RESILIENCE

MAXIMIZING BENEFITS: STRATEGIES FOR COMMUNITY RESILIENCE

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

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INTRODUCTION

American communities are facing growing and shifting climate risks. The evidence is in the growing costs of disasters which soared to more than $300 billion in 2017, breaking 2005's record of $219 billion, according to NOAA data. Underlying these headline-making disasters are the gradual impacts of climate change that can further stretch cities' already thin financial resources and staff time, undercutting other priorities. In anticipation of these challenges, the Center for Climate and Energy Solutions developed a set of briefs we call *Maximizing Benefits: Strategies for Community Resilience*. The five briefs presented in this compendium focus on extreme heat and heatwaves, flash flooding, drought, wildfire, and power outages, which are caused by a number of physical climate impacts. This section introduces these briefs, all of which provide information that can help cities and regions prioritize which resilience strategies to implement first. To aid comparison of different resilience strategies, each brief includes cost data, identifies co-benefits, provides examples of where used (including a case study of a city using that strategy), and offers a series of tools to help get cities improve their climate resilience. While the impacts discussed in the briefs and the strategies identified do not represent the universe of impacts or strategies that could be deployed, the hope is that they can be helpful as cities and regions chart their course to more resilience in the face of our changing climate.

THE CLIMATE CHALLENGE

The Fourth National Climate Assessment (NCA) reports a number of observed impacts, and what we can expect in the coming decades. The NCA explores the regional differences in the severity and scale of these impacts, and considers the challenges specific to urban vs. rural and inland vs. coastal areas. The NCA reports that:

- Global average temperatures have increased by about 1.8 degrees Fahrenheit for the period 1986-2016 when compared to 1901-1960. This trend will continue, resulting in increased energy costs as governments, businesses, and residents deal with warmer temperatures and adverse effects to human health.
- The north-central United States faces up to a 20 percent increase in precipitation in winter and spring by the end of the century. The Northeast and Midwest are facing a 40 percent increase in extreme precipitation events over the same period, leading to greater risk of flash flooding.
- A 20 percent decrease in spring rainfall is projected for the Southwest by the end of the century, along with large declines in snowpack, disrupting snow-dominated western watersheds. Decreased soil moisture will cause stronger and longer future droughts in the Southwest and Southern Great Plains.
- Drought conditions and higher temperatures will contribute to increased prevalence of wildfires. Climate change doubled the area that burned from 1984 to 2015 when compared with the wildfires that would be expected without climate change. Climate change is expected to continue to increase areas burned by wildfires, with an 30 percent increase in the Southeast by 2060.
- Climate change can exacerbate extreme weather like high winds, thunderstorms, hurricanes, heat waves, intense cold periods, intense snow events, ice storms and rainfall, all of which contribute to power outages.

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STEPS TO RESILIENCE

Cities are building resilience to climate impacts, many following a process articulated in the U.S. Climate Resilience Toolkit. Communities can follow the "Steps to Resilience" by first exploring hazards and secondly completing vulnerability assessments to create a comprehensive understanding of current and future local climate risks.

A community then investigates potential resilience strategies, developing a list of feasible strategies that could reduce climate risks. The fourth step in the process is to prioritize which strategies to start with and develop a resilience plan. The briefs are for local governments that are on this fourth step of determining which resilience options should be implemented first, and how to phase in other resilience strategies over time. Cities have limited finances and staff resources for resilience initiatives, so there needs to be a careful analysis of where to start. The briefs are intended to help cities get from a vulnerability assessment and survey options to the fifth step, taking resilience action.

PRIORITIZATION

Assessing and prioritizing resilience strategies can be challenging, in part because the field of climate resilience is continually evolving and innovating, but also because of the slow-moving nature of climate change itself. The benefits of climate resilience are realized over time, some are difficult to monetize, and explaining these to non-climate experts can be daunting. Fortunately, resilience strategies often provide co-benefits such as added green space, reduced energy bills, and improved environmental quality. Identifying and comparing these co-benefits provides opportunity for synergy between resilience and other efforts such as economic development, improving transportation options and addressing inequities in access to education, health services, jobs and city parks.

Comparing resilience strategies based on potential co-benefits and how they might complement existing local priorities can inform prioritization of strategies but also creates buy-in for resilience strategies that improve other aspects of the city. Qualitative understanding of co-benefits is helpful, but many resilience planners must justify costs using quantitative analysis, and

FIGURE 1: Steps to Resilience

Source: U.S. Resilience Toolkit

precise quantification of many of the co-benefits of climate resilience strategies can be difficult. The key to accelerating climate resilience planning may be ensuring it is integrated with other organizational goals.

These briefs, primarily written for use by local government officials, address that challenge by providing a review of key climate resilience strategies employed by local governments today, discussing the co-benefits they provide, and comparing quantitative assessments of the costs and benefits of each. The briefs include a focus on how co-benefits can be monetized, since funding for climate resilience is a particularly thorny challenge. A number of the co-benefits discussed in the papers do not have a tested method for economic valuation. With the goal of helping cities get from understanding vulnerabilities to resilience action, the end of each brief includes a case study of a model city that has successfully employed a number of climate resilience strategies. Each brief concludes with a list of tools spanning from native plant guides to interactive tools that help quantify benefits of specific strategies. The tools provided can further guide the prioritization process and provide information about implementing resilience strategies.

Each paper features a case study of a U.S. city that has led in addressing one of the focus climate impacts. The five cities or metro areas featured are: wildfire management efforts in Austin and Travis County, Texas; the drought initiatives of San Antonio; policies to reduce urban heat island and rising temperatures in Louisville, Kentucky; Philadelphia's plan to manage storm water and reduce flooding; and New Orleans' increased resilience to power outages. The case studies demonstrate how to use multiple resilience strategies, different city offices and partnerships, and

ADDRESSING MULTIPLE CLIMATE IMPACTS

Each brief addresses one climate impact at a time, but from the maps that display the many dimensions of climate change nationally, it is evident that communities are facing a number of simultaneous impacts. For instance, in the western United States, drought, wildfire and flash flooding are intricately linked, with drier conditions increasing the risk of wildfire, wildfire damaging forests and destabilizing soil, and creating flood conditions after fire. Meanwhile the Northeast faces increased extreme summer temperatures as well as greater increases in average and extreme precipitation. Every community faces a different combination of climate risks that interact with local economic, cultural and social conditions.

To respond to the multiple dimensions of climate risks, communities are analyzing strategies that can address several types of impacts. For instance, planting trees or installing bioretention features like rain gardens can reduce risk of flooding, filter rainwater, and cool sidewalks or buildings through shading or evapotranspiration (which in turn can reduce heating and cooling costs). With the correct tree selection and siting, this strategy can address increasing temperatures, flooding and potentially drought.

Users of this document may want to refer to the tables at the end of each chapter to identify the climate resilience strategies whose co-benefits line up with other organizational objectives. Table 1 below provides a comparison of the strategy tables in each of the five factsheets. Referring to the master table below and more detailed tables in each brief can help readers assess where climate resilience and other organizational goals align.

CONCLUSION

Across the United States, communities are seeking out the strategies that can simultaneously address multiple local concerns and climate change impacts. *Maximizing Benefits; Strategies for Community Resilience* contains tools for cities to learn about the potential co-benefits of these strategies, and cities that have already implemented resilience strategies and are reaping economic, social and environmental benefits.

TABLE 1: Comparing Co-Benefits of Resilience Strategies

	BENEFITS											RESILIENCE BENEFITS				
	ENERGY SAVINGS	ECONOMIC DEVELOPMENT	AVOIDED DAMAGES & INVESTMENT	PUBLIC HEALTH/SAFETY	WATER QUALITY	ECOLOGICAL	RECREATIONAL	SEQUESTRATION/ GHG MITIGATION	EQUITY	PUBLIC AWARENESS	CONTINUOUS POWER	HEAT RESILIENCE	FLOOD RESILIENCE	DROUGHT RESILIENCE	WILDFIRE RESILIENCE	POWER OUTAGE RESILIENCE
Cool Pavement	●		▲	▲	▲	▲	▲		▲			★	▲			▲
Cool Roofs	●		▲	●		▲		▲	▲			★				▲
Street Trees	●	▲	●	●	●	●	▲	●	▲			★	★	▲		
Permeable Pavement	●		●	●	●	●	▲	▲	▲			▲	★	▲		
Bioretention	▲	▲	▲	▲	●	●	▲	▲	▲			●	★	●		
Rain Barrels	▲		▲	▲	●	▲				▲			★	●		
Green Roofs	●				▲	▲		▲	▲			●	★	▲		
Detention													★	▲		
Wetlands		▲	●	▲	●	●	▲	▲					★	▲		
Water Conservation	●	▲	●	▲	▲	●	▲	●	▲	▲		▲	▲	★		
Regional Water Conservation	▲	▲	▲	▲	▲	▲	▲	▲	▲				▲	★		
Water Reuse	▲		▲	▲	●	▲	▲	▲						★		
Desalination		▲	▲											★		
Conservation & Parks	▲	▲	▲	▲	●	●	●	●	▲			●	★	●	★	
Building Code	▲	▲	▲	▲	▲	▲			▲			▲	★	★	★	

	BENEFITS											RESILIENCE BENEFITS				
	ENERGY SAVINGS	ECONOMIC DEVELOPMENT	AVOIDED DAMAGES & INVESTMENT	PUBLIC HEALTH/SAFETY	WATER QUALITY	ECOLOGICAL	RECREATIONAL	SEQUESTRATION/ GHG MITIGATION	EQUITY	PUBLIC AWARENESS	CONTINUOUS POWER	HEAT RESILIENCE	FLOOD RESILIENCE	DROUGHT RESILIENCE	WILDFIRE RESILIENCE	POWER OUTAGE RESILIENCE
Public Outreach	▲	▲		●	▲				▲	●		★	★	★	★	▲
Emergency Planning			▲	●					▲	●		★	▲	★	★	★
City Planning	▲	▲	▲	▲	▲	▲	▲	▲	▲			▲	★	★	★	▲
Microgrids	▲	▲	▲	▲				▲			▲	▲	▲		▲	★
Combined Heat & Power	●		▲	▲	●			●			▲	▲	▲		▲	★
Solar PV	●		▲	▲	●			●			▲	▲	▲		▲	★
Backup power *Battery storage*	▲		●	●	▲			▲			●	▲	▲		▲	★
Energy Efficiency	●			●				●				▲				★
Hardened Distribution			●	▲							▲	▲	▲		▲	★
Smart Grid	●				●			●				▲	▲		▲	★
Enhanced Shelters				●						▲		▲	▲		▲	★

This table includes a complete list of the strategies discussed in the five climate impact strategy briefs with the co-benefits they offer. *When comparing strategies, resilience planners should consider which strategies offer the co-benefits that are most valuable for a city. When considering a suite of strategies, planners must consider which co-benefits are excluded or leave climate impacts.*

● *A green dot indicates that a resilience strategy always offers a co-benefit.*

▲ *A yellow triangle indicates that the strategy can yield that co-benefit in the right conditions or with the right design. The five columns on the right are the climate impacts discussed in the briefs.*

★ *For each strategy, a blue star in one of the five right columns indicates which brief discusses that strategy. This table has grouped some similar strategies that are discussed individually in the following briefs.*

RESILIENCE STRATEGIES FOR EXTREME HEAT

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Climate change is contributing to more frequent, severe, and longer heat waves during summer months across the United Sates. The number of heatwaves observed in 2011 and 2012 were triple the long-term average, and require planning for economic, health and environmental tolls.[1]

Local and state governments are already deploying resilience strategies to address urban heat islands, prepare for long-term trends of higher temperatures and plan emergency responses for heatwaves. To help local, county, and state officials understand the role of some common strategies in a holistic approach to managing climate risks, this fact sheet considers a comprehensive set of resilience benefits and co-benefits for those strategies. Estimates of costs are included, if available, though actual project costs will depend on local climate projections and other factors. Identification of co-benefits creates more opportunities for financing, additional design objectives and increases the political viability of these resilience actions. The monetization of each benefit summarized in this fact sheet will be most helpful in prioritizing strategies for closer study in your community. This fact sheet also includes tools that town or city officials and planners can use in assessing local project co-benefits.

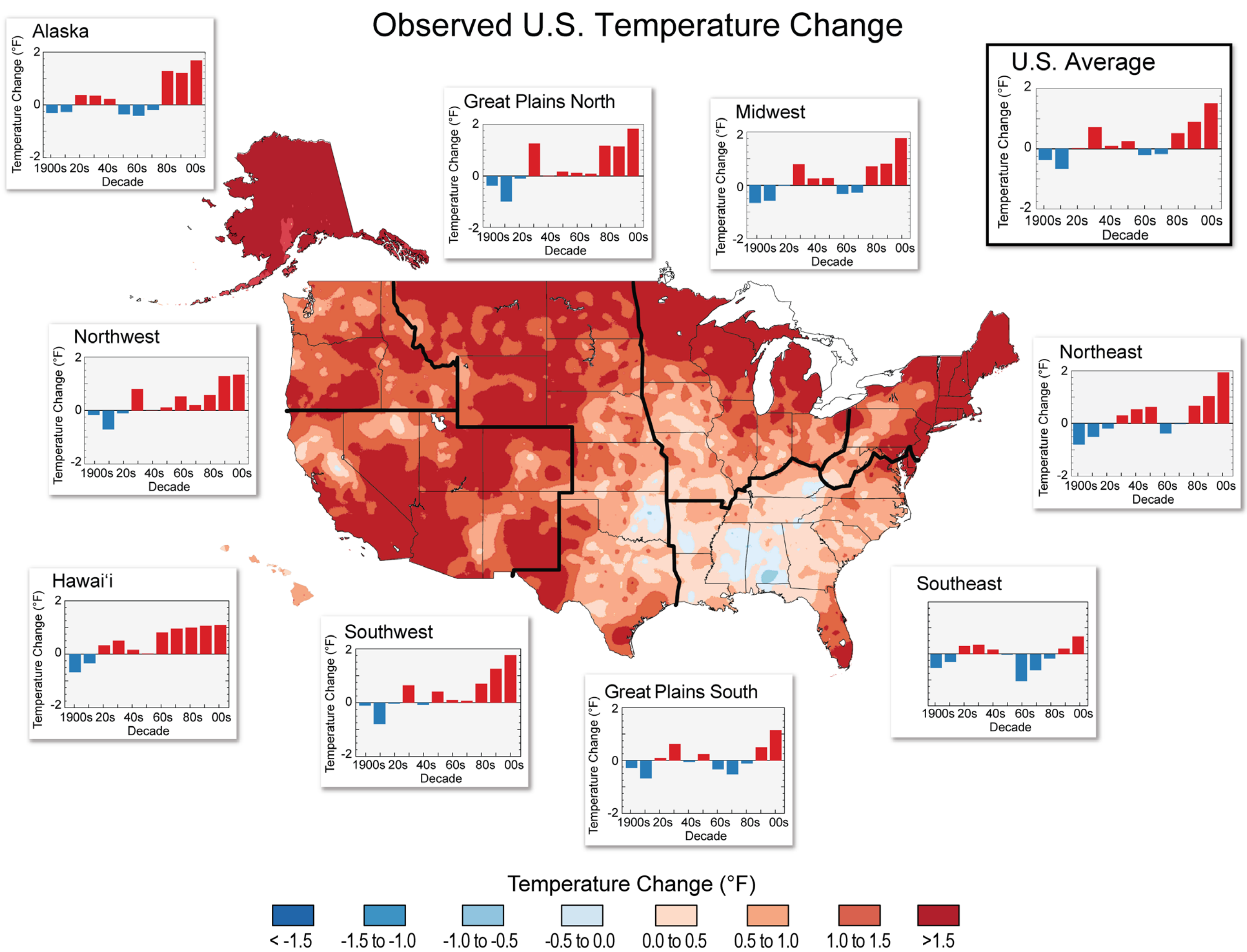
INTRODUCTION: HIGHER TEMPERATURES MEAN GREATER IMPACTS

Extreme heat causes more deaths than any other weather-related hazard—more than hurricanes, tornadoes, or flooding, and an average of more than 65,000 Americans visit emergency rooms each summer for acute heat illness.[2]

Heat will cause economic losses too. The U.S. Environmental Protection Agency (EPA) projects more than 1.8 billion labor hours lost due to extreme heat in 2100, costing more than $170 billion in wages.[3] Higher temperatures contribute to more use of air conditioners and stress on electric grids, resulting in power outages.[4] Electricity demand for cooling increases 1.5–2 percent per 1 degree F increase in air temperature between 68 and 77 degrees.[5] Energy costs to consumers nationwide will increase by 10–22 percent due to increased consumption, costing between $26 and $57 billion by the end of the century,[6] a considerable burden for low-income homes.

The heat is especially burdensome in American cities because of the urban heat island effect. Higher temperatures are amplified because cities' impervious surfaces, like pavement, retain more of the sun's energy while energy usage from heating, ventilation and automobiles produce waste heat. The annual mean air temperature of a city with a population of 1 million or more can be 1.8 to 5.4 degrees warmer than its surroundings, and could be 22 degrees greater at night.[7] While rural areas may not experience as high temperatures as cities, a study in Ohio found that suburban and rural areas were just as vulnerable to heat,[8] and a study comparing heat mortality in Northeastern urban and rural counties found that heat mortality was present in both urban and non-urban counties.[9] To respond to the growing challenges related to extreme heat, communities are implementing strategies that change building design, urban planning, and emergency planning through regulations, incentives, pilot projects, and new climate resilience programs.

FIGURE 1: Observed U.S. Temperature Change



The map shows temperature changes from 1991-2012, compared to the 1901-1960 average (in Alaska and Hawaii, the changes are compared to the 1951-1980 average). The bars on the graph show the average temperature changes by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region.

Source: NOAA NCDC / CICS-NC

CHOOSING COOL ROOFS TO REDUCE HEAT SENSITIVITY

Cool roofing products are made of highly reflective and emissive materials (often light colored) that can remain 50–60 degrees cooler than traditional materials during peak summer weather.[10] About 60 percent of urban surfaces are covered by roofs or pavement, traditionally made of dark materials with low solar reflectance (5–15 percent) that absorb about 90 percent of the sun's energy,[11] transferring that heat energy to the ground or buildings below.[12] Cool roof materials have higher solar reflectance (more than 65 percent) and transfer less than 35 percent of the energy to the buildings below them.[13] Material options depend on the slope of the roof, but include coatings, asphalt shingles, metal, clay tiles, and concrete tiles[14] and can be implemented on commercial or residential buildings.

COST

When compared with conventional roofs, cool roofs can be the same price, but often are 5–10 cents greater cost per square foot than conventional roofing materials (and 10–20 cents per square foot greater for a built-up roof with cool coating). Some roofing options cost significantly more (up to $1.50 per square foot), but these can result in greater reflectivity and greater benefits.[15] The **Key Tools** section provides links to resources for developing an accurate cost estimate and prediction of related energy savings, and guides to cool roofing materials.

