RESILIENCE STRATEGIES FOR FLASH FLOODING

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

The United States is facing increasingly frequent and intense precipitation events and ever higher damages from flooding each year due to climate change and urbanization. Communities, counties, and states are responding by upgrading stormwater and sewage systems with a growing emphasis on strategies to become more resilient to flooding. This paper outlines resilience strategies for flash flooding, with an emphasis on riverine and precipitation-caused flooding. For each strategy, the paper will discuss primary and co-benefits, and associated costs. Costs and benefits will vary based on local conditions and climate projections. A case study of Philadelphia's green infrastructure plan, *Green City, Clean Waters*, provides an example of an applied comprehensive green infrastructure plan based on a cost-benefit analysis. The paper concludes with high-level insights and a list of publications and interactive tools available to start building resilience to flooding.

INTRODUCTION: PRECIPITATION TRENDS AND COSTLY RESULTS

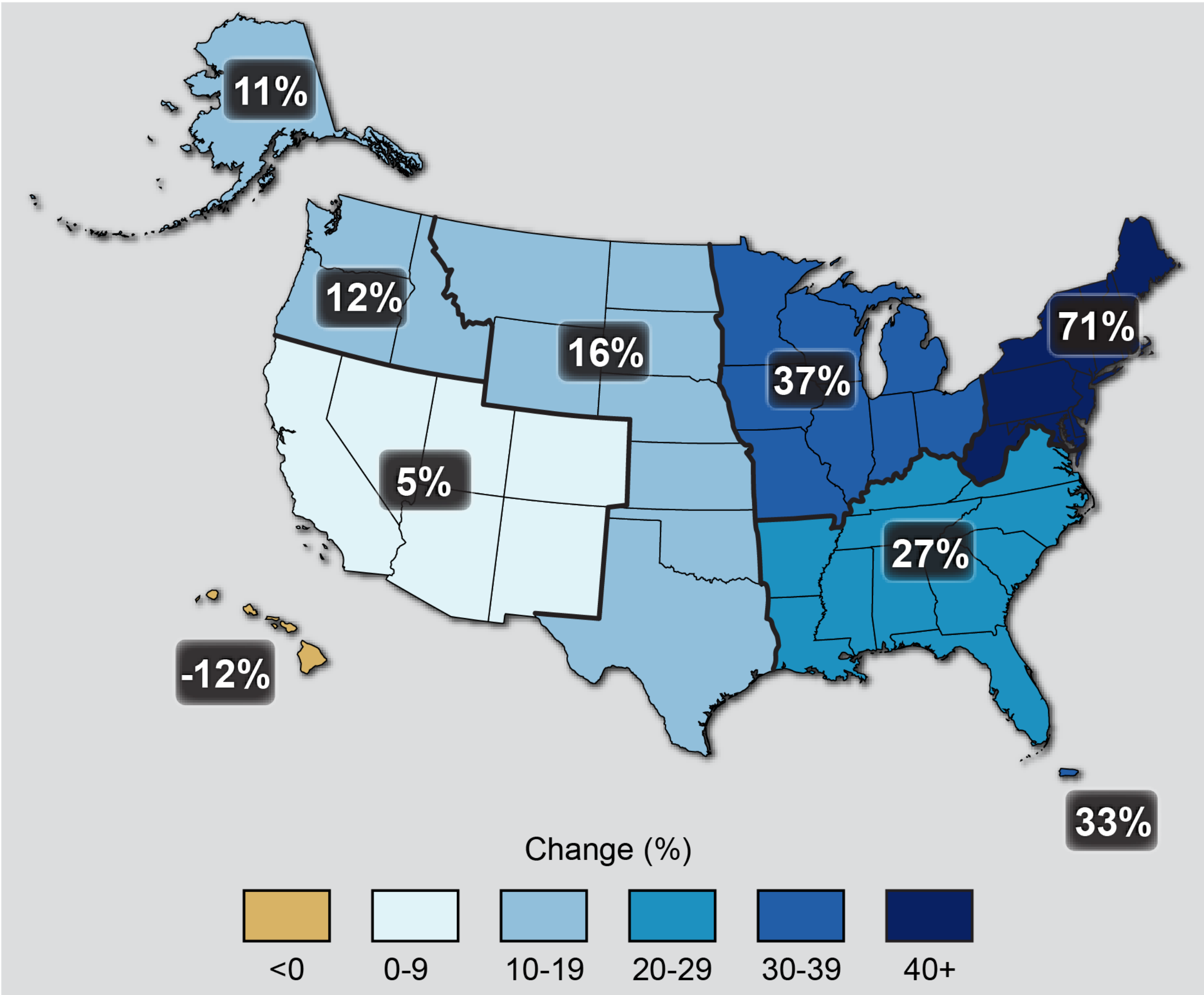
The United States experienced a nationwide 4 percent increase in annual average precipitation from 1900 to 2015.[1] Some regions are observing a mix of increased and decreased precipitation over historical averages by season, but the eastern United States has observed higher averages of maximum daily rainfall, with the northeast experiencing 27 percent higher maximum daily precipitation totals in 2012 than in 1901.[2]

