WATERSHED SCIENCE BULLETIN

Journal of the Association of Watershed & Stormwater Professionals

A program of the Center for Watershed Protection, Inc.

AWSPs
Association of Watershed & Stormwater Professionals

SPRING 2011

Integrating Climate Change Science into Watershed and Stormwater Management

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This photo was taken along Young's Bay estuary in Astoria, OR. The Young's Bay estuary is a component of the Columbia River estuary, a nationally significant estuary in the northwest corner of Oregon that supports some of the largest anadromous fish runs in the world and provides unique habitat for sensitive and endangered species.

From the Editor's Desk

In the *Watershed Science Bulletin*, the Association of Watershed and Stormwater Professionals aims to provide readers with topics that advance practical, science-based solutions to watershed and stormwater management issues. Our inaugural issue in October 2010 reached more than 2,000 professionals and focused on total maximum daily loads (TMDLs)—an increasingly prevalent regulatory requirement for many jurisdictions throughout the United States. I hope that our second issue will reach even more readers given the timeliness and importance of this issue's topic—climate change and watershed management. Although it does not have the regulatory thrust of TMDLs, we believe that this topic will become as prevalent for watershed professionals as TMDLs in the years ahead.

This issue's articles and vignettes illustrate, in many ways, how climate change science is being integrated into watershed management. In Ask the Experts, watershed scientists, administrators, and practitioners provide their perspectives on key elements needed to take effective action to address climate change and further enhance watershed management. I am also very pleased to include in this issue our first Watershed Superstar, whose work to effect change in local watersheds is an inspiration, along with the stunning image captured by the winner of the photo contest.

Why Climate Change?

The hydrologic cycle and associated water resources are intimately related to the science and management of climate change. Numerous land–atmosphere feedback mechanisms regulate and drive variations in climate in the long- and short-term. However, translating global-scale climate change scenarios to local-level management actions is a challenge. From the perspective of practical applications, what can be taken from global climate change model outputs at a 100-km^2 scale to improve our understanding of watershed protection and restoration at smaller, regional scales? If we delve further into the implications of changes in temperature and precipitation patterns and think about how sea level rise may affect property and wetlands loss along the coast, or how drought conditions may affect water supplies, then climate change becomes a more real issue.

Although climate change is becoming an increasingly pervasive theme in natural resource management, it largely remains an intangible topic for local watershed and stormwater management. The practical application of climate change science continues to be challenged by the difficulty of finding information or new resources to dedicate to this problem. As we at the Center for Watershed Protection strive to digest and more fully understand climate change as it relates to watershed and stormwater management, we find that we learn a lot more by asking watershed professionals, such as yourself, about ongoing work and the current thinking in this area.

As a watershed practitioner working at the local level, understanding climate change and what you need to do about it is a daunting task, given the amount of information available through federal and state agencies and organizations. A web-based search on the topic produces more than 42 million hits, and adding the term "watersheds" narrows the search to a mere 1.4 million hits. This information overload for our primary audience of watershed and stormwater practitioners inspired us to tackle this topic in our second issue. The Spring 2011 issue of the *Bulletin* is not a forum to discuss whether climate change is occurring or its causes. Rather, given the regulations and initiatives that already tax resources in local jurisdictions, we wanted to find out what is being done to address how climate change can "fit in" with existing watershed and stormwater management programs and practices.

In This Issue

We aimed for content that focused on two central questions:

- How can a watershed-based management approach effectively address the potential impacts of climate change?
- What can or should communities do now to move forward to address climate change, given the uncertainty surrounding likely climate outcomes in 10 years, 50 years, and beyond?

Clearly, communities, states, and organizations are taking action to address the omnipresent issue of climate change. However, despite widely varied motivations and actions portrayed in both articles and vignettes, many authors and contributors converge on a common theme of integrating climate change into existing programs to gain support and momentum for action.

How can a watershed-based management approach effectively address the potential impacts of climate change?

For this issue, we invited Christopher Pyke, President of the US Green Building Council, to provide us with his perspective on what must be done to make climate change relevant to decision makers and to discuss some meaningful first steps that federal and local agencies may take. Pyke also argues that we should not see climate change as another silo for decision making.

The theme of integrating climate change into existing programs is picked up in our first article, in which **Hirschman et al**. provide specific adaptation strategies to link existing stormwater management efforts to climate change initiatives. The authors advocate refining low-impact development practices and site design standards to accommodate changes in precipitation and runoff conditions, but they acknowledge that more work needs to be done to refine these ideas and to address the specific characteristics of a region. **Summerset** and **Stack et al**. use case studies to share with us how the framework presented by Hirschman et al. may be applied. **Summerset** describes the development of a best management practice selection tool that may be used to enhance decision making with regard to location in the watershed, given the expected warmer and drier conditions in the Southwest. **Stack et al**. explain the need to determine the adequacy of drainage systems, specifically the volumetric capacity of culverts, and the type of analysis for the job. This analysis reinforces the need to evaluate the data sets used in hydrologic and hydraulic analyses as part of local stormwater management programs. A third vignette by **Okay and Culbreth** identifies specific management actions to address the restoration and protection of forested riparian buffers given the added stress of climate change in the Mid-Atlantic region.

A central limitation that keeps many communities from moving forward is the ability to decipher information and data needs. This problem inspired the development of CAKE, the online Climate Adaptation Knowledge Exchange. **Hoffman and Gregg** describe the key attributes and functionality of CAKE, which uses case studies to connect users to applicable climate change adaptation resources that fit their unique situations and needs. To assist communities in Oregon and beyond, **Vynne and Adams** describe the Preparing Watersheds for Climate Change Project, an effort to build resilience in Oregon's watersheds and enable adaptation to the impacts of climate change. Translating the global scale of climate change to local watershed management required the development of a training curriculum to meet the local needs of watershed organizations—from understanding climate change science to providing tools to evaluate impacts.

What can or should communities do now to move forward to address climate change, given the uncertainty surrounding likely climate outcomes in 10 years, 50 years, and beyond?

The integration of climate change science into the practical management of watersheds and stormwater is not solely about water quality, but also the sustainability of water supply. **Davis and Dodson** provide insight into efforts to manage the Great Lakes for sustainable water supplies, focusing on New York State. The authors highlight the limitations of current data collection and monitoring efforts, as well as the water pricing system, and examine the potential effects on the region's adaptation to impending climate change. Vignettes by **Betz et al**. and **Score** further exemplify the specific actions that state agencies may adopt through science-oriented, broad-based, multiagency approaches. **Betz et al**. share the water resources climate change adaptation strategy that is part of the Wisconsin Initiative on Climate Change Impacts. A critical aspect of this strategy was the peer-review process used for the data collection and analysis, which ensured that the recommendations are scientifically defensible and technically sound and that they respond to the needs of Wisconsin water management issues. On to the warmer temperatures of the southeastern United States: **Score** highlights the *Climate Change Action Plan for the Florida Reef System 2010–2015*. Whether you live along the coast or not, you are probably aware of the impacts to the coral reef system, such as coral bleaching, habitat degradation, and overfishing. This vignette emphasizes that the restoration and protection of the reef system is within our grasp given the coordination of resources and expertise.

Lenhart et al. examine a missing link in water and land management in the Midwest. Their analysis of long-term hydrologic patterns in the Mississippi River basin attributes increases in low and mean flow to the interactions among changes in land use, drainage, and precipitation patterns. By providing readers with a critical evaluation of how to interpret changing patterns in hydrology and examine the interaction between land use and climate, this analysis illustrates a pathway to better management decisions. A vignette by **Bason and Homsey** reinforces this need for science to inform policy as it pertains to the inland migration of wetlands on the Atlantic coastal plain for the Delaware Inland Bays.

But what does all of this mean if watershed practitioners don't engage the public in the decision-making process? In the article by **Stiles,** the experience of Wetlands Watch is described along with its revised approach to engage local decision makers and the public in the protection of the first line of defense against the rising coastal waters of the Atlantic Coast—wetlands. Stiles provides insight into a social marketing approach that integrates shoreline ecosystem adaptation needs into current local planning processes. **Eckl** reinforces the findings by Stiles and demonstrates that the words chosen to engage the public and decision makers really do make a difference.

In closing, I hope you'll find that the information and ideas presented in this issue help put climate change in a context that enhances watershed and stormwater management programs such that they protect and sustain the quality and quantity of our valuable water resources. The content of this issue is not meant to feed the debate about climate change; instead, it is meant to help us do what we do best as watershed practitioners: apply our knowledge to manage impacts based on our understanding of watershed dynamics.

–Neely L. Law, PhD, Editor-in-Chief

Guest Editorial: Responsible Decision Making in the Context of Climate Change

Christopher R. Pyke, US Green Building Council

Climate change is a global phenomenon with increasingly well-recognized implications for water resource management. Human activities are altering global climate, including important aspects of the hydrologic cycle and biogeochemical processes. In 2010, the US Council on Environmental Quality (CEQ) recommended that the federal government implement actions to expand and strengthen the nation's capacity to understand, prepare for, and respond to climate change. CEQ concluded that adaptation should be a standard part of agency planning in conjunction with efforts to make scientific information more accessible. Many places and programs have already begun to take effective action to understand climate change impacts and to take adaptive action. For example, public water utilities in the Puget Sound region have considered the implications of changes in snowpack on water supply reliability, the US Navy is expanding the consideration of sea level rise in base planning, and the USDA Forest Service incorporates climate change considerations into its forest management plans.

…we currently manage the Chesapeake Bay as if historical conditions persist today and are likely to continue, despite data and theory to the contrary.

Efforts to protect and restore the Chesapeake Bay represent an example and a test of CEQ's new guidance. Bay restoration efforts are often cited as a national model, both for their complexity and their sophistication. Efforts to protect and restore the Bay have entered a new era defined by the renewed commitments and potentially powerful regulations, including President Obama's Executive Order and the Bay-wide Total Maximum Daily Load (TMDL) allocation. However, despite CEQ guidance and scientific recommendations, climate change is not yet a part of critical decision making in Bay restoration. Federal agencies and state partners routinely design restoration strategies based on historic climatic conditions that are unlikely to represent plausible future conditions.

Human activity, particularly the emission of greenhouse gases, is changing the composition of the Earth's atmosphere and the physical characteristics of the land surface. In the Mid-Atlantic, the result is warming temperatures, changing precipitation patterns, and rising sea levels. We see these trends in physical observations of the environment across a range of scales, and our best available simulation models indicate that these patterns are very likely to continue, and potentially accelerate, throughout this century. Confidence in the magnitude and direction of these future changes varies based on our understanding of different Earth system processes and uncertainty in social and economic choices. In the Mid-Atlantic, we have the greatest confidence in future scenarios for temperature and sea level, and greater uncertainty in future precipitation patterns.

I believe that we know enough to act, and that decisions based solely on historic climatic conditions recklessly ignore the available science and jeopardize Chesapeake Bay restoration goals. We regularly make important decisions under uncertainty. We consider the plausible range of future outcomes and act accordingly: we buy insurance, diversify our assets, and plan for contingencies. In making these decisions, we study trends and characterize uncertainties, and we all know that past performance is no guarantee of future results. However, we currently manage the Chesapeake Bay as if historic conditions persist today and are likely to continue, despite data and theory to the contrary. It is essential and entirely reasonable for Bay Program stakeholders to find practical ways to make resource management decisions that explicitly accommodate changing conditions and prepare to meet performance goals under the full range of plausible future conditions.

Climate change is not a singular new issue; its complexity and scope require coordination across agencies—not another silo alongside existing programs. Effective response will require new considerations across a range of existing decisions. For example, climate change is likely to alter:

- the flow of pollutants into the Bay and their implications for water quality and living resources;
- the performance of environmental monitoring programs intended to measure success and guide regulatory processes;
- the design of regulatory programs, such as the Bay-wide TMDL; and
- the effectiveness of restoration strategies, such as those in watershed implementation plans.

Some suggest that the impacts of climate change will occur far in the future and are irrelevant to current decision making. I strongly disagree for two reasons. First, we are using information about historic climatic conditions to make important decisions today that are expected to yield performance outcomes for decades in the future. These implicit assumptions are not plausible and, in some cases, can lead to inadequate systems that are "locked-in" for decades to come. For example, systems such as stormwater controls and water treatment plants are designed today based on historic conditions and expected to meet performance goals for decades. Consequently, it is important to take action to identify and understand where information about climate contributes substantially to policy outcomes. These "climate-sensitive" decisions represent points of vulnerability and potential opportunities for adaptive action. Second, climate change creates the risk of disrupting critical monitoring systems by confounding changes due to restoration, climate, and further pollution and degradation. Preliminary work to partition and attribute change among drivers has just begun; failure to continue this work may undermine the Bay restoration process by creating ambiguity in the causes of changing conditions.

Relevance of "Everyday Decisions"

Every day, decision makers across the Bay watershed make long-term decisions that will directly determine the performance of key restoration strategies under future conditions. Every time a home is built, a detention pond dug out, a road constructed, or a seawall erected, the project designs are explicitly based on historic climatic conditions. The home is designed based on a typical meteorological year. The pond is shaped to accommodate a design storm. The road is elevated to avoid historic storm surge. The seawall is designed to accommodate historic mean sea level. The products of all of these common decisions are anticipated to perform for decades into the future. Yet they are explicitly, purposefully, carefully designed for a distribution of conditions that, in all likelihood, they will not experience. The engineers making these calculations are capable of planning for a wide range of conditions, yet decision makers do not ask them to plan for the most likely conditions projected for the anticipated performance lifetime of the project at hand. Consequently, each project represents a lost opportunity for adaptation and yet another potentially vulnerable resource. Fortunately, these daily decisions also represent a tremendous opportunity to increase resilience and prepare for changing conditions. We have all the tools we need to make better decisions. We simply need to decide to take responsibility for performance across the lifecycle of our decisions. This change in professional practice may be driven by changes in regulation, client demand, or recognition of potential liabilities. These changes in decision making could be made quickly with far-reaching benefits for resilience and adaptation.

Monitoring and Attribution

Current efforts to protect and restore the Bay are based on sophisticated computer models, but progress will ultimately be measured on the ground and in the water. Climate change also has significant implications for critical monitoring programs by creating another regional-scale driver of change in the system—one that current monitoring systems were not designed to detect and may not be able to separate from other factors. This means that we do not know if we can reliably determine the sources of restoration or degradation. This is a problem because the rates of change anticipated under most climatic scenarios for the Mid-Atlantic are on the same order of magnitude as most optimistic scenarios for Bay restoration. Realistically, both climate change and restoration are long, slow processes that will play out simultaneously for decades into the future. It is essential to understand how these processes will interact. If sources of degradation and restoration cannot be adequately partitioned, climate change has the potential to become an excuse for unmet restoration goals, as stakeholders look to explain performance issues. Bay Program partners must anticipate and prepare for such arguments by ensuring that the monitoring systems can detect and differentiate climate-driven from non-climate-driven change across the watershed. These kinds of capabilities are essential for attributing change to the right cause and determining appropriate restoration priorities.

Today, the science is clear: historic conditions provide an inadequate guide for the future. Yet major decisions, such as the design of the Bay-wide TMDL, continue to rely almost exclusively on retrospective analyses. We know that decisions made on this basis may increase our vulnerability to changing conditions and fail to identify opportunities for adaptation. Uncertainties remain, many of them irreducible in the short-term. Rather than ignore the uncertainties, we should acknowledge and address them through changes in decision-making processes. We can take action today to explicitly recognize when historic climatic information is embedded in our decision making, drawing on examples from across the country (e.g., the Climate Ready Water Utilities Toolbox [US Environmental Protection Agency n.d.]) and around the world (e.g., the Climate Adaptation Knowledge Exchange [n.d.]). We can then critically and systematically evaluate the consequences of these assumptions for management actions and, when it makes a significant difference, we can take action to plan for the full range of plausible conditions anticipated over the lifetime of our decision. This is not radical stuff. This is responsible decision making in the context of climate change.

REFERENCES

Climate Adaptation Knowledge Exchange. No date. CAKE: Climate Adaptation Knowledge Exchange. http://www.cakex.org/

Sutley, N.H. 2010. Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions. Memorandum for Heads of Federal Departments and Agencies. February 18, 2010, 12 pages.

US Environmental Protection Agency. No date. Climate Ready water utilities toolbox. http://www.epa.gov/safewater/watersecurity/climate/toolbox.html

Linking Stormwater and Climate Change: Retooling for Adaptation

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Abstract

Climate change will necessitate a reappraisal of existing approaches for stormwater management. Climate change is anticipated to impact every aspect of the water cycle, and many of the underlying assumptions that stormwater managers use for runoff and storm system design might become outdated if these predictions become a reality. While it is important to link stormwater and climate change, efforts to do so face several unique challenges. This paper addresses how climate change factors may influence such stormwater design hallmarks as the design storm, water quality volume, and stormwater conveyance. Climate change factors suggest that future design changes are needed at the site and community scales to manage stormwater effectively. Examples are presented to supplement this discussion using three case studies that incorporate climate change scenarios into infrastructure modeling, examine how low-impact development practices are predicted to dampen climate change impacts, and integrate climate change into a regional plan. This paper outlines a few key general issues for making the stormwater and climate change link in hopes of furthering this important discussion.

Introduction

Climate change will necessitate a reappraisal of existing approaches for stormwater management. Many of the underlying assumptions that stormwater managers use for runoff and storm system design might become outdated if the predicted impacts on every aspect of the water cycle become a reality (Funkhouser 2007; Oberts 2007). While climate models vary widely, they collectively paint a picture of what might be expected over the next century on an annual and seasonal basis.

The Intergovernmental Panel on Climate Change (IPCC) (Christensen et al. 2007) predicts a temperature increase ranging from 2.5°C to 5.0°C over the next 100 years in the continental United States, with the greatest increases in the northern states and during the winter months. The IPCC also predicts an overall increase in precipitation in the North, but decreased precipitation in the Southwest. The regional differences are expected to be most pronounced in the winter, with northern states experiencing a significant increase in winter precipitation and the already dry Southwest experiencing reduced winter rainfall. This would mean an increase of rain-on-snow events in northern climates and potential severe water shortages in southwestern states that rely on winter snowmelt for their water supplies.

Although these annual conditions present serious challenges in and of themselves, they may be just the tip of the disappearing iceberg. While the total annual rainfall is of course important from a water resources standpoint, stormwater engineers focus primarily on managing individual storm events, and most climate models suggest that most regions will experience a shift to less frequent storms of greater intensity. The potential effects of climate change on individual storm events are uncertain, and would affect stormwater mainstays, such as the *design storm*. This, and other stormwater design parameters, will need to be scrutinized to ensure that future stormwater designs are responsive to changing climate conditions. Further, rising sea levels will impact both flood management and the migration and expansion of existing wetlands on the coasts. Taken together, these impacts will necessarily cause a change in the way we think about stormwater management. Table 1 presents an outline of several climate change factors and the likely effects for stormwater design and management.

The remainder of this paper addresses several aspects of adapting stormwater management to climate change. We present several of the challenges associated with linking stormwater to climate change, followed by a discussion of "designing with uncertainty" at the site and community scales. Each section also includes a profile or case study of a community or institution that is analyzing, and planning for, some aspect of climate change.

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Table 1. Climate change effects on stormwater design and management.

Climate Change Factors	Possible Effects on Stormwater Design and Management
• Increased temperature of atmosphere • Increased temperature of runoff • Changes in rainfall depth, intensity, and frequency • Changes in drought frequency and severity • Decreased soil moisture (antecedent soil moisture between storms) • Increased variability in winds and drying conditions • Sea level rise • In northern climates, more winter precipitation and rain-on-snow events	• Exceedances of storm system capacity and safety • Increase in peak flows • Number of properties and structures subject to flooding • Decrease in annual infiltration volume due to higher evaporation and proportionally more runoff from more intense storms • Decrease in stream baseflow • Wider range of storm events to manage in order to achieve the same level of pollutant load reduction • Increased demand for water supply storage and reliability • Broader application and geographic coverage of drought-tolerant plants for vegetated stormwater practices • Impacts to sensitive waters, wetlands, and coldwater fisheries • Need for more land use planning, such as floodplain management and freeboard requirements for storm conveyance and treatment systems

Sources: Booth 2006; MWH 2009; Oberts 2007; and Shaw et al. 2005.

Challenges of Linking Stormwater Management to Climate Change

To adapt effectively, stormwater managers will need to overcome challenges related to the uncertainty of climate change, coupled with the inherent uncertainty of land use planning and stormwater management. Below, we articulate two brief examples of the challenges involved in linking stormwater and climate change.

Climate Change Impacts Are Offset by Overriding Land Cover Changes

While the expected hydrologic impacts of climate change are noteworthy, they can be dwarfed by the hydrologic changes created by land development. For example, a 0.4-ha (1-acre) site that is converted from a forested condition to a post-development land cover of 40% impervious cover, 40% managed turf (e.g., lawns), and 20% forest may see a ten-fold increase or more in the runoff coefficient and total phosphorus load (based on average values for the Mid-Atlantic), and an increase in peak runoff rates ranging from 50% to 170%, depending on the design storm and local hydrologic factors. By comparison, climate change scenarios could introduce changes in 24-hour rainfall of between 4% and around 25% (Rosenberg et al. 2009; Shaw et al. 2005). In other words, in the stormwater design world, land cover changes will continue to predominate, and changes in rainfall and runoff patterns associated with climate change will require an undetermined level of adjustment above and beyond the overriding land cover change factor (Booth 2006).

Potential Ranges of Change Are Too Large To Inform Engineering Design

Revising stormwater design parameters such as rainfall depth, intensity, and frequency; initial abstraction; and pollutant loading rates is a fairly straightforward exercise. However, whether these factors change by 3% or 40% creates a dramatically different outcome in terms of conveyance, storage, and treatment capacity. At present, the degree of uncertainty in climate change models, as well as region-specific considerations, make it necessary to consider various stormwater design scenarios, depending on the extent and severity of change anticipated (Shaw et al. 2005). This level of uncertainty is probably acceptable for conceptual or modeling exercises but is more difficult to accept for actual stormwater designs, where increases in the number and size of stormwater practices translates directly into increased costs and land area needed for stormwater management.

Understanding Impacts of Climate Change on Stormwater Design at the Site Scale

Even the most careful analysis of rainfall records and climate change model results does not lead to a simple fix for stormwater management design (see Case Study 1). Rather, it only highlights the range in uncertainty, pointing to a need to manage a wide range of project storm events (Rosenberg et al. 2010). However, stormwater engineers need to make design decisions at the site level, and these decisions have traditionally been shaped by selecting specific design storms and treatment volumes. Although the exact criteria vary depending on local and state stormwater requirements, stormwater management generally includes both the relatively large *water quantity* storms and the smaller *water quality* storms. It appears that climate change may affect each of these storms differently. Finally, climate change may impact *rainfall intensity*, which has perhaps the most profound impact on stormwater design.

