# Helping Communities Build Climate Resilience with a Toolkit of Scientific and Local Knowledge

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The last 4 years have been the warmest years on Earth, since reliable record-keeping began in 1880 (NASA 2018, NOAA 2018). Climate scientists project Earth will continue warming at an increasing rate through the 21st century due to the increasing abundance of human-produced heat-trapping gases, such as carbon dioxide and methane. Both long-term global climate change and short-term natural variability patterns (e.g., El Niño-Southern Oscillation) are causing extreme regional weather and climate events with increasing frequency and severity. An extreme event can be any phenomenon that falls within the highest or lowest 10 percent of a probability distribution of observed or anticipated events, such as high or low temperatures, rainfall amounts, water levels, and even socioeconomic phenomenon.

People and the natural and built environments are vulnerable to many types of extreme events. As built environments encroach on sensitive geographies and ecosystems, resilience becomes increasingly relevant for reducing vulnerability. In 2017, the United States experienced 16 extreme weather and climate events, each exceeding $1 billion in damages, for a record-setting combined total of more than $300 billion (NOAA 2018). These losses stemmed from damages caused by severe storms that caused wind damage and produced historical floods (Figure 1), as well as exceptional drought conditions that challenged farmers and water resource managers and exacerbated conditions for damaging wildfires. Since 1980, the United States has sustained 219 weather and climate disasters that cost $1 billion or more, with a cumulative inflation adjusted cost totaling $1.5 trillion.

Every day, communities and businesses across the United States and around the world face challenges stemming from extreme events and changing climate conditions. The impacts of extreme events are felt particularly acutely in cities and towns (Figure 2). In an effort to reduce uncertainty, decisionmakers are increasingly seeking science-based information and tools to help them understand where, how, and why these changes have occurred, and are likely to occur in the future. While climate science has historically been limited in its ability to downscale climate model projections to the operations of a city, the advancement of various science-based software and web applications represent tremendous opportunities for data-informed decisionmaking.

To help meet the public's growing demand for authoritative science information and to help promote resilience of communities and businesses, an interagency partnership of scientists and subject matter experts developed the U.S. Climate Resilience Toolkit (hereafter referred to as the "Toolkit") (U.S. Govt. 2014) managed by NOAA under the auspices of the U.S. Global Change Research Program. The Toolkit is a free and open-source resource that makes it easy for the public to access and understand a broad range


**Figure 1: The Toolkit provides narratives authored by subject matter experts on ten different topics, including one titled "Build Environment," that explain and illustrate how climate change impacts different U.S. sectors.**

Image from NOAA.


**Figure 2: Local first responders use an airboat to transport people to safety during flooding in August 2007 in Oklahoma.**

Photo by Patricia Brach, FEMA, via Wikimedia Commons.

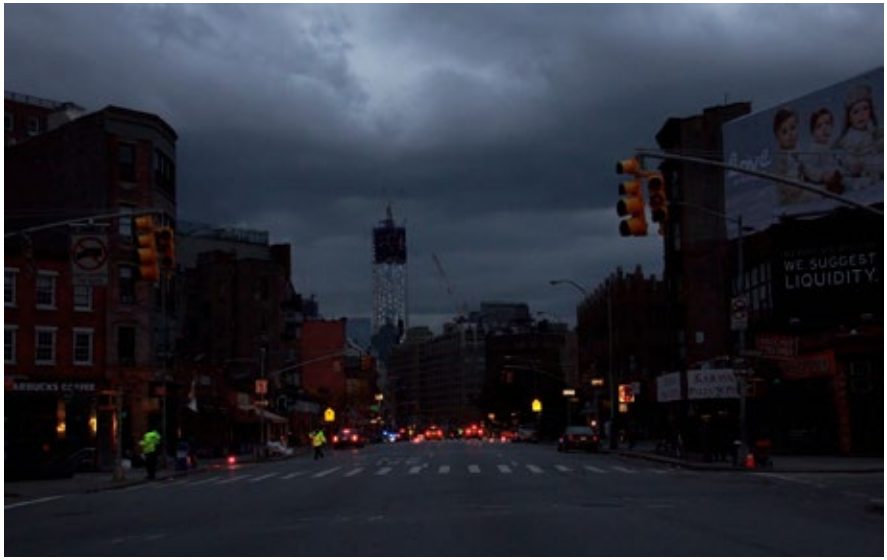


**Figure 3: Hurricane Sandy knocked out power to New York City, causing a blackout below 34th Street. Some areas lost power for more than 3 days.**
Photo by Michael Tapp, via Flickr.