Additionally, heavy rainfall events are more intense. The amount of rain falling on the heaviest rain days has increased by more than 30 percent above the 1901–1960 heavy rain days average in the Northeast, Midwest and upper Great Plains. These frequency of these events is projected to increase between twice and five times, depending on the success of efforts to reduce emissions.[3] The form of precipitation that falls is shifting from snowfall, with nearly 80 percent of weather stations across the contiguous 48 states observing a decrease in the proportion of precipitation that falls as snow.[4] Climate impacts are compounded by urban development, which removes the vegetation and soil that slow and filter water. Development also increases impervious surfaces, which move water over the land and directly into receiving lakes, rivers and estuaries.[5]

Projected riverine and coastal flooding will be costly. With emissions continuing on their current trajectory, the annual average cost of flooding in the contiguous United States is expected to be $747 million greater in 2100, a 31 percent increase from current levels.[6]

Greater precipitation and decreased storage of water in snow threatens water quality and public health by increasing agricultural runoff and causing combined sewer overflows (CSO). Combined sewer systems are designed to collect and treat stormwater and wastewater, and during high intensity rainfall events, systems can discharge untreated wastewater into receiving waters, or a CSO as illustrated in **Figure 2**. The number of CSOs per year in the Great Lakes region would increase between 13 and 70 percent between 2060 and 2099 due to climate change. The study showed less certainty about trends in New England, with the modeled number of CSOs be-

FIGURE 1: Observed Change in Very Heavy Precipitation



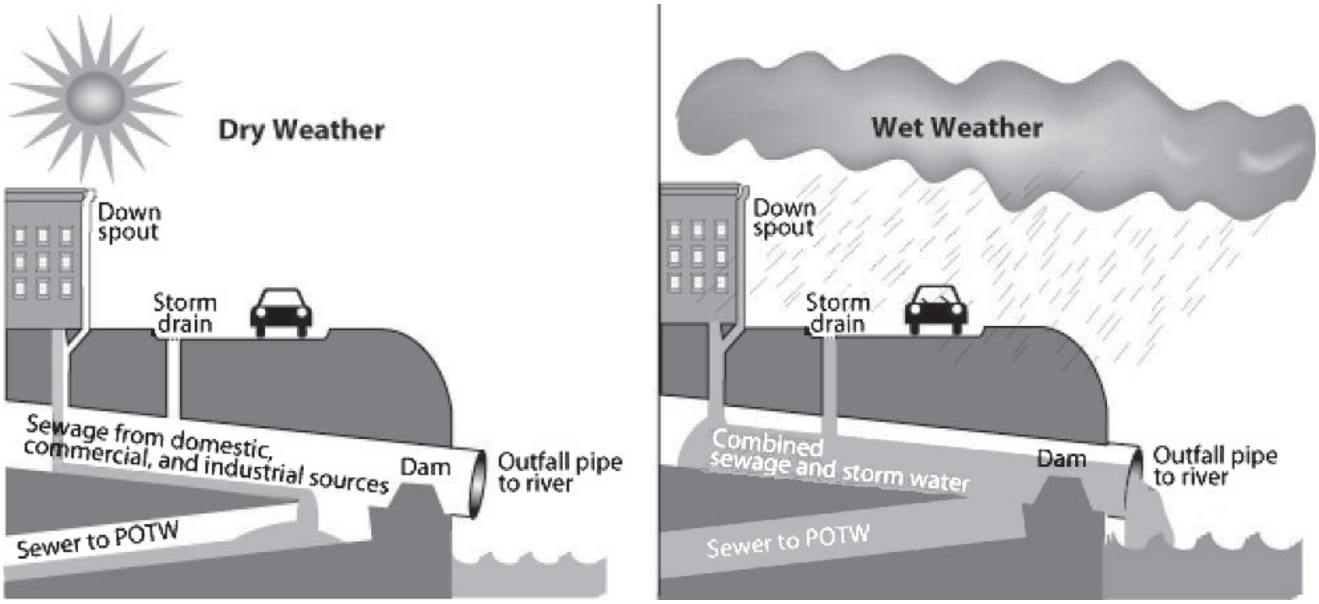
The map shows percent increases in the amount of precipitation falling in very heavy events (the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012.

Source: USGCRP

tween 2025 and 2050 ranging from a 25 percent decrease to a 14 percent increase.[7]

Climate change's contribution to increased CSOs, stormwater runoff,[8] and agricultural runoff[9] has expensive implications for recreation and public health. A California study found that gastrointestinal illness associated with polluted water costs $36.58 per case. In Los Angeles and Orange Counties, between 627,000 and 1.47 million gastrointestinal illnesses occur annually at beaches, with a resulting economic loss between $21 and $51 billion.[10] This also affects recreational access to water. In 2009, there were more than 18,000 days of closings and advisory days at ocean, bay and Great Lakes beaches nationwide, often due to polluted stormwater runoff.[11] The economic losses associated with a closing at a beach on Lake Michigan is as much as $37,000 per day.[12]

FIGURE 2: Combined Sewer Overflow



Combined sewer systems are designed to collect rainwater runoff, sewage and industrial wastewater and transport all wastewater to a treatment plant where it is treated and then discharged to a water body. A combined sewer overflow (CSO) occurs in these systems during periods of heavy rainfall. The wastewater can exceed the capacity of the system, discharging untreated wastewater into waterbodies.