Design Storm for Quantity Control

Many climate change models predict that the depths of relatively infrequent *quantity control* storms will increase as global temperature increases. Various modeling exercises and analyses of historic precipitation records generally support the notion that the rainfall depths of the less frequent storms (e.g., the 100-year flood event) could increase by the greatest percentage.

Design Storm for Quality Control

Nationally, a common design storm for water quality treatment is the "90th percentile" rainfall event. That is, the average annual rainfall depth associated with 90% of runoff-producing precipitation events is used to derive a volume that must be captured and treated by stormwater practices. In many parts of the country, this equates to about 25 mm (1 in) of rainfall. The effects of climate change on the water quality storm are largely unknown. Most analyses seem to indicate that, while large storms will increase significantly, small storm events will remain unchanged. At first glance, this prediction may suggest that the rainfall depth of the water quality storm would remain essentially unchanged, and this may indeed be the case in many regions of the country. However, truly understanding how climate change would affect this design storm event may be more complex and perhaps beyond our current understanding. Two potential factors that may affect water quality designs are the number of storm events in a given year and changes in the seasonality of rainfall under climate change scenarios. For those designers using continuous simulation tools, such as RECARGA (Atchison and Severson 2004) and WinSLAMM (Pitt and Vorhees 2002), a new series of rainfalls will have to be defined to achieve desired water quality benefits.

One somewhat counterintuitive aspect of determining how the water quality storm will be impacted by climate change relates to its calculation. While this storm is typically a small and frequent storm event, it is not generally tied to a return period. One result of this phenomenon is that the depth of this event may be just as influenced by the number of storm events in a particular year as it is by the depth of specific design frequency events. One possible outcome of climate change is that there will be fewer, more intense storms in a typical year. For example, if we assume that the number of storm events in a typical year is reduced to only ten, then the 90th percentile event would effectively be equal to the depth of the one-year storm. This would be a dramatic increase in most regions of the country. For instance, this could increase the water quality storm event from about 25 mm (1 in) to 76 mm (3 in) or more in certain parts of the country.

Other factors to consider are the seasonal and regional impacts of climate change. An increase in winter precipitation in northern regions will probably translate to greater rain-on-snow events. Such events typically produce a relatively high runoff volume and reduce the ability to store spring runoff for summer potable demand. If this trend is truly expected, models that create an annual runoff spectrum, accounting for elevated runoff coefficients during winter months, will prove valuable in developing new design volume curves.

Rainfall Intensity

Perhaps of greatest concern to stormwater designers is the change in rainfall *intensity*. Since rain will probably come in more intense bursts, we need to start thinking about how changes in the peak intensity of rainfall can impact the design and storage characteristics of stormwater practices. For water quantity events, we need to revisit our assumptions regarding the assumed shape of the rainfall hyetograph, which guides hydrologic modeling. As storms become more intense, designers may want to alter their assumptions about the shape of the design storm.

Rainfall intensity is also important for smaller *water quality* storms. Many designers use the "kerplunk" method to size stormwater practices. That is, they provide storage for the event (for instance, as free storage or within soil or gravel layers) and assume that flow enters and is treated in the facility. However, some practices can be easily bypassed by a short but very intense storm event. A good example is a bioretention facility, in which the filter media (with many small, albeit significant pore spaces) can act as a bottleneck and lead to system bypasses when rainfall intensity exceeds a certain threshold. In other words, runoff enters the practice too quickly to allow the soil media storage to effectively fill.

Stormwater Conveyance

For water quantity events, the primary focus is to convey flows safely through the site, without causing flooding. While it is uncertain how much each storm will vary from one event to another, site designs should, at a minimum, use conservative assumptions when designing a conveyance system and should build a certain amount of additional freeboard into drainage and overland flow path designs.

Related to this are assumptions about sheetflow. Stormwater designs may assume that some water will be conveyed (or even deliberately treated) by maintaining sheetflow conditions. However, if rainfall depths and intensities increase, sheetflow could easily be converted to concentrated flow, leading to system performance and maintenance concerns. In the future, sheetflow may require more careful design, such as use of level spreaders and tighter drainage area-to-sheetflow ratios.

Case Study 1: Understanding Future Precipitation and Resulting Watershed Discharge in the Puget Sound Region

A study in the Puget Sound region used hourly historic rainfall data to examine changes in extreme events and climate models to predict changes in future rainfall patterns (Rosenberg et al. 2009, 2010). Such analyses are critical for understanding the implications of climate change in managing stormwater systems. Researchers analyzed extreme precipitation data from weather stations in three major Washington and Oregon metropolitan areas (Seattle–Tacoma, Spokane, and Vancouver–Portland) for changes from 1949 to 2007. The results were generally nonsignificant, except in Seattle–Tacoma, where Rosenberg et al. (2009, 2010) found an increase of about 25% for the 24-hour design storm. The researchers then used two weather research and forecast (WRF) regional climate models (RCMs) to simulate rainfall from 1970 to 2000 and from 2020 to 2050, and again analyzed changes in extreme precipitation between the two periods. Results indicated increases in extreme rainfall intensities, with statistically significant increases of 15% to 22% projected for the 24-hour design storm.

Changes in streamflow projections are more directly related to design storms and, therefore, to changes in stormwater infrastructure needs. Rosenberg et al. (2009, 2010) modeled streamflow in two watersheds representing urban and suburban areas. Hydrologic streamflow simulations were generated using Hydrologic Simulation Program–Fortran with precipitation data from 1970 to 2000 and simulated data from 2020 to 2050. Based on these results, both stream systems exhibited higher flows at the watershed mouth, although the range of predicted changes varied widely, depending on the recurrence interval, watershed, and underlying WRF RCM precipitation data.

The authors determined that "concern over present design standards is warranted" (Rosenberg et al. 2010, 341) and suggested that "drainage infrastructure designed using mid-20th century rainfall records may be subject to a future rainfall regime that differs from current design standards" (Rosenberg et al. 2010, 340). However, the range of projections was too large to modify current stormwater design assumptions.

Designing for Uncertainty at the Site Scale

Since the level of uncertainty in predicting climate change is high, and specific design standard modifications have not been ascertained, the design community needs to focus on broader design principles that build system resiliency for climate change. Designers should rely on approaches that (1) enhance storage and treatment in natural areas, (2) use small-scale storage and treatment, and (3) provide conveyances that allow for a margin of safety for flood conveyance and water quality treatment. These design principles reflect current thinking in stormwater design and the low-impact development (LID) design framework (see Case Study 2). In the face of climate change, the use of distributed storage and open-channel flow practices provide some insurance against flood control and water quality storm events that may be changing now and in the future.

Design modifications of individual stormwater practices may also be necessary in response to the climate change factors noted above. Since our understanding of design storms may change, the design community may want to focus on what may be fairly modest modifications of existing designs to better accommodate more intense rainfall events. The examples below provide two illustrations of how individual practices could be modified at relatively low cost. These examples are intended to be illustrative and not necessarily authoritative with regard to the best possible solution for a particular issue. The intention is to spur thought and discussion on what types of adaptations will be necessary.

Example 1: Reallocating Storage in Bioretention

The Issue: Increasing rainfall depths and intensities may force a rethinking about how storage is allocated to the various layers within a bioretention facility. More frequent high-intensity rainfall will lead to increased bypassing of the treatment mechanism and lower overall performance. The most vulnerable flow path element may be the rate at which water stored on the surface of the filter can effectively percolate down and fill the void spaces within the soil media.

Possible Adaptation: Increasing the surface area allocated for storage above the soil media can create a "holding zone" for water to move down through the soil voids. Importantly, this does not necessarily mean that the surface area (or volume) of engineered soil media needs to increase, as that could have profound cost implications. One possible solution is to have a surface ponding area that is not underlain by soil media, as shown in Figure 1. In fact, this method has already been adopted in existing specifications, such as those on the Virginia Stormwater Best Management Practice (BMP) Clearinghouse, albeit not as a climate change adaptation (Virginia Department of Conservation and Recreation [VADCR] 2010a).

Figure 1. Adaptation of bioretention facility. Additional surface ponding area can be incorporated (light blue line) while the surface area and volume of soil media remain the same (yellow line). The photo shows a conceptual approach of how the design adaptation may be accomplished. Photo courtesy of: Williamsburg Environmental Group, Inc.

Example 2: Pretreatment for Rainwater Harvesting

The Issue: Rainwater harvesting systems are designed to capture a target amount of water. However, both ends of the spectrum feature designed bypasses—first-flush diverters, vortex filters, and additional pretreatment devices to keep leaves and gross solids out of the storage tank (Figure 2) and bypasses for higher flows once the storage device fills to capacity. With changing rainfall depths and intensities, more water than desired may bypass at the front end, resulting in a loss of precious water that could be stored for future use, and overflow at the back end, creating downstream problems.

Possible Adaptation: The efficiencies for vortex filters and other pretreatment devices can be increased so that higher-intensity rainfall events will not lead to excessive bypassing of the storage tank. For instance, some current specifications call for a filter efficiency of 95% for a storm intensity of 25 mm (1 in) per hour (VADCR 2010b). The assumed intensity could be increased to 38 or 51 mm (1.5 or 2 in) per hour. To address more frequent overflows from the tank itself, on-site or off-site downstream infiltration or filtering practices can be coupled with the rainwater harvesting system, as is already called for in some state specifications (Figure 3).

Figure 2. This vortex filter is an example of a pretreatment device for rainwater harvesting. The vortex filter diverts the first amount of rainfall, which tends to have a lot of solids and vegetative debris. Vortex filters come in different sizes based on efficiency curves for rooftop area treated and rainfall intensity. Photo courtesy of: Rainwater Management Solutions, Inc.

Case Study 2: Understanding How LID Stormwater Practices Can Help Communities Attain Climate Change Resiliency

The University of New Hampshire's Stormwater Center (UNH SC) investigated LID stormwater management practices to reduce runoff and manage the more intense storm events expected as a result of climate change impacts. UNH SC used published estimates of the 2-, 10-, and 100-year design storm events. The UNH SC models demonstrated dramatic runoff increases in the future due to climate change. For New Hampshire, Stack et al. (2009) predicted increased mid-twenty-first century precipitation compared to mid-twentieth century (Figure 4).

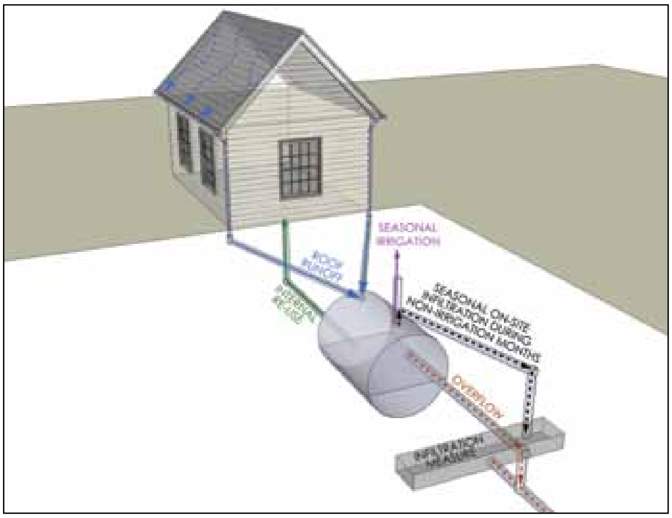

Figure 3. Schematic of a rainwater harvesting system designed for internal use, seasonal irrigation, and treatment in a downstream filtration or infiltration practice during nonirrigation or rainy season months when the tank overflows routinely. Source: VADCR 2010b, figure 6.3.

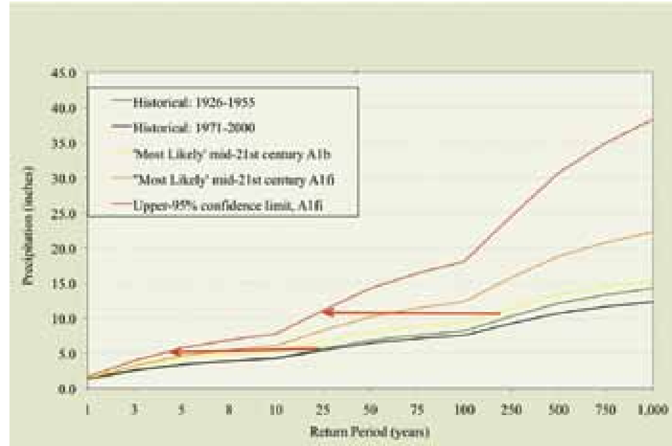

Figure 4. Estimated change in the intensity–return period relationship due to climate change. Source: Stack et al. (2010); reprinted with permission from L.J. Stack, Syntectic International LLC.

UNH SC researchers Robert Roseen, Iulia Barbu, and Tom Ballestero studied a typical site undergoing development. They estimated the total runoff volume for these climate change scenarios for LID practices, predevelopment conditions, and conventional practices, and found that LID practices can reduce the runoff volume for these design storms. In fact, in the typical site scenarios, the LID practices will retain about 15% to 22% of the design storm volume onsite and provide greater groundwater recharge (Ballestero et al. 2009). LID practices demonstrated improved resiliency for the consequences of climate change by reducing storm runoff on-site through infiltration; this also increases groundwater recharge and/or collection and storage for on-site use (Ballestero et al. 2009).

Designing for Uncertainty at the Community Scale

Given the degree of uncertainty, many efforts are underway to frame stormwater management approaches for climate change at the broader community scale. Admittedly, most of these deal more with the infrastructure side of the equation, such as storm system capacity, and less with water quality or stormwater BMP design. However, it is critical to start to frame stormwater management implications and adaptations.

Integrated stormwater and land use solutions have an important role to play in this task. It is safe to assume that we cannot rely solely on "hard," or technological, solutions to deal with such climate change scenarios as more frequent flooding and more prolonged droughts. Solutions that are rooted in the integrated management of stormwater and land use planning will need to play a role. These solutions will include improved floodplain management, urban watershed forestry, and strategies to promote more efficient development patterns at the community and neighborhood scales.

These strategies are necessary to promote multiple and overlapping objectives, such as enhanced stormwater treatment, storage, and use; water conservation; and energy efficiency (see Case Study 3). For instance, land use planning and site and stormwater design can lead to reduced runoff volume; less demand for municipal and potable water supplies (e.g., through rainwater harvesting); and more compact, energy efficient development (e.g., requiring fewer and shorter trips by automobile).

Table 2 provides several conceptual ideas for how integrated stormwater and land use tools can help adapt to both the hydrologic and policy implications of climate change.

Table 2. Climate change and conceptual land use and stormwater management adaptations.

Hydrologic Impacts of Climate Change	Land Use and Stormwater Management Adaptations
More frequent flooding	• Remap floodplains based on "new" frequent and infrequent events. • Adopt stringent regulations to restrict development within floodplains. • Develop mitigation programs to remove susceptible structures from floodplains. • Conduct more frequent cleaning of storm sewer infrastructure in urban areas to maintain hydraulic capacity. • Ensure that all new development has overland relief in case of system failure. • Model storm sewer infrastructure using new climate scenarios and coordinate with emergency response plans.
More prolonged droughts	• Extend rainwater harvesting beyond the individual rooftop scale to the neighborhood or community scale. Use stormwater as a local supplemental water resource—potable and nonpotable. • Adopt small-scale (household) and larger-scale (community) water budgets for indoor and outdoor uses as a tool to prioritize uses and to promote the most efficient use of water. • Implement drought-resistant planting plans for stormwater practices and municipal landscaping. • Promote urban forestry and forest protection to promote shade and the retention of moisture. • Incorporate groundwater recharge into all stormwater practices where safe and feasible.
Increased runoff temperature	• Include trees and other plantings in BMP designs. • Develop methods to reduce straight-piping of runoff to streams; use disconnection methods to direct runoff to buffers, planted areas, pervious parking, forested stormwater practices, etc. • Develop impervious limits and minimum tree canopy requirements for special temperature-sensitive receiving waters (e.g., high-value trout streams).
More combined sewer overflows	• Incorporate runoff volume–reduction measures across the landscape (e.g., for individual homes, streets, and businesses), including rain gardens, rainwater harvesting, and dry wells. • Strategically locate and use open-space areas for runoff capture to reduce flows into the system.
Policy Goals in Response to Climate Change	
Reduce carbon emissions	• Promote compact development to reduce vehicle trips and vehicle miles. • Provide stormwater incentives for redevelopment close to urban centers and more stringent requirements for new (greenfields) development that requires more driving. • Provide stormwater credits for transit and bicycle facilities at development sites. • Consider the energy embodied in BMP materials and installation (e.g., plastic or wood components or land cleared for stormwater practices) as a BMP selection criterion.
Increase carbon sequestration	• Use urban forestry as a stormwater BMP. • Incorporate trees into all or most new stormwater practices. • Design integrated stormwater or carbon sequestration facilities; incorporate planting maintenance plans that maximize carbon uptake.
Increase clean, renewable energy sources	• Incorporate small-scale power generation into some BMP and storm sewer designs that have adequate head. • Co-locate neighborhood-scale stormwater practices with solar, wind, and other renewable-energy facilities.

Source: Adapted from Center for Watershed Protection (2008), table 3.9.

Case Study 3: Adaptive Management To Combat Climate Change in Punta Gorda, Florida

Adaptive stormwater management is called for in the Southwest Florida Regional Planning Council (SWFRPC) Resolution 08-11 (2008) to address water quality, infrastructure, and flooding in the face of climate instability. The City of Punta Gorda, Florida is taking steps (City of Punta Gorda n.d.) to mitigate and adapt to climate change impacts using an adaptation plan that builds on the *Comprehensive Southwest Florida/Charlotte Harbor Climate Change Vulnerability Assessment* (Beever et al. 2009a). The adaptation plan (Beever et al. 2009b) includes detailed mapping, aerial photography, a vulnerability analysis, and involved community stakeholders and decision makers tasked with developing specific implementation actions. Flooding, water quality, infrastructure, water supply, and/or drought were identified as major concerns.

The adaptation plan targets climate stressors by calling for specific stormwater adaptations, such as the following:

- Build roads and sidewalks from porous materials to adapt to more frequent flooding.
- Increase stormwater management capacity to address inadequate water supply and more frequent flooding and to modify the stormwater design criteria.
- Modify stormwater conveyance systems to be relative to sea level instead of at set elevations.
- Construct stormwater infrastructure improvements.
- Require Florida residents and developers to use native landscaping and xeriscaping (the use of plants with less need for watering) to reduce pollutants and to promote water conservation (SWFRPC Resolution 07-01, 2007).

Conclusion

Linking stormwater and climate change will involve adapting several existing concepts. These improvements in stormwater design and implementation are needed to address our current challenges with land use change, pollutant loads, degraded stream health, aging infrastructure, and wise use of water resources. The climate change driver adds some incentive to adopt these practices and to accommodate the uncertainties associated with changing hydrologic conditions. This paper outlines a few key general issues for making the stormwater and climate change link in hopes of furthering this important discussion.

REFERENCES

Atchison, D., and L. Severson. 2004. RECARGA user's manual, version 2.3. Madison, WI: University of Wisconsin–Madison Civil & Environmental Engineering Department, Water Resources Group.

Ballestero, T. P., R. M. Roseen, and I. A. Barbu. 2009. LID practices as a means of resilience and short-term adaptation to climate change. Paper presented at the 2009 New Hampshire Joint Water and Watershed Conference, Concord, NH.

Beever, J. W., III, W. Gray, D. Trescott, D. Cobb, J. Utley and L. Beever. 2009a. Comprehensive Southwest Florida/Charlotte Harbor climate change vulnerability assessment. Southwest Florida Regional Planning Council Charlotte Harbor National Estuary Program technical report 09-3. September 15. Fort Myers, FL: Southwest Florida Regional Planning Council and Charlotte Harbor National Estuary Program.

Beever, J. W., III, W. Gray, D. Trescott, D. Cobb, J. Utley, D. Hutchinson, J. Gibbons, et al. 2009b. City of Punta Gorda adaptation plan. Southwest Florida Regional Planning Council Charlotte Harbor National Estuary Program technical report 09-04. November 18. Fort Myers, FL: Southwest Florida Regional Planning Council and Charlotte Harbor National Estuary Program.

Booth, D. B. 2006. Climate change, urbanization, and stormwater runoff. Abstract #H11J-01. Paper presented at the fall meeting of the American Geophysical Union, San Francisco, CA.

Center for Watershed Protection. 2008. Managing stormwater in your community: A guide for building an effective post-construction program. 833-R-08-001. Washington, DC: US Environmental Protection Agency.

Christensen, J., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, K. Kolli,W.T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A.Sarr and P. Whetton P. 2007. Regional Climate Projections in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, Cambridge University Press, pp. 847-940.

City of Punta Gorda. No date. Growth management. City of Punta Gorda evaluation and appraisal report (EAR) 2011. http://www.ci.punta-gorda.fl.us/depts/growthmgmt/compplan.html

Funkhouser, L. 2007. Stormwater management as adaptation to climate change. Stormwater 8(5). http://www.stormh2o.com/sw_0707_stormwater.html

MWH. 2009. Implications of climate change for stormwater management. Village of Glenview, IL: Stormwater Task Force.

Oberts, G. L. 2007. Climate and stormwater: Coping with change. Stormwater 8(6). http://www.stormh2o.com/sw_0709_climate.html

Pitt, R., and J. Voorhees, III. 2002. SLAMM: The Source Loading and Management Model. In Wet-weather flow in the urban watershed: Technology and management, ed. R. Field and D. Sullivan, 79–101. Boca Raton, FL: CRC Press.

Rosenberg, E. A., P. W. Keys, D. B. Booth, D. Hartley, J. Burkey, A.C. Steinemann, and D. P. Lettenamaier. 2009. Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State. In The Washington climate change impacts assessment: Evaluating Washington's future in a changing climate. Seattle, WA: University of Washington Climate Impacts Group.

Rosenberg, E. A., P. W. Keys, D. B. Booth, D. Hartley, J. Burkey, A.C. Steinemann, and D. P. Lettenamaier. 2010. Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State. Climatic Change 102(1–2): 319–349

Shaw, H., A. Reisinger, H. Larsen, and C. Stumbles. 2005. Incorporating climate change into stormwater design—Why and how? 4th South Pacific Conference on Stormwater and Aquatic Resource Protection, Auckland.

Southwest Florida Regional Planning Council (SWFRPC) Resolution 07-01. 2007. Southwest Florida Regional Planning Council Fertilizer Resolution. Fort Myers, Florida. March 15, 2007.

Southwest Florida Regional Planning Council (SWFRPC) Resolution 08-11. 2008. Stormwater Resolution for New Development and Re-Development. Fort Myers, Florida. August 21, 2008.

Stack, L. J., M. H. Simpson, T. W. Crosslin, J. S. Gruber, R. M. Roseen, J. B. Smith, R. T. Wood. 2009. Stakeholder-driven decision-making for adaptation: Design and implementation of a water infrastructure adaptation plan. NOAA Climate Program Office: Sectoral Applications Research Program.

