

Incorporating Nature-based Solutions Into Community Climate Adaptation Planning



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Cover image: Installation of a living shoreline in Mobile Bay, Alabama to reduce shoreline erosion and protect against storm surge. Nature-based solutions (NbS) to address community climate risks can encompass a wide range of options – from protection of intact natural systems and restoration of degraded ecosystems to the use of engineered systems that emulate natural system functions. Photo: Craig Guillot.

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1 INTRODUCTION

As the growing impacts of climate change affect communities across the country, the need for effective approaches to reduce climate-related risks is becoming increasingly evident. Historically, most approaches to addressing risks from natural hazards have emphasized the use of structural or engineered solutions, such as levees, sea walls, and stormwater drainage channels. The limitations of such hard infrastructure approaches in an era of rapid climate change are becoming all too evident. Recent extreme weather events have caused widespread failures among the nation’s already stressed and deteriorating infrastructure. Additionally, there is a rising gap between the past climatic conditions most of these structures were designed to accommodate, and the current and future conditions they are—or will be—confronting. Indeed, the number of billion-dollar climate and weather-related natural disasters has been increasing dramatically, with more than twice the number of such costly disasters occurring in recent years compared with the 40-year average (NOAA 2021).

Given these growing climate risks and the limitations (e.g., cost, failure points, maladaptation) of relying solely on conventional infrastructure options (Table 1), the role of nature in providing protective benefits to communities is receiving heightened attention. “Nature-based Solutions” (NbS)—known by such terms as natural infrastructure, natural defenses, ecosystem-based adaptation, or natural and nature-based features—can play an important role in community adaptation and resilience by not only ameliorating climate-related risks but also through enhancing the quality of life for community residents.

Nature-based solutions can encompass a wide range of options, from reliance on still-intact natural systems and restoration of key ecosystems to the use of engineered systems designed to emulate natural system functions. Nature-based approaches can also be used in concert with structural options to form hybrid or “green-gray” systems for risk reduction. Key considerations for incorporating natural infrastructure into community adaptation and resilience plans includes determining what nature-based approaches may be appropriate for the location, how effective those approaches would be in addressing key risks, and how sustainable those systems will be in the face of ongoing climate change and other stresses.

This guidance delves into the opportunities for integrating NbS into community adaptation planning processes with a special focus on the “Steps to Resilience” framework (Figure 1). Chapter 1 provides brief overview of NbS and more broadly the role of nature in adaptation and resilience planning. Chapters 2 – 6 looks specifically at the Steps to Resilience planning framework and for each step discusses how NbS relate to and can be integrated into that planning step. This includes a discussion of key barriers to the use of NbS and opportunities for overcoming those obstacles (see Chapter 6). Chapter 7 describes a variety of financial mechanisms and government programs available to support the application of NbS in communities. Chapter 8 offers a series of case studies highlighting successful examples of the incorporation of natural and nature-based features into community adaptation plans and their implementation. Finally, an Appendix provides a checklist of considerations for the application of nature-based solutions.

Table 1. Strengths and Limitations of Conventional and Nature-based Approaches
(Adapted from Sutton-Grier et al. 2015)

Adaptation option	Strengths	Limitations
Conventional approaches	<ul style="list-style-type: none"> Existing expertise and knowledge on design and construction Conducive policy environment 	<ul style="list-style-type: none"> Costly approaches with limited lifetime and protection value Does not adapt with changing climatic conditions Can lead communities into “false sense of security” No ecological co-benefits and can result in habitat loss in degradation of key ecosystem services Can result in mal-adaptation, including increase or transfer of climate risks to other social sectors or adjacent communities
Natural or nature-based approaches	<ul style="list-style-type: none"> Provides wide-ranging co-benefits such as water and air quality improvements, wildlife habitat, carbon sequestration, and community recreational use Cost-effective Natural features grow stronger with time and have the potential to self-recover and self-repair Can often keep pace with changing climatic conditions 	<ul style="list-style-type: none"> Growing but still limited research and data on cost-benefit ratios and engineering efficacy of specific approaches Limited capacity and expertise in the climate adaptation and planning community Socio-cultural, financial, and institutional barriers (See Section 6.4 on how to overcome these obstacles)

1.1 What are Nature-based Solutions?

Natural systems are the basis for a wide variety of services and functions essential for human existence and livelihoods. As people increasingly concentrated in urban and suburban areas and became reliant on built infrastructure, this simple truth was obscured. All too often, nature came to be viewed as a nuisance or dispensable luxury rather than as foundational to a healthy and well-functioning society and economy. Because many of nature’s services exist outside the formal economy and are challenging to monetize (in economic terms are “externalities”), these services historically have been disregarded or undervalued.

The effect of environmental degradation on human lives and livelihoods became widely recognized with the rise of the modern environmental movement in the late 1960s and early 1970s, leading in the United States to passage of landmark environmental legislation, such as the Clean Water Act, Clean Air Act, and National Environmental Policy Act. Although the importance of preserving biodiversity was formalized in the Endangered Species Act of 1973, natural ecosystems (with the exception of wetlands) and the services they provide have not received robust protections. As a result, natural habitats across the United States have continued to be lost or degraded, creating problems not just for wildlife, but also for people. Among the

factors that have contributed to the ongoing conversion of natural ecosystems to human-dominated land uses has been a lack of recognition for the role that natural lands, waters, and ecosystem processes provide to society.

1.1.1 Ecosystem Services

To better document and highlight the role of nature in supporting and sustaining human communities, the concept of “ecosystem services” emerged in the 1990s and has now gained considerable currency (MEA 2005, IPBES 2019). Ecosystem services can be defined as “the benefits people obtain from ecosystems” (MEA 2005), or simply “nature’s contributions to people” (IPBES 2019). In its original formulation, ecosystem services were categorized into the following four general types:

- **Provisioning** – provision of food, fresh water, fuel, fiber, and other goods
- **Regulating** – such as climate, water, and disease, and natural hazard regulation
- **Supporting** – for instance, soil formation and nutrient cycling
- **Cultural** – educational, aesthetic and cultural heritage as well as recreation and tourism

More recently, the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) identified and assessed 18 “contributions from nature” across three major categories: regulation of environmental processes; materials and assistance; and non-material (IPBES 2019). From a community adaptation and resilience perspective, “regulation of environmental processes” is particularly relevant, since this includes many of the ecosystem functions that provide protective benefits, including regulation of hazards and extreme events such as floods, storms, and excessive heat. That said, each of these ecosystem service types are important for community health and prosperity.

1.1.2 Natural Capital

Natural capital is a related concept that can be defined as the world’s stocks of natural assets, including geology, soil, air, water and all living things. The ecosystem services that sustain human existence derive from these stocks of natural capital. Calculating the value of stocks and flows of natural resources and ecosystem services, in both monetary and non-monetary terms, is becoming increasingly mainstream, and “natural capital accounting” is now being integrated into many measures of economic activity and growth. A growing numbers of analytical tools are becoming available to document, measure, and map natural capital, including the [InVEST](#) (Integrated Valuation of Ecosystem Services and Tradeoffs) suite of modeling tools, which now includes an urban resilience-oriented module ([Urban InVest](#)).

1.1.3 Nature-based Solutions

Although the concepts of natural capital and ecosystem services provide an overarching framework for understanding the dependency of people on nature, more recently the concept of “Nature-based Solutions” (NbS) has become a widely used means to describe the potential for natural systems to support communities, including to deliver both climate adaptation and mitigation outcomes. NbS can be as simple as planting trees in urban neighborhoods to provide shade and stormwater management benefits or as complex as reengineering riverine systems to restore natural floodplains and lessen flood risks or constructing coastal reef systems from native

and engineered materials (e.g., oysters and oyster castles) designed to attenuate storm surge and wave action.

In 2016 the International Union for the Conservation of Nature (IUCN) published a collaboratively developed global standard for the application of NbS that defines the term as follows:

Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits (Cohen-Shacham et al. 2016).

The IUCN standard is intended to provide a framework for designing NbS and verifying that they yield the desired outcomes. The core of the IUCN standard is the identification of eight criteria and 28 associated indicators for the application of NbS (Cohen-Shacham et al. 2016). Addressing important societal challenges is embedded in the very definition of NbS and constitutes the first of these criteria. The standard identifies several high-level societal challenges that can be addressed through use of NbS, including climate change mitigation and adaptation, disaster risk reduction, and water security. The IUCN standard represents an important advance in the development and promotion of NbS globally. It is highly conceptual in nature, though, and may not directly serve the needs of many U.S. communities and practitioners seeking to incorporate NbS into their community adaptation planning processes.

There are, however, a growing number of publications that discuss the range of NbS approaches available to address various hazards and climate-related risks and offer case studies of their application. Several previous National Wildlife Federation (NWF) publications explore different aspects of this topic, highlighting examples of different types of NbS, including: [Green Works for Climate Resilience](#) (Reeve and Kingston 2014); [Natural Defenses in Action](#) (Small-Lorenz et al. 2016); [The Protective Value of Nature](#) (Glick et al. 2020); [Building Ecological Solutions to Coastal Community Hazards](#) (Small-Lorenz et al. 2017); and [Softening Our Shorelines](#) (Hilke et al. 2020). The U.S. Army Corps of Engineers publication [Use of Natural and Nature-Based Features for Coastal Resilience](#) (Bridges et al. 2015) offers an excellent overview of the topic, including examples of NbS applicable in coastal regions. See also Chapter 4 (Step 3) for listing of various types of nature-based approaches that are relevant to different types of hazards.

Building on the IUCN global standard described above and informed by NWF and EcoAdapt’s work on climate adaptation and resilience, we have identified the following seven “key considerations” for communities to use in the design and application of nature-based solutions (Box 1). We highlight in later sections which of these key considerations are most relevant to the different steps in the community adaptation planning process.

Box 1. Key Considerations for Use of Nature-based Solutions

- **Recognize natural systems and processes as critical infrastructure.** This should include natural systems that provide essential ecosystem services including protective benefits from hazards, such as flooding, erosion, stormwater, and extreme heat. Recognize, too the non-material value (e.g., cultural, aesthetic, spiritual) of biodiversity and natural ecosystems.
- **Consider climate impacts on priority natural assets.** Ecosystems are themselves being affected by changing climatic conditions, and those vulnerabilities and risks should be understood and addressed in community-based adaptation and resilience planning
- **Consider equity implications in the design and application of nature-based solutions.** To avoid unintentional consequences, such as displacement of disadvantaged communities, nature-based solutions should be planned and implemented with the engagement of local stakeholders and residents.
- **Ensure that nature-based solutions yield net positive biodiversity benefits.** Nature-based solutions should not only provide protective value to communities, but should also yield net biodiversity benefits, for instance through using regionally appropriate designs and materials (e.g., native plants).
- **Seek to protect or restore critical natural infrastructure.** This can involve protection of still intact natural systems, restoration of degraded systems, use of nature-based designs in engineered systems, and/or integration of natural (green) and engineered (gray) approaches in hybrid infrastructure.
- **Give natural features and processes space to function.** Consider how and where climate change may increase community exposures to potentially hazardous natural processes. Don't create new hazards or exacerbate existing risks through inappropriate siting of new development and infrastructure, and consider where—and when—existing infrastructure may need decommissioning or relocation.
- **Integrate nature-based solutions into existing planning processes.** Mainstreaming nature-based solutions into existing programs, policies, and planning processes can facilitate adoption, successful implementation, and funding of these approaches.

1.2 Related Terms and Concepts

Although the term nature-based solutions is in increasingly broad use, the approaches this concept embodies are referred to in a number of other ways. Indeed, various sectors or communities of practice often have alternative preferred terms for referring to these approaches and techniques. These include natural infrastructure, green infrastructure, natural and nature-based features, ecosystem-based adaptation, natural defenses, soft defenses, natural climate solutions, ecological engineering, and engineering with nature. Some of these almost completely overlap with the NbS concept while others apply to specific components or techniques. Below,

we elaborate on a few related terms that have particular relevance to community-based adaptation planning.

Biodiversity. Biodiversity is an overarching concept that refers to the diversity of life on Earth (IPBES 2019). Although often associated with the variety of species inhabiting a given place, biodiversity encompasses multiple levels of biological organization, from genes and species to ecosystems. In turn, each level of organization can be viewed as consisting of three major components: composition, structure, and function (Noss 1990). Nature-based solutions may depend on one or more of these components, for instance, a particular set of species (i.e., composition), a certain ecosystem form (i.e., structure), or particular biological processes (i.e., function).

Natural Infrastructure. Natural infrastructure is a term that refers to natural systems and features that provide benefits and services to people. The term is used especially to contrast with and complement traditional conceptions of infrastructure as consisting only of engineered or built structures. In particular, the term refers to infrastructure that either uses, restores, or emulates natural ecological, geological, or physical processes. The concept of natural infrastructure is increasingly being used in policies and legislative efforts, including the recently enacted bipartisan infrastructure bill, in order to ensure that investments are directed towards the conservation and restoration of forests, wetlands, and other natural systems that make up critical parts of the nation's overall infrastructure.

Green Infrastructure. Green infrastructure is a term that historically has been used to refer the value and role of open space and ecosystem services broadly (e.g., Benedict and McMahon 2006), but is now often used in a narrower sense focusing on nature-based approaches to stormwater management (U.S. EPA n.d.). Other terms applied to such stormwater management approaches include “low impact development” (Ahiablame et al. 2012) and “blue-green infrastructure” (Novotny et al. 2010).

Natural and Nature-based Features. Natural and nature-based features (NNBF) is a concept used by the U.S. Army Corps of Engineers and more broadly within the environmental engineering community (Bridges et al. 2015). NNBF are defined as landscape features that are used to provide engineering functions relevant to flood risk management and other hazard mitigation efforts. Importantly, this concept incorporates both the role of intact or restored natural features, as well as of engineered solutions that emulate natural functions or processes. This approach has recently been elaborated on through the publication of international guidelines on the use of NNBF for flood risk management (Bridges et al. 2021).

Ecosystem-based Adaptation. Ecosystem-based adaptation is a concept used primarily in the international conservation and development community to refer to the role of biodiversity and ecosystems in addressing climate-related vulnerabilities and risks to people and livelihoods (Colls et al. 2009). Although the phrase may suggest that ecosystems are the intended beneficiaries of the adaptation, instead they are the means for achieving human-oriented adaptation outcomes. The term “biodiversity-focused adaptation” has been proposed as a way of more explicitly describing and highlighting the adaptation needs of the species and ecosystems themselves (Stein 2020).

Natural Climate Solutions. Natural climate solutions (NCS) are a subset of nature-based solutions that refers to the role of natural systems such as forests, wetlands, and grasslands in sequestering and storing carbon as part of broader climate mitigation efforts (Fargione et al. 2018). As the global community attempts to limit increases in atmospheric greenhouse gas concentrations to avoid the worst consequences of climate change, natural climate solutions have received heightened attention as a means of achieving national and global climate mitigation goals while contributing to positive biodiversity and ecological outcomes.

Nature-based Thinking. The concept of nature-based thinking (NbT) has recently been introduced in the academic literature (Randrup et al. 2020). The concept calls for a paradigm shift in the existing anthropocentric and solutions-based approaches for managing nature to a broader nature-based, social-ecological (inclusive) approach. NbT is rooted in a) acknowledging the value of nature beyond solutions and services (recognizing nature’s intrinsic value; ‘nature for nature’s sake’), while at the same time b) inclusivity of culturally diverse and community-centered ways of thinking about and relating to nature.

1.3 Nature-based Solutions in Community Adaptation Planning

Central to community-based adaptation planning is an understanding of climate-related vulnerabilities and risks so that strategies can be designed that can substantively reduce those risks. Indeed, such an explicit link between projected climate impacts and intended actions is what distinguishes climate adaptation from other forms of urban or community planning.

1.3.1 The Nature of “Natural” Hazards

Natural systems have a dual role within the context of community adaptation planning. On the one hand, ecological and geophysical processes form the basis for many of the hazards that may affect communities, from flooding and wildfires to landslides. On the other hand, natural systems provide many foundational services to human communities, including protective benefits to reduce risks from extreme weather events and other climate-related hazards. This duality exposes one of the fundamental issues in understanding the relationship between natural systems and natural hazards. So-called natural hazards often result from human activities being situated without regard for natural environmental processes, for instance, the construction of housing within active floodplains or shoreline hardening in response to flood risks. In this sense, “natural hazards” are context dependent: what transforms a natural environmental process into a hazard is its juxtaposition with human assets or activities. When community exposure to hazardous environmental processes is a result of inappropriate siting or land use decisions, these conditions might even be thought of as “unnatural” hazards.

As climate change accelerates, however, the relationship between potentially hazardous environmental conditions and the location of human activities is shifting. Climate change not only is shifting climatic averages in temperature and precipitation, but also leading to unprecedented extreme conditions, such as increasingly powerful storms, droughts, heat waves, and megafires. As a result, even communities that have not historically been exposed to certain hazards are now becoming susceptible. For example, rising sea levels are shifting the baseline for coastal flooding (both from storm surge and tidal flooding) leading to an expansion of areas that

are now exposed to these hazards. Compounding this problem, many of the natural systems that might have provided protective benefits have been lost, degraded, or otherwise compromised.

Given the dual role of natural systems as potential hazards *and* potential solutions, it is important to fully integrate nature and natural infrastructure throughout the community-based adaptation planning process. For example, the community assets targeted in the plans should include a robust set of natural assets, including not only those providing recreational and community well-being benefits, but also those that offer protective benefits. Similarly, these natural assets should be included in assessing what is vulnerable to and at risk from changing climatic conditions. As with human communities, natural systems are being exposed to changing climatic conditions that are beginning to exceed the bounds of historical variability. Species and ecosystems vary in their sensitivity to these climatic shifts as well as their adaptive capacity to accommodate or cope with change. Depending on the type, pace, and scale of climatic impacts, however, many species and ecosystems will themselves require specific adaptation measures to maintain or enhance their capacity to delivery benefits and services.

1.3.2 Equity in Nature-based Solutions

As noted above, the distinction between a natural environmental process and a natural hazard is the juxtaposition of the ecological or geophysical process with human populations or assets that may be negatively affected by that process. The geography of risk is complex, but in many instances is a result of the unequal distribution of opportunities (social, economic, and geographic) that places many lower income and vulnerable communities in proximity to hazardous conditions, both natural and manmade. Compounding these inequities, oftentimes where higher income populations choose to locate in high-risk areas, such as in waterfront or beachfront communities, climate adaptation efforts and resources are more likely to divert to them, with other communities receiving less attention, assistance, and funding.

NbS can have an important role to play in addressing hazards and risks posed by historical inequities in patterns of settlement, land use, and property ownership. For example, many lower income communities have low levels of tree cover, lack equitable access to parks and other open spaces, and are susceptible to flooding from stormwater as well as riverine or coastal floodwaters. The use of natural and nature-based features can effectively address such risks as well as substantively contribute to an improvement in quality of life for community residents. That said, urban greening programs can also have unintended consequences, including contributing to gentrification and the displacement of economically disadvantaged communities. While it is beyond the scope of this guide to fully explore this topic, there is a growing number of organizations focused on the link between enhancing natural infrastructure, including parks and other greenspaces, and affordable housing. In particular, the design of such approaches should fully engage community members to ensure that not only are key climate-related hazards and risks addressed, but this is done so in ways that support the community's own vision for the future (see Sections 3.3 and 4.2.2 for further discussion).

1.4 Structure of the Guide

This guide is structured around “Steps to Resilience” (Figure 1), a generalized climate adaptation planning framework, developed by the U.S. Climate Resilience Toolkit. Steps to Resilience brings together, and is informed by, a number of resilience and adaptation approaches and other resources. The steps of the framework mirror other existing adaptation planning approaches such as the “climate-smart conservation” planning cycle developed by National Wildlife Federation (Stein et al. 2014). Expanding on the Steps to Resilience framework, this guidance document lays out a step-by-step process to incorporate nature-based solutions into community climate adaptation planning.

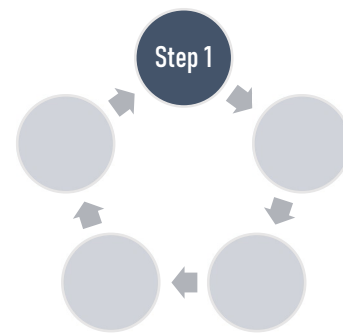
This guide is intended for climate service practitioners who are professionals across different sectors working with communities to steer resilience efforts. It can be used as a stand-alone process; however, the step-by-step process may not always reflect a community’s adaptation planning, which is often context-specific and nonlinear in nature. In that case, each step can help practitioners and communities embed components of nature-based perspective at various stages of their adaptation planning. These considerations of nature-based solutions throughout the planning effort is foundational to their acceptance and implementation as potential solutions within a community. The overall purpose of the guide is intended to help practitioners understand the fundamentals of nature-based solutions and make informed choices in designing and carrying out these approaches in an equitable manner that meet the unique needs and goals of their community.



Figure 1. Steps to Resilience Adaptation Planning Framework. This guide focuses on the incorporation of nature-based solutions into the steps of this adaptation planning framework.

2 EXPLORE HAZARDS (STEP 1)

The key to a successful resilience effort is embedding NbS early in the process. The first step in the adaptation planning process offers practitioners the opportunity to connect communities with their natural assets and set the overall scope of adaptation planning with a nature-based framing. Indeed, recognizing relevant natural systems and processes as critical infrastructure (a “key NbS consideration” in Box 1) is foundational to this stage of the process. The following sections elaborate on important stages in the planning process that require NbS considerations and sets the groundwork for incorporating these strategies in the subsequent sub-steps.



2.1 Identify Community Assets

The concept of NbS is centered on protecting, conserving, and restoring natural assets within a community. In the adaptation planning context, identifying a community's natural assets and features is essential for designing and implementing nature-based strategies. Common-pool natural ecosystems and their services, such as food provisions, recreation, etc., also provide a platform for bringing diverse community members together and building consensus for adaptation planning. Identifying these assets early in the process is also crucial for practitioners to help them understand community interests and establish connections for a meaningful stakeholder engagement throughout the adaptation process.

Key NbS Consideration for Step 1

- *Recognize key natural systems and processes as critical infrastructure*

Practitioners can employ a range of methods to identify a community's natural assets, such as beaches, forests, coral reefs, wetlands, etc., that provide different types of functions and community benefits. Employing a combination of existing data sources, remote sensing, and community knowledge will help build a comprehensive understanding of natural assets and features in an area that is not limited to formally designated parks and recreational amenities (e.g., trails, fishing piers). Rather, practitioners should help communities explore the full range of natural assets such as wetlands and waterways, riparian buffers and floodplains, urban tree canopies, habitat corridors, and remnant natural ecosystem patches that may provide protective benefits or other services. This can help practitioners to steer conversations on multiple co-benefits of natural assets such as climate regulation, storm surge protection and community wellbeing that may have neither been previously discussed nor valued by the community members. For instance, a flood-prone community using mangroves for shrimp culture can be losing its climate regulation value to aquaculture. This thorough understanding is also vital for selecting and implementing the optimum NbS for the community.