Source: U.S. EPA

From initiating pilot projects to developing community-wide comprehensive plans, local and state governments are working to reduce these impacts and damages. This paper provides an overview of several common stormwater-management strategies, focusing on site-specific green infrastructure, an approach to managing precipitation by reducing and treating stormwater at its source,[13] and open space conservation. It highlights resilience benefits and co-benefits (benefits to society, environment and the economy) that can create more opportunities for financing, collaboration and community buy-in for these resilience actions. Please note that the estimated costs and values of benefits vary across communities based on a number of factors including local environment and climate projections. The paper does not discuss traditional (or gray) stormwater infrastructure solutions, such as pipes, tunnels, and treatment plants. Gray infrastructure is an important component of managing stormwater, but is already implemented across cities, and its application as a resilience strategy is usually in conjunction with the strategies outlined below.[14]

SITE-INTEGRATED GREEN INFRASTRUCTURE

Green infrastructure uses vegetation, soils, and natural processes to manage water and improve urban environment. Site-integrated designs manage stormwater onsite with structures that enable infiltration, filtration, storage, and uptake by vegetation structures.[15] The site-integrated features can be added to green spaces, discussed later, to retain greater quantities of stormwater. Property owners and local governments both have a role in installing green infrastructure and reducing impervious surfaces.

STREET TREES

Planting trees and increasing urban canopy cover reduces stormwater runoff by drawing water from the soil for use in photosynthesis and by intercepting and holding rainfall to reduce peak stormwater flows. Tree roots can take up trace amounts of harmful chemicals and hold soil in place during precipitation events reducing the impact of flood waters.[16] A study in Austin, Texas, found that the city's urban forest reduces runoff by an estimated 65 million cubic feet per year.[17]

PERMEABLE PAVEMENT

Permeable, or pervious, pavements reduce runoff by allowing rain water and melting snow to infiltrate. Pervious asphalt and concrete, interlocking pavers, and plastic grid pavers allow water to seep through the pavement to soil or gravel.[18] Permeable pavements can reduce runoff by an estimated 45 to 85 percent.[19]

BIORETENTION (RAIN GARDENS AND BIOSWALES)

Rain gardens are shallow, vegetated basins that collect and absorb runoff from rooftops, sidewalks and streets, allowing stormwater to infiltrate or be absorbed by plants, and released in the air through evapotranspiration. Rain gardens can provide habitat for plants and wildlife, absorb more water than traditional lawns, recharge ground water and remove pollutants from storm water.[20]

Bioswales also absorb, infiltrate, and filter rainwater, but are deeper and often use engineered soils to manage runoff from a large impervious area, usually in commercial or municipal projects. This can require that they use engineered soils and be deeper than rain gardens.[21] Plants, especially thicker grasses and deep-rooted native plants, help filter contaminants out of runoff.[22] Bioretention features can also take other forms, using trees and underground structures to help absorb runoff.

RAINWATER HARVESTING AND DOWNSPOUT DISCONNECTION

Rerouting drainage pipes to rain barrels or cisterns can reduce the quantity of water and peak flow entering stormwater systems in a rain event, storing the water for later use. Rainwater cisterns are larger than rain barrels and can be located above or below ground.[23] Just a quarter inch of rainfall on a typical home roof will fill a rain barrel, which can water a 200-square foot garden.[24]

GREEN ROOFS

Green roofs use plant material and soil media to retain and filter water, slowly releasing it through evapotranspiration and plant use. Green roof design and plants selected is determined by the surrounding environment and desired benefits.[25]

SURFACE AND SUBSURFACE DETENTION

Surface and subsurface detention structures slow runoff by capturing and storing stormwater collected from impervious surfaces surrounding the storage structure.[26] Surface detention structures include ponds and basins, and subsurface detention occurs in vaults, stone storage, pipe storage and plastic grid storage.[27] Some systems can be designed to release stored runoff into the soil surrounding the structure, recharging the groundwater table. Systems can also include pretreatment features to provide water quality and system function improvements.[28]

Benefits

Energy Savings

By adding vegetation and reducing impervious surface, green infrastructure helps reduce temperatures in cities, decreasing energy use related to cooling. Trees cool cities by shading buildings, sidewalks and streets, blocking wind, and through evaporation functions. An Alabama study showed that a house with 50 percent shade coverage during the day used 13.6 percent less electricity than a comparable house with no shade, saving about $29 per month.[29]

