American Rivers
Thriving By Nature

Natural Security

How Sustainable Water Strategies are Preparing Communities for a Changing Climate

NATURAL SECURITY:

HOW SUSTAINABLE WATER STRATEGIES ARE PREPARING COMMUNITIES FOR A CHANGING CLIMATE

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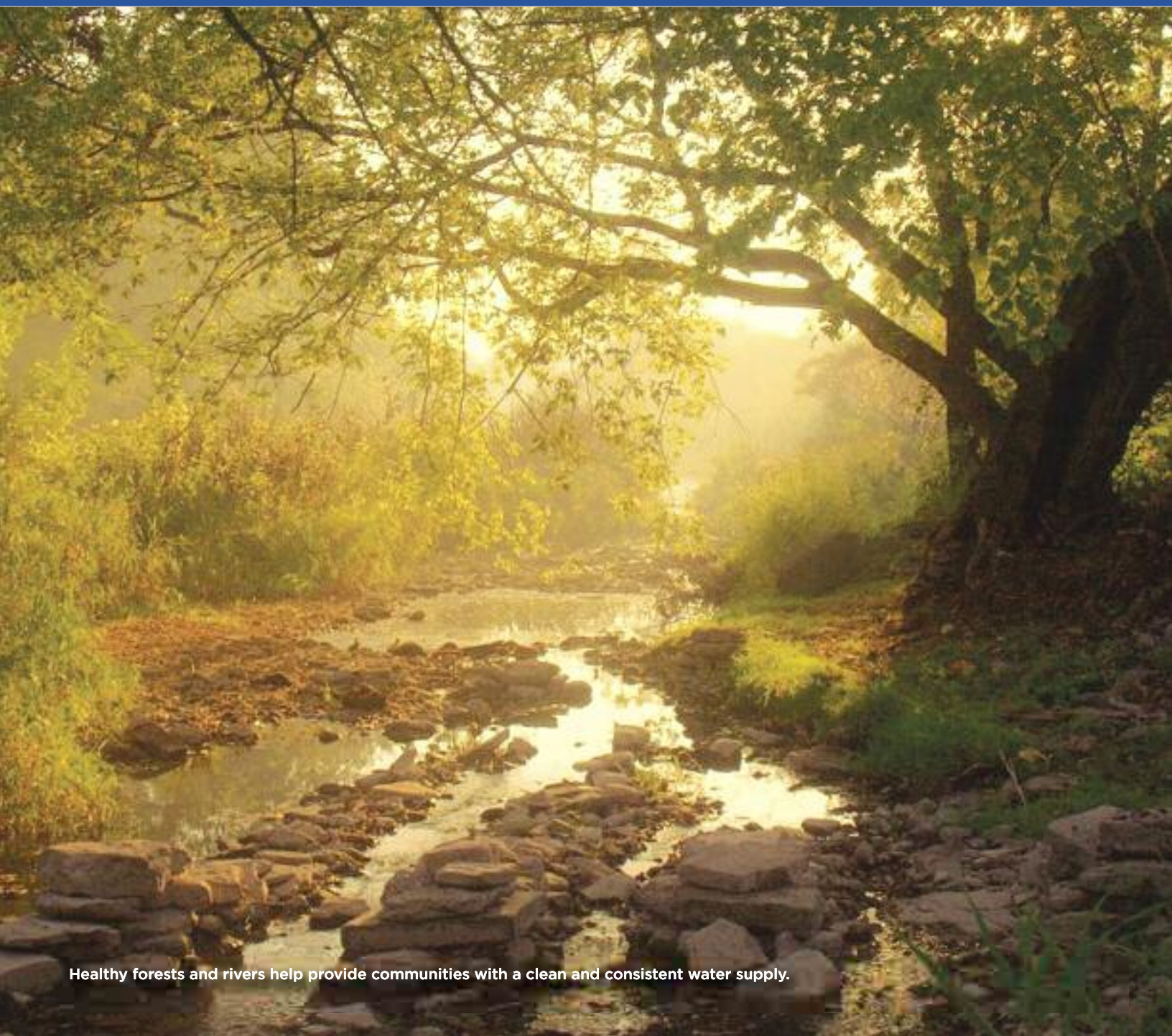
Written by Will Hewes and Kristen Pitts.

ABOUT AMERICAN RIVERS

American Rivers is the leading national organization fighting for healthy rivers so communities can thrive. American Rivers protects and restores America's rivers for the benefit of people, wildlife, and nature. Founded in 1973, American Rivers has more than 65,000 members and supporters, with offices in Washington, DC and nationwide. Visit **www.AmericanRivers.org**.



Healthy forests and rivers help provide communities with a clean and consistent water supply.

Sailboats on Charles River.

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Top: A constructed wetland on Staten Island, New York treats stormwater runoff. Bottom: Rafting on the Colorado River.

EXECUTIVE SUMMARY

Clean water is essential to our health, our communities, and our lives. Yet our water infrastructure (drinking water, wastewater, and stormwater systems, dams, and levees) is seriously outdated. In addition, we have degraded much of our essential natural infrastructure (forests, streams, wetlands, and floodplains). Climate change will worsen the situation, as rising temperatures, increased water demands, extended droughts, and intense storms strain our water supplies, flood our communities, and pollute our waterways.

The same approaches we have used for centuries will not solve today's water challenges. We need to fundamentally transform the way we manage water.

A 21st century approach would recognize "green infrastructure" as the core of our water management system. Green infrastructure is the best, most cost-effective, and flexible way for communities to deal with the impacts of climate change. It has three critical components:

Protect healthy landscapes like forests and small streams that naturally sustain clean water supplies.

Restore degraded landscapes like floodplains and wetlands so they can better store flood water and recharge streams and aquifers.

Replicate natural water systems in urban settings, to capture rainwater for outdoor watering and other uses and prevent stormwater and sewage pollution.

Many forward-looking communities have become more resilient to threats such as flooding, sewage pollution, and limited water supplies by embracing green infrastructure. American Rivers has conducted in-depth research on eight communities' sustainable green infrastructure approaches that provide clean water, conserve rivers and ecosystems, and provide a wide array of benefits to people and wildlife in the face of climate change.

The featured communities have taken steps to prepare themselves in four areas where the effects of climate change will be felt most: public health, extreme weather, water supply, and quality of life. In each case, these communities could achieve even more by extending their use of green infrastructure strategies and working with neighboring communities to apply these approaches throughout their watersheds.

Many forward-looking communities have become more resilient to threats such as flooding, sewage pollution, and limited water supplies by embracing green infrastructure.

IMPROVING PUBLIC HEALTH

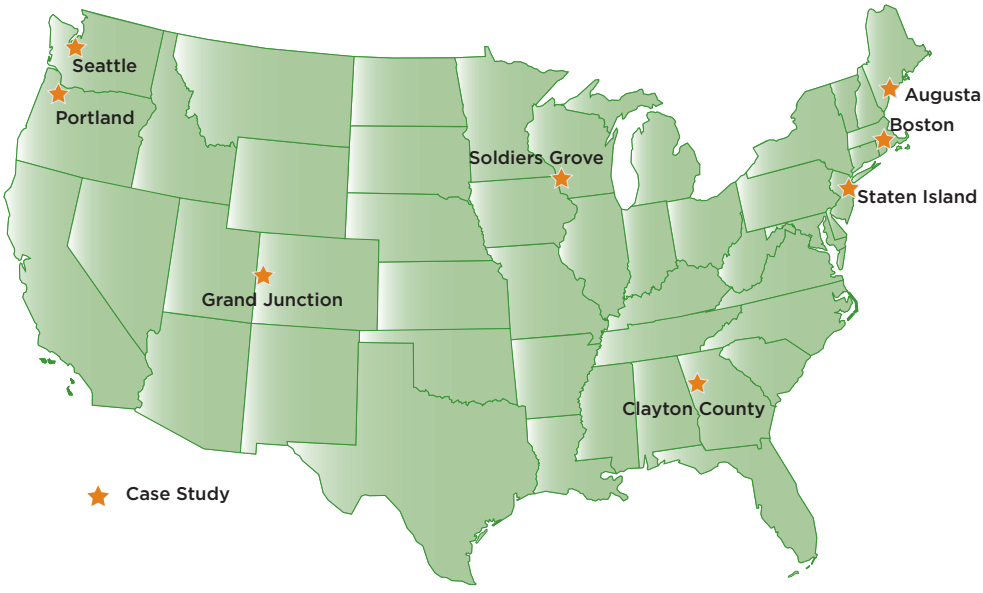
Portland, Oregon—In response to stormwater runoff and sewer overflows that have long degraded water quality and threatened public health, Portland adopted a number of green infrastructure solutions in conjunction with expanding sewer and stormwater pipes. The city's "green street," eco-roof, and downspout disconnection programs, while still in early stages, currently capture 8 percent of the city's annual stormwater runoff and have the potential to absorb about 50 percent. By 2011, Portland's investments will reduce sewage overflows by 96 percent. Green infrastructure will provide the added capacity and flexibility to minimize stormwater problems and protect public health even as extreme storms grow more frequent and intense in a changing climate.

Staten Island, New York—To overcome the problems of septic tanks leaking sewage into streams and persistent flooding caused by stormwater runoff, Staten Island constructed sanitary sewers and created an innovative stormwater system that utilizes streams and wetlands to transport and treat runoff. The program has drastically reduced flooding and improved water quality, effectively removing 65 percent of total organic carbon, 93 percent of fecal coliform from stormwater runoff, and most excess nutrients. As storms and droughts become more frequent and severe, the program will continue to protect public health, clean water, and local streams.

REDUCING FLOOD AND STORM DAMAGE

Soldiers Grove, Wisconsin—After years of major flooding in the Kickapoo River Valley, the Town of Soldiers Grove decided to relocate its downtown out of the floodplain. By 1983, 49 homes and businesses had been moved out of harm's way. While massive floods in 2007 and 2008 devastated surrounding communities, Soldiers Grove remained largely protected. As climate change brings more severe storms and floods, Soldiers Grove's forward-looking relocation effort will minimize losses and keep residents safe.

Charles River Basin, Massachusetts—To prevent recurring floods that had caused extensive damage in Boston and neighboring communities, the Army Corps of Engineers created an innovative plan to acquire and protect more than 8,000 acres of wetlands along the upper reaches of the Charles River. Those wetlands help prevent $40 million in flood damages every year. As precipitation increases and storms become more intense in a changing climate, wetlands will continue to provide cost-effective and natural protection against floods.



Map of case study communities highlighted in this report.

SECURING CLEAN WATER SUPPLIES

Clayton County, Georgia—While most southeastern communities experienced major water shortages during the 2007-2008 drought, Clayton County was an exception. An innovative water recycling system that filters treated water through a series of constructed wetlands helped the county maintain an abundant water supply throughout the record-setting drought. While nearby Atlanta's Lake Lanier shrunk to a 90-day

Communities that work with neighboring communities to adopt these cost effective, flexible solutions will thrive in spite of the great challenges that climate change is bringing.

supply of water, Clayton County maintained a 230-day supply in its reservoirs. As climate change makes precipitation more variable and uncertain, Clayton County's water capturing and recycling system will ensure a secure and reliable water supply for its residents.

Seattle, Washington—Population growth in the Seattle metropolitan area has strained water supplies during the past several decades. To maintain a consistent supply and ensure enough water remains in streams for ecosystem health, Seattle Public Utilities has undertaken a number of water conservation and efficiency measures. The city has reduced water consumption by 26 percent and per capita water use by 33 percent since 1990. Combined with protecting the lands surrounding drinking water sources and taking a flexible approach to planning, water efficiency and conservation measures will allow Seattle to maintain a safe and consistent supply of water even as rising temperatures reduce the snowpack that the city relies on to fill its reservoirs.

ENHANCING LIVABILITY

Augusta, Maine—When the Edwards Dam was removed in 1999, the Kennebec River began to restore itself. Water quality improved and fish stocks rebounded rapidly. The river's restoration has created new recreational opportunities, boosted the local economy, and improved the quality of life in Augusta. As climate change threatens clean water and fish and wildlife, a healthy Kennebec River will be better able to adapt to changing conditions and allow Augusta to remain a vibrant community.

Grand Junction, Colorado—Grand Junction's rivers were once forgotten places with uranium tailings, salvage yards, and a landfill along their banks. Gradually, local river clean-up projects turned into a valley-wide effort to reclaim the rivers as social, economic, and recreational amenities. Through the creation of riverfront trails and parks, restoration of the riverfront has helped stimulate economic growth and improve quality of life in Grand Junction. The community's restoration efforts will help keep quality of life high, in spite of the challenges brought by climate change.

RESILIENT COMMUNITIES

In sharp contrast to traditional water management approaches that rely solely on pipes, levees, and dams, 21st century green infrastructure solutions preserve and restore natural landscapes, prevent wasteful water use, and work with nature rather than against it. While traditional water infrastructure—dams, reservoirs, pipes, and levees—will continue to have a role, this kind of engineered infrastructure is static and only attempts to solve a single problem. It requires a huge expense to build and maintain, damages the environment, and often exacerbates the problem by causing more development in harm's way.

Communities that invest in a broad suite of green infrastructure approaches like the ones described above will lessen the impacts of an increasingly volatile climate by improving the health of valuable ecosystems, providing flexibility to handle a wide range of conditions and uncertainty, strengthening local economies, and securing multiple benefits.

Communities that work with neighboring communities to adopt these cost effective, flexible solutions will thrive in spite of the great challenges that climate change is bringing.

Healthy ecosystems allow communities and wildlife to thrive even as a changing climate brings more floods, droughts and water pollution.

INTRODUCTION

We stand at a crossroads when it comes to water management in the U.S. Behind us lie centuries of mismanagement that have degraded and stressed the nation's lakes, rivers, and streams, while before us stands the looming threat of climate change. The decisions we make now will determine the health of our rivers and communities for years to come. Communities know this all too well. They have been the beneficiaries of good public water infrastructure investment decisions and the victims of the mistakes.

Clean water is our most precious natural resource. We need it to meet our basic needs and protect our health. Clean water drives economic activity as an essential input in manufacturing, energy generation, and other industries. Healthy rivers, lakes, and streams provide venues for recreation and relaxation and improve our quality of life. Yet, time and time again we have failed to protect our water resources. We have destroyed the forests and wetlands that absorb rainfall, control floods, and recharge streams and groundwater. We withdraw and waste huge amounts of water, weakening ecosystems and endangering water supply. We have replaced natural infrastructure with engineered structures that serve a single purpose at great expense, and we have not maintained these built systems. Vast networks of sewer pipes, levees, and dams that we built decades ago have exceeded their intended life, leaving communities at risk of devastating floods and our waterways full of untreated waste.

But the greatest threat to our water resources has yet to be fully felt. Climate change will alter the nation's rivers and lakes in an unprecedented manner. Rain and snowfall will become more unpredictable and more variable, leaving some places with too much water and others with not enough. Heavy storms will increase the risk of floods and wash pollutants into streams and rivers. Prolonged droughts and decreased

We need to fundamentally transform the way we manage water. We need a 21st century approach that recognizes "green infrastructure" as the core of our water management system.

A green street project in Portland absorbs and filters stormwater.

snowpack may cause the taps to run dry in some communities. Rising temperatures and increased runoff will worsen water quality and threaten species such as salmon and trout.

We need to fundamentally transform the way we manage water. The same approaches we have used in the past will not solve the challenges we face today. We need a 21st century approach that recognizes "green infrastructure" as the core of our water management system. Green infrastructure is the best, most cost-effective, and flexible way for communities to meet their needs and deal with the impacts of climate change. It has three critical components:

Protect healthy landscapes like forests and small streams that naturally sustain clean water supplies.

Restore degraded landscapes like floodplains and wetlands so they can better store flood water and recharge streams and aquifers.

Replicate natural water systems in more urban settings to capture rainwater for outdoor watering and other uses and prevent stormwater and sewage pollution.

In this report, we examine how communities have used innovative, green infrastructure solutions to address water management challenges and become more resilient to the floods, droughts, and other challenges that a changing climate will bring. The first sections discuss climate change impacts in more depth and define the concept of resilience. Then, using eight real-world case studies, we demonstrate that restoring natural landscapes, preventing wasteful water use, and working with nature rather than against it can help communities protect public health, reduce flood damages, secure a consistent supply of clean water, and maintain a high quality of life, even as climate change takes hold. In the final section, we envision how a hypothetical community could implement a comprehensive and sustainable approach to water management and maximize its resilience to a changing climate by holistically applying the kinds of strategies profiled in the case study communities.

If communities are to weather the impacts of a changing climate, they must choose the most effective, flexible, and least costly solutions. This report provides a roadmap of how communities can adopt a 21st century approach to water management and thrive in an uncertain future.

THREE CRITICAL COMPONENTS OF GREEN INFRASTRUCTURE:

- PROTECT healthy landscapes like forests and small streams that naturally sustain clean water supplies.
- RESTORE degraded landscapes like floodplains and wetlands so they can better store flood water and recharge streams and aquifers.
- REPLICATE natural water systems in more urban settings to capture rainwater for outdoor watering and other uses and prevent stormwater and sewage pollution.

Top: A green roof in Portland captures runoff and prevents it from entering the sewer system and causing sewage spills.

Top: Wetlands absorb water and release it slowly, buffering communities against droughts. Bottom: Healthy rivers support recreation and economic growth.

CLIMATE CHANGE:

AN UNCERTAIN FUTURE FOR THE NATION'S WATER RESOURCES

Water resources in the U.S. face a range of threats in a warming climate. Many communities will see their water supplies shrink as temperatures rise and precipitation patterns shift. A rise in severe storms will degrade water quality and increase the risk of catastrophic floods. Changes in the timing and location of precipitation combined with rising levels of water pollution will strain ecosystems and threaten the survival of many fish and wildlife species. These shifts will have dramatic impacts on communities, threatening public health, weakening economies, and decreasing the quality of life in many places.

None of this is happening in a vacuum, however. The consequences of shifting weather patterns will depend in large part upon choices that communities have made in the past and are making now. Cities that do not take steps to safeguard their water supply could see the tap run dry. Those that fail to address aging infrastructure will experience greater increases in stormwater runoff and sewer overflows. Most importantly, communities that have done the greatest damage to their natural infrastructure—wetlands, forests, streams, and rivers—will have fewer defenses to protect them against a changing climate. Decisions related to land use planning, flood protection, water infrastructure, and many other facets of community life have a profound impact on a community's vulnerability in a warming world and will play a large role in determining the repercussions of the following changes.

WATER QUANTITY

Rising temperatures will have a profound effect on water availability. Communities already struggling to meet rising demands may be unable to meet the needs of agriculture, industry, ecosystems, and rising populations. Every part of the country will struggle as weather patterns become more unpredictable and render historical climate records obsolete.

Shifting precipitation patterns

Climate change threatens to fundamentally alter where and when water is available across the nation. Precipitation patterns are shifting, benefiting some regions with additional water while reducing snow and rainfall in other areas. Streamflow has decreased two percent per decade over the last 100 years in the central Rocky Mountain region.[1] Southwestern states will experience the greatest decline in precipitation. The region

Communities that have done the greatest damage to their natural infrastructure—wetlands, forests, streams, and rivers—will have fewer defenses to protect them against a changing climate.

could lose 10 percent or more of its annual rainfall by the end of the century[2] and transition to a climate similar to dust bowl conditions.[3] There will also be significant changes in the timing of precipitation. Many areas will receive less summer rainfall as precipitation shifts increasingly to winter months.[4]

Rising temperatures

Western snowmelt-dominated watersheds will be among the hardest hit in a changing climate. Rising temperatures will cause more precipitation to fall as rain rather than snow and will melt mountain snowpack earlier in the season, reducing the natural reservoir that has historically fed western rivers throughout drier summer months.[5] Between 1950 and 1999 the amount of water stored in snowpack decreased in eight of nine western mountain regions due to human-induced changes to the climate.[6] Losses ranged from 10 percent in the Colorado Rockies to 40 percent in the Oregon Cascades.

Combined with shifting precipitation patterns, many western communities that depend on snowpack will face significant summer water shortages. Across the country, warmer temperatures will also increase evaporation from reservoirs and lakes, offsetting increases in precipitation in some regions and magnifying decreases in western areas.[7] Reservoirs on the Colorado River already lose 1.8 million acre-feet of water to evaporation in an average year, about 13 percent of the river's annual flow.[8]

Extended droughts

In addition to shifting averages, the increase in weather extremes presents a serious threat to many communities' water supply. Precipitation is becoming more variable and more uncertain, leading to more frequent and more intense floods and droughts.[9] The southeastern U.S., once considered water rich, has experienced record droughts over the past several years. With the rise in climate variability, this type of multi-year drought will become more frequent and can impact any part of the country. Resulting water shortages have significant economic and environmental costs. Economic losses due to water shortages in California alone could reach $2.6 billion per year in the near future.[10] The 2009 drought is expected to cause nearly $3 billion in economic losses throughout the state.[11]

Water management

These shifts in water supplies will make management of the nation's water resources increasingly challenging. The historical records water managers use to forecast water availability will cease to be an accurate predictor of future conditions. There will also be greater competition for dwindling water resources among agricultural, municipal, industrial, and ecological uses.[12] Management of over-allocated interstate and international rivers, such as the Colorado and Columbia, is already becoming particularly difficult and contentious as runoff patterns shift.[13] The Colorado River is already over-allocated and there will likely be insufficient water to meet the commitments set out in the Colorado River Compact as flows decrease further.[14] Output from heavily utilized groundwater sources, such as the Ogallala and Edwards aquifers, is also expected to decrease significantly due to excessive withdrawal of these ancient stores, and severe water shortages are likely to result.[15] Even in the absence of major climatic changes, water managers in 36 states anticipate water shortages by 2013, with 46 states expecting water shortages under drought conditions.[16]

WATER QUALITY

The same climate shifts that will challenge water availability will also pose a number of threats to the quality of the nation's water resources. Warming temperatures and changing precipitation pat-

terns could make some water bodies unsuitable for recreation, water supply, and other purposes. At a minimum, water management will be more difficult and more costly due to rising pollution levels.

Increased polluted runoff

More frequent and more powerful storms will increase runoff from urban and agricultural areas, picking up pollutants from the landscape and carrying them to nearby waterways.[17] Nutrients, toxics, pathogens, and other contaminants will find their way into urban streams in increasing concentrations, threatening aquatic species and human health. In older communities where stormwater and sewage are transported together in one pipe, heavy storms can overwhelm the system and send raw sewage and polluted stormwater into nearby streams and rivers. These combined sewer overflows (CSO) will grow more frequent as extreme storms increase. In the Great Lakes region, the frequency of CSOs could increase from 13 percent to 70 percent, and the cost of controlling overflows could rise 10 percent.[18] Even in places with separate sanitary sewers, increased stormwater runoff can infiltrate aging pipes, causing them to overflow with raw sewage. More frequent storms will also wash growing volumes of pesticides and fertilizers from agricultural areas into surrounding waterways.[19]

Lower stream and river flows

Lower flows in rivers and streams due to more frequent droughts and shifting precipitation patterns will aggravate pollution problems.[20] As water levels decline in rivers, lakes, and streams, there will be less water to dilute pollutants, resulting in higher contaminant concentrations. This will make it more difficult and costly to meet water quality and drinking water treatment standards and could make waterways unsafe for swimming, fishing, and boating.

Rising temperatures

As the global surface temperature increases, surface water also warms, reducing its ability to hold dissolved oxygen, which is a key determinant of the type of aquatic life that can survive in a freshwater ecosystem.[21] Low dissolved oxygen levels can stress or kill important fish species and other organisms. Warmer water is also more conducive to algal blooms , which can cause fish kills, threaten human health, and increase water treatment costs.[22]

EXTREME STORMS

Rising global temperatures and climate variability will increase the frequency and severity of extreme storm events.[23] The intensity of storms is regulated by the amount of moisture in the atmosphere. Atmospheric capacity to hold moisture increases exponentially with temperature, leading to a greater capacity for heavy precipitation events and floods.[24] Nationwide, the number of storms with extreme precipitation has increased 24 percent since 1948.[25] This trend is expected to continue in the future.

Increased runoff from more severe storms will cause greater pollution.

Rising damages

Resulting floods will claim lives and destroy property, especially in communities built in floodplains. Already in the 21st century, floods caused more property damage and fatalities in the U.S. than any other type of natural disaster.[26] While no single flood event can be directly attributed to climate change, the recurrence of devastating 100-year and 500-year floods throughout the Midwest and other areas in recent years may foreshadow a future where repeated disasters of this magnitude are much more common.

Seasonal variation

Accelerated spring snowmelt will magnify the size of floods from extreme storms in mountainous areas. In the western U.S. especially, more precipitation will fall in the winter and spring, and snowpack will melt earlier in the season. The combination of rapidly melting snow and heavier spring rains could cause catastrophic floods in vulnerable communities.

Heavy precipitation is already causing more flooding and sewage spills. In the Great Lakes region, the frequency of combined sewer overflows could increase 13-70%.

RESILIENCE:

THRIVING IN THE FACE OF CLIMATE CHANGE

Much of the debate related to climate change focuses on reducing greenhouse gases—rightfully so considering that unabated emissions would have catastrophic consequences for the planet. Most communities and policy makers have largely ignored the development of strategies and metrics needed to adapt to shifting weather patterns. Even if all carbon emissions stopped today, we would experience rising temperatures and many other impacts due to past fossil fuel consumption and deforestation.[27] Resilience is a concept that captures a community's ability to withstand these impacts. In order for the term to be useful, however, it must have a clear definition. Resilience has been interpreted differently over decades of use in ecology, disaster management, and other fields.[28] In this report, we propose combining multiple uses of the term to create a unified concept that defines resilience as the ability of a community to absorb disturbances or stresses caused by climate change without experiencing catastrophic losses or losing essential functions. This definition encompasses multiple ideas including the ability to resist impacts from a disturbance, the ability to recover and respond productively, and the capacity to learn and adapt to changing conditions in order to limit future vulnerability. It stands in contrast to the narrower view of resilience that focuses on returning an ecological system to its pre-disturbance state.[29] Instead of focusing on maintaining the "original" condition of an ecosystem or community, we emphasize continued functioning in the face of a changing climate.