2.2 Explore Interactions Between Natural Processes and Hazards

The hazard identification step should be built on a thorough understanding of the relationship between natural environmental processes and climate-related hazards. As discussed in the Chapter 1, natural processes that are influenced by human-induced stressors (e.g., siting, land use and urbanization) can quickly transform into a hazard. When these human-caused stressors are combined with climate-induced factors, the resulting hazards can lead to the loss of natural features and their protective value, causing cascading impacts on the dependent communities.

Practitioners should assess past community experience, knowledgeable experts, and existing scientific information to understand the relationship between a community’s hazards and natural processes. To help guide their assessment, the table below provides examples of natural processes turning into hazards resulting from human-mediated alterations. Activities such as mining, groundwater extractions, or even contributions to global warming significantly influences natural processes. Table 2 considers local drivers caused by human interventions in addition to global climate drivers that can help in fully understanding and assessing a community’s susceptibility to past and future hazards.

Table 2. Natural Processes and Associated Hazards

Natural Process	Hazard	Local Driver	Climate Driver
Floodplains	Floods	Unsustainable development	Extreme rainfall, sea level rise, high tide flooding
Erosion and sedimentation	Coastal floods, avalanches and mudslides	Land use change, dredging, overgrazing and deforestation	Extreme rainfall events, melting glaciers
Forest fire	Wildfires	Human-caused ignitions, historic fire suppression	Extreme heat and drought
Soil composition	Droughts and floods	Overfertilization, overirrigation and other agricultural practices	High temperatures, increase in evaporation
Slope movement	Landslides and rockfalls	Construction of roads and structures on unstable slopes, groundwater discharge	High temperatures, extreme rainfall and snowstorms
Freshwater inflows	Drought, floods, salinity, harmful algal blooms	Damming of rivers, upstream water uses, nutrient pollution	Sea level rise, saltwater intrusion, acidification
Storms and winds	Hurricanes	Development, air pollution	Land and sea warming
Water filtration/purification	Diminished water quality, harmful algal blooms	Over-use of fertilizers and pesticides, land use change, industry	Flooding, drought, high temperatures

2.3 Determine Geographic and Temporal Scale

Considering appropriate geographic and temporal scales is a critical consideration in the early development and implementation of NbS. Adaptation planning is location and context-specific. However, a community's climate risks are heavily influenced by outside factors such as the degree of impervious surfaces and upstream land uses (e.g., deforestation). NbS offers scalable solutions in the face of increasing climate variabilities and extreme events. To fully harness their potential, practitioners will need to understand the broader geographic context and consequences early in the process to create a conducive space for NbS in the later stages. For example, several NbS interventions such as conservation easements and riparian buffers require landscape and seascape-wide considerations combining a range of ecosystems (forests, rivers, coastal waters, etc.). NbS practices also differ based on the consideration of scale and location. For instance, interconnected systems such as watersheds may require large-scale practices such as floodplain restoration. In contrast, stormwater management practices like permeable pavements may require localized site-specific considerations (See Table 3). A well-thought-out plan that understands the landscape and their climate risks beyond the defined geographic scope is not only essential to successful NbS projects but also facilitate upscaling and enhanced connectivity for ecosystems that are resilient to a changing climate.

Table 3. Examples of Nature-based Solutions by Geographic Scale

Watershed/landscape scale	Neighborhood scale
Floodplain restoration	Rain gardens
Wetland protection and restoration	Permeable pavements
Land or conservation easements	Green roofs
Oyster restoration	Waterfront parks

Temporal scale is an equally important consideration for adaptation planning within the context of NbS. The time scale of an adaptation plan depends on several factors such as climate change concern, political will, and the dominant socio-economic sector of the community. Understanding the complexities of ecosystems and the potential climate-induced threats to their species and processes in the near to long-term should also play a central role in deciding the planning horizon. Consideration of NbS interventions is equally essential in determining the time frame. For example, approaches such as wetland restoration can sometimes take decades based on the degraded wetland's physical, chemical, or biological characteristics, whereas installing rain gardens can be a faster short-term solution for controlling runoff. Practitioners should consider short-term versus long-term benefits and tradeoffs associated with different time scales while allowing flexibility when possible. This consideration of NbS operating under different time horizons should be incorporated from the very beginning for successful planning and community support for these projects.

2.4 Guide Communities to Determine their Needs

The need to employ NbS should be driven by people living and having the highest stake in the ecosystem. Communities have longstanding traditions of managing their natural resources, and excluding their perspectives can lead to a lack of participation and disempowerment for local communities leading to failure of local support for NbS and jeopardizing their success (Woroniecki et al. 2020). On the other side, recognizing local community members as agents with extensive local knowledge capable of exercising choice and making decisions can lead to successful and equitable outcomes while encouraging stewardship and empowerment of local communities (Seddon et al. 2021).

Practitioners have a central role in guiding communities and creating spaces for them to identify the full range of natural assets and NbS options, and to inform decisions related to NbS design and implementation. Their role can be to ensure all voices, especially historically marginalized and underrepresented groups, are engaged in the process, and unsustainable outcomes that can marginalize the poor are left off the table. In this sense, practitioners play the role of facilitators in a community's climate adaptation planning. With NbS context, stakeholder-driven efforts help elevate a sense of place and value for the ecosystems and their ecological function. Consider this example in Florida. Residents who participated in the Indian River Lagoon estuary restoration efforts regularly checked on progress (plant growth, etc.), tracked site success via social media, and returned with fellow restoration volunteers for picnics, fishing, and snorkeling activities (Kibler et al. 2018). NbS solutions that require long-term community support and monitoring are more likely to succeed in communities that guide their own vulnerabilities and adaptation decision-making.

2.5 Assemble Key Nature-based Solutions Stakeholders

A successful climate adaptation planning effort relies on effectively engaging multiple and diverse stakeholders throughout the project duration and beyond. One thing to be mindful of when working with communities is that coordination across multiple agencies and planning sectors, as well as collaboration with a diversity of stakeholders, will be essential to ensure that the use of NbS will be as effective as possible in reducing hazard risks and enhancing co-benefits (FEMA 2021a). Indeed, studies have revealed an important connection between various types of land use planning and resilience outcomes, where failure to coordinate across different planning efforts could lead to maladaptive outcomes (Berke et al. 2018).

When considering potential stakeholders, embedding an NbS framing can help fill information gaps, identify solutions and implementation decisions for climate adaptation. This means engaging individuals, such as ecological scientists, urban planners, natural resource managers, conservation organizations, fish, wildlife, and parks agencies, and others to share technical assistance and knowledge of the region's existing natural resources and assets. Similarly, local landowners and indigenous people can provide local and traditional ecological knowledge for resource management that can help uncover and inform specific NbS options.

The consideration of who to engage and when rest with the practitioners and project team. However, within an NbS context, certain factors can influence the choice of participants. First,

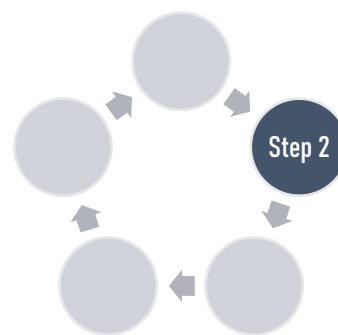
not all experts need to be engaged in each stage of the process. For instance, ecological scientists can help fill the information gaps early in the process, while resource managers can be most valuable during implementation decisions. There can be overlaps in the manner these stakeholders are engaged. However, understanding and respecting stakeholder fatigue will lead to the most meaningful engagement. Secondly, several public and private NbS stakeholders may interact with natural assets and ecosystems in different ways, leading to competing interests and conflicts among the stakeholder groups. Practitioners will need a high level of coordination and negotiation to address these conflicts early in building NbS support on shared community goals.

3 ASSESS VULNERABILITY AND RISK (STEP 2)

Step 2 entails assessing the current and potential future impacts that the hazards identified in Step 1 could have on community assets—both natural and built—and the people that depend on them. In this step, it is important to consider the duality of vulnerability by exploring the impacts of climate change on natural systems as well as the compound impacts on community assets related to natural system degradation. Such assessments should include identification of those assets that are expected to face adverse impacts (i.e., they are vulnerable/at risk), as well as those that are likely to remain viable under a changing climate. Specifically, vulnerability assessments can inform adaptation planning by helping communities identify:

- *Which* assets are likely to be most (and least) affected by current and projected conditions, which can help set priorities for adaptation and management;
- *Why* those assets are vulnerable/at risk, which can inform the development of specific adaptation responses and risk reduction strategies; and
- *Where* and *when* they are vulnerable, which can inform the spatial and temporal aspects of designing and implementing adaptation actions.

Here, we define *vulnerability* generally as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. The related concept of *risk* emphasizes the consequences of a potential event or impact. Although risk is often defined as the product of the likelihood that an event will occur (probability) and the consequences (i.e., magnitude of impact) of that occurrence, in many instances, assigning such probability is difficult—if not impossible—given inherent uncertainties in both the timing and severity of climate-related extreme events. Accordingly, it will be important for communities to also adopt planning approaches that acknowledge and embrace uncertainty, including but not limited to scenario-



Key NbS Consideration for Step 2

- *Consider climate impacts on priority natural assets*

based planning.¹ Distinguishing between likelihood (when possible) and consequence can also help planners and managers set priorities. For example, unlikely events that may have catastrophic consequences (sometimes referred to as “black swan” events) should be considered along with events that may be more certain to occur but have less impact.

As discussed in Chapter 1, however, it is important to recognize that even intact natural systems, many of which may provide protective benefits in addition to other ecosystem services, themselves may be vulnerable to changing climatic conditions—not just to extreme events, which are the primary focus of Steps to Resilience, but also to a range of other climatic factors to which they may be sensitive. For example, even a slight increase in average stream temperatures may be detrimental to salmon and other cold-water fish species that may already be near critical ecological thresholds for temperature (e.g., FitzGerald et al. 2021). And in Florida Bay, corals generally considered to be tolerant to temperature and salinity extremes have been found to be vulnerable to ocean acidification, which is occurring as oceans absorb excess atmospheric carbon dioxide (CO₂) (Okazaki et al. 2013). Acidification reduces the calcification rates of some coral species, which can have significant implications for the persistence of sensitive corals in area where acidification is expected to worsen (Okazaki et al. 2017).

Understanding the many factors that contribute to vulnerability of ecological systems and the species they support will be essential to inform effective adaptation strategies and help ensure that such systems will continue to benefit society for as long as possible. Accordingly, the discussion below includes an overview of tools and approaches for assessing vulnerabilities and risks to natural assets, including fish and wildlife species, habitats, and ecosystems. We follow by highlighting some specific ways in which communities can better understand how the modification of many natural assets due to a variety of human activities can exacerbate the risks from natural hazards, which is likely to be especially useful in brainstorming the use of NbS for hazard risk reduction (Step 3).

3.1 Assessing Vulnerability of Natural Assets

One of the primary reasons communities are increasingly turning to NbS is that many natural systems already are well adapted to natural disturbance regimes and have the capacity to withstand or recover from the impacts (Spalding et al. 2014). For example, the natural deposition of sediments from upstream or upland sources can provide sufficient levels of soil for marshes in deltas and estuaries to rebuild after storms and keep pace with rising sea levels through a process called accretion (Batker et al. 2010). Beaches and other coastal habitats can migrate landward and seaward in response to both acute and gradual changes over time, particularly in the absence of man-made or natural barriers such as seawalls and bluffs (Spalding et al. 2014, Leo et al. 2019). And in many forest ecosystems, periodic wildfires are essential for forest health by clearing dense undergrowth and contributing to habitat complexity.

¹ Rather than try to determine and plan for a single expected future, as is done with forecasts and predictions, communities can use scenarios to: (1) explore a variety of plausible future conditions, (2) evaluate the implications of those conditions for their resources, infrastructure, and other management goals; and (3) identify a portfolio of possible management strategies.

Unfortunately, the combination of changing climatic conditions and other anthropogenic stressors has degraded ecosystems in many areas and significantly reduced their natural adaptive capacity (Seddon et al. 2020). Climate change is likely to further push many ecosystems to their limits, even those adapted to historical disturbances. Indeed, this is already occurring in some systems. For example, studies have found that extensive drought-associated plant mortality is contributing to the conversion of chaparral systems in California to more open sage scrub and grassland (Jacobsen and Pratt 2018). Across the West, there is a growing body of evidence that larger fires and longer fire seasons are driving conversion of forests to non-forested vegetation (Coop et al. 2020). And along the Atlantic and Gulf coasts, accelerating sea level rise has contributed to the conversion of coastal forests to intertidal vegetation, affecting both the composition and function of coastal systems (Kirwan and Gedan 2019).

Thus, it is important to think not only about the vulnerability of human communities to the impacts of extreme weather and climate-fueled natural disasters, but also the climate vulnerability of the natural systems, that provide protective benefits and other services to those communities. Doing so in parallel with assessments for other valued assets will allow communities to identify when and where existing and intact natural systems can continue providing benefits and services, and where it is necessary to proactively protect or restore ecosystems or design specific adaptation strategies to maintain or enhance the capacity of those systems to provide risk reduction benefits.

3.1.1 Approaches for Assessing Ecological Vulnerability

Numerous approaches exist to assess the climate-related vulnerabilities and risks to species and ecological systems (Glick et al. 2011). Determining which approach or approaches are suitable for informing community planning processes is highly context-specific and will depend on the types of resources being assessed, the level of detail or rigor required, the availability of supporting information, and available expertise, funding, or other resources.

The Steps to Resilience Practitioner's Guide highlights a vulnerability assessment framework first proposed in the 2012 Intergovernmental Panel on Climate Change (IPCC) report on extreme events and disasters (SREX report). Within the ecological and natural resource management communities, however, that SREX framework has not been found to be particularly relevant, and vulnerability assessments are generally conducted using the earlier three-part framework that considers *exposure*, *sensitivity*, and *adaptive capacity*.

Exposure. Exposure, under this framework, refers to the character, magnitude, and rate of direct and indirect climate-induced impacts experienced by the target species or system. For instance, increasing temperature, sea level rise, and associated salinity levels are already affecting the distributions of fish and invertebrate species in the bays along the Gulf of Mexico (Fujiwara et al. 2019). This exposure is higher in the Gulf of Mexico because the region is experiencing the highest levels of relative sea level rise in the country (Sweet et al. 2017).

Assessing exposure. Temperature and precipitation are key variables controlling the distribution of species and ecosystems, and changes in these climatic variables are the most widely used indicators of exposure to climate change. Observed changes in temperature and precipitation inform assessments of historical and current climatic conditions, while various types of models

project future changes. The relatively coarse scale output generated from global climate models is transformed to regional or localized understanding of climate impacts through various “downscaling” techniques.

Practitioners will likely rely on available downscaled climate projections for use in vulnerability assessments. Existing websites such as The Climate Explorer, ClimateWizard, National Oceanic and Atmospheric Administration (NOAA) Sea level Rise Viewer, etc., and networks such as the U.S. Geological Survey (USGS) Climate Adaptation Science Centers and NOAA Regional Integrated Sciences and Assessments (RISA) program serve as good resources for obtaining historical and projected climate information. Using projections based on multi-model ensemble means can help address some of the inherent uncertainties in climate projections. Considering multiple future scenarios, however, is a recommended best practice for addressing such uncertainties. Scenario-based planning offers valuable decision-making considerations under uncertainties and allows an evaluation of options that are robust under various plausible outcomes (i.e., “robust decision-making”).

Sensitivity. Sensitivity refers to the extent to which a species or natural system would be affected by or respond to changing direct or indirect climatic impacts. Several intrinsic factors such as physiological characteristics, plasticity, and evolutionary potential can increase or decrease species' sensitivity. From the earlier Gulf of Mexico example, maximum temperature tolerance was an important factor in predicting changes in the distribution of coastal species. Several fish species with lower maximum preferred temperature expanded their range due to increasing temperature trends, whereas the range of fishes with significantly lower maximum preferred temperature declined (Fujiwara et al. 2019).

Assessing sensitivity. The extent to which species and habitats will respond, either positively or negatively, to climate exposure will depend on their sensitivity. Information on ecosystem thresholds or tipping points can be a useful indicator to understand their ability to withstand climate impacts. In addition, identifying how species and ecosystems have responded to climate impacts in the past or analogues information from similar species can help assess sensitivity to future projections.

Practitioners can utilize a range of existing resources to gather this type of information, including a combination of scientific literature, publicly available data sets, and community knowledge. For example, the Fish and Climate Change Database (FiCli) developed by National Climate Adaptation Science Center helps communities obtain summarized information on freshwater fish responses to climate change based on country, habitat type, species, management action, fish traits, and more. Similarly, FishVis Mapper allows users to visualize the possible changes in fish species occurrence in response to global climate change for 13 fish species in streams across the Great Lakes region. Such data and information can be challenging to obtain for all species and ecosystems. The existing community knowledge, particularly traditional ecological knowledge, can fill the gaps in data-limited areas and enrich the existing datasets by providing a holistic view of the ecosystem.

Adaptive capacity. Adaptive capacity refers to the ability of a species or system to cope with or accommodate the climate change impacts. For ecological systems, adaptive capacity depends on

the diversity and flexibility across traits (e.g., metabolic rates, reproductive strategies), organizational levels (e.g., genetic, species, populations), and interactions with suitable habitats (e.g., habitat diversity, connectivity) (Whitney et al. 2017) while for species adaptive capacity is influenced by attributes such as genetic diversity, dispersal capacity, mode of reproduction, and physiological tolerances (Thurman et al. 2020). In continuation of the earlier example, species along the Texas coast that were adapted to colder, temperate waters experienced more intense temperature stress than those adapted to warmer, tropical waters. Changes in habitat availability of salt marshes and seagrasses due to sea level rise and increased temperature drove some species out of their existing habitat, allowing other species better adapted to the new conditions to invade (Fujiwara et al. 2019).

Assessing adaptive capacity. A range of factors influence the species and ecosystem's capacity to adapt. Broader ecological assessments offer valuable information about the adaptive capacities of a system. Literature suggests "adaptive capacity of what, to what, of whom" as the guiding principle of choosing a relevant approach for assessing adaptive capacity (Whitney et al. 2021).

Information gathered for assessing sensitivity can inform the adaptive capacity assessment as well. The external factors that affect adaptive capacity, for instance, habitat connectivity and habitat diversity, may require additional considerations. Practitioners and communities can leverage ecological indicators and existing habitat assessments for understanding adaptive capacity. Large-scale ecological indicators and models that evaluate past and present ecological changes and future adaptation potential of species and fisheries and projected environmental change have been previously used in the literature (Cheung et al. 2015). More recently, Thurman et al. (2020) provided a generalized framework for evaluating the adaptive capacity of species or populations, which applies broadly to animals and plants.

The components of vulnerability can be assessed either explicitly (as in the Habitat Climate Change Vulnerability Index described below) or implicitly (as in the Sea Level Affecting Marshes Model, also described below). Further, it is useful to acknowledge that vulnerability assessments for ecological systems may be qualitative and/or quantitative. For general planning purposes, qualitative (or descriptive) assessments, often based on a review of literature, may be sufficient. In other instances, more quantitative and specific analyses may be needed. For instance, when designing an on-the-ground stream restoration project, specific changes in the timing and extent of streamflow due to heavy downpours could alter the natural ability of the stream to absorb floodwater or affect downstream water quality. Spatial analyses resulting in map-based depictions of vulnerabilities and risks to natural assets may be especially helpful in informing where and how existing ecological systems can be restored or maintained to provide hazard risk reduction benefits to communities.

The following are just two examples of the broad array of tools and approaches available for assessing ecological vulnerability: an index-based framework and a coastal ecological response model. We highlight them given their relative ease of use and potential for broad application. For other examples, Glick et al. (2011) and Stein et al. (2014) are useful resources for communities to refer. In addition, IUCN has developed guidance for selecting and evaluating climate change vulnerability assessment approaches for species (Foden and Young 2016).

Habitat Climate Change Vulnerability Index. NatureServe has developed a tool called the Habitat Climate Change Vulnerability Index (HCCVI), which provides a framework to help conservation practitioners determine the vulnerability of various natural communities or habitat types based on their potential exposure to changing climatic conditions, their sensitivity to those conditions, and their adaptive capacity (NatureServe n.d.). The climate change exposure elements include identification of baseline climate conditions, including historical climatic variability, future climate projections, and their departure from historical conditions. Where possible, changing climate variables are connected to dynamic processes, such as wildfire, hydrology, and sea level rise. For example, Comer et al. (2019) applied the framework to assess the vulnerability of 52 major vegetation types in the Western United States, including an assessment of natural wildfire regime departure. Results suggest that, as of 2014, more than 50% of the area of 50 of the 52 vegetation types were moderately vulnerable to climate change. By the mid-21st century, all but 19 types were shown to face high or very high vulnerability due to elevated exposure.

Sea Level Affecting Marshes Model. Ecological response models provide a variety of ways to assess the vulnerability of wildlife species, habitats, and ecosystems to climate change (Glick et al. 2011). One such model is the Sea Level Affecting Marshes Model (SLAMM), which was designed to simulate the dominant processes involved in wetland conversions and shoreline modifications among a multitude of different coastal habitat types under various scenarios of sea level rise. The model provides an accessible, middle-of-the-road tool that allows for fairly detailed, scientifically sound regional assessments within the constraints of relatively limited data availability, budgets, and time, and it has been applied in a variety of coastal studies across the country (e.g., Glick et al. 2007, 2008, 2013). The SLAMM model addresses the relative sensitivity of habitat types (e.g., saltmarsh, mangroves) to sea level rise based on known ecological traits such as the tolerance for salinity of associated plant species. Elements of exposure to sea level rise are based on land elevation as well as the scenarios of sea level rise modeled. Adaptive capacity is addressed in terms of both intrinsic and extrinsic factors (e.g., marsh accretion rates and presence of hard shoreline armoring). Model results can help coastal managers identify where marshes are likely to persist and where they may be converted to other habitat types, such as mudflats or open water. Further, the model can help inform strategies such as the removal of dikes to facilitate inland habitat migration.

3.2 Approaches for Assessing Hazard Risks Due to Altered Natural Systems

In addition to identifying the vulnerability of natural assets to changing climatic conditions, it will also be important for communities to understand how and where alteration of these systems is likely to exacerbate the impacts of climate-related community hazards such as flooding, coastal erosion, extreme heat, and wildfires. For example, natural floodplains that have been filled for development or armored with dikes and levees can actually increase flooding risk to nearby (especially downstream) communities. Similarly, some areas that are currently considered outside of the 100-year floodplain (i.e., those areas with a 1% chance of flooding each year) are expected to face increased flood risks as climate change leads to heavier downpours, more rapid snowmelt, sea level rise, and other hydrologic changes, many of which will also result in non-

compliance related to water quality regulations, which may also cause further harm to associated natural systems.