BENEFITS

Reduced Energy Use

Cool roofs transfer less heat to the building below, so less air conditioning is necessary to keep indoor air temperatures comfortable. This becomes particularly valuable during peak electrical demand periods on hot days. Cool roofs can reduce cooling system needs and reduce peak electricity demand by up to 10–40 percent.[16]

The annual energy cost savings for a white roof are estimated nationally as 3.3 cents per square foot.[17] These costs vary based on many factors, including local climate, building characteristics, insulation materials, etc. In many cases, these cost savings allow the cool roofs to pay back their premium over traditional roofs in a few years. In cooler climates with greater heat energy expenditures, cool roofs can potentially increase winter heating costs, requiring a careful cost benefit analysis.[18]

Observed savings for individual buildings include:

- For older buildings in New York City, immediate payback was achieved by upgrading a dark roof with light coating. Replacing a black membrane with white paid for itself in five years.[19]
- In Washington, D.C., the average premium for a cool roof is 76 cents per square foot, while the average, calculated energy savings total $1.34 per square foot.[20]
- A California study showed statewide energy savings of 45 cents per square foot from cool roofs (with estimated cost premiums of up to 20 cents). At this premium, cool roofs were cost effective in all but one of California's climate zones (and in that zone, a cool roof with a cost premium of 18 cents or less per square foot is cost effective).[21]
- A study of a retail store in Austin, Texas, found a negligible premium for cool roofing installation but the building experienced an annual energy savings of 7.2 cents per square foot.[22]
- A study in Philadelphia, showed that homes with cool roofs saved 6.4 percent on energy after switching from traditional roofs.[23]

Improved Public Health

By reducing indoor air temperatures, cool roofs can contribute to lower rates of heat-related illnesses and mortality, especially in homes without air conditioning and in top floors of buildings. For example, the 1995 heat wave in Chicago contributed to more than 700 deaths, most of which occurred in the top floors of buildings with dark roofs. In an un-air-conditioned building, replacing a dark roof with a white roof can cool the top floor of the building 2–3 degrees.[24] Philadelphia added cool roofs and insulation to residential buildings that lack air conditioning,[25] and a study showed that daily maximum indoor air temperatures dropped by 1.3 degrees, and maximum ceiling temperatures dropped by an average of 3.3 degrees. Models of mortality rates and temperature show mortality increasing by 1 percent per 1 degree increase when temperatures are in the 80s, 2 percent per 1 degree increase in the 90s, and 5 percent per 1 degree increase in the high 90s. This shows a reduction of a couple degrees can greatly reduce heat-related mortality.[26]

Estimating the impact of cool roofs on heat-related stress on a community-wide scale is challenging. However, simulations of heat events can be used to evaluate how increasing reflectance across urban surfaces may reduce these risks. One study modeled impacts of surface reflectance on meteorological conditions and compared it to historical heat events, finding that increasing urban surface reflectance between 10–20 percent would decrease heat-related mortality 1–5 percent in Baltimore, 1–21 percent in Los Angeles, and 9–10 percent in New York City. This translates to 32 lives saved in Baltimore over a decade, 22 in Los Angeles and 219 in New York City.[27]

IMPLEMENTATION EXAMPLES

- Dozens of cities and some counties and states have mandatory, incentivized, or city-led cool roof initiatives. The geographic diversity of these programs indicates that cool roofs are a widely applicable strategy.

- **Houston** added mandatory cool roofing provisions in 2016, setting standards for roof solar reflectance for new commercial buildings and alterations to existing commercial buildings in its Commercial Energy Conservation Code.[28]
- A **New York City** initiative called NYC Cool Roofs provides no-cost cool roof installations to nonprofits and low-income housing buildings and low-cost installations to certain building owners that still need to cover material costs and agree to share energy data with the city.[29]
- **Philadelphia** passed an ordinance amending the building code to require white coloring or use of highly reflective materials (as identified by Energy Star) on new buildings and additions to buildings.[30]
- **Chicago** Energy Code requires new roofs have a reflectivity of 72 percent or greater and that aging roofs maintain a reflectivity of 50 percent or greater.[31]

INSTALLING COOL PAVEMENTS TO REDUCE HEAT EXPOSURE

Conventional pavements in the United States are made with impervious concrete and asphalt, which can reach peak summertime surface temperatures of 120–150 degrees because of lower solar reflectance (about 5–40 percent).[32] Various types of cool pavement materials have been developed that have higher solar reflectance. Some are also permeable, allowing for more evaporative cooling of pavement surfaces.

While the impacts of cool pavements on air temperature are not well-studied, researchers at Lawrence Berkeley National Laboratory estimated that every 10 percent increase in solar reflectance (across pavement and roofs) could decrease surface temperatures by 7 degrees, and if pavement reflectance throughout a city were increased from 10–35 percent, the air temperature could be reduced by one degree.[33]

COSTS

Cool pavement costs vary by local climate, expected traffic, area being paved, and contractor. The costs range from 10 cents to $10.00 per square foot, with higher cost materials generally having longer service lives. There are also options to coat pavements with cooler surface applications, which can cost between 10 cents and $6.50 per square foot.[34] Cool pavements have not been widely implemented long enough to calculate their benefits per square foot, and doing so is very complicated due to the number of factors addressing temperatures on sidewalks and roads. However cities are implementing the strategy, often on an experimental basis, followed by broader application within their comprehensive set of urban heat island mitigation activities.

BENEFITS

Improved Public Health

Studies on surface reflectivity (of roofs and pavements) in urban settings found potential human health benefits. A 2014 study in Washington, D.C., found that a 10 percent increase in urban surface reflectivity could reduce the number of deaths during heat events by an average of 6 percent.[35] This study is encouraging, but does not isolate the direct influence that pavement installations and cool pavements can play in reducing air temperatures and building energy use.[36]

Reduced Stormwater Runoff

Some cool pavements can also be permeable, allowing air, water, and water vapor into small gaps in the pavement. These pavements address local flooding and urban stormwater issues by allowing water to pass through the voids and into the soil or supporting materials below. Some permeable pavements contain grass, which both absorbs water and is cooler than dark pavement options. Cool, permeable pavements can also reduce the need for other infrastructure such as stormwater drains, bringing down project costs. This may also contribute to public safety because roads with better drainage improve driving conditions. More research is needed in designing pavements that can accomplish these benefits on a larger scale with few tradeoffs.[37]

IMPLEMENTATION EXAMPLES

- **Los Angeles** conducted test applications of a light gray coating called CoolSeal and found up to a 10-degree reduction in pavement temperature. The city is applying the material to a larger neighborhood area to continue testing. The mayor has predicted the city could reduce its urban heat island effect by 3 degrees in the next 20 years, using cool pavements and other measures.[38]

- The **Cool Houston** plan is targeting older parking areas, new streets, and new commercial and residential parking areas for cool paving. The plan emphasizes cool pavement to reduce temperatures and reduce degradation of the pavement due to high temperatures.[39]

INCREASING CANOPY COVER AND VEGETATION TO REDUCE HEAT EXPOSURE

Trees and vegetation can reduce heat by shading buildings, pavement, and other surfaces to prevent solar radiation from reaching surfaces that absorb heat, then transmit it to buildings and surrounding air. A number of studies have quantified the cooling effect of urban vegetation. A study in Phoenix used a microclimate model to measure the impact of trees and cool roofs on air temperatures. The study found that increasing tree canopy cover to 25 percent can reduce temperatures 4.3 degrees, and switching landscaping from xeric (dry) to oasis (adding grass patches to residential backyards) can reduce average neighborhood temperatures 0.4–0.5 degrees.[40] A Philadelphia study attributed a 0.9 degree air temperature reduction during the nighttime hours on the warmest summer day of 2008 to urban trees.[41]

COSTS

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 ranged from $1.37–$3.09 per tree, per year, for the five cities (when considering stormwater runoff, energy savings, air quality and aesthetic benefits).[42]

BENEFITS

Reduced Energy Use

Urban forests can decrease energy costs to consumers and across cities. A Chicago study found that increasing tree cover by 10 percent could lower total heating and cooling energy use by 5–10 percent annually ($50–$90 per dwelling unit). The avoided cooling costs come from the heat reduction noted above, while the reduced heating costs come from blocking winter winds once the trees matured (a benefit that cool roofs and cool pavements do not provide).[43]

The U.S. Forest Service conducted an analysis of Philadelphia's urban forest, which has an estimated 2.9 million trees and a tree canopy that covers 20 percent of the city. Using the i-Tree Eco model (see **Key Tools**) the study found that Philadelphia's urban forest reduces annual residential energy costs by $6.9 million each year and provided an estimated compensatory value for Philadelphia's trees of $1.7 billion.[44] In an i-Tree analysis of Washington, D.C., energy costs to residential buildings are decreased $700,000 annually by the city's trees.[45]

Trees can conserve energy and reduce energy bills in suburban and rural areas as well. Trees planted on the east, west and northwest sides of the home can provide shade in the summer and warmth and windbreaks in the winter. Shade trees planted over patios, driveways and air-conditioning units can reduce home temperatures and energy costs. Tree-shaded neighborhoods can be up to 6 degrees cooler than treeless areas and a landscape planned for shade can reduce home air conditioning costs by between 15 and 50 percent.[46]

Improved Public Health

A study estimating the potential health impacts of urban heat island mitigation strategies 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.[47]

Improved Air Quality

The U.S. Forest Service's Philadelphia study estimated that the city's trees store about 702,000 tons of carbon or 2.6 million tons of CO_2, a value of $93.4 million. Each year Philadelphia's trees remove about 27,000 tons of carbon or 99,000 tons CO_2 (a value of $3.6 million per year) and remove 513 tons of air pollution (an estimated $19 million per year).[48] The Washington, D.C, study estimated that the city's trees store 649,000 tons of carbon, and each year remove 26,700 tons of carbon (with an associated value of $1.9 million per year), and about 619 tons of air pollution (a value of $26 million per year).[49]

Reduced Stormwater Runoff

Trees and vegetation can improve water retention and reduce runoff in storms. In New York City, trees intercept more than 890 million gallons of rainfall each year (at a benefit of over $35 million).[50] A tree with a 25-foot diameter canopy and associated soil can manage one inch of rainfall from 2,400 ft^2 of impervious surface.[51]

Social Benefits

The presence of street trees has been linked to psychological and health benefits. A study in Toronto found that people who live in areas with more trees on the streets have a better health perception.[52] Also, studies around the country have found that up to a certain percent canopy coverage, trees increase property values. In Minnesota, a 2010 study found that a 10 percent increase in tree cover near a home increased home sales prices by an average of $1371 (adding an average 0.5 percent value to a home).[53] A 2015 study in Florida found that property value increased by $1585 per tree.[54]

IMPLEMENTATION EXAMPLES

- **Louisville, Kentucky,** set a goal of achieving 45 percent tree canopy, and the urban forest currently saves more than $5 million of energy costs for consumers annually.[55]
- **Baltimore's** Disaster Preparedness and Planning Project, an all hazards plan, recommends increasing green spaces in vacant lots, building on the city's goal of increasing urban tree canopy to 40 percent by 2037.[56]
- **Indiana's** Department of Natural Resources undertook a study in 2010 of all the environmental services and economic benefits the state's urban tree canopy provides. It found:
  - $9.7 million in energy savings
  - $24.1 million in managed stormwater
  - $2.8 million in improved air quality
  - $1.1 million in sequestered carbon dioxide
  - an estimated $41 million per year from aesthetic and social benefits.[57]

RAISING AWARENESS AND PREPARING FOR EXTREME HEAT

Communities and states are preparing for rising temperatures and extreme heat through emergency planning. Before heat waves occur, city and state emergency management and health services should consider heat vulnerability in their community with special attention on the most vulnerable to heat stress: older adults, infants and children, people with chronic conditions, low-income residents, and outdoor workers.[58] Additionally, those without access to air conditioning are among the most vulnerable during extreme heat events. A compounding vulnerability is that power outages (caused by energy demand or storms) can further limit access to air conditioning.

Specific activities communities can complete to begin preparing for extreme heat include:

- Identifying a heat threshold at which a heat emergency is declared. The way heat affects health differs across the country. Areas where heat is more persistent during the summer or where there is more widespread use of air conditioning may have a higher threshold for experiencing heat stress.[59]
- Determining messaging on heat warnings, safety during heat events, services available, and media channels used to communicate these messages. Consider how to disseminate messages to vulnerable populations, including non-English speakers, and keep in mind that this might require active outreach or checking on vulnerable residents.[60]
- Establish cooling centers in public buildings that remain open so the public can seek relief from the heat, and consider transportation access to and geographic distribution of these centers.
- Understand local, state and partner roles and responsibilities in heat emergencies. Develop a database of facilities and organizations that serve vulnerable populations.[61]

COSTS

Costs vary broadly based on whether emergency heat planning can be integrated in an updated hazard mitigation plan or public health planning. Comprehensive and effective extreme heat event notification and response programs can be developed and implemented at a low cost. Instead of creating a separate heat preparation office or program, cities and states can instead plan for short-term reallocation of existing resources in an extreme heat event.[62] Emergency planning avoids the sometimes high costs of infrastructure investment, but only reduces sensitivity to heat, while the strategies above reduce the heat that people are exposed to.

BENEFITS

Improved Public Health

The benefits of extreme heat planning include reduced hospital visits during heatwaves. A study on Philadelphia's Hot Weather-Health Watch/Warning System found that issuing a warning saved 2.6 lives for each warning day and for three days after the warning ended.[63] A study evaluating the effectiveness of Montreal's Heat Action Plan found that the plan prevented 2–3 deaths on hot days, more than half the deaths attributed primarily to heat.[64]

Improved Awareness of Climate Change Risks and Coordinated Response

The heat planning process can nest into other emergency preparedness or climate resilience activities, and act as a foundation for discussions about climate change impacts to public health and safety. In Philadelphia, a task force comprising public and private organizations serving at-risk individuals, emergency responders or providers of critical infrastructure began developing the Excessive Heat Plan. The Health Department and Southeastern Pennsylvania Red Cross established a telephone hotline for residents with heat-related questions. The plan also taps neighborhood volunteers elected to coordinate neighborhood beautification projects to identify and evaluate the health status of high-risk and hard-to-reach individuals.[65]

IMPLEMENTATION EXAMPLES

- **Arizona** Department of Health Services (ADHS) published the Arizona Climate and Health Adaptation Plan in 2017 to develop interventions and enhance public health preparedness activities related to climate-sensitive hazards.[66] The ADHS also released a Heat Emergency Response Plan in 2014. It assigns tasks to individuals and department branches in a heat event, guides interagency coordination, and provides materials like sample news releases and resources on identifying heat stress to educate the public about the dangers of extreme heat.[67] An assessment of cooling centers in Maricopa County found that the centers offered various services for at least 1,500 individuals daily.[68]
- The **Wisconsin** Climate and Health Program released an *Extreme Heat Toolkit* to support local governments, health departments and citizens in preparing for and responding to heat events. The toolkit acknowledges that Wisconsin does not have a typically warm climate, but in 2012 the state experienced 24 heat-related fatalities, and climate trends analysis indicate extreme heat events will become more likely and longer-lasting. The toolkit includes several guides on heat illness, vulnerable populations, messaging about heat emergencies, and checklists for preparing, anticipating and responding to extreme heat events.[69]

CASE STUDY: LOUISVILLE, KENTUCKY, COMBINES URBAN COOLING STRATEGIES

A 2012 study from the Georgia Institute of Technology found that Louisville was the fastest-warming heat island in the United States.[70] That same year, the city experienced a heat wave, forcing the cancellation of a horse race and widespread damage to infrastructure. Following that record-breaking heat, the city took action on climate change:

- A regional climate and health assessment, the Urban Heat Management Study, was initiated to consider heat management strategies, model the results of managing heat with cool materials, green space, energy efficiency and combined strategies, and conduct a population vulnerability assessment.[71]
- The Louisville Metro Office of Sustainability announced a cool roof rebate program for residents and businesses to apply for a rebate of $1 per square foot of cool roof to incentivize at least 100,000 square feet of new cool roof installations.[72]
- The city has installed cool roofs on eight park

buildings in 2016, nearly 145,000 square feet of cool roofs since 2009 and cool coatings on the top of three parking garages.[73]

- Due to the findings of the assessment study, the city hired a forester[74] and completed an Urban Tree Assessment in 2015 which recommended that the city increase its canopy cover from 37–40 percent and from 8–15 percent in central business district areas.[75]

INSIGHTS

The strategies discussed in this paper offer the primary resilience benefits of reduced temperatures, energy savings and improved public health. These benefits vary greatly between communities and climates, but the **Key Tools** section below provides guidance for estimating costs and benefits in specific locations or projects to choose the right strategy and design.

Analysis of the co-benefits offered by those strategies can help identify no-regrets strategies that provide quantitative benefits like improved property values, reduced flooding damage, or better air quality. Not all benefits are quantitative. Qualitative benefits like social and aesthetic impacts can improve community buy-in, and for some communities can be just as compelling as cost savings or other measured benefits.

Most communities mentioned here are employing multiple strategies, demonstrating that comprehensive heat mitigation planning usually means applying locally

TABLE 1: Costs, Benefits, and Applications of Extreme Heat Resilience Strategies

	ADAPTATION CATEGORY			APPLICATION		BENEFITS								COSTS				
	DECREASE EXPOSURE	DECREASE SENSITIVITY	INCREASE ADAPTIVE CAPACITY	RURAL APPLICATION	URBAN APPLICATION	ENERGY	PUBLIC HEALTH	CARBON CAPTURE	AIR QUALITY	VULNERABLE POPULATIONS	STORMWATER MANAGEMENT	CLIMATE RESILIENCE COORDINATION	SOCIAL BENEFITS	INSTALLATION	MAINTENANCE	CITY COST	INDIVIDUAL	REBATES OFFERED
Cool Roof	●			●	●	●	●		●	●				●	●	▲	▲	▲
Cool Pavement	●				●	●	●			▲	▲			●	▲	▲	▲	▲
Trees	●	●		●	●	●	●	●	●	●	●		●	●	●	▲	▲	▲
Emergency Plan		●	●	●	●		●			●		●			●	●		

The benefits and costs of the strategies overviewed in this fact sheet are summarized above, with dots indicating a benefit that could be expected from one of the four strategies. When weighing different strategies for use in a community, consider the greatest local vulnerabilities and which benefits would address them, then choose strategies that offer these benefits. Be aware of gaps in benefits offered by the strategies prioritized. Yellow triangles indicate benefits and costs that could apply in certain areas, or with specific design choices with that cobenefit in mind. Green circles indicate that these benefits could be expected in most locations, and are often primary benefits or cobenefits associated with the strategy.

optimal strategies to bring down temperatures in specific neighborhoods and buildings. A mix of green infrastructure, careful zoning, and preparedness activities can optimize co-benefits to generate the greatest value as demonstrated by Louisville and communities across the country. **Table 1** shows that each strategy comes with its own sets of benefits and costs. Considering which benefits are most needed in your community, and which combination of strategies may yield them, helps to prioritize local resilience activity.

KEY TOOLS

This fact sheet draws heavily on a few tools and guides that are available to communities and states working to become more resilient to climate impacts.

