximize forest ecosystem services. As a key variable in assessing forest ecosystem functions and services, Evapotranspiration (ET) still remains a challenge to be accurately quantified at landscape scale. To investigate the response of forest ET to drought and disturbance, we estimated ET using a surface energy balance model based on thermal infrared (TIR) imagery and generated a multi-year daily ET datacube at 30 m resolution using a data fusion technique. We estimated ET for an area (~900 km^2) on the humid lower coastal plains in North Carolina, including natural and managed forest as well as croplands. The study period was from 2006 to 2012, with 2007 and 2008 as severe drought years. We evaluated our model using data collected at two AmeriFlux sites (US-NC2 and US-NC1) dominated by a mature and a recently clearcut pine plantation, respectively. We examined plant ET, transpiration (T) and actual-to-reference ET ratio (fRET) to investigate changes in water use patterns in response to land cover type, forest stand age, climatic forcing and disturbance. We show differential response to drought events from different land cover types, with young plantations showing larger impacts than mature pine plantations with significantly deeper rooting systems. Anomalies of fRET, that capture well the signal of drought and disturbance and the subsequent recovery after clearcut, is an effective indicator for water use change detection and monitor. This study provides new insights about detecting and monitoring the water dynamic under drought and disturbance at landscape scale.

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RESPONSE OF EVAPOTRANSPIRATION TO DROUGHT AND MANAGEMENT IN LOBLOLLY PINE FORESTS ON THE LOWER COASTAL PLAIN IN NORTH CAROLINA

Ge Sun, Xiaodong Liu, Bhaskar Mitra, J-C. Domec, M.J. Gavazzi, David Zietlow, S.G. McNulty, J.S. King, and A. Noormets

Abstract—Since 2004, we have monitored energy, water, and carbon fluxes in a chronosequence of three drained loblolly pine (*Pinus taeda*) plantations using integrated methods that include eddy covariance, sap flux, watershed hydrometeorology, remote sensing, and process-based simulation modeling. Study sites were located on the eastern North Carolina coastal plain, representing highly productive ecosystems with high groundwater table, and designated in the Ameriflux network as NC1 (0–10 years old), NC2 (12–25 years old) and NC3 (0–3 years old). The 13-year study spanned a wide range of annual precipitation (900–1600 mm/year) including two exceptionally dry years during 2007–2008. We found that the mature stand (NC2) had higher net radiation (Rn) flux due to its lower albedo (α =0.11–12), compared with the young stands (NC1, NC3) (α=0.15–0.18). Annually about 75 to 80 percent of net radiation was converted to latent heat in the pine plantations. In general, the mature stand had higher latent heat flux [i.e., evapotranspiration (ET)] rates than the young stands, but ET rates were similar during wet years when the groundwater table was at or near the soil surface. During a historic drought period (i.e., 2007–2008) when precipitation was reduced by 40 percent from a norm of 1300 mm/year, the total stand annual ET exceeded precipitation, but only resulted in a moderate decrease (~10 percent) in annual ET. Over a full stand rotation, approximately 70 percent (young stand) to 90 percent (mature stand) of precipitation was returned to the atmosphere through ET. A 50 percent thinning caused a large reduction of Leaf Area Index of aboveground forest canopy, annual ET estimates were similar, 1055 mm prior to vs. 1104 mm post thinning in late 2009. The results suggest that the hydrologic effects of prescribed thinning may be masked by climatic variability and/or total forest ET recovers quickly in the coastal plain pine forest. We conclude that both climatic variability and canopy structure controlled the partitioning of precipitation and solar energy in pine forests. In addition, we conclude that accessible groundwater was an important factor for stabilizing forest water and energy balances during a drought in the lower coastal ecosystems.

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SECTION 12

Posters

LITERATURE-BASED SYNTHESIS OF NUTRIENT STRESSOR-RESPONSE RELATIONSHIPS TO INFORM ASSESSMENT, MONITORING, AND CRITERIA DEVELOPMENT IN RIVERS AND STREAMS

Micah Bennett, Kate Schofield, Sylvia Lee, David Gibbs, Caroline Ridley, and Susan Norton

Abstract—Eutrophication from nitrogen and phosphorus pollution is a major stressor of freshwater ecosystems globally. Despite recognition of this problem by scientists and stakeholders, synthesis of scientific evidence is still needed to inform nutrient-related management decisions and policies, especially for streams and rivers. A rigorous assessment of what is known about nutrient-stressor response relationships and modifying factors is a critical first step for identifying, managing, and restoring aquatic resources impaired by eutrophication. We conducted systematic reviews of the literature that asked: "What are the responses of chlorophyll-a, diatoms, and macroinvertebrates to TN and TP concentrations in lotic ecosystems," and "how are these relationships affected by other factors?" We describe the reviews and discuss preliminary results based on the ~300 publications documenting cause-effect relationships between relevant nutrients and endpoints that were obtained after screening >22,000 publications from academic databases, and >4,000 from other sources, for relevance, duplication, and quantitative effect sizes. These reviews provide a state-of-the-science body of evidence for assessing nutrient impacts to the most widely-used indicators of biological responses to nutrients.

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CUAHSI DATA SERVICES: TOOLS AND CYBERINFRASTRUCTURE FOR WATER DATA PUBLICATION, DISCOVERY, RESEARCH, AND COLLABORATION

Liza Brazil

Abstract—Enabling research surrounding interdisciplinary topics often requires a combination of finding, managing, and analyzing large datasets and models from multiple sources. This challenge has led the National Science Foundation to make strategic investments in developing community data tools and cyberinfrastructure that focus on water data, as it is a central need for many of these research topics.

The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) is a non-profit organization funded by the National Science Foundation to aid students, researchers, and educators in using and managing data and models to support research and education in the water sciences. This presentation will focus on two free and open-source CUAHSI-operated tools that enable: (1) enhanced data discovery online from multiple sources using advanced searching capabilities and (2) flexible publishing tools to easily share products resulting from research and/or data collection.

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IMPACTS OF MOUNTAINTOP REMOVAL COAL MINING ON CARBON AND NITROGEN CYCLING IN WEST VIRGINIA HEADWATER STREAMS

Roger Burke, Ken Fritz, and Brent Johnson

Abstract—Soil and vegetation disturbance associated with mountaintop removal and valley fill (MTR/VF) coal mining have the potential to alter carbon and nitrogen cycling in headwater streams. To assess this possibility, we measured sediment denitrification enzyme activity (DEA), sediment oxygen demand (SOD) and the concentration and stable carbon isotopic composition of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) in stream water during fall, winter, spring, and summer sampling campaigns. Our measurements were conducted in 5 streams that drained nearly 100 percent forested land and 5 streams that were heavily impacted by MTR/VF operations in the Twenty mile Creek watershed, West Virginia. We found that sediment DEA was greater and SOD lower in the MTR/VF streams than in the forested streams, but the differences were not statistically significant. We observed a weak but statistically significant correlation between DEA and SOD ($r^2 = 0.19$, $p < 0.01$). Correlation of similar strength between denitrification rate and SOD has been observed by others in aquatic sediments from various freshwater and marine environments and suggests coupling between carbon cycling and denitrification. DIC concentrations and stable carbon isotopic compositions were significantly greater in the MTR/VF streams than in respective forested streams, likely reflecting enhanced carbonate weathering accompanying MTR/VF disturbance. Although the differences were not statistically significant, DOC concentrations and stable carbon isotopic compositions were slightly greater in MTR/VF than in forested streams, likely indicating mobilization of either geogenic carbon (e.g., coal) or highly weathered soil organic matter from deep in the soil profile. Given the massive disturbance to the terrestrial ecosystem caused by MTR/VF mining, the apparently modest impacts of mining on sediment DEA and SOD suggest that carbon and nitrogen cycling in these streams may be more controlled by local (i.e., riparian) organic matter inputs than by processes occurring in the watershed as a whole.

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EFFECTS OF LARGE WILDFIRES ON WATER QUALITY AND WATER QUANTITY IN THE SOUTHERN APPALACHIANS

Peter Caldwell, K.J. Elliott, J.D. Knoepp, D.R. Zietlow, J.M. Vose, P.V. Bolstad, and C.F. Miniat

Abstract—Wildfires are landscape scale disturbances that can significantly impact hydrologic processes such as surface runoff, sediment yield, and sediment and nutrient transport to streams. In October and November 2016, unprecedented, large, drought-related wildfires (ranging from 1200 to 9700 hectares) of mixed-severity burns occurred across the Southern Appalachian Mountains. We established sites in three burned and three nearby unburned, reference watersheds with the former having a mosaic of moderate and high severity fires. Our objective was to evaluate the impact of fire severity on tree mortality, stream water quality (temperature, chemistry and sediment) and quantity (yield, peak flows, and base flows). We hypothesized that wildfires would result in tree mortality, soil O-horizon consumption, greater stormflow and nutrient and sediment export compared to reference watersheds. We measured immediate and delayed tree mortality in permanent plots, stream stage and water temperature, NO_3 and NH_4, and sediment as total suspended solids (TSS) during baseflow and storm events.

Tree mortality due to the wildfires averaged 27, 27.5, and 34 percent across the three burned watersheds. Plots ranged in burn severity with up to 100 percent tree mortality and 100 percent soil O-horizon removal. Soil inorganic nitrogen (NH_4 + NO_3) concentrations increased with increasing burn severity ($R^2 = 0.29$, $P < 0.001$). Stream nitrate (NO_3-N) concentrations were elevated in burned watersheds (mean 0.07 mg L^{-1}) relative to unburned watersheds (mean 0.02 mg L^{-1}); mean monthly NO_3-N in the most severely burned watershed reached 0.27 mg L^{-1}, well above the maximum monthly NO_3-N in unburned watersheds (0.06 mg L^{-1}). During storm events, stream NO_3-N concentrations in burned watersheds increased up to 300 percent, while unburned watersheds were less flow dependent. The flow-dependent stream NO_3-N concentrations in burned watersheds will result in greater NO_3-N export relative to unburned watersheds. Mean stream TSS concentrations were lower in burned (17.5 mg L^{-1}) than unburned (28.6 mg L^{-1}) watersheds under baseflow conditions; however, TSS concentrations collected during storm events in burned (max 9353 mg L^{-1}) greatly exceeded concentrations in unburned (max 787 mg L^{-1}) watersheds. The 2016 wildfires have thus degraded forest condition and water quality particularly during storm events.

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PARTNERSHIPS FOR WETLANDS RESTORATION— THE U.S. FISH AND WILDLIFE SERVICE COASTAL PROGRAM

Chris Darnell, Samantha Brooke, and Chris Eng

Abstract—Wetlands are the cornerstone of many important and complex ecosystems. Their health and distribution in watersheds provide countless benefits for fish, wildlife, and people. The U.S. Fish and Wildlife Service (USFWS) Coastal Program and its partners restore wetlands, protect coastal habitats through easements, remove impediments to fish passage, and restore riparian habitat. The Coastal Program has decades of experience working on public (local, State, and Federal, including National Wildlife Refuges) and private lands to align Department of the Interior, Service, and partner conservation goals and bring strategic landscape conservation to the wider conservation community. To accomplish this, our locally-based field staff works with an extensive and diverse partner network to implement on-the-ground habitat restoration projects, provide technical assistance, and build conservation capacity. Over the past decade, the Coastal Program has worked with thousands of partners to design over 4,000 habitat improvement projects addressing shared conservation goals. Through our high leveraging ratio we bring non-federal resources to the table and enlist partner support to achieve shared conservation goals. This poster will present several case studies of successful wetland restoration, research, and management partnership projects.

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SOIL HEALTH, SOIL QUALITY, SOIL INDICATORS, AND HOW THE BUREAU OF LAND MANAGEMENT (BLM) USES SOIL INFORMATION

Scott Davis

Abstract—By understanding that the living ecosystem diversity of soils is far greater than above-ground systems the Bureau of Land Management (BLM) is re-engineering its strategy to be more responsive to the Agency and public needs, including addressing the frequent wildfires that are impacting our sagebrush landscapes in the Western United States. The Landscape Approach is a process to assist in establishing our land use planning goals and objectives in assessing and measuring our resource conditions. These steps are followed by monitoring to determine if mitigations and adaptations are needed for plan conformance.

The National Cooperative Soil Survey contains vital data for all levels of BLM's activities, programs, and initiatives addressing our landscapes and land health. It is the foundation of BLM's Assessment, Inventory, and Monitoring (AIM) process which collects the status, condition, trends, amount, location, and spatial distribution of our renewable resources. The key is our partnership with the Natural Resources Conservation Service that informs us on how soils form, their importance and how to use soils information.

Soil health is related to soil quality and land health. Soil quality and soil health are tied to BLM's land health standards, with the appropriate soil quality indicators related to the soil survey and ecological site descriptions and state transition models. Soil quality and soil quality indicators measures functions and can be a chemical, physical or biological property of a soil that is sensitive to disturbance and represents performance of an ecosystem's function. Indicators are dynamic soil properties to evaluate how well soil functions since soil function often cannot be directly measured. Hence, measuring soil quality involves identifying soil properties that respond to management, are correlated with environmental outcomes, and can be easily observed. They are chosen because they correlate with ecosystem processes; integrate soil physical, chemical, and biological properties; are accessible, observable to many users; are sensitive to management and climate; are components of existing databases; and are interpretable. For rangeland-forest health, indicators are used with management practices that manipulate vegetation, or after fire, disturbance, i.e. chemical / physical treatments, seeding, planting, etc.

In summary, soil quality indicators are important because they:

1. Help BLM meet its mission of land sustainability
2. Help BLM meet its land management objectives
3. Help with soil assessment methods, tools
4. Specifically assess BLM's land health standards

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USE OF COUPLED THREE-DIMENSIONAL HYDRODYNAMIC AND WATER-QUALITY MODELS TO SIMULATE NUTRIENT AND PHYTOPLANKTON DYNAMICS IN THE BARNEGAT BAY-LITTLE EGG HARBOR ESTUARY, NEW JERSEY

Vincent DePaul, Frederick J. Spitz, Zafer Defne, Tim Wool, Jeffrey M. Fischer, and Mary M. Chepiga

Abstract—A coupled three-dimensional hydrodynamic water-quality model is applied to the Barnegat Bay-Little Egg Harbor Estuary to better define the nutrient cycling processes and phytoplankton dynamics, as well as, to provide a tool to simulate estuarine response to external stressors. The water-quality model was calibrated to observational data collected in 2012 for dissolved oxygen, total chlorophyll a, and nitrogen and phosphorus species, and validated with an independent dataset collected in 2012. A near-natural condition simulation, with reduced watershed loading representing conversion of developed land to forest, was run using the coupled models.