In highly-developed cities, neighborhoods lacking trees and other green space face disproportionately-higher temperatures during heat waves. Along the coast, some communities with armored shorelines may face higher damages from storm surges and coastal erosion than those with natural saltmarshes and mangrove forests. For example, in coastal North Carolina during Hurricanes Irene and Matthew, properties with bulkheads sustained more damage and experienced greater shoreline erosion compared to properties with natural shorelines (Gittman et al. 2014). And communities within the so-called “wildland-urban interface” (WUI), which is the area where houses are in or near wildland vegetation, may face increased risks from wildfires as more extreme heat and drought, insect outbreaks, expansion of fire-tolerant invasive species such as cheatgrass, and historical management practices that have excluded naturally-occurring fire in historically fire-adapted systems.

The following are just a few examples of a growing array of risk assessment tools and approaches to support decisions on where and how to improve the ability of natural and nature-based features to help protect communities.

3.2.1 Assessing Flood Risks

As noted in Chapter 1, while flooding occurs naturally and can be beneficial for some ecosystems, floods become “hazards” when they have adverse effects on people and the environment. Floods have a wide range of impacts, including loss of life, destruction of property and infrastructure, and disruption to agriculture and other sources of livelihood. In many places, risks from flooding are exacerbated by development and other human activities. Urbanization, in particular, can considerably alter flood hydrology (Ntekos et al. 2010, Mahmoud and Gan 2018). For example, an increase in paved roads, parking lots, and other impervious surfaces have been found to contribute to greater runoff into rivers, streams, and low-lying areas. This can cause flooding and erosion and exacerbate water pollution, which could lead to noncompliance with Clean Water Act requirements. In addition, the construction of levees and the placement of fill materials into areas such as wetlands to allow for development in one part of a floodplain can lead to increased flooding in surrounding areas. These risks are likely to increase in the future due to a combination of human population growth, land-use changes, and an increase in the frequency and intensity of heavy rainfall as climatic conditions continue to change (AECOM and FEMA 2013). To understand these increased risks, scientists have applied a number of assessment approaches, from hydrologic modeling to empirical evidence. For example:

- Ogden et al. (2011) used data from an urbanized catchment near Baltimore, Maryland, and the physics-based gridded surface/subsurface hydrologic analysis (GSSHA) model to examine the relative effect of increases in impervious area, drainage density and width function, and the addition of subsurface storm drains on flood peaks, runoff volumes, and runoff production efficiencies. Their results suggest that changes in imperviousness, among other factors, can have a significant effect on flood peaks during both moderate and heavy downpours.

- Heine and Pinter (2011) used stream gauge records to assess the impact of levees on flood levels in Illinois to provide an empirical test to theoretical and model predictions on the effects on local flood response. They found that, despite large differences in stream sizes, levee alignments, and degree of floodplain constriction, at all sites upstream of levees or within leveed reaches, stages increased significantly during flood events when compared to pre-levee conditions by constricting floodplain conveyance.

3.2.2 Assessing Coastal Risks

The coastal zone is a naturally dynamic place. Beaches, barrier islands, marshes, and other coastal systems change over time as storms, erosion, sedimentation, and other natural forces shape these landscapes. Coasts are also magnets for population centers due to their natural beauty and rich, biodiverse ecosystems that support vibrant economic, recreational, and cultural activities. Those living in the coastal zone know, however, that the benefits also come with risks from storms, coastal flooding, and shoreline erosion. These existing threats are compounded by urbanization, aging infrastructure, and changing climatic conditions, including warming oceans and rising sea levels (Fleming et al. 2018). Recent studies suggest that climate change is also contributing to an increase in tropical cyclone activity, which scientists have linked to warmer oceans and an accompanying increase in atmospheric moisture content. In the coming decades, both wind and rainfall intensity associated with these storms are projected to increase, which could translate into a greater proportion of storms reaching Category 4 and 5 (Knutson et al. 2019). In addition, sea level rise is exacerbating storm surge, contributing to more frequent flooding during high tides, and affecting water quality through saltwater intrusion (Tebaldi et al. 2012, Marsooli et al. 2019). Assessing the risks from one or more of these challenges can be done in a variety of ways, ranging from relatively simple mapping efforts to complex modeling. For example:

- As noted in NOAA’s publication *Adapting to Climate Change: A Planning Guide for State Coastal Managers* (NOAA 2010), communities should not put off adaptation planning efforts even though they may not have all of the information they need. Even a relatively straight-forward “baseline” assessment is important, which generally entails using data about the particular hazards of concern, potential impacts, existing stressors, the area’s physical geography, and exposed assets. Typically, a geographic information system (GIS) data set will help communities better understand the areas likely to experience the greatest risks under a range of scenarios for sea level rise, storm surge, and other factors. For example, [NOAA’s Sea Level Rise Viewer](#) offers a simple tool to help communities visualize the potential impacts through both maps and photos, which can help them identify vulnerable buildings and other infrastructure, human populations, and coastal ecosystems under a range of sea level rise scenarios.
- Sophisticated models can support a more-detailed assessment of a range of interrelated coastal hazards, including sea level rise, storm surge, hydrological changes, erosion, etc. While such assessments require greater investments in time, expertise, and funding, they play an important role in informing both short-term hazard mitigation and long-term adaptation planning. For example, Barnard et al. (2019) developed a dynamic modeling

approach that estimates climate-driven changes in flood-hazard exposure by integrating the effects of sea level rise, tides, waves, storms, and coastal change (i.e., beach erosion and cliff retreat), which they applied along the coast of California. Their assessment suggests that more than \$150 billion of property and 600,000 people could be affected by dynamic flooding by 2100, which represents a three-fold increase in exposed population than what would have been projected if only sea level rise and a static coastline had been considered.

3.2.3 Assessing Risks from Extreme Heat and Drought

Climate change is contributing to an increase in both extreme heat and drought conditions across much of the United States. Heat waves are occurring more often than they used to in major cities across the country, from an average of two heat waves per year in the 1960s to more than six per year during the 2010s (USGCRP 2018). In addition, over the past two decades, there have been twice as many high-temperature records as low-temperature records, and the number of new highs has surpassed the number of new lows in 15 of the past 20 years (USGCRP 2017). In cities, factors such as lack of trees and other green space and large areas of impervious surfaces can exacerbate the impacts of extreme heat through the so-called “urban heat island” effect (Levinson et al. 2019). Further, a combination of higher temperatures and altered precipitation patterns are contributing to increasingly severe droughts, which are compounded by increasing human demand for water (AghaKouchak et al. 2014). Together, drought and heat waves were responsible for the second-highest number of deaths among all the billion-dollar weather and climate disasters from 1980 to 2019, behind tropical cyclones (NOAA 2020). Increasingly, scientists are applying assessment approaches that factor in multidimensional elements of individual events, such as heat waves, as well as the compound risks from concurrent heat and drought. For example:

- To better understand how extreme heat waves are likely to affect urban residents at a landscape scale, Hamstead et al. (2018) applied a mapping approach to identify areas of New York City where people are likely to be particularly vulnerable to extreme heat-related health effects based on both exposure to biophysical elements that exacerbate heat, and sensitivity to heat-related health impacts. This approach enabled them to identify temperature differentials within the city (i.e., “micro-urban heat islands”), which will help inform spatially strategic extreme heat mitigation efforts.
- Following the 2014 California drought, which was characterized by both low precipitation and high temperatures, AghaKouchak et al. (2014) analyzed the potential risk of similar events occurring in light of climate change. After applying the traditional risk assessment method that relies on only one indicator variable (e.g., drought based on deficit in precipitation or temperature based on high quantiles of temperature data), they found that such analysis may not accurately represent concurrent extremes, leading to an underestimation of risk. Rather, they suggest that assessing the probability of occurrence of climatic extremes should be evaluated using a multivariate framework that can account for concurrent hazards. This is particularly important for informing water resource decisions, which are often based on the severity of droughts. Without consideration of the

potential for concurrent extreme heat, drought risk assessments—and associated management responses—will be less reliable.

3.2.4 Assessing Wildfire Risks

Wildfires are a natural and integral part of many forest and grassland ecosystems. By contributing to shifts in ecosystem structure, composition, and function, fires can create heterogeneity across the landscape and enhance biodiversity. Over the past few decades, however, the severity and extent of wildfires have grown considerably, as have the impacts to human communities and the natural ecosystems themselves (Stephens et al. 2018). As noted above, this trend is due to a combination of factors, including overly dense forests due to historical and present-day fire suppression, the expansion of invasive species, and changing climatic conditions (Millar and Stephenson 2015). In addition, the significant increase in people living in the WUI has elevated the risks from wildfire in many areas due to the proximity of structures to flammable vegetation as well as the potential for human-caused ignitions (Radeloff et al. 2018). Scientists can assess the vulnerability of both human communities and natural systems to wildfire in a number of ways, ranging from modeling the likelihood and consequences of wildfire under a range of current and future conditions, to mapping areas that may pose challenges or opportunities for wildfire management activities such as prescribed fire. For example:

- An et al. (2015) developed a statistical model to examine the association of wildfire risk with climatic conditions (seasonal temperatures and precipitation) and non-climate variables (human population density, biomass tree density, annual timber removal, and annual tree mortality) in 48 continental U.S. states. Results show wildfire risk to be positively related to spring, summer, and winter temperatures and human population density, and negatively associated with precipitation. Using Global Climate Model projections for future conditions, the authors found that climate change is likely to intensify wildfire risk compared to the historical baseline across the entire United States, with the greatest increase occurring in the South-Central region.
- As the risk of large and severe wildfire continues to grow, there is growing consensus that human communities, land managers, and fire managers need to learn to live with wildfire (McWethy et al. 2019). Recently, researchers have been exploring ways to align wildfire response decisions, mitigation opportunities, and land management objectives to address fire as both a problem and a solution (e.g., Thompson et al. 2016, Dunn et al. 2020). Toward this, Dunn et al. (2020) developed a risk-science approach that integrates three complementary risk-based analytic tools, including quantitative wildfire risk assessment, mapping of suppression difficulty, and atlases of potential control locations, to integrate wildfire risks and the operational environment. Such analyses can help communities prioritize safety interventions while also restoring fire-dependent ecosystems.

3.3 Integrate Equity and Environmental Justice into Vulnerability Assessments

Climate change will pose disproportionate impacts to socially vulnerable groups. Certain population groups such as racial and ethnic minorities face significantly higher exposure to climate risks due to their geographic location, lack of wealth, private lands, and access to resources, all of which are rooted in decades of disinvestments and systemic inequities. For these reasons, equity and environmental justice should be integrated into assessing climate vulnerabilities as part of Step 2. Natural assets can be important to the quality of life in these communities and offer valuable options for reducing climate risks and enhancing resilience (See Section 4.2.2). But NbS can also fail communities by magnifying existing inequities and creating new ones.

Historically, NbS, such as parks, forests, green roofs, streams, and community gardens, have benefitted predominantly White and more affluent communities (Wolch et al. 2014). For example, in East Boston, most new green infrastructure projects aim to protect the newly constructed luxury housing buildings and offer no flood protection to the older housing stock that constitutes historically working-class Latino and Italian neighborhoods (Anguelovski et al. 2019). As a result, despite a range of green infrastructure projects developed and many in the pipeline, the long-term residents of the East Boston neighborhood, feel socially and culturally excluded from these new green spaces (Anguelovski et al. 2019). Unless NbS efforts are deliberately designed and implemented with equity at the forefront, these communities will continue to face climate-driven challenges. Their adaptive capacity will continue to decline, reinforcing existing inequalities.

Natural assets such as green areas and floodplains can also create new challenges for the socially vulnerable population. One example is the creation of green spaces that can cause an increase in housing costs and property values, ultimately resulting in gentrification and displacement of the very residents these strategies intended to benefit. NbS such as flood buyouts also raise concerns about equity. For example, in a nationwide analysis of the federal buyout program, the findings revealed that the program disproportionately targets urbanized whiter counties, although communities of color and low-income neighborhoods are more likely to accept these buyouts (Elliott et al. 2020). These displaced residents often relocate to equally flood-prone areas, however, with lower adaptive capacities due to losing their social networks, cultural ties, and community resources.

Building on this knowledge of existing inequities early in the process, practitioners should consider concrete strategies centered on community members who are most affected by climate change as well as environmental and social injustices in their risk assessments. Two primary considerations can guide these strategies. First, practitioners should develop social and ecological vulnerability assessments that center on marginalized communities at greater risk of climate impacts. For example, when assessing key vulnerabilities of natural assets, interests of low-income groups and racial minorities should be prioritized in the societal goals. Ecosystems and habitats that support natural resource-dependent indigenous and tribal communities may require additional considerations. Second, understanding the adaptive capacity of socially vulnerable communities as influenced by existing natural infrastructure should be incorporated in

this step. This consideration is a crucial precursor to the next step in the planning process that focuses on identifying appropriate NbS options for climate adaptation. Certain NbS options may be rooted in existing vulnerabilities or be maladaptive for these communities and may require a decision to be left out as potential adaptation solutions.

3.4 Consider Key Vulnerabilities and Hazard Risks

The consideration of natural systems in the vulnerability assessment should be based on a thorough understanding of the key vulnerabilities of these habitats and ecosystems as well as hazard risks posed by climate change. Certain factors such as the ecological significance of the system, the magnitude and likelihood of climate impact, and the conservation and societal goals of the community (Stein et al. 2014) influence a community's risk and consequences faced by hazards such as droughts, flooding, heat, and wildfires. Since the consequences of climate impacts are not felt equally by all groups, involving a range of stakeholders, in particular underserved and marginalized groups, is crucial to ensuring multiple and diverse viewpoints are included in the decisions. Below, we highlight three case studies that provide a snapshot of some of many considerations required to understand the key vulnerabilities of natural assets and risks posed to the communities.

3.4.1 Beaches and Dune Systems on the Gulf Coast: Florida

Conservation and societal goals: Beaches and dune systems act as the first line of defense to coastal challenges of flooding and erosion to the heavily developed coastlines in the state. These systems also buffer the surge caused by hurricanes and tropical storms. In addition, the recreational opportunities provided by beaches add to their cultural significance. Finally, the state's societal values, such as the economic output generated by tourism and fisheries and population development along the coast, also influence key vulnerabilities in Florida.

Ecological significance: Beaches provide crucial nursery habitat for several vital species such as sea turtles, migratory waterfowl, and other coastal wildlife. The beaches in Florida harbor more than 12 species of threatened and endangered animals (sea turtles, beach mice, shorebirds).

Magnitude and likelihood of climate impact: The exact magnitude of climate impacts will depend on geography and beach characteristics. For example, beaches in the Gulf of Mexico coasts are more vulnerable to erosion than the Pacific Northwest and Alaska coasts due to a slow rate of sea level rise experienced in these regions (Sweet et al. 2017). Florida's sandy beaches with a gentle slope and no vegetation are prone to more erosion.

Potential stakeholders: Coastal resource managers, local fishermen, tourism businesses, local communities, academia, and decision-makers.

3.4.2 Urban Forests: Michigan

Conservation and societal goals: Urban forests provide a range of ecosystem services. Detroit's urban trees provide approximately \$24.3 million in benefits each year, including aesthetics, air quality, total net carbon sequestered and avoided, energy, and stormwater peak

flow (Rutledge et al. 2021). Black or African American residents make up the majority of the local population.

Ecological significance: Urban forests are critical to the food web as they provide habitat for a range of insect and bird species. Adverse impacts to the biomass or diversity of this wildlife due to loss of host plants can be consequential at all trophic levels.

Magnitude and likelihood of climate impact: Vulnerability will depend on projected temperature, shifts in seasonal patterns, and extreme precipitation events. Detroit is already observing warming at the rate of 0.4°F and increasing precipitation by 0.95 inches per decade since 1960 (Rutledge et al. 2021). Future vulnerability will depend on the adaptive capacity of tree species and global emission scenarios.

Potential stakeholders: Natural resource managers, community representatives, equity-based organizations, academia, and decision-makers.

3.4.3 Rangelands in the Southwest: Arizona

Conservation and societal goals: Arizona rangelands cover 85% of its land. These rangelands provide open spaces to control runoff and erosion, maintain soil water availability, influence the air, water, soil quality, and biological diversity. These rangelands are particularly important for native people who own 27% of these lands in the state. For the Navajo Nation sheepherders who rely on these habitats for food and livelihood, the rangelands play a central role in maintaining their traditional ways of living.

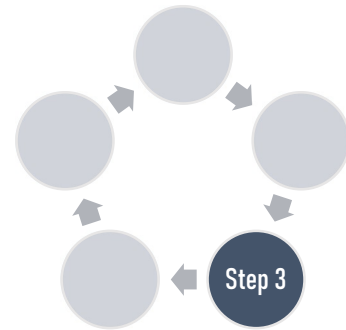
Ecological significance: These lands provide wildlife habitats for a range of birds, animals, and reptiles. The rangelands also support livestock such as bighorn sheep through grazing opportunities. The New Mexico meadow jumping mouse, an endangered species, lives in the rangelands' riparian vegetation.

Magnitude and likelihood of climate impact: As climate changes, rangelands will face diverse impacts to their function and composition. In the Southwest region, warming and reduced precipitation leading to decreasing soil water availability will negatively impact the plant species composition and phenology. In addition, more frequent and severe events such as droughts and wildfires can lead to the mass mortality of shrublands (Briske et al. 2015). Statistically downscaled climate projections for the Southwest project a temperature increase of 2 to 5°C in the region based on the global greenhouse gas emissions (Briske et al. 2015).

Potential stakeholders: Rangeland managers, tribal partners, herders, farmers, ranchers, academia, and decision-makers.

4 INVESTIGATE OPTIONS (STEP 3)

During Step 3 of the Steps to Resilience planning process, NbS options should be identified that have the potential to address one or more of the key vulnerabilities and risks to natural and community assets that were identified in Step 2. It can be helpful to categorize these options by the particular hazard types, such as inland flooding, coastal hazards, extreme heat and drought, and wildfires. Table 4 summarizes many of the approaches that may be relevant for consideration in a variety of common community plans, including hazard mitigation, stormwater management, integrated water resource management, and land use. Given that communities are likely to consider climate adaptation options in other types of plans or programs where multiple hazards may need to be addressed, this chapter also highlights potential NbS approaches relevant to the following key sectors: transportation, human health and social equity, ecosystems and biodiversity, and carbon sequestration and storage.



Key NbS Considerations for Step 3

- Consider equity implications in the design and application of NbS
- Ensure NbS yield net positive biodiversity benefits
- Seek to protect or restore key natural infrastructure
- Give natural features and processes space to function

Table 4. Examples of Nature-based Solutions for Hazard Risk Reduction

Natural hazard	Conventional approaches	Natural or nature-based approaches	Examples
Inland flooding	Dams, dikes, levees, stream channelization, stormwater sewers, combined sewers, pumps	<ul style="list-style-type: none"> • Floodplain and watershed restoration • Green stormwater management • Protecting floodplains from development 	<ul style="list-style-type: none"> • Levee setbacks and dam removal; wetland restoration • Rain gardens; permeable surfaces • Open space acquisition and protection; voluntary buyouts
Coastal hazards	Seawalls, bulkheads, dikes, breakwaters, levees	<ul style="list-style-type: none"> • Coastal habitat protection and restoration • Living shorelines • Protecting coastal areas from development • Moving people and infrastructure away from high-risk areas (“managed retreat”) 	<ul style="list-style-type: none"> • Protecting and restoring coastal wetlands; beaches, dunes, and barrier islands; coral and oyster reefs • Vegetation-only or combined vegetation and structural approaches (e.g., constructed marsh with sills or breakwater structures) • Voluntary buyouts; coastal open space protection

Extreme heat and drought	Dams and reservoirs, air conditioning	<ul style="list-style-type: none"> • Watershed restoration • Urban green infrastructure • Water conservation 	<ul style="list-style-type: none"> • Headwater stream and forest restoration; beaver restoration • Urban forestry; green roofs; cool pavement • Rainwater harvesting; xeriscaping; water-saving agricultural practices
Wildfires	Wholesale suppression of wildfires	<ul style="list-style-type: none"> • Ecological forest management • Learning to live with fire • Reducing edge development in fire prone habitat 	<ul style="list-style-type: none"> • Fuel reduction treatments; prescribed fire; post-fire restoration • Community planning and collaborative risk management; managed wildfire • Update land use/zoning

4.1 Nature-based Solutions by Hazard

4.1.1 Inland Flooding

There is growing recognition that the use of NbS for stormwater and flood management can effectively reduce risks from flooding and riverine erosion, in addition to providing other benefits such as improved water quality, recreational opportunities, and habitat for fish and wildlife. As described below, NbS approaches for flood risk reduction range from floodplain and wetland restoration and green stormwater infrastructure to policies and programs that help restore and protect existing natural systems by preventing new development in hazard-prone areas or encouraging people to move out of harm’s way.²

Floodplain and Wetland Restoration

Restoring streams, floodplains, and watersheds to reestablish their natural flows, ecological processes, and functions is one of the most important and beneficial strategies to reduce flood risks to communities, while providing considerable ecological and economic benefits. Approaches for restoring the ecological integrity of streams and floodplains include levee setbacks and dam removal in areas where those ecological systems have been altered, and wetland restoration throughout the watershed to buffer the impacts of floods. The most appropriate strategy for a given area will depend on the unique characteristics and conditions of the area being restored, as well as the desired management outcomes.

Levee setbacks and dam removal. In the wake of disastrous floods, many communities across the country have invested in efforts to make “room for the river” through levee setbacks, dam removal, and floodplain restoration. According to the U.S. Army corps of Engineers (USACE), the additional floodplain storage provided by levee setbacks reduces flood height and slows peak

² NbS approaches focused on managing stormwater runoff are also often referred to as “low-impact development” (LID), a term used to describe on-site green infrastructure systems or practices that leverage or mimic natural hydrological processes to reduce stormwater runoff and protect water quality.

flows, while also providing additional ecosystem and recreation benefits (Dahl et al. 2017). In Yuba County California, for example, the Three Rivers Levee Improvement Authority worked with the USACE to set back 9,600 feet of levees along the confluence of the Bear and Feather rivers, reconnecting 600 acres of flood-prone agricultural land to the floodplain (River Partners 2014). The project proved successful in capturing floodwaters and reducing risks to nearby communities after the Oroville Dam crisis in 2017, when damage to the main and emergency spillways during an extreme rainfall event prompted the evacuation of more than 180,000 people living downstream (Hollins et al. 2018).

Wetland restoration. Wetlands act as natural sponges, storing and slowly releasing floodwaters after peak flood flows have passed. Research suggests that a single acre of wetland can store up to 1.5 million gallons of floodwater (U.S. EPA 2002). Wetland restoration and protection efforts across the country have been shown to provide significant flood risk reduction benefits. For example, an assessment of flood reduction potential of wetlands in the Eagle Creek watershed of central Indiana found that they reduce peak flows from rainfall by up to 42%, flood area by 55%, and maximum stream velocities by 15% (Javaheri and Babbar-Sebens 2014).