Stormwater resilience strategies can also reduce energy use by water and wastewater utilities, which typically accounts for 35 percent of U.S. municipal energy budgets.[30] Reducing runoff through retention and infiltration features like rain gardens can reduce the energy required to treat runoff. Green infrastructure strategies, like water harvesting, that reduce drinking water consumption reduce the energy costs of drinking water production, treatment and transport.[31]

Economic Development

Green infrastructure projects can create or change spaces to appeal to residents and business owners, increasing property values and improving business. A $15.5 million redevelopment project in Normal, Illinois, created a new community space incorporating stormwater management that led to $160 million in private business—a 16 percent increase in property values and a 46 percent increase in retail sales.[32]

Additionally, green infrastructure can create local jobs that are accessible without high levels of formal education and create opportunity to involve community members and volunteers.[33] Philadelphia estimates that its planned green infrastructure investment will create about 250 entry-level jobs per year through 2026.[34] Amigos de los Rios, a non-profit organization in Eastern Los Angeles County, advocates for the installation of green infrastructure and provides trainings to build skills and job experience through stewardship of the organization's green infrastructure features and parks.[35]

Reduced Sewer Costs

Reducing stormwater runoff limits the cost of treating runoff.[36] In Rhode Island, 67 privately-financed green infrastructure projects remove nearly nine million gallons of stormwater per year from the combined sewer system that runs into Narraganset Bay. This reduction in volume saves the local utility about $9,000 per year in operating costs for the combined sewer flow abatement project.[37]

Public Health

Vegetation in green infrastructure helps reduce air pollutants through direct absorption, reduces electricity generation by reducing cooling needs and limits ozone and smog formation.[38] Lancaster, Pennsylvania's green infrastructure plan, which included planting trees, installing green roofs, permeable pavement, bioretention and infiltration practices provided an estimated benefit of over $1 million per year in air pollution reduction.[39]

Use of vegetation in structures can also lower temperatures, reducing heat stress. A study in Washington, D.C., found that increasing vegetative cover by 10 percent could reduce deaths during heat events by an average of 7 percent compared to past events, saving approximately 20 lives per decade.[40]

Reduced Flood Damages

By reducing peak flow during storms, green infrastructure can reduce flood damages. A Toledo, Ohio study found that the use of green infrastructure to decrease the peak discharge by 10 percent in one watershed would reduce the losses in a 100-year storm by 39 percent. The study also showed that fewer buildings would be damaged in a 100-year storm in a scenario using green infrastructure versus using only gray infrastructure.[41] This can also have implications for property value. A North Carolina study which found that the average value of homes in an area with a 1 percent likelihood of being flooded are 7.8 percent lower than those outside the flood zone.[42]

Savings on Gray Infrastructure

In some locations, and with careful design, green infrastructure can offer construction and operations and maintenance (O&M) savings over its lifetime. In a compared cost benefit analysis of green and gray infrastructure, the Philadelphia Water Department found that green infrastructure would provide twenty times the benefits of traditional, gray stormwater infrastructure.[43] An Environmental Protection Agency (EPA) study analyzing the costs of gray and low-impact development approaches in twelve projects found the green infrastructure option provided project savings between 15 and 80 percent in eleven of the twelve projects reviewed.[44]

Costs and Benefits

Green infrastructure generally has lower installation and construction costs than gray infrastructure, but requires more frequent and less intensive maintenance.[45] O&M varies based on growth rate of vegetation and seasons. Costs vary based on size and what combination of green infrastructure strategies is employed. An EPA report found that the average annual maintenance costs of five sample green infrastructure projects ranged from as low as $780 to $2400 per year for smaller communities versus over $78,000 per year, including monitoring equipment and costs, to maintain green infrastructure across an entire watershed.[46] More detailed estimated or observed costs and benefits, if available, are presented for each strategy below.

Street Trees

Trees provide a number of co-benefits including improving air quality, cooling buildings and having positive impacts on public health. Austin's urban forest removed an estimated 1253 tons of air pollution with an associated value of $2.8 million, based on the number of cases per year of avoided health effects. Its gross carbon sequestration is about 92,000 tons per year with an associated value of $11.6 million per year (not accounting for carbon loss due to tree mortality and decomposition). By shading buildings, trees in Austin reduce energy costs by $18.9 million annually and provide an additional $4.9

million per year by reducing the carbon emissions from fossil-fuel based power sources.[47]

A study of five cities (Berkeley, California; Bismarck, North Dakota; Cheyenne, Wyoming; Fort Collins, Colorado; and Glendale, Arizona) showed that the cities spend $13–$65 annually per tree, but experienced benefits of $31–$89 per tree. For every dollar invested in management, the returns from reduced stormwater runoff, energy savings, air quality and aesthetic benefits ranged from $1.37–$3.09 per tree, per year, for the five cities.[48]