Comparisons of 2012 measured and simulated data show that water-quality distribution patterns are adequately reproduced throughout the system. Analysis of simulated nitrogen concentrations indicate broad areas of moderate to substantial impairment throughout the north, consistent with in-bay measured data and estimated loading from the watershed. Simulated chlorophyll a concentrations of 10 µg/L or greater, indicative of a eutrophic estuary, are widespread throughout the northern segment of the estuary. Simulated total and dissolved inorganic phosphorus concentrations increase along the salinity gradient from north to south. Simulated dissolved oxygen concentrations, while moderately higher than observed data in the surface layer, are consistent with monitored seasonal and spatial trends. Results also indicate that while the system is primarily nitrogen-limited, phosphorus limitation can occur in areas of the northern segment where inorganic nitrogen loading is substantial.

Results from the near-natural condition simulation indicate significant differences in bay-water quality from the 2012 baseline simulation, with the largest differences in the north where estimated load reductions are greatest. Differences in summertime depth averaged water–column concentrations are most significant for total nitrogen and dissolved nitrate, which decreased by approximately 15 and 60 percent, respectively, when averaged throughout the estuary, and by 30 and 87 percent, when averaged throughout the northern segment. Simulated total chlorophyll a concentrations are 36 percent lower throughout the estuary and are 64 percent lower in the northern segment. Simulated near-natural total phosphorus concentrations showed little difference from baseline conditions. Results also indicate little change in simulated dissolved oxygen concentrations, suggesting the importance of sediment diagenesis (or other factors) to oxygen availability in the system.

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APPLICATION OF THE AUTOMATED GEOSPATIAL WATERSHED ASSESSMENT TOOL (AGWA)

D. Phillip Guertin, David C. Goodrich, I. Shea Burns, Yoganand Korgaonkar, Jane Barlow Patel, Benjamin Olimpio, Carl Unkrich, William G. Kepner, and Lainie Levick

Abstract—The Automated Geospatial Watershed Assessment tool (AGWA) (https://www.epa.gov/water-research/automated-geospatial-watershed-assessment-agwa-tool-hydrologic-modeling-and-watershed or www.tucson.ars.ag.gov/agwa) is a GIS interface jointly developed by the U.S. Department of Agriculture (USDA)-Agricultural Research Service, the U.S. Environmental Protection Agency (U.S. EPA), the University of Arizona, and the University of Wyoming to automate the parameterization and execution of a suite of hydrologic and erosion models [Rangeland Hydrology and Erosion Model (RHEM), K2–KINematic runoff and EROsion model (KINEROS2), and Soil & Water Assessment Tool version 2000 and version 2005 (SWAT)]. Through an intuitive GIS interface the user selects a watershed outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM). The watershed model elements are then intersected with terrain, soils, and land cover data layers to derive estimates of the model input parameters. The model is then run, and the results imported back into AGWA for graphical display. AGWA can difference results from multiple simulations to examine relative change over a variety of input scenarios (e.g., climate/storm change, land cover change, implementation of BMPs, present conditions, and alternative futures). This allows managers to identify potential problem areas where additional monitoring can be undertaken or mitigation activities can be focused.

INTRODUCTION

Effective watershed management requires evaluating how changed watershed conditions affect runoff, erosion, and water quality. Assessing the impact of land-use/land-cover change and the management actions to mitigate these impacts supports identifying areas that are vulnerable and at risk for impairment, and identifies monitoring locations relative to watershed-based planning and decisionmaking. In order to be useful, a watershed assessment tool must not only be able to (1) predict the impacts of changing watershed conditions, but also (2) be capable of utilizing readily available data, (3) provide output metrics important for decisionmaking, and (4) be relatively easy to use.

AGWA was designed to support watershed assessment and analysis across a range of spatial and temporal scales, automate the model parameterizing process, and graphically visualize modeling results. The development of AGWA has been a joint effort with the USDA-Agricultural Research Service's Southwest Watershed Research Center, the U.S. EPA Landscape Ecology Branch, the University of Arizona, and the University of Wyoming.

OVERVIEW

AGWA (Miller and others 2007) is a Geographic Information System (GIS) based watershed modeling tool. The guiding principles for the development of AGWA were: (1) it provides simple, direct, transparent, and repeatable parameterization routines through an automated, intuitive interface, (2) it is applicable to ungauged watersheds at multiple spatial and temporal scales, (3) it evaluates the impacts of management or disturbance and can be useful for scenario development, and (4) it uses free and commonly available GIS data layers.

The models currently incorporated in AGWA are KINEROS2 (Smith and others 1995), RHEM (Hernandez and others 2017), and SWAT (Arnold and Fohrer 2005). AGWA supports modeling along a continuum of spatial and temporal scales,

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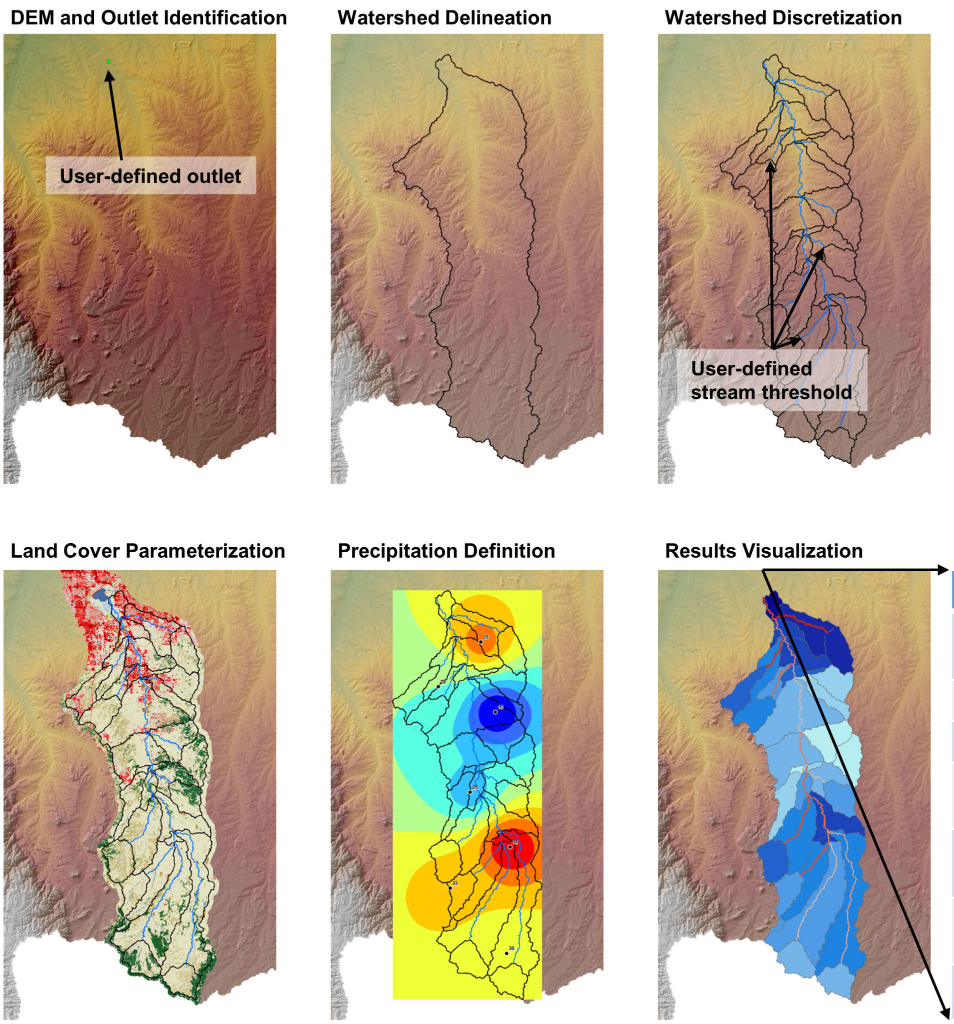
ranging from hillslopes (~hectares) to large watersheds (>1000 km^2) and from individual storm events (minute time steps) to continuous simulation (daily time steps over multiple years). AGWA supports the parameterization and execution of hydrologic models for watershed modeling efforts by performing the following tasks: watershed delineation; watershed discretization into discrete model elements; watershed parameterization; precipitation definition; simulation creation; simulation execution; and simulation results visualization (fig. 1). Various input data are required to support this functionality, including: a raster-based digital elevation model (DEM); a polygon soil map (NRCS SSURGO, NRCS STATSGO, or FAO soil maps); and a classified, raster-based land cover [National Land Cover Dataset (NLCD), North American Land Cover (NALC), and GAP/LANDFIRE datasets are supported via provided look-up tables in AGWA; however, other datasets may be used if accompanied with a related look-up table]. AGWA does not require observed precipitation or runoff to drive the models when used for relative assessment/differencing between scenarios and can use user-defined depths and durations, user-defined hyetographs, or design storms to drive K2, and included weather station-based generated, daily precipitation (U.S. only) to drive SWAT. However, high-quality rainfall-runoff observations are required for calibration and validation of quantitative model predictions (Goodrich and others 2012).



K2 Outputs	SWAT Outputs
Infiltration	Channel Discharge
Runoff	ET
Sediment Yield	Percolation
Peak Flow	Surface Runoff
Sediment Discharge	Transmission Losses
Precipitation	Sediment Yield
	Precipitation

Figure 1—The required steps in AGWA to perform a watershed assessment. A DEM is used to delineate the watershed and subdivide it into model elements (i.e., hillslopes and channels for K2 and subwatersheds and channels for SWAT). The model elements are parameterized based on the DEM, soils, and land cover layers. The precipitation input is then selected from various sources. After the model is executed, the results are imported and visualized in the GIS.

APPLICATIONS

Landscape Change Assessments

Originally, AGWA was designed to evaluate the impacts on runoff, sediment, and water quality from current, historic or future watershed conditions, primarily using land cover/land use data, such as the NLCD. In this context AGWA has been applied in the United States and other parts of the world (Abdulla and Eshtawi 2007, Baker and Miller 2013, Haman and others 2012, Hernandez and others 2010, Kepner and others 2004, 2008, Miller and others 2002, Mirzaei and others 2013, Nazarnejad and others 2012, Yang and Li 2011). Recent research has focused on assessing the potential hydrologic impacts of climate change, including the potential changes in land use and land cover (Barlow and others 2014, Burns and others 2013, O'Connor and others 2016) and developing tools to address the hydrological and erosion impacts of military training exercises (Levick 2017).

A methodology was developed to characterize the hydrologic impacts of future urban growth (Barlow and others 2014, Burns and others 2013, Kepner and others 2015). Future growth is represented by housing density maps generated in decadal intervals from 2010 to 2100, produced by the US-EPA Integrated Climate and Land-Use Scenarios (ICLUS) (Bierwagen and others 2010) project. 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 the hydrologic impacts of future growth, the housing density maps were reclassified to NLCD 2006 land cover classes and used to parameterize the SWAT model using AGWA. Burns and others (2013) conducted this effort in the international San Pedro Basin in southeast Arizona and did not find a substantial impact on average surface runoff or on sediment yield at the watershed outlet for all scenarios. However, over smaller subwatersheds, where development was concentrated, the hydrologic changes are more significant (figs. 2 and 3).

Rangeland Assessments

Effective rangeland management requires the ability to assess the potential impacts of management actions on runoff and erosion at both the hillslope and watershed scales. Many of the current tools for assessing and evaluating the effects of rangeland management practices on soil and water resources originally were developed for traditional cropland agricultural practices. These tools and models assumed a uniform vegetation distribution and surface cover across the landscape, which poorly represents typical rangeland conditions. To address this issue, RHEM (Hernandez and others 2017) was incorporated into K2 to better represent the runoff and erosion processes on rangeland hillslopes. Parameterization approaches to support RHEM were developed for AGWA (Goodrich and others 2011). AGWA, via the KINEROS2 watershed model, executes RHEM for all hillslopes within a watershed. Runoff and sediment are then routed through channels draining the hillslopes, enabling rapid rangeland watershed scale assessments (Weltz and others 2011).

Other tools have been developed for AGWA to support rangeland watershed assessments. RHEM supports complex slope profiles, so the slope definition process was enhanced to include a complex slope weighting process versus the existing uniform slope weighting for overland flow planes contributing laterally to channels (Goodrich and others 2015). Riparian buffer strips and range management practices (grazing system, brush removal, water sources) can also be represented (Goodrich and others 2011, Weltz and others 2011). Barlow (2017) developed procedures to rapidly characterize ponds (i.e., stock ponds, erosion basins) using LiDAR data and incorporate the pond elements into K2.

Post Wildland Fire Assessments

Procedures have been developed to parameterize SWAT and K2 to model the impacts of wildland fire (Goodrich and others 2012). Using a Burn Area Reflectance Classification (BARC) or burn severity data layer, the post-fire vegetation condition is created from the pre-fire land cover layer to reflect the effect of burn severity on soils. Based on previous research (Canfield and others 2005, Goodrich and others 2005, 2012, Sheppard 2016) the soil saturated hydraulic conductivity following fire is extremely low and overland flow roughness is similar to bare ground. However, roughness values recover rapidly, while saturated hydraulic conductivity recovers more slowly with runoff characteristics returning to pre-fire conditions within several years. AGWA is used to model pre- and post-fire conditions to assess the impacts of the fire and identify areas at risk (fig. 4).