Green Stormwater Management

Green infrastructure is an integrated approach to stormwater management that uses features such as rain gardens, green roofs, bioswales (i.e., vegetated trenches), and permeable pavement in strategic areas to capture stormwater runoff as close as possible to where it is generated. While conventional stormwater management approaches focus on speeding passage of water downstream, which can result in flooding and degraded water quality, green infrastructure approaches are specifically designed to slow the flow of runoff to facilitate absorption in soil and vegetation and take pressure off over-capacity sewage treatment plants. This is particularly important in communities that have older “combined sewer systems,” in which one piping system conveys both sanitary sewage and stormwater. Not only does green infrastructure help improve water quality by diverting and filtering pollutants, it can help mitigate surface flooding during storms, often as a significant cost savings. The following are examples of green infrastructure approaches:

Rain gardens. The use of rain gardens, which are planted depressions designed to allow runoff from nearby impervious areas to soak into the ground, has grown in popularity in communities across the country. Research has shown that rain gardens can significantly reduce runoff into storm drains, thereby increasing the capacity of existing drainage systems to handle higher rainfall volumes (Mahler et al. 2019). For instance, a study of a rain garden constructed in the Bronx, New York, found that the system retained an average of 78% of inflows during 26 storms over the period between October 2014 and July 2015 (Feldman et al. 2019).

Permeable surfaces. Increasing the area of pervious, or permeable, surfaces in urban and suburban areas, whether through enhancing vegetated areas or installing gravel or other porous materials, can significantly reduce localized flooding. According to Federal Emergency Management Agency (FEMA), the amount of runoff from a five-year storm (i.e., a heavy rainfall event that has a 20% chance of occurring each year) on a developed parcel can be greater than runoff from a 50-year storm if the parcel had not been developed (FEMA 2005).

Protecting Floodplains from Development

Keeping people out of harm's way is an important strategy for reducing the costs of major floods and enhancing the ability of floodplains to absorb floodwaters and lessen their destructive force. Strategies may include open space acquisition and protection and voluntary buyouts.

Open space acquisition and protection. Protecting open space from development can significantly reduce flood damage to nearby communities. For the conterminous United States as a whole, scientists estimate that preventing development in the more than 100,000 square miles of remaining unprotected natural lands that lie within the current 100-year floodplain would avoid as much as \$397 billion in potential flood damages to new development by 2050 (Wing et al. 2018).

Voluntary buyouts. In places where properties have been extensively and repetitively damaged by flooding, voluntary buyouts—acquisition and removal of properties in hazard-prone areas—can be a cost-effective response to reduce risks from further flooding (Siders 2019). Voluntary buyouts are frequently considered a critical step within a larger strategy of “managed retreat”, which refers to the purposeful movement of people, infrastructure, and other critical assets out of areas where there is a high likelihood of frequent, severe flooding (Spidaliere and Bennett 2020). A number of communities across the country have engaged in buyout programs in response to major flooding events, with the goal of reducing the number of buildings located in high-risk areas. For example, since 1999, the City of Charlotte and Mecklenburg County in North Carolina have overseen a voluntary buyout program that has combined the relocation of families and businesses from flood prone areas with subsequent stream and wetland restoration. As of September 2019, the program has spent \$67 million to acquire more than 400 properties and has restored 185 acres of the floodplain to public open space. The effort has helped communities avoid approximately \$25 million in property damage, and it is expected to prevent an estimated \$300 million in future losses (City of Charlotte 2019).

One thing that is important to recognize when considering voluntary buyouts as an option for communities is that, although buyout programs have been implemented for decades, they have often been done through piecemeal approaches that leave a patchwork of remaining structures and vacant lots, which do not offer the flood reduction benefits that larger green space could provide (Mach et al. 2019). It is also important that buyout programs be founded on sound social and ecological principles (e.g., Berke et al. 2014). For instance, decision-makers must incorporate the needs of the socially vulnerable into buyout programs, such as by taking measures to ensure that affordable homes and jobs are available in areas where people will be relocated (Siders 2019).

4.1.2 Coastal Hazards

Following two decades of particularly destructive tropical storms and hurricanes, coastal communities are expanding their tools for keeping people safe and protecting property and infrastructure. Although hard armoring continues to expand along populated coastal areas across the country, communities are increasingly embracing natural infrastructure as part of the solution (Gittman et al. 2016). Approaches range from protection and restoration of natural systems and use of living shorelines to voluntary buyouts and protection of coastal open space.

Coastal Habitat Protection and Restoration

Coastal habitats, such as freshwater and salt marshes, mangrove forests, beach and dune complexes, and coral and oyster reefs, can provide significant risk reduction benefits to coastal communities (Rezaie et al. 2020). For example:

Coastal wetlands. Coastal wetlands, which include salt marshes, bottomland hardwood swamps, fresh marshes, mangrove swamps, and evergreen shrub wetlands, currently cover about 40 million acres and make up 38 percent of total wetland acreage in the conterminous United States (U.S. EPA n.d.). Together, these systems can significantly reduce the impacts of a variety of coastal hazards on nearby communities. A recent analysis of all 88 tropical storms and hurricanes that impacted the United States between 1995 and 2016 found that affected counties with greater areas of wetland coverage experienced significantly less property damages than those with little or no wetlands (Sun and Carson 2020).

Beaches, dunes, and barrier islands. By their very nature, beaches, dunes, and barrier islands are dynamic systems—as such, efforts to protect and restore these systems to provide benefits to communities may require periodic sand nourishment and plantings to persist and keep pace with rising sea levels and more intense storms. Despite this, the risk reduction and other benefits of such restoration can significantly outweigh the costs. For example, research suggests that large-scale restoration of barrier islands in Louisiana and Mississippi would reduce wave heights by up to 90% and slow peak storm surge by up to two hours relative to what would occur during comparable hurricanes with the barrier islands in their current state (Oliver and Ramirez-Avila 2019). Thus, these systems offer important first lines of defense for coastal communities.

Coral and oyster reefs. Natural coral and oyster reefs act as breakwaters that reduce shoreline erosion and attenuate wave height and energy as waves move landward. Indeed, these systems have been found to provide substantial risk reduction benefits both globally and here in the United States (Ferrario et al. 2014). Scientists estimate that, under various scenarios for coastal storms, the presence of coral reefs along parts of the U.S. coastline reduce flood risks for more than 18,000 people and save more than \$1.8 billion in avoided damages (Storlazzi et al. 2019).

Living Shorelines

Living shorelines refer to a range of shoreline stabilization techniques to reduce erosion through the use of ecological approaches, as opposed to strictly gray infrastructure (NOAA 2015). Living shorelines typically serve to reduce shoreline erosion in ways that enhance habitat value and support natural coastal processes, while also providing added storm protection—often at a lower cost than conventional armoring. A living shoreline generally incorporates natural materials, such as vegetation, rocks, and shells, either used alone or in combination with engineered structures for added stability.

Vegetation only. In some areas, enhancing vegetation in degraded areas or creating vegetative cover in non-vegetated tidal areas can be sufficient to reduce wave height and erosion (Subramanian et al. 2008). For example, field observation research in the Chesapeake Bay found that areas planted with *Spartina alterniflora* demonstrated significant wave attenuation capacity during storms (Garzon et al. 2019). During a 100-year storm, the marsh was found to reduce wave height by 70%.

Combined vegetation and structural approaches. Commonly used structural components include constructed reefs, sills, revetments, and bio-logs (e.g., coir or fiber logs). Often used in more high-energy systems, such approaches can cost-effectively reduce risks. For example, a comparative cost analysis of ten shoreline protection measures in the Hudson River estuary found that, under a scenario of rapid sea level rise, sites with ecologically enhanced features such as vegetated geogrids (i.e., successive layers of soil wrapped in geotextile fabric) and rock sills would have significantly lower maintenance, damage, and replacement costs when compared with those with hard armoring (Rella and Miller 2014).

Protecting Coastal Areas from Development

Protecting and restoring natural open space offers one of the best opportunities to reduce risks to coastal communities while maximizing additional benefits such as habitat for fish and wildlife and opportunities for people to enjoy nature. Strategies can include voluntary buyouts and restoration of acquired lands as well as policies and programs to protect coastal open space from new development in current and future hazard-prone areas.

Voluntary buyouts. As is the case in areas where properties have been heavily damaged from inland floods, some coastal areas are engaged in voluntary buyouts and property relocation to protect both people and assets (often called “managed retreat”). These steps will likely become unavoidable in some areas along the U.S. coastline as sea level rise increases risks from erosion, storm surge, and tidal inundation (Fleming et al. 2018), and managed retreat through proactive relocation of people, buildings, and other infrastructure can result in more equitable and cost-effective long-term benefits in areas where climate change would otherwise cause unavoidable damage and injury or loss of life (Spidalieri and Bennett 2020). Several communities have already begun removing properties damaged or destroyed by erosion and flooding and investing in habitat restoration efforts to enhance coastal resilience. For example, the City of Pacifica in San Mateo County, California, has been partnering with local land trusts and other nongovernmental organizations to purchase and remove vulnerable structures and invest in marsh restoration to address worsening erosion and flooding along the community’s beach (Estuary News Magazine Team 2013). Although the project required considerable upfront investment to implement, it had widespread support from local government leaders and the public and will ultimately save the community money in avoided losses.

Coastal open space protection. There are a number of lands in both current and projected future high-risk areas that could be protected from further development, which not only would avoid risks to people who otherwise might inhabit those areas, but would also provide natural buffers for existing communities and support the preservation of wildlife habitat (Berke et al. 2014). For example, a 2009 study of “intermediate lands” (i.e., areas characterized as low-density development, such as some agricultural lands, but with expected future development) found that conservation easements, land acquisitions, zoning regulations, transfer of development rights, and other non-structural measures could effectively limit development and reduce risk along the Atlantic Coast for areas below 3.2 feet in elevation (Titus et al. 2009).

4.1.3 Extreme Heat and Drought

A number of NbS approaches can be effective in mitigating extreme heat and drought, often in tandem. Strategies range from watershed restoration and urban green infrastructure to water conservation at a variety of scales.

Watershed Restoration

Efforts to restore and protect ecological systems throughout watersheds is essential to sustain water supplies to communities. In particular, protecting headwater streams and forests and restoring beavers to upstream areas can provide a range of benefits to communities in periods of drought.

Headwater stream and forest restoration. Because of their connection to groundwater, wetlands, and subsurface water flows, headwater streams are particularly important for maintaining base flow in larger streams. In the conterminous United States, headwater streams comprise 79% of total river length, and they directly drain more than 70% of land area (Colvin et al. 2019). In addition, forested areas within watersheds support the hydrologic system by collecting and filtering rain and snow and releasing water into rivers, streams, and groundwater aquifers. Forests alone provide about 50% of the surface water supply in the West, and up to 35% of consumed water in the South (Brown et al. 2008, Caldwell et al. 2014). In California, for example, so-called “source watersheds” (i.e., the forests, meadows, and streams that supply water to its reservoir) are considered, by law, as an integral part of the state’s water system infrastructure. Scientists estimate that restoring natural water infrastructure through activities such as prescribed fire and restoration of natural stream channels in five of the state’s major watersheds could yield an average of 300,000 acre-feet, or almost 100 trillion gallons of water annually (Pacific Forest Trust 2017).

Beaver restoration. In addition to supporting numerous species of fish and wildlife, beaver-created wetlands can recharge groundwater, sustain summer water flows, provide natural firebreaks, and reduce downstream flood risk by slowing and retaining floodwaters (Norman et al. 2019). Given this, there has been growing interest in restoring beavers to portions of their former range or implementing “beaver mimicry” by installing instream features that play a similar role in stream geomorphology and hydrology (Pilliod et al. 2018). A number of studies have demonstrated the increased water storage benefits provided by beaver restoration projects. For instance, a study of wetlands and beaver activity over a 54-year period in eastern Alberta, Canada, found that during wet and dry years, the presence of beaver populations was associated with a 9-fold increase in open water when compared with a period when the animals were absent from those sites (Hood and Bayley 2008).

Urban Green Infrastructure

Expanding the area of trees and other vegetation in cities is considered to be one of the most effective and least costly approaches to reducing the urban heat island effect (i.e., an increase in air temperature in cities relative to surrounding areas) (Livesley et al. 2016). Urban green infrastructure approaches may include urban forestry, the use of green roofs, and cool pavement.

Urban forestry. Establishing a tree canopy, in particular, can reduce local temperatures by providing shade. In addition, trees, grass, and other vegetation can reduce heat through the process of evapotranspiration, which draws heat from a surface when liquid moisture is converted into vapor (e.g., Feng 2018). According to the U.S. Environmental Protection Agency (U.S. EPA), shade provided by trees can reduce surface temperatures on exterior walls and rooftops by as much as 45°F, and it can reduce a building’s interior temperature by reducing the amount of sunlight that passes through windows (U.S. EPA 2008).

Green roofs. A “green roof” consists of a waterproofing membrane, a growing medium such as soil, and vegetation along a structure’s rooftop to provide a range of environmental benefits (GSA 2011). Using green roofs in urban areas can help moderate the urban heat island effect, particularly during daytime hours (U.S. EPA 2008). For example, a comparison of temperature data collected at a green roof site and nearby black roofs in the New York City area found that a green roof offers a demonstrable cooling benefit. In particular, peak temperatures on green roofs were, on average, 60°F cooler than black roofs during summer (Gaffin et al. 2010, Culligan et al. 2018).

Cool pavement. The use of so-called “cool pavement” as an alternative to conventional materials, such as impervious concrete and asphalt, also has been shown to reduce outdoor air temperatures, often at a lower cost than green roofs. Current cool pavement approaches, which may entail using lighter-colored and permeable materials, can reduce the amount of heat that is absorbed and stored compared to conventional pavement (Liu et al. 2018, Sen and Roesler 2017).

Water Conservation

Reducing water consumption is an important approach to improve water security in communities faced with frequent drought. Strategies may include conserving water by capturing rainfall for reuse, using less water in landscape management, and encouraging landowners to replace lawns with native, drought-resistant plants. In addition, farmers across the country have found that certain practices, such as no-till farming and use of cover crops, can reduce their annual water requirements.

Rainwater harvesting. In general, rainwater harvesting involves collecting runoff from impervious surfaces such as roofs, driveways, and parking areas and putting it into systems such as rain barrels and cisterns. Although results vary by rainfall levels, the size of the drainage area, and water use patterns, in some regions, a single 50-gallon rain barrel installed at a residential parcel has been estimated to provide as much as a 50% water-saving efficiency for non-potable indoor water demand (Steffen et al. 2013).

Xeriscaping. Outdoor irrigation is the single largest residential end use of water in the United States. Thus, water utilities across the country are seeking ways to reduce outdoor water use through a variety of programs. Xeriscaping, which is the practice of replacing lawns and other irrigation-dependent landscapes with drought-tolerant plants, mulch, and efficient irrigation, is being incentivized through innovative programs by a number of utility providers. In southern Nevada, for example, a five-year study showed that homes that had converted turf lawns to

xeriscaped landscapes saw a 30% annual reduction in total household water use, equating to nearly 100,000 gallons annually (Sovocool et al. 2006).

Water-saving agricultural practices. As droughts have continued to worsen across much of the country, farmers are seeking cost-effective approaches, such as no-till farming and using certain types of cover crops, to manage water resources. For example, following the extensive 2012 drought, which affected more than 80% of agricultural lands nationwide, farmers using cover crops with corn experienced about 79% of typical yields, more than 10% more than those not using cover crops (O'Connor 2013, Bergtold et al. 2019).

4.1.4 Wildfires

Wildland fire management in an era of climate change can have several objectives, including reducing risks to people and property and enhancing the health and resilience of ecosystems. Nature-based approaches for wildfire risk reduction range from ecological forest management practices, such as restoring natural fire regimes (including letting fires burn where safely possible), thinning, and prescribed fire, to policies and programs that help communities adapt to a fire-prone landscape.

Ecological Forest Management

Ecological forest management may include the application of strategic thinning, prescribed fire, and managed wildfire to reduce the risk of high-severity wildfire and promote healthier, more resilient forests (Stephens et al. 2016, Kelsey 2019). Done thoughtfully, the approach can help balance tradeoffs between short-term impacts of treatment (e.g., emissions of carbon dioxide) with long-term benefits of reduced risks of large, high-severity fires. Further, restoring ecological functions of forest systems can protect water resources and reduce flooding in communities within the watershed. Treatment prescriptions vary depending on treatment objectives (which should be clearly established early in the planning process) and forest type. The following are examples of ecological forest management to reduce wildfire risk:

Fuel reduction treatments. Targeted fuel reduction treatments such as mechanical thinning and the use of fuelbreaks (i.e., areas where vegetation is reduced near structures) have been found to significantly reduce the severity of wildfires, as measured by tree mortality, in addition to limiting the loss lives and property. For example, in 2018, the Golf Course Fire west of Grand Lake, Colorado, caused the evacuation of 300 homes as it burned, but no lives or structures were lost due to the success of prior strategic fire management planning and risk-reduction measures that included removal of beetle-killed trees and creation of fuelbreaks on more than 200 acres of land adjacent to subdivisions that were ultimately impacted by the fire (Colorado State Forest Service 2018).

Prescribed fire. Prescribed fire, which entails the deliberate application of fire in ecological systems to achieve a variety of management goals, has proven to be an effective tool in reducing the areal extent and severity of wildfires across a range of forest types. In Fort Benning, Georgia, for instance, researchers evaluated a 30-year record of wildfire, prescribed fire, and drought to determine how prescribed fire has affected wildfire incidence in the region (Addington et al. 2015). From 1982 to 2012, there was an overall increase in the area burned by prescribed fire

corresponding with Fort Benning’s increased use of fire for meeting both fuel reduction and ecosystem management objectives. Over the same period, wildfire incidence declined, and annual wildfire incidence appears to have stabilized at or below 100 wildfires per year, in contrast to the 300-500 annual wildfires earlier in the record.

Post-fire restoration. Certain forest and other wildland management practices may also reduce risks to nearby communities from flooding and landslides following high-severity wildfires, which can burn away much of the vegetation that holds soil in place and slows runoff (Garfin et al. 2016). Risks can remain significantly higher in severely burned areas until vegetation is restored, which can take years to decades (Floyd et al. 2019). Post-fire treatments, such as application of mulch and erosion barriers and aerial seeding with native grasses and other plants may be necessary to mitigate runoff and erosion (Robichaud et al. 2020). For example, an evaluation of post-fire treatment after the 2012 High Park Fire in the Poudre River basin of Colorado found that areas seeded with a native perennial grass mix had greater vegetation cover one year after the fire than unseeded control areas. In addition to helping reduce erosion, the seeded areas had significantly fewer weeds than control areas (Miller et al. 2017).

Learning to Live with Fire

From a risk management perspective, neither pre-fire treatments nor post-fire management stop fire—they only change fire behavior (Calkin et al. 2014). Thus, if the goal is to keep wildfire out altogether, it is likely to be unobtainable. Accordingly, there is growing recognition of the need for communities to learn to live with and adapt to fire (McWethy et al. 2019). Better community planning, including building codes and zoning regulations as well as proactive evacuation planning, can improve public safety and reduce property damage in the event of wildfire. Strategies may include creating “defensible space,” such as through development of firebreaks (i.e., areas cleared of vegetation), and “home hardening,” which consists of renovating existing structures and ensuring that new structures are built with fire-resistance in mind. It will also be necessary to allow some wildfires to burn, particularly where the risks to human communities are low.

Community planning and collaborative risk management. Across the country, efforts aimed at helping communities live with fire have been driven by both regulations (e.g., codes and ordinances) and voluntary, incentive-based approaches. Effective wildfire risk reduction strategies need to focus not just on strategies to reduce impacts to properties and infrastructure, but also on wildfire emergency response to reduce risks, such as identification of effective evacuation routes and emergency shelters (Steelman and Nowell 2019). To minimize future risks, it will also be important to discourage new development in areas where the wildfire hazard is high (Schoennagel et al. 2017). Doing so can offer a variety of benefits. For example, a simulation of housing growth in San Diego County, California, suggests that purchasing conservation lands to prevent development would offer both fire risk reduction and biodiversity benefits, regardless of whether those lands were chosen because of high fire hazard or high species richness (Syphard et al. 2016). Zoning codes can also be updated to prevent development in high-risk zones, such as steep hillsides within the wildland-urban interface (WUI; i.e., along the edges of existing development), or to disincentivize redevelopment of areas where the risk of

another fire occurring is very high. On a community level, expansion of programs such as FireWise Communities USA can help community members and promote measures known to reduce fire risk, such as removing potential fuels around homes and businesses (Kramer et al. 2018).

Managed wildfire. Allowing wildfires to burn naturally, with suppression only under defined management conditions, is increasingly being considered as an important approach to restoring natural fire regimes in the West. This approach differs from prescribed fire in that it relies on natural ignition events, with suppression done only in instances where other management goals, such as community safety, are jeopardized (Schoennagel et al. 2017). The approach has been found to yield significant long-term benefits in Yosemite National Park, which has experienced 40 years of managed wildfire. In addition to reducing the risk of catastrophically large fires, managed wildfire in the park has contributed to an increase in landscape heterogeneity and likely increased resilience to fire and drought (Boisramé et al. 2017).

4.2 Nature-based Solutions for Other Sectors/Concerns

4.2.1 Transportation

Transportation infrastructure across the country, including roads, bridges, parking lots, railroads, and other features, are at risk from a variety of hazards, from flooding and damage from storms and wildfires, to buckling during extreme heat events. Further, having safe and reliable access to transportation is essential to facilitate evacuations of communities in harm's way. Although much of the nation's transportation infrastructure has been designed to accommodate historical hazards, such as through use of culverts and storm drains, bridge elevations, and other conventional engineering approaches, the growing risks associated with climate change have rendered infrastructure in many areas increasingly vulnerable to damages. In addition, the use of impervious and unreflective surfaces on many roads and parking lots exacerbates runoff during storms and exacerbate the urban heat island effect.

In light of these problems, a number of communities have sought to address risks to transportation infrastructure through NbS. In coastal areas, for instance, communities have used approaches such as beach nourishment, marsh creation with breakwaters, constructed dunes, and road relocation, to address both flooding and erosion (FHWA 2018). In areas at risk from inland flooding, damages can be reduced to both infrastructure and nearby communities through various green infrastructure approaches, such as using permeable materials and rain gardens.

In Portland, Oregon, for example, investments in “green streets” (i.e., the use of pervious surfaces in streets and alleyways), along with rain barrels and tree planting, have been estimated to be 3-6 times more effective in managing stormwater per \$1000 invested compared with conventional, gray infrastructure methods (Foster et al. 2011). The city's green street projects retain and infiltrate nearly 43 million gallons per year and have the potential to manage as much as 8 billion gallons—40% of Portland's annual runoff volume (Foster et al. 2011).