of science-based tools, data products, and information services offered by the federal government that are relevant to resilience planning and capacity building. Its primary target audience is applied professionals—such as city planners, resource managers, policy leaders, etc.—who oversee development of climate adaptation plans. The Toolkit is a Web-based framework that aggregates and contextualizes information and tools for three main purposes: to help people 1) make and implement resilience plans; 2) explore how climate conditions are changing in their location and how sectors are being impacted; and, 3) learn what others are doing to address climate-related challenges similar to the ones they face. There is also a curated "Funding Opportunities" page, kept up to date by the Toolkit's core editorial team, on the Website listing federal and nonfederal funding sources to help communities and businesses obtain funds to recover from a disaster and/or mitigate future risks.

Recognizing that 80 percent of Americans live in urban and peri-urban settings (U.S. Census Bureau 2012), we led an interdisciplinary team of subject matter experts in developing the Toolkit's "Built Environment" section. This section of the Toolkit supports the development of resilience at the intersection of the built and natural environments, which requires collaboration among all interested stakeholders before, during, and after extreme events and disasters (Figure 3). Additionally, economic inequality and environmental degradation coupled with deteriorating public infrastructure can further stress our built environments, making some communities more vulnerable to extreme events than others. Building resilience by investing in physical

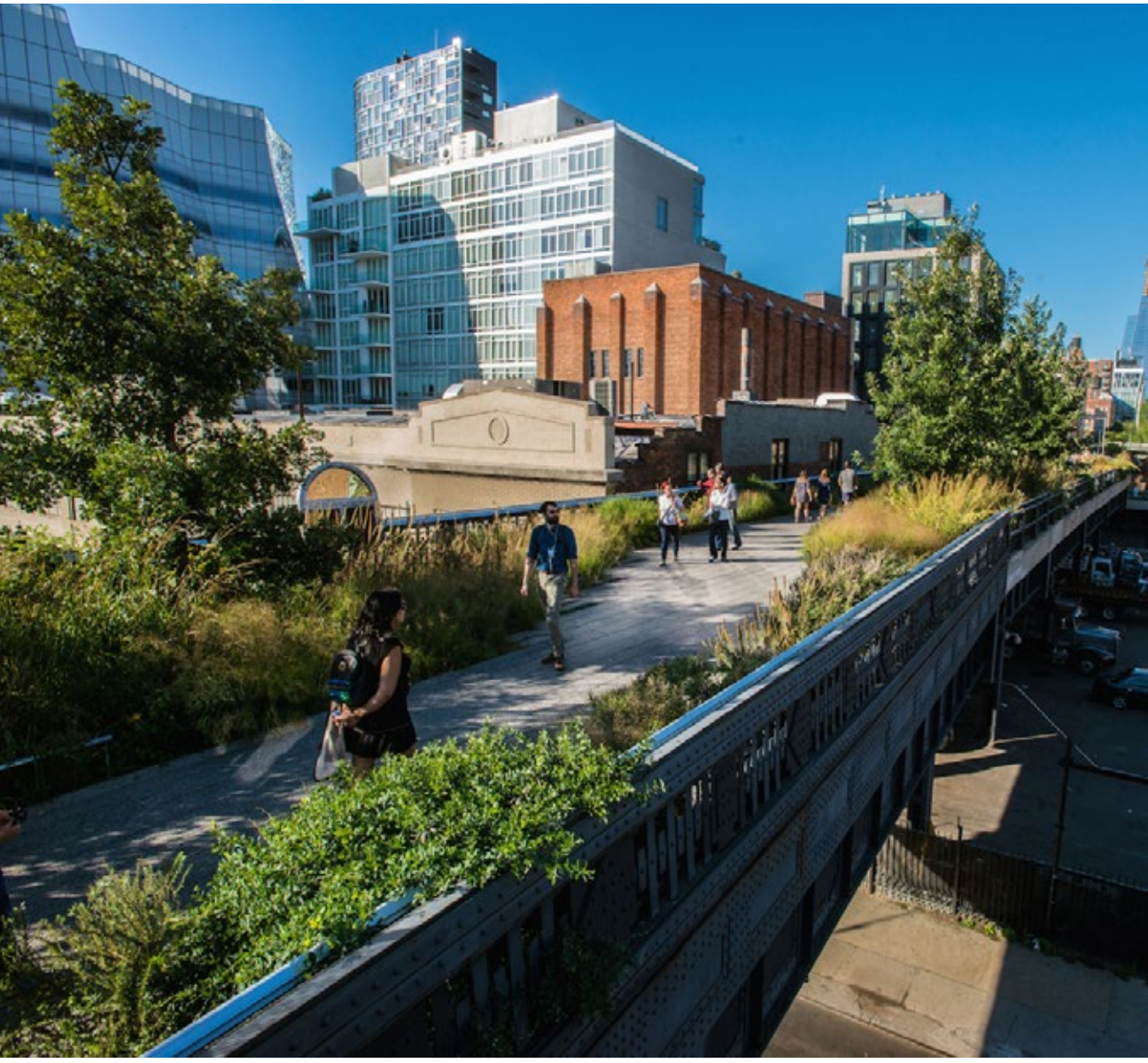

**Figure 4: Green infrastructure in built environments can provide win-win climate adaptation strategies for local residents. New York City's "High Line" is an elevated railway line that was converted into a 1.45-mile-long public park, featuring a wide public walkway and attractive use of vegetation to help mitigate the local urban heat island effect.**

Photo by Lance Chueng, used with permission.

adaptation efforts and/or using nature-based solutions can provide co-benefits for a range of challenges, including mitigation of climate-related impacts.

The Built Environment section contains narratives—often excerpted from authoritative peer-reviewed literature—summarizing ways in which U.S. cities and towns are vulnerable to, and have been impacted by, climate and nonclimate stressors. These narratives are cross-linked with real-world case studies from across the United States, highlighting people in communities and businesses who have successfully taken action to manage their climate risks (Figure 4). Additionally, the topical narratives and case studies are cross-linked with science-based decision-support tools, in order to illustrate how people have used those tools to plan and build resilience.