Stack, L., M. H. Simpson, T. Crosslin, R. Roseen, D. Sowers, and C. Lawson. 2010. The Oyster River culvert analysis project. Syntectic International, Antioch University New England, Climate Techniques, the University of New Hampshire, and the Piscataqua Region Estuaries Partnership. Prepared for the Piscataqua Region Estuaries Partnership, Durham NH, and the EPA Climate Ready Estuaries Program.

Virginia Department of Conservation and Recreation. 2010a. Design specification no. 9: Bioretention. Version 1.8. April 13. Richmond, VA: Virginia Department of Conservation and Recreation.

Virginia Department of Conservation and Recreation. 2010b. Design specification no. 6: Rainwater harvesting. Version 1.9. April 26. Richmond, VA: Virginia Department of Conservation and Recreation.

Watershed Management and Climate Change in New York State: The Great Lakes Compact

Jon W. Davis[a] *and Khristopher Dodson*[b]*

Abstract

Increased water usage and supply uncertainty due to climate change motivated eight states and two provinces in the Great Lakes region to devise comprehensive recommendations on managing water in the Great Lakes basin. If put into place, these recommendations, collectively called the Great Lakes Compact, would put restrictions on out-of-basin water withdrawals and encourage more in-basin conservation programs. This paper presents and discusses key recommendations put forth by the New York Great Lakes Basin Advisory Council, which was assigned the task by the New York State Governor's office of implementing the Great Lakes Compact. It will be increasingly important, particularly for municipal water suppliers and industrial users, to plan further into the future, enact conservation measures, and meter and use water more efficiently. The regulations recommended by the Great Lakes Compact, and the process through which they are being developed, can be used as an example for other watersheds in North America and will potentially lead the nation in preparing for climate change through sustainable water use.

Introduction

As a nation, the United States is experiencing a time of quickly evolving environmental concerns whose impacts will be felt by generations to come—perhaps most notable of these concerns is global climate change. Both the US Environmental Protection Agency (USEPA 2008) and the Intergovernmental Panel on Climate Change (for more information on the latter see Bates et al. 2008) have published decisive and comprehensive reports outlining the impact that climate change will have on America's water and wastewater systems. Municipal leaders and treatment plant operators need to be aware of these impacts and have the knowledge and tools to plan for the long-term challenges that lie ahead.

This paper analyzes one such plan of action by exploring the process used, problems encountered, and recommendations developed by the New York Great Lakes Basin Advisory Council (GLBAC) when it prepared its long-term

Facts about the Great Lakes

- The Great Lakes hold about 23 quadrillion liters (6 quadrillion gallons) of water.
- The Great Lakes contain about 95% of the United States' fresh surface water and 20% of the world's fresh surface water.
- If spread evenly, the water contained within the Great Lakes would cover the continental United States with about 3 m (10 ft) of water.
- The Great Lakes basin drains almost 520,000 km^2 (200,000 mi^2).
- Great Lakes shoreline in the United States is more than 7,200 km (4,500 mi) long, longer than the US East and Gulf Coasts combined.
- The total Great Lakes shoreline is more than 16,000 km (10,000 mi) long, including 35,000 islands.
- The Great Lakes region is more than 1,200 km (750 mi) wide.
- The region is home to more than 33 million people.

Figure 1. Map showing the eight states and two provinces included in the Great Lakes basin.

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plan to conserve and protect the Great Lakes basin in New York State. After a brief outline of the watershed and the potential impacts of global climate change, this paper elaborates on the specific actions the GLBAC proposed and how those actions are intended to work. The article concludes with a brief overview of lessons learned and options for improved future organization.

Climate Change and the Great Lakes Basin

The enormity of scale and diversity of the region makes the Great Lakes basin (Figure 1) an important case study for understanding the effects of climate change on water systems. In the Great Lakes basin, one of the nation's most complex water systems, climate change will have an acute impact if current withdrawal pressures and water quality degradation continue. The Great Lakes Compact (Great Lakes Commission n.d.) will be instrumental in protecting the basin in the future. It provides a "macro" management effort in the Great Lakes basin that will provide insight into effective "micro" plans that can be implemented in segments of the basin or in other, smaller watersheds. However, this will all depend on how the recommendations are implemented and enforced.

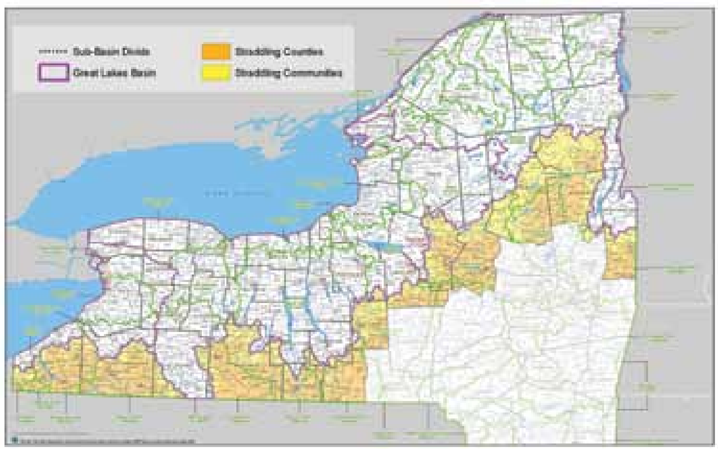


Figure 2. Map of the New York Great Lakes basin showing the communities that straddle the basin, the communities that drain into one of the lakes or the St. Lawrence River, and subwatershed boundaries.

Mortsch et al. (2003) outline some projected impacts of global warming on the Great Lakes basin, including:

- an increase in air temperature,
- a potential decrease in the daily air temperature range,
- total annual precipitation increases,
- a decrease in precipitation during key seasons,
- decreased snowpack and increased rainfall,
- an increased intensity of precipitation events, and
- a potential for increased evapotranspiration with warmer air temperatures.

USEPA (2008) further elaborated the impacts, indicating that warmer climates will increase evaporation from lake surfaces and evapotranspiration from the land surface of the basin and that this, in turn, will increase the percentage of precipitation that is returned to the atmosphere. In addition, water supplies are expected to be affected as the amount of water contributed by each lake basin to the overall hydrologic system will be decreased by 23% to 50%, with consequent decreases in average lake levels from 0.5 to 2 m, depending on the general circulation model used. It is in this framework that the GLBAC (2010) organized and produced its diagnostic analysis of the current and future uses of, and needs for, New York's Great Lakes basin (Figure 2).

The GLBAC's Report

In 2008, the states and provinces that make up the Great Lakes basin signed the Great Lakes–St. Lawrence River Basin Sustainable Water Resource Agreement, a good-faith agreement among member states and provinces establishing rules, procedures, and standards for managing new and increased water withdrawals, diversions, and consumptive uses. The agreement includes measures to prohibit diversions from the Great Lakes basin with specific exceptions; requirements for water conservation and efficient-use programs; in-basin water withdrawal management or regulation programs; and enhanced science, enforcement, public involvement, and consultation with the Tribes and First Nations. The compact outlines the actions and procedures included in the agreement, giving the states and provinces clearly defined roles and responsibilities. The GLBAC was tasked by the New York State Governor's Office with preparing a plan for implementation of the compact in New York, as laid out in the agreement. The purpose of the GLBAC's report was to create an enforceable document through which to stimulate new dialogue within the state about managing New York State's water resources in light of the growing need for renewable energy and threats from climate change and to guarantee sustainable resources and a healthy ecosystem for future generations. The GLBAC used scientific research in the region to better evaluate water usage, threshold levels, and social and economic need and to provide legislative recommendations.

Below, we outline the major issues addressed in the GLBAC report: establishing a baseline water use level, monitoring water use, establishing threshold levels, and developing efficiency and conservation programming. As the GLBAC discovered while preparing management recommendations for New York's Great Lakes basin, the tasks involved in understanding a watershed of this size are self-reinforcing, each one demanding the next.

Establishing a Baseline

The first and most fundamental challenge the GLBAC encountered was the difficulty in determining a baseline (an appropriate level of daily use in the basin) for withdrawals, diversions, and consumptive uses. This baseline is intended to inform regulations on the level of use based on what each facility (e.g., public water supply and industrial facilities) actually uses compared to what it is permitted to withdraw. To do this, the GLBAC, together with the New York State Department of Health and Department of Environmental Conservation, needed to compile an accurate and comprehensive list of all currently permitted withdrawals, presenting the capacity of the existing systems in terms of withdrawal capacity, treatment capacity, distribution capacity, or other capacity-limiting factors. Table 1 shows the number of facilities permitted to withdraw at least 379,000 liters (100,000 gallons) per day.

This compilation of permitted withdrawals required the coordination of all water users from all systems: more than 10,000 public drinking water, industrial, energy, and agricultural users, including those with permitted withdrawals of less than 379,000 liters (100,000 gallons) per day. The GLBAC needed information about each use throughout the recorded history of each water withdrawal site, including the Erie Canal and Lake Champlain Canal, where withdrawals have occurred for more than a century and have never been metered. Compounding the complexity, the baseline had to accommodate potential future increases in withdrawals. Such a task demands a cooperative effort on the part of all water users in the basin to ensure accurate projections.

Monitoring Water Use

To determine the levels of consumptive use, New York State must be able to monitor water use and track that information over time. The State has no statutory authority governing overall water resource withdrawals; thus, neither scientific research nor environmental monitoring activities exist on a statewide or basin-wide scale outside of several highly localized and specialized situations. Historically, the US Geological Survey (USGS) has assessed the groundwater supplies and surface flows using more than 125 gauging stations throughout the state. USGS provides this information to generate a series of monthly reports on New York State's water conditions, including the capacity of several key lakes and reservoirs. With changing federal budgetary priorities, the future status of many of the gauging stations is uncertain.

The GLBAC recommended that the State work with local governments, nongovernmental organizations, research institutions, and federal agencies to effectively monitor water usage in the Great Lakes basin as this information is critical for calculating water supply budgets, determining appropriate water withdrawal levels, and implementing effective conservation measures. Beyond monitoring data, the report also recommends making science-based development and withdrawal decisions that account for watershed health and the cumulative effects of withdrawals and waste and stormwater discharges.

Table 1. The number of registrants and public water supplies with approvals to withdraw more than 379,000 liters (100,000 gallons) per day in the Great Lakes basin through the Public Water Supply Permit Program (PWSPP) and the Great Lakes Water Withdrawal Registration Program (GLWWRP) as of 2008.

	Number of Facilities	Water Use (mld)	Maximum Capacity (mld)
PWSPP	245	2,737 (724 mgd)	4,283 (1,133 mgd)
GLWWRP	100	14,307 (3,785 mgd)	21,727 (5,748 mgd)

Note: mld, millions of liters per day; mgd, millions of gallons per day.
Source: Data courtesy of the New York State Department of Health.

Establishing Threshold Levels

The GLBAC also examined water threshold levels—the minimum amount of withdrawal for consumptive use that would trigger the management and regulation requirements of the compact. Prior to the compact, each state and province had its own threshold level ranging from 38,000 to 19 million liters (10,000 to 5 million gallons) per day. This created uncertainty about how much water was being withdrawn from the basin and, likewise, the volume of water that had to be returned to the basin to support that level of usage. The compact stipulates that amounts greater than 379,000 liters (100,000 gallons) per day over a 30-day period require regulation. Withdrawals below that amount would, depending on existing state and provincial requirements, require withdrawal registrations and/or an effort to achieve reasonable water efficiency through environmentally sound and economically feasible conservation measures.

Because of a lack of comprehensive baseline and monitoring data, and in response to comments received during a public comment period, the GLBAC recommended a provisionary threshold of 379,000 liters (100,000 gallons) per day, in accordance with compact specifications.

Developing Efficiency and Conservation Programming

Perhaps the most pertinent part of the report for water facility operators and municipal leaders were the GLBAC's recommendations to introduce legislation mandating water efficiency and conservation programs. The GLBAC recognized that many (if not most) water systems in New York State function with antiquated or overstressed equipment and/or lack efficiency training and measures. The efficiency recommendations in the GLBAC's report include checking for leaks (even small leaks can waste hundreds or thousands of liters of water per day), reducing the pressure in the distribution system to lessen the stress on existing infrastructure, targeting residential consumers with retrofits and water conservation education (one leaking residential sink can waste more than 70 liters (20 gallons) of water per day, reducing outdoor water use (which accounts for 25% of total urban usage according to the GLBAC), and setting water prices to reflect actual costs of service.

To underscore the need for conservation measures, the GLBAC included information from a survey (Lameka 2004) of public water supply systems throughout the Great Lakes basin for factors such as the linkage among water conservation, water quality, and ecosystem health and the importance of education and financial incentives. The survey, which provides a snapshot of the current state of water conservation practices in the public water supply sector in the Great Lakes region, found that most municipal systems in the basin focus their conservation efforts on meter calibration and replacement and leak detection and repair (Lameka 2004). But, most crucially, the survey found that "more than half (65%) of the facilities who responded do not operate under any formal conservation plan" and that "less than half the facilities provide any sort of education programs (48%)" (Lameka 2004, 31).

The GLBAC recommended that the New York State Departments Health and Environmental Conservation allocate funds, through its water permitting system, to help facilities offset the expense of incorporating the external costs for water delivery (e.g., education, retrofitting, regular testing, and long-term prediction). The GLBAC also recommended that water suppliers seek alternative sources of funding for operations, create intermunicipal agreements to share conservation education expenses, and implement green infrastructure technologies and smart growth planning to reduce water system stresses.

Discussion

The GLBAC (2010) report stressed the need to compile a complete data set to understand the complexities of the Great Lakes basin and its subwatersheds. To do this, the State needs to fund additional research that will provide the data necessary to set an appropriate baseline. Without a clear and accurate baseline, it will be impossible to set an appropriate regulatory threshold. Monitoring is key, especially considering that state and federal monitoring, mainly through USGS, is inadequate and that climate change can increase the variability in, or decrease the predictability of, the quantity of water in watersheds used for public water supply withdrawals. Although its report (GLBAC 2010) makes this clear, the GLBAC is largely powerless to do more than make recommendations to the New York State Department of Environmental Conservation (NYSDEC), which itself has limited capacity to take on these tasks. It could soon be up to the individual public water supply facility to conduct their own monitoring of water sources to be able to consistently provide water services; conservation measures would then also be a tool to ensure the sustainability of any water supply. With these information gaps filled, water managers should then begin extending their typical timelines and begin to manage for long-term sustainability. Municipal water suppliers might currently be considered well-prepared if they have planned one year in advance, but with the potential effects of climate change (e.g., displaced populations, reduced water sources, and drier weather) adding to the current stresses in municipal water operations (antiquated infrastructure, declining tax bases, and aging operator populations), it seems prudent to be well-suited to deal with major long-term changes. Water managers must modify their decision-making timeframes to reconcile the daily and annual issues of water supply operators (e.g., Will the drought continue? Will the municipal board pass a much-needed rate increase? Are we in regulatory compliance?) and the decadal and longer time frames over which watershed health may be impacted by a changing climate.

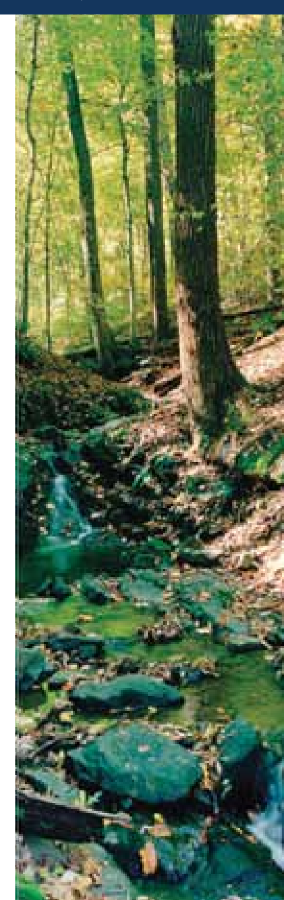
Further research by federal, state, and municipal water boards is needed to understand the intricate workings of the watershed, how much water is used by the inhabitants of the basin, how much water is returned to the basin (naturally or through municipal systems), how much can be withdrawn sustainably from the watershed, how the watershed is predicted to react to increased use, and, finally, how it could react to a changing climate. These all impact not only the watershed but its users. To plan for the future, the current state of the watershed must be well-understood by addressing the above issues.

To facilitate a more long-term look at watershed services, the scientific community and applicable agencies (NYSDEC and the New York State Department of Health, in particular) need to ensure that municipal leaders and engineers receive accurate projections and data with which to make more informed decisions. The daily operations of a water system (and the knowledge base of its operators) need to reflect the potential future complications that every watershed could face as a result of global climate change.

Conservation and education measures are key actions that will help ease the strain on current water systems to prepare for potential future stresses. Education must start with the operator, then the municipal leader (the mayor or supervisor) and the associated board. Many town, city, and village boards need to better understand the cost implications of current water pricing structures to ensure that they can make effective decisions to maintain municipal services at a sustainable level. This can then provide the general public with an appropriate funding structure for education and conservation measures. Often, conservation measures need to be incentivized through service fee discounts or other mechanisms. Incentives provided to water uses may allow for increased system capacity through the resulting conservation measures; this could allow water system operators to potentially create excess capacity to account for greater variability in the quantity of water in current sources.

The GLBAC (2010) report stresses the importance of such conservation and education measures and provides a few examples of how best to do this. Unfortunately, education, which may very well be the key to a successful and sustainable municipal water system, is currently undervalued.

Implementation of the GLBAC's recommendations is integral to the sustainable management of the Great Lakes. Regional, interstate, and international partnerships must be recognized and given the authority to present lawmaker's recommendations that should not only be legislated, but also enforced. This becomes an increasing challenge as rising staff and funding cuts in state agencies make the enforcement of legislative mandates, such as those recommended by the GLBAC (2010) report, seem less realistic. In fact, the greater variability in water supply that climate change may bring will mean that some watersheds within the Great Lakes basin may need to adhere to more stringent withdrawal standards; the GLBAC (2010) report falls short of recommending a more flexible regulatory mechanism to provide for more localized (and more stringent) threshold levels. Defining sustainable water withdrawal to meet current and future demands is the basis for creating this flexibility (e.g., what is good for Buffalo and its watershed may not be good for the



Adirondacks). The interconnectivity of watersheds demands a new management matrix that (1) is based on the complexity of each water system, (2) includes triggers to allow for a tiered threshold system, and (3) allows localized watersheds to adapt to withdrawal pressures (or the lack thereof).

Conclusion

The compact and, by extension, the GLBAC (2010) report, set the groundwork for future sustainability for our water systems. The GLBAC's (2010) research-based recommendations, once adopted into law, can move New York and the rest of the Great Lakes states and provinces well into the future in terms of planning for climate change. However, the GLBAC (2010) report itself is only the beginning. It will take an informed decision on the part of state lawmakers to legislate these recommendations and an even more politically savvy legislature to provide the resources necessary to enforce the recommendations. Much of the success of the compact will hinge on political will and public participation.

REFERENCES

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof. 2008. Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change. Paper presented at the 28th session of the Intergovernmental Panel on Climate Change, Budapest.

Great Lakes Basin Advisory Council (GLBAC). 2010. Our Great Lakes water resources: Conserving and protecting our water today for use tomorrow. August.

Great Lakes Commission. n.d.. The Great Lakes basin compact. http://www.glc.org/about/glbc.html

Lameka, P. 2004. Briefing Paper: Summary of current water conservation practices in the public water supply sector of the Great Lakes-St. Lawrence Basin. Environment Canada, Downsview, Ontario, 21pp.

Mortsch, A., and J. D. Scheraga. 2003. Climate change and water quality in the Great Lakes region: Risks, opportunities, and resources. A report prepared for the Great Lakes Water Quality Board of the International Joint Commission. Washington, DC: International Joint Commission.

US Environmental Protection Agency. 2008. National Water Program strategy: Response to climate change. EPA 800-R-08-001. Washington, DC: US Environmental Protection Agency.

Increased Streamflow in Agricultural Watersheds of the Midwest: Implications for Management

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Abstract

Traditionally, flows that did not cause flooding were thought to be inconsequential for agricultural watershed management. However, flow volume plays an important role in flow duration and Total Maximum Daily Loads (TMDLs), particularly for nitrate-nitrogen. Prolonged below-bankfull flows may also increase bank saturation and the frequency of mass wasting, leading to increased sediment and phosphorous loading and reduced index of biotic integrity scores. Low, mean, and high flows below the bankfull elevation have increased in many upper midwestern watersheds in the past 30 years, although large floods have not increased significantly at most of our study sites. Using the indicators of hydrologic alteration suite of statistical metrics, we found that streamflow has increased in agricultural watersheds (> 67% agricultural land use) in annual mean flow, most monthly median values, and many flow duration metrics during the 1980–2009 time period compared to 1940–1979. As a percentage, flow has increased most in December and least in August through October. At the same time, the streamflow-to-precipitation (Q:P) ratio has increased in the past three decades compared to the previous several decades. The overall change in Q:P, the timing of increased flow, and the reduced streamflow variability, as measured by the coefficient of variation, suggest a mechanism of subsurface tile flow and/or increased groundwater flow. Management actions are needed in agricultural watersheds of the Upper Midwest to reduce water volume as well as peak flow to meet TMDL requirements.

Introduction

Extreme high and low flows have been the primary focus of watershed management, particularly from the water resources engineering perspective (Mays 2001). Global circulation models (GCMs) for climate change predict that extreme events and flow variability will increase, making them even more important from a management perspective. Both floods and extreme low flows have clear consequences for humans and for aquatic biota. Consequently, management approaches for addressing these problems are well established in the field of watershed management (Mays 2001; Brooks et al. 2003).

In contrast, the watershed management field has not made a widespread effort to manage flows below the bankfull level in agricultural watersheds because many in the field believe that their impacts are minimal. Nevertheless, increased low and mean flows have occurred recently in many upper midwestern watersheds concurrently with climatic and land use changes. Despite the lack of management, less-than-flood-level flows are important because they increase the duration of high flow, adding to the cumulative transport of sediment and nutrients and increasing annual loads (Cleland 2002). This has crucial implications for total maximum daily loads (TMDLs) and nutrient management issues. For example, the Gulf of Mexico hypoxia problem is primarily caused by excess nitrates—a pollutant carried in dissolved form (Goolsby et al. 2000). The cumulative loading of dissolved substances in the Mississippi River is directly related to the amount of streamflow (Donner et al. 2004; Raymond et al. 2008). Streamflow volume increases have become an issue in urban stormwater management (Minnesota Pollution Control Agency [MPCA] 2005) and are being addressed with infiltration practices in some areas.

Increased flows below the bankfull level also may have important impacts on stream ecology and channel stability (Richter et al. 1996). Sediment and particulate phosphorus loading may increase from prolonged flow duration since bank failure events tend to occur more frequently following saturation of streambanks, when stability conditions are at their lowest (Thorne 1999). Therefore increased streamflow levels will tend to promote more frequent mass wasting events, even below bankfull events.