ASSESSING HEALTH VULNERABILITY TO CLIMATE CHANGE (2014)

This guide from the Centers for Disease Control (CDC) helps local health departments assess local vulnerabilities to health hazards associated with climate change. This targeted climate and health vulnerability assessment can be used to implement public health interventions for those that are the most vulnerable. It provides a conceptual framework on how to define vulnerability, and assess exposure, and includes a case study.

https://www.cdc.gov/climateandhealth/pubs/assessing-healthvulnerabilitytoclimatechange.pdf

COOL ROOFS AND COOL PAVEMENTS TOOLKIT (2012)

Developed by the Global Cool Cities Alliance to help homeowners and city officials transition to cool roofs and pavements, this toolkit includes technical information about design, costs and benefits.

https://www.coolrooftoolkit.org

GUIDELINES FOR SELECTING COOL ROOFS (2010)

The U.S. Department of Energy provides guidance on choosing materials and how to analyze expected costs with potential savings in this publication.

https://energy.gov/sites/prod/files/2013/10/f3/coolroof-guide.pdf

HEAT ISLAND COMPENDIUM (2008)

This EPA resource describes urban heat island causes, impacts, and reduction strategies in depth. The guide includes a chapter of activities that help implement the other strategies on a city-wide level.

https://www.epa.gov/heat-islands/heat-island-compendium

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 freely accessible tools aid communities in completing city-, county-, or statewide tree surveys, and in identifying and measuring the services that one tree or a whole urban forest can provide. The suite is updated periodically with newer data and additional benefits to measure. It is also adding a smartphone app.

https://www.itreetools.org

ROOF SAVINGS CALCULATOR

Developed by Oak Ridge and Lawrence Berkley National Laboratories, the Roof Savings Calculator is based on hourly performance, added together for annual savings based on weather data for a select location. The calculator can be used to estimate energy savings for residential and commercial buildings.

http://rsc.ornl.gov

U.S. RESILIENCE TOOLKIT

As an interactive website, this tool allows users to discover climate hazards and develop solutions that reduce climate-risk. It provides a library of tools for individuals and city officials including case studies of how communities, businesses and individuals are documenting vulnerability and taking action (with several related to extreme heat).

https://toolkit.climate.gov

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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

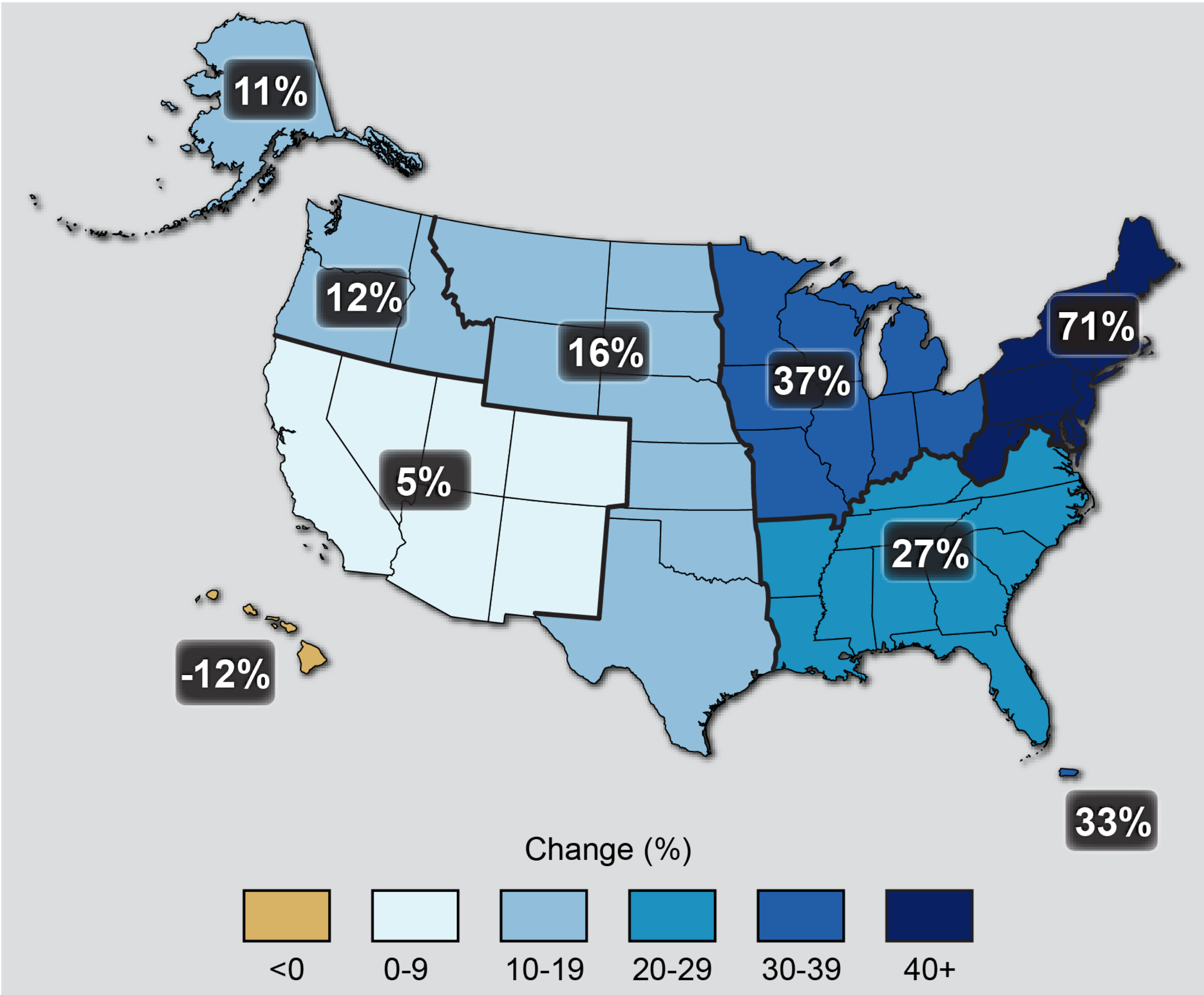
The United States experienced a nationwide 4 percent increase in annual average precipitation from 1900 to 2015.[1] Some regions are observing a mix of increased and decreased precipitation over historical averages by season, but the eastern United States has observed higher averages of maximum daily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



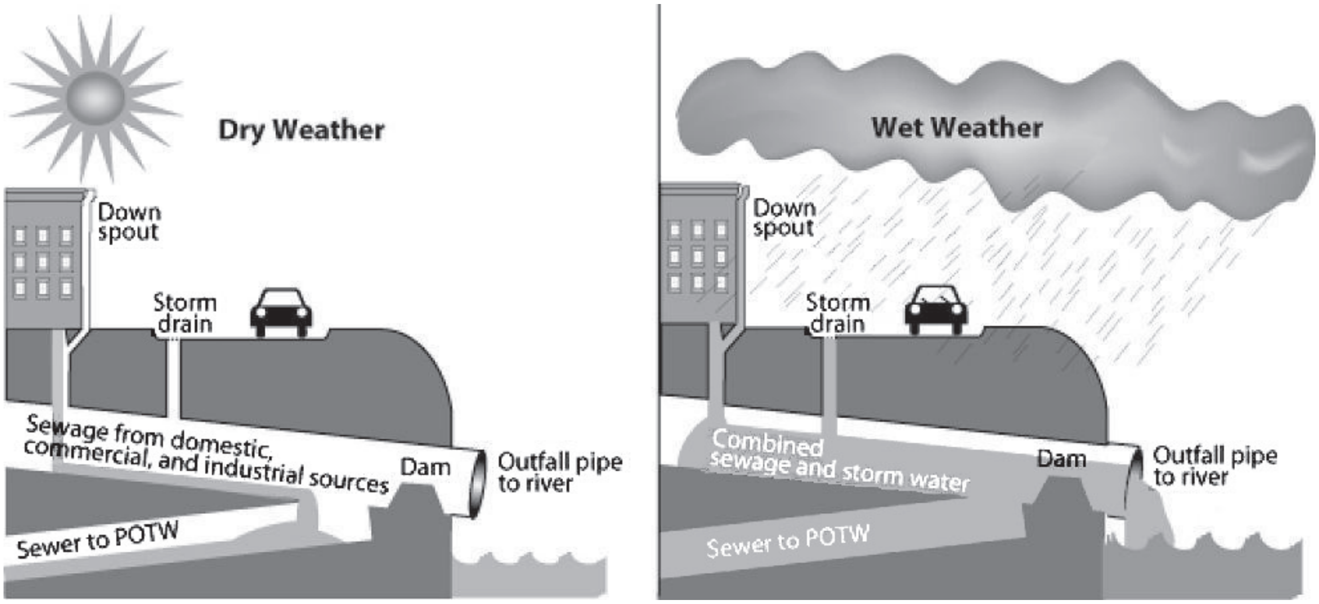
The map shows percent increases in the amount of precipitation falling in very heavy events (the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958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

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

A warming atmosphere is giving extra energy to storms, making the hurricanes, tornadoes, and thunderstorms of today more intense than those of the past. This trend is projected to accelerate in the years to come. These stronger storms are more likely to cause power outages, and the loss of power can be costly in terms of lives lost, economic impact, and public health. This fact sheet outlines strategies that local governments could implement to reduce the frequency and duration of power outages and help communities better withstand them when they do occur. For each resilience strategy, the paper discusses costs and co-benefits, both of which are important considerations for implementing strategies. A case study of New Orleans looks at the different strategies put in place since Hurricane Katrina caused widespread destruction in 2005 and the performance of those strategies to the hurricanes that have made landfall since. The paper also includes a list of tools for quantifying the co-benefits of the resilience strategies discussed.

INTRODUCTION: THE GROWING THREAT OF STORM-RELATED POWER OUTAGES

Severe storms are by far the most common type of billion-dollar weather and climate disaster in the United States. According to data collected by the National Oceanic and Atmospheric Administration (NOAA), storms account for 95 of the 227 such events from 1980–2017.[1] Tropical cyclones (including both tropical storms and hurricanes) are less prevalent in that database (40 events) but are the most deadly and costly. These events cause direct damage to property, infrastructure, and crops, but the indirect damage they cause is also consequential. Key among these indirect impacts are power outages which cost the U.S. an estimated $20–$55 billion annually.[2]

Evidence is accumulating that climate change is increasing the intensity of all types of storms, though the limitations in historic observations of hurricanes, tornadoes, and other events make it difficult to attribute the extent to which human activity is involved.[3] There is, however, broad consensus in model projections that hurricane strength, precipitation intensity, thunderstorm frequency, and winter storm activity will all increase in the future.[4] A 2013 Department of Energy report found that electricity transmission and distribution systems face increasing risks from stronger storms (e.g. utility poles knocked down by high wind events).[5] Flooding and increased heat can also result in power outages when they damage electricity system infrastructure such as power lines, substations, or transformers. These various weather-related events all result in power outages that can take days or even weeks to restore.

There are many strategies that local governments can use to increase resilience to power outages. While power outages may be impossible to completely avoid, resilience strategies can reduce the duration and severity of these events and their impact on people. This fact sheet highlights resilience benefits and co-benefits (societal, environmental, and the economic) that can create more opportunities for financing, collaboration, and community buy-in for these resilience actions. The estimated costs and values of individual benefits vary across communities based on a number of factors, including the local environment and climate projections. A separate

C2ES publication, *Resilience Strategies for Flash Flooding*, covers resilience strategies to heavy precipitation and the subsequent flooding that often follow storms.[6] Local governments seeking resilience for all aspects of storms should consider recommendations from both publications.

ELECTRICITY SYSTEM HARDENING

When electricity distribution systems, such as long-distance transmission lines or feeder lines that serve individual houses, are damaged by storms, communities suffer from the disruption in services that follow. There are strategies to make energy systems more resilient (typically referred to as "system hardening"). For example, wooden poles to support transmission lines might be replaced with steel poles that can withstand higher wind speeds. Lines can be buried underground to avoid wind damage, although flooding still poses risks. Tree trimming, also known as "vegetation management," can create an open space around wires that prevents wind and other storm-related damage (i.e., trees bringing down power lines).

Other hardening options aim to promote faster recovery, such as participating in mutual aid agreements with other jurisdictions or stockpiling replacement parts. Emerging technology solutions, like wires designed to disconnect from poles when debris falls on them, can also promote faster recovery. This prevents the falling debris from dragging down multiple poles, which can cause more widespread outages and take longer to repair.

For electricity system hardening, the measure of success is not necessarily avoided outages but rather a reduced amount of time an outage lasts. For example, Florida Power & Light, a utility serving many parts of South Florida, has been hardening its system after widespread damage from Hurricane Wilma in 2005. When Hurricane Irma struck the same area in 2018, power was restored in several days compared to several weeks following Wilma.[7] Reducing outage time improves resilience by hastening the community's return to normal conditions.

Many resilience solutions exist for energy systems, and the industry is beginning to implement them across the country.[8] Not all local governments will have control over their utilities to implement these strategies, and many hardening efforts require regulatory approval from state utility commissions. Regardless of whether it operates its own utility, local governments can be helpful partners in promoting more resilient electricity distribution systems.[9] The following discussion describes electricity hardening costs and benefits from a community perspective.

COSTS

Some system hardening options can be quite costly. Converting overhead distribution lines to underground ones is estimated to cost $536,760–$12,000,000 per mile in urban areas, $1,100,000–$11,000,000 per mile in suburban areas, and $1,100,000–$6,000,000 per mile in rural areas.[10] Undergrounding new distribution lines (for example, as part of a new development) is somewhat less costly at $1,141,300–$4,500,000 per mile in urban areas, compared to $126,900–$1,000,000 per mile for overhead lines in suburban areas.[11] Upgrading existing wooden poles to stronger, more resilient materials such as steel and concrete costs $16,000–$40,000 per mile, according to recent utility experience in both Texas and Florida.[12] However, steel poles are more durable than wood, so lifetime maintenance costs may be more comparable depending on local circumstances. The electric utility in Tucson found that the cost of steel poles to replace wooden ones in its system were nearly double, but they had a 60-year lifetime compared to 30-years for wood poles, so the lifecycle costs were approximately the same (but the steel poles have the added benefit of better withstanding high winds, making the system more resilient).[13]

BENEFITS

Shortening the duration of power outages has both economic and social benefits, as described below.

Reduced Economic Losses

System hardening actions can shorten outage duration times after major events by several days, which significantly reduces economic losses. Quantification methodologies for the economic losses from power outages are complicated, and very little work has been done to study long-duration outages (in part because these are rare events). But for outages lasting more than a day there can be spillover effects to the broader economy, making every day of outage more costly than the last.[14]

Public Health Benefits

Power outages are known to negatively impact health, often in indirect ways. For example, following a power outage related to a 2009 ice storm in Kentucky, 10 people died from carbon monoxide poisoning because they had been using generators, kerosene heaters, and propane heaters inappropriately.[15] Additional negative health impacts of power outages include illness from consuming food that spoiled after lack of refrigeration and accidental deaths that occur in darkness.[16] Electricity system hardening can prevent some outages and shorten others, thus limiting the exposure to these risks.

IMPLEMENTATION EXAMPLES

- In June 2012 a meteorological phenomenon with very high wind speeds known as a "derecho" affected many parts of the Midwest and Mid-Atlantic regions with hurricane-force winds that downed trees. West Virginia suffered some of the worst damage, exacerbated by a heat wave that immediately followed the derecho. 63 percent of West Virginians were without power for two weeks or more in the extreme heat. To shorten power restoration times in future events, the state public service commission ordered utilities to switch from an as-needed management program to a four-year cycle of continual maintenance, whereby trees near power lines would be trimmed regularly. For one utility, Appalachian Power, the costs to do so are estimated to be $44.472 million. Customer electricity rates increased 3.24 percent to pay for the increased tree trimming.[17]
- Entergy is a utility that serves several states along the Gulf Coast and has long experience with hurricanes. The utility began replacing wooden poles with stronger materials after Hurricane Betsy made landfall in 1965. A 2007 internal study by the utility found that 99 percent of its structures near the coast survived the winds of Hurricanes Katrina and Rita in 2005 because of this hardening effort, although the financial value of this resilience was not estimated.[18] While methodologies for monetizing the value of these avoided losses are limited, it no doubt made recovery efforts faster.
- New York City suffered major power outages after Hurricane Sandy in 2012. To prevent similar impacts from happening again, a four-year system hardening program was undertaken by the utility ConEd. The utility installed smart switches and undergrounded some electricity lines. Hardening actions to protect from flooding were implemented as well. As of October 2017, the utility reported that the upgrades avoided 250,000 customer outages.[19]

SMART GRID

The term "smart grid" refers to a group of technologies including smart meters and communications networks that allow parts of the electricity system to remotely communicate with each other and with grid operators. These technologies can promote resilience by quickly identifying sections of the grid that are impacted by storms and isolating them so that power outages are not widespread.[20] Smart grid technologies can also preemptively turn off power to a small area before a storm to prevent system-wide damage. Each of these uses reduce the extent of power outage, and can lead to shorter recovery times as well since there will be less system damage following a storm.

Smart grid technologies are already widely installed across the country. A 2017 survey of electric utility smart meter plans found that 76 million households had smart meters installed as of December 2017 and 90 million households, or about 60 percent, will have the technology by 2020.[21] Where they are deployed, they have already been shown to reduce the occurrence and duration of power outages. CenterPoint Energy, the investor-owned utility in Houston, avoided nearly 41 million minutes of outage time after Hurricane Harvey because of the smart grid infrastructure it had previously deployed.[22]

Smart grid technologies, like electricity system hardening, are implemented by utilities subject to approval by state regulatory commissions (except in the case of municipal utilities). Local governments without a municipal utility will need to partner with utilities and state regulators to champion the resilience benefits that system upgrades can provide.

COSTS

Deploying a smart grid requires investment in both physical hardware and operation and maintenance (O&M).

Hardware components include meters and switches while O&M investments include network communications, educating consumers on usage, and servicing equipment in the field. The cost of an individual smart grid component is not a good measure of the cost of this strategy since the resilience benefits of a smart grid result only once the infrastructure is widely deployed. In other words, a single smart meter does not provide resilience benefits until a threshold of deployment is reached. However, project costs are often described as a per meter value, to allow for better comparison between projects. These per-meter values typically include network installation and O&M costs.

A report by the Northeast Energy Efficiency Partnerships (NEEP) reviews smart grid deployment projects in the Northeast from 2007 to 2015.[23] The eight projects reviewed varied in size, year of implementation, and location, all of which can affect the cost of installation. Total project costs, including capital and O&M, ranged from $124 million to $1.66 billion, depending on the size and year. On a per-meter basis, the total costs of the smart grid projects ranged from $205 to $531 per meter.

BENEFITS

Reduced Energy Costs

Many of the energy cost savings that customers realize in a smart grid come from reduced operations costs for the utility which are then passed along as rate reductions to customers. Utilities save costs when using smart grids because crews are no longer needed to manually read meters for billing, energy theft can be prevented, and service can be remotely connected or disconnected when customers move in or out of buildings. The NEEP study that reviewed several smart grid deployment projects in the Northeast saw expected utility O&M savings of $19 million to $1.383 billion, or $74 to $354 per meter.[24]

Smart grids can provide additional energy cost savings by enabling various types of consumer efficiency programs. In Chicago, one program lets customers opt into hourly pricing and provides tips on reducing energy use during the times of the day when it's most expensive. Program participants reduced their energy costs 15 percent, on average, between December 2012 and December 2015.[25] Another smart meter-enabled program lets customers with central air conditioners opt to have the compressor cycle during summer months, as a way to reduce total systemwide energy use. Participating customers receive up to a $10 per month credit on their electricity bill.[26]

Reduced Greenhouse Gas Emissions

Smart meters can be read remotely for billing instead of sending a meter reader in a truck to the site. This leads to reductions in greenhouse gas emissions from vehicles, with the greatest reduction benefit coming in areas with the lowest population density. A 2012 evaluation of smart meter deployment across the country found greenhouse gas reductions of 12–59 percent due to the smart meters.[27] Estimates for utility ComEd, serving Chicago, are that in 2017 its deployment of smart meters and the smart meter-enabled customer energy savings programs noted above led to 2,671 fewer metric tons of carbon dioxide emitted.[28]

IMPLEMENTATION EXAMPLES

- CenterPoint Energy, an investor-owned utility serving the Houston metropolitan area, upgraded its entire distribution system, including more than 2 million meters, to a smart grid between 2010 and 2014. It installed smart meters, communications systems, and data management software. The total project cost $514,519,057, or $241 per meter on average. Between 2012 and 2014, the utility saw annual cost savings of around $20 million. Between 2011 and 2014, customer outages were reduced by 15.5 million minutes. By avoiding the use of trucks to deploy meter reading crews, the utility avoided use of 950,000 gallons of fuel between 2011 and 2014, with resulting avoided greenhouse gas emissions.[29] When outages in that period did occur, power was restored to customers up to 35 percent faster. The biggest test of CenterPoint's smart grid resilience came when Hurricane Harvey impacted Houston in 2017. During the storm and its impacts, the capabilities of the smart grid avoided 41 million minutes of outage time for Houston residents, in part because electricity could be directed away from flooded substations, thus preventing equipment damage that takes a long time to repair. The utility could also remotely turn off power within the mandatory evacuation zone that the city established due to flooding after the storm. During the recovery effort, the data management and communications capabilities of the smart grid helped the utility restore power faster than would have been done without the technology.[30]

- The city of Chattanooga built a high-speed internet network in 2009 which then enabled development of a smart grid to serve the community. The city-owned utility deployed smart meters, switches, and sensors for the roughly 180,000 customers in the community. The project, which cost $369 million to deploy, delivers $23.6 million in annual cost savings to the utility and $43.5 million in indirect annual economic benefits to the community, mostly from reduced electricity outages. During a severe storm in 2012, the city was able to restore power 55 percent faster than would have been possible without the smart grid.[31]

DISTRIBUTED ENERGY RESOURCES

Loss of power can be fatal, especially when critical services are disrupted. In the widespread power outages following the June 2012 derecho, and its accompanying high-speed winds, 9-1-1 communications services for more than 3.6 million people in the Midwest and Mid-Atlantic were interrupted, in some cases for several days, in large part because service providers did not have backup power in place at central offices.[32]

One way to provide backup power is through distributed energy resources. Distributed energy resources (DER) are located onsite, so they may be less at risk of being disrupted when storms prevent electricity transmission and down distribution wires. They include microgrids, combined heat and power (CHP) systems, rooftop solar installations, backup power generators, and battery storage systems. Local governments can consider adding DER to municipal buildings as a way of ensuring continuity of government function during power outage. Incentives to encourage DER in other locations can also promote wider community resilience, especially for buildings providing critical services, like hospitals.