Helping people build resilience is the Website's main purpose. Toward this end, the Toolkit offers a five-step planning framework, called "Steps to Resilience," that integrates a range of different content types into topical, geographical, and purposeful frames of reference. This framework guides users through a deliberative process whereby they can access, explore, discuss, coproduce, and integrate information together for the purpose of building shared mental models as they address these fundamental questions:

- Do climate-related hazards threaten assets we value?
- If so, what is the risk, and are we willing to tolerate that level of risk?
- If the risk is intolerable, what options exist to reduce or eliminate the risk?
- Which options are viable and affordable, and in what priority order might we pursue them?
- How will we plan and implement particular actions?
- How will we define and measure success, and how will we monitor progress and take corrective actions where needed?

## Defining and Measuring Success

The team that built the Toolkit (managed by the second author of this article) thought that, to be successful, it must be useful, user-friendly, and actually used (Mitchell et al. 2016). The team's first task was to aggregate scientific information that the audiences would find relevant and potentially useful for decisionmaking. The second task was to integrate, contextualize, and design

the information in ways that would make it easy for the audience to find and use. The third task—by far the most ambitious of the three—was to engage directly with people in communities and businesses around the country to help them use the Website in their resilience planning and capacity building efforts.

There are many ways to measure success, and no single measure is entirely instructive of how well the Toolkit is performing in these three areas. As such, a multi-pronged approach is used to evaluate the Toolkit Website (Mergel 2013). The first monitors visitor statistics, including number of return visitors, as one indicator of the reach of the site and whether people consider the Toolkit to be useful. If people find the Website to be useful, the Toolkit's program manager hypothesized that they will visit the Website on more than one occasion and they will encourage friends and colleagues to visit it. The observed total number of Website visits has been increasing at an accelerating rate (Janssen et al. 2016). The Toolkit received 889,961 visits through the first three-quarters of the federal government 2017 fiscal year, which is a 76 percent increase over the previous year's visit rate. The annual target growth rate for the Website is 10 percent. Moreover, approximately 34 percent of those visits were by return visitors, a 1 percent increase over the previous year.