The Minnesota River Basin (MRB), a focal area for this research, illustrates how watershed response to climate change may not fit preconceived notions based on generic GCM predictions. Watersheds in different regions respond variably to climate changes because runoff and other hydrologic processes are mediated through the unique combinations of the existing land cover, geology, and surface and subsurface drainage networks.

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Methods

We used two complementary statistical approaches to analyze streamflow trends and changes to watershed hydrologic processes in the upper midwestern states, focusing around Minnesota (Figure 1). The indicators of hydrologic alteration (IHA) test for changes in streamflow that may be of ecological importance by comparing two periods of time—before and after a chosen impact, alteration, or climatic change (Richter et al. 1996). In this study, we completed an IHA analysis at 18 watersheds to compare the time periods 1940–1979 and 1980–2009. These time periods capture the longest period of streamflow conditions that are desirable when assessing hydrologic alteration from anthropogenic sources available starting after the Dust Bowl, a period of anomalously low precipitation (Schubert et al. 2004). Of the 16 sites, 13 had stream discharge records dating back to 1940, and three sites (Bois Brule, Sturgeon, and Pigeon) were missing several years from the early 1940s. We conducted significance testing using a boot strapping–like approach whereby the data are reshuffled many times to create a larger population by which to assess significance at the 0.05% level.

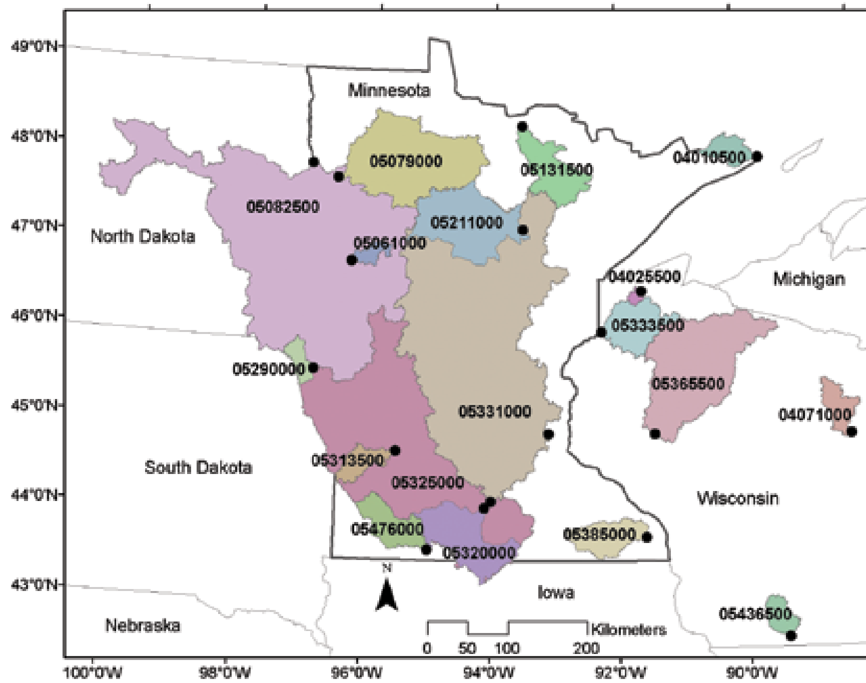

Figure 1. Location of US Geological Survey gauging stations and their corresponding watershed drainage areas included in the indicators of hydrologic alteration and streamflow-to-precipitation ratio analyses.

We analyzed the streamflow-to-precipitation (Q:P) ratio, that describes the percentage of streamflow resulting from precipitation, in more detail on a data subset consisting of the four watersheds located within the MRB. We hypothesized that the Q:P ratio would be indicative of a change in hydrologic process, not just climatic variation. An increase in the Q:P ratio from land use change indicates human alteration rather than climate changes. If a watershed experiences increased streamflow without a concurrent increase in rainfall, clearly some change in land use, drainage, or water withdrawal has altered the Q:P ratio. Both rainfall and runoff are subject to widely varying climatic fluctuations.

We selected the MRB because large changes in streamflow have occurred there, contributing to increased nutrient and sediment loading to the Mississippi River. We selected four watersheds with varying drainage areas located within the MRB based on the availability of long-term streamflow data. We calculated Q:P ratios for these watersheds using mean annual discharge (Q) and precipitation (P) values. We obtained discharge data through the Surface Data for Minnesota website of the US Geological Survey (USGS n.d.). We obtained precipitation data for the climate divisions overlapping the MRB watersheds through the Western Regional Climate Center (n.d.). To address watersheds that overlap several climate divisions, we calculated mean monthly and annual precipitation using the Thiessen polygon method. We then converted precipitation and streamflow to volumes using the watershed drainage area to obtain a Q:P ratio.

To identify whether Q:P ratios have changed over time, we calculated ratios using seasonal (lumped three-month time periods) and annual data. To eliminate any discharge data gaps and to keep relatively consistent time intervals, the two data periods used in the Q:P analysis were 1950–1979 and 1980–2008. We completed the seasonal and annual analyses using a Mann–Whitney nonparametric test of significance to determine if the two time periods have the same distribution of Q:P ratios. We defined seasons as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November).

We examined the response of upper midwestern watersheds to recent climate change in the form of precipitation increases to better understand potential future responses to climate change, assuming that the hydrologic processes at work will be the same in the future, although possibly varying in scale. We used Minnesota's ecoregion divisions to assess the relative response of different regions to climate change and to identify hydrologic management issues specific to streams in those regions. In particular, we examined in more detail the management consequences for large increases in the Q:P ratio experienced in the southern agricultural watersheds, focusing on the control of streamflow volume in these watersheds. We also briefly examined summer low flow in streams along the north shore of Lake Superior in the northern forested region.

Findings

Mean annual flows have increased in most of the MRB and Red River basin streams as well as in the Des Moines, Sugar, and Root Rivers—specifically, in all watersheds dominated by agricultural land cover (Table 1). Mean annual flow either decreased or did not increase significantly in each of the northern Minnesota and Wisconsin watersheds with more than 67% forest land cover.

Median monthly flows have increased in most months in watersheds with > 67% agricultural land cover (Table 1). The months with the lowest percentage increase were April

Table 1. Summary data for the IHA analysis of 16 watersheds in Minnesota, Wisconsin, and the eastern Dakotas. Flow in the 1980–2009 time period is compared to that of the 1940–1979 time period by the percentage (%) change in the magnitude or number of months with significant change.

Station Location	USGS Gauging Station #	Predominant Land Use Category (%)	Change in Mean Annual Flow (%)	Change in Coefficient of Variation (%)	Months with a Significant Median Monthly Change (% of 12 Months)	Months with a Significant Low-Flow Change (% of 12 Months)
Blue Earth River at Mankato, MN	05320000	> 67 ag	73	–29	83	42
Bois Brule at Brule, WI	04025500	> 67 forest	–2	–13	92	17
Buffalo River at Hawley, MN	05061000	mixed	42	–7	67	67
Chippewa River at Chippewa Falls, WI	05365500	> 67 forest	–7	5	8	–42
Des Moines at Jackson, MN	05476000	> 67 ag	100	–26	83	50
Little Fork River at Little Fork, MN	51315000	> 67 forest	–8	–14	42	42
Little Minnesota River at Peever, SD	05290000	> 67 ag	27	–33	100	100
Minnesota River at Mankato, MN	05325000	> 67 ag	75	–23	92	75
Mississippi River at St. Paul, MN	05331000	mixed	31	–11	50	33
Mississippi at Grand Rapids, MN	05211000	> 67 forest	4	–7	0	0
Oconto River at Gillett, WI	04071000	> 67forest	–9	–11	0	8
Pigeon River at Grand Portage, MN	04010500	> 67 forest	–9	–13	33	33
Red River at Grand Forks, ND	05082500	> 67 ag	56	–10	75	33
Red Lake River at Crookston, MN	05079000	> 67 ag	6	–6	17	8
Root River near Houston, MN	05385000	mixed	57	–36	100	83
St. Croix River at Grantsburg, WI	05333500	> 67 forest	–6	–7	0	0
Sugar River at Brodhead, WI	05436500	> 67 ag	29	–32	92	100
Yellow Medicine River at Granite Falls, MN	05313500	> 67 ag	77	–38	92	58

and August to October; (Figure 2). Low flows increased in 42%–100% of months in streams within the MRB, as well as the Des Moines, Root, and the Buffalo Rivers (the latter is a Red River tributary). In contrast, the northern forested watersheds had low-flow increases in the winter months, but total annual streamflow volume, as indicated by mean annual flow, actually decreased in most cases. The cause of low-flow increases in northern forested watersheds of the Midwest is not well understood. It may be related to warmer temperatures at the beginning and end of the winter season reducing the frozen period (Johnson and Stefan 2006). As a consequence of earlier snowmelt, streamflow in the late spring and summer may be reduced as the timing of streamflow has shifted. Low flows have negative impacts on recreational fishing in streams along the North Shore of Lake Superior, such as the Pigeon River (USGS gauging station 04010500). Streamflow variability, measured by the coefficient of variation, decreased in 15 of 16 streams during the current time period.

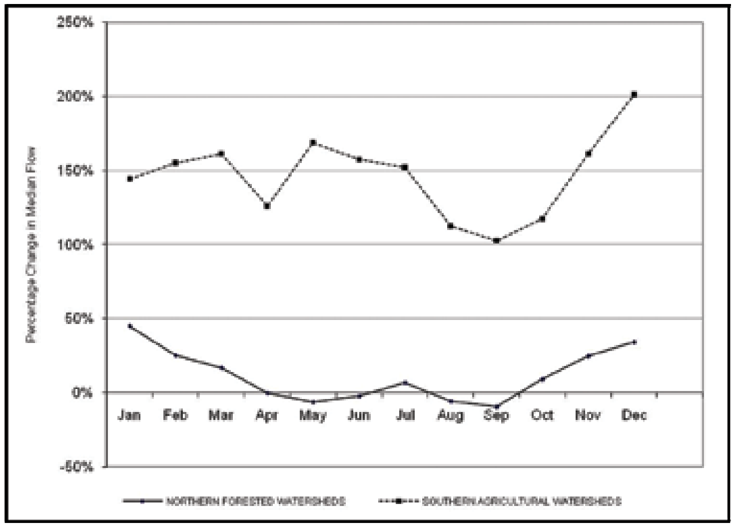

Figure 2. Median monthly flow increases by percentage change during 1980–2009 vs. 1940–1979 in the northern forested watersheds (> 67% forest cover) and the southern and western agricultural watersheds (> 67% agricultural land cover). Each value is an average from all watersheds in Table 1 in each land cover category.

Results of the Mann–Whitney test indicate that the annual Q:P ratios significantly increased in three of the four MRB watersheds from 1950–1979 to 1980–2008 (Table 2). Little Minnesota River near Peever, South Dakota (USGS gauging station 5290000), is the smallest of the four watersheds and also had missing streamflow data during 1982–1989 and after 2003.

Seasonal results of the Mann–Whitney analysis indicated that Q:P ratios in three of the four MRB watersheds significantly increased (p-value < 0.05) from 1950–1979 to 1980–2008 in spring, fall, and winter (Table 3). Summer was the only season without a significant difference in any of the Q:P ratios between time intervals. Minnesota River at Mankato, Minnesota (5325000), had significant differences only in fall and winter.

Table 2. Minnesota River basin annual Q:P ratios for the 1950–1979 and 1980–2008 time intervals.

USGS Gauging Station	Mean Annual Discharge (m^3 $second^{-1}$)		Mean Annual Precipitation (cm $year^{-1}$)		Annual Q:P		p-value[a]
	1950–1979	1980–2008	1950–1979	1980–2008	1950–1979	1980–2008	
5290000	1.2	2.0	49.9	57.6	0.06	0.09	0.170
5313500	3.4	5.6	63.1	68.9	0.10	0.15	**0.037**
5320000	22.8	40.8	72.5	81.2	0.15	0.25	**0.005**
5325000	90.7	158.4	64.6	70.7	0.11	0.18	**0.002**

[a] p-values in bold were considered significant at a maximum 0.05 level resulting from a Mann–Whitney nonparametric analysis of annual Q:P ratios.

Table 3. Minnesota River basin seasonal Q:P ratios for the 1950–1979 and 1980–2008 time intervals.

USGS Gauging Station	Analysis Period	Seasonal Q:P Ratio				p-value[a]			
		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
5290000	1950–1979	0.31	0.02	0.01	0.02	**0.031**	0.588	**0.050**	**0.007**
	1980–2008	0.41	0.05	0.09	0.08				
5313500	1950–1979	0.31	0.06	0.04	0.06	**0.034**	0.200	**0.005**	**0.007**
	1980–2008	0.37	0.10	0.14	0.24				
5320000	1950–1979	1.17	0.41	0.52	0.44	**0.040**	0.077	**0.000**	**0.003**
	1980–2008	1.79	0.69	1.01	1.14				
5325000	1950–1979	0.27	0.08	0.10	0.10	0.075	0.053	**0.001**	**0.004**
	1980–2008	0.36	0.13	0.19	0.26				

[a] p-values in bold were considered significant at a maximum 0.05 level resulting from a Mann–Whitney nonparametric analysis of seasonal Q:P ratios.

Discussion

In streams within the Upper Midwest, flows ranging from low to moderately high (but below the bankfull flow) have increased, yet large floods (greater than ten-year flood) did not increase significantly during the 1980–2009 time period despite significantly more annual precipitation in most watersheds, with the IHA methodology. In the MRB, our results indicate that Q:P ratios are increasing and contributing to greater flow volumes, particularly during late fall and winter. Evapotranspiration is highest during the summer months, which may explain why Q:P ratios did not increase significantly between June and August (Table 3). Though annual precipitation has increased across southern and western Minnesota, this, alone, could not account for the 70% average annual streamflow increase that occurred in the MRB rivers. Much larger precipitation increases would be required to produce such large streamflow increases.

The discharge could have increased as a result of an increase in baseflow or runoff from storm flow. The greatest percentage of flow increase occurred during months that are typically baseflow periods, suggesting that the mechanism for increased flow was some combination of increased subsurface tile drainage and groundwater flow that altered the pathway by which water is delivered to streams (Schilling and Libra 2003; Schilling et al. 2008). In the MRB, the use of tile drainage, which increases baseflow (Fore 2010) has risen drastically since the 1980s. However, tile drainage is not yet prevalent in the Dakotas; this may explain why, although Little Minnesota River near Peever, South Dakota (USGS gauging station 5290000), is in the MRB, the change in the annual Q:P ratio was not significant (Sugg 2007). In Minnesota, streamflow is typically lowest in February and can, therefore, be used as a proxy for baseflow since minimal surface runoff contributes to the total discharge (Ruhl et al. 2002). Although winter precipitation has decreased and mean maximum temperatures remain below freezing, mean February streamflow in the 1980–2008 time interval has increased in each of the MRB watersheds by an average of 170% compared to the 1950–1979 time period.

The MRB demonstrates the interactive effects of land use and climate change. Land use and drainage changes in the past 30 years have increased low to moderately high flows, but not the large floods as predicted in many climate change scenarios, creating a different set of management issues. There is now a need for streamflow volume control practices in upper midwestern watersheds, particularly to reduce loads of nitrate and other dissolved pollutants carried in tile and groundwater flow. In addition to improved nutrient management, these practices will be critical for addressing the Gulf of Mexico hypoxia problem and will require management strategies that differ from those used for volume control in urban areas (MPCA 2005).

The use of perennial crops and native plants that transpire more water can help reduce water yield. Although large land cover changes would require major shifts in policy, incremental changes are possible (Jordan and Warner 2010). March to June is a particularly critical time period in upper midwestern watersheds because the highest streamflow and Q:P ratio occurs at this time. Snowmelt runoff, combined with the increased runoff from relatively bare fields that occurs early in the growing season, leads to greater streamflow in April. The fall months, which experience the greatest increase in Q:P ratio (Table 3), are another critical time period for the reduction of excess water, sediment, and nutrients.

Increased hydrologic storage through the restoration of lakes and wetlands could help reduce flow and nitrate loading (Leach and Magner 1992). Wetlands in the MRB are thought to be particularly effective at reducing small, frequent floods (with less than a two-year recurrence interval), as the largest floods tend to fill all available storage capacity (Miller 1999). To reduce spring outflow from subsurface drainage, controlled or conservation drainage is another tool that may be used to reduce streamflow volume when drainage is not needed for crop growth, particularly during the high-flow season of March to May (Cooke et al. 2008). The technique may apply to surface ditches as well as subsurface pipes.

The hydrologic response of the northern forested regions to slight precipitation increases contrasted sharply with southern agricultural watersheds…

Lower flows have been considered inconsequential to sediment transport and streambank erosion, since floods in the one- to two-year recurrence range are thought to do most of the work in moving sediment and forming channels (Leopold et al. 1964). Yet increased flow durations lead to a greater frequency of mass wasting by prolonging the duration of moderate flows that partially saturate the streambanks and increase the rate of streambank collapse. For example, Odgaard (1987) found that mean daily flow levels at only one-third of the bankfull discharge or higher were related to bank erosion events.

Unfortunately, it is much more difficult to manage increased bank erosion on a large watershed scale because of the time, cost, and labor-intensive nature of most streambank erosion reduction projects. It would be possible to target channel areas producing the most sediment, but in the long-term, the reduction of water yield via watershed management may be the most sustainable solution.

The hydrologic response of the northern forested regions to slight precipitation increases contrasted sharply with southern agricultural watersheds, highlighting the importance of land use and drainage changes for streamflow response in these regions. In northern forested streams, increased winter streamflow and earlier snowmelt runoff may lead to reduced flow later in the summer, creating higher temperatures that are detrimental to numerous fish species. This is likely to be important in northern Minnesota and Wisconsin for recreational fishing in areas such as the north shore of Lake Superior, where sport fishing is a big part of the tourist industry.

Conclusion

The dissimilar response of the southern agricultural watersheds (exemplified by the MRB case study) compared to northern forested watersheds provides insight into the hydrologic processes responsible for streamflow change and related management issues. By examining the hydrologic response to recent climate changes, this analysis provides clues as to how different regions of the Upper Midwest may respond to future climate changes. Future hydrologic responses are being simulated through hydrologic modeling work currently underway. Still, it is unclear whether flows in the Minnesota and Red River basins will continue to increase in upcoming decades or will taper off with the increasingly higher temperatures and greater evaporation predicted by GCMs. Currently, flow volumes and Q:P ratios are increasing at a rate disproportionate to that of precipitation alone in watersheds exhibiting a large expansion of tile drainage in recent decades.. These hydrologic changes represent a management challenge because they have not been perceived as a management issue in the past. It will be necessary to reduce water, nutrient, and sediment yields for TMDLs in many upper midwestern agricultural watersheds for the foreseeable future using some of the management practices discussed in this paper.

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REFERENCES

Brooks, K. N., P. F. Folliott, H. M. Gregersen, and L. F. DeBano. 2003. Hydrology and the management of watersheds. 3rd ed. Ames, IA: Iowa State University Press.

Cleland, B. 2002. TMDL development from the "bottom up"—Part II: Using duration curves to connect the pieces. Proceedings of the Water Environment Federation, National TMDL Science and Policy 2002: 687–697.

Cooke, R. A., G. R. Sands, and. L. C. Brown. 2008. Drainage water management: A practice for reducing nitrate loads from subsurface drainage systems. In Final Report: Gulf hypoxia and local water quality concerns workshop, Upper Mississippi River Sub-basin Hypoxia Nutrient Committee, 19–28. St. Joseph, MI: American Society of Agricultural and Biological Engineers.

Donner, S. D., M. T. Coe, J. D. Lenters, T. E. Twine, and J. A. Foley. 2004. Modeling the impact of hydrological changes on nitrate transport in the Mississippi River basin from 1955 to 1994. Global Biogeochemical Cycles 16(3): 1043.

Fore, Z. 2010. Tile drainage: Research results, economics, and where do we go from here. St. Paul, MN: University of Minnesota Extension Service.

Goolsby, D. A., W. A. Battaglin, B. T. Aulenbach, and R. P. Hooper. 2000. Nitrogen flux and sources in the Mississippi River basin. Science of the Total Environment 248:75– 86.

Johnson, S., and H. Stefan. 2006. Indicators of climate warming in Minnesota: Lake ice covers and snowmelt runoff. Climatic Change 75:421–453.

Jordan, N., and K. D. Warner. 2010. Enhancing the multifunctionality of US Agriculture. BioScience 60(1): 60–66.

Leach, J., and J. A. Magner. 1992. Wetland drainage impacts within the Minnesota River basin. Currents III(2): 3–10.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. San Francisco: W. H. Freeman.

Mays, L. W. 2001. Water resources engineering. New York: John Wiley & Sons.

Miller, R. C. 1999. Hydrologic effects of wetland drainage and land use change in a tributary watershed of the Minnesota River basin: A modeling approach. MS thesis, University of Minnesota–Twin Cities.

Minnesota Pollution Control Agency. 2005. Minnesota stormwater manual. St. Paul, MN: Minnesota Pollution Control Agency.

Odgaard, A. J. 1987. Streambank erosion along two rivers in Iowa. Water Resources Research 23:1225–1236.

Raymond, P. A., N. H. Oh, R. E. Turner, and W. Broussard. 2008. Anthropogenically enhanced fluxes of water and carbon from the Mississippi River. Nature 451:449–452.

Richter, B. D., J. V. Baumgartner, J. Powell, and D. P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4): 1163–1174.

Ruhl, J. F., R. Kanivetsky, and B. Shmagin. 2002. Estimates of recharge to unconfined aquifers and leakage to confining aquifers in the seven-county metropolitan area of Minneapolis–St. Paul, Minnesota, United States. Water Resources Investigations Report 02-4092. Reston, VA: US Geological Survey.

Schilling, K. E., M. K. Jha, Y.-K. Zhang, P. W. Gassman, and C. F. Wolter. 2008. Impact of land use and land cover change on the water balance of a large agricultural watershed: Historical effects and future directions. Water Resources Research 44:W00A09.

Schilling, K. E., and R. D. Libra. 2003. Increased baseflow in Iowa over the second half of the 20th century. Journal of the American Water Resources Association 39(4):851–860.

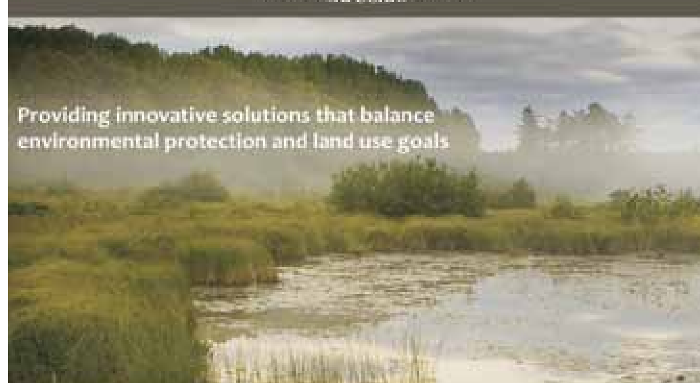
Schubert, S. D, M. J. Suarez, P. J. Pegion, R. D. Koster, and J. T. Bacmeister. 2004. On the cause of the 1930s Dust Bowl. Science 303(5665): 1855–1859.