Working from this definition, this report focuses on *how* communities can become more resilient in light of a changing climate. Taking steps to adapt to a changing climate does not guarantee that communities or ecosystems will become more resilient. In fact, management actions can either enhance or diminish resilience.[30] In this report we propose a suite of water management strategies that make communities better able to weather the impacts of climate change and maintain the flexibility to respond to shifting conditions. This section outlines four ways in which the solutions discussed in this report build resilience: strengthening ecosystems, creating flexible infrastructure, diversifying local economies, and providing multiple benefits.

SUSTAINING ECOSYSTEMS

In debates over land use, pollution control, and the preservation of natural resources, there is often a perception that the choice comes down to people versus the environment. A town can either protect wetlands or allow new development that could increase tax revenues.

RESILIENCE:
The ability of a community to absorb disturbances or stresses caused by climate change without experiencing catastrophic losses or losing essential functions.

Where rivers, wetlands, and forests are able to withstand the impacts of a changing climate and continue to provide ecosystem services, communities will suffer fewer negative consequences, be better able to recover from disturbances, and will have the flexibility to adapt to changing conditions. In a word, they will be more resilient.

This is a false choice. Whether they acknowledge it or not, every community depends on rivers, forests, and wetlands to provide clean water, protect public health and property, and drive economic growth. In a changing climate, the services provided by healthy ecosystems will be even more important to protect communities from severe storms, filter rising pollution levels, and maintain a consistent supply of clean water. For example, wetlands and forests can absorb the floodwaters that will strike with increasing regularity in a changing climate, preventing the loss of life and destruction of homes and businesses. The ability of communities to survive and prosper will depend in large part on the health and resilience of ecosystems and their ability to provide vital services.

How then can a community make ecosystems more resilient and ensure that they continue to provide vital services? Much like communities, ecosystems have a limit to the amount of stress they can absorb before they undergo fundamental changes and lose essential functions.[31] A more resilient ecosystem is better able to withstand disturbances and rebuild itself if damaged. In the past, human activities have undermined resilience and the self-repairing capacity of ecosystems.[32] We must instead focus on reducing existing stresses and providing natural buffers so that ecosystems can absorb the effects associated with a changing climate. This could mean reducing nutrient-laden agricultural or urban runoff by installing a stream buffer. Healthier stream systems will be better able to process the excess nutrients carried by increasingly severe storms without experiencing large algal blooms or loss of biodiversity. The management strategies profiled in this report improve the ability of ecosystems to withstand the impacts of climate change and recover from the unpredictable extremes of an uncertain future. In order to create truly resilient ecosystems, however, communities must work together to implement these strategies across entire watersheds, not just at the local level. It is only through coordinated, basin-wide action that communities can ensure that their natural resources will be capable of weathering the profound effects climate change will have on all ecosystems.

In sum, community resilience is closely connected to the health and resilience of the ecosystems on which it relies. Where rivers, wetlands, and forests are able to withstand the impacts of a changing climate and continue to provide ecosystem services, communities will suffer fewer negative consequences, be better able to recover from disturbances, and will have the flexibility to adapt to changing conditions. In a word, they will be more resilient.

FLEXIBLE INFRASTRUCTURE

Sustainable water management strategies function better in a changing climate both because of their innate ability to handle a wide range of conditions and because they can be more easily adapted to changing conditions. In fact, communities are better off using these strategies even without the added impetus of climate change. Wetlands absorb rainfall and protect communities from flooding.[33] A typical one-acre wetland can store one million gallons of water on average.[34] Wetlands also buffer against drought by recharging groundwater and gradually filtering and releasing water, maintaining constant stream flow even during dry periods.[35] As extreme droughts and floods grow more common, this ability to buffer ecosystems and communities from a wide range of conditions will be essential to thriving in the face of climate change. Construction of a flood control levee, on the other hand, might reduce damages from heavy rains, but it will not help protect against droughts.

Another key benefit of sustainable water strategies is that they are decentralized and can be scaled up according to need. Traditional engineering solutions such as dams, sewer expansion projects, or water supply pipelines cost billions of dollars and require years to complete the design, permitting, and environmental review processes. Once they are completed, it is difficult or impossible to alter their capacity or function to adapt to changing conditions. For example, if a deep tunnel project designed to control combined sewer overflows does not incorporate climate change projections into the planning process, making adjustments to expand its capacity would be extremely costly

Healthy wetlands will buffer communities from more frequent and severe droughts and floods.

and time consuming. Green infrastructure, on the other hand, provides a community with the ability to embed additional green roofs, rain gardens, and swales throughout the urban landscape in order to slow and retain stormwater as additional capacity is needed, precluding the need for additional pipes or treatment plants. This can be done without extensive permitting and environmental reviews and can be expanded over time. Water efficiency efforts can similarly be enhanced to address increasing droughts and shrinking water supplies as the climate shifts.

This flexibility is essential for communities that struggle with stormwater, sewer overflows, or water supply problems as they face the uncertainty of climate change. Rigid engineering systems that seek to control water are inflexible and static, undermining resilience and increasing the likelihood of collapse.[36] Building resilience is about dealing with unpredictability and innovating as conditions change.[37] Decentralized approaches such as green infrastructure and water efficiency allow a community to learn and adapt their water infrastructure as the local impacts of climate change become evident. They do not lock a community into one set of solutions in the face of future uncertainty.

In order to maintain a flexible, responsive infrastructure, however, communities must have the financial flexibility to adapt and adjust their public works investments. In every case study we examine in this report, the sustainable water management strategies provide substantial cost savings over traditional engineering solutions. Clayton County's wetland and water reuse system proved far less costly than an advanced treatment plant while also providing water supply benefits. Portland has saved tens of millions of dollars on stormwater management by incorporating green infrastructure. Other analyses have found similar savings.[38] The savings provide communities with greater financial flexibility to continue adapting their infrastructure to changing conditions, which in turn allows them to minimize damages and recover from disasters. In an era of economic uncertainty, declining tax revenues, and growing budget deficits, this flexibility will be essential.

STRENGTHENING LOCAL ECONOMIES

The economic consequences of a changing climate are difficult to predict, but there is no doubt that the impacts will be significant. Unabated emissions could lead to a five to 20 percent reduction in global GDP.[39] Locally, the impacts could be greater depending on the economic industries that support a community. The strength of local economies is undoubtedly closely intertwined with the overall well-being of communities. Reducing the vulnerability of key industries to climate change and water im-

Downspouts disconnected from sewers prevent sewage overflows, and rainwater can be captured in rain gardens as at this building in Portland.

pacts while limiting local government service expenses can help protect and boost local economies.

Proactive efforts to reduce the vulnerability of individual industries and create a broader economic base can build resilience to the potential economic impacts of a changing climate. The strategies discussed in this report strengthen ecosystems and improve their ability to withstand the impacts of climate change. This will help ensure that the economic sectors that depend on a clean and consistent supply of water will also be less vulnerable. The Charles River wetlands, for example, help maintain water quality in the lower basin where river recreation and the scenic values of the protected riverfront generate considerable economic activity. In addition, a number of communities have created new industries and fueled growth by reconnecting to their rivers and promoting their natural resources. Restoration efforts in Grand Junction and Augusta have helped revitalize local economies and expand recreation and tourism activities. These new economic activities diversify the local economic base and provide a greater ability for a community to respond to change.[40] Finally, the solutions discussed in this report have made communities more livable and more attractive places to do business. A better quality of life will help employers attract the best workers, making it more likely that a community will create new jobs and retain existing ones.

River restoration efforts promote recreation and boost economic growth.

ACHIEVING MULTIPLE BENEFITS

All of the water management strategies discussed in this report have benefits that extend far beyond their primary goal of reducing runoff, improving water quality, or reducing flooding. Many of them address multiple water management challenges. For example, healthy wetlands absorb floodwaters, filter pollutants, provide wildlife habitat, and buffer against droughts. Other strategies provide benefits unrelated to flooding or water supply. In addition to controlling stormwater, green roofs lower ambient air temperatures, decrease heating and cooling bills, and improve air quality. These multiple benefits address the immediate needs of a community such as unhealthy levels of air pollution, poor water quality, and deteriorating infrastructure in addition to building resilience to the impacts associated with rising temperatures. On a pragmatic level, these multiple benefits can be a primary motivating factor for local leaders that have limited resources to deal with what they perceive as more immediate and tangible problems than climate change.[41] They can also increase a community's resilience to a diverse range of threats from declining air quality to heat waves and help them prepare for an uncertain future.

Healthy ecosystems benefit communities and provide vital wildlife habitat.

CASE STUDIES

The eight case studies presented in this section demonstrate how innovative and sustainable water management strategies allow communities to overcome existing water management problems and prepare for the larger challenges that a changing climate will bring. Each case study describes the historical problems that the community faces, the strategy they are using to address the problem, the tangible benefits demonstrated to date, and how this will help reduce vulnerability as the climate shifts. The success of these projects proves that a water management strategy based on protecting natural landscapes, restoring degraded ecosystems, and replicating natural water systems can solve a diverse range of water management challenges.

The case studies are organized into four categories to highlight the primary benefit provided to communities by each management strategy: protecting public health, securing reliable clean water supplies, reducing flood and storm damage, and maintaining a high quality of life. As temperatures rise and weather becomes more unpredictable, these strategies will become even more important. Organizing the case studies into these four categories is not meant to reinforce the outdated notion that water supply, flood control, and stormwater management should be addressed separately. Instead we emphasize that water is best managed in an integrated and comprehensive fashion by highlighting the multiple benefits each approach provides. For instance, the green infrastructure projects used in Portland help recharge groundwater, lower temperatures, and beautify neighborhoods in addition to controlling stormwater. While each strategy is particularly effective in addressing one issue, communities can utilize a suite of similar approaches as they prepare to respond to the pressures that a changing climate presents.

Green infrastructure will provide the added capacity and flexibility to minimize stormwater problems and protect public health even as extreme storms grow more frequent and intense in a changing climate.

IMPROVING PUBLIC HEALTH

Portland, Oregon— Integrating Gray and Green Infrastructure

Summary

In response to stormwater runoff and sewer overflows that have long degraded water quality and threatened public health, Portland adopted a number of green infrastructure solutions in addition to expanding sewer and stormwater pipes. The city's "green street," ecoroof, and downspout disconnection programs, while still in early stages, currently capture 8 percent of the city's annual stormwater runoff and have potential to absorb about 50 percent. By 2011, Portland's investments will reduce sewage overflows by 96 percent. Green infrastructure will provide the added capacity and flexibility to minimize stormwater problems and protect public health even as extreme storms grow more frequent and intense in a changing climate.

Challenge

As with many older cities in the U.S., Portland has spent decades working to save its rivers and streams from the sewage and stormwater pollution it produces every time it rains. At the root of the problem are the acres of streets, roofs, and parking lots that have replaced forests and wetlands as the city developed. Rather than soaking into the ground and replenishing water supplies, the city's ample rainfall gathers on hard surfaces and flows into the sewer system and local waterways. Stormwater runoff picks up oil, fertilizers, heavy metals, pathogens, and other pollutants as it flows through the city. Portland's annual average precipitation of 37 inches creates 20 billion gallons of stormwater runoff per year.[42]

In addition, much of the city is served by a combined sewer system, which transports sewage and stormwater runoff in the same pipes. These systems are common in older cities throughout the Great Lakes and coastal regions. When stormwater exceeds the capacity of the pipes, which may occur even during small storms, the system is designed to send the excess flow of raw sewage and stormwater, called a combined sewer overflow (CSO), into local waterways. More modern separate sewer pipes serve newer sections of the city, but the combined system still services approximately 35 percent of Portland's area and 60 percent of its population.[43] Nearly every time it rains, raw sewage flows into the Columbia Slough and the Willamette River from the city's 55 outfall pipes.[44]

Stormwater and sewage pollution take a heavy toll on human health and local ecosystems. Nationwide, stormwater runoff is a leading cause of water pollution.[45] The pathogens contained in untreated sewage and stormwater can cause diarrhea, skin and eye infections, organ failure, and even death.[46] Up to 3.5 million

Portland, Oregon

Left: 60% of Portland's population is served by a combined sewer system that dumps raw sewage into local waterways when it rains. Middle: Sewer overflows in Portland have a long history of contaminating the Willamette River and making it unsafe for recreation. Right: Nationwide, up to 3.5 million people fall ill from coming in contact with raw sewage every year.

people fall ill from contact with untreated sewage in the U.S. every year,[47] mostly during swimming, boating, or other recreational activities. Stormwater also has significant impacts on freshwater ecosystems and aquatic species by increasing water temperatures, altering river flows, and transporting pollutants that reduce oxygen levels and accumulate in organisms' tissues, sometimes at toxic levels.[48]

Stormwater runoff and sewer overflows have long been a threat to human and ecosystem health in Portland. CSOs contribute over 40 percent of bacteria loading to the mainstem Willamette.[49] Along with urban runoff, they have historically been major causes of poor water quality in both the Columbia Slough and Lower Willamette River, leading to violations of standards for dissolved oxygen, temperature, pH, phosphorus, bacteria, and a range of toxic pollutants including mercury.[50] Dangerous chemicals transported by runoff have been found in fish of both the Willamette and Columbia Slough, including PCBs, dioxins, mercury, and pesticides. High consumption of fish from the Willamette can increase the risk of cancer and lead to immune system and developmental problems.[51]

With the Willamette River Basin home to over 70 percent of Oregonians and 75 percent of Oregon's economy, clean water is particularly important, especially in the Portland metro area.[52] Since the early 1970s, Portland has worked to increase access to the river with riverside parks, picnic areas, boat ramps, a yacht club, and a marina in its downtown.[53] Pleasure boating, water skiing, and angling on the Willamette are all increasing, making recreation the fastest-growing use of the river.[54] This increase in river recreation will raise the risk of exposure to waterborne disease, making it imperative that Portland improve water quality and provide a safe environment for paddlers.

Portland's Approach

Portland has embraced a combination of traditional engineering solutions and innovative green approaches to solving its stormwater and sewage problems. In 1991, under an agreement with the state, the city committed to spending $1.4 billion to reduce sewer overflows system-wide by 96 percent by 2011.[55] The CSO reduction plan called for construction of new sewer lines and large pipes to store sewage during storms and prevent it from entering the river. More recently the city has turned to small-scale green techniques such as green roofs, swales, and downspout disconnections which replicate natural systems such as forests and wetlands by retaining and filtering stormwater. This approach reduces the amount of stormwater that enters sewers, reducing the potential for overflows. Portland has conducted pilot projects and instituted a number of incentives for green infrastructure over the past decade. In 2008, the city significantly expanded these efforts through its Grey to Green initiative,

Left: A combination of gray and green infrastructure improvements will reduce overflows 96% by 2011 and make the river safer for recreation.
Middle: Across the city, curb extensions, rain gardens, green roofs and other green infrastructure techniques capture stormwater.
Right: Clean water is essential to protecting public health as river recreation in Portland continues to expand.

which will invest $50 million in green infrastructure over five years.[56] This initiative will increase the number of green streets, ecoroofs, and trees while protecting undeveloped open spaces and restoring native vegetation. Portland is pioneering the integration of green and gray infrastructure to control water quality problems and is demonstrating how communities can save money, protect public health, and preserve vital water resources.

Programs

Portland has a variety of sustainable stormwater programs that focus on reducing runoff from different parts of the city including private homes, city streets, and rooftops. A description of the results of these programs is found in the Benefits section below.

Private Homes: Portland has a number of incentives to encourage homeowners to reduce stormwater runoff from their property. Since 1994, 56,000 residents have participated in the downspout disconnection program, which helps homeowners disconnect from the sewer system the pipe that drains water from their gutters.[57] Instead of gathering on roofs and flowing into overburdened sewer pipes, rainfall is diverted to lawns and gardens. Since 2006 the city has also offered stormwater bill discounts to ratepayers who keep stormwater from leaving their property through the Clean River Rewards Program.[58] Residents can install rain barrels, cisterns, rain gardens, or other projects to control their stormwater. The city offers free workshops to help participants plan projects, obtain permits, and ensure proper installation and maintenance.

Green Streets: Portland has worked to decrease the runoff from city streets by building swales, rain gardens, and curb extensions to retain and absorb stormwater. Under the Green Streets Program, the city has experimented with these types of fa-

Green roofs in Portland retain 60% of rainfall on average, preventing sewer overflows into the Willamette River.

cilities in pilot projects since 1990, three of which have received honor awards from the American Society of Landscape Architects for General Design.[59] In 2007, the Portland City Council approved a Green Streets resolution and policy to promote and incorporate green street facilities into future projects.[60] The city plans to build 920 Green Street facilities in public rights of way through the Grey to Green initiative by 2013.[61]

Green roofs: Green roofs, also known as ecoroofs, refer to the installation of vegetation and soil over a synthetic, waterproof membrane on a roof surface. The vegetated surfaces retain rainfall and reduce stormwater runoff, provide energy savings, and improve air quality. Portland has installed greenroofs on nearly 90 buildings since 1996 and plans to add another 43 acres by 2013.[62] The city has expanded the area by requiring all new or replaced roofs on city buildings to have at least 70 percent ecoroof coverage and by offering incentives to residents.[63] Stormwater fee reductions through the Clean River Rewards program are available for properties with ecoroofs. In 2008, Portland's Grey to Green initiative added grant incentives which pay up to $5 per square foot of new ecoroof projects.[64]

Kansas City, Missouri—10,000 Rain Gardens

Kansas City has a combined sewer system that overflows more than 20 times per year, dumping 6.3 billion gallons of untreated sewage and stormwater into local waterways.[92] In response to pressure from EPA and residents, the city launched the 10,000 Rain Gardens Program in 2005.[93] The Rain Garden program is a public-private initiative involving citizens, corporations, educators, nonprofits, and local government agencies that works to educate the public and promote citizen involvement in reducing flooding and improving water quality. Since 2005, they have registered 254 rain barrels, 304 rain gardens, and two green roofs in the Kansas City Metropolitan Area.[94] Kansas City has recently incorporated rain gardens and other green infrastructure approaches into its sewage overflow and stormwater plans, with $5 million dedicated to the 10,000 Rain Gardens program over the next ten years[95] and over $200 million planned for green infrastructure projects.[96]

Planning

The City of Portland employs a watershed management approach in which all of its services and activities are designed and implemented in a manner that protects and enhances watershed health. The city evaluates the condition of its watersheds and works with various stakeholders, from watershed councils to state, federal, and city agencies to improve their health. Watershed plans help prioritize localized actions such as stormwater retrofits to existing development to maximize water quality improvements. The city has also emphasized monitoring to assess the effectiveness of its strategies. Prior to the city's recent commitment to green infrastructure, Portland conducted a number of pilot projects. Monitoring data from these projects provided the city with the information needed to make a science-based assessment of how green strategies could contribute to meeting future stormwater goals.

Funding

When Portland began experimenting with green infrastructure as a

Chicago, Illinois—Green Roofs

With over 517,633 acres of green roofs, Chicago has more vegetated roof space than any other city in the country.[97] The city has encouraged green roof construction through a variety of incentives, such as expanding the number of units developers are allowed to build on a property if they install a green roof.[98] The city also offers an express lane for the permit process, allowing projects with green roofs to be reviewed, free of processing fees, and permitted in 30 days, compared to the usual 90 to 100 days. In addition, Chicago requires any developer who receives city assistance (e.g. to rehabilitate a brownfield) to include a green roof. These initiatives will reduce runoff, improve air quality, and keep the city cool as temperatures rise.

stormwater control measure, such approaches were not common. Early funding for the construction and monitoring of demonstration projects came from EPA grants.[65] Today, funding primarily comes from stormwater rates, which were established in 1977.[66] The first year of the $50 million, 5-year Grey to Green initiative will be paid for by increasing stormwater rates by $0.11 per month.[67] Strategic partnerships with other departments are a new but growing source of funding.[68] For example, Portland's Bureau of Environmental Services has partnered with the city's Office of Transportation to create safe routes for pedestrians that are also designed to handle stormwater runoff.

Permitting

Portland's investment in green infrastructure doesn't only help make the city more sustainable, it is also a key part of meeting Clean Water Act requirements. Portland was first required to obtain a stormwater permit in the early 1990s when EPA began regulating stormwater. Under the permit, the city is required to control stormwater pollution to the maximum extent practicable. In Portland's Stormwater Management Plan (2006) and biannual compliance reports, the city relies heavily on its green infrastructure initiatives to demonstrate that it is meeting permit requirements. In its most recent compliance report the city lists the Grey to Green Initiative, Green Streets Program, Clean River Rewards and a variety of other green infrastructure projects in discussing its efforts to reduce stormwater discharges.[69] In addition, these green infrastructure initiatives are helping the city reduce CSOs as required under the agreement with the state. While much of the reduction is being accomplished by traditional engineering approaches, the downspout disconnection program removes more than a billion gallons of stormwater from the sewer system every year, and the growing number of greenroofs, swales, and other projects are further decreasing runoff.

Benefits

Portland's natural stormwater management programs, while still relatively new, have already demonstrated their effectiveness in controlling stormwater runoff. The Downspout Disconnection Program removes about 1.5 billion gallons of stormwater from the sewer system every year.[70] Green Street projects have been shown to retain up to 94 percent of rainfall and to reduce pollutants by 90 percent.[71] Citywide, Green Street projects currently retain and infiltrate 42.6 million gallons of stormwater per year and have the potential to manage 7.9 billion gallons, or 40 percent of Portland's runoff annually.[72] Ecoroofs in Portland have shown similarly impressive results, reducing peak storm flows 81-100 percent and retaining an average of 60 percent of the runoff.[73] Finally, the Clean River Rewards Program has enlisted 36,000 households as of October 2008, all of whom are working to reduce

reduce runoff from their property.[74] These green infrastructure projects retain stormwater, reduce flooding, and remove pollutants.

It is still too early to assess what effect Portland's green infrastructure initiatives are having on water quality throughout the basin. Many of the projects have yet to be fully implemented, although the above results from pilot projects suggest the potential for significant benefits. Portland's traditional sewage infrastructure projects have led to significantly lower CSO discharges to the Columbia Slough since 2000 and have dramatically increased water quality.[75] Water quality in the Columbia Slough and Willamette River will likely improve further with the completion of the city's big pipe project, however there will still be room for improvement from green initiatives. Both waterways are listed as impaired under the Clean Water Act. The Columbia Slough still suffers from elevated temperatures and high heavy metal concentrations and the Willamette River exceeds standards for temperature, mercury, and fecal coliform.[76]

Recreation along the river has increased in recent years, largely due to improvements in water quality. Portland celebrated its first Riverfest in the summer of 2008 to draw attention to the river as an urban asset.[77] Boating of all sorts is extremely popular and there is a robust paddling community. The Willamette River Water Trail has recently been completed and is increasing in popularity as well.[78] While certain activities such as swimming have long been considered unsafe due to poor water quality, more residents are beginning to swim again as bacteria levels drop and the idea of swimming in the river regains acceptance. These improvements in water quality have allowed the Portland Triathlon to use the Willamette River for the swimming stretch of the race for the past two years.

While Portland's integrated approach is proving successful, the green infrastructure projects have demonstrated a number of benefits that traditional concrete pipes do not. Green infrastructure has saved the city significant amounts of money, as demonstrated by the Brooklyn Creek Basin project. Combined sewer pipes in this basin are close to 100 years old, lack the capacity to handle current runoff volumes, and result in sewage overflows into the Willamette River. Solving these problems with pipes alone would cost an estimated $144 million.[79] By integrating green techniques such as swales and trees into the same stormwater plan, the cost will drop to $81 million, saving $63 million.[80] In addition, Portland's Green Street, downspout disconnection, and rain garden projects promote groundwater infiltration and recharge groundwater supplies. Ecoroofs reduce the urban heat island effect, improve air quality, and lower heating and cooling costs. Green Streets also beautify neighborhoods and make roads safer for pedestrians and cyclists by improving sidewalk connectivity and providing vegetated pedestrian islands to cross busy roads.

Climate Change

While Portland has made significant steps towards addressing its water problems, climate change threatens to reverse some of this

Fortunately, Portland's emphasis on green infrastructure provides the city with the flexibility to weather an uncertain future.

progress. Temperatures in the region are expected to increase 2.7-5.8° F by 2040.[81] Precipitation will shift towards winter months, resulting in average increases in streamflow volumes of 15 percent in winter months and decreases of 30 percent in late spring and summer by 2040.[82] Mountain snowpack, which acts as a natural reservoir that maintains summer streamflow, will decline, further limiting summer water supplies. Extreme storms will also grow more frequent and severe. Despite these seemingly confident predictions, the defining characteristic of the future will be uncertainty as precipitation grows more unpredictable and more variable from year to year. Historical records cease to be an accurate predictor of future conditions.

These changes will have important consequences for Portland's water resources. The seasonal shift in weather patterns will exacerbate winter flooding while intensifying summer water shortages. More frequent and severe storms will overwhelm sewage and stormwater infrastructure, sending more polluted wastewater into local waterways. Water systems will need the capacity to handle large amounts of precipitation and the flexibility to manage highly variable conditions. Water quality will be threatened by increased pollutant concentrations and rising temperatures, which encourage pathogen survival, lower dissolved oxygen levels, and cause frequent algal blooms.[83] Salmon and other cold water fish will be especially vulnerable to these changes. As temperatures rise, oxygen levels fall, inhibiting salmon growth rates and making the fish more vulnerable to toxins, parasites, and disease.[84] As much as 20 percent of salmon habitat in the Columbia River Basin (which includes the Willamette River) could reach or exceed the critical 69.8° F threshold, above which salmon survival declines.[85]

Towards Resilience

Portland's integration of traditional and green stormwater management strategies allows the city to address current CSO problems and increase the resilience of its infrastructure and ecosystems to the impacts of climate change. As precipitation shifts towards wetter winter months and the frequency and intensity of extreme storms increase, the pressure on Portland's sewage and stormwater infrastructure will increase. The projected 15 percent increase in winter precipitation will yield an additional three inches of winter precipitation,[86] although the intensity of the storms will determine the effect on flooding and CSOs. The upgraded sewers were not designed to accommodate climate change and are built to handle a storm of 1.2 inches over 24 hours up to four times per winter.[87] If the floods of January 2009 are indicative of future conditions, the extensive upgrades to Portland's sewage and stormwater systems may be insufficient. Those storms dumped over three inches of rain on Portland in 24 hours,[88] resulting in street flooding, road closings, mudslides, and elevated levels of bacteria in the water.[89]

As discussed above, green infrastructure absorbs stormwater runoff and the attendant pollutants, preventing runoff from entering the sewer system and causing overflows. It will counteract the increase in severe weather by effectively adding capacity to the city's stormwater infrastructure, increasing its ability to safely handle heavy storms and prevent CSOs and runoff. Green infrastructure has the added advantage that it is flexible and can be scaled up according to need. If precipitation patterns exceed historical trends used to design sewage and stormwater infrastructure, expanding capacity of pipes and treatment plants would be extremely expen-

sive. Because green infrastructure projects are decentralized and have fewer permitting requirements, new capacity can be added relatively easily by expanding existing initiatives and continuing to embed these techniques throughout the landscape. In addition, because green approaches are more cost effective, Portland will have greater financial flexibility to adapt to climate change with limited funding.