Surveys and listening sessions are utilized to assess whether, and to what extent, audiences perceive the Toolkit to be user-friendly and whether and how they use it. Surveys and listening sessions have been conducted both by external evaluation teams and the Toolkit's core editorial team to maintain a steady flow of user feedback throughout the Website's development. More recently, the core team deployed a new Website survey, created to help measure the audience's perceptions in five key dimensions: 1) awareness of the site's existence and purpose; 2) trust of the Website's contents; 3) satisfaction with the site's scope; 4) usability of the site's information and functions; and, 5) control mutuality, or the degree of symmetry of communications between the Website's users and editors. As two-way communication is essential for building relationships, the Website's editors respond to all incoming emails in a timely manner—most within 24 hours, all within 1 week.

Through user feedback and engagements with user communities, we have heard and observed members of our target audience expressing value for the site's usefulness and user-friendliness, and that they *use* the site to help them in their work. For example, after the newly-elected Trump administration began removing references to climate change from government Websites in early 2017 (Davenport 2018), we received a flurry of emails from stakeholders (including architectural designers and city planners) urging us not to take the Toolkit offline because they said they use the site in their work. And, 3 months into our online user survey, the results (based on 142 respondents) showed high user ratings—significantly higher than government-wide

averages of user ratings (on a scale of 10-100). Specifically, in the category of user satisfaction, users rated the Toolkit a 79 (government average = 73); users rated the relevance and usefulness of the Toolkit's content an 85 (government average = 78); users rated the Toolkit's design an 84 (government average = 74); users' likelihood of recommending the Toolkit to a friend or colleague rated an 89 (government average = 76); and users' likelihood of returning to the Toolkit rated an 89 (government average = 82) (Petras et al. 2017). While it's still too early to declare the Toolkit a success, and there are opportunities for improvements based on user feedback, there is good evidence to date that suggests it is being well-received and used by our target audience.

## Case Studies

To successfully help people and communities build resilience, the Toolkit's core editorial team believes that it is critical to facilitate engagement with subject matter experts, and it is also important to help people learn from others like them. Case studies can serve as inspirational templates that others can learn from and emulate. To promote this peer-to-peer learning, the Toolkit includes case studies, which predated the Toolkit, to highlight how communities are already incorporating resilience into their planning and stewardship activities. The tools, processes, and resources showcased in these case studies guide communities in identifying valued assets and threats, as well as in assessing their exposure to vulnerability and risk as a means to focus and prioritize their work. Each case study includes direct links to relevant tools in the Toolkit's compendium of more than 350 decision-support tools and other resources designed to aid communities, businesses, and resource managers in adapting and replicating the highlighted work. The following case studies in urban forestry, stormwater management, and coastal dune restoration represent exemplar cases for highlighting the value of the Toolkit and the myriad tools that are accessible through it. For each of the following cases, the associated tools and resources referenced in the narrative may be directly accessed on each case's landing page on the Website.

Case Study

# Fortifying Chicago's Urban Forests[4]

Chicago is at the center of one of the most populous metropolitan areas in the United States. Approximately 10 million people live in the region, in neighborhoods that range from high-density urban settings to suburbs with yards and open space between single-family homes. Trees in yards and parks across the region provide some shade when temperatures rise, but the region's tree canopy—the percentage of the ground covered by tree branches and leaves—is lower than in many other cities in the Midwest. The loss of 13 million ash trees to an invasive insect, the emerald ash borer, has further reduced the canopy in many areas. The cost of removing and replacing ash trees has exhausted many municipal budgets in the region, leaving little money to care for the remaining trees or time to plan ahead.

Faced with the decline of urban trees, concerned stakeholders joined together in partnership with Leslie Brandt, a climate change specialist with the USDA Forest Service's Northern Institute of Applied Climate Science, to form the Chicago Region Trees Initiative. The goals were to improve management skills and knowledge; to increase the region's tree canopy; and, to incorporate species that are resistant to pests and climate-related impacts. The partners used habitat suitability modeling, projected changes in heat and hardiness zones, and an assessment of tree species' adaptive capacity to assess the vulnerability of more than 150 tree species that are currently growing or recommended for planting in the region. The assessment showed that some of the least vulnerable trees in the region are nonnative invasive species. Conversely, results indicated that many of the species native to the area are vulnerable to changing conditions.

