Site Planning for Disaster Mitigation Guidebook

PD&R

Site Planning for Disaster Mitigation Guidebook

Prepared for
U.S. Department of Housing and Urban Development
Office of Policy Development and Research

Prepared by
MAKERS architecture and urban design, LLP

June 2023

Acknowledgments

The guidebook was prepared by MAKERS architecture and urban design, LLP (MAKERS) for the U.S. Department of Housing and Urban Development (HUD), Office of Policy Development and Research, Affordable Housing Research and Technology Division.

Review Panel

We are grateful to the following professionals who provided technical guidance throughout the development of this guidebook and reviewed the final content.

M. Austin Allen, Ph.D., ASLA
Interim Associate Dean and Associate Professor of Practice, School of Architecture,
University of Texas at Arlington

Alexander J. Felson, MLA, Ph.D.
Professor and Elisabeth Murdoch Chair of Landscape Architecture, Director, Urban Ecology and Design Lab,
University of Melbourne

Jonathon Godt, Ph.D.
Associate Director, Natural Hazards Mission Area, U.S. Geological Survey

Stephanie Grigsby, ASLA, AICP
Board of Directors, Design Workshop

Kristina Hill, Ph.D.
Associate Professor and Program Director, Institute of Urban and Regional Development, University of California, Berkley

Greg Hoffmann, PE
Water Resources Engineer, Center for Watershed Protection

Dwane Jones, Ph.D.
Dean, College of Agriculture, Urban Sustainability, and Environmental Sciences (CAUSES) of the University of the District of Columbia (UDC)

Laura Lightbody
Director, Flood-Prepared Communities, Pew Charitable Trusts

Anna Marandi
Officer, Flood-Prepared Communities, Pew Charitable Trusts

Molly Mowery, AICP
Executive Director, Community Wildfire Planning Center

Sissy Nikolaou, Ph.D., P.E., BC.GE, F.ASCE
Earthquake Engineering Group Leader, Materials and Structural Systems Division, National Institute of Standards and Technology

Stephen L. Slaughter, LEG
Associate Program Coordinator for Landslide Hazards, Natural Hazards Mission Area,
U.S. Geological Survey

Elaina Sutley, Ph.D.
Associate Dean for Diversity, Equity, Inclusion and Belonging, School of Engineering, University of Kansas

James Schwab, FAICP
Principal, Jim Schwab Consulting

Mari R. Tye, Ph.D., CEng
Project Scientist, Climate Change Research, Climate and Global Dynamics Lab, National Center for Atmospheric Research

Shannon Van Zandt, Ph.D.
Professor, Landscape Architecture & Urban Planning and Director, Center for Housing & Urban Development, Texas A&M University

Additional Reviewers

We are also grateful to the following professionals who reviewed the final content of the guidebook.

Whittni O'Brien
Program Analyst, FEMA, Public Assistance Program Design Branch

Daniel Schreiber
Attorney Advisor, FEMA, Office of Chief Counsel

Jonathan Westcott
Civil Engineer, FEMA, Building Science Branch

Alison Ecker, AICP, ASLA
Associate, SWA Group

Daniel Abramson
Associate Professor, College of Built Environments, University of Washington

Bob Freitag
Senior Lecturer and Director of the Institute for Hazards Mitigation Planning and Research, University of Washington

Project Team

HUD

Mark Reardon, Ph.D., Contracting Officers Representative

Regina Gray, Ph.D.

Angela Hodges, Contracting Specialist

Cathy Baker, Contracting Officer

Mark Shroder, Ph.D.

Calvin Johnson, Ph.D.

MAKERS

Julie Bassuk, AICP, Program Manager

Rachel Miller, Project Manager

Katy Saunders, PLA, Alternate Project Manager

Beth Batchelder, Administration and Coordination Lead

Ian Crozier, AICP, Lead Planner

Grace Arsenault, Planning Support

Yifan Xing, Planning Support

Foreword

The *Site Planning for Disaster Mitigation Guidebook* is the result of collaboration across industries, disciplines, and organizations involved in site planning analyses, including experts in natural hazards and hazard mitigation. HUD commissioned this guidebook to provide guidance on how local site planning can mitigate natural disasters and, in doing so, help create and preserve sustainable, hazard-resilient communities. The guidebook was designed to provide a comprehensive, modern guide for site planning for disaster mitigation, including new and innovative technologies and planning approaches, with a focus on employing strategies in urbanizing counties and growing cities.

As HUD continues to improve its understanding of disaster risk and mitigation, this guidebook is an important tool for incorporating emerging and innovative approaches to disaster mitigation through site planning and analyses. Specifically, this guidebook focuses on techniques that can be applied at the site scale to reduce the physical exposure of natural hazards. It addresses a range of natural hazards, including flooding, strong winds, heat and drought, wildfire, landslides, earthquakes, and tsunamis. The guidebook provides techniques and methods designed to create resilient and people-friendly places that support health, wellbeing, social connections, community building, safety and inclusion. The guidebook first examines current drivers and hazard interactions before discussing site planning principles and equity considerations. It then reviews methods of analysis and emerging trends regarding natural hazards and impacts. Finally, it presents hazard mitigation approaches, strategies, and considerations related to best practices.

As natural hazards become more frequent and intense due to climate change, site planning should consistently include natural hazard analysis and mitigation strategies. While strategies for hazard mitigation continue to evolve, it is important to evaluate analysis and planning methods that address interactions between natural hazards and disasters, particularly as new technologies emerge and pilot projects further our understanding of effective mitigation methods. HUD will continue to collaborate with planning professionals, hazard mitigation experts, community leaders and other key stakeholders to elevate the latest insights and evidence-based practices to develop and sustain healthy, safe, thriving and resilient communities.

Solomon J. Greene

Principal Deputy Assistant Secretary for Policy Development and Research
U.S. Department of Housing and Urban Development

Contents

List of Exhibits

Definitions

Adaptation pathways A series of adaptation choices involving trade-offs between short-term and long-term goals and values. These choices are processes of deliberation to identify solutions that are meaningful to people in the context of their daily lives and to avoid potential maladaptation.[1] An adaptation pathway is a "decision-making strategy that is made up of a sequence of manageable steps or decision-points over time." A series of triggers (environmental or social change) and options are identified in advance to "acknowledge that while not all decisions can be made now, they can be planned, prioritized, and prepared for. It is a useful approach for dealing with uncertainty."[2]

Climate change adaptation In human systems, the process of adjustment to actual or expected climate and its effects to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

Climate change mitigation A human intervention to reduce emissions or enhance the sinks of greenhouse gases. In climate policy, mitigation measures are technologies, processes, or practices that contribute to mitigation, for example, renewable energy technologies, waste minimization processes, and public transport commuting practices.[3] In community planning and site selection, a primary climate mitigation measure is efficient land use and transportation systems to minimize vehicular emissions. In site planning, climate mitigation measures might include microgrids, recycling, trees, wetlands, grasses, and other carbon-friendly materials and practices.

Community Development Block Grant (CDBG) program provides annual grants to states, cities, and counties to develop viable urban communities by providing decent housing and a suitable living environment and by expanding economic opportunities, principally for low- and moderate-income persons.[4]

Community Development Block Grant–Disaster Recovery (CDBG-DR) program provides grants to rebuild the areas affected by presidentially-declared disasters and provides crucial seed money to start the recovery process. These flexible grants help cities, counties, and states recover from presidentially declared disasters, especially in low-income areas, subject to the availability of supplemental appropriations.

Community Development Block Grant–Mitigation Funds (CDBG-MIT) program provides grants to areas impacted by recent disasters to implement actions that will mitigate future disaster risks and reduce losses from future disasters.

Equity The term "equity" means the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment, such as Black, Latino, and Indigenous and Native American persons, Asian Americans and Pacific Islanders and other persons of color; members of religious minorities; lesbian, gay, bisexual, transgender, and queer (LGBTQ+) persons; persons with disabilities; persons who live in rural areas; and persons otherwise adversely affected by persistent poverty or inequality.

Exposure The inventory of elements in an area in which hazard events may occur (Cardona et al., 2012).[5] The people, property, systems, or functions that could be lost to a hazard. Exposure generally includes what lies in the area the hazard could affect.[6] The Federal Emergency Management Agency (FEMA), for its risk index, defines exposure as the representative value of buildings (in dollars), population (in both

	people and population equivalence dollars), or agriculture (in dollars) potentially exposed to a natural hazard occurrence.
Green infrastructure	Approaches that combine aspects of grey infrastructure with nature-based solutions to create hybrid systems that improve resilience to climate impacts while also resulting in environmental, economic, and social co-benefits. Examples include bioswales and bioretention, green streets, green roofs, etc.[7]
Green stormwater infrastructure	Infrastructure designed to mimic nature and capture rainwater where it falls. Green infrastructure reduces and treats stormwater at its source while also providing multiple community benefits.[8]
Grey infrastructure	Infrastructure designed to move urban stormwater away from the built environment, including curbs, gutters, drains, piping, and collection systems. Generally, traditional gray infrastructure collects and conveys stormwater from impervious surfaces, such as roadways, parking lots, and rooftops, into a series of piping that ultimately discharges untreated stormwater into a local water body.[9]
Hazard mitigation	Any sustainable action that reduces or eliminates long-term risk to people and property from future disasters.[10]
Infrastructure	The basic equipment and structures (such as roads, bridges, buildings, water lines, and sewer systems) that are essential for functional, healthy, and vibrant communities.[11]
Natural hazard	Environmental events that have the potential to produce harm or produce other undesirable consequences to societies and the built environment.[12]
Natural hazard vs. disaster	A natural hazard becomes a disaster when the event results in harm to humans or the built environment.[13]
Natural Infrastructure	Projects that use existing or rebuilt natural landscapes (forests, floodplains, wetlands, etc.) to increase resilience to climate impacts.[14]
Nature-based solutions	Restoring and/or emulating nature to increase human, ecosystem, and infrastructure resilience to climate impacts. Nature-based solutions include both green and natural infrastructure.[15]
Post-Disaster Recovery	A set of strategies to help a community rebuild after the event of a natural disaster.[16]
Resilience	The level of preparedness for anticipated natural disasters and ability to adapt to changing conditions and withstand and recover rapidly from disruptions.[17] Mitigation, which includes actions taken in advance of a hazardous event to reduce impacts, is one step to increasing resilience. Resilience also includes the “capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure.”[18]
Risk	Risk is the estimated impact that a hazard would have on people, services, facilities, and structures in a community. It refers to the likelihood of a hazardous event resulting in an adverse condition that causes injury or damage. It depends on three factors: hazard, vulnerability, and exposure.[19]
Social vulnerability	Susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood.[20]
Sustainability	Meeting the needs of the present without compromising the ability of future generations to meet their own needs.[21]
Vulnerability	Susceptibility to physical injury, harm, damage, or economic loss. It depends on an asset’s construction, contents, and economic value of its functions.[22]

Acronyms

ADA	Americans with Disabilities Act
APA	American Planning Association
ASFPM	Association of State Floodplain Managers
BFE	Base Flood Elevation
CDBG	Community Development Block Grant
CDBG-DR	Community Development Block Grant – Disaster Recovery
CDBG-MIT	Community Development Block Grant – Mitigation
COVID-19	Disease caused by coronavirus SARS-CoV2
CMRA	Climate Mapping for Resilience and Adaptation
EJ	Environmental Justice
EO	Executive Order
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standard
FIRMs	Flood Insurance Rate Maps
GHADs	Geologic Hazard Abatement Districts
GIS	Geographic Information System
GSI	Green Stormwater Infrastructure
HAB	Harmful Algal Bloom
HIZ	Home Ignition Zone
HUD	U.S. Department of Housing and Urban Development
ICC	International Code Council
NACTO	National Association of City Transportation Officials
NEPA	National Environmental Policy Act
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NRI	National Risk Index
SFHA	Special Flood Hazard Areas
SLR	Sea Level Rise
SUMMEER	Sustainable Material Management Extreme Events Reconnaissance
TDR	Transfer of Development Rights
ULI	Urban Land Institute
WUI	Wildland-Urban Interface
USGS	United States Geological Survey

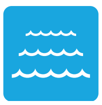
Icons Used in the Guide

Natural Hazards

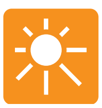
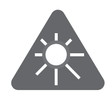
Natural hazards addressed in this guidebook are highlighted with the following icons:

Increased Risk

Some site planning strategies that mitigate disaster for one natural hazard may have negative implications for another. In these cases, the following icons are used:

 **Flooding** (including coastal and inland) 

 **Strong wind** 

 **Heat wave/drought** 

 **Wildfire** 

 **Landslide** 

 **Earthquake** 

 **Tsunami** *Not applicable*

People-friendly design considerations are represented with the following icons:

 **Strategy fosters people-friendly design**

 **Strategy may inhibit people-friendly design**

1

Overview

Cities are major population centers and economic hubs. They are responsible for generating much of the world's GHG emissions, and they are also the most vulnerable to increasing natural disasters and extreme weather events. This places urban areas at the forefront of climate response.[23]

—Matt Bucchin and Aaron Tuley. 2022. "Planning for Climate Mitigation and Adaptation."

Heavy rainfall causes flooding on street. Source: Joe Flood, NOAA

Purpose

Natural hazards are becoming more frequent and more intense due to climate change.[24] Development patterns that promote sprawl[25] and population growth into vulnerable areas can exacerbate the risk to communities.[26] To minimize their potential harm, site planners will need to adapt their practices for our communities to survive and thrive. This guidebook is a collection of best site planning practices to mitigate natural disasters and preserve and create more sustainable, hazard-resilient communities. It focuses on techniques relevant to (1) rapidly urbanizing communities and (2) residential development and offers ideas and paths to more resilient site analysis and planning.

Given the range of site types, local conditions, and political environments across the nation, readers can expect to glean techniques relevant to their locale from the guidebook and then work with local experts and technical resources to refine their approaches. Urban and regional planners and public works professionals may also find techniques that could translate into locally applicable development codes and design standards.

Resilience planning and hazard mitigation is still an emerging area of site planning practice. While some of the strategies identified in this document are well-tested and have been in use for years, others represent emerging ideas, or are being used in new ways. This document focuses on areas of emerging guidance. When topic areas are adequately covered elsewhere or have limited mitigation benefits, it identifies and references other sources. A good example of evolving strategies is the emergence of green stormwater infrastructure (GSI). Approaches have changed over time as they are adopted in different regions and as the strategies mature from pilot studies to standard infrastructure. The National Pollution Discharge Elimination System (NPDES) required stormwater management programs and the implementation of stormwater control measures, which led to an early focus on pollution reduction and water quality benefits from GSI in several regions.[27] As GSI strategies have become widely adopted and effective at managing stormwater, engineers and designers are now looking at how to employ GSI strategies as a network solution, as well as combining GSI approaches with traditional infrastructure to help manage larger flood challenges.[28]

Strategies for hazard mitigation will continue to evolve as planners and designers learn from pilot projects, as the interactions between natural hazards and disasters become more evident, and as new technologies emerge. Many of the resources included in this guidebook point to online information and tools where updated information may be more readily available.

Exhibit 1-1. Damage to Homes from Hurricane Ian

Damage to homes and the coast of western Florida following Hurricane Ian, Oct. 1, 2022. Source: U.S. Coast Guard photo by Petty Officer Third Class Riley Perkofski

What Is Site Planning?

Site planning is the practice of arranging elements such as buildings, landscaping, pathways, and open spaces on a defined piece of land (typically single or aggregated contiguous parcels or lots). Site planning addresses a wide range of characteristics, such as site size, topography, local climate, geology, relationship to surrounding sites, and adherence to rules, laws, regulations, and executive orders about how the site can be developed. It aims to identify a plan that meets the unique characteristics of the site and surrounding community, delivers the goals of the development program (the uses for which the site is being developed), limits exposure to hazards, minimize impacts to environmental systems, and complies with all laws, regulations, and executive orders.

Site planning is an iterative process that can happen at different scales, depending on the size of the project area, which may be a single parcel of land or aggregated parcels, and each can range in size and shape. It involves professionals from multiple disciplines working together to identify project opportunities and address challenges. Although sometimes undertaken by a single private developer, site planning can often be a complex process that involves multiple public, private, and/or non-profit stakeholders based on the underlying regulations, land ownership, and project goals.

Exhibit 1-2. Discussions During a Site Planning Meeting

Site planning is a collaborative and interdisciplinary process that requires coordination between many different professionals and often active participation with community members. Source: MAKERS

How Can Site Planning Mitigate Natural Disasters?

Site analysis can identify the natural hazards that may impact a site, physical characteristics that may increase or reduce risks posed by those natural hazards, and opportunities to mitigate physical exposure to natural hazards by careful site selection and site planning strategies. Site planning mitigation approaches include protecting natural systems, buffering sites from impacts, managing stormwater, and considering the form and placement of buildings, open space, site circulation, and utilities to physically protect people and assets from damage, provide emergency and evacuation access, and prevent or lessen downstream disasters.

Who Is This Guidebook for?

The intended audience is urban and regional planners, real estate developers, landscape architects, architects, engineers, builders, and other housing industry professionals. It aims to help site planners contemplate potential hazards and select mitigation techniques and strategies most relevant to their site.

Scope

Site Planning Focus

This guidebook focuses on techniques that can be applied at the site scale to reduce the physical exposure of homes/buildings and related assets to natural hazards.

Beyond Site Planning

Site planning takes place within the context of a larger environment and considers large-scale geographic, market, and natural systems. However, this guidebook limits its scope to site-scale-specific strategies. Many important strategies and tools to avoid or mitigate natural hazard exposure exist outside the scope of site planning and are, therefore, not a focus in this guidebook, except where they intersect with site-scale mitigation considerations. Community planning and large-scale infrastructure solutions occur at subarea (a part of a municipality), city, state, and regional scales, complementing the site-scale focus of this guidebook. Building-scale interventions (e.g., structural techniques to withstand seismic shaking) also complement site planning considerations, especially where building must occur in risky places.

Related topics (e.g., social vulnerability, emergency response, and post-disaster recovery planning) are integral to resilience but not comprehensively addressed here, except those issues with a direct tie to site planning, such as emergency access considerations.

Beyond Site Planning: Building Codes

Current or recently adopted versions of consensus building codes that include natural hazard design provisions provide structural and building material strategies that can significantly mitigate risks and ensure buildings and infrastructure are more resilient to hazards. Adherence to these codes is crucial to building community resilience; they should be referenced when developing new projects.

FEMA's Building Science division has a variety of helpful tools, including the Building Codes Adoption Playbook (https://www.fema.gov/sites/default/files/documents/fema_building-codes-adoption-playbook-for-authorities-having-jurisdiction.pdf) and other resources (Building Science | FEMA.gov).

See also Local Building Codes under the Mitigation Strategies.

Hazards Addressed

The guidebook focuses on the natural disaster types most relevant to residential development in urbanizing areas and for which site planning techniques are effective as mitigation. Of the 18 natural disasters identified in FEMA's National Risk Index for Natural Hazards, this guidebook addresses the hazards outlined on the following pages. Interactions and relationships between disasters are described in Natural Hazard and Disaster Interactions.

Flooding

Floods are the most common natural hazards in the U.S., as well as the costliest.[29] While the risk of flooding varies, communities across the United States can experience floods, and the United States has seen an increase in these events and resulting damage in recent years. Climate change,[30] population growth in vulnerable areas, and development patterns that increase flood risks are key drivers.[31] This guidebook explores the following flood types: Inland/riverine, coastal, urban/stormwater, and compound.

Site planning strategies can direct, slow, detain, block, and store water to prevent flooding onsite and downstream, as well as accommodate evacuation.

Strong Wind

Wind hazards come from major events such as hurricanes, tornadoes, and severe storms. Strong wind events can affect site planning with considerations for what site elements may move or come loose from wind and how to protect site elements from flying debris. Winds can also interact with other natural hazards to exacerbate risks, such as wildfires,[32] drought-driven dust storms[33], hurricanes, and severe storms that result in floods.

Some site planning strategies reduce wind effects on a site through building siting and massing, employing open space buffers, strengthening utilities or locating them underground, and using trees and vegetation as wind-breaks where it is feasible and safe.

Hazard Icons

The hazard icons found here are later used in the Mitigation Approaches chapter to identify strategies applicable to each hazard. A complete legend of all icons used in this document is provided on page 4.

Example hazard icon

Exhibit 1-3. Coastal Flooding

"Storm Surge" at Assateague Island. Source: NPS Climate Change Response, Flickr

See Site Analysis – Flood

Exhibit 1-4. Home Damaged by Wind Storm

Tornado damage in The Villages, Florida. Source: "House4", D. Frisch, © 2007, CC BY 2.0, Flickr

See Site Analysis – Strong Wind

Heat and Drought

Heat waves and droughts are distinct but related natural hazards that have major implications for site planning, both individually and when combined.[34] Heat waves are periods of abnormally hot weather. Drought is an extended period of dry conditions that impact agriculture, habitats, and/or people.[35] Droughts often emerge slowly, over a period of months or years, and can persist through different seasons and even after precipitation events. They can have significant and wide-ranging impacts on buildings, infrastructure, water resources, natural systems, industry, and agriculture.

Site planning strategies can increase shade, airflow, and ventilation to mitigate heat waves and reduce drought impacts. Restoring natural drainage patterns and infiltration, promoting healthy soils and vegetation, managing stormwater and runoff, and water conservation strategies can further mitigate the impacts of droughts.

Exhibit 1-5. Drought Impacts

Source: "Zmiana klimatu Drought Poland". Marcelina C., © 2019, CC BY 4.0, Wikimedia Commons

See Site Analysis – Heat/ Drought

Wildfire

Wildfires are a natural process important to ecological health and cultural history in the United States. Although the prevalence of fire depends on the ecosystem and geographic region, wildfires are an essential part of healthy forest and wildland ecosystems throughout the country.[36] Many Native American communities used fire as a landscape management tool, routinely burning areas to clear and manage land to promote the growth of key food resources.[37] In recent decades, wildland managers and forest ecologists have come to better appreciate the role that fire plays within a healthy ecosystem and the need to better manage wildlands with fire in mind.[38]

Wildfires are also increasingly resulting in major disasters as development pushes into more vulnerable areas and as fires become larger and more intense due both to climate change and a century of wildfire prevention approaches to forest management that lead to a build-up of fuel in forests and wildlands.[39] Prescribed burns in these areas can present significant challenges for forest managers. Site planning strategies that limit development in highly-vulnerable areas, accommodate evacuation and emergency access, manage open spaces and vegetation, and harden structures against fire reduce risks on a site.

Exhibit 1-6. First Creek Fire, Chelan

Source: "WA_15-08-26_0434", 2015 Forest Service, USDA, Flickr

See Site Analysis – Wildfire

Landslide

Often landslides are addressed as a singular process that involves the downslope movement of soil, water, rock, and debris. However, a range of landslide processes can adversely affect site planning in different ways. This guidebook addresses landslides broadly and as a downslope hazard of debris that can be exacerbated by land use activities.

There are generally two landslide categories that affect site planning: shallow and deep landslides.[40] Shallow landslides are small and driven by intense rainfall or surface water flows that saturate the soil. The fast movement of shallow landslides can threaten public safety and have significant downstream impacts. Deep landslides impact large areas but are typically slow-moving hazards that can be activated by land use changes and development. Both types can threaten communities, roads, and infrastructure. Although the risks to developed areas are significant, landslides are a natural geologic process that can benefit ecosystem biodiversity and functioning in open spaces and natural systems.[41]

Site planning that reduces the impacts of land use and development can help by avoiding high-risk areas, maintaining vegetation, reducing erosion, stabilizing slopes, and protecting assets.

Exhibit 1-7. House Sliding Into the Ocean at San Pedro Sunken City Area, California

Source: Mark Stout

See Site Analysis – Landslide

Earthquake

Earthquakes occur due to the sudden and rapid shaking of the earth as plates move against or away from each other, releasing deep energy expressed by seismic waves all the way to the surface. Communities exposed to varying levels of this hazard include some major cities that developed before there was a clear understanding of seismic risk. Population growth and related development have continued in many of these areas.[42] Consensus building codes offer seismic design guidelines and mitigation solutions with strategies for selection of materials, performance objectives, and use of seismic protection technologies. Some site planning approaches, including ground improvement, can reduce seismic impacts by addressing foundation stability, shelter, and site evacuation. Other approaches may include locating critical facilities or development away from high-risk areas (e.g., liquefaction-prone land) and designing infrastructure, roads, and buildings for earthquake resilience.

Exhibit 1-8. Earthquake and Tsunami in Chile

Source: IFRC, , © 2010 International Federation of Red Cross, CC BY-NC-ND 2.0, Flickr

See Site Analysis – Seismic

Tsunami

Tsunamis are waves, typically caused by earthquakes and/or landslides, that can have very destructive impacts on coastal communities. Tsunamis can range in size from small waves that cause minimal damage to large waves that result in catastrophic disasters.[43] Population growth in coastal areas has resulted in development that is highly vulnerable to tsunamis.

Site planning strategies that direct development away from highly vulnerable areas and provide early warning and evacuation options are ways to address tsunami risks on a site.

Exhibit 1-9. Tsunami Damage in American Samoa

Source: "FEMA – 42023 - Tsunami Damage in American Samoa" by Casey Deshong, FEMA 2009, Wikimedia Commons

See Site Analysis – Seismic

Hazards Not Addressed

Other disaster types—including avalanches, hail, lightning, cold waves/winter weather, and volcanic activity—are not included for the following reasons:

- There are limited site planning interventions to prevent or lessen their impacts.
- Some of these disasters are better addressed at the community planning and/or building design scale rather than the site planning scale.
- Some are less likely to impact rapidly urbanizing communities, which is a focus of this guidebook.

People-Friendly Design

This guide offers site planning techniques to mitigate the disasters described previously. At the same time, an overarching site planning goal is to create people-friendly places that support health, wellbeing, social connections, community building, active lifestyles, and places that are safe and comfortable for diverse humans to enjoy. Mitigation techniques and people-friendly design can be at odds or combined for mutual benefit. Thus, when describing mitigation approaches, this guide includes considerations to encourage people-friendly design.

The placement and orientation of site elements (buildings, sidewalks, landscape, streets, parking, trails, plazas, playgrounds, etc.) can foster social interaction, trust building amongst neighbors, community health, and social well-being.[44] Some site planning techniques that increase the chances for human interaction and neighborly relationships include:

- Compact development; walking, biking, and rolling facilities; and transit orientation to foster active transportation and healthy commutes.
- Frequent entries and active ground floors along streets and public spaces.
- Outdoor or indoor shared common spaces amongst a small group of neighbors.

- Variety of home types for a greater chance at remaining in the neighborhood throughout life's phases.
- Clear transitions between public and private space.
- Appropriate distance (i.e., setbacks) between home entries and sidewalks for comfortable human interaction.
- Building types that support eight or fewer units sharing an entry.

Some hazard mitigation site planning strategies co-benefit sociability, such as the provision of shaded, comfortable gathering spaces in hot climates and trails that also serve as redundant evacuation routes. However, some can inhibit sociability by making it harder for people to spontaneously interact, such as elevated buildings that challenge interactions between people on the first floor and those on the sidewalk. Likewise, too much space between buildings, which could be a good strategy to reduce wildfire spread or conserve natural areas, could make it harder for neighbors to interact.

In addition to social interaction site planning techniques, there are many other people-friendly design techniques (e.g., access to nature, providing seating, weather protection, appropriate solar access in public spaces, layout, and design for active living). A key site planning strategy that often works in concert with many of the strategies in this guidebook is to design sites to include access to nature, parks, and green spaces, which benefits mental and physical health.[45] Similarly, site planning for compact, transit-oriented development with safe pedestrian/bicycle/rolling connections—which supports active lifestyles—is also mutually beneficial with many disaster mitigation approaches.

How to Use This Guidebook

A typical site planning process includes an analysis of site conditions and opportunities followed by the arrangement of desired elements on a site. This guidebook provides information needed by site planners to overlay disaster mitigation onto that process and ensure the resiliency of resulting site plans.

The contents of the guidebook's chapters are summarized to help you locate the most relevant information based on your background knowledge and intended application.

- **Chapter 1: Overview.** Describes the scope of the guidebook, its organization, and how to find the most relevant information for your site.
- **Chapter 2: Current Drivers and Hazard Interactions.** Provides foundational context for understanding 1) the relevance of disaster mitigation to other complex considerations and 2) the interactivity of multiple hazards.
- **Chapter 3: Site Planning Basics.** Defines site planning, reviews site planning steps, introduces equity considerations, and describes the first step in identifying relevant hazards.
- **Chapter 4: Site Analysis.** Describes how to identify and understand hazard exposure when analyzing a site and introduces emerging trends, including compounding/cascading natural hazards and their impacts.
- **Chapter 5: Mitigation Approaches.** Layers hazard mitigation strategies and considerations onto a typical site planning process, introducing readers to a comprehensive set of best practices.

Quick Guide

1. **Identify relevant hazards** for your site in Initial Hazard Identification.
2. **Inventory/analyze existing conditions** using the considerations raised in Chapter 4's Site Analysis section(s) for your hazard(s).
3. **Identify site planning strategy options** by scanning through the Strategy Summary matrix below or Mitigation Approaches for icons representing relevant hazards.
4. **Select suitable strategies** for your site. See the guidance for potentially applicable strategies and elevate options with co-benefits and cut options that may be politically or financially infeasible or inhibit other relevant strategies' effectiveness. When strategies may help in terms of one hazard but present vulnerabilities for another, consider which strategies could layer to cover gaps.

Strategies Summary

Site planning strategies mitigate hazards in different ways, with some providing broad benefits that support underlying natural systems and others addressing specific risks or impacts. Selecting strategies to mitigate natural hazards will always be project-specific in response to unique site conditions, program and community needs, and how other strategies are used. The following table of mitigation strategies covered in this document offers a high-level overview of how the strategies relate to each natural hazard. More details are covered within each section in Chapter 5: Mitigation Approaches.

The icons in exhibit 1-10 mean the following.

● Strategy mitigates the adverse impacts from this natural hazard, or the strategy benefits people-friendly design.

■ Strategy may increase the risk of adverse impact from this natural hazard and/or conflict with people-friendly design.

▲ Strategy may mitigate aspects of this natural hazard and also increase risks or benefits and conflict with people-friendly design.

Exhibit 1-10. Strategy Matrix

Mitigation Strategy	Natural Hazard							
	Flood	High Wind	Heat Wave & Drought	Wildfire	Landslide	Earth-quake	Tsunami	People-Friendly Design
Site Selection and Avoidance								
Site Selection								
Development regulations	●	●	●	●	●	●	●	●
Flood hazard avoidance	●							
Avoid hazards on coastal sites	●	●			●	●	●	
Landslide avoidance					●			
Seismic considerations					●	●	●	
Tools To Avoid Hazard Areas								
Districts, land transfers, and buy-outs	●	●	●	●	●	●	●	▲
Protect, Buffer, and Restore Existing Natural Systems								
Protect and buffer existing natural areas								
Natural area conservation	●	●	●	●	●		●	
Sensitive environmental area buffers	●	●	●	▲	●		●	
Restore natural processes and systems								
Daylighting streams	●		●	●	●			
Stable slopes			●	■	●			
Development - Topography Integration	●	●	●	●	●	●		

Mitigation Strategy	Natural Hazard							People-Friendly Design
	Flood	High Wind	Heat Wave & Drought	Wildfire	Landslide	Earth-quake	Tsunami	
Site Layout, Circulation, and Access								
Building placement								
Compact development	●		●	▲	●		●	●
Siting for soils	●		●		●	●		
Soil stabilization and shoring	●		●		●	●		
Building spacing for wildfire				●				■
Passive cooling			●	■				
Tsunami inundation space	●						●	
Human experience	●	●	●	▲	●	●	●	●
Circulation layout								
Redundancy	●	●		●	●	●	●	
Emergency response access	●	●		●	●	●	●	
Orientation for cooling		■	●	■				●
Multimodal access	●		●					●
Parking	●		●					●
Streets as site protection								
Elevated streets	●					■		●
Green streets	●	●	●	■	●			●
Cool corridors	●		●					●
Early warning, evacuation, shelter and lifelines access								
Early warning systems	●	●		●		●	●	
Clear evacuation routes and signs	●	●		●	●	●	●	
Safe room location		●						
Vertical evacuation	●						●	■
Resilience hub	●	●	●	●	●	●	●	▲
Community lifelines	●	●	●	●	●	●	●	
Stormwater and site protection								
Greening the grey – managing stormwater								
Bioswales and rain gardens	●		●	▲	●			●
Floodwater detention and retention basins	●		●	●	●			■
Permeable paving	●		●	●	●			
Coastal shorelines – edge protection strategies								
Impact reduction strategies	●	●			●		●	
Living shorelines	●	●	●		●			
Coastal structures	▲				▲		●	

Mitigation Strategy	Natural Hazard: Flood	High Wind	Heat Wave & Drought	Wildfire	Landslide	Earth-quake	Tsunami	People-Friendly Design
Upland flood protection strategies								
Floodable open space	●		●	●	●		●	●
Vegetated berms	●	●	●		●		●	▲
Flood-friendly culverts	●				●			
Large-scale flood protection								
Flood control infrastructure	●							■
Open space and green infrastructure								
Healthy soil								
Construction impact reduction	●	●	●	●	●			
Soil amendments	●	●	●	▲	●			
Contamination and water movement	●			●	●	●		
Protecting soils from drought	●		●	●	●	●		
Site restoration post-wildfire	●		●	●	●			
Trees and vegetation								
Native plants and biodiversity	●	●	●	●	●			
Right plant, right place	●	●	●	●	●			
Tree spacing		▲	▲	▲				
Planting and pruning	●	●	●	●				
Outdoor water use and irrigation			●	▲				
Trees as windbreaks		●	●	■				
Wildfire mitigation and open space management								
Defensible space zones				▲				
Fire breaks and fuel breaks				●				
Trails and open space				●				●
Water								
Connecting to water	■		●	●				●
Water features			●					●
Utilities								
Locating utilities on site								
Resilient utility easements	●	●	●	●	●	●	●	
Power utilties								
Underground power and communication lines	▲	●	●	●		▲		●
Strengthen above-ground utilities	●	●		●		●	■	
Microgrid approaches for supply and backup	●	●	●	●	●	●	■	

Mitigation Strategy	Natural Hazard							People-Friendly Design
	Flood	High Wind	Heat Wave & Drought	Wildfire	Landslide	Earth-quake	Tsunami	
Waste and recycling								
Onsite waste anchoring and enclosure	●	●		●	●	●		●
Post-disaster waste and recycling space	●	●		●	●	●		●
Wastewater								
Sewer system connections	●			●	■	●		
Community wastewater systems	●							
Outfall location and protection	●						●	
Water supply								
Firefighting water supply				●				
Efficient water infrastructure	▲		●	●				
Back-up water supply	●		●	●				
Buildings								
Local building codes								
Follow local building codes	●	●	●	●	●	●	●	
Building form								
Elevating buildings	●			■		■	●	■
Flood protection and dry floodproofing	●							
Manufactured home placement	●	●						
Floating and amphibious structures	●							
Reducing wind risks through building form		●						
Surfaces								
Fire safe structures				●				
Shade structures			●					▲
Cool and collecting surfaces	●		●	▲				●
Water conservation and recycling	●		●	●				

Endnotes

[1] Intergovernmental Panel on Climate Change (IPCC). 2022a. "Climate Change 2022: Impacts, Adaptation and Vulnerability Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." https://doi.org/10.1017/9781009325844.

[2] CoastAdapt. 2017. "The Adaptation Process - Coastal Climate Adaptation Decision Support (C-CADS)." https://coastadapt.com.au/coastal-climate-adaptation-decision-support-c-cads.

[3] IPCC. *Climate Change 2022*.

[4] U.S. Department of Housing and Urban Development. "Community Development Block Grant Program." https://www.hud.gov/program_offices/comm_planning/cdbg.

[5] Cardona, Omar-Dario et al. 2012. "Determinants of Risk: Exposure and Vulnerability." In *Managing the Risks of Extreme Events and Disasters to Advance: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press: 65–108.

[6] Federal Emergency Management Agency (FEMA). 2021. "National Risk Index for Natural Hazards." https://www.fema.gov/flood-maps/products-tools/national-risk-index.

[7] Luedke, Heather. 2019. "Nature as Resilient Infrastructure – An Overview of Nature-Based Solutions." White paper. Environmental and Energy Study Institute. https://www.eesi.org/papers/view/fact-sheet-nature-as-resilient-infrastructure-an-overview-of-nature-based-solutions.

[8] U.S. Environmental Protection Agency. "Why You Should Consider Green Stormwater Infrastructure for Your Community." https://www.epa.gov/G3/why-you-should-consider-green-stormwater-infrastructure-your-community.

[9] U.S. Environmental Protection Agency.

[10] FEMA. 2021. "Hazard Mitigation Assistance Grants." https://www.fema.gov/grants/mitigation.

[11] U.S. Environmental Protection Agency. "Why You Should Consider Green Stormwater Infrastructure for Your Community." https://www.epa.gov/G3/why-you-should-consider-green-stormwater-infrastructure-your-community.

[12] National Risk Index for Natural Hazards.

[13] National Risk Index for Natural Hazards.

[14] Luedke, Heather. "Nature as Resilient Infrastructure – An Overview of Nature-Based Solutions."

[15] Luedke.

[16] Institute for Policy Research and Engagement (IPRE), The University of Oregon. "Oregon Partnership for Disaster Resilience." https://opdr.uoregon.edu/.

[17] National Risk Index for Natural Hazards.

[18] IPCC. *Climate Change 2022*.

[19] National Risk Index for Natural Hazards.

[20] National Risk Index for Natural Hazards.

[21] Brundtland, Gro Harlem. 1987. *Our Common Future: Report of the World Commission on Environment and Development*. United Nations.

[22] National Risk Index for Natural Hazards.

[23] Bucchin, Matt, and Aaron Tuley. 2022. *Planning for Climate Mitigation and Adaptation*. PAS Report 601. American Planning Association. https://www.planning.org/publications/report/9250330/.

[24] IPCC. 2022a. *Climate Change 2022*.

[25] Mowery, Molly, Anna Read, Kelly Johnston, Tareq Wafaie. 2019. "Planning the Wildland-Urban Interface." *PAS Report 594*. American Planning Association.

[26] Wing, O.F., J.W. Lehman, and P.D. Bates. 2022. "Inequitable Patterns of US Flood Risk in the Anthropocene," *Nature Climate Change*: 156–162.

[27] McPhillips, Lauren E., and Marissa A. Matsler. 2018. "Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities," *Frontiers in Built Environment* 4 (26). https://doi.org/10.3389/fbuil.2018.00026.

[28] New York City Department of Environmental Protection. "Green Infrastructure." https://www.nyc.gov/site/dep/water/green-infrastructure.page.

[29] PEW Charitable Trusts. "Flood-Prepared Communities." https://www.pewtrusts.org/en/projects/flood-prepared-communities.

[30] IPCC. 2022b. *North America, Climate Change Impacts and Risks*. Fact sheet. Cambridge, UK: Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_FactSheet_NorthAmerica.pdf.

[31] Wing, Lehman, and Bates. 2022. "Inequitable Patterns of US Flood Risk in the Anthropocene."

[32] Bénichou, N. et al. "National Guide for Wildland-Urban Interface Fires." 2021. Ottowa, ON: National Research Council Canada. https://doi.org/10.4224/40002647; Mowery et al., "Planning the Wildland-Urban Interface."

[33] Schwab, James C. et al. 2013. *Planning and Drought*. Planning Advisory Service Report American Planning Association: 6.

[34] American Planning Association. 2019. *Falling Dominoes: A Planner's Guide to Drought and Cascading Impacts*. APA Report. Washington, DC: American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/Falling-Dominoes-Planners-Guide-to-Drought-and-Cascading-Impacts.pdf.

[35] Schwab et al., *Planning and Drought*: 2.

[36] Schwab, James C., Stuart Meck, and Jamie Simone. 2005. *Planning for Wildfires*. PAS Report 529/530. American Planning Association: 32–33. https://www.planning.org/publications/report/9026859/.

[37] Turner, Nancy J. and Sandra Peacock. 2005. “Solving the Perennial Paradox - Ethobotanical Evidence for Plant Resource Management on the Northwest Coast.” In *Keeping It Living - Traditions of Plant Use and Cultivation on the Northwest Coast of North America*, edited by Douglas Deur and Nancy J. Turner. Seattle WA: University of Washington Press: 126.

[38] Schwab, Meck, and Simone. *Planning for Wildfires*, 33.

[39] Mowery et al. “Planning the Wildland-Urban Interface,” 5.

[40] Washington State Department of Natural Resources. “What Are Landslides and How Do They Occur?” Fact sheet. https://www.dnr.wa.gov/publications/ger_fs_landslide_processes.pdf.

[41] Sears, Tricia R. et al. *Preparing for Landslide Hazards: A Land Use Guide for OR Communities*. 2019. Government report. Oregon Department of Land Conservation and Development. https://www.oregongeology.org/Landslide/Landslide_Hazards_Land_Use_Guide_2019.pdf.

[42] Jaiswal, Kishor S. et al., “Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States,” *Earthquake Spectra* 31 (1): S201–20, https://doi.org/10.1193/111814EQS195M.

[43] Grassi, Beth, Elena Suleimani, and Lea Gardine. 2019. “Why a Small Tsunami Is Not a False Alarm.” University of Alaska Fairbanks, Alaska Earthquake Center. https://earthquake.alaska.edu/why-small-tsunami-not-false-alarm.

[44] Montgomery, Charles. 2013. *Happy City: Transforming Our Lives Through Urban Design*. New York, NY: Farrar, Straus, and Giroux.

[45] Petersen, Heidi. Matt Bursa, and Jared Green. “Health Benefits of Nature.” American Society of Landscape Architects. https://www.asla.org/healthbenefitsofnature.aspx.

2 Current Drivers and Hazard Interactions

Wildland-urban interface (WUI) areas "vary based on a number of factors at multiple scales, including the type and quantity of vegetation, topography, fire history, development patterns, and proximity to wildlands. In other words, the WUI is not a fixed geographic location, but rather is based on a dynamic set of conditions—and planners have the ability to influence it.[46]

—Mowery et al. from "Planning the Wildland-Urban Interface."

Southern California neighborhood scarred by wildfire. Source: Jon Keeley, USGS

Current Drivers

Climate Change and Compounding Hazards

Natural hazards are having more significant impacts on communities. This impact is due to climate change increasing the intensity and/or frequency of individual hazards and the interplay between hazards and community exposure.[47] Compounding and cascading hazards, events that trigger or exacerbate the impacts of other natural hazards, can make impacts more severe and exposure to risk less clear.[48] The Site Analysis chapter highlights site analysis and planning approaches to help site planners anticipate the risks of compounding and cascading natural hazards.

Exhibit 2-1. Landslide Impacting Residential Community

A debris flow in Marin County, California, triggered by intense rainfall, destroyed several homes and injured one person in February 2019. Source: USGS/Brian Collins

Sustainability, Resilience, and Climate Adaptation

Natural hazard mitigation can improve environmental and community sustainability, site resilience, and help communities adapt to climate change. Increasing awareness of natural hazard exposure at the site planning scale, mitigating impacts as much as possible, and forward-thinking regional and community-scale land use policies (e.g., compact development in already urban areas with lower exposure to natural hazards) help ensure our communities are resilient to extreme weather impacts and climate change. The Site Analysis chapter's sections on defining risk respond to the need for more attention on natural hazard exposure—and increasing risks—as communities also look for opportunities to grow and build more housing. Education and direct engagement with communities about current and future risks are critical to deciding when to move out of harm's way and when to adapt in place.

Climate change mitigation is also fundamentally connected to natural hazard mitigation. A community's ability to adapt to future hazard impacts will depend on how much those impacts increase due to climate change. Most of the natural hazard mitigation strategies included in this guidebook are examples of climate change adaptation, and many benefit ecological systems and sustainability. While this document focuses specifically on strategies that mitigate the impacts of natural hazards, many of them also provide co-benefits to climate change mitigation (e.g., compact development, passive cooling, microgrids, etc.)

Exhibit 2-2. Restoring a Living Shoreline

Several National Oceanic and Atmospheric Administration (NOAA) volunteers plant Switch Grass previously grown in 26 NOAA offices on a newly created Living Shoreline during the 2010 NOAA Restoration Day event at the NOAA Cooperative Oxford Lab in Oxford, Maryland. Source: NOAA—Flickr, Attribution 2.0 Generic (CC BY 2.0)

Socio-economic Considerations

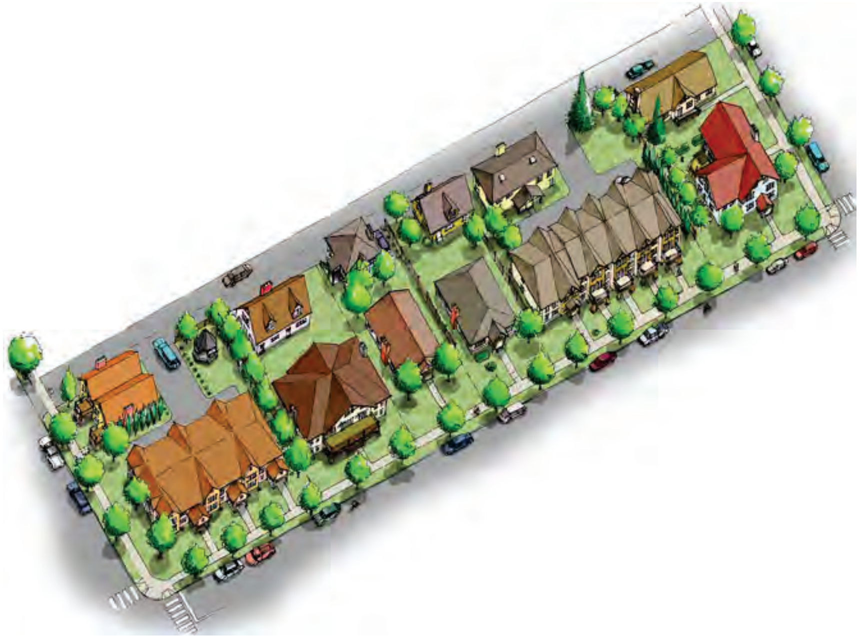
The United States is in a housing crisis with a lack of affordable housing for its growing population; more housing needs to be built.[49] However, solving this crisis without building on land that is vulnerable to hazards presents challenges. Homes and businesses exist in their current locations due to complex and compelling reasons. Communities have developed where they are—and often continue to see development pressure there—because of the access to resources and opportunities their place and development patterns provide.[50] Further, disasters often disproportionately impact underserved and vulnerable people due to historical patterns of inequity and discrimination, as they are more likely to live in areas susceptible to hazards, been excluded from planning and policy making processes, and have less access to the resources necessary for mitigation or recovery.

Over the last several decades, growth and development in the United States have trended toward urbanization and the creation of megaregions in several areas of the country.[51] Given the urban population centers, their land values, and the number of people and assets that need protection, mitigation strategies need to reflect a range of options and recognize where nature-based solutions can enhance resilience and when structural or grey infrastructure approaches are needed to ensure protection. The guidebook's Mitigation Approaches chapter includes both nature-based and grey infrastructure solutions and highlights the benefits and potential conflict areas for each hazard, so site planners can weigh the benefits and potential risks when integrating multiple strategies across the site. Meeting or surpassing local building codes, or the consensus State or National code if no local code has been adopted, is also critical as it can effectively mitigate many natural hazard risks.

Exhibit 2-3. Example Site Plan

Source: MAKERS

Exhibit 2-4. Housing Type Variety



Communities throughout the United States are exploring how to create new housing options to address the affordable housing crisis. Source: MAKERS

Social Equity, Wellbeing, and Vulnerable Populations

Natural hazards have a disproportionate impact on vulnerable and underserved communities, and this trend could increase if more work is not done to center social vulnerability and social equity in hazard mitigation and climate change adaptation.[52] The term "equity" means the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities that have been denied such treatment. For example:

- Hurricane and extreme weather events in low-lying Gulf Coast communities have been catastrophic on low-income households, communities of color, persons with disabilities, indigenous populations, and individuals with disabilities living in these areas.[53]
- Housing in flood hazard zones, particularly inland, is often defined as an area's affordable housing stock.[54]
- Places with high concentrations of communities of color, many of which are in areas formerly redlined, tend to be hotter and suffer more urban heat impacts.[55]
- People with lower incomes seeking affordable housing sometimes move to wildland-urban interface areas, where sites can be more exposed to wildfire and landslide risks.[56]
- In areas with high levels of climate risk, people with resources are moving away from hazardous areas, leaving behind people with limited resources, resulting in negative consequences to social cohesion and community resiliency.
- Many low-income communities lack safe, accessible social infrastructure (i.e., community centers, libraries, community gathering places, etc.) that can facilitate disaster preparation and post-disaster recovery.[57]

Significant climate displacement and migration in the future are possible as the most vulnerable communities are least able to withstand natural hazard impacts. Designing human-oriented communities that support health and well-being —regardless of their socioeconomic status, race, ethnicity, or other demographic factors— while building resiliency to natural hazards are important principles for climate change adaptation.

Exhibit 2-5. Providing Feedback at a Community Engagement Event

Engaging communities in the site planning process is critical to ensuring plans are equitable and meet community and hazard resilience needs. Source: MAKERS

Cost Benefit of Hazard Mitigation and Disaster Preparation

Investments in hazard mitigation can be cost-effective over the lifetime of a project, as the losses from site damage that are avoided have been shown to exceed the money spent on mitigation. For example, high-quality design and public sector mitigation for riverine floods provided a seven-times return on investment, increased occupant safety, reduced business interruption, and benefitted the local economy. According to an analysis by the National Institute of Building Sciences, natural hazard mitigation saves $6.00 on average for each dollar spent on federal mitigation grants.[58]

Natural Hazard and Disaster Interactions

This section clarifies "hazard" and "disaster" differences and introduces how hazards and disasters can compound or cascade to cause complex impacts and disasters. Understanding the relationships between natural hazards, as well as how climate change is increasing the intensity of multiple types of natural hazards, is critical to understanding the relationship between natural hazards and disasters that play out in communities. For example, climate change is increasingly altering natural systems and patterns around the globe and changing natural hazards. Storms and heavy rains are becoming more intense, which leads to more frequent and significant flooding. In areas subject to drought, dry and stressed vegetation increase wildfire risk and intensity. Hillsides recovering from past wildfires are more susceptible to landslides following even typical rainfall events.

Exhibit 2-6. Natural Hazard Interactions Diagram

Diagram illustrating common hazard interactions. Arrows point from the initial natural hazard that can trigger subsequent natural hazards. For some hazard interactions, this correlation can work both ways. Although natural hazard interaction is an emerging area of scientific research, the diagram also highlights how many different types of natural hazards can result in floods.

Cascading Natural Hazards

The interaction of natural hazards is an emerging area of scientific research.[59] Time and sequence are critical factors; some natural hazards can trigger subsequent natural hazards, and otherwise unrelated natural hazards can compound in a short period of time. The high-tide storm surges New York City experienced during Hurricane Sandy illustrate the destructive potential of compound natural hazards.[60]

While storm, wildfire, and landslide events happen within a relatively short timeframe, some natural hazards, such as droughts, can unfold over years or decades. This type of slow-moving hazard can increase the risk of other natural disasters over time. For example, multi-year droughts increase the risk of flooding, landslides, land subsidence (gradual settling or sudden sinking of the Earth's surface), heat waves, and wildfires.[61]

When Does a Hazard Become a Disaster?

A natural hazard is a natural occurrence. Storms, floods, wildfires, cycles of drought, earthquakes, tsunamis, and other natural hazards are processes that, although often destructive, can also contribute to the health and resilience of an ecosystem. Flood events are part of a natural cycle of a river system, fostering diverse shoreline habitats and building rich soils and flat landscapes that have historically attracted people to build farms and communities near their banks. Similarly, many tree and plant species require low-burning wildfires to clear out space for new growth and prompt seeds to germinate to create new forests.

Natural hazards become disasters when they damage or destroy infrastructure and/or communities. Poorly located and/or constructed infrastructure and buildings that do not meet current building codes can also create more extensive disasters. Disasters also often occur when people are unaware of the underlying risk or when people ignore, do not understand, or are unable to respond to warnings and early evacuation orders. Evacuation may be particularly challenging for members of low-income communities that may have limited options for evacuation transportation.[62] Some may have economic restrictions, resulting in them being unable to leave the jobs or businesses upon which they and their families depend.

Climate change increases the risk of extreme weather and some hazard events, and in some cases causing them to be more intense and destructive. For cities to become more resilient, mitigating natural hazards will mean not only stopping or avoiding the biggest impacts but learning to adapt to some natural hazard impacts without causing major disasters. Communities that plan for development and growth in areas where hazard risks are lower, build code-compliant buildings and infrastructure, and understand how to respond to evacuation orders will be better able to reduce the extent of future disasters.

Cascading and Compound Disasters

Natural hazards can result in disasters in ways that are increasingly complex. Just as natural hazards can interact and have compound impacts, the impacts from natural disasters can cascade or compound in relationship to community development patterns, social and economic dynamics, and infrastructure vulnerabilities. Disaster management experts increasingly need to think about the cascading impacts from natural disasters, to better understand near-term and future vulnerabilities.

Cascading disasters occur when one natural hazard triggers either another natural hazard or an infrastructure impact, which compounds negative consequences. Events can be non-linear and happen over extended periods of time with complex feedback loops.[63] One example is the continued impacts from drought in the western United States on the Colorado River. In recent years, water levels have dropped significantly in key reservoir lakes, which has reduced the production of hydroelectric power and created water supply challenges in a system that serves over 40 million people.[64] Although regional water managers have been planning for water scarcity, coordinating water rights across multiple states and jurisdictions remains challenging and highlights how cascading impacts of drought can have wide-ranging impacts on natural resources, land use planning, and growth.

Compound disasters occur when multiple natural hazards, or a combination of natural hazards and other disasters, coincide at the same time or happen in rapid succession. Coastal flooding that is exacerbated by high tides and sea level rise is an example of a compound disaster. It is also important to consider the other types of disasters that can compound the impacts from natural hazards and recovery efforts. In Japan, flooding triggered a landslide event, and this disaster was compounded by the COVID-19 pandemic, which restricted recovery efforts.[65]

Exhibit 2-7. Tidal Flooding in Norfolk, Virginia

Scenes of roads and public access areas begin to nuisance flood as high tide creeps into Norfolk, Virginia, after a few days of rainfall on May 20, 2020. Source: Aileen Devlin | Virginia Sea Grant – Flickr Attribution-NoDerivs 2.0 Generic (CC BY-ND 2.0) https://www.flickr.com/photos/virginiaseagrant/49939446671/

Navigating Uncertainty

Although the impacts of climate change are becoming more apparent, navigating uncertainty is essential to planning for resilience. For example, long-term projections remain uncertain as they will depend on "future emissions pathways and the response of the underlying physical processes."[66] For coastal sites with some current exposure to storms and periodic flooding, consideration must be given to the level of future risk under different relative sea level rise scenarios. The City of Boston, Massachusetts, recently established guidelines for adaptation and development of the urban waterfront, integrating regional relative sea level rise projections into their base-flood assumptions.[67] However, waterfront communities also have to grapple with the long-term uncertainty of how high sea levels will rise and weigh decisions about development in that context. New York City's Climate Resiliency Design Guidelines address the challenges and considerations needed to make future investment decisions.[68]

Uncertainty also exists with riverine flooding, even in systems where there are established patterns of flooding. Rivers can change course following large, disruptive events, as was evidenced in the Yellowstone area flooding in the spring of 2022.[69] Sites near rivers that are not currently within floodplains could become more exposed if major flood events or cascading hazards, such as a flood and landslide, damage flood protection infrastructure or cause the river to change course.

Uncertainty is not limited to floods—wildfires, strong winds, heat waves, droughts, and landslides, are all influenced by climate change and predicted to increase. Earthquakes and tsunamis, although not directly influenced by climate change, can also lead to more intense disasters due to higher relative sea levels, increased landslide risks, and other factors.

Case Study: 2022 Yellowstone River Flood

Historic flooding of the Yellowstone River in Montana highlighted the vulnerabilities of infrastructure and the cascading impacts following a natural disaster. The flood damaged a water treatment facility, which led to water shortages in the community. The water levels in the river during the flood surpassed local plans and disaster preparations, and the facility was not designed to withstand a 0.2-percent annual probability (a.k.a. "500-year") flood.[70]

Exhibit 2-8. Yellowstone River Damage to Floodplain Structures

Source: NPS-Gina Riquier Public Domain Mark 1.0, Flickr

Endnotes

[46] Mowery et al. "Planning the Wildland-Urban Interface."

[47] IPCC. "North America, Climate Change Impacts and Risks." Fact sheet.

[48] AghaKouchak, Amir et al. 2018. "How Do Natural Hazards Cascade to Cause Disasters?" *Nature* 561 (7724): 458–60. https://doi.org/10.1038/d41586-018-06783-6; Asia-Pacific Climate Change Adaptation Information Platform. 2021. "Building Resilience to Compound and Cascading Disaster Risks." https://ap-plat.nies.go.jp/adaptation_literacy/resources/e_learning/drr/index.html.

[49] Badger, Emily, and Eve Washington. 2022. "The Housing Shortage Isn't Just a Coastal Crisis Anymore," The New York Times, July 4. https://www.nytimes.com/2022/07/14/upshot/housing-shortage-us.html.

[50] Howell, J., & Elliott, J. R. (2018). As Disaster Costs Rise, So Does Inequality. Socius, 4. https://doi.org/10.1177/2378023118816795.

[51] Hagler, Yoav. 2009. Defining U.S. Megaregions. Regional Planning Association. https://s3.us-east-1.amazonaws.com/rpa-org/pdfs/2050-Paper-Defining-US-Megaregions.pdf.

[52] U.S. Environmental Protection Agency. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. https://www.epa.gov/cira/social-vulnerability-report.

[53] Adeola, Francis O., and J. Steven Picou. 2012. "Race, Social Capital, and the Health Impacts of Katrina: Evidence from the Louisiana and Mississippi Gulf Coast," Human Ecology Review 19 (1): 10–24; Yuqi Lu. 2017. "Hurricane Flooding and Environmental Inequality: Do Disadvantaged Neighborhoods Have Lower Elevations?" Socius 3. https://doi.org/10.1177/2378023117740700.

[54] Wing, Lehman, and Bates. "Inequitable Patterns of US Flood Risk in the Anthropocene."

[55] Sherman, Amy. 2020. "The Heat Is On," Planning Magazine, American Planning Association. https://www.planning.org/planning/2020/aug/the-heat-is-on/.

[56] Mowery et al. "Planning the Wildland-Urban Interface."

[57] Klinenberg, Eric. 2018. Palaces for the People: How Social Infrastructure Can Help Fight Inequality, Polarization, and the Decline of Civic Life. New York, NY: Penguin Random House; Alan Latham and Jack Layton. 2019. "Social Infrastructure and the Public Life of Cities: Studying Urban Sociality and Public Spaces," Geography Compass 13 (7): e12444. https://doi.org/10.1111/gec3.12444.

[58] Multi-Hazard Mitigation Council. 2019. Natural Hazard Mitigation Saves: 2019 Report. Washington, DC: National Institute of Building Sciences. https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf.

[59] AghaKouchak et al. "How Do Natural Hazards Cascade to Cause Disasters?"

[60] Lemonick, Michael D. 2012. "Sandy's Storm Surge Explained and Why It Matters." Climate Central, October 29. https://www.climatecentral.org/news/hurricane-sandys-storm-surge-explained-and-why-it-matters-15182.

[61] American Planning Association. "Falling Dominoes: A Planner's Guide to Drought and Cascading Impacts," 7–12.

[62] Kousky, Carolyn, and Carlos Martin. 2020. "Low-Income Households Should Be Prioritized After Disaster Strikes." University of Pennsylvania. https://riskcenter.wharton.upenn.edu/lab-notes/low-income-households-should-be-prioritized/.

[63] Asia-Pacific Climate Change Adaptation Information Platform. "Building Resilience to Compound and Cascading Disaster Risks."

[64] Schwartz, John. 2021. "Two of America's Largest Reservoirs Reach Record Lows amid Lasting Drought," The New York Times, July 27. https://www.nytimes.com/2021/07/27/us/lake-powell-water-level.html.

[65] Asia-Pacific Climate Change Adaptation Information Platform. "Building Resilience to Compound and Cascading Disaster Risks."

[66] Sweet, W.V. et al. 2022. Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. Silver Spring, MD: National Oceanic and Atmospheric Administration. https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf.

[67] Boston Planning and Development Agency. 2019. "Coastal Resilience Design Guidelines." https://www.bostonplans.org/getattachment/d1114318-1b95-487c-bc36-682f8594e8b2.

[68] NYC Mayor's Office of Resiliency. 2020. "Climate Resiliency Design Guidelines." https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v4-0.pdf.

[69] U.S. Geological Survey. "How the 2022 Yellowstone Flood Affected a Monitoring Site on the Gardner River." https://www.usgs.gov/observatories/yvo/news/how-2022-yellowstone-flood-affected-a-monitoring-site-gardner-river.

[70] Robbins, Jim, Thomas Fuller, and Christine Chung. 2022. "Flooding Chaos in Yellowstone, a Sign of Crises to Come," The New York Times, June 15. https://www.nytimes.com/2022/06/15/us/yellowstone-national-park-floods.html; "Yellowstone Flooding Threatens Water Supply in Montana's Largest City, Billings" https://www.cbsnews.com/news/yellowstone-flooding-billings-water-supply-montanas-largest-city/.

3

Site Planning Basics

> *. . . the U.S. has built—and continues to build—too many homes in the wrong places, environmentally speaking. Expanding housing supply through sprawling single-family subdivisions at the urban fringe rather than infill development in existing neighborhoods has increased the number of people and homes living in environmentally risky locations.*[71]

—Jenny Schuetz, from "Dysfunctional Policies Have Broken America's Housing Supply Chain"
www.brookings.edu

Wind damage to structures following Hurricane Michael, 2018. Source: Margaret Lamont, USGS

What Is Site Planning

Site planning is the practice of arranging elements such as buildings, landscaping, pathways, streets, impervious surfaces, and open spaces on a defined piece of land. It involves a process of analysis and experimentation to develop an optimal plan that responds to the unique characteristics of the site and surrounding community, delivers the goals of the development program (the uses for which the site is being developed), limits exposure to hazards, minimizes impacts to environmental systems, and complies with all laws, regulations, and executive orders.

Site planning addresses a wide range of characteristics, such as site size, topography, local climate, geology, relationship to surrounding sites, setbacks, and adherence to rules, laws, regulations, and executive orders about how the site can be developed. These factors interact with essential components of the design program, including intended uses, the intensity of use, circulation, environmental systems, infrastructure systems, and resources available to accomplish the development.

Many players and professions are involved, and the site planner's role is to interpret, negotiate, and integrate the various elements into a cohesive, safe, functional, and beautiful site plan. Site planners rely on interdisciplinary expertise and turn to other professionals to understand issues and find solutions for physical and economic feasibility.

In recent decades site planning has become more focused on sustainability as the field responds to climate change, pollution and environmental justice concerns, and the loss of habitat and biodiversity. The current focus on compact urban development, landform-based grading, nature-based solutions, water conservation, and energy efficiency are just some examples of how the practice is working to reduce impacts to the environment and natural systems.

A Typical Site Planning, Design, and Development Process Might Look Like This:

- A housing developer acquires a five-acre parcel with the goal of creating a housing development.
- The developer identifies their goals or "program" – for instance, adding as much housing to the site as is feasible and creating a desirable residential community that will be easy to market.
- The developer or their site planner analyzes site characteristics to determine how they affect the project. For instance, the presence of a wetland reduces the site's buildable area, local zoning codes prevent development more than four stories tall, and the threat of flooding requires specific infrastructure and building design. At the same time, views of a nearby forested stream can enhance the value of the site.
- The developer, site planner, and designers/architects/landscape architects adapt their program for the site, like fitting together puzzle pieces, to create a plan that best achieves the development program given site opportunities and constraints.
- The developer, site planner, and design team refine the site plan and develop design and construction documents to adhere to local building codes and other laws, regulations, and executive orders.
- The developer requests permits for the plan from the City or local development authority.
- The developer hires contractors, prepares the site, and begins to build.

Site Planning Process

The site planning process includes the following steps, which often overlap and repeat to inform the final design:[72]

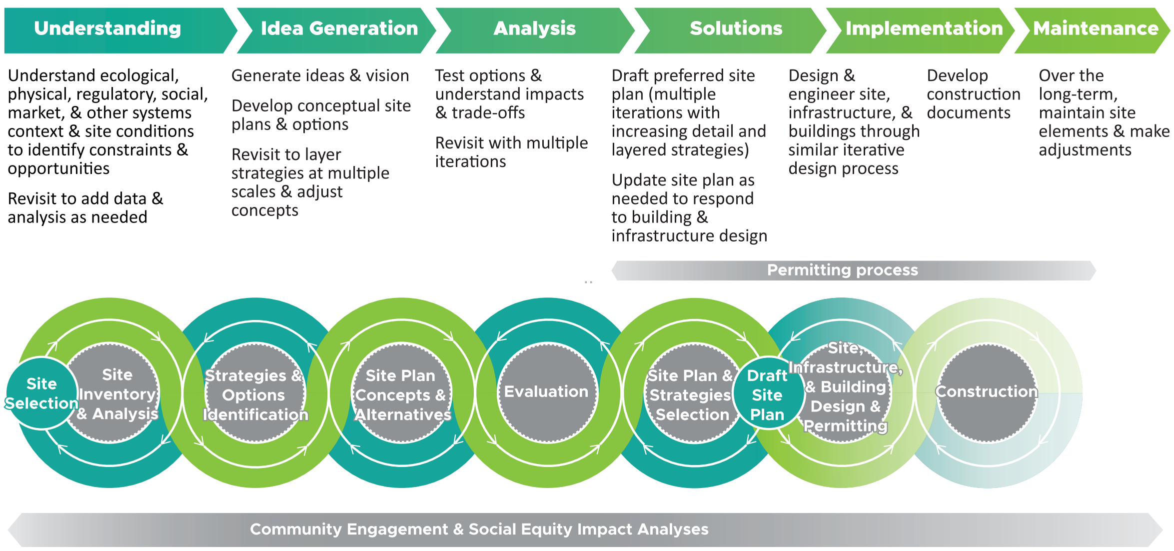
- Site selection and land assembly.
- Visioning and project programming.
- Site analysis.
- Site planning.
  - Strategies and options identification.
  - Site plan alternatives and concepts.
  - Evaluation.
  - Strategies selection.
  - Site plan proposal.
- Community engagement (ideally runs through the whole process).

Exhibit 3-1. Example Site Plan

Site plan layering multiple scales and types of strategies, including an existing transportation system, new smaller-scale street and path network, vegetation and green stormwater infrastructure, a variety of housing types oriented for maximum social connections, and places for gathering and play. Source: MAKERS

Site planning is an iterative process of learning about the site and weighing the tradeoffs and implications of strategies to meet site planning goals. The process starts with core principles and project goals, explores alternative paths to achieving them, analyzes options in various configurations, and, as the strategy options are sorted and sifted in an iterative process, gradually moves toward an optimal layout that best balances the many factors at play. Ideally, this iterative process continues through building and landscape design and even after construction, as site users become intimately familiar with their site and undertake efforts to improve it for their purposes. Resources available can constrain or bolster the site planning process and development. The following sections describe the site planning stages in more detail.

Exhibit 3-2. Iterative Site Planning Process



Source: MAKERS, adapted from Kapoor 2020

Visioning, Programming, and Community Engagement

Typically, early in the process, property owners, real estate developers, and site planners develop preliminary goals and programming ideas for a project. Sometimes a small property owner/developer team develops the vision, but early visioning can also be done by local governments and/or public entities that would like to shape the future of a community. Developers can then pick up these ideas and develop more specific project programs (i.e., what activities and uses should be accommodated on the site) from this early visioning work. This early visioning is critically important for projects with community resilience, sustainability, and/or climate adaptation goals, because these objectives may require emerging practices or strategies that will require close collaboration with local communities.

Site plans benefit from collaboration or co-design with local communities, including local Tribe consultation, particularly when marginalized, disadvantaged, or structurally excluded communities may be impacted by the site's design. Community engagement helps inform the most appropriate solutions for the site, reflect local values in the site plan, identify unintended consequences of potential actions, and build a broad base of support if needed for any political permitting processes. Ideally, community engagement begins early (at the site inventory phase) and continues through the process.

Exhibit 3-3. Community Engagement Activities

Community engagement activity at a community fair for a streetscape and mobility improvements project. Source: MAKERS and Corey Crocker/UDistrict Small Businesses

Site Selection and Land Assembly

When selecting a site for housing development, there are many factors to consider, including exposure to natural hazards. The increasing frequency and severity of many natural hazards are causing communities, hazard mitigation specialists, community planners, and property owners to rethink land use and development feasibility on some sites and take new approaches to site development. When feasible, selecting a site with lesser risks can be the best way to avoid disasters. See the Site Selection and Avoidance section for more information.

Site Analysis

Understand What is Allowed

At the earliest stage, the site planner looks at local zoning, development regulations, and design standards to understand what is permissible on the site in terms of land uses; size and shape of buildings; shape, size, and access to lots; environmentally protected areas such as streams and wetlands; parking capacity; and types and size of plantings. Depending on the funding sources used, additional requirements may need to be me[‡], such as accessibility requirements or site and neighborhood standards.

These regulations often implement community plans for where and how to accommodate population growth. Hazard mitigation plans provide essential guidance on vulnerability and locally appropriate mitigation measures.

The proposed site plan must ultimately be permitted by the local agency, so the plan either needs to follow the rules or the site planner

‡ During site selection, recipients of HUD funds must comply with the requirements of Title VI of the Civil Rights Act of 1964, Section 109 of the Housing and Community Development Act of 1974, and the Fair Housing Act, as implemented by HUD's regulations, that prohibit the site selection of housing that perpetuates and reinforces segregation. Recipients must also comply with the obligation to affirmatively further fair housing, which requires them to take meaningful actions to overcome patterns of segregation, promote fair housing choice, eliminate disparities in opportunities, and foster inclusive communities free from discrimination. Such meaningful actions include site selection that promotes integration and increased opportunities for groups protected by the Fair Housing Act.

must work with the local agency to be granted a variance or rezone to accommodate the plan. Of note, many of the strategies included in this guide recommend going beyond regulations to better mitigate natural hazards.

More specific information is provided in Planning and Regulatory Context.

Site Inventory and Analysis

To identify and understand a site's unique conditions, site planners inventory and analyze the following characteristics:[73]

- **Site form:** Geology (surficial), soils, groundwater, topography, alterations, and historical use by humans (brownfields, landfill, contamination on site, on adjacent sites, etc.).
- **Natural systems:** Sun exposure, wind, rainfall, hydrology and drainage, vegetation/landscape ecology (patches, mosaics, corridors, ecotones, forest succession)/wildlife ecology (habitats, buffers, habitat corridors), critical environments (coastal marshes and dunes, freshwater wetlands, ponds, riparian corridors, steep slopes, forests). As part of the critical environmental areas review, site planners identify constraints and unbuildable areas, including those placed at risk by natural hazards. Resources for understanding data needs and natural hazard exposure and risk are included in the Site Analysis chapter.
- **Context and surroundings:** Access, infrastructure type (roads, utility connections, dams, etc.) and condition (particularly for sub-grade systems), views, existing or legacy structures, noise, locale/genius loci, and human activities.
- **Demographics:** Characteristics, including social vulnerabilities, of existing and potential site users.