What all of this means is that Portland will have a resilient and flexible infrastructure that will be able to protect public health in a changing climate. Even as the potential for exposure to waterborne disease increases with the rise in river recreation, Portland's innovative approach will allow it to minimize risk by limiting CSOs and runoff.

While protecting public health is the main concern in a changing climate, Portland's integrated approach to CSO and stormwater control will build resilience to a changing climate in other ways. It also adds resilience to local ecosystems and aquatic organisms, both important drivers of the regional economy. Of particular concern is the region's prized fishery which includes multiple species of salmon and trout. The combined pressure from existing problems and climate change will put an enormous strain on ecosystems and could make them unsuitable for certain species. Fortunately, Portland's infrastructure investments relieve existing pressures. Green infrastructure is particularly valuable because it prevents stormwater from flowing into local waterways, reducing the temperature spike that runoff causes, and infiltrating it into the ground, where it eventually flows back to the river as cooled groundwater. By minimizing existing stresses and reducing the impacts of a changing climate, the city is greatly increasing the ability of these ecosystems and organisms to survive and thrive in a warming world. This in turn will help Portland maintain a healthy economy and high quality of life in future years.

Finally, green infrastructure builds resilience to a number of impacts of climate change not related to water quality. Traditional big pipe solutions, in addition to costing billions of dollars, sit empty in dry years and provide no additional benefits. Green infrastructure will benefit Portland in any condition by reducing air pollution, cooling urban areas, and beautifying neighborhoods. These strategies also promote groundwater infiltration, augmenting an important back-up water supply for Portland. Since 1985, the city has had to rely on groundwater on five occasions due to contamination from rain events in its primary reservoir and on an additional twelve occasions due to low water levels in summer.[90] These water supply challenges will only increase as the climate shifts, and Portland could need up to 5.5 billion gallons of additional storage to offset climate-related water losses.[91] Due to these multiple benefits, green approaches will help the city minimize the impacts of heat waves and decreased water availability and will help Portland remain a vibrant, resilient community.

Green Street projects currently retain and infiltrate 36.9 million gallons of stormwater per year and have the potential to manage 7.9 billion gallons.

IMPROVING PUBLIC HEALTH
Staten Island, New York— Utilizing Natural Drainage Systems

Summary

To overcome the problems of septic tanks leaking sewage into streams and persistent flooding caused by stormwater runoff, Staten Island constructed sanitary sewers and created an innovative stormwater system known as the Bluebelt Program that utilizes streams and wetlands to transport and treat runoff. These programs have drastically reduced flooding and improved water quality. Bluebelt facilities effectively remove most excess nutrients, 65 percent of total organic carbon, and 93 percent of fecal coliform from stormwater runoff. As storms and droughts become more frequent and severe, the Bluebelt program will continue to protect public health, clean water, and healthy streams.

Challenge

While Staten Island became the fifth borough of New York City in 1898, it remained largely undeveloped until completion of the Verrazano-Narrows Bridge in 1964. Once the bridge established direct road access to the rest of the city, the island experienced rapid growth.[99] Sewage and stormwater infrastructure, however, did not accompany the construction boom. Residential septic systems proliferated in the absence of sanitary sewers. The lack of storm sewers or any sort of formal drainage system, in combination with naturally high water tables, led to significant flooding problems.[100] New York City constructed stormwater and sanitary sewers on the island in the 1960s and 1970s. However, the southern portion of Staten Island, known as South Richmond, remained without sewers because the City could not come up with a strategy for building sewers that did not damage protected wetlands. During heavy rainstorms, South Richmond continued to experience chronic flooding, which resulted in property damage, eroding foundations, and severe street flooding.[101] At the same time, soil saturation and inadequate septic system upkeep led to basement sewage back-ups and septic failures that sent untreated sewage into groundwater and surface streams.[102]

Stormwater and leaking septic systems posed a significant threat to public health, the economy and ecosystems throughout South Richmond. Stormwater runoff is one of the leading causes of contamination in American waterways.[103] Septic systems are an often-overlooked source of water pollution; nearly a quarter of American households use onsite septic systems to dispose of their wastewater,[104] and 10-30 percent of these systems fail every year,[105] leaking pathogens, nutrients, and other pollutants into groundwater and surface waters. The pathogens contained in stormwater and improperly treated sewage can cause diarrhea, skin and eye infections, organ failure, and even death.[106] Stormwater also has significant im-

Staten Island, New York



Left: Staten Island's lack of adequate drainage caused frequent flooding.
Middle: Without a sanitary sewer system, residents relied on septic systems, many of which leaked regularly.
Right: Stormwater and sewage from septic systems contaminated local waterways and threatened public health.

pacts on freshwater ecosystems and aquatic species by increasing water temperatures, altering river flows, and transporting pollutants that reduce oxygen levels and accumulate in organisms' tissues.[107] For years, residents of South Richmond lived with these problems. One resident recollects septic pollution so bad it caused duck and fish die-offs.[108]

Staten Island's Approach

In an effort to address these problems, the New York City Department of Environmental Protection (NYC DEP) developed a two part plan involving a sanitary sewer system routed around protected wetlands and an innovative stormwater management program. The stormwater plan consists of storm sewers that carry runoff from streets and parking lots to existing streams and wetlands. Before stormwater reaches the stream, it passes through a variety of constructed wetlands, basins, and filters, called Bluebelt facilities.[109] These Bluebelt facilities slow the runoff, remove contaminants, minimize erosion and flooding, and promote groundwater infiltration. The filtered stormwater runoff then flows into streams, which serve as natural drainage corridors that transport runoff from the urban area. The city restores and daylights these streams by re-establishing their naturally meandering channel to reduce water velocity and prevent erosion. The result is an interconnected system of stormwater pipes, wetlands, and streams that drain runoff, filter out pollutants, and recharge groundwater and streams around the island.

NYC DEP began acquiring land along wetland corridors for the project as early as 1991. The agency has since purchased over 250 acres of natural waterways and over 12,000 acres of land which are known collectively as the Bluebelt system.[110] Since construction began in 1997, 40 Bluebelt facilities have been completed, with another eight under construction, two in the design stage, and 40 yet to go.[111] The program currently covers 16 watersheds and is in the process of expanding to wetlands in three additional watersheds. The total area included in the Bluebelt program makes up 14,000 acres or 36 percent of Staten Island's land area.[112] New York City's sustainability plan, PlaNYC, calls for an additional 4,000 acres to be added to the program by 2030.[113]

Planning

Throughout the initial Bluebelt design process, NYC DEP has taken an integrated planning approach that includes engineers, landscape architects, environmental planners, and wetland restoration ecologists from consulting firms and nonprofits.[114] This planning team has prepared four environmental impact statements to evaluate the potential effects on local hydrology and water quality.[115] The project has been carefully designed to protect mature trees, minimize disturbance to existing natural areas, remove invasive plant communities, protect new plantings from herbivores, and restore native vege-

Left: The interconnected system of stormwater pipes, wetlands, and streams efficiently drains runoff and prevents flooding.
Middle: In 2007 a storm that dumped 3 inches of rain in one hour flooded parts of the city but left South Richmond unscathed.
Right: The percentage of homes using septic systems has decreased from 60% in 1998 to 30% today.

tation.[116] The planning team examined over one hundred different stormwater facility designs leading to careful selection of the most appropriate Bluebelt facilities for each individual project.[117] The planning team also incorporates maintenance considerations into the design process. The constructed wetlands are designed to allow easy removal of sediment, which must be regularly removed to ensure continued effectiveness.[118]

Funding

Because the Bluebelt program integrates stormwater management and sanitary sewage collection, planners have been able to secure funding for land acquisition and Bluebelt facility construction through ongoing city-wide water infrastructure initiatives.[119] The city derives much of its water and wastewater infrastructure funding through water and sewer rates.[120] In 1992, after recognizing they could reduce sewer construction costs through the Bluebelt program, the city allocated $22 million for the initial purchase of wetlands in South Richmond.[121] Because the Bluebelt program is funded as part of a larger capital sewer project, exact funding numbers are not available. However, the city estimates that the program has saved over $80 million in construction costs compared with conventional stormwater sewers.[122] Annually, maintenance for the Bluebelt program costs about $700,000 in contractor services.[123] In addition, a staff of 6 full-time NYC DEP employees works on the expansion of the Bluebelt system. The city has minimized maintenance costs through community involvement in the "Adopt-a-Bluebelt-Program," which encourages citizens to maintain and enhance Bluebelt facilities by organizing clean-ups and reporting illegal activities.

The constructed wetlands protect local waterways by removing most pollutants, including 93% of fecal coliform, an indicator of dangerous pathogens.

Permitting

Interagency coordination with departments overseeing parks, recreation, transportation, and city planning was instrumental in successfully navigating the permitting process for the Bluebelt system. Under the Freshwater Wetlands Act, the Bluebelt program would have required over 90 separate Freshwater Wetland permits, one for each Bluebelt facility.[124] Instead, the NYC DEP worked with the state Department of Environmental Conservation to create an approval process that incorporated drainage plans and Bluebelt sites within each watershed into a single permit at the watershed level. This allowed NYC DEP to meet permit requirements and complete the process more rapidly.

Benefits

The Bluebelt program has been highly successful in resolving flooding and improving water quality across the island. It has won numerous awards from environmental, engineering, and landscape architecture groups and is widely viewed as a leading example of innovative stormwater management. The improved drainage has proven its value on several occasions in recent years. When the remnants of Hurricane Ivan hit New York City in 2004, areas of the city experienced property damage and were evacuated due to flooding, while South Richmond, which was hit with 2.25 inches of rainfall in two hours, experienced no flooding.[125] Again in August of 2007, parts of

New York City flooded when 3 inches of rain fell in one hour, inundating the subway system.[126] At the same time, the location that was once home to South Richmond's worst drainage problems experienced no flooding.[127] Nor were there any flood reports in other parts of South Richmond. Reduced flooding has improved winter road conditions and minimized property damages. Marie Bodnar, the Community Board District Manager for the community, praises the Bluebelt program: "It's the best program ever introduced to South Richmond. The Bluebelt program has helped solve a multitude of problems, saved money, and created a more tranquil and pleasant living environment."[128]

The stormwater and sewage infrastructure investments have also greatly reduced the threat to public health throughout South Richmond. The construction of separate sanitary sewers allows homeowners to phase out on-site septic systems which have a history of contaminating local water resources.[129] In 1998, approximately 60 percent of homes relied on septic tanks, while less than 30 percent currently use them.[130] The Bluebelt facilities have also been effective in reducing the impacts of stormwater on the island's waterways. Constructed wetlands reduce discharge to streams around the island by 30-55 percent and lower stormwater velocity 5-23 percent.[131] By reducing the velocity and volume of stormwater runoff, the constructed wetlands minimize erosion and flooding, both of which have been significant problems throughout the island in the past. Constructed wetlands also effectively remove pollutants from stormwater runoff including most excess nutrients, 65 percent of total organic carbon, an important measure of overall water quality, and 93 percent of fecal coliform, an indicator of feces and pathogens.[132] While water quality data from streams and coastal waterways is limited, monitoring shows that the Bluebelt facilities are effectively removing excess nutrients and contaminants that would otherwise cause algal blooms, reduce dissolved oxygen levels, and threaten public health.

These improvements in stormwater drainage and sewage disposal greatly benefit local communities and wildlife. The value of homes near the Bluebelt system has consistently appreciated in recent

Griffin Park—Greenville, North Carolina—Natural Drainage Systems in New Development[143]

How do the costs of green infrastructure stack up against traditional engineering approaches for stormwater management? One study of a new development in North Carolina compared the costs of a 300-acre project. The study found that a natural drainage system would generate some extra expenses, such as $102,400 for rain gardens—more than twice as much as a traditional detention pond. Reductions in other expenses, however, would more than offset those costs. Instead of installing 9,434 linear feet of pipes at a cost of $291,794, the developer could install 4,182 feet of piping, reducing costs by more than 50 percent. Additional savings would come from installing fewer curbs and gutters, reducing road width, and surfacing alleys with crushed stone rather than asphalt or concrete. Altogether, engineering costs would drop by 31 percent. Development costs per lot would fall 30 percent, to $6,234 from $8,934. The developer of the property has since incorporated natural drainage systems into the development.

Seattle, Washington—Natural Drainage Systems

Streets cover one quarter of Seattle's total area, resulting in large volumes of stormwater runoff. In an effort to reduce runoff, Seattle has installed natural drainage systems in pilot projects throughout the city. One example is the 2nd Avenue Street Edge Alternative (SEA) project in the Pipers Creek watershed. Instead of traditional curbs, gutters, and pipes, SEAs use innovative drainage design and landscaping that mimics the natural landscape prior to development. The final project reduced imperviousness by more than 18 percent, using swales, trees, shrubs, and wetlands.[144] Years of monitoring show that the SEA project is able to reduce the total volume of stormwater leaving the street by 98 percent for a 2-year storm event.[145] The City of Seattle has since undertaken natural drainage projects in several other watersheds.

years, enhancing the city's tax base.[133] Community members take pride in the Bluebelt program and actively work to protect it and raise awareness. In a recent city-wide survey, 86 percent of residents from the South Richmond area found their neighborhood to be an excellent or good place to live.[134] An advisory committee made up of about 30 citizens acts as a liaison to the wider community and assists in the program development.[135] Linkages between existing parks and protected lands have resulted in increased habitat connectivity and the return of native wildlife. Red-backed salamanders, green frogs, white egrets, Canada geese, red-tailed hawks, and a number of turtle species have returned to the island.[136] The city has worked to accommodate wildlife communities by building bat boxes, installing fish ladders for migratory fish like American eels, and improving culverts to mimic natural conditions for bottom-dwelling organisms.

Climate Change

Climate change poses a major threat to communities throughout the Northeast, especially those that struggle with stormwater, sewage, and flooding problems. Over the past century temperatures in New York State have increased 1.9°F, annual average precipitation has risen 10 percent, and sea level has risen almost an inch.[137] Projections show a continuation of these trends with temperature increases of 2.5-9°F, precipitation increases of 5-10 percent, and sea level rises of 14-19 inches throughout the region by 2080.[138] There will also be greater variation and unpredictability in precipitation patterns from year to year. Precipitation will shift more to winter months, and there will be longer dry spells and more severe droughts. Low flows will provide less water to dilute contaminants, aggravating pollution problems in urban streams. Warmer temperatures will encourage the spread of pathogens, create more algal blooms, and lower dissolved oxygen, further aggravating water quality problems. Of greatest concern to communities struggling with stormwater and sewage management will be the increase in severe storms. Heavy rain- and snowstorms are likely to become both more frequent and more severe.[139] This trend will increase flooding and polluted runoff flowing to local waterways.

Towards Resilience

By building sanitary sewers and the Bluebelt system, South Richmond has solved most of its chronic water quality and flooding problems, but it has also taken steps that will protect public health and the island's ecosystems in an uncertain future. The pathogens from failing septic systems and stormwater runoff posed a significant threat to residents, and that threat will only grow as the climate shifts. More extreme storms will cause additional flooding and runoff, and soil saturation will increase septic system

The Bluebelt system will protect residents from flooding and water pollution even as the climate shifts.

failures. In addition, the risk of waterborne disease is likely to increase in a warmer climate as higher water temperatures and increased turbidity improve conditions for pathogen survival.[140] The construction of sanitary sewers and Bluebelt facilities will limit the impact of these changes by reducing the number of failing septic systems and preventing extreme storms from causing more polluted runoff from flowing into streams and coastal waters. As a result, South Richmond is better prepared to absorb the impacts of a changing climate without witnessing a rise in waterborne disease or other health problems.

The Bluebelt system also provides the communities and ecosystems in South Richmond with a flexible system that can accommodate a wide range of climate conditions. Traditional storm sewers, if properly designed, might accommodate the increase in extreme weather. During dry periods, however, these costly pipes would sit empty and provide no additional benefits. Staten Island's program provides benefits that will help South Richmond adapt in numerous ways unrelated to stormwater. First, the Bluebelt system improves the health of the island's ecosystems, provides valuable habitat and strengthens populations of wildlife and aquatic species. By removing existing stresses on ecosystems and wildlife, the Bluebelt system will help many species survive the changes brought on by climate change without suffering irreversible harm. Restored ecosystems and open space also beautify neighborhoods, improve quality of life, raise property values, and strengthen local economies, all of which will make the communities of South Richmond better able to thrive in a shifting climate. While traditional stormwater management would have provided an inflexible and one-dimensional solution to existing problems, wetlands and stream restoration have built a system that can better respond to the full range of conditions climate change promises to bring.

Finally, the Bluebelt system has saved New York $80 million in construction costs, providing the city with additional financial flexibility to face future challenges. By utilizing ecosystem services provided by wetlands and streams, the Bluebelt program is able to meet the island's stormwater needs at a lower cost than traditional sewers. The savings will allow the city to meet other critical needs, improve water infrastructure elsewhere, or simply reduce future financial obligations. This will improve the city's ability to further adapt to climate change as it takes hold.

While the Bluebelt system addresses development-related stormwater problems and provides some adaptation capacity to the impacts of climate change, the system was not planned with climate change in mind.[141] The dual pressures of continued development and a shifting climate will test the capacity of the system, and it may be found wanting if climate extremes are not considered in ongoing planning for the Bluebelt system. The system will likely need additional capacity if it is to handle the projected 2.5-6 inch increase in winter precipitation and severe storms that are forecasted over the next few decades.[142] While progress towards solving South Richmond's stormwater and sewage problems to this point is laudable, consideration of changing conditions will be key to ensuring that the community is able to weather an uncertain future.

REDUCING FLOOD AND STORM DAMAGE
Soldiers Grove—Moving Out of Harm's Way

Summary

After years of major flooding in the Kickapoo River Valley, the Town of Soldiers Grove decided to relocate its downtown out of the floodplain. By 1983, 49 homes and businesses had been moved out of harm's way. While massive floods in 2007 and 2008 devastated surrounding communities, Soldiers Grove was left largely unscathed. As climate change brings more severe storms and floods, Soldiers Grove's forward-looking relocation effort will minimize losses and keep residents safe.

Challenge

Originally settled on the banks of the Kickapoo River in the 1850s, the community of Soldiers Grove thrived due to southwestern Wisconsin's abundant forests and fertile soils. However, starting in the late 1800s, extensive logging, agriculture, and urbanization stripped the watershed of its vegetation, and the Kickapoo began to flood the communities that had sprung up along its banks.[146] Flooding soon became a serious and permanent problem, inundating Soldiers Grove in 1907, 1912, 1917, 1935, and 1951.[147] Nearly the entire business district was located within the floodplain, making floods especially disastrous to the community.

After years of requests, Congress finally took action in 1962 and approved construction of a dam 36 miles upstream of Soldiers Grove and a levee at the village to be planned and constructed by the Army Corps of Engineers (Corps).[148] When the Corps presented plans for the levee to the village in 1974, however, it soon became apparent that it was not an economically viable solution. The village would have to contribute an amount equal to twice the town's annual property tax revenue for maintenance every year.[149] The following year, construction of the upstream dam was canceled after it was discovered that it would endanger rare plants and cause water quality problems. As a result, after spending nearly $18 million, the Corps ended all Kickapoo Valley flood control projects, ending any hope for federal flood control assistance.[150]

Meanwhile, the community of Soldiers Grove was slowly dying. Small family farms that once kept the village's businesses running had been declining since the end of World War II. The railroad through town was discontinued in 1939 and the major highway, US-61, was moved to bypass the business district in the 1950s.[151] By 1975, the local economy was failing, and 36 percent of families in the village earned less than $3,000 a year,[152] far less than the regional median income of over $12,000 at the time.[153]

Soldiers Grove's Approach

Without federal support, residents turned to relocation as the only viable alternative. In March of 1975,

Soldiers Grove

Left: The Kickapoo River near Soldiers Grove has a long history of flooding.
Middle: Downtown Soldiers Grove during one of the many floods that inundated the community throughout the 20th century.
Right: The 1978 flood devastated the community of Soldiers Grove yet brought Federal support for relocation.

the village hired a relocation coordinator and put together a Citizen's Planning Committee to advise the relocation efforts.[154] With several small state and regional grants, Soldiers Grove undertook a feasibility study, which concluded the only viable option was to relocate the town at an estimated cost of $3 million.[155] A second study investigating implementation and funding options put the cost closer to $6 million. By the end of 1976 the village board took the unprecedented move of passing a resolution in favor of relocation.[156] Although it did not commit the village to any specific actions, the resolution was highly contentious due to lack of federal funding and disagreement among home and business owners. In 1977, the village invested $90,000 of its own funds to purchase a site for the new downtown.[157] Although several small grants from state sources were awarded to help relocate Soldiers Grove, they were far from sufficient to fund the move.

In July of 1978, the Kickapoo River hit the village with a record flood. The flood left two dead, inflicted a half-million dollars in damages to the business district, and destroyed several buildings.[158] With a statewide mandatory floodplain zoning ordinance in place as of 1975, new development and major repairs on buildings within the floodplain were prohibited, leaving the village with few options for recovery.[159] The extent of the damage spurred then-U.S. Senators William Proxmire and Gaylord Nelson to help secure federal support for relocation. The Department of Housing and Urban Development granted the village $900,000 in the fall of 1978 to begin relocation.[160]

Before starting the process, however, Soldiers Grove worked with the University of Wisconsin to conduct studies on the best possible land use plan for relocation, options for energy efficiency, and the community's business capacity.[161] These studies helped the community finalize relocation plans and explore the possibility of committing to solar energy and energy efficiency. Spurred by the energy crisis of the 1970s, Soldiers Grove decided to move past rebuilding in a traditional manner and instead invested in passive solar, super-insulated, energy efficient buildings. New buildings incorporated advanced technologies that reduced heating bills by 75 percent.[162] The village also passed ordinances requiring new buildings to meet

As climate change brings more severe storms and floods, Soldiers Grove's forward-looking relocation effort will minimize losses and keep residents safe.



Left: Floods in 2007 and 2008 devastated neighboring Gays Mills but not Soldiers Grove.
Middle: City park along river near where the downtown used to stand.
Right: The 2008 flood scoured Soldiers Groves community park, near where the old downtown once stood.

thermal performance standards twice as stringent as those required by state law at the time and mandating that all new commercial buildings receive at least half their heating energy from the sun—the first such ordinance in the nation.

By 1983, the relocation process was completed. The business district, made up of 39 businesses, was moved a half-mile to the south to ground 55 feet above the old town center.[163] The new business district once again borders U.S. Highway 61. In addition, 10 families moved to homes outside of the floodplain, and 12 homes were elevated to protect them from high water. Other residential neighborhoods remained outside of the floodplain. The vacated area was planted with native vegetation and converted into a municipal park. It now houses basketball and tennis courts, picnic areas, baseball fields, a skateboard park, and a playground.[164] Although original relocation plans called for the removal of levees that had been built in the late 1960s around the old downtown, those levees remained after relocation.[165]

Planning

Years of planning preceded the relocation of Soldiers Grove. Much of it was organized by the relocation coordinator the town hired in 1975. The coordinator directed all relocation efforts and pursued funding with assistance from the village president and the Citizen's Planning Committee. Through local and regional grants, Soldiers Grove was able to research their options and create a comprehensive flood prevention plan. When the 1978 flood provided the needed catalyst to secure federal funding, the comprehensive prevention plan was converted into a flood recovery plan and provided an outline for action. The studies conducted in cooperation with the University of Wisconsin helped Soldiers Grove to explore rebuilding opportunities and embrace a sustainable plan for their new business district.

Funding

Due to the small population and limited financial resources of Soldiers Grove, the village had to piece

Grand Forks, North Dakota & East Grand Forks, Minnesota—Levee Set-back and Greenway

Sitting on the banks of the Red River, Grand Forks, ND and East Grand Forks, MN have experienced twelve major floods since 1870.[187] The record flood of 1997 was particularly destructive as it flooded 75 percent of Grand Forks and 95 percent of East Grand Forks, resulting in the evacuation of 56,000 people and up to $2 billion in damages.[188] Within four months of the flood, the communities began relocating 1,100 homes and businesses out of the most affected neighborhoods.[189] Due to low soil stability, the Corps decided to set the flood control levees back from the river, allowing the river to naturally overflow onto the newly-vacated floodplain. In addition, a consultant worked with local citizens to develop a plan for a new recreational area along both sides of the river. From there, the communities took charge of the plan and have since created a popular open space area called the Greenway. Completed in 2006, it includes over 2,000 acres of green space with trails, campgrounds, boat access, golf courses, and other recreational opportunities. The Greenway is home to festivals, races, and tournaments, and is an important driver of the local economy.