4.2.2 Social Equity and Human Health

In addition to reducing the risks of injuries and death resulting from natural hazards, NbS can also offer health benefits more broadly. For example, access to urban green space—defined broadly as areas that are well-maintained, properly configured to support tree health, and designed in a way that appeals to urban dwellers— has been shown to considerably enhance human health by reducing chronic disease, promoting mental well-being, and providing safe places to exercise (Jennings et al. 2017, Kondo et al. 2018). Yet, across the United States, significant disparities exist among populations, with factors such as race/ethnicity, socio-economic status, and geographic location limiting access to such spaces to many people (Jennings et al. 2017). To address this challenge, a number of communities are looking at ways to enhance urban green space to vulnerable populations to promote health and social equity.

For example, the Proctor Creek Watershed in Atlanta, Georgia, had long been plagued by pollution and stormwater management challenges, in addition to experiencing high crime rates, unemployment, and divestment of public resources in infrastructure (Jennings et al. 2017). To address these challenges, community leaders partnered with Park Pride, a local parks advocacy organization, to include parks and green infrastructure elements, such as rain gardens and bioswales, in the upper watershed. The project has improved environmental conditions and has enhanced community engagement with nature.

4.2.3 Ecosystems and Biodiversity

Conservation of ecosystems and biodiversity is an important American value, and communities across the country are engaged in efforts to reduce human-caused stressors and enhance ecological systems for a variety of benefits. As noted above, in addition to the protective value of many natural systems for reducing hazard risks, healthy ecosystems support habitat for fish and wildlife, provide food, water, timber, and other natural resources, offer recreational opportunities, and support local economies. Indeed, the many ecosystem services provided by natural systems are a reason why NbS approaches are especially important and valuable.

At the same time, however, natural systems themselves are at risk from changing climatic conditions. Indeed, the combination of climate change and non-climate stressors have already degraded ecosystems in many areas and significantly reduced their natural adaptive capacity (Seddon et al. 2020). Given this, conservation practitioners across the country are increasingly engaged in efforts to address the impacts of climate change on species and ecosystems through climate-smart conservation (Stein et al. 2014).

Whether communities are focusing on restoring or protecting certain ecological systems for risk reduction benefits or other wildlife or natural resource-related goals, the development of climate adaptation strategies and actions will be essential to ensure that those benefits will endure for as long as possible. For NbS, this may entail strategies such as choosing plants that are likely to thrive in both current and future climatic conditions when restoring a forest (Butterfield et al. 2017); artificially seeding coral reefs where there is low natural larval supply due to coral bleaching (NAS 2019a); and beneficial use of dredge materials to facilitate marsh accretion under rising sea levels (Bridges et al. 2015).

4.2.4 Water Quality

While each of the climate-related hazards highlighted above can adversely affect water quality, a variety of NbS approaches can ameliorate the impacts. For example, restoration of natural floodplains has been found to improve water quality by trapping and filtering sediments, nutrients, and pathogens, which can be exacerbated by extreme runoff and development throughout the watershed (Richardson et al. 2011). This increased run-off or other climate-related changes in local hydrology can also result in regulatory non-compliance due to exceedance of regulatory thresholds for total maximum daily loads of priority pollutants (Murphy 2010) as well as Combined Sewer overflow events. These types of regulatory violations are costly for local communities in terms of fees and required modifications, as well as damaging to the receiving water ecosystems and the services they provide.

As noted above, green infrastructure for stormwater management, including rain gardens, green roofs, and other features, can reduce the potential for combined sewer overflows during heavy downpours, which can lead to the release of sewage and other harmful pollutants into surface waters (e.g., Chen et al. 2019). In addition, certain design and construction considerations for rain gardens, such as various amendments in soil media and an emphasis on plant-based mechanisms such as absorption and filtration can remove pollutants from urban runoff and recharge groundwater (Sharma and Malaviya 2021).

In some areas, ecological forest management has proved effective in avoiding negative watershed and water quality consequences of severe wildfire (Rhoades et al. 2019). For example, post-fire management, such as application of mulch, not only reduces soil loss and the potential for landslides, but it can also help improve water quality in other ways, such as through a reduction in carbon and nitrogen transport (Pierson et al. 2019). Further, by altering the chemical composition and thickness of forest detritus, prescribed burning and other forest management practices in coastal plain forests have been shown to reduce leaching of dissolved organic carbon and total dissolved nitrogen when compared to unmanaged watersheds (Majidzadeh et al. 2019). Additionally, NbS that can reduce climate impacts can decrease the use of chemicals (e.g., fertilizer, pesticides, flame retardant) that when applied to the landscape can all adversely affect water quality.

4.2.5 Carbon Sequestration and Storage

As noted in the Introduction, in addition to the growing attention to NbS for hazard risk reduction, people are also increasingly focusing on natural solutions for climate mitigation. Natural climate solutions harness nature's inherent ability to sequester atmospheric carbon in soils, water, and living organisms (NWF 2020). Many of the ecological systems and NbS approaches described above also have the potential to sequester and store considerable amounts of carbon, offsetting emissions from burning fossil fuels and other sources (NWF 2020).

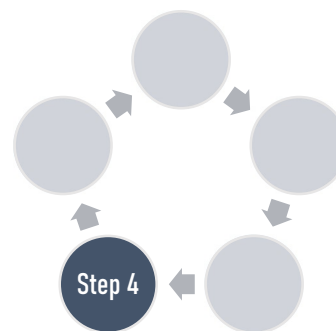
For example, in 2018, U.S. forests sequestered more than 750 million metric tons of carbon dioxide equivalent (MMT CO₂ eq.) (U.S. EPA 2020). Urban trees alone store an estimated 643 MMT of carbon, and they currently sequester an estimated 25 million tons annually (Nowak et al. 2013). Climate-smart agricultural practices such as cover cropping, reduced tillage, rotational grazing, and diversified cropping systems have the potential to sequester carbon while also

providing benefits for soil, water, and wildlife. Fully implementing these practices could remove as much as 100-200 MMT CO₂ annually by 2050 (Mulligan et al. 2020). Further, oceans and coastal ecosystems, including mangroves, seagrass, and salt marshes, also play a valuable role in mitigating climate change. These repositories of “blue carbon” sequester more carbon per unit area than forests, and they can store carbon in their soils for centuries (NAS 2019b).

It is important to note, however, that there may be significant trade-offs between managing lands and water for carbon sequestration and other values, such as biodiversity conservation. For instance, growing trees or planting fast-growing invasive species in a grassland ecosystem may maximize carbon sequestration but cause negative impacts to grassland birds, pollinators, and other native wildlife. Natural carbon sequestration efforts should always be compatible with other ecological values and never undermine natural ecosystem resilience or the services and benefits natural systems provide.

5 PRIORITIZE AND PLAN (STEP 4)

Brainstorming in Step 3 can result in a long list of options, which may benefit different goals at different times under different conditions. Determining which actions are most appropriate to take and when is an essential step in the path to resilience. It is also useful in this step to begin to consider how you would evaluate the effectiveness of the action or actions you select in order to determine if modification is needed and share your outcomes with others.



The U.S. Climate Resilience Toolkit (USCRT) lays out several key questions to help in the evaluation and prioritization process:

- **Value:** Will the action reduce risk?
- **Trade-offs:** With limited resources what is possible?
- **Planning:** Timelines and milestones that mark and measure progress
- **Decision Points:** Will the action protect what you value?

These questions are relevant to determining if any particular adaptation action is appropriate, but can also be used to determine if NbS approaches are appropriate, are better suited than a conventional approach, and/or are capable of providing additional benefits to human communities and/or ecosystems. Based on this four-part evaluation framework, Table 5

Key NbS Considerations for Step 4

- *Recognize natural systems and processes as critical infrastructure*
- *Consider climate impacts on priority natural assets*
- *Consider equity implications in the design and application of NbS*
- *Ensure NbS yield net positive biodiversity benefits*
- *Seek to protect or restore critical natural infrastructure*
- *Give natural features and processes space to function*
- *Integrate nature-based solutions into existing planning processes*

summarizes guiding questions for prioritizing nature-based solutions, along with some specific questions that reflect the Key Considerations for NbS.

Table 5. Summary of Guiding Questions to Prioritize Nature-based Solutions

	Action
Value	<p>Will this action reduce risk (e.g., flood control, fire control, heat reduction) and achieve desired outcome (e.g., transportation, housing, drinking water, food security, ecosystem function)?</p> <p>Will this action reduce risk for the target community?</p> <p>Will this action reduce risk for the ecosystem upon which its function is dependent?</p> <p>How will this action enhance or benefit the associated ecosystem?</p> <p>What is the long-term or life-term cost differential (including but not limited to dollars, personnel hours, greenhouse gas emissions) between the NbS and non-NbS action options?</p>
Trade-offs	<p>With limited resources what is possible?</p> <p>Might an NbS offer a lower-cost alternative to reduce risk, including installation, maintenance and future modification?</p> <p>How might a hybrid NbS/non-NbS strategy be appropriate?</p> <p>Are there any potential mal-adaptations or unintended consequences (conflicts or harms to other community or ecosystem values, services or features)?</p>
Planning	<p>When do you want/need to implement the action?</p> <p>Do phenology or ecological thresholds impact timing of implementation?</p> <p>What needs to happen in order to implement?</p> <p>Do you have the resources required to implement the action?</p> <p>By when do you expect to see benefit from the action?</p> <p>How will you be able to you measure the benefit (or the harm) caused by the action?</p>
Decision Points	<p>What is the underlying goal you are trying to meet with this action and will the action meet that goal?</p> <p>When will you know if the action is working?</p> <p>Will the action need to be modified if conditions change?</p> <p>How can you adjust course if the action is not working?</p>
Key NbS Considerations	<p>Are you considering nature-based solutions as critical infrastructure in the form of ecosystem services and for the value of nature itself?</p> <p>Will climate change affect the natural assets upon which adaptation will rely?</p> <p>Were local stakeholders and residents part of planning and implementation?</p> <p>Are there equity implications in the design and application of your nature-based solution?</p> <p>Will your nature-based solution yield net positive benefits for biodiversity?</p> <p>Does your nature-based solution protect or restore critical natural infrastructure?</p> <p>Will your nature-based solution provide natural features and processes space to function?</p> <p>Can you integrate your nature-based solution into an existing planning process?</p>

As mentioned earlier, the value of NbS is not only for the community assets it can protect or the services it can provide, but also for the ecosystems and natural assets themselves. This means that in prioritizing adaptation options and developing plans, it is best to consider the direct and co-benefits of NbS, along with the full range of costs and cost savings that are the result of that broader array of benefits. In other words, NbS allows you to consider impact and benefit holistically rather than within the narrow frame of an individual project or myopic target.

5.1 Value

Nature-based solutions are no different than any other adaptation solution in that the primary goal for application is risk reduction, although they clearly have added benefits for the associated ecosystems. In order to understand if and how NbS is a good match for risk reduction in your system you need to, just as you would in the evaluation of any adaptation solution, determine its efficacy in similar situations and consider how it could be assessed in your application. There are three primary ways to determine if any given NbS will be suitable: modeling, field-based experiments, empirical evidence. Results from any one of these means can be a good starting point for identifying a good match. Additionally, the practitioners may be able to use the results of other groups modelling, field experiments or empirical data analysis to help make local prioritization and planning decisions.

Modeling. Models can be used to identify, design and evaluate possible actions for prioritization and planning. The [U.S. EPA Green Infrastructure Modeling Toolkit](#), for example, can be used to evaluate green and grey infrastructure management of water runoff from the project site to watershed scale. U.S. EPA also offers [basic guidance](#) on how to select a model to undertake such analyses. Modeling can be helpful for project designers, land use planners, decisionmakers and community members. Models can play a role in monitoring and evaluation by offering informed projects of how a system will respond that can then be confirmed with field-based experiments or other empirical evidence.

Field-based experiments. Field experiments to assess the effectiveness of NbS adaptation strategies in actual individual application is a vital element for determining if a particular solution may be appropriate. Models and lab experiments may contain assumptions that are based on our historic knowledge and not what is actually happening in a climate changing world—making field experiments also vital for updating models. For example, results from Silliman et al. (2019) indicated that in opposition to previous lab experiments, salt marsh vegetation can effectively reduce coastal erosion.

Empirical evidence. While models can provide projections of what might happen given assumed parameters and field-based experiments can allow us to assess the effectiveness of actions under controlled or limited conditions, empirical evidence can tell us how effective an adaptation action has been at decreasing risk and increasing resilience as the effects of climate change, or related hazards, are experienced. There is a good deal of empirical evidence on fire treatment (e.g., Fernandes 2015), water management (e.g., Heine and Pinter 2011) and ecosystem services as hazard insurance (e.g., Dallimer et al. 2020). Methods used for collecting empirical evidence can be the foundation of monitoring and evaluating how well an adaptation solution works after it is implemented.

In addition to understanding how NbS can address the risk of climate hazards, there is also value to be considered in relation to how use of NbS might interact with other social and ecological goals. In fact, as previously mentioned, the IUCN criteria (Cohen-Shacham et al. 2016) for project evaluation asserts that NbS should garner both social and ecological benefits.

Diversity, equity, and inclusion. From a local perspective, NbS can often result in increased or protected greenspace, natural features or revegetation. These features can improve mental and physical health outcomes for communities (Kardan et al. 2015) and often support social and ecological community cohesion that can be undermined by grey infrastructure solutions. NbS, when prioritized in underrepresented and marginalized groups, can reduce social vulnerabilities to climate change and build overall resilience in these communities. These same features, however, can result in neighborhood gentrification, which can reduce the affordability of housing and services, and displace people from community (Bockarjova et al. 2020). In an analysis of 119 planning documents from 19 U.S. cities, Hoover et al. (2021) found that most plans do not explicitly include environmental justice considerations in green infrastructure planning. It is necessary to take intentional actions to reduce potential adverse socio-economic effects of any NbS options while ensuring the benefits are felt by all. NbS should be prioritized in communities that are supportive of their implementation (Hoover et al. 2021).

Species and habitat protection and restoration. Using natural systems to achieve adaptation solutions for issues such as flood control, shoreline protection, or water treatment can also result in the protection or restoration of habitat, species preservation, and increased connectivity across landscapes that help both ecological function and species conservation.

Public health. NbS through use of increased vegetation and the creation of green space can improve local health outcomes by improving air quality both locally and regionally, decrease urban heat island effects that exacerbate climate induced heat stress, and increasing resident exercise and activity, including increasing non-motorized transit which further reduces greenhouse gas emissions.

The following (Sections 5.1.1 to 5.1.3) pose key questions to ask regarding “value” as part of these evaluations.

5.1.1 Risk and Outcomes

Will this action reduce risk (e.g., flood control, fire control, heat reduction) and achieve desired outcome (e.g., transportation, housing, drinking water, food security, ecosystem function)? There are a variety of tools for identifying NbS that are likely to support different risk reduction needs or support desired outcomes. Examples include:

- [Green Infrastructure Effectiveness Database](#) (NOAA) is a database of literature assessing the effectiveness of NbS. It is searchable by a host of parameters including hazard, infrastructure type, scale and location. While it does not provide condensed guidance, it can help users research options.
- [Joint Fire Science Program Fuel Treatment Effect and Effectiveness](#) (US Forest Service) conducts studies to assess the effectiveness of different fire fuel treatment approaches to

fire damage reduction. The site includes several case studies of specific treatment approaches, as well as basic overall findings from over two decades of research.

- [Innovative Drought and Flood Mitigation Projects](#) (FEMA 2017) evaluates the feasibility and effectiveness as well as benefits and costs for several NbS, including floodplain and stream restoration and green infrastructure. The associated “climate resiliency snapshots” can help identify which actions will reduce what risks, as well as a number of other factors relevant for prioritization such as effectiveness timeframe, feasibility, environmental consistency, economic reasonability, social/political acceptability, sustainability and financial need.
- [Engineering with Nature](#) (Bridges et al. 2018, Bridges et al. 2021), a U.S. Army Corps of Engineers product with a focus more on operational rather than ecological efficiency, includes a two volumes atlas of case studies highlighting NbS and hybrid solutions for flood risk that leverage a variety of ecosystems (e.g., beaches and dunes, wetlands, islands, reefs, riverine systems, floodplains) as well as techniques (e.g., use of vegetation and natural materials, environmental enhancement infrastructure).

Will this action reduce risk for the target community? Obviously, it is essential that an adaptation action reduce risk for the target community or goal. The effectiveness should be evaluated for both NbS and non-NbS options. Assuming that non-NbS options will be more robust than NbS options should not be a foregone conclusion as failures have been documented (Briaud et al. 2008, Gray et al. 2017, Koskinas et al. 2019).

In addition to how the action might directly reduce risk for the community’s desired outcomes, consider if NbS could add additional benefits related to other non-target climate risks (e.g., shading, water management, erosion reduction) or other community benefits unrelated to climate (e.g., recreation, open space, habitat for appreciated species, food security).

Will this action reduce risk for the ecosystem upon which its function is dependent? Designing an NbS that will have long-term efficacy requires incorporating measures that are also focused on ensuring the long-term viability of the ecosystem from which the NbS is derived. This can result in an array of additional benefits for the community and the ecosystem (e.g., non-target climate risk reduction, sustainability goals, water and air quality, reduction in invasive species, habitat protection, species protection). While these may or may not be in the direct interest of the planning process, they are likely to be valuable benefits for other partners or jurisdictions.

5.1.2 Ecosystem Benefits

How will this action enhance or benefit the associated ecosystem? At the core of effective NbS is a functional ecosystem, that can support greater natural responsiveness to changing conditions. Thus, an essential element of NbS design is the care and protection of the underlying ecosystem. This can include restoration, reintroductions, habitat protection or other ecosystem management techniques. To design these appropriately, the practitioners must not only define the risk reduction desired for the human community but the relevant benefits the ecosystem will also require to have suitable function. In fact, at the heart of NbS as defined by IUCN is the need for NbS to not only provide benefit for both people and biodiversity but also to directly benefit the ecosystem (Cohen-Shacham et al. 2016, Maes and Jacobs 2015).

5.1.3 Cost Difference

What is the long-term or life-time cost differential (including but not limited to construction, maintenance, greenhouse gas emissions, concomitant costs and benefits) between the NbS and non-NbS action options? Evaluation in a prioritization and planning process should never fail to consider the cost and benefits of NbS and non-NbS alternatives. This must also be done for the full scope of the costs and benefits since, as mentioned previously many of the NbS benefits will come from not only the targeted risk reduction but additional resilience provided by the associated functional ecosystem.

When FEMA (2021a) makes the “business case” for NbS they include a number of parameters that should be included in the beneficial valuation of NbS projects. These include the hazard mitigation benefits, as well as community co-benefits and cost savings. Co-benefits includes ecosystem services (e.g., improved water and air quality, improved water supply, healthier wildlife habitat), economic benefits (e.g., increased property value, improved property tax base, green jobs, improved triple bottom line), and social benefits (e.g., cooler local temperature, improved public health, added recreational space. Cost savings could include avoided flood loss, stormwater management, reduced drinking and water treatment costs. It should be noted that maintenance, retrofit and repair costs for NbS may also be considerably lower as “healthy, intact ecosystems are often adapted to natural disturbances such as floods and wildfire” with the “capacity to withstand or recover from extreme weather- and climate-related hazards and adjust to ongoing environmental change” (Glick et al. 2020). For more on the assessment of Cost-Benefit Analysis in relation to NbS, see Section 6.4.3.

5.2 Trade-offs

The following (Sections 5.2.1 and 5.2.2) pose questions to ask of regarding “trade-offs” as part of evaluations.

5.2.1 Limited Resources

With limited resources what is possible? As with any project resilience actions are limited by available resources, including planning for the long-term maintenance of the function of the action. It may often be that long-term resource to outcome value of NbS is higher since natural system can often respond to hazards whereas grey infrastructure tends to have discrete, pre-determined failure points that are often costly to adjust.

Might an NbS offer a lower-cost alternative to reduce risk, including installation, maintenance, and future modification? In making the business case for NbS, FEMA (2021a) offers three elements—the efficacy of hazard mitigation benefits, community co-benefits and community cost savings. These cost savings can come from not only from the avoided hazard damage (e.g., flooding, fire), but from reduced costs for services such as stormwater management and drinking water treatment. Savings include lower materials costs, reduced need for expensive below-ground excavation, less land disturbance, lower maintenance costs, and reduced need for additional infrastructure owing to inherent ecosystem functions (e.g., water filtration and storage).

How might a hybrid NbS/non-NbS strategy be appropriate? In most cases both green and gray strategies will need to be employed to achieve the desired suite of goals and maintain local community services. There are ways to maximize benefit from each (e.g., risk reduction, cost, longevity, co-benefits) when intentionally designing NbS and non-NbS systems together (Andersson et al. 2017, Liqueste et al. 2016)

5.2.2 Mal-Adaptation and Unintended Consequences

Are there any potential mal-adaptations or unintended consequences (conflicts or harms to other community or ecosystem values, services, or features)? There may be both social and ecological impacts from any adaptation solution (NbS or non-NbS) that are not desired. It is important to think broadly about these unintended consequences and reconsider design to reduce or eliminate them. This can include socio-economic impacts such as gentrification or community isolation, as well as ecological impacts such as ecosystem engineering that undermines natural function (e.g., use of invasive species, modification of hydrology or introduction of pollutants) (Seddon et al. 2020).

5.3 Planning

The following (Sections 5.3.1 to 5.3.3) pose questions to ask regarding “planning” as part of evaluations.

5.3.1 When to Act

When do you want/need to implement the action? Consider the timeline within which you are expect the solution to garner benefit. Is it just needed for the present year, the coming decade, or longer? This will have implications for not only the design of the solution (NbS or non-NbS) but also may determine which type of solution will be most cost and outcome effective. For example, if you are expecting flooding conditions in the next several months it would not be successful to begin a habitat restoration project. It may also not be realistic to undertake a hard infrastructure construction project. Rather it may require interim steps to ameliorate harm while allowing natural systems to take effect.

Do phenology or ecological thresholds impact timing of implementation? Just as grey infrastructure projects are generally not constructed during seasonal inclement weather, NbS implementation may need to be undertaken during the right timing if it requires a restoration element for example. It is important to consider how natural systems behave over time and under different conditions. It should be noted that NbS may be well suited to address seasonal impacts of climate change as natural ecosystem responses are already attuned to such fluctuations.

By when do you expect to see benefit from the action? Based on your knowledge of the potential solution options, you should determine when you expect to experience the benefit of the action, as well as the expected longevity of the action. What are the potential failure points for the NbS and non-NbS options? Can duplication of function be used to ensure there is a back-up plan at any identified failure point?