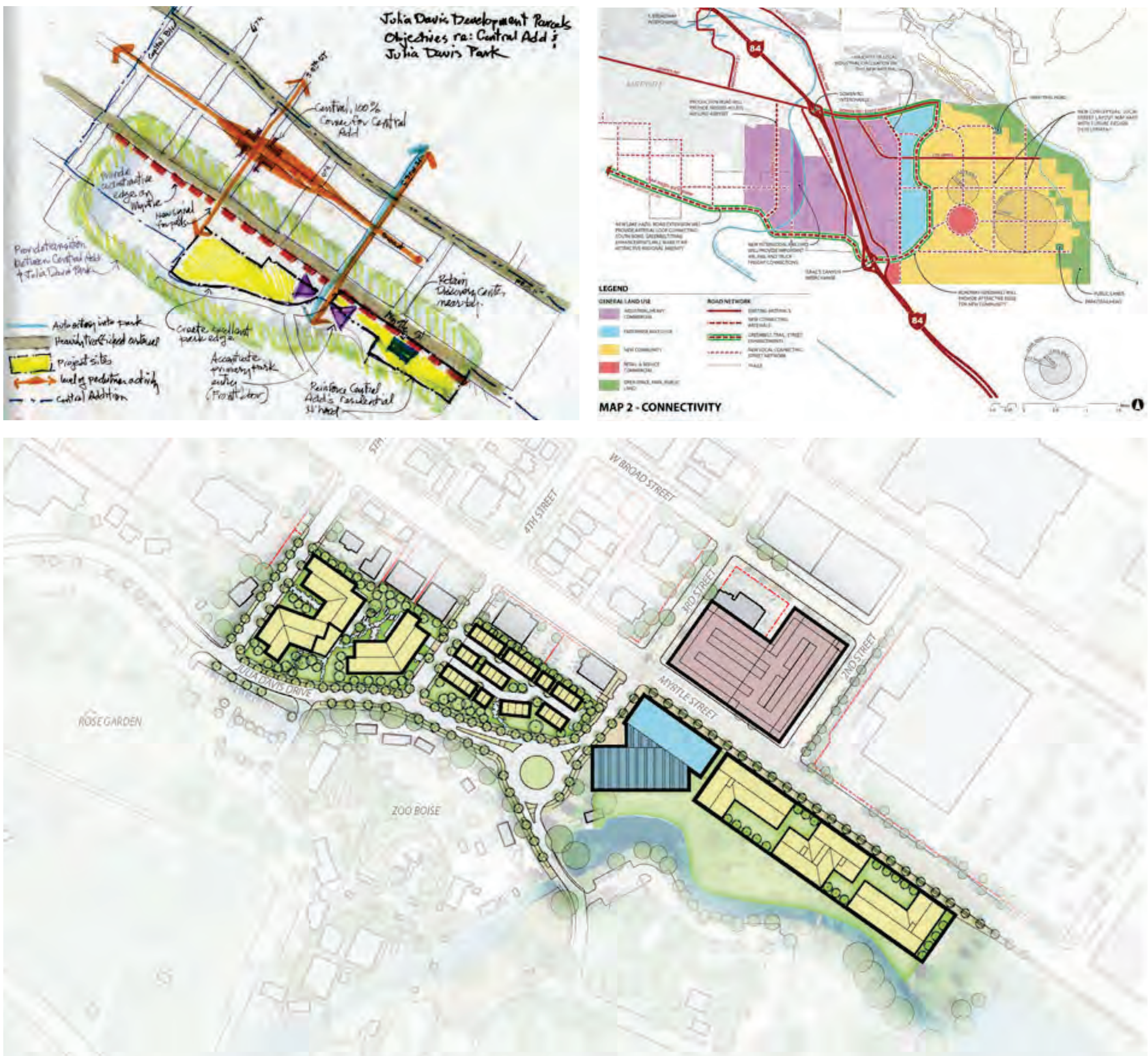
Site planners often supplement quantitative and mapped data with direct site observation and qualitative data from interviews and community engagement processes. The result is an understanding of the site's constraints and opportunities.

Site Planning

Strategies and Options Identification

After understanding opportunities and site constraints, including potential hazards, the site planner identifies potential options. Depending on the site's size and desired program, there may be many goals—each with associated site planning strategies—such as creating people-friendly spaces, supporting transit and active transportation, protecting ecosystem functions, and maximizing development feasibility and return-on-investment. In this guidebook, site planners may reference the Strategies Summary matrix to identify potential mitigation strategies. This initial look provides a range of options for consideration.

Exhibit 3-4. Example Alternative Land Use and Circulation Site Plans



Graphics illustrating steps within a site planning process. Clockwise from top left: diagram of important connections, context and circulation analysis, and final phased development plan. Source: MAKERS

Site Plan Concepts and Alternatives

The following steps outline a simplified alternatives development process. This guidebook's mitigation approaches are organized to follow a site planning process from a larger scale, driving decisions to a smaller scale and/or layering of strategies (see Mitigation Strategy Organization by Site Planning Process sidebar). Alternatives can be developed at a sketch level, as site planners shift, size, and reshape "puzzle pieces," and used internally and/or with community members. Alternatives may also be formally developed for federal or local environmental review at varying levels of detail. Although this is shown as a mostly linear process, site planners must shift between scales and strategies and revisit earlier decisions as elements are tested.

General Site Layout and Circulation. Site planners typically begin with large-scale decisions first (e.g., avoiding a risky site or part of a site), laying out the big pieces—circulation and land use—to understand major decision drivers for how the site will be organized and used. At this stage, the site planner explores what generally fits on the site, how people can get there, and opportunities to connect natural systems for maximum ecosystem services.

Mitigation Strategy Organization by Site Planning Process

This guidebook's mitigation approaches are organized to follow a site planning process from larger scale, driving decisions to smaller scale choices and/or a layering of strategies. Although this is an iterative process, a generalized flow includes the following decision points.

General site layout and circulation:

- Site Selection and Avoidance
- Protect, Buffer, and Restore Existing Natural Systems
- Site Layout, Circulation, and Access

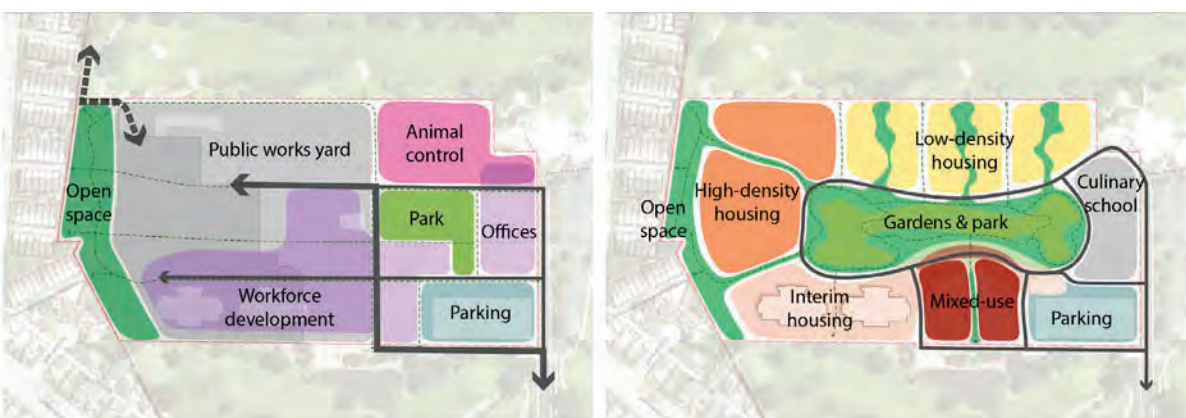
Integrated pieces:

- Stormwater and Site Protection
- Open Space and Green Infrastructure

Layering smaller-scale strategies:

- Utilities
- Buildings

Exhibit 3-5. Example Alternative Land Use and Circulation Site Plans



Plans illustrating the layout and relationship of different site elements, such as open space, parking, housing, facilities, etc. Source: MAKERS

Integrated Pieces. Site planners apply mid-scale and integrated elements that influence how natural and human systems across the site are used. For example, stormwater systems span the entire site and future building and infrastructure forms, so their integration throughout the site plan must be considered early. As these systems begin to take shape, the site planner may need to adjust earlier assumptions about land use placement and size. For example, if the site planner learns an area can be protected from flooding, they may adjust that part of the site concept to show more intense land uses. If they learn a vegetated system needs more space to function properly, they may shrink or move previously laid out land uses.

Layering Smaller-Scale Strategies. Although a misnomer such as "smaller-scale strategies" has enormous impacts on larger-scale systems, these elements can come later in the process because decisions revolve around physically smaller areas of change (e.g., feet rather than acres). For example, the decision to include a street/trail/infrastructure corridor has been made, and its general placement is known, but now the site planner provides more detail on its cross section and what elements are included. The site planner looks for opportunities to layer strategies for multiple benefits (see Principles). Building and infrastructure form (e.g., green roof treatment) begins to take shape. Much of this work may happen following the selection of a preferred site plan concept; there is some overlap with the following evaluation process.

Note, architecture and landscape design typically continue beyond the conceptual site planning stage of a development process and may be accomplished by an entirely different team of professionals. Building form will continue to change as the program, space needs, structural, and aesthetic considerations are clarified and arranged in the architectural design processes, which may then require adjustments to the site plan.

Evaluation

After developing alternative site plan concepts, the site planner (often alongside community members and other reviewers) evaluates trade-offs and implications of varying site layouts and selects the best combination of elements to effectively meet project goals and mitigate risks. The Principles, or similar goals, objectives, values statements, or principles developed for the specific project, may be used as evaluation criteria to compare the pros and cons of the alternatives.

In the context of this guidebook, site planners may weigh the various mitigation strategies. CoastAdapt's Coastal Climate Adaptation Decision Support (C-CADS) process,[74] although designed for larger-scale climate adaptation efforts in Australia, provides a useful framework for "Identifying decision criteria to evaluate your options," "Initial screening of options," assessing and evaluating options, and making decisions under uncertainty.[75] This evaluation framework highlights questions that can help screen out infeasible strategies, elevates those with layered co-benefits (e.g., trees which provide shade during extreme heat events, absorb water during flood events, buffer pedestrians from vehicle traffic, and increase attractiveness and access to nature), identifies when to use multiple mutually supportive strategies, and helps clarify the advantages and disadvantages for selected strategies.

For formal environmental review, viable alternatives are evaluated in an environmental assessment or environmental impact statement/review document by state and/or federal ecology/environmental/natural resources/other departments to compare environmental impacts of all options.

Site Plan and Strategies Selection

Using the evaluation methods described previously, site planners (with the property owner, developer, stakeholders, community members, etc.) select the combination and arrangement of site elements that best meet project goals. In developing the preferred site plan, the site planner will likely layer and refine strategies in more detail than in the initial alternatives development phase.

Planning and Regulatory Context

The federal government, states, tribes, counties, cities, townships, and other local governments set plans, policies, regulations, and programs to require and encourage development that meets public goals. Site planning takes place within this context and is influenced by the following:

- Community planning, such as comprehensive growth management, hazard mitigation, stakeholder engagement, and climate action planning.
- Regulations, such as zoning, development and design standards, environmental review, fair housing and civil rights requirements (including Title VI of the Civil Rights Act of 1964, Section 109 of the Housing and Community Development Act of 1974, the Fair Housing Act, Section 504 of the Rehabilitation Act, and the Americans with Disabilities Act), critical areas, shoreline rules, permitting requirements, building codes, and any local covenants, conditions, and restrictions (CC&Rs).
- Fair housing and civil rights requirements, including Title VI of the Civil Rights Act of 1964, Section 109 of the Housing and Community Development Act of 1974, the Fair Housing Act, as well as Section 504 of the Rehabilitation Act and the Americans with Disabilities Act.
- Programs, such as Federal Emergency Management Agency flood insurance and the U. S. Department of Housing and Urban Development (HUD) housing development and rehabilitation funding.

Comprehensive Plans

The goal of most land use planning—and its associated zoning and development standards—is to balance community growth and economic development with the impacts of such development on environmental systems, natural resources, infrastructure and public services capacity, existing residents, and civic assets. Land use or comprehensive planning typically takes place at multiple scales, including the state, regional, and local levels:

- States may analyze demographic and economic trends to forecast population growth.
- Regional entities may further analyze growth in their region and work with counties and cities to accommodate growth targets and plan commensurate transportation systems.
- Local jurisdictions may plan citywide, countywide, and their subareas and neighborhoods in even further detail. This plan may be called comprehensive, general, or community planning.

These plans set the goals and policies, and the local governments translate them into zoning and development codes. Many topics (e.g., land use, transportation, natural environment, public services, economic development, utilities, capital facilities, hazard mitigation, climate action, and adaptation) may be included in these plans or addressed in topic-specific plans.

Many community planning strategies more effectively address hazard mitigation than can be accomplished on a single site. For example, some local jurisdictions are developing long-term plans to move their communities out of natural hazard risk areas (e.g., tsunami risk zones), a concept called "managed retreat." Others may employ short-term measures (e.g., beach nourishment to slow shoreline erosion) or interim uses (e.g., vacation rentals in lieu of permanent homes) on sites exposed to increasing hazard risks. In these cases, allowing some temporary uses on impacted sites may support a community's ability to transition and adapt over time. Large infrastructure and climate adaptation planning (e.g., levees) may also be done in tandem with land use planning.

Regional Planning

Regional plans typically affect several jurisdictions, such as hazard mitigation planning, growth planning, farmland irrigation, or transportation infrastructure. These plans may be produced by metropolitan or regional planning organizations, one or more state governments, a coalition of local governments, one or more federal agencies, or some combination. They may or may not have regulatory authority. In the case of many regional planning agencies, compliance with their plans ensures eligibility for state and federal funding (e.g., transportation improvements, community development). They often provide guidance for local jurisdictions when developing land use plans and regulations. For the site planner, they may include valuable context for rules implemented by the local government.

Development Regulations

To regulate the impact of development, land use rules place limits on what types of development may be allowed where (zoning) and how large, intense, or impactful development may be (development and design standards). Development codes traditionally place maximum limits on a building's bulk and scale, but in some cases, communities set minimum building heights or densities and parking maximums to favor development in places designated for growth. Incentive programs may also be available, allowing for a more profitable development program in exchange for site improvements or features that support community goals, such as the retention of mature trees that help to reduce urban heat islands.

This guidebook includes strategies and principles that could be infused as appropriate in local development codes.

Federal Programs

Federal policies and programs affect the legality, financial feasibility, and funding sources for potential development. Some relevant programs include:

- National Flood Insurance Program (NFIP) Flood Insurance Rate Maps (FIRMs) and associated insurance rates managed and administered by the Federal Emergency Management Agency (FEMA) through the Federal Insurance and Mitigation Administration (FIMA). FEMA must ensure that all projects comply with appropriate Environmental and Historic Preservation laws, regulations, and executive orders. See more information in Chapter 4: Site Analysis.
- Federal agencies must comply with the National Environmental Policy Act (NEPA) and other federal regulations, laws, and executive orders. NEPA requires federal agencies to assess the environmental effects of their federally funded projects early and before actions that could have a physical impact or help prevent choice limiting actions. NEPA regulations require all agencies to have procedures and the capability to comply with NEPA.
- HUD funding (e.g., physical noise abatement requirements, stronger accessibility requirements under the Americans with Disabilities Act [ADA], Section 504 of the Rehabilitation Act, and the Fair Housing Act, as well as the obligation to affirmatively further fair housing under the Fair Housing Act, Title VI of the Civil Rights Act of 1964, and noise abatement).
- Many federal funding programs help communities plan for, mitigate, and adapt to natural hazards and climate change.

FEMA Floodplain Management Directives Executive Order 11988: Floodplain Management, 1977

Executive Order (EO) 11988 requires federal agencies to avoid, to the extent possible, the long and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative. (FEMA.gov)

Executive Order 11990: Protection of Wetlands, 1977

The purpose of this EO is to "minimize the destruction, loss or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands." To meet these objectives, the Order requires federal agencies, in planning their actions, to consider alternatives to wetland sites and limit potential damage if an activity affecting a wetland cannot be avoided. (FEMA.gov)

Executive Order 13690, Establishing a Federal Flood Risk Management Standard (FFRMS)

The Federal Flood Risk Management Standard is a flood standard that aims to build a more resilient future. As stated in Section 1 of Executive Order 13690, "It is the policy of the United States to improve the resilience of communities and federal assets against the impacts of flooding. (FEMA.gov)

Executive Order 12898: Environmental Justice for Low Income & Minority Populations, 1994

On February 11, 1994, President Clinton signed E.O. 12898. This Executive Order directs federal agencies to make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high adverse human health or environmental effects of its activities on minority and low-income populations. (FEMA.gov).

Endnotes

[71] Schuetz, Jenny. 2022. "Dysfunctional Policies Have Broken America's Housing Supply Chain," Brookings blog, February 22, https://www.brookings.edu/blog/the-avenue/2022/02/22/dysfunctional-policies-have-broken-americas-housing-supply-chain/.

[72] Hack, Gary. 2018. *Site Planning: International Practice*.

[73] Hack, Gary.

[74] CoastAdapt. https://coastadapt.com.au/.

[75] CoastAdapt. "The Adaptation Process - Coastal Climate Adaptation Decision Support (C-CADS)."

4

Site Analysis

Americans who live near a coast are far more likely than those who live inland to point to rising sea levels that erode beaches and shorelines as a major impact in their community.[76]

—Brian Kennedy from *"Most Americans Say Climate Change Affects Their Local Community, Including 70 Percent Living Near Coast"* | www.pewresearch.org

Coastal erosion following a large storm. Source: Andrew Stevens, USGS

Introduction

During site analysis, a site planner inventories existing conditions to understand constraints and opportunities for integrating the desired development program onto the site. This guidebook focuses on hazard-related analysis methods and ways of thinking about the site to identify mitigation opportunities (e.g., natural features that could remain onsite and act as protection from hazards) and increase overall site resilience.

This chapter includes the following sections:

- **Initial Hazard Identification.** This section highlights traditional site analysis data sources to identify relevant hazards at a high level on your site. The following sections illustrate why and how to look beyond these traditional sources to understand future risks.
- **Hazard-specific site analysis guidance.** For each hazard, sections include:
  - **Where this hazard occurs,** which describes typical places where the hazard occurs and introduces the FEMA National Risk Index as a starting point to understand some potential risks on the site. The guidebook also highlights the importance of supplementing this national-level information with local maps, data, and resources. The FEMA National Risk Index (NRI) is a planning-level tool intended for high-level comparisons and should not be used for risk assessment at the local level. In some cases, there is no nationwide data available, although the NRI will be updated over time as data availability improves. Historical data also do not capture all future risks. See FEMA's Disclaimer for the NRI for more information: https://hazards.fema.gov/nri/disclaimer.
  - **Note:** because "flood" includes multiple types of flooding, this section adds information about how the various types are different.
- **Risks and Considerations.** This section describes at a high level what is unique about site analysis for a particular hazard. It includes information to help a site planner think differently about their site once they know a hazard applies. A common theme is that because hazards are changing, new ways of mapping and defining their risks are necessary.
- **Site Analysis particular to the hazard.** This section provides guidance on data and site analysis approaches critical to understanding the site-specific hazard risks and key opportunities for site planning to mitigate them.

Initial Hazard Identification

When analyzing a site, along with inventorying other conditions listed in the Site Planning Basics' Site Analysis section, site planners identify critical environmental areas (e.g., steep slopes, wetlands, soil liquefaction areas) to understand constraints and unbuildable areas, including those impacted by natural hazards. To begin understanding which natural hazards are relevant to the site, some key traditional resources include:

- Local jurisdictions' Geographic Information Systems (GIS) data about local flood hazards, landslide hazards, tsunami inundation zones, seismically unstable terrain, and urban heat vulnerabilities.
- Local hazard mitigation and risk assessment plans and resources.
- Regional watershed plans.
- FEMA FIRMs, which are available for many sites in the United States.
- FEMA's National Risk Index map, which highlights hazards at a national level[77] (best for high-level comparisons, not intended to replace local risk assessment information).
- Soils and geology information from the United State Geologic Service (USGS) and local state agencies.
- Wildlife habitat information from both state and federal agencies.
- Local experts, such as geologists; civil, structural, and geotechnical engineers; hydrologists; floodplain managers; and other technical experts for specific site assessments.

However, as climate change leads to changing weather patterns, rising seas, and other impacts across the globe, site analysis cannot rely solely on historical data to predict future conditions and must incorporate resources that include climate forecasts and predictive modeling. Many Federal, State, and Local agencies, as well as some academic and non-profit entities, are developing tools to assist professionals in better understanding hazard risks on their sites. The following sections provide more information on how to analyze a site for hazard risks and identify opportunities for mitigation. Some mitigation approaches may arise as clear opportunities when analyzing the site; in this case, references to the applicable strategies in the Mitigation Approaches chapter are included.

Flood

Key Statistics

$900 billion
in damage and economic losses were caused by floods in the United States since 2000.[78]

55 states
and United States territories have residents that are impacted by floods.[79]

99 percent
of counties in the United States were impacted by floods between 1996 and 2019.[80]

Where Floods Occur

Riverine (Inland) Floods

When significant rainfall and/or rapid snowmelt increases water flow beyond a river's natural (or constructed) channel, the river floods into the adjacent floodplain areas. For centuries people have developed communities and often constructed levees in these floodplains, drawn to the industrial, commercial, and agricultural opportunities these sites provide. Over the last several decades, many areas that were once farmland or uninhabited floodplains have developed into suburban or exurban communities. As climate change alters weather patterns and levees age, more people are impacted by riverine floods.

Exhibit 4-1. Riverine Flooding

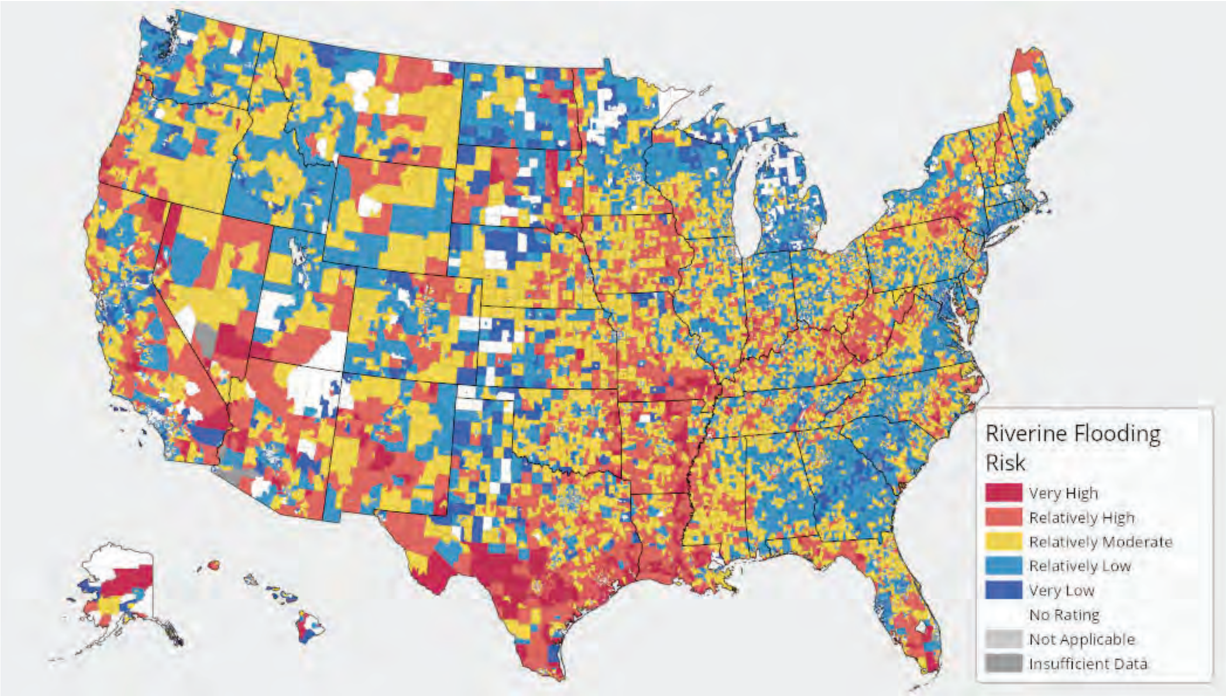
Left: Flooding in a residential area of Austin, Texas. Right: 2011 flood in Minot, North Dakota.
Sources: Roschetzky (left); National Guard (right)

The upstream-downstream relationship for inland and riverine flooding is also an important consideration for site planning, as development in one community can easily impact adjacent neighbors and those downstream. For example, developed areas with high levels of impervious surfaces, including roads and parking areas, can exacerbate flood risks in downstream communities, making them vulnerable to recurring floods, as was seen in Ellicott City, Maryland, and many other communities throughout the United States.[81]

The FEMA National Risk Index map provides a high-level glimpse at current flood risks in the United States. However, this map does not account for all future flood risks.

See Site Analysis – Introduction for more information about the FEMA National Risk Index (NRI) Maps.

Exhibit 4-2. National Risk Index for Riverine Floods



Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) map (https://hazards.fema.gov/nri/map) for riverine flooding, which shows widespread elevated risk across the United States (accessed in 2022). Map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Coastal Flooding

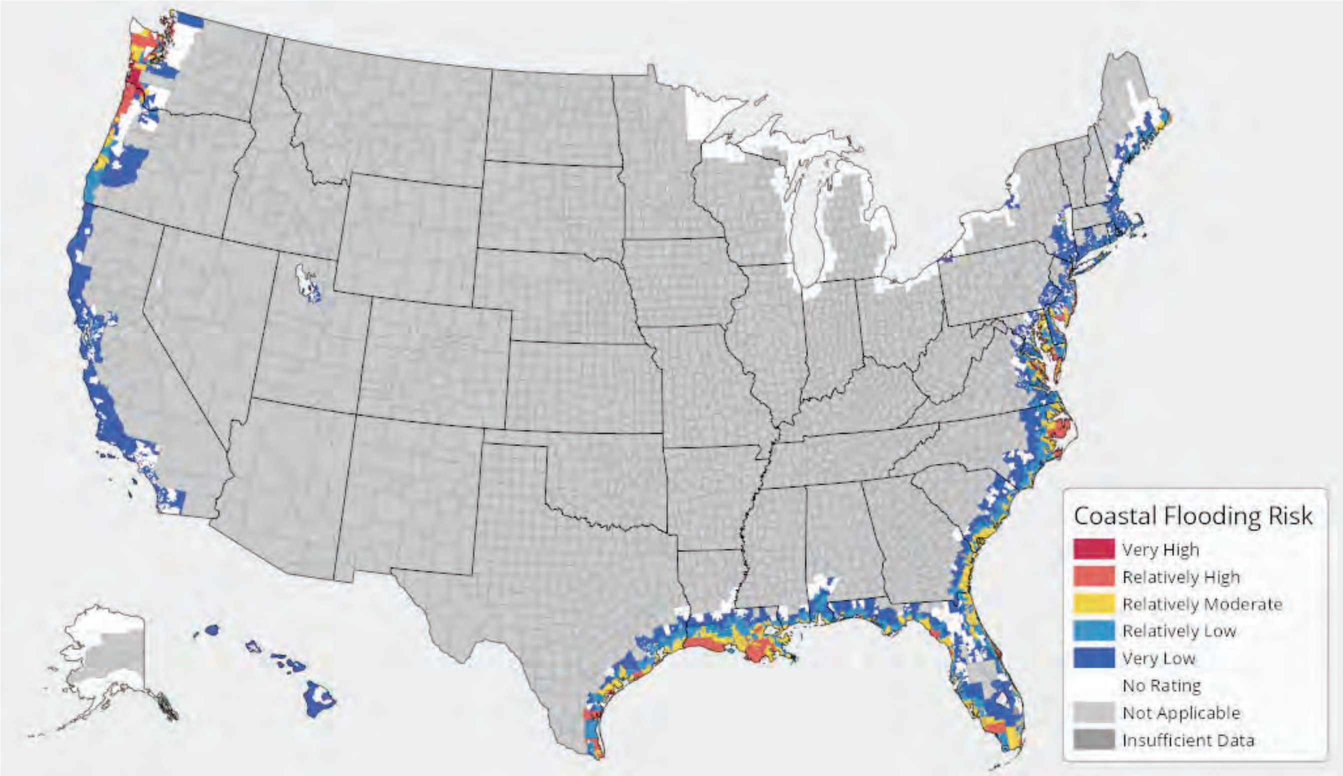
A combination of factors heightens the flood potential in many coastal areas. Coastal sites can be vulnerable to storms, such as hurricanes, which can cause storm surges that flood low-lying areas. Storm surges that correspond to high tides or combine with heavy rain events can be particularly damaging, as occurred with Hurricane Harvey in coastal areas in Texas in 2017. Coastal sites that are located close to rivers can also be downstream of, and potentially impacted by, upstream development and land use changes. Furthermore, growth pressures in coastal areas are particularly high in the United States, as people are drawn to the economic opportunities, natural amenities, and views that coastal sites offer.

Global climate change and sea level rise present further challenges for coastal communities. Sea level rise is not a uniform change—coastal landform and seismic activity also play a role. In some areas, land subsidence, due to large-scale seismic changes, is further exacerbating the impacts of sea level rise, while in other areas, uplift has a mitigating impact on local sea level rise change. Relative sea level change refers to the amount of change in sea level height relative to the land in a particular location.[82]

Exhibit 4-3. Coastal Flooding in Houston, Texas, Damages Road and Infrastructure

Source: Eric Overton

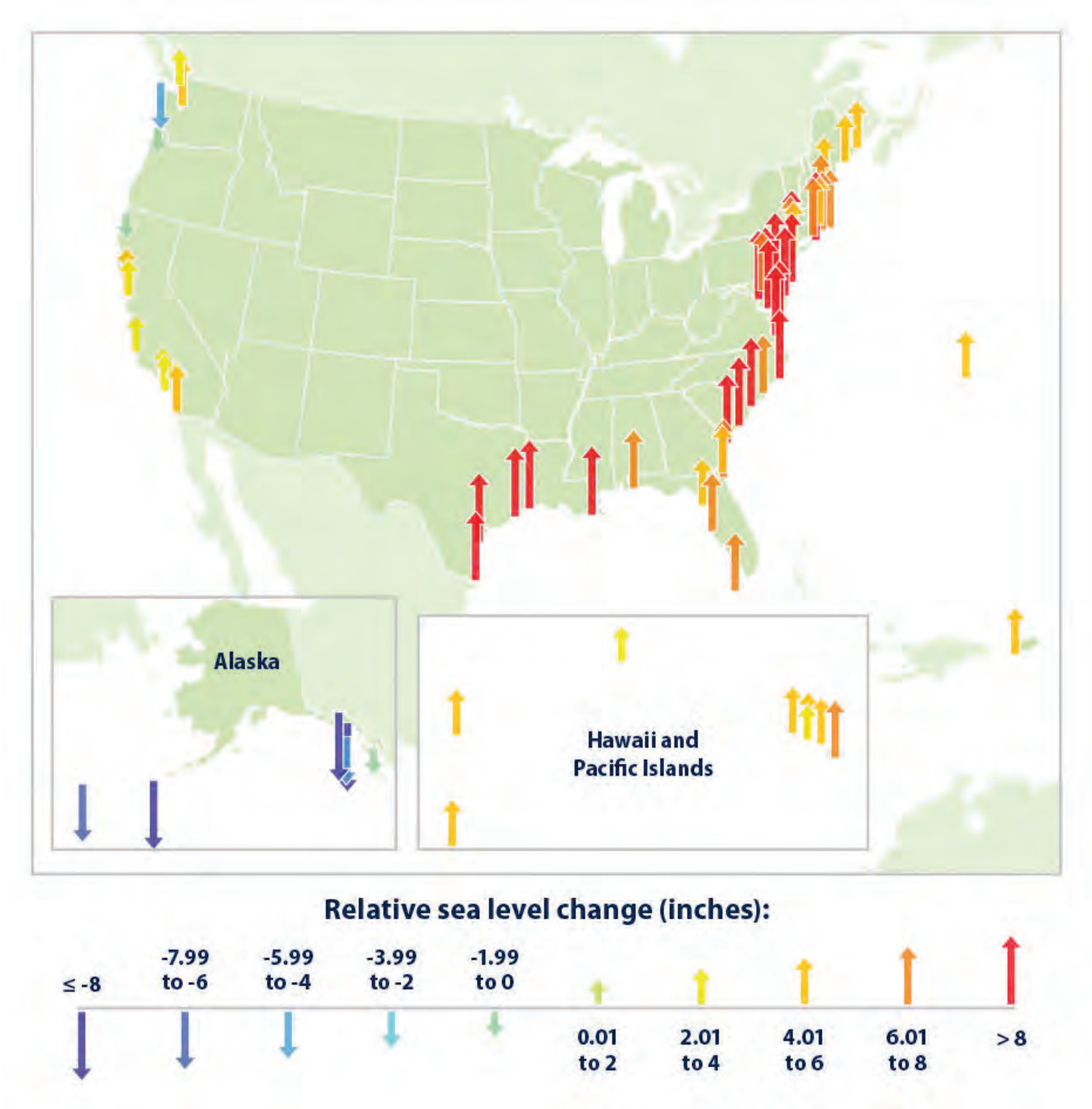
Exhibit 4-4. National Risk Index for Coastal Floods



Map showing Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) map (https://hazards.fema.gov/nri/map) for coastal flooding, which shows elevated risk in the Pacific Northwest, Florida, and in Mid-Atlantic (accessed in 2022). Map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

High-Tide Flooding, also referred to as sunny-day or nuisance flooding, is a recurring flood that corresponds with some high tides in coastal areas. These floods have become increasingly common in coastal areas in recent decades, particularly in areas that have higher levels of relative sea level change.

Exhibit 4-5. Relative Sea Level Change in the United States



Map illustrating "cumulative changes in relative sea level from 1960 to 2021 at tide gauge stations along U.S. coasts. Relative sea level reflects changes in sea level as well as land elevation." Source: [U.S. Environmental Protection Agency Climate Indicators—Sea-Level Rise](#)

Urban and Stormwater Flooding

Another important type of flood event that has received significant attention in recent decades from planners, designers, and hazard management professionals is urban or stormwater flooding. Urban floods happen when runoff overwhelms a community's stormwater management system, resulting in flooding of streets and sometimes low-lying commercial, industrial, or residential areas. In addition to causing potentially hazardous foods, these events also degrade water quality by discharging polluted runoff into local waterbodies.

Compound Flood Events

Multiple flood types can combine and compound. This combination can be common in coastal communities, where rising groundwater combined with sea level rise limits the ability of the ground to absorb water from riverine or urban floods. Bigger and more intense storms can also lead to compound flood events in inland areas, as storm surges push floodwaters inland, and runoff from heavy rainfall compounds local flood impacts.

Exhibit 4-6. Post-Flood Evacuation

Texas National Guard soldiers aid in post-flood evacuation in Houston following Hurricane Harvey. Source: Lt. Zachary West, 100th Mobile Public Affairs Detachment/ Texas Military Department (via Flickr CC BY-ND 2.0)

Risks and Considerations

FEMA Flood Maps

FEMA has created FIRMs for communities throughout the United States to implement the NFIP (see sidebar), which categorizes flood risks into different zones. High-risk flood zones are referred to as Special Flood Hazard Areas (SFHA). The base flood is the national standard used by NFIP and Federal Agencies to regulate development and determine whether flood insurance is required. Periodic revisions to FIRMs often result in properties being added to the flood zone and increase insurance requirements for residents, property owners, and businesses.

Exhibit 4-7 provides an overview of current FEMA flood zones. Mitigation strategies to reduce flood risks are required in all Special Flood Hazard Areas for a site to be eligible for the NFIP. Applicable strategies vary depending on the underlying flood risk zone, and not all strategies are allowable in all zones.

Although mitigation may not be required for sites in low, moderate, or undetermined risk areas, incorporating flood mitigation into a site can increase resilience given that flood risks are increasing, and the FIRM maps do not fully account for all existing flood hazards. Developing site plans based on bigger storm events can help increase community resilience. Many communities require more stringent standards, such as designing for a 0.2-percent annual chance flood (also referred to as a 500-year flood.) ASCE 7-22—Minimum Design Loads and Associated Criteria for Buildings and Other Structures,[83] the American Society of Civil Engineers recently updated manual, moved to the 500-year flood in Chapter 5: Flood Loads section, and future work on ASCE 24 Flood Resistant Design and Construction standards will also reference the 0.2-percent annual chance flood, more stringent than the minimum NFIP requirements.[84]

Key Flood Definitions

Special Flood Hazard Area (SFHA)

High-risk flood zones that have at least a 1-percent annual chance of flooding. The SFHA is the area where the National Flood Insurance Program's (NFIP's) floodplain management regulations must be enforced and the area where the mandatory purchase of flood insurance applies.

Base Flood

A flood having a 1 -percent chance of being equaled or exceeded in any given year. This definition is the regulatory standard of the NFIP and Federal Agencies and is also referred to as the "100-year flood" or the "1-percent annual chance flood."

Base Flood Elevation

The elevation of surface water resulting from a flood that has a 1-percent chance of equaling or exceeding that level in any given year. Base Flood Elevations (BFEs) are typically shown on Flood Insurance Rate Maps (FIRMs).

What is a 1-percent annual chance?

The risk from the 1-percent annual chance flood is more significant than many people understand. Importantly, the annual chance of flooding compounds with time. The base flood risk over 30 years (the length of a typical mortgage) is 26 percent. This statistic implies that there is a 1 in 4 chance that a property in the 1-percent flood area will experience the 1-percent or greater flood hazard during the 30 years.

Exhibit 4-7. Federal Emergency Management Agency Flood Hazard Zones

Flood Zone Type	Description
High-Risk Inland Special Flood Hazard Areas (SFHA)	
Zone A	Areas with a 1-percent annual chance of flooding and a 26-percent chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
Zone AO	River or stream flood hazard areas, and areas with a 1-percent or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet. These areas have a 26-percent chance of flooding over the life of a 30-year mortgage. Average flood depths derived from detailed analyses are shown within these zones.
Zone AH	Areas with a 1-percent annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet. These areas have a 26-percent chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
Zones A1-A30	These zones are known as numbered A Zones (e.g., A7 or A14). This designation is the base floodplain where the FIRM shows a Base Flood Elevation (BFE) (old format).
Zone AE	The base floodplain where base flood elevations are provided. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
Zone A99	Areas with a 1-percent annual chance of flooding that will be protected by a federal flood control system where construction has reached specified legal requirements. No depths or base flood elevations are shown within these zones.
Zone AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam). Mandatory flood insurance purchase requirements will apply, but rates will not exceed the rates for unnumbered A zones if the structure is built or restored in compliance with Zone AR floodplain management regulations.
Zone AR/AE, AR/AH, AR/AO, AR/A1-A30, AR/A	Areas with dual flood risks. These areas have both the presence of a non-accredited flood protection system that is being restored and areas that are subject to flooding from other water sources. Mandatory flood insurance purchase requirements and floodplain management standards apply.[85]
High-Risk Coastal SFHA	
Zone V	Coastal areas with a 1-percent or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26-percent chance of flooding over the life of a 30-year mortgage. No base flood elevations are shown within these zones.
Zone VE and V1-30	Coastal areas with a 1-percent or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26-percent chance of flooding over the life of a 30-year mortgage. Base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

Flood Zone Type	Description
Moderate and Minimal Risk Flood Zones Areas outside of SFHAs where flood risk is lower. Mandatory flood insurance purchase requirements and floodplain management standards do not apply.	
Zone B and X (shaded)	Area of moderate flood hazard, usually the area between the limits of the 1-percent and 0.2-percent annual chance of flooding. B Zones are also used to designate base floodplains of lesser hazards, such as areas protected by levees from the 1-percent annual chance of flooding, or shallow flooding areas with average depths of less than one foot or drainage areas less than 1 square mile.
Zone C or X (Unshaded)	Area of minimal flood hazard, usually depicted on FIRMs as above the 0.2-percent annual chance of flooding level. Zone C may have ponding and local drainage problems that do not warrant a detailed study or designation as base floodplain. Zone X is the area determined to be outside the 0.2-percent annual chance of flooding and protected by a levee from the 1-percent annual chance of flooding.
Zone D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted in these areas. Flood insurance is optional.

Source: Federal Emergency Management Agency, National Flood Insurance Program "Flood Insurance Manual - Risk Rating 2.0: Equity in Action"

Flood Insurance Rates and Risk Rating 2.0

FEMA uses FIRM maps and SFHAs to inform where floodplain management standards apply and the rates for NFIP. In 2020, FEMA updated the NFIP Flood Insurance Manual, implementing a new pricing methodology called Risk Rating 2.0. This methodology "calculates a rate based on a series of unique variables and flood hazards for each building, rather than relying on flood zones and Base Flood Elevations to evaluate the flood risk for broad classes of properties."[86] The new methodology allows FEMA to better assess flood risks, provides property owners with more individualized information to inform flood insurance decisions, and provides states and local governments with a better understanding of flood risks.[87]

Traditional Mapping Limitations

FIRMs are often the default standard used to identify risk, but they have significant limitations:[88]

- FIRMs may be unavailable in smaller communities or out of date due to a lack of topographic information, changes in topography due to development, and other factors.
- FIRMs primarily represent the 1-percent-annual-chance of flooding from a single flood and do not provide a comprehensive view of flood risks.[89]
- FIRMs are based on historical flow data, so they are not the best predictors of future risks influenced by climate change.
- FIRMs do not capture flood risks outside of FEMA's mapped flood zones or increased risks within the SFHAs.[90]

Given these limitations, site planners, owners, developers, and designers should thoroughly analyze a site for potential flood risks and not assume that FIRM zones indicate a comprehensive assessment of risk. Referencing a 0.2-percent annual chance of flood maps, where available, when developing site plans can help increase resilience. Recently, FEMA has announced plans to update maps and tools that will bring a more comprehensive and improved understanding of flood risks.[91]

Repetitive Loss Property Buyout

Another key challenge with the National Insurance Program is the prevalence of repetitive loss properties, or properties impacted multiple times by floods and rebuilt in the same location. Research from the Pew Charitable Trusts indicates that there are thousands of such properties across the United States, and that those properties have cost the NFIP $12.5 billion, close to one-half the program's debt. FEMA, HUD, and other agencies are exploring new approaches to break this cycle. Federal Agencies and some States are looking at property buyouts in flood prone communities to reduce flood impacts and the costs of repetitive loss properties. For more information, see The Pew Charitable Trusts research.

Base Flood Versus Design Flood Elevations

In contrast to the Base Flood Elevation, the design flood elevation is the minimum level of flood protection that must be provided to meet FEMA and NFIP requirements. The design flood elevation will always at least be as high as the base flood elevation, but communities can also require higher design elevations to increase flood protection in vulnerable areas.[92] Some coastal communities also account for future sea level rise projections when they establish local design flood elevations.

Changing Flood Risks

The U.S. Environmental Protection Agency (EPA) tracks a broad range of indicators to assess the impacts of climate change, including heavy precipitation and tropical cyclone activity. These indicators suggest an increase in intense rainfall events, particularly single-day events.[93] They also indicate that the intensity of cyclones has increased, although it is unclear if they are increasing in frequency over the long term.[94]

The EPA also tracks river flooding, coastal flooding, and sea levels as indicators. The indicators show that increases or decreases in flood frequency and intensity generally align with increases or decreases in heavy rainfall events. They also highlight regional differences in flood events, with areas such as the Northeast and parts of the Midwest seeing bigger, more frequent storms while Western and Southwest regions are seeing smaller, less frequent floods.[95]

Sea Level Rise and Coastal Environments

While major flood events that cause extensive damage often garner the most attention, small frequent flooding can have even more extensive economic costs over time.[96] High-tide flooding is an increasing challenge for many East Coast and Gulf Coast communities that face higher levels of relative sea level change.[97]

Back-flooding of infrastructure is another challenge that some communities are facing, as stormwater systems can become a source of flooding.[98] In coastal areas, back-flooding of salt water can also impact parks and green spaces, where the plants cannot tolerate the salt build-up.

Sea level rise is also increasing erosion and habitat loss in coastal ecosystems. As these areas offer a natural buffer from storms and coastal flooding, the loss of these protective ecosystems can exacerbate the impacts of floods in coastal areas.

Emerging research also suggests a need for greater recognition of the threats of sea level rise due to rising groundwater levels. Saltwater intrusion into aquifers is a challenge faced by some Bay Area California communities, requiring costly infrastructure investments.[99] Rising groundwater can increase exposure to other hazards, such as a building's vulnerability to earthquakes and foundation degradation.[100]

Groundwater can also move pollutants below the ground, a significant concern in coastal areas adjacent to brownfields and former industrial sites with a history of toxic waste and pollution.[101] Routine site functions, such as stormwater filtration, may contaminate groundwater if contaminated soils are not addressed during redevelopment.

In coastal areas impacted not only by storms and sea level rise but also tsunami risks, thoughtful decisions need to be made around the location of critical facilities and infrastructure, housing, and both land and vertical evacuation routes.

See the Mitigation Approaches chapter for site planning strategies relevant to flooding and coastal areas.

Acknowledging Uncertainty

With these changes in flood risks come new impacts to communities, many of which are unaware of and unprepared for a flood impacting their community. Furthermore, as was highlighted in the Chapter 2 section: Acknowledging Uncertainty, there is much uncertainty about the long-term potential hazard risk. Acknowledging this uncertainty in the earliest stages of the site planning process will be important to developing resilient communities.

Growth Pressures on Flood Hazard Areas

"A recent study indicated a 26.4-percent increase in flood risks in the US by the year 2050. The same study also showed that population growth in vulnerable areas will increase the risk more than climate change alone."[102]

Despite the known and emerging flood challenges, there continues to be population and job growth in vulnerable areas. This growth suggests an urgent need to coordinate hazard mitigation and climate adaptation planning with growth planning. Despite a recent increase in hazard mitigation planning, gaps in planning integration persist throughout the country. A recent study by the Pew Charitable Trusts surveyed state resilience plans and found that 98 percent did not account for population growth projections in their risk models, and 84 percent do not or only minimally consider disproportionate impacts on socially vulnerable communities.[103]

The future resilience of communities will depend largely on how planners, developers, designers, and emergency managers work together to identify safe places to add housing. Cities and towns of all sizes are facing a critical shortage of housing and an affordability crisis that most severely impacts people with lower incomes, people of color, and other vulnerable communities. Communities need to increase resilience to natural hazards and find opportunities to build housing. Doing both will require coordination, partnerships, creative approaches, and a willingness to consider risks and benefits from multiple perspectives.

Some organizations are looking carefully at how communities can accommodate growth while also reducing flood risks. The Bay Conservation and Development Commission's report on sea level rise vulnerability and adaptation needs in the San Francisco, California, area points out the need to balance adaptation strategies with smart growth priorities, noting that shifting development out of vulnerable areas could lead to encroachment in greenfield areas. The report highlights the many negative impacts of this type of growth, including increased commute times and costly expansion of infrastructure, schools, and other community services.[104] The report also highlights how development can be an adaptation tool by generating fees and taxes to support adaptation strategies and by showcasing more resilient design practices that can buffer older development.[105]

Exhibit 4-8. Flooded Construction Site in a Residential Area

Flooded work site at a house by the Bound Brook at Middlesex gage, Middlesex, New Jersey, 2011. Source: U.S. Geological Survey

Natural Hazard Interactions

Exhibit 4-9. Compound Flood and Landslide Hazard Interactions

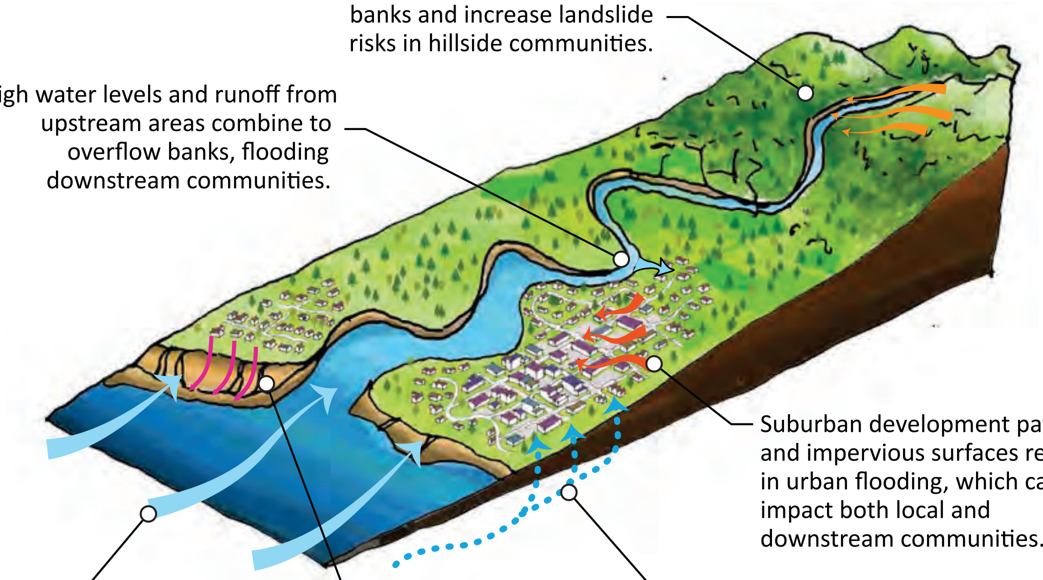


Illustration showing compound flood impacts from sea level rise (SLR), rising groundwater, and urban flooding; impacts on coastal erosion due to sea level rise; and the impact of flooding on upland landslides. Source: MAKERS

Exhibit 4-10. Natural Hazard Triggers for and From Flood

Natural Hazards That Can Trigger Floods	Natural Hazards That Can Be Triggered by Floods
Hurricanes	Landslides (erosion and hydrologic changes)
Landslides (due to hydrologic changes)	Upstream/downstream flooding
Wildfire (due to soil changes that increase runoff)	
Earthquakes	
Drought (runoff)	
Upstream/downstream flooding and flood management	
Severe storms	
Heavy rainfall	

Site Analysis

New tools and site analysis approaches are needed to ensure site planners, property owners, and developers have a comprehensive understanding of a site's current and future flood exposure and risk, as well as potential impact to downstream sites, and can develop plans that increase resilience for future residents and the surrounding community. Key information and site analysis steps include:

- Reference FEMA Flood Insurance Rate Maps (FIRM) and also gather additional information about the types of floods that could impact the site in the future. Seek maps and local resources that incorporate predictive risk models so that climate change impacts are considered in the site analysis.
- Consult with professionals from multiple disciplines to ensure a thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- If there are existing flood risk zones on the site, identify them by type and assess the allowable site and building mitigation strategies that will be required by FEMA to reduce overall flood hazard risk for the project and allow for participation in the NFIP.
- Develop site plans based on a 0.2-percent annual chance of flooding flood events or lower.
- Reference existing watershed plans to understand a site's location within the larger watershed context, including upstream and downstream conditions.
- Identify and map habitat areas and conservation priorities, as natural areas can help manage runoff, store floodwaters, provide buffers, etc. If feasible, work with professionals to conduct a full ecological assessment of the site.
- In coastal areas where sea level rise may be changing groundwater levels, identify and map existing brownfields, former industrial and contaminated sites that could be a source of pollution, as well as their relationship to sewer lines. Sites between a contaminated site and a stream, creek, or tributary could be at greater risk of having contaminated groundwater flowing beneath structures, and pollution vapors can enter a building through cracked sewer lines and foundations.
- Identify aging infrastructure (e.g., levees, utility lines below ground, culverts, bridges, small dams) that is on site or provides access or flood protection to the site. If damaged, it could increase hazard exposure.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to flood hazards.

See Protect, Buffer, and Restore Existing Natural Systems.

See Contamination and Water Movement, Protect, Buffer, and Restore Existing Natural Systems.

- Understand the geologic and geotechnical conditions and history of a site to identify factors that could negatively affect a development—for example, presence of an active fault, weak soils such as uncontrolled fill, organic soft mud and clays, or unstable and vulnerable soils whose strength is affected by natural hazards, such as liquefiable sands or aeolian soils that are vulnerable to flood, rain, or earthquake.
- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities and considers the potential for impact, positive or negative, on people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.
- Review development regulations early in the project to identify permitting requirements and potential barriers for implementing nature-based solutions and/or emerging flood protection and resilience strategies. Coordination with local officials can help identify potential challenges early in the planning process and make it easier to integrate resilience strategies into the project.
- Establish protective design flood elevations. Communities may require a flood elevation study or have designated design flood elevations to which buildings and assets should be designed. Identify critical drivers (e.g., increasing flood risk, sea level rise, project type, and demographics) and work with hydrologists and hydraulic engineers to conservatively set a design flood elevation appropriate for local conditions. Adding 2 or 3 feet of additional freeboard can help reduce potential losses due to flooding.
- Plan for elevating the ground level of homes by 2-3 feet above the crown elevation of existing streets to allow for street flooding without encroachment into homes.

See Elevating Buildings, Protect, Buffer, and Restore Existing Natural Systems.

Resources

- State and local hazard mitigation and/or climate adaptation plans.
- Technical assistance from local floodplain management offices, U.S. Army Corp of Engineers and/or other agencies.
- Flood Factor—https://riskfactor.com/
  Map resource based on a probabilistic flood model that shows any location's combined risk of flooding from rain, rivers, tides, and storm surge.
- FEMA Flood Map Service Center—
  https://msc.fema.gov/portal/home
- National Oceanic and Atmospheric Administration (NOAA)—Sea Level Rise Viewer—
  https://coast.noaa.gov/slr/#/layer/slr
- National Risk Index for Natural Hazards—
  https://hazards.fema.gov/nri/
- Naturally Resilient Communities— https://nrcsolutions.org/moving-people-out-of-harms-way-property-buyouts/
- FEMA Base Flood Elevation Viewer for FEMA Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas)—
  https://webapps.usgs.gov/infrm/estbfe/
- Pew Charitable Trusts—Flood Prepared Communities—
  https://www.pewtrusts.org/en/projects/flood-prepared-communities
- 2022 Sea Level Rise Technical Report—
  https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
- FEMA Building Code Adoption Tracking Tool (BCAT)—
  https://geo.stantec.com/National_BCAT_Portal/viewer/
- Climate Mapping for Resilience and Adaptation (CMRA)—
  https://resilience.climate.gov/
  This resource integrates information from across the federal government to help people consider their local exposure to climate-related hazards.
- International Code Council (ICC) model codes one line code access—
  https://www.iccsafe.org/products-and-services/i-codes/the-i-codes/

Strong Wind

Key Statistics

$1.1 trillion
in damage was caused by tropical cyclones (or hurricanes) between 1980 and 2021.[106]

6,697 deaths
were caused by tropical cyclones between 1980 and 2021.[107]

1,200 tornadoes
hit the United States every year.[108]

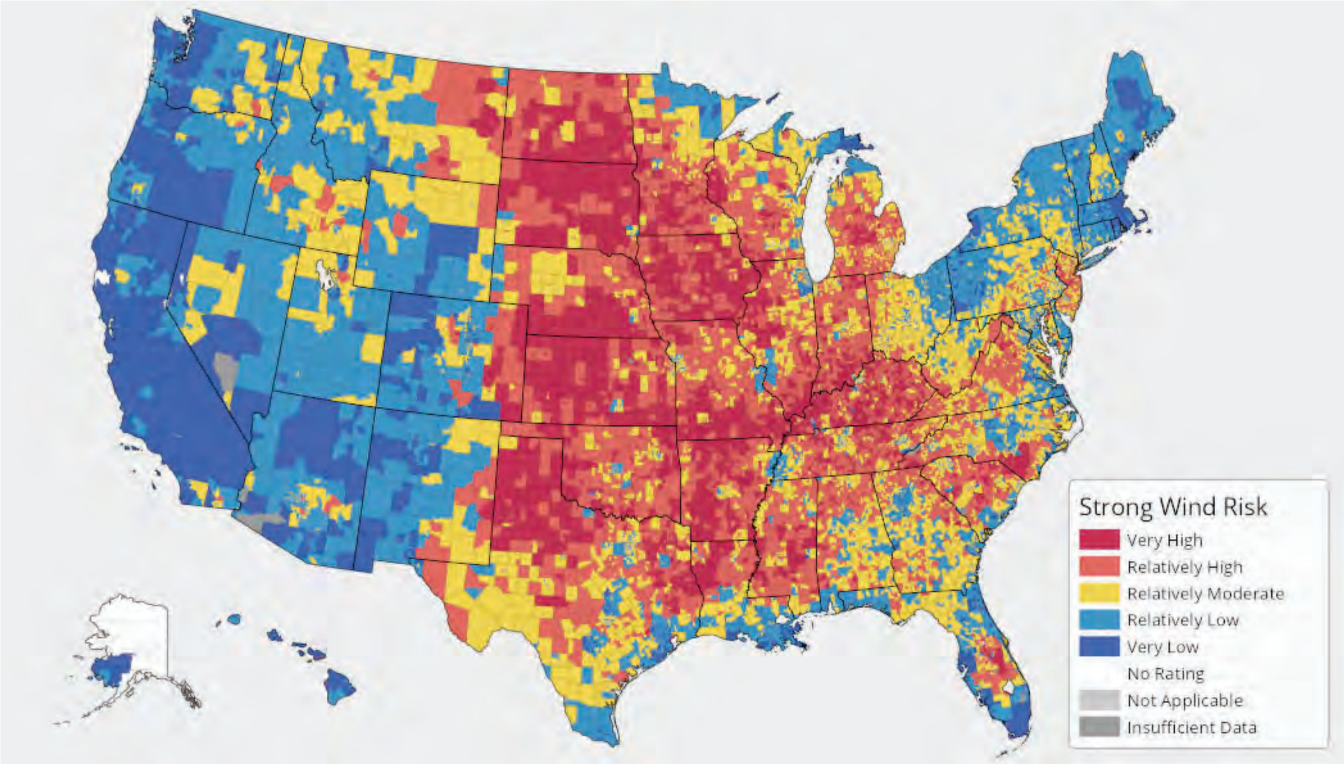
Where Strong Winds Occur

This guidebook considers wind hazards that come from major events such as hurricanes, tornadoes, and severe storms. This section highlights how strong-wind events can impact sites and considers both current and future wind hazards so that site planners can better identify potential risks. This section also touches on how winds can interact with other natural hazards to exacerbate risks, such as wildfires and drought-driven dust storms. Strong wind events such as hurricanes and severe storms can also result in flooding hazards, so site planners working in areas susceptible to strong wind should also review the flood section of this document.

Many regions in the United States are exposed to wind hazards. FEMA's National Risk Index (Risk Index) highlights varying strong wind (strong wind, hurricane, and tornado) risks predominately in the central and southeast areas of the United States. However, the map in exhibit 4-11 does not account for all current or future strong wind hazards.

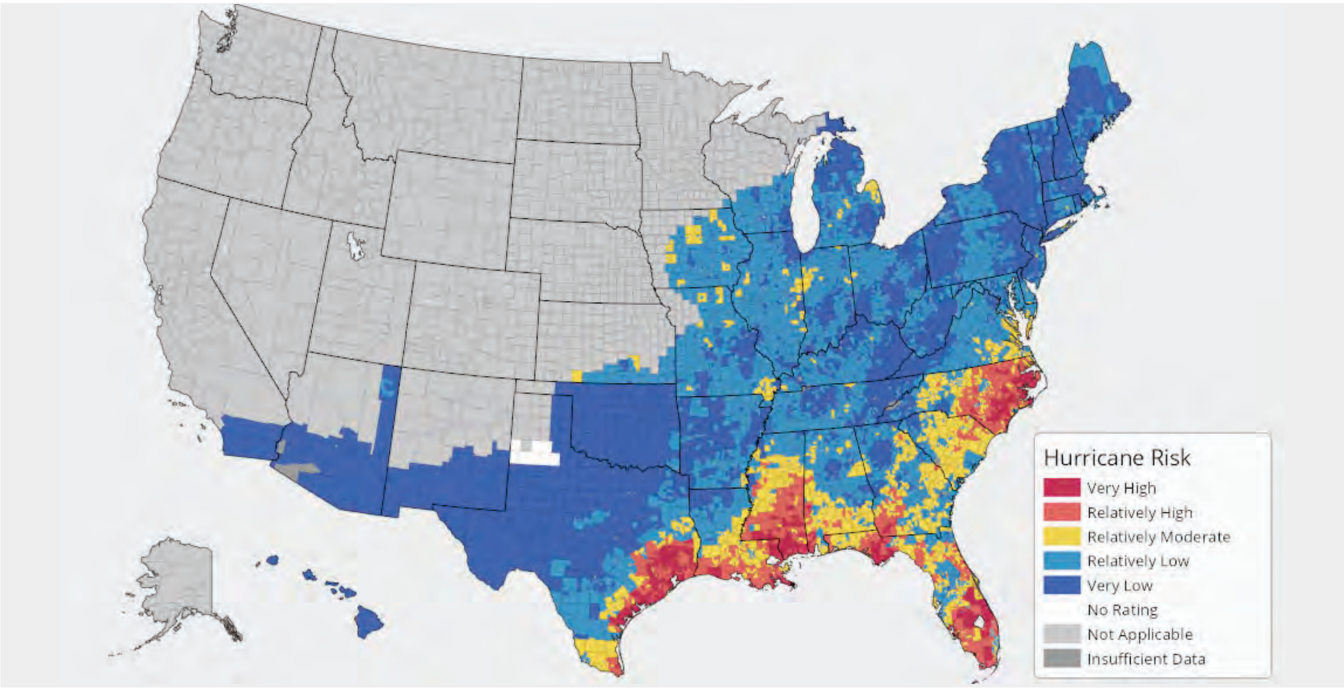
See Site Analysis – Introduction for more information about the FEMA National Risk Index (NRI) Maps.

Exhibit 4-11. Strong Wind Risk Index



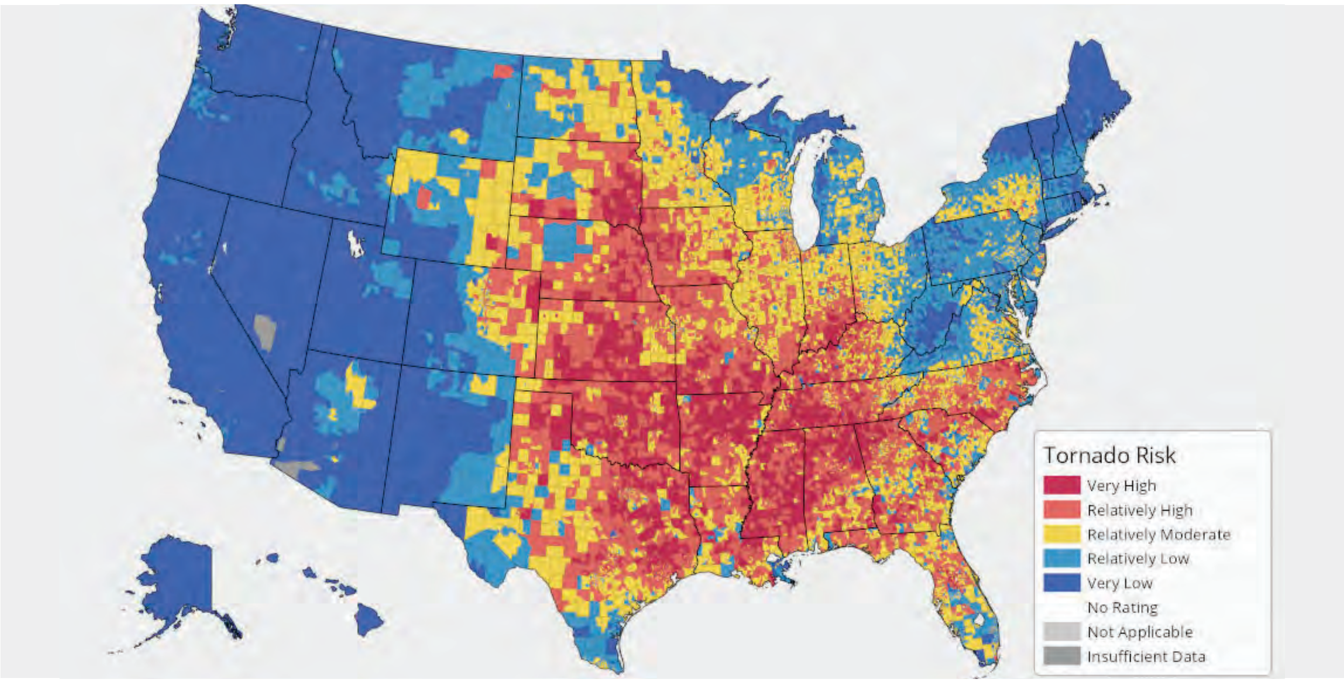
Map showing Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) map (https://hazards.fema.gov/nri/map) for Strong Winds, which shows a clear prevalence of risk in the central portion of the United States and pocket of elevated risk in areas along the east coast (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf) Source: FEMA NRI

Exhibit 4-12. Hurricane Risk Index



Map showing Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for Hurricanes, which shows a clear prevalence of risk in the central portion of the United States and pocket of elevated risk in areas along the east coast (accessed in 2022). Map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation. (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Exhibit 4-13. Tornado Risk Index



Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for tornados, which shows a clear prevalence of risk in the central portion of the United States and pocket of elevated risk in the southeast (accessed in 2022). Map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation.(https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Risks and Considerations

Current and Future Risks

High wind and intense storm events such as hurricanes have increased in frequency in recent decades. While more data is needed to fully assess how the frequency is changing, future hurricanes and extratropical cyclones (storms that impact middle-latitudes, such as nor'easters in the Northeastern part of the United States) are anticipated to be more intense as water and air temperatures rise.[109] In recent years, intense storms have also become more costly. Although the EPA does not track strong windstorms separately from tropical cyclones, they are seeing an increase in heavy precipitation events that are sometimes accompanied by strong winds.[110] Researchers are also exploring the link between storms with lightning strikes and wind and wildfire risks.[111]

Scientists are still working to understand how climate change may influence tornados, and this study is a current focus of ongoing research. While the total yearly count of tornados has not changed significantly, there has been a change in variability, with some periods of calm and some periods of increased activity.[112] In addition, the region impacted by tornadoes has shifted to the east in recent decades, which is an important trend given the area's large population centers and exposure to other hazards.[113] This area is also prone to derechos, or intense, straight-line windstorms.

Site planners need to understand the potential for more intense windstorms and use tools to help predict potential impacts and assess vulnerabilities in and around their site. The American Planning Association encourages the use of emerging tools, such as predictive wind models that forecast future wind speeds and storm scenarios.[114]

Exhibit 4-14. Dust Storm Over Phoenix, Arizona

Strong winds can also create dust storms, and arid communities, or those experiencing drought, can be vulnerable. On September 8, 2014, a dust storm hit Phoenix, Arizona. Source: DB Anderson, Flickr

Natural Buffers

Strong wind events present a challenge to site planners, given the unpredictable nature of impact and limited ways that individual sites can mitigate strong-wind events. In high-risk coastal zones that fall regularly in the path of hurricanes and other severe storms, planners and designers are looking to landscape-scale nature-based solutions, such as open space buffers, to absorb impacts from extreme weather.[115] Large buffers and conservation areas can also help slow and absorb the impact of storms on inland communities. On a smaller scale, stands of trees can provide a microclimate benefit on individual sites.[116] Utilizing trees as windbreaks is a long-established practice in agricultural lands, and also it helps to reduce evapotranspiration and aid with soil conservation.[117] However, trees can often be damaged by wind and become a hazard to people and property during and immediately after an event.[118] Thoughtful approaches to site analysis are needed to weigh the multiple benefits of existing trees and natural infrastructure with the potential for risk.

Structures and Storm Damage

Damage from windstorms is often focused on limiting damage to structures, which is outside of the focus of this guidebook. Meeting or exceeding local building codes that include natural hazard design provisions, or the consensus state or national code if no local code has been adopted, can significantly mitigate natural hazard risks. See the resources section of this chapter for more information on building in high-wind areas.

Infrastructure Vulnerabilities

Above-ground infrastructure can be highly vulnerable during high-wind events, creating further hazard risk for communities, as well as increasing disruption and impact during disaster recovery.

Shelter and Evacuation

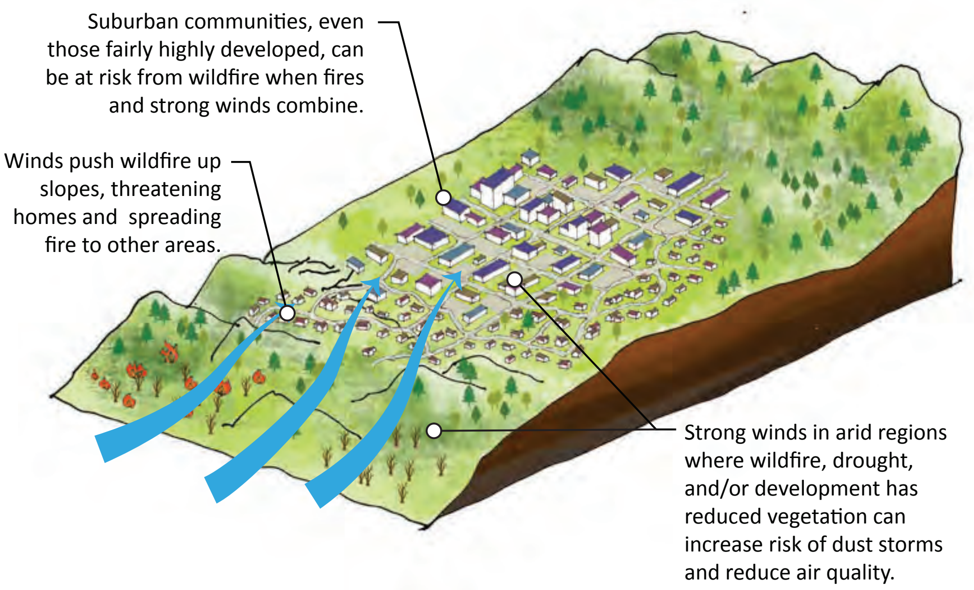
The warning time ahead of strong wind events can vary from a few days, as is the case with some hurricanes, to a few minutes, as is the case with many tornados. Site planners working in highly vulnerable coastal areas need to consider site evacuation strategies and allow for multiple modes of evacuation and redundant routes.[119] In tornado-prone regions, onsite storm shelters are often recommended and are required for critical facilities such as schools and hospitals.[120] Site planners need to assess soil conditions to ensure underground shelters are located appropriately and are not vulnerable to other hazards, such as flooding.[121]

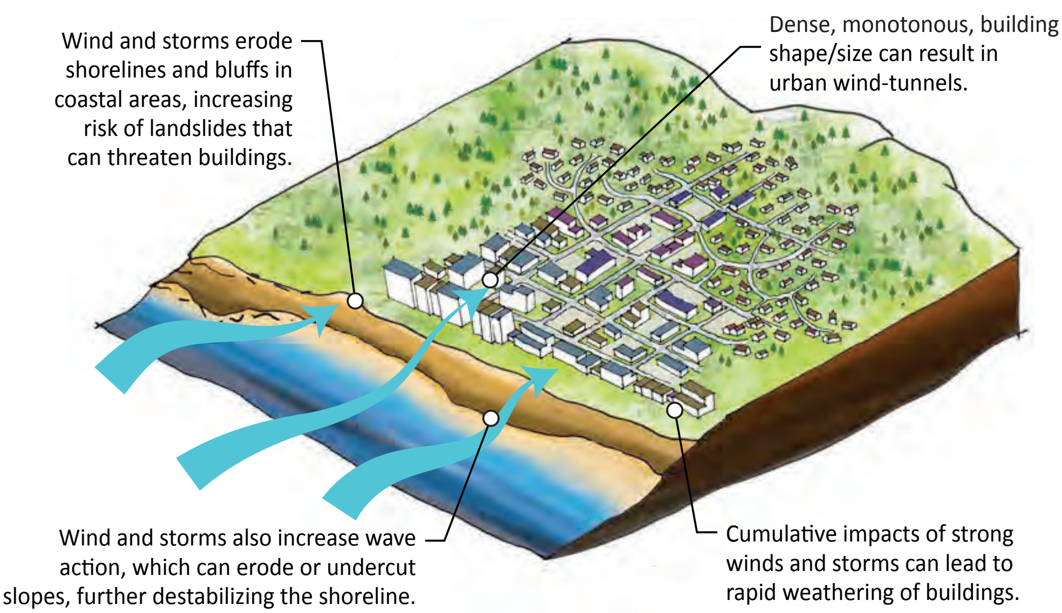
Exhibit 4-15. Wind Damage from Hurricane Katrina

Hurricanes and severe winds can damage buildings through wind forces or by blowing trees and other site elements into structures. Source: National Oceanic and Atmospheric Administration

Natural Hazard Interaction

Exhibit 4-16. Strong Wind Interactions with Wildfire and Coastal Erosion





Winds combined with wildfire can have catastrophic impacts. Strong winds can also be destructive to coastal areas. Impacts on coastal development can include severe erosion following a hurricane and/or cumulative damage to buildings through rapid weathering and repeated storms. Source: MAKERS

Exhibit 4-17. Natural Hazard Triggers for and From Strong Winds

Natural Hazards That Can Trigger High Winds	Natural Hazards That Can Be Triggered by High Winds
Hurricanes. Severe Storms. Natural wind barriers can be negatively affected by drought.	Erosion due to high wind can cause landslides. Wildfire can be spread by high winds.