Soldiers Grove's relocated business district sits half a mile to the south and 55 feet above the old town center, safe from even the largest floods.

together a number of external funding sources to pay for the relocation. Numerous state and regional grants supported coordination and planning of the relocation. The total cost of the project was $6 million. Federal assistance covered 60 percent of that amount, and state, local, and private investments made up the balance.[166] Major federal funding included over $3 million from the Department of Housing and Urban Development (Community Development Block Grants), $500,000 from the Economic Development Administration, and $650,000 from Department of Interior Land and Water Conservation funds.[167]

Benefits

The Soldiers Grove relocation has rescued the town from the recurring floods that threatened residents' lives and the town's existence. The improvement in flood safety is indisputable. In August of 2007, flood waters churning down the Kickapoo River recorded the largest flood in the history of the village.[168] After more than a foot of rain, the river raged over Soldiers Grove's abandoned downtown. The waters inundated the municipal park and campgrounds, taking ten days to finally recede, but the village sustained little damage beyond a partially collapsed road. While Soldiers Grove stood protected, downstream communities did not. Gays Mills, located within the Kickapoo's floodplain 10 miles from Soldiers Grove, received the worst damage. The river crested at over 19 feet in Gays Mills, more than 6 feet above flood stage.[169] Approximately 75 homes were damaged and inundated with up to four feet of water.[170] Many residents lost cars, furnishings, and other belongings. Electricity and gas services were out for days. Damages throughout Crawford County, home to both towns, totaled $10 million.[171]

Ten months later, while the region was still recovering from the previous year's disaster, a new flood record was set. In June 2008, the Kickapoo crested near 21 feet, inundating riverside communities. Despite the enormous destruction elsewhere, none of the relocated homes in Soldiers Grove flooded. Floodwaters overwhelmed an old levee, damaging the riverside park and 30 homes that had been floodproofed, but not relocated in 1978. Elsewhere the damage was far worse. Approximately 175 homes and businesses were damaged in Gays Mills alone.[172] Just a week prior, the Gays Mills Village Board had approved a study by the Corps of Engineers to find ways to prevent future floods and earmarked money to buy out some of the

homeowners that live in the most flood prone areas of the village.[173] Some residents of the town have given up following the 2008 flood, and 30-45 homes remained vacant months later. An estimated 120 people (1/5 of the population) have not returned to the town.[174] In November 2008, the Village Board voted to move ahead with a FEMA proposal for partial, voluntary relocation.[175] Thirty years and several devastating floods later, Gays Mills now starts down the path that Soldiers Grove chose in the 1970s.

The relocation of Soldiers Grove has also helped revitalize and stabilize a community in decline. It gave the community an opportunity to embrace a more sustainable future through energy efficiency and solar heating. As of 1991, eight out of ten businesses were still heated by solar energy.[176] The town park built on the site of the old business district receives frequent use. The town's economic activity has reversed its decline. By the time relocation was completed in 1983, the town had added several new businesses and gained 47 jobs relative to 1978.[177] The town center is once again adjacent to the state highway, which is a source of economic activity. Since 1983, the population of Soldiers Grove has stabilized at roughly 600 people[178] and 75 percent of surveyed citizens consider the relocated village to be as good as or better than the previous location.[179]

Climate Change

A changing climate poses a serious threat to flood-prone communities throughout the Midwest. Already in the past 20 years, the region has experienced record-breaking floods in 1993, 2007, and 2008. Throughout the Great Lakes region, annual average precipitation is expected to increase five to 10 percent by the end of the century,[180] but it is the continued rise in severe storms that will present the greatest challenge. The intensity of storms is regulated by the amount of moisture in the atmosphere. Atmospheric capacity to hold moisture increases expo-

Tulsa, Oklahoma—Urban Relocation

Situated on the wide Arkansas River in a region known as tornado alley for its violent summer thunderstorms, Tulsa, OK is well acquainted with flooding. While average rainfall is approximately 37 inches, storms have produced as much as 15 inches of rainfall in a few short hours. In the 1970s and 1980s, recurring floods made Tulsa home to the most federally declared flood disasters in the nation, with nine declared disasters in 15 years.[190] The city passed its first floodplain ordinance in 1977 and subsequently moved 33 homes out of high risk areas. Another 30 homes were moved in 1979. But it wasn't until the Memorial Day flood of 1984, the worst in Tulsa's history, when the necessity of a comprehensive flood management program became evident. The historic flood killed 14 people, injured 288 others, destroyed or damaged over 7,000 buildings, and caused $184 million in damages.[191] In response, the city relocated 300 homes and a 228-pad mobile home park through a voluntary buy-out program. They also instituted rebuilding restrictions, built structural and non-structural flood control works, and created master drainage plans. Since then, Tulsa has cleared more than 900 buildings from its floodplains, although 8,500 buildings remain in harm's way.

nentially with temperature,[181] meaning that the 6-8° F increase in annual average temperature throughout the region by 2100[182] will cause a rise in the number of extreme storms. In fact, projections show that extremely heavy precipitation events in southern Wisconsin will become 10 to 40 percent stronger by the end of the century.[183] This will lead to more frequent flooding, increased property and infrastructure damage, higher insurance rates, increased clean-up and rebuilding costs, and a greater threat to human health. Communities that have historically been victims of damaging floods will need to adapt to these changing conditions or risk even greater destruction in the future.

Extreme precipitation events in southern Wisconsin will grow 10-40% stronger by the end of the century, but Soldiers Grove is well prepared to meet the challenge.

Towards Resilience

By moving out of the floodplain, Soldiers Grove has corrected the mistakes of its founders who stripped the watershed's natural flood protection and placed their homes in harm's way. The move was also essential to ensuring a viable future in a shifting climate. One need look no further than neighboring Gays Mills to envision what Soldiers Grove would have experienced without relocation. The two 500 year floods that stormed down the Kickapoo River in less than ten months wreaked havoc in Gays Mills, while Soldiers Grove stayed largely safe and dry. Gays Mills has to once again go through the costly and onerous process of rebuilding. If these floods foreshadow future conditions as climate models predict, the relocation will save lives and prevent the repeated loss of homes and businesses. Despite the success of relocation, however, the damages Soldiers Grove experienced in 2008 show where the town can continue to improve. The old and deteriorating levees surrounding the old downtown will need to be removed, and the homes on the edge of the floodplain that were damaged in the floods may need to be relocated.

The importance of preserving floodplains in a changing climate is not confined to the immediate reduction in flood damages. Massive floods like those that struck Gays Mills in 2007 and 2008 do more than destroy property. They undermine community cohesiveness, drive families away, and weaken the local economy. Following the 2008 flood, Gays Mills is in disarray and many residents have not returned. 87 percent of the town's businesses suffered direct economic losses from the 2007 flood, while 62 percent lost money due to the 2008 flood.[184] Business owners felt that the flood changed the dynamics of the town, noting especially "lack of community leadership, deteriorating aesthetics, and increasing uncertainty about the future of the village."[185] An economic analysis following the 2007 flood found that a one month closure of the 19 Gays Mills businesses located in the floodplain would lead to a $2.3 million economic loss for the county.[186]

Instead of halting economic activity and spending scarce financial resources on clean-up, Soldiers Grove has been able to continue life as normal. In a future defined by floods like those that struck Wisconsin in 2007 and 2008, Soldiers Grove will be a more resilient community because of its capacity to limit damages and recover more quickly. Rather than leaving themselves at the mercy of unpredictable weather patterns, the relocation project has allowed Soldiers Grove to determine its future, and it will reap the benefits for years to come.

REDUCING FLOOD AND STORM DAMAGE
Charles River Basin—Wetland as Flood Protection

Summary

To prevent recurring floods that had caused extensive damage in Boston and neighboring communities, the Army Corps of Engineers created an innovative plan to acquire and protect over 8,000 acres of wetlands along the upper reaches of the Charles River. Today, the wetlands help prevent $40 million in flood damages every year. As precipitation increases and storms become more intense in a changing climate, wetlands will continue to provide cost-effective protection against floods.

Challenge

The Charles River watershed, home to 20 percent of Massachusetts's population, is the most densely populated river basin in New England.[192] Since 1870, urban and suburban development from Boston, Cambridge, and surrounding communities has paved over much of the lower river's wetlands and natural landscapes, reducing natural water storage and causing downstream flooding.[193] When hurricanes and major rain events swept across the region, such as in 1938 and 1955, flooding caused widespread damage throughout the basin. The 1955 flood resulting from Hurricane Diane caused over $5 million in damages (over $40 million in today's dollars[194]) to communities along the lower Charles River.[195] In March of 1968, the watershed experienced its worst flood yet, when three straight days of rain and melting snow set record water levels and flooded roads, basements, and subways throughout the lower basin.[196]

Following the 1955 disaster, local leaders began searching for a solution to the recurring flooding throughout the watershed. Led by Representative Tip O'Neill, Congress directed the Army Corps of Engineers (Corps) to undertake a comprehensive study of the entire Charles River Watershed in 1965.[197] The Corps' final report, published in 1972, emphasized the critical role that wetlands played in storing excess floodwaters and reducing damage on the upper and middle portions of the Charles River. Wetlands reduced peak river flows by 65 percent in the 1955 disaster.[198] In 1968, floodwaters rushed through the lower basin in a matter of hours, while peak flows from the upper basin took three to four days to reach a dam near the mouth of the river.[199] The entire volume of stormwater produced during the 1968 flood from the upper and middle reaches took over a month to reach the dam.[200] This prevented a rapid release of floodwater and protected residents downstream.

Even as the Corps of Engineers' study was revealing the importance of the Charles River wetlands, they continued to disappear due to development. The construction of Interstate 495 had already begun and

Charles River Basin

Left: Heavy rains inundated communities along the lower stretches of the Charles River.
Middle: The 1955 flood resulting from Hurricane Diana caused over $5 million in damages ($40 million in today's dollars).
Right: Wetlands that prevented flooding in the upper basin were disappearing at the rate of 1% per year due to development.

would soon open up rural land along the Charles River to development.[201] Studies at the time showed that wetlands in Massachusetts were disappearing at a rate of one percent per year, with the greatest pressure on the Charles River wetlands.[202] New roofs, roads, and parking lots would reduce natural flood storage and create additional runoff as pavement replaced vegetation. Destroying upper basin wetlands would not only extend flooding problems throughout the watershed, it would also worsen the lower basin's predicament, as floodwaters would move downstream more quickly. If local leaders were to solve the lower basin's recurring flooding and prevent those problems from spreading upstream, they would need to preserve existing wetlands and relieve the pressure from accelerating development.

Approach

The Corps was nearing completion of its study on the lower basin prior to the 1968 flood. They found that the dam at the mouth of the river was incapable of providing flood control and proposed construction of a new dam and pumping station just downstream of the existing structure. The proposal also called for levees and a second dam along the middle portion of the Charles River at an estimated cost of $100 million ($618 million in today's dollars).[203] However, when the 1968 flood hit, the Corps witnessed the capacity of the wetlands to store flood waters and decided to preserve them.[204] Based on flood hydrograph records, they calculated that a 100-acre wetland stored the same amount of water, 55 acre feet, as an average flood control reservoir in New England.[205] In fact, while the Corps explored potential impoundment sites, they could not find any with as much storage capacity as the wetlands.[206]

In 1972, the Corps began work to alleviate flooding in the lower basin by replacing the existing dam at the mouth of the river. The new dam was completed in 1978 with a large pumping station to discharge 630,000 gallons of water per minute into Boston Harbor when the river gets too high.[207] The proposed dam and levee system in the upper basin was removed from the plan after the Corps released its watershed report recommending wetland acquisition for flood protection.[208] In an expedited process, extensive mapping and study of the wetlands determined that approximately 10,000 acres of the 20,000 acres of wetlands in the basin had floodwater retention capacity.[209] In the end, 17 sites, ranging from 118 to 2,340 acres were selected for acquisition.[210]

The next challenge was to secure federal funding in order to purchase the wetlands. The Corps found overwhelming public support for wetland acquisition after completion of its watershed study.[211] State and federal officials and legislators took note of public sentiment and supported the project. However, the project was held up in Congress for over a year due to opposition to extending federal flood control author-



Left: 75% of the remaining wetlands in the watershed were protected.
Middle: The wetlands protect Boston and other downstream communities along the Charles River from flooding.
Right: The Charles River also supports recreational activities such as fishing, rowing, and other water sports.

Napa, California—Restoration of a Living River

From 1961 to 1997, Napa, California flooded on 19 separate occasions, resulting in over $542 million in damages.[253] The Army Corps of Engineers proposed channelizing the river and building levees in both 1975 and 1988, but the community rejected the idea. When the Corps proposed the same solution again in 1995, community members developed a coalition to work with the Corps towards a more sustainable solution.[254] The result is the Napa River Flood Project, which will restore 650 acres of tidal wetlands, reconnect the river to the historical floodplain, clean up contaminated sites, create terraced river banks, replace bridges, and construct floodwalls, levees, and bypass channels in selected areas. When completed in 2011, the project will protect roughly 2,700 homes, 350 businesses, and over 50 public properties from 100-year flood levels and reduce the $26 million of annual average flood damages.[255] The end result will be a living river that sustains migrating fish and wildlife and protects residents from floods.

ity to non-structural land acquisition.[212] Congress finally authorized the Charles River Natural Valley Storage Area (CRNVSA) in 1974 under the Water Resources Development Act, allowing for the acquisition of wetlands and easements in the watershed.[213] Not only was this the first time that Congress approved and appropriated money to buy land to reduce risk of flood damage, but from this moment on, all future flood control projects across the nation were required to consider non-structural alternatives and to offer equal funding opportunities for these projects.[214]

Working in partnership with the Charles River Watershed Association, the Corps began implementing the wetland protection project in 1974. They started by contacting over 550 land owners within the watershed.[215] The Corps offered fair market value for properties and the option of a special restrictive easement for landowners that wanted to retain the title to their lands. In 1977 the Corps began purchasing land and acquiring easements, prioritizing parcels by location, storage capacity, and threat of development.[216] By 1983, the Corps had purchased 3,211 acres and acquired easements on 4,882 acres of private land.[217] The protected area includes 75 percent of all existing wetlands in the Charles River watershed.[218] The Corps monitors the wetlands to ensure that the terms of easements are upheld by systematically surveying all 31 property segments in 16 communities.[219] The Massachusetts Division of Fisheries and Wildlife manages the wetlands, enforces laws, stocks trout, and improves habitats through a lease arrangement with the Corps.[220]

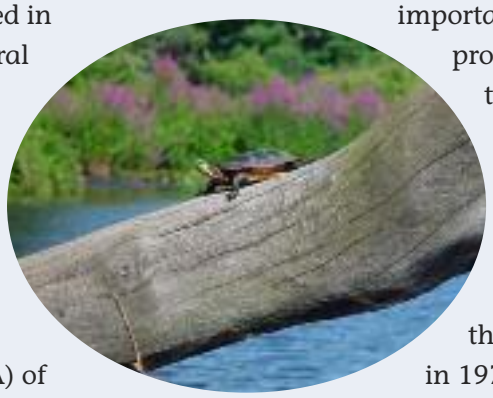
Because the Corps could only protect 75 percent of the wetlands in the basin, Congress required a commitment from the state to enforce its Inland Wetlands Act and floodplain zoning more stringently to protect the remaining 25 percent of the wetlands.[221] Congress also required local interests to prevent any developments that would modify the drainage characteristics of the CRNVSA.[222] Most local communities cooperated readily by adopting local zoning laws to protect their wetlands.[223]

Planning

The Corps of Engineers has been the primary agency involved with the research, acquisition and protection of the basin's wetlands. A number of Corps studies were instrumental in establishing the need for wetland preservation and guiding the implementation of the project. As mentioned above, the first step in the process was the watershed study that Congress requested in 1965. Having established the importance of wetlands in that report, the Corps Hydrology Branch conducted a study using advanced engineering to guide land acquisition based on the flood protection value of various wetland parcels. Full-time cartographers and appraisers were hired by the Corps to work on the real estate planning phase to negotiate acquisition and easement contracts of wetlands.[224] A General Design Memorandum was also prepared to identify planning decisions as well as state and Federal roles, and included a schedule of the funding necessary for the completion of the project to be updated periodically.[225] Throughout the planning process the Corps involved the public. Thirty representatives from affected communities along the Charles River served on the Citizen Advisory Committee as liaisons between the Corps and citizens.[226]

Funding

Funding for federal flood control projects such as the Charles River wetlands requires several steps. The project must first be authorized by the appropriate committees in the House of Representatives and the Senate. Once authorized, the project can receive funding, which is typically appropriated in phases over several years. Congress authorized funding for the Charles River wetland project in the Water Resources Development Act (WRDA) of 1974.[227] The initial 1975 appropriation totaled $100,000, while the 1976 allocation increased to $290,000. These initial sums were used for aerial surveys, mapping, and mathematical modeling.[228] Appropriations grew as land acquisition began and totaled $8.3 million over the life of the project.[229] While local or state interests are typically asked to share 20 percent of the total cost of the project, the Commonwealth of Massachusetts already owned 20 percent of the lands selected for acquisition, and the federal government accepted these properties as the state's share.[230] Every year, $300,000 for operation and maintenance costs is supplied through WRDA to support three full-time positions and two interns.[231]



Benefits

Protection of the Charles River wetlands has provided numerous benefits to the 16 communities within the CRNVSA and their downstream neighbors. Without protection, the Corps estimated in 1976 that 40 percent of all existing wetlands at the time would have been lost to development by 1990.[232] The most important benefit of the project has been protection from the destructive floods that previously plagued the basin. When heavy rainfall threatened the basin in 1979, the protected wetlands and flood-control dam in the lower basin controlled the floodwaters, preventing an estimated $14 million in damages (in 1979 dollars).[233] The wetlands have protected downstream communities during floods many times since. The World Wildlife Federation estimates that the wetlands currently prevent $40 million per year in flood damages.[234] Neighboring communities outside of the watershed demonstrate what would happen in the absence of strong wetland protection. In May of 2006, the community of Lawrence, which lies at the confluence of the Merrimack, Shawsheen, and Spicket rivers, received 8.73 inches of rain over several days, resulting in an estimated $19 million in flood damages.[235] At the same time, communities along the Charles River, including Boston and Cam-

The wetlands provide vital habitat for wildlife.

The wetlands prevent an estimated $40 million in flood damages every year.

bridge, received 8.99 inches—the second highest four-day total in 134 years of record-keeping—and suffered almost no flood damage.[236] The Merrimack and Ipswich rivers surpassed flood levels when they reached their highest levels on May 15, 2006. The Charles River did not crest until two days later and remained well below flood level during and after the heavy rains.[237]

The 16 communities within the Charles River Natural Valley Storage Area benefit from much more than just flood prevention. All of the protected lands owned by the Army Corps of Engineers are open to the public for recreation including boating, walking, sightseeing, fishing, and bird watching.[238] Also available for public use along the Charles River are parcels of state-owned land managed by the Division of Fisheries and Wildlife and a number of small parks managed by local municipalities and conservation trusts. This open space improves the quality of life for local residents but also stimulates the local economy by attracting tourists. Hunting and fishing in the Charles River Natural Valley Storage Area is valued at over $30 million annually.[239] The Corps estimates that the 212,000 annual visitors spend $4.51 million within 30 miles of the CRNVSA.[240] In addition, properties adjacent to the protected wetlands have shown direct benefits to local residents through increased property values. In a survey, 14 of 15 realtors and appraisers reported that properties adjacent to the wetlands had higher property values and were easier to sell.[241] A statistical analysis verified that homes next to wetlands were worth 1.5 percent more than other homes in the region.[242] Overall, the combined amenity value of living close to the wetlands is valued at $216,500 per year.[243]

Finally, the wetlands provide significant downstream water quality benefits. While no formal water quality studies have specifically focused on the Charles River wetlands, these ecosystems have a well-established ability to naturally remove sediment and other contaminants.[244] Until recently, the river was plagued with sewage and other pollutants from the region's industrial past. Clean-up efforts in the 1960s helped improve water quality, but problems persist, most notably urban runoff from continued development. The intact wetlands minimize these threats by trapping sediment, excess nutrients, and other contaminants that would otherwise pollute the river and threaten recreational uses. The Charles River is an iconic setting for sailing, rowing, and other activities. River recreation helps bring hundreds of thousands of visitors to the region each year.[245] All told, the water quality benefits of the wetlands are estimated at nearly $25 million per year.[246] In addition, by preventing development along the river, the wetlands' protected status has kept developers from building

more roads and parking lots, which would deliver a host of pollutants to the river.

In all, the Charles River wetland protection project has been a great benefit to the watershed. In contrast to a flood control dam which would have cost over $100 million and provided few, if any, additional benefits, wetland purchases and easements cost less than $10 million and contribute over $95 million to the regional economy every year.[247]

Climate Change

With shifting precipitation patterns, the threat of flooding is growing. Despite a severe drought in the early 1960s, average annual precipitation has increased 5-10 percent across the Northeast since 1900.[248] This trend will continue for the foreseeable future, and the Northeast will experience an increase in average annual precipitation of 10 percent, or four inches, by the end of the century.[249] More importantly for flood damage purposes, the intensity of storms will increase significantly throughout the Northeast. The number of heavy precipitation events is projected to increase eight percent by 2050 and 12-13 percent by the end of the century.[250] These trends will be aggravated by warming winter temperatures and earlier snow melt, both of which will increase flood risk. Finally, sea level rises will bring additional pressure on coastal flood control systems. By the end of the century, sea level is expected to rise between seven and 23 inches, increasing the risk of coastal flooding in the lower basin.[251]

Towards Resilience

The preservation of wetlands within the upper Charles River basin make the river and the communities along its banks better able to weather a changing climate. The wetlands have demonstrated time and again that they are able to handle the most extreme storms the region has to offer and that riverside communities can depend on this natural buffer to protect them. Preservation of the watershed's wetlands has several important implications in a changing climate. As extreme storms become more frequent, the protected wetlands will continue to absorb floodwaters and release them gradually over the course of weeks or months, avoiding the deadly peak flows

Reno, Nevada—Truckee River Flood Protection[256]

About every 10 years, the Truckee River overflows its banks, causing tremendous damage to homes, businesses, and infrastructure. In the 1997 New Year's Day Flood, damages exceeded $1 billion in six counties. In response, the cities of Reno and Sparks, Washoe and Storey counties, the Corps of Engineers, and other stakeholders came together to plan a flood project. Over six years, the Truckee River Flood Project's Community Coalition clocked over 20,000 volunteers hours in more than 500 meetings to develop the community-supported Living River Plan. The $1.4 billion plan includes flood protection and river restoration projects along 50 miles of the Truckee River that will enhance recreational opportunities and fish passage. The 45 flood protection measures listed in the plan include setback levees and floodwalls, terraced riverbanks, bridge replacements, a stormwater detention facility, and restoration of the floodplain. The project is expected to be completed by 2025.

that can take lives and destroy communities. On the other hand, paving over these wetlands to support development would allow floodwaters to pick up speed and move rapidly downstream, amplifying the impact of more frequent and intense storms to come.

By proactively improving the health of the river and limiting the effects of climate change, the Charles River and the species that depend on it will be better able to absorb the negative impacts without devastating consequences.

The second important implication of the CRNVSA project is the lack of development in flood-prone areas, which is key to ensuring safe communities in a changing climate. Giving the river room to expand to accommodate high waters is critical. As the Charles River reaches the Millis-Medfield region, its normal 50-foot width has the ability to expand to over 1.5 miles wide under flood conditions.[252] Keeping communities out of the floodplain will reduce their vulnerability as weather events become more extreme. In combination with the flood control dam in the lower basin, communities along the Charles are well equipped to withstand large floods without suffering devastating losses. The same is not true of neighboring watersheds that are stripped of their wetlands, and this vulnerability will be magnified as the climate shifts. However, as climate change shifts precipitation patterns further from the historical average, the CRNVSA's capacity and flexibility will be taxed and tested. Heightened storm intensity and frequency will likely produce record floods and may demand additional storage capacity.

The wetland protection project also has important implications for the ability of ecosystems and wildlife to weather a more extreme climate. The rising number of severe storms will wash more pollutants off the landscape into waterways, but the CRNVSA will greatly limit the impacts on water quality. The loss of the wetlands' natural filtering capacity and greater floodplain development could have had devastating impacts on the health of the Charles River watershed in a warming world. By proactively improving the health of the river and limiting the effects of climate change, the Charles River and the species that depend on it will be better able to absorb the negative impacts without devastating consequences. It will improve the likelihood that future stresses will not exceed the ecosystem's capacity to adapt to change.

Finally, the CRNVSA has important benefits for the regional economy and finances of basin communities. A significant portion of the recreation and tourism industry in the area is dependent on a healthy Charles River. The protected wetlands preserve water quality and ensure that these industries remain viable in an uncertain future. This will in turn help maintain a strong, diversified economic base that will help insulate the region from economic fluctuations due to climate change. In addition, flood control and other ecosystem services provided by the wetlands prevent towns and cities within the basin from having to expend scarce resources on flood recovery, water treatment, or stormwater control. Flood damages in other watersheds have been considerable in recent storms, and they will only grow with more severe storms. By avoiding these costs, Charles River communities will have more financial flexibility and will be better able to meet the uncertainties and costs of climate change.

The wetlands will protect Charles River communities as the climate shifts and help maintain a high quality of life.

SECURING CLEAN WATER SUPPLIES
Clayton County, Georgia—Withstanding Drought with Wetlands and Water Reuse

Summary

While most southeastern communities experienced major water shortages during the 2007-2008 drought, Clayton County, Georgia was an exception. An innovative water recycling system that filters treated water through a series of constructed wetlands helped the county maintain an abundant water supply throughout the record-setting drought. While Atlanta's Lake Lanier shrunk to a 90-day supply of water, Clayton County maintained a 230-day supply in its reservoirs. As climate change makes precipitation more variable and uncertain, Clayton County's water recycling system will ensure a secure and reliable water supply for its residents.