AGWA is used by the U.S. Department of the Interior National Burned Area Emergency Response (BAER) team for rapid post-fire watershed assessments. To date, AGWA has been used on more than 50 fires since 2011. For example, AGWA was used on the Elk Wildfire Complex that burned over 130,000 acres east of Boise, ID, in August of 2013. Initially, the BAER team identified approximately 16,000 treatable acres within the burned watersheds that consisted of high burn severity and steep slopes. AGWA was used to simulate the watershed response for pre-fire and post-fire conditions to identify areas of high-risk for runoff and erosion. The interdisciplinary BAER team used spatially explicit AGWA results in an interactive process to locate polygons across the burned area that posed the greatest threat to downstream values-at-risk. The group combined the treatable area, field observations, professional judgment, accessibility, and AGWA output to target seed and mulch treatments that most effectively reduced the threat. Using this process, the BAER team reduced the treatable acres from the original 16,000 acres to between 2,000 and 4,000 acres depending on the selected alternative. The final awarded contract for post-fire mulch treatments cost roughly $600 per

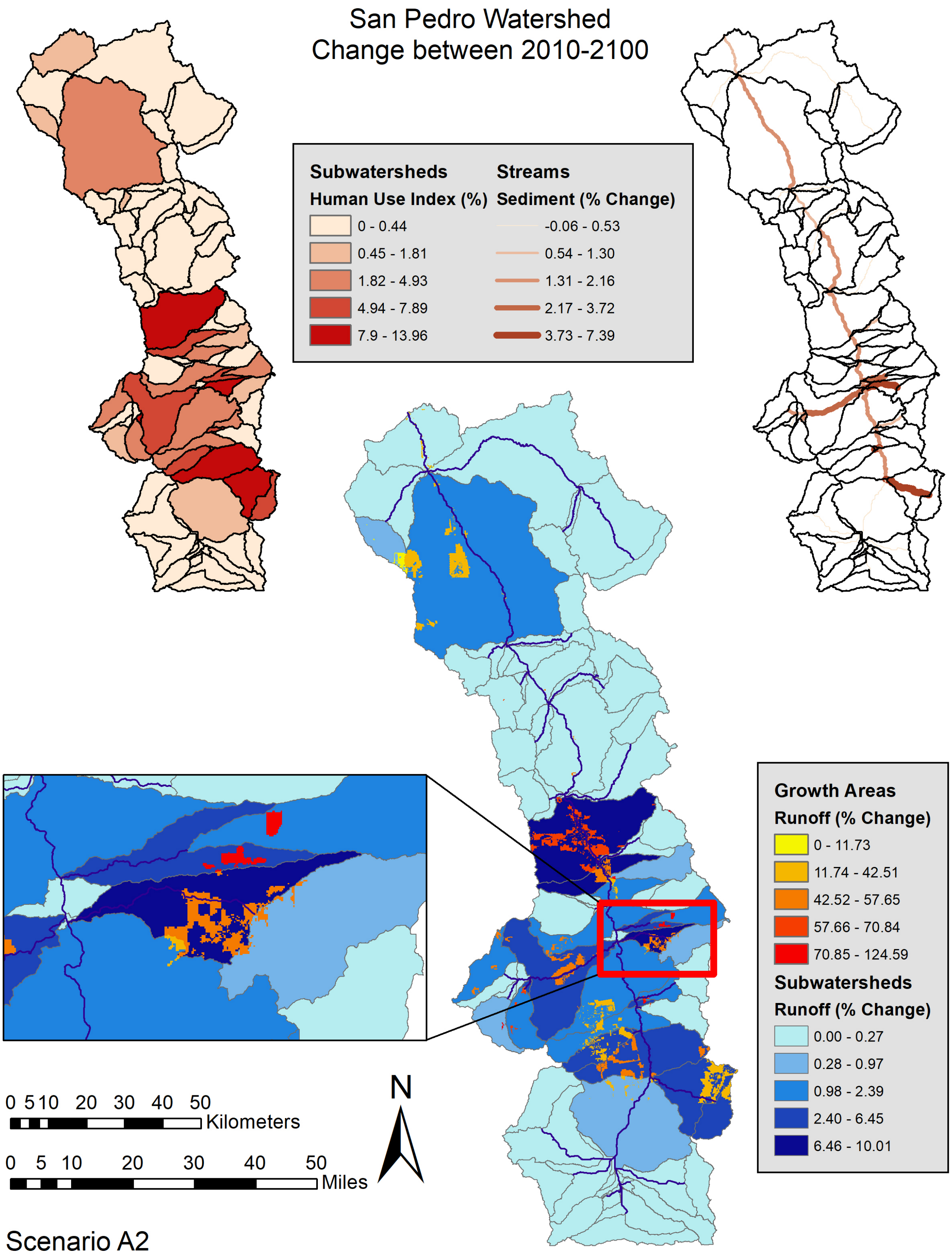


Figure 2—Change in Human Use Index (HUI; the percentage of a watershed that is characterized as developed for human use), sediment yield, and surface runoff (both average and explicit) in percent from 2010 to 2100 for scenario A2.

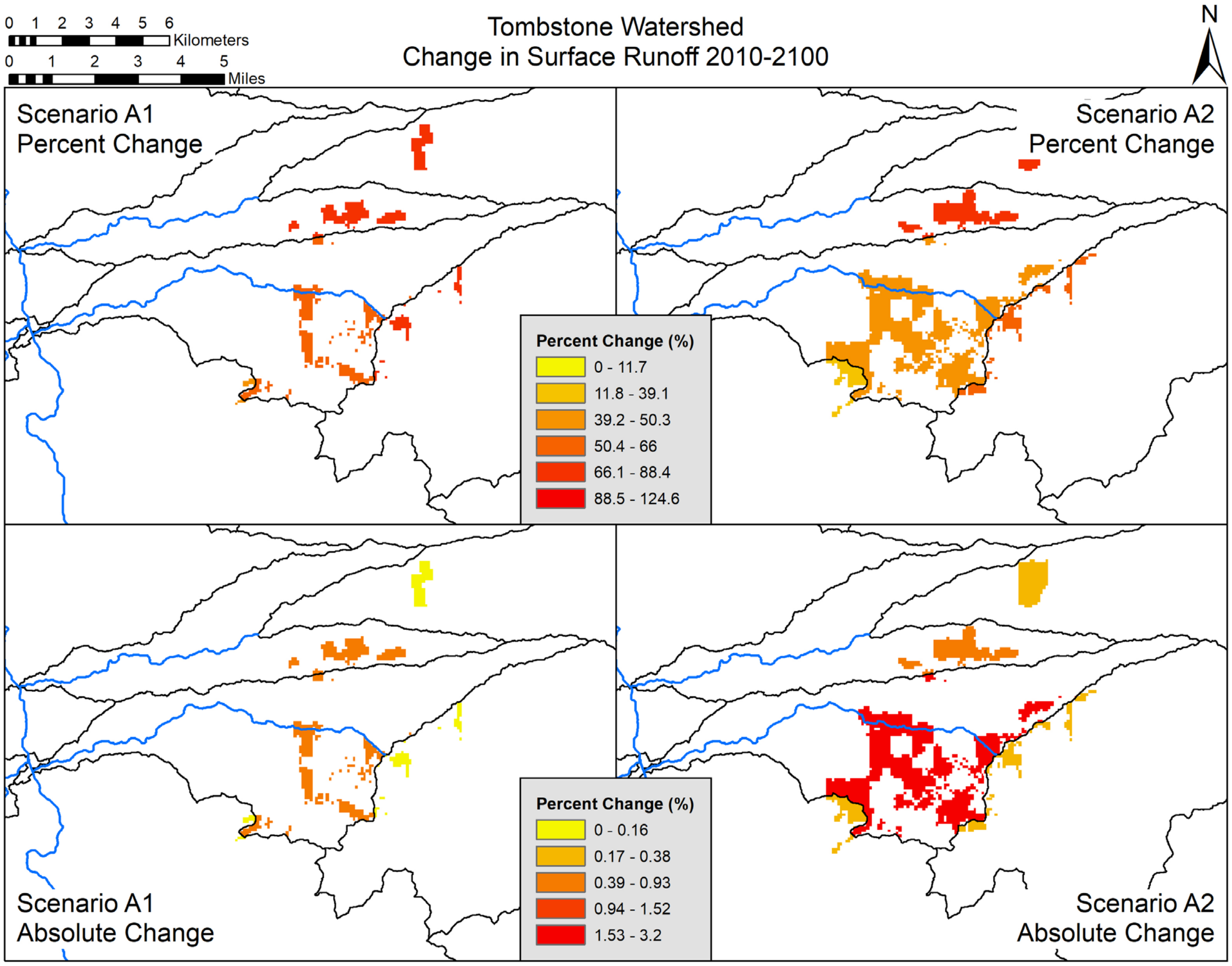


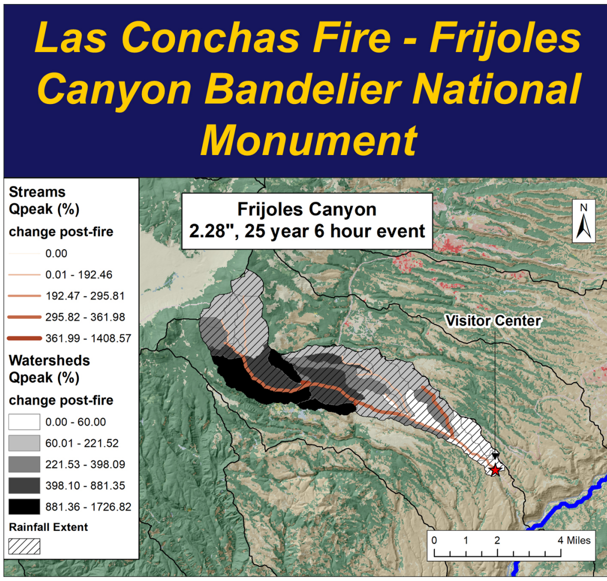
Figure 3—Subwatersheds 340 and 341 for scenarios A1 (medium population growth; fast economic development; high global integration) and A2 (high population growth; greatest land conversion; high domestic migration resulting in new population centers) from 2010 to 2100 show how a larger absolute change in one scenario can undergo a smaller explicit percent change (average subwatershed percent change divided by the ratio of changed land cover area to entire subwatershed area). Explicit percent change emphasizes that local change may be much greater than average watershed or even average subwatershed percent change can describe.

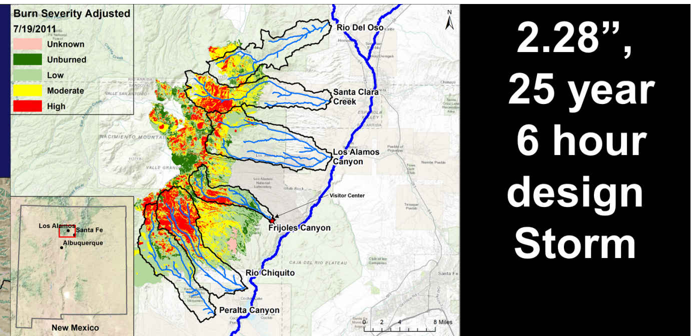
acre; therefore, BAER/AGWA targeted treatment applications resulted in a total savings of ~$7.2 to $8.4 million by only treating the reduced acreage of high fire risk.

Since wildfire severity impacts post-fire hydrological response, fuel treatments can be a useful tool for land managers to moderate this response. Sidman and others (2015) conducted a spatial modeling approach that couples three models (FuelCalc, FlamMap, and FOFEM) used sequentially to allow managers to model the effects of fuel treatments on post-fire hydrological impacts. Post wildfire hydrological response was then modeled using K2 within AGWA. This approach provides a viable option for landscape scientists, watershed hydrologists, and land managers hoping to predict the impact of fuel treatments on post-wildfire runoff and erosion, and compare various fuel treatment scenarios to optimize resources and maximize mitigation results. Jones and others (2017) used AGWA in a return on investment (ROI) analysis to quantify how the amount and placement of fuel treatment interventions would reduce sediment loading to the Strontia Springs Reservoir in the Upper South Platte River watershed southwest of Denver, CO, following an extreme fire event. They used K2 and AGWA to model the expected change in post-fire erosion due to fuel treatments. Positive ROI's were found when fire mitigation treatments were placed in priority areas.

Sustainable Urban Development

Urban hydrology and green infrastructure (GI) can be modeled using the AGWA Urban tool and the K2 model. The K2 model provides an urban modeling element with nine overland flow components that can be used to represent various land cover types commonly found in the built environment while treating runoff-runon and infiltration between and within the components in a physically-based manner (Guertin and others 2015). GI treatments that are





	Pre-fire Outlet	Post-fire Outlet	Percent Change
Peak Flow (cfs)	2490	8931	259
Peak Sediment (T/s)	13.98	117.07	737
Sediment Yield (tons/ac)	5.04	20.77	312
Total Sediment (tons)	59400	244829	312

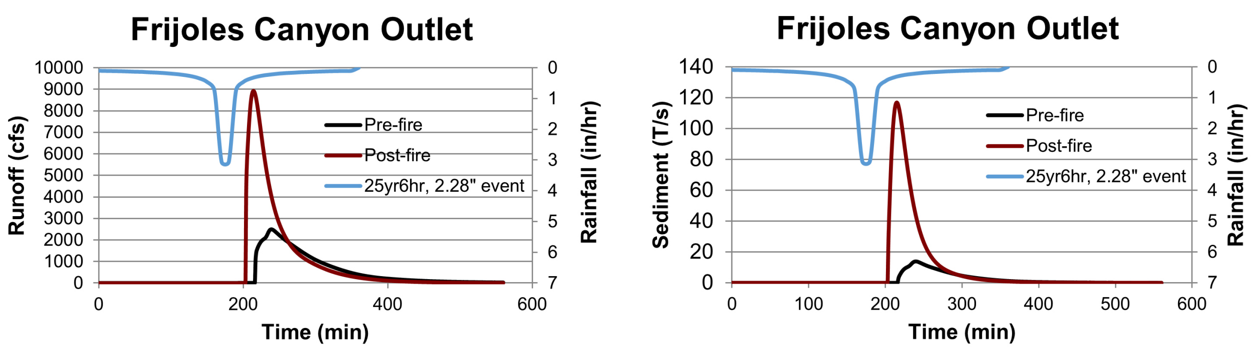


Figure 4—Typical post-fire assessment results produced by AGWA (including the use of English units). For this example, the Value-At-Risk (VAR) was the Bandelier National Monument Visitor Center. The simulations are for a 25-year, 6-hour return period rainfall event. A Soil Conservation Service Type II hyetograph was used for the rainfall representation. For this watershed, the high burn severity areas were in the southwest portion of the watershed where the change in peak flows from the hillslope modeling elements was 1700 percent, resulting in a 259-percent increase in peak flow at the visitor center.

currently available in the AGWA Urban tool are active and passive water harvesting, infiltration basins and bio-retention cells, and pervious surfaces. Home or commercial lots can be individually characterized using the nine overland flow components to represent different GI designs.

The AGWA Urban tool was validated on the La Terraza subdivision watershed in the city of Sierra Vista, AZ. Sixty-six parcels were modeled using 47 rainfall events, from June 2005 to September 2006, to compare observed runoff volumes and peak flow rates with simulated results. Comparison of simulated and observed runoff volumes resulted in a slope of 1.0003 for the regression equation with a coefficient of determination value (R^2) of 0.8017. Comparison of observed and simulated peak flows had a slope of 1.1203 with an R^2 value of 0.8341. A roof runoff analysis was performed for 787 events, from January 2006 through December 2015, to assess the water augmentation from roof runoff capture. Simulation results indicated a 15 percent capture of the average monthly rainfall volume on the watershed, with a volume capture of 0.28 m^3/m^2 of roof area. Additionally, rainfall captured from roofs has the potential to provide up to 70 percent of the domestic annual per capita water use in this region. Five different scenarios were simulated over the same period to compare the effectiveness of GI implementation at the lot level on runoff and peak flows at the watershed outlet. Simulations indicate that higher runoff volume reduces the effectiveness of retention basins (average volume 53.41 m^3, average 30 percent reduction) more than permeable driveways (average 14 percent reduction), or rainwater harvesting cisterns (3.78 m^3 capacity, average 6 percent reduction). Analysis of peak flows at the watershed outlet revealed the highest peak flow reduction for retention basins, whereas permeable driveways showed more reduction of smaller peak flows as compared to rainwater harvesting cisterns (Korgaonkar and others, in press).