Site Analysis

Site planners working in areas vulnerable to hurricanes, tornadoes, and other strong windstorms need to plan for more intense windstorms in the future. Site data and analysis, such as the following, account for future risks and can help site planners identify conditions that can increase risks or help mitigate the impacts of strong wind events:

- Reference predictive wind models when developing site plans to ensure site design and structures account for future wind levels.
- Consult with professionals from multiple disciplines to ensure a thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- On larger sites, document existing open spaces that may serve as buffers or insulate the site from strong winds.
- Include prevailing wind patterns in the site analysis to identify areas that are highly exposed or naturally protected from the wind.
- Carefully assess existing vegetation and trees to ensure they are in good condition and are not likely to increase vulnerability. Work with arborists to identify appropriate tree-pruning strategies. Trees can be a fall hazard during strong wind events.
- Larger stands of existing trees can serve as beneficial windbreaks during storms and should be highlighted in onsite analysis documents. If feasible, work with professionals to conduct a full ecological assessment of the site.
- Larger stands of existing trees can serve as beneficial windbreaks during storms and should be highlighted in onsite analysis documents.
- Investigate older and potentially vulnerable infrastructure that could become hazardous in a high-wind event and work with utility service providers and community planners to mitigate risks.[122]
- Consider the risks from airborne debris if nearby structures or site elements are damaged by wind.
- Consider the potential for dust storm exposure on sites vulnerable to drought and dry conditions.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to wind hazards.

See Protect, Buffer, and Restore Existing Natural Systems.

See Tree Spacing and Planting and Pruning.

See Trees as Windbreaks.

See Safe Room Location.

- In tornado-prone locations, assess local soil conditions for below-ground shelter options and look for opportunities for shelter spaces in existing or proposed buildings.
- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities, and considers the potential effects, positive or negative, to people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.
- Ensure strict compliance with building codes. Consider increasing the design wind speed above the code minimum to enhance the wind resistance of the structure.

See Follow Local Building Codes.

Resources

- Protect Your Property From Severe Winds—FEMA https://www.fema.gov/sites/default/files/2020-11/fema_protect-your-property_severe-wind.pdf
- Wind Factor – https://riskfactor.com

Additional Resources for Structures

There are many structure-specific strategies to mitigate the impacts of strong winds, many of which are required by local building codes. For areas without locally adopted building codes, refer to the State Building Code, if adopted, or the Model International Building Codes.

For more information, see the following guidance:

- Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (Fourth Edition)—FEMA 2011
- Mitigation Ideas for Natural Disasters—FEMA 2013 https://www.fema.gov/sites/default/files/2020-06/fema-mitigation-ideas_02-13-2013.pdf

Heat Wave and Drought

Key Statistics

1,200 years

since the western United States last experienced a period of megadrought similar to current conditions.[123]

13 percent

increase in cooling load for an urban building, attributed to the heat island effect.[124]

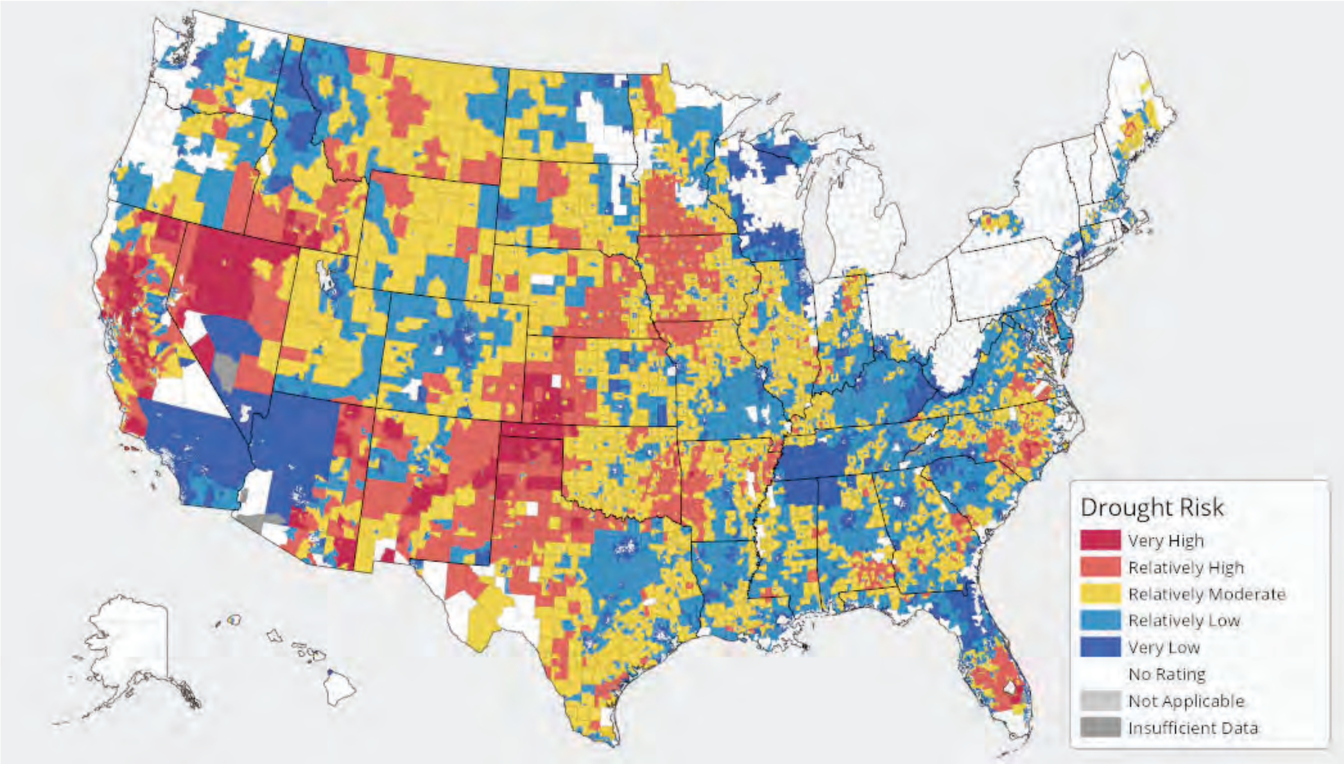
Up to 35°

decrease in surface temperatures is provided by trees. Trees also reduce summer air temperatures by 2° to 9°F.[125]

Where Heat Waves and Droughts Occur

Droughts happen throughout the United States, as the NRI map in exhibit 4-18 illustrates, but there are clear concentrations of risk in the west, southwest, and southern Florida. As noted in previous sections, the NRI is a planning-level tool and does not account for all current and future risks.

Exhibit 4-18. Drought Risk Index



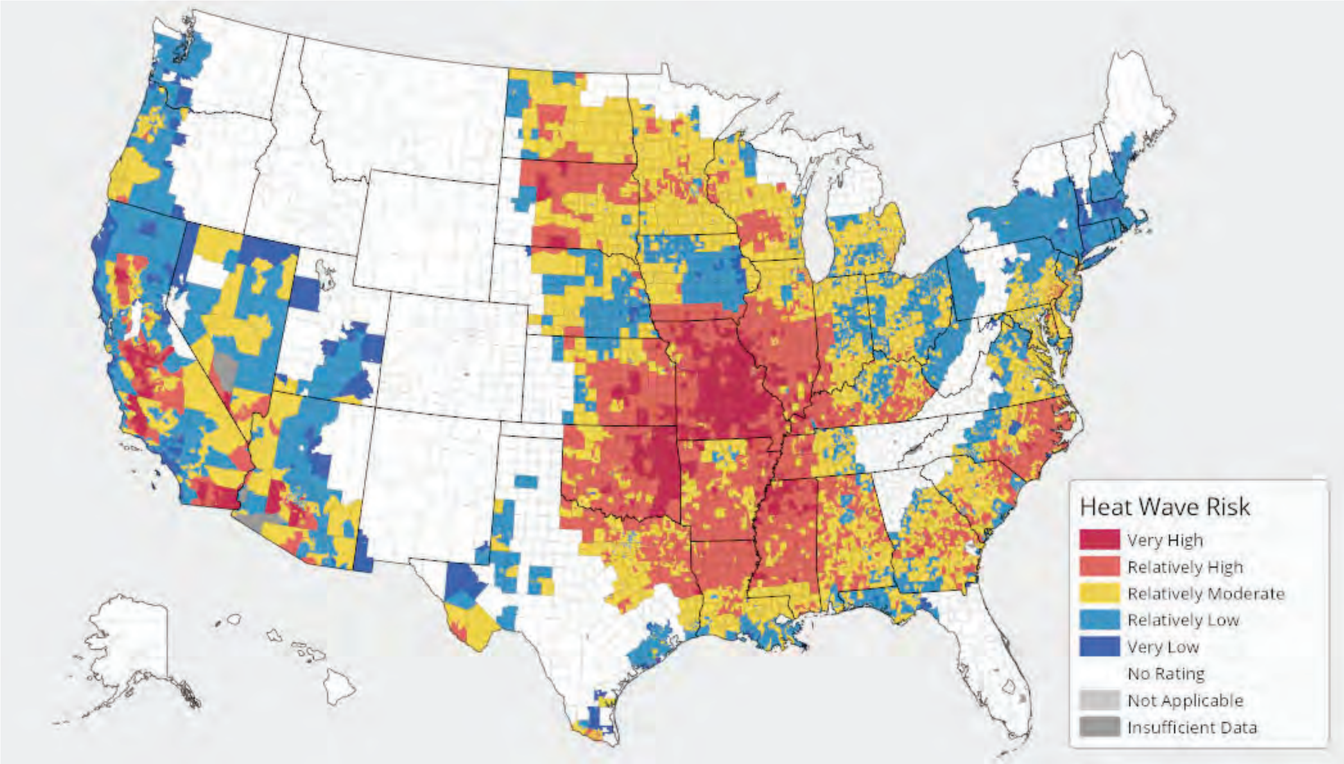
Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for drought, which shows elevated risk in the central and western portions of the United States (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Heat waves can accompany droughts and are frequent in many of the regions where droughts are a challenge. However, heat waves can also be stand-alone events and often are a significant risk in urban areas, where temperatures tend to be higher due to lack of vegetation, the predominance of impervious ground and building surfaces that absorb heat, and waste heat from buildings, transportation, and industry.

The NRI map's data on heat wave risks (exhibit 4-19) are not complete for all locations in the United States but clearly show a focus on the hotter regions in the southwest, mid-west, and southern areas.

See Site Analysis – Introduction for more information about the FEMA National Risk Index (NRI) Maps.

Exhibit 4-19. Heat Wave Risk Index



Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for a heat wave, which shows elevated risk in several areas on the east coast, west coast, and central United States, as well as large areas of "No Rating" meaning there was a component score within the risk index of zero, so the risk index could not be calculated (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Risks and Considerations

Climate Change and Future Risks

As climate change causes global temperatures to rise, heat waves are occurring more frequently, and hot temperatures are lasting longer than has historically been the case.[126] Droughts have also expanded, particularly the in the western and southwestern United States.[127] Scientists predict that areas prone to drought will experience more intense and frequent drought conditions in the future.

Weather pattern changes and more extreme weather events can also influence the intensity and duration of a drought period. Climate change is altering the timing of precipitation and reducing snowpack, a key source of late spring and summer water for habitats and people. Increasing heavy precipitation events can also create challenges for places experiencing drought, as soils hardened by extended dry weather cannot easily absorb sudden large volumes of rain. This hard soil can result in runoff, increased flood risks, and extend the drought, as the rain cannot infiltrate and recharge aquifers.[128]

Droughts

Water Scarcity and Water Quality

Exhibit 4-20. Outdoor Water Restrictions in Drought-Prone Community

Source: David Greitzer

Water shortages can have far-reaching implications. Extended periods of water scarcity can lead to complex conflicts between communities, agriculture, and industries. Significant shortages can also impact infrastructure, as rivers provide drinking water, power from hydroelectric dams, and water for industrial and agricultural uses. For example, due to the prolonged drought currently impacting the western United States, some reservoir levels are nearing historic lows, which is threatening the ability of hydroelectric dams to provide consistent power sources to the region and threatening water supplies.[129]

Droughts can also negatively impact water quality in the form of sediment, increased temperatures, and increased nutrient levels when heavy rain and drought cycles promote the rapid growth of organic material that is washed downstream. Low water levels in lakes and streams also intensify the in-water pollutant load, which further imperils habitat and challenges water purification processes.[130] Drought can also impact local infrastructure, particularly underground pipes and conduit, due to excessive water pumping during drought periods.[131]

Site planners locating infrastructure on drought-prone sites should work with engineers and/or emergency managers to understand risks to existing infrastructure and ensure new infrastructure is designed for future site conditions.

Vegetation Stress and Soil Impacts

Droughts can significantly increase stress on vegetation and dry and hardened soils, and decrease soil fertility, all of which can increase risks for wildfire, floods, land subsidence, erosion and dust storms, heat wave impacts, and other natural hazards.

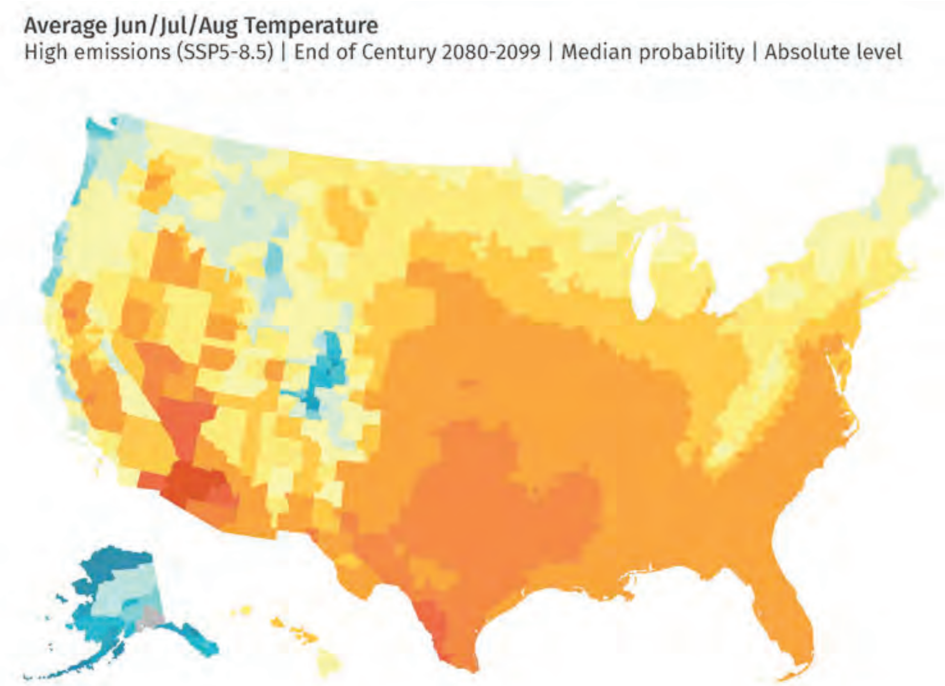
Heat Waves

The United States is facing increasing public health risks from heat waves that disproportionately impact vulnerable communities, including seniors, people with low-incomes, and communities of color.[132] Heat waves are most impactful in urban communities, where development patterns, impervious and heat-absorbing road and building materials, waste heat from mechanical systems, and transportation contribute to higher temperatures.[133]

Exhibit 4-21. Urban Heat Islands

Person utilizing mist cooling strategy during hot weather. Urban heat islands can pose a significant public health threat to people who live in cities and urban areas. Source: Khmelnytskyi Bogdan

Exhibit 4-22. Projected Summer Temperature by 2080–2090



Map of projected average summer temperatures by 2099 shows significant hot spots in the southwestern and southern United States. Source: [Climate Impact Map, 2019] via Katharine Burgess and Elizabeth Foster, "Scorched—Extreme Heat and Real Estate"

Site planners that understand their site's microclimates, local weather patterns, and climate trends will be better able to locate development to take advantage of areas providing some natural refuge from the heat. Documenting prevailing wind direction and wind speeds, seasonal temperature ranges and humidity levels, and solar radiation can help site planners design for hotter temperatures.[134] Conservationists are increasingly looking to north-facing slopes as areas for protection, as they tend to have cooler temperatures.[135] Documenting slopes and understanding the potential benefits of these microclimates can increase resilience.

Strain on electrical grids, sometimes due to increased use of air-conditioning (especially in places impacted by wildfire smoke), can result in power outages. Infrastructure in climates not designed for high temperatures may fail unexpectedly, as was the case in Portland, Oregon, in 2021, when transit service was slowed and in one case canceled because the transit infrastructure was threatened by extreme temperatures.[136]

Growth Pressures

Growth is another factor in heat wave and drought-prone areas, particularly as many urban areas have expanded into megaregions.[137] Sustainable approaches to growth and development are a key opportunity; as Urban Land Institute (ULI) researchers point out, "The built environment is ultimately both a contributor to and a solution for extreme heat, especially in cities, and presents numerous opportunities for mitigation and adaptation at the building and neighborhood scales."[138]

Natural Hazard Interactions

Exhibit 4-23. Drought and Heat Wave Cascading Impacts

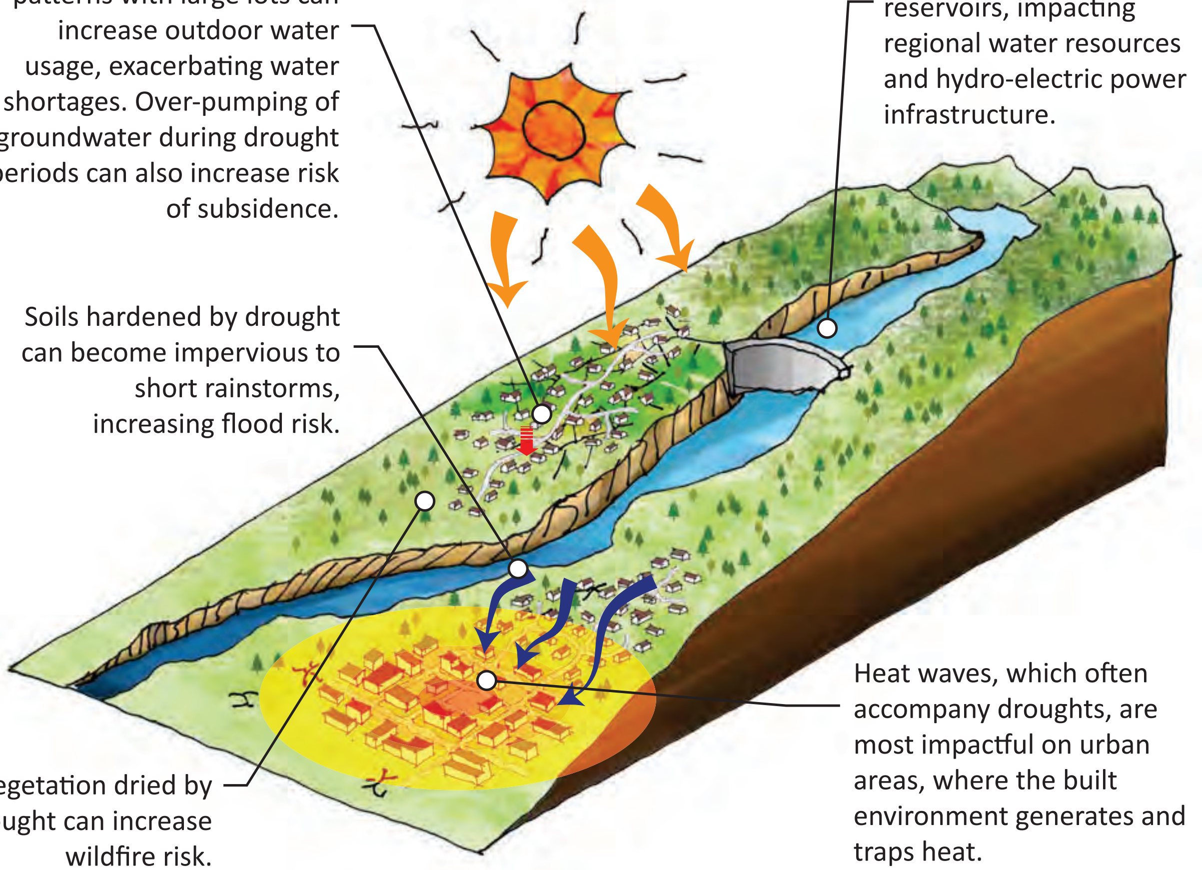


Illustration depicting drought and heat wave impacts. Droughts are slow-moving natural hazards that can cascade into floods, wildfires, subsidence, heat waves, and other hazards. Source: MAKERS

Exhibit 4-24. Natural Hazard Triggers for and from Heat Wave and Drought

Natural Hazards That Can Trigger Heat Wave and Drought	Natural Hazards That Can Be Triggered by Heat Wave and Drought
Wind (at a very high level). Drought can exacerbate heat waves.	Vegetation dried by drought can act as fuel for wildfire. Drought-hardened soils are less suited to absorbing runoff, causing flooding. Landslide (runoff, vegetation stress).

Site Analysis

In areas where there are drought and heat wave concerns, site planners should identify potential risks as well as opportunities for mitigation and adaptation.

- Understand current and future local climate conditions, including likely days of hot weather, precipitation changes, etc.
- Consult with professionals from multiple disciplines to ensure thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- Understand how heat waves could strain road, transit, stormwater, water, sewer, power, and/or communications infrastructure that is located on or provides service to the site.
- Identify water sources, availability, and conservation measures and requirements.
- Identify site microclimates, including areas of shade and solar exposure, wind patterns, proximity to surface water bodies (offers cooling), and heat gain areas. Consider seasonal differences, humidity, solar radiation, and wind speed. Identify opportunities for passive cooling, increasing ventilation, and natural refuge from high temperatures.
- Assess site vegetation and soils (type, health, native and non-native, water needs, ecosystem service benefits) to help conserve water, mitigate drought impacts, and mitigate and/or adapt to higher temperatures. If feasible, work with professionals to conduct a full ecological assessment of the site.
- Account for drought's impact on soil. Expansive soils can damage or destroy building foundations when exposed to extreme wet and dry periods. Extended droughts can also harden soils, limiting infiltration capacity even when wet weather returns. This limited infiltration can increase the risks of flooding from runoff and lead to water quality challenges. Furthermore, in extended droughts, people tend to over-pump groundwater resources, which can result in land subsidence, a potential threat to buildings and infrastructure.
- Consider the effects of drought conditions, subsidence, and heat waves on infrastructure.
- Consider modeling for thermal comfort, considering solar exposure, shadows, urban heat island intensity, and wind.
- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities and considers the potential effects, positive or negative, to people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to heat and drought hazards.

See Water Supply.

See Siting for Soils.

See Protecting Soils from Drought.

See Passive Cooling and Orientation for Cooling.

Resources

- State and local hazard mitigation and/or climate adaptation plans.
- Heat Factor—https://riskfactor.com
- EPA—Adapting to Heat
  https://www.epa.gov/heatislands/adapting-heat
- Urban Land Institute – Drought Resilience
  https://americas.uli.org/research/centers-initiatives/urban-resilience-program/drought-resilience/
- Urban Land Institute – Extreme Heat
  https://americas.uli.org/research/centers-initiatives/urban-resilience-program/extreme-heat-2/
- Boston – Heat Resilience Plan
  https://www.boston.gov/environment-and-energy/heat-resilience-solutions-boston

Wildfire

Key Statistics

7 million acres
have been burned annually by wildfires over the last 20 years, which is double the average burned in the 1990s.[139]

$24 billion
in damages were caused by wildfires in 2017, the costliest year for wildfires. Wildfires caused $22 billion in damages in 2018 and $16.5 billion in 2020.[140]

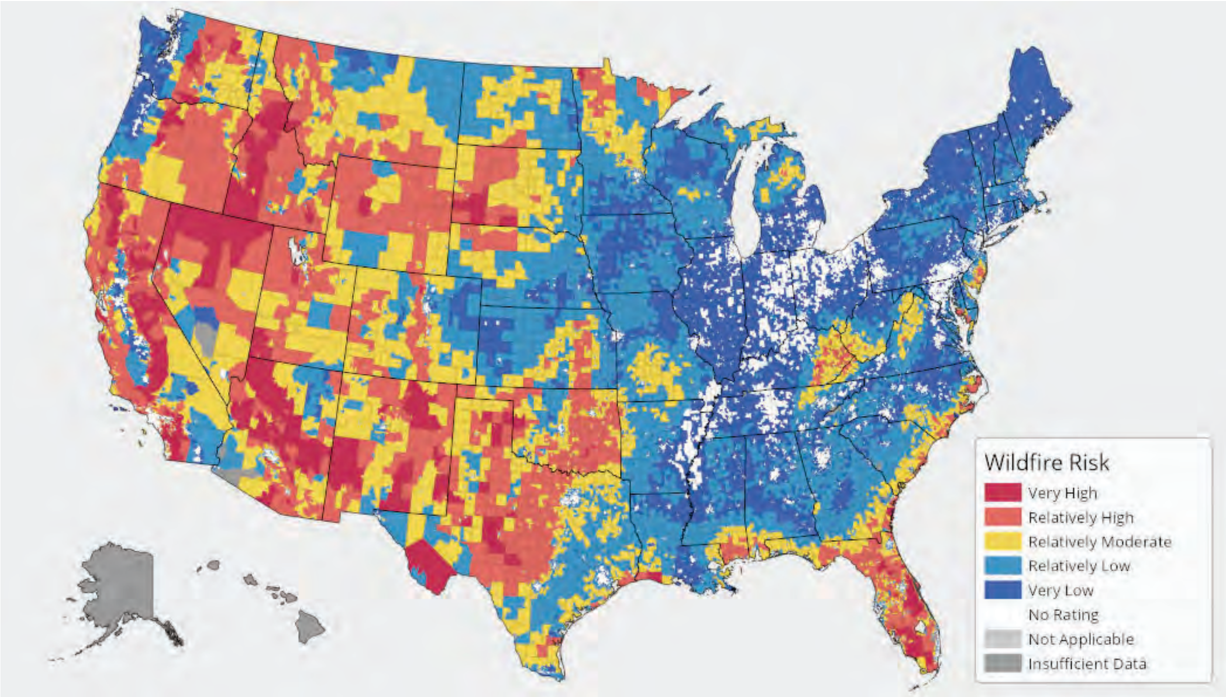
43.5 million
housing units are located in wildland-urban interface (WUI) areas. Found in every state in the United States, roughly one-third of the United States population is located in WUI areas.[141]

Where Wildfires Occur

Wildfires occur in many areas but are particularly common in western states, as well as areas of the central and southeastern United States. FEMA's Risk Index shows some of the current wildfire risks, although this map is not comprehensive of all current risks. Although many once believed wildfires were only a significant threat to rural communities, many suburban and urban communities are also affected. In December 2021, the Marshall Fire started as a grass fire and tore through a suburban community in Boulder County, Colorado, destroying over 1,000 homes and causing more than $500,000,000 in damages.[142]

See Site Analysis – Introduction for more information about the FEMA National Risk Index (NRI) Maps.

Exhibit 4-25. Wildfire Risk Index



Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for wildfires, which shows elevated risk throughout the western United States and in parts of the southeast (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technicaldocumentation.pdf). Source: FEMA National Risk Index

Risks and Considerations

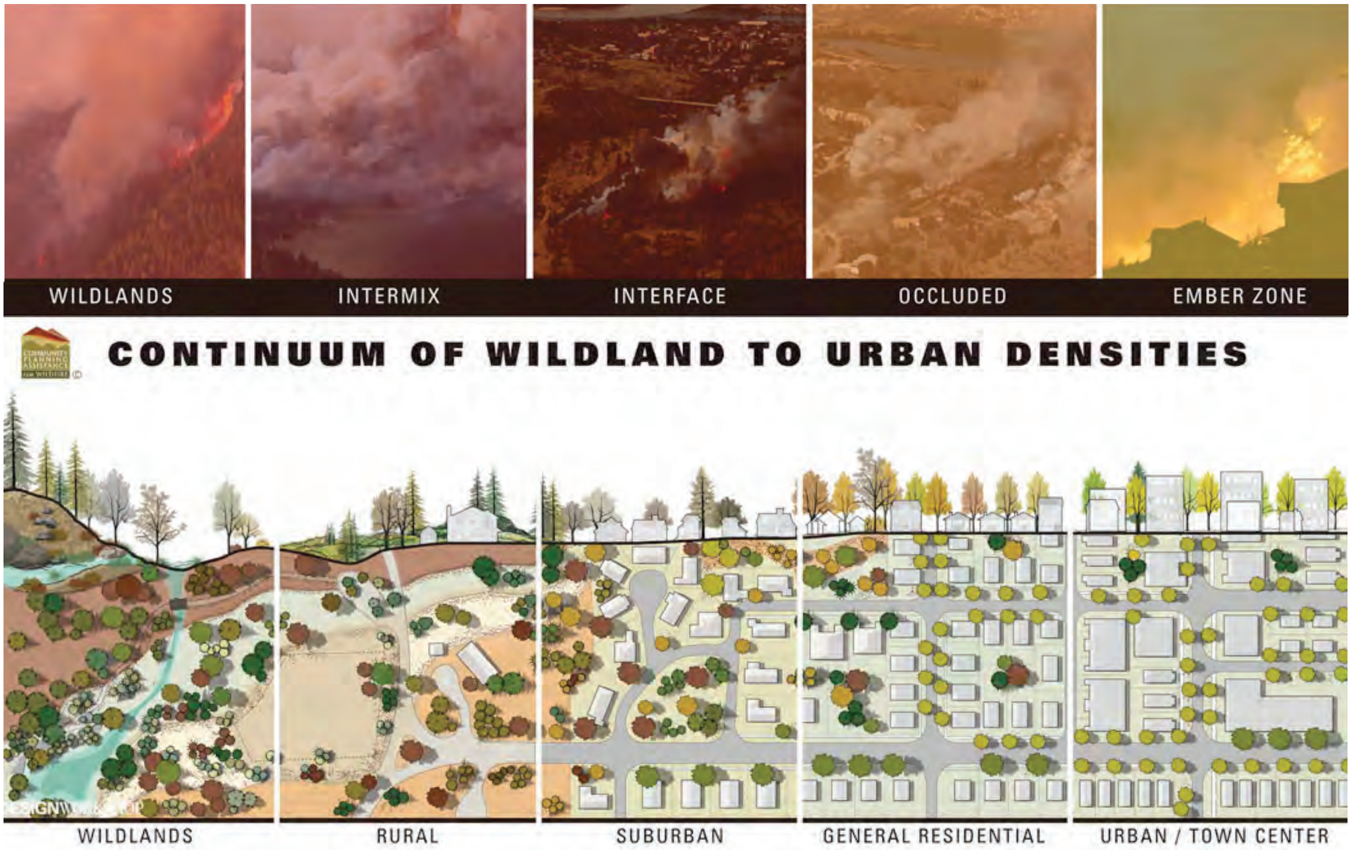
Increasing Risks

Wildfires have been increasing in severity and frequency in recent years, which is impacting communities on a broad scale. There are several factors that influence this trend. For decades, the United States Forest Service and other wildland management entities pursued fire suppression as a key management approach and worked to reduce how fire impacted wildlands. This practice resulted in a build-up of forest vegetation, which has increased the fuel in wildlands across the United States.[143] Secondly, population growth in and around wildlands, often referred to as the wildland-urban interface (WUI), means that more communities are exposed to fires when they occur. WUI areas can be any developed area where conditions allow for the ignition and spread of wildfire through the combination of vegetation and structures or infrastructure.[144] Thus, the WUI covers a spectrum of development that can span from rural to urban settings.

Exhibit 4-26. Wildfire Burning in a Hillside Community in Colorado

Source: joseph gruber

Exhibit 4-27. Continuum of Wildland to Urban Densities



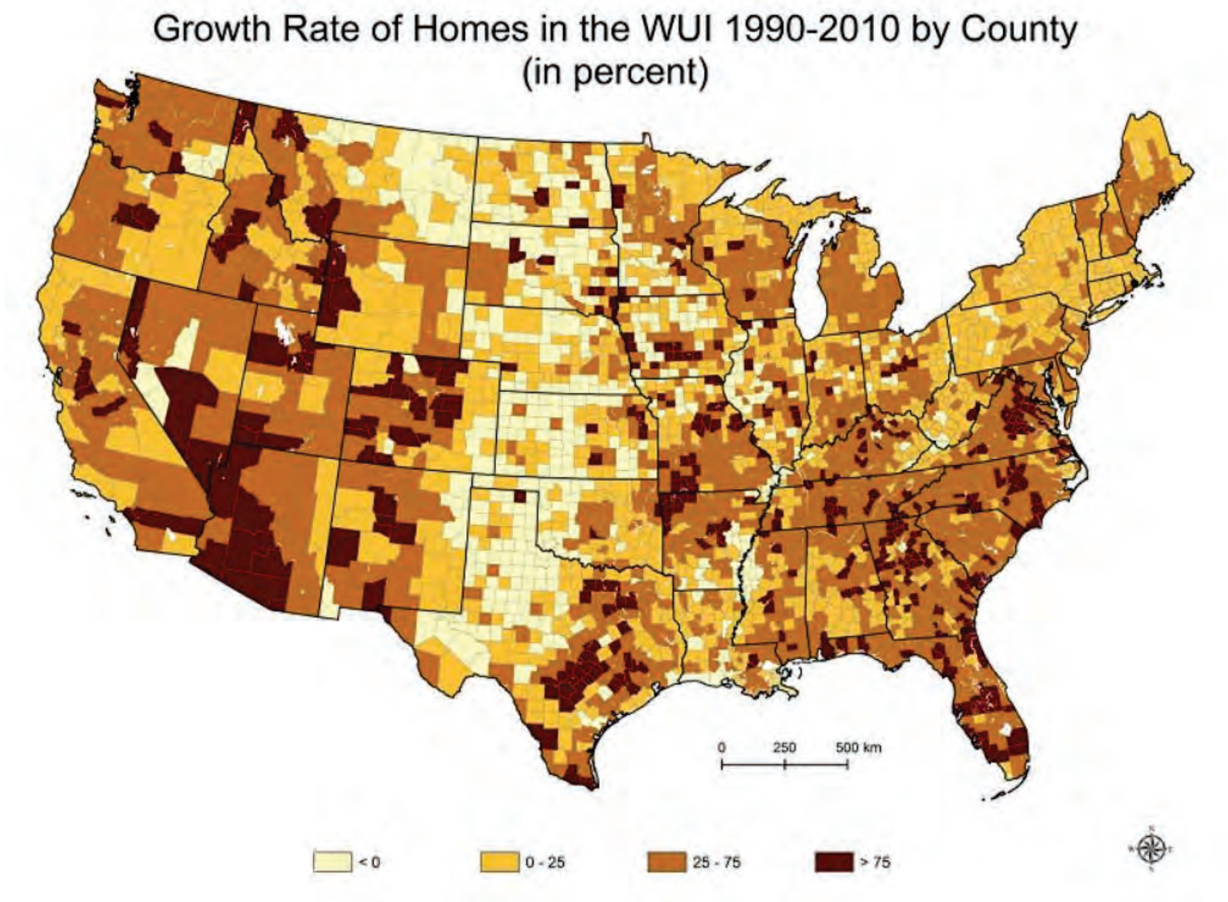
Wildland-urban interface areas can exist within a continuum of development, from wildlands or urban areas. Source: Community Planning Assistance for Wildfire, a program of Headwaters Economics

Climate change is also reshaping wildfire patterns throughout the United States. Extended spring and summer, extreme temperatures, and changes in snowpack and precipitation patterns create dry conditions and stress vegetation, which has increased the frequency of fires and extended the length of the wildfire seasons.[145] The area burned by wildfires also appears to be increasing, with the top 10 years of the largest acreage burned occurring since 2004.[146] These impacts will continue and may worsen as temperatures continue to rise due to climate change.

Growth Pressures

Increased population growth also contributes to wildfire risk. Between 1990 and 2010, WUI lands were the fastest growing areas in the United States. This growth was predominantly driven by housing development, a trend anticipated to continue.[147] Since wildfire ignition is often human-caused, the increased population in the WUI also heightens the risk.

Exhibit 4-28. Home Growth Rate in the Wildland-Urban Interface



WUI = wildland-urban interface. Source: U.S. Department of Agriculture Forest Service via Mowery et al. (2019), "Planning the Wildland-Urban Interface"

Site Planning and Fire Behavior

Site planners, particularly those working in WUI areas, should understand how sites can influence wildfire behavior and risk. Scientists have identified three key factors that influence the behavior of wildfires: fuel, weather, and topography.[148] Fire models that incorporate potential fire behavior can also inform site and community planning decisions about where to locate development.

Fuel Sources

Combustible sources of fuel include wildland vegetation (trees, understory, and grassland), cultivated vegetation (i.e., landscaping), structures, decks, fences, propane tanks, and other features in the built environment. Vegetation around homes can significantly increase wildfire risk to the structure, and management of vegetation around structures is recommended. This issue impacts multiple sites; fire can spread through connected properties that have not reduced fuels through active management.

Plant species can also play a role in the spread and intensity of a wildfire.[149] Certain types of vegetation are highly flammable and should be avoided in wildfire-prone areas. Vegetation can also become fire-prone if it lacks moisture, such as in periods of drought or if it is in poor health. When assessing site vegetation, site planners identify plant species that are flammable or otherwise in poor condition and consider whether these plants should be removed or thinned. Protecting or adding plants that are native and/or adapted to wildfire conditions can contribute to the site's overall resilience.

Built items around structures and building materials such as roofs and siding can also become a source of wildfire fuel.[150] These items can include mulch, patio furniture, decks, organic material in gutters, and even building materials such as siding. Site planners working on infill sites or around existing development should note the proximity of fuels to structures when evaluating a site for development.

Analyzing wildfire fuel sources in the context of the site is also important, as sites located near or adjacent to unmanaged forests or open spaces can be exposed to sources of heat and embers. Consultation with qualified forestry and fire behavior specialists may be necessary to evaluate local wildland conditions that could influence the risk to development.

Weather and Topography

Analyzing site topography, weather and microclimate conditions, plant communities, and surrounding context are fundamental to site planning. In the context of wildfires and development in WUI areas, site planners need to understand how these conditions relate to wildfire risk.

Wind exposure. Wind is the most critical factor influencing fire behavior in that it can increase or decrease soil moisture, bend flames, carry embers to nearby locations, supply a fire with oxygen, and direct the fire path.[151] Close attention to local wind patterns and site conditions is important. Trees can provide a beneficial windbreak but should also be identified as potential fuel sources.

Weather, precipitation, and microclimate. Precipitation, temperature, and humidity can all influence wildfire behavior. Local climate patterns, future projections, and microclimate conditions (e.g., shaded areas) can all influence wildfire risk.

Topography. Slopes play an important role in fire behavior and influence how a fire can start and spread:[152]

- Flames, rising heat, and turbulent air within a fire can heat, dry, and ignite upslope fuels.
- Embers and/or burning material can roll downhill.
- Nighttime cooling and weather changes can cause winds to blow down slopes.
- Firefighting activities are more challenging on slopes.

Other aspects of site topography, including aspect, terrain, and elevation, can also influence wildfire exposure and risk. South-facing slopes are the most exposed and tend to have higher fuel loads. Sites with varied terrain can result in complex wind patterns and fire behavior and increase the speed of spread. Air temperature changes in some higher elevations can also create unstable fire behavior.[153] Site planners working on or near slopes should understand how topography can influence fire behavior and identify areas where future development would be least exposed.

Emergency Response and Infrastructure Needs

Emergency Access

Preparing an emergency plan that covers service centers and evacuation routes is essential. Also important in mitigating wildfire hazard exposure is ensuring adequate (i.e., redundant) emergency access and evacuation routes.[154]

Water Source Stability and Supply

Water supply is essential to development and must be carefully considered not only in terms of a community's regular use but also in terms of emergency response needs. Water is a critical tool to fight wildfires; however, fire suppression agencies often exhaust an area's water supply before fully suppressing the fire. Water can also be contaminated by fire, which temporarily reduces community water supplies.

Power Source and Supply Options

One of the leading causes of wildfires is sparks from substations and other electric infrastructure. Wildfires are also caused when above-ground power lines in undeveloped areas snap during storms or due to downed power poles. Pivoting to community microgrids and removing above-ground power networks reduces risks by removing fire-prone infrastructure from fuel-rich areas. These safety precautions also create a more stable power supply during widespread emergencies that impact the regional power grid.

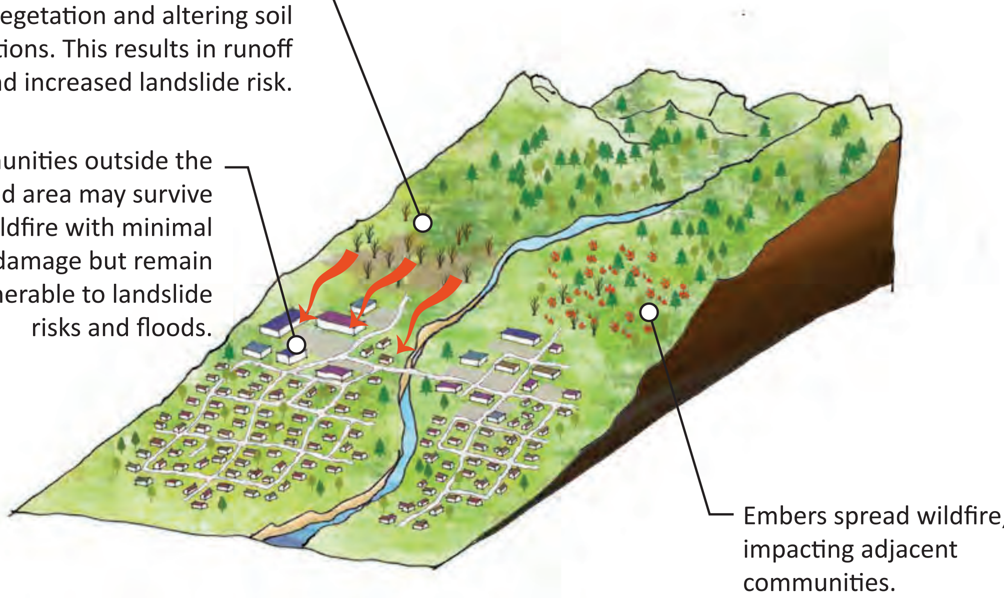
Exhibit 4-29. Wildfire Risk With Utility Corridors

Overheated power utility corridors have ignited significant wildfires in recent years and can increase risk in some areas.
Source: iStock 1292455183

Natural Hazard Interactions

In addition to increased wildfire risk from human interaction in the WUI, other hazards may increase the risk of wildfire.

Exhibit 4-30. Wildfire and Landslide Cascading Hazards



Wildfire impact on a region and the subsequent risk of landslide to nearby communities. Source: MAKERS

Exhibit 4-31. Natural Hazard Triggers for and from Wildfire

Natural Hazards That Can Trigger Wildfire	Natural Hazards That Can Be Triggered by Wildfire
High Winds can lead to the rapid spread of wildfire. **Heat Waves and Drought** can reduce the amount of moisture within the soil and living vegetation, creating highly flammable fuels that will burn aggressively. **Severe Storms** can often trigger wildfires through lightning, which is then compounded by high winds.	**Landslides** are common following wildfires where native vegetation cover is disturbed or destroyed, and soils repel water, increasing runoff, erosion, and the risk of debris-flow landslides. **Drought and Desertification** can worsen due to wildfire depleting moisture in soils and destroying vegetation. **Flooding** triggered by runoff from burned areas often follows wildfires. **Winds** generated by wildfire carry tinder and embers to other locations, which can trigger additional wildfires.

Site Analysis

Site planners, particularly those working in WUI areas, need to consider wildfire exposure and use emerging tools to reduce wildfire risks:

- Reference local and regional hazard mitigation plans and other tools to understand local wildfire risks.
- Consult with professionals from multiple disciplines to ensure thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- Understand and identify potential wildland and built fuel sources on and adjacent to the site. If feasible, work with professionals to conduct a full ecological assessment of the site.
- Understand how weather and topography influence wildfire behavior and incorporate this information into site analysis.
- Observe and document onsite wind conditions and investigate directional and seasonal patterns in WUI areas. Areas sheltered from winds by site topography or other features should also be noted.
- Identify existing water sources and understand the capacity to support the development and wildfire response.
- Identify power sources to assess whether these sources increase wildfire risk and/or may be vulnerable during a wildfire.
- Understand increased risks from landslides and flooding in areas already affected by fire as well as increased risks in areas downstream or downhill of burned areas.
- Assess the flammability of any structures in close proximity to proposed buildings on the site (i.e., flammable building materials, exposed vents, etc.)
- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities and considers the potential effect, positive or negative, to people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to wildfire hazards.

See Building Spacing for Wildfire.

See Water Supply.

See Power Utilities.

See Fire Safe Structures.

Resources

- Local Community Wildfire Protection Plans (CWPPs), if available; state planning, land management, and natural resources agencies/departments
- State and local hazard mitigation and/or climate adaptation plans.
- Fire Factor—https://riskfactor.com
- U.S. Department of Agriculture Forest Service: Wildfire Risk to Communities—https://wildfirerisk.org/
- National Interagency Fire Center—https://www.nifc.gov/
- Urban Land Institute - Wildfire Resilience https://americas.uli.org/research/centers-initiatives/urban-resilience-program/wildfire-risk/

Landslide

Key Statistics

$2.5–5.5 billion
in damages are caused by landslides in the United States each year (adjusted for inflation).[155]

25–50 people
are killed on average each year by landslides in the United States.[156]

Where This Hazard Occurs

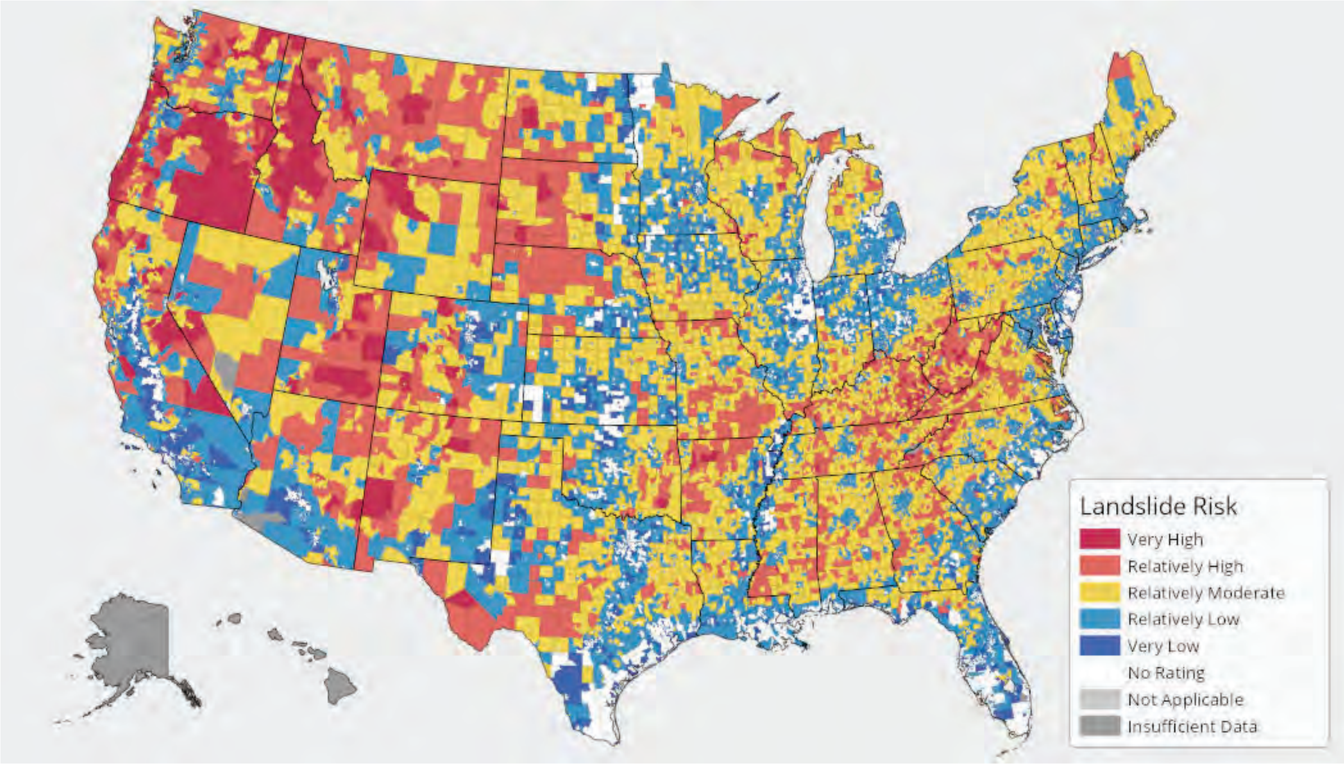
Broadly speaking, landslides are a downslope movement of debris that can be exacerbated by land use activities. Two landslide types that should be considered in impact site planning: shallow and deep landslides. Generally, shallow landslides are small and driven by intense rainfall or channelized surface water that saturates the soil and can mobilize into a flowing landslide. These flowing landslides can move at high speeds, reaching locations far from where they originated and causing impacts across a large area. Houses, roads, and utilities can be severely damaged or destroyed. The speed of shallow landslides can also create significant public safety threats.[157]

Conversely, deep landslides can occur over a very large area (up to many acres) but are slow moving hazards, generally starting hundreds if not thousands of years ago. These ancient landslides remain on the landscape, often without movement or obvious evidence of the underlying risk. Land use activities, such as grading and vegetation removal, can reactivate these landslides. In addition, sustained periods of above average precipitation (months to years) can also reactivate deep landslides. Generally, deep landslide reactivation movement is slow and isolated, so houses, roads, and utilities can be severely damaged, but the threat to public safety is low due to the slow movement.

See Site Analysis – Introduction for more information about the FEMA National Risk Index Maps.

Landslides are a common and widespread phenomenon in the United States,[158] but there are areas where risks are more prevalent. The Risk Index identifies hot spots of landslide risk throughout the west and in mountainous regions of the east coast, but there are landslide risks in every state. Landslides that are not caused by people are part of a natural geologic process that can benefit ecosystem biodiversity and functioning. Landslides supply materials to help maintain habitat in streams and create disturbances that allow for new plant growth and new habitats.[159] Landslides can also be caused by people, often through development, industry, natural resource extraction, and other intensive human uses of natural landscapes. Landslides can threaten communities, roads, infrastructure, and/or public safety and can result in significant disasters if not managed and/or mitigated.

Exhibit 4-32. Landslide Risk Index



Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for landslides, which shows widespread elevated risk across the United States (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Risks and Considerations

Increasing Risks

The risk from landslides has grown substantially as population growth and development into hillslope and wildland-urban interface areas has increased. Some existing communities are grappling with a new awareness of landslide risks to their homes, roads, and infrastructure, driven by evolved mapping technology and a better understanding of geologic conditions that can trigger landslides. That said, significant gaps in landslide occurrence maps persist,[160] and development pressures continue into potentially landslide-prone areas.

Exhibit 4-33. Damage From a Deep Landslide

In 1998 and after three years of above average rainfall, an ancient landslide in western Washington started to move again. Over 130 houses, including roads and utilities, all built on and adjacent to the ancient landslide, were slowly destroyed. Source: [J. David Rogers and Washington Geological Survey]

Landslide risks are also increasing due to climate change, as rising temperatures lead to changes in precipitation patterns and more extreme weather events. Other natural hazards, also influenced by climate change, can trigger landslides, including floods and wildfires, which can change soil stability or moisture and can cause slopes to collapse.[161] Increasingly extreme weather events suggest that landslides are likely to be more common in the future.

Exhibit 4-34. Homes in Oregon at Risk of Landslides From Bluff Erosion

Source: WestWindGraphics

Insurance Considerations

A typical homeowner's insurance policy does not cover damage from landslides, despite widespread risks across the country, many of which are not fully recognized or understood.

For more discussion on insurance and landslide risks see the following resource:

[Landslide insurance | Washington state Office of the Insurance Commissioner]

Impacts of Development

Many typical site development practices can increase the risk of landslides:

- **Grading** a site to produce developable pads on slopes, including slope cutting or filling, which can reduce slope stability.
- **Hydrology changes,** such as relocating or eliminating a stream or swale can affect site drainage and cause increased soil saturation during heavy rain, reducing slope stability.
- **Overwatering** of lawns and landscaping at the top of slopes adds weight and reduces stability.
- **Impervious surfaces** such as asphalt, pavement, and building roofs channel rainfall into stormwater flows, which can cause erosion or slope saturation if not properly directed.
- **Removal of vegetation** reduces slope stability, especially when trees with deep, anchoring roots are removed. Unplanted slopes are also highly susceptible to erosion.

See Development-Topography Integration.

See Compact Development and Greening the Grey—Managing Stormwater.

See Slope Stabilization.

Exhibit 4-36. Landslide Impacts in Residential Areas

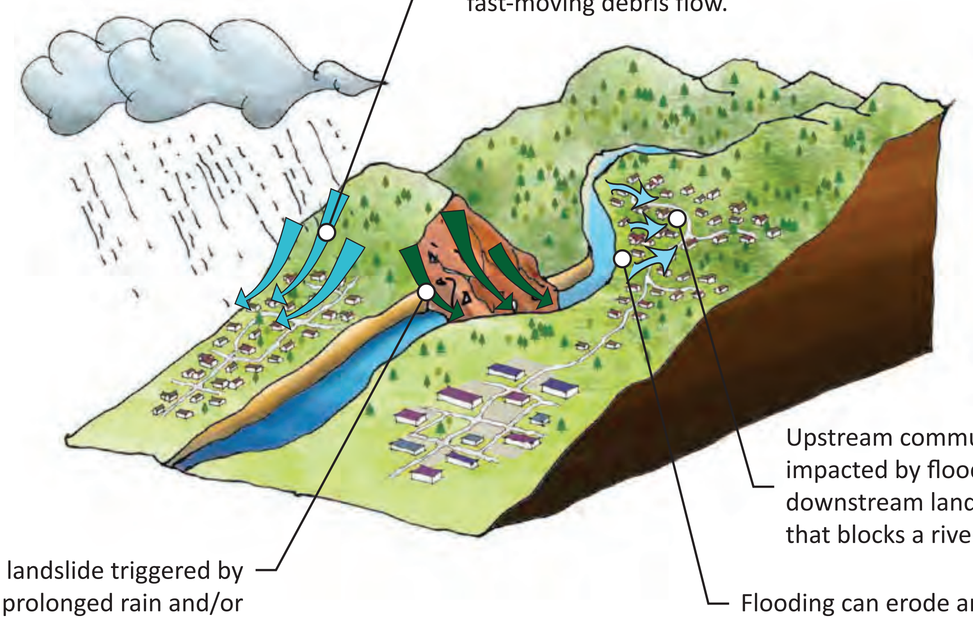
Left: Aftermath from the 2005 Laguna Beach, California, Landslide. This photo shows one of the houses damaged by the 2005 Laguna Beach Landslide. Right: A debris flow in Marin County, California, triggered by intense rainfall, destroyed several homes and injured one person in February 2019. The view is looking from the top of the landslide downslope. Sources: U.S. Geological Survey (USGS)/Pam Irvine, California Geological Survey, via Flickr, 2.0 Generic (CC BY 2.0) (left); Brian Collins, USGS (right)

Exhibit 4-35. Damage From Oso Landslide, Washington

The 2014 SR530 "Oso" landslide in Washington State that took 42 lives, destroyed dozens of buildings and a section of a state highway, and also blocked a river that resulted in upstream flooding. Source: "Aerial view of side of hill and SR 530 after the March 22, 2014, landslide", © 2014 Washington State Department of Transportation, CC BY-NC-ND 2.0, Flickr

Natural Hazard Interactions

Exhibit 4-37. Landslide and Flood Impacts



Landslides can cause flooding by disrupting hydrological systems. Landslides can happen naturally, but development patterns in sloped areas can also increase landslide hazard risks. Source: MAKERS

Exhibit 4-38. Natural Hazard Triggers for and From Landslide

Natural Hazards That Can Trigger Landslide	Natural Hazards That Can Be Triggered by Landslide
Wildfires damage or destroy vegetation and can create soils that repel water, increasing runoff and erosion and increasing risk for debris-flow landslides. **Hurricane and heavy rain** events saturate soil, increasing the weight of a slope, while permeation into the slope reduces its strength. **Earthquakes** often cause landslides in many different terrain types, including areas with minimal slope. Increased precipitation before the earthquake saturates the soil and increases the risk of landslide or ground movement. **Flooding** can cause landslides, especially when floodwaters rapidly recede, leaving behind saturated slopes and riverbanks.	**Flooding** can occur when landslides block rivers. **Tsunami/displacement wave** can occur when a landslide flows into a body of water such as a lake or bay or when there is an underwater landslide.

Site Analysis

Site planners working in landslide hazard areas and on sloped sites should be aware that landslide risks may be present even outside of mapped hazard locations and that landslide risks are likely to increase over time.

- Review soil, landslide hazard, and topographic maps to identify slopes, soil types, highlight known landslide hazard areas, and identify water flows on a site.
- Consult with professionals from multiple disciplines to ensure a thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- Refer to local landslide hazard plans as well as watershed plans, stormwater management guidance, and other spatial analysis resources to assess how adjacent development patterns may influence hydrology, erosion, etc.
- Understand that deep landslides are slow-moving hazards that can cover a large area and impact a site absent of adjacent steep slopes or other evidence of land movement.
- Perform a geotechnical evaluation to understand risks and influence site planning and design development. (This evaluation is a common requirement on sloped sites.)
- Inventory site vegetation to identify areas where plant root systems may or may not contribute to slope stability. If feasible, work with professionals to conduct a full ecological assessment.
- Consider how local impacts from climate change may influence future conditions at the site through increased rain events, flooding, wildfires, drought, or other events.
- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities and considers the potential for impact, positive or negative, to people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to landslide hazards.

See Landslide Avoidance.

See Soil Stabilization and Shoring.

Resources

- U.S. Geological Survey (USGS)—U.S. Landslide Inventory—A web-based interactive mapping resource that is compiled from local, state, and federal agencies. While this inventory is updated annually, it is not a comprehensive resource, as there are significant gaps in landslide risk mapping across the county, with no state having a complete inventory of landslides. https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=ae120962f459434b8c904b456c82669d
- USGS—Landslides 101—https://www.usgs.gov/programs/landslide-hazards/landslides-101
- Homeowners Guide to Landslides for Washington and Oregon—https://file.dnr.wa.gov/publications/ger_homeowners_guide_landslides.pdf
- Geology in the Public Interest—https://www.publicgeology.org/

Earthquakes and Tsunamis

Earthquakes and tsunamis are combined in this section, as tsunamis are often caused by earthquakes.

Key Statistics

9.2 magnitude

earthquake, which struck south-central Alaska in 1964, is the largest ever recorded in the United States. The earthquake was felt throughout Alaska and as far away as Seattle. Tsunami waves created by the earthquake caused damage in Oregon and California.[162]

28 million

people live in areas that have a high potential to experience damaging shaking from an earthquake.[163]

143 million

people in the continental United States live and work in areas with some potential risk of damaging shaking from earthquakes. When Alaska, Hawaii, and Puerto Rico are added, the number increases to nearly one-half of all Americans.

Where Earthquakes and Tsunamis Occur

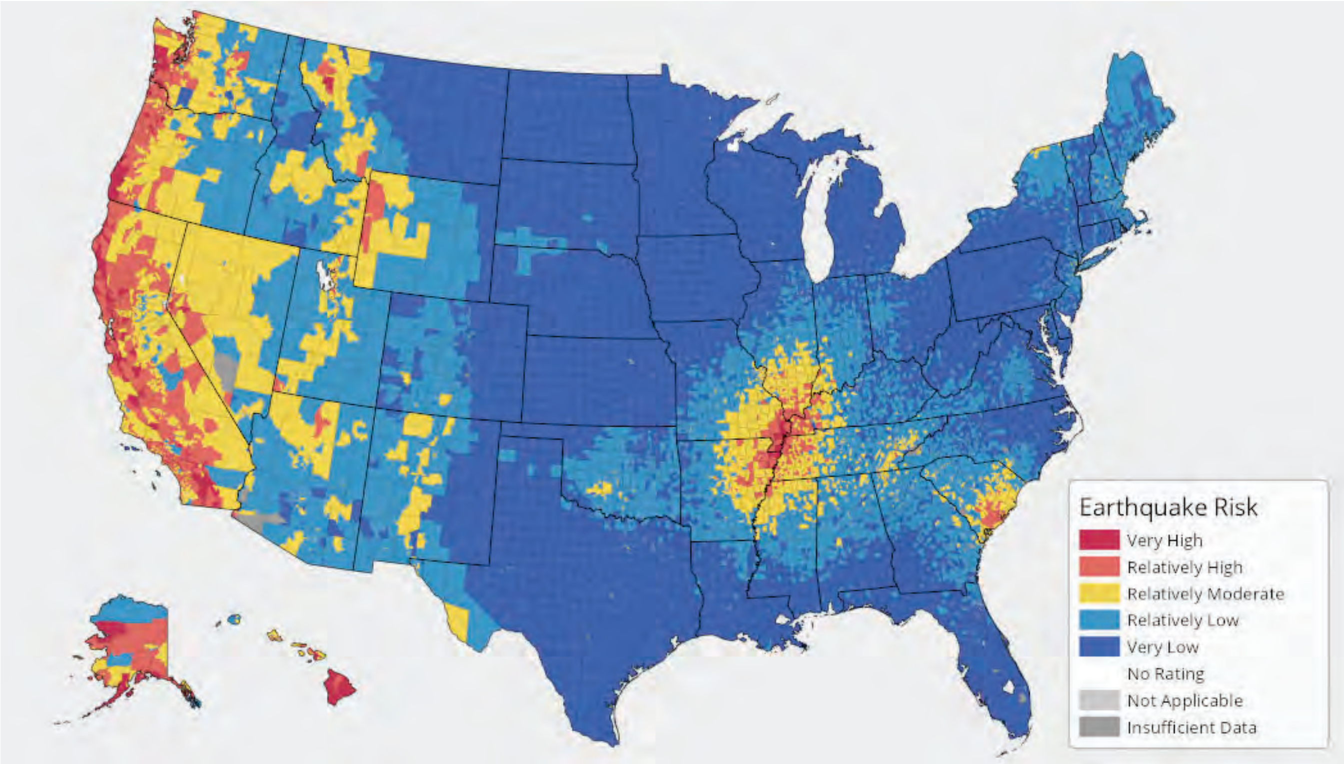
Earthquakes

Earthquakes occur more frequently on the West Coast, Alaska, and Hawaii, but there are varying levels and frequencies of seismic activity in other parts of the country.

Communities exposed to varying levels of earthquake hazards include some major cities developed before there was a clear understanding of seismic risk. Population growth and related development have continued in many of these areas. The use of consensus building codes, such as those maintained by the International Code Council (ICC), provides for life safety design for earthquakes. These modern codes offer seismic design guidelines and mitigation solutions with strategies for selection of materials, performance objectives, and use of seismic protection technologies. Some site planning approaches, such as ground improvement, can reduce seismic impacts by addressing shelter, evacuation, and foundation stability.

See Site Analysis – Introduction for more information about the FEMA National Risk Index (NRI) Maps.

Exhibit 4-39. Earthquake Risk Index

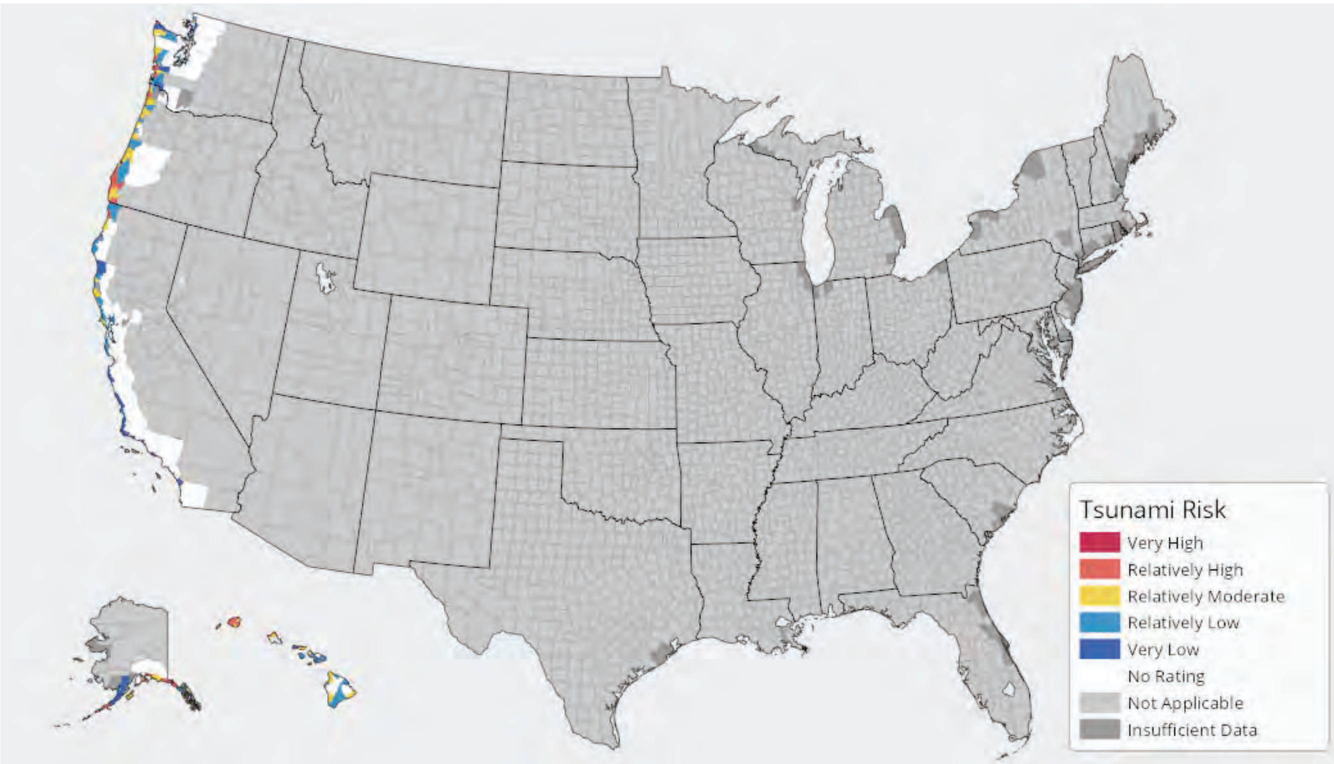


Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for earthquakes, which shows elevated risk along the west coast and in pockets in the central United States and the southeast coast (accessed in 2022). For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Tsunamis

Tsunamis are considered co-seismic hazards, as they are often caused by earthquakes and/or volcanic activity. Landslides in and around water can also result in displacement waves, which can have similar impacts as tsunamis. Tsunami risks in the United States are concentrated on the coastal communities of the West Coast, Alaska, and Hawaii, and include several major cities and population centers, smaller coastal cities and towns, and tribal communities. Consensus building codes also include design provisions for tsunami loads and effects.

Exhibit 4-40. Tsunami Risk Index



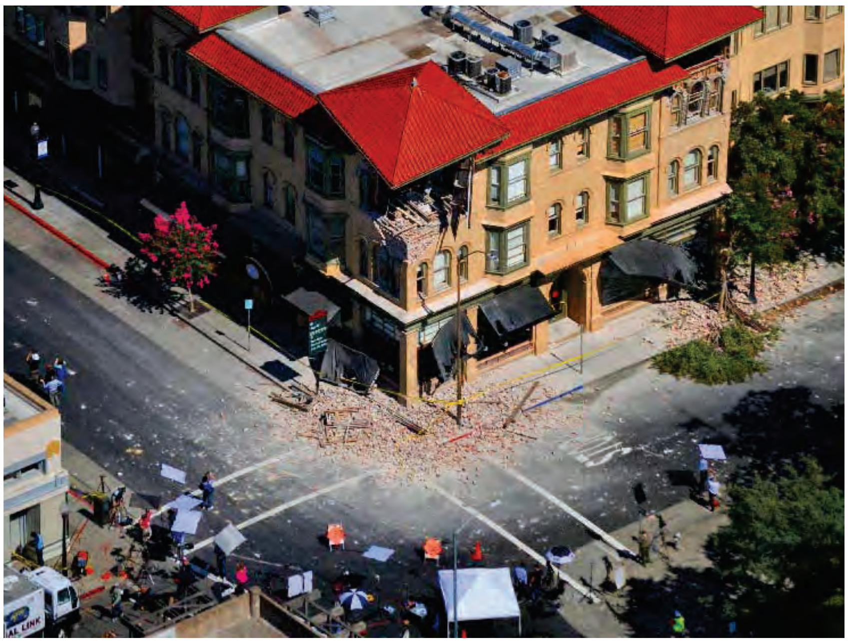
Map of Federal Emergency Management Agency's (FEMA) National Risk Index (NRI) (https://hazards.fema.gov/nri/map) for tsunamis, which shows elevated risk along the western coast of the United States and in Alaska and Hawaii (accessed in 2022). The map is based on available data and does not cover all future hazard risks. For comprehensive details about how the NRI can help you and its limitations, see the National Risk Index Technical Documentation (https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf). Source: FEMA NRI

Risks and Considerations

Earthquake Damage

Severe earthquakes can cause widespread damage across a region. Shaking can cause ground movement and other landform ruptures, which can damage subsurface infrastructure, such as water and sewer lines, and aboveground infrastructure, including power and communications utilities.[164] Transportation infrastructure, including roads, bridges, overpasses, embankments, and toll structures, can also be vulnerable to earthquake damage. Losses in heavily populated areas can result in significant economic effects from physical damage and greater effects from disaster recovery time, and even potential loss of human life. Subsidence in coastal areas can increase relative sea level rise and exacerbate flood and storm impacts.[165]

Exhibit 4-41. Earthquake Damage



At left, damage resulting from the August 2014 South Napa, California, Earthquake as observed from USGS rapid-response overflight operation. Source: U.S. Geological Survey. At right, liquefaction-related tilting of home in San Francisco from the 1906 earthquake. Source: G.K. Gilbert of the U.S. Geological Survey.