5.3.2 Enabling Conditions

What needs to happen in order to implement? Because of historic bias toward grey infrastructure solutions to environmental challenges, there may be specific hurdles for local implementation of NbS. It will be necessary to take this into account as part of your planning process and timeline. Issues may include legal requirements around risk reduction infrastructure, funding restrictions, insurance requirements, and unsupportive constituency perceptions. Ensuring positive local enabling conditions will be necessary to proceed with an NbS project.

Do you have the resources required to implement the action? As with any adaptation solution (NbS or non-NbS) you will need to carefully map out the needs of a project. Such as list includes constituent outreach (to identify needs and co-explore options), design, permitting, implementation, construction, maintenance, and monitoring.

5.3.3 Effectiveness

How can/will you be able to measure the benefit (or harm) caused by the action? Knowing the risk you are trying to reduce, the co-benefits you hope to garner and the possible adverse outcomes that could be caused, you can develop a list of metrics to track in order to determine the effect of your action. It is important to identify a set of metrics prior to implementation so that you can collect baseline data and develop a monitoring calendar to determine the required frequency of assessing these metrics over time. Additionally, you could consider tracking metrics at a “control site” where you do not implement the actions but is suspected to also be vulnerable to the same climate impacts.

5.4 Decision Points

The following (Sections 5.4.1 and 5.4.2) pose questions to ask regarding “decision points” as part of evaluations.

5.4.1 Meeting your Goals

What is the underlying goal you are trying to meet with this action, and will the action meet that goal? As with any adaptation action, it is necessary to clearly articulate what resilience goal or goals you are trying to achieve in order the proposed action can achieve that goal. Simply protecting open space or habitat will not necessarily confer the benefit you desire if the mode of action is clearly understood. This could be determined through modeling, field-based research or empirical data, including from traditional ecological knowledge (TEK).

When will you know if the action is working? While it is often presented that the effectiveness of climate change adaptation actions will not be seen for years or decades (NPS 2021), there can be opportunities to assess the on-going optimal function of the natural system (e.g., species composition, environmental quality) as well as events that can be observed as proxies for long-term climate impact (e.g., extreme weather events, local catastrophe) in the nearer term. Near and mid-term monitoring can also be useful for monitoring changing climate-related conditions around the resilience action (e.g., changing temperature, precipitation, pH, dissolved oxygen).

When evaluating efficacy and benefits it may be necessary to consider timing in relation to ecosystem cycles (e.g., seasonal, interannual) to ensure that accurate assessments are made. Assessing decision points will require more than a single data point, and very likely a variety of data from different times of the year across (and perhaps beyond) the area of interest.

5.4.2 Adjusting Course

Will the action need to be modified if conditions change? Knowing if modification of your plan or actions is required in order to ensure continuation of their desired benefits either requires identification of predetermined thresholds or monitoring to identify those thresholds. The same events that cause measurable impact in the near term (e.g., seasonal flooding, wildfires, near-term sea level rise), can be used as decision points for potential adaptive management-type modification. For example, in some cases managers have used certain amounts of sea level rise as indicators of the need for the next phase of management actions (Trulio et al. 2007).

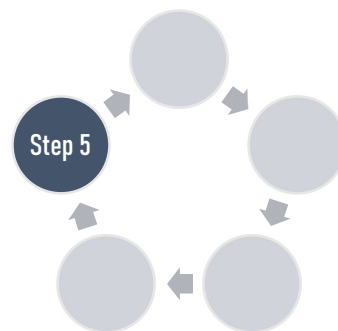
How can you adjust course if the action is not working? When a measure indicates that the action is not delivering the intended benefit or the ecosystem is being adversely impacted, it may be time to adjust course. This speaks to the need to develop not a single action in a resilience plan, but rather a suite of actions that are appropriate at different points along the anticipated trajectory of climate change impact. Again, this can also indicate the need for a hybrid approach that is both NbS and non-NbS.

5.5 Key Considerations for NbS for planning and prioritization

The Key Considerations for Use of Nature-based Solutions identified in Box 1 should also be used for criteria in evaluating adaptation options. Ideal and effective NbS will exemplify each of these key considerations. Table 5 includes representative questions to assess the inclusion of these considerations in the adaptation strategies being evaluated.

6 TAKE ACTION (STEP 5)

This section discusses opportunities for executing on-the-ground nature-based solutions. In most cases, it will often make more sense to integrate natural infrastructure projects into existing planning efforts, rather than embarking on a new and separate planning process. After mainstreaming, coordination across efforts, implementation and monitoring can move these projects from planning to action. However, a range of barriers can make implementation of nature-based solutions difficult to achieve. The section concludes by discussing some of the common implementation barriers, and ways to overcome them.



Key NbS Consideration for Step 5

- *Integrate nature-based solutions into existing planning processes*

6.1 Mainstream Nature-based Solutions Within Existing Planning Processes

One of the ways to ensure action on NbS approaches is to mainstream and integrate them into existing policy and planning processes. Mainstreaming helps implement NbS by taking advantage of already existing decision-making structures and funding streams within a community (Stein et al. 2014). This section highlights two examples of planning initiatives across the country that are well positioned to integrate NbS:

6.1.1 Hazard Mitigation Plans

A community's local hazard mitigation plan includes its potential hazards, mitigation goals, and specific actions and projects to mitigate those hazards. To receive funding from FEMA's hazard mitigation assistance grant programs, such as FEMA's Building Resilient Infrastructure and Communities (BRIC) program, proposed activities or projects must be consistent with a state's hazard mitigation plan. With programs like BRIC providing for a more significant annual investment in pre-disaster mitigation, ensuring NbS are incorporated into both state and local hazard mitigation plans is an important step. Initial rounds of BRIC funding have also prioritized nature-based features, providing further incentive for communities to explore these approaches.

Many hazard mitigation plans are now contemplating nature-based strategies. For example, in a study reviewing 103 local hazard mitigation plans, more than 60% of plans included some sort of nature-based mitigation actions (Kihslinger et al. 2021). Across the Gulf Coast, several counties had well-developed NbS goals and actions in their hazard mitigation plans, with counties in Louisiana, Mississippi, and Alabama having particularly well-developed mitigation actions (Environmental Law Institute 2020). Some of these actions, such as partnering with the Land Trust for the Coastal Mississippi Plain to preserve open space in Harrison County or creating bioengineered oyster barrier reef fringing the Biloxi Marsh in Louisiana's Orleans Parish, serve as good examples for other communities that are interested in incorporating nature-based actions in their mitigation action plans.

While some local hazard mitigation plans integrate NbS, the degree to which these strategies are developed in both local and state-level plans varies widely across communities and geographies. In future iterations of these plans, there are still opportunities to include specific NbS-related actions and prioritize their implementation, to ensure that such approaches will qualify for FEMA disaster funding (Kihslinger et al. 2021).

6.1.2 Comprehensive Land Use Plans

A community's comprehensive land use plan plays a vital role in guiding a city or county's future development and long-term vision. This is because the plans hold the legal authority to guide and influence community development over the next coming decades. The plans also provide an avenue to embed NbS, particularly green infrastructure concepts, in the local policy instructions and implementation ordinances right from the initial planning stages (Kim and Tran 2018).

Despite the growing need to utilize green infrastructure to balance urban development with ecological benefits, these concepts are not fully integrated into the local comprehensive plans. One recent study evaluated local comprehensive plans of 60 municipalities of the United States. It concluded that most jurisdictions have not sufficiently incorporated the key concepts of green

infrastructure planning, except Sumter County in Florida (Kim and Tran 2018). Similar results were found in coastal cities and counties of Texas, where local plans do not include specific goals or benefits of green infrastructure (Woodruff et al. 2021).

As cities and counties amend their local plans, there is a critical need to integrate green infrastructure to address their planning challenges. In their analysis, Kim and Tran (2018) found that local plans that were regularly updated and involved more qualified local planners performed better in incorporating green infrastructure principles. In addition, communities with limited technical and human capacities can leverage the expertise of groups such as the [Green Infrastructure Federal Collaborative](#) that can help develop resources, engage with the public, and advance the implementation of green infrastructure.

6.2 Coordinate Across Planning Efforts

One thing to be mindful of when working with communities is that coordination across multiple agencies and planning sectors, as well as collaboration with a diversity of stakeholders, will be essential to ensure that the use of NbS will be as effective and equitable as possible in reducing hazard risks and enhancing co-benefits (FEMA 2021a). Indeed, studies have revealed an important connection between various types of land use planning and resilience outcomes, where failure to coordinate across different planning efforts could lead to maladaptive outcomes (Berke et al. 2018).

For example, if a community chooses to implement a buyout program in an area prone to repeated flood events as part of its Hazard Mitigation Plan, but the community's Comprehensive Plan seeks to expand development in the same location, not only would the plans be incompatible, but the latter would increase the vulnerability of the new homes and businesses (Berke et al. 2018). To address this issue, Berke et al. (2015) offer a "plan integration for resilience scorecard" to help communities assess the degree to which its suite of plans can work together to address natural hazards in different geographic areas.

6.3 Implement and Monitor

Incorporation of NbS into plans is essential, but implementing, monitoring, and maintaining these projects are critical next steps. Implementation of NbS depends on stakeholder collaborations (see Section 2.5), planning (see Section 5.3), coordination (see Section 6.2), and the availability of funding options (see Section 7.1) that are discussed elsewhere in this guide. Additionally, careful consideration of monitoring and evaluation throughout the project's lifespan and beyond can help build public trust and support for NbS and facilitate upscaling (Kabisch et al. 2016; Albert et al. 2021).

Ideally, monitoring should be carried out before and after the implementation (Kumar et al. 2021). There are three main components to monitor NbS projects: (1) identification of project goals; (2) selection of relevant performance indicators/metrics; and (3) selection of appropriate measurement methods, tools, and sensors (Kumar et al. 2021). Several methods such as modeling, field-based experiments and empirical evidence are described in Section 5.1. In

addition, evaluation can be carried out quantitatively or qualitatively by comparing case studies, laboratory studies, and systematic literature reviews to assess NbS effectiveness.

NbS-specific indicators can be helpful in monitoring and evaluation as they allow for comparisons and measurements for project effectiveness. Several studies have emerged over the last decade that developed indicators and metrics for measuring NbS success (Kabisch et al. 2016; Kumar et al. 2021; Ordóñez et al. 2019). For instance, one study suggested quantitative data – peak discharge reduction for various flood event return periods (e.g., 10, 20, 50, 100 or 200 years), flood duration, and decline in the annual flood likelihood – collected from hydrometric stations, airborne and space-based observations for monitoring the performance and efficiency of nature-based flood mitigation actions (Kumar et al. 2021). While these indicators can be helpful in data-intensive communities, other communities can also incorporate a collaborative indicator development approach. For example, Kabisch et al. (2016) co-developed four sets of indicators for measuring NbS performance (centered on integrated environmental performance, human health and well-being, citizen involvement, and transferability) through participatory workshops with 34 expert stakeholders. When deciding NbS indicators for a specific community, the exact choice will rely on their particular location, climate risks, and availability of existing resources.

6.4 Overcoming Barriers to Action

To effectively implement NbS, it is crucial to identify, understand, and address the barriers that constrain the implementation of these options. Several barriers, such as ineffective public involvement, lack of political and financial support, uncertainty regarding implementation and effectiveness, and institutional fragmentation, hinder the successful uptake and implementation of NbS. This section explains the barriers relevant to the practitioners in more detail and describes possible solutions to address them. It is worth noting that the specific obstacles and challenges will depend on the socio-political context of a particular community.

6.4.1 Social and Cultural Context

Barrier 1. Public participation and acceptance. Lack of public participation and support to NbS as adaptation options will likely cause impediments to their adoption and long-term success. Factors such as inadequate information and concerns over the effectiveness of these solutions can cause this resistance among community members (Krauze and Wagner 2019).

Solution. Overcoming this barrier require mobilizing and informing communities of the risk reduction and multiple co-benefits provided by NbS. Practitioners can serve as a catalyst to bridge this knowledge gap by sharing case studies and examples that demonstrate the effectiveness of NbS and facilitating open dialogues about any uncertainty surrounding these solutions. For instance, in Sweden, municipal staff employed a range of strategic citizen involvement strategies such as planning walks, planning games, digital dialogues, and targeted media outlets to raise awareness of the potential of NbS (Wamsler et al. 2020). Resources such as NOAA's [Green Infrastructure Effectiveness Database](#) can also be leveraged to improve understanding and provide accessible information to the communities.

Barrier 2. Social equity and environmental justice. An active public participation process may not translate to a socially inclusive process. The resulting NbS outcomes may not always be just, particularly for the underrepresented groups of the communities. This can be driven by the exclusion of the perspectives from underrepresented groups, often overburdened and under-resourced, in the planning process that most high-income individuals dominate. Similarly, NbS, such as urban green spaces, have led to unjust outcomes, for instance, green gentrification, displacing lower-income racial minority populations by better-off inhabitants (Bockarjova et al. 2020).

Solution. Building equity considerations in the NbS planning, implementation, and monitoring processes can be the first and most crucial step towards alleviating these concerns. Equity, a “Key NbS Consideration” in this guidebook, can be applied through recognizing the rights and interests of different actors, building on inclusive and effective participation, and ensuring equitable distribution of costs and benefits amongst all the relevant actors (Albert et al. 2021). NbS designed with these considerations can reduce climate-related vulnerabilities for marginalized groups while providing additional co-benefits to support their overall resilience. Targeted outreach to support representation in the NbS planning process can help to monitor tradeoffs closely and ensure just benefits for all community members.

6.4.2 Institutional and Organizational Context

Barrier 3. Institutional fragmentation. Sectoral silos can be particularly harmful to the multifunctional NbS that require multiple perspectives and responsibilities that may not fit into the existing decision-making structures of local authorities (Ershad Sarabi et al. 2019; Kabisch et al. 2016). NbS projects require cross-cutting planning, coordination, and innovative thinking across different departments (urban planning, environment, emergency management, housing, etc.) that may be outside the realm of traditional agency structure and functioning.

Solution. The possible solutions will require a paradigm shift from business-as-usual planning to improve internal cooperation and intersection among various departments and agencies. While achieving these changes requires systemic change in how communities consider NbS, several practical steps can be taken to push these changes. Creating partnerships among different stakeholders by developing a shared understanding of NbS and their benefits have been recognized as the most significant driver of NbS implementation in the literature (Ershad Sarabi et al. 2019). Practitioners can facilitate the networking, communication, and integration of different stakeholders early in the planning process, for example, the community forest initiative in England bringing together six local authorities and charities, local businesses, and landowners to increase the region's existing canopy cover by 2050.

Barrier 4. Path dependency. Transitioning to NbS requires changing the familiar knowledge, which can cause fear of the unknown, making the most familiar solutions the preferred choice for implementation (Ershad Sarabi et al. 2019; Kabisch et al. 2016). This path dependency can be linked to urban planners and engineers trained with traditional hard infrastructure solutions such as levees and breakwater construction for addressing coastal erosion and other climate-driven

changes. These conventional approaches are also profoundly engrained in certain cultural contexts. For instance, seawalls are widely preferred and perceived as an effective adaptation response among four Pacific island nations (Narayan et al. 2020).

Solution. The solutions discussed earlier – bridging knowledge gaps and partnerships across stakeholders – can be crucial to address the societal and behavioral changes required to break the path dependency. During this transition, hybrid solutions where NbS is integrated with existing functional *gray* infrastructure can break the path dependency among the communities (Davies and Laforteza 2019). For example, despite the existing bulkheads, the Clear Lake Forest Homeowner Association community in Harris County, Texas, decided to construct a volunteer-led living shoreline with breakwater and marsh plants to control erosion that could withstand Hurricane Harvey in 2017.

6.4.3 Financial and Regulatory Context

Barrier 5. Financial resources and incentives. Another well-known and significant barrier to NbS is the limited financial resources for their implementation. The federal government is responding to this challenge by taking specific actions, for example, incentivizing nature-based projects through grants such as BRIC. While these grant programs can help accelerate NbS, upscaling and maintaining these solutions will require a continuous funding stream with targeted investments in disadvantaged communities.

Solution. Practitioners play a central role in leveraging these funding sources to manage their community's vulnerability and build resilience. In doing so, the practitioners should avoid relying on a single financial option and continue exploring new funding opportunities (See Section 7.1) and incentives (See Section 7.2) to support NbS in their community. In addition, supporting major federal funding programs and competitive grant programs identified in Section 7.3 can ensure continued allocations to these programs over the years regardless of the changes in political leadership.

Barrier 6. Policies and processes. NbS are dynamic systems that provide a multitude of benefits in addition to hazard risk reduction, including values like recreation, wildlife habitat, carbon sequestration, and water quality improvement, which may be more difficult to quantify through benefit-cost analyses (BCAs). NbS grow and adapt, providing more benefits as time goes on, with the ability to self-repair and adapt to climate stress – qualities that are not currently able to be captured by FEMA's BCA Toolkit calculations.³ Similar challenges exist with benefit-cost analyses in the Army Corps context. The Corps' BCAs typically do not capture critical benefits provided by natural infrastructure, especially when that infrastructure can lessen the impact of a future storm or natural disaster, and they fail to account for the costs of ecosystem services lost as a result of a structural project. Additionally, the agency's BCAs do not equitably evaluate

³ FEMA's BCA Toolkit is guided by policies like the Office of Management and Budget (OMB) Circular A-94, which prescribes a 7% discount rate for projects (OMB 1992). This OMB policy is often cited as a hindrance to approval of nature-based projects, as it artificially discounts nature-based project benefits by 7% every year based on the time value of money, rather than more accurately reflecting the continued and expanding services that nature-based solutions provide over time.

flood damage benefits provided to economically disadvantaged communities and communities of color, including by relying on home prices to value flood damage reduction benefits which can create significant barriers to the approval of critical projects.

Solution. Agencies such as FEMA are working to create a conducive policy environment for nature-based projects, though challenges in terms of BCA remain. For example, although FEMA recently updated its policy to facilitate more complete consideration of ecosystem services benefits in the BCA calculation, the list of ecosystem service benefits available for applicants to utilize in the BCA Toolkit remains somewhat limited. Additional guidance from FEMA and other federal agencies for applicants on how to document feasibility and effectiveness for nature-based projects to improve the quality and competitiveness of applications received will be important. However, practitioners and communities can guide and encourage local feasibility and effectiveness studies that are critical to informing benefit values for use with FEMA’s BCA Toolkit. This can be done through partnerships with local universities, public agencies, scientists, and experts to conduct research on the cost-effectiveness of NbS that can support BCAs and justify new investments (Kabisch et al. 2016). For example, Texas General Land Office worked with a technical group composed of experts from public agencies, private companies, and non-governmental organizations to create an Ecosystem Services Benefits Tool. The tool helps evaluate the benefits of ecosystem restoration projects for projects seeking federal grant funding that typically requires traditional BCAs as part of the application.

Barrier 7. Regulatory and permitting landscape. In some circumstances, the regulatory landscape itself – developed with structural infrastructure in mind – can disadvantage new, more innovative NbS. For example, despite the recent creation of an Army Corps general permit for living shorelines, in many states the permitting process for seawalls or bulkheads is still faster than that for living shorelines, a “softer” shoreline stabilization approach. This can be an active deterrent to a landowner or community looking for a quick erosion reduction solution (Hilke et al. 2020). Regulatory frameworks and permit requirements that were not designed with NbS in mind can also cause impediments to ecosystem priorities and NbS uptake (Seddon et al. 2020).

Solution. Adjustments must be made at all levels – from federal to local – to ensure that there is regulatory parity for NbS, and that existing laws and permitting requirements do not disadvantage such approaches from a timeline or cost perspective. Practitioners and their communities can be change agents in tackling this challenge by mainstreaming NbS into informal and formal planning regulations progressively (Wamsler et al. 2020). In Maryland, one of the pioneering states in living shorelines adoption, a project team funded on-ground living shoreline projects through Shore Erosion Control Law and collected continuous data to show their efficacy, leading to the Living Shorelines Protection Act in 2008. The act has been instrumental in requiring landowners to pursue living shorelines as the preferred method to reduce erosion unless they seek a waiver by demonstrating the ineffectiveness of these approaches on the property in question. Highlighting examples and case studies discussed in this guide and beyond, practitioners can strategically and incrementally advocate changes in regulatory landscape and build support among city officials, political

leaders, and other actors, including city residents and community groups, ultimately embedding NbS in their formal community planning.

7 RESOURCES FOR IMPLEMENTING NATURE-BASED SOLUTIONS

7.1 Funding and Financing Mechanisms

Identifying and accessing investment opportunities is crucial yet challenging for communities and practitioners. Having a thorough understanding of their available options and leveraging diverse investment streams are two critical considerations for the communities to harness NbS projects' potential fully. The two most significant vehicles for these investments are funding and financing.

Funding mechanisms include grants and donations provided by federal, state, and philanthropic sources (e.g., USDA Urban and Community Forestry Program, NFWF Coastal Resilience Fund) to provide a one-time cost of specific NbS projects. The money is not repaid by the recipient. Some of these programs have match requirements, though they may waive or reduce those requirements for economically-disadvantaged communities.

Financing mechanisms such as loans (e.g., Clean Water State Revolving Funds) and bonds (e.g., General Obligation Bond in Miami, Florida, Environmental Impact Bonds) can provide the needed supplementary project funds. However, they require repayment and interest for their use.

Table 6 provides examples of existing and emerging mechanisms that can inspire communities to jumpstart their NbS projects. Detailed descriptions and examples of such investments are discussed below.

Table 6. Summary of Funding and Financial Mechanisms

Source	Mechanism	Type	Examples
Public	Federal grants	Funding	Community-based Restoration Program (National Oceanic and Atmospheric Administration) Building Resilient Infrastructure and Communities (BRIC) Grant Program (Federal Emergency Management Agency) Coastal Program (U.S. Fish and Wildlife Service) Readiness and Environmental Protection Integration (REPI) Program (U.S. Department of Defense)
	State grants	Funding	Florida Resilient Coastlines Program (Florida Department of Environmental Protection) Resiliency through Restoration Initiative (Maryland Department of Natural Resources)

			Outdoor Equity Grants Program (California Department of Parks and Recreation)
	Loans	Financing	Clean Water State Revolving Fund (U.S. Environmental Protection Agency)
Private	Environmental Impact Bonds	Financing	Environmental Impact Bond (Quantified Ventures)
	Disaster insurance	Financing	California Wildfire Resilience Insurance (The Nature Conservancy)
Public-private	Competitive grants	Funding	National Coastal Resilience Fund (National Fish and Wildlife Foundation)
	Blended finance	Financing	Nature+ Accelerator Fund (International Union for Conservation of Nature, Mirova Natural Capital, and the Global Environment Facility)
Community-led	Crowdfunding programs	Funding	In Our Backyards New York City
	Community grant programs	Funding	Portland Clean Energy Community Benefits Fund

7.1.1 **Public Investments**

Public investments are the largest source of funding and financing for NbS projects. The sector currently makes up to 86 percent of investments made for NbS-related projects worldwide (UNEP 2021).