Permeable pavement

A Wisconsin Department of Transportation report estimates material costs for pervious pavement are 50 cents to $1 per square foot for porous asphalt, $2 to $7 per square foot for pervious concrete and $5 to $10 per square foot for concrete pavers with $400-$500 in maintenance per half-acre parking lot per year for vacuum sweeping. These costs are higher than for non-permeable materials, however there is less need for drainage systems under the paved surface.[49] A study in San Diego found that if the onsite soil allows for moderate or high infiltration, using permeable pavers can yield an 8 to 28 percent cost savings over a traditional design by reducing the need for curbs, drainage, or an underground detention system.[50]

Bioretention (Rain Gardens)

The cost of installing a rain garden could be as little as $3.00 to $5.00 per square foot. If the garden requires soil amendments or other expensive design considerations, the cost could be closer to $5 to $10 per square foot.[51] An estimated total cost of excavation, soil, gravel, filtering materials, optional drainage and storage under the garden and plantings is $1200 for a 200 square foot garden.[52] In a Naperville, Illinois case study, bioswales and other infiltration techniques saved over $400,000 over conventional design by limiting need for irrigation systems and lowering maintenance costs.[53]

Rainwater Harvesting and Downspout Disconnection

Rain barrels prices range from $50 to $200, with lower cost self-constructed options also available.[54] Water can be used for landscaping purposes to reduce water bills (or electric bills if a house uses a well). The barrel's cost-effectiveness depends on local rainfall and water prices. In some communities, a household can purchase subsidized rain barrels or install a rain barrel to receive credits on their stormwater fees.[55]

Green Roofs

A Toronto study found green roofs could reduce peak summertime roof membrane temperatures by 35 degrees Fahrenheit and reduce summertime heat flow through roofs by 70 to 90 percent compared with a conventional roof. A green roof on a single story commercial facility could save $710 over a conventional roof.[56]

Surface and subsurface detention

Subsurface retention and detention costs range between $0.50 and $30 per gallon of rainwater stored[57] with one study in Bellingham, Washington reporting the cost to develop underwater stormwater vaults cost as $12.00 per cubic foot of storage.[58] According to a study from the EPA, dry ponds (a surface detention strategy) cost $6.80 per cubic foot of storage.[59]

Implementation Examples

- **St. Paul, Minnesota** built an 11-mile $957 million light rail extension which included $5 million in green stormwater infrastructure to reduce runoff and improve water quality. The city constructed rain gardens, bioretention planters, permeable paver stones and tree trenches, mitigating approximately 50 percent of stormwater runoff, easing the burden on the traditional sewer system.[60]
- **Lancaster, Pennsylvania** developed a comprehensive Green Infrastructure Plan to address the city's combined sewer overflows during intense precipitation events. The estimated cost to manage the combined sewer overflows with gray infrastructure was over $250 million, and green infrastructure saved $120 million in capital cost and avoided operational costs of $661,000 per year.[61]
- **Tucson, Arizona** has a program to offer neighborhood groups funds and staff support to plan and construct stormwater harvesting projects to enhance their neighborhood.[62] The city published a *Water Harvesting Guidance Manual*[63] and devel-

oped *Green Streets Active Practice Guidelines* which requires capturing or infiltrating stormwater runoff with green infrastructure in all publicly funded roadway development projects.[64]

ZONING AND CONSERVATION

Communities set aside open space to provide a buffer for rivers, absorb stormwater runoff, and reduce flood risk to areas of development using riparian setbacks to protect areas near watercourses from development,[65] preserving or constructing wetlands,[66] or establishing a network of urban green spaces or parks.[67] These strategies can be implemented through zoning laws, master planning,[68] and even hazard mitigation plans.[69]

PARKS AND OPEN SPACE

Parks and open space can be planned as part of an interconnected green space system with the goal of improving stormwater management and reducing flooding. All parks with green space offer stormwater services through vegetation and porous soils. Applying site-specific strategies discussed above can optimize water retention and filtration services.[70]

Costs and Benefits

Lower Sewer Costs

Parks and open space reduce the amount of water processed by stormwater and sewer systems. In Philadelphia, the cost of managing stormwater is 1.2 cents per cubic square foot. A U.S. Forest Service study estimated that Philadelphia's parks reduced runoff by 496 million cubic feet, providing a stormwater retention value of $5,949,000.[71]

Local Economy

Parks add an average of 5 percent property value to nearby homes, with one study showing that parks add nearly $7 million in added tax capture in Washington, D.C. Parks and attractive public spaces can also contribute to increased tourism in some cities.[72] In Alachua County, Florida, conservation of environmentally significant lands has been prioritized for improving water quality as well as reducing flood conditions. The resulting increase in land value for properties adjacent to open space more than offsets the property tax revenue loss associated with acquiring open space for preservation.[73]

Public Health

Parks and open space provide areas for residents to exercise and access natural areas. They provide spaces for growing trees and other vegetation that improves air quality. By reducing the city's overall pervious surface, parks also contribute to lower temperatures and reduced heat stress. A study in Philadelphia looking at the economic benefits of water and air pollution found that the cost savings in avoided medical expenses due to park use was estimated to be more than $69 million.[74] While weighing gray and green infrastructure options, Philadelphia calculated that installing green infrastructure would result in avoided health impacts of 1 to 2.4 premature fatalities every year, more than 700 cases of respiratory illness days and avoid more than $130 million in healthcare costs over 40 years.[75]