Challenges

In recent years the Southeastern United States has faced major water supply challenges. Communities throughout the region have seen water supply reservoirs drop dramatically, falling below 50 percent capacity in some cases.[257] Lake Lanier, a major water source for metropolitan Atlanta, reached record lows in December of 2007.[258] A region historically blessed with abundant water is now facing shortages due to growing populations, rapid development, mismanagement, and extended droughts. Development has brought acres of roofs and parking lots that turn rainfall into polluted runoff where once it was allowed to soak into the ground and recharge water supplies. Inefficient irrigation and wasteful water use in homes and businesses throughout the region force ever larger withdrawals from rivers, aquifers, and reservoirs. The severe droughts of the past several years have been the final straw that has pushed demand beyond available supply in many places. Communities are now faced with the pressing question of how to ensure a clean, reliable water supply for current and future generations.

Clayton County's Approach

Amidst the bleak water supply realities that have faced the region in recent years, one bright spot has been Clayton County, Georgia. Located south of Atlanta, the county's reservoirs have remained near capacity even in record drought conditions. The Clayton County Water Authority (CCWA) uses an innovative water recycling wetland system to bolster water supply and has undertaken a number of water quality and efficiency initiatives. The use of recycled wastewater provides a consistent drought-resistant supply of water, while the wetlands gradually release water over time, reducing vulnerability to droughts.

Clayton County's wetland systems consist of a series of interconnected, shallow ponds filled with native vegetation. Wastewater is first processed in an advanced treatment facility and then dis-

Clayton County, Georgia

Left: In recent years, extended droughts have caused water shortages throughout the southeast.
Middle: Shrinking water supplies forced many communities to impose restrictions.
Right: Runoff from rapid development throughout the region threatens water quality.

charged to the constructed wetlands which remove remaining pollutants such as excess nutrients like nitrogen and phosphorus. A portion of the water in the wetlands infiltrates into the groundwater supply, but the majority flows on the surface into one of CCWA's water supply reservoirs. Water typically takes two years under normal conditions to filter through wetlands and reservoirs before being reused and takes less than a year under drought conditions.[259] The first section of constructed wetlands, known as the Panhandle system, was completed in 2003 and has a treatment capacity of 4.4 million gallons per day (mgd).[260] The adjacent Huie wetland system is coming online in phases. Thus far three phases of the construction have been completed with a capacity of 9.3 mgd.[261] Additional sections of the Huie system will be completed in 2010 and 2012 which will bring the total capacity of the system to around 24 mgd.[262] While the wetlands constitute an important part of CCWA's larger water supply system, which has a total capacity of 42 mgd,[263] the county also pulls water from the Flint River and reservoirs located on smaller streams.

In addition to investing in water reuse, Clayton County has taken a number of steps to protect its water supply from drought and contamination. In order to improve efficiency and avoid unnecessary waste, CCWA has undertaken a successful leak detection program and participated in a regional residential toilet rebate program that provides incentives to replace older toilets with more efficient models.[264] The county has also worked to reduce stormwater pollution in order to protect the small streams that recharge water supply reservoirs. In its 2001 Watershed Management Plan, CCWA outlined a number of ordinances and actions it could take to protect water quality. The plan includes a tree preservation ordinance that requires developers to protect at least 10 percent of existing trees on new developments and redeveloped properties; a soil erosion and sedimentation ordinance restricting all land-disturbing activities within 25 feet of State waters; and landscaping guidelines that require at least 15 percent vegetated area on commercial, industrial, and multi-family residential properties.[265] The Watershed Management Plan also established a standard for controlling erosion from new developments, which requires developers to install wider stream buffers, preserve open land, and use green infrastructure techniques such as constructed wetlands, infiltration trenches, and swales to capture and filter stormwater.[266] Clayton County has directly undertaken a number of stream restoration projects, water quality monitoring, and green space purchases to protect water quality. In 2007, CCWA took over responsibility for stormwater management throughout the county, which had previously been carried out by municipalities.



Left: A series of wetlands recycles wastewater and recharges water supplies.
Middle: Clayton County has maintained plentiful water supplies even during droughts.
Right: The wetlands also provide recreation and enhanced quality of life for local residents and valuable habitat for a variety of wildlife.

West Palm Beach, Florida—Natural Wetlands as a Drinking Water Source[294]

Grassy Waters in West Palm Beach, Florida is more than just a wetland and prairie preserve; it is also an important drinking water source. The 20 square miles of wetlands provides most of the drinking water for 130,000 people in West Palm Beach and surrounding municipalities. The city sends up to 10 million gallons per day of highly treated water to the marshy expanse. The reclaimed water takes about two years to filter through native plants and soil before being pumped to the city's reservoir where it is processed for drinking. Filtering water through the vegetation and soil helps remove remaining impurities such as nitrogen and phosphorous.

Planning

Water supply has long been a challenge in Clayton County due to limited surface water and groundwater supplies. In the late 1990s CCWA began searching for ways to improve efficiency, minimize operating costs, and expand capacity of its wastewater and water supply infrastructure. Since 1980, the county has operated a land application system (LAS) which sprays treated wastewater onto 2,500 acres of forested land where it gradually soaks into the ground and flows into the county's reservoirs. This system was initially constructed because the Flint River, which would have otherwise received the wastewater discharge, was severely degraded and could not handle the waste loads it was receiving. Despite generally low permeability of the Upper Flint watershed geology, the land application system returned 70 percent of the reclaimed water to the water supply reservoir as stream flow.[267]

In the late 1990s, CCWA developed a number of long-term plans outlining the steps needed to reach its clean water goals. The Master Plan, published in 2000, identified necessary capital improvements to the county's water infrastructure and committed the county to transitioning from the land application system to constructed treatment wetlands. CCWA decided to switch to the wetland system because of its ability to remove pollutants at a low operating cost. Maintenance for the system is minimal, and it effectively removes the remaining 20 percent of pollutants present in wastewater when it leaves the treatment plant.[268] It also requires less land, taking up just 15 to 25 acres compared to100 acres for the LAS.[269]

In 2001, CCWA also completed a planning process to protect the Flint River watershed. This effort was motivated by the realization that CCWA could not ensure sufficient clean water in the future without protecting the entire watershed.[270] The Flint River begins at the Hartsfield-Jackson International Airport (the world's busiest), in an area where population has increased over 200 percent since the 1970s.[271] While efforts to clean up wastewater discharges improved water quality in the 1990s, increased impervious surfaces and runoff have created a growing pollution problem. As CCWA conducted watershed assessments in formulating its watershed plan, it became clear that not only were their water resources limited, but increased urbanization was having negative impacts on the quality of its available water resources.[272] The resulting watershed management plans from Clayton County and nearby Henry and Fayette Counties are helping Clayton County maintain a safe and consistent supply of water despite pressure from rapid urbanization.

Funding

Clayton County's forward-thinking water supply system and watershed

protection efforts have required a significant commitment of resources. CCWA is building the wetland system on land it first purchased for the land application system in the late 1970s. Funding for the land purchase and the construction of the LAS primarily came through the Federal Construction Grants program under the Clean Water Act. Permitting, design, and construction of the wetland system will total $55 million through 2025.[273] The wetlands have been built using low-interest loans from the State Revolving Fund, bonds, and ratepayer revenue.[274] To fund improvement projects for all water related services, CCWA has increased water rates in recent years, beginning with a six percent raise in 2006 and five percent increases each year between 2007 and 2010.[275] Approximately four cents of every dollar collected for water and sewer service is set aside for watershed protection.[276] CCWA's stormwater program is funded primarily by stormwater fees which amount to $3.75 a month for residential properties and an amount based on impervious surface for commercial and industrial customers.[277]

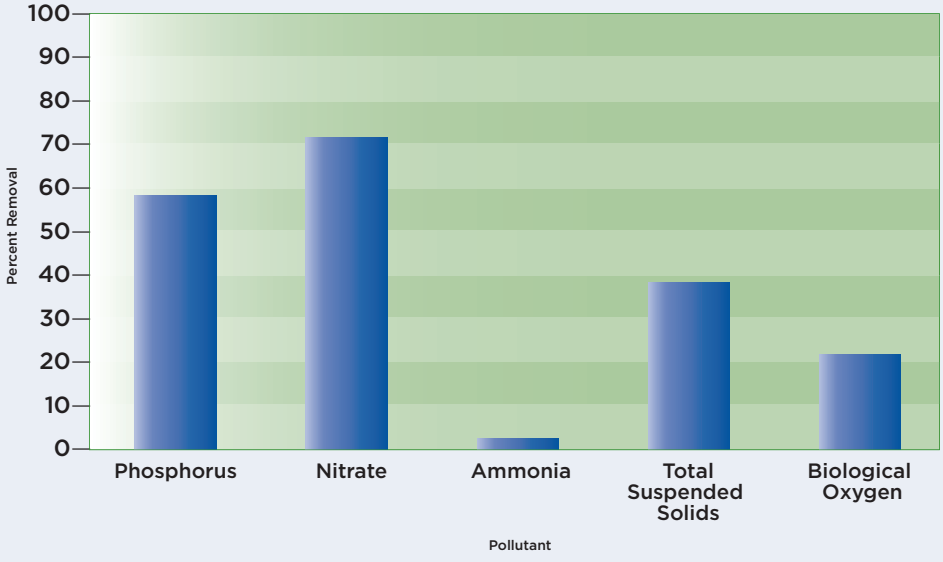
Permitting

Clayton County has gone through a number of permitting processes in order to construct its wetland system. A National Pollutant Discharge Elimination System (NPDES) permit was required for constructed wetlands, following an extensive review and approval process through the Georgia Department of Natural Resources.[278] The first step in this process was for the Georgia Environmental Protection Division to set discharge limits by determining the amount of pollutants the wetlands can handle. An antidegradation analysis was then performed, followed by a Design Development Report and an Environmental Information Document to assess the environmental impact of the constructed wetlands. The Georgia Environmental Protection Division then conducted a site visit to verify the proposed wetland site was suitable for construction. After site approval, Clayton County submitted an application for an NPDES permit and began construction once it was issued. The county was also required to submit an operations manual and watershed plan before they could begin operation of the wetland system.[279]

> It became clear that not only were their water resources limited, but increased urbanization was having negative impacts on the quality of its available water resources.

Benefits

Clayton County's investment has clearly demonstrated the value of wetlands and water recycling over



Data from CCWA.

CCWA's reservoirs maintained at least a 230 day supply while the Atlanta area had only a 90 day supply in its main reservoir.

the past several years. During one of the worst droughts of the past 50 years, CCWA's reservoirs maintained at least a 230 day supply while the Atlanta area at one point had only a 90 day supply of water in its main reservoir, Lake Lanier.[280] The county is nonetheless continuing to expand the capacity of its water reclamation system. When the last sections of the Huie wetland are completed, the Panhandle and Huie systems will be able to produce over 28 mgd. As a result, the wetland system will be able to supply all of Clayton County's demand for water, which currently stands at about 26 mgd.[281]

The constructed treatment wetlands have also improved ecosystem health for people and wildlife. The wetlands have been shown to reduce nitrates by 72 percent on average, total phosphorus by 59 percent, total suspended solids by 38 percent, and biological oxygen demand by 22 percent on average.[282] This decreases treatment costs for drinking water and reduces the amount of pollutants

The wetlands are a valuable community asset that attracts visitors from around the world.

flowing into local waterways. The wetland system also has a number of habitat and recreation benefits. The wetlands are a refuge for 130 species of birds and a diverse array of other wildlife.[283] Four thousand acres of protected forest land are available for public recreation, including fishing, bow hunting, and hiking. A wetland center and nearby trails serve as educational facilities and host an annual Wetland and Watershed Festival as well as elementary school field trips. Over 20,000 people visit the wetlands annually, including international visitors from as far away as Australia.

Finally, the wetlands are more cost-effective than other alternatives and have saved Clayton County considerable amounts of money. Building a wastewater treatment system using constructed wetlands costs about $5.00 per gallon of capacity. In contrast, capital construction costs of a conventional advanced treatment facility are roughly $10.00 per gallon of capacity.[284] The operating costs of the wetland system are also significantly lower. Because it relies on gravity flow and natural pollutant processing, the wetland system is very energy efficient and has reduced CCWA's monthly energy bill by 66 percent.[285] Maintenance of the system is also simpler than the land application system, which has allowed the county to reduce its maintenance staff from 12-15 people to four.[286]

Climate Change

The region's water supply problems will not lessen as temperatures rise, precipitation becomes more variable, and population increases. Georgia is expected to experience average temperature increases of 4-5° F in winter months and 6-7° F in summer months by the end of the 21st century.[287] Higher temperatures will result in more evaporation from water reservoirs, higher stream temperatures, increased demand, and worsening water quality. Changes in rainfall are less predictable, but projections show a slight increase in annual average precipitation and a rise in winter rainfall at the expense of the hotter summer months.[288] Water supply forecasts based on past trends will not provide an accurate assessment of future conditions. Most importantly, precipitation will become more variable and increasingly unpredictable, leaving the region more vulnerable to droughts such as those that have occurred in recent years. An increase in the frequency and severity of extreme storms will cause more flooding, stormwater runoff, and sewer overflows, aggravating water quality problems, polluting source waters, and making water treatment more costly.[289]

Towards Resilience

Climate projections suggest that the dry conditions of past years offer a glimpse into what the future could hold for the southeastern U.S. Warmer temperatures and declining summer precipitation will lead to worsening droughts and water shortages. If that is the case, Clayton County's water supply system has clearly demonstrated that it is able to meet the challenge. As neighboring communities went dry in recent years, CCWA continued to provide a safe and consistent supply of water and was able to avoid the water restrictions that other communities experienced.[290] There are two key elements of Clayton County's water system that make it well adapted to more arid and unpredictable weather patterns. Recycled wastewater is a drought-resistant supply that may decrease slightly during droughts, but will never disappear completely. The use of a wetland system also helps buffer against arid conditions because wetlands release water gradually, delaying the effects of drought.[291] With the combination of reuse and treatment wetlands will ensure a continuous inflow and gradual release of treated water to the county's water supply reservoirs. Even in a changing climate, Clayton County will be able to withstand extended droughts and continue to provide clean water to homes and businesses.

Clayton County's water management strategies build resilience beyond the immediate drought-protection benefits. The water reuse system and watershed protection efforts allow the county to maintain the health of the ecosystems they rely on for water supply, recre-

The wetlands will help Clayton County maintain a clean and consistent supply of water even as the climate shifts.

Clayton County will be able to withstand extended droughts and continue to provide clean water to homes and businesses.

ation, and other needs. By increasing water reuse and improving efficiency in homes and businesses, more water can be kept in the Flint River, helping offset low flows, high temperatures, and poor water quality resulting from drier conditions. Watershed protection efforts are essential for protecting the quality of Clayton County's waterways from the increase in polluted runoff due to climate change. Over 26 percent of the Flint River watershed is covered with impervious surfaces that prevent groundwater infiltration and generate polluted runoff.[292] Stream health declines as impervious cover in a watershed increases, and extreme degradation results when imperviousness exceeds 25 percent.[293] In such a highly developed and rapidly growing area, more severe storms could greatly exacerbate water quality problems. Clayton County's wetlands, stream buffers, open space purchases, and vegetation preserved by county-wide ordinances will capture and purify stormwater, helping to buffer waterways from increased runoff. These efforts will help maintain a healthy river system in the face of climate change and will ensure that it can continue to provide the valuable ecosystem services on which Clayton County relies.

Clayton County has taken simple and effective steps to protect itself from drought and is making progress towards improving water quality as well. The county manages wastewater, stormwater, and water supply in a holistic manner in recognition of the close interconnections between them. However, they must do more if they are to be truly resilient to the impacts of a changing climate. While the wetland system responded well to the record drought of the past few years, CCWA's water supply system could be vulnerable to a more protracted dry spell. The county should incorporate climate change projections into its water supply planning to ensure the system will be able to withstand future changes. In addition, the county needs to expand its watershed protection efforts and stormwater management if it is to avoid the worst impacts of a changing climate. The county must protect existing green space from ongoing development and increase the use of stream buffers, swales, and other green infrastructure techniques to reduce the impacts of runoff from impervious surfaces. With such extensive development throughout the watershed, there is much room for improvement.

Middleburg, Ohio—Big Darby Headwaters Preserve[295]

As a tributary to the Scioto River, Big Darby Creek is part of a larger watershed that provides drinking water for tens of thousands of people south of Columbus.[296] Small streams contribute up to 55 percent of the flow in larger rivers[297] and, as a result, have a large impact on the quantity and quality of water available to many communities. To protect the quality of this vital water source, Columbus is looking upstream to the Big Darby's headwaters. The city is receiving a lower rate on its loan through the Clean Water State Revolving Fund—the primary source of federal wastewater infrastructure funding—in exchange for sponsoring upstream source water protection. In 2006, the City of Columbus sponsored the Nature Conservancy's Big Darby Headwaters Preserve project at a cost of nearly $1.5 million. The new preserve is at the headwaters of the Big Darby Creek—the place where the Big Darby becomes a permanent stream. By protecting the stream at its source, Columbus is reducing pollution from farms and development near the headwaters, thereby securing cleaner water as it flows into the Scioto River.

SECURING CLEAN WATER SUPPLIES
Seattle, Washington—Reducing Demand through Conservation and Efficiency

Summary

Population growth in the Seattle metropolitan area has strained water supplies over the past several decades. To maintain a consistent supply and ensure enough water remains in streams for ecosystem health, Seattle Public Utilities has undertaken a number of water conservation and efficiency measures. The city has reduced water consumption by 26 percent and per capita water use by 33 percent since 1990. Combined with protecting the lands surrounding drinking water sources and taking a flexible approach to planning, water efficiency and conservation measures will allow Seattle to maintain a safe and consistent supply of water even as rising temperatures reduce the snowpack that the city relies on to fill its reservoirs.

Challenge

Seattle faces a challenge similar to many other cities in the western U.S.: a growing population and limited water supply. King County, home to much of the Seattle metropolitan area, has seen population growth of over 95 percent since 1960.[298] Seattle Public Utilities (SPU), which supplies drinking water to the greater Seattle area, serviced fewer than a million customers in 1975, while today it supplies roughly 1.45 million.[299] Such rapid growth inevitably results in increased demand for limited water supplies. In fact, in 1995 SPU forecasted that water demand would exceed supply by 2005.[300] Summer months present the greatest water supply challenge for the city, as rainfall is scarce and demand soars due to outdoor watering and irrigation.[301]

Limited water availability can have far-reaching impacts on economies, ecosystems, and quality of life. Economic losses due to drought average $6-8 billion nationwide every year.[302] Washington State has declared drought emergencies five times since 1977, most recently in 2005. The 2001 drought was one of the worst on record. Agriculture, which accounts for three-quarters of the state's water consumption, was hit especially hard. Economic losses in the industry exceeded $1.2 billion and job losses totaled 2,144.[303] Low river flows decreased energy production, which forced the Bonneville Power Administration to pay over $400 million to energy-intensive industries in order to keep them closed during the drought.[304] Two to three thousand aluminum workers lost their jobs for months as a result. Wildfires, fed by the dry conditions, burned 223,857 acres and cost $138 million to suppress.[305] Low river flows and elevated water temperatures increased stress on aquatic organisms, killing millions of salmon fry in the Columbia River.[306]

Seattle's Approach

Driven by growing water demand and environmental concerns, Seattle began investigating water effi-

Seattle, Washington



Left: Rapid population growth in the region has stretched available water supplies.
Middle: The Cedar River watershed, Seattle's primary source of water, is owned by the city.
Right: Planners have repeatedly forecast that the city would experience water shortages in the near future.

ciency and conservation in the late 1980s. Their first step was to introduce tiered water rates in 1988 that charge progressively higher rates as a customer's water consumption increases.[307] The city also increased summer water rates to discourage waste during the warm months when supplies are lowest. During most of the year, water rates are $2.95 per cubic foot (ccf), but from mid-May to mid-September, rates increase to $3.25-$9.64/ccf depending on how much water a household uses.[308] The city has also altered plumbing codes to require efficient fixtures in new construction and remodeling projects and invested in its water supply infrastructure to reduce losses from leaks.[309] Sewer rates are an added incentive to save water, as Seattle meters sewage discharges from homes and businesses and charges customers accordingly. Sewage rates are roughly twice as high as drinking water rates, encouraging wise use of all water coming into households.[310]

Seattle has also employed a variety of incentives to replace antiquated plumbing fixtures and change wasteful behavior. Early programs included the Home Water Savers Program, through which the city gave away 330,000 efficient showerheads and provided free installation of water-saving showerheads, faucets and toilets to residents of apartments and condominiums.[311] Showerhead distribution programs continue, with nearly 80,000 households participating in 2007.[312] The WashWise program, which provides rebates for efficient washing machines, processed nearly 7,000 rebates in 2007 alone.[313] Incentives are also available for new construction and remodeling projects including rebates for efficient toilets, showerheads, and sprinkler systems.[314] A variety of educational workshops and programs have taught residents how to reduce water use in gardening and other everyday activities. Through its commercial programs, Seattle has replaced thousands of toilets and urinals by providing cash rebates. Commercial water efficiency audits and incentives for irrigation efficiency improvements are also available.[315]

Water-efficient showerhead.

In 1999, the Saving Water Partnership, a group of 18 regional water utilities, created the one percent Water Conservation Program, designed to reduce personal and business water consumption in the region by one percent each year through 2010. Accomplishing this goal would save 14.5 million gallons of water per day and offset the

Left: Seattle has reduced water consumption by 26% despite a 16% increase in population.
Middle: The city has distributed thousands of efficient water fixtures.
Right: Seattle now has sufficient water to meet its needs for years to come.

A promotional flier sent to customers to encourage efficient watering practices.

increased demand from projected population growth.[316] Through the partnership, participating utilities have implemented nearly 70 cost-effective conservation and efficiency measures targeting various residential and commercial uses.[317]

Seattle also does an exceptional job of safeguarding its source waters by protecting their watersheds. The Cedar River has been the primary source of water for the greater Seattle area since 1901 and the city owns the entire 90,638 acre watershed.[318] Approximately 30 percent of Seattle's water supply comes from the South Fork of the Tolt River, which began supplying Seattle in 1964. The city owns 70 percent of this watershed while the U.S. Forest Service owns most of the remaining land.[319] Seattle has banned agricultural, industrial, and recreational activities throughout much of these watersheds in order to protect water quality.[320] By limiting the disturbance in critical water supply areas, Seattle has maintained the forests and wetlands that ensure a safe and consistent supply of water, thereby limiting treatment costs and reducing vulnerability to drought.

Planning

In the mid 1990s, faced with potential water shortages in the near future, SPU conducted a water Conservation Potential Assessment (CPA) to create a portfolio of water supply options including new supply, water reuse, conservation, and enhanced system efficiency. One option consisted of constructing a new pipeline called the Tacoma-Seattle Inter-tie.[321] The CPA found they could save up to 31 million gallons a day (mgd) over 20 years through conservation and efficiency at a similar cost to the Tacoma-Seattle Inter-tie which would supply 22 mgd.[322] SPU chose to go forward with conservation and efficiency measures, and they continue to conduct water conservation assessments periodically to evaluate the available options and guide future conservation and efficiency initiatives. Following the successful completion of the one percent Water Conservation Program in 2010, Seattle is planning to continue with a new regional water conservation commitment for 2011-2030 with expected cumulative savings of 15 mgd.[323] SPU also performs conservation surveys to better understand residential customers' perceptions and attitudes towards water conservation and long-range water demand forecasts to help plan for the future.

Seattle and surrounding municipalities have also put into place a number of water management plans and technologies to assist in better predicting and adapting to drought conditions. In response to the drought of 1987, SPU created the first of many Water Shortage Contingency Plans, providing guidelines on how to manage water supplies in the case of extended drought.[324] After the 1992 drought, they established snowpack telemetry sites to supply real-time snow and climate data.[325] The drought of 1997 led to the incorpo-

ration of El Nino forecasts into reservoir management decisions.[326]

Funding

The estimated total cost of the one percent Water Conservation Program is $54 million dollars over ten years. Of that, $36 million is being allocated to domestic conservation efforts, while the remainder is reserved for the commercial sector.[327] Overall, 75 percent of Water Conservation Program funding is being used for capital improvements such as installation of efficient technologies and 25 percent is going towards outreach and targeting behavior changes.[328] Conservation programs are primarily paid for through charges to connect to the water system and water rate revenue.[329] Since the beginning of conservation efforts in 1991 through 2011, water rates will have risen over 300 percent.[330] Between two and four percent of the revenue collected each year goes to support water efficiency, while the majority of water rate revenue is spent on capital projects.[331] Rate increases are proposed by the Mayor and voted on by the Seattle City Council through an open public process, with opportunities for public input during committee meetings or directly to individual council members.

Permitting/Regulations

Like all municipalities in Washington, Seattle is obligated to meet water conservation requirements mandated by a variety of state and federal laws. State laws requiring conservation include the Water Use Efficiency Act of 1989, which requires public water suppliers to incorporate conservation in their water system plans, the Municipal Water Law of 2003 and the Water Use Efficiency Rule of 2007.[332] This rule requires water suppliers to establish water saving goals, install service meters, meet leakage standards, develop a water use efficiency program, evaluate and implement water use efficiency measures, and report on progress annually. In addition, the Washington Department of Ecology requires all water systems experiencing population growth to implement conservation programs before seeking new water rights.[333] Finally, because Seattle's water supply is home to populations of threatened bull trout and Puget Sound Chinook salmon,

San Antonio, Texas—Water Conservation = Saving $$$

Water conservation can translate into saving more than a few pennies. When San Antonio committed to reducing per capita water use, it ended up saving millions of dollars.[360] San Antonio's water conservation campaign includes leak repairs, water-smart landscaping guidance, and vouchers and rebates for water efficient toilets, clothes washers, shower heads, and irrigation systems. The water utility also has a strongly tiered rate structure, under which rates increase sharply for customers that use large amounts of water.[361] Through these programs, the city has reduced per capita consumption from 225 gallons per day to 140 gallons per day since 1982. The city has spent slightly over $300 for each acre-foot of water it has saved through efficiency and conservation. Comparatively, new water rights from San Antonio's primary supply, the Edwards Aquifer, currently cost about $5,000 per acre-foot.[362] New supply by dam or pipeline projects could cost $600–1,000 per acre-foot.[363] By conserving water instead of seeking new water supplies, San Antonio has saved nearly $550 million.[364]

Tucson, Arizona—Lessons from the Desert

Located in the heart of the Sonoran Desert, where 12 inches of precipitation falls in an average year, Tucson has no choice but to be mindful of its water consumption.[365] Years of population growth and pumping from aquifers has lowered the water table to such an extent that the once-perennial Santa Cruz River no longer flows at the surface except during large storms.[366] In its struggle to provide a sustainable water supply to the growing area, Tucson has recently turned to conservation, efficiency, and reuse. The city is implementing progressive water pricing, water-smart ordinances, and a number of rebate programs for high-efficiency appliances, and fixtures. In October of 2008, Tucson became the first city in the country to require commercial developments to capture and use rainwater.[367] Beginning in 2010, 50 percent of a development's landscaping water will come from rainfall. Additionally, all new homes built in Tucson after 2010 will need to include plumbing for gray-water systems that re-use water from showers and laundry for flushing toilets and irrigation.[368] Today, Tucson uses a portion of its Colorado River water from the Central Arizona Project to recharge groundwater supplies. In addition, for close to 20 years, the city has been recycling treated wastewater to irrigate parks, schoolyards, golf courses, and other facilities.[369]

the city is required under the Endangered Species Act to develop a habitat conservation plan before it can divert water from the river.[334] Maintaining the necessary flows for these species' habitat requires Seattle to improve conservation and efficiency and minimize withdrawals.