Importantly, not every distributed energy resource provides resilience to power outages, and sometimes their deployment actually increases vulnerability. For example, most rooftop solar installations “trip off” by default when the electricity grid loses power, as a safety precaution for utility workers.[33] Many solar installations owners don’t understand this possibility and can be left unprepared for power outages because they incorrectly anticipate their solar panels will provide them with power.

MICROGRIDS

Microgrids are electrical systems that pair electricity generation (from renewables, diesel, or other fuel) with electricity demand. They vary significantly in size, fuel source, and design, and these factors all determine system costs. Microgrids may or may not be able to operate during an outage on the broader grid, depending on how they are designed. Islandable microgrids, those that can operate offline from the grid, have greater resilience benefits. Some CHP systems can also be operated as islandable microgrids. A separate C2ES report *Microgrid Momentum: Building Efficient, Resilient Power* examines the financing and legal considerations for microgrids, which differ by state and can affect microgrid costs.[34]

COMBINED HEAT AND POWER

Combined heat and power systems combine electricity generation and thermal energy (e.g. steam) production in a single system. Typically, the facility with the CHP system would use all the steam generated for its heating needs and have excess electricity to sell. Municipal office buildings could install CHP systems, or municipal services like wastewater treatment could use them. District energy systems, which can be centrally built and serve multiple buildings, are an example of a CHP application. Cities can build and operate district energy systems to serve downtown buildings with heat and electricity, as has been done in Nashville, St. Paul, and other cities. Large energy users like hospitals and universities may also build them. CHP systems of any type tend to result in cost savings for system owners because they are more efficient than separate systems and use less fuel overall.[35]

SOLAR + STORAGE

Solar PV systems generate electricity directly from solar energy. The number of installations is still relatively low, but growing rapidly because of declining costs and policy incentives. As mentioned above, PV systems are not typically designed to operate during power outages. The solar PV cells generate direct current (DC) electricity, which is then typically connected to an inverter to convert the DC electricity into alternating current (AC) electricity. The power grid and many appliances use AC electricity. A PV system's inverter will send power to the grid, and most of them will automatically disconnect the system when an outage affects the grid. However, specially designed inverters can be included in solar PV installations along with onsite batteries to allow the system to be islandable. Such systems are called solar + storage, and they provide resilience benefits by being able to provide some power during system outages, at least for as long as the battery can last.

BACKUP POWER AND/OR BATTERY STORAGE

Backup power is typically provided by gasoline- or diesel-fueled generators, but batteries are becoming another backup power option, especially when solar panels are installed on critical facilities or nearby. Cities can also consider how battery electric vehicles and fuel cell vehicles (EVs) are emerging as new potential devices to promote resilience to power outages. New technology is just beginning to be tested to allow vehicle-to-building (V2B) and vehicle-to-grid (V2G) interactions that can use vehicle batteries to power buildings or the grid at large. Even without V2B or V2G technology, EVs provide a redundant fuel source when motor fuel distribution is disrupted, as can happen following very large storms like hurricanes. Early EV adopters were pleased to find they could charge their vehicles and avoid long lines at gas stations that affected most drivers in the New York City region after Hurricane Sandy struck.[36]

Backup power for critical municipal services is a key resilience strategy, but cities can also provide incentives to homeowners and business owners to install backup power systems, including battery storage systems. Making sure the population can withstand a day or two without power makes them more resilient. This is especially important for individuals with medical devices at home. These critical customers may require special consideration from government and utilities in emergency planning.

COSTS

The costs of DER projects depend on the fuel used, power generating capacity (size), and other local factors. Costs are typically declining for all forms of distributed energy. State policies and electricity rate designs also influence the total net costs of DER projects.[37]

Microgrids

The upfront costs of microgrids can often be more expensive than buying grid power and installing traditional backup power such as gasoline- or diesel-fired generators. A benefit-cost analysis of five potential microgrids serving critical facilities in New York state found that all five had costs in excess of benefits, at least when the analysis included the value of electricity alone and excluded benefits of continuous power during long-duration outages. In the analysis, the case with the largest financial benefits was one where backup generators were already installed at a wastewater treatment plant and a fire station. The cost of installing a microgrid (distribution lines and control equipment) to connect these facilities with a nearby elementary school ranged from $439,000 to $919,000, depending on whether two or three facilities were part of the microgrid. Ongoing monthly variable costs were estimated at $5,000–$8,000.[38] The study authors concluded that installing traditional backup generators at the school was likely a lower cost option.

Identifying revenue streams from grid services and other electricity system benefits can change the benefit-cost analysis, though. Another site from the same study, in Suffolk County, developed a financially viable community-wide microgrid by combining benefits of solar power and avoided costs of new transmission to serve about 40,000 residents of East Hampton, New York. The microgrid also provides backup power to water pumping stations and a fire station. The solar generation of the microgrid ensures these critical facilities will continue operating, even if diesel supplies to operate their existing backup power units are interrupted. The project had 20-year costs (installation, operation, and maintenance) of $40.4 million, and 20-year benefits of $40.5 million when accounting for avoided transmission and $40.7 million when accounting for avoided power outages of up to one week per year.[39]

Combined Heat and Power

For services with high heating and power needs, such as hospitals or wastewater treatment plants, CHP systems typically provide cost savings, relative to buying power from the grid and generating thermal energy onsite, because a single system provides both functions. In addition, many CHP systems can operate when the power grid is offline, avoiding the need to purchase and maintain other backup systems.

System costs depend on the size, fuel used, and configuration. The city of Hampton Falls, NH, for example, replaced a fuel oil-fired furnace in its Public Safety Building with a CHP system fueled with propane and solar panels that provides electricity (offsetting grid purchases) and thermal energy. That small-scale project cost $78,000 to install and will offset $8,127 in annual energy costs, achieving a payback period of 7–10 years.[40] Similarly, the Winnebago County Sherriff's Office in Wisconsin installed a CHP system in 2007, then expanded it in 2009 to provide 2.5 MW power, building heat, and hot water. That system cost $3 million to install and has saved over $900,000 each year in energy costs, relative to buying power and generating heat onsite.[41]

Solar + Storage

The typical installation costs of solar PV systems in 2016 are estimated to be $15,581 for a small-sized system suitable for residential application. Simultaneously installing a battery increased the upfront cost by $13,987 to $29,568 for an AC-coupled system. Retrofitting an existing PV installation with an AC-coupled battery added $17,205 to the PV system costs.[42] The full cost of ownership of these systems would also consider operation and maintenance costs plus the reduced energy costs due to lower utility bills. Local policies will affect the utility bill reduction of DER, for example the kind of net metering policy that a state has in place.[43]

Backup Power

Diesel generators, which are widely used for backup power, cost less to install than many other DER, typically a few thousand dollars for a unit serving a single building. Operations and maintenance costs over the lifetime of the generator will vary with usage and diesel prices. Installing sufficient backup capacity to power critical services can be much more costly, though, because of the large size of the systems required. A study of supplying backup power to critical services in two Connecticut towns found that lifetime costs for backup diesel generation could be $15–$54 million dollars, depending on the size of the load being served. The study authors point out that while diesel generators had the lowest lifetime costs of any technology studied, they become much more expensive during long duration outages, and, since diesel supplies may run out during prolonged outages, they may not be the most attractive option available to communities.[44]

BENEFITS

Benefits of DER projects depend upon the type of fuel and the design of the project. Projects that use renewable electricity sources will have more environmental benefits than others. Projects designed to guarantee backup power supply will have greater continuous power benefits.

Reduced Energy Costs

As noted above, DER systems can lower energy costs, in some cases completely offsetting the capital costs of the energy generator and any electrical equipment needed for connecting and integrating the system with the grid. Today, CHP and solar + storage projects are more likely to have cost savings, relative to non-DER alternatives. Microgrids and backup power systems tend to be more expensive than relying on grid power alone, so they may be more attractive for critical systems where the resilience benefits are large. Each project will need to be evaluated for its own cost savings, but some illustrative examples demonstrate the potential savings that can be achieved. The town of Fairfield, Conn. implemented a community microgrid in 2015 that used multiple DER components to provide year-round heat and power to the town's police and fire headquarters, emergency communications center, a cell tower, and a homeless shelter.[45] The town is saving $70,000 in heating and power costs annually, and can provide services even during power outages. A completely solar-powered microgrid being constructed at a Seattle community center is expected to save $4,000 in electricity costs annually.[46] The center will also be used as a shelter during emergencies, providing community resilience benefits.

Continuous Power

Onsite sources of continuous power help avoid economic losses that power outages can cause through loss of productivity, loss of inventory, or other damages. The loss that any individual community experiences after a severe storm will depend upon the specifics of the storm. Major hurricanes that cause widespread outages lasting days are extremely costly. Just the outage-related costs of Hurricane Ike and Sandy are estimated to be $24 to $45 billion and $14 to $26 billion, respectively.[47] In comparison, a 13-hour outage affecting just the San Diego region in 2011 caused an estimated $93–$118 million in damages across the local economy.[48] U.S. Department of Energy has developed the Interruption Cost Estimate Calculator (ICE Calculator) to estimate losses due to power outages, though the tool only applies to outages of up to 24 hours in duration (see Tools). Very large storms can cause outages lasting several days or weeks.

For certain facilities, a continuous supply of electricity is of extremely high value. This is the case for critical services like hospitals, emergency shelters, and emergency responder stations. Uninterrupted power is increasingly becoming critical in homes where residents rely upon medical equipment for survival, and a power outage is a matter of life and death. To help protect this segment of the population, the U.S. Department of Health and Human Services created the emPOWER Map tool that shows the location of 2.5 million Medicare beneficiaries who use electricity-dependent equipment (EmPOWER Map described in "Tools" section below). Emergency responders and utility providers can use this information to better serve these individuals.

Traffic signals are another critical city service that can benefit from continuous power. A 2009 summary of battery backup systems (BBS) for traffic signals found that costs of BBS ranged from $5–$100, for batteries that can provide backup power for 2–10 hours. DER + BBS systems, for example natural gas-fuels systems like that installed in Overland Park, Kan. cost $30,000, but can operate for as long as natural gas supplies are available. Across the country, BBS have been found to reduce traffic accidents up to 90 percent. Industry practices value a car accident at $44,900, making BBS cost-effective based on the continuous power benefit alone.[49] Solar + BBS traffic signals are too newly available to have typical pricing values, although they are attracting interest, for example in Miami-Dade County, FL where a few temporary solar-power traffic lights were deployed in the power outage that followed Hurricane Irma in 2017.[50]

Improved Local Air Quality

The current default choice for backup power for many critical services is diesel generators. While these generators are reliable (so long as fuel supply is sufficient) and affordable, they do generate criteria air pollutants. Criteria air pollutant emissions from diesel generators cause negative health and environmental effects, and the carbon monoxide they emit can be fatal when diesel generators are used without sufficient ventilation, as sometimes happens in homes during prolonged power outages.

While EPA requires pollution controls on diesel generators, emissions are not eliminated and still occur during use. A study following a 2001 blackout event in California estimated that the use of diesel generators during the outage resulted in the emission of 14.7 tons of nitrogen oxides, 0.3 tons of sulfur dioxide, 0.4 tons of particulate matter, 2.5 tons of carbon monoxide, and 0.1 tons of volatile organic compounds.[51] Important to note, however, is that this power outage was planned in advance, lasted about 5 hours, and did not result in loss of power to critical services. In the case of long duration unplanned power outages, emissions of criteria pollutants would be expected to be much higher. Using a renewable energy DER option instead of diesel backup would reduce or, eliminate all of these emissions.

Reduced Greenhouse Gas Emissions

DER systems that use solar can also reduce the use of fossil fuels, even during normal power conditions, which provides a greenhouse gas benefit. The Las Vegas Metro Police Department installed solar + storage systems to power three emergency response communication towers. Those systems generate 165,973 kWh annually and will avoid 4,643,747 pounds of greenhouse gas emissions over their lifetime.[52]

For CHP systems, most of the greenhouse gas reduction benefit comes from the efficiency of combined heat and power, as opposed to the carbon intensity of the fuel used for electricity generation (see "Tools" section below for an EPA calculator). For example, a CHP system at South Oaks Hospital in Amityville, N.Y. with a 250 kW natural gas-fired generator and a 47 kW solar system uses 29 percent less fuel than separate electricity- and steam-generating systems would, resulting in 2,600 tons of avoided carbon dioxide each year (and $900,000 in annual energy savings for the hospital). The hospital has been able to provide continuous services through major blackouts since its installation, including Hurricane Sandy.[53]

Public Health and Safety

By providing power during widespread and long-duration power outages, resilient DER lets critical service providers continue their work of protecting public health and safety. Power outages are often responsible for the indirect deaths caused by hurricanes—through exposure to heat or cold, vehicle accidents when traffic signals don't work, and carbon monoxide poisoning from improper ventilation of diesel generators. A Florida law, passed in 2018, requires nursing homes and assisted living facilities to have emergency backup power; the law passed following the deaths of eight nursing home residents in the power outage that followed the landfall of Hurricane Irma.[54]

IMPLEMENTATION EXAMPLES

- Sterling, Mass. installed a 2 MW/3.9 MWh battery storage system that can provide up to 12 days of backup power to its police station.[55] The project cost $2.5 million to install. During normal conditions, the system generates electricity in the afternoon and evening hours, and it saved $400,000 in energy costs in its first year of operation.[56]
- A new transit-oriented development in Denver, Peña Station NEXT, used a public-private partnership to identify multiple stakeholders in a solar-powered microgrid with battery storage. Stakeholders Panasonic, Xcel Energy, Younicos, Denver, and the Denver International Airport all benefit from the project. The battery storage helps to integrate solar energy into the local grid during normal operations, thus helping both the utility and city achieve renewable energy goals, while Panasonic will have guaranteed back up power from the batteries in case of power outages.[57]
- The Acton-Boxborough Regional School District in Massachusetts examined two options for adding islanding capability to two schools that also serve as emergency shelters for the community. The schools have existing natural gas-fired backup generation and solar PV. Adding batteries and the electrical equipment necessary to allow islanding would cost $1,040,000 upfront with annual O&M costs of $13,000. Alternatively, replacing the existing gas backup with an islandable CHP system would cost $475,000 upfront with annual O&M costs increasing $22,513 relative to the existing system.[58]
- A hospital in Southern California is upgrading its existing CHP system with solar + storage and the electrical control equipment to form an islandable microgrid.[59] The project will provide three hours of electricity demand for the hospital when a power outage affects the grid. The system will reduce the hospital's demand for electricity purchased from the grid, both because of the onsite solar + storage and automatic demand response capabilities. The annual energy cost savings are estimated to be $141,000, and the annual greenhouse gas emissions reductions are estimated at 263 tons.

BUILDING ENERGY EFFICIENCY

Policies to promote energy efficiency, especially in residential buildings, improve community resilience to power outages. After major events, power may not be restored for several days. If ambient temperatures are extremely hot or cold during these outages, it can become a public health emergency. For example, of the 159 U.S. fatalities attributed to Hurricane Sandy, 50 were due to power outages that followed the storm, with hypothermia being a key cause of death.[60]

Efficient buildings retain their space conditioning (cooling or heating) longer during power outages, making building occupants more resilient to severe storms. A study of buildings in New York City found that if single family homes undertook efficiency upgrades, they could retain indoor temperatures of over 60 degrees during a week-long power outage in the winter, as opposed to falling below 35 degrees in just three days under existing, average efficiency performance.[61] This could improve health outcomes for residents living in such conditions and avoid burst pipes and other costly impacts associated with wintertime power outages.

Additionally, increasing energy efficiency can reduce peak electricity demand on hot summer days. Increasing daytime and nighttime temperatures due to climate change stress the power grid, and transmission lines do not work as efficiently.[62] This increases the risk of blackouts and brownouts due to system overloading during heat waves. Thus, energy efficiency provides resilience benefits in two ways: it can improve people's ability to withstand the outages that do happen because of storms or other extreme weather and help avoid outages from heat waves.

Energy efficiency projects that increase resilience to storm-induced power outages include increasing building insulation, window caulking, and repairing roofs. Each of these projects helps extend the period of time that a building can maintain a comfortable temperature when the power is off. Other efficiency projects like lighting upgrades share some co-benefits identified below, but they provide limited resilience to outages.

COSTS

Building energy efficiency upgrades that increase resilience vary in costs by project type and by location. Many of these upgrades are currently funded through the Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP). Both of these federal programs are administered by states and can fund energy efficiency improvements in eligible residential buildings. In Washington, D.C., the project expenses in its WAP program include attic air sealing at $2.53 per linear foot, spray foam insulation for $4.10 per linear foot, and wall insulation for $3.50 per square foot.[63] The Department of Energy reports that the average cost of all efficiency measures in WAP households is $3,545 per home.[64]

BENEFITS

Reduced energy costs

Building efficiency improvements lower costs for the homeowner and for broader society. The typical household wastes $200–$400 annually on heating and cooling expenses that arise from leaks and other inefficiencies, so reducing these leaks can save money right away.[65] Single family homes participating in WAP save an average of $283 in annual energy costs.[66] For low-income households, who tend to spend a larger share of their income on energy bills, the greater spending power that lower energy costs provides increases their ability to withstand unforeseen expenses.[67] This benefits the community at all times, not just in the aftermath of severe storms.

Societal benefits accrue from the avoided costs of new power generation and other electricity infrastructure that energy efficiency provides. Climate change is estimated to require an additional $50 billion in U.S. power system costs by 2050 because of the greater need for cooling as the Earth warms.[68] Efficiency can help offset these increased energy costs.