Under certain conditions, earthquakes can trigger the phenomenon of soil liquefaction, when the ground vibration causes unconsolidated, water-saturated soils to soften and behave like liquid. Low-lying areas are often most vulnerable to liquefaction-induced damage, which includes large lateral movements of the liquefied ground towards the water mass and structural and foundation damage (i.e., tilting) to buildings and infrastructure. In communities whose sites have subsurface soils and groundwater conditions that expose them to seismically induced liquefaction, modern (consensus) codes require that liquefaction is addressed either by design (such as appropriate foundation systems) or by intervention to the site before any buildings are in place (such as installation of drains or improving the ground beforehand).

Human-caused groundwater changes can also result in increased seismic activity, as has been documented in mid-western areas due to wastewater disposal from oil and gas production operations.[166] Widespread subsidence can be another result of human-driven groundwater changes, as is evidenced by Mexico City in Mexico, a historic city built on a dry lake-bed that has significant challenges with land subsidence, earthquakes, and flash flooding that persist into current day.[167] In San Joaquin Valley, California, agricultural land uses over the last century have resulted in significant land subsidence from over-pumping and aquifer system compaction, resulting in subsidence in the region that ranges from 1 to 28 feet.[168]

Exhibit 4-43. Subsidence in the San Joaquin Valley

Image of subsidence in the San Joaquin Valley, California, occurring between 1988 and 2013 due to over-pumping and aquifer system compaction. Source: U.S. Geological Survey

Structures can be damaged by the shaking of the ground during an earthquake, impacts from exterior or interior non-structural elements (e.g., falling debris, equipment, furnishings), and changes to the overall landform and the soil conditions where foundations bear in. Mitigating damage from earthquakes is a key focus of engineering and architectural designs in seismic-prone regions. See the resources section for links to more detailed resources on earthquake considerations for structures.

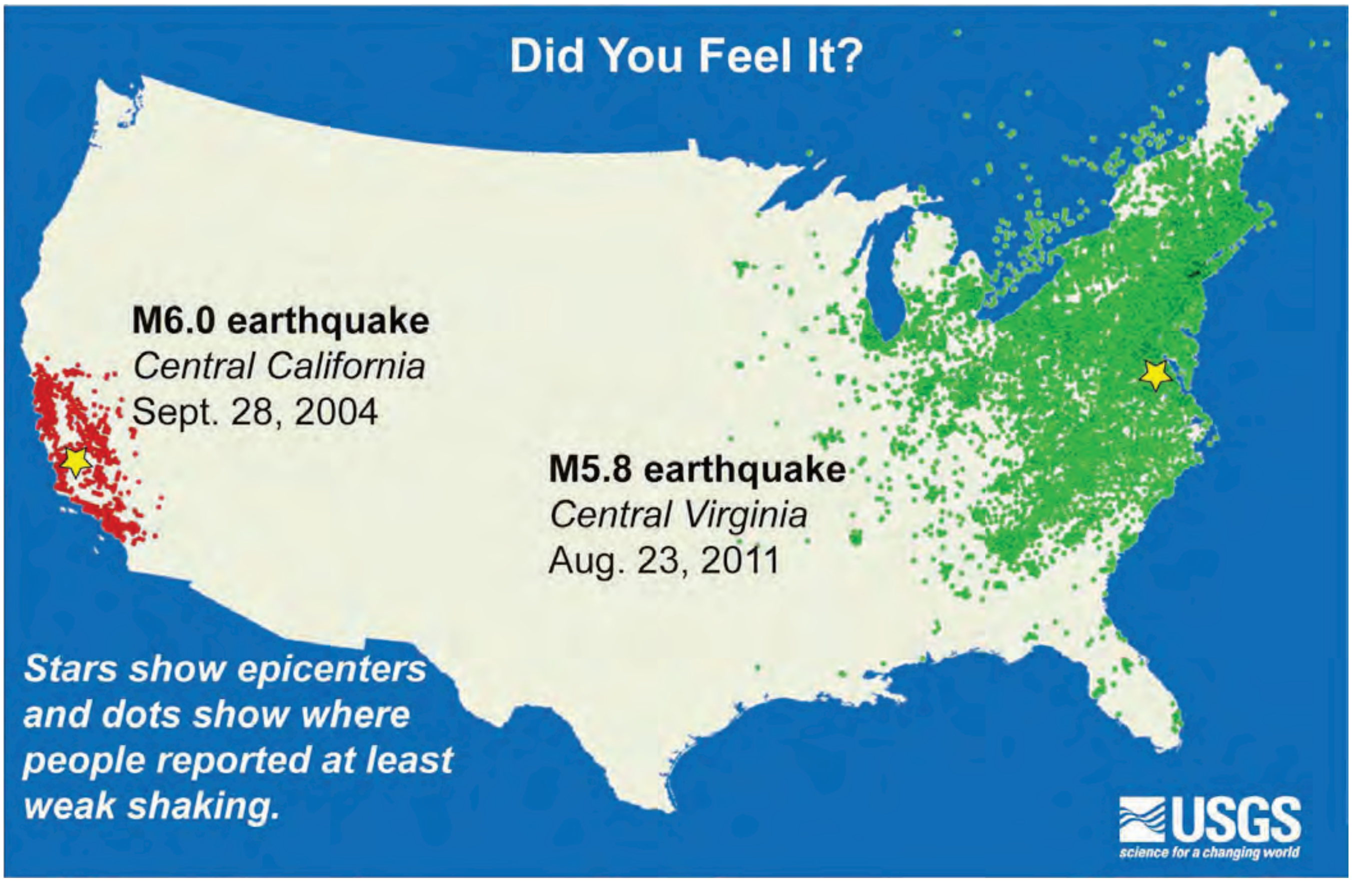
The extent of damage and the area and population that are impacted by an earthquake are not only dependent on the magnitude of the earthquake, but also the distance from the earthquake epicenter. This factor has significant variabilities between the east and the west parts of the United States. For example, the moderate magnitude 5.8 Mineral, Virginia, earthquake became the most felt event in modern United States history, with the main "felt area" extending more than 500 miles from the epicenter. Some reports came from a maximum distance of 1,000 miles, an astonishing distance for an earthquake of this magnitude, covering an area where more than one-third of the United States population resides. The slow decay of this earthquake energy is a regional characteristic that can be attributed to the older, less worked,

Exhibit 4-42. Earthquake Damage

Liquefaction caused by an earthquake in Christchurch, New Zealand. Source: "The Palms in Liquefaction," Peter Prue, February 22, 2011, Christchurch, New Zealand, Flickr, CC BY-SA 2.0

and harder regional bedrock that generates high frequency earthquake motions and that can travel great distances before subsiding. An actual comparison of maps from the United States Geological Survey Did You Feel It? dataset illustrates this striking difference.[169]

Exhibit 4-44. Comparisons of USGS "Did You Feel It" maps



Comparison of USGS Did you Feel It? Maps from the 2011 M5.8 Mineral, VA (green), and the 2004 M6.0 Central California (red) earthquakes. Stars show epicenters and dots show locations where people reported at least weak shaking. Source: USGS

Tsunami Damage

Tsunamis occur when an earthquake offshore, or even across the ocean, results in large waves that can damage or destroy coastal communities. Most tsunami waves are less than 10 feet tall but can exceed 100 feet in extreme events. When a tsunami comes ashore, it may look like a fast-rising flood or a wall of water. Sometimes, before the water rushes on land, it will drain away suddenly, showing the ocean floor like a very low, low tide. A large tsunami can flood low-lying coastal areas more than a mile inland. The first wave may not be the largest or most damaging. Waves may repeatedly flood and recede from the land for many hours.[170] Tsunami waves are challenging to predict, as the wave action depends on a number of factors. Coastal wetlands, dunes, and forests can act as natural buffers against tsunamis. Climate change and human development have reduced the size and capability of these natural features to serve as buffers.[171] While the physical impacts of tsunamis are local, the devastation from large tsunamis can have regional and national impacts to social and economic systems.

Exhibit 4-45. Tsunami Damage

Tsunami Damage in Downtown Banda Aceh, Indonesia, in 2004. Source: Michael L. Bak, January 1, 2005, U.S. Military, Public Domain

Climate Change and Seismic Hazards

Scientists are still gaining an understanding of how climate change may change seismic activity in the future, but recent research indicates there are ways that climate change influences seismic risk. Melting glaciers have been shown to influence the timing and severity of seismic events.[172] Sea level rise is increasing groundwater levels in many coastal areas, which can, in turn, increase the potential for soil liquefaction during an earthquake.[173] Scientists are currently working to better understand how sea level rise may increase liquefaction risks in low-lying areas. Site planners working in coastal areas with seismic risk need to be aware of the potential for sea level rise to create seismic hazards beyond what current maps show and to work with local community planners, hazard mitigation specialists, geotechnical engineers, and geology specialists to understand how higher water tables could increase hazard risks. Furthermore, subsidence from earthquakes that occur in coastal areas can exacerbate the effects of sea level rise, increasing the risk for coastal communities, both from earthquakes and tsunamis. Seismic risk in areas previously covered with permafrost is also a serious concern.

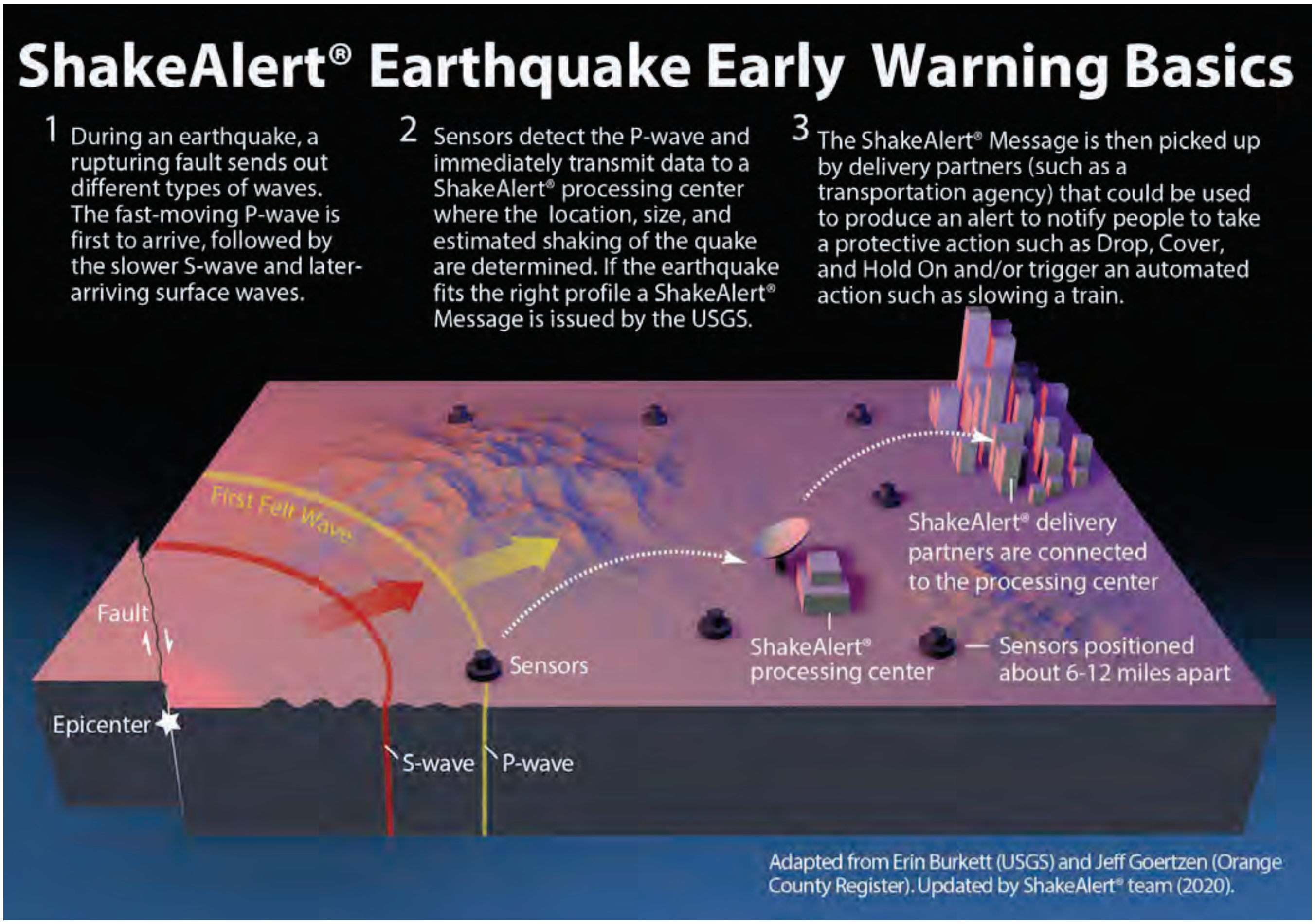
Dry soils, caused by extreme droughts, can stress and crack foundations and cause subsidence, making structures more vulnerable to earthquake events, as has been documented in Europe.[174] Climate change is also altering site conditions that can weather the material of buildings and infrastructure faster and in more ways than what the original design intent at the time of construction was, when climate change may not have been so severe as they are now. This may leave structures potentially more vulnerable to damage from high wind, corrosive salt spray, humidity, and other conditions, including earthquakes that are not directly connected to climate changes. The deadly 2021 collapse of a multistory condominium in Surfside, Florida, raised questions in the engineering and scientific communities about maintenance and the need to pay closer attention to changing soil conditions in coastal areas due to sea level rise and other climate effects.[175]

Warning and Evacuation

Earthquakes

For earthquakes, the focus is on preparation and disaster recovery rather than evacuation, as there is virtually no reliable prediction method that can accurately forecast when, where, and with what magnitude earthquakes may occur. West coast states have developed warning systems that can give communities seconds of lead time to address critical facility functions and take cover. These few seconds of warning can save lives and prevent cascading effects, such as major fires. Since 2022, the USGS and its partners established ShakeAlert®, an earthquake early warning system for the West Coast of the United States that detects significant earthquakes so quickly that alerts can reach many people before shaking arrives, offering a message that indicates that an earthquake has begun and that shaking is imminent.[176]

Exhibit 4-46. ShakeAlert® early warning system



Overview of how the ShakeAlert Earthquake Warning System works. Source: USGS

Tsunamis

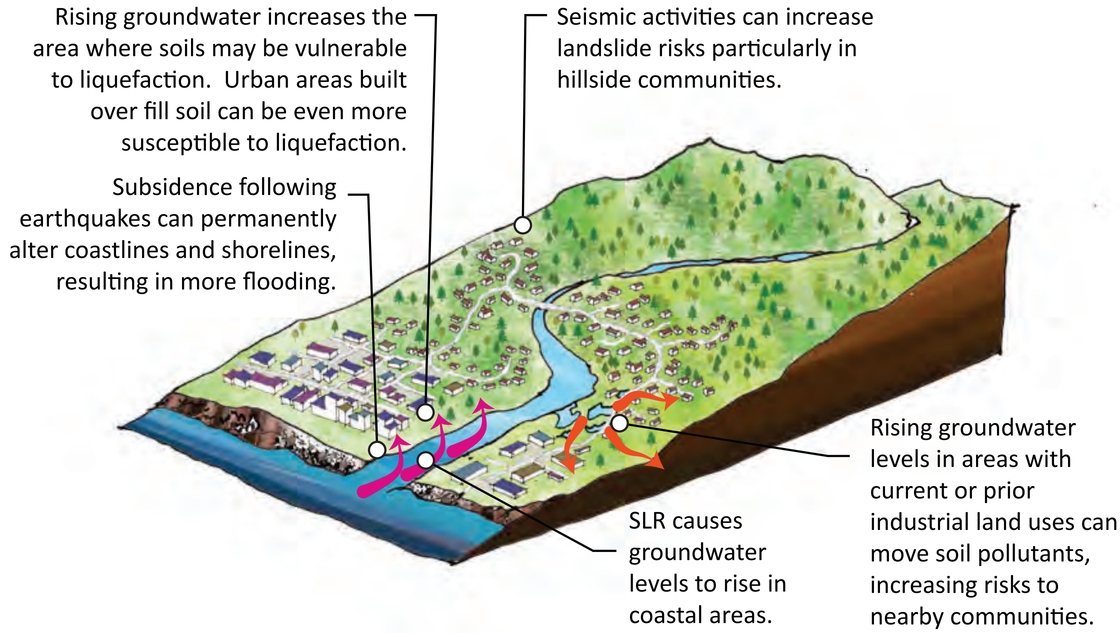
For tsunamis, evacuation is an important strategy for saving lives. Advanced warning times depend on the location of the community and the earthquake and can range from minutes to hours. Some areas may have time to evacuate via roads, but for some low-lying coastal communities, or when there is limited warning, vertical evacuation structures allow people to quickly get above the inundation area.[177] Vulnerable populations (older adults, children, etc.) and critical facilities, such as hospitals, schools, nursing homes, and incarceration facilities, will face additional challenges with timed evacuation. Established in coordination with the National Tsunami Hazard Mitigation Program, a federal/state partnership led by NOAA, the United States TsunamiReady® voluntary program helps communities prepare for tsunamis and minimize tsunami-related losses through better planning, education, and awareness.[178]

Exhibit 4-47. Vertical Evacuation Structure

A vertical evacuation structure built to protect the Shoalwater Bay Indian Tribe from tsunami effects in Washington State. Source: Washington Military Department, https://mil.wa.gov/news/celebrating-nations-first-tsunami-vertical-evacuation-tower

Natural Hazard Interactions

Exhibit 4-48. Seismic Hazards and Sea Level Rise



SLR = sea level rise. Rising groundwater can increase the risk of liquefaction in coastal areas, many of which are highly developed. Rising groundwater can also move pollutants from contaminated soils, threatening adjacent communities.
Source: MAKERS

Exhibit 4-49. Natural Hazard Triggers for and from Earthquakes and Tsunamis

Natural Hazards That Can Trigger Tsunamis	Natural Hazards That Can Be Triggered by Earthquakes	
Earthquake	Landslides	Wildfire
Landslide	Flooding	Drought
	Natural Hazards That Can Be Triggered by Tsunamis	
	Landslides	
	Flooding	

Site Analysis

Site planners working in areas with seismic and tsunami hazards should understand risks and their relationship to the impacts of climate change.

- Map and identify existing seismic hazard areas, liquefaction zones, aquifer recharge areas, and areas for potential subsidence and also consider the impacts of climate change.
- Consult with professionals from multiple disciplines to ensure a thorough understanding of the site's physical and ecological conditions and how it can accommodate future development. Specific expertise will range depending on the project. Typical projects often include geotechnical engineers, biologists, archaeologists, land-use planners, civil and traffic engineers, structural engineers, architects, and landscape architects.
- Understand how soil health and conditions can contribute to resilience against earthquakes/liquefaction.
- Understand that subsidence can be caused by over-pumping groundwater resources in drought-prone environments.
- Understand local sea level rise predictions and how they might exacerbate liquefaction and tsunami risks or increase weathering pressure on coastal structures. Consider the need for more seismically appropriate design in more areas than current codes may require.
- Understand the geologic and geotechnical subsurface conditions and site history to identify factors that could negatively affect a development (e.g., presence of active faults, weak soils such as uncontrolled fill, organic soft clays or soils) whose strength is affected by natural hazards such as liquefiable sands or aeolian soils that are vulnerable to flood, rain, or earthquake.
- Coordinate with local and state officials to understand tsunami risk factors, including the area of impact, warning time, and availability of local warning systems, and factor these risks into site selection. Identify local early warning infrastructure that could be utilized or expanded by site development.
- In tsunami hazard areas, assess if there are locations on site that are at a safe elevation above the wave inundation area. Evaluate both road and vertical evacuation opportunities for low-lying coastal communities.
- Make sure site and site improvements, including structures, do not direct the tsunami waves upward or to where it could cause additional damage. Consider whether the proposed building or other structure locations may increase the potential for tsunami damage on the site.
- Assess infrastructure connections to adjacent areas to determine whether tsunami impacts to the site could result in disruptions to other areas. Independent infrastructure may be preferable in tsunami hazard areas.

See Strategies Summary matrix and the Mitigation Approaches chapter for site planning strategies relevant to earthquake and tsunami hazards.

See Soil Stabilization and Shoring.

See Early Warning, Evacuation, Shelter, and Lifelines Access.

- Conduct a demographic inventory and analysis of the communities around the site to ensure the project assesses existing community vulnerabilities, and considers the potential effects, positive or negative, to people with low incomes, communities of color, persons with disabilities, and other traditionally underserved populations.

Resources

- FEMA-Seismic Building Codes—https://www.fema.gov/emergency-managers/risk-management/earthquake/seismic-building-codes
- USGS—Western Geographic Science Center—Tsunamis—https://www.usgs.gov/centers/western-geographic-science-center/science/tsunamis#howmany
- Ready.gov—Tsunamis—https://www.ready.gov/tsunamis
- National Tsunami Hazard Mitigation Program—https://nws.weather.gov/nthmp/
- U.S Tsunami Warning System—https://ntwc.ncep.noaa.gov/

Endnotes

[76] Kennedy, Brian. 2020. "Most Americans Say Climate Change Affects Their Local Community, Including 70% Living Near Coast." Pew Research Center blog. https://www.pewresearch.org/fact-tank/2020/06/29/most-americans-say-climate-change-impacts-their-community-but-effects-vary-by-region-2/.

[77] National Risk Index for Natural Hazards.

[78] Lightbody, Laura. 2022. "FEMA's New Flood Insurance Policy Is Fairer—and Rewards Mitigation." PEW Charitable Trusts, Flood-Prepared Communities. https://pew.org/3k0PCIy.

[79] Lightbody.

[80] Federal Emergency Management Agency (FEMA). "Historical Flood Risk and Costs." https://www.fema.gov/data-visualization/historical-flood-risk-and-costs.

[81] Hersher, Rebecca, and Ryan Kellman. 2019. "After the Water: Flash Floods Pose Existential Threat to Towns Across U.S." National Public Radio (NPR) Visuals. https://apps.npr.org/ellicott-city/.

[82] U.S. Environmental Protection Agency (EPA). "Climate Change Indicators: Sea Level." https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level.

[83] American Society of Civil Engineers. 2021. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.* https://doi.org/10.1061/9780784415788.

[84] American Society of Civil Engineers. 2013. *Flood Resistant Design and Construction, ASCE Standard 24*. https://ascelibrary.org/doi/book/10.1061/asce24.

[85] FEMA. *Flood Insurance Manual - Risk Rating 2.0: Equity in Action, Appendix D.* https://www.fema.gov/sites/default/files/documents/fema_nfip-flood-insurance-full-manual_102022.pdf.

[86] FEMA, 3–1.

[87] FEMA, 3–1.

[88] Schwab, James C., et al. 2016. *Subdivision Design and Flood Hazard Areas.* PAS report. https://www.planning.org/publications/report/9112664/.

[89] FEMA. "The Future of Flood Risk Data." https://www.fema.gov/fact-sheet/future-flood-risk-data-ffrd.

[90] Wing, Lehman, and Bates. "Inequitable Patterns of US Flood Risk in the Anthropocene."

[91] FEMA. "The Future of Flood Risk Data."

[92] FEMA. 2007. *Design Guide for Improving Critical Facility Safety from Flooding and High Winds*, Risk Management Series. https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf.

[93] EPA. "Climate Change Indicators: Heavy Precipitation." https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation.

[94] EPA. "Climate Change Indicators: Tropical Cyclone Activity." https://www.epa.gov/climate-indicators/climate-change-indicators-tropical-cyclone-activity.

[95] EPA. "Climate Change Indicators: River Flooding." https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

[96] Moftakhari, Hamed R., et al. 2017. "Cumulative Hazard: The Case of Nuisance Flooding," *Earth's Future* 5 (2): 214–23. https://doi.org/10.1002/2016EF000494.

[97] EPA. "Climate Change Indicators: Coastal Flooding." https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding.

[98] Beach, Jessica L. "Saving 450 Years of History in the Nation's Oldest City: A Look at Flood Mitigation Projects." https://www.citystaug.com/DocumentCenter/View/666/Davis-Shores-Backflow-Valve-Presentation-PDF.

[99] Bay Conservation and Development Commission (BCDC) and Metropolitan Transportation Commission/Association of Bay Area Governments (MTC/ABAG). 2020. *Adapting to Rising Tides Bay Area: Regional Sea Level Rise Vulnerability and Adaptation Study*. San Francisco, CA: 1–32. https://www.adaptingtorisingtides.org/wp-content/uploads/2020/03/ARTBayArea_Main_Report_Final_March2020_ADA.pdf.

[100] Poitras, Travis et al. "Liquefaction and Sea-Level Rise," U.S. Geological Survey, ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/b5f973b6e4da45258c0b5a5368ca26f7.

[101] "Adapting to Rising Tides," 2–36.

[102] Wing, Lehman, and Bates. "Inequitable Patterns of US Flood Risk in the Anthropocene."

[103] Burnstein, Eric Tjon, and Amy Rogin. 2021. *State Flood Resilience and Adaptation Planning Challenges and Opportunities.* Urban Institute.

[104] "Adapting to Rising Tides," 2–44.

[105] "Adapting to Rising Tides," 2–45.

[106] NOAA Office for Coastal Management. "Fast Facts - Hurricane Costs." https://coast.noaa.gov/states/fast-facts/hurricane-costs.html.

[107] National Oceanic and Atmospheric Administration.

[108] National Oceanic and Atmospheric Administration. "Severe Weather 101 Tornado Basics." https://www.nssl.noaa.gov/education/svrwx101/tornadoes/.

[109] EPA. "Climate Change Indicators - Tropical Cyclone."

[110] EPA.

[111] Bucchin and Tuley. *Planning for Climate Mitigation and Adaptation.*

[112] Henson, Bob. 2021. "Climate Change and Tornadoes: Any Connection?" *Yale Climate Connections.* https://yaleclimateconnections.org/2021/07/climate-change-and-tornadoes-any-connection/.

[113] Henson.

[114] Drane, Kara W. 2019. *Hazard Mitigation Policy Guide.* American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/hazard-mitigation-policy-guide.pdf.

[115] FEMA. *Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities.* https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions#:~:text=Nature%2Dbased%20solutions%20are%20sustainable,Reduce%20flood%20risk.

[116] Forman, Richard T.T. 2014. *Urban Ecology – Science of Cities.* Cambridge, MA: Cambridge University Press: 140–42.; Mary Duryea and Eliana Kampf. 2007. "Chapter 5 - Wind and Trees: Lessons Learned from Hurricanes." University of Florida. https://edis.ifas.ufl.edu/entity/topic/series_urban_forest_hurricane_recovery_program.

[117] U.S. Department of Agriculture. "Practices – Windbreaks." https://www.fs.usda.gov/nac/practices/windbreaks.php.; Duryea and Kampf. "Chapter 5 - Wind and Trees: Lessons Learned from Hurricanes."

[118] Duryea and Kampf. "Chapter 5 - Wind and Trees: Lessons Learned from Hurricanes."

[119] Li, Anna C.Y., et al. 2022. "Shelter Location and Transportation Planning under Hurricane Conditions," *Transportation Research Part E: Logistics and Transportation Review:* 715–29.

[120] Baxter, Julie et al. 2013. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards.* FEMA; FEMA. 2021. *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home (Fifth Edition)*. https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf.

[121] Drane. "Hazard Mitigation Policy Guide"; FEMA. *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home (Fifth Edition).*

[122] Tye, Mari R., and Jason Giovannettone. 2021. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions.* https://ascelibrary.org/doi/pdf/10.1061/9780784415863.fm.

[123] Cook, Edward R., et al. 2021. "Large Contribution from Anthropogenic Warming to an Emerging North American Megadrought," Science 368 (6488). https://doi.org/10.1126/science.aaz960.

[124] Burgess, Katharine, and Elizabeth Foster. 2019. *Scorched - Extreme Heat and Real Estate.* Urban Land Institute.

[125] Burgess and Foster.

[126] EPA. "Climate Change Indicators: Heat Waves." https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves.

[127] EPA. "Climate Change Indicators: Drought." https://www.epa.gov/climate-indicators/climate-change-indicators-drought.

[128] Schwab et al. "Planning and Drought."

[129] Hodge, Tyler. 2022. *Short-Term Energy Outlook Supplement: Drought Effects on California Electricity Generation and Western Power Markets.* Washington DC: U.S. Energy Information Administration, Independent Statistics & Analysis; Jason Plautz. 2022. "Southwest Megadrought Pushes Hydropower to the Brink," *E&E News, Energywire,* May 31. https://www.eenews.net/articles/southwest-megadrought-pushes-hydropower-to-the-brink/.

[130] Schwab et al. "Planning and Drought," 3.

[131] American Planning Association. *Falling Dominoes: A Planner's Guide to Drought and Cascading Impacts.*

[132] Burgess and Foster. *Scorched – Extreme Heat and Real Estate;* Sherman. "The Heat Is On."

[133] Campbell, Iain, et al. 2021. *Beating the Heat: A Sustainable Cooling Handbook for Cities. United Nations* Environment Programme.

[134] Burgess and Foster. Scorched - *Extreme Heat and Real Estate,* 24.

[135] Cornett, Meredith. 2017. "Adaptation as Acceptance: Toward a New Normal in the Northwoods," *Cool Green Science* blog. The Nature Conservancy. https://blog.nature.org/science/2017/10/11/adaptation-as-acceptance-toward-a-new-normal-in-the-northwoods/.

[136] Baker, Mike, and Sergio Olmos. 2021. "The Pacific Northwest, Built for Mild Summers, Is Scorching Yet Again," *The New York Times,* August 13. https://www.nytimes.com/2021/08/13/us/excessive-heat-warning-seattle-portland.html.

[137] Hagler. "Defining U.S. Megaregions."

[138] Burgess and Foster. *Scorched – Extreme Heat and Real Estate,* 3.

[139] Hoover, Katie, and Laura A. Hanson. 2022. "Wildfire Statistics," *In Focus.* Congressional Research Service.

[140] Masters, Jeff. 2021. "Reviewing the Horrid Global 2020 Wildfire Season," *Yale Climate Connections.* http://yaleclimateconnections.org/2021/01/reviewing-the-horrid-global-2020-wildfire-season/.

[141] Mowery et al. "Planning the Wildland-Urban Interface," 4, 22.

[142] Gabbert, Bill. 2022. "Marshall Fire Updated Damage Assessment: 1,084 Residences Destroyed," *Wildfire Today,* January 7. https://wildfiretoday.com/2022/01/07/marshall-fire-updated-damage-assessment-1084-residences-destroyed/.

[143] Schwab, Meck, and Simone. "Planning for Wildfires," 31.

[144] Mowery et al. "Planning the Wildland-Urban Interface," 5.

[145] Bucchin and Tuley. 2022. "Planning for Climate Mitigation and Adaptation," 23–24.

[146] EPA. "Climate Change Indicators: Wildfires." https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires.

[147] Mowery et al. “Planning the Wildland-Urban Interface,” 13.

[148] Mowery et al. 39–44.

[149] Schwab, Meck, and Simone. “Planning for Wildfires,” 33.

[150] California Department of Forestry and Fire Protection. “Prepare for Wildfire - Defensible Space.” https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/.

[151] Mowery et al. “Planning the Wildland-Urban Interface,” 42–43.

[152] Mowery et al., 43..

[153] Mowery et al., 43–44.

[154] Living with Fire. “Get Prepared - What Can I Do Before a Fire?” https://www.livingwithfire.com/get-prepared/.

[155] National Research Council. 1985. *Reducing Losses from Landsliding in the United States.* Washington, DC: National Academies Press. https://doi.org/10.17226/19286.

[156] National Research Council.

[157] U.S. Geological Survey, “Landslides 101.” https://www.usgs.gov/programs/landslide-hazards/landslides-101.

[158] Highland, Lynn, and Peter T. Bobrowsky. 2008. “The Landslide Handbook: A Guide to Understanding Landslides.” Reston, VA: U.S. Geological Survey: 29.

[159] Highland and Bobrowsky, 36.

[160] Mirus, B.B., et al. 2020. “Landslides Across the USA: Occurrence, Susceptibility, and Data Limitations,” *Landslides.*

[161] AghaKouchak et al. “How Do Natural Hazards Cascade to Cause Disasters?”

[162] U.S. Geological Survey, “Could a Large Tsunami Happen in the United States?” https://www.usgs.gov/faqs/could-large-tsunami-happen-united-states.

[163] Jaiswal et al. “Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States.” https://www.usgs.gov/news/featured-story/nearly-half-americans-exposed-potentially-damaging-earthquakes.

[164] National Oceanic and Atmospheric Administration “Facts - What Is Subsidence?” https://oceanservice.noaa.gov/facts/subsidence.html.

[165] National Aeronautics and Space Administration. “Understanding Sea Level – Subsidence.” https://sealevel.nasa.gov/understanding-sea-level/regional-sea-level/subsidence.

[166] U.S. Geological Survey, Office of Communications and Publishing. “Induced Earthquakes Raise Chances of Damaging Shaking in 2016.” https://www.usgs.gov/news/featured-story/induced-earthquakes-raise-chances-damaging-shaking-2016.

[167] Nikolaou, Sissy, et al. 2019. “Dried Lakes Do Tell Tales: Seismic Soil Amplification in Mexico City,” *Geostrata Magazine* 23 (2). https://doi.org/10.1061/geosek.0000131.

[168] Sneed, Michelle. “Land Subsidence in the San Joaquin Valley.” U.S. Geological Survey. https://www.usgs.gov/centers/land-subsidence-in-california/science/land-subsidence-san-joaquin-valley.

[169] Nikolaou, Sissy. 2013. “The Eastern United States,” *Structure Magazine*. https://www.structuremag.org/?p=836.

[170] National Oceanic and Atmospheric Administration. “U.S. Tsunami Warning System.” https://www.noaa.gov/explainers/us-tsunami-warning-system.

[171] French, Emily L., et al. 2019. “Designing Public Open Space to Support Seismic Resilience: A Systematic Review,” *International Journal of Disaster Risk Reduction* 34: 1–10.

[172] Rollins, Chris, Jeffrey T. Freymueller, and Jeanne M. Sauber. 2021. “Stress Promotion of the 1958 Mw~7.8 Fairweather Fault Earthquake and Others in Southeast Alaska by Glacial Isostatic Adjustment and Inter-Earthquake Stress Transfer,” *Journal of Geophysical Research: Solid Earth* 126 (1): e2020JB020411. https://doi.org/10.1029/2020JB020411; “Melting Glaciers Contribute to Alaska Earthquakes,” *ScienceDaily.* https://www.sciencedaily.com/releases/2021/03/210318170319.htm.

[173] Petersen. “Liquefaction and Sea-Level Rise.”

[174] Wüest, Marc, David Bresch, and Thierry Corti. 2001. *The Hidden Risks of Climate Change: An Increase In Property Damage from Soil Subsidence in Europe.* Zurich: Swiss Reinsurance Company Ltd.

[175] Parkinson, Randall W. 2021. “Speculation on the Role of Sea-Level Rise in the Tragic Collapse of the Surfside Condominium (Miami Beach, Florida U.S.A.) Was a Bellwether Moment for Coastal Zone Management Practitioners,” *Ocean & Coastal Management* 215. https://doi.org/10.1016/j.ocecoaman.2021.105968.

[176] U.S. Geological Survey. “ShakeAlert Earthquake Early Warning Basics.” https://www.usgs.gov/media/images/shakealert-earthquake-early-warning-basics.

[177] National Tsunami Hazard Mitigation Program. 2001. “Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards.” https://mitigation.eeri.org/files/DesignForTsunamis.pdf.

[178] National Oceanic and Atmospheric Administration. 2016. “U.S. Tsunami Warning System.”

5

Mitigation Approaches

> *A climate resilient community is one that is adequately prepared to survive, recover, adapt, and thrive in the face of future shocks and stressors. Moving forward, planners will need to integrate resilience thinking as part of climate mitigation and adaption solutions to create sustainable, livable, and more climate-resilient communities.*[179]
>
> —Matt Bucchin et al. from "Planning for Climate Mitigation and Adaptation."

Mudslide in California neighborhood. Source: Staff Sgt. Cristian Meyers, California Air National Guard

Introduction

The following sections offer site planning approaches to mitigate physical exposure to hazards. The strategies are grouped by site planning topic in order to:

- Follow the site planning process, emphasizing large-scale decisions (e.g., avoiding a risky site or part of a site), laying out the circulation and land use framework, then planning for infrastructure and building design features (e.g., green roof treatment) relevant to site planning.
- Highlight strategies with multiple benefits across hazards and typical site planning goals (e.g., access to nature, safe and comfortable public spaces).
- Note potential areas of conflict where a strategy mitigates one hazard but increases vulnerability to another.

Key site planning steps under which strategies are grouped include:

- Site selection and avoidance.
- Natural systems and processes.
- Site layout, circulation, and access.
- Stormwater and site protection.
- Open space and green infrastructure.
- Utilities.
- Buildings.

Icons in This Chapter

Hazards

Icons are used in this chapter to highlight the hazards addressed by each mitigation strategy. Descriptions of each hazard are provided alongside their icon in Chapter 1, starting on page 9.

Example hazard icon showing strategy mitigates this hazard

In some cases, a strategy that mitigates disaster for one natural hazard may have negative implications for another.

Example icon showing strategy may increase the risks of this hazard

People-friendly Design

Icons are also used to identify hazard mitigation site planning strategies that co-benefit or inhibit sociability.

Strategy fosters people-friendly design

Strategy may inhibit people-friendly design

A complete legend of all icons used in this document is provided on page 4.

Principles

Site planning for hazard resilience is not a one-size-fits-all process—each project and site has unique needs and conditions that need to be weighed against a site's overall hazard exposure. The following principles combine resilience, sustainable design, people-centered planning, and disaster preparation and recovery themes. They are intended to inform decision-making around how best to employ the mitigation strategies in the following sections.

Resisting

- Consider history of the site and avoid highly vulnerable sites.
- Acknowledge uncertainty and plan for the *future* condition of the site when evaluating and selecting site protection and resilience strategies.
- Support natural systems to buffer the site from hazard impacts.
- Follow the most recent local building codes and reference standards.

Adapting

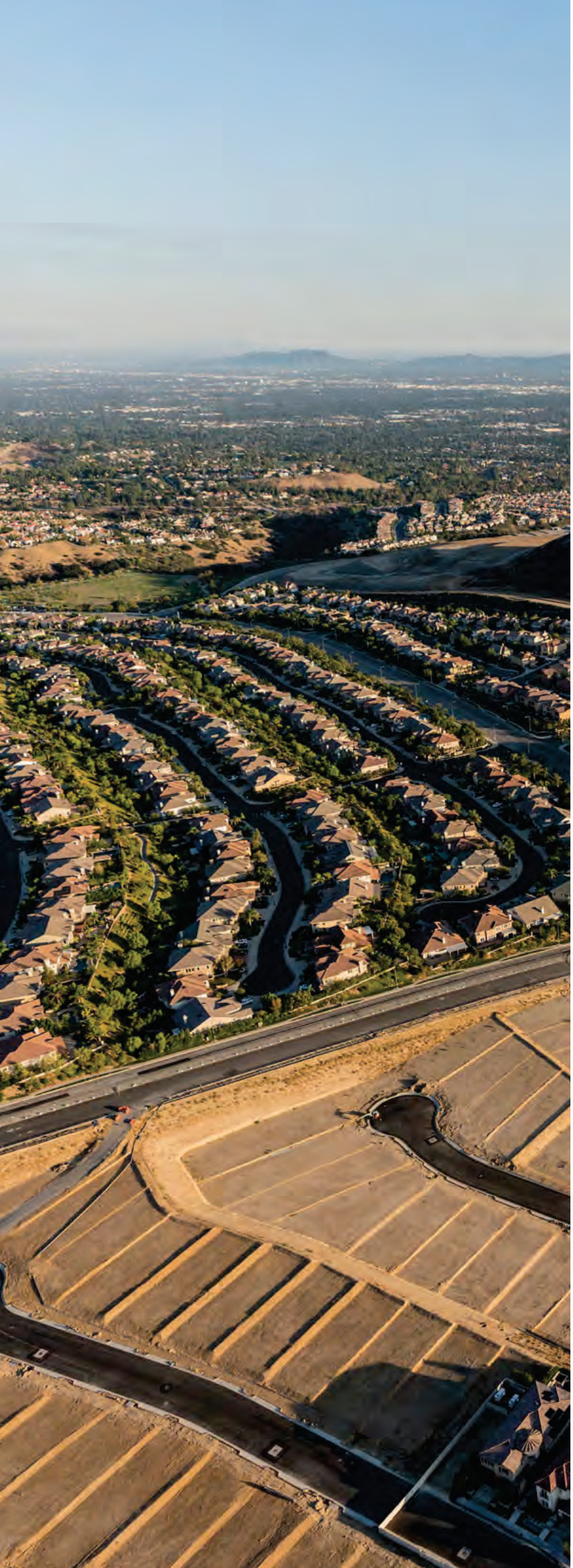
- Allow for graceful failure by planning the site and systems to absorb impacts while still supporting key functions and offering some protection.
- Layer multiple benefits, such as site protection, environmental sustainability, and community health.
- Support diversity, including use types, income levels, biodiversity, etc.
- Provide multiple lines of protection and varying scales of interventions.
- Foster social ties through engagement, communication, and designing for social interactions.

Recovering

- Provide redundant evacuation and emergency access routes.
- Include back-up power and communication infrastructure.
- Plan for post-disaster response needs and access.

Transforming

- Consider regenerative approaches that integrate human and natural systems for mutual benefit.
- As feasible, test innovative solutions and approaches through pilot or temporary projects.
- Plan for change—use adaptive management strategies that allow the site and community to evolve with changing conditions.



Site Selection and Avoidance

This section highlights strategies and tools to avoid sites most exposed to impacts from natural hazards. Communities need to think carefully about how and where to develop housing, infrastructure, and public facilities as they face increased exposure to natural hazards and their complex, often unpredictable interactions and impacts. While many strategies help communities adapt to changing conditions, some sites are increasingly exposed to repeated floods, wildfires, prolonged droughts, and other hazards. Site planners, developers, and community planners will have to make complex and often challenging decisions—using information from civil engineers and other experts—about how and where existing communities should grow and develop new housing and infrastructure. In some cases, avoiding sites once thought to be developable may be the most resilient choice.

Site Selection

Land Use and Development Regulations

Update regulations to prevent development in high-risk sites (local municipality).

Land use and development regulations that direct development away from highly vulnerable sites are highly effective tools for mitigating future disasters, particularly from floods, landslides, tsunamis, and some wildfires. These strategies can also help mitigate some damage from hazards that threaten large geographic regions, such as strong wind, droughts, and earthquakes, by limiting development on sites where damage from these events is most likely.

In the Bay Area of California, planners estimate that if historical development patterns continue, over 38,000 homes could be added in areas at risk of flooding.[180] Some communities, such as those in the wildland-urban interface (WUI), are adopting regulations pre-disaster that would apply to post-disaster rebuilding efforts, both to alleviate some post-disaster decision-making and ensure future development is more resilient. Regulations can range from community-scale land use to site- and building-scale design requirements.[181]

Support is increasing for no-rebuild areas, development limits, buyout programs, and other strategies limiting development in high-risk areas as communities are experiencing more severe impacts from natural hazards. FEMA's 2013 guidance on mitigation strategies to reduce natural hazard risk suggests doing more to manage or restrict development in areas with flooding, landslide, erosion, subsidence, and/or multiple hazard risks.[182] The American Planning Association's Hazard Mitigation Policy Guide includes several recommendations to restrict development in hazard-prone areas, including in floodplains and areas susceptible to landslides.[183] Thus, site planners need to understand how to employ tools to assist developers in making these decisions.

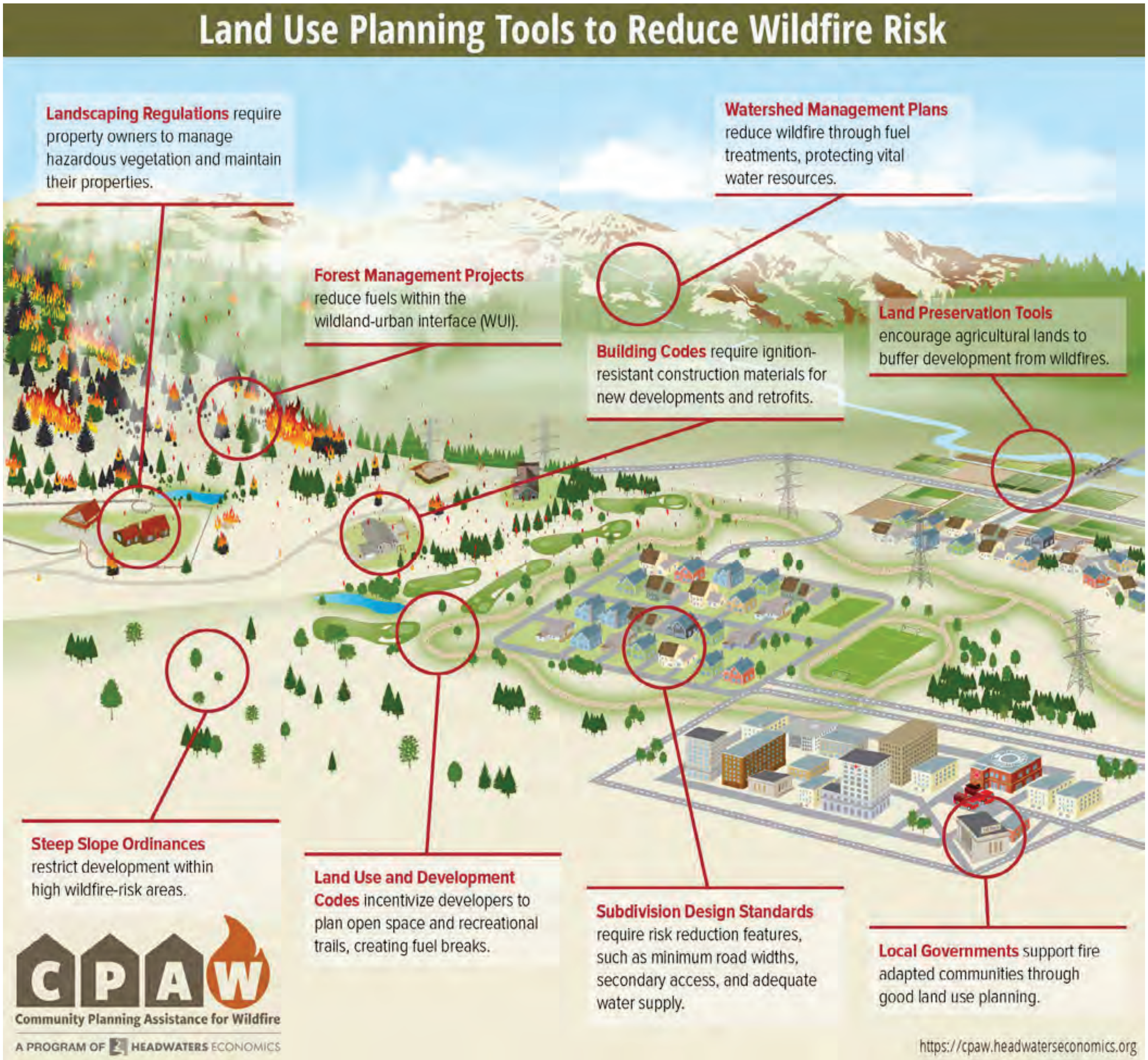
Land use and development regulations are most effective when used in conjunction with building codes and other site and community planning strategies. Exhibit 5-1 illustrates how regulations at different scales can be combined to reduce overall wildfire risks.

Mitigation Benefits

Reduces community risk by limiting development:

- In areas highly vulnerable to floods.
- In locations highly vulnerable to hurricanes and strong winds.
- Where water resources are constrained by drought.
- In locations highly vulnerable to wildfire.
- In areas on or adjacent to landslide hazard areas.
- In high-risk seismic areas, such as liquefaction zones, which may reduce the scale of disaster following an earthquake.
- In tsunami hazard areas.
- Fosters a more resilient community.

Exhibit 5-1. Land Use and Community Planning Strategies to Protect Communities From Wildfire



Graphic illustrating how land use and open space regulations, building codes, and development standards work together to reduce wildfire risks. Source: Community Planning Assistance for Wildfire, a program of Headwaters Economics

Avoid Flood Hazard Zones

Limit development in flood hazard zones, and areas vulnerable to future flooding, whenever possible.

Limiting further development of the floodplain is essential to increase resilience to natural hazards. The Association of State Floodplain Managers (ASFPM) encourages communities to adopt No Adverse Impact standards, which ensure that the actions of communities and property owners in floodplains do not infringe on the property rights of others. While the standards still allow development in floodplains, development actions must be mitigated and should align with the local community or watershed plans.[184] However, given the prevalence of floodplain development throughout the United States, avoiding further development in floodplains can provide multiple benefits beyond hazard reduction. These benefits include improving water quality, recharging aquifers, and adding wildlife habitat and recreation opportunities.[185] FEMA also recommends that manufactured homes be located outside of floodplain areas to the extent possible due to the vulnerabilities of that housing type.[186] Lower-income homeowners are also less likely to recover financially when impacted by natural disasters.

Decisions to avoid a vulnerable site or develop one and employ mitigation strategies are complex, should be considered on a case-by-case basis, and discussed with local planners. Site planners should comply with hazard mitigation requirements but also understand the ecosystem services provided and the potential benefits of avoiding development in floodplains.

Resources

- FEMA - Mitigation Ideas—
  https://www.fema.gov/sites/default/files/2020-06/fema-mitigation-ideas_02-13-2013.pdf
- Association of State Floodplain Managers—No Adverse Impact—
  https://floods.org/resource-center/nai-no-adverse-impact-floodplain-management/
- American Planning Association—Hazard Mitigation Policy Guide https://www.planning.org/publications/document/9203323/
- American Planning Association—Subdivision Design and Flood Hazard Areas
  https://www.fema.gov/sites/default/files/2020-06/apa_subdivision-design-and-flood-hazard-areas_10-31-2016.pdf
- Pew Charitable Trusts—Flood Prepared Communities
  https://www.pewtrusts.org/en/projects/flood-prepared-communities
- Floodplains By Design (Washington State)—
  https://www.floodplainsbydesign.org/

Mitigation Benefits

Reduces potential for damage and impacts to future communities and downstream impacts to existing communities.

Avoid Hazards on Coastal Sites

Fully assess coastal sites that are exposed to multiple natural hazards and consider alternative development approaches when feasible.

Coastal sites are exposed to multiple hazards, including hurricanes and storms, sea level rise, erosion, and landslides. In some coastal areas, subsidence and seismic risks from earthquakes and tsunamis are also important considerations.[187] Coastal areas also tend to be significant population centers and areas of growth, which increase urban flood and heat island impacts. Given the compound hazard risks, thoughtful site selection and limiting the development footprint and providing space for natural systems to absorb and insulate upland areas from coastal impacts can greatly enhance site resilience. Limiting development along coastal areas can also provide adaptation space for future sea level rise, as uncertainty remains about how high sea levels will rise.[188] In areas where there is existing development, allowing some low-impact interim uses in vulnerable areas may help a community adapt over time.

Site contamination is also an important consideration in coastal areas, as flooding and rising groundwater levels could mobilize pollutants through flood events or groundwater flows. How sea level rise and increased flooding will impact contaminated sites remains uncertain. In the Bay Area of California, sea level rise is expected to elevate groundwater and increase salinity intrusion in many low-lying areas, which will threaten underground infrastructure and potentially change how contaminants and saltwater move through the ground.[189] Site planners should identify potential sources of onsite contamination and consider the potential for contamination to move underground to lower-lying sites.

While there are coastal sites where hazard exposure can be effectively reduced through mitigation, including low-lying sites vulnerable to storm surge and sea level rise, sites on or near former industrial areas, or sites downstream from development that could exacerbate flood patterns, the best strategy may be to avoid or concentrate development in lower-risk, upland areas.[190] Developing upland of existing low-lying and vulnerable development could also offer opportunities for a managed retreat from the earlier development over time.[191]

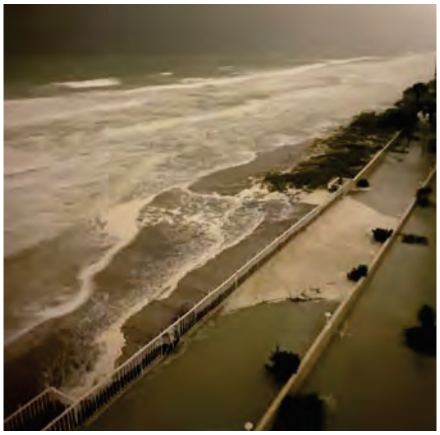
FEMA has developed detailed guidance and site selection criteria for residential development on coastal sites, highlighting hazard exposure, avoidance, and construction requirements applicable to a range of development.[192]

Mitigation Benefits

Promotes sensitive development in coastal areas that reduces impacts in areas vulnerable to:

- Coastal flooding, storm-surges, and sea level rise.
- Hurricanes and coastal storms.
- Coastal erosion and landslides.
- Earthquake damage, such as liquefaction zones.
- Tsunamis.

Exhibit 5-2. Florida Gulf Coast Beaches During Tropical Storm Eta



Tropical Storm Eta had effects on Florida's Gulf Coast beaches, including dune erosion and overwash. This image from the coast cam at Madeira Beach, Florida, captured high water levels and resulting overwash of sand onto the patio of the Shoreline Resort. The U.S. Geological Survey (USGS) Coastal Change Hazards team works to predict these types of events to provide forecasts to coastal communities. Source: USGS

Resources

- Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas, (Fourth Edition)—FEMA, 2011 https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf
- USGS Coastal Change Hazard Team https://www.usgs.gov/programs/cmhrp/science/coastal-change-hazards

Case Study—Biloxi-Chitimacha-Choctaw tribal community, Isle de Jean Charles

The Biloxi-Chitimacha-Choctaw tribal community of Isle de Jean Charles, located on the Louisiana coast, has been heavily impacted by sea level rise and lost 98 percent of its landmass over the last 60 years. A plan to relocate this community is the first community-scale resettlement program driven by climate change in the United States. An interdisciplinary team that included design professionals, a geographer, a climate policy specialist, and a sociologist worked collaboratively with the tribe to develop the resettlement strategy.[193] Participation in the program was voluntary, but ultimately 37 of 42 eligible households chose to relocate to a site approximately 1 hour away that is 12 feet above sea level.[194]

This resettlement program was supported by funding from the U.S. Department of Housing and Urban Development. In 2022, the Biden Administration announced a new program to increase resilience in Tribal Communities threatened by climate change. For more information, visit:

- https://isledejeancharles.la.gov/about-isle-de-jean-charles-resettlement
- https://www.doi.gov/pressreleases/biden-harris-administration-announces-bipartisan-infrastructure-law-funding-build
- https://www.nytimes.com/2022/11/02/climate/native-tribes-relocation-climate.html

Exhibit 5-3. Land Disappearing Into Gulf due to Climate Change

Raised homes cannot avoid rising waters from climate change. Source: Dave Malkoff,© 2016, CC BY-NC-SA 2.0, Flickr

Landslide Avoidance

Avoid development on and adjacent to slopes vulnerable to or with mapped landslides and establish buffers to protect vulnerable areas.

Slopes vulnerable to landslides are an extreme hazard to properties and human life, and many municipalities place restrictions on development around slopes through grading ordinances and geologic hazard area restrictions.[195] As is highlighted in Site Analysis, landslide risks are increasing throughout the United States, and climate change is expected to exacerbate this trend.[196] In some areas, slopes that may have been relatively safe in the past are now more vulnerable due to the combined impacts from climate change, including higher precipitation, flooding, erosion, and higher saturation of the soils. Site planners working on sites on and around slopes should consult with local professionals to ensure development is allowable and will not further exacerbate landslide risk in the area. In areas with landslide hazard mapping, site planners should look for ancient landslides that may have occurred, as these landslides can be present on the landscape. Ancient landslides can be large and can exist on gentle or steep slopes.

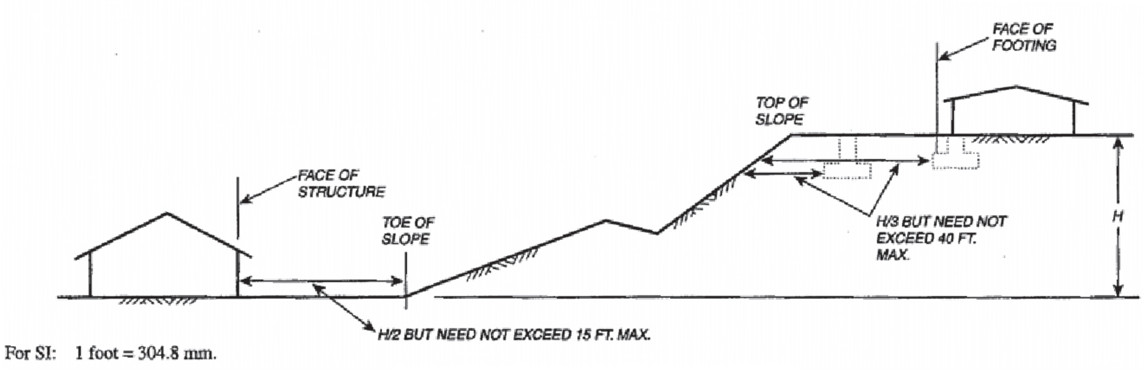
Establishing buffers between development and slopes is a common strategy and often a geologic hazard protection requirement. Buffers ensure that no development occurs within a certain distance from or on a slope, including grading, utilities, paving, and structures. These protections can be employed at both the toe (bottom) and the top of the slope, depending on site conditions. Often coupled with setback requirements, which direct where development can be located, buffers and setbacks can offer robust protection from landslides when planned in coordination with local professionals in response to site conditions.[197] Buffer and setback areas can be planted with native vegetation to further stabilize soils.[198] In areas prone to wildfire, top-of-slope setbacks allow for vegetation management and/or emergency response access, as wildfires can move quickly up the sides of slopes and threaten structures close to the edge.[199]

Mitigation Benefits

Reduces impacts on and around slopes vulnerable to landslides.

See Wildfire Mitigation and Open Space Management for more information.

Exhibit 5-4. Guidance to Reduce Wildfire Risks on a Slope



Example from Spokane, Washington, of setback guidance around slopes greater than 33 percent that complies with the International Building Code. Source: City of Spokane, Development Services Center, Build-10 Slopes and Setbacks; https://static.spokanecity.org/documents/business/resources/guidesheets/site/slopes-and-setbacks.pdf

In addition to buffering slopes from development, site planners should ensure that development does not change hydrologic conditions on or above slopes through runoff from impervious surfaces, as adding water to steep slopes can significantly increase landslide risks.[200]

See
for more information on how site restoration can increase slope resilience to landslide hazards.

Consider Seismic Hazards

Example from Spokane, Washington, of setback guidance around slopes greater than 33 percent that complies with the International Building Code. Source: City of Spokane, Development Services Center, Build-10 Slopes and Setbacks; https://static.spokanecity.org/documents/business/resources/guidesheets/site/slopes-and-setbacks.pdf

Promotes sensitive development in areas with seismic hazards and reduces impacts in areas:

- Vulnerable to landslides, which may be triggered by an earthquake.
- Prone to severe earthquake damage, such as liquefaction zones.
- Where there are tsunami risks.

Seismic hazard areas are prevalent in the United States, so avoiding seismic hazard zones is often unrealistic given development patterns in areas where risk is higher, such as the west coast. However, site planners should consider how the risks associated with strong earthquakes, such as soil liquefaction and tsunamis, may impact proposed uses and connections to nearby essential facilities, such as schools, hospitals, emergency response centers, and commercial areas.[201] Careful assessment to ensure there is adequate support for vulnerable populations and multiple access points for emergency response and evacuation is recommended.

Although seismic events are not increasing in frequency or magnitude due to climate change, the risk of impact from earthquakes is somewhat influenced by changes in hydrology and soil conditions. In low-lying areas, scientists and planners are exploring how changes in groundwater levels due to sea level rise might increase liquefaction risks and earthquake vulnerability.[202]

Areas susceptible to tsunami hazards require further planning to reduce hazard exposure, as the impacts from these events, while rare, can be catastrophic. Tsunami hazard areas can be large and complete avoidance may not be possible. Planners siting facilities for vulnerable communities, including housing, schools, and medical facilities, should try to avoid tsunami hazard zones.

Resources

- Liquefaction and Sea Level Rise—United States Geological Survey (USGS) Storymap
  https://geonarrative.usgs.gov/liquefactionandsealevelrise/

Consider seismic hazards from earthquakes, proximity to active faults, seismic soil liquefaction, and tsunamis during site selection and avoid highly vulnerable sites when possible.

Mitigation Benefits

See Early Warning, Evacuation, Shelter, and Lifelines Access for more strategies to address Tsunami hazards.

Tools to Avoid Hazard Areas

Districts, Land Transfers, and Buy-Out Programs

Consider district-based approaches, hazard abatement districts, Transfer of Development Rights (TDR), and property buy-out programs to reduce hazard risks.

Communities across the United States are looking for new approaches to increase resilience, reduce natural hazard exposure and risk, and adapt to changing conditions. However, natural hazards often work on a landscape scale, impacting multiple properties. The effectiveness of some site-scale hazard mitigation actions is limited if not done in collaboration with adjacent parcels.

In response, some communities are collaborating across parcel boundaries, working together to identify infrastructure improvement needs and establish guidelines to shape future development. The City of Boston's 2016 climate resilience and adaptation plan, Climate Ready Boston, highlighted the vulnerability of the City's waterfront area to storm surges, sea level rise, and coastal flooding. To address these hazards, the City established an overlay zoning district and resilience design guidelines to shape future infill development and adaptation of the urban waterfront. The guidelines established a new base flood elevation that accounts for both coastal flood impacts and projected sea level rise. They also provide mitigation strategies for existing buildings and infill development that range in scale from building retrofits and individual site strategies to district-scale infrastructure solutions to protect multiple properties.[203] Other communities, such as Seattle, Washington, are exploring district-based solutions to increase resilience within some neighborhoods or small geographic areas.[204] Zoning that recognizes hazard risks can facilitate buy-outs and/or allow space for hazard impacts (e.g., parcel-specific flooding) to increase resilience for the overall community.[205]

Mitigation Benefits

Helps communities grow while increasing resilience and adapting to extreme weather and natural hazard impacts.

Provides alternative sites or development strategies, helping communities avoid sites highly vulnerable to:

- Floods.
- Windstorms.
- Heat wave and drought impacts.
- Wildfires.
- Landslides.
- Earthquakes.
- Tsunamis.

Mitigation Considerations

Incorporate social equity as a central consideration for any program that impacts low-income and/or communities of color.

Exhibit 5-5. Limitations of Individual Action for Comprehensive Flood Protection

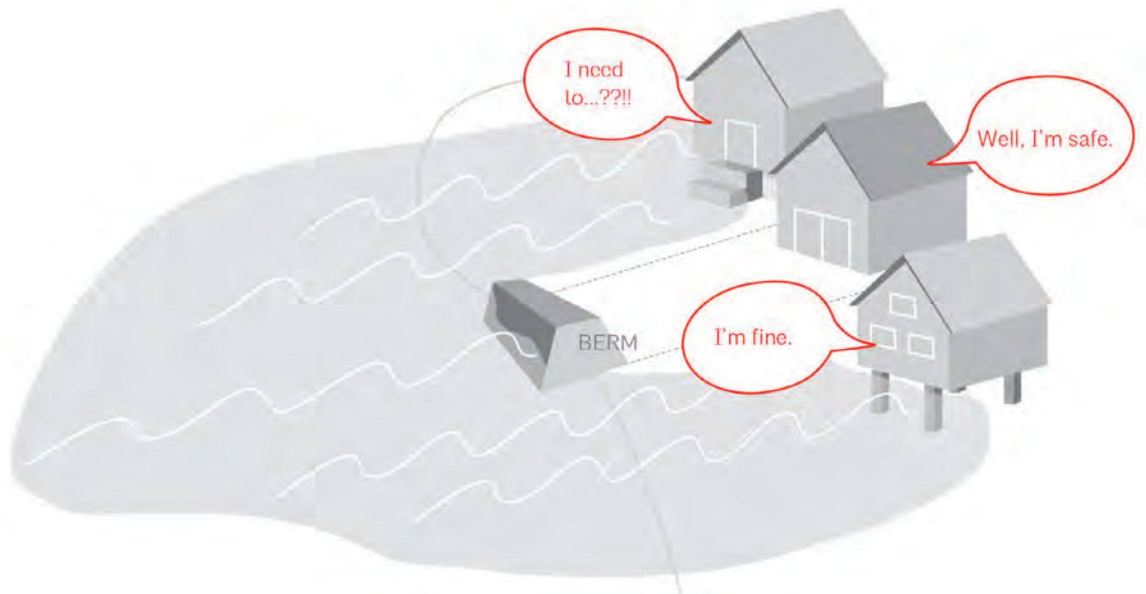


Illustration of the challenges of coordinating flood protection in areas where multiple small properties are impacted. Berm and levee-type structures can also increase risks for adjacent neighbors and lead to a false sense of security if there are large floods that overtop flood protection heights. Source: American Institute of Architects Disaster Assistance Handbook

Taking a district approach to reduce hazard exposure and risk is not a new phenomenon. The State of California established Geologic Hazard Abatement Districts (GHADs) in 1979 to help prevent, mitigate, abate, or control landslides, land subsidence, soil erosion, coastal erosion, and other geologic hazards. GHADs are public agencies formed by communities that are permitted to acquire, construct, manage, or maintain improvements on public or private lands.[206] GHADs can offer a unique and effective tool for transferring hazard risk, but there are a number of considerations with this approach, such as how to ensure proper oversight.[207] While the model is distinct to California and has been used primarily to address geologic hazards, it could offer a model for district-level hazard mitigation. For example, in 2022, the City of Isleton, California, formed the first GHAD with the purpose of addressing floods.[208]

Transfer of development rights is another tool that aims to direct development to locations designated for future growth. The tool has been most widely used to conserve farmland and environmentally sensitive areas, but it has also been used to direct growth away from geologic and landslide hazard areas. The tool allows property owners to realize financial value while communities guide the location and form of development.[209] The tool can be effective in guiding growth to desirable places, and support is growing to apply it to hazard mitigation contexts, including flooding.[210]

Buy-out programs can be particularly effective when relocating a small number of properties, as this approach provides space for natural systems while directing growth to areas less vulnerable to hazards.

Resources

- Geologic Hazard Abatement Districts (California)—
https://www.conservation.ca.gov/cgs/Pages/GHAD.aspx
- https://nrcsolutions.org/moving-people-out-of-harms-way-property-buyouts/
- Renewal Enterprise District: Sonoma County and Santa Rosa Wildfire Recovery—
https://resilientca.org/projects/f00c9951-0f05-431a-b882-7f32e4607771/
- US Army Corps of Engineers - Out of Harm's Way Without Harm—Bridging the Equity Gap: Flood Resilience for the Whole Community webinar series—
https://www.youtube.com/watch?v=Ok_5_T28AUY

Case Study—The Corporación del Proyecto ENLACE del Caño Martín Peña

This community in San Juan, Puerto Rico, demonstrates one approach for increasing resilience within a low-income, underserved community while also insulating it from development pressure, gentrification, and displacement risk. Caño Martín Peña (Caño) is a tidal water channel that runs through San Juan. The area is home to over 25,000 people who live in eight different communities along the water, mostly in informal settlements. The Caño is a heavily polluted water channel that often floods. In the 1990s, the local government developed plans to improve infrastructure throughout the area. The community, highly vulnerable to displacement from this project, mobilized and ultimately transformed the City's infrastructure project into an equitable development plan to improve infrastructure, address soil and water quality issues, mitigate flooding, and develop affordable housing.

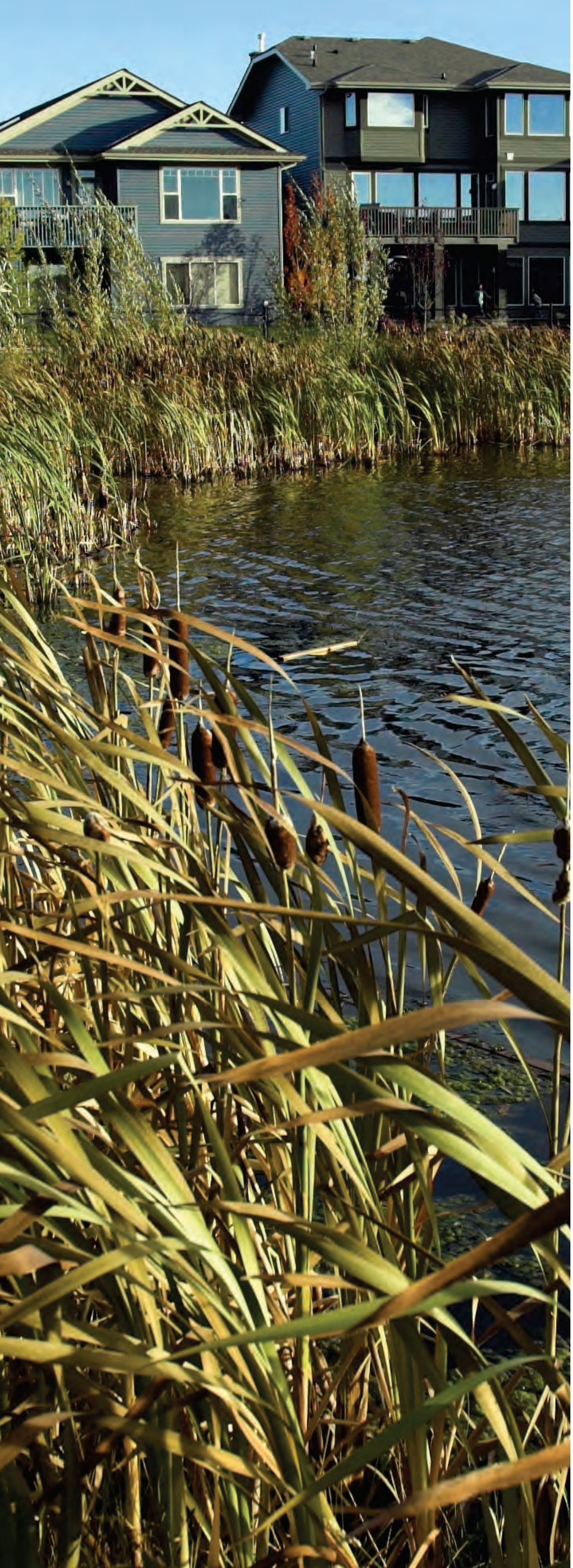
In 2002, the City created the Caño Martín Peña Special Planning District, which led to a plan to improve water quality issues, improve the environment, and address flood issues. In 2004 the Puerto Rico government created ENLACE, a public corporation that allowed residents a way to collaborate on implementing the improvement plan. ENLACE works closely with a non-profit organization comprised of local community members to ensure the plan's implementation is informed with community input. A land trust also operates in coordination with ENLACE, providing opportunities for community members to relocate to safer areas within their own community.[211] The ENLACE project has been internationally recognized for its innovative approach to equitable development and environmental restoration.

For more information visit:

- https://www.epa.gov/urbanwaterspartners/urban-waters-and-cano-martin-pena-martin-pena-channel-puerto-rico
- https://urbanwaterslearningnetwork.org/resources/proyecto-enlace-del-cano-martin-pena-restoring-ecosystem-building-resilient-communities-puerto-rico/

Exhibit 5-6. Images of Caño Martín Peña, San Juan, Puerto Rico

Top: Flooded street and buildings in 2010. Bottom: A sign posted outside a property that was acquired to implement restoration and environmental improvements marks the future width of the channel and restricts the building of new structures in this area. Source: U.S. Environmental Protection Agency https://www.epa.gov/urbanwaterspartners/photo-gallery-cano-martin-pena



Protect, Buffer, and Restore Existing Natural Systems

This section highlights strategies for protecting and buffering existing natural infrastructure, such as habitats, systems, and processes that can help absorb natural hazard impacts and increase the overall resilience of the site. Natural systems can absorb floodwaters, moderate wave action, physically buffer assets from harm, manage stormwater, regulate temperatures, provide shade, and provide habitat that supports biodiversity. Giving natural areas the space and ability to provide ecosystem services increases site resilience.