A user can also modify how water is routed through a watershed. Ponds for storm water retention/detention, sediment retention, or flood and water mitigation can be inserted anywhere on the channel network. Channel reaches can also be modified to reflect management practices. Water can be diverted from the main channel to a side channel or basin, representing a natural or constructed wetland. Channel reach characteristics can also be modified including: (1) altering length to represent changes in sinuosity, (2) altering width as a surrogate for braided channels (wider) or incised channels (narrower), (3) altering slope to affect stream energy, (4) altering roughness to affect stream velocity and represent treatments like channel cleaning, and (5) altering the infiltration capacity. Channel reaches can also be removed (paved over) or added (drainage). Roads can be used to route water through an urban watershed.

FLOOD RISK ASSESSMENT

K2 has been used for flood risk assessment where AGWA is used to characterize and parameterize the watersheds (Yatheendradas and others 2008). In a research project with the National Weather Service, procedures have been developed to use NEXRAD radar rainfall estimate as input into K2 to make flash flood forecasts (Schaffner and others 2010, 2014; Unkrich and others 2010). Boyanova and others (2014) and Nedkov (2012) used K2/AGWA to map flood regulating ecosystem services. Norman and others (2010) used K2/AGWA to assess the impact of small, inexpensive, stormwater retention structures in Mexico relative to flood risk in the Ambos Nogales Watershed along the U.S.-Mexico border (fig. 5).

SUMMARY

AGWA is a user friendly hydrologic and erosion modeling tool that has been designed to support watershed assessment and analysis of disturbance or management scenarios. AGWA is designed to support modeling at different temporal and spatial scales. Watershed issues AGWA can address include (1) assessing the impact of historical or future landscape or climate change, (2) assessing the impact of disturbances such as fire and livestock grazing, (3) identifying sub-catchments/stream reaches that are at risk for increases in runoff or sediment load, (4) evaluating the effect of best management practices, including different GI designs, and (5) supporting watershed assessment and planning activities. AGWA is designed to be an Add-In extension for ESRI ArcGIS up to ArcGIS 10.x. Development is currently underway for ArcGIS Pro.

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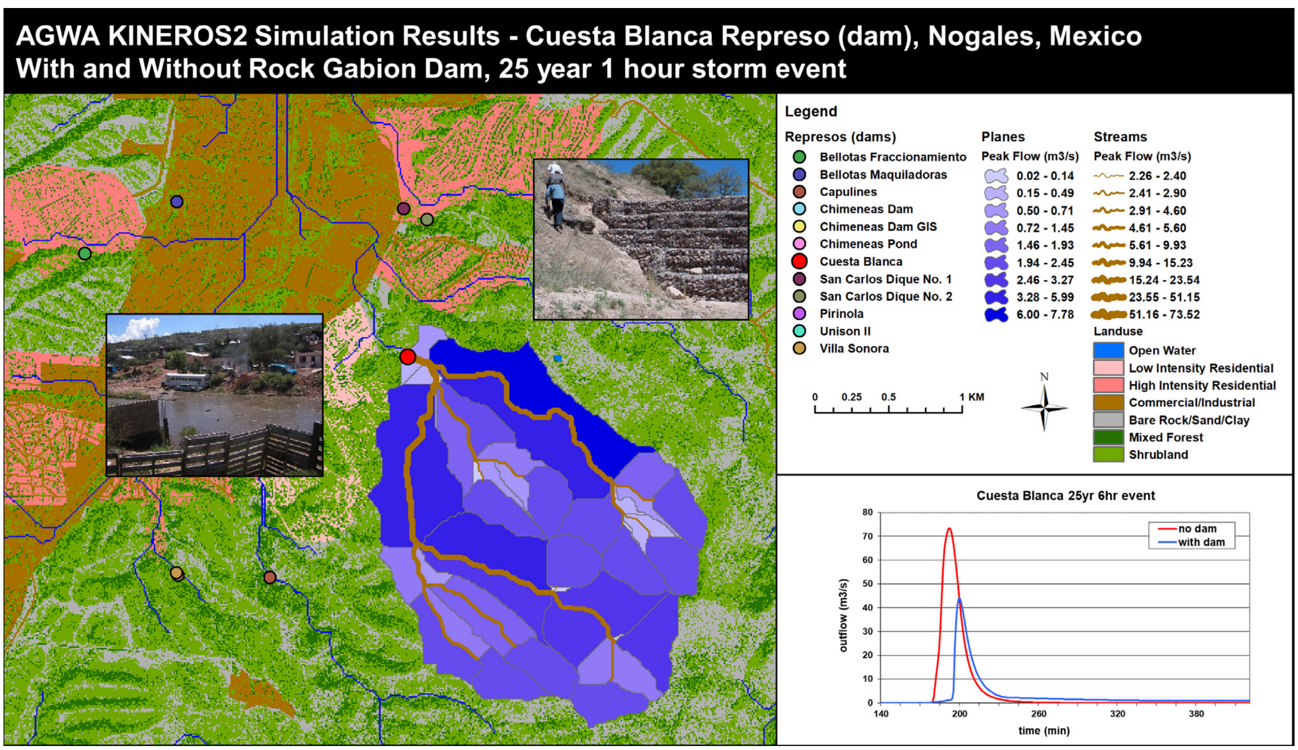

Figure 5—Flood Risk Assessment using AGWA-KINEROS2. This example shows the evaluation of a rock gabion dam in the Ambos Nogales Watershed, Nogales, Mexico, for a 25-year 6-hour return period rainfall event. Multiple structures were modeled throughout the watershed to evaluate flood risk for current and future urbanization.

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MODELING MITIGATION ACTIVITIES IN NORTH CAROLINA WATERSHEDS

Laura Gurley and Ana Maria Garcia

Abstract—The North Carolina Department of Environmental Quality (NCDEQ) has implemented several strategies for basin-wide nutrient management, yet gaps remain in understanding the complexities of nutrient and sediment transport. In particular, improved assessment of the status of nutrient loadings to lakes and estuaries is needed, including characterizing nutrient and sediment sources, relative contributions, and identifying additional monitoring needs. In addition, the NCDEQ Division of Mitigation Services (DMS) uses watershed planning to identify the best locations to implement stream, wetland, and riparian-buffer restoration. As part of this process, DMS develops River Basin Restoration Priority (RBRPs) plans to identify priorities for the protection and restoration of water quality. To better understand the influences of human activities and natural processes on surface-water quality, the U.S. Geological Survey (USGS) developed the SPARROW (SPAtially Referenced Regressions On Watershed attributes) modeling framework to relate water-quality monitoring data to upstream sources and watershed characteristics that affect the fate and transport of constituents to receiving surface-water bodies. The core of the model consists of using a nonlinear-regression equation to describe the non-conservative transport of contaminants from point and nonpoint sources on land to rivers, lakes and estuaries through the stream and river network. A SPARROW modeling framework is being developed specifically for North Carolina to support decisionmaking for watershed restoration activities. In this presentation we illustrate the process, showcasing specific restoration datasets and activity metrics such as extent of riparian buffer and easements. We also present preliminary results for incorporated as explanatory variables in the baseline total Nitrogen (N), total Phosphorus (P), and total suspended solids (TSS) NC-SPARROW models.

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MANURE AND FERTILIZER INPUTS TO LAND IN THE CHESAPEAKE BAY WATERSHED, 1950-2012

Jeni Keisman, Olivia H. Devereux, Andrew E. LaMotte, Andrew J. Sekellick, and Joel D. Blomquist

Abstract—Understanding changing nutrient concentrations in surface waters requires quantitative information on changing nutrient sources in contributing watersheds. For example, the proportion of nutrient inputs reaching streams and rivers is directly affected by when and where those nutrients enter the landscape. The goal of this report is to contribute to the U.S. Geological Survey's efforts to describe spatial and temporal patterns in nutrient inputs to the landscape in the Chesapeake Bay watershed, thereby informing efforts to understand changes in riverine and estuarine conditions. The magnitude, spatial variability, and changes over time in nutrient inputs from manure and fertilizer were evaluated in the context of changes in land use and agricultural practices from 1950 through 2012 at three spatial scales: the entire Chesapeake Bay watershed, the 53 8-digit Hydrologic Unit Codes (HUC8s) contained within the watershed, and a set of 7 regions that were determined by aggregating geographically similar HUC8s. The expected effect of agricultural Best Management Practices (BMPs) on agricultural nutrient inputs from 1985 through 2012 was also investigated. Nitrogen (N) and phosphorus (P) inputs from manure increased gradually over time at the scale of the entire watershed. Fertilizer-N inputs showed steeper increases, with greater inter-annual fluctuations. Fertilizer-P inputs were less variable, increasing moderately from 1950 through the mid-1970s, and declining thereafter. Nutrient inputs and farming practices varied geographically within the watershed, with implications for the potential impact of these inputs on downstream water quality and ecosystem health. Temporal and spatial patterns in the intensity of agricultural nutrient inputs were consistent with the magnitude and concentration of livestock populations and the intensity of row crop agriculture. Reported implementation of the animal and land- use change BMPs that were evaluated were expected to have little effect on agricultural N inputs. Animal BMPs were expected to have a more measurable impact on manure-P inputs, particularly in areas with large poultry populations. Understanding these patterns is important for explaining the changes that have been observed in nutrient loads to the rivers and streams of the Chesapeake Bay watershed, and their impacts on the water quality and ecosystem health of Chesapeake Bay itself.

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RHODODENDRON MAXIMUM REMOVAL AFFECTS TREE WATER USE, HERBACEOUS-LAYER VEGETATION AND TREE SEEDLING RECRUITMENT

Chelcy F. Miniat, Sandra N. Hawthorne, and Tristan M. Cofer

Abstract—Forest ecosystems dominated by eastern hemlock (*Tsuga canadensis*) are undergoing fundamental changes in function and composition from infestations of hemlock woolly adelgid (*Adelges tsugae*). We proposed that the first step to restoring southern Appalachian riparian forests following hemlock mortality is eliminating the evergreen shrub, *Rhododendron maximum*. We hypothesized that removing the dense rhododendron subcanopy would increase light transmittance, soil moisture and temperature; and subsequently, enhance herbaceous-layer diversity, promote tree seedling recruitment, and increase water use of remaining hardwood trees. Treatments were designed to remove only rhododendron (CR), remove rhododendron and organic soil (CFFR), and untreated, reference (REF). We installed permanent plots across treatments and locations and measured light transmittance, soil water content (SWC), herbaceous-layer cover and diversity (Shannon's index and species richness), tree seedling recruitment, and overstory tree daily transpiration (Et).

As expected, cutting the rhododendron subcanopy (CR and CFFR) immediately increased light transmittance in the spring months across locations, and increased SWC in the CFFR. Cutting without partially removing the organic soil layers (CR) did not significantly alter SWC. Herbaceous-layer cover and diversity increased on CR and CFFR. Herbaceous-layer cover was related to light and SWC, while diversity was only related to light. Tree seedling density was significantly related to SWC ($R = 0.602$, $P < 0.001$), but not to light transmittance ($R = 0.130$, $P = 0.363$). Tree seedling density was low before treatment (1.8±0.2 seedlings/m^2) and increased to 24.5±5.8 and 21.8±3.2 seedlings/m^2 two growing seasons after treatment, CR and CFFR, respectively. Tree seedling recruitment ranked *Betula* spp. > *A. rubrum* > *L. tulipifera*. These species likely recruited quickly because they maintain a viable seed bank under a rhododendron subcanopy. The first growing season after treatment (2016), a relatively dry summer/fall, the mean daily transpiration (Et) of hardwood trees was 24 percent greater in CFFR than REF (t-test, $P < 0.05$). In 2017, a wetter summer/fall, Et was again greater for most tree species in CFFR. These vegetation responses have important implications for potential recovery of riparian forests following hemlock mortality.

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HYDROLOGIC AND VEGETATION MANAGEMENT INFLUENCE OXYGEN DYNAMICS, NITROGEN PROCESSING, AND INFORM WATER MANAGEMENT IN AGROECOSYSTEMS

Rachel Nifong, Jason M. Taylor, and Lindsey Yasarer

Abstract—With increasing consumer demand for sustainable agricultural production and continued concern for coastal economies, excess nitrogen (N) runoff from agricultural areas remains a major challenge to reducing the environmental footprint of high intensity agriculture. To address this challenge, producers need simple and innovative approaches that reduce runoff from agricultural fields while maintaining high productivity. Agricultural ditches act as the primary water-soil interface on farms and are a pivotal, but currently underutilized, location to implement low-cost management practices to increase both on-farm and landscape-scale mitigation of excess N runoff. To date, studies evaluating management practices in Lower Mississippi River Basin ditches have relied on small scale mesocosms and core based methods. Yet it is unclear how these studies inform larger scale observations that incorporate diel patterns in light and temperature which can influence primary production, oxygen (O^2) dynamics, and related N processing. To examine larger spatial and temporal scales, we explored how hydrologic and vegetation management practices interact to influence diel N and O^2 dynamics by manipulating hydrologic residence time and the presence of rice cutgrass (*Leersia oryzoides*) in six experimental ditches. We measured plant nutrient uptake, denitrification fluxes, and metabolism using in situ dissolved solute and gas sampling techniques over three 24 hour diel experimental runs. Results indicate that ditches with vegetation promote N retention and have more pronounced O^2 dynamics which can alter expected N removal pathways.

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LAND-USE-MEDIATED *ESCHERICHIA COLI* REGIMES IN AN APPALACHIAN WATERSHED

Fritz Peterson, Jason A. Hubbart, Elliott Kellner, and Evan Kutta

Abstract—Improved mechanistic understanding of the anthropogenic processes that result in pathogenic contamination of receiving waters is important for improved prediction, mitigation and prevention of water quality impairment due to land use practices. A high resolution experimental watershed sampling regime was implemented in the West Run Watershed, in Morgantown, WV. Daily grab samples were collected from six monitoring sites for 6 weeks (n=294). Samples were analyzed using Environmental Protection Agency (EPA) certified IDEXX methodology to determine *E. coli* concentration at each sampling location. The forested sub-catchment had the lowest mean value ($\bar{x}$ = 118.22) and the smallest standard deviation (σ = 186.12). The agricultural sub-catchment, had the highest mean value ($\bar{x}$ = 582.41) and highest standard deviation of (σ = 398.52) of all sites. There was a marked difference between the *E. coli* concentrations from different sites related to land use practices. Percent agricultural land cover was significantly ($p < 0.04$) correlated to the study average *E. coli* concentration. Results agree with previous studies that reported un-impacted areas are often associated with good water quality, whereas developed land uses (e.g., agriculture) can have detrimental impacts on water quality. This work advances scientific understanding of anthropogenic *E. coli* loads, thus advancing mitigation strategies and new development practices.