Implementation Examples

- **Atlanta's** Historic Fourth Ward Park was designed to provide surrounding areas with a multipurpose green space while improving stormwater management through a two-acre retention pond bordered by plantings and a walkway, an underground cistern that allows for the reuse of non-potable water, an increase in pervious groundcover, and recreational amenities. The green infrastructure features in the park are estimated to have saved more than $15 million, compared with installing conventional draining infrastructure.[76]
- **Hoboken, New Jersey,** redeveloped a six-acre former manufacturing site as a parking and stormwater retention facility with green space, establishing a resilience park. The city is also designing Southwest Park, also designed to hold stormwater runoff.[77]

WETLANDS AND FLOODPLAIN CONSERVATION

Coastal wetlands provide vital flood reduction services in areas that experience flash and coastal flooding. A study in Ocean County, New Jersey, found that locations with salt marshes save 16 percent in flood losses every year and reduce annual flood risk by 70 percent when compared to properties where marshes have been lost.[78]

In communities that experience riverine flooding, land conservation in and near a floodplain gives the river space to flood, and can slow flood waters. In Milwaukee, the Sewerage District developed the Greenseams program to identify areas with water-absorbing soils in regions experiencing high growth and purchase land or conservation easements in these watersheds where flood risk is increasing. Properties are chosen for proximity to water, water-absorbing soils, environmental corridor and natural area designations and connectivity to public spaces. The program has protected 104 properties, preserving over 3,000 acres of flood-prone land in the Milwaukee area.[79]

Costs and Benefits

Water Quality

Coastal wetlands also trap sediments and filter water to improve water quality. In Phoenix, a 12-acre constructed wetland was established to process about 2 million gallons of wastewater each day in place of an upgrade to a wastewater treatment plant that would have cost as much as $635 million.[80] Wetlands absorb nutrients and pollution that can cause algae growth that degrades water quality, kills fish and affects human health.

Environmental

Coastal wetlands contribute to many aspects of healthy coastal areas. They anchor shorelines, keeping beaches and sand dunes in place, protect upland environments from erosion during storms, and provide natural habitat for amphibians, reptiles, birds and mammals. They are particularly vital to migratory bird species and fish and shellfish. About one-third of the plants and animals listed as threatened or endangered in the United States depend on wetlands.[81]

Recreational

Coastal wetlands host a number of recreational uses. On the Gulf Coast, tourists spend nearly $8 billion on recreational fishing, $6.5 billion on wildlife watching and $5 billion on hunting, much of which occurs in coastal regions. In the counties and parishes particularly dependent on wildlife activities, tourism jobs can account for 20 to 36 percent of private sector employment.[82]

Fisheries

Wetlands provide habitat for fish and shellfish, with much of the nation's fish industries relying on wetlands. In the Southeast, nearly all commercial catch and over half the recreational harvest are fish and shellfish dependent on estuary-coastal wetlands.[83]

Implementation Examples

- The Staten Island Bluebelt program in **New York City** preserves natural drainage corridors (or Bluebelts) allowing them to convey, store and filter stormwater while providing the community with open space and natural habitat. The wetlands combined are an area of 10,000 acres.[84] New York City has expanded the program beyond Staten Island to better manage flooding in different areas of the city. In 2012 the Department of Environmental Protection announced the completion of a bluebelt wetland in the New York Botanical Garden that can filter more than 350,000 gallons of stormwater during a heavy rain storm to reduce combined sewer overflows and control recurrent flooding along roadways.[85]
- In **Cambridge, Massachusetts,** the 3.4-acre Alewife Stormwater Wetland was conserved and restored to absorb up to 3 million gallons of water to address the basin's average 63 sewer overflows per year. A boardwalk, overlooks, environmental education opportunities and an amphitheater were included in the design, providing recreational benefits.[86]

POLICY STRATEGIES TO HELP COMMUNITIES WITHSTAND FLOODING

Even with a robust green infrastructure program, increased extreme precipitation means a crucial component of resilience is being prepared for an extreme flood that overwhelms the resilience features already in place. To do this, communities should consider what structures are in harm's way and discourage further building in area with flood risk. The last line of defense is making sure residents and businesses are prepared to act and remain safe during floods.

BUILDING CODE

There are a number of flood resilient design and construction practices that can help buildings withstand flood conditions. Elevating the lowest floor and mechanical equipment physically removes people and property from serious damage in some floods. Property owners can use water-resistant materials to reduce damage in lower levels of the home and only use those floors for storage (wet floodproofing) or seal the building's exterior and use removable barriers to keep lower levels dry even in flood events (dry floodproofing).[87] Communities can choose to extend floodplain boundaries beyond the traditional areas with one-percent chance of flooding so larger areas with flood risk follow flood-resilient building codes.[88]

Building code can also require that new development, or any redevelopment, captures and infiltrates the first inch or 1.5 inches of rainfall in a precipitation event.[89] New development can integrate green infrastructure strategies offering savings over retrofitting existing buildings.