Protect and Buffer Existing Natural Areas

Natural Area Conservation

Conserve significant natural areas near development to provide nature-based natural hazard mitigation.

Protecting and buffering natural areas and systems on development sites is another way to increase site resilience and decrease exposure to natural hazards. Natural systems provide a variety of ecosystem services—clean air and water, flood control, shade, wind protection, temperature regulation, and improved soil health.[212] When preserved and allowed adequate space to function, these natural systems can help mitigate impacts from natural hazards.[213]

Some examples include:

- Coastal wetlands and marshes, dunes, and living shorelines offer protection from storm surges, decrease erosion, and provide flood storage.
- Wetlands, riparian corridors, and buffers along rivers and streams can help clean, cool, and slow water and provide flood storage. Daylighting rivers and streams in urban areas create more area for the system and increase storage capacity, which can reduce downstream impacts from floods.[214]
- Forests and trees offer shade and windbreaks and help to retain water and promote soil health. Native vegetation can also retain soil, helping to prevent erosion and landslides. Coastal forests, such as mangroves, reduce wave action and can absorb some tsunami impacts.[215]
- Greenway corridors and open-space conservation can serve multiple functions that overlap with those mentioned previously. North-facing slopes can also offer refuge for plants and animals as temperatures increase, as their indirect exposure to the sun regulates temperatures.[216]

Preserving and increasing buffers around natural areas may be challenging on brownfield or infill development sites where significant work may be needed to restore and/or enhance the function of natural areas. Changes to site hydrology, significant regrading or excavation, removal of native vegetation, encroaching invasive vegetation, and compaction of site soils are all common challenges in these areas. Site planners should recognize and consider site restoration opportunities to help degraded sites regain the functions and natural systems connectivity to offer natural resilience and hazard mitigation.

FEMA has recognized the value of nature-based solutions and natural system conservation in hazard mitigation.

Mitigation Benefits

Provides broad ecosystem benefits that:

- Help absorb storm surges and manage floodwaters.
- Slow wind speeds and buffer sites from some impacts.
- Provide shade, regulates air temperature, and promotes soil conservation.
- Provide forest and wildland health. Natural areas with rivers or streams can provide some buffer for developed areas.
- Reduce erosion from water and wind, and maintains vegetation cover, which can reduce some landslide risk.
- Absorb some tsunami impacts.

Mitigation Considerations

- Natural areas adjacent to developed areas need to be carefully managed to reduce wildfire risks.

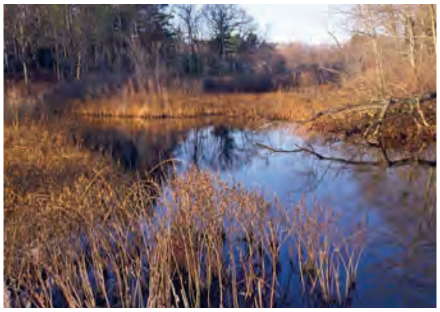
Exhibit 5-7. Coastal Dunes

Source: National Oceanic and Atmospheric Administration

Resources

- Building Community Resilience with Nature-Based Solutions: A Guide for Local Officials—FEMA (2021) https://www.fema.gov/sites/default/files/documents/fema_riskmap-nature-based-solutions-guide_2021.pdf
- Naturally Resilient Communities—https://nrcsolutions.org/

Exhibit 5-8. Park River Wetland—Byfield, Massachusetts



Source: National Oceanic and Atmospheric Administration Photo Library

Exhibit 5-9. Native Plant Shoreline Restoration

Lake Hiawatha, New Jersey, shoreline habitat restoration sign. Source: Runner1928, © 2014, CC BY-SA 3.0, Wikimedia Commons

Exhibit 5-10. Greenway Corridor

“Turtle Creek Trail” greenway in Beloit, Wisconsin. Source: © 2012 Mark’s Postcards from Beloit, CC BY-NC-ND 2.0, Flickr

Sensitive Environmental Area Buffers

Meet or exceed buffer requirements to provide space for natural processes and reduce impacts to environmentally sensitive areas.

Environmentally sensitive waterbodies in the United States, such as lakes, streams, and wetlands, are protected by the Clean Water Act and regulated by a mix of federal and state agencies and communities. Responsibility for the protection of other environmentally sensitive areas, such as steep slopes and geologic hazard areas, varies by state and region. Site planners must follow local regulations and meet minimum standards and buffers. In some cases, site planners can choose to surpass the minimum buffer requirement to add space for natural processes and functions. In some areas, overlaying habitat protection buffers required around streams and wetlands can create a large buffer, which provides space for natural system functioning.[217]

In some areas, clearing, grading, and filling are allowed within environmentally sensitive buffers; limiting these activities would further protect environmentally sensitive areas. Providing public access within buffer areas may be considered to create an amenity and connect communities to natural systems, as long as impacts are minimized.

In wildfire-prone areas, expanding natural areas might increase fuel sources and wildfire risk adjacent to the development. However, protecting environmentally sensitive areas can also promote forest and wildland health and concentrate development into the least-vulnerable site areas. See the following Protection from Wildfire Fuel for more information.

Protection from Wildfire Fuel

Although proximity to natural areas is an asset for many communities, in wildfire-prone regions, open space proximity also means a potential wildfire fuel source. Site planners should assess land around proposed project sites for wildfire risks. Avoiding proximity to open space may not be possible or desirable, given the many benefits natural spaces provide. However, open space "hazardous fuels" must be managed to reduce potential threats to nearby development. Some researchers and designers are exploring how large open spaces, with stands of relatively non-flammable trees and grasslands carefully managed through grazing, could increase community resilience.[218]

Understanding management practices on adjacent land can be helpful in evaluating a site's wildfire risk. For example, sites near conservation or other environmentally sensitive areas could face restrictions to active wildfire management due to competing conservation and preservation goals.[219] Furthermore, in WUI areas, land managers can face property owner fear of land management strategies such as prescribed burns or thinning.[220] Early collaboration between developers, property owners, and wildland managers is important and can offer opportunities to increase site resilience.

Mitigation Benefits

- Provides space for floodwaters and reduces impacts from runoff and erosion.
- Buffers development from coastal storms and wind.
- Conserves soil, reduces dust, and reduces air temperatures.
- Promotes forest and wildland health and concentrates development in less vulnerable locations.
- Reduces direct landslide risks, promotes healthy vegetation on and near slopes, and reduces impact from runoff and erosion.
- Natural coastlines can help absorb some tsunami impacts.

Mitigation Considerations

- Open spaces need to be carefully managed to not increase fuel sources adjacent to development.

Resources

- EPA - Urban Runoff: Model Ordinances for Aquatic Buffers— https://www.epa.gov/nps/urban-runoff-model-ordinances-aquatic-buffers
- USFS—Riparian Forest Buffers— https://www.fs.usda.gov/nac/practices/riparian-forest-buffers.php
- Beginning with Habitat (Maine)—www.beginningwithhabitat.org

Restore Natural Processes and Systems

Daylighting Streams

Daylight creeks to increase flood storage and reduce downstream flood impacts.

Daylighting involves removing obstructions that block or cover a river or stream and restoring the shoreline so that the water flows naturally above ground. Daylighting streams and rivers that have been piped or otherwise covered by development helps to restore hydrological connections and accommodate increased flows during heavy rainfall events or floods. Daylighting has multiple benefits, from reducing downstream flood impacts, providing habitat for wildlife, adding space for trees and water to cool urban environments, and creating opportunities for people to connect to their natural surroundings.

Resource

- Daylighting Rivers and Streams—Naturally Resilient Communities https://nrcsolutions.org/daylighting-rivers/

Mitigation Benefits

Provides space for floodwaters, reduces runoff, and improves water quality.

Reduces site and water temperatures.

Restoring streams and shorelines encourages infiltration, which can reduce some wildfire risk.

Reduces runoff and erosion, which can increase landslide risks.

Exhibit 5-11. Daylighting Creek as Natural Amenity

Thornton Place development in Seattle, Washington, incorporated the daylighting of Thornton Creek as a natural amenity within a mixed-use development on the site of a former shopping mall parking lot. Source: MAKERS

Slope Stabilization

Stabilize slopes vulnerable to landslides.

On sloped sites where development is feasible and will not increase landslide risks, restoring slopes within or adjacent to the site can increase hazard resilience. If recommended by a professional, slopes may be carefully graded to reduce weight and better drain the surface or subsurface.[221] The slope should be fully revegetated following grading activities, preferably with native plants, which, once established, have root structures to help hold the slope in place.[222] Slope restoration should be designed and executed by licensed or certified professionals familiar with local geologic conditions. On slopes that are actively moving, added vegetation alone will not stabilize the slope. In these situations, grading and/or slope engineering may be needed alongside revegetation strategies. Revegetation strategies are also most effective on shallow landslides and may not stabilize deep landslide risks.

Use of modern remote technologies such as InSAR and LiDAR can monitor slopes over years and identify patterns of erosion and deposition of soil volumes that can give early warning of increased risk of instability.

In wildfire-prone regions, slope stabilization strategies that employ vegetation can increase wildland fuel sources, so thoughtful site planning is needed.[223] Careful management of vegetation close to structures and the use of native plants naturally adapted to local fire conditions can help increase site resilience. Coordinating with professionals who specialize in wildland restoration is recommended.

Mitigation Benefits

Where paired with vegetation, helps conserve soil, buffer winds, and reduce temperatures.

Reduces landslide risks on sloped sites.

Mitigation Considerations

Revegetation strategies in wildfire-prone regions can increase wildfire fuel.

Exhibit 5-12. Slope Restoration Diagram

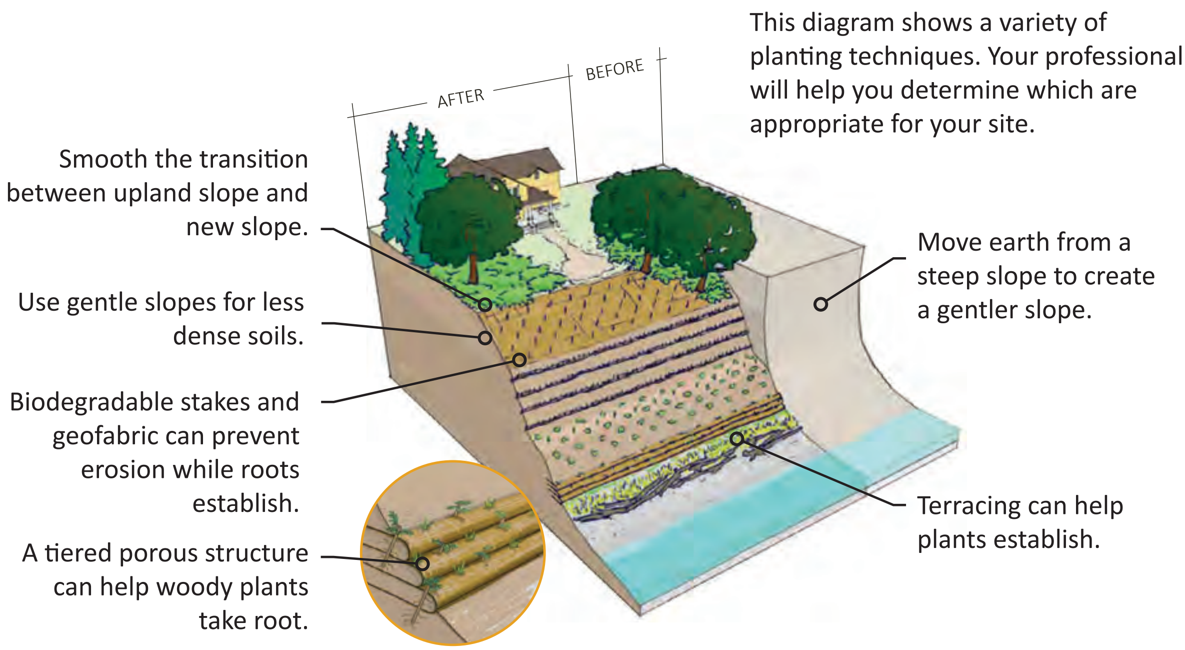


Illustration of planting techniques for slope stabilization in a coastal area. Source: MAKERS/Washington Department of Fish and Wildlife. Your Marine Waterfront

In locations where there is significant wildfire risk, using vegetation to stabilize slopes may conflict with wildfire management goals calling for fuel source reduction. Grading guidelines for the City of Colorado Springs acknowledge this conflict and note that select vegetation removal may be needed to meet overall wildfire management targets.[224] This conflict is an important consideration, as fires often sweep up the sides of slopes and threaten structures at the top.[225] Despite this challenge, adding native vegetation remains a critical tool in landslide slope stabilization. On sites in wildfire-prone regions where extensive slope restoration is required, careful coordination with professionals is recommended to ensure the project meets both landslide hazard reduction and wildfire management goals.

For slopes near development or infrastructure where grading and revegetation strategies will not adequately address risk, engineering strategies can be effective. Site planners should consult appropriate professionals.

Resources

- Introduction to Landslide Stabilization—
  https://pubs.usgs.gov/circ/1325/pdf/Sections/AppendixC.pdf
- Landslides: Investigation and Mitigation—
  http://onlinepubs.trb.org/Onlinepubs/sr/sr247/sr247.pdf

Development-Topography Integration

Integrate development around natural topography and drainage.

Site planners should integrate new development into the existing topography of the site as much as is feasible to preserve natural drainage and hydrology. Site grading changes hydrologic connections and drainage patterns and can also destroy vegetation and disrupt soil structure, which can lead to erosion and reduce ecological functions.

Working within a site's natural topography minimizes the need for grading and promotes resilience and ecological health.[226] Often referred to as landform grading, this approach minimizes disturbance to the natural landform so as not to degrade the landform and increase the threat from erosion and landslides. Approaches to landform grading include:[227]

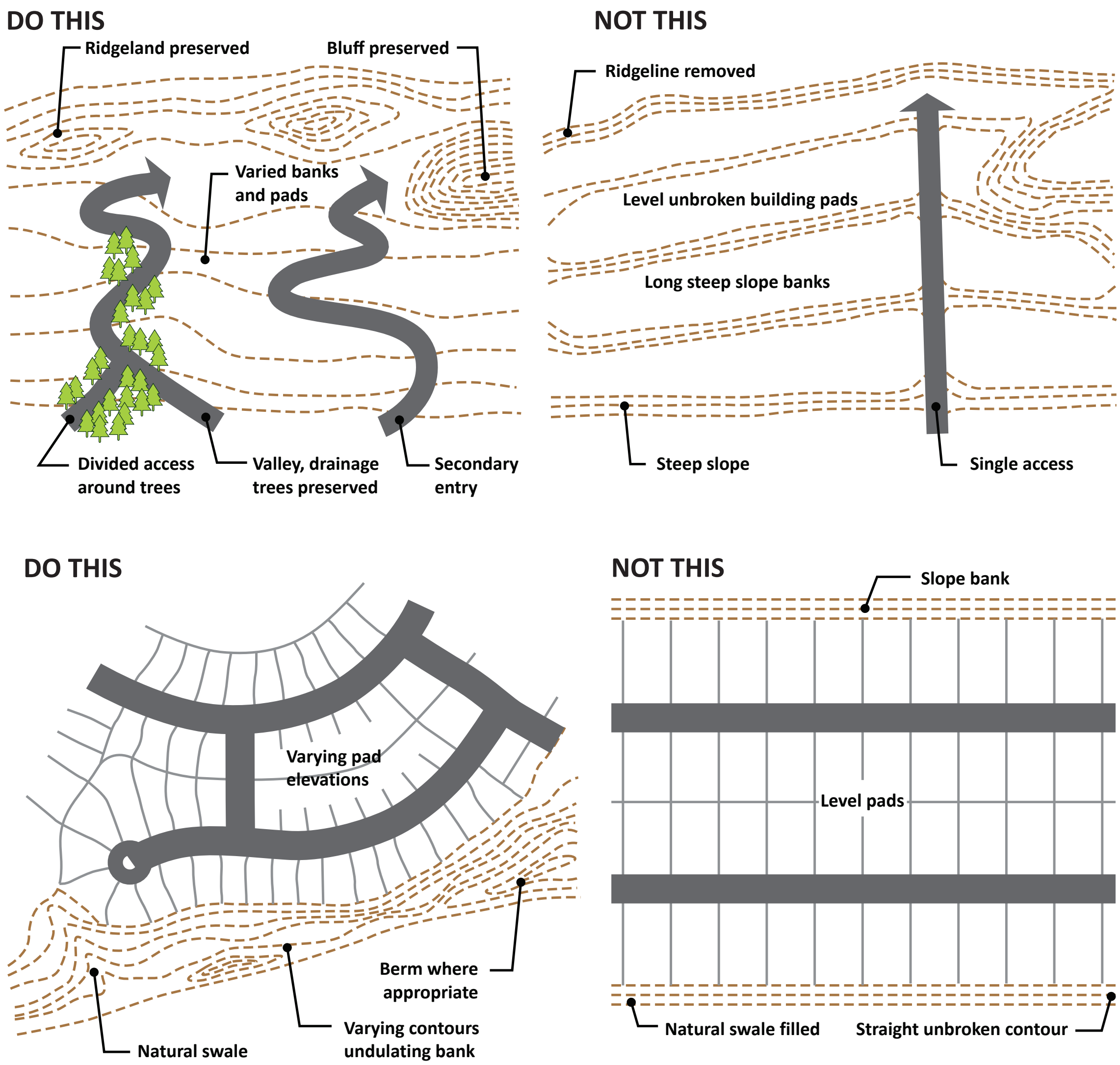
- Place development to minimize the need for site grading.
- Preserve features such as ridgelines, bluffs, and site drainage.
- Use the existing landform to provide cut and fill slopes that are compatible with the existing site character.
- Create site pads at varied elevations across the site rather than large, level site pads.
- Divide access roads around major site features, such as large trees.
- Provide a variety of slope bank gradients to provide a more natural appearance to the final landform.

On larger hillside sites with a range of slopes and unrestricted development, decreasing development density as the slope increases is one way to create a more resilient site plan. Slope density regulations are a common zoning requirement in communities where there is significant hillside development.[228]

Mitigation Benefits

- Preserves natural drainage patterns, reducing runoff and erosion.
- Protects vegetation that provides windbreaks and buffers.
- Promotes healthy soil and vegetation, which helps retain water and reduce temperatures.
- Promotes healthy vegetation, which can reduce wildfire risk.
- Reduces overall grading impacts, preserves vegetation, and reduces erosion.
- Reduces grading impacts that can increase seismic risks.

Exhibit 5-13. Landform Grading Practices



Diagrams illustrating preferred approaches for landform grading on a hillside. Source: MAKERS, updated from LA County Grading Guidelines via James C. Schwab et al. (2005) “Landslide Hazards and Planning,” pages 60–62

Site Layout, Circulation, and Access

This section describes best practices for the placement of buildings, streets, and paths and covers evacuation and early warning strategies. The physical form and layout of communities can reduce the impacts of natural hazards through the safer placement of site elements and well-planned emergency access and evacuation. The physical form of a community can also mitigate climate change, as compact communities use less energy and water. The built environment also influences human experience and behavior, which can encourage social connections that aid overall community resilience.

Building Placement

Compact Development

Plan for compact development.

Compact development refers to site planning that prioritizes preserving open space by placing buildings closer together and limiting street width and parking areas where feasible.[229] This pattern of development allows the site planner to accommodate the desired program of uses while preserving natural features like wetlands, forests, or streams.[230] In addition to aesthetic and environmental benefits, undeveloped land can help mitigate natural hazards like flooding, extreme heat, and tsunamis, the effects of which are amplified by smooth, hard, impervious surfaces like pavement and building roofs. Centrally managed open space is also more efficient to maintain[231] and potentially reduces water use.

Compact development also helps hazard mitigation by reducing carbon emissions when developments can be located closer to urban centers and transit resources, and encourages multimodal connections, reducing the reliance on vehicles. Lowering carbon emissions mitigates climate change and reduces the potential for increasing natural hazard impacts in the future.

Mitigation Benefits

- Reduces impervious surfaces and stormwater runoff and can reduce development pressure in areas vulnerable to flood hazards.
- Reduces impervious surfaces, which lowers heat-gain.
- Decreases sprawl which can increase risk in areas vulnerable to wildfire.
- Reduces erosion by reducing runoff from impervious surfaces.
- Decreases development pressure in areas vulnerable to tsunami hazards.
- Promotes health and social connection.

Mitigation Considerations

- In wildfire prone regions, compact development must follow local regulations to reduce the risk of fire spreading between buildings.

See Natural Area Conservation.

Exhibit 5-14. Compact Community Incorporating Multiple Green Stormwater Management Strategies

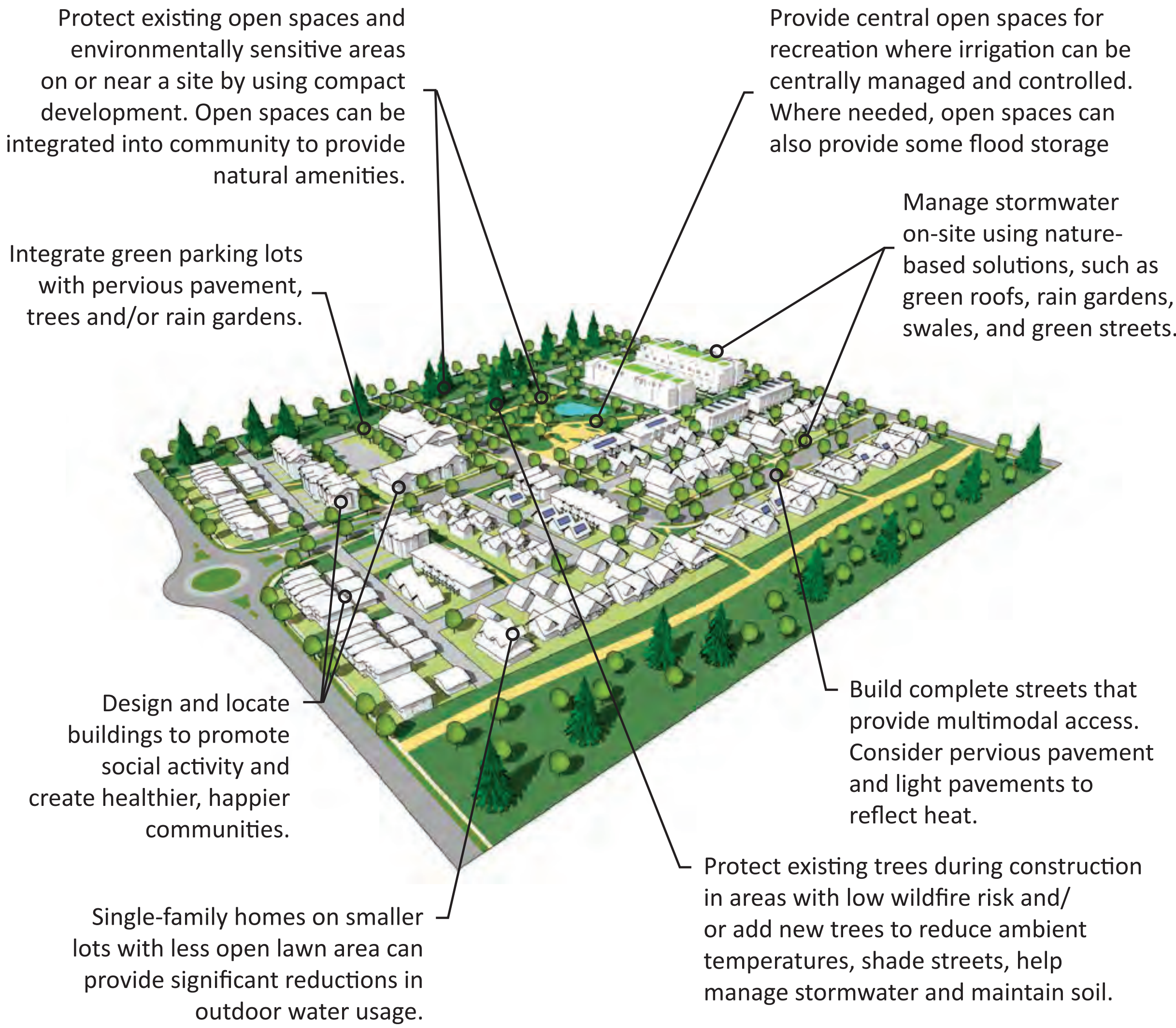


Illustration highlighting elements of site planning for compact development. Source: MAKERS

Resources

- SITES Rating System—https://sustainablesites.org
- LEED for Neighborhood Development—https://www.usgbc.org/leed/rating-systems/neighborhood-development
- Urban Land Institute - “Enhancing Resilience through Neighborhood-Scale Strategies” https://knowledge.uli.org/-/media/files/research-reports/2022/neighborhood-resilience-final.pdf?rev=82240cae00164eaeb11273484aed3a4b

Siting for Soils

Align site development with soil conditions.

A site's soil and underlying geology are vital to its ability to support development and be resilient, especially to floods, droughts, and earthquakes. As noted in Site Analysis, soil conditions are fundamental to site planning. Site planners should consider both local soil types and building foundation needs and options early during project development.

Some high-level considerations for evaluating local soils include:[232]

- Loam, rock, and some sandy soils are optimal for foundations as they provide good stability and drainage, especially in areas with access to bedrock that can support taller building loads. Other soil types may also support tall buildings if building foundations are adequately designed to local conditions.
- Peat soils or soils with high levels of organic material are not preferable for building foundations.
- Clay soils can be problematic as they have limited infiltration leading to drainage challenges. Some clay soils, known as expansive soils, expand and contract as moisture levels change. Expansive soils can damage building foundations, particularly in regions prone to droughts.
- Soils that are not suitable for structures may still be beneficial for vegetation, habitat, and open space uses.

Mitigation Benefits

Reduces flood risk by limiting development impacts onsite drainage.

Lowers risk of foundation, structure, and/or infrastructure damage as soils shrink, harden, and/or subside by avoiding high-risk soils.

Ensures soils can support development, reducing site impacts that can increase erosion.

Ensures soils can support development during an earthquake.

See Healthy Soil Strategies.

Soil Stabilization and Shoring

Stabilize soils, use shoring techniques, and/or promote infiltration when needed to support development.

Below-ground conditions are important to consider when siting buildings and are crucial in determining structural loads and density.[233] In areas with the potential for increased subsidence due to drought, or liquefaction due to changing groundwater levels and seismic activity, site planners should carefully investigate soil conditions and consider potential change. When avoidance is not possible, site planners should work with civil and geotechnical engineers to identify the most appropriate soil stabilization and strengthening methods and/or engineering solutions to support safe development.

There are available technologies that can alter the soil conditions, called ground improvement. These techniques include stabilization, drainage, densification, inserting grouting mixes, creating stone column drainage systems that also act as partial foundation, using foundation temporary support as permanent foundation element (as in the World Trade Center), and choosing the right type of foundations. A modern approach includes also allowing control failure below ground in the foundations in order to significantly reduce the loads that can be transferred to the development. Encouraging water to infiltrate the soil

Mitigation Benefits

Reduces soil subsidence caused by changing groundwater levels, which can lead to flooding

Promotes infiltration and groundwater recharge, which can slow or reduce subsidence.

Reduces risk from landslides on some slopes.

Can reduce some damage to structures or infrastructure during earthquakes.

can also be important in areas where there is a risk of subsidence. Some strategies include:

- Promote aquifer recharge by employing nature-based solutions and green stormwater infrastructure strategies.
- Inject treated wastewater (regional scale).

Building Spacing for Wildfire

Use fire-safe building design for compact developments in wildfire-prone regions and manage overlapping ignition zones around buildings.

The Home Ignition Zone (HIZ) is the area immediately surrounding structures in wildfire-prone communities where careful management of vegetation and other site features is necessary to reduce wildfire risks.[234] The area at risk can extend to about 100 feet from a structure's foundation, although it may be extended further based on local conditions and requirements. Dense neighborhoods, where buildings are 30 feet or closer, have an increased wildfire risk because of radiated heat and the potential for flames and embers jumping across adjacent structures. At the same time, compact development can help reduce risk at the regional scale by minimizing development in wildland-urban interface areas.

Compact development can reduce risk by avoiding the most vulnerable site areas and incorporating fire-safe building design.[235] Ignition zones in more compact communities will overlap, which increases the need for regular maintenance to clear flammable materials and vegetation.[236]

For development within existing communities, buildings that are not fire-safe should have ample spacing through lot and block designs to reduce the risk of structure-to-structure fires. This spacing requirement may conflict with goals for infill development and compact community form (for example, to reduce social isolation and infrastructure costs), so site planners may need to work with local planners and emergency managers to balance goals. Existing buildings can be retrofitted to be more fire-safe, and communities are starting to develop grant programs that support homeowner investment in fireproofing.

Detached structures and attachments such as decks, outbuildings, wood fences, propane tanks, and garages should also be carefully sited in accordance with fire-safe zone principles.[237]

Mitigation Benefits

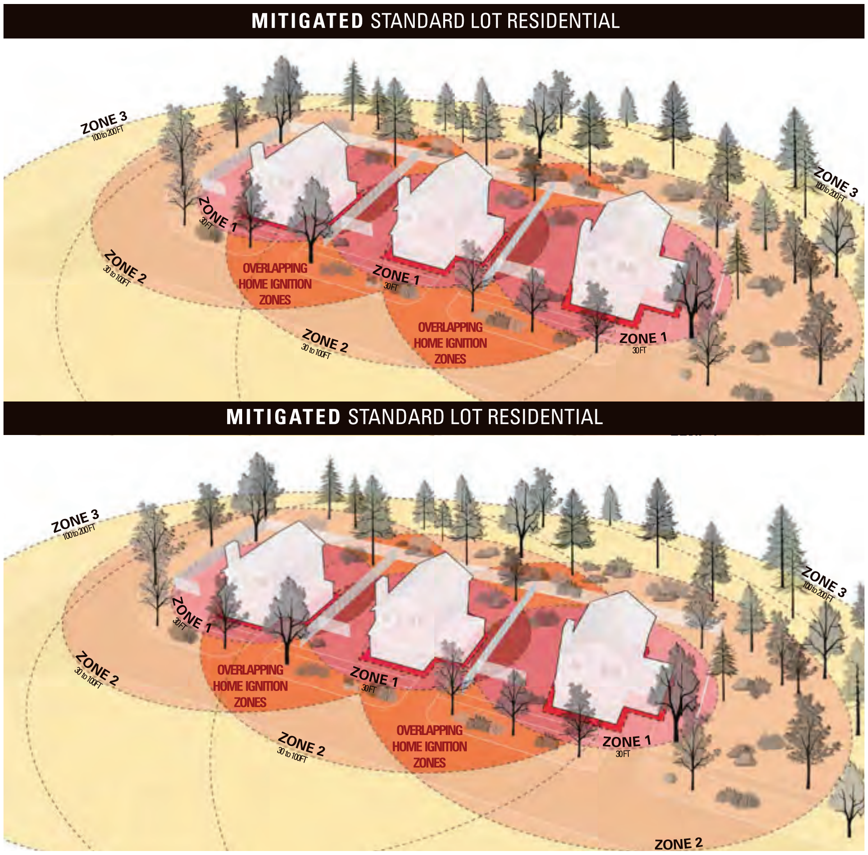
Reduces wildfire fuel sources on and around buildings.

Mitigation Considerations

Spacing buildings further apart can limit opportunities for active living and social cohesion.

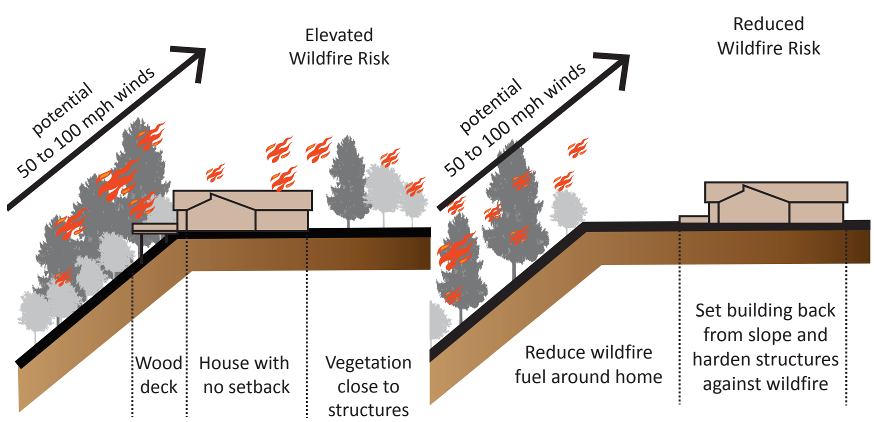
See Open Space and Green Infrastructure— and — sections for how the area between buildings should be treated.

Exhibit 5-15. Structure Spacing and Overlapping Ignition Zones



Mitigation options for suburban communities where lot sizes and structure spacing can cause ignition zones to overlap. Source: Community Planning Assistance for Wildfire, a program of Headwaters Economics

Exhibit 5-16. Setbacks Can Reduce Wildfire Risks on Slope



Illustrations showing higher-risk building location (left) and how setbacks, vegetation management, and structure hardening can decrease risk (right). Source: MAKERS updated from Schwab et al. (2005), Planning for Wildfires

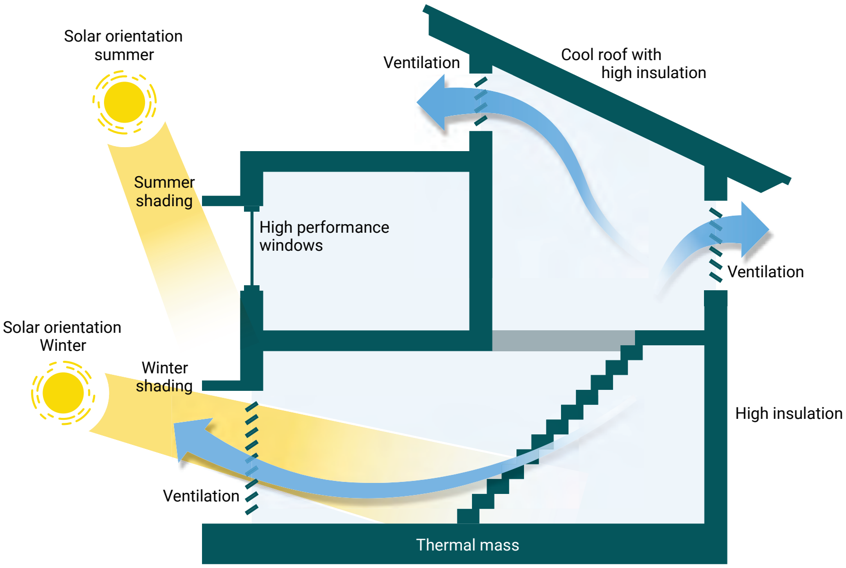
Passive Cooling

Consider passive cooling approaches and tailor them for buildings in wildfire zones.

Passive heating and cooling strategies use building orientation and other strategies to increase ventilation and align with solar gain, promoting shade and cooling in summer months and allowing solar gain in cooler winter months. Such strategies can reduce energy costs and minimize air conditioning needs in some climates, offering a way to mitigate rising temperatures and urban heat island effects.[238] They can also lower carbon emissions and aid climate change mitigation, which reduces the potential for increasing natural hazard impacts in the future.

However, in wildfire environments, where fires often spread from embers carried by winds, passive cooling strategies that invite air to circulate through vents and other openings are a significant hazard. Local building codes and/or insurance policies typically require small openings and mesh coverings to prevent embers from igniting attic spaces.[239] While passive heating and cooling strategies can still be feasible, thoughtful approaches and careful consideration of wildfire mitigation are needed in WUI and/or drought-prone areas.

Exhibit 5-17. Passive Heating and Cooling Approaches



Source: Adapted from ESMAP 2020b

Passive heating and cooling approaches have many benefits but need to be carefully planned in wildfire environments so as not to encourage embers into the structure. Source: Iain Campbell et al. (2020), "Beating the Heat: A Sustainable Cooling Handbook for Cities"

Mitigation Benefits

Increases natural ventilation and reduces heat gain during heat-stress.

Improves energy efficiency and reduces waste heat.

Mitigation Considerations

Buildings in wildfire-prone environments must follow local building codes to reduce potential for embers to enter naturally ventilated buildings.

Tsunami Inundation Space

Arrange buildings and site elements to steer the force of the tsunami waves where avoiding hazard areas is not feasible.

Avoiding tsunami hazards is the most robust way to reduce risk, but in areas where avoidance is not feasible, arranging buildings, along with walls, ditches, and "low-friction" paved areas, can help steer the force of the tsunami around more vulnerable structures.[240] Generous building spacing can provide space for floods caused by tsunamis and reduce the threat of blocked evacuation routes in the event of building collapse during earthquakes.[241]

Mitigation Benefits

Reduces flooding in adjacent areas by providing space for tsunami waves.

Reduces damage to buildings from smaller tsunamis.

Human Experience

Organize buildings to support human interaction.

Building, parking, and common space arrangement play a powerful role in how people use and experience a site. Orienting entrances and windows toward common areas, such as well-used streets, courtyards, plazas, and parks, can increase social interactions and create a sense of connection.[242] Community safety is improved when site users are aware of their surroundings and feel a sense of community and ownership. This perception can help build motivation to address maintenance issues, prepare emergency plans and supplies, and take leadership in a moment of crisis.

Resources

- Happy Cities, Happy Homes Interactive Toolkit—https://happy-city.vercel.app/happy-homes-toolkit.
- Claire Cooper-Marcus and Wendy Sarkissian, Housing as if People Mattered.
- Gehl, Life between Buildings.
- Oscar Newman, Creating Defensible Space (note, this resource is about human perception of ownership over public space, not about wildfire defensible space strategies).

Mitigation Benefits

Communities with strong social ties can be more resilient to disasters, as they facilitate community-scale preparation, communication, and evacuation.

Communities with strong social connections can better prepare for and recover from:

- A flood event.
- Windstorms.
- Heat wave and drought impacts.
- Wildfires.
- Landslides.
- Earthquakes.
- Tsunamis.

Mitigation Considerations

Compact development in wildfire prone regions must follow local structure hardening regulations to reduce risk of fire spreading between adjacent buildings.

Circulation Layout

Redundancy

Provide redundant evacuation routes.

Multiple egress routes increase evacuation options ahead of or following a disaster, even if some are blocked by damage or debris or congested by evacuation traffic.

Evacuation routes differ depending on the type of disaster and local conditions. Vertical evacuation routes in towers or buildings can offer redundancy for tsunami evacuation (See Vertical Evacuation). In rural settings, trails can double as evacuation routes in the case of a wildfire or flood emergency.[243]

Mitigation Benefits

Increases options for evacuation:

- From flood hazard areas.
- From storms where there is adequate advance warning.
- From wildfire.
- Ahead of or following a landslide.
- To higher elevation areas prior to a tsunami.
- Following some earthquakes.

See Emergency Response Access, and Early Warning, Evacuation, Shelter, and Lifelines Access strategies.

Emergency Response Access

Arrange site circulation for easy emergency response access across the site.

Ensuring access for emergency response is critical for rescue activities and protecting property from wildfire. A co-benefit is that the routes double as redundant evacuation routes.

The following techniques improve emergency access:[244]

- **Multiple ingress-egress routes—**Communities should have multiple ingress and egress points. Avoid dead-end streets. In flood and tsunami hazard areas, directing response crews to safe elevations can also be important.
- **Secondary roads**, or internal grids with multiple entrances, increase circulation options for emergency vehicles (and double as multiple evacuation routes—see Redundancy).
- **Road clearance**—Internal roads within communities must accommodate emergency response teams. Some wildfire-prone communities recommend that roads have a minimum of 20 feet width and 13.5-foot vertical clearance. Clearing roadside vegetation reduces risk.

Mitigation Benefits

Increases access for emergency response crews:

- During and after floods.
- During and after storms.
- During and after wildfires, which includes firefighting activity as well as emergency response and rescue.
- Following a landslide.
- Following a tsunami.
- Following an earthquake.

- **Bridges and culverts** leading to the home should have posted load limits and be designed to support emergency response crews. Culvert size can also increase flood risks in some communities.[245]
- **Driveways** should be a minimum of 12 feet wide with a 12-percent or less grade. Driveways should also be clear of flammable vegetation for 10 feet on both sides and have at least a 13.5-foot vertical clearance. Key access for fire response is required for electronic gates. Turnouts on long driveways allow for 2-way traffic.
- **Turnarounds** on internal streets or long driveways to support emergency response truck turning movements.
- **Street signs and house numbers**—Nonflammable street signs should be posted at all intersections. House numbers should be visible from the street, 6 inches high minimum, and made from non-flammable material.

The following communication and organization strategies can aid during evacuations:

- Identify locations for emergency identification and alert systems, such as fire cameras and community-wide alarms.
- Creating easy-to-read emergency maps that are available at site entrances can help emergency response crews quickly know who may need help with the evacuation.
- Establish a temporary refuge site—a flat, open, central, and easily accessible area, accessible to persons with disabilities, (e.g., open lawn, parking lot, golf course) where people can gather, get info, and safely wait for emergency response if they are unable to evacuate themselves.

See Flood-Friendly Culverts.

See Early Warning, Evacuation, Shelter, and Lifelines Access strategies.

See Resilience Hubs and Trails and Open Space.

Exhibit 5-18. Improving Preparedness for Emergency Access During Wildfires

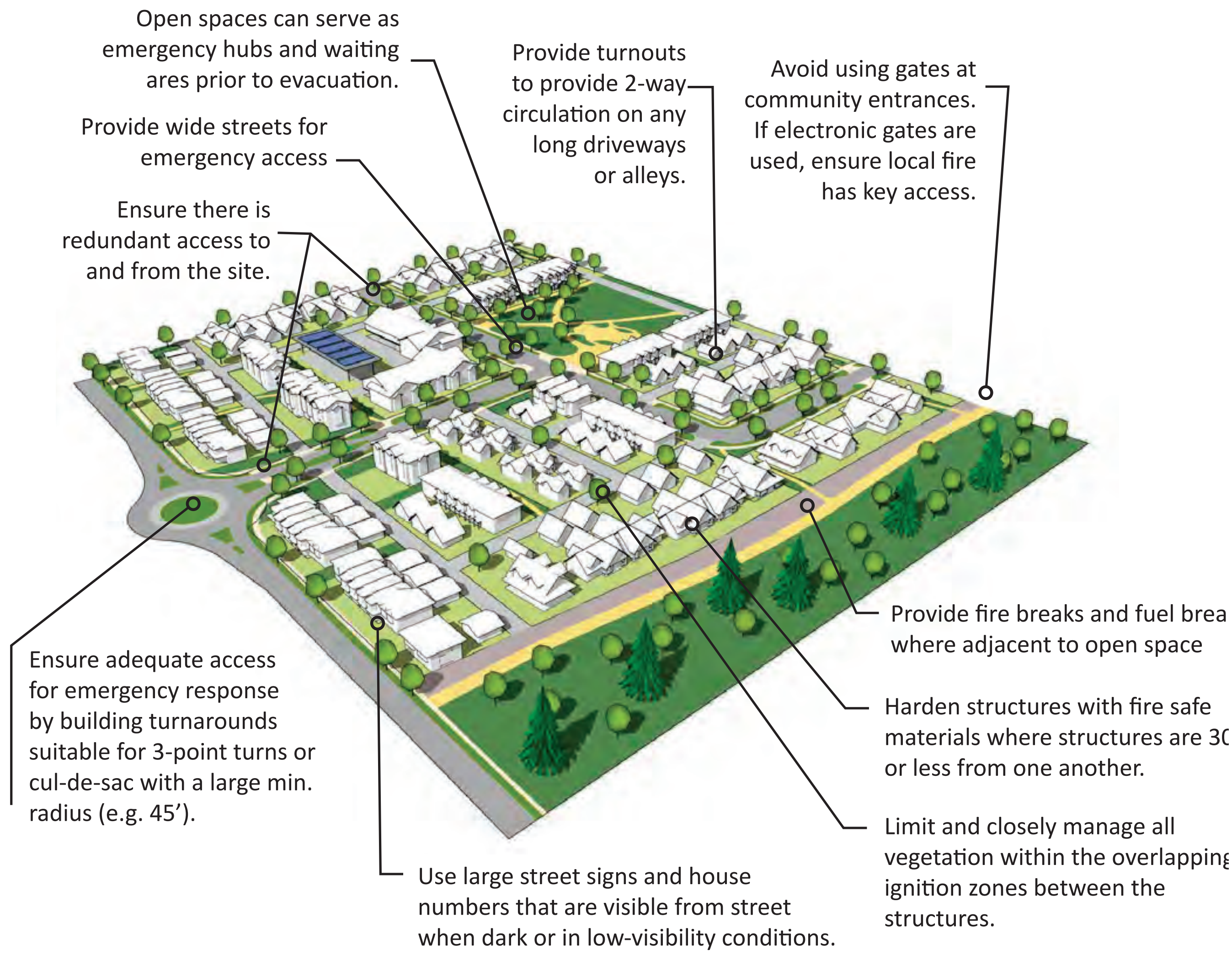


Illustration showing emergency access and evacuation considerations. Source: MAKERS updated and adapted from Living with Fire—Fire Adapted Communities

Orientation for Cooling

Orient streets and arrange buildings and open spaces to encourage airflow.

On larger sites with new internal roads and compact form, arranging streets, building mass, and open spaces to increase airflow can help keep streets cooler for people walking and biking. Strategies include:[246]

- Orient streets to align with prevailing winds.
- Orient larger buildings to direct desired wind flow along streets, considering orientation for active and human-oriented street fronts.
- Integrate open spaces into the development to provide surface variation.

Wind modeling during planning and design may be needed to ensure strategies to promote ventilation that does not result in wind tunnels or street canyons. These results can create challenging wind currents that decrease human comfort.[247]

Although wind models can aid planners and designers to align site development to local wind conditions, winds are naturally variable and change with the increase in extreme weather events. Model data are augmented with local observations to help identify site-specific wind patterns.[248]

Mitigation Benefits

Promotes natural ventilation and reduces urban heat.

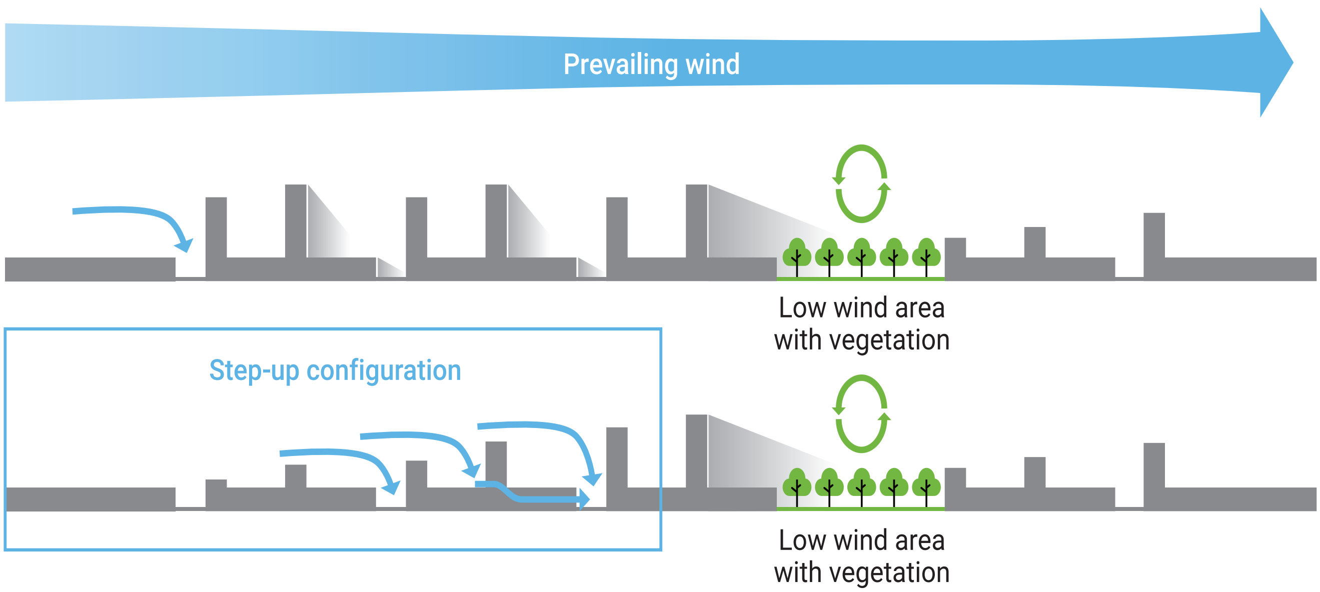
Increases comfort for people, particularly at street-level.

Mitigation Considerations

Modeling may be needed to ensure building arrangements do not result in wind tunnels or street canyons.

Ensure natural ventilation via street network does not increase risk from wind-driven wildfire.

Exhibit 5-19. Urban Canyon Effect on Ventilation



Uniform tall buildings create wind shadows and reduce ventilation at the street level. Stepped building heights can increase ventilation for pedestrians. Green spaces adjacent to tall buildings provide convection. Source: Campbell et al. (2021), "Beating the Heat: A Sustainable Cooling Handbook for Cities"

Multimodal Access

Design sites for multimodal access to promote public and community health.

Places that support walking, biking, rolling, and riding transit—and do not require the use of a motor vehicle—accomplish the following:

- Broad public health benefits associated with reduced vehicular and human collisions, casual low-impact exercise, reduced air pollution, and increased social connection and sense of belonging.[249]
- Reduced heat produced by vehicles.[250]
- On-street stormwater management and street trees for shade when layered with pedestrian and bicycle infrastructure (e.g., sidewalks buffered with a landscape strip).

Mitigation Benefits

When combined with green street strategies, manages stormwater runoff.

Reduces carbon emissions and waste heat from single-occupancy vehicles.

Creates shade and reduces urban heat when combined with green street strategies.

Manages stormwater runoff, creates shade, etc., when combined with green street strategies.

Exhibit 5-20. Multimodal Street

Multimodal streets provide access for people walking, riding bicycles, riding transit, and driving cars. Image from Seattle, Washington.
Source: MAKERS

Parking

Provide the minimum feasible onsite parking.

Vehicle parking consumes a large amount of space in urban areas. Reducing parking reduces impervious surfaces and pavement heat islands, promotes human-scale development, and supports active transportation. Parking structures can reduce the footprint of the parking areas and be combined with green roofs and other strategies to further mitigate the heat. Where surface parking areas are provided, integrating trees, green infrastructure, and shade structures can help mitigate flooding and lower temperatures in urban areas. Increasing infrastructure for electric vehicles can also improve overall site resilience, as electric vehicles generate less waste heat than traditional gas-powered vehicles.[251] Some electric vehicles can also serve as a backup power source, a potential benefit for communities that may experience frequent power outages due to natural hazard impacts on the regional power network.[252]

Exhibit 5-21. Solar Shade Structure Over Parking

Solar photovoltaic arrays installed on parking lot carports in the Confederated Tribes of the Grand Ronde Community of Oregon. The arrays are part of a 42-kilowatt facility-scale solar system installed in April 2010. The solar system generates 60 percent of the electrical needs of the Grand Ronde Tribal Housing Authority office and maintenance shop and continues to pay for itself through avoided energy costs, positioning the agency to achieve its projected 33-year payback on its investment. Source: GRTHA via Flickr

Mitigation Benefits

Limiting impervious coverage, which:

- Reduces runoff, flooding, and erosion.
- Reduces air temperatures.
- Creates open space for people and/or natural systems.

Streets as Site Protection

With more than 4.2 million miles of roads and streets in the United States, connecting to almost every residential address, streets hold enormous potential as hazard mitigation tools.

Elevated streets

Elevate streets to create safer high-water flood routes.

Elevating streets above the base flood elevation can ensure a large site has internal evacuation routes during flood events.[253] Elevating streets should be done prior to developing adjacent sites. On large sites platted for development, streets and lots can be raised together, which makes the building-to-street relationship better support people-friendly design. Raising streets that have pre-existing utility infrastructure underneath can increase costs but may provide an opportunity to replace aging infrastructure.[254] Elevating streets above the height of adjacent properties creates significant flood risks, so careful planning and design are needed. They should also be above water level following earthquake-caused subsidence to support evacuation.

Raising streets is a time-tested and effective strategy to reduce the impacts of flooding and was employed in American cities like Chicago and Seattle in the 19th Century. New York City elevated streets after Hurricane Sandy to protect vulnerable neighborhoods in the Rockaways along the Atlantic coast.[255] In the context of climate change and sea level rise, designers continue to explore the strategy. The City of Miami Beach, Florida, elevated streets in recent years to combat flooding.[256] When this approach is chosen, site planners should consider if the taller structures may be more exposed to other dynamic effects of earthquakes or wind. These elevations should include bracing or proper strengthening to protect from multiple hazards.

Mitigation Benefits

Can reduce impacts from nuisance flooding and protects evacuation routes during larger floods.

Provides an opportunity to replace aging community infrastructure.

Mitigation Considerations

Elevated streets can be more vulnerable to earthquake damage.

Case Study—Arverne by the Sea

Arverne by the Sea, a 2000+ unit master-planned, mixed-use community in the Rockaways in Queens, New York, was under construction in 2012 when Superstorm Sandy hit. The project included a number of resilience strategies that helped protect the site from damage. Beaches and dunes buffered some of the storm impacts. The site had been elevated to raise streets and buildings away from flood risks, and streets were also located away from prevailing winds to reduce coastal storm and flood impacts. Underground utilities and reinforced structures provided further protection. All of the strategies helped protect the development during the storm, and the site was able to recover quickly.

- https://developingresilience.uli.org/case/arverne-by-the-sea/

Exhibit 5-22. Arverne by the Sea Community, Queens, New York

Top: Arverne by the Sea site plan showing development on the Rockaway Peninsula in Queens, New York. Bottom: Image of new homes along the boulevard. Source: Ehrenkrantz Eckstut & Kuhn Architects (EE&K), a Perkins Eastman company

Green Streets

Create green streets to prevent downstream flooding.

Green streets integrate green stormwater infrastructure (GSI) elements like bioswales, bioretention facilities, and grade-control slotted weirs into road design to treat and manage stormwater. They can increase flood resilience by helping to slow, store, and/or absorb stormwater runoff from heavy rainfall events. In areas with frequent flooding, especially in coastal areas with high winds and potential salt-water intrusion, green streets must be designed and built to be highly durable. The durability of edging and curbs is especially important—once curbs are damaged, the entire road can fail.[257] Green streets are also effective strategies for improving human safety and comfort on roads by buffering people from fast-moving traffic.

Parking lots also offer great opportunities for implementing green stormwater infrastructure strategies, reducing the overall impervious area that helps reduce urban heat as well as manage stormwater.

Exhibit 5-23. Green Street Infrastructure

FEMA illustration (left) of a green street, a type of nature-based solution. Green streets make use of an abundant resource – road space – to increase flood resilience. Bioretention swale in Milwaukee, Wisconsin (right) collects and treats street runoff during heavy precipitation. Sources: Federal Emergency Management Agency. (left) Aaron Volkening, June 2013, Flickr, CC BY 2.0. (right).

Resources

- National Association of City Transportation Officials (NACTO) Design Guides—
  Urban Bikeway Design Guide - Green Infrastructure, NACTO
  https://nacto.org/publication/urban-street-stormwater-guide/
- Stormwater Best Management Practice—Street Design and Patterns, EPA
- Green Infrastructure in Parks: A Guide to Collaboration, Funding, and Community Engagement, EPA, 2017

Mitigation Benefits

- Manages stormwater and can reduce flooding.
- Increases access for emergency response during and after storms.
- Promotes infiltration and provides opportunities for shade trees and plantings.
- Promotes natural drainage and reduces erosion.
- Can help reduce vehicle speeds and create a more people-centered streetscape.

Mitigation Considerations

- Green streets in arid or wild-fire prone regions may require additional maintenance to ensure dry vegetation does not increase wildfire risk.

See Greening the Grey—Managing Stormwater.

Cool Corridors

Design streets or pathways as cool corridors that allow people to safely walk, jog, bike, or roll outdoors on hot, sunny days.

Cool corridors refer to linked spaces in an urban environment that use trees, shade structures, light-colored pavement, vegetation, and/or water bodies to create cooler, shadier travel routes on hot days. Cool pavements have lower temperatures than conventional pavements and can assist in reducing the urban heat islands.[258] Deciduous trees are particularly helpful for providing seasonal shading during the hottest months. Cool corridors can be created along streets or through open spaces like parks. Routing pedestrian and bike paths through these corridors can keep these options viable even on very hot days.[259] Supporting outdoor gathering spaces and active transportation encourages community health and social well-being. Also, see Water Features.

Mitigation Benefits

- Helps manage stormwater when street trees are included.
- Provides shade and reduces temperatures.
- Increases comfort and safety for people walking, riding bicycles, and using transit.

Case Study: Phoenix, Arizona, Cool Corridors

The City of Phoenix plans to establish 100 “cool corridors” by 2030 along routes with high pedestrian traffic and little existing shade. The City is working with volunteers to plant drought-resistant trees, instructing road crews to apply a light-colored paint-like solution to asphalt roadways, and working with private property owners to increase shade structures and features like misters and landscaping.[260]

Exhibit 5-24. Cool Corridor Installation

Volunteers and City staff work to install the first official cool corridor in Phoenix, Arizona. Source: City of Phoenix

Early Warning, Evacuation, Shelter, and Lifelines Access

Early Warning Systems

Include emergency early warning systems when developing a new site in a hazard zone.

Special early warning systems are available for many kinds of disasters, including tornados, windstorms, wildfires, earthquakes, and tsunamis. Early warning for earthquakes is an effective approach to warn residents of impending ground shaking. In addition to warning people, these systems can be used within buildings to stop and open elevators and open emergency response and medical facilities to ensure doors do not jam during shaking. Rising water alarms can also warn residents about potential flooding, which can be especially useful at night when people may be asleep and unaware of rising floodwaters. Tsunami warning systems provide advance notice of a potential tsunami, alerting people to seek shelter at higher elevations. Typically funded and operated by a public entity, early warning systems can sometimes be installed by private developers as part of the overall site infrastructure.

Resources

- NIST Earthquake-Resilient Lifelines: NEHRP Research, Development and Implementation Roadmap—https://www.nehrp.gov/pdf/nistgcr14-917-33.pdf
- UC Berkeley Disaster Lab—https://disasterlab.berkeley.edu

Mitigation Benefits

Provides critical warning and evacuation notices during flash-flood events.

Directs people to take shelter when there is elevated risk of tornadoes and other severe windstorms.

Provides critical evacuation warnings for wildfires.

Provides a few seconds of warning to prepare critical infrastructure, building systems, etc.

Provides critical warning and evacuation notices ahead of tsunamis.

Clear Evacuation Routes and Signage

Create clear, visible signage and wayfinding for evacuation routes.

Confusion and disorientation can be deadly when a disaster is imminent. Clear signage for how to access evacuation routes or onsite shelters is essential to reduce delay and confusion when an emergency evacuation is necessary. In wildfire-prone areas, large street signs and house numbers that are visible from the street can help aid evacuation in smoky, low-visibility conditions and aid in emergency response.[261] In tsunami-prone communities, signage on the ground, sometimes referred to as "blue lines" that indicate safe elevations, can also guide people to safe locations within a site or community.[262] Evacuation route signage for tsunamis should display information for those people evacuating by foot in addition to those exiting by vehicle. All evacuation signage should be clearly visible at night as well as during the day.

Evacuation routes and signage may be less directly applicable to extreme heat events, but clear identification and communication about onsite or nearby cooling centers can help save lives during a heatwave, particularly for vulnerable populations such as older adults and people who are low-income.

Evacuation and access via water in coastal areas is also an important consideration. Water-based operations, such as commercial fishing fleets, require safe harbors to reduce the potential for impacts to their businesses. Some communities have dedicated harbors of refuge upstream from development to allow commercial fishing boats places to go during a storm.[263] Emergency response and supply deliveries may also be easiest via water in some coastal areas when roads are damaged and inaccessible to vehicles.

Mitigation Benefits

Aids evacuation and emergency response:

- To hurricanes.
- During wildfires, where visibility can be limited.
- Following landslides.
- Following earthquakes.
- After flood events, directing people to safe locations outside of flood events.
- Ahead of tsunami waves, directing people to critical evacuation routes and higher elevations.

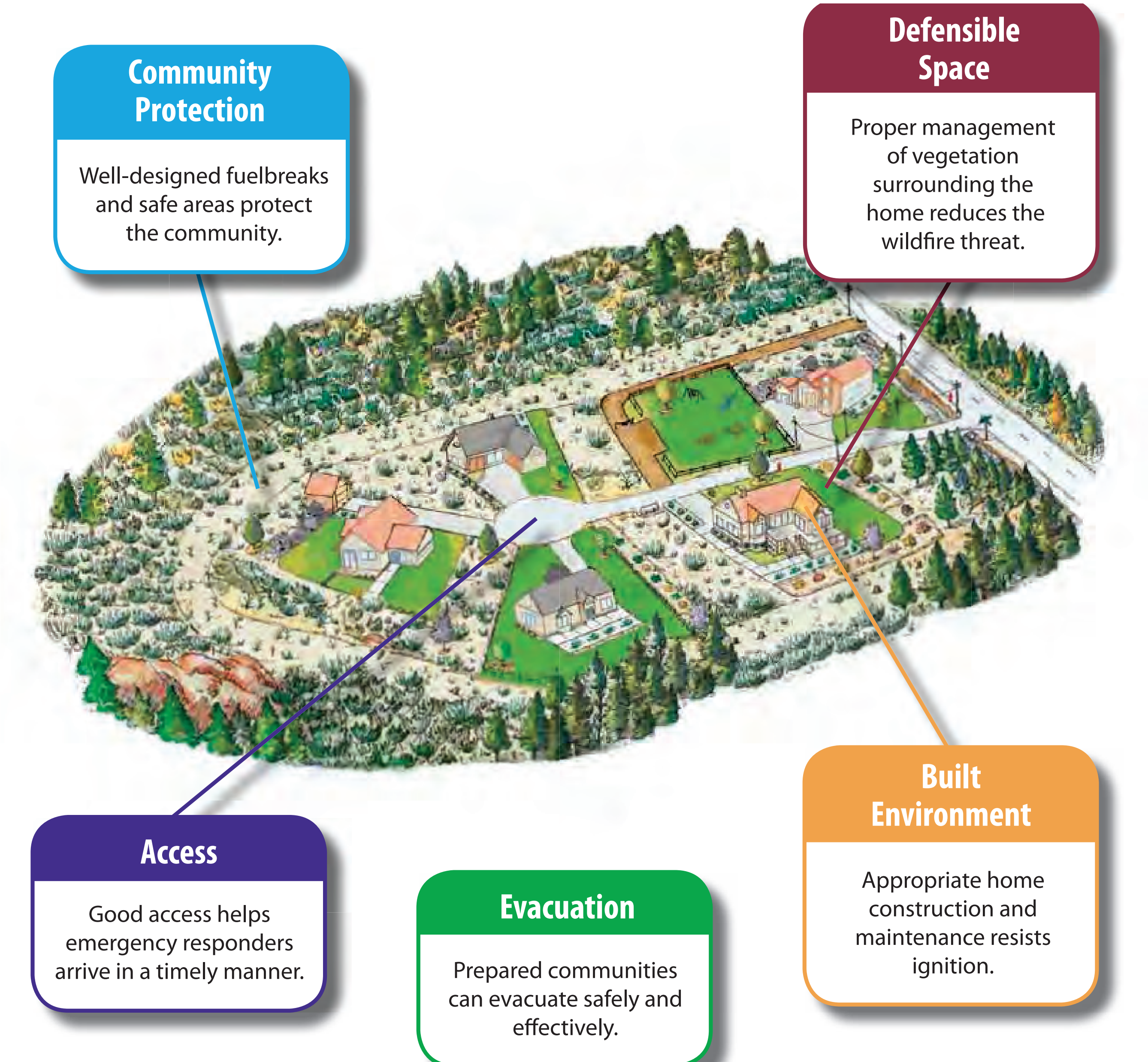
Exhibit 5-25. Tsunami Evacuation Route Sign in Aberdeen, Washington

Tsunami evacuation signs direct people to safety at higher elevations. Source: MAKERS

Exhibit 5-26. Street Marking Delineates Tsunami Inundation Zone

Blue line signage on the street directs people to safe elevations that are outside the tsunami inundation zone. Source: [Oregon Department of Emergency Management]

Exhibit 5-27. Community Planning Strategies to Protect Communities From Wildfire



Access for emergency response and firefighting and evacuation routes are both important aspects of increasing wildfire resilience in communities. Source: [Community Planning Assistance for Wildfire, a program of Headwaters Economics]

Safe Room Location

Create places for people to shelter on site in areas vulnerable to high-wind events.

Sites vulnerable to strong windstorms, tornados, and hurricanes should integrate safe rooms in or adjacent to buildings to allow people quick, easy access in the event of a sudden windstorm. Safe rooms should not be located in flood hazard zones with high-velocity wave action or in Coastal A Zones.[264] Safe rooms in buildings in some flood hazard areas may be allowed if they are elevated above the ground floor and base flood elevation level. This elevated safe room may result in the need for an alternate safe space in some tornado-prone areas.

Mitigation Benefits

Provides onsite shelter options during high-wind storm events.

Exhibit 5-28. Federal Emergency Management Agency Guidance on Safe Room Siting in Flood Hazard Zones

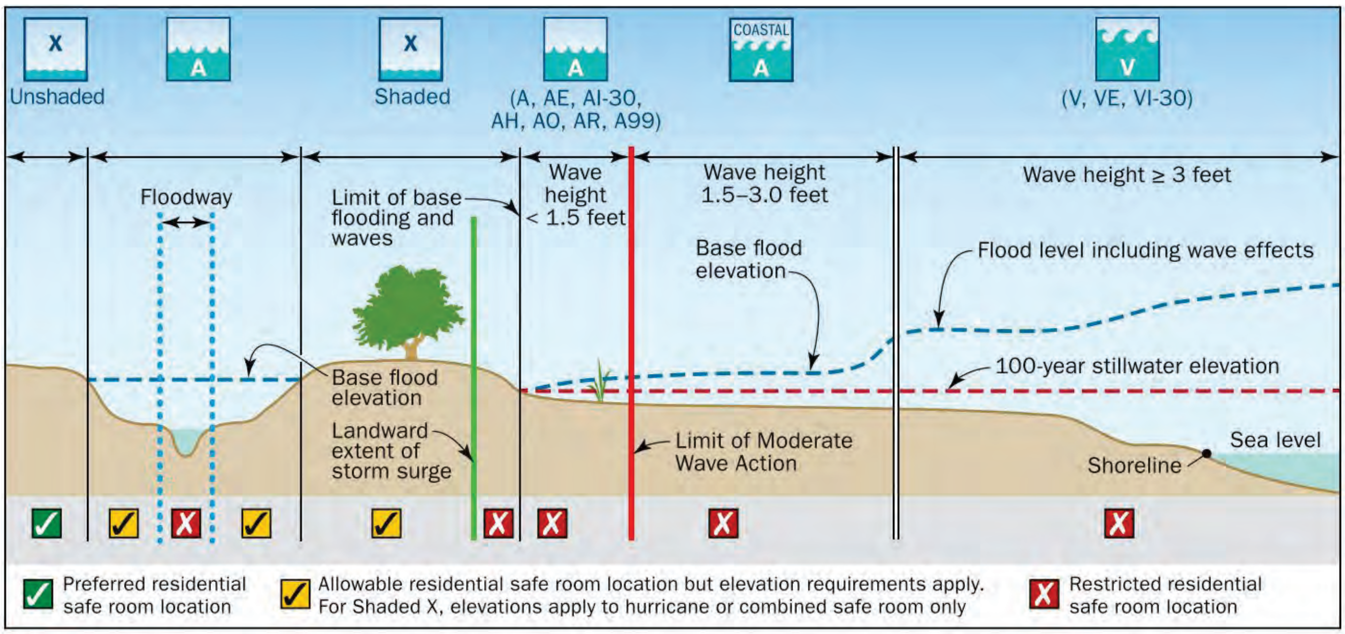


Diagram of Federal Emergency Management Agency's (FEMA) guidance on safe room locations. Letters called out at the top of the graphic (X, A, V, etc.) refer to FEMA Flood Hazard Zones. See Exhibit 4-7 in Chapter 4—Site Analysis for descriptions. Source: FEMA, "Taking Shelter From the Storm"

Resources

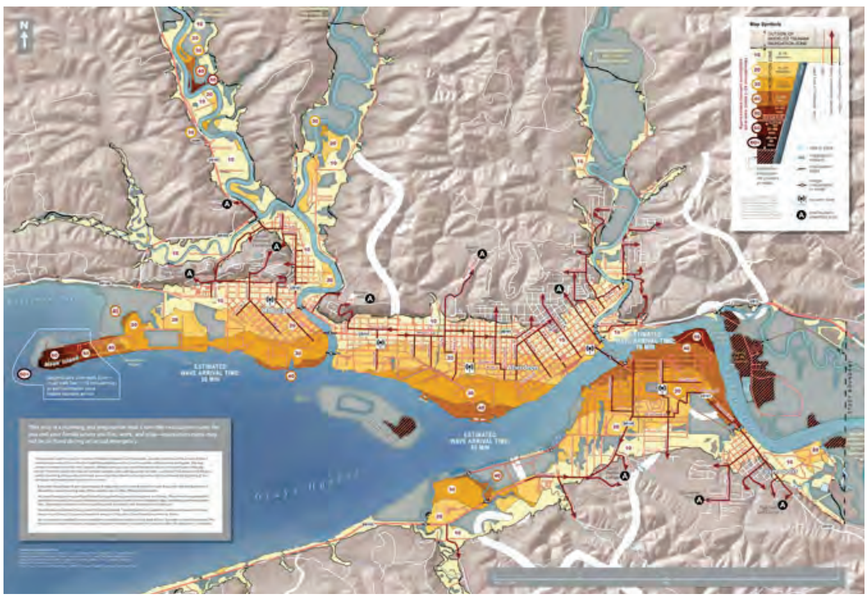
- FEMA P-320—Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business

Vertical Evacuation

Create vertical evacuation structures on low-lying sites in tsunami zones.

Site planners should understand the warning time that future users of the site will have prior to evacuation. In some cases, there may not be time for a full evacuation in the event of a tsunami, such as on low-lying peninsulas with few potential evacuation routes. Some communities faced with these risks are building vertical evacuation structures to allow people to get above the inundation zone and incorporating vertical evacuation in buildings like schools and city halls. In a free-standing structure, consider ways to activate the ground floor so that it contributes to a street's vibrancy and sociability. Consider ways for the structure to also serve as a viewpoint for community enjoyment.

Exhibit 5-29. Walking Evacuation Route Map for Hoquiam, Washington



Source: Washington State Department of Natural Resources

Vertical evacuation structures can provide onsite evacuation options for people living in tsunami zones where there may not be time for a land evacuation due to the lack of warning time before the arrival of a tsunami or because of the lack of elevation in low-lying areas. Vertical evacuation structures can be "permeable," allowing waves to flow beneath them, such as a tower on vertical piers.[265] Buildings can also serve as evacuation structures and be coupled with other uses to provide multiple benefits to a community. Ocosta Elementary School in Westport, Washington, is an example, with a capacity for 2,000 students and town residents.[266]

Mitigation Benefits

Provides onsite evacuation for low-lying areas during a flash-flood.