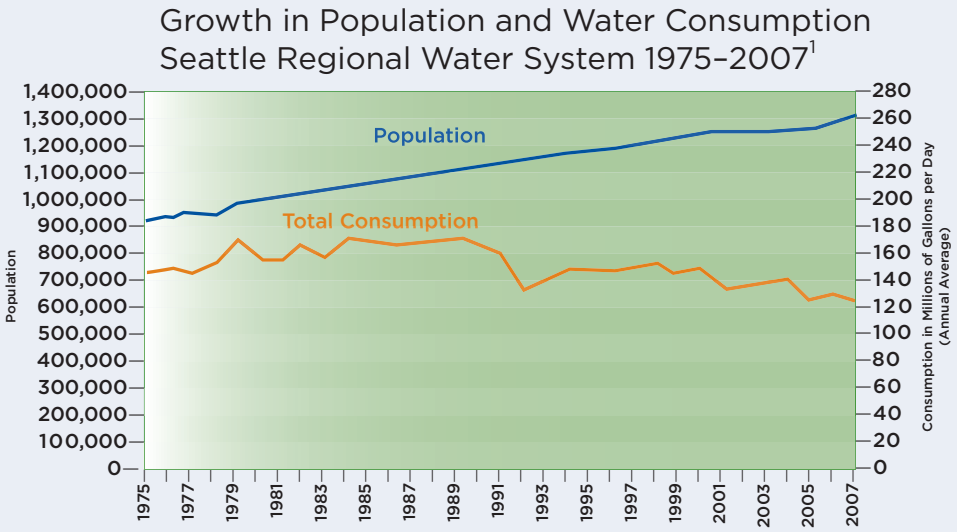
Seattle's conservation efforts go well beyond what these laws and regulations require. SPU incorporates conservation and demand forecasts in its Water System Plans, maintains an exceptionally low leakage rate of three percent and reports on progress towards meeting efficiency and conservation goals in annual reports.[335] SPU's habitat conservation plan is a 50-year plan designed to both provide certainty for Seattle's drinking water supply and protect and restore fish and wildlife habitat. Water conservation efforts have helped the city reduce diversions from the river and maintain guaranteed minimum instream flow requirements for aquatic species.[336]

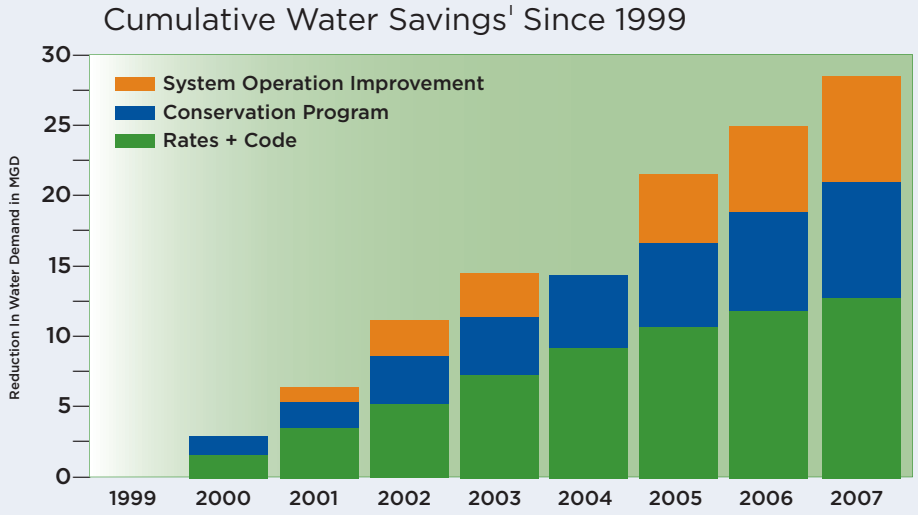
Benefits

Seattle's innovative water supply programs have been highly successful, allowing the city to reduce annual water consumption despite a steadily increasing population. Between 1990 and 2007, water consumption dropped 44 mgd, or 26 percent, despite a 16 percent increase in population.[337] Water use per capita has fallen from 150 gallons per day to less than 100 gallons per day.[338] Residential and commer-

cial conservation programs accounted for approximately 30 percent of the savings while increased rates, updated plumbing codes, and operational improvements accounted for the remaining 70 percent.[339] The region is also on track to meet its future conservation goals and expects to achieve the 2010 target under the one percent Program.[340] SPU has repeatedly forecasted that demand would exceed supply in the near future, only to push their water shortage predictions back due to the success of conservation and efficiency programs.[341] In 1997 they predicted shortages by 2013 but revised that estimate to at least 2020 in 2001. They currently expect to have sufficient water through at least 2060, although this forecast does not take climate change into account.[342]

Through its water conservation and efficiency programs, SPU has saved money by avoiding costly new investments in water supply infrastructure. While neighboring Tacoma has invested $237 million in its water supply expansion, Seattle has avoided capital-intensive projects such as the Tacoma-Seattle Intertie.[343] Water efficiency has provided the city with a cost-effective and reliable new source of supply. The decrease in water consumption has further led to reduced wastewater volumes and lower energy demand associated with transportation and treatment of drinking water and wastewater. By using less water through efficiency measures, home





[1]This chart provides historical progress rather than an absolute count of cumulative savings. All program catagories are shown as annual average savings.

Top: Even as population has grown, water consumption has dropped due to conservation and efficiency measures.

Bottom: All of Seattle's water conservation measures have helped to reduce water consumption.

By embracing source water protection, conservation and efficiency, and a flexible planning approach that incorporates climate change, Seattle has built a water supply system with the ability to respond to the unpredictable impacts of a shifting climate.

and business owners also lower water and sewer bills.

By investing in water conservation and efficiency, SPU has also protected vital ecosystems and wildlife. Reduced water consumption leaves more water in the river for aquatic organisms. While Seattle has historical water claims to 350 mgd from the Cedar River, it typically uses only a third of its claim and allows the river to keep the rest.[344] In 2004, Seattle agreed to a binding set of minimum flows in the Cedar River and to protect and restore habitat for 83 species of fish and wildlife that may be affected by water supply operations including Chinook, Sockeye and Coho salmon and steelhead trout.[345]

Climate Change

Seattle's water supply challenges are complicated significantly by climate change. Temperatures in the Pacific Northwest are expected to rise 5-7° F by the end of the 21st century, with greater increases in summer months.[346] Precipitation is projected to grow 5-10 percent in winter months and decrease 15-20 percent in summer months.[347] Most critically, snowpack in the Cascade Mountains that feeds rivers and streams throughout summer months will likely decline 32-71 percent by 2059.[348] Many sites in the Cascades have already seen snowpack levels shrink by more than 40 percent since 1950.[349] The continued loss of snowpack will be accompanied by a shift towards earlier snow melt, which will further decrease summer stream flows.[350] Glaciers are also shrinking, and models estimate that a 3.6° F temperature increase would lead to the loss of 65-75 percent of glaciers in the North Cascade Mountains.[351]

Seattle is heavily dependent on snowpack and glaciers for its summer water supply. The decreases will affect the volume of water that flows into Seattle's primary reservoirs on the Cedar and Tolt rivers, and climate models suggest that Seattle's water supply could decrease 14 percent by 2040.[352] Such a decline could cause shortages and reduce the amount of water kept in the rivers for habitat protection. The combination of increased water temperatures and altered flows will likely reduce the reproductive success of salmon and other cold water fishes while giving non-native, warm water fish greater advantage.[353] The historical streamflow patterns that water managers have used to forecast water availability will become obsolete as conditions change.

Towards Resilience

The combination of population growth and climate change will make it very difficult to guarantee a safe and consistent supply of drinking water. Fortunately, by embracing source water protection, conservation and efficiency, and a flexible planning approach that incorporates climate change, Seattle has built a water supply system with the ability to respond to the unpredictable impacts of a shifting climate. No community can completely insulate itself from these daunting threats, but Seattle is a model for building a flexible, resilient water supply system.

Climate change will mean less water when it is most needed, exacerbating supply and demand conflicts especially in summer months. Throughout the West, rivers and aquifers are already seriously overallocated, leaving little room for adjustment as the climate shifts. If extended droughts become more common, there will be no additional water supply to meet the

needs of people and ecosystems. These communities will likely be forced to implement emergency restrictions that will slow the economy, reduce quality of life, and still leave insufficient water in streams and rivers for fish and other species. Even worse, some communities may respond by building new dams. Dams are extremely costly, reduce ecosystems' ability to respond to changing conditions, and will lose increasing amounts of water to evaporation as temperatures rise.[354]

Seattle, on the other hand, has excess supply and a commitment to efficiency that will provide an inexpensive insurance policy against the uncertainty of a warming climate. The city's excess water supply provides a buffer against more variable precipitation patterns and will help the city avoid disruptive emergency restrictions. By reducing water withdrawals, Seattle is maintaining healthy watersheds that can continue to supply clean water even as a shifting climate aggravates water quality problems. Finally, as the most cost-effective way to ensure future supply, Seattle's conservation and efficiency initiatives put the city on a firm financial footing by reducing treatment costs and avoiding costly new water supply projects. Greater financial flexibility will allow the city to respond to other climate impacts as they arise. Numerous studies by the Intergovernmental Panel on Climate Change and others have found that efficiency can be an effective and inexpensive strategy for adapting water supply systems to climate change.[355]

Seattle's source water protection efforts further add to the resilience of the city's water supply system. The intact streams, wetlands, and forests in the Cedar and Tolt river watersheds will provide a buffer against many of the impacts of climate change. They will prevent erosion, slow runoff, and remove pollutants, preventing a decline in water quality and lowering treatment costs even as severe storms grow more frequent.[356] These natural systems also absorb rainfall, recharge groundwater, and provide consistent stream flow during dry periods.[357] Riverbank vegetation shades and cools water, which will help reduce the impact of rising temperatures on stream health and aquatic species.

Finally, Seattle has embraced a planning approach that will allow it to effectively respond to increasing temperatures. As part of its climate change adaptation strategy, SPU works to continuously identify and evaluate all possible impacts to its existing supply system and potential responses. SPU works with the University of Washington's Department of Civil Engineering and researchers with the Climate Impact Group to explore the potential impacts of climate change on Seattle's reservoirs.[358] SPU also invests in data systems that allow them to respond to changing conditions. A network of sensors provides real-time snowpack measurements which are used to guide operations, project conservation targets, and adjust water rates. This data allows the city to manage its reservoirs to maximize water storage for use in dry summer months and minimize the risk of flooding.[359] In a highly variable and unpredictable climate, these planning and monitoring efforts will be essential to ensuring a consistent supply of clean water and maintaining healthy ecosystems.

ENHANCING LIVABILITY
Augusta, Maine— From Working River to Restored River

Summary

When the Edwards Dam was removed in 1999, the Kennebec River began to come back to life. Water quality improved and fish stocks rebounded rapidly. The restoration of the river has created new recreational opportunities, boosted the local economy, and improved the quality of life in Augusta. As climate change threatens water quality and fish and wildlife, a healthy Kennebec River will be better able to adapt to changing conditions and allow Augusta to remain a livable community.

Challenge

For much of its history Augusta, Maine has relied on the Kennebec River as a primary driver of the local economy. The river transported mast pines for the shipbuilding industry in the early 1800s and later delivered timber to riverside paper mills.[370] The Edwards Dam was built just north of downtown Augusta in 1837 to power sawmills, a grist mill, and a machine shop.[371] Effluent from paper mills and other industries, as well as raw sewage, was piped to the river, severely degrading water quality and habitat. This rendered the Kennebec useless for purposes other than power generation and the transportation of pulpwood, sewage, and waste. The community of Augusta largely turned its back to the polluted river, and few people viewed it as an economic resource. Instead, it was viewed as an open sewer.[372] The Clean Water Act of 1972 and the banning of log drives in 1976 resulted in significant water quality improvements in the Kennebec.[373] Augusta residents began to realize the Kennebec could again benefit the community with further clean-up efforts and the return of fish species. One major obstacle stood in the way.

While the Kennebec and its tributaries have numerous dams, the Edwards Dam was the first obstruction encountered by migratory fish headed upstream to their spawning grounds, making it especially destructive to the fishery. The Kennebec once supported a number of commercial fisheries, but following the construction of Edwards Dam, both commercial and recreational fishing essentially disappeared. Two years after the dam was completed, alewife and Atlantic salmon populations on the Kennebec and its tributaries were declining rapidly.[374] Production of Atlantic salmon had declined by 90 percent by 1881.[375] American shad populations also decreased rapidly, leading to the demise of the industry in 1867.[376] The sturgeon industry crashed by 1880 when annual catches that had averaged 320,000 pounds per year in the early 1800s dropped to 12,000 pounds.[377]

Beginning in the late 1970s, cities across the country began to rediscover their riverfronts through revi-

Augusta, Maine



Left: Edwards Dam on the Kennebec River at Augusta before dam removal.
Middle The Edwards Dam and poor water quality decimated fish populations.
Right: Augusta turned its back on the degraded river.

talization efforts, utilizing rivers as resources that contribute to a sense of community, cultural heritage, the local economy, and quality of life. Augusta, however, continued to operate with its back towards its river. While owners of seven upstream dams began assisting the Maine Department of Marine Resources with alewife restoration efforts, the owners of Edwards Dam refused.[378] When Edwards Manufacturing Company's textile mill closed in 1980, the company began selling the 3.5 megawatts of electricity generated by the dam to the state utility, Central Maine Power.[379] The Company then made a deal with the City of Augusta to co-license the dam in 1992 in exchange for three percent of gross profits from the dam.[380] Once the City of Augusta began profiting from the dam, officials became opposed to removal despite the potential economic benefits it would bring to the community.[381]

Augusta's Approach

Removal of the Edwards Dam was the culmination of a decades-long effort to revive the Kennebec River and its fisheries. The struggle centered on the dam's 30-year operating license, which expired in 1993 and would have to be renewed by the Federal Energy Regulatory Commission (FERC) to continue operations.[382] The Kennebec Coalition, made up of four environmental groups including American Rivers, filed for and received intervenor status, which allowed them to participate and influence the relicensing process.[383] The relicensing process was not resolved by the 1993 deadline, and the dam continued to operate on annual permits pending resolution of the license application.[384] In early 1996, FERC released its draft environmental impact statement (EIS) recommending approval of a new license for the dam with construction of fish passage facilities worth $8.9 million and an additional $1 million towards environmental remediation.[385]

In the wake of the draft EIS, the coalition and concerned citizens continued to argue for removal. A key turning point came during a public hearing when local fisherman stayed late into the evening and convinced FERC commissioners to rethink parts of the EIS.[386] Soon after the hearing, the Kennebec Coalition filed a 7,000 page response to the draft EIS with extensive proof that the economic and ecological realities favored removal.[387] Four out of five fish species in question had never been documented to successfully use fish passage facilities, while historical records showed species rebounds when the dam had previously been breached. FERC's recommendations failed to consider the additional spawning habitat that removal would provide and the potential increase in recreation and tourism. The Kennebec Coalition demonstrated that removal could generate $48 million annually through increased sport fishing alone.[388]

In July of 1997 the final EIS acknowledged that the benefits of removal far outweighed the costs of



Left: The Kennebec River has made a dramatic recovery since removal of the dam.
Middle: Stonefly larvae, indicators of good water quality, are now abundant.
Right: Striped bass, Atlantic salmon, sturgeon and other fish have begun using the new habitat.

installing fish passage facilities and recommended dam removal. Fish passage facilities would cost 1.7 times as much as removing the dam, while the effectiveness of the fish passage was unknown.[389] In November of 1997, the FERC Commissioners voted 2-1 to deny relicensing of the Edwards Dam and ordered removal of the dam. This was the first dam to have its license renewal refused by FERC.[390] The initial plan called for Edwards Manufacturing to pay for removal, to which dam owners were adamantly opposed. In an effort to circumvent the funding roadblock, the parties reached a settlement in May 1998 that transferred ownership of the dam to the state, which would be responsible for removal. The agreement also required fish passage at seven upstream dams and called for a partnership between Augusta and the state to improve the Kennebec River waterfront. Dam removal began in June of 1999 and was completed on October 12, 1999, opening a 17 mile stretch of river to flow freely for the first time in 162 years.[391] As is discussed below, the previously dammed stretch saw improved water quality and the return of migratory fish within a year.[392]

Josephine County, Oregon—Wild and Scenic Rogue[427]

The Rogue River has been protected from development and degradation since 1968 due to its classification as a Wild and Scenic River. Recent studies show that recreational activities such as white-water rafting, fishing, and commercial jet-boat tours on sections of the river located within Josephine County, Oregon have greatly benefited the local economy. In the 2007 season, recreation contributed $13.9 million in total economic output throughout the county, including $7.4 million in personal income and 222 full- and part-time jobs.

However, removal of the dam was only the first step towards restoring the river and surrounding communities. As part of the Edwards Dam removal agreement, Augusta formed the Capitol Riverfront Improvement District (CRID) to provide access to the river, protect scenic characteristics, and promote economic initiatives. The State Planning Office took responsibility for the dam's former mill site, a mildly contaminated brownfield, restored it as part of the dam removal project, gave it to Augusta for use as a park and helped the city secure grants to improve the riverfront.[393] Mill Park, as it is now called, serves as a community resource with 17 acres of park space along the river near downtown Augusta.[394] The city also built a canoe and kayak launch with parking and access to the river. CRID furthermore works to revitalize historic buildings in the city by working with private developers. Projects include the conversion of the old Central Maine Power building into affordable housing in the downtown area and the redevelopment of the riverfront Arsenal buildings into a historic site with retail businesses, new housing developments, walking trails, and a boat dock.[395] The Arsenal redevelopment is expected to help rejuvenate the downtown, attract visitors, and increase recreational boating. Finally, the Kennebec River Rail Trail, which was completed in 2007, connects Augusta to three other river towns.[396]

Dam removal has improved recreational opportunities on the Kennebec River near Augusta, ME.

Additional river restoration and riverfront redevelopment activities throughout the river basin complement Augusta's improvements. The agreement that secured the removal of the Edwards Dam also required installation of fish passage facilities at seven upstream dams in order to allow sea run fish to reach available habitat in the lower Kennebec watershed and migrate downstream to the sea. While most dams under the agreement now have fish passage facilities, owners of the Fort Halifax Dam—located 18 miles upstream of Augusta at the mouth of the Sebasticook River—were unable to meet the costs of fish passage and removed the dam in the summer of 2008.[397] In addition, the basin-wide Kennebec River Initiative is organizing a cooperative effort to secure the future of the river as a vital ecological, recreational, cultural, and economic asset and to foster revitalization efforts in river communities. The Kennebec River Action Plan lists over 40 projects currently underway or planned for the Kennebec River.[398] The projects focused on Augusta include a boat launch, public trails, and redevelopment of the Statler mill site.[399]

Funding

Dam removal and fisheries restoration efforts totaling $7.25 million were paid for by the upstream dam owners and a downstream shipyard, Bath Iron Works.[400] The Kennebec Hydro Developers Group, made up of seven upstream dam owners, paid $4.75 million in exchange for additional time to install fish passage facilities.[401]

Removal of the Edwards Dam has not only resulted in improved habitat for fish, it has also improved water quality and allowed aquatic organisms to thrive. Prior to removal, the segment directly above the dam did not even attain Class C water quality standards, the lowest classification in Maine.

Bath Iron Works paid $2.5 million as partial mitigation for their expansion into 15 acres of endangered fish spawning habitat.[402] Total costs of removal came to $3 million with $2.1 million spent on construction and the rest on planning and permitting.[403] The remaining fund of over $4 million went to a 15-year program to restore migratory fish to the river.[404] Funding for redevelopment activities has come from a variety of sources including appropriations from the City of Augusta and the State of Maine, as well as grants from the Maine Community Foundation.[405] In late 2008, Augusta

The economic impact of recreational fishing along the restored river totals $65 million annually.

and neighboring Gardiner received a $495,000 grant through Maine's Riverfront Community Development Bond Program for riverfront trails, public access, and habitat improvements along the Kennebec River.[406]

Benefits

The Kennebec River has undergone a dramatic revival in the past 10 years. Since removal, fish and wildlife populations have rebounded, and riverbank communities have rediscovered their long forgotten river and its tributaries. All native fish species, which had maintained resident populations downstream of the dam, have begun to spread into the newly available habitat upstream of the old dam site.[407] In the spring following the dam's removal, schools of alewives and striped bass migrated past the former dam site. Within a year, Atlantic salmon, American shad, and sturgeon were also migrating up the river.[408] Recreational fishermen recorded high catches of striped bass as far north as Waterville in 2006 and 2007, although there were unexplained declines in 2008.[409] Wild American shad have begun spawning in multiple areas upstream of Augusta, and salmon redds—gravel depressions where they spawn—have been observed above the former dam site.[410] In June of 2006, four salmon entered the fish lift at Lockwood Dam, 22 miles upstream of the old Edwards Dam site.[411] Fish-eating raptors such as osprey, bald eagles, heron, cormorants, and kingfishers are now common on this reach of river.

Removal of the Edwards Dam has not only resulted in improved habitat for fish, it has also improved water quality and allowed aquatic organisms to thrive. Prior to removal, the segment directly above the dam did not even attain Class C water quality standards, the lowest classification in Maine.[412] There were very few bottom-dwelling insects, known as benthic macroinvertebrates, due to the poor conditions. However, after dam removal, water quality improved rapidly. Invertebrate samples prior to dam removal routinely collected less than 100 specimens, while post-removal samples collect between 2,000 and 3,000. The abundance of individual species nearly tripled following removal.[413] The number of caddisfly, mayfly and stonefly larvae, indicators of good water quality and an

Marinette County, Wisconsin—Outstanding Resource Waters[428]

In Marinette County, Wisconsin, 52 streams or stream segments are designated as outstanding resource waters and an additional 109 stream sections are designated as exceptional resource waters. These designations, required under federal Clean Water Act obligations for Wisconsin to adopt an "anti-degradation" policy, are designed to prevent any lowering of water quality—especially in those waters that have significant ecological or cultural value. A 1995 Department of Natural Resources report found these protective designations helped spur job growth in the tourism industry. The study found that tourism activities, which at the time accounted for 28 percent of Marinette County's economic output, generated $42.7 million and 1,135 jobs.

important food source for fish, has increased. The 17-mile stretch of river above the dam went from failing to meet Class C water quality standards to meeting Class B standards in just two months following removal and have maintained that classification since.[414]

Restoration of the Kennebec has also revived the City of Augusta and the local economy. The Kennebec now offers numerous recreational opportunities including fishing, canoeing, kayaking, and bird-watching. A new boat launch upstream of Augusta provides boaters with easy access to the river. A recent study shows that anglers spend more money when visiting the Kennebec fishery at Augusta than they did previously.[415] This study estimates the total annual economic impact from recreational fishing to be $27.5 million on the freshwater section of the Kennebec between Waterville and Augusta and $37.5 million on the tidal section from Augusta to Merrymeeting Bay.[416] Dam removal has been even more valuable to the local recreational fishery than was expected. In addition, properties near Edwards Dam that sold for less than comparable properties farther from the dam have increased in value; the penalty for homes close to the former dam site has essentially disappeared. Upstream, depressed home values near the Fort Halifax and Lockwood dams have increased slightly but remain significantly lower than the value of homes farther from the dam sites.[417] Restoration efforts have also greatly increased pride in the river, especially among those who witnessed the river prior to the Clean Water Act.[418] In 2008, the Spring Running Festival held its 3rd annual celebration of life on the Kennebec River at Mill Park.[419] Over 900 people attended the festival in 2008, in addition to roughly 50 canoe and kayaks taking part in the coinciding 17-mile Fort to Fort Canoe/Kayak Expedition.[420] In 2007, a weekly farmer's market began at Mill Park and will soon have an open air pavilion for shelter at the park.[421] Waterfront Wednesdays presents free concerts in the summer.

Climate Change

A changing climate holds many challenges for river communities throughout the Northeast, especially where dams already stress fragile ecosystems. Dams and heavy development reduce the ability of river ecosystems to respond to changes in flow and temperature, new sources of pollution or other disturbances.[422] Climate change will bring many of these shifts to river ecosystems throughout the Northeast. The region is expected to see significant changes in temperatures and rainfall in the coming decades. Average temperatures will increase 6-7°F by the end of the century.[423] Average precipitation is expected to increase 10-15 percent in winter months and up to five percent in the summer.[424] The increase in extreme weather and year-to-year variation in precipitation and temperatures, however, will likely prove the most taxing shift for many ecosystems and communities. Heavy rain- and snowstorms will become more severe and more frequent.[425] Combined with higher winter precipitation and earlier spring snowmelt, these storms will result in increased flooding and erosion. They will also wash pollutants from streets and farms into surrounding waterways. At the same time, extended droughts such as the one that hit the state from 1999 to 2002 will grow more common.