GREEN INFRASTRUCTURE INCENTIVES

Communities and counties can raise money for community green infrastructure projects, and incentivize or reward individual actions that reduce stormwater runoff with stormwater utility fees. More than 1,400 communities have stormwater utilities,[90] which charge homes and businesses for the amount of runoff generated by their property while generating a revenue stream to invest in stormwater runoff solutions. A stormwater fee can be used to reduce impervious cover, increase filtration and increase green space by offering credits or fee reductions in exchange for installing green infrastructure on site.[91]

Tax credits, rebates, and development incentives can lower costs for individual projects that have community-wide benefits. For instance, Philadelphia offers tax credits for green roof installations. Milwaukee and King County, Washington, share the cost of green infrastructure with the property owner. Communities can also provide grants to proposed green infrastructure projects. The New York City Green Infrastructure Grant Program distributed more than $11 million to 29 green retrofit projects from 2011 to 2013.[92]

COMMUNITY FLOOD AWARENESS

Local communities can develop public information strategies to contact residents and property owners in areas with flood risk. Outreach can include preparing fact sheets or case studies, sending newsletters or mailings to residents in vulnerable areas and giving workshops for targeted groups or the public.[93]

Costs & Benefits

Discounted Flood Insurance

For communities participating in the National Flood Insurance Program, the Community Rating System (CRS) recognizes any community floodplain management activities that reduce flood risk to the community. Communities can earn up to a 45 percent discount on flood insurance rates.[94] Implementing green infrastructure strategies, protecting floodplains and conducting awareness outreach can improve a community's CRS score providing residents with savings on premiums.[95]

Damages Avoided

In Colorado, FEMA conducted a study analyzing losses avoided through regulatory or policy flood mitigation activity. The mitigation project restricted development in a special flood hazard area and redefined boundaries of the special flood hazard area. The project cost about $5,689,000, and yielded an estimated $22 million in losses avoided in a 2013 flood event.[96] This is in line with estimates that for every $1 of mitigation, there is $6 savings in post-disaster costs.[97] Lives saved is more challenging to model, but is a key consideration for communities as they weigh flood resilience strategies.

IMPLEMENTATION EXAMPLES

- **Cedar Rapids, Iowa,** acquired 1,356 flood-damaged properties using funds from FEMA's Hazard Mitigation Grant Program, and the Department of Housing and Urban Development's Community Development Block Grant. The acquired properties are being demolished to re-establish floodplain and areas for flood management systems with some redevelopment in the lower-flood risk areas that will be better protected by floodplain and flood management systems.[98]

TABLE 1: Co-Benefits of Resilience Strategies for Flooding

	BENEFITS								
	ENERGY	ECONOMIC DEVELOPMENT	SEWER/GREY INFRASTRUCTURE SAVINGS	PUBLIC HEALTH	FLOOD DAMAGE REDUCTION (REDUCED FLOOD INSURANCE)	WATER QUALITY	ENVIRONMENTAL	RECREATIONAL	REBATES/INCENTIVES OFFERED
Street Trees	●	●	●	●	●	●	●	▲	▲
Permeable Pavement	●	▲	●	▲	●	●	●	▲	▲
Bio Retention	●	▲	●	▲	●	●	●	▲	▲
Rain Barrels	●	▲	●	▲	●	●	●		▲
Green Roofs	●	▲	●	▲	●	●	●		▲
Water Detention		▲	●		●	●			▲
Parks & Open Space	●	●	●	●	●	●	●	●	
Wetlands	●	●	●	●	●	●	●	●	
Building Code	●	▲	▲	●	●		●	▲	▲
Flood Awareness	●	▲	▲	▲	▲				▲

Table 1. The benefits and costs of the strategies overviewed in the factsheet are summarized above, with dots indicating a benefit that could be expected from each of the strategies. When weighing different strategies for use in a community, consider the greatest local vulnerabilities, which benefits would address them and choose strategies that offer these benefits. Be aware of gaps in benefits offered by the strategies prioritized. The yellow triangles indicate benefits and costs that could apply in certain areas.

- **Boston** requires that any building projects assess methods for onsite stormwater retention, and that all properties must infiltrate the first inch of stormwater that falls onsite.[99]

CASE STUDY: PHILADELPHIA IMPROVES WATER QUALITY, REDUCES RUNOFF, AND INVESTS IN THE LOCAL ECONOMY

In 2011, Philadelphia adopted *Green City, Clean Waters,* a plan to reduce stormwater pollution through the use of green infrastructure. The plan aims to reduce stormwater pollution entering Philadelphia's waterways by 85 percent by the end of the project life in 2026.[100]