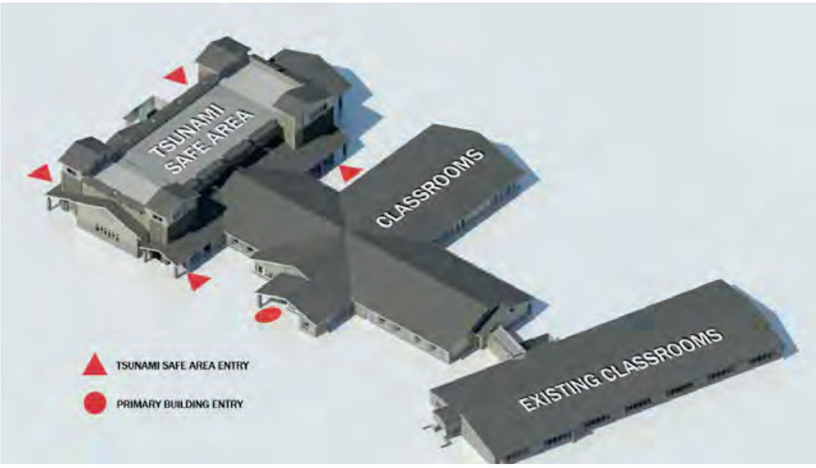
May also provide storm-surge refuge for residents unable to evacuate.

Provides onsite evacuation for low-lying areas where there is limited time to evacuate.

Mitigation Considerations

Design measures may be needed to ensure evacuation towers are integrated with the community, visually and functionally.

Exhibit 5-30. Tsunami Shelter Design for Ocosta Elementary, Westport, Washington



Birds-eye illustration of Ocosta Elementary School, Westport, Washington, showing educational spaces and the tsunami-safe area on the roof. Source: TCF Architecture

Resilience Hubs

Include accessible community centers and open spaces that can serve as emergency gathering spaces.

Community centers and open spaces can serve as resilience hubs to aid evacuation prior to or during an emergency. These hubs can also provide a place for information, coordination, and community connection in the chaotic post-disaster period. Research on open space usage after earthquake highlights the following beneficial attributes:[267]

- Clear sight lines.
- Easy to access.
- Have water, sanitation, power/lighting, and wayfinding/communication.
- Large spaces can serve as ad-hoc medical space and temporary shelter, but smaller spaces can also be valuable.

Community center buildings can serve as cooling centers, store emergency food and water, and provide a place to charge electronics. Buildings with back-up power sources can be particularly valuable when hazards result in power outages. Some structures could also be designed to serve as emergency shelters or offer vertical evacuation.

There are some risks with using open spaces for gathering during or post-disaster. During some wildfires, people can be safe outside if kept away from fuel sources,[268] but can also be at risk if fire conditions change suddenly. People gathering outside in urban areas are often more vulnerable to injury during earthquakes from material falling from damaged buildings. Aftershocks are common following earthquake events and can cause additional damage to weakened structures. In addition, if open spaces are located in a low spot or below a slope

Mitigation Benefits

Provides space for gathering and communication prior to, during, and/or following a:

- A flood event.
- Windstorms.
- Wildfires.
- Landslides.
- Earthquakes.
- Tsunamis.
- Can provide shade and serve as a cooling center during a heat wave
- Aids disaster preparation, evacuation coordination, and/or post-disaster recovery

Mitigation Considerations

Work with emergency management officials to ensure open space conditions are safe and to coordinate post-disaster recovery planning.

then they may be vulnerable to floods or heavy rains that trigger landslides. Post-disaster gathering areas within open spaces should be clear from adjacent buildings and buffered from slopes that could become vulnerable post-disaster. Planning for the use of open spaces for wildfires should only be done in close coordination with fire professionals.

See also Early Warning, Evacuation, Shelter, and Lifelines Access and Microgrid Approaches for Power Supply and Emergency Back-Up.

Community Lifelines

Facilitate redundant access to lifeline systems if a disaster is likely to cut off access to external systems.

Community Lifelines is a framework developed by FEMA to improve disaster response. Lifelines are the critical services on which a community depends. Initial responses after a disaster will focus on stabilizing lifelines impacted by disasters.[269]

There are seven categories of community lifelines:

- Safety and security.
- Food, water, and shelter.
- Health and medical.
- Energy (power and fuel).
- Communications.
- Transportation.
- Hazardous materials (protection from).

Some community lifelines may not be included as features of a site plan for a residential community. However, site planners should be aware of the proximity to local lifeline services. Categories of lifelines that are distant from the site or separated by a piece of vulnerable infrastructure, such as a bridge, may not be available following an emergency.

Mitigation Benefits

Increase community resilience by protecting access to critical services:

- During and after a flood.
- During and after a strong windstorm.
- During a heat wave.
- During and after a wildfire.
- Following a landslide, or when landslide risks are elevated.
- Following an earthquake.
- Following a tsunami.

Exhibit 5-31. Community Lifelines

Source: Federal Emergency Management Agency, Lifelines Fact Sheet

Stormwater and Site Protection

This section covers strategies for managing stormwater and protecting sites from floods, which are increasing and are already the most common and costly disaster in the United States.

"It's also time to embrace the life-giving power of water itself and look beyond engineered outcomes to a different measure of success based on a living planet index. The space where water meets land propagates our most ecologically and culturally productive zones and has been consistently eroded in the last century as expansive riverbanks have been canalized, flows severed, and basins paved. To reclaim them, we must conceive future landscapes that move beyond "green vs. gray" and into new imaginative territories of design, empathy, and empowerment."[270]

- Kate Orff from the Forward to
"Landscape Architecture for Sea Level Rise"

Greening the Grey—Managing Stormwater

Traditional approaches to stormwater management focused on "grey infrastructure"—hard structures, such as catch basins and sewer pipes, that would channel stormwater away from communities and direct the water into detention ponds, treatment plants, and nearby waterways. Over time this grey infrastructure approach has led to a number of challenges, including decreased water quality in nearby waterways, damage to ecological systems and habitat, decreased soil permeability and groundwater recharge, and increased flood impacts, particularly for downstream communities.[271] Heightened demand on urban drainage systems due to increased rainfall and expansion of impermeable surfaces from the development of urban areas has further overburdened grey stormwater systems. Failures of these systems can lead to additional flooding, exposure to hazardous waste, disruption in utilities service, impacted drinking water resources, and structural and property damage.[272] In addition, grey infrastructure approaches can be costly to build and are often not adequately flexible for the stressors of today's climate reality.[273] Traditional cost-benefit analysis often fails to recognize these impacts to infrastructure.

Adding nature-based solutions, such as green stormwater infrastructure, expands a site's ability to absorb and treat stormwater where it falls, lessening the burden on grey infrastructure. This modification can be particularly important in developed areas where sewer and drainage systems are combined, as heavy rainfall events can quickly overwhelm drainage systems, resulting in raw sewage outfalls into adjacent waterways. As a result, integrating green infrastructure solutions into a stormwater system can protect communities from the impacts of natural hazards and can contribute toward a community's resilience against climate change. Sustainability co-benefits of green infrastructure include ecosystem connectivity, heat absorption and shade provision, carbon sinks, and benefits to human well-being and mental health through increased green spaces and opportunities for outdoor activity. Understanding the site-specific climate conditions is necessary for developing an effective implementation strategy of green stormwater infrastructure techniques into the existing or planned site infrastructure.[274]

Exhibit 5-32.Grey and Green Infrastructure

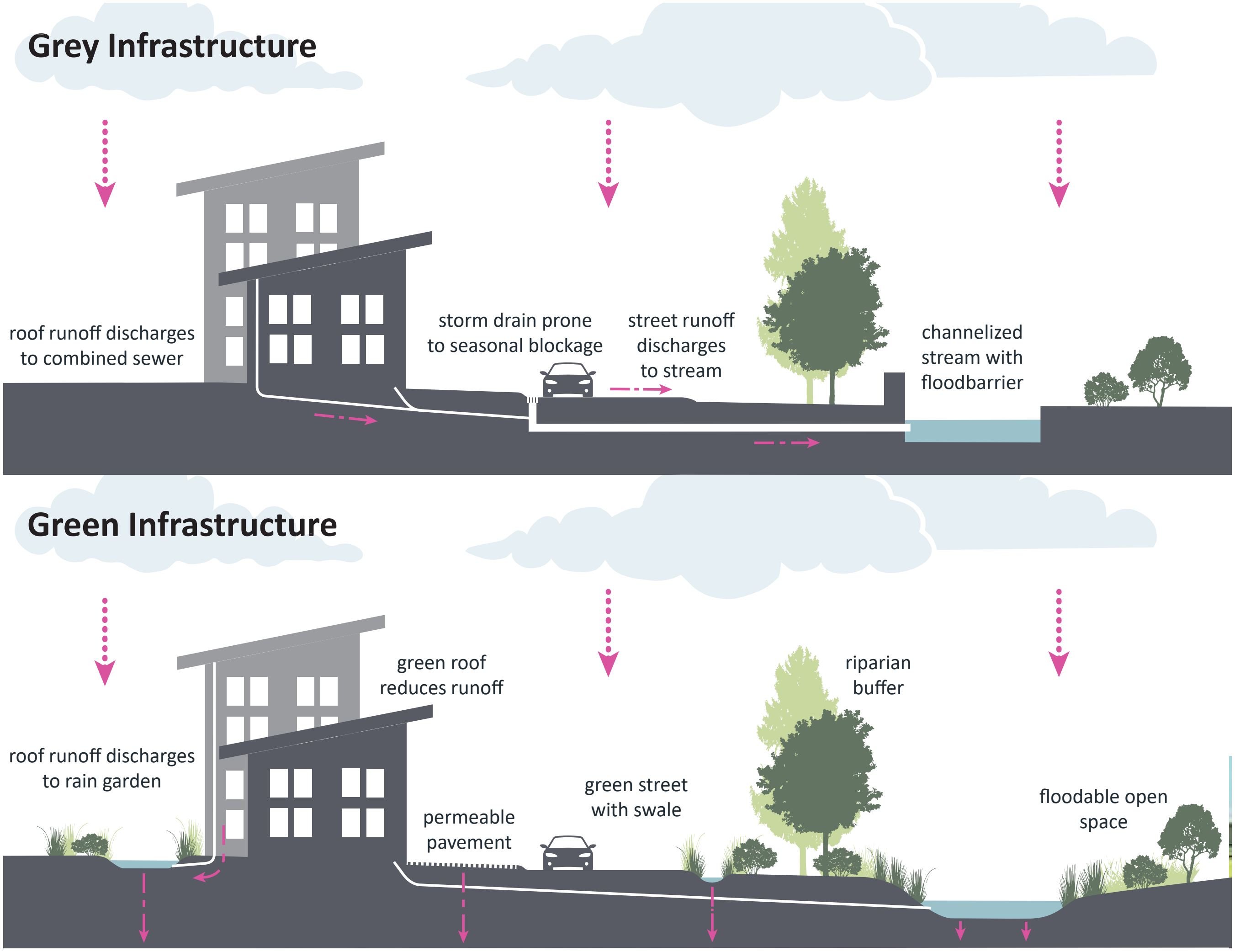


Illustration of grey infrastructure and green infrastructure. Source: MAKERS updated and adapted from Depietri and McPhearson (2017)

Bioswales and Rain Gardens

Use nature-based solutions such as bioswales and rain gardens to manage and treat stormwater runoff on site.

Bioswale and rain garden strategies have multiple benefits for a site that can increase resilience to natural hazards. Stormwater runoff can exacerbate flood risks during heavy rain and flood events. By collecting and managing stormwater within the boundaries of a site, these systems reduce the impact of stormwater runoff and erosion on downstream communities. Vegetation within bioswales and rain gardens can also help clean and cool water before it reaches other water systems, such as nearby streams and rivers. This filtering helps improve water quality, which can increase resilience of the overall site. Furthermore, infiltrating water into the ground stores water in the soil, which can help trees and site vegetation survive periods of hot weather and drought, an important consideration as unhealthy trees and vegetation are more vulnerable to wildfire.

The value of green stormwater infrastructure is well-documented, and communities across the country are integrating these practices into their site plans and communities. Site planners should consider the following when planning natural drainage strategies:[275]

- Reference local stormwater manuals and natural drainage guides for best practices that take into account local climate and precipitation patterns.
- Assess soil types on the site and test infiltration rates before designing and implementing natural drainage strategies. Sites with clay or heavily compacted soils may require amendments or additional planning before natural drainage practices can be implemented.
- Consider the benefits of all materials within the rain garden or bioswale system, from soil to mulches and amendments, and plants.
- Select deep-rooted plants that are acclimated to the wet-dry cycle that is typical of bioretention facilities. Consider using native plants where feasible.
- Consider maintenance needs when planning natural drainage strategies.
- Infiltrating water on or around slopes can increase landslide risks. Work with geologists, geotechnical engineers, or other professionals when considering natural drainage strategies on sloped sites.
- In wildfire-prone areas, follow local defensible space guidance when locating vegetated bioswales and rain gardens and select drought-tolerant plants that will not become overly dry and increase wildfire risk. Routine maintenance may also be needed to ensure bioswales and rain gardens do not increase wildfire risk.

Mitigation Benefits

- Reduces stormwater runoff and downstream flooding and improves water quality.
- Retains water in the soil, which can reduce drought stress on vegetation and aid soil conservation.
- Promotes infiltration, which can support healthy vegetation and reduce some wildfire risk.
- Helps reduce flooding and erosion, which can increase landslide risks.
- Connects people to natural spaces and wildlife.

Mitigation Considerations

- Careful placement, plant selection, and regular maintenance needed to ensure vegetation does not increase wildfire risk.

Resources

- Naturally Resilience Communities—
https://nrcsolutions.org/rain-gardens/
- US—Green Infrastructure Design and Implementation (Links to regional design manuals, tools, and more information.)
https://www.epa.gov/green-infrastructure/green-infrastructure-design-and-implementation#Design%20Manuals
- Green Infrastructure Foundation—
https://greeninfrastructurefoundation.org/
- American Society of Landscape Architects—Water and Stormwater Management
https://www.asla.org/waterandstormwater.aspx
- American Society of Civil Engineers—Water Quality Impact & Solutions
https://www.asce.org/communities/institutes-and-technical-groups/environmental-and-water-resources-institute/water-quality-impact-solutions
- FEMA - Building Community Resilience with Nature Based Solutions—
https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions

Exhibit 5-33. Rain Garden

FEMA illustration of a rain garden (left), a type of nature-based solution. The High Point development in Seattle, Washington, (right) incorporated many rain gardens and other natural drainage features into the site design. Sources: Federal Emergency Management Agency (left); MAKERS (right)

Floodwater Detention and Retention Basins

When needed, increase onsite stormwater storage by including detention and retention basins in the project.

Stormwater detention basins are designed to capture and slow stormwater during typical precipitation events and large storms, thus reducing flood impacts. Dry detention ponds gather stormwater and then release the water slowly into the system. Wet detention ponds and retention basins are designed to retain a permanent pool of water at all times of the year, while often providing temporary stormwater storage above the permanent pool.[276]

Exhibit 5-34. Stormwater Detention Basin

Stormwater detention pond in Memorial Park, Kimberly, Wisconsin. Source: Aaron Volkening, November 2017 CC by 2.0, Flickr

As an added benefit, some detention basins are designed for water treatment. Some flood detention strategies can also be designed to become an amenity for the site, similar to a central water feature. In some wildfire-prone sites where there is water availability, wet-detention ponds may offer storage solutions that can be used to fight wildfires.[277] Wet detention ponds can also be located within an open space to provide a fuel break. If detention basins are to be used as a site amenity, however, careful consideration must be given to water quality and access concerns. Stormwater can carry harmful contaminants, and the nutrients (phosphorus and nitrogen) present in stormwater can sometimes lead to harmful algal blooms (HABs) in detention basins that are toxic to humans, pets, and wildlife.[278]

Resource

- https://nrcsolutions.org/floodwater-detention/

Mitigation Benefits

Reduces some flood impacts during storm events.

Stores water on the site and/or promotes infiltration of water into soil.

Serves as fuel breaks and provides some back-up water supply for fighting wildfires.

Helps reduce flooding and erosion, which can increase landslide risks.

Mitigation Considerations

Detention basins should be carefully designed and integrated into the site in a way that promotes safety for local residents and provides amenities (trails, attractive plantings, etc.) whenever possible.

See Streets as Site Protection – Green Streets.

Permeable Paving

Use porous paving strategies to further reduce impervious surface coverage.

Porous paving, sometimes called permeable paving, is a pervious alternative to traditional hardscape areas and works in concert with natural drainage strategies to reduce flood hazards and infiltrate water, which can be beneficial in drought-prone locations. Pervious concrete, porous asphalt, and modular concrete pavers are all forms of porous paving. Permeable pavements are often used in low-traffic and pedestrian spaces, and designs that support higher volumes of traffic are available for use in city streets. Permeable sidewalks need to ensure that surfaces meet Americans with Disability Act (ADA) requirements, although most products currently available meet ADA standards. Site planners should consider the following when weighing permeable pavement strategies:

- Reference local stormwater manuals and design guides for best practices that take into account local climate and precipitation patterns. Permeable pavements also have specific benefits for cold-weather climates, potentially reducing the need for salt and promoting faster ice melting.[279]
- Assess soil types on the site and test infiltration rates before installing permeable paving.
- Assess maintenance requirements before selecting a paving solution, as all permeable pavement systems require regular maintenance. Some permeable pavements may be unsuitable where salts are used for deicing.

Resources

- EPA—Soak Up The Rain—Permeable Pavement https://www.epa.gov/soakuptherain/soak-rain-permeable-pavement
- USGS—Evaluating the potential benefits of permeable pavement on the quantity and quality of stormwater runoff https://www.usgs.gov/centers/upper-midwest-water-science-center/science/evaluating-potential-benefits-permeable-pavement
- NACTO—Permeable Pavement https://nacto.org/publication/urban-street-stormwater-guide/stormwater-elements/green-stormwater-elements/permeable-pavement/
- FEMA—Building Community Resilience with Nature Based Solutions https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions

Mitigation Benefits

- Infiltrates and/or retains stormwater, helping to reduce runoff and downstream flood impacts.
- Reduces impervious surface coverage and provides green space and shade that lowers temperatures.
- Infiltrates water, reducing some wildfire risk.
- Helps reduce flooding and erosion, which can increase landslide risks.

Exhibit 5-35. Permeable Paving

FEMA illustration of permeable paving (top) a type of nature-based solution. Bottom: Car parked on permeable pavers. Sources: Federal Emergency Management Agency (top); Normand Lemieux, September 2021 CC by SA 4.0, Wikimedia Commons (bottom)

Coastal Shorelines—Edge Protection Strategies

Given the complex forces that drive flood challenges in coastal environments, combining both traditional (aka grey) and nature-based solutions (aka green or soft) at the site or neighborhood scale is often needed to meet site needs for resilience and protection.[280] Despite the limitations and challenges of grey infrastructure, these approaches are still effective at protecting sites and communities from some impacts and may be needed where nature-based solutions are unable to provide adequate protection. For example, while researchers recognize the negative effects of sea walls on shoreline habitat and morphology, they also highlight that sea walls can provide important protection to existing coastal communities, particularly those vulnerable to tsunamis and large storm surges.[281] In cases such as this, opportunities to implement nature-based solutions alongside grey infrastructure can lead to robust improvements in overall site resilience.

The following strategies reflect a range of approaches that can be combined across a site to protect from coastal flooding while utilizing nature-based solutions. There are many different types of shorelines across the United States and significant regional differences between coastal areas. Consult local resources prior to identifying site strategies.

Impact Reduction Strategies

Consider near-shore opportunities to protect coastal sites from floods (large site or district scale).

Near-shore features and in-water structures can reduce the impacts from storm surges and high-tide flood events in coastal communities,[282] although these strategies are more often taken at a regional or community-wide scale. Hard engineering approaches typically use concrete, riprap, armored blocks, or other hard infrastructure to manage flood events. Such strategies include breakwaters, groins, jetties, tide gates and surge barriers, and polders. Walls installed below the water's surface can reduce some risk from tsunami waves.[283]

Nature-based solutions can be integrated into or used alongside hard infrastructure to further reduce the impacts of floods on sites while also enhancing ecological functions. Such strategies include constructed wetlands, artificial reefs, living breakwaters, and floating islands.

Resources

- NYC Urban Waterfront Adaptive Strategies https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf
- Naturally Resilient Communities—https://nrcsolutions.org/

Mitigation Benefits

- Protects coastal and shoreline development from some storm surges and sunny-day flooding.
- Nature-based approaches may disrupt or dissipate some winds.
- Calms wave action, which can reduce landslide risks from erosion.
- Reduces some wave energy.

Exhibit 5-36. Constructed Reef Breakwater

U.S. Department of Fish and Wildlife (DFW) employees construct an oyster reef breakwater structure at Gandy's Beach, New Jersey. Source: U.S. DFW, May 2016, Flickr

Living Shorelines

Use nature-based strategies to recreate and restore living shoreline edges.

In addition to protecting and restoring existing natural systems, planners and designers are also exploring how to create or use natural systems to increase site resilience against natural hazard impacts. Living shorelines are stabilized shoreline edges made of natural materials such as plants, sand, and/or rock that are designed to grow over time. Living shorelines can consist entirely of vegetation or can be combined with structures to help anchor the shoreline in place. These shorelines are often hybrid strategies, where structural solutions are employed alongside strategies that provide ecological benefits. Living shorelines are more resilient against storms than some coastal structures, such as bulkheads, as they can absorb impacts and continue to grow and provide protection.[284]

Living shoreline strategies include the following:[285]

Vegetated Shorelines. Vegetated shorelines employ the root structures of native coastal plants to reduce erosion, dissipate wave energy, and hold the shoreline in place. These strategies are most appropriate in sheltered locations where there is low-wave action. These approaches do not protect upland areas from storm surges. Structural elements can be added to further stabilize the slope. Linear edging material such as geotextile tubes, rock gabion baskets, or living reefs can anchor the toe of the slope and help hold the shoreline in place. Sills of rock or living reef material can also be placed parallel to the shoreline to reduce wave action and allow more space for marsh and wetland restoration behind the sill.[286]

Beaches and Dunes. Beaches and dunes are naturally changing environments that respond and shift in response to coastal winds, waves, tides, and storms. They can help mitigate storm impacts by serving as a buffer between the coastal edge and upland development. Restoring shorelines to provide new beach and dune habitats can help buffer communities from storm impacts and reduce erosion impacts by providing a natural material source that can be transferred to other areas along the coastline through natural wave action and tidal forces. These forces need to be carefully understood to ensure shoreline restoration is resilient to current forces and future change. Communities that have pursued beach nourishment strategies, in which sand is imported to the site to repair previous beach erosion, have often found that the sand has eroded again within a short period of time.[287]

Planners and designers are also starting to think of new ways to integrate the natural protective aspects of dune landscapes into urban coastal areas.

Mitigation Benefits

- Provides space for coastal flood and storm surges.
- Reduces some wind speeds through varied topography and vegetation.
- Often incorporates vegetation, which can reduce air and water temperatures.
- Absorbs wave action, reducing coastal erosion that can increase landslide risk.

Exhibit 5-37. Dune Restoration

Restored vegetation at NASA's Kennedy Space Center, Florida, beaches in 2019. Source: KSC-20190415-PH_KLS01_0047, © 2019 NASA Kennedy, CC BY-NC-ND 2.0, Flickr

- Sand engines are large deposits on dredged sand material that are placed on the shoreline (rather than the beach) to allow tidal and wave action to naturally extend the beach and create protective barrier forms.[288]

Resources

- NYC Urban Waterfront Adaptive Strategies—https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf
- Landscape Architecture for Sea Level Rise (Book)
- NOAA Guidance for Considering the Use of Living Shorelines—https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf

Coastal Structures

Use shoreline structures, such as seawalls, bulkheads, or revetments, only in areas with pre-existing hardened shorelines to protect sites that have existing development or other important community resources.

Given the prevalence of development in coastal areas throughout the United States, there is a crucial need to protect coastal areas from increasing flood risks. While nature-based solutions are necessary tools for increasing resilience, structural solutions are still needed in some cases to protect existing communities, commercial centers, and infrastructure. Shorelines hardened with structural solutions can result in negative ecological impacts on or adjacent to a site, including increased wave action and erosion at the edges of the structure, destruction of wildlife habitat, and reduction in water quality. Coastal structures are also limited to the forces and flood levels that they are designed to withstand, and they can fail in major storms if water levels and wave action surpass those design parameters.

Despite these impacts, such strategies are sometimes needed to protect existing development and resources or to protect against major flood risks, such as tsunamis. Consider opportunities to combine with soft shoreline strategies or integrate ecological design elements to help support ecological functions.

Examples of shoreline structures include:

Seawalls and Bulkheads. Seawalls are stone, concrete, and or metal structures that run parallel to the shore to protect upland site areas during major storm surges. They are effective in environments with high wave energy that are vulnerable to large surges.[289] As a secondary benefit, seawalls that are designed with public access in mind can provide space for passive recreation opportunities. Seawalls may not be a suitable mitigation strategy in areas where surge heights are lower, where natural shorelines are desired, or where land availability is low.[290] By nature, seawalls are inflexible and cannot adapt to sea level rise. They also increase erosion through increased wave action and disruption of sediment transport along the shoreline.[291]

Similar to seawalls, **bulkheads** are vertical retaining walls that hold soil in place to stabilize the shoreline edge. They are not designed to provide protection from major flood events but can prevent erosion impacts from typical wave and tidal action.[292] They can sometimes provide recreational space in urban environments, but they also share many of the same ecological limitations of sea walls. Twenty-five percent of New York City's shoreline is protected by bulkheads.

More recent approaches to seawalls and bulkheads have incorporated strategies to increase ecological functions while also protecting infrastructure, such as roughened surfaces to allow near-shore habitat growth and light penetration for overhanging structures to support wildlife.

Mitigation Benefits

- Protects developed areas against major flood risks and storm surges.
- Absorbs wave action, reducing coastal erosion that can increase landslide risk.
- Provides some protection for developed areas against tsunamis.

Mitigation Considerations

- Can increase erosion on adjacent shorelines, which increases flood risks.
- Can increase erosion on adjacent shorelines, which increases landslide risks.

Exhibit 5-38. Seawall Helps to Protect From Erosion

Behind the Seawall, Cape Hatteras, North Carolina. Source: © 2012 Zach Frailey, CC BY-NC-ND 2.0, Flickr

Revetments. Revetments are common in urban areas where the shoreline edge is armored with large rocks or concrete blocks to protect the underlying sloped shoreline from erosion. They mitigate wave action, and although they do not provide protection from flooding or major storms, they are relatively resilient to flood damage, as rock material can typically resettle in place.[293] Revetments can have negative impacts on intertidal habitats and lead to increased erosion on adjacent unreinforced sites. They are best used in sites where there are pre-existing hardened shoreline structures.

Revetment edging material can be made of human-made or natural materials and typically use irregular forms rather than solid-wall materials. Specific approaches include:[294]

- Riprap.
- Concrete jacks or tetrapods.
- Artificial reefs.
- Oyster reefs.

In-Water Surge Barriers. These structures are made of steel and concrete, providing protection from storm surge (e.g., post-Sandy feasibility studies in Gowanus, Newtown Creek, and Coney Island).

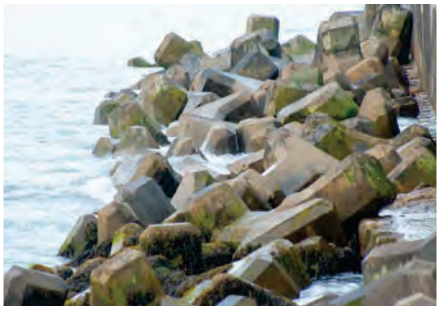
Breakwaters. Breakwaters are off-shore structures that are constructed to reduce wave action and protect the shoreline area from erosion. Integrating living elements into the breakwaters can help increase overall shoreline resilience. Strategies include:[295]

- Living Breakwaters—Incorporate natural features, such as oyster habitat.
- Rubble Mound Breakwaters—Traditional rock barriers that absorb wave energy through voids in rock material.
- Segmented Breakwaters—Wave action is reduced, but some waves and sediment are still allowed to reach the shoreline.
- Floating Breakwaters—Protects shoreline with lesser impacts to shoreline water circulation.

Resources

- NOAA Office for Coastal Management—Digital Coast - https://coast.noaa.gov/digitalcoast/
- NYC Urban Waterfront Adaptive Strategies— https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf
- San Francisco Bay Shoreline Adaptation Atlas— https://www.sfei.org/adaptationatlas
- Landscape Architecture for Sea Level Rise, Edited by Galen D. Newman and Zixu Qiao, 2022.

Exhibit 5-39. Tetrapod in Brighton, England



Concrete Sea Defenses. Source: Dominic Alves, © 2010, CC BY 2.0, Flickr

Upland Flood Protection Strategies

Floodable Open Space

Design waterfront and riverfront parks with flooding in mind, especially when considering building materials, lighting or electrical systems, and vegetation.

Waterfront and riverfront parks can provide the residents of a community with open space for active and passive recreation and can preserve a physical connection to the water. Using this space for flood protection as well as a park can create redundancy and foster social sustainability. Maintaining open space also provides flexibility for further adaptation to climate change.[296] Site planners should consider the following design and management needs:

- Design approaches such as shoreline terracing can be used within floodable open spaces to provide space for flood storage, retain sediment during high-water events, and disperse wave action while also connecting people using the site to the waterfront.[297]
- Consider maintenance, both prior to a flood and clean-up afterward. Site furnishings and other elements in the park may need to be anchored to ensure they are not damaged or moved by floodwaters and cause damage to other areas of the site.[298]
- Floodable parks in marine areas need to carefully select plants that are salt tolerant and resistant to erosion.

Resources

- Naturally Resilient Communities—Waterfront Parks
  https://nrcsolutions.org/waterfront-parks/
- NYC Parks—Designing and Planning for Flood Resiliency
  https://www.nycgovparks.org/planning-and-building/planning/resiliency-plans/flood-resiliency
- FEMA - Building Community Resilience with Nature Based Solutions
  https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions

Mitigation Benefits

- Provides space for floodwaters during storms and/or for sunny day flood events.
- Integrates green space into the site, reducing air temperatures.
- Encouraging infiltration reduces wildfire risk.
- Dissipates wave action from storms, reducing erosion along the shoreline.
- Can help dissipate wave action from some small tsunamis.
- Provides natural and open space for people.

Exhibit 5-40. Constructed Wetland as Part of Brownfield Restoration

Constructed wetland, Renaissance Park, North Chattanooga 7, Tennessee. Source: Lawrence G Miller, ©2009, CC BY-NC-ND 2.0, Flickr

Exhibit 5-41. Floodable Park

FEMA illustration of a floodable park, a type of nature-based solution. Source: Federal Emergency Management Agency

Vegetated Berms

Use vegetated berms for flood and tsunami protection within floodable open space areas.

Vegetated berms can be used to provide flood protection, disperse wave action, and provide tsunami protection. They can be integrated into open spaces at different scales and provide different levels of site protection. In coastal areas, vegetation should be salt tolerant to provide greater site resilience.

Dredging and mounding is one approach for creating vegetated berms by removing silt from the riverbed and strategically placing it on the shore. This tactic can lower water levels by deepening or widening the riverbed and reduce the extent of flooding by creating physical barriers on the riverbank.[299] When conducted at a regional scale it can also effectively address erosion and moderate storm surge. However, dredging and mounding can have large-scale environmental impacts.

Consider lines of sight and natural surveillance goals to ensure the addition of vegetated berms maintains human comfort and safety.

Mitigation Benefits

- Provides Floodable Open Space.
- Reduces some wind speeds.
- Reduces air temperatures through shade and vegetation.
- Dissipates wave action, reducing erosion and landslide risks.
- Helps dissipate wave action from some small tsunamis.
- Provides natural and open space for people.

Mitigation Considerations

- Ensure clear sightlines to promote safety and comfort.

Flood-Friendly Culverts

Size culverts to appropriately disperse water in the event of a flood.

Adequately sized culverts can be an effective means to disperse water during a flood without impacting traffic on roadways or rail lines. Culverts that are too small to handle large amounts of water passing through can cause flooding and impact roadways. Additionally, they may increase the speed of the water that flows through, resulting in downstream erosion and increased turbidity.[300]

Resource

- Naturally Resilient Communities—Flood Friendly Culverts— https://nrcsolutions.org/flood-friendly-culverts/

Mitigation Benefits

- Allows for movement of large volumes of water during floods.
- Reduces runoff outside of the stormwater system, which can lead to erosion and increase landslide risks.

Large-Scale Flood Protection

Flood Control Infrastructure

For larger sites, or for sites employing district strategies for hazard mitigation, consider structural and hybrid strategies for flood control.

Although typically regional strategies, structural flood control strategies can reduce flood risks on individual sites, such as a planned development. As with Coastal Structures, flood control infrastructure is engineered for certain flood conditions and can fail if flood levels exceed the design parameters.

Levees and Dikes. Levees and dikes are structural or earthen barriers that stretch along shorelines or rivers. When incorporated at the district-wide scale, they can offer protection to low-lying areas from surge events and flooding. As a secondary benefit, levees and dikes can provide passive recreation opportunities and areas for roadways.[301] Without proper design and implementation, levees can reduce sightlines and accessibility and create a sense of separation from the water. By nature, levees and dikes are inflexible and cannot adapt to sea level rise or increasing severity of storm surges caused by climate change. This result can create a levee effect, where development is drawn to areas behind the levee, assuming a higher degree of protection than exists.[302]

Open Ditches. Providing drainage in the simplest form, open ditches are linear landforms that collect and convey water away from roads and fields. Mostly common in agricultural and conservation contexts, variations on open ditch strategies can be employed to create new opportunities for flood resilience.

Polders are low-lying land between dikes or other landforms that can be drained by pumps and ditch systems to reclaim land for agricultural or other uses.[303] Water management strategies in the Netherlands have famously employed polders, dikes, and other water management strategies to reclaim large amounts of land that was once covered by the sea.

Canals, which have served transportation and freight functions in many European cities for centuries, also play an important role in water management. Canal networks can also help lower groundwater levels, potentially reducing flooding impacts and providing space for development. Although these drainage strategies often rely on dikes and other regional flood-protection infrastructure, in some low-lying communities, these strategies may provide some opportunities for adapting to rising water levels and flood impacts.

Mitigation Benefits

Reduces flood risks across a large area by blocking floodwaters, altering the water table, and/or draining water away from a site.

Mitigation Considerations

Can create barriers between water and community and isolate neighborhoods from their surroundings.

See Coastal Structures.

Exhibit 5-42. Temporary Levee Holds Back Flood

Temporary levee in Velva, ND. Source: Source: Patrick Moes, 2011 U.S. Army Corps of Engineers, Flickr

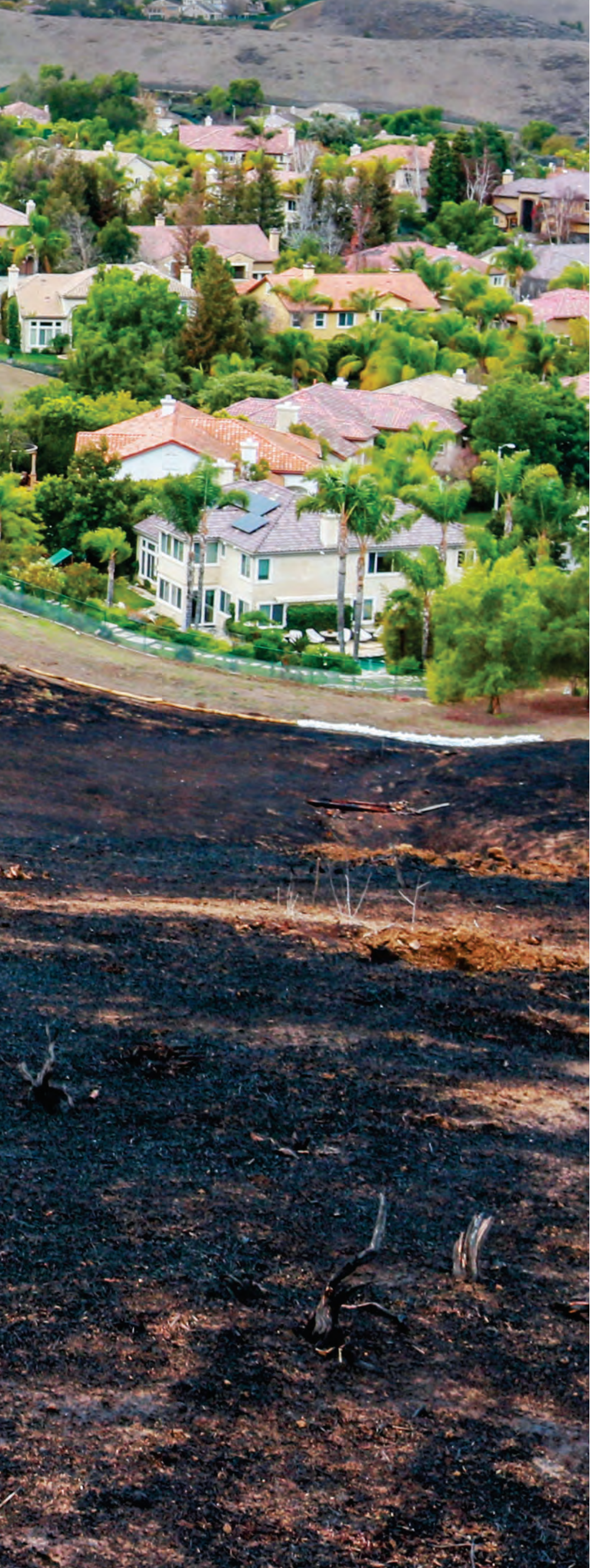
Exhibit 5-43. Canal in Amsterdam, The Netherlands

Amsterdam's canals reflect the underlying water management and engineering that allows the city to thrive despite being below sea level. Source: D Enchev CC BY 2.0, Pxhere

Case Study – Netherlands Water Management in Residential Developments

The Netherlands is a global leader in innovative water management. The following residential development examples illustrate different ways that green infrastructure, development, and water management infrastructure can work together across different sites.

- Stad van de Zon, Heerhugowaard, the Netherlands—Planned community within a polder area that is CO2 neutral and has many innovative water strategies. https://www.urbangreenbluegrids.com/projects/stad-van-de-zon-heerhugowaard-the-netherlands/
- Plan Tide, Dordrecht, the Netherlands—Example of “unpoldering” a landscape to reconnect site with tidal forces https://www.urbangreenbluegrids.com/projects/plan-tide-dordrecht-the-netherlands/
- Ruwenbos district in Enschede—Example of a community that developed around natural drainage, and it also employs open space strategies. https://www.urbangreenbluegrids.com/projects/ruwenbos-enschede-the-netherlands/



Open Space and Green Infrastructure

This section explores how open space elements, such as soil, trees, and water, can be used to increase overall resilience. Open spaces with healthy natural systems can absorb hazards' impacts and protect sites. This section explores how open spaces (e.g., parks and trails) can serve as hazard-mitigating green infrastructure while also providing recreation and other functions in a community.

Healthy Soil

Healthy soils provide important ecosystem services that can help sites be more resilient when exposed to natural hazards, including storing water, improving water quality, reducing dust, and promoting vegetation growth. Soil is also a habitat for plants, microbes, and soil animals, many of which provide important services that support overall ecosystem functions.[304] However, in urban areas and other infill sites, soils are often degraded through disturbance, compaction, loss of vegetative cover, and pollution.[305]

Construction Impact Reduction

Follow best practices to reduce soil compaction, preserve soils, and protect existing drainage and vegetation.

Construction activities, heavy equipment, and material storage can disturb and compact soils, create dust, cause erosion, and impact trees and vegetation. Developing a plan to preserve existing soils valuable for vegetation and following best practices during construction can help ensure onsite soils are impacted to the least degree feasible and restored at the end of construction, minimize negative impacts to air and water quality, and protect existing trees.[306] This plan provides a broad foundation for overall site resilience that can help mitigate some hazard risks, from reducing runoff, preventing erosion that can increase landslide risks, infiltrating water into soils, and reducing stress on trees and vegetation from heat and drought.

Checking the weather ahead of construction activities can also help reduce the chance for construction to trigger wildfire during times when wildfire risk is high.[307]

Resources

- Sustainable Sites Initiative—From the ground up: Sustainable sites start with healthy soils
  https://www.sustainablesites.org/ground-sustainable-sites-start-healthy-soils
- Sustainable Landscape Construction, Third Edition by Kim Sorvig and J. William Thompson—
  https://islandpress.org/books/sustainable-landscape-construction-third-edition
- Up By Roots: Healthy Soils and Trees in the Built Environment by James Urban—
  http://www.jamesurban.net/up-by-roots

Mitigation Benefits

Reduces soil compaction, which promotes onsite water retention and infiltration.

Promotes healthy trees and vegetation, which are less vulnerable to damage from windstorms.

Reduces soil disturbance and compaction, which promotes water retention and aids soil conservation.

Promotes healthy trees and vegetation that provide shade and lower temperatures.

Promotes healthy trees and vegetation, which can be less vulnerable to wildfires.

Reduces overall site impacts from construction, which can increase landslide risk.

Exhibit 5-44. Soil and Stream Protection During Construction

"Environmental Protection" in Statesville, North Carolina. Source: © 2012 NCDOTcommunications, CC BY-2.0, Flickr

Soil Amendments

Amend soil when appropriate to improve soil health and boost productivity.

Soil amendments, such as compost or other organic materials, are commonly added to soils in landscape areas and some agricultural lands. Mulches, often placed on top of the soil to retain moisture, can also add beneficial nutrients and structure to the soil.

Many mulches contain woody material, which can be a fire hazard in wildfire-prone places. Only non-flammable mulches should be used to address soil health in these locations.[308]

Biochar is another type of soil amendment that has been growing in popularity in recent years due to its ability to both store carbon and improve soil health. The technique has roots in indigenous land-management practices in Brazil and is formed when biomass sources, typically wood waste, are burned while deprived of oxygen to form a porous carbon substance.[309] Biochar does not add nutrients to the soil, but it can help the soil retain both nutrients and moisture. Research on biochar has mostly been done in the context of agriculture, but more recently, researchers have been studying biochar in other contexts, such as its potential to address the negative impacts of drought and salt stress on soil fertility.[310] Biochar can have some detrimental impacts on plant growth, so a thorough investigation is needed to determine if it will be beneficial to a site.[311]

Resources

- Climate Hubs—U.S. Department of Agriculture
  https://www.climatehubs.usda.gov/hubs/northwest/topic/biochar
- After the Fire—Wood Waste Put to Work
  https://www.fs.usda.gov/features/after-fire-wood-waste-put-work

Mitigation Benefits

Provides broad benefits by ensuring soils can infiltrate and store water.

Decreases tree and vegetation vulnerability to windstorm damage.

Increases water retention and aids in soil conservation.

Promotes trees and vegetation that provide shade, lower temperatures, and help retain water in the soil.

Helps retain water in the soil and promotes healthy vegetation, which can reduce wildfire risks.

Reduces impacts from runoff and erosion by retaining water in the soil.

Mitigation Considerations

Use non-flammable mulches in arid and wildfire-prone environments.

Contamination and Water Movement

Address soil contamination to reduce the risk of pollution spreading following a natural hazard.

There are several strategies to mitigate soil contamination. Small areas of contamination can sometimes be removed from the site, removing the future risk of spread. Capping, or adding a clean soil buffer on top of contaminated soils, is a common strategy to address polluted sites. Phytoremediation, which uses plants to clean soil pollution, is an emerging strategy. However, phytoremediation takes time, which is sometimes in conflict with development requirements. Mitigation strategies should consider how changes in groundwater, or disruptions due to natural hazards, can increase the risks of exposing or spreading the contamination. Future impacts from natural hazards can also disturb site soils and expose people or natural systems to contamination. In coastal areas impacted by sea level rise, rising groundwater or flooding can move toxins into a site.[312]

Mitigation Benefits

Reduces the potential that:


Floods and groundwater level changes will disturb and/or spread contaminated soil.


Contaminated soils could be exposed following a wildfire.


A landslide will disturb and/or spread contaminated soil.


An earthquake will disturb and/or uncover contaminated soil.

Exhibit 5-45. Flood Debris Can Contaminate Soils

Debris after high flooding of the Mississippi River in 2011. Source: “20110514-NRCS-LSC-0194,” 2011 US Department of Agriculture, Flickr

Protecting Soils from Drought

Incorporate green infrastructure strategies that promote infiltration and aquifer recharge.

Green infrastructure that facilitates onsite drainage, infiltration, and vegetation cover can increase resilience to droughts. Since drought-prone regions often have different native and adapted plant communities, planners should use strategies specific to their locale.

Resources

- National Drought Mitigation Center—https://drought.unl.edu/
- Naturally Resilient Communities—https://nrcsolutions.org/
- https://www.epa.gov/water-research/drought-resilience-and-water-conservation

Mitigation Benefits

Promotes infiltration and water retention in the soil and reduces runoff from overly dry soils.

Encourages infiltration and water retention in the soil and aids soil conservation.

Helps retain water in the soil and promotes healthy vegetation, which can reduce wildfire risks.

Reduces runoff and erosion, which can increase landslide risks.

Reduces or slows some impacts from subsidence.

See Soil Stabilization and Shoring, Construction Impact Reduction, Soil Amendments, Greening the Grey—Managing Stormwater, and Native Plants and Biodiversity.

Site Restoration Post-wildfire

Stabilize and rehabilitate soils after wildfires.

As noted in the Site Analysis section, wildfires are part of healthy wildland ecosystems and reduce fuels, provide space for new growth, and promote fire-adapted plants. However, fire can negatively impact soil health, particularly as climate change causes more intense and frequent fires. Wildfires can burn through organic materials and remove vital nutrients, reducing soil fertility. Care should be taken after severe wildfires to reduce soil fertility loss and mitigate risks from secondary hazards, such as landslides and floods. Restoration actions will be site specific but may include planting trees, reestablishing native species, restoring habitats, and removing invasive plants.[313]

Resources

- Burned Area Emergency Response—U.S. Forest Service https://www.fs.fed.us/naturalresources/watershed/burnedareas-background.shtml
- Burned Area Rehabilitation—https://www.doi.gov/wildlandfire/burned-area-rehabilitation

Mitigation Benefits

- Reduces some flood risks following a wildfire.
- Helps retain soil on site and promotes infiltration through restoration and vegetation.
- Promotes healthier forest regrowth.
- Reduces some landslide risks following a wildfire.

Exhibit 5-46. Habitat restoration after wildfire

Sharps Fire Planting and Habitat Restoration (21). Source: © 2019 BLMIdaho, CC BY 2.0, Flickr

Trees and Vegetation

Trees and vegetation provide a wide range of ecosystem benefits, including:

- Significant shade and surface temperature reduction by up to 35 degrees Fahrenheit.[314]
- Cooling benefits through evapotranspiration and reduced evaporation of water from the soil.[315]
- Aerating compacted soils and assisting with stormwater management.[316]
- Water conservation and soil infiltration through native shrubs, grasses, and understory vegetation root systems.
- Acting as windbreaks that can help reduce and prevent soil erosion.[317]
- Structural and biological diversity by providing wildlife habitat.
- Carbon sequestration.

Given the value of these ecosystem services, trees and vegetation contribute to site resilience and can aid in natural hazard mitigation. That said, in some natural hazard contexts, including wildfires and high-wind events, trees and vegetation can create some vulnerabilities. The value of trees and vegetation typically outweigh the risks, although landscapes should be carefully planned and managed in wildfire-prone areas and in areas vulnerable to hurricanes and strong-wind events.

Exhibit 5-47. Trees Integrated Into the Streetscape

FEMA illustration of urban tree canopy coverage, a type of nature-based solution. For more FEMA guidance on using nature-based solutions for risk management, see Building Community Resilience with Nature-Based Solutions, https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions. Source: Federal Emergency Management Agency

Native Plants and Biodiversity

Select native, drought-tolerant plants that promote biodiversity, especially in dry climates.

Using native plants can provide multiple benefits for a site. Native plants tend to have stronger root systems and are naturally adapted to the local climate. Native plants also increase biodiversity on a site, both at the species-scale, where native plants are typically more resilient to hazard impacts, and at the site-scale, where they create habitat and attract wildlife.

Selecting native plants that are drought-tolerant for the local site and soil conditions can also be a way to reduce water usage on a site. Water-smart landscapes (e.g., xeriscaping) can offer solutions that require no supplemental irrigation.

Mitigation Benefits

May have natural adaptations that increase:

- Resilience to floods.
- Resilience to storms.
- Wildfire resilience.
- Provides shade, helps lower temperatures, and typically requires less water.
- Provides strong root-structure to soil, helping retain soil and reduce some landslide risks.

See Outdoor Water Use and Irrigation, Tree Spacing, and Planting and Pruning.

Resources

- Water-smart Landscapes—EPA
  https://www.epa.gov/system/files/documents /2021-12/ws-outdoor-water-smart-landscapes.pdf
- Ladybird Johnson Wildflower Center—Research and Ecological Design Resources
  https://www.wildflower.org/our-work
- USDA Forest Service Climate Change Atlas—
  https://www.fs.usda.gov/nrs/atlas/
- Climate Change Response Framework—
  https://forestadaptation.org/

Right Plant, Right Place

Select and manage plants appropriate to the local conditions and needs of each site.

Selecting the right plants for the local site conditions is a guiding principle of landscape architecture and is particularly relevant for hazard mitigation. Given the benefits of healthy trees and vegetation in protecting sites from different types of natural hazards, sizing plants appropriately, ensuring there is adequate space for growth, and following planting best practices can help ensure that trees and other plants will grow to maturity and be resilient to natural hazard impacts. As temperatures rise and plant hardiness zones change, thoughtful plant selection is needed to ensure the health and resilience of plants in the future.

Specific approaches include:

- Include salt-tolerant vegetation when designing landscapes in coastal areas that are susceptible to coastal flood impacts. Coastal landscape areas vulnerable to flooding should include vegetation that can withstand salt-water flooding events. Plants should be flushed with water and amendments following floods to remove and bind toxic salt from soils.[318]
- Avoid using plants with flammable characteristics in wildfire-prone areas. Some plants can increase the intensity of fire behavior and should be avoided on sites vulnerable to wildfire.[319] Choose plants without the following characteristics that increase vulnerability to wildfire: waxes, oils or resins, dense growth structure, fast growth, and shedding bark.[320]
- Explore how planting trees might provide local flood and site contamination protection. Some tree species (e.g., cypress, poplars) can help raise the water table locally through osmosis. This strategy can act as a mini dike on a site, providing some protection from groundwater flooding and potentially insulating a site from the spread of containments in nearby areas.

Resources

- USDA Forest Service Climate Change Atlas—
  https://www.fs.usda.gov/nrs/atlas/
- Climate Change Pressures in the 21[ST] Century—Climate Hubs, USDA
  https://usfs.maps.arcgis.com/apps/MapSeries/index.html?appid=96088b1c086a4b39b3a75d0fd97a4c40

Mitigation Benefits

Promotes healthy trees and vegetation that:

- Aid infiltration and reduce some flood impacts.
- Are more resilient to storm impacts.
- Can promote infiltration, conserve soil, create shade, and lower temperatures.
- Can reduce wildfire risks.
- Can reduce some landslide risks.

Exhibit 5-48. Use Salt-Tolerant Plants In Coastal Flood Zones

Dune Grass in Sandy Cove, Newfoundland, Canada. Source: Ryan Hodnett, © 2019, CC BY-SA 4.0

Exhibit 5-49. Avoid Plants With Flammable Characteristics in Wildfire-Prone Areas

Peeling bark on trees and shrubs can increase wildfire risks. Source: Pxhere

Exhibit 5-50. Trees Provide Local Flood and Site Protection

Balsam Poplar (Populus balsamifera) thrives in riparian zones. Source: Matt Lavin, June 2020, Flickr

Tree Spacing

Consider hazard risks and landscape goals when spacing trees and vegetation.

There are many considerations and areas of conflict when determining how to space trees on a site, particularly along streets where multimodal access, buried utilities, lighting, vegetation, and pedestrian amenities are choreographed within a relatively narrow corridor. Trees can also be significant sources of risk in areas susceptible to wildfires and strong windstorms. (See Wildfire Mitigation and Open Space Management.) Site planners need to consider the following:

- Tree spacing should always be based on the width of the tree at maturity.
- Typical approaches to tree spacing are based on the centerline of the tree and encourage closed canopies to produce shade on streets and open spaces. In wildfire-prone areas, however, tree spacing should be based on the overall width of the tree at the widest point to reduce fuel loads and slow the spread of fire from tree to tree.
- In areas vulnerable to strong wind events, planting trees in groupings can decrease the risk of damage to trees, as wind impacts are distributed across the overall mass of vegetation. (See Trees as Windbreaks.)
- Distancing large trees from buildings and power lines in areas vulnerable to strong wind events can help reduce the risk from fall hazards, which are a common source of injury and death from strong wind hazards. However, strict adherence to setbacks can also eliminate opportunities for trees, which have many beneficial aspects to site planning. Thoughtful location and massing of trees are recommended in areas prone to strong windstorms.
- There may be areas of conflict in tree spacing on sites exposed to multiple hazards, such as sites exposed to both extreme wind and wildfire. Site planners need to weigh the risks and benefits of each strategy, ensure the final plan aligns with local regulations, and identify alternative ways of mitigating hazard exposure on the site.

Mitigation Benefits

Spacing or massing trees offer some windbreak benefits.

Massing trees provides shade and reduces temperatures.

Managing trees and vegetation around development can reduce wildfire risks.

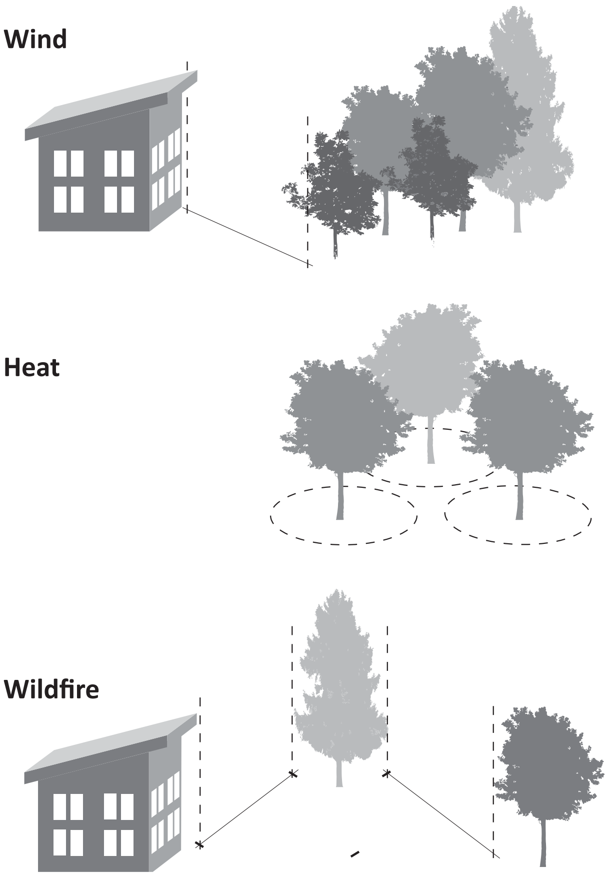
Mitigation Considerations

Trees can be significant hazards to buildings, cars, and people during wind and heavy rainstorms. Additional potential for conflict on sites with multiple hazard vulnerabilities.

Massing trees for shade or windbreaks can increase wildfire risks.

Spacing trees to reduce wildfire and/or wind risks can limit shade options near structures.

Exhibit 5-51. Trees Spacing Considerations to Reduce Hazard Risks



Wind

Massing trees helps distribute wind loads and provides some windbreak benefit to the site. Ensure planting area is large enough to support multiple trees and prune regularly. Locate large trees away from structures to reduce potential for damage from falling limbs during storms.

Heat

Space trees to provide areas of closed canopy and shade along streets and in parks and open spaces.

Wildfire

Space trees according to defensible space zones and based on outer edge of vegetation at mature size. This helps reduce fuel loads and slow wildfire spread.

There are many factors that influence tree spacing on streets and in landscapes. This exhibit illustrates approaches that benefit specific hazard risks. It also highlights potential areas of conflict on sites that are exposed to multiple hazards, such as heat and wildfire. Source: MAKERS

Planting and Pruning

Utilize proper pruning and maintenance practices.

Proper pruning practices ensure that trees stay healthy and will not add to risks from wildfires, hurricanes, and other extreme weather events.[321] Completing a landscape management plan can help ensure a seamless transition into maintenance after construction. Improper pruning can lead to increased health risks for trees and can also increase risks to natural hazards, such as wind, by creating an imbalanced overall structure. For example, professionals suggest that the removal of lower branches can actually increase wind stress on trees, as it puts significant stress on particular branches rather than allowing the overall form of the tree to take on the wind.[322] Pruning activities will also vary depending on the species of the tree and other pruning goals, which can include the production of fruit and flowers. Tree pruning by certified arborists or other professionals is highly recommended and a common requirement.

Resources

- Up By Roots: Healthy Soils and Trees in the Built Environment by James Urban—http://www.jamesurban.net/up-by-roots
- Wind and Trees, Lessons Learned from Hurricanes—Duryea and Kampf 2007

Mitigation Benefits

Promotes overall tree health, which can aid stormwater management.

Promotes overall tree health and helps manage risks from windstorms by removing weak branches, dead or dying limbs, etc.

Promotes overall tree health, which can increase shade, promote infiltration, and reduce temperatures.

Promotes overall tree health and manages potential risks for wildfire by removing dead or dying materials, etc.

Outdoor Water Use and Irrigation

Reduce the need for outdoor water use.

Outdoor water usage accounts for more than 30 percent of total household water use on average, although that percentage can double for households in arid regions.[323] Reducing the need for irrigation can have significant water conservation benefits.

Site planners should consider the following:

- Limiting areas that require irrigation (e.g., reduce lawn areas and use alternative groundcovers, low water use landscaping, or xeriscaping).
- When needed, only use efficient irrigation systems.
- The use of outdoor sprinkler systems to support emergency firebreaks may be needed in some regions wildfire-prone to slow fires. However, this design may conflict with outdoor water usage limits in some areas. The use of outdoor irrigation should supplement other mitigation strategies as exposed sprinklers can be vulnerable to embers and may impact water levels to fight fires elsewhere.[324]

Resource

- WaterSense—Outdoors, EPA
  https://www.epa.gov/watersense/outdoors

Exhibit 5-52. Xeriscaping Landscape to Conserve Water

Los Angeles, California, Air Force Base's 61st Civil Engineering and Logistics Squadron uses drought-tolerant plants and landscaping known as "xeriscaping" to minimize water use as part of Air Force resource conservation efforts. Source U.S. Air Force photo by Sarah Corrice via Flickr

Mitigation Benefits

Reducing outdoor water usage conserves water for other community uses.

Xeriscaping can reduce the accumulation of flammable vegetation debris.

Mitigation Considerations

Outdoor sprinkler systems can be beneficial in providing emergency fire breaks during wildfires.

Trees as Windbreaks

Select and maintain trees as windbreaks, where appropriate.

In agricultural landscapes, trees have long been used as windbreaks and help conserve soils (prevent erosion), buffer winds, and slow evaporation.[325] In coastal areas exposed to hurricanes, and other sites that experience strong wind events, thoughtful design and management of trees and landscape areas will ensure sites are safe and resilient to natural hazards.

Researchers studying the impacts of hurricanes on trees and urban forests in Florida found that:[326]

- The higher the wind speed, the more likely the tree was to fall.
- Stands of existing trees can provide some buffer for one another, and planting clusters of at least five trees results in more resilience.

Selecting strong tree species with healthy growth structures and performing regular pruning also increased landscape resilience following hurricane impacts.

- Older and unhealthy trees were more likely to fall during a strong windstorm or hurricane.
- Trees with more space to grow were more likely to survive than those with limited space or poor root conditions.

Trees can be valuable assets on sites with hurricane and strong wind exposure, but landscapes with trees should be carefully designed, selected, and planted according to best practices and receive regular pruning to reduce the potential for damage during storms.

Exhibit 5-53. Examples of Windbreaks

Left: Trees along a roadway provide a windbreak "Windbreak (8639298497)." Right: Using trees as windbreaks around farmland and structures is a common strategy to reduce wind and promote soil conservation. Linker Farm, Judith Basin County, Montana. June 2020. Sources: https://www.geograph.org.uk/photo/2188333 (left); U.S. Department of Agriculture—Natural Resource Conservation Service Montana (right)

Mitigation Benefits

Can reduce some wind impacts on a site and aid in soil conservation.

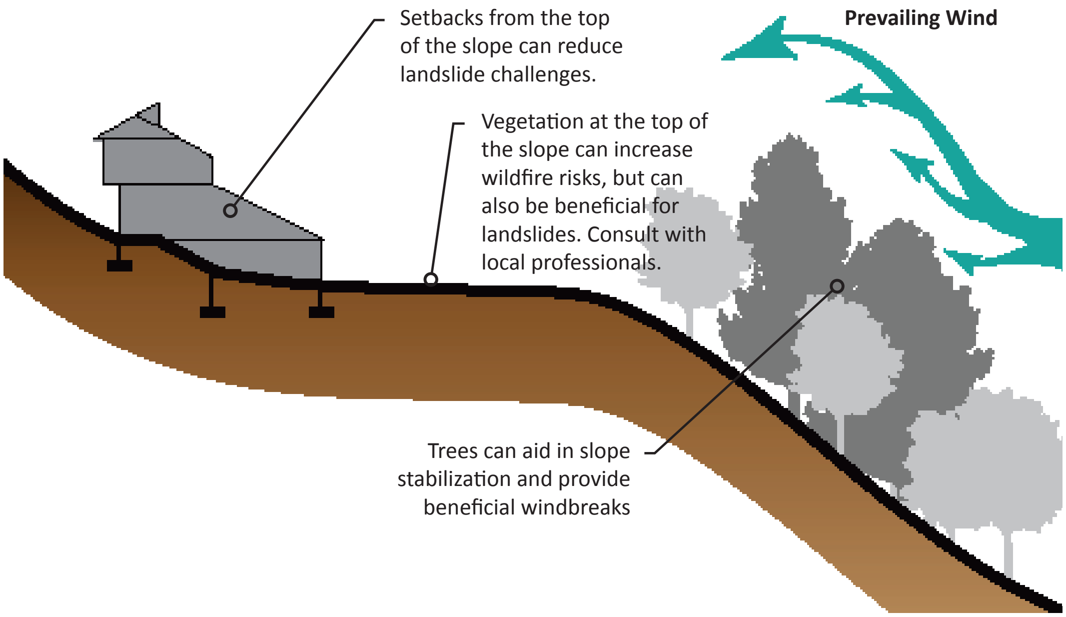
Promotes shade and helps reduce temperatures.

Mitigation Considerations

Massing of trees can increase wildfire risks.

See Defensible Space Zones, Tree Spacing.

Exhibit 5-54. Tree Windbreak on a Hillside



Using trees to buffer hillside communities from winds can be beneficial for reducing landslides and wind impacts, but setbacks and fuel breaks are needed in wildfire-prone communities. Source: MAKERS updated from Department of Landscape Architecture, California State Polytechnic University 1988, "Site Design for Hillside Development."

Site planners using trees as windbreaks in wildfire-prone regions should follow local regulations, defensible space guidance, and open space management best-practices. Providing adequate setbacks for structures, at the tops of slopes, where winds can lead to the rapid spread of fire, is particularly important.

Exhibit 5-55. Windbreak Supporting a Natural Area Buffer

Forested windbreak supports grassland habitat buffer next to farmland near Geraldine, Montana. Similar approaches can be integrated around communities to help buffer some of the impacts from winds. Photo was taken August 2009. Source: U.S. Department of Agriculture—Natural Resource Conservation Service Montana

Wildfire Mitigation and Open Space Management

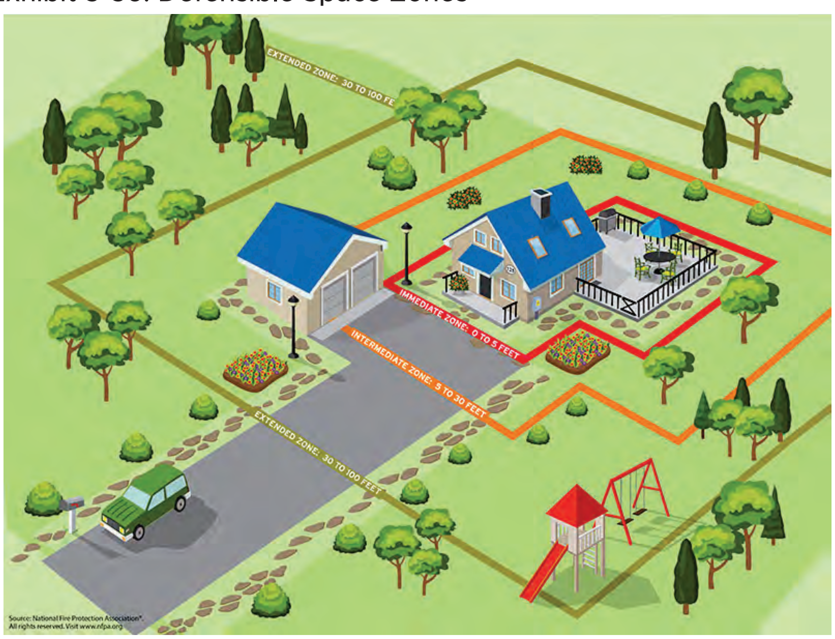
Open spaces and vegetation in wildfire-prone regions are an asset for recreation, flood protection, and stormwater management, reducing heat and mitigating drought impacts, but they are also significant fuel sources that can increase wildfire risk on a site. Thoughtful approaches to integrating and managing trees, vegetation, and open space on and adjacent to sites are critical in this context.

Defensible Space Zones

Use Defensible Space zones to reduce wildfire risk.

Defensible Space is a strategy to reduce wildfire risk, particularly for residential properties. The strategy establishes zones with tailored management recommendations, working outward from the primary structure, to reduce wildfire fuel sources and risks. Each zone has different management recommendations. States may have different zone definitions and/or distance or spacing requirements, so planners need to reference local codes and guidance. Exhibit 5-57 illustrates the framework established by the National Fire Protection Association; however, there are many helpful resources that address Defensible Space. Site planners should reference local wildfire and land management agencies to ensure alignment with local regulations.

Exhibit 5-56. Defensible Space Zones



Overview of Defensible Space strategies. Source: National Fire Protection Association

Mitigation Benefits

Reduces wildfire risks by managing trees, vegetation, and other potential fuel sources around structures.

Mitigation Considerations

May limit use of trees to shade buildings and/or areas of the site.

- Fire Safe House: Although not always explicitly incorporated into Defensible Space guidance, wildfire mitigation strategies start at the structure. See the Buildings section for more information on how building design and materials can reduce fire risks.
- Immediate Zone—typically up to 5 feet from the structure: Remove all combustible materials, including wood mulch, combustible items (outdoor furniture, fencing, arbors, etc.), and dead or dry vegetation. Replace with non-combustible materials such as gravel or pavers.
- Intermediate Zone—typically within 30 feet from the structure: Remove low branches and dead vegetation, separate trees and shrubs, and limit flammable vegetation.
- Extended Zone—typically 30-100 feet or more, depending on site conditions and local regulations: Remove fuel sources such as debris and dead vegetation, create space between shrubs and trees, and prune low branches and shrubs that can serve as ladder fuel.

Tree Spacing Considerations for Wildfire

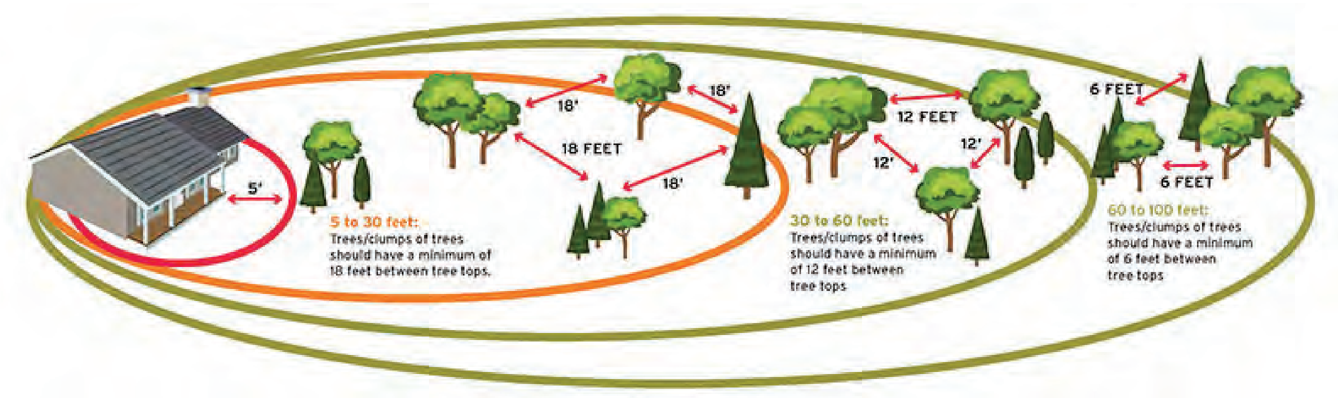
- Tree spacing recommendations will vary based on the underlying defensible space zone and also in response to site topography. Tree spacing should increase as the slope increases. Tree spacing guidelines may also vary between regions—reference local guidelines.
- Tree spacing to reduce wildfire risk is based on the overall diameter of the mature tree at its widest, often referred to as the dripline. This approach differs from typical approaches to tree spacing, which measures trees from the centerline of the trunk.
- Tree spacing requirements for wildfire may reduce the use of trees to provide shade for buildings and/or areas of the site that are adjacent to the development.

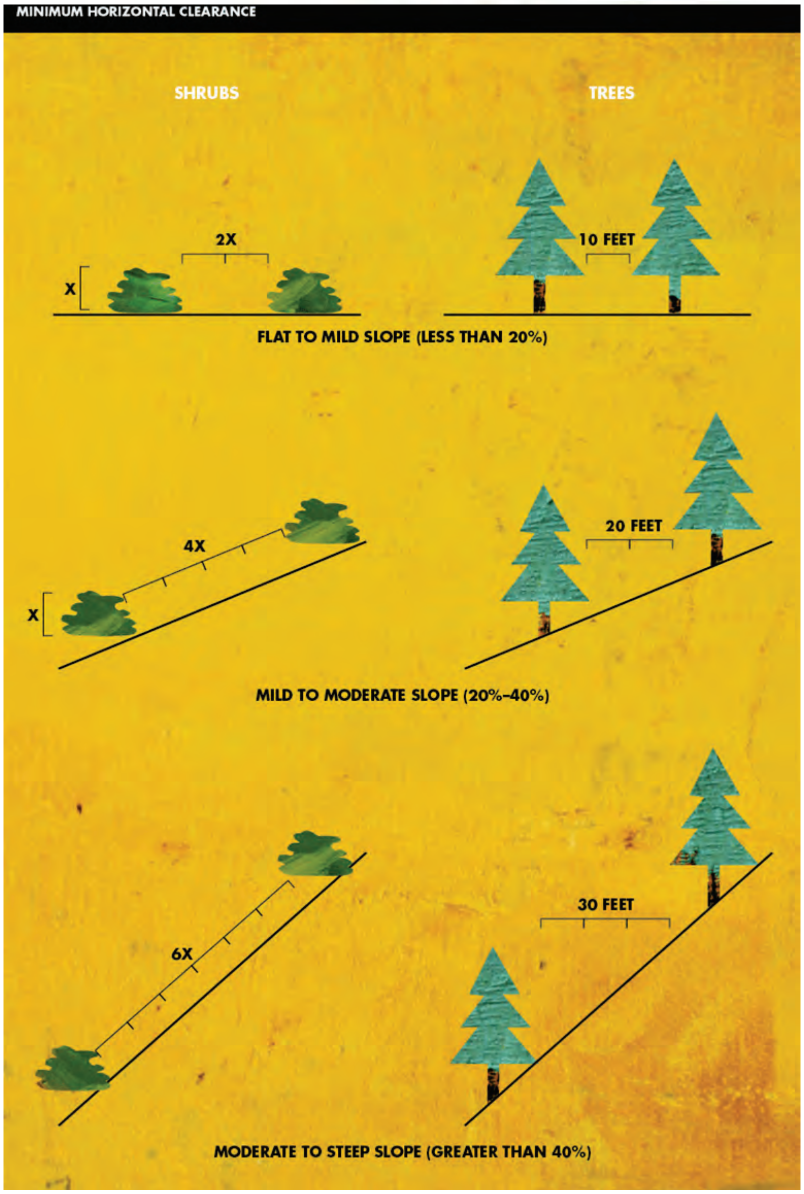
See Tree Spacing.