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DISSOLVED ORGANIC MATTER COMPOSITION IN A SMALL AGRICULTURAL WATERSHED IN THE ATLANTIC COASTAL PLAIN, GEORGIA, USA

Oliva Pisani, David D. Bosch, Alisa W. Coffin, and Timothy C. Strickland

Abstract—Carbon cycling is an important process in agricultural systems and its accurate quantification is critical for designing effective policies. Dissolved organic matter (DOM) represents a large component of the carbon pool in aquatic systems and agricultural practices have been shown to alter its amount, composition and bioavailability. To build on an existing water quality monitoring program (ongoing since 1967) and as part of the Long Term Agroecosystem Research (LTAR) Network, bi-weekly water samples are being collected at sites located in the Little River Experimental Watershed (LREW) near Tifton, GA. The LREW (334 km^2) is situated in the headwaters of the Suwannee River Basin, in the Coastal Plain region of the Southeastern, United States. It includes heavily vegetated, slow-moving stream systems with broad flood plains, poorly defined stream channels and gently sloping uplands. The LREW is characterized by forested riparian buffers surrounding the streams and the land-use is primarily commercial forestry and agriculture, including tilled cropland and pasture, where the fields are irregularly shaped and relatively small (mean ~ 6.5 ha). Beginning in October of 2016, DOM characteristics of bi-weekly water samples from the LREW were assessed through the analysis of optical properties using UV-Vis and excitation-emission matrix fluorescence spectroscopy, coupled with parallel factor analysis. Here, we present the first year of optical measurement results obtained to elucidate the impact of different land-use and conservation practices on DOM composition and transport. The aim of this long-term study will be to characterize episodic and base flow relationships between DOM composition and precipitation, nutrient loads, land-use, and dissolved carbon transport in a small agricultural watershed.

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MODELING DRIVERS OF PHOSPHORUS LOADS IN CHESAPEAKE BAY TRIBUTARIES AND INFERENCES ABOUT LONG-TERM CHANGE

Karen R. Ryberg, Joel D. Blomquist, Lori A. Sprague, Andrew J. Sekellick, and Jennifer Keisman

Abstract—Causal attribution of changes in water quality often consists of correlation, qualitative reasoning, listing references to the work of others, or speculation. To better support statements of attribution for water-quality trends, structural equation modeling was used to model the causal factors of total phosphorus loads in the Chesapeake Bay watershed. By transforming, scaling, and standardizing variables, grouping similar sites, grouping some causal factors into latent variable models, and using methods that correct for assumption violations, we developed a structural equation model to show how causal factors interact to produce total phosphorus loads. Climate (in the form of annual total precipitation and the Palmer Hydrologic Drought Index) and anthropogenic inputs are the major drivers of total phosphorus load in the Chesapeake Bay watershed. Increasing runoff due to natural climate variability is offsetting purposeful management actions that are otherwise decreasing phosphorus loading; consequently, management actions may need to be reexamined to achieve target reductions in the face of climate variability.

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POTENTIAL TO USE DIATOM ASSEMBLAGE RESPONSES TO INFORM NUTRIENT REDUCTION BENCHMARKS FOR IMPROVING WATER QUALITY IN MISSISSIPPI ALLUVIAL PLAIN STREAMS

Jason Taylor and Matthew Hicks

Abstract—Anthropogenic alterations to large river floodplains disrupt natural disturbance regimes that maintain the ecological integrity of lowland stream ecosystems. Conversion of forested floodplains to intensive agriculture can also lead to excess nitrogen and phosphorus runoff from farms to stream networks. As a result, streams within large river floodplain regions are generally habitat limited, exposed to alterations of natural temporal and acute geomorphological and hydrologic regimes, and often experience widespread nutrient enrichment, all factors that limit development of field-derived stressor-response relationships for establishing nutrient reduction goals that promote ecological integrity. To address this, we sampled diatom assemblages from 25 streams that were located within the Mississippi Alluvial Plain (MAP) but drained portions of upstream ecoregions with greater variation in land management, and represented a measurable gradient in total phosphorus (TP) and nitrogen (TN). We collected epidendric diatom assemblage samples from instream woody debris, as this was the primary stable habitat for diatom colonization found within our study systems. Our regional nutrient gradient was skewed toward higher concentrations and ranges of previously reported diatom assemblage response thresholds indicative of oligotrophic conditions were not well represented. Despite this, ordination analysis identified a gradient in species composition associated with increasing TP and decreasing dissolved oxygen. Results indicated a significant shift in diatom assemblage structure associated with differences in TP between streams representing moderately and highly enriched conditions in MAP streams. The highly enriched systems were represented by a distinct set of indicator species. While our results do not address potential criteria for identifying high quality, oligotrophic streams, given the current regional context, using diatom assemblage responses has potential for helping set benchmarks to reduce nutrient impacts and monitor effects of agricultural best management practices within MAP streams.

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FACTORS AFFECTING THE EXTENT OF TIDAL FRESHWATER WETLANDS AND ASSOCIATED BIOGEOCHEMICAL FUNCTIONS

Carl Trettin, Craig Allan, S. Panda, W. Tang, and D. Amatya

Abstract—Tidal freshwater wetlands (TFW) exist in low-gradient landscapes where the normal marine tide amplitude functionally dams freshwater discharge during the tidal cycle. The hydrologic effect is that the riparian zone of these tidal freshwater streams are continuously wet, never drying down which is common for many bottomland swamps on lower coastal plain flood plains. As a result, these soils should be wetter and have more reduced conditions than corresponding riparian zones upstream beyond the tidal reach. A major limitation for considering the differences in the ecosystem processes of these wetlands is that there isn't a single data resource to describe their distribution and characteristics. Here we consider the wetlands in the riparian zone of the Cooper River in South Carolina to determine the utility of existing data to identify TFW, consider hydrologic setting for assessing TFW, and synthesize pilot studies on the East Branch of the Cooper River that consider the interactions of TFW hydrologic setting and soil carbon dynamics. Although the National Wetland Inventory (NWI) contains modifiers to recognize tidal hydrology, that modifier is used inconsistently within a single stream reach. Accordingly, NWI in conjunction with Lidar can be used to identify the upper reach TFW. The next challenge is identifying the lower limit of saltwater. Again, the reported statewide saltwater limit for South Carolina significantly underestimates the extent. Finally, soil maps do not provide a basis for distinguishing tidal and non-tidal riparian zones. As a result, the existing data sources underestimate the distribution of TFW in this basin. The TFW have a significantly "wetter" setting with the mean high water table varying between 0.2 and 0.8 m depending on location within the upper tidal reach, as compared to greater than 1.5 m on the non-tidal riparian zone. Measurements of CH4 and CO2 confirm the functional linkage of the emissions to micro-topographic features within the tidal riparian zone. 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.

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WATERSHED RESPONSE TO LONGLEAF PINE RESTORATION–APPLICATION OF PAIRED WATERSHEDS ON THE SANTEE EXPERIMENTAL FOREST

Carl C. Trettin, Devendra M. Amatya, Alton H. Gaskins, Chelcy F. Miniat, Alex Chow, and Timothy Callahan

Abstract—Restoration of longleaf pine (LLP) is a prominent land management objective throughout the Southeastern United States. Several recent tree- and plot-scale studies suggest that water yield from LLP-dominated landscapes may increase relative to loblolly or mixed pine hardwoods due to differences in stand structure and the higher water use efficiency of LLP. Here we present a new long-term, watershed scale study to test those hypotheses, whereby a watershed dominated by loblolly pine is being restored to LLP using operational silvicultural treatments. We are using a paired watershed approach at the Santee Experimental Forest in South Carolina. Hydrologic responses are being measured using established and new stations for monitoring rainfall, climate, water table, soil moisture, stream flow, and water quality. Vegetation and soil responses will be determined through longitudinal assessment of established inventory plots. Simulation models are being used to guide field data collection and projecting long term hydrological responses under multiple scenarios. This study was implemented in 2018 with the baseline assessment, and the treatments will be installed in 2019-2020.

INTRODUCTION

Restoration of longleaf pine *(Pinus palustris)* ecosystems is a prominent land management objective throughout the Southeastern United States, and it is the principal goal described in the recently approved Forest Plan for the Francis Marion National Forest. While there have been numerous studies regarding the longleaf pine (LLP) ecology, silviculture, and the associated responses of ecosystem services (Samuelson and others 2012), there are major uncertainties regarding the effects of watershed-scale restoration on the hydrology and carbon balance (Brantley and others 2018). The linkage between watershed-scale LLP restoration and hydrologic and biogeochemical processes is particularly important as regional considerations on water resource management and carbon sequestration expand (Brantley and others 2018). In contrast to loblolly pine (*Pinus taeda* L.) stands, LLP stands have a much lower stocking with the understory generally dominated by grasses and sedges, potentially influencing on both soil moisture and water uptake as well as above- and below-ground carbon balance. As a result of these differences in stand structure and composition, it may be expected that LLP stands will exhibit less rainfall canopy interception loss and more infiltration of precipitation. Additionally, studies examining the water use of LLP stands suggest that they consume less water through transpiration than loblolly due to both the lower stocking and reduced water use to support its metabolic functions (Ford and others 2004, Gonzalez-Benecke and others 2011, McLaughlin and others 2013, Vose and others 2003). Based on leaf physiological traits from a 1-year study comparing longleaf to loblolly and slash pine forest stands in a lower Mississippi valley site, Samuelson and others (2012) concluded that their results do not support the contention that LLP has a more conservative leaf water use strategy than the other two pine species. However, those studies have been done on individual trees or small field plots, hence there is considerable uncertainty scaling those responses to a watershed, due in large part to the spatial heterogeneity of soil conditions, micro-topography, interactions between overstory and understory vegetation in water use competition. Watershed hydrological responses to forest disturbances such as fires and thinning, are scale dependent (Hallema and others 2018; Liu and others 2018). Nonetheless, Lockaby and others (2013) suggested restoring LLP could be a management strategy to increase water yield from forested landscapes.

Paired watershed studies provide the basis to assess hydrologic responses to land management treatments. The paired watershed approach, where two neighboring

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watersheds (one reference and one treatment) are monitored concurrently during calibration (pre-treatment) and post-treatment periods (Clausen and Spooner 1993, Jayakaran and others 2014, Loftis and others 2001, Ssegane and others 2013), has been extensively used to assess effects of silvicultural practices on water yield, other hydrologic variables and ecosystem services (Bliss and Comerford 2002, Bosch and Hewlett 1982, Brown and others 2005, Tomer and Schilling 2009). This approach is used primarily on 1st order watersheds (Bren and Lane 2014) although its applicability for predicting effects on flood events on larger systems has been challenged (Alila and others 2009).

Our objective is to implement a watershed-scale study that incorporates silvicultural treatments for restoring LLP that are typical of the lower coastal plain to address important questions regarding the effects on water resources, forest carbon stocks, and ecosystem services. The principal hypothesis guiding this study is that LLP restoration will result in an increase in water yield from the watershed. The approach for this study is to utilize the paired watershed monitoring complemented by modeling on the Santee Experimental Forest, which is located within the Francis Marion National Forest, near Charleston, SC. The following is an overview of the new study that was initiated in 2018.

EXPERIMENTAL APPROACH

The Watersheds

Paired watersheds on the Santee Experimental Forest (SEF) that have been gauged since the 1960s are used in this study. The treatment watershed (WS-77) is a 155 ha 1st order watershed, that is paired with a 160 ha reference watershed (WS-80). These are parts of the headwaters of Huger Creek, a 4th order stream (fig. 1), which is a major tributary of East Branch of Cooper River that drains into to Charleston Harbor. This low-gradient watershed with elevations ranging from about 9.75 m towards the northwest to about 5.79 m at the outlet drains into Fox Gulley Creek via 1.26 km long stream further down to Turkey Creek, a tributary of Huger Creek. The vegetation on WS-77 is dominated by loblolly pine, a result of the earlier silvicultural research in the late 1970s. In contrast the vegetation on WS-80 is a mixed hardwood-pine forest, a result of natural regeneration following the large-scale blow-down of the forest during Hurricane Hugo (September, 1989). Soils on the watersheds are poorly to moderately-well drained sandy clay loam surface soil overlaying clay that are typified by the Wahee and Craven soil series in the uplands and the Megget and Betheera soils in the riparian zones (fig. 2). The climate is warm-humid temperate, with average daily temperature of 17.8 ^{o}C and annual rainfall

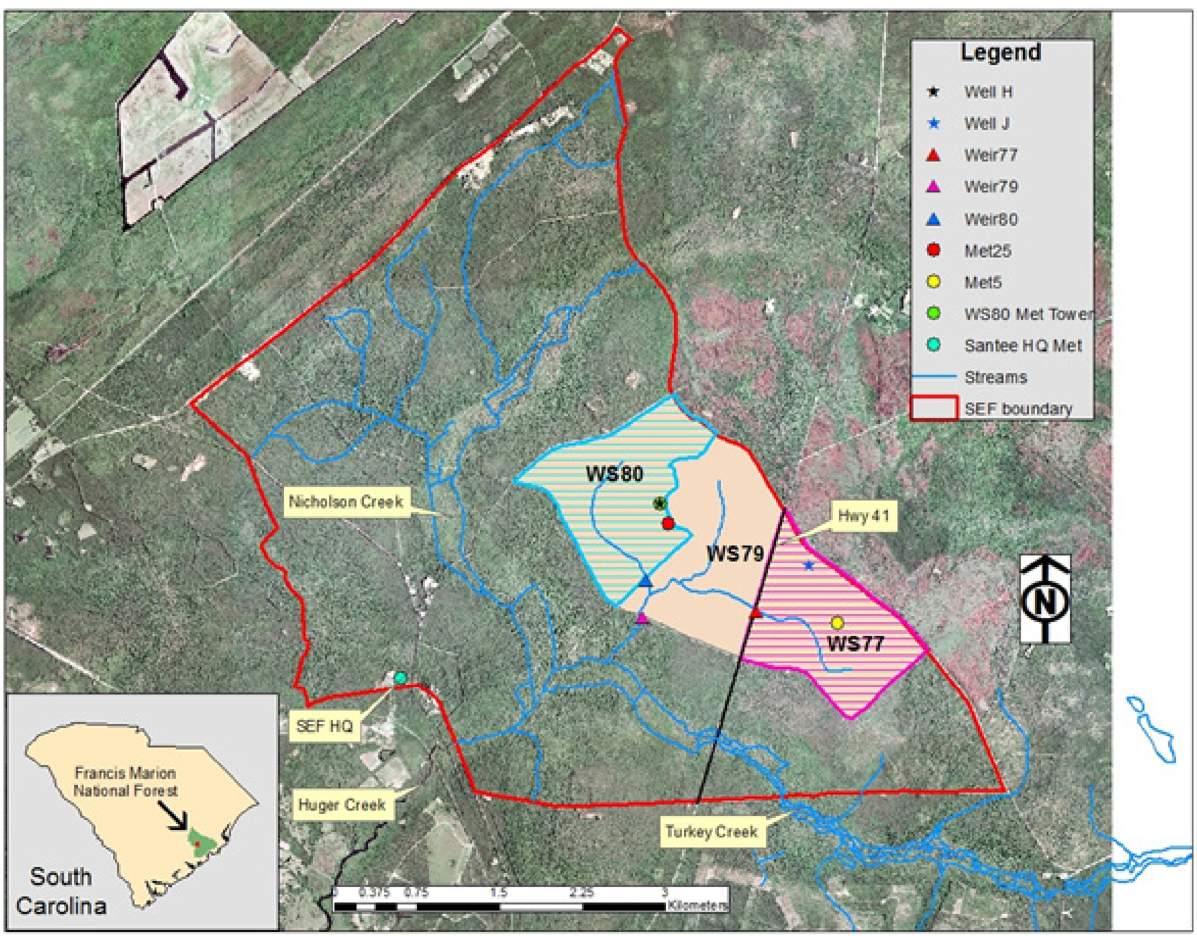

Figure 1—Location and layout of Santee Experimental Forest showing the experimental watersheds WS77 (study site) with the control WS80 in the paired system, SC.