Representatives from counties, municipalities, and park districts worked with experts in a series of workshops on urban forest vulnerability and adaptation. Using a structured process, they evaluated which impacts and adaptive capacity factors had the largest effects on vulnerability. Finally, they implemented a five-step adaptation project to incorporate climate change considerations into real-world projects and planning efforts, which included planting resilient trees. The Chicago Region Trees Initiative is integrating climate-change-related goals into a regional tree master plan and updating its recommended planting list to encourage climate-adapted species. Communities across the Chicago region are working to incorporate vulnerability information and adaptation strategies in their work. Looking to the future, the initiative is seeking grant funding they will use to create real-world demonstrations of adaptation that resulted from the workshops.

4. Adapted and excerpted from https://toolkit.climate.gov/case-studies/fortifying-chicagos-urban-forest

Case Study

# Improving Water Quality by Dealing with the First Inch of Rain[5]

Just outside the northeastern boundary of Washington, D.C., the suburban city of Mount Rainier, MD, features affordably priced homes, pedestrian-friendly streets with sidewalks, and a handful of historic buildings. Mount Rainier lies within the watershed of the Anacostia River, which flows into the Potomac River. In turn, the Potomac flows into the ecologically productive Chesapeake Bay. Unfortunately, the Anacostia—sometimes referred to as Washington's "forgotten river"—is severely polluted with toxic sediments, agricultural nutrients, and trash. In keeping with its "green" values, Mount Rainier city staff recognized that controlling urban runoff could reduce the influx of pollutants into the river.

Acknowledging the potential to improve water quality in the region, the city established an Urban Green Infrastructure Plan to develop guidelines to improve the city's stormwater management. Mount Rainier's Green Team Committee—a group dedicated to increasing sustainable practices in the community—worked with the City Council, city staff, and the nonprofit Low Impact Development Center to ensure the plan would meet Mount Rainier's goals. The Plan set a goal for the city to limit polluted runoff into streams by becoming stormwater neutral—state defined as the ability of an area to capture, infiltrate, retain, or evapotranspire the first inch of rainwater that falls in any storm event. Capturing and slowing just 1 inch of rain can deliver larger-than-expected benefits for water quality because the first inch of stormwater runoff—sometimes called the "first flush"—contains the highest abundance of pollutants from the land. Additionally, capturing the first inch of rainfall reduces the speed at which runoff reaches nearby streams, reducing the likelihood of problematic flooding and erosion farther downstream.

The Plan includes recommendations to reduce stormwater runoff in a variety of situations. Examples include installing adequately sized gutter downspouts and draining rain barrel overflows to landscape areas or rain gardens; capturing stormwater from driveways and patios using slot drains along the downslope edge of the paved area; and planting trees to increase evapotranspiration, reduce erosion, and provide shade for urban areas. In order to document any reduction in stormwater runoff, the plan needed a reliable method to calculate before-and-after runoff rates and to evaluate the effectiveness of various strategies. The city chose to use the U.S. Environmental Protection Agency's "Stormwater Calculator", featured in the Toolkit's "Tools"

5. Adapted and excerpted from https://toolkit.climate.gov/case-studies/improving-water-quality-dealing-first-inch-rain

compendium, which utilizes data on local soil conditions, topography, and rainfall records to estimate annual rainfall and runoff from sites. Once these calculations are complete, the tool estimates the effectiveness of various practices and combinations of practices to help users select appropriate strategies for their stormwater-reduction design. The process of using the Stormwater Calculator helps users analyze a real-world problem to find solutions that work.

Since the plan was established in 2013, Mount Rainier has been implementing a vigorous tree-planting effort; began using pavers to create permeable parking lots and alleys; and, has converted one of the city's main roads, Buchanan Street, into a "green street." Additionally, many residents have planted rain gardens in their yards. Mount Rainier's Thomas Stone Elementary School and the Mount Rainier Nature Center have also planted rain gardens. In 2015, Mount Rainier was certified by Sustainable Maryland as a "Sustainability Champion." As a participating community in Sustainable Maryland, the town has access to grants, incentives, and technical support to further promote sustainable and resilient practices. This case highlights a valuable example of co-benefits that serve the advancement of environmental quality at the intersection of sustainability and flood resilience.