Towards Resilience

Restoration efforts on the Kennebec have been successful in reviving the river from more than a century of neglect. These efforts will be beneficial well into the future as Augusta deals with another man-made challenge: climate change. Removal of the Edwards Dam and restoration of the Kennebec River will allow Augusta and neighboring communities to minimize negative impacts and maintain a high quality of life as temperatures rise. Even if the most dire predictions don't come true, however, the restoration efforts are clearly no-regrets solutions. Augusta and other communities will still benefit from better water quality, more recreational opportunities, a stronger economy, and a healthy fishery. Keeping the dam in place would not have provided the immediate benefits or long-term flexibility to

deal with climate change.
The improvements in water quality and free-flowing nature of the Kennebec will allow the river to absorb climate-related stresses and remain a valuable community asset as temperatures rise. Water quality in the Kennebec remains much improved since the removal of the Edwards Dam. Climate change will threaten these gains by increasing polluted runoff and water temperatures. By improving water quality proactively, however, the river will be better able to assimilate the additional stresses without losing its capacity to support fish and wildlife populations or benefit river communities. Restoring the river's free-flowing nature will also provide important flexibility to the basin. Free-flowing rivers have more flexibility to efficiently drain runoff and utilize their floodplains to accommodate increases in volume. In a review of large river basins around the world, scientists have found that dam-impacted or otherwise disturbed basins are much more likely to experience increased flooding, water shortages or loss of biodiversity under changing conditions and therefore will need intensive management.[426]

River restoration efforts also greatly improve the likelihood that a healthy fishery can be maintained on the Kennebec in the face of a shifting climate. As described above, the Edwards Dam had been the primary obstacle to the Kennebec River fishery for decades. While a small remnant population of native fishes remained below the dam, most of the historical habitat had been closed off. Climate change will pose numerous challenges to fish species in the Kennebec. Rising water temperatures and the increase in polluted runoff will increase stress on many species, especially cold-water fish such as Atlantic salmon. As water temperatures begin to increase, fish and other aquatic organisms will need to adapt by migrating to cooler waters. Rivers and riverbanks serve as critical corridors for fish and wildlife movement. The additional habitat opened by the removal of the Edwards Dam will provide fish species with more flexibility as conditions change.

Finally, a healthy, resilient Kennebec and restored fisheries have important implications for the quality of life and economic resilience of communities in the basin. Already, Augusta has seen property values rise and the local economy grow since removal of the dam. A more robust economy will help Augusta withstand the economic impacts of a changing climate. Perhaps most importantly, Augusta has become invested in the health of the Kennebec River again. By investing in restoration, redeveloping the riverbanks, building trails, and encouraging recreational use, the community is more likely to maintain the health of the Kennebec in the future. If this remains the case, the river can continue to provide recreational opportunities, a venue for festivals and concerts, and an overall higher quality of life. Maintaining such a vital resource will help the community weather the impacts of climate change and remain culturally and economically vibrant for years to come.

A free flowing Kennebec River is better able to adapt to a changing climate and maintain a high quality of life in nearby communities.

ENHANCING LIVABILITY
Grand Junction, Colorado—Restoration of a Community Asset

Summary

Grand Junction's rivers were once forgotten places with uranium tailings, salvage yards and a sanitary landfill along their banks. Gradually, local river clean-up projects turned into a valley-wide effort to reclaim the rivers as social, economic, and recreational amenities. With riverfront trails and parks, restoration of the riverfront has helped stimulate economic growth and improve quality of life in Grand Junction. The community's restoration efforts will help keep quality of life high in spite of the challenges brought by climate change.

Challenge

Grand Junction derives its name from its location at the confluence of the Colorado (previously named the Grand River) and Gunnison rivers. For decades, Grand Junction and neighboring communities degraded and ignored the rivers. From 1951 to 1970, the Climax Uranium Company processed uranium and vanadium in Grand Junction, primarily for the U.S. Atomic Energy Commission. During its 19 years of operation the mill produced 2.2 million tons of low-level radioactive waste tailings, much of which was left at the processing site on the north bank of the Colorado River.[429] Throughout the 1950s, a gravel mining company operated nearby and dug a deep hole into a northern side-channel of the Colorado River. When gravel mining operations moved elsewhere, the hole was used as a sanitary landfill and dumpsite for uranium tailings.[430] The community also used the floodplain as a salvage yard, filling it with scrap metal and cars for years, giving rise to the nickname "Grand Junk-tion."[431] Limited access to the riverfront restricted recreational use of the river and few residents viewed the river as an asset to the community.

A volatile economic environment added to the challenge facing Grand Junction and its neglected rivers. Throughout the late 1970s and early 1980s, oil companies flocked to Western Colorado to harvest oil shale. As they set up projects, masses of people moved to the area and populations in some small towns increased 400 percent by 1980. When Exxon canceled these plans and shuttered its Colorado operations in 1982, the regional economy collapsed. Within five years, Grand Junction lost 10 percent of its population and saw over 4,000 foreclosures, leaving nearly 15 percent of homes vacant.[432] The oil shale bust turned Grand Junction into a ghost town with few economic prospects.

Grand Junction's Approach

In an effort to revive itself from the oil shale bust, the City of Grand Junction recognized that it needed to diversify its economic base and

Grand Junction, Colorado

Left: For many years Grand Junction polluted the Colorado River and ignored its potential recreational and economic benefits.
Middle: Radioactive mine tailings, salvage yards, and a landfill lined the river in Grand Junction.
Right: The oil shale bust in the 1980s devastated Grand Junction's economy.

attract new residents and tourists. With an ample housing stock and beautiful natural surroundings including red rock canyons, mesas, mountains, and lakes, Grand Junction promoted itself as a destination for retirees and outdoor enthusiasts.[433] As part of this effort, the city needed to confront the consequences of its industrial past and reconnect to its greatest natural assets: the Colorado and Gunnison rivers.

Restoration efforts began in 1985 when the local Lions Club created a committee to review the possibility of cleaning up and beautifying the Southern entrance to the city at the confluence of the two rivers.[434] The parcel of land they were interested in was a 30-acre weed- and junk-infested island known as Watson Island. The Grand Junction/Mesa County Riverfront Commission was formed in 1987 to purchase Watson Island and provide guidance for its clean-up and redevelopment.[435] For two years, volunteers spent countless hours cleaning the island by hand. The city hauled away 25 years of salvage yard scrap metal, 4,000 tires and over 400 truckloads of waste to the landfill.[436] Restoration was completed in 1991 and the island is now home to hiking trails, an amphitheater, a botanical garden, and a butterfly house.[437] While previous efforts to revitalize the riverfront failed to engage the community, residents now began to see its rivers as a potential social and economic resource. What began as a local clean-up project expanded into a valley-wide effort to reclaim the rivers and their floodplains as social, economic, and recreational amenities.

Since the Watson Island project, the Grand Junction/Mesa County Riverfront Commission has undertaken a number of riverfront restoration initiatives. One prominent project was restoration of the Climax Mill site. Grand Junction residents had long been concerned about the leftover mine tailings contaminating the Colorado River, groundwater supplies and neighborhoods. The U.S. Department of Energy began a three year clean-up of the 30-foot mound of untreated tailings in 1989.[438] Upon completion, the 107-acre parcel of land was turned over to Grand Junction and has since been developed into a park that will soon include bike trails, an amphitheater, a boat launch, board walks, and a civic center.[439]

Another focus of the riverfront redevelopment has been the Jarvis Property, a parcel of land that housed a landfill, uranium mill tailings, and a salvage yard of over 5,000 vehicles. After lengthy negotiations, the City of Grand Junction bought the 60-acre property with assistance from the Trust for Public Land in 1991.[440] Clean-up was largely undertaken through the U.S. Department of Energy's (DOE) Uranium Mill Tailings Remedial Action Program. The original DOE remediation plan consisted of temporarily storing the cars offsite while removing the 300,000 cubic yards of uranium tailings and then returning the 5,000 salvage vehicles to the site.[441] The Riverfront Commission



Left: The city has cleaned up polluted sites and embraced the river.
Middle: Improved access to the river has increased recreational activities and boosted the economy.
Right: A series of trails and parks stretches along the river in and near Grand Junction.

convinced DOE to permanently move the cars to a disposal site, remove the tailings, and leave the excavated area open as fish habitat. DOE would also pay the city the money it would have used to return the vehicles to their original site, which the city used to buy the land. The DOE agreed to this proposal and has used similar solutions many times since in other communities.[442] Today, hiking and biking trails connect the Jarvis Property with Watson Island to the east and other riverside parks to the west. Grand Junction recently developed a plan to redevelop the property into a mixed use area that includes housing and green space.[443]

In addition to restoration of riverfront properties, Grand Junction, surrounding towns, and state agencies are working to improve recreational opportunities on the river. Grand Junction is connecting its restored properties with a pedestrian pathway commonly referred to as the Riverfront Trail. The first sections of trail were constructed by the Grand Valley Audubon Society and community volunteers in 1987.[444] Since then, more than 30 miles of trails have been created throughout Mesa County.[445] The long-term vision would connect many towns along the Colorado River with over 140 miles of trails.[446] In addition, the Colorado Division of Wildlife and Colorado State Parks have created a state park along the Colorado River around Grand Junction that has five sections linked together by the Riverfront Trail. The State Park has nearly two dozen miles of trails for hiking, biking, and horseback riding and venues for fishing, swimming, boating, and many other activities.[447]

Planning

Restoration activities in Grand Junction began without an overarching plan for the final result. Success from Watson Island led to discussions with city, county, state, and federal agencies and the creation of a vision for an extended riverfront system of parks and trails throughout the Grand Mesa Valley, an area that includes three cities and over 100,000 people.[448] The Riverfront Commission has since been charged with planning, advocating, and implementing a strategy to redevelop and reclaim the riverfront within the city and county. The commission is made up of 12 citizens who volunteer their time on the Board of Directors.[449]

River restoration efforts in the Grand Junction area have revitalized the local economy, strengthened ecosystems, and greatly improved the quality of life for area residents.

Funding

Funding for the Riverfront Project has come from a variety of local, regional, state, and federal partners. The largest source of funding is the statewide Great Outdoors Colorado Program (GOCO), which uses lottery revenue to support parks and open space. In 1996, Mesa County received a $9 million grant for the Riverfront Project through GOCO and used the money for land acquisitions, easements, and improvements to parks and trails.[450] In addition, GOCO grants have funded numerous smaller riverfront projects.

Grand Junction has also pieced together funding from a variety of smaller sources. Energy remediation funds made up a majority of the early clean-up funding. The Energy Impact Assistance Fund, a federal program designed to help communities affected by mining and energy development, provided $200,000 toward the purchase and restoration of Watson Island in 1988.[451] Programs created by the Colorado Division of Wildlife, such as "Watchable Wildlife" and "Fishing is Fun," provided additional funding for a number of projects.[456] The Colorado Division of Wildlife also promised that five percent of money received for wildlife mitigation projects would be spent on expanding the Riverfront Trail.[458] Finally, the Colorado Riverfront Foundation, created shortly after the Riverfront Commission to allow people to make tax-deductible contributions, provides an ongoing source of funding for smaller projects.

Dallas, Texas—Trinity River Corridor Project[484]

The Trinity River Corridor Project brings together numerous flood protection, recreation, environmental restoration, economic development, and transportation initiatives into one massive project. Planned for completion in 2014, the project is the largest urban development effort ever undertaken by Dallas, covering 20 miles of the Trinity River and 10,000 acres. Included in the overall project are wetland construction, restoration of the river's natural meanders, creation and restoration of habitat, trails, and boardwalks, athletic fields, boat launches, open space, a white water course, fishing access, and development of new residential and commercial districts. The overall project will enhance livability and transform flood protection into an opportunity for community revitalization and economic development.

Grand Junction has also stretched available resources by minimizing costs and partnering with the community and governmental agencies. Much of the Watson Island clean up was carried out by volunteers from the community, and volunteers continue to contribute thousands of hours every year to the state park.[454]

Grand Junction expanded the trail system without purchasing additional land by securing permission from the Corps of Engineers to build trails on top of levees when the Corps renovated them to strengthen flood protection.[455] In the early years of the riverfront restoration process, Grand Junction also benefited from

Denver, Colorado—South Platte River[485]

For years the South Platte River in Denver was filled with sewage and garbage. In 1965 a disastrous flood tore through the basin and caused over $375 million in damages in the Denver metropolitan area.[486] Following the disaster, Denver began to restore the river. Unsightly businesses were relocated, major polluters were brought under control, and railroads were rerouted to make way for parks and greenways along the river. The Platte River Development Committee (now the South Platte River Greenway Foundation) has since built 150 miles of trails, numerous boat launches, whitewater chutes, and wildlife reserves. The parks serve as facilities for community events including concerts, outdoor movies, festivals, and races.

the depressed economic climate which allowed the city to acquire critical pieces of property for less than they would have been sold otherwise.

Benefits

River restoration efforts in the Grand Junction area have revitalized the local economy, strengthened ecosystems, and greatly improved the quality of life for area residents. The expansion of trails and parks around Grand Junction has reconnected the community with valuable natural resources that had previously been neglected and ignored. Residents have embraced the results of the restoration activities. Over 450,000 visitors come to Colorado Rivers State Park annually to enjoy the 137 campsites, three boat launches and 105 picnic areas on 639 acres of land.[456] Recreational opportunities include biking, fishing, swimming, camping, hiking, boating, wildlife observation, ice skating, and educational activities. A 1995 survey found that 80 percent of Grand Junction respondents used the Riverfront Trail System and that 92 percent of respondents regarded the trail as valuable, very valuable or extremely valuable.[457]

The restored rivers have had impacts on the community beyond recreation and tourism. They have become an integral part of community life and spurred cultural growth. There are numerous community events around the river including concerts, triathlons, bike rides, raft races, and festivals. The annual Robb River Rally includes a walking and biking tour and entertainment in honor of the late James M. Robb, the visionary who originally conceived of a riverfront system of trails and parks.[458] On Watson Island, native gardens, the butterfly house, and the amphitheater offer educational and entertainment venues. During the summer, the Colorado Riverfront Foundation hosts a series of free concerts at the Colorado River State Park at Fruita.

Although just one of many attractions in the area, the riverfront restoration project has helped revive Grand Junction's economy following the oil shale bust. Successful marketing of the region's natural amenities and recreational opportunities helped the population in Mesa County to grow nearly 45 percent from 1990 to 2000.[459] One study concluded that tourism accounts for 17 percent of the jobs and 11 percent of the income in Mesa County.[460] It also found that tourists directly or indirectly pay one-third of the sales taxes generated in the region.[461] Since suffering through an economic slump in the mid-1980s, Grand Junction's population and economic indicators now exceed the highest levels of the oil shale boom period of the late 1970s and early 1980s. Once dependent on mining and agriculture, Grand Junction now has a more stable and diverse economy because of its improved quality of

life and outdoor amenities, and it serves as a regional hub for trade, services, finance, education, transportation, and health care.[462]

Grand Junction's river restoration activities have also benefited wildlife and local ecosystems by removing contaminants and increasing riparian habitat. Aquifers lying below past mill tailing piles have been contaminated to the point that they are considered un-useable; however the influence of these contaminants on the aquatic ecosystem is largely unknown.[463] A study on a nearby uranium mill found aquatic macroinvertebrates in downstream stretches to have elevated uranium in their tissues.[464] The removal of mine tailings and junk yards reduces the risk of future contamination of the rivers and groundwater around Grand Junction. In addition, the restored vegetation and green space along the Colorado and Gunnison rivers provides a buffer that can capture polluted stormwater and reduce the amount of pathogens, fertilizers, and other contaminants flowing into the rivers. It also provides critical habitat for deer, fox, lizards, herons, and countless waterfowl and birds. At the Jarvis Property, a large wetland serves as a breeding site for endangered fish species including razorback sucker and Colorado pikeminnow during high water runoff.

Finally, the riverfront movement has inspired an ethic of citizen involvement in protecting the natural resources that are vital to the community and the local economy. This is best evidenced by the number of new initiatives begun since the riverfront project. Civic groups and students have volunteered countless hours that not only helped create new recreational opportunities but also created great pride and ownership in the project.[465] The Urban Trails Committee works to develop bicycle and pedestrian trails within Grand Junction and to connect these paths to the river trail. The Tamarisk Coalition started removing tamarisk, an invasive shrub that crowds out native vegetation, from the Colorado riverfront in Grand Junction in 2000 and has since broadened its efforts to the state and even to Mexico.[466] The Colorado Riverfront Trail's vision has also expanded to over 140 miles to link Glenwood Springs, CO to Moab, UT.[467] Progress on the Riverfront Project has been the result of tireless community effort and continues to move forward as the river becomes part of everyday life of Colorado River communities. Land acquisition, easements, and funding remain the biggest obstacles to continuing forward, but individuals and communities are now determined to build trails and protect surrounding open space, however long it takes.

Climate Change

Across Colorado, communities are faced with the challenge of adapting ecosystems, infrastructure, and key industries to the impacts of a changing climate. Average temperatures in the region increased 2° F between 1977 and 2006 and are expected to rise an additional 6-7° F by the end of the century.[468] Average precipitation will likely increase 5-10 percent in winter months and decrease 5-10 percent in summer.[469] Rising temperatures could cause a precipitous decline in lower elevation snowpack by 2050.[470] Peak runoff from melting snowpack has shifted to two weeks earlier in the spring since 1978 and is projected to continue this trend, resulting in reduced late summer flows.[471] The amount of runoff draining into the Colorado River could decrease 6-20 percent by 2050.[472] More important than the averages, however, will be the greater extremes in precipitation and temperatures. More extreme storms will raise the risk of flooding and wash more pollutants from urban streets and agricultural areas into nearby waterways.[473] Rising temperatures will also degrade water quality by reducing dissolved

oxygen and increasing the concentration of pollutants due to higher evaporation rates.[474] Warmer water may cause trout populations throughout the western U.S. to decline by as much as 64 percent.[475]

These changes will present a significant challenge to economies, ecosystems, and the quality of life in many communities, especially those that are in economic decline and have degraded their natural resources. Reduced water availability and increased demand will create shortages and conflicts among water users. Recreation and tourism activities such as fishing and rafting will be threatened due to decreasing water levels and worsening water quality in rivers and lakes. Recreation on waterways could also become a growing threat to public health as severe storms wash more polluted stormwater from the landscape.[476] Revenue from fishing and hunting in Colorado could drop substantially, hurting the $1 billion industry.[477]

Towards Resilience

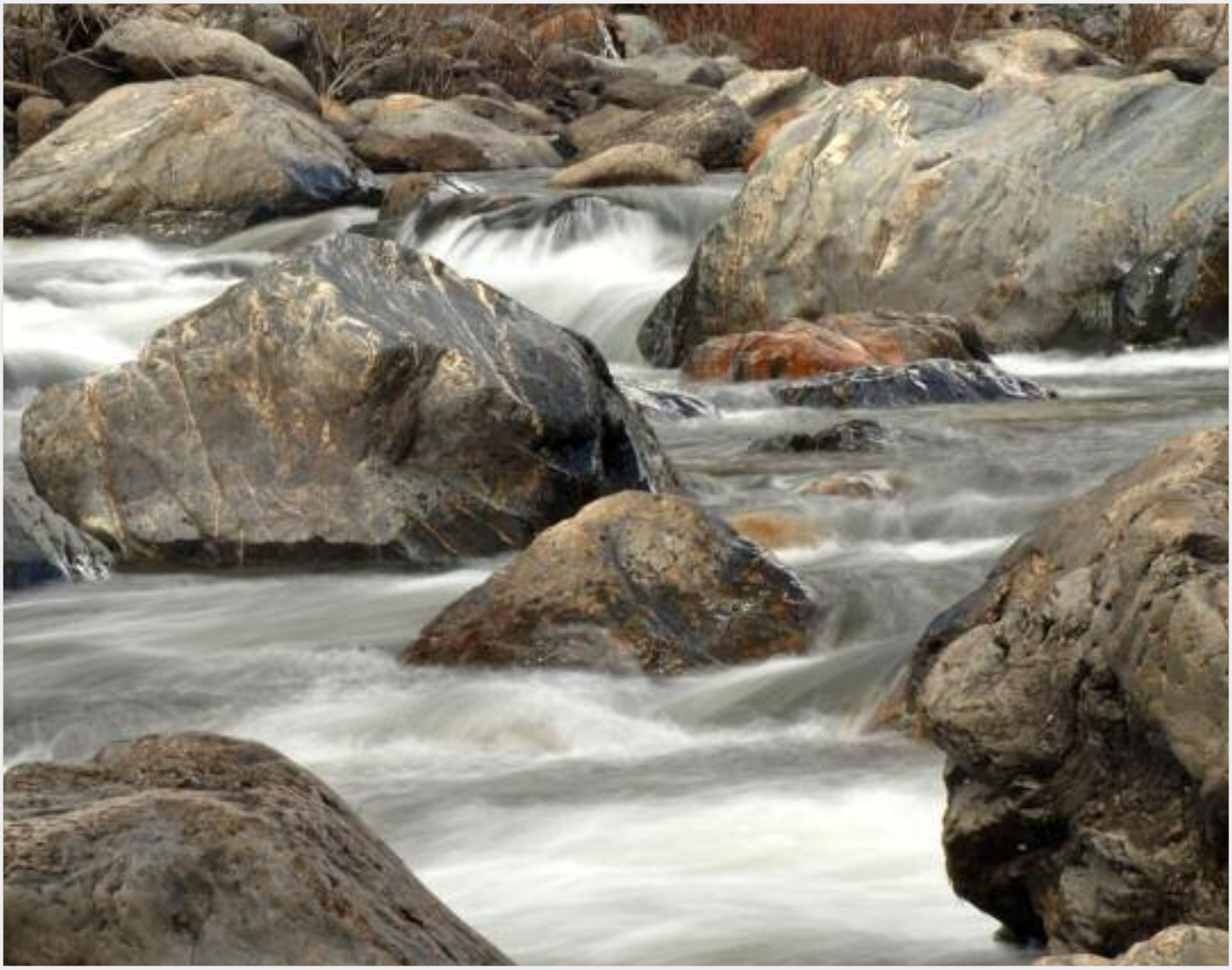
By restoring its riverfront and embracing the Colorado and Gunnison rivers, Grand Junction has not only corrected decades of neglect; it has also increased its ability to absorb the impacts of climate change and remain a vibrant community with a high quality of life. Quality of life depends on a number of factors including natural resources, economic conditions, social and cultural resources, human health, infrastructure, and public safety.[478] Climate change will challenge many of these areas by increasing waterborne disease, worsening water quality problems, and threatening the supply of clean water that drives the local economy. Fortunately, Grand Junction's restoration efforts have strengthened its natural resources, economic base, and social and cultural capital, making them more resilient to the impacts of a warming climate.

Grand Junction's restoration activities will help shelter its river ecosystems from rising temperatures and polluted runoff in a warming world. Ecosystems can withstand varying degrees of disturbance such as increased levels of pollution. When these changes exceed a certain threshold, however, ecosystems can undergo fundamental shifts and suffer extensive damages.[479] By reducing historical stresses, the rivers and the species that depend on them will be better able to absorb the impacts of climate change and continue to provide essential services to Grand Junction residents. Cleaning up polluted sites along the riverbanks and restoring green space that can absorb stormwater runoff will minimize the impact of more severe storms. Vegetation on the riverbanks will provide shade and moderate water temperatures that would stress vulnerable fish populations. Protecting open space and minimizing floodplain development provides a natural buffer to protect against floods and recharge stream baseflow. A healthy river system can in turn remain an important contributor to the high quality of life enjoyed by Grand Junction's residents by providing aesthetic benefits and boosting economic activity.

Grand Junction's efforts to promote and protect its natural resources also make the local economy more resilient to climate change. River restoration and the expansion of recreation and tourism opportunities have created new economic activities and strengthened existing ones, thereby expanding and solidifying the city's economic base. As a result, the city has maintained strong economic growth in recent years and has fared better than many surrounding communities during the recent economic downturn.[480] Economic diversity will be key to building resilience to the natural hazards and other pressures that climate change will bring.[481] By relying on a greater diversity of industries, Grand Junction will be less vulnerable to an economic downturn in one area. The parks and green space also help Grand Junction retain employers because it is easier to attract the best workers to more livable communities. While the city may see some economic contraction due to future impacts of climate change, it is better positioned to withstand turbulence due to its efforts to restore the riverfront and expand recreation and tourism activities. A strong local economy is in turn a key determinant of a

community's quality of life, as economic activity determines income, employment opportunities, and the cost of living.[482]

Finally, a less tangible result of its restoration efforts is increased dedication to conservation of natural resources. Much of the restoration activity was carried out by volunteers, and the ongoing efforts to remove invasive species and improve access to the river demonstrate the level of pride and dedication the community has for its riverfront area. Studies show that community members involved in conservation efforts are more willing to work to improve their community in the future.[483] Continued efforts to preserve Grand Junction's rivers will be crucial in adapting to climate impacts, and community dedication to these resources will be one of the greatest assets in protecting the rivers. These activities will in turn protect the social and cultural activities that have resulted from the river restoration efforts. Concerts, races, and festivals strengthen community ties and make the city a more attractive place to work and live. A continued dedication to the rivers' health will maintain these and the other benefits that contribute to Grand Junction's high quality of life.



Top: City of Grand Forks Greenway.
Bottom: A riverside park in downtown Boston.

BLUEPRINT

FOR A MODEL RESILIENT COMMUNITY

The eight communities discussed in the previous section have all adopted sustainable and innovative approaches to address a particular water management problem. And while these improvements have increased the ability of these communities to withstand the impacts of climate change, none have implemented the strategies to the maximum extent possible or integrated multiple solutions to address community water needs comprehensively.

In this final section of the report, we envision how a hypothetical community can integrate all the strategies discussed in the previous case studies to become a model of resilience to the impacts of a changing climate. In order to ground our recommendations in the real-world challenges that many communities face, we chose as a starting point a representative medium-sized Midwestern city with problems that affect communities across the country. We provide details of this city's actual problems—water quality, flooding, water supply, and green space—and describe the efforts currently being undertaken to remedy them, fully acknowledging that many communities are struggling to meet similar challenges with scarce resources. We have not yet found a city that has achieved an optimal set of water management solutions.