Resources

- Preparing Homes for Wildfire—
  https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire
- Community Planning Assistance for Wildfire—
  https://cpaw.headwaterseconomics.org/resources/

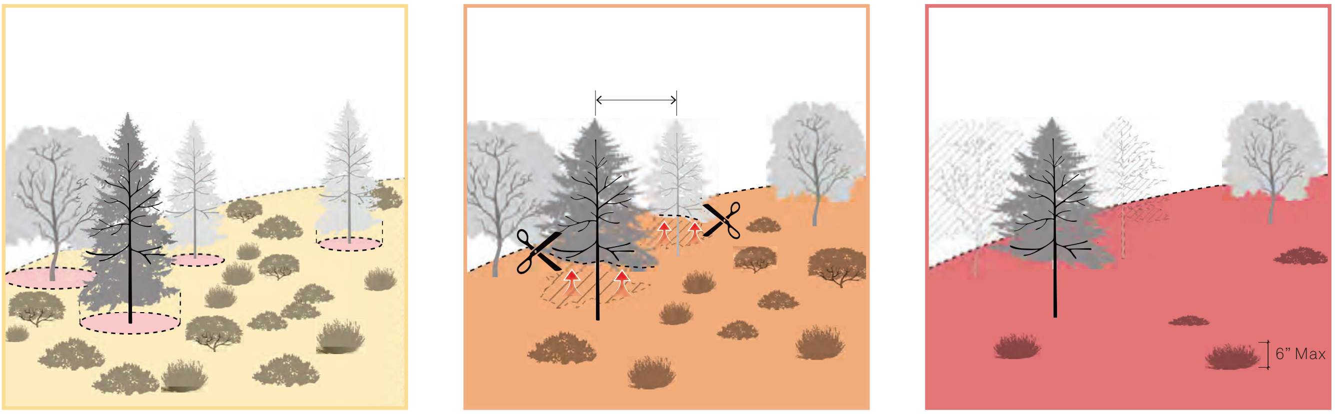
Exhibit 5-57. Tree Spacing





Tree spacing considerations across Defensible Space zones. Guidance for tree spacing can vary; site planners should consult local resources. Sources: National Fire Protection Association (top); Ready for Wildfire—Tree spacing on slopes (bottom)

Exhibit 5-58. Vegetation Management Strategies



ZONE 3

Thinned, Pruned Trees, and Reduced Surface Vegetation

- Encourage a mix of age, size, and species of appropriately spaced and pruned trees
- Appropriately maintain grasslands, through mowing, grazing, or prescribed fire

ZONE 2

Spaced, Pruned, and Limited Low-Growing Surface Vegetation

- Prune trees 6FT to max 1/3 of tree height from ground
- Create distance between conifer tree crowns in Zones 2 and 3, dependent on site conditions

ZONE 1

Reduced, Discontinous, and Intensively Maintained Vegetation

- Limit trees to provide adequate horizontal and vertical spacing
- Maintain grass to a maximum height of 6IN

Vegetation management approaches across wildfire zones. Source: Community Planning Assistance for Wildfire and Design Workshop 2019

Fire Breaks and Fuel Breaks

Use fire breaks and fuel breaks to slow or stop fires.

Firebreaks and fuel breaks are barriers that separate vegetated fuels from other structures or vegetation. They are often linear, such as paved roads, dirt trenches, or zones planted with fire-resistant vegetation.

Firebreaks are strips of bare soil or fire retarding vegetation meant to stop or control fire. Firebreaks typically do not have any fuels, such as trees. This type of break can be seen around structures or near infrastructure, such as under power lines.

Fuel breaks are areas where vegetation has been altered to stop the spread of fire.[327] Importantly, fuel break areas may still burn, but the spacing of trees and careful management of vegetation slows the spread of the wildfire. There are various types:

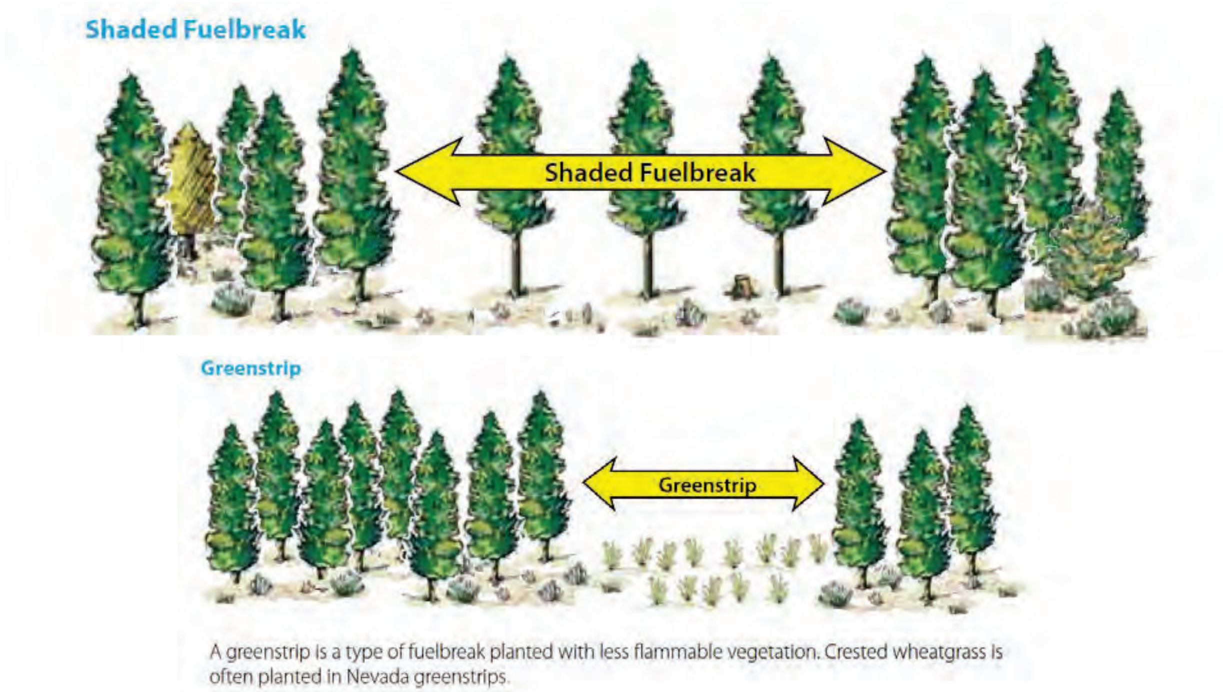
- Shaded fuel breaks are areas where vegetative fuels have been thinned and/or removed, often created on forest lands.
- Greenstrip fuel breaks are areas planted with less flammable vegetation.
- Guidance for overall widths of firebreaks and fuel breaks varies based on local regulations, site conditions, and topography, so site planners should follow local regulations and guidance and work with trained forestry and fire professionals.

Mitigation Benefits

Manages wildland fuel on a site to slow wildfire spread.

See Trails and Open Space.

Exhibit 5-59. Example Types of Fuel Breaks



Source: Smith, Sistare, and Nejedlo, (2011) “Fire Adapted Communities: The Next Step in Wildfire Preparedness.”

Trails and Open Space

Use trails and/or open spaces as a fire management tool.

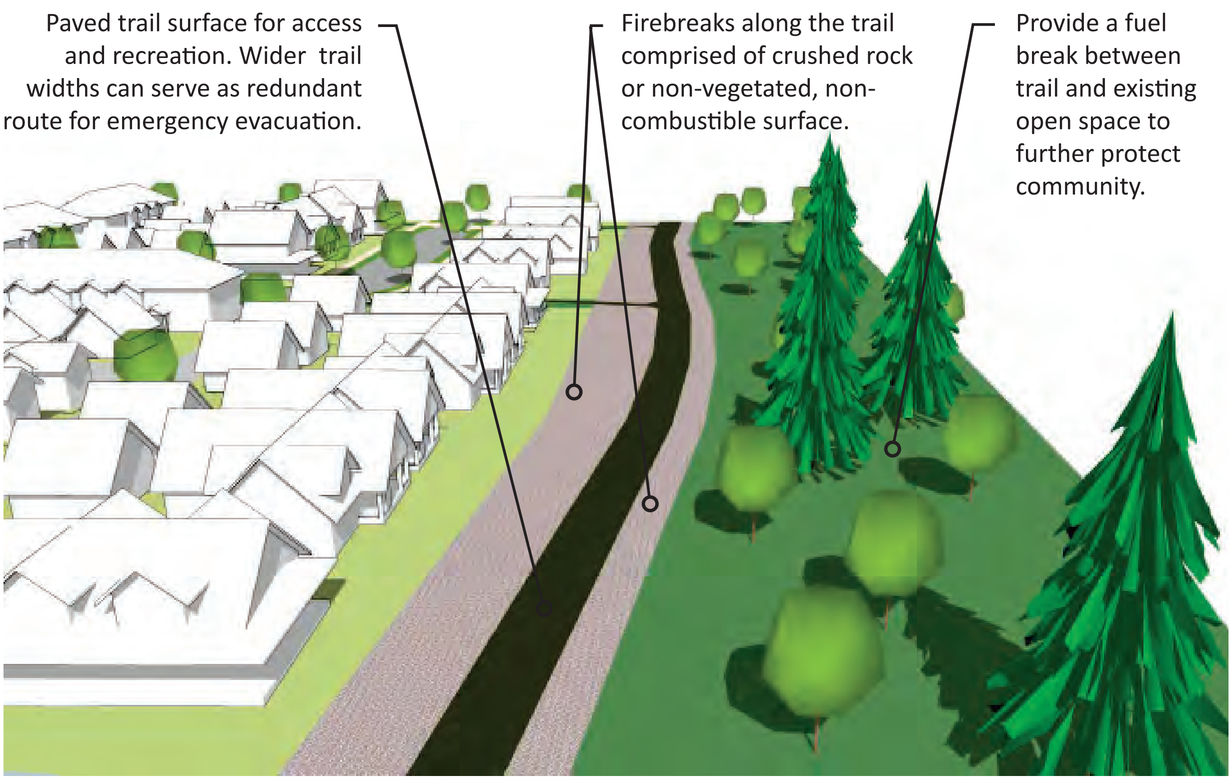
Outdoor recreational areas, agricultural lands, and/or open spaces can also be tools to mitigate fire. Well maintained trails can be used for recreation while doubling as fire breaks and fuel breaks.[328]

On a large scale, open spaces such as farmland can function as a fire break,[329] while smaller open spaces like sports fields or parks can serve as staging areas in emergencies. Such open spaces can play multiple functions, providing trail systems, utility corridors, and general open space recreation functions.[330]

Mitigation Benefits

- Can slow wildfire spread and buffer communities from some impacts.
- Trails and open spaces offer amenities to local residents.

Exhibit 5-60. Trail Designed as a Firebreak



Trail serving as a fire break between a community and open space. Source: MAKERS

Exhibit 5-61. Community Adjacent to Irrigated Vineyard

Irrigated vineyard provides an open-space buffer between the Esencia planned community in Rancho Mission Viejo, California, and wildfire fuel. "With sustainability as a key driver, SWA Group's plan for the Esencia residential community in Southern California's Rancho Mission Viejo was established based on intensive scientific and ecological studies of the site, which resulted in the protection of the most sensitive land within an extensive open space preserve of over 17,000 acres. Citrus groves … were planted along a vulnerable hillside edge as a form of a community-scale, irrigated agriculture wildfire buffer." Source: SWA photo by David Lloyd - https://www.swagroup.com/projects/esencia-planned-community/

Water

Connecting to Water

Provide open space access to shorelines, rivers, and streams where feasible to cool open spaces.

Integrating open space connections to streams, rivers, and shorelines can help cool sites, as winds that pass over water tend to be cooler. Providing public access to shorelines, adding bridges across small creeks, and trails around stormwater retention basins are all ways that sites can connect people to water and offer opportunities for cooler outdoor recreation, even in hot weather. Managed open spaces around water, such as riparian areas, may also provide some buffer protection from wildfire.[331]

Flood risks do need to be considered when connecting to existing areas of open water. Using trails and open space for these connections can also provide opportunities for floodable open spaces, which helps mitigate risks.

Mitigation Benefits

- Provides opportunities for cooling.
- Managed open spaces with water may provide some protection from wildfire.
- Provides access to nature.

Mitigation Considerations

- Consider flood risks when connecting sites to water.

Exhibit 5-62. Accessible Beach Near Residences

Weather Watch Park in Seattle, WA. Source: John M Feit, Seattle Department of Transportation Blog

Water Features

Use spray parks, fountains, and/or open water features to mitigate urban heat stress.

Water features are popular amenities for children in community parks and can help mitigate urban heat stress.[332] In the context of warmer future temperatures, site planners should ensure water sources can support the demand of these features. Water-saving approaches, such as misters, may offer similar delight on sites with tighter water budgets but are less effective in high-humidity climates. Planners should ensure surface materials can stay cool and safe on hot weather days. In areas vulnerable to wildfire, open-water features can also be located to break up the continuity of fuel across the site, potentially reducing the speed and/or intensity of the wildfire's impact on the site.

Mitigation Benefits

- Provides opportunities for cooling.
- Provides recreation space.

Exhibit 5-63. Spray Parks

Spray parks can help people cool down during hot weather.

Utilities

This section covers the utilities that typically serve communities, including power, water supply, sewer and wastewater, and waste and recycling. Extreme weather and storms can severely impact utilities and, thus, the community's ability to function normally. Locating utilities carefully and strengthening them against impacts can increase site resilience and reduce the scale of a disaster following a major storm or other event. Considering future resource availability and emergency response needs can also help ensure communities are resilient to service disruptions and/or fluctuations in the water supply. Energy-efficient communities also mitigate climate change, which can prevent natural hazard impacts from worsening over time.

Locating Utilities On Site

Resilient Utility Easements

Plan and design onsite utility easements to minimize vulnerability to hazards and increase overall site resilience.

Easements for utilities, both above and below ground, should be sited to minimize risk from natural hazards. Utility easements should be located outside of flood and landslide hazard zones whenever feasible.[333] Utility transmission lines located in flood hazard areas should be redundant with other systems whenever possible to ensure continued service to the area in the event of a flood or natural hazard. Any utility transmission lines that contain toxic or flammable materials should be buried at least below the calculated maximum depth scour for a 1-percent annual chance of flood.[334]

Infrastructure that must be located within tsunami hazard areas should serve as small an area as possible. Where infrastructure connections cannot be avoided, redundant infrastructure connections can increase resilience. Larger infrastructure, such as switching stations, should not be located in tsunami hazard areas.

Utility easements on wildfire-prone sites can be designed to serve as a wildfire break which both minimizes the risk to the utility and increases overall community resilience.[335]

Mitigation Benefits

Reduces some impacts by:

- Locating utilities outside of flood-prone areas.
- Buffering utilities from winds.
- Buffering utilities from extreme heat.
- Locating utilities underground or buffering them from wildfires.
- Locating utilities outside of landslide-prone areas.
- Locating utilities outside of high-risk seismic areas, such as liquefaction-prone sites, where feasible.
- Locating utilities outside of tsunami inundation areas, where feasible.

See also **Strengthen Above-Ground Utilities**, **Trees and Vegetation**, and **Wildfire Mitigation and Open Space Management**.

Power Utilities

Above-ground power lines and poles and other facilities are the most vulnerable component of the electric grid.[336] Overhead electrical and communication lines are major contributors to the ignition of wildfires, as seen in the California Camp Fire Wildfire of 2018. Overhead power lines can also be significantly damaged by wildfire, as well as pose a risk to first responders and the heavy equipment used for fire suppression. Overhead power lines are also vulnerable to damage from hurricanes in coastal areas, strong wind events, floods, and earthquakes. Due to the colocation of power lines and rights-of-way, downed power lines can also impede egress in the event of a natural disaster.[337]

The effects of power outages on a community can be widespread, and the loss of power and communications in the event of a natural disaster can have catastrophic effects. An interruption of power can have major impacts on critical infrastructure such as water treatment plants, pumping stations, and hospitals. Impacts can also be felt by the community in their homes as power outages can lead to loss of heating and cooling, which can be especially harmful in events of extreme temperatures, as well as loss of refrigeration which can impact food storage. These effects are exacerbated in many rural and indigenous communities where monitoring is more difficult and response times to address power outages are longer.[338] To better understand the overall resilience benefits, the American Planning Association (APA) has recommended communities analyze the resilience benefits of underground electric distribution systems in coastal areas, places vulnerable to strong wind events and wildfire, and areas vulnerable to severe winter weather, and require underground power lines in places where it would be most beneficial.[339] New, decentralized approaches to power supply, such as microgrid strategies, can also reduce a community's reliance on long-distance power transmission and limit the local impacts to power supply following a natural hazard.[340]

Exhibit 5-64. Power Lines Damaged by Wildfire

"East Troublesome Fire damage" in Colorado. Source: Ron Burbridge, © 2020

Locate New Power and Communication Lines Underground

Consider locating site power utilities underground to increase site resilience, particularly in coastal areas and places vulnerable to strong winds, wildfire, and extreme heat.

Site planners should carefully weigh the resilience benefits against potential risks and costs when making decisions about locating power and telecommunication lines above or below ground. Underground power lines can avoid some of the site-scale impacts that above-ground utilities face and allow for faster recovery post-disaster once regional service is restored.[341] The APA highlights the hazard mitigation benefits of undergrounding utilities in high-risk areas in their Hazard Mitigation Policy Guide.[342] Furthermore, locating power and telecommunication lines below ground can provide the added benefit of freeing-up right-of-way space, allowing site planners to plant larger street trees, expand sidewalks, and/or add bike lanes. Despite these benefits, underground utilities can still be vulnerable to damage from some natural hazards, including earthquakes, major floods, extreme temperatures, excavation work, and corrosion. Additionally, higher installation and maintenance costs, as well as longer wait times for locating and repairing damaged lines, are associated with undergrounding of utilities.[343] Site planners must also ensure power utility infrastructure aligns with local regulations and power utility service requirements.

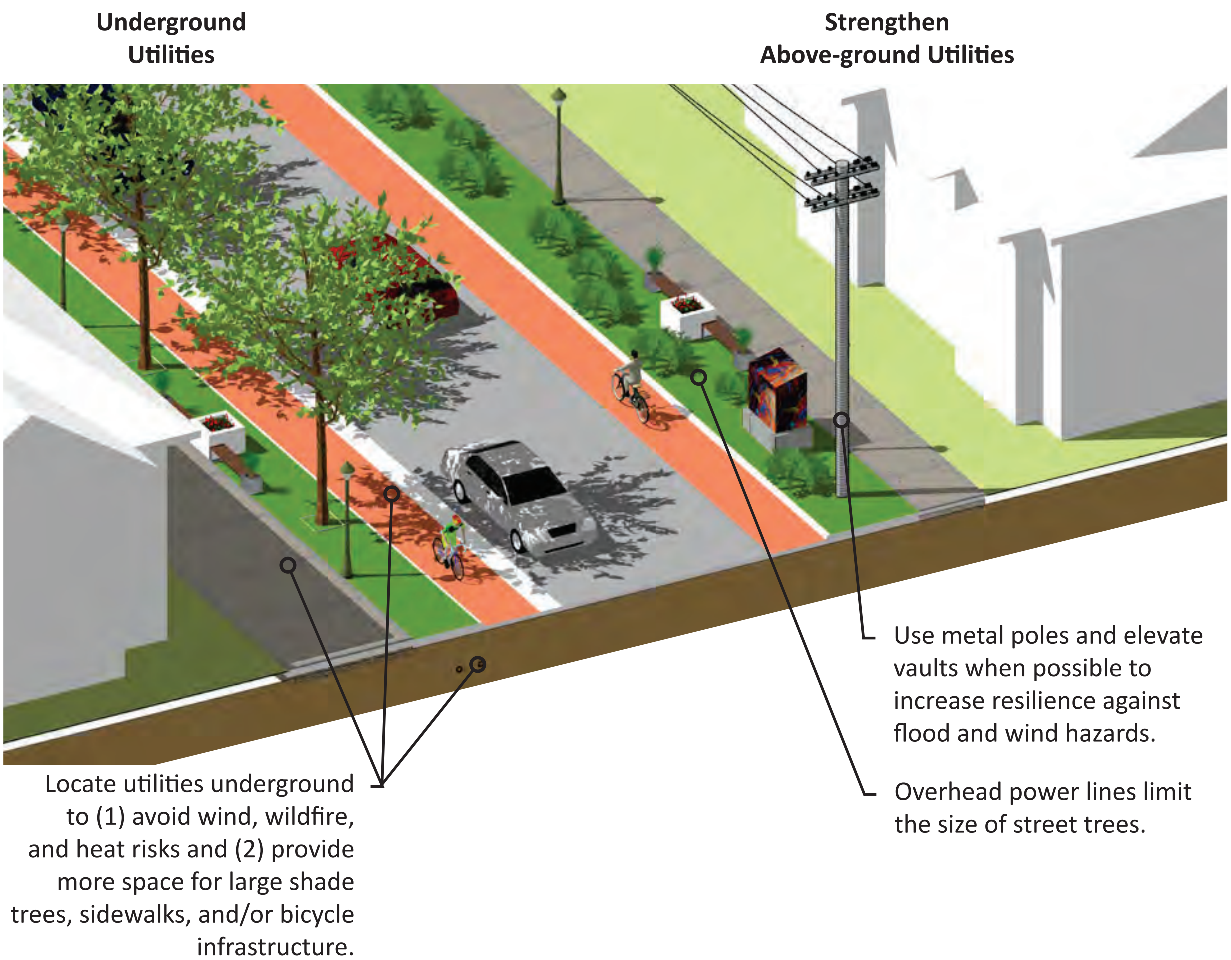
Mitigation Benefits

- Protects utilities from above-ground damage during floods.
- Protects utilities from wind damage.
- May offer some protection from heatwave impacts.
- Protects utilities from wildfires and reduces risk of new wildfires starting from contact with overhead lines.
- May reduce some impacts to overhead utilities from shaking in smaller earthquakes.
- Frees up right-of-way space for trees, pedestrians, and/or multimodal facilities.

Mitigation Considerations

- Underground utilities must meet strict standards to ensure they are safe during floods.
- Major earthquakes can disrupt or damage underground infrastructure.

Exhibit 5-65. Underground Versus Strengthening Above-Ground Utilities



Source: MAKERS

Strengthen Above-Ground Utilities

Strengthen above-ground power utilities in areas vulnerable to natural hazards where locating service underground is not feasible or will not increase resilience.

Strengthening utility poles and other infrastructure elements associated with electrical power services is a strategy that can be beneficial to multiple natural hazards, although the specific approaches may vary depending on the specific risks. Hardening utilities against extreme weather includes elevating equipment, reinforcing poles and other equipment against wind loads, and installing physical barriers.[344] Hardening strategies to combat wildfires may include using non-combustible poles to support above-ground power lines.[345] Emerging remote monitoring technology can also be installed on utility poles to allow for early detection of potential wildfire risks.[346]

Careful coordination of site trees and vegetation around above-ground utilities is critical to ensure the trees will not create hazards and maintenance challenges as they grow to a mature size. Vegetation should be kept clear of above-ground power lines. Tree setbacks, selection of fire-resistant understory plants, and regular pruning and maintenance of vegetation in areas adjacent to overhead power lines are all strategies that can reduce wildfire risks. See Trees and Vegetation for more information.

In areas prone to flooding, hardening strategies like waterproofing and raising electrical boxes and conduits above the floodplain may reduce the impacts to the power grid and service. The use of proper materials is also essential where coastal flooding may cause corrosion and damage from saltwater inundation.[347] Design approaches, such as using different circuits for site lighting in areas of the site that are more vulnerable to flooding, can prevent the failure of the entire system if the low-lying areas flood.[348]

Case Study—Babcock Ranch

Babcock Ranch is a planned community located 12 miles inland from Fort Meyers, Florida. The community was planned and designed around goals for sustainability and hazard resilience. The community was located on a naturally high-ground site with elevations up to 25’ above sea level, and all development areas are outside of flood zones. Surface water management incorporates natural systems, native plants, and historic drainage flows, and all structures are designed to withstand winds of up to 145 MPH.[349] Utilities are located underground, and the site is powered by a large solar farm that also feeds energy back into the grid.

When Hurricane Ian hit the Fort Meyers area in 2022, the community withstood the storm with minimal damage and no loss of power. For more information, see:

- https://babcockranch.com/babcock-ranch-resilient-design/

Mitigation Benefits

- Protects utilities from some flood damage.
- Protects utilities from some wind damage.
- Protects utilities from some wildfire damage.
- Protects utilities from some earthquake damage.

Exhibit 5-66. Steel Utility Pole

Aaron Manning, Saint Tammany Parish, Louisiana, March 2011.

- https://resilience.iii.org/resilience-blog/general/advance-mitigation-better-building-codes-pay-off/
- https://www.resilientdesign.org/babcock-ranch-a-solar-town-proves-resilient-during-hurricane-ian/

Resource

- UC Berkeley Disaster Lab—https://disasterlab.berkeley.edu/

Microgrid Approaches for Power Supply and Emergency Back-Up

Consider opportunities for microgrid power connections emergency power supply from onsite power generation and storage.

As areas have become more frequently impacted by power service interruptions, either from storms, wildfire risk, or resource management needs due to drought, local power generation and emergency power supply are strategies that site planners and emergency managers are increasingly using to augment site resilience. Advancements in meters, switches, and microgrids have made it easier to compartmentalize outages and control the electric grid, while renewable energy technologies have also made local energy production feasible and increasingly cost-effective. Microgrids can offer a solution to disturbances to the main electrical grid because they allow disruptions—planned or not—to be isolated to one part of the electric grid.[350] Microgrid communities are designed to operate when grid-connected and as an island, meaning that microgrids can disconnect and generate power locally during a service interruption. Conversely, disruptions to supply within a microgrid can be compartmentalized and will avoid the impact of disruptions to the main grid.[351]

Microgrids bring the added benefits of increasing renewable energy sources that reduce carbon emissions, as wind and solar are both decentralized power sources commonly used in microgrids. Lowering carbon emissions aids climate change mitigation and reduces the potential for increasing natural hazard impacts in the future. Generating energy closer to where it will be used is also more efficient, reducing the amount of energy lost during transmission.[352] Rooftop solar installations have become common in recent years, but creative approaches can sometimes offer multiple site benefits. Examples include shade structures for parking areas, installations over pathways, integrating solar panels with agricultural areas, and covering reservoirs to limit evaporation.

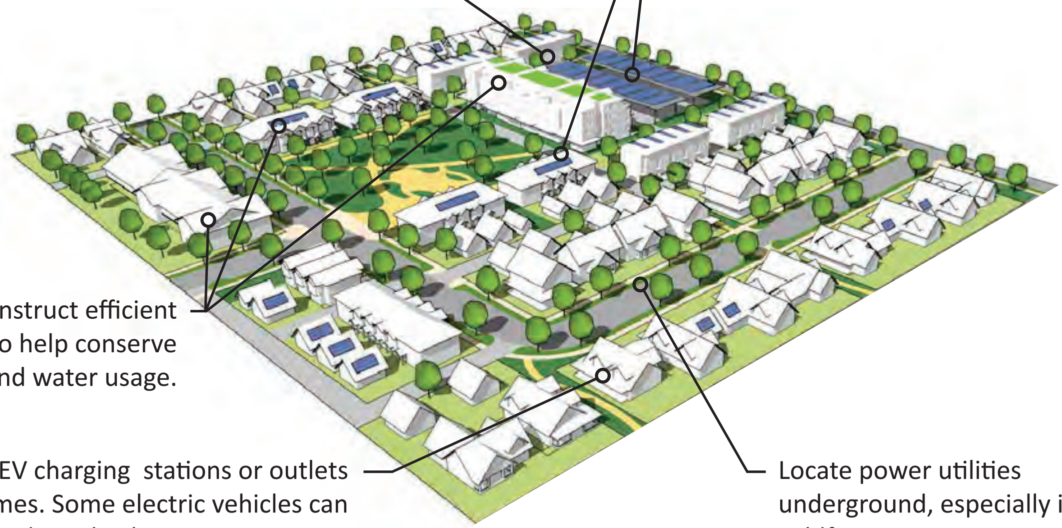
Emergency backup supplies can be added to a microgrid community through battery storage on site. As electric vehicles become more common, some car manufacturers and urban planners are exploring how vehicles can be used to supply back-up power.[353]

Mitigation Benefits

Offers power service stability during:

- Outages caused by floods.
- Outages caused by windstorms.
- Disruptions caused by heat waves.
- Outages and disruptions caused by wildfire.
- Outages caused by landslides.
- Outages caused by some earthquakes.

Exhibit 5-67. Localized Micro-Grid Electrical Infrastructure Strategies



Source: MAKERS

The microgrid model can also work at a small scale and help residents and/or local businesses function following a natural hazard. Power outages can be devastating to small restaurants, which lose money on spoiled food, etc. The Get Lit Stay Lit program in New Orleans, Louisiana, helps local restaurants purchase and install solar panels and batteries, reducing energy costs and helping to prepare for hurricane and flood impacts. The program also provides work training on solar panel installation.

Resource

- Get Lit, Stay Lit program—
  https://www.feedthesecondline.org/programs/getlitstaylit

Exhibit 5-68. Electric Vehicles and Microgrids

Testing electric vehicles (EV) at the National Renewable Energy Laboratory in Jefferson County, Colorado. The Optimization and Control Lab's EV grid integration research bays perform advanced high-power chargers to determine how they can be added to the grid, potentially combining buildings and EV charging. Source: Department of Energy via Flickr

Waste and Recycling

Damage from natural hazards creates a significant amount of waste material that can be burdensome for communities during the post-disaster recovery phase. Key issues include the volume and composition of waste, availability of temporary sites to manage the debris, hazardous materials and environmental concerns, economics, and social considerations.[354] Although post-disaster recovery is often beyond the scope of when site planners are typically involved, for places highly vulnerable to natural hazards, or those that have been impacted in the past, site planners may consider the following strategies. For more information, visit the following source:

- Converge Natural Hazards Centers—University of Colorado, Boulder Extreme Events Reconnaissance and Research Networks—Sustainable Material Management Extreme Events Reconnaissance (SUMMEER). https://converge.colorado.edu/research-networks/

Onsite Waste Anchoring and Enclosure

Protect outdoor waste and recycling areas from natural hazard impacts through anchoring, secure enclosures, or relocation to buildings.

In the event of a natural hazard, such as a flood, onsite waste and recycling areas (i.e., dumpsters, waste receptacles, etc.) that are not properly anchored or enclosed can cause further site and structure damage (projectile that damages other structures, flammable material, etc.). Enclosed waste areas can have positive co-benefits to people-friendly design by improving aesthetics and creating a place for chance social interaction.

Mitigation Benefits

Reduces site damage during:

- Floods.
- Windstorms.
- Wildfires, if potentially flammable waste is stored on site.
- A landslide.
- An earthquake.
- Enclosing waste and recycling areas can have aesthetic benefits for the site.

Space for Post-Disaster Waste and Recycling

Consider post-disaster waste management needs when developing site plans in coastal areas and other places highly vulnerable to natural hazards.

Open spaces, surface parking lots, and other areas of the site could be used post-disaster for temporary waste and recycling staging and management. Well-designed open spaces provide community gathering spaces, as well.

Mitigation Benefits

Increases resilience post-disaster by providing adequate space for community clean-up and waste removal from:

- Flood damage to site and buildings.
- Wind damage to sites and buildings
- Wildfire damage to site and buildings.
- Landslide damage to site and buildings.
- Earthquake damage to site and buildings.
- Identifying spaces for post-disaster recovery coordination can increase community resilience by raising awareness of potential risks.

Wastewater

Wastewater infrastructure is an important consideration for site planners when developing new residential areas. In many rapidly urbanizing areas, communities oversee a public sewage system that can be updated or extended to provide service for the community, sometimes as an incentive to promote more housing and economic growth. Sites that are connected to existing infrastructure are typically the most resilient, but community-based approaches can allow for improvements to aging systems that are a key hazard vulnerability in many communities. See the following resource for more information:

- Climate Change and Onsite Wastewater Treatment Systems in the Coastal Carolinas, North Carolina Sea Grant—https://ncseagrant.ncsu.edu/program-areas/sustainable-communities/climate-change-and-onsite-wastewater-treatment-systems-in-the-coastal-carolinas/

Sewer System Connections

Connect new development to municipal sewage systems when possible.

Sites that are connected to municipal sewage systems are more resilient to impacts from floods and natural hazards and provide greater protection for the natural environment.[355] Aging septic systems can pollute water during floods, especially in coastal areas.[356] Upgrading from septic to municipal systems can reduce this risk. Sites that are connected to existing infrastructure also typically align with local and regional growth planning and provide better opportunities for compact development, multimodal access, and other smart-growth development practices. In areas where existing infrastructure is limited or must be extended, work with local planners and emergency managers to identify potential opportunities for increasing community resilience through wastewater system upgrades.

Mitigation Benefits

Supports compact development and promotes water quality.

Supports compact development.

Newer infrastructure designed for seismic risks may withstand greater earthquake impacts.

Mitigation Considerations

On sloped sites or where there may be landslide risks, locate sewer lines to drain away from the slope.

Community Wastewater Systems

Replace and upgrade aging wastewater systems where connections to public infrastructure are not available or feasible.

In some rapidly urbanizing communities, connections to municipal sewer systems are not available, and site planners must look to onsite options for managing wastewater. Community wastewater systems, which are similar to septic systems but take a community-scale approach to wastewater treatment, can provide options for effective, safe wastewater treatment for communities and the local environment.[357] Such strategies may be particularly valuable in infill development situations where a community-based approach could replace older septic systems that are vulnerable to flooding, particularly in coastal areas. Site planners should work with local planners to determine the infrastructure solutions that work best for the site.

Mitigation Benefits

Addresses pollution and water quality concerns in coastal communities vulnerable to flooding.

Outfall Location and Protection

Locate and protect outfalls to reduce the risk of back-flooding, particularly in coastal areas.

Stormwater pipes can be vulnerable to back-flooding where open pipes outfall in areas where water levels fluctuate during high tides, storm surges, and/or flood events. Installing outfall flap gates where appropriate can prevent contaminated floodwaters from traveling up into pipes.[358]

Resource

- Preventing Stormwater Flooding Along the Hampton River—WaterWorld https://www.waterworld.com/water-utility-management/article/14207511/red-valve-company-preventing-stormwater-flooding-along-the-hampton-river

Mitigation Benefits

Addresses back-flow flooding issues in coastal communities.

May reduce back-flow flooding issues during small tsunamis.

Exhibit 5-69. Backflow Device Prevents Stormwater Flooding in Australia

“Backflow devices installed in Chelmer along the Brisbane River in Queensland, Australia, for preventing stormwater flooding”. Source: Kgbo

Water Supply

A safe and consistent water supply is fundamental to housing development and is a resource that is carefully managed at local, regional, and state levels. However, as climate change disturbs weather and precipitation patterns, water resources in many areas of the country are under threat from extreme heat and prolonged drought.[359] Communities, particularly in the western United States, are starting to make difficult decisions on how to allocate diminishing water resources. Some communities have halted plans for growth as a result.[360] Other communities, particularly those that rely on resources from adjacent communities, have faced disruption or the elimination of water service to their homes as a result of prolonged drought.[361]

The impacts to water resources are not limited to extreme heat and drought. In recent years, floods have impacted municipal water treatment plants, temporarily threatening water service to large numbers of people. Coastal areas are also susceptible to contaminants like saltwater infiltrating aquifers due to sea level rise, compound flood events, or rising water tables.[362] This contamination could result in drinking water becoming unsuitable for consumption or degradation of ecosystems that rely on freshwater from aquifers.

As discussed in Site Analysis, site planners should carefully review existing water sources for a site and assess the potential for water source instability in the future. In areas where water instability is possible, compact development, green infrastructure and nature-based solutions, low-water landscapes, efficient irrigation, and water harvesting and storage are all water conservation strategies that can be integrated into a site.

See the related strategies in the following sections for more information: Site Layout, Circulation, and Access, Open Space and Green Infrastructure, and Buildings.

Firefighting Water Supply

Work closely with local planners and fire and emergency management officials to ensure sufficient water supply infrastructure in wildfire-prone communities.

Water supply challenges and limitations can be major challenges during a wildfire. Access to water for fire suppression may be obstructed if lines or hydrants are exposed to fire.[363] The amount of water that is available during a wildfire may also be reduced due to increased demand at the community level. Rapidly urbanizing communities, particularly in wildland-urban interface (WUI) areas, may rely on older infrastructure that has limitations in flow or supply.[364] Rural and indigenous communities may rely on wells and pumps, which may be unmaintained or unregulated, for fire suppression.[365] Non-gravity water pumps that use electricity may become inoperable during a fire if power to the pump is interrupted or not accessible, requiring the use of back-up generators or diesel-fueled pumps.[366] Site planners should work closely with local planners and fire and emergency management officials to ensure the site has robust water infrastructure that is sufficient to meet current needs and resilient to changing future conditions.

Mitigation Benefits

Ensures development has adequate water supply for wildfire response or a plan for alternate water sources.

Exhibit 5-70. Forest Fire Water Supply

Dry Fire Hydrant in East Haven, Vermont.
Source: Artaxerxes

Efficient Water Infrastructure

Use high-quality and efficient water supply infrastructure on site.

Using high-quality, efficient water infrastructure on site can help minimize the risk of leaks and waste. If a site will be using some existing infrastructure, careful inspection of underground systems and monitoring may be needed to ensure the system is not vulnerable to damage due to changes in groundwater levels, salt-water intrusion from sea level rise, flooding, subsidence, and landslides.

Mitigation Benefits

Can reduce risk of leaks that cause local flooding.

Conserves water for other uses within the community.

Conserves water for other uses within the community, such as wildfire response.

Mitigation Considerations

Underground systems can be vulnerable to changes in groundwater levels, etc.

Back-up Water Supply

In areas highly vulnerable to wildfire, drought, and floods, work with local planners and emergency officials to identify opportunities for backup water supply sources, either via municipal resources or onsite storage.

Access to safe drinking water is essential for the post-disaster recovery of a community. Essential health and emergency facilities, such as hospitals, have to prepare for the possibility of water shortages in the event of an emergency.[367] While site planners may not always be able to provide onsite sources for emergency use, early coordination with local planners and emergency management officials can help identify potential challenges and opportunities, which can increase the overall resilience of the site.[368]

Case Study—San Diego Water Management and Successful Water Conservation

Some communities that have taken steps to address water conservation are seeing success. The City of San Diego, California, and other Southwestern communities have been able to reduce water through adaptation strategies, allowing these communities to continue to explore growth even during severe drought conditions. Adaptation strategies range in scale from home and site to regional and include:

- Replacing lawns with low-water landscapes and limiting outdoor water use.
- Low-flow plumbing fixtures.
- Preventing leaks.
- Water recycling and desalination.
- Shifting water rights.

Resource

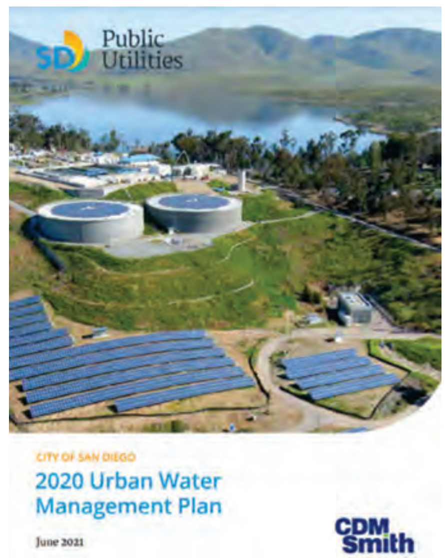
- Yale Environment 360—"A Quiet Revolution: Southwest Cities Learn to Thrive Amid Drought" https://e360.yale.edu/features/a-quiet-revolution-southwest-cities-learn-to-thrive-amid-drought

Mitigation Benefits

Provides water source stability in areas highly vulnerable to:

- Service disruptions due to floods.
- Service instability and disruptions due to heat waves and droughts.
- Service disruptions and emergency response needs due to wildfire.

Exhibit 5-71. San Diego's Plan for Water Management



2020 Urban Water Management Plan. Source: City of San Diego, California

Buildings

This section, at a high level, addresses strategies for the shell or form of a building and how it connects to the site, such as elevating buildings and green roofs. Considering how building surfaces reflect or absorb heat, withstand and direct wind, and manage or produce runoff are all important considerations that influence resilience.

This section does not provide detailed guidance on architectural and structural design of buildings, material selection (including recycled materials, lower carbon generating materials, etc.) details, or interior systems (i.e., energy efficient, low carbon approaches, etc.) However, these issues are important subjects that can contribute significantly to overall site resilience and play a critical role in climate change mitigation. All construction must meet or exceed the requirements of the local building code or the consensus state or national code if no local code has been adopted. Site planners should reference sources from FEMA, HUD, local building codes, and local planning and emergency management offices for guidance in this area.

Local Building Codes

Many strategies are included in local building codes, such as structural systems and materials for: [369]

- Wind hazard resilience (e.g., tie-downs for hurricanes).
- Seismic hazard resilience.
- Fire.
- Flood.

Follow Local Building Codes

Plan projects to align with most recent local building codes and reference standards.

Building codes are updated regularly to ensure local codes align with best practices and current approaches. Careful adherence to local codes has been shown to reduce property losses from natural hazards across the country.[370] As areas are exposed to more natural hazards, ensure that projects comply with the most recent local building codes and reference standards.

If there are cases where local standards are outdated or unavailable, or if emerging resilience strategies conflict with local standards, work closely with local community planners to determine the best approach for the project. All construction must meet or exceed the requirements of the local building code or the state building code if no local code has been adopted. If the state has not adopted a building code, then the latest edition of the relevant International Code Council consensus codes must be used. For one-and two-family residential construction, use the International Residential Code (IRC). For all other buildings follow the International Building Code (IBC).

Site planners should also consider surpassing building code requirements, as this approach can increase site and building resilience. The code is a minimum that is calibrated to limit structural collapse. Going beyond code reduces that probability even further. Programs like FORTIFIED can be a tool for achieving higher levels of performance, and, in some areas, building to these standards can reduce insurance premiums. Also, several FEMA products, such as FEMA 232, Home Buildings Guide for Earthquake Resistant Design and Construction, and FEMA P-804, Protect Your Property from High Winds: Wind Retrofit Guide for Residential Buildings, identify a series of "above code recommendations" to provide better performance.

Resources

- FEMA Building Code Playbook—https://www.fema.gov/sites/default/files/documents/fema_building-codes-adoption-playbook-for-authorities-having-jurisdiction.pdf
- FORTIFIED—https://ibhs.org/fortified/

Mitigation Benefits

Following codes can reduce:

- Floodwater damage to building materials and mechanical systems.
- Windstorm damage to building envelopes and roofs.
- Heat wave and drought impact on building systems and materials.
- Potential for ignition during wildfire.
- Landslide damage to structures or foundations.
- Earthquake damage to buildings or foundations.
- Tsunami wave impacts to buildings and foundations, and floodwater impact to building materials and mechanical systems.

- FEMA 232—Homebuilder's Guide to Earthquake-Resistant Design and Construction
https://www.fema.gov/node/homebuilders-guide-earthquake-resistant-design-and-construction
- FEMA P-804—Wind Retrofit Guide for Residential Buildings
https://www.fema.gov/sites/default/files/2020—08/fema_p804_wind_retrofit_residential_buildings_complete.pdf

Building Form

The form of the building and how it connects to the site is an important consideration when building on sites that are vulnerable to natural hazards, such as floods and strong windstorms. These strategies are particularly common, and in many cases required, when building in coastal areas, which are vulnerable to storm surges and hurricanes, in addition to nuisance flooding and sea level rise. Many of these strategies are also employed in areas vulnerable to riverine flooding. The ultimate strategy used to address flood and/or storm hazards is influenced by federal, state, and local regulatory requirements, so site planners must be familiar with relevant regulations.

Resources

- Coastal Climate Resilience: Urban Waterfront Adaptive Strategies (New York City) — https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf
- Coastal Flood Resilience Design Guidelines (Boston) — https://www.bostonplans.org/getattachment/d1114318-1b95-487c-bc36-682f8594e8b2
- Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas (Fourth Edition)—FEMA, 2011 https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf
- Reducing Flood Risk To Residential Buildings That Cannot Be Elevated—FEMA, 2015 https://www.fema.gov/media-library-data/1443014398612-a4dfc0f86711bc72434b82c4b100a677/revFEMA_HMA_Grants_4pg_2015_508.pdf

Elevating Buildings

Elevate buildings above the design flood elevation by raising the existing grade below the structure or by using structural solutions, such as piles or floodable ground floors.

Elevating buildings above the design flood elevation is a strategy to address flood hazards at the building scale. The following considerations are important when weighing options for building elevation:

- In coastal areas, assess and integrate future sea level rise projections into the design flood elevation to ensure sites and buildings are resilient to future sea level rise risks.[371]
- FEMA requires and restricts mitigation strategies for sites and buildings based on the underlying flood hazard zone. Site planners must meet or exceed any requirements associated with the site's flood hazard zone.[372]
- Elevating homes can negatively impact human interaction at the street level when inactive uses (e.g., garages) fill the ground floor. On the other hand, elevating up to about 6 feet can have positive benefits for compact development (in this case, narrow setbacks between the home and the street) for clearly delineating a transition to private space and providing a natural viewing area onto the street.
- Elevating buildings above street level can impact ADA accessibility, so ramps, elevators, and stair lifts may be necessary.
- Elevating commercial uses above sidewalk level can make it harder to provide ADA-accessible frequent entries, which is helpful for supporting smaller business spaces and providing a lively street environment.

Elevating on Fill[373]

- On larger sites, elevating buildings can be done by raising the grade of the building site to be above the design flood elevation.
- Elevating building sites can create complications when connecting to adjacent streets and infrastructure. Site planners should consider both the feasibility and benefits of elevating larger portions of a site rather than just the building site.
- The type of fill material used to elevate the structure is an important consideration with implications for public safety, resilience, and environmental health. Site planners must follow federal, state, and local regulations.
- In some cases, elevating structures using fill can reduce flood insurance requirements or allow for the site to be removed from the flood hazard zone.
- Elevating on fill can also provide opportunities for open space improvements around the structure.

Mitigation Benefits

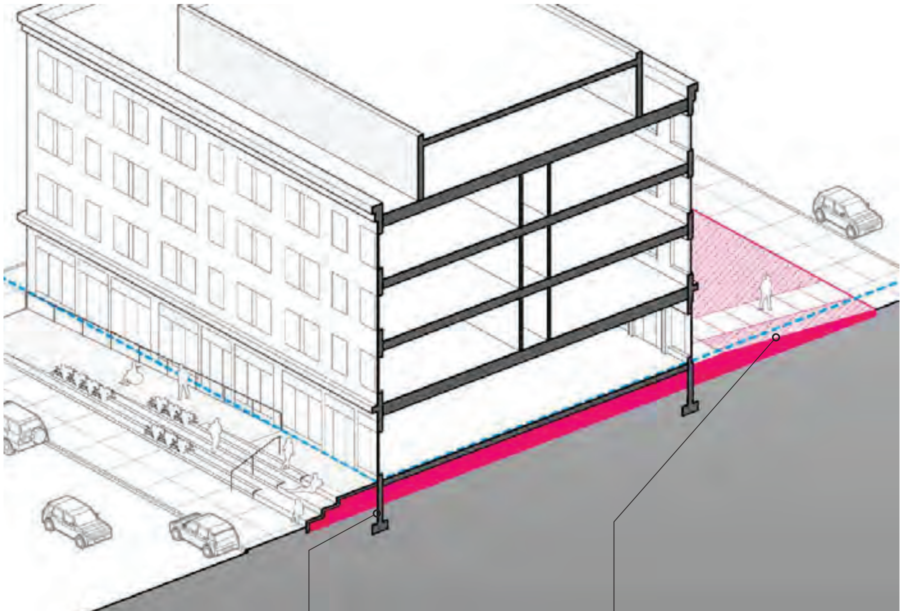
- Can reduce harm to buildings during floods.
- Can provide vertical evacuation.

Mitigation Considerations

- Use fire-resistant materials to elevate and enclose structures in wildfire-prone regions.
- Elevated buildings are more vulnerable to seismic risks, requiring specialized structural and/or foundation designs.
- Can create access challenges and awkward connections between site and the building.

Exhibit 5-72. Elevation of a New Building on Fill in an Urban Environment

Technical Considerations



Structural stability

Buildings and sites elevated on fill must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion.

Use Restrictions

Use of this strategy should not result in habitable spaces below the SLR-DFE, such as basement units.

Foundations

Solid foundation walls below the lowest occupiable floor should be designed with flood openings to relieve flood pressure, should water exceed 1' of depth above the lowest adjacent grade.

Materials

Building materials below the SLR-DFE should be resistant to water damage.

Sloping to Adjacent Grade

Fill may be graded to slope up from adjacent ground level or be held in place by retaining structures. The toe and surface of fill slopes must be protected from erosion and scour under design flood conditions, and maximum fill slopes must not be exceeded.

Fill must be designed so as not to adversely affect nearby structures by diverting harmful floodwaters and waves or increasing flow velocity.

Source: City of Boston, Massachusetts, Coastal Flood Resilience Design Guidelines

Elevating on Piles and Open Foundations[374]

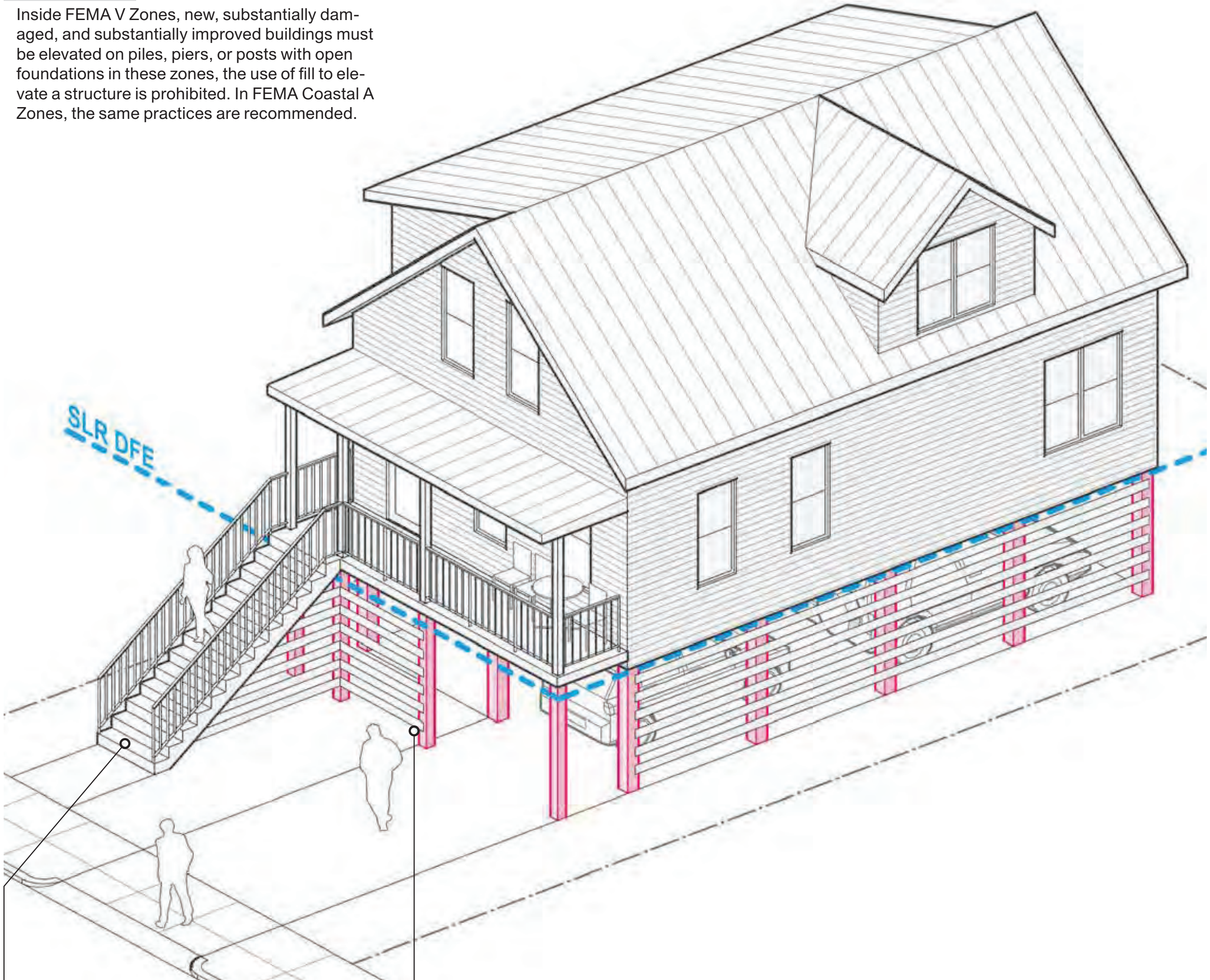
- On smaller sites, or where grading activities are restricted or cost-prohibitive, buildings can be elevated using piles, which allow floodwaters to pass underneath the structures.
- This strategy is most applicable to coastal sites where there will be strong wave action and is a requirement for new buildings in V Flood Risk Zones. (See exhibit 4-7 FEMA Flood Hazard Zones in Site Analysis for flood zone definitions.)
- Breakaway walls or lattice walls are sometimes used to enclose the space below the first floor but uses are typically limited to parking and some storage areas below the structure. Such passive uses can create a sense of vacancy at the street level, which can be challenging when designing to create pedestrian-oriented spaces.
- Although elevating on piles has many benefits for floods, structures raised significantly above grade can have increased natural hazard risks from strong wind and earthquakes and may need engineering upgrades.[375]

Exhibit 5-73. Elevation of a New Building on an Open Foundation

Technical Considerations

Suitability

Inside FEMA V Zones, new, substantially damaged, and substantially improved buildings must be elevated on piles, piers, or posts with open foundations in these zones, the use of fill to elevate a structure is prohibited. In FEMA Coastal A Zones, the same practices are recommended.



Stairs, Decks, Porches

Appurtenant structures (e.g., stairs, decks, porches) must be designed either to structurally resist design flood loads or break-away without damaging the building or its foundation. Decks and porches must be designed to allow flooding to pass through them, so as to not adversely affect adjacent or nearby structures by diverting harmful floodwaters and waves.

Materials

Building materials below the DFE should be resistant to water damage.

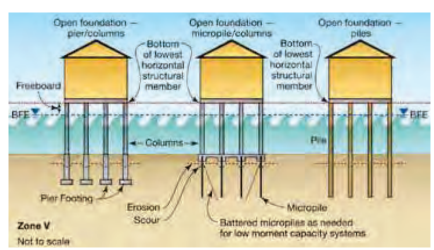
Structural stability

Elevated open pile, pier, or post foundations must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion. The diagram below illustrates NFIP-compliant foundations.

Below-grade Enclosures

Existing below-grade enclosures (basements, crawlspaces, etc.) should be filled to match the adjacent grade. The fill must be compacted and designed to resist scour and erosion.

Enclosures below the lowest floor should be designed either to be free of obstruction or with breakaway walls and flood openings.



Examples of NFIP-compliant foundations: piers / columns on pier footings, columns on micropiles, and piles.

Source: FEMA. May 2013. Foundation Requirements and Recommendations for Elevated Homes.

Source: City of Boston, Massachusetts, Coastal Flood Resilience Design Guidelines

Elevating on Enclosed Foundations and Wet Floodproofing[376]

- Elevating structures on solid foundations that are made from flood-damage-resistant materials and are designed to withstand forces during flood events is another strategy to mitigate flood risks.
- Often accompanied by wet floodproofing strategies, these foundation spaces are designed so that water can enter and exit the space by gravity. These approaches require foundations to be above existing grade (or existing subgrade spaces filled to match existing grade) so that no water is trapped within the structure, and there are equal rates of rise and fall within the enclosed space and outside.
- Wet floodproofing protects a building from some structural damage during floods but not from wave action or high-velocity flows. Thus, this strategy is best suited to A flood risk zones, and FEMA does not allow this approach in V flood risk zones.
- Utility connections for these structures must either be elevated or dry floodproofed.
- Enclosed wet floodproofed spaces can be designed to provide parking, building access, and limited storage.

Exhibit 5-74. Coastal Home Elevated on Piles Under Construction, Wilmington, North Carolina

Source: MAKERS

Exhibit 5-75. Elevation of a New Building on a Closed Foundation That Utilizes Wet Proofing Strategies

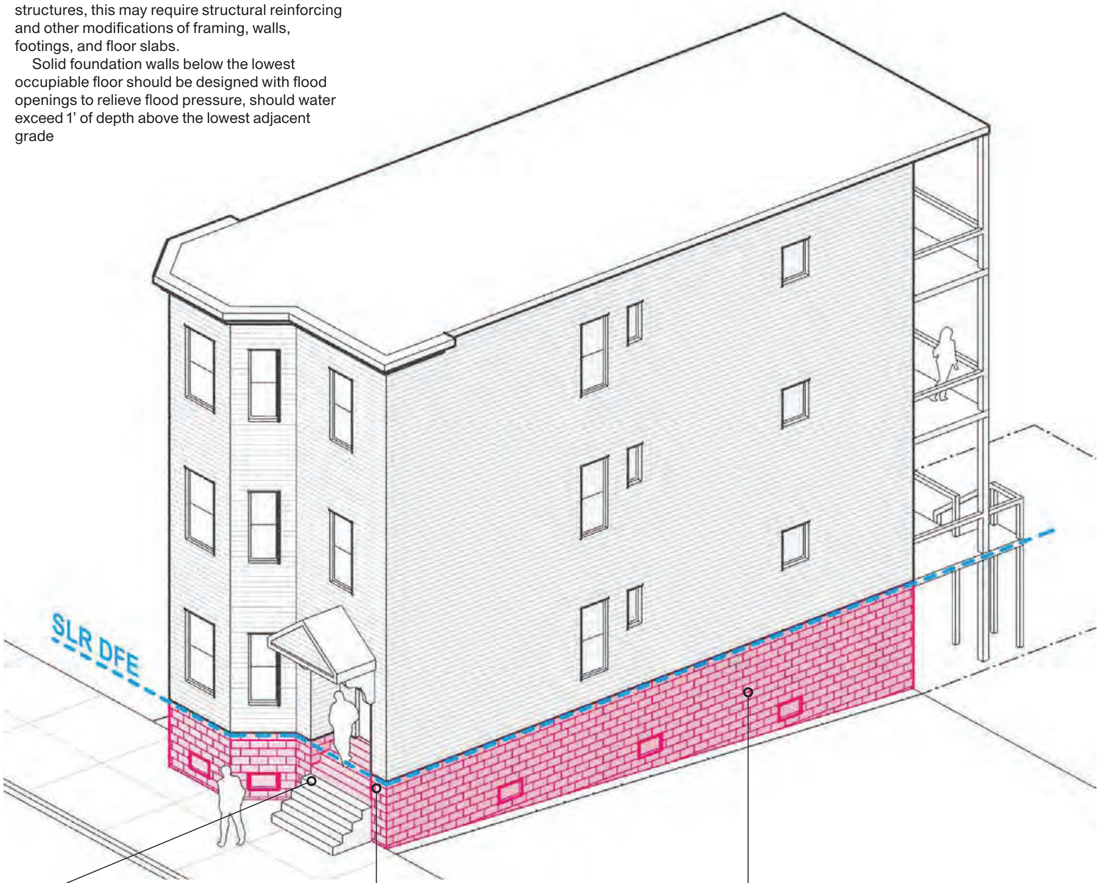
Technical Considerations

Foundations

Elevated solid wall foundations must be designed to structurally resist site-specific design flood loads, be geotechnically stable, and be protected from scour and erosion. For retrofits of existing structures, this may require structural reinforcing and other modifications of framing, walls, footings, and floor slabs.

Solid foundation walls below the lowest occupiable floor should be designed with flood openings to relieve flood pressure, should water exceed 1' of depth above the lowest adjacent grade

Scour and erosion depths and the need for structural fill should be considered to ensure that the foundation will not be undermined in design flood conditions.



Access

Access from grade to the lowest floor should be carefully considered for design integration into both the building and the public realm. The modification of building access and height may trigger building, accessibility, and other applicable code requirements, and therefore should be coordinated.

Stairs, Decks, and Porches

Appurtenant structures (e.g., stairs, decks, porches) must be designed either to structurally resist design flood loads or break away without damaging the building or its foundation.

Decks and porches must be designed to allow flooding to pass through them, so as to not adversely affect adjacent or nearby structures by diverting harmful floodwaters and waves.

Basements

Existing below-grade enclosures (basements, crawlspaces, etc.) should be filled to match the lowest adjacent grade. The fill must be compacted and designed to resist scour and erosion.

Materials that can be used for fill include compacted soil, crushed stone encased with a concrete slab, and controlled low strength material (“flowable fill”). Consult with a contractor or engineer to determine the most suitable material depending on project requirements.

Building materials below the DFE should be resistant to water damage.

Source: City of Boston, Massachusetts, Coastal Flood Resilience Design Guidelines

Resource

- FEMA Technical Bulletins—
  https://www.fema.gov/emergency-managers/risk-management/building-science/national-flood-insurance-technical-bulletins

Flood Protection and Dry Floodproofing

Protect buildings from flood events by installing flood walls around the structure or by designing the ground floor to resist flood water loads and infiltration.

Flood protection and dry floodproofing strategies protect buildings from flood damage by preventing floodwaters from entering the building. Flood protection barriers around structures include flood walls and other structural site protection strategies.

Mitigation Benefits

Prevents flood water from entering building.

Permanent Flood Walls

- Typically, flood walls are constructed from concrete or other durable material and are typically between the structures and the shoreline to provide a protective barrier.

Exhibit 5-76. Flood Wall

Floodwall in Sunbury, Pennsylvania. Source: Jakec

Deployable Flood Walls[377]

- Deployable floodwalls are typically stored when not needed and only installed in the event of a storm or flood. These strategies require space for storage and onsite management and operations to ensure proper installation and regular maintenance checks.
- Deployable floodwalls can vary in form. Those that use hydrostatic pressure to lift the floodwall into place may be most appropriate in more urban environments and for multi-family and mixed-use developments. Others are inflatable, using either air or water to form a temporary barrier around a site, and can be installed by property owners to protect smaller structures.
- Sandbags are a common temporary flood wall approach that many communities have used to protect structures from floods. While they can be effective as an emergency response, they take time, resources, and some group labor to install. In areas where floods are common, having deployable strategies in place increases site resilience and offers protection against fast-moving foods.

See Coastal Structures and Upland Flood Protection Strategies.

Dry Floodproofing[378][379]

- Dry floodproofing strategies focus on preventing water from entering the building envelope and include the following:
  - Walls and slabs resistant to water pressure and debris impacts.
  - Watertight doors and windows when closed.
  - Impermeable door and window coverings (removable or permanent).
  - Paints, membranes, gaskets, and sealants to prevent, and sump pumps to control, water seepage.
  - Backflow or shutoff valves to protect floodwater from entering sewer and drainage systems.

Exhibit 5-77. Deployable Flood Wall

Flooded road, Medina, North Dakota rest area flood protection. Source: Bri Weldon, 2011

- Sealed joints and utility penetrations.
- Electrical equipment and circuits that are protected to the flood protection level.
- Back-up or emergency power for pumps and other seepage control measures.

- FEMA currently recommends dry floodproofing strategies only for commercial and mixed-use buildings and not for residential structures. Local regulations may restrict the use of dry floodproofing to mitigate flood risks for residential structures. Dry floodproofing is also not allowed by FEMA in V flood risk zones.

Manufactured Homes Placement

Protect manufactured and mobile homes and similar detached accessory dwelling units from flood and wind hazards.

Manufactured homes should be located outside of flood risk zones. In areas vulnerable to strong winds, manufactured homes should not include carport attachments and/or open coverings and should be anchored to the site as much as is feasible.[380] Guidance for manufactured homes may also be applicable to detached accessory dwelling units.

Resource

- FEMA P-85 Protecting Manufactured Homes from Floods and Other Hazards—
http://www.fema.gov/library/viewRecord.do?fromSearch=fromsearch&id=1577

Mitigation Benefits

Reduces risk for a housing type vulnerable to damage from floods.

Reduces risk for a housing type vulnerable to damage from windstorms.

Floating and Amphibious Structures

Consider non-traditional and emerging strategies, such as for amphibious and floating structures, as techniques evolve and mature.

Floating structures are designed to float on water at all times and can respond to local tidal fluctuations as long as the water is relatively protected. Although not common in the United States, pocket floating house communities have existed for decades, including some in major west coast cities, such as Sausalito, California, and Seattle, Washington. Floating structures differ from houseboats in that they are permanently anchored to a site. They can also have negative impacts on shoreline ecology, increasing the risk of pollution into adjacent waters and reducing opportunities for natural shoreline areas. As a result, local regulations often discourage or prohibit the construction of new floating structures. In other parts of the world, these strategies are more common. In the Maldives, planning is underway for an entire floating city.

Amphibious structures are an emerging architectural concept where structures are constructed on the ground but are designed to float during floods. Utilities are designed to either break away or extend via long connections. Many approaches utilize modular homes as these types of structures are relatively easy to retrofit with a floating foundation.[381] Amphibious structures may also provide an alternative to the significant elevation of structures, which can also lead to wind and seismic hazard risks in coastal and earthquake-prone environments.

Neither floating nor amphibious structures are currently recognized by FEMA as a flood mitigation strategy.

For more information visit:

- https://www.prosunarchitects.com/lifthouse
- The Buoyant Foundation—
  https://www.buoyantfoundation.org
- Urban Green Blue Grids for Resilient Cities—
  https://www.urbangreenbluegrids.com/projects/amphibious-homes-maasbommel-the-netherlands/
- Maldives—
  https://maldivesfloatingcity.com/gallery/

Mitigation Benefits

Structures can adapt to changing water levels.

Reducing Wind Risks through Building Form

Consider wind risk when massing and locating a building on a site.

A building's form influences the overall risk in strong wind environments. Consider the following strategies to protect buildings from wind damage:

- Consider wind risk and overall airflow when massing buildings and laying out site development areas. (See also Buildings.)
- Avoid gable roofs, or locate the gable ends to not be oriented in the primary wind direction (but weigh this design against considerations for rainwater and snow drainage and loads). Wind-resistant roof shapes, such as hip-over-gable, can increase overall resilience by protecting buildings from damage and the site and adjacent structures from wind-borne debris.[382]
- For elevated buildings, covered crawlspaces and enclosed elevated piers help prevent wind pressures on the underside of the building. Wind loads on the underside of elevated buildings can be as high as wind pressures on the roof if the structure is elevated too high.
- Avoid roof material that can add to air-borne debris in the event of a strong wind event.
- Consider shutters for windows to prevent windows breaking and subsequent building damage.

Mitigation Benefits

Reduces wind risk via overall structural design.

Exhibit 5-78. Wind Damage to Roof

Roofs and other building materials can be vulnerable to wind damage during storms. Source: Pxhere

Surfaces

Fire Safe Structures

Harden structures to reduce wildfire risk.

In wildfire-prone environments, strategies that focus on hardening structures complement defensible space zones for managing trees, vegetation, and open spaces close to the structures and further reduce wildfire risks. Structure hardening strategies focus on reducing flammable material and limiting opportunities for embers to ignite fires.

CalFire's Get Prepared website recommends the following structure-hardening strategies.[383]

Roof and Gutters

- Fire-resistant roof materials, such as composite, metal, clay, or tile.
- Installing spark arresters on chimneys
- Cover rain gutters or keep open gutters free of plant debris. Install corrosion-resistant and non-combustible drip edges for extra protection of the roof's edge.

Vents

- Cover all vent openings with 1/16- to 1/8-inch metal mesh. Do not use fiberglass or plastic mesh.
- Use ember and flame-resistant vents.

Eaves and Soffits

- Eaves should be boxed in and protected with ignition-resistant or non-combustible material.

Windows

- Install dual-paned windows with one pane of tempered glass to reduce the chance of windows breaking during a fire.
- Consider limiting the size and number of windows that face large areas of vegetation.
- Install screens in all windows that can be opened to increase ember resistance.

Walls

- Use ignition-resistant building materials such as stucco, fiber cement wall siding, fire retardant, treated wood, or other approved materials. This precaution is particularly important when neighboring homes are within 30 feet of other homes.

Mitigation Benefits

Reduces wildfire risk via building materials and structure design.

Exhibit 5-79. Ignition Resistant Clay Roof

Source: Santiago Manuel

- Fill gaps in siding and trim materials with good quality caulk and replace poor condition building materials.

Decks, Patios, and Fences

- Replace deck boards that are less than 1-inch thick or in poor condition with thicker, good condition boards. Use metal flashing on decks.
- Remove plant debris from the deck surface and gaps between the decking and the house.
- Use the same ignition-resistant material for patio covers as a roof.
- Remove plant debris, wood pile, and other potential fire fuel materials under decks. Consider enclosing the side of decks with materials that are properly vented or 1/8-inch wire mesh. Do not use wooden lattice to enclose decks.
- Maintain wooden fences in good condition and create a non-combustible fence section or gate next to the house for at least 5 feet.
- Store firewood at least 30 feet away from home.

For more information, see:

- Ready for Wildfire-Hardening your Home—
https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/hardening-your-home/
- Living with Fire—Fire Safe Homes
https://www.livingwithfire.com/get-prepared/

Shade Structures

Use shade structures on buildings and over parking areas to reduce heat gain in urban areas and where extreme heat is common.

Overhead canopies are commonly integrated into the ground floors of commercial and mixed-use buildings to provide weather protection for the adjacent sidewalk and pedestrian space. These overhead structures also help shade the sidewalk and main temperatures for pedestrians. Structural canopies can be used in combination with street trees to provide more robust shade solutions, which may be particularly helpful on east-west streets where adjacent buildings are less helpful in providing shade.

In hot environments, shade structures can reinforce community gathering places, such as park shelters, a canopy (which can also serve as rain cover) over a plaza or courtyard, wide shaded sidewalks, or private or shared backyards and open spaces. To keep pedestrians at the street level comfortable, shade structures should not radiate absorbed heat or reflect heat down onto the sidewalk, and structures should be designed to accommodate appropriate visual connections for natural surveillance.

Guidance for Comfortable Pedestrian Routes[384]

- For walking routes that are safe during the entire summer, target shade coverage on walking corridors should be greater than or equal to 62 percent.
- For walking routes that are safe for 95 percent of summer afternoon hours, target shade coverage should be 30 percent or more.
- For walking routes that are safe for 90 percent of summer afternoon hours, target shade coverage should be 20 percent or more.

