U.S.Department of Transportation
Federal Highway Administration

TRAILS AS RESILIENT INFRASTRUCTURE

GUIDEBOOK | December 2023

Gambles Mill Eco-Corridor (Photo: RES (Resource Environmental Solutions))

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 2023	Final Report

4. TITLE AND SUBTITLE

Trails as Resilient Infrastructure Guidebook

5. FUNDING NUMBERS
DTFH6117D00008L /
693JJ321F000345

6. AUTHOR(S)

Jeffrey Ciabotti, Quinn Kelly, Emily Lauderdale, Kristen Lohse, Stephanie Weyer, Michael Hintze, Katie Heuser, Cindy Camacho, John Crumpton, Evie Dentinger

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Cambridge Systematics
101 Station Landing, Suite 410
Medford, MA 02155

Toole Design Group, LLC
8484 Georgia Ave #800
Silver Spring, MD 20910

AECOM
5438 Wade Park Blvd, Suite
200
Raleigh, NC 27607

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Department of Transportation
Federal Highway Administration
Office of Human Environment
1200 New Jersey Avenue SE
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

FHWA-HEP-24-007

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public on the FHWA website at https://www.fhwa.dot.gov/environment/recreational_trails/publications/

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This guidebook demonstrates how trails are part of resilient transportation infrastructure, how trails can be planned and designed to be resilient and sustainable, and how trails have a role in emergency planning and response. Trails of all kinds are places for recreation, exercise, and active transportation. Trails are also a crucial tool for making communities more resilient in the face of climate change and other emergencies. This guidebook examines the ways in which trails can be made more resilient and how trails can serve as resilient infrastructure, providing information and guidance in support of these goals.

14. SUBJECT TERMS
bicycle, bike, climate, design, emergency, infrastructure, maintenance, pedestrian, resilience, resiliency, trail, trails, walk

15. NUMBER OF PAGES
126

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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Contents

1. Introduction and Context 5

1.1. Purpose of Guidebook **..... 6**

1.2. The Role of Trails in Climate Mitigation and Adaptation **..... 10**

2. Planning and Implementation 13

2.1. Planning for Resilient Trails **14**

2.2. Pursuing Equity in Trail Planning and Design ..**23**

3. Evaluating Vulnerability 30

3.1. Event Types and Risk Factors **.....31**

3.2. How to Evaluate Vulnerability **.....38**

4. Design and Engineering for Resilience ... 43

4.1. Resilient Trail Design Principles**.....44**

4.2. Siting, Grading, and Drainage **.....47**

4.3. Natural Infrastructure **.....51**

4.4. Materials **.....54**

4.5. Structures **.....59**

4.6. Trail Construction**.....63**

4.7. Design Strategies for Emergency Response and Evacuation **.....66**

5. Emergency Response Planning 69

5.1. Trails in the Context of Emergency Management**.....70**

5.2. Planning for Trails as Emergency Response Routes**.....71**

5.3. Emergency Operations and Management **.....73**

6. Maintenance and Management 76

6.1. Maintenance**.....77**

6.2. Management **.....80**

7. Conclusion..... 85

8. Case Studies 86

8.1. Bear Creek Greenway**.....87**

8.2. CV Link**.....90**

8.3. Gambles Mill Eco-Corridor**.....93**

8.4. Greater Grand Forks Greenway **.....96**

8.5. Houston Bayou Greenways**.....98**

8.6. Katy Trail**.....101**

8.7. New York-New Jersey Trail Conference **.....103**

8.8. Paradise Multiuse Paths **.....106**

8.9. Prison Hill Recreation Area **.....109**

9. Glossary and Acronyms 113

10. Endnotes 120

1. Introduction and Context

Figure 1: Sunrise over the Perrine Memorial Bridge along the Canyon Rim Trail in Twin Falls, ID (Photo: Toole Design)

1.1. Purpose of Guidebook

This guidebook ("the Guide") demonstrates how trails are part of resilient transportation infrastructure, how trails can be planned and designed to be resilient and sustainable, and how trails have a role in emergency planning and response. Trails of all kinds are places for recreation, exercise, and time outside. Trails are used for active transportation, whether for daily commuting or errand running, and also during unique events or emergencies. Trails are also a crucial tool for making communities more resilient in the face of climate change and other emergencies. This guidebook examines the ways in which trails can be made more resilient and how trails can serve as resilient infrastructure, providing information and guidance in support of these goals.

Key Terms

Trail refers to all types of trails for recreation and transportation, including shared use paths, paved and natural surface trails, and trails for both motorized and nonmotorized use. (Volpe Center White Paper)

Resilience refers to the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. (23 U.S.C. 101(a)(24))

See Glossary and Acronyms for a complete list of key terms.