Sugg, Z. 2007. Assessing US farm drainage: Can GIS lead to better estimates of subsurface drainage extent? Washington, DC: World Research Institute.

Thorne, C. 1999. Bank processes and channel evolution in the incised rivers of North-Central Mississippi. In Incised River Channels, edited by S.E. Darby and A. Simon. John Wiley & Sons Ltd.

US Geological Survey. No date. USGS surface-water data for Minnesota. http://waterdata.usgs.gov/mn/nwis/sw

Western Regional Climate Center. No date. WRCC Climate Division monitoring products. http://www.wrcc.dri.edu/divisional.html



Sea Level Rise Adaptation at the Local Government Level in Virginia

William A. Stiles, Jr.[a]

Abstract

The tidal region of Virginia has the highest rate of sea level rise on the Atlantic Coast, threatening shoreline communities and the tidal ecosystem. Wetlands Watch has worked for nearly four years in this region to initiate local government sea level rise adaptation planning and to see those plans implemented through land use and other regulatory decisions. Early efforts, focused on protecting the tidal ecosystem from climate change impacts, produced insufficient responses. Current work, focused on protecting coastal communities and businesses from an increasing risk of storm surge inundation driven by sea level rise, have proven more effective. The goal of this shift is to use concerns about infrastructure and public safety to stimulate early adaptation work and insert shoreline ecosystem adaptation needs into the process once it has commenced. In the course of this work, Wetlands Watch has catalogued numerous existing, mandated planning efforts at the local and regional levels that serve as effective planning tools for climate change impacts. We are now developing these tools into a toolkit for local government policymakers.

Sea Level Rise Impacts in Virginia

Rates of relative sea level rise in Virginia are the highest along the Atlantic Coast, reaching 0.44 m (1.45 ft) over the last century at the Sewells Point tide gauge in Norfolk (Table 1; Williams et al. 2009). Future projections for rates of sea level rise in the Chesapeake Bay region (Pyke et al. 2008) show a significant increase, with the centennial rate predictions running from a minimum of 0.7 m (2.3 ft) to as much as 1.58 m (5.2 ft) in the coming century.

Table 1. Rates of relative sea level rise along the Atlantic Coast.

Tide Gauge Station	Rate of Sea Level Rise (mm year^{-1})
Portland, ME	2.12 ± 0.09
Boston, MA	2.65 ± 0.1
Providence, RI	2.57 ± 0.17
The Battery, NY	2.77 ± 0.05
Atlantic City, NJ	3.98 ± 0.11
Baltimore, MD	3.12 ± 0.16
Hampton Roads, VA	4.42 ± 0.16
Wilmington, NC	2.22 ± 0.25
Charleston, SC	3.28 ± 0.14
Miami, FL	2.39 ± 0.22

Source: Williams et al. 2009.

In the low-lying areas of Virginia's tidal region, these current and projected rates of sea level rise threaten natural ecosystems and developed areas alike. In the tidal ecosystem, the projected higher sea levels are expected to cause a range of impacts: a loss of primary coastal dunes to erosion; a loss of existing submerged aquatic vegetation (due to increased water depth, possible decreases in water clarity resulting from algal blooms and sediments, and increases in water temperature); and the inundation of vegetated wetlands in the intertidal zone (Pyke et al. 2008).

Tidal wetlands, if healthy and afforded adequate sediment, can accrete vertically and keep pace with the gradual rates of sea level rise observed over the last century. However, vegetated tidal wetland accretion rates, currently in the range of 3–4 mm year^{-1} in the Chesapeake Bay (Stevenson et al. 1996) will probably not be sufficient to keep pace with the minimum predicted centennial rate of relative sea level rise of around 7 mm year^{-1}.

With rates of sea level rise higher than the ability of the coastal ecosystem to adapt *in situ*, the intertidal zone of the coastal ecosystem will move landward. When this shoreward movement encounters steep slopes, high banks, or hardened shoreline infrastructure, the wetlands will "drown" in place, unable to stay in the intertidal zone as that zone shifts (Titus et al. 1991).

Using the then-expected centennial rate of sea level rise of 60 cm, Wetlands Watch (2007) predicted tidal ecosystem impacts and estimated tidal wetland losses in the next century of 50% to 80%, depending on the type of wetland and on shoreline development and erosion control decisions. This range of estimates was confirmed by two subsequent studies, one by the National Wildlife Federation (2008) and the other by Cahoon et al. (2009).

A recent analysis of future shoreline development and erosion control decisions (Titus et al. 2009, 1) illustrates the threat to shoreline ecosystems along the Atlantic Coast:

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"Almost 60% of the land below 1 m along the US Atlantic coast is expected to be developed and thus unavailable for the inland migration of wetlands. Less than 10% of the land below 1 m has been set aside for conservation."

Developing Local Government Adaptation Strategies

After estimating wetland loss and tidal impacts, Wetlands Watch began work at the local government level in Virginia to initiate sea level adaptation strategy development. Because shoreline development conditions are a major factor in coastal ecosystem loss—with the vast majority of the tidal shoreline in Virginia privately owned[1]—and because local governments control most private property development and erosion control decisions, local governments are central to sea level rise adaptation strategy development.

The main focus of our work was to place conditions on the development and redevelopment of shoreline parcels through the long-range comprehensive planning process required of each locality in Virginia, Code of Virginia (Va Code) § 15.2-2223 (2010). These plans usually have a 20-year horizon and are the logical places to start long-range climate change adaptation planning. In areas of the state with tidal waters, localities are also required to include water quality protection measures, including shoreline setbacks, in their long-range planning and zoning, Va Code § 10.1-2100 (2010). Local governments have additional planning, land use, and regulatory authorities that also may be useful in sea level rise adaptation strategies.

…use of the term climate change generated distracting debates about the source of the change… However, many of these participants accepted the reality of sea level rise…

In 2008, Wetlands Watch secured funding from the National Fish and Wildlife Foundation (NFWF) to explore the development of a shoreline conservation strategy to protect the shoreline ecosystem from climate change impacts. This project involved examining the planning and regulatory tools available to the shoreline locality as well as investigating how to develop a social marketing strategy sufficient to generate public support for climate change adaptation. Staff reviewed available literature on land use planning, zoning, and other authorities placing restrictions on the development of shoreline property. We reviewed state and federal natural resources regulatory authorities and conducted interviews with local government planning staff, as well as local and state regulatory staff, on the potential ability to include climate change impacts in their program decisions.

We undertook a similar process to develop a social marketing strategy, although a literature review revealed few practical examples of social marketing directed at climate change adaptation. General social marketing information provided some guidance and emphasized the need to (1) find issues of concern to the target audience, (2) put the issues into a local context, (3) make the impacts personal and real, and (4) show the immediate impact of the threat and the cost of inaction.

Wetlands Watch staff worked in Mathews County, Virginia (the target locality), as well as in numerous other localities in Virginia's tidal region from 2008 to 2010. Our representatives spoke at numerous public meetings, testified and appeared before government bodies, consulted with local and regional planning staff, and offered comments on government land use and regulatory decisions. The focus of this work was to convince local governments of the need to plan for and act on projected climate change impacts.

We made some progress in the draft long-range land use plan for the target locality, which includes "possible climate changes and rising sea levels" in its comprehensive land use plan (County of Mathews,93). Other localities along Virginia's tidal shoreline have also begun including sea level rise impacts in their long-range land use plans. During this period, the Virginia Commission on Climate Change (2008) developed an outline of a state-level adaptation action plan.

Challenges to Local Government Adaptation Efforts

While these actions represent advances in state and local government public policy awareness, Wetlands Watch observed significant challenges to its initial, narrow focus on protecting the shoreline ecosystem from climate change impacts.

[1] Many federal and Virginia State government documents indicate that 85% of the Chesapeake Bay shoreline is privately owned, although I am not aware of any peer-reviewed documentation for that claim. The percentage of ocean shoreline in Virginia that is privately owned has not been estimated.

First, the use of the term *climate change* generated distracting debates about the source of the change (anthropogenic or natural), its severity and certainty, the scientific basis for it, and a whole suite of issues that were fueled by the national debate over the need for greenhouse gas mitigation efforts. Wetlands Watch staff members encountered this at public information sessions and when they provided presentations across the tidal reaches of Virginia. Participants in these sessions raised issues to counter the evidence of anthropogenic climate change and to deny that climate change was a problem. However, many of these participants accepted the reality of sea level rise and provided anecdotal confirmation of worsening storm surges over time.

Second, staff encountered challenges to moving public policy to better protect wetlands and the coastal ecosystem. According to the Virginia Department of Environmental Quality (2010), the State has yet to meet its commitment for "no net loss" of tidal wetlands, set in state law in 2000, Va Code § 62.1-44.15 (2010). In the 2008 annual report to the Chesapeake Bay Program, Virginia's Secretary of Natural Resources (2008, 13) could not report on the acreage of wetlands restored toward its Chesapeake Bay 2000 Agreement goals because the State does not have a central wetlands tracking database. Given this inability to address conventional threats to Virginia's wetlands, generating government policy and a management response to deal with additional, future threats to the coastal ecosystem proved very difficult.

Finally, while some local government planning documents acknowledge that climate change impacts exist, little concrete action was occurring. An informal survey of local and regional government elected officials and planning staff in Virginia's tidal region contacted by Wetlands Watch could not find a single restriction on development that has occurred solely as a result of climate change and sea level rise impacts. The survey did find that some localities have imposed additional *freeboard*, or elevation of living space above the floodplains in tidal areas, because of concerns over rising sea levels, but development and redevelopment is still allowed with those conditions.

As Wetlands Watch staff reviewed initial approaches to climate change adaptation, we noted that local policymakers and the general public were less concerned about the shoreline ecosystem than more immediate concerns, such as emergency management, economic development, and transportation. Contacts with state, regional, and local government planners also revealed that many of the data needs and policy tools for addressing inundation threats to communities generally were the same needed to address shoreline resilience and adaptation strategies for ecosystem protection: maps with high-resolution vertical accuracy, inundation models with storm surge built in, shoreline evaluations, and the like.

In response, we refined our social marketing approach to focus on the protection of shoreline communities and businesses from the present risk of storm surge inundation occurring along with accelerating rates of sea level rise. This new approach projected the distant, global issue of future climate change onto the present local landscape using images that people could understand: worsening tidal flooding events in their communities. This approach focused on impacts that were measurable and visible, such as new storm surge maps prepared by the map modernization program of the Federal Emergency Management Agency (FEMA) and resulting expansions in mandatory zones for federal flood insurance coverage. It replaced a lower-priority issue of wetlands protection with higher-priority issues of public safety, critical infrastructure protection, and threats to local economies.

Wetlands Watch reasoned that stimulated action along Virginia's tidal shoreline to protect critical infrastructure and personal safety could generate an adaptation response more quickly than with a traditional shoreline ecosystem protection campaign. Once shoreline adaptation strategy planning began, we expected that some of the overlapping data and technical needs could be addressed. As the strategy developed, measures to restrict development along the tidal shoreline would keep the shoreline open and resilient, simultaneously providing tidal shoreline ecosystem benefits. Staff theorized that specific consideration of environmental services and protection of the shoreline ecosystem could be inserted back into the process later, but that an initial emphasis on emergency protection would accelerate the adaptation process.

Broadened Focus for Adaptation Efforts

Starting in mid-2009, Wetlands Watch activities commenced networking with shoreline businesses, local governments (including planning, regulatory, emergency and floodplain management, and economic development staff), public utilities, and economic development organizations in the tidal region of Virginia on the new target of infrastructure protection and public safety. Staff reviewed the legal authorities and requirements for planning among this set of partners, assessing data and technical needs, to identify overlap with those needed for determining sea level rise impacts on the shoreline ecosystem.

Wetlands Watch's work in the early stages of the NFWF planning project focused mainly on land use and natural resources planning and regulatory programs. With our broader focus, staff began to examine other planning programs and documents in the emergency management, transportation infrastructure, and economic development fields. As a result, we discovered a wider array of policy tools with which to begin sea level rise adaptation planning. For example, many federal economic development, transportation infrastructure, and emergency management programs require local and regional governments to engage in long-range planning before federal funds can be obligated. FEMA requires a hazard mitigation plan before a community is eligible for most agency post-disaster mitigation programs (Title 42 United States Code [USC] Section 5165). And the US Department of Commerce requires a comprehensive economic development strategy (CEDS) prior to applying for Economic Development Administration funds (42 USC Section 3162). Periodic updates to these plans present opportunities to discuss local and regional climate change impacts and their emergency management and economic development consequences.

When Wetlands Watch examined some of those plans for localities in Virginia, we discovered that climate change impacts—at least sea level rise and increasing coastal storm surge inundation—were already being included in these planning processes. For example, the Hampton Roads Partnership (2010) produced a regional CEDS that lists sea level rise as a potential threat to the regional economy. And the current hazard mitigation plan for the City of Poquoson (2009), a low-lying city in southeastern Virginia, contained a discussion of the inundation threats driven by sea level rise. Other localities in the tidal regions of Virginia were similarly addressing sea level rise impacts in emergency management and economic development documents.

…we discovered that climate change impacts—at least sea level rise and increasing coastal storm surge inundation—were already being included in these planning processes.

This new social marketing focus allows us to more readily engage nontraditional partners in Wetlands Watch's work, especially those in the private sector. It also enables us to leverage for a broader set of events to drive adaptation work. For example, concerns over financial risk in tidal shoreline communities have caused a withdrawal of private wind and personal property insurance availability. Fleishman (2006) reported on this trend, and Wetlands Watch, through interviews with representatives from insurance providers, has documented the withdrawal of more than 50% of the private insurance market for primary residence and business coverage along Virginia's Atlantic Ocean and Chesapeake Bay shorelines. Efforts to reduce risk along Virginia's tidal shoreline can address the concerns of private insurers and lead to a potential partnership among homeowners and the private sector in Wetlands Watch's refocused work to initiate adaptation planning for storm surge and sea level rise.

In May, 2010, Wetlands Watch held a half-day, mediated workshop with coastal planners at the annual meeting of the Virginia Chapter of the American Planning Association. At that session, we presented our draft toolkit of planning and regulatory authorities identified during the NFWF planning process as useful in sea level rise adaptation and discussed social marketing approaches. Planners at that workshop helped refine the adaptation approaches and tools being used; Wetlands Watch is currently using this information to create a toolkit and social marketing package for use at the local and regional levels in Virginia to promote adaptation to sea level rise. Wetlands Watch will continue to collaborate with this community of planners going forward.

Summary and Next Steps

Adaptation to climate change impacts in coastal Virginia has proven difficult using a traditional natural resources–based approach. Distant impacts, indifference toward ecosystem protection, and conflicts with the present economic goals of local governments and individual landowners conspire to limit the effectiveness of adaptation efforts focused solely on the shoreline ecosystem.

Once such adaptation work is reframed and focused on an immediate impact—such as increasingly serious storm surges—and responses are framed in terms of the protection of public safety, critical infrastructure, and local economies, more support can be gained for early adaptation. Since the early technical needs for any shoreline adaptation effort are similar (e.g., maps with high vertical resolution, modeling of shoreline inundation, and shoreline situation surveys), much of the initial work for shoreline ecosystem adaptation can be accomplished using this approach.

Virginia still lags its neighboring states in supporting sea level rise adaptation efforts. Unlike Maryland and North Carolina, detailed digital elevation maps have yet to be produced, state agencies are not being tasked to support this work, and state political leaders are not visibly promoting adaptation efforts. Unfortunately, efforts to address the federal budget deficit, combined with the end of federal stimulus funding, also threaten to curtail federal support for climate change adaptation work. This increases the importance of efforts by Wetlands Watch and others to work with local governments to find ways to insert sea level rise adaptation planning and action strategies into ongoing local government programs. Wetlands Watch is expanding its collaboration with the community of professional planners in Virginia and is adding floodplain and emergency managers, municipal government organizations, and the private sector to this network of partners.

Our next steps will involve securing foundation funding to develop a pilot sea level rise adaptation strategy in an example community along a reach of tidal shoreline. This effort will test both the toolkit of policy options and our social marketing approaches. Wetlands Watch plans to then use this experience to further refine both tools and social marketing efforts and to replicate its work elsewhere along the tidal shoreline in Virginia.

REFERENCES

Cahoon, D. R., D. J. Reed, A. S. Kolker, M. M. Brinson, J. C. Stevenson, S. Riggs, R. Christian, E. Reyes, C. Voss, and D. Kunz. 2009. Coastal wetland sustainability. In Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. A report by the US Climate Change Science Program and the Subcommittee on Global Change Research, ed. J. G. Titus, 57–72. Washington, DC: US Environmental Protection Agency.

City of Poquoson. 2009. City of Poquoson multihazard mitigation plan. City of Poquoson, VA; Lakewood, CO: AMEC Earth and Environmental, Inc.

County of Mathews. 2010. Mathews County comprehensive plan 2030. County of Mathews, VA.

Fleishman, S. 2006. Sea change in insurers' coastal coverage. The Washington Post, December 30.

Hampton Roads Partnership. 2010. Vision Hampton Roads. Norfolk, VA: Hampton Roads Partnership.

National Wildlife Federation. 2008. Sea level rise and coastal habitats in the Chesapeake Bay region. Reston, VA: National Wildlife Federation.

Pyke, C. R., R. Najjar, M. B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, et al. 2008. Climate change and the Chesapeake Bay: State-of-the-science review and recommendations. Annapolis, MD: Chesapeake Bay Program, Science and Technology Advisory Committee.

Stevenson, J. C., and M. S. Kearney. 1996. Shoreline dynamics on the windward and leeward shores of a large temperate estuary. In Estuarine shores: Evolution, environments, and human alterations, ed. K. F. Nordstoom and T. C. Norman, 233–258. Hoboken, NJ: John Wiley and Sons Ltd.

Titus, J. G., R. A. Park, S. P. Leatherman, J. R. Weggel, M. S. Greene, P. W. Mausel, S. Brown, G. Gaunt, M. Trehan, and G. Yohe. 1991. Greenhouse effect and sea level rise: The cost of holding back the sea. Coastal Management 19:171–204.

Titus, J. G., D. J. Hudgens, D. L. Trescott, M. Craghan, W. H. Nuckols, C. H. Hershner, J. M. Kassakian, et al. 2009. State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic Coast. Environmental Research Letters 4(4): 044008. http://iopscience.iop.org/1748-9326/4/4/044008/

Virginia Commission on Climate Change. 2008. Final report: A climate change action plan. Richmond, VA: Virginia Commission on Climate Change.

Virginia Department of Environmental Quality. 2010. Draft 2010 305(b)/303(d) water quality assessment integrated report. Richmond, VA: Virginia Department of Environmental Quality.

Virginia Secretary of Natural Resources. 2008. Implementation of the Chesapeake Bay 2000 agreement. November. Richmond, VA: Virginia Secretary of Natural Resources.

Wetlands Watch. 2007. Letter to Virginia Governor Tim Kaine. May 31, 2007.

Williams, S. Jefress, B. T. Gutierrez, J. G. Titus, S. G. Gill, D. R. Cahoon, E. R. Thieler, K. E. Anderson, D. FitzGerald, V. Burkett, and J. Samenow. 2009. Sea-level rise and its effects on the coast. In Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. A report by the US Climate Change Science Program and the Subcommittee on Global Change Research, ed. J. G. Titus, 11-24. Washington, DC: US Environmental Protection Agency.

Recommendations for Developing Saltmarsh Buffer Widths as Sea Levels Rise

The Delaware Inland Bays are three shallow coastal lagoons of great recreational and ecological importance to the state and region. Their 777 km^2 (300 mi^2) mixed-use watershed contributes excess nutrients that have eutrophied the 78 km^2 (30 mi^2) estuary (Figure 1). Acting to moderate the effects of this pollution are approximately 4,000 ha (10,000 acres) of saltmarsh that define the boundary between the land and the Bays. Because these signature ecosystems of the estuary are critical to maintaining water quality and aquatic life, their protection is of the highest priority for the Delaware Center for the Inland Bays National Estuary Program (the Center). Now more than ever, meeting the Center's conservation and management plan goal of maximum protection for saltmarshes is dependent on an understanding of marsh response to rising seas.

Figure 1. Aerial photograph of the connection between the Indian River Bay, a temperate coastal lagoon, and the Atlantic Ocean. (Photograph by Chris Bason)

Figure 2. Tidewater inundates a residential lot for sale in a study development during a nor'easter in the Indian River Bay watershed, Delaware. This illustrates that wide buffers can protect homeowners as well as marshes. (Photograph by Chris Bason)

Rising sea levels press marsh boundaries landward over adjacent uplands, while at the same time marsh edges are eroded by wave action to become shallow bay bottom. The net result is the inland migration of a marsh system observable over a human lifetime. Maximizing future marsh acreage under conditions of rising sea level requires unobstructed pathways for saltmarsh migration.

Construction adjacent to marshes can act as a barrier to marsh migration; such construction became increasingly common during the past two decades. From 1992 to 2007, development within the Inland Bays' watershed increased by 67 km^2 (26 mi^2) or 57%, with much construction occurring adjacent to tidal areas.

Recognizing that an existing County wetland buffer ordinance was inadequate and unenforced, the Center developed recommendations for enhanced buffers between marshes and new development. This work was part of a complete set of recommendations for a water quality buffer system submitted for consideration to the State of Delaware in 2008 during the development of the pollution control strategy (PCS) for the Bays. The PCS was designed to reduce nitrogen and phosphorus loads to the Bays from 40% to 85%, in accordance with established total maximum daily load regulations.

The Center's recommendations for saltmarsh buffers were based on research by the University of Delaware's Wendy Carey, who estimated rates of marsh migration by interpreting aerial photography over the period 1944–1989. During this period, the tidal prism of the estuary's inlet to the ocean increased by nearly five times as a result of scouring caused by its earlier stabilization with rock jetties. This created higher high tides at the landward boundary of marshes, which probably added to the effect of regional sea level rise on the landward migration of marshes.

Marsh migration rates varied based on the slope of the adjacent lands, with marshes next to gradually sloping lands (≤ 0.08 rise over run) migrating an average of 1.7 m (5.7 ft) per year, and those next to steeply sloping lands (> 0.08 rise over run) 0.3 m (1.1 ft) per year. The Center converted the rates to the number of years it would take for marshes to migrate across buffers of different widths and slopes (Table 1); the resulting values thus function as simple planning horizons for effective buffers.