Shade structures over parking areas that have green or reflective roof coverings can also help reduce heat in urban areas. Shade structures that incorporate solar panels can provide multiple benefits by providing sustainable energy sources while also shading impervious surface lots.

Mitigation Benefits

Reduces heat gain on buildings, parking areas, and pedestrian routes.

Promotes a healthier pedestrian environment.

Mitigation Considerations

Ensure shade structures over sidewalks do not trap or direct heat toward pedestrians.

Exhibit 5-80. Shade Strategy Over a Courtyard

Shade feature over a courtyard increases comfort for people using the space, reduces temperatures, and provides some overhead weather protection. Source: MAKERS

Cool and Collecting Surfaces

Use cool, green, and/or blue roof strategies to reduce heat, help manage runoff, and provide amenity space for people.

Traditional roof surfaces that use dark, impervious surfaces are a major source of heat gain in urban environments that contribute to the overall urban heat island effect. Cooler roof surface strategies include:

- Cool roofs, which use lighter-colored roof surface material to reflect light and reduce heat gain.
- Green roofs, where plants provide green space and help manage and treat runoff from the roof surface.
- Blue roofs are non-vegetated systems that focus on collecting stormwater for use on site or for temporary detention to reduce storm impacts on local infrastructure.

Cool and green roof strategies can also apply to exterior wall surfaces to further reduce heat gain within urban environments. Green walls are vertical plant systems that attach to external or internal building walls. They are less common than green roofs but offer an innovative and attractive way of cooling the urban environment while also integrating plants and green space.

Mitigation Benefits

Helps manage stormwater and reduce runoff.

Reducing heat gain can reduce heat and drought impacts.

Reducing heat gain can reduce wildfire impacts.

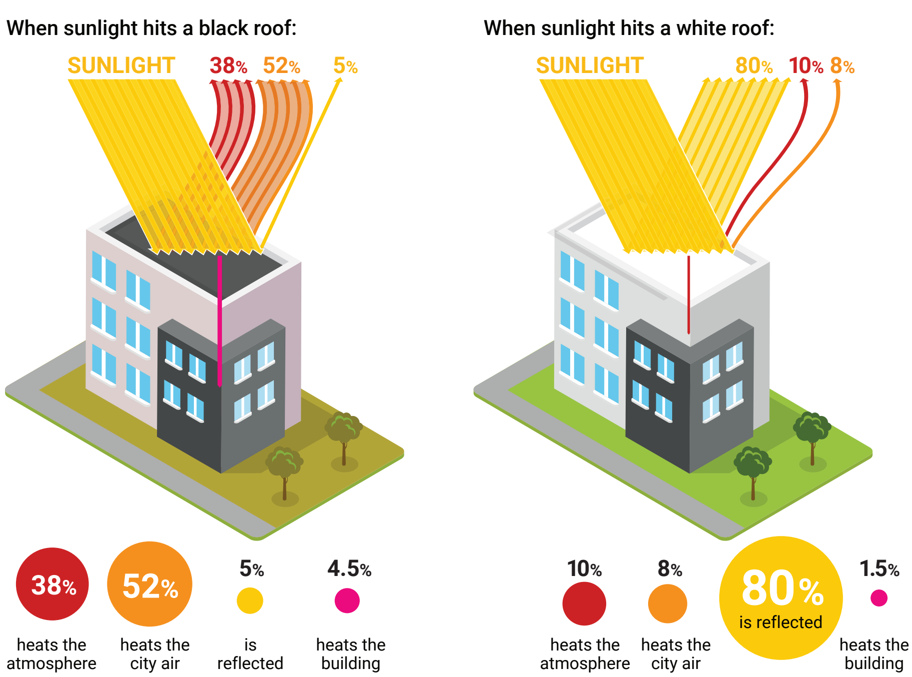
Following codes can reduce the impact of tsunamis on buildings.

Mitigation Considerations

Green roof designs in wildfire-prone environments must follow local building codes and maintain green roofs to reduce wildfire risks.

See Greening the Grey—Managing Stormwater.

Exhibit 5-81. Effects of Roof Type on Heat Absorption



Difference between traditional roof surfaces with dark, impervious materials and cool roofs with lighter materials. Source: Campbell et al. (2021), "Beating the Heat: A Sustainable Cooling Handbook for Cities"

Green roof and wildfire risks

Despite the multiple benefits of green roofs in reducing urban heat, managing stormwater runoff, and providing green spaces for people and wildlife, special consideration is needed in wildfire-prone regions to ensure this strategy contributes to a site's overall resilience. In-depth research into this topic is limited, but a series of small studies and observances following individual instances of fires on green roofs in the United States (Portland, OR), Canada (Montreal), and the United Kingdom (London) suggest the following considerations for site planners:

- Per the 2018 edition of the International Building Code, vegetative roof systems have to meet the same fire classification requirements as the roof covering and assembly materials.[385]
- Soil is not a highly combustible material, and green roof substrates typically are not high in organic material that could increase wildfire risk.
- It is challenging to directly compare traditional roofs with green roofs in terms of wildfire risk, but test studies did show that thicker and denser green roofs provide greater protection than thinner green roof systems, although these thin systems also provided some protection. Steel decking below the green roof resulted in better performance of the green roof under fire conditions.[386]
- Plant material, such as grasses, that could easily dry out or require maintenance can be a significant flammability risk in drought-prone environments. Such plants should be avoided in wildfire-prone environments, and all green roofs should be carefully managed to ensure the space is clear of dry plant material.[387]
- Sedums naturally retain moisture and do not tend to dry out and shed material the way grasses can. Many green roof experts recommend at least 60-percent coverage of sedums in a green roof, a threshold that could be increased in wildfire-prone environments.[388]
- Emerging research is showing that appropriately designed green roofs can actually outperform some traditional roof structures in terms of wildfire resilience, although more research is needed to fully verify these findings.[389]

Exhibit 5-82. Green Roof With Sedum

Source: Pxhere

Resources

- General Information about Green Roofs—
  http://www.greenroofs.org/
- NYC Department of Environmental Protection Blue Roof and Green Roof Study—
  http://www.nyc.gov/html/dep/html/stormwater/green_pilot_project_ps118.shtml

Water Conservation and Recycling

Harvest runoff from building surfaces and consider options for onsite water recycling.

In drought-prone environments, conserve and store water on and within a building to help with overall site resilience. Harvest water from roof surfaces and downspouts and store it on site to supplement outdoor water sources. This strategy is relatively common and is growing in use. Harvesting water for reuse within the building is also a strategy that some planners and designers are pursuing, although this strategy is more challenging, as it must navigate local regulations for grey water and recycling processes, which vary widely. Work closely with local community planners and public works officials to determine what is feasible for their projects.

Mitigation Benefits

- Helps manage stormwater and reduce runoff.
- Conserves water for other community uses.
- Retaining and infiltrating water on site can reduce wildfire risks.

Exhibit 5-83. Water Conservation and Re-Use

Rain Barrel. Source: Aqua Mechanical, © 2016

Endnotes

[179] Bucchin and Tuley. *Planning for Climate Mitigation and Adaptation,* 40.

[180] *Adapting to Rising Tides,* 2–43

[181] Mowery et al. "Planning the Wildland-Urban Interface," 95–100.

[182] Baxter et al. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards,* 15, 23, 36–37, 60, 77.

[183] Drane. *Hazard Mitigation Policy Guide,* 18–20.

[184] Association of State Floodplain Managers. "No Adverse Impact Floodplain Management." Association of State Floodplain Managers. https://www.floods.org/resource-center/nai-no-adverse-impact-floodplain-management/.

[185] Schwab et al. "Subdivision Design and Flood Hazard Areas," 25–26.

[186] Baxter et al. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards,* 27.

[187] Felter, Elizabeth, and Marya Morris. *Coastal Zone Management. Planning Advisory Service,* American Planning Association. https://www.planning.org/publications/report/9026904/.

[188] Felter and Morris, 71.

[189] "Adapting to Rising Tides," 36–37.

[190] Felter and Morris. "Coastal Zone Management," 38–39.

[191] Department of City Planning of New York. *Coastal Climate Resilience: Urban Waterfront Adaptive Strategies.* New York, NY: Department of City Planning of New York: 72–73. https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf.

[192] Federal Emergency Management Agency (FEMA). 2011. *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas* (Fourth Edition). https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf.

[193] King, Aaron. 2020. "Landscape Architects Can Reduce the Pain of Climate Migration," *THE DIRT*, November 19. https://dirt.asla.org/2020/11/19/landscape-architects-can-help-reduce-the-pain-of-climate-migration/.

[194] Setyawan, Kezia. 2022. "After 10 Years, Isle de Jean Charles Residents Will Soon Have a New Place to Call Home." WWNO New Orleans Public Radio - Coastal Desk, February 17. https://www.wwno.org/coastal-desk/2022-02-17/isle-de-jean-charles-residents-expected-to-move.

[195] Sears et al. *Preparing for Landslide Hazards: A Land Use Guide for OR Communities,* 12–13.; James C. Schwab, Paula Gori, and Sanjay Jeer. 2005. *Landslide Hazards and Planning*. American Planning Association: 53–54. https://www.planning.org/publications/report/9026862/.

[196] Sears et al. *Preparing for Landslide Hazards: A Land Use Guide for OR Communities*, 2.

[197] Schwab, Gori, and Jeer. *Landslide Hazards and Planning*, 48–51.

[198] Washington Geological Survey and Oregon Department of Geology and Mineral Industries. *A Homeowner's Guide to Landslides for Washington and Oregon.* https://www.dnr.wa.gov/publications/ger_homeowners_guide_landslides.pdf.

[199] Schwab, Meck, and Simone. *Planning for Wildfires*, 39.

[200] Highland and Bobrowsky. *The Landslide Handbook: A Guide to Understanding Landslides*, 33.

[201] Baxter et al. Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards, 12.

[202] Petersen. "Liquefaction and Sea-Level Rise."

[203] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines."

[204] Zehner, Emma. 2021. "Resilience District Concept Gathers Momentum in Seattle." Lincoln Institute of Land Policy - Climate and Health Equity. https://www.lincolninst.edu/publications/articles/2021-04-climate-health-equity-resilience-district-concept-gathers-momentum-in-seattle.

[205] "Adapting to Rising Tides," 2–44.

[206] Schwab, Gori, and Jeer, *Landslide Hazards and Planning,* 62.

[207] Schwab, Gori, and Jeer. *Landslide Hazards and Planning,* 80–82.

[208] Landers, Jay. 2022. "California City Forms Abatement District to Reduce Flood Risk," American Society of Civil Engineers, May 24. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2022/05/california-city-forms-abatement-district-to-reduce-flood-risk.

[209] Schwab, Gori, and Jeer. *Landslide Hazards and Planning*, 65.

[210] Schwab et al. *Subdivision Design and Flood Hazard Areas*, 21.

[211] Urban Waters Learning Network. 2017. "Proyecto ENLACE Del Caño Martin Peña: Restoring an Ecosystem and Building Resilient Communities in Puerto Rico." https://urbanwaterslearningnetwork.org/resources/proyecto-enlace-del-cano-martin-pena-restoring-ecosystem-building-resilient-communities-puerto-rico/.

[212] U.S. Environmental Protection Agency (EPA). "Ecosystem Services Research." https://www.epa.gov/eco-research/ecosystem-services-research.

[213] FEMA. "Building Community Resilience with Nature-Based Solutions: A Guide for Local Communities"; Naturally Resilient Communities. "Using Nature to Address Flooding. https://nrcsolutions.org/.

[214] Naturally Resilient Communities. "What Kind of Hazards Does Your City Face?" https://nrcsolutions.org/strategies/.

[215] Pearce, Fred. 2014. "Mangrove Forest Planted as Tsunami Shield," *New Scientist*, December 16. https://www.newscientist.com/article/mg22430005-200-mangrove-forest-planted-as-tsunami-shield/.

[216] Cornett. "Adaptation as Acceptance: Toward a New Normal in the Northwoods"; Jared Green. "Interview with Kristina Hill." American Society of Landscape Architects. https://www.asla.org/ContentDetail.aspx?id=28548.

[217] Schwab et al. *Subdivision Design and Flood Hazard Areas,* 8.

[218] Moritz, Max, et al. 2022. "Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire," *Frontiers in Forests and Global Change*. https://doi.org/10.3389/ffgc.2022.848254.

[219] Bénichou et al. *National Guide for Wildland-Urban-Interface Fires*, 98.

[220] Mowery et al. "Planning the Wildland-Urban Interface," 71.

[221] Transportation Research Board. 1996. *Landslides: Investigation and Mitigation,* ed. A.Keith Turner and Schuster L. Robert. Washington, DC: National Academy Press: 441.

[222] *A Homeowner's Guide to Landslides for Washington and Oregon.*

[223] Tice, Paul R., et al. 1996. *Hillside Development Guidelines Manual.* City of Colorado Springs: 27. https://coloradosprings.gov/sites/default/files/planning/dab/hillside.pdf.

[224] Tice et al., 29.

[225] Schwab, Meck, and Simone. *Planning for Wildfires*, 39.

[226] Tice et al. *Hillside Development Guidelines Manual*.

[227] Schwab, Gori, and Jeer. *Landslide Hazards and Planning*, 60–62.

[228] Schwab, Gori, and Jeer, 40–41.

[229] Meck, Stuart. 2007. "Cluster Development: Modern Application of an Old Town Form," *Zoning Practice* 8. American Planning Association.

[230] Schwab et al. "Subdivision Design and Flood Hazard Areas."

[231] Meck. "Cluster Development: Modern Application of an Old Town Form."

[232] Hack. *Site Planning: International Practice,* 39.

[233] Hack, 42.

[234] Mowery et al. "Planning the Wildland-Urban Interface," 36 and 44.

[235] Mowery et al., 102.

[236] Mowery et al., 49–50.

[237] Mowery et al., 49–50.

[238] Campbell et al., *Beating the Heat: A Sustainable Cooling Handbook for Cities*, 25.

[239] Mowery et al. "Planning the Wildland-Urban Interface," 47.

[240] National Tsunami Hazard Mitigation Program. "Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards," 24.

[241] Bahrainy, Hossein. 1998. "Urban Planning and Design in a Seismic-Prone Region (The Case of Rasht in Northern Iran," *Journal of Urban Planning and Development* 124 (4).

[242] Happy Cities. "Happy Homes Interactive Toolkit." https://happycities.com/happy-homes-toolkit.

[243] Mariposa County. 2021. Mariposa County Recreation and Resiliency Plan. https://www.mariposacounty.org/DocumentCenter/View/88174/Mariposa-Recreation-and-Resiliency-Plan_Final_210304_compressed?bidId=.

[244] "Get Prepared - What Can I Do Before a Fire?"

[245] Schwab et al. "Subdivision Design and Flood Hazard Areas," 75.

[246] Campbell et al. *Beating the Heat: A Sustainable Cooling Handbook for Cities*, 23.

[247] Forman. *Urban Ecology – Science of Cities*, 141.

[248] Hack. *Site Planning: International Practice*, 61.

[249] Happy Cities. "Walkability." https://happycities.com/happy-homes-toolkit/walkability-principle.

[250] Campbell et al. *Beating the Heat: A Sustainable Cooling Handbook for Cities*, 71.

[251] Campbell et al., 72.

[252] Dhanesha, Neel. 2022. "GM's Pilot Program with PG&E Is Using Electric Vehicles to Back up California's Power Grid," *Vox*, March 9. https://www.vox.com/recode/22969335/california-gm-electric-cars-power-grid-batteries-blackouts.

[253] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 55.

[254] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 66–67.

[255] Urban Land Institute. "Arverne by the Sea," *ULI Developing Urban Resilience.* https://developingresilience.uli.org/case/arverne-by-the-sea/.

[256] Schuler, Timothy A. 2018. "High Streets: In Miami Beach, Elevating Streets is not Without Growing Pains," *Landscape Architecture Magazine*," August 9. https://landscapearchitecturemagazine.org/2018/08/09/high-streets/.

[257] New York City Department of Parks & Recreation. 2017. *Design and Planning for Flood Resiliency - Guidelines for NYC Parks*, 112.

[258] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 59.

259 Sherman. "The Heat Is On."

260 City of Phoenix Newsroom. "Phoenix Plants First Cool Corridor at Cesar Chavez Park." https://www.phoenix.gov:443/newsroom/environmental-programs/2321.

261 "Get Prepared - What Can I Do Before a Fire?"

262 Oregon Office of Emergency Management and Department of Geology and Mineral Industries, "Oregon Tsunami Evacuation Wayfinding Guidance." https://www.oregon.gov/oem/Documents/Tsunami_Evacuation_Signage_and_Wayfinding_Guidance.pdf.

263 Louisiana Sea Grant. 2012. *Seeking Refuge Before the Storm: Needs of Commercial Fishermen*. http://www.laseagrant.org/wp-content/uploads/Harbor-of-Refuge.pdf.

264 FEMA. *Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home* (Fifth Edition), 22.

265 FEMA. 2021. "Shoalwater Bay Tribe Builds Evacuation Tower to Provide Tsunami Safety for Community," June 30. https://www.fema.gov/blog/shoalwater-bay-tribe-builds-evacuation-tower-provide-tsunami-safety-community.

266 FEMA. 2021. "Project Safe Haven: Tsunami Vertical Evacuation Systems on Washington State's Pacific Coast." https://www.fema.gov/node/465491.

267 French et al. "Designing Public Open Space to Support Seismic Resilience: A Systematic Review."

268 "Get Prepared - What Can I Do Before a Fire?"

269 FEMA. 2021. "Community Lifelines Implementation Toolkit." https://www.fema.gov/emergency-managers/practitioners/lifelines-toolkit.

270 Newman, Galen D. and Zixu Qiao. 2022. *Landscape Architecture for Sea Level Rise.* New York, NY: Routledge: vii.

271 EPA. "Why You Should Consider Green Stormwater Infrastructure for Your Community."

272 Pour, S.H., et al. 2020. "Low Impact Development Techniques to Mitigate the Impacts of Climate-Change-Induced Urban Floods: Current Trends, Issues and Challenges," *Sustainable Cities and Society* 14.

273 Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, xi.

274 Pour et al. "Low Impact Development Techniques to Mitigate the Impacts of Climate-Change-Induced Urban Floods: Current Trends, Issues and Challenges."

275 EPA. "Green Infrastructure Design and Implementation." https://www.epa.gov/green-infrastructure/green-infrastructure-design-and-implementation.

276 Newman and Qiao. Landscape Architecture for Sea Level Rise, 290–93. Naturally Resilient Communities

277 National Fire Protection Association. "Dynamics of Wildfire – Firewise." https://www.nfpa.org/assets/gallery/firewise/operationWater/step3.htm.

278 Lewitus, Alan J., et al. 2008. "Lagoonal Stormwater Detention Ponds as Promoters of Harmful Algal Blooms and Eutrophication along the South Carolina Coast," *Harmful Algae* 8 (1): 60–65. https://doi.org/10.1016/j.hal.2008.08.012.

279 Selbig, William R. 2019. "Evaluating the Potential Benefits of Permeable Pavement on the Quantity and Quality of Stormwater Runoff," U.S. Geological Survey, March 17. https://www.usgs.gov/centers/upper-midwest-water-science-center/science/evaluating-potential-benefits-permeable-pavement.

280 Depietri, Yaella, and Timon McPhearson. 2017. "Integrating the Grey, Green, and Blue." In *Nature-Based Solutions to Climate Change in Urban Areas: Linkages Between Science, Policy, and Practice*, edited by Nadja Kubisch. Springer. https://doi.org/10.1007/978-3-319-56091-5_6.

281 Depietri and McPhearson.

282 Newman and Qiao, *Landscape Architecture for Sea Level Rise*, section 3.

283 Scheel, Hans J. 2014. "New Type of Tsunami Barrier," Natural Hazards 70 (1): 951–56. https://doi.org/10.1007/s11069-013-0834-4.

284 National Oceanic and Atmospheric Administration. "Understanding Living Shorelines." https://www.fisheries.noaa.gov/insight/understanding-living-shorelines.

285 Newman and Qiao. *Landscape Architecture for Sea Level Rise*, Part 3-229-298.

286 National Oceanic and Atmospheric Administration. "Understanding Living Shorelines."

287 National Oceanic and Atmospheric Administration.

288 Newman and Qiao. *Landscape Architecture for Sea Level Rise*, 280.

289 Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 80–81.

290 Department of City Planning of New York, 80–81.

291 National Oceanic and Atmospheric Administration. "Understanding Living Shorelines."

292 Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 73.

293 Department of City Planning of New York, 76–77.

294 Newman and Qia. *Landscape Architecture for Sea Level Rise*, 265–67.

295 Newman and Qiao, 259–61.

296 Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 54.

297 Newman and Qiao. *Landscape Architecture for Sea Level Rise*, 262–65.

298 New York City Department of Parks & Recreation. *Design and Planning for Flood Resiliency - Guidelines for NYC Parks*, 41.

299 Newman and Qiao. *Landscape Architecture for Sea Level Rise*, 281–84.

300 Naturally Resilient Communities. "Flood-Friendly Culverts."

[301] Newman and Qiao. *Landscape Architecture for Sea Level Rise*, 234–36.

[302] Hutton, N.S., G.A. Tobin, and B.E. Montz. 2018. "The Levee Effect Revisited: Processes and Policies Enabling Development in Yuba County, California," *Journal of Flood Risk Management*. https://doi.org/10.1111/jfr3.12469.

[303] Newman and Qiao, *Landscape Architecture for Sea Level Rise*, 256.

[304] Forman, *Urban Ecology – Science of Cities*, 105.

[305] Forman, 92–94.

[306] Urban, James. 2008. *Up By Roots: Healthy Soils in the Built Environment.* Atlanta, GA: International Society of Arboriculture: 163–64.

[307] Azwell, Thomas. 2022. "On the Edge Merging Wildfire Research and Design to Reimagine Frontline Communities," presented at American Society of Landscape Architects 2022: Designing a Better Future, San Francisco, CA, November 12. https://2eb88d5a26c9d8f57ffb-aeafbf82c2963100e9056663ea595989.ssl.cf1.rackcdn.com/ASLA_314_RCKHTXDX_15_SAT-C07-On-the-Edge-Merging-Wildfire-Research-and-Design-in-Reimagining-Frontline-Communities.pdf.

[308] California Department of Forestry and Fire Protection. "Ready for Wildfire - Fire Smart Landscaping." https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/fire-smart-landscaping/.

[309] U.S. Department of Agriculture. "Biochar." Climate Hubs. https://www.climatehubs.usda.gov/hubs/northwest/topic/biochar.

[310] Ali, Shafaqat, Muhammad Rizwan, and Muhammad Farooq Qayyum. 2017. "Biochar Soil Amendment on Alleviation of Drought and Salt Stress in Plants: A Critical Review," *Environmental Science and Pollution Research*: 12700–12712.

[311] Spokas, Kurt. "Biochar." USDA Soil and Water Management Research. https://www.ars.usda.gov/midwest-area/stpaul/swmr/people/kurt-spokas/biochar/#:~:text=DEFINITION%3A%20Biochar%20is%20black%20carbon,stable%20form%20(carbon%20sequestration).

[312] "Adapting to Rising Tides," 2–36.

[313] US Forest Service. "After the Fire." https://www.fs.usda.gov/science-technology/fire/after-fire.

[314] Burgess and Foster. *Scorched - Extreme Heat and Real Estate*, 32.

[315] EPA. "Using Trees and Vegetation to Reduce Heat Islands." https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands.

[316] Forman. *Urban Ecology – Science of Cities*, 224.

[317] Natural Resources Conservation Service. "Windbreaks for Conservation," *Agriculture Information Bulletin* 339. https://www.fs.usda.gov/nac/assets/documents/morepublications/windbreaksforconservation.pdf.

[318] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 58.

[319] Schwab, Meck, and Simon. "Planning for Wildfires," 39.

[320] California Department of Forestry and Fire Protection. "Ready for Wildfire - Fire Smart Landscaping."

[321] California Department of Forestry and Fire Protection; Duryea and Kampf, "Wind and Trees: Lessons Learned from Hurricanes," chapters 5, 3.

[322] Urban. *Up By Roots: Healthy Soils in the Built Environment*, 331–32.

[323] EPA. "WaterSense Statistics and Facts." https://www.epa.gov/watersense/statistics-and-facts.

[324] Mowery et al. "Planning the Wildland-Urban Interface," 45.

[325] Natural Resources Conservation Service. "Windbreaks for Conservation," 3

[326] Duryea and Kampf. "Wind and Trees: Lessons Learned from Hurricanes."

[327] "Get Prepared - What Can I Do Before a Fire?"

[328] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 60.

[329] Moritz et al. "Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire."

[330] Mariposa County. *Mariposa County Recreation and Resiliency Plan*, 122.

[331] Moritz et al. "Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire."

[332] Burgess and Foster. *Scorched - Extreme Heat and Real Estate*, 32.

[333] Schwab et al. "Subdivision Design and Flood Hazard Areas," 76.

[334] Schwab et al., 76.

[335] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 67.

[336] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 61.

[337] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 77.

[338] Bénichou et al., 79.

[339] Drane. "Hazard Mitigation Policy Guide," 21, 23.

[340] Stout, Sherry, and Eliza Hotchkiss. "Distributed Energy Generation for Climate Resilience." National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy17osti/68296.pdf.

[341] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 66.

[342] Drane. "Hazard Mitigation Policy Guide," 21, 23.

[343] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 79.

[344] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 66.

[345] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 80.

[346] Crichton, Danny. 2021. "Gridware Is Building Early-Detection Sensors for Power Grid Failures and Wildfires," *TechCrunch*, February 17. https://techcrunch.com/2021/02/17/gridware-is-building-early-detection-sensors-for-power-grid-failures-and-wildfires/.

[347] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 48–49.

[348] New York City Department of Parks & Recreation. *Design and Planning for Flood Resiliency - Guidelines for NYC Parks*, 140.

[349] Kitson and Partners. 2019. "Storm Ready - Babcock Ranch." https://www.babcockranch.com/wp-content/uploads/2019/09/Storm-Ready-2.pdf.

[350] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 65.

[351] Stout and Hotchkiss. "Distributed Energy Generation for Climate Resilience."

[352] Gastelum, Diana. 2022. "The Role of Microgrids in Building Climate Resilience in Boston's Frontline Communities," *Climate-XChange*, January 7. https://climate-xchange.org/2022/01/07/the-role-of-microgrids-in-building-climate-resilience-in-bostons-frontline-communities/.

[353] Dhanesha. "GM's Pilot Program with PG&E Is Using Electric Vehicles to Back up California's Power Grid," *Vox*.

[354] Jalloul, Hiba, et al. 2022. "A Systematic Approach to Identify, Characterize, and Prioritize the Data Needs for Quantitative Sustainable Disaster Debris Management," *Resources, Conservation and Recycling* 180. https://doi.org/10.1016/j.resconrec.2022.106174.

[355] Mills, Jr., C.H., and William R. Whitson. 2019. "As Hurricanes Continue to Wreak Havoc, Disaster Recovery is Still a Broken Landscape for Small Cities." National League of Cities. https://www.nlc.org/article/2019/09/04/as-hurricanes-continue-to-wreak-havoc-disaster-recovery-is-still-a-broken-landscape-for-small-cities/.

[356] North Carolina Sea Grant. "Climate Change and Onsite Wastewater Treatment Systems in the Coastal Carolinas." https://ncseagrant.ncsu.edu/program-areas/sustainable-communities/climate-change-and-onsite-wastewater-treatment-systems-in-the-coastal-carolinas/.

[357] Massner, Kyler. "Community Septic Systems," Sustainable Development Code, *Sensitive Lands and Wildlife Habitat,* chapter 1.3. https://sustainablecitycode.org/brief/allow-community-septic-systems/.

[358] Beach. "Saving 450 Years of History in the Nation's Oldest City: A Look at Flood Mitigation Projects."

[359] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 88.

[360] Healy, Jack, and Sophie Kasakove. 2021. "Drought in Utah Town Halts Growth," *The New York Times*, July 20. https://www.nytimes.com/2021/07/20/us/utah-water-drought-climate-change.html.

[361] Healy, Jack. 2023. "Skipped Showers, Paper Plates: An Arizona Suburb's Water Is Cut Off," *The New York Times,* January 16. https://www.nytimes.com/2023/01/16/us/arizona-water-rio-verde-scottsdale.html.

[362] "Adapting to Rising Tides," 2–37.

[363] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 84.

[364] Mowery et al. "Planning the Wildland-Urban Interface," 16.

[365] Bénichou et al. "National Guide for Wildland-Urban-Interface Fires," 81.

[366] Bénichou et al., 81.

[367] Centers for Disease Control and Prevention and American Water Works Association. *Emergency Water Supply Planning Guide for Hospitals and Healthcare Facilities*. Atlanta: U.S. Department of Health and Human Services, Updated 2019. https://www.cdc.gov/healthywater/emergency/pdf/emergency-water-supply-planning-guide-2019-508.pdf.

[368] Tye and Giovannettone. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*, 93.

[369] FEMA. "Coastal Construction Manual."

[370] Compass PTS JV. 2020. *Building Codes Save: A Nationwide Study*. Washington DC: Federal Emergency Management Agency. https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study.

[371] Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 25.

[372] FEMA. "Federal Flood Risk Management Standard." https://www.fema.gov/floodplain-management/intergovernmental/federal-flood-risk-management-standard; Executive Order 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input, 2015. https://www.federalregister.gov/documents/2015/02/04/2015-02379/establishing-a-federal-flood-risk-management-standard-and-a-process-for-further-soliciting-and.

[373] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 42–43; Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 34–35.

[374] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 44–45; Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 30–31.

[375] English, Elizabeth C., Carol J. Friedland, and Fatemeh Orooji. 2017. "Combined Flood and Wind Mitigation for Hurricane Damage Prevention: Case for Amphibious Construction," *Journal of Structural Engineering* 143 (6). https://doi.org/10.1061/(ASCE)ST.1943-541X.0001750.

[376] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 40–41; Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 32–33, 44-45; Department of City Planning of New York, 40-41.

[377] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 46–47; FEMA. "Protect Your Home from Flooding - Low-Cost Projects You Can Do Yourself." https://www.fema.gov/sites/default/files/documents/fema_protect-your-home-from-flooding-brochure_2020.pdf.

[378] Department of City Planning of New York. "Coastal Climate Resilience: Urban Waterfront Adaptive Strategies," 38–39, 46–47; Boston Planning and Development Agency. "Coastal Resilience Design Guidelines," 46–47.

[379] FEMA. "Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-Use Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program," *National Flood Insurance Program Technical Bulletin*. https://www.fema.gov/sites/default/files/documents/fema_technical-bulletin-3_1-2021.pdf.

[380] Baxter et al. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*, 46.

[381] English, Elizabeth, Natasha Klink, and Scott Turner. 2016. "Thriving with Water: Developments in Amphibious Architecture in North America," *E3S Web of Conferences* 7. https://doi.org/10.1051/e3sconf/20160713009.

[382] Baxter et al. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*, 46–48.

[383] "Get Prepared - What Can I Do Before a Fire?"

[384] Campbell et al. *Beating the Heat: A Sustainable Cooling Handbook for Cities*, 78.

[385] Clagett, Leslie. 2019. "Ways to Design a Fire-Resistant Green Roof System," *Architectural Record*, September 27. https://www.architecturalrecord.com/articles/14294-ways-to-design-a-fire-resistant-green-roof-system.

[386] Miller, Roxanne, and Nataliia Gerzhova. 2021. "Understanding the Behaviour of Fire and Green Roofs," *Living Architecture Monitor*. https://livingarchitecturemonitor.com/articles/green-roofs-fire-su21.

[387] Miller and Gerzhova.

[388] Clagett. "Ways to Design a Fire-Resistant Green Roof System."

[389] Miller and Gerzhova. "Understanding the Behaviour of Fire and Green Roofs."

References

Adeola, Francis O., and J. Steven Picou. 2012. "Race, Social Capital, and the Health Impacts of Katrina: Evidence from the Louisiana and Mississippi Gulf Coast," *Human Ecology Review* 19 (1): 10–24.

AghaKouchak, Amir, Laurie S. Huning, Felicia Chiang, Mojtaba Sadegh, Farshid Vahedifard, Omid Mazdiyasni, Hamed Moftakhari, and Iman Mallakpour. 2018. "How Do Natural Hazards Cascade to Cause Disasters?" *Nature* 561 (7724): 458–60. https://doi.org/10.1038/d41586-018-06783-6.

Ali, Shafaqat, Muhammad Rizwan, and Muhammad Farooq Qayyum. 2017. "Biochar Soil Amendment on Alleviation of Drought and Salt Stress in Plants: A Critical Review," *Environmental Science and Pollution Research* 24: 12700–712.

American Planning Association. 2019. Falling Dominoes: *A Planner's Guide to Drought and Cascading Impacts.* APA Report. Washington DC: American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/Falling-Dominoes-Planners-Guide-to-Drought-and-Cascading-Impacts.pdf.

American Society of Civil Engineers. 2013. *Flood Resistant Design and Construction, ASCE Standard 24*. https://ascelibrary.org/doi/book/10.1061/asce24.

American Society of Civil Engineers. 2021. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. https://doi.org/10.1061/9780784415788.

Asia-Pacific Climate Change Adaptation Information Platform. 2021. "Building Resilience to Compound and Cascading Disaster Risks." https://ap-plat.nies.go.jp/adaptation_literacy/resources/e_learning/drr/index.html.

Association of State Floodplain Managers. 2019. "No Adverse Impact Floodplain Management." https://www.floods.org/resource-center/nai-no-adverse-impact-floodplain-management/.

Azwell, Thomas. 2022. "On the Edge Merging Wildfire Research and Design to Reimagine Frontline Communities." Conference Presentation presented at the American Society of Landscape Architects 2022- Designing a Better Future, San Francisco, CA, November 12, 2022. https://2eb88d5a26c9d8f57ffb-aeafb-f82c2963100e9056663ea595989.ssl.cf1.rackcdn.com/ASLA_314_RCKHTXDX_15_SAT-C07-On-the-Edge-Merging-Wildfire-Research-and-Design-in-Reimagining-Frontline-Communities.pdf.

Badger, Emily, and Eve Washington. 2022. "The Housing Shortage Isn't Just a Coastal Crisis Anymore." *New York Times*. https://www.nytimes.com/2022/07/14/upshot/housing-shortage-us.html.

Bahrainy, Hossein. 1998. "Urban Planning and Design in a Seismic-Prone Region (The Case of Rasht in Northern Iran," *Journal of Urban Planning and Development* 124, no. 4.

Baker, Mike, and Sergio Olmos. 2021. "The Pacific Northwest, Built for Mild Summers, Is Scorching Yet Again." *The New York Times*. https://www.nytimes.com/2021/08/13/us/excessive-heat-warning-seattle-portland.html.

Baxter, Julie, Karen Helbrecht, Stacy Franklin Robinson, Sara Reynolds, Adam Reeder, and Hilary Kendro. 2013. *Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards*. FEMA.

Beach, Jessica L. 2018. "Saving 450 Years of History in the Nation's Oldest City: A Look at Flood Mitigation Projects." Presented at the Florida Stormwater Association Annual Conference, June 13, 2018. https://www.citystaug.com/DocumentCenter/View/666/Davis-Shores-Backflow-Valve-Presentation-PDF.

Bénichou, N., M. Adelzadeh, J. Singh, I. Gomaa, N. Elsagan, M. Kinateder, C. Ma, A. Gaur, A. Bwalya, and M. Sultan. 2021. "National Guide for Wildland-Urban Interface Fires." Ottowa, ON: National Research Council Canada. https://doi.org/10.4224/40002647.

Board, Transportation Research. 1996. *Landslides: Investigation and Mitigation*. Edited by A. Keith Turner and Schuster L. Robert. Washington, DC: National Academy Press.

Boston Planning and Development Agency. 2019. "Coastal Resilience Design Guidelines." https://www.bostonplans.org/getattachment/d1114318-1b95-487c-bc36-682f8594e8b2.

Brundtland, G.H. 1987. "Our Common Future: Report of the World Commission on Environment and Development." Document. United Nations.

Bucchin, Matt, and Aaron Tuley. 2022. "Planning for Climate Mitigation and Adaptation." *PAS Report 601*. American Planning Association. https://www.planning.org/publications/report/9250330/.

Burgess, Katharine, and Elizabeth Foster. 2019. *Scorched - Extreme Heat and Real Estate*. Urban Land Institute.

Burnstein, Eric Tjon, and Amy Rogin. 2021. *State Flood Resilience and Adaptation Planning Challenges and Opportunities*. Urban Institute.

California Department of Forestry and Fire Protection. 2019. "Prepare for Wildfire - Defensible Space." Cal Fire. https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/.

California Department of Forestry and Fire Protection. 2019. "Ready for Wildfire - Fire Smart Landscaping." https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/fire-smart-landscaping/.

Campbell, Iain, Sneha Sachar, Julia Meisel, and Rushad Nanavatty. 2021. *Beating the Heat: A Sustainable Cooling Handbook for Cities*. United Nations Environment Programme.

Cardona, Omar-Dario, Maarten K. Aalst, Jörn Birkmann, Maureen Fordham, Glenn McGregor, Rosa Perez, Roger S. Pulwarty, E.Lisa F. Schipper, and Bach Tan Sinh. 2012. "Determinants of Risk: Exposure and Vulnerability." In *Managing the Risks of Extreme Events and Disasters to Advance: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: 65–108.

CBS News. 2022. "Yellowstone Flooding Threatens Water Supply in Montana's Largest City, Billings." https://www.cbsnews.com/news/yellowstone-flooding-billings-water-supply-montanas-largest-city/.

Centers for Disease Control and Prevention and American Water Works Association. 2019. "Emergency Water Supply Planning Guide for Hospitals and Healthcare Facilities." https://www.cdc.gov/healthywater/emergency/pdf/emergency-water-supply-planning-guide-2019-508.pdf.

City of Phoenix Newsroom. 2022. "Phoenix Plants First Cool Corridor at Cesar Chavez Park." https://www.phoenix.gov:443/newsroom/environmental-programs/2321.

Clagett, Leslie. 2019. "Ways to Design a Fire-Resistant Green Roof System." *Architectural Record*. https://www.architecturalrecord.com/articles/14294-ways-to-design-a-fire-resistant-green-roof-system.

CoastAdapt. 2017. "The Adaptation Process - Coastal Climate Adaptation Decision Support (C-CADS)." https://coastadapt.com.au/coastal-climate-adaptation-decision-support-c-cads.

CoastAdapt. "Home." n.d. https://coastadapt.com.au/.

Compass PTS JV. "Building Codes Save: A Nationwide Study." 2020. Research Report. Washington DC: Federal Emergency Management Agency. https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study.

Cook, Edward R., A.Park Williams, Jason E. Smerdon, Benjamin I. Cook, John T. Abatzoglou, Kasey Bolles, Seung H. Baek, Andrew M. Badger, and Ben Livneh. 2020. “Large Contribution from Anthropogenic Warming to an Emerging North American Megadrought,” *Science* 368, no. 6488. https://doi.org/10.1126/science.aaz960.

Cornett, Meredith. 2017. “Adaptation as Acceptance: Toward a New Normal in the Northwoods.” *Cool Green Science (Blog).* The Nature Conservancy. https://blog.nature.org/science/2017/10/11/adaptation-as-acceptance-toward-a-new-normal-in-the-northwoods/.

Crichton, Danny. 2021. “Gridware Is Building Early-Detection Sensors for Power Grid Failures and Wildfires.” TechCrunch. https://techcrunch.com/2021/02/17/gridware-is-building-early-detection-sensors-for-power-grid-failures-and-wildfires/.

Department of City Planning of New York. 2013. “Coastal Climate Resilience: Urban Waterfront Adaptive Strategies.” https://www1.nyc.gov/assets/planning/download/pdf/plans-studies/sustainable-communities/climate-resilience/urban_waterfront.pdf.

Department of Landscape Architecture, California State Polytechnic University. 1988. “Site Design for Hillside Development.” California State Polytechnic University.

Depietri, Yaella, and Timon McPhearson. 2017. “Integrating the Grey, Green, and Blue.” In *Nature-Based Solutions to Climate Change in Urban Areas: Linkages Between Science, Policy, and Practice*, edited by Nadja Kubisch. Springer. https://doi.org/10.1007/978-3-319-56091-5_6.

Dhanesha, Neel. 2022. “GM’s Pilot Program with PG&E Is Using Electric Vehicles to Back up California’s Power Grid.” *Vox*. https://www.vox.com/recode/22969335/california-gm-electric-cars-power-grid-batteries-blackouts.

Drane, Kara W. 2019. “Hazard Mitigation Policy Guide.” American Planning Association. https://planning-org-uploaded-media.s3.amazonaws.com/publication/download_pdf/hazard-mitigation-policy-guide.pdf.

Duryea, Mary, and Eliana Kampf. 2007. “Wind and Trees: Lessons Learned from Hurricanes.” University of Florida, Institute of Food and Agricultural Sciences. https://edis.ifas.ufl.edu/entity/topic/series_urban_forest_hurricane_recovery_program.

English, Elizabeth, Natasha Klink, and Scott Turner. 2016. “Thriving with Water: Developments in Amphibious Architecture in North America,” *E3S Web of Conferences* 7: 13009. https://doi.org/10.1051/e3sconf/20160713009.

Federal Emergency Management Agency (FEMA). 2023. “Hazard Mitigation Assistance Grants.” https://www.fema.gov/grants/mitigation.

———. 2022. “Building Community Resilience with Nature-Based Solutions: A Guide for LocalCommunities.” https://www.fema.gov/emergency-managers/risk-management/nature-based-solutions#:~:text=Nature%2Dbased%20solutions%20are%20sustainable,Reduce%20flood%20risk.

———. 2022. “Flood Insurance Manual— Risk Rating 2.0: Equity in Action.” https://www.fema.gov/sites/default/files/documents/fema_nfip-flood-insurance-full-manual_102022.pdf.

———. 2021. “National Risk Index for Natural Hazards,” August 16. https://www.fema.gov/flood-maps/products-tools/national-risk-index.

———. 2021. “Requirements for the Design and Certification of Dry Floodproofed Non-Residential and Mixed-Use Buildings Located in Special Flood Hazard Areas in Accordance with the National Flood Insurance Program,” *National Flood Insurance Program Technical Bulletin.* https://www.fema.gov/sites/default/files/documents/fema_technical-bulletin-3_1-2021.pdf.

———. 2021. "Shoalwater Bay Tribe Builds Evacuation Tower to Provide Tsunami Safety for Community." https://www.fema.gov/blog/shoalwater-bay-tribe-builds-evacuation-tower-provide-tsunami-safety-community.

———. 2021. "Taking Shelter From the Storm: Building or Installing a Safe Room for Your Home (Fifth Edition)." https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf.

———. 2020. "The Future of Flood Risk Data." https://www.fema.gov/fact-sheet/future-flood-risk-data-ffrd.

———. 2011. Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas, Fourth Edition. https://www.fema.gov/sites/default/files/2020-08/fema55_voli_combined.pdf.

———. 2007. "Design Guide for Improving Critical Facility Safety from Flooding and High Winds." https://www.fema.gov/sites/default/files/2020-08/fema543_design_guide_complete.pdf.

———. n.d. "Community Lifelines Implementation Toolkit." https://www.fema.gov/emergency-managers/practitioners/lifelines-toolkit.

———. n.d. "Federal Flood Risk Management Standard." https://www.fema.gov/floodplain-management/intergovernmental/federal-flood-risk-management-standard.

———. n.d. "Historical Flood Risk and Costs." https://www.fema.gov/data-visualization/historical-flood-risk-and-costs.

———. n.d. "Project Safe Haven: Tsunami Vertical Evacuation Systems on Washington State's Pacific Coast." https://www.fema.gov/node/465491.

———. n.d. "Protect Your Home from Flooding—Low-Cost Projects You Can Do Yourself." https://www.fema.gov/sites/default/files/documents/fema_protect-your-home-from-flooding-brochure_2020.pdf.

Federal Register. 2015. "Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input." https://www.federalregister.gov/documents/2015/02/04/2015-02379/establishing-a-federal-flood-risk-management-standard-and-a-process-for-further-soliciting-and.

Felter, Elizabeth, and Marya Morris. 2016. "Coastal Zone Management." Planning Advisory Service Report. Planning Advisory Service, American Planning Association, February 1. https://www.planning.org/publications/report/9026904/.

Forman, Richard T.T. 2014. *Urban Ecology – Science of Cities*. Massachusetts: Cambridge University Press.

French, Emily L., S. Jeff Birchall, Karen Landman, and Robert D. Brown. 2019. "Designing Public Open Space to Support Seismic Resilience: A Systematic Review," *International Journal of Disaster Risk Reduction* 34: 1–10.

Gabbert, Bill. 2022. "Marshall Fire Updated Damage Assessment: 1,084 Residences Destroyed." Wildfire Today. https://wildfiretoday.com/2022/01/07/marshall-fire-updated-damage-assessment-1084-residences-destroyed/.

Gastelum, Diana. 2022. "The Role of Microgrids in Building Climate Resilience in Boston's Frontline Communities." Blog. Climate-XChange. https://climate-xchange.org/2022/01/07/the-role-of-microgrids-in-building-climate-resilience-in-bostons-frontline-communities/.

Grassi, Beth, Elena Suleimani, and Lea Gardine. 2019. "Why a Small Tsunami Is Not a False Alarm." University of Alaska, Fairbanks—Alaska Earthquake Center. https://earthquake.alaska.edu/why-small-tsunami-not-false-alarm.

Green, Jared. n.d. Interview with Kristina Hill." Blog. American Society of Landscape Architects, News, https://www.asla.org/ContentDetail.aspx?id=28548.

Hack, Gary. 2018. *Site Planning: International Practice*. MIT Press.

Hagler, Yoav. "Defining U.S. Megaregions." America 2050. https://s3.us-east-1.amazonaws.com/rpa-org/pdfs/2050-Paper-Defining-US-Megaregions.pdf.

Happy Cities. "Walkability." n.d. https://happycities.com/happy-homes-toolkit/walkability-principle.

———. "Happy Homes Interactive Toolkit." n.d. https://happycities.com/happy-homes-toolkit.

Healy, Jack. 2023. "Skipped Showers, Paper Plates: An Arizona Suburb's Water Is Cut Off," *The New York Times,* January 16, 2023. https://www.nytimes.com/2023/01/16/us/arizona-water-rio-verde-scottsdale.html.

Healy, Jack, and Sophie Kasakove. 2021. "Drought in Utah Town Halts Growth," *The New York Times,* July 20, 2021. https://www.nytimes.com/2021/07/20/us/utah-water-drought-climate-change.html.

Henson, Bob. 2021. "Climate Change and Tornadoes: Any Connection?" *Yale Climate Connections.* https://yaleclimateconnections.org/2021/07/climate-change-and-tornadoes-any-connection/.

Hersher, Rebecca, and Ryan Kellman. 2019. "After The Water: Flash Floods Pose Existential Threat To Towns Across U.S." National Public Radio (NPR) Visuals, November 7. https://apps.npr.org/ellicott-city/.

Highland, Lynn, and Peter T. Bobrowsky. 2008. "The Landslide Handbook: A Guide to Understanding Landslides." Reston: U.S. Geological Survey.

Hodge, Tyler. 2022. "Short-Term Energy Outlook Supplement: Drought Effects on California Electricity Generation and Western Power Markets." Washington DC: U.S. Energy Information Administration, Independent Statistics & Analysis.

Hoover, Katie, and Laura A Hanson. 2023. "Wildfire Statistics." Congressional Research Service.

Hutton, N.S., G.A. Tobin, and B.E. Montz. 2018. "The Levee Effect Revisited: Processes and Policies Enabling Development in Yuba County, California," *Journal of Flood Risk Management,* https://doi.org/10.1111/jfr3.12469.

IPCC. 2022. "Climate Change 2022: Impacts, Adaptation and Vulnerability Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." https://doi.org/10.1017/9781009325844.

———. 2022. "Fact Sheet - North America, Climate Change Impacts and Risks," Cambridge University Press. https://www.ipcc.ch/report/ar6/wg2/downloads/outreach/IPCC_AR6_WGII_FactSheet_NorthAmerica.pdf.

Jaiswal, Kishor S., Mark D. Petersen, Ken Rukstales, and William S. Leith. 2015. "Earthquake Shaking Hazard Estimates and Exposure Changes in the Conterminous United States," *Earthquake Spectra* 31, no. 1_suppl: S201–20. https://doi.org/10.1193/111814EQS195M.

Jalloul, Hiba, Juyeong Choi, Nazli Yesiller, Derek Manheim, and Sybil Derrible. 2022. "A Systematic Approach to Identify, Characterize, and Prioritize the Data Needs for Quantitative Sustainable Disaster Debris Management," *Resources, Conservation and Recycling* 180: 106174. https://doi.org/10.1016/j.resconrec.2022.106174.

Kapoor, N, V.K. Bansal, M. Jain. 2020. "Development of Creative Problem Solving-based Framework for Site Planning in Hill Areas." *Frontiers of Architectural Research* 9 (2): 450-466. https://doi.org/10.1016/j.foar.2019.12.003.

Kennedy, Brian. 2020. “Most Americans Say Climate Change Affects Their Local Community, Including 70% Living near Coast.” *Pew Research Center* (blog). https://www.pewresearch.org/fact-tank/2020/06/29/most-americans-say-climate-change-impacts-their-community-but-effects-vary-by-region-2/.

King, Aaron. 2020. “Landscape Architects Can Reduce the Pain of Climate Migration.” THE DIRT, November 19, 2020. https://dirt.asla.org/2020/11/19/landscape-architects-can-help-reduce-the-pain-of-climate-migration/.

Kitson and Partners. 2019.“Storm Ready - Babcock Ranch.” Babcock Ranch. https://www.babcockranch.com/wp-content/uploads/2019/09/Storm-Ready-2.pdf.

Klinenberg, Eric. 2018. *Palaces for the People: How Social Infrastructure Can Help Fight Inequality, Polarization, and the Decline of Civic Life*. New York, NY: Penguin Random House.

Kousky, Carolyn, and Carlos Martin. 2020. “Low-Income Households Should Be Prioritized After Disaster Strikes.” University of Pennsylvania, 2020. https://riskcenter.wharton.upenn.edu/lab-notes/low-income-households-should-be-prioritized/.

Landers, Jay. 2022. “California City Forms Abatement District to Reduce Flood Risk.” American Society of Civil Engineers. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2022/05/california-city-forms-abatement-district-to-reduce-flood-risk.

Latham, Alan, and Jack Layton. 2019. “Social Infrastructure and the Public Life of Cities: Studying Urban Sociality and Public Spaces.” *Geography Compass* 13, no. 7: e12444. https://doi.org/10.1111/gec3.12444.

Lemonick, Michael D. 2012. “Sandy’s Storm Surge Explained and Why It Matters.” Climate Central. https://www.climatecentral.org/news/hurricane-sandys-storm-surge-explained-and-why-it-matters-15182.

Lewitus, Alan J., Larissa M. Brock, Marianne K. Burke, Krista A. DeMattio, and Susan B. Wilde. 2008. “Lagoonal Stormwater Detention Ponds as Promoters of Harmful Algal Blooms and Eutrophication Along the South Carolina Coast,” *Harmful Algae*, Vol. 8, No. 1: 60–65. https://doi.org/10.1016/j.hal.2008.08.012.

Li, Anna C.Y., Linda Nozick, Ningxiong Xu, and Rachel Davidson. 2012. “Shelter Location and Transportation Planning Under Hurricane Conditions,” *Transportation Research Part E: Logistics and Transportation Review*, 715–29.

Lightbody, Laura. 2021. “FEMA’s New Flood Insurance Policy Is Fairer—and Rewards Mitigation.” PEW Charitable Trusts; Flood-Prepared Communities. https://pew.org/3k0PCIy.

Living with Fire. n.d. “Make an Evacuation Plan.” https://www.livingwithfire.com/get-prepared/.

Louisiana Sea Grant. 2012. “Seeking Refuge Before the Storm: Needs of Commercial Fishermen.” http://www.laseagrant.org/wp-content/uploads/Harbor-of-Refuge.pdf.

Lu, Yuqi. 2017. “Hurricane Flooding and Environmental Inequality: Do Disadvantaged Neighborhoods Have Lower Elevations?” *Socius* 3: 2378023117740700. https://doi.org/10.1177/2378023117740700.

Luedke, Heather. 2019. “Fact Sheet | Nature as Resilient Infrastructure – An Overview of Nature-Based Solutions.” Environmental and Energy Study Institute. https://www.eesi.org/papers/view/fact-sheet-nature-as-resilient-infrastructure-an-overview-of-nature-based-solutions.

Mariposa County. 2021. “Mariposa County Recreation and Resiliency Plan.” https://www.mariposacounty.org/DocumentCenter/View/88174/Mariposa-Recreation-and-Resiliency-Plan_Final_210304_compressed?bidId=.

Massner, Kyler. n.d. “Community Septic Systems.” Sustainable Development Code. https://sustainablecitycode.org/brief/allow-community-septic-systems/.

Masters, Jeff. 2021. “Reviewing the Horrid Global 2020 Wildfire Season,” *Yale Climate Connections*. http://yaleclimateconnections.org/2021/01/reviewing-the-horrid-global-2020-wildfire-season/.

McPhillips, Lauren E., and Marissa A. Matsler. 2018. “Temporal Evolution of Green Stormwater Infrastructure Strategies in Three US Cities,” *Frontiers in Built Environment* 4, no. 26. https://doi.org/10.3389/fbuil.2018.00026.

Meck, Stuart. 2017. “Cluster Development,” *Zoning Practice* no. 8. American Planning Association.

Miller, Roxanne, and Nataliia Gerzhova. 2021. “Understanding the Behaviour of Fire and Green Roofs,” *Living Architecture Monitor*. https://livingarchitecturemonitor.com/articles/green-roofs-fire-su21.

Mills, Jr., C.H., and William R. Whitson. 2019. “As Hurricanes Continue to Wreak Havoc, Disaster Recovery Is Still A Broken Landscape for Small Cities.” National League of Cities. https://www.nlc.org/article/2019/09/04/as-hurricanes-continue-to-wreak-havoc-disaster-recovery-is-still-a-broken-landscape-for-small-cities/.

Mirus, B.B., E.S. Jones, R.L. Baum, J.W. Godt, S. Slaughter, M.M. Crawford, J. Lancaster, T. Stanley, D.B. Kirschbaum, and W.J. Burns. 2020.“Landslides Across the USA: Occurrence, Susceptibility, and Data Limitations,” *Landslides*.

Moftakhari, Hamed R., Amir AghaKouchak, Brett F. Sanders, and Richard A. Matthew. 2017. “Cumulative Hazard: The Case of Nuisance Flooding,” *Earth’s Future* 5, no. 2: 214–23. https://doi.org/10.1002/2016EF000494.

Montgomery, Charles. 2013. *Happy City: Transforming Our Lives Through Urban Design*. New York City: Farrar, Straus, and Giroux.

Moritz, Max, Rob Hazard, Kelly Johnston, Marc Mayes, Molly Mowery, Katie Oran, Anne-Marie Parkinson, David A. Schmidt, and Graham Wesolowski. 2022. “Beyond a Focus on Fuel Reduction in the WUI: The Need for Regional Wildfire,” *Frontiers in Forests and Global Change*. https://doi.org/10.3389/ffgc.2022.848254.

Mowery, Molly, Anna Read, Kelly Johnston, and Tareq Wafaie. 2019. “Planning the Wildland-Urban Interface,” *PAS Report 594*, American Planning Association.

Multi-Hazard Mitigation Council. 2019. “Natural Hazard Mitigation Saves: 2019 Report.” Washington DC: National Institute of Building Sciences. https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf.

National Aeronautics and Space Administration. n.d. “Understanding Sea Level.” https://sealevel.nasa.gov/understanding-sea-level/regional-sea-level/subsidence.

National Fire Protection Association. n.d. “Dynamics of Wildfire— Firewise.” https://www.nfpa.org/assets/gallery/firewise/operationWater/step3.htm.

National Oceanic and Atmospheric Administration (NOAA). 2023. “What Is Subsidence?” https://oceanservice.noaa.gov/facts/subsidence.html.

———. n.d. “Hurricane Costs.” https://coast.noaa.gov/states/fast-facts/hurricane-costs.html.

———. n.d. “Severe Weather 101 Tornado Basics.” https://www.nssl.noaa.gov/education/svrwx101/tornadoes/.

———. n.d. “Understanding Living Shorelines.” https://www.fisheries.noaa.gov/insight/understanding-living-shorelines.

———. “U.S. Tsunami Warning System.” News & Features, 2016. https://www.noaa.gov/explainers/us-tsunami-warning-system.

National Research Council. 1985. "Reducing Losses From Landsliding in the United States." Washington, DC: National Academies Press. https://doi.org/10.17226/19286.

National Tsunami Hazard Mitigation Program. 2001. "Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards." National Tsunami Hazard Mitigation Program. https://mitigation.eeri.org/files/DesignForTsunamis.pdf.

Naturally Resilient Communities. n.d. "Using Nature to Address Flooding." https://nrcsolutions.org/.

Naturally Resilient Communities. n.d. https://nrcsolutions.org/strategies/.

New York City Department of Environmental Protection. n.d. "Green Infrastructure." https://www.nyc.gov/site/dep/water/green-infrastructure.page.

New York City Department of Parks and Recreation. 2017. *Design and Planning for Flood Resiliency - Guidelines for NYC Parks*.

Newman, Galen D., and Zixu Qiao. 2022. *Landscape Architecture for Sea Level Rise*. New York: Routledge.

Nikolaou, Sissy, Guillermo Diaz-Fanas, Evangelia Garini, and Beki McElvain. 2019. "Dried Lakes Do Tell Tales: Seismic Soil Amplification in Mexico City," *Geostrata Magazine* 23 (2). https://doi.org/10.1061/geosek.0000131.

Nikolaou, Sissy. "The Eastern United States." *Structure Magazine,* March 2013. https://www.structuremag.org/?p=836.

North Carolina Sea Grant. "Climate Change and Onsite Wastewater Treatment Systems in the Coastal Carolinas." https://ncseagrant.ncsu.edu/program-areas/sustainable-communities/climate-change-and-onsite-wastewater-treatment-systems-in-the-coastal-carolinas/.

NYC Mayor's Office of Resiliency. 2020. "Climate Resiliency Design Guidelines." https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v4-0.pdf.

Oregon Office of Emergency Management and Department of Geology And Mineral Industries. n.d. "Oregon Tsunami Evacuation Wayfinding Guidance." https://www.oregon.gov/oem/Documents/Tsunami_Evacuation_Signage_and_Wayfinding_Guidance.pdf.

Oregon Partnership for Disaster Resilience. n.d. https://opdr.uoregon.edu/.

Parkinson, Randall W. 2021. "Speculation on the Role of Sea-Level Rise in the Tragic Collapse of the Surfside Condominium (Miami Beach, Florida U.S.A.) was a Bellwether Moment for Coastal Zone Management Practitioners," *Ocean & Coastal Management* 215: 105968. https://doi.org/10.1016/j.ocecoaman.2021.105968.

Pearce, Fred. 2014. "Mangrove Forest Planted as Tsunami Shield," *New Scientist*. https://www.newscientist.com/article/mg22430005-200-mangrove-forest-planted-as-tsunami-shield/.

Petersen, Heidi, Matt Bursa, and Jared Green. n.d. "Health Benefits of Nature." American Society of Landscape Architects blog. https://www.asla.org/healthbenefitsofnature.aspx.

Petersen, Travis Poitras, Alex Grant, Anne Wein, Keith Knudsen, Kevin Befus, Monica Erdman, Kimber Petersen. n.d."Liquefaction and Sea-Level Rise." U.S. Geological Survey, ArcGIS StoryMaps, February 9, 2022. https://storymaps.arcgis.com/stories/b5f973b6e4da45258c0b5a5368ca26f7.

Pew Charitable Trusts. "Flood-Prepared Communities." n.d. https://www.pewtrusts.org/en/projects/flood-prepared-communities.

Plautz, Jason. 2022. "Southwest Megadrought Pushes Hydropower to the Brink," *E&E News,* Energywire. https://www.eenews.net/articles/southwest-megadrought-pushes-hydropower-to-the-brink/.

Pour, S.H., A.K. Abd Wahab, S. Shahid, M. Asaduzzaman, and A. Dewan. 2020. “Low Impact Development Techniques to Mitigate the Impacts of Climate-Change-Induced Urban Floods: Current Trends, Issues and Challenges,” *Sustainable Cities and Society* 14.

Robbins, Jim, Thomas Fuller, and Christine Chung. 2022.“Flooding Chaos in Yellowstone, a Sign of Crises to Come.” *The New York Times*. https://www.nytimes.com/2022/06/15/us/yellowstone-national-park-floods.html.

Rollins, Chris, Jeffrey T. Freymueller, and Jeanne M. Sauber. 2020. “Stress Promotion of the 1958 M_w~7.8 Fairweather Fault Earthquake and Others in Southeast Alaska by Glacial Isostatic Adjustment and Inter-Earthquake Stress Transfer,” *Journal of Geophysical Research: Solid Earth* 126 (1): e2020JB020411. https://doi.org/10.1029/2020JB020411.

San Francisco, CA: Bay Conservation and Development Commission (BCDC) and Metropolitan Transportation Commission/Association of Bay Area Governments (MTC/ABAG). 2020. *Adapting to Rising Tides Bay Area: Regional Sea Level Rise Vulnerability and Adaptation Study.* https://www.adaptingtorisingtides.org/wp-content/uploads/2020/03/ARTBayArea_Main_Report_Final_March2020_ADA.pdf

Scheel, Hans J. 2014. “New Type of Tsunami Barrier,” *Natural Hazards* 70 (1): 951–56. https://doi.org/10.1007/s11069-013-0834-4.

Schuetz, Jenny. 2022. “Dysfunctional Policies Have Broken America’s Housing Supply Chain.” *Brookings* blog. https://www.brookings.edu/blog/the-avenue/2022/02/22/dysfunctional-policies-have-broken-americas-housing-supply-chain/.

Schuler, Timothy A. 2018. “High Streets,“ *Landscape Architecture Magazine*. https://landscapearchitecturemagazine.org/2018/08/09/high-streets/.

Schwab, James C., Chad Berginnis, Terri Turner, Anna Read, and Nicholas Walny. 2016. “Subdivision Design and Flood Hazard Areas.” Planning Advisory Service (PAS) Report. American Planning Association. https://www.planning.org/publications/report/9112664/.

Schwab, James C., Paula Gori, and Sanjay Jeer. 2005. “Landslide Hazards and Planning.” Planning Advisory Service (PAS) Report. American Planning Association. https://www.planning.org/publications/report/9026862/.

Schwab, James C., Marilyn Hall, Marsha Prillwitz, Jeff Brislawn, Kelly Redmond, Mark Svoboda, and Cody Knutson. 2013. “Planning and Drought.” Planning Advisory Service Report, American Planning Association.

Schwab, James C., Stuart Meck, and Jamie Simone. 2005. “Planning for Wildfires.” Planning Advisory Service (PAS) Report. American Planning Association. https://www.planning.org/publications/report/9026859/.

Schwartz, John. 2021. “Two of America’s Largest Reservoirs Reach Record Lows amid Lasting Drought,” *The New York Times*, July 27. https://www.nytimes.com/2021/07/27/us/lake-powell-water-level.html.

ScienceDaily. 2021.“Melting Glaciers Contribute to Alaska Earthquakes.” https://www.sciencedaily.com/releases/2021/03/210318170319.htm.

Sears, Tricia R., Marian Lahav, William J. Burns, and Justin McCarley. 2019. “Preparing for Landslide Hazards: A Land Use Guide for OR Communities.” Oregon Department of Land Conservation and Development. https://www.oregongeology.org/Landslide/Landslide_Hazards_Land_Use_Guide_2019.pdf.

Selbig, William R. 2019. “Evaluating the Potential Benefits of Permeable Pavement on the Quantity and Quality of Stormwater Runoff.” U.S. Geological Survey. https://www.usgs.gov/centers/upper-midwest-water-science-center/science/evaluating-potential-benefits-permeable-pavement.

Setyawan, Kezia. 2022. "After 10 Years, Isle de Jean Charles Residents Will Soon Have a New Place to Call Home," WWNO New Orleans Public Radio. https://www.wwno.org/coastal-desk/2022-02-17/isle-de-jean-charles-residents-expected-to-move.

Sherman, Amy. "The Heat Is On." 2020. *Planning Magazine,* American Planning Association. https://www.planning.org/planning/2020/aug/the-heat-is-on/.

Smith, E., S. Sistare, and G Nejedlo. 2011. "Fire Adapted Communities: The Next Step in Wildfire Preparedness." Reno, NV: University of Nevada Storey County Extension. https://www.livingwithfire.com/wp-content/uploads/2018/10/FAC-Storey-County-sp1107.pdf.

Sneed, Michelle. 2018. "Land Subsidence in the San Joaquin Valley." U.S. Geological Survey. https://www.usgs.gov/centers/land-subsidence-in-california/science/land-subsidence-san-joaquin-valley.

Spokas, Kurt. "Biochar." 2020. USDA Soil and Water Management Research: St. Paul, MN. https://www.ars.usda.gov/midwest-area/stpaul/swmr/people/kurt-spokas/biochar/#:~:text=DEFINITION%3A%20Biochar%20is%20black%20carbon,stable%20form%20(carbon%20sequestration).

Stout, Sherry, and Eliza Hotchkiss. 2017. "Distributed Energy Generation for Climate Resilience." Presented at the National Adaptation Forum, St Paul, MN. https://www.nrel.gov/docs/fy17osti/68296.pdf.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, and W. Brooks. 2022. "Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines." NOAA Technical Report NOS 01. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean. https://aambpublicoceanservice.blob.core.windows.net/oceanserviceprod/hazards/sealevelrise/noaa-nos-techrpt01-global-regional-SLR-scenarios-US.pdf.

Tice, Paul R., Brett U. Veltman, Bonnie L. Olson, and Larry C. Larsen. 1996. *Hillside Development Guidelines Manual*. City of Colorado Springs. https://coloradosprings.gov/sites/default/files/planning/dab/hillside.pdf.

Turner, Nancy J., and Sandra Peacock. 2005."Solving the Perennial Paradox - Ethobotanical Evidence for Plant Resource Management on the Northwest Coast." In *Keeping It Living—Traditions of Plant Use and Cultivation on the Northwest Coast of North America*, edited by Douglas Deur and Nancy J. Turner. Seattle, WA: University of Washington Press: 101–50.

Tye, Mari R., and Jason Giovannettone. 2021. *Impacts of Future Weather and Climate Extremes on United States Infrastructure: Assessing and Prioritizing Adaptation Actions*. Reston: American Society of Civil Engineers. https://ascelibrary.org/doi/pdf/10.1061/9780784415863.fm.

Urban Waters Learning Network. 2017. "Proyecto ENLACE Del Caño Martin Peña: Restoring an Ecosystem and Building Resilient Communities in Puerto Rico." https://urbanwaterslearningnetwork.org/resources/proyecto-enlace-del-cano-martin-pena-restoring-ecosystem-building-resilient-communities-puerto-rico/.

Urban, James. 2008. *Up By Roots: Healthy Soils in the Built Environment*. Atlanta, GA: International Society of Arboriculture.

Urban Land Institute. 2021. "Arverne by the Sea." https://developingresilience.uli.org/case/arverne-by-the-sea/.

U.S. Department of Agriculture (USDA). n.d. "Biochar." USDA Climate Hubs. https://www.climatehubs.usda.gov/hubs/northwest/topic/biochar.

———. n.d. "Windbreaks." https://www.fs.usda.gov/nac/practices/windbreaks.php.

———. n.d. "Windbreaks for Conservation." https://www.fs.usda.gov/nac/assets/documents/morepublications/windbreaksforconservation.pdf.

U.S. Department of Agriculture Forest Service. n.d. "After the Fire." https://www.fs.usda.gov/science-technology/fire/after-fire.

U.S. Department of Housing and Urban Development. n.d. "Community Development Block Grant Program." https://www.hud.gov/program_offices/comm_planning/cdbg.

U.S. Environmental Protection Agency (EPA). 2023. "Green Infrastructure Design and Implementation." https://www.epa.gov/green-infrastructure/green-infrastructure-design-and-implementation.

———. 2022. "Climate Change Indicators: Tropical Cyclone Activity." https://www.epa.gov/climate-indicators/climate-change-indicators-tropical-cyclone-activity.

———. 2022. "Using Trees and Vegetation to Reduce Heat Islands." https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands.

———. 2022. "Climate Change Indicators: River Flooding." https://www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

———. 2022. "Water Sense Statistics and Facts." https://www.epa.gov/watersense/statistics-and-facts.

———. 2022. "Why You Should Consider Green Stormwater Infrastructure for Your Community." https://www.epa.gov/G3/why-you-should-consider-green-stormwater-infrastructure-your-community.

———. 2021. "Climate Change Indicators: Heat Waves." https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves.

———. 2021. "Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts." https://www.epa.gov/cira/social-vulnerability-report.

———. 2016. "Climate Change Indicators: Coastal Flooding." https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding.

———. 2016. "Climate Change Indicators: Drought." https://www.epa.gov/climate-indicators/climate-change-indicators-drought.

———. 2016. "Climate Change Indicators: Heavy Precipitation." https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation.

———. 2016. "Climate Change Indicators: Sea Level." https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level.

———. n.d. "Climate Change Indicators: Wildfires." https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires.

———. n.d. "Ecosystem Services Research." https://www.epa.gov/eco-research/ecosystem-services-research.

U.S. Geological Survey. 2022. "How the 2022 Yellowstone Flood Affected a Monitoring Site on the Gardner River." https://www.usgs.gov/observatories/yvo/news/how-2022-yellowstone-flood-affected-a-monitoring-site-gardner-river.

———. 2020. "ShakeAlert Earthquake Early Warning Basics." https://www.usgs.gov/media/images/shakealert-earthquake-early-warning-basics.

———. 2016. "Induced Earthquakes Raise Chances of Damaging Shaking in 2016." https://www.usgs.gov/news/featured-story/induced-earthquakes-raise-chances-damaging-shaking-2016.

———. n.d. "Could a Large Tsunami Happen in the United States?" U.S. Geological Survey. https://www.usgs.gov/faqs/could-large-tsunami-happen-united-states.

———. n.d. "Landslides 101." https://www.usgs.gov/programs/landslide-hazards/landslides-101.

Washington Department of Fish and Wildlife. Your Marine Waterfront. 2016. https://wdfw.wa.gov/sites/default/files/publications/01791/wdfw01791.pdf

Washington Geological Survey and Oregon Department of Geology and Mineral Industries. n.d. *A Homeowner's Guide to Landslides for Washington and Oregon.* https://www.dnr.wa.gov/publications/ger_homeowners_guide_landslides.pdf.

Washington State Department of Natural Resources. 2017. "Fact Sheet - What Are Landslides and How Do They Occur." Washington State Department of Natural Resources. https://www.dnr.wa.gov/publications/ger_homeowners_guide_landslides.pdf

Wing, O.E.J., W. Lehman, and P.D. Bates. 2022. "Inequitable Patterns of US Flood Risk in the Anthropocene," *Nature Climate Change*: 156–162.

Wüest, Marc, David Bresch, and Thierry Corti. 2007. *The Hidden Risks of Climate Change: An Increase In Property Damage from Soil Subsidence in Europe*. Zurich: Swiss Reinsurance Company Ltd.

Zehner, Emma. "Climate and Health Equity—Resilience District Concept Gathers Momentum in Seattle." 2021. https://www.lincolninst.edu/publications/articles/2021-04-climate-health-equity-resilience-district-concept-gathers-momentum-in-seattle.

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, DC 20410-6000

January 2025