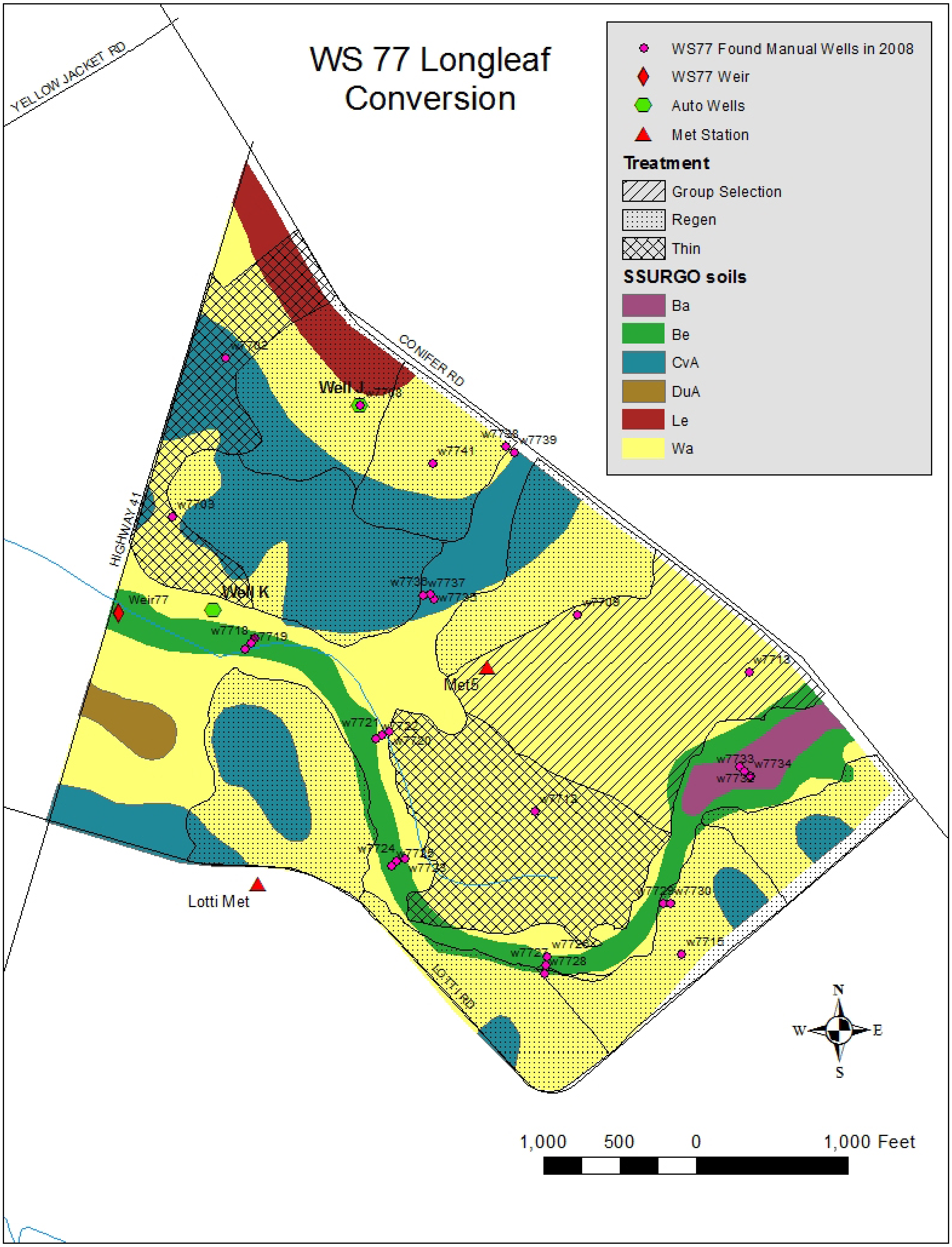

Figure 2—Distribution of soil types and existing vegetation shown together with proposed treatments for longleaf pine regeneration on WS77. Shown also are various monitoring stations on the watershed.

of about 1370 mm. More details on the watersheds are described by Harder and others (2007), Amoah and others (2012), and Dai and others (2013).

An attribute of this study is that the WS-77 and WS-80 have been used for paired watershed analyses since the late 1960s. Accordingly, there's a long-term record to support the comparative analyses for this study. During early calibration (1969-1976), a statistically significant relationship between monthly flow was established between control and treatment watersheds (Binstock 1978) to evaluate effects of partial prescribed burning from 1976-1980 (Richter and others 1983). That relationship reversed for 10 years following Hurricane Hugo, in 1989, in response to the significant stand damage (Hook and others 1991), and then returned to the pre-hurricane disturbance pattern by 2004, following stand recovery (Jayakaran and others 2014).

A recent summary of measured annual rainfall and streamflow for the watersheds WS-77 and WS-80 is presented in table 1, in addition to annual Penman-Monteith (P-M) potential evapotranspiration (PET) estimated for WS-80 using data from the tower weather station (fig. 1) for 2011 to 2017. The mean runoff of coefficient values observed in recent period (table 1) are similar to those reported for the historic period before Hurricane Hugo (Amatya and others 2006). The relationship between the WS-77 and WS-80 are shown in figure 3. For: (A) storm event outflow for pre- and Post-Hugo periods, (B) post-Hugo regression of daily flows (red line) compared against the pre-Hugo (dashed blue line) period for the same frequencies, and (C) monthly streamflow for the 2004-2017 post-Hugo period. Both the event outflow and daily flow (figs. 3A and 3B) indicate that the post-Hugo relationships with data from 2004-2013 are quite similar with no significant difference with the 1969-1978 pre-Hugo relationship, indicating a full hydrologic recovery. Therefore, the post-Hugo monthly relationship between the paired watersheds obtained with daily data extended through 2017 shown in figure 2C is proposed to be used as pre-treatment relationship to examine the watershed-scale effects on monthly water yield. The effect will be evaluated by comparing the mean measured monthly flow from WS-77 with the mean of expected monthly values from the treatment, had it not been disturbed.

Table 1—Measured annual rainfall, streamflow and runoff coefficient (ROC for Watershed 77, 80, and estimated annual Penman-Monteith potential evapotranspiration (P-M PET) for 2011-2017

	Watershed 80			Watershed 77			
Year	Rainfall	Flow	ROC	Rainfall	Flow	ROC	P-M PET
	mm	*mm*		*mm*	*mm*		*mm*
2011	934	31	0.03	977	58	0.06	1351
2012	1174	28	0.02	1148	59	0.05	1239
2013	1433	219	0.15	1502	350	0.23	1017
2014	1375	199	0.14	1340	305	0.23	1123
2015	2171	967	0.44	2146	948	0.44	1098
2016	1743	556	0.32	1709	590	0.34	1197
2017	1443	217	0.15	1555	421	0.27	1254

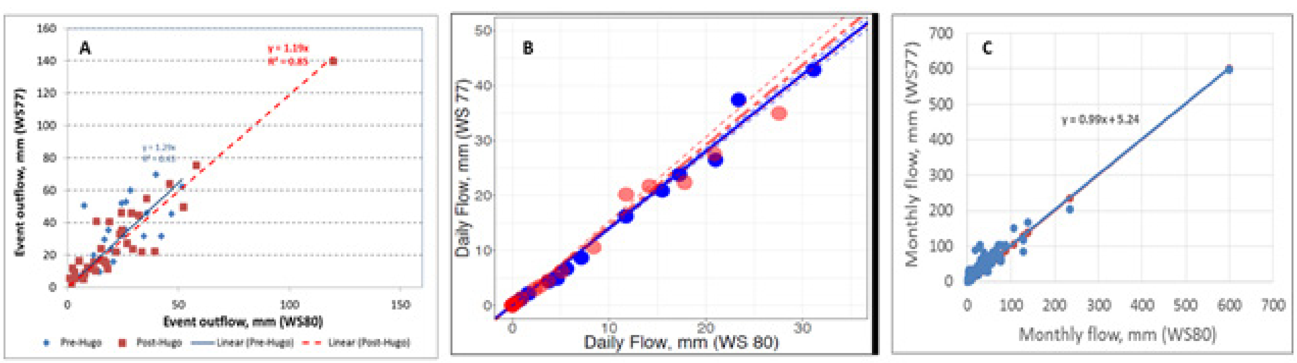

Figure 3—Relationships between the treatment (WS77) and the reference (WS80) for (A) storm event outflow for pre- and post-Hugo periods, (B) post-Hugo regression of daily flows (red line) compared against the pre-Hugo (dashed blue line) period for the same frequencies, and (C) monthly streamflow for the 2004-2017 post-Hugo period.

Treatment Design

Utilization of operational silvicultural practices of the Francis Marion National Forest is implicit to the objective of this study. Accordingly, three practices are routinely considered to initiate changes in the forest composition and structure to establish a LLP forest, (a) clear-cut followed by replanting (i.e., regeneration), (b) thinning, and (c) group selection.

(a) Regeneration cut: This treatment is used where there isn't a basis for natural regeneration of LLP. Existing forest stands are clear-cut (approximately 56 ha), followed by flat planting LLP seedlings on 3 x 3 m grid. (b) Thinning: In stands that have some LLP present (approximately 65 ha), thinning provides the capability to retain an overstory canopy and foraging trees for the red cockaded woodpecker (*Picoides borealis)*, while providing conditions that are favorable for LLP regeneration. The stocking of the current stand is reduced to approximately 15 m^2 ha^{-1} (60 square feet per acre) of basal area. (c) Group Selection: This is a hybrid approach suited to areas without LLP; in this system the small openings are clear-cut with the balance of the forest thinned (approximately 20 ha). Accordingly, the thinned stand is reduced to a basal area of 15 m^2 ha^{-1} (60 square feet per acre) and the clear-cut patches are planted on a 3 x 3 m spacing.

These three treatments were allocated to WS-77 based on the composition of the existing forest, resulting in about 73 percent of the watershed being manipulated (fig. 2), resulting in the watershed being a mosaic of young LLP, mature loblolly pine, and bottomland hardwoods. South Carolina Best Management Practices were used in the treatment layout; as a result the riparian zones are not harvested and remain as bottomland hardwoods. To prepare the watershed for harvesting, a prescribed fire was conducted in March, 2018. Following the harvest, which will occur in 2019-2020, another prescribed fire will be used to reduce logging residue. The site will be planted during the winter following the post-harvest fire.

Experimental Design and Analyses

The paired watershed approach provides the design framework for this study for addressing the hydrological responses associated with LLP restoration of WS-77 with respect to the short- and long-term effects on seasonal and annual water yield, flow frequency duration, and storm event hydrograph parameters. We will utilize the 2004-2018 as the baseline calibration period for comparing watershed responses. The relationships from this long-term baseline should provide a sensitive basis for detecting changes in WS-77 relative to the reference watershed. It is also important to note that this baseline period includes several extreme precipitation events that occurred in the region in October 2015 and 2016 and September 2017, and also dry periods of 2007, 2011, and 2012, thereby providing a robust basis for accommodating the influences of extreme events during the treatment assessment period.

Quantification of the watershed-scale assessment of effects of restoration on water and carbon yield on the treatment watershed (WS-77) will be conducted by constructing seasonal and annual budgets for pre- and post-treatment conditions based on measurements of hydro-meteorological variables and nutrients, dissolved organic carbon (DOC), soil C, and biomass.

Since long-term continuous monitoring is resource restricted, we also intend to use validated hydrologic models to further understand process interactions and evaluate impacts of various management treatments. Earlier studies using the process-based MIKE SHE (DHI 2005) model that simulates ET, infiltration, unsaturated flow, saturated flow, and overland flow for predictions of water table depth and streamflow on the watersheds at Santee Experimental Forest (SEF) within the Francis Marion National Forest (FMNF) were found more satisfactory (Dai and others 2010, 2013) than the quasi-physically based DRAINMOD (Skaggs 1978) model WS-80 (Harder and others 2007) and WS-77 (Amoah and others 2012). MIKE SHE will be used to test the sensitivity of various management and climate scenarios beyond the treatments implemented in WS-77. The modeling will be able to project for short term and long term (full stand rotation) effects of conversions to LLP. We expect that it may take at least 20 years before the watershed-scale effects of the LLP restoration on the water budget can be affirmed experimentally. However, during that time data will be used to validate and advance the application of simulation models for characterizing the response to the restoration treatments.

Monitoring and Measurements

Hydro-meteorologic monitoring—The established hydrology and climate monitoring stations on the SEF will be used to support the monitoring for this study. Those stations include a full meteorological station at the SEF headquarters (approximately 2 km from WS-77), an above-canopy meteorological station on WS-80, and three field precipitation stations within the watersheds that also include air and soil temperature. Stream flow is measured at the outlet weirs, and water quality samples are obtained using flow proportional sampling. Water table depth within the watersheds are monitored in wells selected to represent the network of manual wells that were established in 1991 (fig. 4). Those wells are being augmented to provide measurements of the restoration treatments on the dominant soils (e.g., Wahee, Craven). For details on the historic rainfall, streamflow, water quality, and weather data collected on the paired watersheds since 1964 see descriptions by Binstock *(*1978), Richter *(*1983), Amatya and others (2006), Dai and others (2013).