Through a GIS-based exercise, the Center evaluated the impact of the recommended buffer widths on randomly selected development project parcels proposed to the State. The percentage of developable land for a project that the most protective saltmarsh buffers encompassed ranged from less than 1% to 64% (Figure 2). This, predictably, was dependent on the amount of saltmarsh in or adjacent to the development and the slope of the uplands adjacent to the marshes.

Overall, the work illustrated (1) the surprising speed at which marsh systems can move across the Mid-Atlantic coastal plain, where rates of sea level rise are relatively high; (2) how buffer widths that maximize pollutant removal in coastal plain freshwater streams (between 24 to 46 m, or 80 to 150 ft) may provide only a few years of protection for many saltmarshes; and (3) that development site design would have to change significantly to accommodate marsh migration for low-elevation sites with gradual slopes.

The results of this analysis were influential in the decision by the State of Delaware to assume regulation of saltmarsh buffers for new major subdivisions under the Inland Bays PCS in 2008. However, the State decided not to define the width of buffers based on the provided migration rates of marshes, but instead included an option intended to offer flexibility for developers whereby they could choose to establish either 100 foot or 50 foot salt marsh buffers dependent on the level of stormwater quality management practices incorporated on the subdivision.

In 2010, researchers at the University of Delaware began a new remote sensing study of marsh change that will include refinement of estimated migration rates by sampling an expanded number of marshes. The study, expected to be completed by 2013, will also examine changes in the rate of marsh change over time (including changes since the previous analysis) and explore potential relationships between marsh migration rates and both climate and development. Historical aerial photography and satellite imagery will be used in the analysis.

List of Sources

Bason, C. W. 2008. Recommendations for an Inland Bays watershed water quality buffer system. Rehoboth Beach, DE: Delaware Center for the Inland Bays.

Brinson, M., R. R. Christian, and L. K. Blum. 1995. Multiple states in the sea-level induced transition from terrestrial forest to estuary. Estuaries 18:648.

Carey, W. L. 1996. Transgression of Delaware's fringing tidal salt marshes: Surficial morphology, subsurface stratigraphy, vertical accretion rates, and geometry of adjacent and antecedent surfaces. PhD diss., University of Delaware.

Weston Environmental Consultants. 1995. The Delaware Inland Bays comprehensive conservation and management plan: Technical appendix. Dover, DE: Delaware Inland Bays Estuary Program.

For More Information

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Table 1. The average number of years it would take for marshes to migrate across buffers of different widths by the slope of the buffer for two of Delaware's Inland Bays. (A gradual slope is defined as ≤ 0.08, and a steep slope is > 0.08). Data are derived from migration rates estimated for the period 1944–1989.

	Rehoboth Bay		Indian River Bay	
Buffer Width m (ft)	Gradual Slope	Steep Slope	Gradual Slope	Steep Slope
15 (50)	10	35	8	61
23 (75)	14	52	12	91
31 (100)	19	69	17	122
61 (200)	38	139	33	244
91 (300)	57	208	49	366
122 (400)	76	278	66	488
152 (500)	95	347	82	610

Adaptive Approaches for Riparian Forest Management To Offset Climate Change Effects

Riparian forest buffers are corridors of trees and other vegetation located landward from the edges of waterways. Despite the many ecosystem benefits and services riparian buffers provide for watersheds, they continue to disappear from the landscape (see box). Although threatened primarily by land use conversion, riparian buffers are also impacted by invasive plant competition, drought, insects, disease, and wildlife damage. Climate change is an added stressor that may exacerbate these threats and may, itself, impact forest buffers.

Maryland's Critical Area Law and Virginia's Chesapeake Bay Act protect existing riparian forest buffers. Even with these efforts, however, it is not clear for most watersheds whether the net forest buffer area has increased. A 2006 study demonstrated that, over eight years, 1.1% to 5.2% of forest buffers area was lost to land use conversions in rapidly developing counties of Maryland, Pennsylvania, and Virginia.

Table 1. Suggested adaptive actions to offset climate change effects on riparian forest buffers.

Projected Climate Change Factors for Mid-Atlantic	Implications for Forest Buffers	Recommended Adaptive Actions and Practices
Increased frequency of floods, sea level rise, and land subsidence	• Increased decline of riparian forest community diversity • Loss of forest edge species undercut by flood surges • Decreased habitat and shoreline stability	• Agencies, local organizations, and industry project managers should use flood-tolerant riparian species. • Waterfront landowners and managers should use natural stabilization techniques to protect shorelines and streambanks. • State and local governments are advised to modify forest buffer ordinances and criteria to extend forest buffer widths and plant farther upstream to protect against flooding and erosion.
Extreme, prolonged drought periods	• Poor growth, development, and survival of young forest buffers • Defoliation and mortality related to reduced soil moisture	Agencies, organizations, and industry project managers are encouraged to: • use healthy and vigorous tree stock of minimum diameter 6.33 mm (0.25 in) and • use root and soil amendments to increase water availability for new plantings.
Increased temperatures	• Species migration to cooler regions • Increased numbers of forest pests • Increased invasive plant species competition	• Agencies, organizations, and industry project managers are encouraged to practice "over-restoration," with a 10% increase in riparian cover to compensate for potential plant losses. • Invasive monitoring and removal should be a key element of riparian forest management plans and policies for riparian landowners and managers. Guidelines are available from Maryland DNR, Division of Forestry. • Federal agencies and research institutions should develop maps of endemic forest infestations by pests, disease, and nonnative plants to facilitate preemptive treatment.

The evaluation of potential risks to riparian forest buffer restoration and protection is limited by the sparse literature available on this topic. Despite the paucity of relevant literature, we found and reviewed 62 articles and reports on climate change and forestry. Based on this review, we developed a set of adaptive actions for the Mid-Atlantic region and introduced them to the Chesapeake Bay Forestry Work Group. The Work Group recognized the actions as appropriate to address future climate change impacts on riparian forest buffers (Table 1).

List of Sources

Okay, J., and T. G. Culbreth. 2010. *Riparian forest buffer management & protection to offset climate change effects. An annotated bibliography*. Prepared for the Chesapeake Bay Forestry Work Group.

For More Information

For more information regarding full citations or to download the entire annotated bibliography, visit the calendar item from the Forestry Work Group meeting on September 1, 2010 at http://archive.chesapeakebay.net/calendar.cfm?eventdetails=10993.

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CAKE: Your Online Climate Adaptation Destination

Many natural resource managers and planners understand the need for climate change adaptation but feel lost or overwhelmed when it comes to actually doing it. Part of the problem is that they often start with a general question, such as "*what are all of the changes that will result from climate change, and how can I respond?*" rather than a more focused question, such as "*what do I do, and how should I adjust that for the reality of climate change?*" Answering the former question leads to a deluge of information that is difficult to organize and prioritize, while answering the latter triggers a more practical and focused response that is related to an organization's mission or an individual's responsibilities. An overarching goal of the online Climate Adaptation Knowledge Exchange (CAKE) is to answer this more focused question by providing a range of adaptation resources and short case studies demonstrating how actual groups are adapting their work to climate change. CAKE was established on the principle that we learn best by sharing and doing.

EcoAdapt is a scientific research and educational 501(c)(3) nonprofit incorporated in the District of Columbia with a goal of bringing together diverse players in the conservation, policy, science, and development communities to reshape conservation and development in response to rapid climate change.

CAKE, a joint project of EcoAdapt and Island Press with initial funding by the Kresge Foundation, aims to build a shared knowledge base for managing natural systems in the face of rapid climate change. Target audiences include natural resource management and conservation professionals, researchers, policymakers, and teachers. It is a free online resource and, while user registration is encouraged to allow fuller participation in the CAKE community, it is not required.

CAKE includes four core components—a virtual library, case studies, a directory, and tools—along with a monthly advice column and resource support pages targeted to individual adaptation workshops. The tools section, which is currently in development, will include web-based mapping, modeling, and visualization programs as well as a range of guidebooks, exercises, curricular material, and more. All case studies and directory entries, as well as many virtual library items, are georeferenced, meaning that users can search by text, map, or a combination of the two. Case studies to date come primarily from EcoAdapt's ongoing survey of adaptation efforts in North America, but anyone can submit case studies. CAKE staff will vet them for completeness and relevance before posting them.

Initial survey funding from the Gordon and Betty Moore Foundation focused on coastal regions; more recent funding from the Wilburforce Foundation has allowed us to expand to western states, territories, and provinces. EcoAdapt seeks to expand coverage and to create targeted collections focused on particular issues, such as adaptive management or watershed-scale adaptation.

One can approach CAKE in a number of ways. A user might do a text or keyword search for a particular climate change impact (e.g., sea level rise or flooding) to see what resources exist or how others have adapted to it. One might also search for a particular management problem (e.g., stormwater management or water quality) or a particular type of tool (e.g., a visualization or runoff tool). A user could use the map function to find local resources—for instance, to help highlight local case studies at a workshop or to find local experts to assist with planning efforts. Another powerful element of CAKE is the inter-linkage among its various components. From a case study page, a user may link to the directory entry of a contact person or organization or to related tools, library items, or even other case studies. Likewise, a particular tool or library item may be linked to case studies, illustrating how to put the tool or other resource into practice.

Visit and explore CAKE at www.cakex.org, and put yourself in the directory or suggest case studies, tools, or library items to add.

For More Information

To learn more, contact Rachel Gregg (Rachel@ecoadapt.org) or Kate Graces (kgraves@islandpress.org) or visit www.cakex.org.

Contributors

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Arizona NEMO Preparing Watershed Communities for Climate Variability with Best Management Practices

The scientific community continues to compile evidence that the climate is changing and that observed and projected future changes will have significant impacts on the ecosystems and natural resources of our communities. The Arizona Nonpoint Education for Municipal Officials (NEMO) program recognizes that the arid Southwest will continue to become warmer and drier; these climate changes will increase the vulnerability of the state's most precious natural resource—water. The Arizona NEMO program has risen to meet this challenge by integrating watershed management and community planning. The NEMO program emphasizes the linkages between water supply and water quality with research-based professional education and encourages community stakeholders to engage in better land use decisions and best management practices (BMPs) tooled from bioengineering techniques that will protect and restore water resources from nonpoint source (NPS) pollution. For the arid Southwest, this community-based resource management technique is adaptive and resilient to environmental changes.

…the arid southwest will continue to become warmer and dryer; these climate changes will increase the vulnerability of the state's most precious natural resource—water.

To enable policymakers and shareholders to address the adverse impacts of climate change (e.g., extreme droughts), NEMO provides education on the characterization and modeling of watershed responses to precipitation and NPS transport. This modeling identifies physical, biological, and social characteristics of a watershed from publicly available mapped information. NEMO then uses ArcGIS (Environmental Systems Research Institute, Inc.) software to construct a spatial database that includes topography, land cover, soil type, geology, vegetation, hydrologic features, and population characteristics.

After developing the GIS database, NEMO staff performs watershed classifications to identify important resources and rank ten-digit hydrologic unit code subwatershed areas based on the likelihood of NPS contribution to stream water quality degradation. NEMO then designs BMPs, including structural, vegetative, and managerial conservation practices. When implemented, the BMPs reduce and prevent the detachment, transport, and delivery of NPS pollution to surface water and groundwater. The choice of BMP design will depend on the pollutant(s), the impaired area, and the level of engineering required to protect and/or restore the water body. However, the nature of the climate change may dictate the category of BMP that needs to be implemented. In the case of the arid Southwest, where predictions of a warmer and drier climate will increase water demands (on an already stressed supply) while adversely impacting land cover (creating erosion opportunities), these changes will call for the implementation of BMPs that are designed for the upland zone, such as low-impact development for site detention of runoff in urban areas as well as grazing management and grade stabilization structures for erosion control and the sustainability of native vegetation in rural and ranchland locations. These categories of BMPs will provide a frontline phase of protection, while BMPs designed for the transition, overbank, bank, and toe zones can provide additional protection against NPS pollutants reaching and impairing the water supply.

This type of analysis and selection tool will help to prioritize the types of BMPs that can protect water quality and supply while also enabling communities to adapt to climate change.

List of Sources

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, et al. 2003. Climate change, human impacts, and the resilience of coral reefs. Science 301:929–933.

For More Information

More information about the arid region–specific BMP manual, as well as the NEMO watershed-based plans, can be found at: http://www.ArizonaNEMO.org.

Contributor

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Adaptation Strategies To Address Climate Change Impacts on Wisconsin's Water Resources

Wisconsin's water resources are an important part of what defines the state and its people. The Mississippi River, Lake Superior and Lake Michigan, about 135,000 km (84,000 mi) of streams, 15,000 lakes, 2.1 million ha (5.3 million acres) of wetlands, and a plentiful, though finite, supply of groundwater support industrial and agricultural activities and enrich our recreational opportunities.

In February 2011, the Wisconsin Initiative on Climate Change Impacts (WICCI) released its first climate change adaptation strategy report. A statewide collaborative effort, WICCI focuses on adaptation strategies and how to prepare for climate change proactively at state and local levels rather than focusing on the mitigation of greenhouse gases. The project is a partnership among the Wisconsin Department of Natural Resources, the University of Wisconsin, and other state agencies and institutions. WICCI has more than a dozen working groups composed of hundreds of scientific experts and stakeholders that have been charged with developing risks, vulnerabilities, and adaptation strategies related to Wisconsin's changing climate (Figure 1). This vignette highlights the WICCI findings on water resources.

Figure 1. The Wisconsin Initiative on Climate Change Impacts is made up of hundreds of experts across multiple agencies, institutions, and disciplines.

The Climate Working Group of WICCI developed future climate forecasts by downscaling 14 global climate models to the state level. One of the first efforts of this kind in the country, this modeling was possible because of the availability of long-term, fine-scale weather data in Wisconsin. Researchers predict that the state's average annual temperature will warm by 2°C and 5°C (4°F and 9°F) by the middle of the century, with warmer winters and warmer nights.

Precipitation changes are more difficult to predict, but researchers expect less precipitation in the form of snow. Winter and spring precipitation is likely to increase by about 20%. As air and water temperatures increase, we can expect to see longer ice-free periods and increased potential evaporation. Storm intensities are expected to increase, with slightly more frequent events of greater than 5.1 cm (2 in) of precipitation in a 24-hour period.

Climate scientists also analyzed seasonal and annual precipitation and temperature data from 1950 to 2006 to document historic climate changes. Our climate has changed, and an analysis of historic water resources data shows that water resources are intimately linked to regional climate conditions that are also changing.

Robust data sets of ice cover dating back to the 1850s show that average ice cover has decreased by about 20% in southern Wisconsin, reflecting warmer temperatures. Lake levels in northern Wisconsin have gradually decreased and are currently at the lowest levels in the 70-year record. In the southern part of the state, water levels appear to have increased since the 1960s. Changes in both ice cover and water levels parallel other historic and ongoing climate changes statewide.

Mean annual stream baseflow has increased overall statewide by about 14% over the past 56 years, consistent with a 10%–15% increase in precipitation over the same time period (Figure 2).

Using the historical databases and the climate projections, water resources specialists identified the major impacts of climate change on water resources. Through a series of workshops, WICCI's Water Resources Working Group (WRWG) then developed several adaptation strategies to address these impacts. The six major impacts and adaptation strategies that WRWG has identified thus far are as follows.

Increased flooding will have impacts on infrastructure and agricultural land. Identify, map, and prioritize potentially restorable wetlands in floodplain areas; restore prior-converted wetlands in upland areas to provide storage and filtration; mitigate storm flows and nutrient loading downstream; and develop both long-term and short-term changes to community infrastructure.

Harmful blue-green algal blooms will occur more frequently with increased summer temperatures. Increase monitoring of inland beaches and develop better prediction tools for blue-green algal toxins and associated changes in water quality to improve predictive capacity. Develop statewide standards for blue-green algal toxins and take appropriate action to protect public health.

Demand for water and groundwater extraction will increase as a result of precipitation projections and warmer growing season temperatures. Encourage major water users such as power plants to locate in areas with adequate and sustainable water sources, including large rivers or the Great Lakes; encourage rural and urban water conservation through incentives and regulation; and promote integrated water management by planning water use based on long-term projections of supply and demand and by tying water use to land use and economic growth forecasts.

Seepage lakes will change as a result of variable precipitation, recharge, or increased potential evapotranspiration with additional implications for water chemistry, habitat, and shorelines. Enhance and restore shoreline habitat (using, for example, coarse wood, littoral and riparian vegetation, or bioengineered erosion control) to withstand variations in water levels; in headwater areas or near watershed divides, enhance infiltration by reducing impervious surfaces in urban and riparian areas and changing land management practices; change planning and zoning for lakeshore development to account for changes in water levels; and adjust and modify expectations and uses of lakes, especially seepage lakes, by recognizing that some lakes are not suited for all uses.

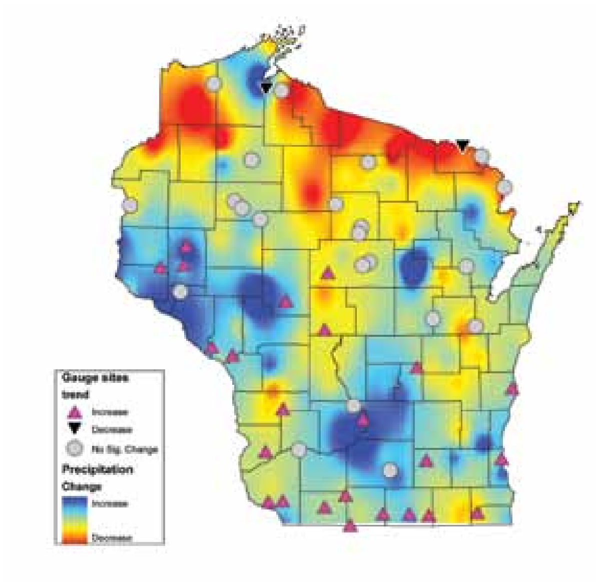

Figure 2. From 1950 to 2006, Wisconsin as a whole has become wetter, with an increase in annual precipitation of 7.9 cm (3.1 in). This observed increase in annual precipitation has primarily occurred in southern and western Wisconsin, while northern Wisconsin has experienced some drying. The southern and western regions of the state show increases in baseflow, corresponding to the areas with the greatest precipitation increases. Map prepared by Eric Erdmann, Wisconsin Department of Natural Resources, in 2010. Sources: Greb and Kucharik et al. (2010)

Sediment and nutrient loading will increase as a result of earlier and more intense spring runoff events. Resize manure storage facilities, wastewater facilities, stormwater drains, and infrastructure to accommodate increased storm flows to protect water quality; reverse the loss of wetlands; restore prior-converted wetlands to provide storage and filtration by mitigating storm flows and nutrient loading; protect recharge and infiltration areas and riparian buffers to reduce overland flow of polluted runoff; and incorporate water management strategies based on climate projections into farm-based nutrient management plans.

The spread of aquatic invasive species is likely to increase. WRWG continues to develop adaptation strategies for this projected change.

WRWG is moving into the next phase of implementation and has already defined and funded new research priorities and projects, along with discussions to modify water quality monitoring programs to address climate change at the state and watershed levels. In addition, WRWG is developing outreach and education strategies.

A separate working group has dealt with stormwater; its report is available on the WICCI website.

List of Sources

Greb, S. R. No date. Historic trends in flows of Wisconsin's rivers and streams. Unpublished data. Madison, WI: Wisconsin Department of Natural Resources.

Kucharik, C. J., S. P. Serbin, S. Vavrus, E. J. Hopkins, and M. M. Motew. 2010. Patterns of climate change across Wisconsin from 1950 to 2006. *Physical Geography* 31(1):1-28.

Magnuson, J. J., J. T. Krohelski, K. E. Kunkel, and D. M. Robertson. 2003. Wisconsin's water and climate: Historical changes and possible futures. In *Wisconsin's waters: A con-*

fluence of perspectives, ed. C. Meine, 23–36. Madison, WI: Wisconsin Academy of Sciences, Arts and Letters.

Wisconsin Initiative on Climate Change Impacts. 2011. *Wisconsin's changing climate: Impacts and adaptation*. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Department of Natural Resources, Madison, WI.

For More Information

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Contributors

This vignette was prepared by Carolyn Rumery Betz, University of Wisconsin–Madison; Tim Asplund, Wisconsin Department of Natural Resources; and Jim Hurley, University of Wisconsin–Madison.

A Climate Change Action Plan for the Florida Reef System

The Florida Reef System is the third-largest coral reef ecosystem in the world, spanning more than 556 km (300 nautical mi) from Martin County, Florida, on the Atlantic coast, south through the Keys, to the Dry Tortugas (Figure 1). It includes a rich diversity of sensitive coral habitats ranging from hardbottom, nearshore patch reefs to reef flats to deep and outlier reefs, as well as associated seagrass, beach, and mangrove habitat. For decades, overfishing, land-based pollution, and direct habitat degradation from human activities—along with climate-related threats, such as extreme water temperatures and ocean acidification—have threatened this system (Figure 2).

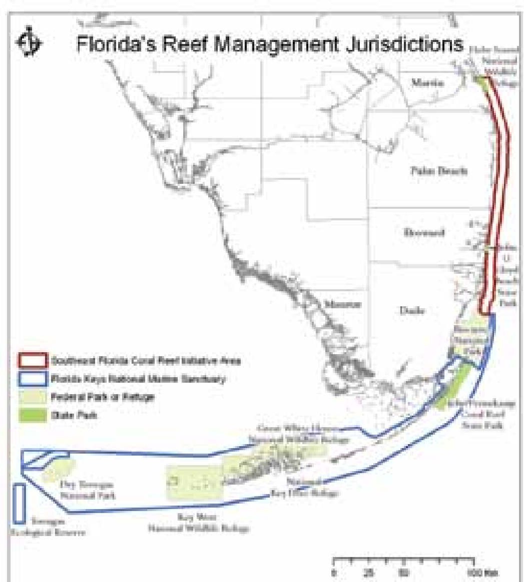

Figure 1. The extent of the Florida Reef System with respect to Florida's reef management jurisdictions. Map courtesy of The Nature Conservancy.

The Florida Reef Resilience Program (FRRP), established in 2004 in response to these threats, brings together diverse interests, expertise, and management authorities. The FRRP evolved organically across disciplines, user groups, and resource management entities that leveraged resources and focused efforts on the emerging challenges. A steering committee representing fishing, diving, science, management, and the environmental community spearheaded the development of a holistic five-year plan: the *Climate Change Action Plan for the Florida Reef System 2010–2015*.

The plan is designed to accomplish three main goals (1) increase reef resilience through active management, (2) reduce impacts from reef-dependent communities and industries via outreach and adaptation planning, and (3) execute targeted research. It outlines a coordinated response to climate change–related threats, including efforts by state, federal, and local partners working across political, social, and jurisdictional boundaries. Built on well-established principles for helping corals resist, tolerate, and recover from negative impacts, the plan describes actions that reef managers can undertake, in collaboration with stakeholders and other partners, to minimize the damage and associated impacts caused by climate change on reefs and reef-dependent industries, such as tourism and fishing.