Reduced greenhouse gas emissions

Energy savings from efficiency can also reduce greenhouse gas emissions by reducing the consumption of fossil fuels. Evaluating the greenhouse gas reductions of individual building efficiency is difficult, because air sealing and other insulation improvements tend to be part of whole-house programs that also include, for example, lighting replacements. Nonetheless, a meta-analysis of residential energy efficiency programs finds that air sealing provides larger efficiency gains than lighting upgrades, and the greenhouse gas reductions from efficiency programs are around 1,000 tons per year (actual reductions will depend on the local carbon intensity of the electricity grid).[69]

Improved Public Health

Sealing leaks in the building envelope can reduce the amount of outdoor allergens and dust that can enter a home, leading to fewer asthma attacks, since these allergens are usual asthma triggers. Increased attic and wall insulation makes homes less drafty, keeping internal temperatures closer to a healthy range, and reducing incidence of thermal stress for residents. A survey of residents before and after home efficiency improvements found that asthma sufferers had 11.5 percent fewer emergency room visits in the year after weatherization, total medical care needs for cold-related illness fell 1.4 percent, and total medical care needs for heat-related illness fell 1.1 percent.[70] These health benefits over the first year of improved building efficiency are valued at $202.00 (asthma), $17.29 (cold), $8.52 per person (heat) per person.[71]

COMMUNITY PREPAREDNESS OUTREACH

Local governments have strong expertise in planning for hurricanes, tornadoes, blizzards, and other extreme storms. However, as climate change makes these extreme events more intense, planners should at least make sure they are using best practices for preparedness. Climate resilience can be improved by making sure that preparedness steps account for worst case scenarios (e.g., a severe heat wave following a hurricane) and cascading failures from power outages (e.g., loss of water treatment plants after prolonged outages). Some groups may need targeted preparedness information like people with disabilities or people with limited English language proficiency.

A variety of non-structural solutions exist to prepare communities to better withstand power outages. Readiness campaigns, using social media and other channels of communication, can encourage residents and businesses to stock up on critical supplies and educate them about what to do and where to go if the power is out. Early warning systems and emergency notifications, using text messages or conventional media like radio or television, can tell people when they might consider evacuation. All messages should be made available in as many locally-spoken languages as possible. When resources are not available to translate materials into multiple languages, community-based organizations or other trusted messengers can help spread information throughout non-English speaking communities. Emergency recovery efforts after prolonged power outages may need to consider additional health concerns, for example whether food in refrigerators and freezers is still safe to eat.

Emergency preparedness outreach can extend beyond being prepared to withstand power outages. Outreach to residents about securing objects that can be blown around by wind inside can prevent damage caused by flying debris.[72] Property owners can also be educated about tree plantings, maintenance, and pruning near utility wires, since many power outages after storms are the result of fallen trees or branches from private property, over which the local utility has no control.

COSTS

Many emergency preparedness outreach documents already include information on how individuals can prepare for power outages. Typical preparation steps involve monitoring weather reports, keeping batteries and flashlights on hand, charging cell phones in advance of a storm, and keeping refrigerators closed to preserve food.[73] Ensuring that emergency preparedness outreach also includes information on improving preparedness for power outages may not carry additional costs since this is part of current best practice.

Programs to improve tree maintenance on privately- or municipally-held land near power lines (in order to avoid outages due to falling branches) vary in cost. A study of Connecticut vegetation management programs advised municipalities in the state to budget $5,000 per mile for tree pruning, removal, and planting near roadways.[74] In Washington, D.C., enhancing the utility's vegetation management programs to remove dead or dying trees was estimated to cost an additional $3,000 to $5,000 per mile more than routine maintenance.[75]

BENEFITS

Improved public health

Communities that improve their resilience to storms will see fewer fatalities and faster return to normal economic activity following storms. A review of kidney patients affected by Hurricane Sandy found that those who received dialysis treatment in advance of the storm (a type of emergency preparedness action commonly undertaken by health professionals when power outages are anticipated) were 21 percent less likely to be hospitalized than patients who did not receive the early treatment. The early treatment patients also experienced a 28 percent lower 30-day mortality rate.[76]

Improved Awareness of Climate Change Risks

An emerging approach to emergency preparedness is a "Whole Community" approach, one that involves regular engagement with the full diversity of groups within a community.[77] This type of engagement allows emergency managers to better understand the climate risks and vulnerabilities of community members. This direct outreach also gives local government officials the opportunity to educate members of the public about climate risks facing the community. The benefit of improved awareness of climate change risks is a social outcome, and social outcomes are rarely assessed as part of program evaluation. However, evidence from community interviews suggests that preparedness outreach results in improved social capital and higher levels of trust between government and the public.[78]

IMPLEMENTATION EXAMPLES

- Leaders in Long Beach, Calif. held multiple community workshops focused on climate resilience. In these workshops, leaders gained a better understanding of the base level of knowledge of climate risks in the community.[79] Following the community outreach, a personal action guide was created to communicate to individuals the actions they could take to build resilience, including how to use less energy on hot summer days to avoid the risk of power brownouts and blackouts.[80]

- PEPCO, an electric utility serving Washington, D.C. and parts of Maryland, administers the Emergency Medical Equipment Notification Program. Utility customers can voluntarily participate in the program to receive advanced notifications of scheduled power outages and severe storms that could disrupt service.[81]

ENHANCING COMMUNITY EMERGENCY SHELTERS

Shelters can provide basic needs to residents who may be displaced because of storms. Similarly, community cooling centers can provide life-saving respite from extreme heat, and they may be especially critical when power outages prevent residents from running fans and air conditioners at home. Cities often use existing municipal properties, like schools, libraries or community centers, for these purposes.

To maximize the resilience benefits of these emergency shelters, local governments should take steps to ensure there is sufficient backup power (from traditional diesel generators or DER/solar+storage as discussed above) at these shelters during extended power outages.

COSTS

Using an existing building as a shelter generally imposes little additional cost. A 2014 survey of cooling centers in Maricopa County, Ariz. found that 33 of 53 cooling centers managers, or 62 percent, incurred no additional costs. The others did have extra costs from providing bottled water, higher energy bills, and extra staff hours, though many of these costs were lowered through community donations.[82] For short power outages or brownouts that might occur during a heat wave, existing buildings can improve community resilience without modifications. However, if buildings are to serve as emergency shelters during long-duration events, onsite backup power is required.

Select Florida schools that serve as emergency shelters have been retrofit with solar + storage systems that cost $74,000–$90,000 per school for 10kW solar panel installations and a 40 kWh battery. These shelters remained open with power following Hurricane Irma in October 2017 (even when gas supplies ran out for other backup generators). Additionally, these systems are estimated to save the school $1,500–$1,600 annually in electricity costs.[83]

BENEFITS

Public health and safety

Lives are saved when cooling centers are available during heat waves—times when the grid can be down or people may be forced not to use air conditioners because of high costs. Despite the clear connection between reduced heat exposure and reduced heat stress, very little observational data exists to attribute cooling centers to reduced fatalities. However, there is strong evidence that cooling centers, as part of a wider heat response plan, saved hundreds of lives during heat events in Chicago and St. Louis in 1999.[84]

IMPLEMENTATION EXAMPLE

- Broward County, Florida has distinct Special Needs Shelters for evacuation of people who require electricity for medical equipment. These shelters all have back-up power onsite. Additionally, the county provides transportation to the shelter, when needed.[85]

CASE STUDY: NEW ORLEANS IMPROVES ITS ELECTRICITY SYSTEM RESILIENCE

Hurricanes are a recurring threat in New Orleans. Since the destruction that followed Hurricane Katrina in 2005, many electricity system hardening actions were undertaken to improve the city's electricity resilience. Although power outages still do follow hurricane landfalls, the power restoration times have improved. A review of the power restoration following Hurricane Isaac's impact in 2012, for example, found that the local utility Entergy New Orleans beat industry standards in returning power service (although many residents still called for improvements, especially regarding the way that power outage duration estimates are communicated).[86]

TABLE 1: Co-Benefits of Resilience Strategies for Power Outages

	BENEFITS						
	LOSS AVOIDANCE	ENERGY SAVINGS	CONTINUOUS POWER	IMPROVED AIR QUALITY	REDUCED GHG EMISSIONS	PUBLIC HEALTH AND SAFETY	CLIMATE RESILIENCE COORDI-NATION
Microgrids	▲	▲	▲	▲	▲	▲	
Combined Heat and Power	▲	●	▲	●	●	▲	
Solar PV	▲	●	▲	●	●	▲	
Backup power/Battery Storage/EVs	●	▲	●	▲	▲	●	
Building Energy Efficiency		●			●	●	
Hardening Distribution Systems	●		▲			▲	
Smart Grid		●		●	●		
Emergency Preparedness outreach	▲					●	●
Enhanced Shelters						●	▲

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 and depending upon the design characteristics of the strategy.

Building on this history of progress, the city of New Orleans is implementing additional programs that will improve the city's resilience to power outages. Some of these programs are included in the city's comprehensive resilience strategy, released in 2015, that identified electricity system vulnerabilities to stronger tropical cyclones and hotter summers.[87] Example programs include:

- Researchers from Sandia National Laboratory used computer modeling to simulate a "worst-consequence" hurricane impacting the city, and then mapped the locations for microgrids that would provide the greatest benefits to community well-being following a hurricane. Locations of hospitals, grocery stores, and municipal services all factored into the decision for priority locations.[88] In all, 22 locations for microgrids were identified, and the city is pursuing implementing these projects.
- The City Council developed the Energy Smart New Orleans program in 2011, which is administered by Entergy New Orleans. Homes and businesses can receive energy audits and receive subsidized weatherization and other efficiency improvements through the program—qualified

low-income households receive weatherization upgrades up to $3,000 in value at no charge to them. Between 2014 and 2016, low-income households received upgrades resulting in 1,644 kW in annual electricity demand reductions.[89] Efficiency savings from other programs in Energy Smart New Orleans, including businesses and commercial buildings, have generated even greater savings, relieving stress on the electricity grid and thereby decreasing the risk of power outage during hot weather.

- The city's hurricane preparedness information is located in a single place, and includes information on pruning trees ahead of storms, preparing for power outages, registering as someone who needs electricity for medical equipment, and other best practices. The preparedness guide is available in three languages.[90]

INSIGHTS

Severe storms and extended power outages may be rare occurrences, but when they do strike they can devastate an entire region. Climate change is strengthening these storms, making it more likely that when they do occur they will be stronger than in the past. While many examples of best practices come from hurricanes, cities across the country face risks of power outage and can apply the same lessons. There are many steps communities can take to increase resilience to storm-related power outages, and they have co-benefits like reduced energy costs, cleaner air, and improved public health and safety. Many of these strategies are low cost, and even those that are more expensive (like distributed energy resources) are seeing rapid cost declines and technology advances.

A critical determinant of a community's storm resilience is the resilience of its local electricity supply, and this is often outside the jurisdiction of local government. However, local leaders can be partners and allies of electric utilities as they work together to increase resilience. New technologies like rooftop solar and electric vehicles have a large potential to increase community resilience, but only under certain conditions. To ensure that deployment of these new technologies comes with resilience benefits, local leaders can explore programs to incentivize battery systems and V2B/V2G for rooftop solar and EVs, respectively. Education programs may also be needed so that residents have appropriate expectations of the resilience these technologies provide.

KEY TOOLS

Several tools are available to support decision making around adoption of resilience strategies to severe storms.

CHP ENERGY AND EMISSIONS SAVINGS CALCULATOR

This calculator, provided by EPA, is a spreadsheet-based tool to compare fuel consumption and emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides for CHP systems and traditional separate systems. Emissions are region-specific, and take into account the local electricity mix.

https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator

ENERGY STAR PORTFOLIO MANAGER

This federal tool can be used to benchmark energy consumption of buildings, allowing policymakers to track the greenhouse gas emissions reductions that building efficiency programs deliver. The Portfolio Manager can be applied in a variety of building types and is being used by several cities in implementing building benchmarking policies.

https://portfoliomanager.energystar.gov

HHS EMPOWER MAP

The U.S. Department of Health & Human Services records the location of every Medicare beneficiary who uses electric medical equipment. These 2.5 million people have an especially critical need for continuous electricity service. Community plans to increase resilience to power outages can use this map to identify neighborhoods and municipal services that may take higher priority in planning.

https://empowermap.hhs.gov

HOME ENERGY SAVER

Homeowners can use public tools like DOE's Home Energy Saver, to calculate energy and cost savings for different efficiency upgrades, including wall and attic insulation, that also improve resilience to severe storms.

http://hes.lbl.gov/consumer

ICE CALCULATOR

The Department of Energy's Interruption Cost Estimate (ICE) calculator estimates the economic losses of power outages and can help assess the cost-benefit ratio of backup power or distributed energy resources.

http://www.icecalculator.com

LOCAL ENERGY EFFICIENCY POLICY CALCULATOR (LEEP-C)

This tool, created by the American Council for an Energy-Efficient Economy (ACEEE), calculates the community-wide energy and cost savings of policies that local governments might implement to improve efficiency. It includes 23 different policy types and can be tailored by the user.

http://aceee.org/research-report/u1506

SOLARRESILIENT

This tool, developed by the U.S. Department of Energy and the City of San Francisco, helps facility managers identify the backup power needs of a building and appropriately size a solar + storage system to meet those needs. It is particularly designed for use in resilience planning for city critical services.

https://solarresilient.org

WEATHER READY NATION

The National Weather Service provides up-to-date emergency preparedness information for a variety of natural hazards, including severe storms. The tips and tools provided on this platform can help communities better prepare for approach storms, thus reducing the damage they cause and enabling faster recovery.

http://www.weather.gov/wrn

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RESILIENCE STRATEGIES FOR DROUGHT

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Across the United States, the risk of drought is expected to grow due to reduced precipitation and higher temperatures caused by climate change. Drought's far-reaching impacts can ripple through communities, regions, watersheds, economies and ecosystems. This fact sheet overviews strategies for areas with a projected increase in drought conditions to become more resilient. It concludes with a community case study that has used a number of these strategies, and a list of tools to help communities evaluate the costs and benefits of resilience strategies.

CHANGING CONDITIONS

Drought is defined as a trend away from the a precipitation norm toward persistent reduced precipitation, causing a reduction in water supplies. The United States has experienced drought driven by natural variation in seasonal or annual precipitation in the past, but in recent years the U.S. has suffered a number of significant droughts. It is difficult to attribute these events to climate change, but human-induced climate change combined with natural variations can affect the severity of a drought event. Climate change could cause the warmer temperatures and seasonal shifts that contribute to more intense droughts. U.S. population growth and 20th century water supply projects have simultaneously increased demand for water from both residential and agricultural uses, adding to water stress.[1]

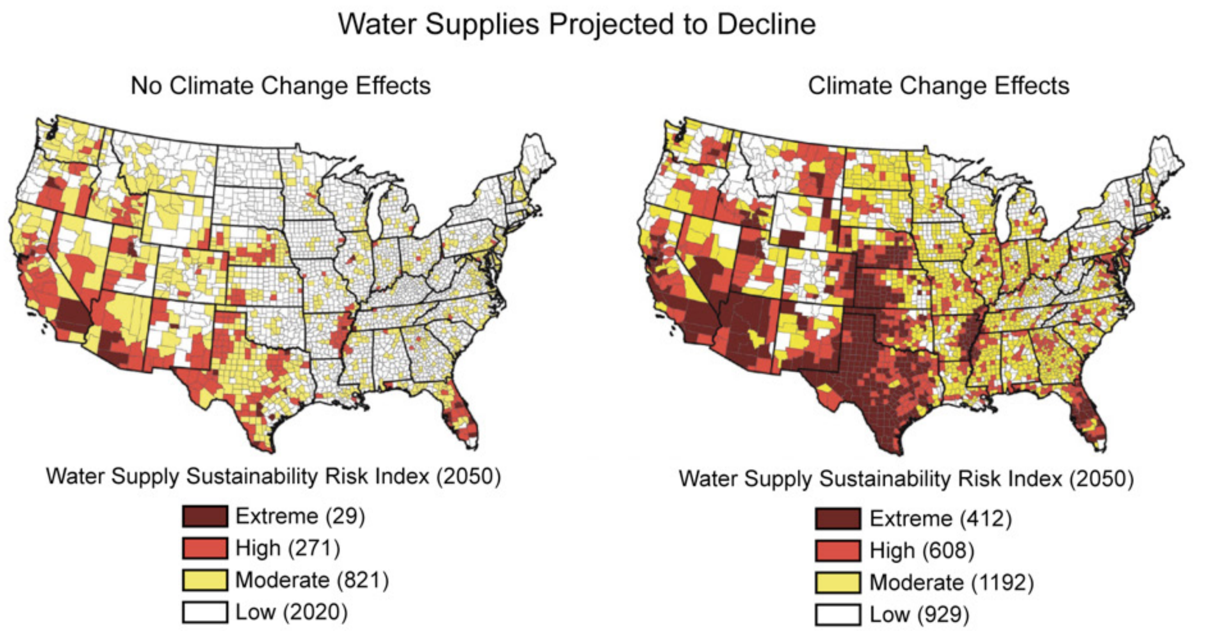
Projected climate impacts include significant reductions in precipitation in the southwest, and higher future temperatures that will likely contribute to greater frequency and intensity of drought. Among scientists who study this issue, there is medium confidence that soils will be drier in the future, even in regions with projected increases in average total precipitation.[2] In addition, seasonal changes in precipitation could cause longer and more uncertain timing of dry seasons.[3]

Warmer future climates are very likely to reduce snowfall accumulations, causing earlier spring runoff that will disrupt many Western watersheds, also contributing to drought risk.[4] In the highest emissions scenarios, projections show several western U.S. snowpacks disappearing by 2100, which could result in chronic drought in affected areas.[5]

Droughts can have far-reaching impacts including degraded water quality, low river flows with ecological implications, saltwater intrusion in tidal river areas and land subsidence.[6] If the past decade is any indication, the cost of drought in the U.S. will continue to grow. In 2015, severe drought caused $2.7 billion in economic losses in California alone.[7] Drought directly affects agriculture, the landscaping industry, and even hardware retailers. Agricultural losses due to drought conditions resulted in $787.2 million in losses for Georgia in 2007. In addition, recreational activities are impacted, including hunting, fishing, skiing and snowmobiling—all of which can significantly impact local economies.[8] Drought can also cause costly structural damage as drying soil shifts, damaging foundations and underground infrastructure. A 2011 drought in Texas caused over 700 water main breaks per day in Houston and severely damaged home foundations (with repairs typically ranging from $15,000 to $20,000 per home).[9]

Communities across the country should be evaluating their current risk of drought and how it could be

FIGURE 1: Effect of Climate Change on Water Supplies



Climate Change is projected to reduce water supplies mostly in the southwestern, central and southeastern regions of the United States. Today 10 percent of counties are at high or extreme risk of water shortages, and in 2050 that proportion of at-risk counties will grow to 32 percent. Projections assume an increase in greenhouse gas emissions through 2050 and a slow decline after.

Data: National Climate Assessment, 2014

affected by climate change. This fact sheet overviews a number of strategies that can help address this risk and highlights their associated co-benefits (social, economic and environmental benefits beyond the intended resilience outcomes). Estimates of costs are included, where available, though project costs will depend on local climate projections, material prices, and other factors. Identifying co-benefits can create additional opportunities for financing, help align resilience efforts with existing priorities and increases the political viability of these resilience actions. The monetization of each benefit summarized in this fact sheet will be most helpful in prioritizing strategies for closer study in your community.

WATER CONSERVATION AND PUBLIC EDUCATION

Communities in drought-prone regions generally have extensive water conservation efforts underway, serving as models for areas now facing the prospect of increased drought conditions in the future. Water conservation is often spearheaded by water utilities or local nonprofits, and carried out by local governments, individuals and businesses. This section overviews some key technologies and equipment available to help reduce water use on an individual level and the policy strategies that can encourage or require widespread implementation.