Vegetation and soil monitoring—Both WS-77 and WS-80 have a network of forest inventory plots (0.04 ha) that were systematically distributed across the watersheds in 1991. A subset of those plots have been selected to provide a basis for assessing the stand treatment effects on the two major soil types (Wahee and Craven) (fig. 4). On each of those plots tree and ground layer vegetation were measured in May-July,

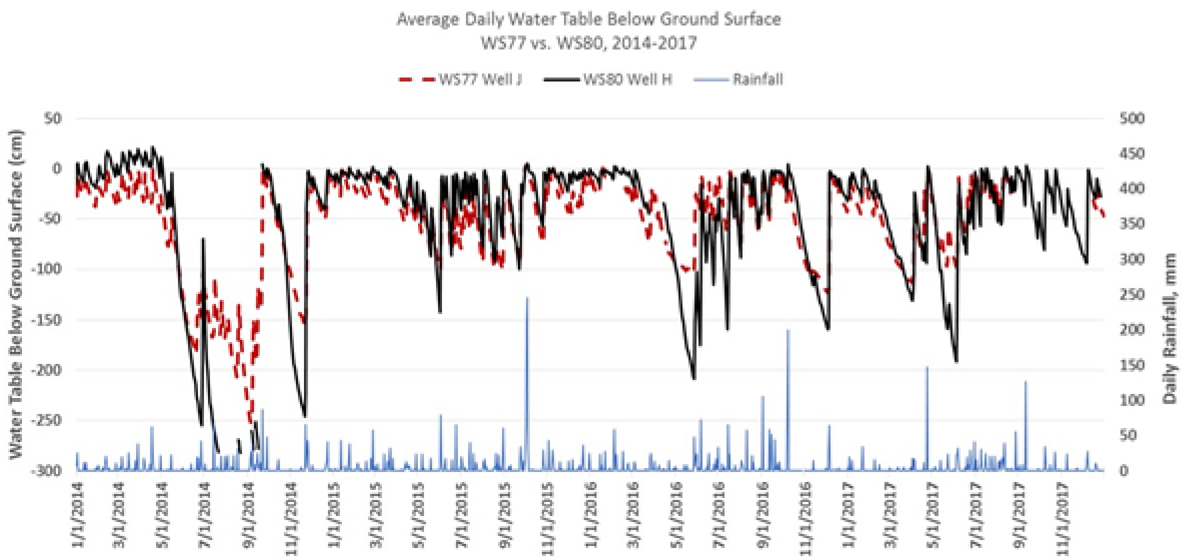

Figure 4—Water table depth below soil surface on the treatment (WS-77) and reference (WS-80) watersheds, and rainfall for 2014-2017.

2018, to provide a baseline on the forest structure and species composition. Soils were also objectively sampled on each plot to a depth of 1 m to provide a baseline on physical and chemical properties. The intent is to utilize these plots as a basis for assessing changes in vegetation and soil properties associated with the conversion process and subsequent stand development.

Change in soil water storage is a major factor in determining whether LLP affects the stand water balance and hydrologic response to storm events. To support the associated assessments, shallow ground water wells (2.5-3.0 m) and soil moisture monitoring stations are being installed on the stand treatments and major soil types. Where practical, existing wells are being utilized, however several new wells have been installed. Each of the wells is instrumented with a WL-16 water level logger. Each of those sites will also be instrumented with a Stevens Hydra soil moisture monitoring station, configured to measure 3 depths (30, 60, 90 cm) at two locations within a 20 m radius of the station.

Leaf area index (LAI) is another parameter that is closely associated with plant water use and carbon dynamics. While the SEF does not routinely monitor LAI of the watersheds, plans are to collect a 12 month pretreatment baseline using a Licor LAI2000, and then maintain monthly measurements through the conversion process in order to characterize the redistribution of LAI across the watershed as a result of the treatments and the subsequent stand development.

Data Analyses

Climatic and streamflow data together with the soil moisture data will be analyzed to quantify the water balance on both watersheds. All climatic data will be processed for estimating daily/monthly, and annual Penman-Monteith (P-M) potential evapotranspiration (PET) for a forest reference. Water table data together with soil drainable porosity will also be used to assess changes in soil water storage. Seasonal rainfall-runoff relationships will be established to examine seasonal runoff coefficient (ROC-as percentage of rainfall that leaves the watershed as streamflow), and water balance for pre- and post-treatment years will be analyzed for detecting seasonal changes in water yield and evapotranspiration (ET), if any. Event-based analyses will consider the conversion treatment's effects on storm runoff and its characteristics.

The watershed water budget for a period of interest will be constructed as follows:

$$\pm\Delta S = P - O - ET \qquad (1)$$

where

ΔS = change in soil water storage (mm) for a given period

P = total precipitation (mm) for the period

O = total streamflow (mm) for the period

ET = evapotranspiration (mm) for the period.

For the selected periods when water table is at or very near surface at the beginning and the ending period ΔS can be assumed negligible (zero), leaving the ET for the period as

$$ET = P - O \qquad (2)$$

Since ET is generally near the potential ET (PET) for saturated conditions with water table near the surface, the ET calculated by equation 2 will be verified against the estimated

PET also, besides verifying with ET calculated by equation 1 where ΔS is calculated as average soil moisture measured on replicated stands/soils.

Daily stand level ET will be estimated using equation 1 where ΔS is obtained from the soil moisture and water table data. The estimate will also be checked following the method of Fisher and others (2005) that uses estimated PET, soil field capacity (FC) determined from soil water retention data to be obtained from laboratory analysis of undisturbed field soil core samples, and measured soil moisture (SM). The method assumes daily ET approximating PET when the SM equals or exceeds the FC otherwise ET is reduced by the ratio of SM/FC. In the absence of soil moisture data for any period, change in soil water storage may also be approximated using volume drained versus water table depth relationship also to be obtained using soil water retention data and saturated hydraulic conductivity measured in the field or laboratory (Harder and others 2007).

Seasonal regression relationships of streamflow (water yield) between the watersheds using long-term pre-treatment data (2004-2018) will be established as discussed above. For the initial hydrologic response analyses that reflects the stand conversion step, regression parameters of relationship will be compared against the one to be obtained from streamflow data soon after treatment (2019-21). Similarly storm hydrograph and water table responses will be assessed during the conversion process.

Model Applications

A key component of this study is model applications. The empirically based findings assessing ecosystem responses to the LLP restoration may not be mature for at least two decades. Hence the application of hydrologic and ecosystem models afford the opportunity to (a) simulate responses based on anticipated conditions of the restored LLP forest, and (b) test the applicability of models to describe the conversion process. The opportunities for modeling applications on the SEF are particularly rich given the long-term data record on the watersheds and existing simulation results from previous studies (Dai and others 2013).

The initial phase of modeling will focus on the application of the MIKESHE model to simulate the hydrologic response during the conversion processes and the anticipated changes when the LLP is well established (e.g., > 20 years). The pre-stand conversion portion of that simulation will be validated with pre-treatment (2004 - 2018) water table and streamflow data. Subsequent monitoring (e.g., 2019-2021) will be used to validate the watershed-scale hydrologic responses during the conversion process. A multi-criterion validation will be used with distributed soil moisture and water table data to affirm confidence on the model's internal structure and capability to predict hydrology on a distributed watershed-scale. Such a validated model then can be applied to assess the long-term effects of LLP restoration on watershed hydrology of the study watershed and larger similar watersheds within the region. We will also encourage the application of other watershed hydrologic models to provide a basis of comparison.

Spatially distributed daily water table information is needed to simulate the carbon and greenhouse gas dynamics of these forested watersheds that are characterized by low relief and a significant proportion of wetlands (Dai and others 2011). Accordingly, our intent will be to use Forest DNDC, a process based forest biogeochemical model, in a linked modeling framework with the simulated hydrology to predict changes in forest and soil carbon stocks and greenhouse gas fluxes. As noted for the hydrologic modeling, we will encourage applications of other forest biogeochemical models including DRAINMOD-FOREST (Tian and others 2012).

PERSPECTIVES

Paired watershed studies have been used for decades to assess the cumulative effects of forest stand management practices on hydrologic processes and the associated interactions with soils and vegetation. Accordingly, it is the most suitable approach, when a stable and statistically significant relationship (Ssegane and others 2013) exists, to assess how the myriad factors that cumulatively affect water yield will manifest at the watershed scale. While the basic question regarding water yield will be answered through the stream discharge measurements, the real value of this study will be realized through analyses of the regulating factors, particularly the soil moisture, so that the response can be interpreted mechanistically. Accordingly, careful consideration of ET from the tree canopy layer and ground vegetation layer is fundamental.

The initial decade of this study will address the stand conversion phase of the restoration treatment, which is analogous to many other hydrologic response studies that have been conducted over the past 50 years. Accordingly, it presents the opportunity to thoroughly validate simulation tools for assessing hydrologic, vegetation, and soil responses, which should then provide a robust basis for applications in other areas of the Southeastern United States.

The value afforded by this long-term study will not be realized without a strong collaboration. There are a host of science and management related questions, driven by either measurements or modeling, which could be addressed through the application of the LLP restoration treatments, so we hope that this paper will help increase awareness of the opportunities potentially available for partners interested in this subject

ACKNOWLEDGMENTS

We would like to acknowledge Julie Arnold, Andy Harrison, Santee Experimental Forest, Artheera Bayles, College of Charleston, and Mohamed Hamidi, Nazarbayev University, Astana, Kazakhstan. for work to install the study and develop background information for this paper. We also appreciate the review comments from Ge Sun and Johnny Bogs, U.S. Department of Agriculture Forest Service and Doug Aubrey, University of Georgia for their helpful review comments. Long-term climate and hydrology data for the Santee Experimental Forest is available at: http://cybergis.uncc.edu/santee/.

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SIMULATIONS OF HYDROLOGY AND WATER QUALITY FOR IRRIGATED FIELDS NEAR YAKIMA, WASHINGTON

Richard M.T. Webb

Abstract—Reliable tools are needed by farmers and managers to estimate and mitigate impacts of altered hydrology and degraded water quality downstream of agricultural areas. The Water, Energy, and Biogeochemical Model (WEBMOD) (Webb and Parkhurst 2017) was used to simulate daily variations of hydrology and water quality for 5 square kilometers of irrigated fields draining to the DR2 Drain, southeast of Yakima, WA (fig. 1).

INTRODUCTION

WEBMOD was developed within the Modular Modeling System and shares many process algorithms with the Precipitation Runoff Modeling System (Markstrom and others 2015). Inputs included meteorological observations from the Harrah Agromet station, irrigation schedules from the Sunnyside Valley Irrigation District (Zuroske 2009), and simple representations of seasonal variations of upgradient groundwater and canal leakage. Native vegetation consists of grass and shrubs as the fields lie in the rain shadow of the Cascades (McCarthy and Johnson 2005). Approximately 20 cm of precipitation fall each year, far less than the meter of potential evapotranspiration estimated for the area (fig. 2).

However, in this surcharged flow regime (Weiskel and others 2007), approximately 100 cm of water (volume divide by drainage area) flowed past the gage at the DR2 outlet after the installation of a stream gage in the spring of 2003.

SIMULATIONS OF A SURCHARGED SYSTEM

With precipitation as the only source of water, the simulated discharge was an order of magnitude less than the observed discharge (fig. 3).

WEBMOD simulates the additional inputs (and actual evapotranspiration) to balance the water budget: 80 cms of irrigation from the Sunnyside Canal, diverted from

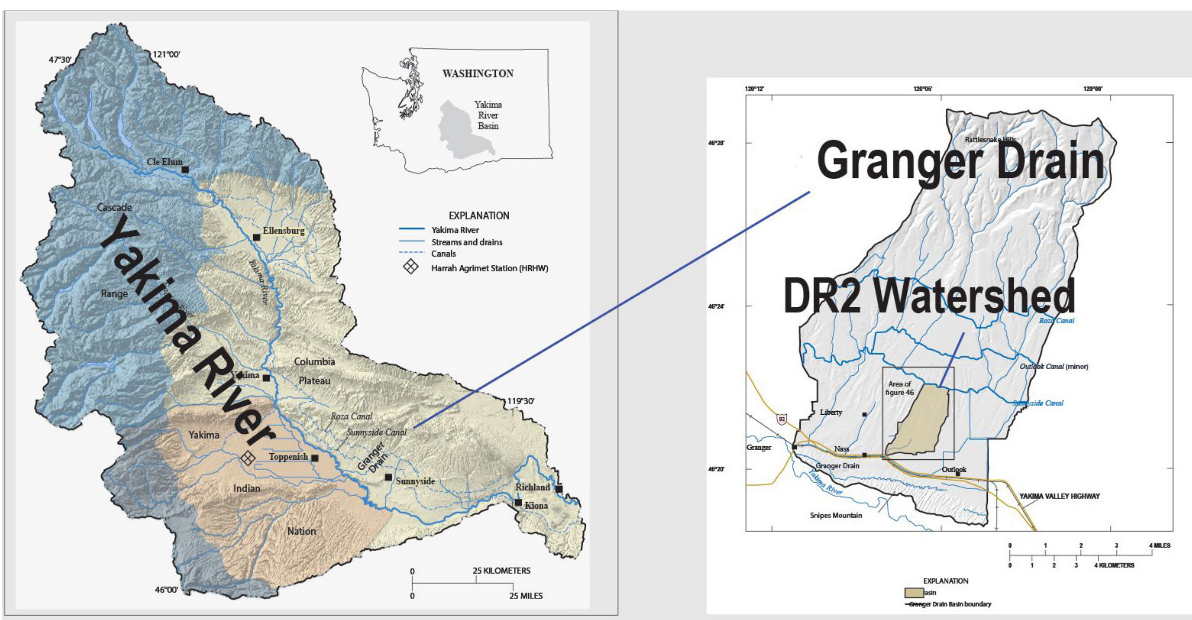

Figure 1—Location map of the Yakima River, the Granger Drain, and the DR2 watershed (modified from Fuhrer and others 2004 and Payne and others 2007)

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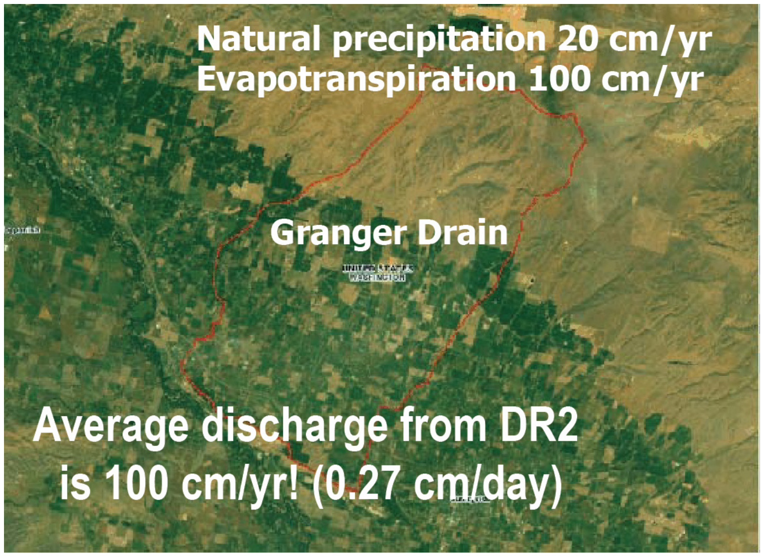

Figure 2—Granger Drain watershed. Northern non-irrigated areas are grasses and shrubs. Green fields to the south are irrigated with water from the Rosa, Outlook, and Sunnyside Canals located in figure 1.