The plan includes a range of detailed recommended actions addressing outreach, social resilience, research, and management which, if implemented, should increase the overall resilience of the entire Florida reef system. Top actions include the following:

- Continue and expand the FRRP disturbance response monitoring.
- Implement a marine zoning plan that incorporates resilience and connectivity between reefs.
- Include sea level rise adaptation and mitigation planning in local land use comprehensive plans.
- Evaluate and revise existing monitoring programs to optimize their effectiveness in the context of climate change
- Decrease negative user impacts.
- Target outreach across sectors.

Figure 2. Florida coral reefs in good condition (A) and bleached (B, C). Photos courtesy of the National Oceanic and Atmospheric Administration (A) and the Florida Keys National Marine Sanctuary (B, C).

- Forecast and project impacts to dependent communities to help develop a response plan.
- Increase understanding in the region regarding potential climate change impacts on coral reefs.
- Ensure a long-term water quality monitoring program throughout the entire reef tract.
- Map areas of high and low resilience to prioritize investment of management effort.

This plan, building on the concept of resilience to help a region cope with the reality of climate change, is the first of its kind in Florida and may act as a catalyst to spur climate adaptation up the Florida peninsula, throughout the Caribbean, and beyond. The plan and its process are being actively disseminated via presentations at regional and international trainings, science and policy meetings, and via online knowledge-sharing sites such as the Climate Adaptation Knowledge Exchange (see related vignette, this issue). The FRRP concept and framework can be used by watershed or other professionals faced with complex challenges that span jurisdictions, management authorities, and interest groups and in cases for which meaningful solutions rely on collaboration and the targeting of limited resources. It is particularly appropriate when integrated, multisector action is needed in an environment of little legislative or governmental guidance and leadership.

The plan was released in June 2010; the FRRP will oversee its implementation, and The Nature Conservancy will provide primary coordination. Core FRRP partners include the Florida Department of Environmental Protection, the National Oceanic Atmospheric Administration, and Australia's Great Barrier Reef Marine Park Authority along with several other agencies, universities, and organizations, including: EcoAdapt, University of South Florida, University of Miami, Rosenstiel School of Marine and Atmospheric Sciences, Florida Fish and Wildlife Conservation Commission, Southeast Florida Coral Reef Initiative, Florida Institute of Technology, Mote Marine Laboratory, Nova Southeastern University, and the Florida Keys National Marine Sanctuary.

For More Information

For more information, please visit http://www.frrp.org or contact EcoAdapt at info@EcoAdapt.org or The Nature Conservancy at info@tnc.org.

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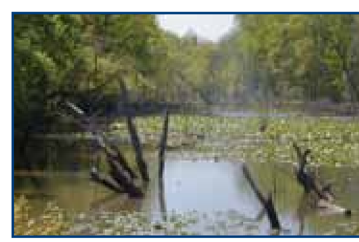
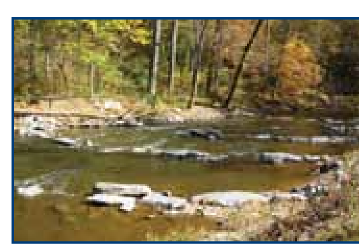
This vignette was prepared by Alex Score, EcoAdapt, Alex.Score@EcoAdapt.org.





Building a Network of Climate-Resilient Watersheds in Oregon

The impacts of climate change are already apparent in Oregon's water systems. Changing patterns of flooding and drought, precipitation, and temperature directly affect water quality and quantity, creating new challenges for watershed managers. Because of the complexities of climate change, new considerations and approaches to watershed management are needed. Managers can no longer assume a static range of climate variability, but instead must consider projections for future climate change when developing and implementing restoration projects and standards. Consideration for future conditions allows managers to build system resiliency and to respond more effectively when impairments occur. Building resilience now will increase the likelihood that Oregon watersheds can continue to provide the services on which both human and natural communities depend.

To support these efforts, the Climate Leadership Initiative (CLI)[1] has implemented a project on building resiliency across Oregon's watersheds using a five-systems approach (Figure 1). The audience for the Preparing Watersheds for Climate Change Project (hereafter, the Watershed Climate Project) is broadly defined as "watershed managers" to include the full range of participants in Oregon's community-based volunteer watershed management program[2]. This includes professional resource managers, informed community participants active in local watershed councils, and lay audiences concerned with watershed health. The principle learning objectives of the Watershed Climate Project are to (1) achieve a general understanding of climate change among watershed managers, (2) promote an understanding of projected climate impacts to Oregon watersheds developed by the Oregon Climate Change Research Institute (OCCRI), (3) facilitate an understanding of how to develop and integrate climate adaptation strategies into existing watershed council processes, and (4) effectively communicate climate change issues to local watershed constituents.

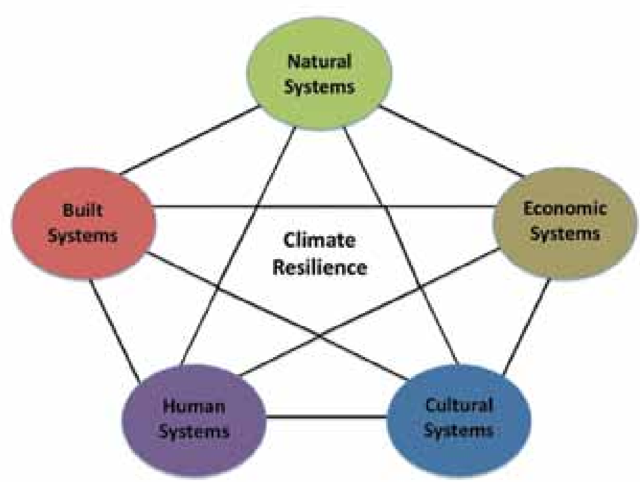


Figure 1. Five-systems approach to building climate resiliency in watersheds.

The Watershed Climate Project has completed the following activities (1) a statewide needs assessment of watershed council staff in 2009 to assess knowledge of, and concerns about, climate impacts, as well as capacity and resource needs for the implementation of climate resiliency strategies; (2) workshops in 2009–2010 for watershed managers to identify local climate impacts and climate resiliency strategies; and (3) the *CLI Watershed Council Resilience Guide*, released in early 2011, which outlines step-by-step climate action planning for watersheds, including indicators for assessing and monitoring resiliency. Among its future initiatives, the Watershed Climate Project will collaborate with state agencies, research institutions, and organizations to (1) develop protocols for climate change consideration in total maximum daily load programs, (2) define and evaluate indicators, and (3) develop case studies on climate action planning for watersheds. Funding for the project has been secured from foundation sources as well as the Oregon Watershed Enhancement Board, a state agency funded primarily through lottery dollars.

The insights provided by the 2009 statewide needs assessment indicate a broad understanding among watershed managers that climate change will probably have negative impacts on watershed health and a corresponding high degree of concern about the nature of those impacts. The assessment further found that watershed managers lack specific, localized projections for changing climatic conditions

[1] The Climate Leadership Initiative is a social science–based global climate change research, education, and technical assistance program of The Resource Innovation Group, a 501(c)3 organization based in Eugene, Oregon.

[2] The Oregon legislature established watershed councils in 1995 under House Bill 3441. Oregon's watershed councils are locally organized, voluntary, nonregulatory groups intended to improve the conditions of local watersheds.

within the watersheds they manage. The majority felt that they lacked the understanding, capacity, and resources needed to incorporate adaptive responses into existing watershed management activities.

To meet these needs, CLI developed and refined a training curriculum in 2009–2010 using a five-systems approach that provided an overview of principles and methods for climate resilience. The five-systems approach considers all aspects of the watershed by identifying climatic impacts to natural systems (e.g., landscapes, streams, and biodiversity), human systems (e.g., emergency response, health care, and education), built systems (e.g., transportation, irrigation, communications infrastructure, and buildings), cultural systems (e.g., species and places of cultural importance), and economic systems (e.g., forestry, agriculture, manufacturing, and tourism) as well as examples of resilience strategies that are beneficial across multiple systems. The training curriculum draws extensively from the literatures of adaptive resource management, natural systems resilience, human psychology, and climate change communications to build capacity among watershed managers for developing response strategies.

The training program included a series of presentations, facilitated participant discussion with question-and-answer periods for presenters, and a series of tabletop exercises in which participants worked through future climate projections developed by OCCRI. The modeling, which was provided by OCCRI and the USDA Forest Service Pacific Northwest Research Station, featured downscaled climate projections (i.e., at an 8-km^2 scale compared to global climate models that provide regional projects at a scale of 150 km^2).

The resilience guide supplements training materials and provides step-by-step guidance for applying the tools described during the training sessions, including indicators for monitoring resiliency and a process for initiating climate action planning. The resilience guide identifies how watershed managers can use local climate data to develop a whole-systems approach to climate action planning and to develop strategies under conditions of uncertainty. For example, the resilience guide identifies approaches to integrating the flexibility and adaptability of projects and provides case studies. It also provides specific tools and exercises to facilitate the planning process—for example, mapping past events and responses and evaluating priority strategies for implementation. Finally, CLI has developed a professional networking website using "Yammer" networking technology as a means of facilitating ongoing conversation and sharing among watershed managers concerned with climate change adaptation issues within their local watersheds.

Although the Watershed Climate Project was initiated in Oregon, the methods, tools, and lessons learned are transferable to watersheds across the country where practitioners or decision makers are beginning to consider climate impacts and the need for resilience strategies. CLI continues to work with the watersheds and associated communities across Oregon to prioritize, fund, and initiate the implementation of strategies. The project released the resilience guide to watersheds in the Pacific Northwest in winter 2010–2011 and will make it available to other regions in summer 2011.

For More Information

For more information, please contact Stacy Vynne (stacy@trig-cli.org). The survey results, reports, modeling data, and the resilience guide are available at www.climateleadership.org.

Contributors

This vignette was prepared by Stacy Vynne, project manager, and Steve Adams, managing director of the Climate Leadership Initiative, a program of The Resource Innovation Group.

What's in a Name? Not Much if It's "Climate Change"

Our choice of words affects how the general public responds to issues—whether at local, national, or even global scales.

With public opinion polls routinely finding the issue of "climate change" toward the bottom of the priority list for most Americans, it may be time to begin paying attention to the words we use to engage the public. The latest assessment report by the Intergovernmental Panel on Climate Change finds that the increase in global temperatures is *very likely* attributable to greenhouse gas (GHG) pollution from human activity. As the United States has yet to act on GHG emission regulations, it is very likely that US GHG emissions will continue to rise, along with their long-term impacts.

Figure 1. Google Trends (from December 18, 2010) in tracking website hits for the search terms "global warming" (top blue line) and "climate change" (top red line) by users in the United States from 2004 to 2010. The bottom graph indicates the use of the terms "global warming" (bottom blue line) and "climate change" (bottom red line) in online news articles.

For a while, it appeared as though the general public was interested in learning more about "global warming." After the release of *An Inconvenient Truth* in 2006, Americans stampeded to Google to learn more about "global warming" (Figure 1). So what went wrong?

The language has changed since then, and their enthusiasm has waned. "Climate change" overtook "global warming" as the predominant term used in the news media. Google Trends data reveal the consequence: back when the press wrote about "global warming," the public conducted Google searches about "global warming." Now that the press writes about "climate change," the public doesn't seem to respond much at all.

A few years ago, Frank Luntz urged those opposed to GHG regulations to use the phrase "climate change" as his research had found that voters greeted this term with complacency but responded with alarm to "global warming." In 2010, he released the presentation "The Language of the Clean Energy Economy." This time, his purpose is to advance solutions to GHG pollution. His presentation is packed with useful advice to help regain some of the ground we have lost over the past few years.

Among his time-tested recommendations, Mr. Luntz suggests that if we want to build political support for GHG regulations, we must use the same words that the voters do, such as "clean," "healthy," and "safe." We must avoid jargon—especially the terms "carbon-neutral" or "anthropogenic." Even more importantly, Mr. Luntz urges us to define our purpose more broadly than "preventing global warming." In particular, we must stress the benefits of clean energy technologies in terms of gaining "energy independence" from the Middle East and the prospects of new jobs in industries that have a future.

Mr. Luntz's advice is useful for inside-the-beltway political players sparring over law, policy, and the public purse. But what about engineers, scientists, and public servants out on the front line? What about people like you—anticipating harsher weather and rising waters, creek by creek, acre by acre, neighborhood by neighborhood? Allow me to channel Mr. Luntz and provide some practical advice: If you want to build public support for stream restoration, erosion prevention, or polluted runoff reduction, it is more important for you to stress the traditional benefits of this work—clean water, improved flood safety, and a home for wildlife—than the need to prepare for climate extremes or the historical rationale for your efforts, such as floodplain development and channelization.

List of Sources

Google. No date. Google trends. http://www.google.com/trends

For More Information

For more information, contact Eric Eckl, Water Words That Work, LLC, eric.eckl@waterwordsthatwork.com.

Contributor

This vignette was prepared by Eric Eckl, founder of Water Words That Work, LLC, a marketing agency that helps nature protection and pollution control organizations professionalize and modernize their communications.

Oyster River Culvert Analysis Informs Coastal Climate Change Adaptation

Many coastal communities in the eastern United States are experiencing an unusual and persistent increase in heavy and extreme storms that is generally consistent with climate change projections. Existing drainage systems were not designed to safely pass the volume of water resulting from these events, and new systems still are being designed using 50-year-old standards. As a result, there is an increased likelihood that drainage components will fail, damaging infrastructure and property, causing loss of life, and degrading both fluvial and estuarine aquatic ecosystems. However, published adaptation research and planning guides remain typically characterized by general resilience building or regional vulnerability studies.

On October 5th, 2010, the White House Council on Environmental Quality issued its *Progress Report of the Interagency Climate Change Adaptation Task Force*, one of the key findings of which is that the federal government must "…promote and implement best practices for adaptation…."[1] A recent study by a team in New Hampshire is helping to actualize these goals. The Oyster River Culvert Analysis Project assessed the capacity required for a coastal watershed's stormwater drainage system to accommodate mid-twenty-first century climate change and population growth. This study delivered results in a form understandable to, and usable by, planners, resource managers, and decision makers. The project was performed by Syntectic International, led by Latham Stack and Michael Simpson, under contract to the Piscataqua Region Estuaries Partnership. It was one of six pilot projects selected nationwide for funding under the US Environmental Protection Agency's Climate Ready Estuaries Program. The study estimated adaptation costs, developed methods for managing uncertainty, and examined the capacity of nonstructural methods such as low-impact development (LID) to mitigate climate change impacts. The project

[1] US Council on Environmental Quality, Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Action in Support of a National Climate Change Adaptation Strategy (Washington, DC: Council on Environmental Quality, 2010), page 8.

challenged the validity of the commonly held assumption that climate model output is too uncertain to support reliable, quantified, and actionable information for local-scale adaptation needs.

For this project, a multidisciplinary team used conservative, well-established analytical methods. The team computed runoff using the *curve number* method and modeled current and projected culvert capacities using standard civil engineering formulas. To project population growth, they performed a build-out to current zoning standards. They estimated future precipitation using state-of-the-art statistical methods and output from the highly-regarded Geophysical Fluid Dynamics Laboratory 2.1 coupled-climate model. The team used a statistical downscaling method, validated against historical rainfall records. They projected mid-twenty-first century precipitation amounts for two greenhouse gas emissions trajectories: the optimistic (A1b), and the pessimistic (A1fi) scenarios. They developed an achievable LID scenario that would maintain, on each building site, 25 mm (1 in) of the precipitation falling on impervious surfaces. The team estimated replacement and upgrade construction costs, and the resulting impact on town budgets and property tax burdens.

Key findings include the following:

- Of the watershed's culverts, 5% are already undersized for the 1971–2000 rainfall pattern, and 32% have impaired conditions that reduce flow capacity.
- The mid-twenty-first century design storm is estimated to be 35% and 64% greater, for optimistic and pessimistic climate change scenarios, respectively, than that historically used for specifying drainage systems. What historically had been a 1-in-25-year (i.e., a 4% probability) storm is projected to become a 1-in-7.5-year event. And what had historically been a 1-in-150-year storm is projected to become a 1-in-25-year event.
- Of the culverts in the watershed, 17% and 28% probably will be undersized by mid-twenty-first century, for optimistic and pessimistic climate change scenarios, respectively.
- Watershed-wide, the cost of upsizing at-risk culverts is estimated to be 9% greater than the cost of replacing all culverts with ones of identical size at the end of service life. Spread over a 30-year period, this adds 0.02% to annual town budgets. Preparing a community's drainage system for climate change is estimated to cost 65%–80% less than repairing damage to road–stream crossings that results from undersized culverts.
- Uncertainty in climate model output is not an obstacle to adaptation. For culverts in the watershed, 65% are projected to be adequately sized even for the upper 95% confidence limit of the pessimistic climate change scenario. Adapting the watershed's drainage system for pessimistic climate change costs only 5% more than adapting for an optimistic expectation, so incorporating a safety margin to accommodate uncertainty carries little penalty. Because of the discrete sizes of premanufactured drainage components, an upgrade for a culvert undersized for optimistic climate change generally will provide adequate capacity for the most-likely pessimistic climate change conditions.
- Most culverts projected to be undersized are on rural, low-traffic roads; as a result, the risk from failure of these components is lower than if failure occurred in highly-populated neighborhoods or high-traffic roads.
- A practical and politically palatable LID standard can significantly mitigate the impacts of optimistic, but not pessimistic, climate change. For the study site, under optimistic climate change impacts LID can reduce the number of culverts requiring upgrading by 25%–100%. However, as rainfall becomes more extreme, the goal of maintaining on-site 25 mm (1 in) of rainfall on impervious surfaces becomes less significant. Under pessimistic impacts, LID reduces the number of culverts requiring upgrading by only 5%–8%.

This study makes a significant contribution to climate change adaptation of estuaries and coastal watersheds by proposing a simple yet reliable model capable of generating specific estimates of civil infrastructure vulnerabilities. These results may be of interest to planners, resource managers, stakeholders, and decision makers, as they consider preparing for predicted increases in rainfall intensity and watershed runoff. The authors hope that this work will increase awareness of the need for, and practicality of, climate change adaptation.

List of Sources

Delworth, T., A. J. Broccoli, A. Rosati, R. J. Stouffer, V. Balaji, J. A. Beesley, W. F. Cooke, et al. 2006. GFDL's CM2 global coupled climate models. Part 1: Formulation and simulation characteristics. *Journal of Climate* 19(5): 643–674.

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, et al. 2000. *IPCC special report on emissions scenarios*. Cambridge, UK: Cambridge University Press.

US Council on Environmental Quality. 2010. Progress report of the Interagency Climate Change Adaptation Task Force: Recommended action in support of a national climate change adaptation strategy. Washington, DC: Council on Environmental Quality.

US Department of Agriculture Natural Resources Conservation Service. 1986. Urban hydrology for small watersheds. TR-55. Washington, DC: US Department of Agriculture.

For More Information

A copy of the project report can be found at http://www.prep.unh.edu/resources/pdf/oyster_river_culvert-prep-10.pdf. Or contact Latham Stack at lstack@syntectic.com.

Contributors

Contributors to this vignette include Latham Stack, Syntectic International LLC; Michael Simpson, Antioch University New England; Thomas Crosslin, Climate Techniques; Colin Lawson, Antioch University New England; Derek Sowers, Piscataqua Regions Estuaries Partnership; and Robert Roseen, University of New Hampshire Stormwater Center.

Water, Climate Change, and Forests: Watershed Stewardship for a Changing Climate

By Michael J. Furniss, et al. Portland, OR: USDA Forest Service, Pacific Northwest Research Station, 2010.

Reviewed by Laurel Woodworth, Center for Watershed Protection

Water, Climate Change, and Forests takes a big-picture look at the likely impacts of climate change on our nation's waterways and asserts that forests will serve as safety nets for maintaining our supplies of fresh water. This recently released report is less a detailed how-to manual for forest managers than it is a manifesto of how the USDA Forest Service (USFS) believes it will need to respond to climate change, not only to protect forests and habitats, but also to preserve water resources.

The strength of this 75-page report lies in its introduction and background. The facts and figures in these pages give the reader a thorough synthesis of the hydrological responses and cumulative effects of climate change. The introduction makes it clear that this piece is strictly about *adaptation* to climate change, not the benefits that forests may provide in *mitigating* the effects of climate change. The report assumes that the global temperature will rise and that a myriad of climatic and ecological changes will result. In this context, the authors advocate a framework to prepare and learn to adapt in three distinct sections: "Think," "Collaborate," and "Act." The report closes with examples of how USFS is evaluating forest and watershed management in the context of climate change to target and prioritize actions.

The climate change picture painted in these pages is often dire, making the juggling act of forest management in the uncertain future seem like an impossibly complicated task. Yet the report persuades us with a wealth of revealing maps and statistics that we don't have a choice—if we don't have forests, we won't have clean water (or enough water, period). As clean freshwater sources become increasingly scarce, forested lands will remain the "water towers" of the nation as they store and filter a huge proportion of the water we depend on. In fact, as the report points out, 50% of fresh water in the United States originates from forested headwater lands, 18% of which is National Forest acreage.

The language used in this report makes it accessible to scientists in a broad range of fields, as it is not rife with agency lingo or technical silvicultural terms. Though not as detailed as some foresters may like, *Water, Climate Change, and Forests* comprehensively examines the unique and important relationship between intact, healthy forests and watershed resilience and sends a call-to-action to forest managers to *think* critically, *collaborate* broadly, and *act* swiftly to relieve the stress of climate changes on our nation's watersheds. To be fair, no one will know in detail how climate change will impact forests until it happens, but this report does a nice job of gathering up the evidence we do have and making a plan for the future of forest management.

The report and complete citation may be downloaded at: www.fs.fed.us/pnw/pubs/pnw_gtr812.pdf

HAVE A QUESTION YOU'D LIKE US TO ASK OUR EXPERTS? *The upcoming Fall 2011 issue will focus on the influence of watershed land cover on the condition of downstream water resources. AWSPs members and Bulletin subscribers may email their questions to bulletin@awsps.org. The Bulletin features interviews with experts in the watershed and stormwater professions to discuss the topic of each issue. In this issue, four professionals weigh in with diverse perspectives on climate change in the context of watershed management. Here is what our experts had to say…*

NOAA's Multi-Level Approach to Climate Change Margaret Davidson

Director, NOAA Coastal Services Center

Margaret Davidson is the director of the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. Before joining NOAA, she was executive director of the South Carolina Sea Grant Consortium and also served as special counsel and assistant attorney general for the Louisiana Department of Justice. She has focused her professional work on environmentally sustainable aquaculture, mitigation of coastal hazards, and impacts of climate variability on coastal resources. Davidson earned her juris doctorate in natural resources law from Louisiana State University. She later earned a master's degree in marine policy and resource economics from the University of Rhode Island. Davidson holds a faculty appointment at the University of Charleston; serves on the adjunct faculties of Clemson University and the University of South Carolina; has served on numerous local, state, and federal committees; and has provided leadership for national professional societies.