The U.S. Environmental Protection Agency (EPA) developed the WaterSense label to show that any product with the label is at least 20 percent more efficient without sacrificing performance.[10] Since 1989, eight states have set water efficiency standards for all faucets, toilets and shower heads installed statewide and California has mandated new efficiency standards that are more stringent than WaterSense.[11]

Outdoor water conservation can reduce the annual summer peak in water demand when water supplies are often the most stressed. About one third of nation-wide residential water use is devoted to landscape irrigation.[12] Steps that individuals can take to reduce outdoor water consumption include:

- Use native plants or choose plants that need less water.
- Practice xeriscaping, a comprehensive landscaping approach for water conservation that combines planning and design to create landscapes that need less water and retain more water onsite.
- Group plants according to water needs and then water according to each groupings' specific needs.
- Maintain healthy soils with mulching to minimize runoff and retain water.
- Minimize turf areas, or choose grasses that require less water.
- Avoid watering during the heat of the day.
- Use efficient irrigation systems that reduce leakage and water demand. An automated system offers irrigation controller technology that uses local weather data to inform when to irrigate and can be controlled by smartphone apps. Look for the WaterSense label (which is also applied to outdoor water components).
- Capture runoff from rooftops with rain barrels or cisterns (rainwater harvesting). Capturing rainwater for outdoor uses reduces the demand on drinking water and avoids the energy (and associated greenhouse gas emissions) needed to treat it.[13]

Synthetic grass can also replace water-intensive lawns and is being employed in California and other states. Synthetic grass reduces water consumption, but does not offer the co-benefits of natural vegetation like infiltrating rainwater, and retains and emits more heat than natural landscapes.

In partnership with local water suppliers, communities can and have enacted policies to encourage, or require public and commercial adoption of these conservation practices. Policy options can range from incentives for water efficient appliances, to water pricing systems that penalize large users (e.g., block water pricing that increases with use rather than decreases), to strict mandates that limit water use. Engaging residents about an area's vulnerability to drought and the importance of individual conservation measures is a key element of successful water conservation initiatives.

CITY PLANNING

Drought as well as other climate impacts, should be considered throughout local government planning processes. Planning decisions affect future water consumption by influencing the size of homes and yards. A Utah study found that households on 0.2-acre lots used half the water of those on 0.5 acre-lots.[14] A study in Ipswich, Massachusetts, compared residential water use in two future land use scenarios: traditional suburban development and smart growth with higher residential densities. Higher-density growth yielded a 5 percent reduction in water use over time without any additional conservation programs.[15]

CODES AND ORDINANCES

Communities can encourage or require individual water conservation through plumbing codes and conservation ordinances. An ordinance can require property owners to replace inefficient fixtures and repair plumbing leaks. Outdoor water conservation ordinances can require water-efficient irrigation devices or define maximum water allowances based on square footage of the landscape and the climate of the region. California provides towns with a Model Water Efficient Landscape Ordinance that includes guidance on what size landscapes to include in ordinances, recommends limiting high water-use plantings to only 25 percent of residential landscapes, and sets maximum applied water allowances. It also sets out requirements for irrigation systems requirements, soil health and permeability.[16]

WATER PRICING

Pricing water and services to accurately reflect the cost of providing water and wastewater services can help water-users be more conscious of their use and incentivize conservation. Conservation pricing can be designed and implemented to reduce water consumption, reduce impacts on utility revenue, reward customers for choosing water-efficient appliances, target inefficient uses of water, delay costly water supply expansion projects and avoid financial hardships on low-income customers.[17] Elements and price structures that utilities can employ to encourage conservation, include:

- Water meters at all single family and multifamily dwellings
- Increasing block rates use tiered per-unit pricing that increases with water usage
- Water surcharges are a higher rate for excessive

water use, as defined by a water utility.

- Seasonal rates change based on weather conditions and the corresponding demand for water.[18]

There are a number of considerations that go into choosing conservation pricing structures such as the size of the water system, and how rate increases might affect low-income customers in a community. A literature review of how rate increases affect consumption found that a 10 percent rate increase corresponded with a 5 percent average reduction in consumption.[19]

RETROFIT AND LANDSCAPE REBATES

Communities can offer rebates on low-flow or water-conserving indoor fixtures, or offer the fixtures directly to residents for a low price or free. Rebates can also fund the conversion from turf to low-water use landscaping based on the amount of lawn removed, installation of water efficient irrigation, or other local conservation considerations. The San Diego County Water Authority set up a turf replacement incentive program in 2012 to prompt the replacement of more than 1 million square feet of water-intensive turf grass with low-water-use landscaping. The utility also offers classes on installing low-water landscapes, plant fairs that offer discounts on low-water-use plants and an online home water-use calculator.[20]

LEAK DETECTION AND REPAIR

A regular leak detection survey or audit of water distribution systems and repair of leaks can conserve water before it reaches a faucet. Every day, nearly 6 billion gallons of treated drinking water is lost, wasting the equivalent of an estimated 14 to 18 percent of daily water use.[21] Cities and water utilities have access to new technologies to aid with leak detection and repair including smart meters to detect leaks in residential water connections, water sensors that can send the utility alerts about low water pressure, and probes to ease water main inspections. Individuals can also be empowered to perform water audits with kits to help measure water use and leaks, or a nonprofit or utility can offer free audits to individuals.

The Massachusetts Water Resource Authority (MWRA) requires its member communities to carry out leak detection. Communities can also initiate a survey.[22] The MWRA's leak detection and repair programs are primarily credited with a 20 percent drop in water use over five years in its service area.[23] Birmingham Alabama's water audit in 2011 revealed more than 2.8 billion gallons of water loss with a value of $962,914 in 2011. The audit identified nearly 14 miles of pipe that needed immediate replacement.[24]

PUBLIC EDUCATION AND OUTREACH

Water conservation programs require education and outreach to the public which can be carried out by local governments, utilities, or in partnership with local non-profits. The Alliance for Water Efficiency lists the key goals of any education program as informing and educating the public about: reasons water conservation is necessary; benefits of conserving water; liabilities of not conserving water and; actions needed to achieve water conservation goals. Some utilities reported reduced water usage by over 20 percent after public education campaigns. It is important to note that behavior change may not be permanent, and to ensure long-term change, education should accompany other water conservation strategies like those described above.[25]

COSTS

For individual users, low-flow fixtures can have higher upfront costs compared to traditional fixtures, but many are comparably priced. A low-flow toilet, for example, can cost about $100 more than a traditional toilet, but depending on water rates, users can recoup the costs in a few years.[26] Low-flow faucets and showerheads are generally priced comparably with traditional fixtures.[27]

The cost of installing drought-tolerant landscape is higher upfront, but needs less maintenance than non-drought-tolerant landscaping, which may struggle in areas with drought conditions. The estimated replacement cost of traditional landscaping with drought-tolerant landscaping can range from $1.50 to $2.50 per square foot.[28] Synthetic turf lawns cost an estimated $5 to $20 per square foot, but can be eligible for rebates, and yield significant water savings.[29] These cost ranges are only estimates and depend on many variables including plant choice, hardscape (fixed landscape infrastructure like fencing and stonework), and labor costs.

The costs to a community or utility for developing incentive programs vary based on population, but the

Inland Empire Utilities Agency in California did a 2005 cost-benefit analysis of its conservation programs and found, across all programs, an average return of $1.52 for every dollar spent, with the toilet rebate program (costing about $38,000 for 630 units) and toilet exchange program (costing about $109,120 for 1760 units) returning about $2.40 for every dollar spent.[30] Rebates for landscape conversion to drought-tolerant landscape were found to be less cost-effective at the community level. In Orange County for instance, turf removal rebates had a greater cost per acre foot of water conserved than other water conservation strategies.[31]

The cost of leak detection varies based on system and geographic location. The Massachusetts Water Resources Authority (MWRA) offers leak detection contracts to communities for about $145 per mile of water main to be inspected.[32] A three-year leak detection survey in Decatur, Illinois, a city of 79,000 people with a 528-mile water distribution water, cost $80,000. The repair of the identified leaks cost $70,000 with an return of $5 in savings for every dollar invested. The leak detection and repair program identified water losses amounting to $944,000 and the city was able to prioritize easy repairs on fire hydrants and water service leaks right away.[33]

Outreach campaigns to explain water conservation to water-users varies broadly in cost. The estimated budget for outreach required to carry out and explain water conservation policies or campaigns is between $10,000 and $50,000 for a basic print campaign depending on agency size.[34]

BENEFITS

Water and electricity bill savings

Water conservation provides considerable savings to individuals. The EPA estimates that replacing bathroom faucets with WaterSense-labeled models alone can save a family $240 in water and electricity costs (mostly from water heating) over the faucet's lifetime. Replacing showerheads with water efficient models can reduce an average family's water consumption by 2,700 gallons per year, and reduce electricity costs by $70 per year. In total, the average family spends more than $1,000 per year on water, but can save more than $380 from installing WaterSense fixtures.[35] WaterSense smart sprinklers can save the average home more than 8,000 gallons per year, with the potential to save $435 million in water costs each year, nationally.[36]

Water conservation also helps communities and states save on energy costs. The California Energy Commission documented that 19 percent of the state's electric energy load is used to pump, treat, and distribute drinking water and collect and treat wastewater.[37] In 2015, the governor of California mandated a 25 percent reduction from 2013 levels in water consumption, resulting in savings of 524 billion gallons of water from June 2015 to May 2016, energy savings of 1830 GWh, and avoided greenhouse gas emissions of 521,000 metric tons of carbon dioxide equivalents (the equivalent of taking 111,000 cars off the road for a year).[38]

Water affordability

Water conservation campaigns and policies can be structured to help low-income households or areas be able to afford water. Portland, Oregon, transitioned to consumption-based billing in 1993, but developed programs for low-income customers. Programs included discounted bills, water audits, and toilet rebates.[39] Water conservation campaigns can also lower the municipal costs, especially if new construction of water infrastructure is avoided, and pass on savings to rate payers, as has been observed in Tucson[40] and Gilbert, Arizona,[41] (described in the Implementation Examples).

Less Landscape Maintenance

A public demonstration drought-tolerant garden in Santa Monica showed that sustainable landscapes use less than a fifth of the water of traditional landscaping, and require about a third of the maintenance of a traditional garden.[42] Another study found that xeriscaping can provide an estimated 36 cents per square foot savings annually due to decreased maintenance costs. Synthetic lawns or xeriscaping also can reduce costs of watering, fertilizer, and a hired gardener or lawn mower.

Ecological Benefits

Plants that are native to arid areas can lower maintence costs and provide ecological benefits as well. They are typcially better suited to native soils, needing less fertilization to reduce harmful run-off, are less susceptible to pests reducing pesticide application, and can provide habitat for local wildlife.

Reducing water demand can also augment streamflow, restore wetlands, or enhance water quality.

Avoided water diversion allows waterways to support environmental benefits like water quality, flood control, and species habitat and recreational benefits, including fishing, boating, and swimming. Low stream flows can also reduce or eliminate recreational opportunities like rafting and fishing, which is a significant part of the American West's economy. The Colorado River alone is estimated to support a $26.4 billion recreation industry, and this value is closely tied to instream flows that depend on water conservation and reuse.[43] Within cities, conservation can leave more water for urban green spaces, which offer health and economic benefits like lowering temperatures and avoiding heat illness or stress.[44]

Flexible implementation

Water efficiency programs can be deployed in stages, with immediate benefits when compared with large infrastructure projects. Investments targeted to lower-income areas can help areas where infrastructure or appliances are older and less efficient. In the early 1990s, the City of Los Angeles used community-based-organization deployments for deploying low-flush toilets. This created employment opportunities in the areas with the highest unemployment rates.[45] Conservation programs like watering restrictions can be adjusted when drought conditions have passed, or when water supplies are restored.

IMPLEMENTATION EXAMPLES

- **Albuquerque, New Mexico,** implemented a Water Conservation Landscaping and Water Waste Ordinance in 1995 that bans turf installation for new commercial developments. The city also offers a rebate of $1 per square foot, and $1.50 per square foot on steep slopes, for turf removal and replacement with native vegetation. This effort along with the city's Long-Range Water Conservation Strategy helped Albuquerque reduce its per-capita water usage from 250 gallons per person, per day in 1995 to 148 gallons per person per day in 2011.[46]
- In **Gilbert, Arizona**, water conservation initiatives from 2001 through 2016 helped customers avoid the costs of acquiring, delivering and treating additional water supplies for a growing population. The fees for a new customer to connect to the water system in 2015 are 45 percent lower than if per capita demand had not been reduced. Water rates and wastewater rates are also 5.8 percent lower than if there had been no water conservation.[47]
- **Boston** reduced consumption from 125.5 billion gallons in 1980 to 70.9 billion gallons in 2009, a 43 percent reduction. The city spent $40 million to improve water efficiency but avoided $500 million in costs for upgrading the system. This was accomplished through repair of leaks, requiring low-flow toilets in new construction and retrofitting homes with efficient plumbing fixtures.[48]
- **Tampa, Florida,** addressed its dependence on drought-sensitive open water sources (which provided 75 percent of the city's drinking water) through a variety of measures. Starting in 1989, the water department modified the plumbing code to require water-efficient plumbing fixtures in new and renovated construction, and began distributing water conservation kits to homeowners. The city's per capita water use from 1989 to 2001 decreased by 26 percent.[49]

REGIONAL WATER CONSERVATION

URBAN-RURAL PARTNERSHIP

The U.S. Geological Survey estimates that irrigated agriculture accounted for 38 percent of U.S. freshwater withdrawals in 2010, and agriculture accounts for about 80 to 90 percent of U.S. consumptive water use.[50] This demand for water presents opportunities for towns and cities to engage with agricultural producers and rural water users to enact watershed-wide conservation incentives and policies. Agricultural water consumption can be reduced through soil moisture monitoring, managing soil capacity to retain more water, conservation tillage, efficient irrigation and crops that are better able to withstand water stress and withdraw water from the soil.[51]

In an urban-rural partnership, cities work with agricultural water users to reduce consumption on farms, freeing up water supply for urban use while reducing water-related costs of farming, and farmers' vulnerability to water shortages and drought.

Urban-rural partnerships can be cost-effective water supply strategies for cities and farms,[52] and are most successful when tangible water quality improvements are identified that also improve farm operations, improve soil quality, and create regulatory certainty for municipalities and producers.[53]

WATERSHED COORDINATION

It is critical to manage for drought resilience at the watershed level, despite the local nature of water suppliers and management agencies. Watersheds cross local and state boundaries creating a need for inter-basin cooperation. Watershed-scale management can be scoped to provide a number of other benefits like enhancing fisheries, expanding surface and groundwater storage, improving habitats and water conservation.

COSTS

There is little data available about the cost of implementing an urban-rural partnership or basin-wide conservation efforts. In the San Diego case, detailed below, the cost, per cubic meter, of water conserved through agriculture to urban water transfers, was $0.57, while the comparative costs for other water recycling and storage methods were higher (only local stormwater capture and urban water conservation were a lower price).[54]

BENEFITS

Avoided Costs

Similar to the benefits that result from water conservation, watershed and urban-rural partnerships to address water shortages can help communities avoid the costs associated with building alternative water supply systems.

Ecological Benefits

Agricultural conservation allows water conservation to occur upstream of cities, limiting the water lost in transit to urban areas. Agricultural water diversions can harm fish and wildlife, so agricultural conservation can benefit ecological health and ecosystem services in addition to enhancing recreational opportunities in waterways.[55] Watershed-scale drought planning can also benefit aquatic species and include habitat restoration goals.

Agricultural Benefits

Water conservation in agriculture can increase yields and improve crop quality. Water efficiency improves the reliability of a farmer's existing water supplies and reduces vulnerability to drought. Farmers can use income from water transfers to fund purchase of irrigation technology, and for complex irrigation management like irrigation scheduling or applying less water to plants in more drought-tolerant growth stages. On-farm and water-district-level water efficiency could result in agricultural water savings of 4.3 million acre-feet per year in California, and 0.4 million acre-feet of those water savings could be made available to other uses.[56]

Watershed drought coordination can also benefit farms. In the Blackfoot River watershed in Montana, individual irrigators and streams suffered in droughts. In 2000, water users developed the Blackfoot River Drought Response Plan to improve the health of the river during normal periods and provide certainty for irrigators during droughts by determining drought indicators that trigger water conservation.

IMPLEMENTATION EXAMPLES

- **San Diego** developed an urban-rural water conservation partnership in which the city compensates farmers in surrounding areas for implementing agricultural water conservation measures. Some growers implemented conservation measures that resulted in a 55% reduction in agricultural use within 3 years. Agricultural and residential water conservation efforts helped San Diego maintain the same city-wide water use in 2010 as in 1995 despite a growth in population by over 400,000.[57]
- **Colorado** and other western states are employing "alternative transfer methods" which generally allow agricultural producers to maintain ownership of their water rights. The Arkansas Valley Super Ditch in Colorado began a pilot project phase in 2015 allowing temporary water transfers. Irrigators lease water to cities in 3 out of every 10 years and receive payment for leased water. Farmers reduce consumptive water use by planting non-irrigated crops in their crop rotation or fallowing fields.[58]
- Water users in the **Yakima Basin, Washington** launched the Yakima Basin Integrated Water

Resource Management Plan to bring together more than two dozen stakeholders and develop an integrated management approach for the Yakima River which provides water to towns, supports $4 billion in agricultural production,[59] fisheries, a river ecosystem, and is important to the culture and economy of Native American tribes. The plan includes restoration elements to help fish populations, make structural and operational changes to existing facilities, create surface water and groundwater storage, protect habitat and the watershed, enhance water conservation and establish a market-based water bank to reallocate water, including during periods of drought. The overall cost of implementing the plan over decades is estimated to cost between $3.2 and $5 billion.[60]

ALTERNATIVE WATER SUPPLY

When reducing demand is not enough, communities can consider additional sources of water. By diversifying water supply and identifying alternative water sources for emergencies, communities can improve their resilience to drought. This can include approaches like building piplines to existing water supplies, enlarging or adding reservoirs to increase storage, drilling or acquiring groundwater wells, and establishing emergency interconnections with nearby water or power utilities. This paper will focus on less traditional strategies that can address increasing drought conditions. Water reuse and desalination have been included in some cities' drought or water management plans for the coming decades and are being implemented in select cities.

WATER REUSE

Water reuse or recyling is the use of highly treated wastewater, called reclaimed water, for potable or nonpotable purposes. Communities are implementing inexpensive water reuse programs that serve specific outdoor facilities such as golf courses or parks or more advanced systems like agricultural use, creation of wetlands and industrial reuse like in cooling towers. Some communities are treating wastewater for potable uses, or are considering the option for future scenarios of drought or increased water demand. California already reuses an estimated 13 percent of wastewater generated, with additional potential for reusing 1.2 to 1.8 million acre-feet per year.[61]

This can also be carried out on-site, to reduce the consumption of treated drinking water and the amount of wastewater that needs treatment. On-site systems separate graywater (any wastewater not from toilets and sometimes kitchen sinks and dishwashers) from blackwater (water that could carry sewage) and treats the gray water for reuse.[62]

DESALINATION

Desalination refers to the process of removing dissolved solids, mostly salts and other minerals, from water. The process is most often used to convert seawater or brackish groundwater to potable water, but can also be applied to treat wastewater in reclamation and reuse projects. Desalination plants are being constructed around the U.S., with 117 municipal desalination plants built between 2000 and 2010. Florida has the most municipal desalination plants with 148 as of 2013.[63]

COSTS

The costs of installing non-potable reuse facilities vary based on the size of the facilities and the intended use of the water. A National Academies of Sciences report found that the capital costs (construction of plants, pipelines, well fields and engineered natural systems) for water reclamation and reuse varies from $1.14 to $18.75 per thousand gallons (kgal) capacity. Costs of operations and maintenance were between $0.05 and $1.18 per kgal per year (averaging $0.69 per kgal). Potable reuse projects generally have higher capital costs, ranging from $3.90 to $31 per annual kgal capacity and from $0.31 to $2.38 per kgal capacity (averaging $0.95 per kgal) for operations and maintenance, but this can vary. A Denver analysis of future water supply options found that potable water reuse was cheaper than expanding the existing nonpotable system throughout the city.[64]

Desalination is often the most expensive drought strategy. One-third to one-half of the operating cost is spent on electricity to run the desalination systems, and this can make the price unpredictable. Desalination plants should rely on low carbon energy sources like nuclear or renewable energy to avoid additional greenhouse gas emissions. In November 2012, San Diego County Water Authority approved the purchase of desalinated water from the Carlsbad desalination facility costing about $1,600 per acre-foot.[65] Desalination can also have negative impacts, including the disposal of byproducts created during the deslination process. Careful management and disposal can avoid contamination of other estuaries and wetlands near facilities.[66]

BENEFITS

Water reclamation and recycling has many of the same benefits as water conservation by reducing demand on natural surface water sources. These include ensuring affordable water for customers, avoiding water diversion, avoiding aquifer stress and depletion, decreasing discharge of wastewater into sensitive water bodies and the additional possible benefit of using recycled water to enhance wetlands or riparian habitats.