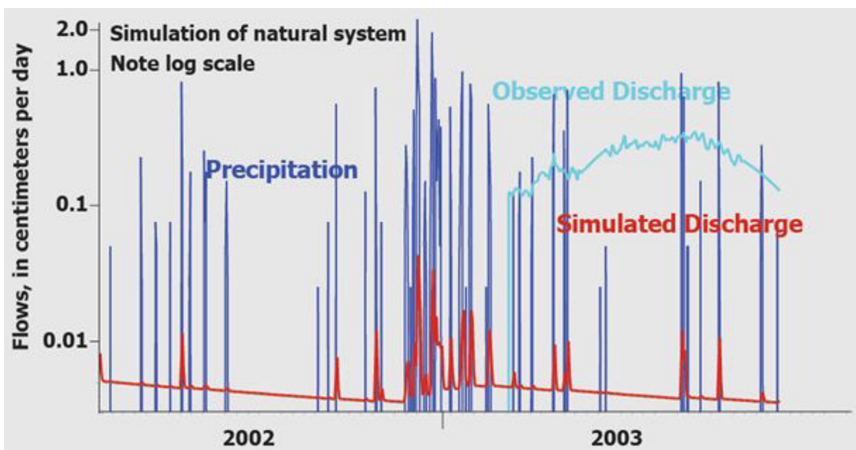

Figure 3—Precipitation (blue), simulated discharge (red), and observed discharge (cyan) for calendar years 2002 and 2003. A stream gage was installed at the DR2 outlet in the spring of 2003.

the Yakima River (fig. 4); 10 cm of leakage through the earthen floor of the canal that is the northern boundary [seepage measurements showed a loss of 1 cfs per mile of canal (0.0176 $m^3/s/km$)]; and 60 centimeters of upgradient groundwater flowing south under the canal. Leakage only occurs during the irrigation season from March to October as the canal is dry over the winter. The flux of upgradient groundwater is assumed to be greatest during the early irrigation period when heads are greater in the irrigated fields to the north, reducing during the second half of the season as the difference in heads north and south of the canal diminish (fig. 5). Actual evapotranspiration of 70 cm closes the budget. The observed and simulated discharge now match much more closely.

SIMULATION OF CONSERVATIVE MIXING

WEBMOD simulated conservative mixing of three sources with constant chloride concentrations: precipitation, 0.2 mg/L; Sunnyside canal water applied as irrigation and leakage through the earthen canal bottom, 0.8 mg/L, and upgradient groundwater, 20.0 mg/L. The simple but robust model matches observations of daily discharge and specific conductivity measured in the DR2 drain. Specific Conductance (SC) correlates well with chloride concentrations (SC, in microseimens per centimeter = 39.7[Cl, in mg/L], R^2=0.8), so this fixed conversion factor was used to show simulated variations in specific conductance and chloride concentrations hindcast for 1998 to 2005 (fig. 6).

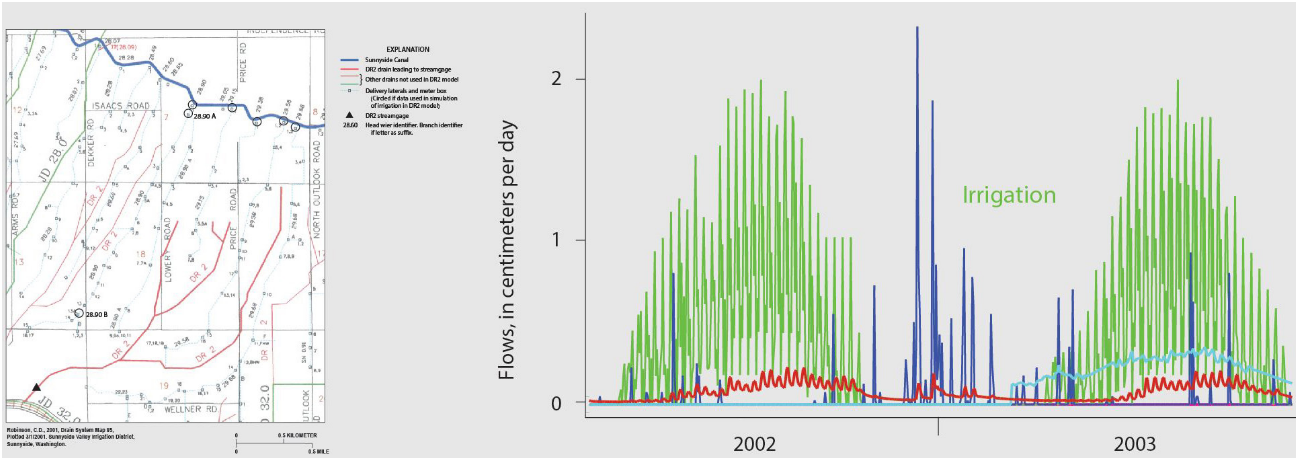

Figure 4—Left: Irrigation map with Sunnyside canal in blue, laterals in light blue, delivery boxes as squares, and drains as red. The black triangle locates the DR2 gage at the outlet. Right: Precipitation (blue), simulated discharge (red), and observed discharge (cyan), and irrigation (green) for calendar years 2002 and 2003.

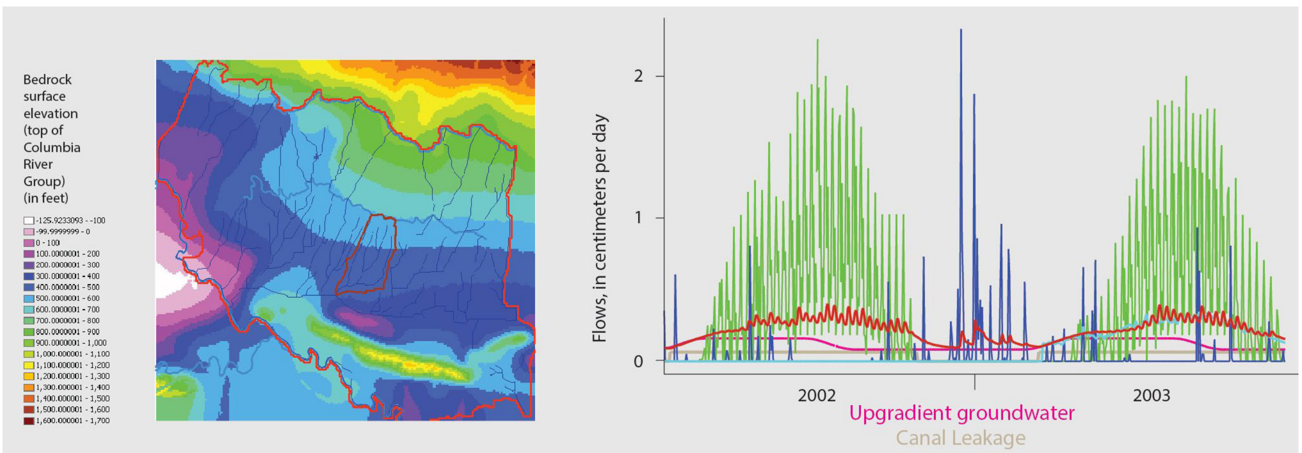

Figure 5—Left: Elevations of bedrock that approximates the water table elevations with outline of irrigated area flowing under Sunnyside canal and through the DR2 watershed on its way to Granger Drain. The DR2 watershed is the interior red polygon. Right: Precipitation (blue), simulated discharge (red), observed discharge for 2002 (cyan), upgradient groundwater (fuchsia), and canal leakage (gold).

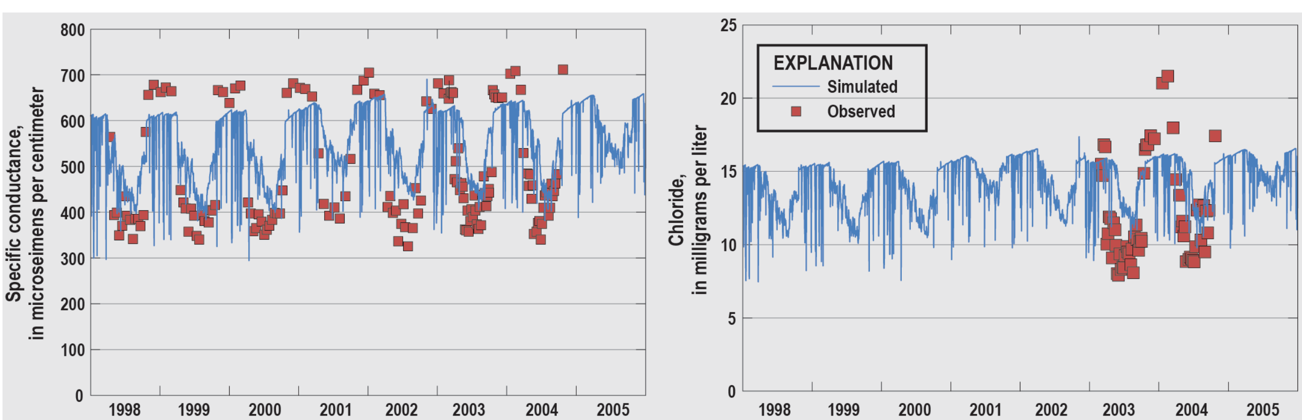

Figure 6—Observations (red squares) and WEBMOD simulations (blue line) of specific conductance and chloride concentrations at the DR2 outlet from 1998 to 2005. Simulated values are bracketed by observations. Observed variance is greater that the simulated variance likely because farmers occasionally shunt their allotment of water directly to the drain in response to the "use it or lose it" policy.

SUMMARY

WEBMOD is a watershed model that is tightly coupled with the geochemical engine PHREEQC (Parkhurst and Appelo 2013, Parkhurst and others 1980) to simulate conservative and reactive transport of solutes that cycle among the atmosphere, soils, regolith, and streams. Originally developed to simulate the hydrology and geochemistry of pristine watersheds, WEBMOD has been enhanced to simulate the fluxes of water and solutes in heavily managed watersheds. With these additional capabilities, WEBMOD is a new-generation predictive model that can be used to identify combinations of landscapes and soils where impaired water quality can be expected in response to changing deposition, climate, and land use. Watersheds susceptible to impairment can then be included in targeted monitoring programs to make the most efficient use of limited laboratory and human resources.

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A CONTINENTAL-SCALE ASSESSMENT OF SOIL MOISTURE MONITORING OF FOREST AND GRASSLAND ECOSYSTEMS IN THE UNITED STATES

Cynthia West, Liza Jenkins, and Richard Pouyat

Abstract—Soil moisture monitoring in forest and grassland ecosystems is often overlooked by national efforts to coordinate soil moisture monitoring, which have mostly included the agriculture and water resource sectors. A workshop held recently by the U.S. Forest Service and Michigan Technological University with various stakeholders, scientists, and natural resource managers focused on contemporary and emerging research and management issues related to the importance of soil moisture monitoring in forest and grassland ecosystems. The overarching goal of the workshop was to develop a strategic plan to envision a new continental-scale approach of research and monitoring of soil moisture across forest and grassland areas of the United States. Specific objectives were to (1) assess the research and data available to monitor soil moisture for various purposes including the development of indicators, or thresholds, of soil moisture that relate to forest health, draught and water supply; (2) discuss currently available and emerging technology used in measuring soil moisture in situ and by remotely sensed platforms; (3) explore opportunities to expand and integrate existing networks to fill spatial and temporal gaps in data; and (4) determine research needs and needed technological advances for measuring soil moisture. Presentations were given on existing soil moisture monitoring networks such as the Soil Climate Analysis Network (SCAN), existing remote sensing platforms such as the Soil Moisture Active Passive (SMAP) mission, and the current effort to develop a National Soil Moisture Network (NSMN). Presentations were also given on the relationship between soil moisture, at different spatial and temporal scales, to forest health, forest productivity, fire, and watershed function. Next steps include: drafting a roadmap to expand and maintain the soil moisture network into forested landscapes and to engage with key stakeholders to determine what information is most important to address their needs.

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HYDROLOGY OF A SUGARCANE PRODUCTION SYSTEM AND ASSOCIATED ECOSYSTEM SERVICES

Paul White

Abstract—Sugarcane (*Saccharum* sp.) is cultivated on over 172,000 ha in Louisiana and generates a projected economic impact of $3 billion dollars annually. Much of the area now under production was once occupied by bald cypress (*Taxodium distichum*) wetlands. The humid, sub-tropical climate receives 1650 mm of precipitation annually, exhibits a shallow water table (<1.5 m), and is periodically flooded. Despite these limitations, sugarcane is widely cultivated due to its adaptability. In addition, certain varieties have shown tolerance to high water conditions. A new management practice was initiated in 2017 that increased plant population by up to 50 percent by widening rows, with a concomitant reduction in field drains. Supporting ecosystem services, including water quality, photosynthesis, sugar production, and carbon sequestration may be affected by the different management practice. Thus, the research will evaluate water flux and storage at the plot (time domain reflectometry probes), field (run-off collection), or farm-level (eddy covariance) over time under different cropping intensities. The goal of the project is to quantify changes to supporting services and identify linkages to off-site ecosystem services.

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These proceedings contain the full-length papers, extended abstracts, and research abstracts of oral presentations and posters given at the Sixth Interagency Conference on Research in the Watersheds (ICRW)—Working Watersheds and Coastal Systems: Research and Management for a Changing Future, held at the National Conservation Training Center, Shepherdstown, WV, July 23-26, 2018.

The Sixth ICRW focused on "working watersheds." These so-called watersheds and coastal systems provide a wide array of useful economic goods and services (e.g., agricultural products, urban development, recreation, etc.). However, maintaining aquatic condition and functional integrity while balancing issues arising in working watersheds such as nutrient loading, landscape disturbance, and invasive species requires creative scientific approaches and adaptive management. The conference was structured to present and address key research and management issues faced by watershed managers and scientists throughout the United States. Research was presented by Federal, State, and local scientists, academics, and non-governmental organizations focusing on managing the complex watershed systems and watershed components (e.g., streams, rivers, lakes, estuaries, etc.). Thematic areas included watershed monitoring and management, hydrologic modeling, restoration, remote sensing research, climate change, extreme climatic events, and focal research areas (e.g., Appalachian watersheds, trans-boundary systems, evapotranspiration), as well as ecosystem-specific themes such as wetlands.

The conference was hosted by the U.S. Environmental Protection Agency, Office of Research and Development, with material and in-kind support from the following organizations: Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), the U.S. Department of Agriculture (USDA) Forest Service, the USDA Agricultural Research Service, the U.S. Geological Survey, the Bureau of Land Management, and the U.S. Fish and Wildlife Service. The Sixth ICRW was built on the foundation laid by the previous lead and hosting organizations: USDA Agricultural Research Service (2003), USDA Forest Service (2006 and 2015), U.S. Geological Survey and CUAHSI (2009), and the Bureau of Land Management and National Park Service (2011). The Seventh ICRW will be hosted by the USDA Agricultural Research Service in Tifton, GA, March 2020.

Keywords: Appalachian watersheds, coastal habitats, coastal wetlands, extreme climatic events, evapotranspiration, hydrologic modeling, land use, monitoring, stream and river networks, transboundary waters, watershed management, watershed science.

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