Q: How is your agency involved in climate change? Does NOAA address water resources specifically as an aspect of climate change?

A: NOAA and other agencies are working toward establishing national climate services to provide local governments with the resources to help address climate change issues (see list of recommended resources, below). For example, the agency's Data & Services webpage features a section called "Climate and You," which provides information and resources to link climate change to community planning needs. The issue of water resource protection has been recognized by NOAA as one of the top five issues affected by climate change. Future water resource planning will need to incorporate measures to account for climate change.

Q: What is a key first step that federal, state, and local government agencies can take now to address the potential impacts on water resources from climate change?

A: Synchronization of planning efforts at all three levels is necessary to adequately address the potential impacts on water resources from climate change. Also, we need an "intervention strategy" for land use planning that would bring together developers, councils of governments, and others to talk about growth, since decisions for future growth and economic development are determined outside the public sector realm. Finally, municipal planners need to update current watershed plans, conservation plans, and floodplain management plans. One problem occurring due to climate change is that, in some cases, the floodplain mapped by the Federal Emergency Management Agency (FEMA) and the observed floodplain may be different, which can result in growth in flood-prone areas.

Q: What major group could, if it came to the table, make a difference in implementing climate change work in our watersheds?

A: The private sector is a big player that really needs to be brought to the table, and also the Chamber of Commerce, developers, and builders since they influence where local growth takes place. If they were included in the climate change discussion, we could determine how development is occurring to keep future development out of changed floodplain areas.

Q: What methods or techniques can effectively engage people in the discussion about climate change and/or watersheds?

A: Our agency determines the technical assistance to offer to other agencies and local governments through a needs assessment survey. We found that storytelling is more effective than lectures at engaging people. We also found connections between planning required for catastrophic events (flooding, wildfires, and drought) and planning required to address climate change. This approach works well in areas where people may not be sold on the idea that climate change is real, but can understand the impact of community disasters.

Q: Share one of your favorite success stories for climate change in watershed planning.

A: The National Integrated Drought Information System (NIDIS) project in the Upper Colorado River basin. The Colorado River basin (CRB) is the location for the first NIDIS pilot project to improve the capacity to manage drought-related risk using a collaborative, interagency approach, lead by NOAA. NIDIS was authorized by the federal government through legislation in 2006 for the development and coordination of drought risk information to support proactive decision-making. The CRB project includes drought early warning systems, custom drought index tools, water supply indicators, weekly webinars to monitor drought conditions, and more.

Interviewed by Chris Swann
Center for Watershed Protection

EPA Fosters Resiliency at the Local Level to Address Climate Change
Karen Metchis

Senior Policy Advisor for Climate Change, USEPA Office of Water

Karen Metchis currently serves as the US Environmental Protection Agency (USEPA) Office of Water's senior policy advisor for climate change. She coordinates the National Water Program's efforts to address climate change, including the challenges of adapting to impacts on water resources. Karen has been at USEPA for 18 years. Before joining the Office of Water ten years ago, she worked in the Office of Air and Radiation and the Office of Policy.

Q: How is your agency involved in climate change? Does USEPA address water resources specifically as an aspect of climate change?

A: The USEPA National Water Program established a workgroup in 2007 to evaluate climate change implications for water resources and for USEPA's water programs. In 2008, the workgroup published a strategy that included 44 "key actions" that could be initiated with existing resources and that the National Water Program planned to undertake during 2008 and 2009. Subsequently, the Workgroup published a *Key Action Update* for 2010 and 2011. Over the past four years, USEPA's implementation of these key actions resulted in significant momentum to address this issue, and the workgroup is now revising the strategy.

Climate-related program examples underway include Climate Ready Estuaries, Climate Ready Water Utilities, WaterSense (for residential water use efficiency), and the Green Infrastructure Initiative (to use "natural infrastructure" to help manage stormwater).

Q: Can you explain how climate change is expected to affect stormwater planning and water quality in lakes, rivers, and streams in noncoastal areas?

A: The phrase "stationarity is dead" is a catch phrase for the fact that the hydrological cycle that we planned our communities around is shifting. We rely on information derived from historical records during the past 100 years for designing infrastructure, planting crops, and managing water supplies. Scientists tell us that we can expect a range of shifts in different parts of the country and the following impacts (1) warmer air temperatures will result in warmer water that holds less dissolved oxygen; (2) heavier precipitation will increase flooding, streamflow variability, and erosion due to higher water velocity; (3) altered precipitation patterns or drought can affect drinking water supply availability; (4) rising sea levels will inundate shorelines, displacing wetlands and altering the tidal ranges; (5) increased evapotranspiration and changes in stream and lake flow may change wetland and lake size; and (6) altered aquatic species composition will result in, for example, increases in the populations of those species better adapted to warmer waters. The US Global Change Research Program website (see below) details the expected changes in the country's regions and different sectors of society.

Q: What is a key first step that federal, state, and local government agencies can take now to address the potential impacts on water resources from climate change?

A: A few key steps are for communities or planners to conduct vulnerability assessments and implement "win-win strategies" that build resilience over a range of impacts, using methods such as green infrastructure, low impact development, energy and water conservation programs, and source water protection strategies. There is a growing body of tools that we can readily access (e.g., USEPA's Climate Ready Water Utilities toolbox and the Climate Resilience Evaluation and Awareness Tool). Finally, educating the public is crucial.

Q: What major group could, if it came to the table, make a difference in implementing climate change work in our watersheds?

A: An authoritative body with regional expertise needs to provide guidance for how to use the best available projections, information and methods at the local scale where decisions are made. This provision of reliable, accepted information will help local action begin or gain momentum. But it is important to note that this information will not be handed to us on a silver platter – this is going to require us to become "knowledgeable users" of information as we develop more and better tools and learn how to apply them.

Q: Share one of your favorite success stories for climate change in watershed planning.

A: One recent example of a successful project supported by the Climate Ready Estuaries initiative involves the Charlotte Harbor National Estuary Program and the City of Punta Gorda, Florida which developed a city-wide climate change adaptation plan. They conducted three workshops that included interactive exercises to engage the public in helping to consider and prioritize vulnerabilities and adaptation strategies. The plan was approved by the City Council in November 2009. The top adaptation strategies that were agreed upon include: seagrass protection and restoration; xeriscaping and native plant landscaping; explicitly indicating in the comprehensive plan which areas will retain natural shorelines; constraining locations for certain high-risk infrastructure; restricting fertilizer use; promoting green building alternatives through education, taxing incentives, and green lending; and drought preparedness planning.

City of Punta Gorda Adaptation Plan
http://www.chnep.org/projects/climate/PuntaGordaAdaptation-Plan.pdf

Interviewed by Greg Hoffmann
Center for Watershed Protection

"No regrets" Approach Advocated
John Jacob

Coastal Community Development Specialist, Texas Sea Grant College Program
Director, Texas Coastal Watershed Program

John Jacob is the coastal community development specialist for the Texas Sea Grant College Program and the director of the Texas Coastal Watershed Program. He holds a joint appointment with the Texas A&M Sea Grant Program and Texas AgriLife Extension Service through the Department of Recreation, Parks, and Tourism Science. He has coast-wide responsibility for inland environmental problems that have a direct impact on the quality of Texas bays, estuaries, and coastal waters. Preeminent among these issues are the mitigation and abatement of runoff pollution from both rural and urban sources and the preservation and restoration of valuable natural habitats, such as wetlands. His current project, Coastal CHARM (Community Health and Resource Management), aims to enable coastal communities in Texas to improve the quality of life in cities and towns while preserving and enhancing the natural coastal environment. The Texas Coastal Watershed Program provides education and outreach to local governments and citizens about the impact of land use on watershed health and water quality.

Q: How is your work involved in climate change? Do you address water resources specifically as an aspect of climate change?

A: Planning for climate change is not addressed directly or quantitatively through my program, but it is considered within the framework of existing programs—for example, with storm surges, building in the floodplain, and sea level rise. I work specifically with coastal communities and advocate for resilient communities under any circumstance. We promote the idea of freeboard, adequate buffers, and good planning to deal with uncertainty.

Q: Can you explain how climate change is expected to affect stormwater planning and water quality in lakes, rivers, and streams in noncoastal areas?

A: Stormwater planning that takes into account climate change should focus on the potential for larger and more frequent storms, including hurricanes. But a key point here is that most coastal communities are not planning like they should for the storms we have now, let alone climate change impacts. We need to work with our coastal communities and noncoastal communities on simple, good planning principles. For example, do not build in the flood plain and stay out of storm surge zones. When communities need to build in a hazard zone (and almost all coastal cities by definition have to do that), then simply build better and stronger. Building a better, more walkable city also incorporates more resiliency features (for example, check out the January 2011 issue of *Zoning Practice* by the American Planning Association, which discusses smart growth and coastal hazards in the recommended resources at the end of this section). All of these are things that can be done without having to bring up the often contentious issue of climate change.

The main issue of a larger "envelope of uncertainty" would be similar for coastal and noncoastal areas. Larger storms moving inland could very much affect channel dynamics. We would therefore like to have larger buffers along our stream channels—something we would like to have anyway for a variety of reasons, making this a "no-regrets" way to adapt to climate change. In addition, in coastal and noncoastal areas alike, we should plan for variability and engage the community.

Q: Can you list actions that federal, state, and local government agencies can take now to address the potential impacts on water resources from climate change?

A: Federal flood insurance subsidies should be removed because development in the floodplain is essentially a moral hazard. The federal government can improve assistance by providing dollars, flood maps, and community incentives, such as the Community Rating System (see recommended resources) to local jurisdictions.

Action at the local level is needed more than at the federal level. For success on any level, local stakeholders should be involved in all aspects of climate change planning and should be the primary drivers of the process. It will be very important to focus on "no-regrets" kinds of policies that have ancillary benefits across a range of areas.

Q: What are your top two "good" and "bad" issues associated with climate change?

A: Good: The most important thing we can do in my opinion is build better cities. By better cities, I mean walkable cities, built to a pedestrian scale. As discussed in the *Zoning Practice* article, the proximity and density required for a walkable city allows a series of characteristics that enable greater resiliency. For example, a denser city or community requires much less land and can therefore choose where development occurs. Mixed use, the comingling of residential and commercial areas, might result in easily accessible "community safe rooms," to borrow a phrase from FEMA. Townhomes and smaller lot homes use much less water than the ¼-acre lots that are typical of modern suburban developments. We should be building better cities as a standard practice, so all of these things I mentioned are "no-regrets" policies.

Bad: For the much of the clientele I work with, it is often counterproductive to address climate change directly. It is unfortunately a politically charged topic. Concentrating too much on the direct approach is a "bad" issue for me. No one disputes that coastal population growth is occurring. This growth invariably puts more people in harm's way. Climate change does exactly the same thing - growth just greatly exacerbates the potential harm. The point is that we can perhaps be more successful by helping communities do planning efforts that include hazard mitigation plans, for example. For the coast, hazard mitigation is climate change adaptation. Just about everyone can sign off on hazard mitigation (even though it requires some serious nudging) and that is not the case with climate change adaptation.

Interviewed by Lori Lilly
Center for Watershed Protection

Making Global Climate Change Science Relevant to Local Management
Ken Potter

Professor, University of Wisconsin–Madison

Ken Potter is a faculty member of the Department of Civil and Environmental Engineering at the University of Wisconsin–Madison. He holds a BS from Louisiana State University and a PhD from Johns Hopkins University. Ken's research focuses on (1) stormwater modeling, management, and design; (2) adaptation of water resource management to climate change; (3) hydrologic modeling, design, risk estimation, and budgets; and (4) aquatic system restoration. His interdisciplinary research provides a technical basis for the sustainable use of aquatic resources and for restoring degraded aquatic resources. Ken is a fellow of the American Association for the Advancement of Science, American Geophysical Union, and Woodrow Wilson International Center for Scholars.

Q: How is your research involved in climate change? Do you address water resources specifically as an aspect of climate change?

A: I am involved in two climate change–related research projects that involve flood-related infrastructure, such as stormwater management practices, wastewater treatment plants, bridges, and flood protective works. Our research team uses downscaled daily precipitation projections based on 15 global circulation models used in the latest Intergovernmental Panel on Climate Change report. Our research includes interactions with municipal engineers, wastewater treatment plant operators, the Wisconsin Department of Transportation, and private consultants.

Q: Can you explain how climate change is expected to affect stormwater planning and water quality in lakes, rivers, and streams in noncoastal areas?

A: The climate projections for the period 2046–2065 indicate modest increases in the 10- and 100-year daily rainfall quantiles. Also, significant increases in the frequency of 75-cm (3-in) rain events are expected, with high variability across the 15 models. Finally, substantial increases in winter and spring precipitation and in the fraction that will occur as rain appear likely.

The predicted increases in the daily rainfall quantiles are relatively modest and vary widely across models; as a consequence, the research team does not believe that the projections will be used in stormwater planning. However, the projected increases in the frequency of moderate rainfalls have significant water quality implications.

Q: What do you think are the key drivers of climate change with respect to watershed planning and stormwater management, and what do we need to know about them to move forward and take action?

A: For Wisconsin, the major drivers are large rainfall events, which cause flooding, as well as smaller rainfall events that affect water quality. Increases in winter–spring precipitation and in the rain fraction will likely impact watershed flooding. However, the direction of the impact is unclear. For many Wisconsin watersheds, spring snowmelt is the dominant flooding cause. Based on our preliminary modeling, the projected change in winter–spring climatology may result in a decrease in snowmelt flooding. However, if this is the case, there will be an increase in groundwater flooding. In the last two years, many communities have suffered from groundwater flooding. In fact, the Village of Spring Green (Wisconsin) was the first community in the United States to receive FEMA funding to relocate homeowners displaced by groundwater flooding.

Q: Can you list actions that federal, state, and local government agencies can take now to address the potential impacts on water resources from climate change?

A: The US Weather Service should complete national coverage of NOAA Atlas 14 (precipitation frequency reports) and develop a mechanism for upgrading the statistics every decade, resurrect the national storm catalog and develop the capacity to augment it using gauge and radar data, and promote the use of calibrated radar rainfall data for measuring and modeling rainfall at the watershed scale. All states should mandate minimum stormwater standards for new development. State and local governments should require the use of Atlas 14 for stormwater management and design.

Q: What major group could, if it came to the table, make a difference in implementing climate change work in our watersheds?

A: It is my experience that widespread skepticism exists regarding climate change, and regulators are cautious in terms of how to address it as part of their decision making. As a consequence, it is better to present climate change in the context of other risks, such as the vulnerability to flood risk, and encourage actions that reduce this risk. Climate change information would inform both actions and lead to resiliency in systems.

Interviewed by Cecilia Lane
Center for Watershed Protection

Here are some of the top resources for climate change and watershed management recommended by our experts:

NOAA Climate Services portal for agencies:
http://www.climate.gov

National Integrated Drought Information System (NIDIS):
http://www.drought.gov

National Academy of Sciences—Adapting to the Impacts of Climate Change:
http://americasclimatechoices.org/index.shtml

Climate Change Indicators in the United States:
http://www.epa.gov/climatechange/indicators/pdfs/ClimateIndicators_full.pdf

Climate Change Risk Perception and Management: A Survey of Risk Managers:
http://www.ceres.org/zurichreport

USEPA Watersheds:
http://water.epa.gov/type/watersheds/

Climate Ready Water Utilities toolbox:
http://water.epa.gov/infrastructure/watersecurity/climate/index.cfm

Climate Resilience Evaluation and Awareness Tool:
http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm

Climate Ready Estuaries:
http://www.epa.gov/climatereadyestuaries/

USEPA headquarters activities and regional activities:
http://water.epa.gov/scitech/climatechange/upload/Highlights_Fact_Sheet.pdf
http://water.epa.gov/scitech/climatechange/upload/Region_Highlights_Fact_Sheet.pdf

Water Utility Climate Alliance:
http://www.wucaonline.org/html/

NOAA Sea Grant Climate Community of Practice:
http://gulfseagrant.tamu.edu/community.htm

Mississippi and Alabama Sea Grant:
http://tx.stormsmartcoasts.org/

Community Rating System
http://tx.stormsmartcoasts.org/home/crs-primer/

Smart growth and walkability resources, such as Smart Growth America:
http://www.smartgrowthamerica.org/

New Urbanism:
http://www.newurbanism.org/

American Planning Association, Zoning Practice:
http://www.planning.org/ZoningPractice/

Jacob, John and Tommy Pacello. 2011. Coastal Hazards and Smart Growth. Zoning Practice Issue Number 1, Practice Resilience.

Watershed Superstar

The Association of Watershed and Stormwater Professionals (AWSPs) sponsors a Watershed Superstar contest as a way to highlight the achievements of watershed professionals. AWSPs solicited nominations for the first such award in the Fall 2010 issue of the *Watershed Science Bulletin.* A panel of three watershed professionals from the Center for Watershed Protection, Inc. judged applicants based on their accomplishments as well as the unique qualities that make up a Watershed Superstar, including ambition, innovation, collaboration, and dedication. AWSPs is now accepting nominations for the next Watershed Superstar to be featured in the Fall 2011 issue of the *Bulletin.* The deadline for nominations is May 1, 2011. For additional information and to submit your entry, please visit www.awsps.org.

The *Bulletin* received an impressive collection of more than a dozen applications for Watershed Superstar. Each applicant has made a significant and positive impact on his or her local watershed, and some have done so at national and international levels! The dedication and commitment shown by these applicants demonstrates what can be done to protect and restore our watersheds—one project, one mile, at a time. Congratulations to everyone for their contributions.

The Watershed Superstar for Spring 2011

Nancy McClintock

Assistant Director, Watershed Protection Department, City of Austin, Texas

Nominated by Victoria Li and Kathy Shay

Nancy McClintock has been a pivotal leader in water quality protection in Central Texas for nearly 25 years. Her tireless work has inspired and guided successful agreements, land preserves, award-winning educational programs and cutting-edge technical approaches during her tenure with the City of Austin. Her accomplishments include many that are measured, not only by the final product, but also by her capacity to build partnerships and have some fun along the way. Below are some highlights of her work in Austin, Texas.

Nancy played an essential role in shepherding the Watershed Protection Department from its infancy to the nationally recognized leader in natural resources stewardship that it is today. She was the key driver in establishing the Environmental Integrity Index, a comprehensive rating system that is now recognized as a national benchmark for determining stream health. She helped spearhead the Watershed Master Plan, which promoted the integration of flooding, erosion, and water quality issues to find solutions that went beyond traditional, one-dimensional engineering. She is especially proud of the groundbreaking staff research that led to the discovery of coal-tar based pavement sealants as a major contributor of PAH pollution, and ultimately to Austin's passing of the nation's first ban on those products.

One of Nancy's greatest legacies is the protection of more than 12,000 ha of Hill Country land that feeds Austin's symbol of environmental health—Barton Springs. Nancy guided the City's efforts on bond propositions totaling $128,000,000 that allowed the City to purchase land and conservation easements that will forever keep these lands undeveloped, contributing to clean, plentiful water for Hill Country springs and streams.

As a member of the Stakeholder Committee for the Regional Water Quality Protection Plan for the Barton Springs Zone, Nancy worked with a diverse stakeholder group that included ranchers, developers, and environmentalists to define guiding principles that recognize the need to preserve our unique environment and offer economic incentives.

Finally, Nancy's code of conduct allows her to reach across previously unbridgeable divides. She has accomplished her tasks with a warm smile, a folksy wit, and an understanding that people do their best work when inspired. Austin and Central Texas, as well as the national watershed community, are better today—and, more importantly, will be able to remain so in the future—because of the efforts of this unique and caring person.

Honorable Mention…

Darion Warren

Project Construction Manager, City of Jackson, Mississippi

Nominated by Mauricka McKenzie

Darion is a rising Watershed Superstar in the City of Jackson, Mississippi. In a short time, Darion has turned around the local stormwater management program—which was characterized by high staff turnover, heavy fines, and a lack of funding—to one characterized by action and innovation. Darion's commitment has inspired others to think more innovatively regarding solutions to stormwater problems. He has worked closely with stormwater equipment manufacturers and stormwater consultants to determine cost-effective solutions to problems. Over the past two years, he has developed more than 30 individual stormwater pollution prevention plans (SWPPP) and inspected all of the affected facilities for annual compliance with the developed SWPPPs. He spearheaded the city's first stream cleanup event, which featured considerable participation by partnerships between nonprofit organizations and corporations, along with very high media campaign participation by television stations. He has acquired and attended more stormwater management courses and stormwater inspection and erosion control certifications than anyone else in the municipal public service arena in Jackson, Mississippi. And he recently earned a master's degree in management from Belhaven University while working full time.

He has, singlehandedly, accomplished the work of three staff persons. Because of his accomplishments, responsiveness, and enthusiasm, the public works director has proposed significant monetary resources for the next fiscal year's stormwater implementation program. Though only 29 years old, Darion has a strong desire to excel in his work in the area of watershed protection.

AWSPs Photolog Contest Winner

The Association of Watershed and Stormwater Professionals (AWSPs) sponsored a photolog contest as a way to feature the watersheds in which we live, work, and play. Entries were accepted between October and December 2010, and the winner was selected by the Center for Watershed Protection, Inc.

And the winner is....

Scott Hansen for his photo, "Lowcountry Shrimp Dock." The photo was taken at the Gay Seafood Company on St. Helena Island in Beaufort County, South Carolina. The abundance of seafood and marshlands in this coastal community supports the local seafood and tourism industries. Recognizing the importance of natural resources to the community, Beaufort County has been adopting and strengthening controls on stormwater runoff since 1998. As a result, more than 85% of the designated shellfish harvesting waters remain open for harvesting. This percentage has remained the same since the county adopted its first water quality controls in 1998; during this same time period, the county's population increased by 30%.

Sponsor Index

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STORMWATER PROFESSIONALS

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Next Issue

Be on the lookout for the Fall 2011 issue of the *Watershed Science Bulletin*, which features the next generation of research on the influence of watershed land cover (e.g., impervious surfaces, forest, wetlands, grasslands, cropland, pasture, and managed turf) on the condition of downstream water resources. For additional information, visit www.awsps.org/watershed-science-bulletin.

Upcoming Events

- May 18, 12–2 pm, Webcast: Ultra-Urban Stormwater Design and Retrofitting (www.cwp.org/our-work/training/webcasts)
- July 13, 12–2 pm, Webcast: The Top Actions That Local Governments Can Take To Address Numerical Goals, Such as TMDLs & WIPs (www.cwp.org/our-work/training/webcasts)
- September 14, 12–2 pm, Webcast: Rainwater Harvesting as a Stormwater Management Practice (www.cwp.org/our-work/training/webcasts)

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