Energy Savings and Avoided Costs

On-site water recycling can produce benefits related to avoided investment in water infrastructure to transfer water to the site and wastewater from the site. In Los Angeles, water recycling offered energy savings over pumping water from the Los Angeles Basin, also contributing to improved air quality.[67] Desalination facilities can also help communities save money on transporting water. In El Paso, Texas, the cost of importing fresh water was about $6 or $7 per thousand gallons versus between $4 and $5 per thousand gallons to desalinate.[68]

IMPLEMENTATION EXAMPLES

- **El Paso, Texas,** has the world's largest inland desalination plant, which allows the city to access brakish groundwater resources. The plant can produce up to 27.5 million gallons of fresh water each day. Desalination doubles as a comprehensive water treatment technology, removing other pollutants in the process. The wells for the plant are strategically placed to slow or prevent brakish water intrusion in freshwater wells.[69]
- **Phoenix** reuses nearly 100 percent of its wastewater, and Arizona Public Service Company's Palo Verde Nuclear Power Plant is cooled by reused water.[70]

EMERGENCY PLANNING FOR DROUGHT

Communities can develop drought plans to prepare the community (including citizens, local government and industry) to address drough conditions. Drought planning can be included in a local hazard mitigation planning process[71] or through local, regional or statewide water management planning, water shortage contingency planning, in a separate climate resilience plan, or other city documents. Drought planning typically includes:

- Designating a drought task force or planning team
- Drought monitoring
- Adopting a local definition of drought and different alert levels that trigger phasing in and out of local, state, federal responses to drought
- Provisions for communicating with a drought planning team, groups or agencies with interests related to drought and the public
- A vulnerability assessment to analyze past impacts and causes of continued vulnerability
- Specific planning about how to help the public understand regional water supply vulnerability to drought, and how individual choices and actions can reduce water consumption
- Communication planning for during the drought with coordination between involved entities
- Identification of other resilience strategies to be implemented.[72]

Drought risk should be communicated to the community before the start of a drought. Outreach programs can explain water conservation, the drought plans in place, and how residents and businesses will be expected to respond in drought conditions through mass, targeted and daily communication. Use of electronic messaging and social media platforms can also extend and better target messages. Communications can leverage past outreach from water utilities as well.[73] There is little data on the costs of developing an emergency drought plan so this paper will next discuss the benefits.

BENEFITS

Behavior Change

In the process of developing drought planning documents, early engagement can build support for municipal drought mitigation and also understanding of regional water stress. Alerting residents to challenges with drought can also create a collective consciousness and concern about the issue, contributing to more effective conservation outreach. For instance, during California's drought in 2015, Sacramento-area residents reported water wasters 5-10 times more frequently than the rest of the state and cut water use by 35 percent.[74]

IMPLEMENTATION EXAMPLES

- **Arizona's** Department of Water Resources requires annual water use reports and system plans from drinking water providers in the state. System water plans must include a water supply plan, water conservation plan and drought preparedness plan.
- **Tucson, Arizona,** developed a Drought Preparedness Plan in 2005. It provides water efficiency incentives and recycles wastewater for irrigation. Tuscon spends $3 million a year on conservation education programs.[75]
- **Las Vegas** responded to a 10-year drought by adopting an Emergency Action Plan establishing drought management measures and water use restrictions. Part of this plan was to implement an outreach campaign that through presentations, community meetings and media reports helped reduce water use by 26 percent.[76]

CASE STUDY: SAN ANTONIO

Most communities facing some form of drought threat need to take a multi-faceted approach and implement a combination of the strategies outlined above. San Antonio provides a model for developing a comprehensive suite of strategies to improve resilience to drought. San Antonio's population has grown by 80 percent in the last 30 years, but water demand has only grown by 20 percent. San Antonio achieved these reductions in consumption through a number of initiatives.

The San Antonio Water System (SAWS) utility required and incentivized retrofits for residential and commercial water conservation. Rebates were offered for water-saving improvements like irrigation systems, and custom rebates created incentive for businesses to upgrade equipment. Rebate programs resulted in the replacement of over 250,000 traditional toilets and urinals with low-flow models.[77]

The utility and city also supported outdoor conservation. Residents are encouraged to use native, drought-tolerant plants. SAWS offers incentives to eliminate unnecessary spray irrigation, convert to drip irrigation and establish drought tolerant landscape. Over 2 million square feet of water-intensive grass has been replaced with low water-use plants or permeable patios through the WaterSaver Landscape Coupon program. These water conservation incentives were paired with a tiered rate structure to discourage water waste.[78] The utility also offered services to customers like water-saver irrigation consultants, which reduced household usage by 84 million gallons per year, and repairing leaks at no cost for low-income customers.

The utility's work complemented city initiatives like its 2010 Sustainable Buildings Ordinance to increase energy efficiency as well as water efficiency in buildings.[79] The city has also passed a small addition to the sales tax to purchase conservation easements to protect sensitive land over the recharge zones for the city's aquifer. San Antonio has the nation's largest direct recycled water system, with infrastructure capacity to deliver up to 35,000 acre-feet per year of treated recycled water through more than 130 miles of pipeline to commercial and industrial customers, golf courses and parks.[80] San Antonio also has an aquifer storage and recovery facility that stores enough water to supply the city for four months[81] and has invested in a brackish desalination plant that can produce 12 million gallons of water per day.[82]

Incentives and ordinances are supported by education through years of media campaigns, educational events and home conservation consultations. SAWS seeks to engage 100,000 citizens per year through face-to-face conservation education by partnering with community organizations.[83]

The city conducted an analysis, comparing the costs avoided by conservation programs to the capital costs of operations and maintenance of new water supplies, potable water delivery, and wastewater treatment, without conservation, from 2010 to 2060. The study found that for every dollar invested in conservation, the utility saved $4 on the capital costs, operation and maintenance of new water supplies.[84] In 2011, San Antonio's conservation efforts saved 120,000 acre-feet of water, or $84 million in just one summer.

Looking to the future, SAWS is exploring additional drought resilience projects like direct potable reuse of treated wastewater, stormwater management to enhance aquifer water levels, and expanding its brakish water desalination plant. San Antonio's short term plans include continued encouragement of water conservation to reduce total planned per capita consumption in an average year from 124 gallons per capita per day in 2017 to 112 gallons per capita in 2025. The utility has set an even more aggressive conservation goal of 88 gallons per capita per day in 2070.[85]

KEY INSIGHTS

This paper draws examples mostly from the west where droughts are natural, historic, occurrences, but communities are now facing more severe and longer periods of drought, and in different regions. These communities that have been conscious of drought and water-use for decades, if not centuries, serve as models for other communities. Most of the communities mentioned in the paper are employing multiple strategies, with San Antonio providing a prime example of developing multi-pronged plans to encourage individual conservation, recycle water, and find additional storage and sources for times of drought. Using multiple strategies helps a community be more resilient to changing climate conditions.

Water conservation is the most cost-effective strategy for reducing water consumption and becoming more resilient to potential climate impacts that incease draught conditions. Desalination is the most expensive drought strategy, but costs may come down as the technology is improved, becoming more competitive because of the high cost of water transport. Water conservation or reusing wastewater provide numerous co-benefits including instream-flow habitat, reduced energy consumption and cost of water pumping and treating, and reduced cost of updating water storage options. Strategies with these co-benefits can improve city resilience to other climate impacts like drought and flooding.

Table 1 (on the following page) shows that each strategy offers benefits and costs. Considering which benefits are most in-line with other community priorities, and which combination of strategies may yield them, helps to prioritize local resilience activity.

TOOLS

Several tools are available to support decision making around adoption of resilience strategies to drought.

AQUEDUCT (WORLD RESOURCES INSTITUTE)

This series of mapping tools help companies, investors, government and other users understand where and how water risks and opportunities are emerging worldwide. Maps look at flood imapcts, as well as river basins' exposure to water stress, interannual variability, seasonal variability, flood occurrence and drought.

http://www.wri.org/our-work/project/aqueduct

CLIMATE RESILIENCE EVALUATION AND AWARENESS TOOL (CREAT) CLIMATE SCENARIOS PROJECTION MAP (EPA)

Users can look at projections for precipitation (as well as other climate impacts) in hot and dry, central, and warm and wet scenarios in the years 2035 and 2060.

https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=3805293158d54846a29f750d63c6890e

CONSERVATION TRACKING TOOL (ALLIANCE FOR WATER EFFICIENCY)

The Tracking Tool is an excel-based model that can evaluate water savings, costs, and benefits of conservation programs for a specific water utility. Information entered into the tracking tool provides a standardized methodology for water savings and benefit-cost accounting including a library of pre-defined conservation activities users can use to build conservation programs. The tool is available for free to Alliance for Water Efficiency members.

http://www.allianceforwaterefficiency.org/Tracking-Tool.aspx

CREATING RESILIENT WATER UTILITIES CASE STUDY AND INFORMATION EXCHANGE (EPA)

A set of maps that provide links to brief stories of planning efforts being conducted by water utilities in the United States to build resilience to natural hazards and other water management challenges. The utilities have shared experiences and lessons learned to assist other

TABLE 1: Co-Benefits of Resilience Strategies for Drought

	BENEFITS									
	AVOIDED INDIVIDUAL COSTS	AVOIDED COMMUNITY COSTS	AFFORDABILITY	LESS LANDSCAPE MAINTENANCE	ENERGY SAVINGS	ECOLOGICAL	SOCIAL AND HEALTH	ADAPTABLE IMPLEMENTATION	AGRICULTURAL	INCREASED AWARENESS
Indoor Conservation	●	●	●		▲	▲	▲	●		▲
Outdoor Conservation	●	●	●		▲	▲	▲	●		▲
City Planning	▲	▲	▲	▲	▲	▲	▲			
Conservation Ordinances	●	▲	▲	▲	●	▲				▲
Water Pricing	▲	●	▲		▲	▲	▲	●		▲
Landscape Rebates	●	▲	●	▲	▲	●	▲	●		▲
Plumbing Retrofit Rebates	●	▲	●		▲	▲	▲	●		▲
Community Leak Detection and Repair	▲	●	▲		▲	▲	▲	●	▲	
Public Education	▲	▲	▲	▲	▲	▲	●	●		●
Water Reuse/Recycling	▲	▲	▲		▲	▲	▲			
Desalination		▲				▲				
Urban-Rural Partnerships	▲	●	▲		●	●		●	▲	
Watershed Management	▲	▲	▲		▲	●	▲		▲	
Emergency Planning		▲					●			●

The benefits of the strategies overviewed in the factsheet are summarized above, with green dots indicating a benefit that could be expected from each of the strategies. The yellow triangles indicate benefits and costs that could apply in certain areas or circumstances, especially if the strategy was designed or implemented to that purpose. 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.

water sector utilities that are currently developing their own plans or responding to recent events.

https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=03d35ca84b5944f8b3ab59bf3a981462

NATIONAL DROUGHT MITIGATION CENTER

The NDMC at the University of Nebraska-Lincoln helps people and institutions develop and implement measures to reduce vulnerability to drought. Resources include monitoring tools, planning tools, and information about current and historic drought conditions.

http://drought.unl.edu/

NATIONAL INTEGRATED DROUGHT INFORMATION SYSTEM (NOAA)

This tool coordinates and integrates drought research building on existing federal, tribal, state, and local partnerships. NIDIS's website is a portal into data, maps and tools that can be used to inform drought planning. For example, the Soil Moisture Map displays interactive soil moisture and soil temperature data. Users can select the location, whether they'd like temperature or moisture data, and at what depth the data should be from (between 2 inches and 40 inches).

www.drought.gov

WATERSENSE CALCULATOR (EPA)

The calculator allows users to estimate how much water, energy and money can be saved with WaterSense labeled products in a home or apartment building.

https://www.epa.gov/watersense/watersense-calculator

WATERSENSE REBATE FINDER (EPA)

Users can search for money-saving rebates in their area. The site categorizes the types of rebates, elligible building types, and the states where the rebate is available.

https://www.epa.gov/watersense/rebate-finder

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RESILIENCE STRATEGIES FOR WILDFIRE

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

The risk of wildfire is expected to grow across the United States due to reduced precipitation in some regions, and higher temperatures caused by climate change. Wildfire has far-reaching impacts that can ripple through communities, regions, watersheds, and ecosystems. This paper overviews a number of adaptation strategies for areas with a projected increase in wildfire conditions. For each strategy, it will discuss design and operation costs, and primary and co-benefits. The paper includes a community case study of Austin, Texas, which has used a number of these strategies, and a list of publications and interactive tools to help communities become more resilient to wildfire.

INTRODUCTION: FUTURE WILDFIRE RANGE, FREQUENCY AND SEVERITY

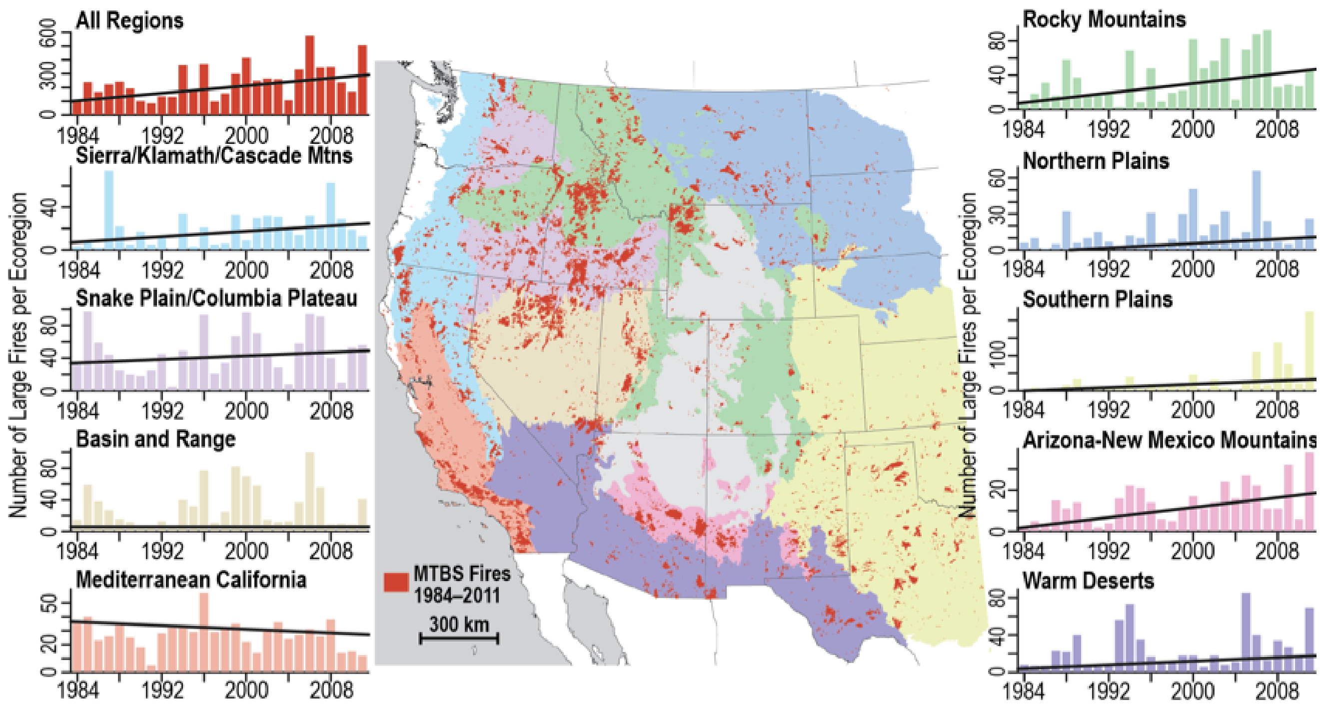
Climate change is expected to cause increased temperatures, drier conditions, and insect outbreaks in the decades to come, all of which will likely increase the risk of wildfires, especially in the western United States.[1] Human-caused climate change can be blamed for more than half the documented increases in fuel aridity (the extent to which dryness can turn trees and other organic matter into fuel for wildfires) since the 1970s. Wildfires are also affecting larger areas, causing a doubling of the cumulative areas of the United States affected by wildfire since 1984.[2] Indirectly, climate change may also increase wildfire risk through warmer temperatures that could increase bark beetle populations. Bark beetles, such as mountain pine beetle, spruce beetle, and southern pine beetle, infest and reproduce in live trees.[3] Bark beetles can affect wildfire risk by killing trees and creating fuel for wildfires, though the relationship between climate change, bark beetles, and wildfire risk is complex and varies geographically.[4]

The number of large fires per year has increased steadily from 1984 to 2011 in much of the West.[5] The most dramatic increase in wildfires has been observed in Alaska. An attribution study found that anthropogenic climate change makes Alaska's severe fire season 33 to 50 percent more likely.[6]

Wildfires have far-reaching adverse effects, including degraded air quality, erosion, and damaged habitat. Degraded air quality can be a particular public health concern for communities. Wildfires near San Diego in 2007, for example, coincided with excess emergency room visits for asthma, respiratory problems, chest pain, and lung disease. During peak fire particulate matter concentrations, it was 50 percent more likely for a person to seek emergency care than in non-fire conditions.[7] After a wildfire, landscapes are also more prone to flash-flooding and erosion, because of vegetation losses and changes to runoff. For instance, in New Mexico, the greatest threat to lives and property after wildfire is the flash flooding that can come in the summer and early fall.[8] Wildfire and the resulting runoff and ash can affect regional water-supply reservoirs, disrupt downstream drinking water supplies,[9] harm lives, destroy infrastructure, and affect energy distribution, with many communities losing or having to shut off their power in fire conditions.

These impacts and efforts to prevent fires result in significant costs for the United States. In California alone during 2017, more than 7,000 wildfires were recorded with a total cost (including fire suppression, insurance and recovery) close to $180 billion. Nationally, the U.S. Forest Service reports an increase in annual budget

FIGURE 1: Wildfire Trends in the Western United States



Trends in the annual number of large fires in the western United States from 1984 to 2011. The areas are divided into ecoregions, seven of which are experiencing a significant increase in large wildfires (greater than 1000 acres) each year.

Source: Philip Dennison et al., "Large wildfire trends in the western United States 1984-2011," Geophys. Res. Lett., 41, 2928-2933, doi: 10.1002/2014GL05957

allocated to wildfire from 16 percent of the 1995 budget to more than 52 percent of the 2015 budget.[10] These growing suppression costs force the Forest Service to divert funds from fire prevention to suppression efforts, or "fire borrowing." While climate change has increased the risk of wildfires, these risks are compounded by forest management and fire suppression practices that allow the accumulation of easily burned wood (fuel) as well as continued housing development in forested areas.