Case Study

# Restoring Natural Dunes to Enhance Coastal Protection[6]

Barrier islands in New Jersey are like a ribbon of sand along the coast. The linear islands originally formed as ocean waves and currents pushed sediments from the ocean floor into beaches and dunes after the last ice age. Over the centuries, undisturbed dunes migrated back and forth across their beaches, moving inland as prevailing winds removed sand from one side of the dune and deposited it on the other. As homes and businesses crowded New Jersey's shore in the early- to mid-20th century, development encroached on the inland side of natural dune systems, narrowing the width of beaches and reducing the area that could supply sand to either side of the dunes. Roads and other structures effectively pinned down the formerly dynamic system. Over the years, the height and protective abilities of the dunes diminished. As glaciers melt and warming seawater expands, rising sea levels increase the risk of flooding along all coasts, especially during storms.

When Hurricane Sandy hit New Jersey's beaches in October 2012, neighborhoods that sit inland of developed beaches received the full brunt of the storm's waves and storm surge. In other areas, where natural beach dunes were still in place, damage was less pervasive. Increasingly, shore communities like Seaside Heights, NJ, are recognizing the benefits of preserving or enhancing the natural infrastructure that dune systems offer.

Instead of pursuing costly engineering solutions or beach replenishment programs to address their vulnerability, some towns "work with nature" to rebuild dunes. For instance, planting beach grasses and installing and maintaining sand fences can help hold sand in place. Sand fencing helps capture wind-blown sand and also controls pedestrian traffic to protect fragile dune vegetation. Modifying paths to the beach so they are angled rather than perpendicular to the beach is another dune-enhancing strategy; this change reduces the opportunity for either wind or waves to move sand from the dune directly inland. These projects offer multiple advantages including cost-effectiveness; a capacity to continue adapting to changing conditions; and, improving habitat for fish and wildlife. An example of this type of project can be seen in Seaside Heights, which is famous for its oceanfront boardwalk, amusement rides, and arcades. Here, the city chose to rebuild after Hurricane Sandy in part by recreating sand dunes at the end of the boardwalk in order to serve as protection from future storms.

As coastal communities begin to explore their vulnerability, the "Climate

6. Adapted and excerpted from https://toolkit.climate.gov/case-studies/restoring-natural-dunes-enhance-coastal-protection

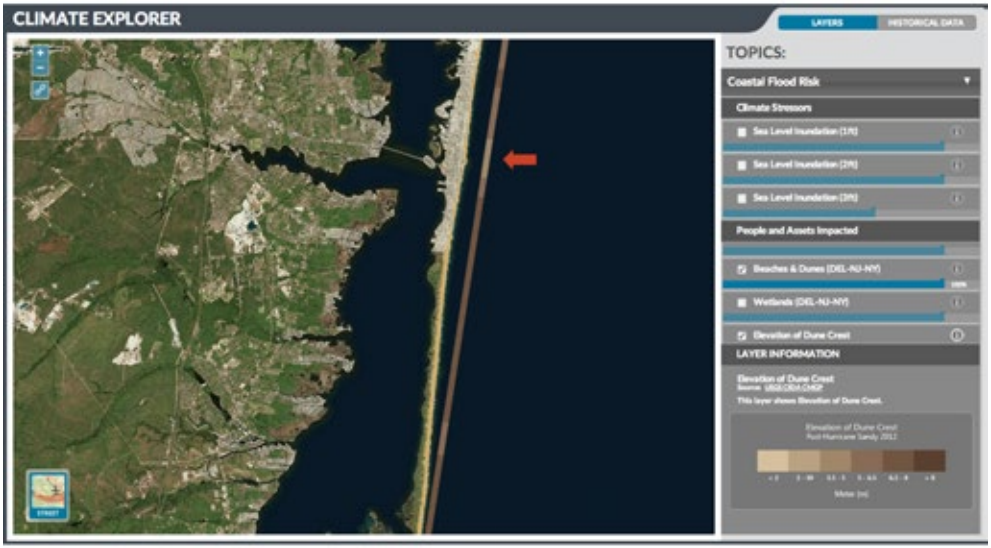


Figure 5: The Toolkit's "Climate Explorer" is a Web-based mapping and graphing tool that enables users to explore decision-relevant climate variables from observed history and model projections out to 2100. This screenshot shows a U.S. map of the projected number of days in 2090 in which temperature will exceed 95 °F in two possible future scenarios. The "lower emissions" side of the map (left) shows a future in which humans emit enough heat-trapping gas to drive up radiative forcing at Earth's surface to 4.5 watts per square meter. The "higher emissions" side (right) shows a radiative forcing of 8.5 watts per square meter, which is the course humans are currently on. Dark red shows areas where as many as 225 days per year are projected to exceed 95°F, pale yellow represents 25 days per year, and white represents 0 days. Source: https://toolkit.climate.gov/climate-explorer2/ (2017)

Image from NOAA.