Federal grants. Several federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (U.S. EPA), U.S. Department of Interior (U.S. DOI), Federal Emergency Management Agency (FEMA), and U.S. Department of Housing and Urban Development (HUD) provide competitive grants that allow communities to develop NbS projects and seek technical assistance. Several of these programs are discussed in detail in Section 7.3.

When leveraging these federal funding opportunities, communities and practitioners benefit from outside-of-the-box thinking (FEMA 2021a). For example, shorelines stabilization projects such as living shorelines and wetland restoration are eligible for grants through the U.S. Fish and Wildlife Service Coastal Program, NOAA Community-based Restoration Program, and U.S. EPA Clean Water Act Nonpoint Source Grants. They are also eligible for FEMA hazard mitigation program funding, as well as for a new surface transportation resilience grant program (PROTECT grants), authorized by the American Investment and Jobs Act. This means that multiple co-benefits provided by NbS make them eligible for a wide variety of grant opportunities, some of which may be less obvious than others. For instance, communities in New Jersey solicited DOD's Readiness and Environmental Protection Integration (REPI) program for a landscape-scale NbS project that created an 11,000 acres buffer at Naval Weapons Station Earle, protected and restored 1.7 million acres of salt marshes and streams that covered five

military bases. Similarly, communities in the Gulf coast continuously leverage the money provided by RESTORE Act – funded after the *Deepwater Horizon* oil spill - for ecosystem conservation and restoration projects.

State grants. Communities can also leverage grants administered by state agencies that can be relatively easier to navigate and less competitive than federal funding opportunities. State grants can be beneficial for low-income communities that may not be able to match the cost-share eligibility of specific federal funding sources.

Certain state-wide programs can cater and align closely with the community's climate risks and social concerns. For example, through the Florida Resilient Coastlines Program, local communities and practitioners in Florida can seek funding and technical assistance to assess their vulnerabilities and develop strategies to cope with sea level rise and associated flooding and erosion. States like California and Colorado provide Outdoor Equity Grants and connect underserved communities to state parks, public lands, and other natural areas.

Loans. When the federal funding for NbS projects is fully tapped, communities have the option of borrowing money from the local government in the form of low-interest loans. These loans can allow communities to continue their NbS projects and bridge funding gaps. However, some loan programs may offer high market rate interests on repayment quickly, making them an unsuitable option for communities with limited financial capacity.

The Clean Water State Revolving Fund (SRF) Program is one of the largest public sources of water quality financing that can support green infrastructure projects that have water quality benefits. The Clean Water SRF provides communities with low-interest loans, but a significant portion of the SRF dollars may also be distributed in the form of grants or principal forgiveness loans. For example, Camden County, New Jersey, received more than \$5 million in low-interest loan from the state's CWSRF for building NbS throughout the City of Camden, including rain gardens and porous concrete sidewalks. The project shows an estimated cost savings of \$3.1 million over the 30-year loan period and trained 240 youths in the project maintenance (FEMA 2021a). Factors such as the extent of present risks, socio-economic concerns, and availability of shovel-ready projects can help communities decide whether or not to seek loans for their NbS project funding.

7.1.2 Private Investments

Private finance only contributes 14 percent to the existing NbS funding (UNEP 2021). Even though the private sector now significantly adds to climate finance, the sector's particular support towards NbS remains considerably low (UNEP 2021). Although grants from the public sector play a central role, the urgency to accelerate and upscale NbS require communities to seek support and investments from the private sector.

Environmental Impact Bonds. An Environmental Impact Bond (EIB) can provide upfront capital to the communities for various environmental projects. These bonds utilize a Pay-for-Success model where private investors earn returns based on the project performance. This model attracts the impact investing business community who are interested in opportunities in social and environmental areas.

Communities in Washington DC, Virginia, Georgia, and Iowa have partnered with Quantified Ventures to develop nature-based projects. For example, in Atlanta, Georgia, bonds created through Quantified ventures have provided \$14 million to finance six green infrastructure projects for stormwater management to economically and environmentally vulnerable neighborhoods that lacked access to funding.

Disaster insurance. Local communities can defend their natural assets and NbS against extreme climate and weather-related events through insurance. The claims can support the post-disaster recovery of communities situated in harm's way and build future resilience by maintaining habitats such as coral reefs, forests, wetlands, and dune systems. New insurance models are being tested and implemented for lowering premiums for risk-reduction measures such as NbS (Kousky et al. 2021).

Examples of insurance used for NbS are still in the pilot stages. The Nature Conservancy conducted the Wildfire Resilience Insurance project in California and found that landscape-scale ecological forestry can significantly reduce expected residential home losses from wildfires and consequently reduce residential insurance premiums. The project resulted in an innovative wildfire parametric insurance product that has been developed based on acreage burned and severity of burned acreage.

7.1.3 Public-Private Investments

The partnership between public and private entities can capitalize on the funds and capacities across different entities and can yield successful NbS projects. These partnerships need to be sustained through good working relationships, regular coordination, exchange of information, and well-defined business case of NbS for the continued involvement of both sectors.

Competitive grants. A growing pool of public and private entities are coming together to create grant opportunities for NbS projects. The National Coastal Resilience Fund is a prime example that provides funding to coastal communities across the country for restoring and expanding natural infrastructure projects. The fund is administered by the National Fish and Wildlife Foundation. It includes a combination of public (NOAA, U.S. EPA, U.S. DOD) and private (TransRe, AT&T) partners contributing to the grant budget.

Blended finance. Blended finance is an innovative approach to incubate and accelerate NbS projects by attracting the return-seeking private sector with the help of public and philanthropic funds. Globally, Nature+ Accelerator Fund combines the unique set of expertise of leading public and private institutions to offer financing for NbS focused projects in coastal resilience, forest protection, forest landscape restoration, and sustainable agriculture. The fund is a collaborative effort between the IUCN, Mirova Natural Capital, and the Coalition of Private Investment in Conservation (CPIC). Investors will be offered 30% "first loss" protection to mitigate early-stage risk with Global Environment Facility (GEF) already providing the \$8 million anchor investor in the fund. Another example is the Community Development Financial Institutions Fund (CDFI Fund) that invests federal dollars alongside private sector capital for building resilience in underserved communities. To help guide the investors and entities, Earth Security has launched the [Blended Finance Playbook for Nature-based Solutions](#) that provides a practical roadmap for using blended finance opportunities.

7.1.4 Community-Led Initiatives

Communities, themselves, can garner support and funding for their small-scale NbS projects. This funding can be helpful for communities to receive attention and attract donors that can ultimately fund even large NbS initiatives. Two examples of various ongoing innovative community-led initiatives are provided below.

Crowdfunding platforms. Communities nowadays can take advantage of social media platforms to fund their own neighborhood needs. While the crowdfunding instrument may not provide a substantial amount of money compared to other sources, this type of fund generation can help improve a community's social fabric by bringing local volunteers, non-profit groups, and donors together. For example, in New York, local communities raised money through the crowdfunding website IOBY to rebuild the community garden that serves as an important community resource. The effort also attracted local donors and received a \$2000 grant from the NYC Citizen's Committee.

Community grant programs. Through advocating, organizing, and campaigning, communities have the power to champion their climate adaptation programs. An excellent example is Portland's first-ever climate justice fund passed in 2018 to support low-income communities and communities of color in the face of climate change and economic disparities. The fund will distribute \$50 million each year for clean energy programs, green infrastructure projects while creating green jobs in the historically underinvested communities. Frontline leaders in the Portland area representing communities of color along with businesses and community organizations were instrumental in the success of this initiative.

7.2 Incentives for Developers

NbS project developers are also eligible for wide-ranging incentives, fee reductions and tax credits. These programs vary between states and cities. Below, we discuss some examples of available incentives from all across the country. Practitioners and communities can further explore the options available to them and encourage developers to pursue these opportunities.

7.2.1 Development Incentives

Developers can leverage incentives such as expedited processing, zoning upgrades, and exemptions for using NbS. For example, the state of Delaware has shortened the permitting timeline for certain smaller living shoreline projects landward of mean low water. These incentives can also support developers for NbS practices such as conservation easements that limit development in hazard-prone areas. In Washington State, the [Forestry Riparian Easement Program \(FREP\)](#) compensates small landowners for intact trees left next to streams, wetlands, seeps, or adjacent unstable slopes to protect their riparian functions. Landowners receive 50% of the stumpage value of the qualifying timber in a lump sum with a 50-year easement on the land title.

7.2.2 Fees

Stormwater fee programs can provide financial incentives for developers to reduce the property's stormwater impacts and imperviousness while creating a dedicated stream of funding for future green infrastructure projects. The City of Lancaster, Pennsylvania, charges a stormwater

management fee to all property owners based on impervious surfaces on their property. The city, however, also offers stormwater credits that can reduce this fee up to 50% for residents with green infrastructure practices installed on their property.

7.2.3 Rebates and Tax Credits

Developers and property owners can earn tax credits and reimbursements for installing NbS projects. In the Kenai Peninsula Borough of Alaska, landowners receive a partial refund on their income tax for habitat protection and restoration projects within 150 feet of the water bodies protected under the Habitat Protection District. The [RainWise program](#) in Seattle provides rebates to cover the cost of green infrastructure practices for stormwater management. The program has offered average rebates of \$4400 to more than 2000 projects for installing rainwater cisterns and rain gardens on the properties.

7.2.4 Credit Trading Programs

Credit trading programs can help developers and communities to trade their stormwater runoff by market buying and selling mechanisms. In 2020, The Nature Conservancy established the [StormStore pilot program](#), which allows developers in Cook County, Illinois, to construct offsite NbS projects by buying credits from private landowners with existing rain gardens, bioswales, or other natural infrastructure. The StormStore marketplace can equally benefit communities through decentralized NbS for stormwater management.

7.2.5 Awards and Certification Programs

Communities and developers can work together to incorporate resilient NbS practices in the development projects. These awards can help build awareness and increase property values among the residents while providing them co-benefits of NbS, for example, decreased energy consumption and urban heat island effect through green roofs. In addition, the awards can attract communities and businesses, thereby peaking the financial interests of developers. Programs such as [U.S. Green Building Council's LEED certification](#) and the [Living Building Challenge](#) are already encouraging developers to think creatively throughout the design and construction phases of new developments. In Virginia, communities surrounding the Elizabeth River are taking action to protect the water quality of Chesapeake Bay by making their homes [River Star](#). The certified homes in Chesapeake, Norfolk, and Portsmouth also become eligible for funding opportunities administered through the program to install living shorelines and rain gardens on their properties.

Box 2. Restoration Dollars through the 2021 Bipartisan Infrastructure Bill

The bipartisan Infrastructure Investment and Jobs Act (IIJA), which was signed into law in November of 2021, contains critical investments in nature-based solutions. Overall, the bill contains more than \$50 billion in investments to protect against droughts, heat, floods and wildfires, most of which will be spent out over the coming five years. This impressive sum spans many agencies. For example, nearly \$1 billion is available for habitat restoration efforts through NOAA and for the National Coastal Resilience Fund administered by the National Fish and Wildlife Foundation (NFWF). The Army Corps received \$1.9 billion for ecosystem restoration

efforts, and over \$5 billion additional for coastal storm and inland flood risk reduction projects, for which nature-based solutions would be an appropriate use of funding. Billions more were made available for wildfire risk reduction under the authorities of the U.S. Forest Service and the Department of the Interior. Another \$5 billion is available to FEMA, spread between the BRIC program, the Flood Mitigation Assistance Program, and a new hazard mitigation revolving loan fund. The Department of Transportation received \$8.7 billion for the Promoting Resilient Operations for Transformative, Efficient, and Cost Saving Transportation (PROTECT) Grants, for which NbS projects are eligible.

On top of these resilience investments, the IJA also injected over \$50 billion in water-related infrastructure and programs at the EPA and the Department of the Interior to improve water quality and fight drought, some of which can support green infrastructure and NbS. It also invested in EPA's regional geographic programs, including \$1 billion for restoration of the Great Lakes, \$238 million for the Chesapeake Bay, and \$89 million for Puget Sound.

These funds for environmental restoration and resilience will be an important pathway for large-scale NbS projects in the communities. Once this money is funneled through the federal programs to the local level, communities and practitioners can advocate and influence their priority projects to state leaders and decision-makers who will make important decisions about which projects receive funding.

7.3 Federal Disaster Programs that Can Support Nature-based Solutions

Various federal agencies across the U.S. government play a major role in building our nation's resilience and investing in mitigation activities. For example, the National Oceanic and Atmospheric Administration (NOAA), the Natural Resources Conservation Service (NRCS), and the U.S. Fish and Wildlife Service (USFWS) administer various grant programs that support resilience through ecosystem restoration. Other agencies, including the U.S. Army Corps of Engineers (USACE) and the Department of Transportation (DOT), have a major role to play in shoring up the resilience of our public infrastructure. Additionally, the Small Business Administration (SBA) and Economic Development Administration (EDA) invest in the economic resilience of communities and businesses in pre- and post-disaster environments. The above agencies may provide support to communities in the form of direct funding (often grants or low-interest loans), and/or through technical assistance and other tools. Notably, the Federal Emergency Management Agency (FEMA) and the Department of Housing and Urban Development (HUD) provide significant funding pre- and post-disaster that communities can access in order to invest in resilience projects that are informed by local and state needs. Funding from these agencies is only likely to increase, and represents a significant potential resource for implementing nature-based solutions for hazard risk reduction.

Below we detail some of the federal disaster programs that are available to communities to support NbS. It is important to note that while some of these programs are designed to prioritize nature-based approaches, many support a much broader set of eligible activities. As communities seek funding for natural infrastructure projects, it is important they understand the requirements associated with each federal funding stream.

7.3.1 Federal Emergency Management Agency (FEMA) Programs

FEMA administers many programs that have a history of investing in hazard mitigation and recovery efforts, and are well poised to incorporate climate change and future conditions into current mitigation practices to ensure a resilient nation for years to come.

Hazard Mitigation Grant Program (HMGP). The Hazard Mitigation Grant Program (HMGP) provides funds directly to states after a presidentially-declared disaster, in order to allow states to rebuild in a way that they direct to promote resilience and reduce risk, in accordance with state hazard mitigation plans. HMGP can fund mitigation projects anywhere in the state post-disaster declaration, and can fund projects for undamaged public facilities and private nonprofits, as well as for individual homes and businesses. HMGP has historically been FEMA’s largest mitigation program, but that could change with greater investment in pre-disaster mitigation programs like BRIC (FEMA 2021b).

Building Resilient Infrastructure and Communities (BRIC) Program. FEMA’s new BRIC program awards pre-disaster hazard mitigation funding through an annual competitive grant cycle. The program provides funding for a variety of activities beyond mitigation project implementation, such as capability- and capacity building funding, and mitigation planning. In 2021, BRIC will make \$1 billion available through grants, which presents a great opportunity to fund innovative and large mitigation projects in a pre-disaster or “blue skies” environment (Executive Office of the President 2021). Additional resources are expected in future years through the required set-aside from other disaster amounts expended out of the Disaster Relief Fund, and \$1 billion in additional funding was recently appropriated through the bipartisan Infrastructure Investment and Jobs Act (Infrastructure Act) to be distributed over fiscal years 2022-2026.

BRIC awards grants through a multi-stage competitive process that includes eligibility determination, technical panel review, and Qualitative Panel evaluations. The BRIC program awards points to projects based on various factors like incorporation of NbS, consideration of future conditions, existing state and local building codes, outreach and partnership utilization, and projects benefiting small and impoverished communities (FEMA 2021c).

Eligible applicants include states, territories, and federally recognized Tribal governments, which are responsible for compiling, prioritizing, and submitting all sub-applicant projects in their jurisdiction. Typically, this responsibility is held by the State Hazard Mitigation Officer (SHMO). SHMOs are typically based out of the state, territory, or Tribal Emergency Management Agencies (EMA). Local governments, other non-EMA state agencies, and federally or non-federally recognized Tribes can function as sub-applicants writing grant applications for individual projects. Sub-applicants should coordinate with state EMAs (the applicant) for state specific guidelines, internal deadlines, and technical assistance that can greatly assist in the production of successful applications. Homeowners, businesses, and nonprofits can work with their local government sub-applicant to apply for BRIC funding for private property.

Flood Mitigation Assistance (FMA). The Flood Mitigation Assistance (FMA) program, much like BRIC, is a pre-disaster grant program appropriated and awarded on a yearly cycle. This program’s goal is to specifically reduce damages and protect people and communities from flood

hazards. FMA provides funds for mitigation projects on structures insured under the National Flood Insurance Program, with a special emphasis on repetitive loss structures. FMA can also fund community scale projects that reduce flood risk and flood mitigation planning (FEMA 2021d). \$160 million is available for FMA funding in FY 21; however, due to the Infrastructure Investment and Jobs Act, the program is set to receive an additional \$700 million per year from FY 2022 to FY 2026, on top of amounts otherwise appropriated.

Safeguarding Tomorrow Through Ongoing Risk Mitigation (STORM) Act. The STORM Act was signed into law in January 2021 and authorizes FEMA to provide capitalization grants to states or eligible tribal governments to establish revolving loan funds to provide hazard mitigation assistance to local governments to reduce risks to disasters and natural hazards. The Infrastructure Act provides \$500 million to the STORM Act, or \$100 million per year for five years. This new FEMA grant program may finance water, wastewater, infrastructure, disaster recovery, and community and small business development projects (FEMA 2021e).

7.3.2 Housing and Urban Development (HUD)

Community Development Block Grant (CDBG) Program. HUD has a program that is sometimes authorized and appropriated by Congress after disaster events called Community Development Block Grant-Disaster Recovery (CDBG-DR) Program. CDBG-DR is a supplemental appropriation for disaster recovery. Conventional (non-supplemental) CDBG funds can be used for disaster recovery purposes, but the CDBG-DR Program specifically was developed to appropriate significant funding to the most at need communities for long-term disaster recovery, addressing needs which are left unmet by other federal sources. These funds typically follow the statutory authority of the broader CDBG program; however, there can be implementation and allocation-specific directions provided by Congress for each individual supplemental appropriation dependent on the type of disaster event, the community affected, and the unmet needs.

CDBG-DR funds are appropriated at the discretion of Congress, and occasionally the executive branch. CDBG-MIT (mitigation) or CDBG-CV (COVID-19)— newer designations made by Congress in recent years—are also considered under the larger umbrella of special CDBG-DR appropriations as they are all supplemental appropriations related to the larger CDBG program.

In 2018 Congress appropriated \$12 billion specifically for mitigation efforts through CDBG from qualifying disasters from 2015, 2016, and 2017. HUD was able to bring \$3.9 billion of existing general CDBG funds to the program as well. This created a unique opportunity for communities in disaster impacted areas to conduct high impact mitigation and resilience projects to prevent similar future disasters, transforming resilience investments during the recovery phase (HUD 2021). In 2021, Congress also appropriated \$186 million for eligible 2018 disasters (HUD 2021). These CDBG-MIT funds encouraged the use of green techniques and building standards, and consideration of changes in future conditions that should be incorporated to create green resilient designs.

All CDBG funds are flexible in nature, which is one of the best aspects of this program highlighted by communities. Generally, all CDBG funds must be utilized for activities that meet one of the following objectives (HUD 2001):

- To benefit low- and moderate-income people,
- To aid in the prevention or elimination of slums or blight, or
- To meet an urgent need for the purposes of health or safety.

Additionally, localities that receive CDBG-DR funds may also utilize any previously awarded unspent general CDBG grants for disaster recovery. CDBG-DR specific appropriations may be used for a variety of purposes such as:

- FEMA non-federal cost share requirements,
- Long-term recovery, rather than immediate disaster recovery needs, or
- “Unmet needs” not addressed by FEMA, Economic Development Administration, or the Small Business Administration.

8 NATURE-BASED SOLUTIONS IN ACTION: CASE STUDIES

The following case studies illustrate the use of NbS to protect communities from climate-related hazards, while simultaneously promoting increased health and climate resilience in the natural systems. These examples demonstrate a variety of approaches, including the use of floodplain restoration, living shorelines, urban forests, and innovative green stormwater treatment facilities, among others. The case studies presented here outline how each solution is implemented, and also highlight successful funding strategies, partnerships, public outreach, and other critical steps taken to address common obstacles that arise in NbS projects.

8.1 Reducing Community Flood Risk Through Dam Removal

The Rattlesnake Creek Dam was built in 1904 to create a reservoir that would provide water for the city of Missoula, Montana. It was used as the primary water source until 1983, when the reservoir became contaminated with *Giardia* and the City switched to a different source. Worsening structural damage of the dam increased the risk of breach or failure, putting downstream communities at risk of severe flooding. This is of particular concern in the context of climate change, which is expected to increase precipitation extremes, including the risk of extreme flooding (Conant et al. 2018).

8.1.1 Project Goals

The goal of this project was to remove the century-old dam and reestablish stream connections between the Rattlesnake Wilderness and the Clark Fork River, followed by streambank and floodplain restoration to enhance floodwater storage, increase fish and wildlife habitat, and improve recreational opportunities. Project activities include:

- Removal of the deteriorating dam and associated infrastructure, with close attention paid to the use of sediment Best Management Practices (BMPs), fish salvage, and other efforts to minimize turbidity and other impacts that can have negative short-term impacts on the ecosystem;
- Planting and seeding to restore native riparian forests, wetland habitats, and natural streambank vegetation, followed by installation of fencing to protect newly-planted areas and allow vegetation to become well-established;
- Monitoring of streambank and floodplain vegetation and surveys for birds, amphibians, and reptiles to document recovery of wildlife to the area; and
- Installation of a parking area, accessible trail loop, creek access points, and an informational kiosk to improve recreational opportunities along the Rattlesnake Greenway.

8.1.2 Implementation and Outcomes

The City of Missoula acquired the former Mountain Water Company in 2017, but it took several years to secure the funding and partnerships necessary to accomplish a project this large. The City and Missoula Water collaborated with several external partners including Trout Unlimited, the Watershed Education Network, and the Montana Department of Fish, Wildlife, and Parks. As a public-private partnership, they were able to obtain funding from the Federal Emergency Management Agency's (FEMA) Hazard Mitigation Grant in addition to grants from the Montana Department of Natural Resources and Conservation, the Open Rivers Fund, Patagonia, and NorthWestern Energy. The total project cost was \$1.37 million, and although 95% of this amount came from federal, state, and private grants, numerous local businesses, individuals, and organizations also contributed. Dam removal was completed in the summer of 2020, followed by restoration of the stream channel and floodplain and monitoring of ecosystem recovery. Work on trails, creek access, and the information kiosk will take place in 2022.

Removal of the Rattlesnake Creek Dam has successfully eliminated concerns associated with dam breach or failure, reducing flooding hazards in downstream communities. Additionally, restoration of 5 acres of wetlands and floodplains has the potential to slow water velocity and store floodwaters, further reducing flood risks to both human communities and natural systems. With the dam removed, maintenance and operation costs are also reduced for Missoula Water.