Starting with this snapshot of the challenges the city faces at present, we envision how a hypothetical community—we'll call it Greenville—could create a more sustainable future by holistically implementing four major initiatives. We outline the steps that would address existing problems and make Greenville's water resources—and thus the entire community—more resilient to a changing climate. Drawing from the case studies in the previous section, we demonstrate how an integrated suite of green water management practices would build resilience and ensure greater security and economic prosperity into the future—even in the face of great uncertainty.

This section provides a broad outline for building community resilience, but much more detail is needed to translate these principles into an implementable plan. This section is meant to create a picture of how a set of cost-effective, proven solutions can help a community better prepare for an uncertain future. An ex-

Drawing from the case studies in the previous section, we demonstrate how an integrated suite of green water management practices would build resilience and ensure greater security and economic prosperity into the future—even in the face of great uncertainty.

Like many communities, the hypothetical "Greenville" faces a variety of water challenges from flooding and sewer overflows to limited water supplies.

tensive planning process would be needed to adapt this vision to the particulars of a given community. For example, if green infrastructure techniques are being used to capture stormwater, planners would need to set targets for reducing imperviousness based on runoff patterns throughout the watershed. That would translate to a certain number of green roofs, rain barrels or swales. Since this planning is very site-specific and depends on detailed engineering studies, we do not specifically quantify the solutions proposed here. Instead, we demonstrate how the solutions build overall resilience and identify policies that can help implement them.

MEETING MULTIPLE WATER CHALLENGES

Greenville sits on the banks of the Green River in the upper Midwest. Following settlement in the 1800s, the land was cleared of hardwoods and transformed into a mix of farm land and growing towns. This allowed agriculture to expand, but the rapid alteration of the region's hydrology through the draining of wetlands and other activities created a number of problems that still plague the city. Today, much of the land surrounding Greenville is urbanized, and the city struggles with flooding, stormwater runoff, sewage overflows, a vulnerable water supply, and insufficient green space.

Adding to these substantial challenges is the threat of a changing climate. By the end of the century, temperatures across the region are expected to rise by 6° to 7° F.[487] Average precipitation will increase slightly and shift to spring and winter, leaving the summer months drier.[488] Of greatest concern is the expected rise in extreme weather. Precipitation will become more variable and unpredictable, making severe storms and extended droughts more common.[489] Heavy precipitation events that only occur every 20 years at present could happen every four to six years on average by the end of the century.[490] These storms will cause more floods, sewer overflows, and stormwater runoff. At the same time, there will also be more frequent droughts. Extended dry spells combined with reduced summer precipitation and higher temperatures will decrease groundwater recharge, lower water levels in rivers, cause small streams and wetlands to dry up, and threaten water supply.[491] With less water to dilute contaminants, pollution concentrations could rise in many water bodies. Rising temperatures will also deplete oxygen levels and cause more algal blooms in many waterways, stressing aquatic species.[492]

Water Quality and Public Health

As Greenville has expanded and developed, sewer overflows and polluted runoff have increasingly threatened public health and ecosystems.

By integrating green infrastructure techniques, increased water efficiency and floodplain restoration, Greenville can protect itself from the worst impacts of climate change.

Combined Sewer Overflows (CSOs). Greenville's sewer system was developed over the course of more than a century. Newer parts of the city have separate stormwater and sewage pipes, but older sections are served by a combined sewer system that transports sewage and stormwater in the same pipes. During dry weather, the combined and separate systems transport sewage to one of the city's two wastewater treatment plants in the southern part of town. When rains exceed one-quarter of an inch, however, the combined system discharges raw sewage and polluted stormwater from more than 100 outfalls along the Green River and other smaller streams. Dozens of CSOs occur every year, dumping billions of gallons of untreated sewage into local waterways. Upstream communities also have combined sewer systems that discharge into the Green River. Large withdrawals from the city's streams and rivers for water supply purposes further aggravate the problem by decreasing the amount of water available to dilute contaminants.

Greenville's sewer overflows present a major threat to public health. Despite the well-known pollution problems and bans on recreational activities in some of the city's waterways, residents continue to fish, kayak, wade, and swim in polluted streams. This puts them at risk of falling ill from the many bacteria and viruses found in CSOs and stormwater runoff. These pathogens can cause a wide variety of health problems, and hundreds of thousands of people across the nation fall ill every year as a result.[493] CSOs also affect fish and wildlife. One overflow in the 1990s killed over half a million fish in the Green River. Finally, CSOs have negative impacts on the city's economy, especially property values. Residential properties near a CSO-contaminated stretch of river are up to 40 percent less valuable than comparable properties further from the contamination.

Stormwater. Another major source of water pollution is stormwater runoff from Greenville and upstream farms and communities. Within the city, impervious surfaces such as roofs, parking lots, and streets have expanded as the city has grown. During storms, rainfall collects on these hard surfaces and carries nutrients, toxics, and other pollutants into the sewer system and local waterways. In the 1970s and 1980s rapid development around Little Green Creek, a small tributary of the Green River, led to a nearly 20 percent increase in impervious surfaces. As a result, annual runoff volume increased by 80 percent and lead, copper, and zinc levels rose 50 percent. Nutrients and pesticides from upstream farms also add contaminants to the stressed waterways. Seventy percent of the Green River basin is used for agriculture. Streams in the Green River

Basin have some of the highest pesticide concentrations of any water body in the country. High levels of metals and organic compounds in streambed sediments in Greenville trigger fish consumption advisories.

Current Strategies

In recent years, Greenville has committed to investing more than $3 billion in its sewage and stormwater infrastructure. The largest investment is in the city's aging combined sewer system. In order to meet Clean Water Act requirements, the city approved a $1.8 billion plan that will reduce CSOs more than 95 percent. The plan consists of numerous construction projects including expansion of sewer lines, upgrades to treatment plants, and an underground tunnel that will be capable of storing over 200 million gallons of sewage and stormwater during heavy storms. Greenville is investing an additional $650 million over a 20- to 30-year period to expand capacity and limit overflows in its sanitary sewer system. The third major investment focuses on improving the city's stormwater infrastructure. With funding from a stormwater utility the city created several years ago, Greenville is undertaking dozens of construction projects to improve drainage and stormwater management. The city is also working to limit runoff from private property through ordinances and a stormwater design manual that sets minimum standards for controlling runoff from new development and redevelopment projects. Discounts on stormwater bills provide an incentive to property owners that control runoff. In total, Greenville plans to spend approximately $3 billion on traditional infrastructure to address water quality issues. The expansion plan does not take climate change into account.

While most of the water infrastructure projects already completed or being planned use traditional engineering approaches, Greenville is beginning to embrace green infrastructure strategies. There are few specific plans as of yet, but the city is exploring how it can replicate natural water infrastructure to encourage more sustainable water management. In 2008, Greenville announced that it would incorporate constructed wetlands and street trees into its CSO reduction efforts. The city has already created a small green street project that uses native vegetation to retain and infiltrate stormwater and plans to build the first green roof on a city-owned building in the near future. Greenville is also revising its stormwater ordinance and design manual to encourage developers to use green infrastructure strategies as a first line of defense, absorbing rainwater before it can flow into sewers.

The Sustainable Approach: Green Infrastructure

Greenville's stormwater and CSO problems will be an increasing burden on the city's residents and ecosystems as strong storms become more frequent. The city's commitment to invest billions of dollars in its clean water infrastructure could provide clean, healthy waterways despite the impacts of climate change if funds are used in the most efficient manner. Greenville has the opportunity to create a more effective and flexible infrastructure by investing in green infrastructure as a core component along with expanded and rehabilitated sewers. Green solutions have a proven ability to control stormwater and CSOs but they are also less costly than traditional engineering approaches. This would allow the city to reduce existing sewage and stormwater problems and address projected increases in extreme weather, which the current CSO and stormwater control plans do not. Green infrastructure approaches would also help the city reduce air pollution, lower temperatures during summer heat waves, beautify neighborhoods, and create wildlife habitat.

Specific recommendations include:

Sewage and stormwater infrastructure: Greenville should direct a significant portion of the $3 billion it plans to invest in clean water infra-

structure over the next 20-30 years to green strategies. Investing in green roofs, wetlands and trees would allow the city to reduce the number and size of sewer pipes and pump stations and to scale back expansions of treatment plant capacity.

Green streets: Narrowing streets and installing swales, rain gardens, and pervious pavement would reduce runoff from roads and prevent it from entering sewers. Greenville should first retrofit all streets throughout the CSO area and then extend green street projects into areas with separate sanitary sewers, starting with critical areas that create the most runoff.

Green roofs: Greenville should install green roofs on all city-owned buildings. The city should also provide incentives to downtown building owners until at least 80 percent of large buildings in the downtown area have green roofs.

Wetlands: Constructed wetlands should be integrated into existing open space areas and designed to capture and filter polluted runoff, especially along waterways.

Urban trees: Urban trees face a variety of pressures from development and poor maintenance. Greenville should improve maintenance of existing trees and expand the canopy through an extensive tree planting campaign.

Private homes and developments: A large amount of the city's impervious surfaces are privately owned, and Greenville cannot solve its stormwater problems without the help of property owners. Residents that live in single family homes can disconnect their gutter downspout from the sewer, reducing the amount of roof runoff entering the system. They can redirect stormwater from their property into rain barrels or rain gardens. Developers can funnel runoff from multi-unit buildings to constructed wetlands or swales that infiltrate stormwater into the ground rather than allowing it to flow into the sewer or nearby streams.

Ordinances: Greenville could strengthen its existing ordinance and design manual for stormwater control to require that all new development and redevelopment projects maintain pre-development hydrology (i.e., that no more runs off the site than did previous to development), reduce impervious surfaces by a given percentage, retain the first ½ inch or inch of runoff or install pre-approved green infrastructure techniques.[494]

Incentives: The city could provide free downspout connections to interested homeowners and discounts on stormwater bills for installing rain gardens, rain barrels or other measures to reduce imperviousness on their property.

Storm and Flood Damage

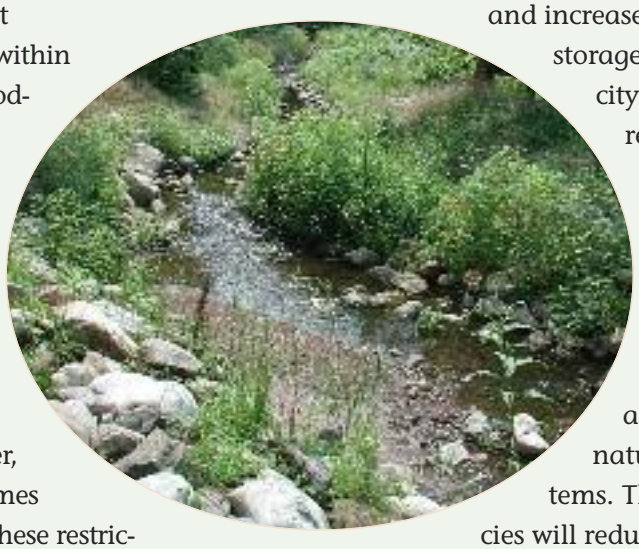
Flooding is a recurring problem in Greenville. Following a devastating flood in the early part of the 20th century that destroyed thousands of homes and caused nearly 100 deaths, the city was fortified with a system of levees, floodwalls, straightened stream channels, and dams. Major floods nonetheless continued to plague the city. Between 1993 and 2005 floods caused over $100 million in property damages and took several lives. There is also significant localized flooding during smaller storms due to a lack of sufficient stormwater drainage in parts of the city. This often results in flooded basements and streets. Over a five year period, Greenville residents filed more than 10,000 complaints about drainage and flooding problems. Much of this is a direct result of urbanization and development within the floodplain. The increase

> Greenville has the opportunity to create a more effective and flexible infrastructure by investing in green infrastructure as a core component along with expanded and rehabilitated sewers.

in severe storms will worsen Greenville's flooding problems.

Current Strategies

Over the past century, the city has built a complex system of flood control dams and levees along its streams and rivers. Today, flood walls line the Green River and a number of smaller streams. The Corps of Engineers is currently undertaking an expansion of levees along a stretch of the Green River in the northern part of the city. This project was spurred by a recent flood that nearly caused a catastrophic levee failure. As a participant in the National Flood Insurance Program (NFIP), Greenville has also adopted and enforced floodplain management ordinances to limit development within and along floodplains. Since 2000, an ordinance has restricted construction or alteration of structures in the floodplain. However, numerous homes built prior to these restrictions still stand in the floodplain and have been repeatedly damaged.



The Sustainable Approach: Natural Flood Protection

For much of its history, Greenville has relied on structural flood control projects that provide a false sense of security to vulnerable property owners. Even now the city is continuing to build levees to protect homes located in the floodplain. As we have seen time and again, in New Orleans in 2005, along the Mississippi River in 1993, and on many other occasions, structural flood protection structures can—and do—fail. When they fail, levees and dams can unleash devastating floods that destroy property and take lives.[495] With more severe storms in a warming climate, the consequences of Greenville's continued reliance on structural approaches will be magnified. A safer and more cost-effective strategy would reduce runoff from upstream areas, remove vulnerable structures, prohibit floodplain development, and increase flood storage within city limits by restoring and constructing wetlands, stream buffers, and other natural systems. These policies will reduce repeated damages and save lives.

Reducing vulnerability: Like many communities Greenville has attempted to protect vulnerable homes and businesses with dams and levees, only to experience continued damages and rising costs of maintaining flood defenses. The city should instead stop all development in vulnerable areas and remove existing structures in those areas where possible.

Voluntary buy outs: As a first step, Greenville should offer buy outs to the dozens of repetitive loss structures (buildings that have sustained flood damages worth 25 percent or more of the structure's value twice in ten years). The city should also remove other homes and businesses from frequently flooded areas that don't yet meet this definition to provide an additional buffer should future flood areas expand. Greenville should consider removing structures behind levees that may appear safe now but could be at risk in a changing climate. Other cities have removed thousands of structures in order to reduce their long-term vulnerability to floods, demonstrating that large-scale buy outs are possible.[496] Federal programs such as the Federal Emergency Management Agency's Flood Mitigation Assistance Program could provide financial assistance for relocation.[497]

Strengthening ordinances: While Greenville has already passed an ordinance to limit floodplain development, the city should consider strengthening it to incorporate climate projections and determine what areas will be vulnerable to flooding in the future.

Protecting high density development: In the highest density areas

with high-value buildings (e.g downtown) where relocation is not feasible, the city should strengthen existing flood defenses to handle the projected increase in extreme weather.

Increasing natural flood storage: Greenville can further reduce flood risk by restoring and protecting natural areas such as wetlands, stream buffers, and trees throughout the city. Flood prone areas that have been cleared of vulnerable structures can be replaced with open space or wetlands that can absorb flood waters and release them slowly to reduce high peak flows. The city could purchase additional open space along streams and wetlands in order to ensure that these areas remain completely undeveloped.[498] Planting new trees and protecting the existing tree canopy also provides valuable flood storage capacity where there is not a large amount of open space.

Reducing upstream runoff: While flooding in Greenville is caused in part by the proliferation of impervious surfaces and floodplain development within the city limits, loss of wetlands and forests for agricultural activities upstream has increased and accelerated runoff throughout the river basin.[499] Greenville can restore this natural flood protection by rebuilding wetlands and natural vegetation throughout the floodplain and working with watershed organizations, farmers, and other landowners to retire critical lands from farming and other activities that disturb the natural hydrology, allowing these areas to absorb rainfall instead of sending it downstream. Federal programs such as the Natural Resources Conservation Service's (NRCS) Floodplain Easement Program can provide financial support for restoring farm lands to prevent downstream flooding.[500]

Adequate Water Supply

Greenville gets 75 percent of its water supply from reservoirs on the Green River and two smaller streams. The remainder is pumped from groundwater aquifers. While these sources are sufficient to meet current demand, limited treatment capacity and poor water quality threaten water supply at times. A moderate drought in the summer of 2007 caused water use to rise more than 50 percent, mostly due to increased outdoor watering. This increase in demand exceeded the pumping and processing facilities' capacity, leading the city to ask residents to voluntarily reduce water consumption in order to avoid overtaxing the system. High levels of nutrients from urban and agricultural runoff also pose a threat to some of Greenville's water sources. The Green River Reservoir, which supplies 80,000 residents, has recurring algal blooms that cause taste and odor problems. There was also a toxic algal bloom in the Green Creek Reservoir in the summer of 2007, which prompted recreational advisories from state health officials. Finally, water withdrawals have significant impacts on ecosystems and wildlife. In summer, the combination of low rainfall and increased outdoor watering means that much of the water from the Green River is removed for water supply purposes, reducing its ability to absorb pollutants and degrading water quality.

Current Strategies

Until recently, Greenville only had a voluntary water conservation policy. Even during water shortages, residents were asked, but not required, to reduce their water consumption. In 2009, the Greenville City Council passed a water conservation ordinance that requires mandatory water conservation practices during times of declared drought. During shortages, residents are not allowed to water lawns, wash vehicles or fill empty swimming pools. The ordinance also commits the city to establishing a water rate structure that increases the cost of water as consumption rises. The city currently uses a declining block rate structure which charges customers less for each unit of water as consumption increases.

The Sustainable Approach: Water Conservation and Efficiency

While Greenville does not face severe water shortages like many western communities, it is vulnerable to shortages because of limited treatment capacity. Rather than undertaking a costly expansion of its water supply facilities, the city could solve multiple problems by increasing effi-

ciency and conservation efforts. Water efficiency is the most cost effective way of overcoming water shortages because it both negates the need for new construction and lowers pumping and treatment costs.[501] By reducing withdrawals, the city can also leave more water in streams, alleviating the low flows in summer that degrade water quality and harm fish and wildlife.

Rate structure: Water rates can be designed to promote conservation by charging customers more for higher water consumption. Greenville's current rate structure achieves the opposite effect by lowering costs as water use rises. The city should adopt strongly tiered rates that reward customers for conserving water. Conservation-oriented water pricing can result in a 13-17 percent reduction in household water use without decreasing utility revenues.[502]

Conservation: Greenville has adopted an enforceable conservation policy that limits water use during droughts. The city should ensure that the regulations are strong enough to achieve necessary reductions in a climate that will bring more frequent and more severe droughts. The city should also extend mandatory conservation requirements throughout summer months to decrease water withdrawals even when drought conditions are not in effect.

Efficiency: Greenville can further reduce overall water consumption through a variety of incentives and regulations. The city could provide rebates or direct installation of efficient toilets, showerheads, faucets, and appliances. The city could also require the installation of efficient fixtures in new development, redevelopment or upon resale of homes. Replacement of wasteful appliances and fixtures can decrease household water consumption by as much as 35 percent.[503]

Leak detection: A leak detection and repair program would allow Greenville to reduce water losses by locating and fixing leaks in the city's aging water supply system. About 15 percent of public water supply nationwide is lost due to leaks.[504]

Public education: Altered rate structures, conservation requirements, and efficiency incentives will accomplish little without proper outreach to the public. Residents should be provided with information explaining why efficient water use is necessary, what actions they can take, what resources are available, and detailed information on their water consumption patterns.

Strong Economy and Quality of Life

Greenville has made significant efforts to create green space and revitalize its downtown, but it still bears scars from poorly planned development and economic decline in the 1960s and 1970s. Nearly all of the county's native vegetation was destroyed during decades of intensive agriculture and rapid urbanization. Recreation on a number of the city's waterways is unsafe due to poor water quality, and a city ordinance prohibits swimming in the combined sewer area. In addition, parts of downtown continue to suffer from neglect. Following the Second World War, middle-class families and businesses relocated to the suburbs, leaving blighted neighborhoods throughout the city. Abandoned homes in turn led to a proliferation of drugs and violence. Nearly 8,000 homes remain vacant today. This combination of limited green space, poor water quality, and blighted neighborhoods has depressed property values, limited recreational activities and decreased the quality of life in Greenville.

Current Strategies

Over the last two decades, Greenville has worked hard to increase the quality of life by developing trails and park space and revitalizing the downtown area. It has created a number of recreational trails along the city's rivers and streams. There are nearly 60 miles of trails for biking and walking and over 25 miles of water trails for canoeing. The city plans to nearly double park acreage and expand the trail system to 200 miles, connecting 12,000 acres of park land and open space. More than two million users are expected to use the greenways every year when the current plan is completed.

Greenville is taking a similarly ambitious approach to restoring its downtown. The city has already invested billions of dollars to revitalize its downtown. The new restaurants, hotels, shopping, and entertainment facilities opened as a result of the renewal efforts have redefined the downtown as a major event center and bolstered the city's $3.5 billion tourism industry. In blighted neighborhoods the city plans to rehabilitate deteriorating homes, build new houses, create rental housing opportunities for low-income households, and convert more land into greenspace.

The Sustainable Approach: Expanding Green Space

Greenville's poorly planned development, neglect of its water resources, and economic decline have stripped the community of its natural beauty, polluted its streams, and left many of its neighborhoods blighted. While the city has taken steps to increase green space and revive neglected areas, the quality of life in Greenville will not reach its full potential until all of these problems are addressed. Continuing to expand and connect parks and trails and improving water quality will help build a vibrant community that is better adapted to climate change. Planting more trees and using other natural stormwater management techniques will help moderate rising temperatures and make the city greener and more appealing. An interconnected system of greenways and open spaces will also create valuable habitat for wildlife and help control stormwater runoff.

Expanding greenways: Greenville already has an impressive system of trails and parks that it plans to expand in coming years. The city can continue to increase this network, especially in blighted neighborhoods. The Parks Department can expand the greenway system by partnering with other city departments such as the Department of Public Works on joint, multi-use projects. Given the flooding and stormwater benefits of increasing natural areas within the city, expansion of greenways should be coordinated with stormwater and flood control projects to ensure the maximum benefit.

Improving water-based recreation: The city's greenways and parks will not reach their full potential without improved water quality that can support a variety of recreational activities. The quality of life in Greenville will suffer as long as the streams remain heavily polluted and unsafe for swimming. If the current stormwater and sewer projects achieve their goal, however, additional public access points along streams can help expand recreation and tourism. In that case, organized recreation on the river and entertainment activities such as races, concerts, and festivals could help promote the use of trails, parks, and the river.

The solutions discussed in this chapter can create a safe, healthy community capable of withstanding floods, droughts, and rising temperatures. Under this scenario, Greenville would transition from a city beset by numerous problems and vulnerable to the impacts of climate change to a vibrant, green community with healthy waterways, extensive green space, a secure water supply, improved neighborhoods, and numerous recreational opportunities. Taken together these sustainable water management strategies would make Greenville resilient to the impacts of a changing climate.

CONCLUSION:

A TRULY RESILIENT COMMUNITY

The water management strategies presented in this report demonstrate how communities can protect healthy landscapes, restore degraded ecosystems, and replicate natural water systems in urban settings to adapt to a changing climate. These solutions build resilience in a number of ways.

Healthier Ecosystems: All communities depend on healthy ecosystems to provide clean water, control floods, and sustain the economy. By eliminating CSOs and stormwater runoff, restoring forests and wetlands, and maintaining minimum stream flow throughout the year, communities can ensure that these valuable ecosystem services will benefit future generations as well. Decades of neglect have left many communities' natural resources degraded and vulnerable to the rising temperatures and extreme weather a changing climate will bring. These combined pressures could stress ecosystems to the point of collapse, which would leave them unable to benefit the community. Reducing these stresses before the worst impacts of climate change are felt, however, will increase the ecosystems' ability to absorb impacts without losing essential functions. With healthy, resilient ecosystems, communities will be better prepared to weather storms, droughts, and rising temperatures.

Increased Flexibility: Many older communities are investing billions of dollars to control CSOs through expanded pipes and deep tunnels. Yet these projects mostly do not factor in changing precipitation patterns, and it will be very difficult to adapt them once they are constructed. Green infrastructure, on the other hand, can be scaled up to need as conditions change. In addition, while none of the solutions recommended in this report are cheap, they can provide cost savings over traditional approaches that are extremely costly. Particularly for flood management, removing structures from vulnerable areas can provide long-term cost savings by avoiding future damages and the need to repair and upgrade structural defenses. With fewer disasters to r espond to and levees to maintain, communities will have greater financial flexibility to respond to climate change or other pressing priorities.

Stronger Local Economy and Quality of Life: Climate change will have significant impacts on economies throughout the country and around the globe. Worldwide,

Decades of neglect have left many communities' natural resources degraded and vulnerable to the rising temperatures and extreme weather a changing climate will bring.

there could be a 5-20 percent reduction in economic output if emissions are not limited.[505] Impacts on local economies will depend on the vulnerability of key industries and steps communities take to adapt. By restoring rivers and streams, encouraging recreation, increasing green space, and making the city a more livable place, communities can create a more vibrant and stable economy that will add new jobs while preserving the ones it already has. All things being equal, employers will be more likely to stay in places that offer a high quality of life for their employees.

Multiple Benefits: While the strategies discussed in this report have benefits across water management sectors, they can also help communities adapt to other impacts of climate change. Increased vegetation decreases urban heat island effects and reduces air pollution. Chicago originally started using green roofs to control stormwater, but now views them as a primary defense against heat waves. Urban trees can absorb carbon dioxide and a variety of air pollutants. Given limited budgets, communities will be better able to withstand the wide variety of climate change impacts if they maximize the benefit of their investments.

If any community is to realize the full potential of the solutions presented here, it is essential to create an integrated plan for implementation that does not artificially separate water supply, flood control, and clean water infrastructure. The interconnected benefits demand that communities coordinate planning across water management sectors. For example, green space can reduce stormwater runoff, limit flood damages, reduce the cost of drinking water treatment, and improve recreational opportunities. If all aspects of water management are incorporated into the planning process, a community can create an integrated approach that maximizes benefits and is more cost effective. Even better, they can work with neighboring communities in their watershed to ensure that upstream actions support its own steps. If it takes these steps, the city can create flexible systems that minimize the impacts of climate change. The end result will be a truly resilient community prepared for an uncertain future.

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