Explorer" feature of the Toolkit can help users assess whether and where their valued assets are exposed to environmental hazards. The Climate Explorer provides interactive graphs and maps of climate projections and observations (Figure 5). For instance, it can display historical temperature and precipitation observations for hundreds of climate stations and offer map layers of valued assets and climate threats. In the case of coastal dunes, the Climate Explorer allows communities to visually compare beach width and dune height. Users are able to visualize a variety of different geographic scales, as demonstrated in Figure 1, which shows the narrow barrier islands and beaches along New Jersey's shore. The strip of tan and brown colors along the shoreline indicate the elevation of the dunes along the coast (e.g., the darker the color, the higher the dunes). By using the Climate Explorer, community stewards—including scientists, planners, and policymakers—can identify areas where the beach width and dune height have shrunk as a result of development and craft targeted policies and projects to restore dunes and enhance resilience to flooding.

## Conclusions

The manifestations and implications of extreme events and climate change are increasingly well understood in the built environment. While interdisciplinary datasets, analytical models, and tools are informing decisionmaking, the relative immaturity of the field of climate adaptation science dictates that much of the most impactful exchange of knowledge is based on qualitative case studies that identify best practices and trial-and-error experiences. The Toolkit not only collects and curates these case studies, submitted by each section's team of subject matter experts, it also provides corresponding references to relevant datasets and tools. To this end, the Toolkit connects on-the-ground practitioners with a broader community of practice. As such, the Toolkit is more than an aggregation of data and tools. It is an innovative platform that that seeks to connect different actors who may vary in their motivation, expertise, agency, and level of technical facility. In the future, the challenge is to disseminate knowledge across scales, as well as to define, validate, and diffuse best practices that represent aspects of innovation in the name of resilience and adaptation. From a broader perspective, the Toolkit bridges the knowledge gap between scientific data, decision-support tools, and emerging best practices that are central to the adaptive capacity of the public, private, and civic sectors in the United States.

## Literature Cited

Davenport, C. 2018. How much has 'climate change' been scrubbed from federal websites? A lot. The New York Times. January 10. https://www.nytimes.com/2018/01/10/climate/climate-change-trump.html (accessed Aug. 13, 2018)

Janssen, M.; Konopnicki, D.; Snowdon, J.L.; Ojo, A. 2017. Driving public sector innovation using big and open linked data (BOLD). Information Systems Frontiers. 19(2): 189–195. https://doi.org/10.1007/s10796-017-9746-2.

Mergel, I. 2013. A framework for interpreting social media interactions in the public sector. Government Information Quarterly. 30(4): 327–334. https://doi.org/10.1016/j.giq.2013.05.015.

Mitchell, C.L.; Burch, S.L.; Driscoll, P.A. 2016. (Mis) communicating climate change? Why online adaptation databases may fail to catalyze adaptation action. Wiley Interdisciplinary Reviews: Climate Change. 7(4): 600-613. https://doi.org/10.1002/wcc.401.

National Aeronautics and Space Administration [NASA]. 2018. January 18. Long-term warming trend continued in 2017: NASA, NOAA. Press Release. Washington, DC: National Aeronautics and Space Administration, Goddard Center for Space Studies. https://www.nasa.gov/press-release/long-term-warming-trend-continued-in-2017-nasa-noaa (accessed Aug. 13, 2018).

National Oceanic and Atmospheric Administration [NOAA]. 2018. August 1. 2017 State of the climate: Global surface temperature. Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/featured-images/2017-state-climate-global-surface-temperature (accessed Aug. 13, 2018).

Petras, S.; Reed, H.; Stallard, K. 2017. Government websites report 2017. Ann Arbor, MI: CFI Group.

U.S. Census Bureau. 2012. 2010 Census urban area facts. Washington, DC: U.S. Department of Commerce, Census Bureau. https://www.census.gov/geo/reference/ua/uafacts.html.

U.S. Government. 2014. U.S. climate resilience toolkit. http://toolkit.climate.gov. (accessed Feb. 9, 2018).