Engineering and economic analyses showed that green infrastructure, with some application of traditional infrastructure, was the best option due to its many co-benefits, because features could be installed in a decentralized manner servicing multiple watersheds (when compared to a tunnel solution) and because green infrastructure benefits are experienced with each installation of a new feature. Site-specific green infrastructure is also more adaptive over a 25-year period because designs and plans can be altered more easily for small, distributed, projects than with gray infrastructure.[101] The plan uses decentralized plant- and soil-based green infrastructure to reduce the city's combined sewer overflows. The Philadelphia Water Department is designing or has constructed more than 1,000 projects already in the city, including tree trenches, rain gardens, porous paving projects, swales and stormwater wetlands.[102] The projects are capable of keeping 1.5 billion gallons of polluted water out of rivers and creeks every year.[103]

Economic analysis of the first five years of the plan shows that the industry that has grown around green infrastructure has had an economic impact of nearly $600 million within the city of Philadelphia, supports 430 local jobs and generates nearly $1 million in local tax revenues. Over the lifetime of the 25-year plan, the Philadelphia Water Department will invest approximately $1.2 billion in stormwater infrastructures with a $3.1 billion impact on the local economy, supporting about 1,000 jobs per year and generating $2 million per year in local tax revenues.[104]

INSIGHTS

Green infrastructure allows for incremental implementation. Communities are able to start small with pilot projects and guidance for homeowners, and can build up to an integrated, comprehensive green infrastructure plan.

Because green infrastructure can be phased in, designs and plans can be altered over the course of implementing a comprehensive plan making it a more adaptive process. Gray infrastructure is more challenging and expensive to retrofit after its design and construction are complete.

Green infrastructure offers more co-benefits than gray infrastructure. Those co-benefits are often highly visible and local, including open space, opportunities for recreation, and wildlife habitat. Highlighting and, when possible, quantifying these benefits makes a case for green infrastructure to different users and funding sources.

Green infrastructure and open space conservation can be linked with local economic development efforts like downtown revitalization and city beautification. Parks and green infrastructure can create and sustain local jobs and capitalize on volunteer efforts.

KEY TOOLS

A number of tools in the form of websites and guides are available to communities and states increasing their resilience to the impacts of flooding and climate change.

COMMUNITY SOLUTIONS FOR STORMWATER MANAGEMENT

The guide describes how communities can develop comprehensive long-term community stormwater plans that integrate stormwater management with broader plans for economic development, infrastructure investment and environmental compliance and outlines the elements the EPA looks for in stormwater plans.

https://www.epa.gov/sites/production/files/2016-10/documents/draftlongtermstormwaterguide_508.pdf

GREEN INFRASTRUCTURE WIZARD (GIWIZ)

GiWiz is an interactive web application that connects users to EPA Green Infrastructure tools and resources. A user can select the aspect of green infrastructure they would like to learn more about, and the program generates a customized report of linked resources including case studies, reports, mapping tools, outreach materials and data.

https://cfpub.epa.gov/giwiz

A GUIDE TO ASSESSING GREEN INFRASTRUCTURE COSTS AND BENEFITS FOR FLOOD REDUCTION

This tool from the National Oceanic and Atmospheric Administration (NOAA) lays out a process for communities to assess the costs and benefits of green infrastructure to reduce flooding. It shows a watershed-based approach to documenting the costs of flooding, projecting increased flooding due to climate conditions, costs associated with land use and climate conditions. The guide also shows how to calculate the benefits of reducing flooding with green infrastructure in the long term.

https://coast.noaa.gov/data/digitalcoast/pdf/gi-cost-benefit.pdf

I-TREE

Developed by the U.S. Forest Service, this suite of tools provides urban and rural forestry analysis, including tools to assess benefits. The tools are freely accessible and aid communities in completing city, county, or statewide tree surveys, and identifying and measuring the services that one tree or a whole urban forest can provide. The suite is updated periodically with newer data, additional benefits to measure, and is adding a smartphone app.

https://www.itreetools.org

NATIONAL STORMWATER CALCULATOR

EPA's National Stormwater Calculator (SWC) is a software application that estimates the annual amount of rainwater and frequency of runoff from a specific site. Estimates are based on local soil conditions, land cover, and historic rainfall records. It is designed to be used by anyone interested in reducing runoff from a property, including site developers, landscape architects, urban planners, and homeowners. The SWC accesses several national databases that provide soil, topography, rainfall, and evaporation information for a chosen site. The user supplies information about the site's land cover and selects potential green infrastructure controls to calculate the possible runoff reductions that can be accomplished by installing that feature. The SWC also allows users to consider how runoff may vary based on historical weather and potential future climate conditions.

https://www.epa.gov/water-research/national-stormwater-calculator

RAIN GARDEN APP

NOAA's rain garden smartphone app helps users install a rain garden by offering video tutorials, diagrams, text and tools to guide how to size and place a rain garden, select plants, and install and maintain the garden. The tool helps users determine soil type, measure the size of the drainage area, and manage multiple projects.

https://coast.noaa.gov/digitalcoast/tools/rain-garden

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C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

2101 WILSON BLVD. SUITE 550 ARLINGTON, VA 22201 703-516-4146 **C2ES.ORG**