This paper reviews a number of strategies that can be part of a comprehensive approach to managing climate risks related to wildfire. These community-wide resilience strategies and the associated co-benefits can inform decision makers about how local, county, and state governments and property owners can apply the most effective strategies. The paper also includes estimates of the cost to develop or implement these strategies, though project costs will vary based on the location and project design. Identification of co-benefits creates more opportunities for financing and can inform additional design objectives that can increase the viability of a resilience project. This paper also includes tools that local officials and planners can use in assessing local project co-benefits and a case study of Austin, Texas where a number of these strategies have been implemented.

ZONING, BUILDING CODES, AND LANDSCAPE MANAGEMENT

While wildfire risk is exacerbated by climate change, development patterns have also played a role in increasing risk. The number of houses in the wildland-urban interface (WUI), or areas where structures or human development intermingle with undeveloped wildland, grew dramatically from 31 million housing units in 1990 to 43 million in 2010 in the United States, a more than 30 percent increase in a 20-year span.[11] Due to growing damages from fires and the greater populations living in areas with wildfire risk, there is opportunity to reduce fire risk by managing the number of people living in harm's way, and make individual structures less vulnerable to fire. WUI Code and community wildfire protection plans encourage land conservation in the WUI and dense development in areas with less risk. Zoning and building code policies can also space homes to create barriers to stop wildfire from spreading and encourage use of fire-resistant building materials.

ZONING AND DEVELOPMENT CODES

Communities can limit the development in the WUI using smart growth (a development strategy that includes compact design to create walkable neighborhoods and preserve open space) and land conservation. The strategy can also be used to incentivize dense development in lower wildfire risk areas. Communities should assess wildfire risk to determine where it is elevated and what should be designated as WUI to inform these decisions.[12] Within an area designated as WUI, new development should be minimized as a lower density of structures can prevent rapid movement of wildfire. Communities can incentivize developers within WUI areas to plan open space and recreational trails to create fuel breaks to limit the spread of fires while also offering community benefits.[13]

LANDSCAPING REGULATIONS

Community development standards combined with permit review can ensure building owners or developers are taking steps to reduce fire risk surrounding buildings. Reducing flammable vegetation around a structure and creating a low-fuel buffer creates a "defensible space" around buildings. Individuals and homeowners can create defensible space by removing vegetation within 3-5 feet of their home, removing dead plant materials, thinning trees, pruning lower tree branches, and keeping grass mowed.[14] Fire-resistant plants and landscaping materials can also help protect the home and as an added bonus are often drought tolerant, making them more likely to thrive in dry, fire-prone areas. In addition, high-moisture plants that grow close to the ground or have low sap or resin content are less flammable.[15] Local government officials can review site plans for wildfire mitigation measures like defensible spaces and having access to an adequate water supply before issuing building permits. Communities can require existing homes to maintain defensible space, as in San Diego, where the Fire Rescue Department requires 100 feet of vegetation management from structures and regularly inspects properties for compliance.[16]

If regulations on building design or development are not locally politically feasible, effective community outreach can play an important role in preparing individuals for wildfire. For instance, communities or local non-profits can offer free consultations about fire risk to residents, or services where cleared fuels can be chipped or collected from property.

FIRE-RESISTANT CONSTRUCTION AND RETROFITS

Choosing fire-resistant building materials and design can reduce risk for individual buildings and the community when widely implemented. California's Department of Forestry and Fire Protection (CalFire) offers a number of recommendations to fire-proof a building on its website:

- Use composition, metal, or tile instead of wood or shingle roofs.
- Cover vent and chimney openings with metal mesh.
- Use dual-paned windows with one pane of tempered glass to reduce the chance they will break in a fire. Home design should also limit the number of windows that face vegetation.
- Use ignition resistant building materials such as stucco fiber cement, wall siding, fire retardant and treated wood for walls, decks, patios, and fences.
- Have multiple garden hoses that can reach all areas of property.[17]

These measures can be incentivized by waiving application and processing fees or offering even a modest, 5-10 percent rebates on the cost.[18] Fire-proof building design and materials can also be required by plan review procedures and development regulations. The Tools section of this paper includes a number of other guides to fire-resistant construction. In addition to less flammable buildings, construction of new homes or new neighborhoods should require multiple accesses, a minimum road width that allows fire truck access, adequate water supply, and signage to help fire-rescue workers to aid in fire suppression efforts if wildfires do occur.[19]

COSTS

Zoning, building code, and landscape management to manage fire risk should be elements of WUI code, community ordinances or planning processes, folding the cost into other planning processes. Creating defensible space around buildings is one of the most cost-effective ways to protect a building from wildfire, but estimated costs for treating properties vary based on the terrain and how much vegetation needs to be cleared.[20] Steps to make buildings more fire resistant vary greatly in cost from inexpensive actions such as pruning tree branches near the home to actions that could cost considerably more, like replacing flammable siding with non-flammable materials.[21]

BENEFITS

Savings on Insurance

Fire prevention can reduce community home insurance costs. For example, Angel Fire, New Mexico, formed a community wildfire protection plan in 2009, triggering the thinning of a number of areas recommended for treatment. Thinning has also occurred along highways and evacuation routes, and the addition of a million-gallon water tank, new fire station, and new equipment improved Angel Fire's Insurance Services Office rating. The new rating could save homeowners 10 to 15 percent in insurance premiums.[22] State Farm is developing a market incentive for fire risk mitigation by initiating a pilot program for assessing properties for wildfire risk and rewarding properties participating in Firewise, a federal program that teaches how to adapt to wildfire risk.[23]

Public Health

Health benefits from wildfire risk mitigation are challenging to quantify, but there are potentially significant costs avoided in reducing wildfire-related health impacts including respiratory and heart distress. A California study found a 42 percent increase in emergency department visits for heart attacks and a 22 percent increase in visits for heart disease among individuals 65 and older during wildfires.[24]

Property Values

A study of housing prices in Southern California estimates that house prices drop about 10 percent after a wildfire. In areas that experienced a second wildfire, housing prices dropped by an additional 22 percent. The study also finds that homebuyers underestimate the risk posed to different properties.[25] The lowered property values of buildings left standing highlights the importance of community-scale fire risk mitigation.

The Flagstaff, Arizona, Fire Department found that thinning stands of trees around a home can improve property values because homebuyers prefer a forest with medium canopy closure and moderate tree density. Market value increases an average of $200 or more for each quarter-acre of land that is thinned around a home or property, and a buffer of thinned vegetation around a home can increase the overall market value by $40,000.[26]

IMPLEMENTATION EXAMPLES

- **Flagstaff, Arizona**, adopted a modification of the International Wildland-Urban Interface Code in 2008. The fire department began working with community development staff to require hazard mitigation for wildfires on all properties prior to development. The city's Regional Plan 2030 includes guidance on investments on forest health and watershed protection measures, public awareness of the region's forests, and protection of diverse ecosystems.[27]
- A **Caughlin Ranch, Nevada**, homeowners' association (HOA) enacted a number of changes including: banning bark mulch, increasing the grounds crews' activities to reduce hazardous fuel between parcels, and hosting community fire safety meetings in partnership with an agricultural extension. They also changed the HOA's rules to make it easier to replace flammable vegetation with fire-resistant plants.[28]
- **Colorado Springs, Colorado**, passed a roof ordinance that banned wood shake roofs and required roofing materials and assembly to keep fire from penetrating the roof and igniting the structure below. From 2002 to 2016, more than 69,000 roofs were replaced or upgraded to fire-resistant roofing.[29] The city also has a map of wildfire risk ratings, offers property owners free on-site consultations with the

Wildfire Mitigation office to learn about wildfire risk on a specific property, and runs a neighborhood chipping program to dispose of tree branches and hazardous vegetation. Residents also can receive a tax credit for the costs incurred from wildfire mitigation measures.[30]

VEGETATION MANAGEMENT AND FOREST RESTORATION

Wildfire risk is worsened by climate change but is also a function of the accumulated fuel in an area. Fuel refers to live and dead plant biomass that can be ignited by fire. Fuels can be managed to reduce the risk of severe wildfires by allowing some natural fires to burn, using prescribed fires, thinning forests, removing excessive dead vegetation, and using grazing to limit vegetation.[31] All of these strategies, if used correctly, can help reduce fuel and in many cases restore ecosystem health.[32]

A study in Washington state found that in areas treated with both thinning and prescribed burns, more than 57 percent of trees survived wildfires while only 19 percent of trees survived in areas treated with thinning alone. In the untreated areas, only 14 percent of trees survived wildfire.[33]

COSTS AND BENEFITS

Managing forests and reducing fuels can be expensive, but the benefits can far exceed the costs. A California study modeling fire impacts found a return of $1.90 to $3.30 for every dollar spent. The study considered a number of benefits of fuel-treatment including structures saved and avoided damages, avoided fire clean up, carbon sequestration, timber from treatment, biomass, transmission lines saved, and avoided water quality degradation.[34]

Forest products

In some cases, fuel treatment could result in biomass collected from mechanical treatments that could provide wood products. The cleared biomass could be used for energy production or small diameter forest products. Distance from wood processing facilities and access to a biomass market can limit these benefits. There is potential for a market to develop around increased biomass production, and this is a future benefit to consider.[35]

Ecological Benefits

Reducing fuel for wildfire can have the dual objective of forest restoration. In California, disrupted fire cycles have caused a greater number and density of trees. Removing smaller diameter trees helps old growth forests return to a more natural state while reducing fuel for fires.[36] The ecological benefits of thinning vary based on methods used and the local environment and some studies have found that forest treatments can harm some species.[37]

IMPLEMENTATION EXAMPLES

- **Denver Water** spent more than $27 million in water quality treatments, sediment and debris removal, reclamation, and infrastructure projects after two large fires in 1996 and 2002. Since 2010, Denver Water has helped pay for forest thinning and wildfire fuels reduction projects upstream of the city to reduce potential future wildfire damages.[38]
- **Los Alamos, New Mexico**, worked with Los Alamos County and the U.S. Forest Service to thin forestland around the city and a nuclear weapons lab following the Cerro Grande fire in 2000.[39] A 2011 fire was the largest in state history, but partially due to fuel reduction efforts, no homes in Los Alamos were lost while 63 homes in other communities were destroyed.[40]
- **Flagstaff, Arizona**, issued $10 million in bonds in 2013 to support the U.S. Forest Service's forest thinning beyond the city's limits and counteract funding deficiency. The city's Wildland Fire Management division also did some treatment work in the forests surrounding Flagstaff. In response to public resistance, the department partnered with Northern Arizona University's Ecological Restoration Institute to do public outreach, providing literature and explanations based on scientific studies about why forestry thinning is important.[41]

PUBLIC EDUCATION AND PREPAREDNESS

Greater frequency of wildfire and longer wildfire seasons add to the importance of public safety officials regularly communicating with residents to encourage household- or business-level risk mitigation, build public support for public wildfire risk management, and to inform residents about being prepared for wildfires.

Public Education

Residents should understand wildfire risk as it affects their neighborhood or property specifically, and the value of implementing risk reduction activities on individual property, like creating defensible space. Preparedness messaging about wildfire risk mitigation is most effective when it's carried out by a number of partners including public policymakers, officials, local community and business leaders.[42] Raising public awareness also can build public support for wildfire management projects in the broader community, like prescribed fire. Increased interactions between wildfire agencies and the community build trust and contribute to support for public wildfire mitigation actions.[43]

Emergency Preparedness

Wildfire emergency preparedness should be part of the hazard mitigation, emergency response, and climate resilience planning processes (if applicable) in areas with wildfire risk. To prepare for wildfire emergencies, communities can develop wildfire education, warning systems, evacuation procedures and routes, and training for homeowners who may choose to remain on well-prepared properties to extinguish embers and spot fires.[44] Residents should also be taught how to create personal wildfire preparedness plans.

Communication continues after wildfires to warn about post-fire hazards like flooding and drinking water contamination and explain relief and recovery actions. Some fire-prone communities include wildfire response and recovery in their hazard mitigation planning or determining the funding available for grant funding and preparedness for post-wildfire floods.[45]

COSTS

Integrating wildfire management and risk reduction in a hazard mitigation plan, comprehensive plan, or other planning activities carries a small additional cost. A community wildfire preparedness plan could have greater costs associated with it depending on the community size, fire risk data available, and resources at hand. Public education campaigns on wildfire can be cost effective. A 2009 study on wildfire prevention education programs in Florida found $35 of benefits for every dollar spent.[46]

BENEFITS

Increased Awareness and Public Trust

While educating residents about fire risk, agencies can build trust with the community through outreach programs. Trust is built by both individual practitioners and agencies as a whole, through effective outreach, sincere engagement with stakeholders, transparent decision making, and cooperation with other agencies.[47]

Public Health and Safety

Clear communication about wildfire risk and how residents should act in emergencies can reduce life loss and health impacts from wildfire. There are not studies quantifying this benefit, but news reports following California's 2017 and 2018 fires blamed local and state governments for not using available alert systems to communicate with residents and called for improved warning systems.[48]

IMPLEMENTATION EXAMPLES

- **Colorado Springs** developed a local Firewise program and a strong community education effort in the Colorado Springs Fire Department Mitigation Section. The city's outreach included a "Sharing the Responsibility" campaign to involve residents in mitigation activities. Fire Adapted Communities estimates that the mitigation efforts resulted in $517 in benefits for every $1 spent in the three neighborhoods with the greatest impacts.[49]
- A 2006 wildfire in Oregon forced a neighborhood near Deschutes National Forest to evacuate. The community had developed an evacuation plan and had built a strong relationship with Forest Service personnel through its preparedness activities. This set the stage for strong communication between the community and Forest Service during the fire, and residents received updated, thorough information about the firefight at twice-daily meetings.[50]

TABLE 1: Costs and Benefits of Wildfire Resilience Strategies

		BENEFITS					
		Insurance Savings	Public Health	Property Values	Relationship Building	Public Safety	Ecological
STRATEGIES	*Zoning and Building Code*	▲	▲	▲		▲	●
	Wildfire-Resilient Landscapes	▲	●	▲		▲	▲
	Fire-Resistant Construction	▲	●	●		▲	
	Vegetation Management	▲	▲	▲		▲	▲
	Public Education	▲	▲	▲	●	●	
	Emergency Preparedness	▲	▲		●	●	

Table 1. The table above demonstrates the benefits (in columns) of the strategies overviewed in the factsheet (in rows). Green circles indicate a benefit that could be expected from each of the strategies. Yellow triangles indicate benefits that could apply in certain areas or circumstances, especially if the strategy was designed or implemented to that purpose. 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.

CASE STUDY: AUSTIN AND TRAVIS COUNTY, TEXAS

An estimated 45 percent of Austin's residents live in the WUI. Following especially devastating fires in 2011, Austin and Travis County formed a Joint Wildfire Task Force.[51] The task force's goal was to make sure communities in the region were more fire adapted. The city developed a comprehensive joint city-county Community Wildfire Protection Plan (CWPP),[52] a non-regulatory document that aims to restore and maintain landscapes, create and support fire-adapted communities, and implement a risk-based management response to wildfires across municipality lines. To ensure implementation and administrative support, the CWPP was added as an appendix to the Hazard Mitigation Plan.[53]

A Wildland Fire Division formed within the Austin Fire Department to collaborate with other departments and manage wildfire risk, mainly by constructing fire buffers by clearing or thinning vegetation[54] and prescribed fires in wildlands.[55] The Wildland Fire Division also partnered with the Austin Energy Green Building Program to incorporate best practices for wildfire safety into the green building rating system with the goal of future affordable housing construction complying with best practices for wildfire and to also demonstrate that wildfire safety can be a marketing strategy for developers.[56]

Austin has designated nearly 30 percent of city land as conservation lands which limits the number of future structures at risk within high hazard areas. Integrating international WUI code is a priority of revising the city's land development code, thought that process was stalled in 2018.[57] The Austin Community Climate Plan, approved in 2015, contains wildfire resilience strategies including establishing and updating emergency evacuation routes for flooding and wildfire.[58]

The City of Austin distributed wildfire risk information to its residents through the "Ready, Set, Go!" guide and the city government's website. Residents can request a fire assessment of their property, view maps of wildfire risk in Austin and surrounding Travis County. They can also learn about how to limit wildfire risk on their property and prepare for wildfire.[59]

KEY INSIGHTS

Wildfires are becoming more severe, common and expensive due to increased temperatures, decreased soil moisture, and insect outbreaks related to climate change. Additionally, increased development in the WUI has put more structures at risk. Wildfire impacts public health, public safety, the environment, and drinking water access during and after the fire.

Wildfire resilience is more than a matter of adapting to changing conditions: It also requires reducing exposure to the risk, or limiting development in the

WUI. Wildfire resilience strategies can be costly up front, although many have a high benefit-cost ratio over their lifetimes. Communities are seeing returns on their investments with lower wildfire insurance rates, lesser impacts on public health during fires and improved property values. Table 1 shows the benefits offered by each strategy. When choosing which strategies to prioritize, consider which benefits are most aligned with other community priorities, and which combination of strategies may yield them. Because wildfire risk is tied to higher temperatures, drought, and flooding, comprehensive resilience planning for multiple impacts is critical for communities.

TOOLS

FIRE ADAPTED COMMUNITIES

The Fire Adapted Communities Learning Network, an effort supported by U.S. Department of Agriculture, Department of the Interior and The Nature Conservancy, engages residents and other actors including fire departments, business owners, and land managers. The network shares best practices and exchanges information about strategies like evacuation planning, wildfire protection plans and WUI codes. A Fire Adapted Communities Self-Assessment tool is also available on the website which helps communities evaluate their progress in wildfire adaptation and identify priorities and potential actions. The tool is for non-profits, fire departments, state governments, and emergency management offices.

www.fireadaptednetwork.org

FIREWISE

Firewise is a program of the National Fire Protection Agency that encourages local solutions for wildfire safety by involving homeowners, community leaders, planners, developers, firefighters, and others in creating fire-adapted communities. The recognition program provides instructional resources to guide how individuals can work together to reduce wildfire risk. To participate, communities must form a Firewise board, complete a wildfire risk assessment, create an action plan, and meet a required minimum for hosting events and investing in Firewise actions for a year.

https://www.nfpa.org/Public-Education/By-topic/Wildfire/Firewise-USA

HOME BUILDER'S GUIDE TO CONSTRUCTION IN WILDFIRE ZONES

This series of technical factsheets published by the Federal Emergency Management Agency (FEMA) provides recommendations for building design and construction methods in wildland-urban interface.

https://www.fema.gov/media-library-data/20130726-1652-20490-4085/fema_p_737.pdf

INSURANCE INSTITUTE FOR BUSINESS & HOME SAFETY

IBHS provides a series of regional wildfire retrofit guides which include a risk assessment checklist and cost estimator to help home and business owners choose retrofit projects. There is a separate guide available for each region with fire risk.

https://disastersafety.org/ibhs/ibhs-regional-wildfire-guides/

WILDLAND URBAN INTERFACE TOOLKIT

This U.S. Fire Administration website is a compendium of tools and other information that can be used to assess wildfire risk, develop codes and standards, develop outreach, create wildfire protection plans and training materials.

https://www.usfa.fema.gov/wui_toolkit/

WILDFIRE SAFETY SOCIAL MEDIA TOOLKIT

The Wildfire Safety Social Media Toolkit has safety and preparedness messages that local governments and others can use to promote wildfire resilience. These messages are provided for public use by the Department of Homeland Security and can be used directly or customized.

https://www.ready.gov/wildfire-toolkit

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