This project has also had important benefits beyond reducing flood hazards. For instance, the restoration of 1,000 feet of stream channel has reconnected habitat for fish and wildlife, including access to spawning areas for valued species such as native trout in the headwaters of the Clark Fork River. Native wetlands and riparian vegetation increase water filtration and groundwater recharge, captures and stores carbon, and provides habitat for threatened birds, amphibians, and other wildlife. New trails and public access points also enhance recreational opportunities for the public, supporting the regional economy.

8.1.3 Case Study Sources

[Rattlesnake Dam Removal Project](#) – Engage Missoula

[Rattlesnake Dam Removal is Almost Complete](#) – Trout Unlimited

[Photo Essay: Rattlesnake Creek Dam Removal and Restoration](#) – UC Davis School of Education

8.2 Using Living Shorelines to Protect Alabama’s Gulf Coast

Oyster reefs have disappeared from large areas of the Gulf Coast due to overfishing, pollution, disease, and storm-related damage. Because oyster reefs absorb wave energy, they protect shorelines from coastal erosion during storms. They also provide habitat for fish, crabs, and birds, and improve water quality by filtering nutrients and sediment. Over the coming century, rising sea levels and storm surge are likely to increase rates of coastal erosion and shoreline change, particularly in areas where natural buffers such as nearshore reefs and coastal vegetation have disappeared. In many areas, natural buffers have been replaced by hardening measures such as bulkheads, seawalls, and jetties that stabilize the immediate area, but these may have detrimental impacts on adjacent shorelines by changing the movement of sediment. The shoreline is no further threatened by rising sea levels and elevated storm surge.

8.2.1 Project Goals

The goal of this project was to create a natural buffer (e.g., “living shoreline”) by restoring oyster reefs, protecting the shoreline from storm surge and sea level rise while also providing wildlife habitat and water filtration services. Project activities were focused on:

- Restoring oyster habitat and associated ecosystem services on two tracts in Mobile County;
- Stabilizing and restoring 0.3 miles of shoreline; and
- Creating jobs for residents of Mobile County, primarily related to fisheries and ecosystem restoration.

8.2.2 Implementation and Outcomes

To implement this project The Nature Conservancy in Alabama obtained a \$2.9 million grant from NOAA through the American Recovery and Reinvestment Act. The funds were designated for oyster restoration efforts, and to accomplish this TNC partnered with the Dauphin Island Sea Lab (DISL), Alabama Department of Conservation and Natural Resources State Lands Division, and the National Wildlife Federation, as well as many community volunteers. The project was conducted between November 2009 and September 2012, when TNC utilized three different restoration techniques at two locations (Mobile Bay and Portersville Bay). These techniques included placing bagged shells, reef balls, and ReefBLK (SM) cages each along 500 meters of shoreline (1,500 in total in total) to see which technique was most successful for oyster seeding and reef building. There was a 4-month delay during the course of the project, when the April 2010 Deepwater Horizon accident occurred. However, a number of local fisherman and other people whose jobs were displaced by the oil spill contributed to the project.

The Nature Conservancy conducted post-restoration monitoring of the sites to determine whether the techniques were successful and created several outreach initiatives including K-12

lesson plan development and teacher training workshops, an outdoor display, and signage near the restoration sites.

Overall, The Nature Conservancy project team created 3 acres of oyster reefs along two miles of shoreline, as well as 30 acres of tidal marsh and seagrass habitats. The project created a total of 30 full-time jobs and contributed to the jobs of over 100 others including scientists, engineers, laborers, and project coordinators.

The success of this project has facilitated the creation of a longer-term program called the 100–1000: Restore Coastal Alabama Partnership. The goal of the program, which includes over 40 public and private partners, is to build 100 miles of oyster reefs and restore 1,000 acres of marsh and seagrass to promote coastal resilience and economic growth in the region. Specifically, they are focused on providing habitat for oyster larvae, restoring nursery habitat for commercial and recreational fish, reducing wave energy and shoreline erosion, and stabilizing sediments.

Upon completion of this project, TNC continues to maintain and monitor 10 other living shoreline projects along the Alabama Gulf Coast.

8.2.3 Case Study Sources

[Oyster Reef Breakwater Restoration Project on Alabama's Gulf Coast](#) – CAKE

[Coastal Alabama Restoration](#) – Conservation Gateway

[Alabama's Living Shorelines](#) – The Nature Conservancy

8.3 Creating Cooler Cities by Expanding Urban Forests

The Chicago metropolitan area is home to over 10 million people, but the city's tree canopy has historically been low compared to other cities in the Midwest. Introduction of the invasive emerald ash borer exacerbated the problem by causing the loss of 13 million ash trees and further reducing tree cover in the city. This is of particular concern in the context of climate change, which is expected to place additional stress on urban trees due to warmer temperatures, heavy rain and flooding, drought, and further expansion of invasive insects and diseases.

8.3.1 Project Goals

In 2013, a group of concerned citizens came together to form the Chicago Region Trees Initiative, a regional collaborative effort to restore and improve Chicago's urban forest. Their goals were to improve management skills and knowledge, increase the City's tree canopy, and incorporate species that are less vulnerable to invasive pests and climate change. They are also working to ensure that street trees are more equitably distributed to ensure that all people and wildlife in the region benefit from them.

8.3.2 Implementation and Outcomes

The Chicago Region Trees Initiative partnered with Leslie Brandt of the Northern Institute of Applied Climate Science (NIACS) and the U.S. Forest Service to assess the vulnerability of the region's urban forest to climate change, and develop an adaptation plan that would support a more resilient forest in the future. NIACS used habitat suitability modeling, projected changes in

heat and hardiness zones, and information about the adaptive capacity of component tree species to determine how individual species and the forest as a whole is expected to respond to future changes (Brandt et al. 2017). Then they used a structured stakeholder-driven process to develop adaptation strategies based on the vulnerability factors that had been identified, and incorporated this information into project planning to ensure their future planting efforts would be climate-informed.

Following the vulnerability and adaptation process, the Chicago Regional Trees Initiative has worked on developing a regional tree master plan and a suggested planting list of species that are better suited for the future climate. Their website includes a number of other initiatives, including tree planting programs, a network to connect communities with experienced foresters, interactive maps that include socioeconomic data to identify priority areas for planting efforts, sample tree preservation ordinances, and training opportunities for community members.

8.3.3 Case Study Sources

[Fortifying Chicago's Urban Forest](#) – U.S. Climate Resilience Toolkit

[Programs](#) – Chicago Region Trees Initiative

[Climate Change Response Framework: Chicago Wilderness Region](#) – NIACS

8.4 Using Algae Farms to Treat Stormwater and Create Wildlife Habitat

The Indian River Lagoon is a shallow estuary located on the east coast of Florida, protected from the Atlantic Ocean by a series of barrier islands. The lagoon is over 155 miles long, stretching from Volusia County south into Palm Beach County, and ranges between 0.5 and 5 miles in width. Because it is surrounded by coastal development and receives stormwater runoff from agricultural areas, excess nutrients (e.g., dissolved nitrogen and phosphorus) heavily impact water quality. Harmful algal blooms are common, particularly in the northern reaches of the lagoon (Mamoua et al. 2019). Warming temperatures and more frequent heat waves are likely to exacerbate existing water quality issues, allowing the proliferation of harmful algal blooms that kill wildlife and cause respiratory issues or illness in humans. More extreme precipitation events followed by periods of drought can also increase the risk of algal blooms by causing large amounts of nutrient-laden runoff to enter the system, where it becomes concentrated as water evaporates (Paerl et al. 2019).

8.4.1 Project Goals

The goal of this project was to build a facility that could filter stormwater flowing through the County's canal system before it reaches the Indian River Lagoon, while also creating wetland habitat for threatened and endangered birds and other wildlife.

8.4.2 Implementation and Outcomes

Egret Marsh Stormwater Park and Wildlife Sanctuary began operation in April of 2010, and cost \$7.3 million to construct. The site was designed by County Stormwater Engineer Keith McCully, and utilizes the HydroMentia Algal Turf Scrubber system, which grows and harvests algae to remove dissolved nutrients from stormwater. Water from the Lateral D canal is pumped onto a 5-acre concrete pad, which provides the right conditions for algae growth. Every 2 weeks, the algae

is scraped off, then dried and placed into the landfill. The algae-free water then moves into three polishing ponds that continue remaining pollutants, and then eventually ends up in a shallow marsh created to provide wildlife habitat in addition to water filtration. Finally, the clean water reenters the canal system where it is delivered to the Indian River Lagoon.

The Egret Marsh Stormwater Park filters 8–10 million gallons of stormwater per day and has resulted in measurable water quality improvements, helping to prevent harmful algal blooms by removing an average of 13,000 pounds of nitrogen and 3,000 pounds of phosphorus from system per year. It has also become a thriving wildlife sanctuary, providing habitat for a range of threatened and endangered birds as well as reptiles and amphibians.

The site is protected as a wildlife sanctuary and is not open to the public. However, group tours of the algal farm and wildlife sanctuary can be arranged and the Indian River County Stormwater Division, and the site is popular with students, birders, and other local groups.

8.4.3 Case Study Sources

[Egret Marsh Stormwater Park Virtual Tour](#) (video) – Indian River County

[County Stormwater Facilities](#) – Indian River County

[HydroMentia Algal Turf Scrubber® Selected for Egret Marsh Regional Stormwater Facility](#) – HydroMentia

[Beneficial Algae? Growing Algae to Remove Excess Nutrients](#) – University of Florida Institute of Food and Agriculture Sciences

[Algae Farm – A New Birding Site!](#) – Pelican Island Audubon Sanctuary

8.5 Reducing Wildfire Risk Through Cultural Burning in the Klamath River Basin

Ecosystems in the Klamath River Basin of northwestern California evolved in the presence of fire, including frequent low-intensity burns conducted by area tribes such as the Karuk. Cultural burning and other traditional management practices favored the development of healthy, productive forests with high species diversity and resilience to disturbances such as insects, disease, and large, high-intensity fires (Karuk Tribe 2019). However, Euro-American settlement of the region in the mid-1800s resulted in the loss of tribal management and introduction of widespread fire suppression that have allowed dense growth of small trees and the accumulation of ladder and surface fuels (McIntyre et al. 2015; Steel et al. 2015; Norgaard et al. 2016). Many fire-dependent species that provide traditional foods and cultural materials have also declined, such as black oak (*Quercus kelloggii*), California hazelnut (*Corylus cornuta californica*), and beargrass (*Xerophyllum tenax*), along with habitat for wildlife such as elk that depend on frequent fire to maintain open grasslands (Norgaard et al. 2016).

Climate change is already driving significant changes in California, including warmer, drier conditions and severe droughts that have lengthened the fire season, increased the risk of extreme fire behavior, and contributed to large, high-intensity fires (Goss et al. 2020; Keeley and Syphard 2021). In 2020, the August Complex Fire became the largest ever recorded in the state after it burned over 1 million acres in northern California, and it was followed shortly by the

Slater Fire in September 2020 that burned through the community of Happy Camp, headquarters of the Karuk Tribe (Cal Fire 2020).

8.5.1 Project Goals

The Karuk Tribe is working to revitalize the use of cultural burning within their ancestral lands with the goal of reducing the risk of extreme fire events, promoting culturally valued species, restore healthy, productive ecosystems that are resilient to climate changes and disturbances, and promote tribal health and well-being through the restoration of traditional management and ceremonial practices. In order to accomplish this, the tribe is undertaking a number of activities including:

- Research and planning focused on promoting tribal sovereignty, assessing climate change vulnerability, developing in-depth adaptation plans, and understanding barriers to the expansion of cultural burning;
- Advocating for changes in federal policies that limit the use of cultural burning and prescribed fire; and
- Collaborating with organizations such as the Western Klamath Restoration Partnership to increase the use of cultural burns on private and federal lands.

8.5.2 Implementation and Outcomes

Over the past decade, the Karuk Tribe has published a series of detailed reports focusing on Karuk Traditional Ecological Knowledge (TEK) and knowledge sovereignty (Norgaard 2014a; Norgaard 2014b); the vulnerability of culturally valued species, tribal programs, and tribal management authority to more frequent high-severity wildfires (Norgaard et al. 2016); and barriers to expanding the use of cultural burning and prescribed fire (Clark et al. 2021). Additionally, the Tribe released an in-depth Climate Adaptation Plan (Karuk Tribe 2019), which demonstrates how traditional management practices such as cultural burning can facilitate increased resilience to climate change for plants, wildlife, and humans. The plan highlights numerous benefits of these practices, including the protection of both public and tribal resources from climate-driven increases in high-severity wildfires.

The Karuk is contributing to initiatives such as the Somes Bar Integrated Fire Management Project, which will replicate traditional fire regimes on 5,600 acres of privately and federally owned lands near Orleans. The project is a partnership between the Western Klamath Restoration Partnership, the U.S. Forest Service, and the Karuk Tribe, and includes the utilization of traditional ecological knowledge to reduce the risk of high-severity fire in the area's dense forests.

The Karuk Tribe is recognized as a leader in climate change adaptation, demonstrating how traditional ecological knowledge and cultural practices can restore healthy, resilient ecosystems. Cultural burning reduces accumulated fuels, decreasing wildfire risks for human communities as well as the negative impacts of large, high-severity fires on the plant communities and wildlife. These practices improve overall air quality by preventing the toxic smoke associated with intense fires, particularly in developed areas, and supports climate change mitigation by preventing the generation of emissions and loss of carbon stocks from severe fires. Reductions in forest density

that occur with frequent low-intensity burning helps maintain water supplies, which is critical in drought-prone systems like California, and the smoke produced during these fires lowers stream temperatures to reduce heat stress on salmon. Restoring cultural burning restores diverse, productive forests that provide excellent wildlife habitat, and increases the availability and quality of species that provide foods, basketry materials, and other supplies to the Karuk. Finally, the restoration of tribal management practices supports the economic, social, and cultural well-being of tribal members, and is an important step towards full tribal sovereignty (Norgaard et al. 2016; Karuk Tribe 2019; Long et al. 2021).

8.5.3 Case Study Sources

[Karuk Climate Change Projects](#) – Karuk Tribe

[The Karuk’s Innate Relationship with Fire: Adapting to Climate Change on the Klamath](#) – U.S. Climate Resilience Toolkit

[The Karuk Used Fire to Manage the Forest for Centuries. Now They Want To Do That Again](#) – KQED

[A Restoration Story Unfolds: The Somes Bar Integrated Fire Management Project](#) – Wild California

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APPENDIX: CHECKLIST FOR INTEGRATING NATURE-BASED SOLUTIONS INTO ADAPTATION PLANNING

The purpose of this guide is to support the integration of nature-based solutions into the U.S. Climate Resilience Toolkit “Steps to Resilience” framework. The following checklist briefly summarizes considerations embedded throughout this guidance for each step of the Steps to Resilience framework. This checklist can serve as a starting point for practitioners to understand and implement effective nature-based approaches for climate adaptation and resilience planning in their communities. This guide is not an exhaustive treatment of NbS approaches and options, however, a community’s specific needs, goals, resources, and hazards will ultimately guide the identification and selection of appropriate NbS adaptation options.

Overall: Key Considerations for Use of Nature-based Solutions

- Recognize natural systems and processes as critical infrastructure
- Consider climate impacts on priority natural assets
- Consider equity implications in the design and application of nature-based solutions
- Ensure nature-based solutions yield net positive biodiversity benefits
- Seek to protect or restore critical natural infrastructure
- Give natural features and processes space to function
- Integrate nature-based solutions into existing planning processes

Step 1. Explore Hazards

- Identify the full range of community’s natural assets
 - Include community members to inventory natural systems
 - Work with community groups to map natural assets (wetlands, riparian buffers, habitat corridors, etc.) that provide protective benefits
 - Engage community members in conversations on myriad co-benefits for natural assets
- Establish connections between natural processes and hazards
 - Recognize community’s land-use practices and their influence on natural hazards
 - Promote learning opportunities that connect the dots between global climate change and community hazards
- Determine appropriate geographic and temporal scales
 - Conduct landscape and watershed-wide assessments to understand a community’s risks
 - Explore a range of NbS options based on watershed/landscape (e.g., floodplain restoration) or neighborhood scale (e.g., rain gardens)
 - Develop adaptation planning timeframe that allows for ecosystems complexities
 - Evaluate short-term versus long-term benefits and tradeoffs associated with NbS interventions with different time scales
- Guide communities to determine their needs
 - Leverage community knowledge and ecological stewardship early in the process

- Facilitate well-represented and equitable roundtables to include all voices in adaptation planning
- Promote a stakeholder-driven process that helps elevate a sense of place and value for the ecosystems and their ecological function
- Assemble key nature-based solutions stakeholders
 - Seek technical assistance and knowledge of the region's existing natural resources and assets from individuals, such as ecological scientists, urban planners, natural resource managers, conservation organizations, fish, wildlife, and parks agencies
 - Engage natural resource-dependent landowners as well as tribal and indigenous communities
 - Coordinate and negotiate competing interests and conflicts to build support for NbS on shared community goals

Step 2. Assess Vulnerability and Risk

- Conduct a climate vulnerability assessment of your community by identifying
 - Which assets are likely to be most (and least) affected by current and projected conditions, which can help set priorities for adaptation and management
 - Why those assets are vulnerable/at risk, which can inform the development of specific adaptation responses and risk reduction strategies, and
 - Where and when they are vulnerable, which can inform the spatial and temporal aspects of designing and implementing adaptation actions
- Consider duality of vulnerability by exploring the impacts of climate change on natural systems as well as the compound impacts on community assets related to natural system degradation
- Include vulnerability of natural assets in climate vulnerability assessments
 - Determine the viable approach or approaches for assessing the climate-related vulnerabilities and risks to species and ecological systems
 - Apply the determinants of vulnerability – exposure, sensitivity, and adaptive capacity – to social as well as ecological systems
- Identify best-available risk assessment tools and approaches for assessing hazard risks due to altered natural systems
- Integrate equity and environmental justice concerns in vulnerability assessments
 - Assess areas of higher exposure to climate risks to underserved communities due to the lack of protective value of natural assets
 - Identify vulnerabilities and risks for socially vulnerable populations that may result from unintended consequences of NbS siting and implementation
 - Develop social and ecological vulnerability assessments that center the risks of vulnerable communities at greater risk of climate impact
- Identify key vulnerabilities collectively based on the ecological significance of the habitats and ecosystems, the magnitude and likelihood of climate impact, and the conservation and societal goals of the community

Step 3. Investigate Options

- Brainstorm NbS options for your community based on the hazards
 - Floodplain and wetland restoration, green stormwater management, protecting floodplains from development for inland flooding
 - Coastal habitat protection and restoration, living shorelines, protecting coastal areas from development for coastal hazards
 - Watershed restoration, urban green infrastructure, water conservation for extreme heat and drought
 - Ecological forest management and learning to live with fire for wildfires
- Consider climate adaptation options in other types of plans or programs where multiple hazards may need to be addressed

Step 4. Prioritize and Plan

- Determine the most appropriate action based on available NbS options
- Employ USCRT's key questions to help guide the prioritization process
 - Value: Will the action reduce risk?
 - Will this action reduce risk for the target community?
 - Will this action reduce risk for the ecosystem upon which its function is dependent?
 - How will this action enhance or benefit the associated ecosystem?
 - What is the long-term or life-term cost differential (including but not limited to dollars, personnel hours, greenhouse gas emissions) between the NbS and non-NbS action options?
 - Trade-offs: With limited resources what is possible?
 - With limited resources what is possible?
 - Might an NbS offer a lower-cost alternative to reduce risk, including installation, maintenance and future modification?
 - How might a hybrid NbS/non-NbS strategy be appropriate?
 - Are there any potential mal-adaptations or unintended consequences (conflicts or harms to other community or ecosystem values, services or features)?
 - Planning: Timelines and milestones that mark and measure progress
 - When do you want/need to implement the action?
 - Do phenology or ecological thresholds impact timing of implementation?
 - What needs to happen in order to implement?
 - Do you have the resources required to implement the action?
 - By when do you expect to see benefit from the action?
 - How will you be able to you measure the benefit (or the harm) caused by the action?
 - Decision Points: Will the action protect what you value?
 - What is the underlying goal you are trying to meet with this action and will the action meet that goal?
 - When will you know if the action is working?

- Will the action need to be modified if conditions change?
- How can you adjust course if the action is not working?
- Develop additional questions and criteria for project prioritization based on community needs and goals

Step 5. Take Action

- Mainstream nature-based solutions within planning initiatives
 - Refer to Hazard Mitigation Plans, Comprehensive Land Use Plans, Coastal Zone Management Plans, etc. from other communities to serve as best-practices
 - Update and involve qualified local planners in planning efforts
 - Seek external support to fill technical and human capacity gaps
- Coordinate across planning efforts to assess the degree to which your community's suite of plans can work together to address natural hazards in different geographic areas
 - Use existing scorecards from the literature
 - Review community plans and identify areas of competing interests
 - Continue stakeholder engagement throughout the process
- Implement an NbS project based on the considerations included in this checklist
- Monitor and evaluate throughout the project's lifespan to build public trust and future upscaling
 - Conduct site tours
 - Collect field data and measurements on NbS performance
 - Use community voices and lived experiences to share multiple co-benefits (such as recreation, increased wildlife)
- Identify the barriers that constrain the implementation of NbS options in your community
 - Public participation and acceptance
 - Share case studies and examples that demonstrate the effectiveness of NbS
 - Facilitate open dialogues about any uncertainty surrounding NbS adoption
 - Social equity and environmental justice
 - Recognizing the rights and interests of different stakeholders
 - Conduct targeted outreach to support representation in the NbS planning process
 - Institutional fragmentation
 - Create partnerships among different stakeholders by developing a shared understanding of NbS and their benefits
 - Facilitate networking, communication, and integration of different stakeholders early in the planning process
 - Path dependency
 - Bridge knowledge gaps by sharing resources and inviting experts on NbS projects (e.g., USACE's Engineering with Nature team)
 - Encourage hybrid solutions where NbS is integrated with existing functional gray infrastructure
 - Financial resources and incentives

- Explore new funding opportunities and avoid over-relying on a single source of funding
- Consider sources that may not directly be intended for NbS projects
- Support major federal funding programs and competitive grant programs to ensure continued allocations to these programs
- Policies and processes
 - Foster partnerships with local universities, public agencies, scientists, and experts to research the cost-effectiveness of NbS that can support benefit-cost analyses and justify new investments
 - Advocate for options such as the inclusion of a “write your own” option for ecosystem service benefits in FEMA’s benefit-cost analysis toolkit that would help accommodate regional differences in ecosystems not accounted for under the current toolkit
- Regulatory and permitting landscape
 - Mainstream NbS into informal and formal planning regulations progressively
 - Advocate, strategically and incrementally, for changes in the regulatory landscape and build support among city officials, political leaders, and other actors