How Trails and Climate Change are Connected

Climate change is having a clear impact on weather patterns and landscapes, causing flooding, extreme heat, drought, and wildfire. These changes are expected to increase in severity over time, needing mitigation and adaptation responses at all scales and across all types of infrastructure.[1] As communities and regions increasingly invest in trails, they will play an expanded role in both climate mitigation and adaptation.

Multiuse trails serve both recreational and transportation functions and can help reduce carbon emissions by shifting more trips to walking, biking, and rolling. This includes trips made using micromobility and other electric-assisted devices. Urban, suburban, and rural trail corridors present opportunities for managing stormwater, improving water quality, providing wildlife habitat, and inhibiting the spread of fires, among other benefits.

However, trails can also be particularly vulnerable to climate impacts. Many trails are located within riparian and coastal corridors, forests, or on slopes, making them prone to flooding, fire, erosion, and landslides. This guidebook promotes an understanding of how to design and maintain trails as adaptive, sustainable infrastructure that can support resilient communities and ecosystems.

Trails are also cultural and social resources that support public health and local economies. However, not all communities have equitable access to trails and their benefits. Many people in disadvantaged and underserved communities lack access to trails and open spaces due to historic and ongoing disinvestment, often as a result of structural racism.[2] Additionally, the renewal of interest in urban greenspace has, in many communities, driven development at the expense of low-income residents and communities of color.[3]

Projects such as waterfront conversions from industrial to park use and conversions of inactive rail corridors to trails are planned in tandem with residential and commercial developments that can raise rents and property taxes to unaffordable levels for existing residents, while also decreasing existing

residents' sense of community and feeling that they belong.[4] For these reasons, this Guide also addresses equity in trails planning and design as it pertains to climate resilience and environmental justice.[5]

Existing resources for trail planners, designers, and managers do not sufficiently address the diversity of trail contexts, changing conditions, and often-limited resources available to respond to the challenges of climate change.[6] The Guide seeks to address this gap by identifying best practices in context-based trail planning and design, siting, construction, management, and maintenance. The Guide builds on a white paper by the Volpe National Transportation Systems Center (Volpe Center) who, in support of the Federal Highway Administration's (FHWA) Recreational Trails Program, conducted a literature review and interviews with national trail organizations on resilience and emergency response on trails.[7]

Trail Types and Uses

The Guide considers all terrestrially based[8] trail types, whether short- or long-distance and whether in rural, urban, or suburban contexts. This includes both hard- and natural-surface trails that support any of the following nonmotorized and motorized trail activities:

- Pedestrian activities, including walking, hiking, and use of assistive devices;
- Human-powered skate activities such as roller-skating, in-line skating, and skateboarding;
- Biking, mountain biking, or use of other human powered cycles;
- Equestrian activities, including carriage driving
- Nonmotorized snow activities, including fat-tire (snow) biking, snowshoeing, cross-country skiing, and backcountry skiing;
- Micromobility uses such as e-bikes, e-scooters, e-skateboards, and one-wheels; and
- Motorized activities, including all-terrain vehicle riding, dirt-biking, and snowmobiling.

Components of a Trail

Trails should be understood not just as single paths, but rather as features within a broader context, including landscape, materials, and amenities. For the purposes of this guide, trails are described in terms of a range of components that vary according to trail type. The essential components of all trails include:

- The travel surface, whether paved or unpaved, and its structural cross section;
- The trail shoulders or immediate space to either side of a trail; and
- Access points, whether trailheads, other intersecting trails, or informally created connections (e.g., neighborhood access paths, desire lines, etc.).

Other trail components that may or may not be present include:

- Social and/or resting areas adjacent to the travel surface, including amenities such as benches and water fountains;
- Structures such as bridges, boardwalks, tunnels, and culverts; and
- Information, which can include interpretive or wayfinding signs, blazes, maps, etc.

The wider administrative boundaries within which trails exist, such as a linear urban right-of-way, conservation or other easement, or large recreational area, may also be considered a trail component as the boundaries define trail context and the limits of work. Trails may influence and be influenced by land outside of official boundaries, such as watersheds, wetlands, riparian or coastal flood zones, fire-prone forestland, and neighborhoods.

Climate Impacts to Trails

Across all types of trail uses and regions, climate change threatens to reduce access to trails, impact users' comfort and experiences, and force trail operators to adapt their construction and maintenance programs. For example:

- **Sea level rise will increase flood risk or permanent inundation of coastal trails.** For instance, sea levels are rising faster in the mid-Atlantic than in most parts of the world and threaten to submerge large portions of the Harriet Tubman Underground Railroad State Park and Blackwater National Wildlife Refuge, two sites in Maryland that help interpret Harriet Tubman's work on the Underground Railroad. The experience of these sites, both of which include small networks of walking trails for birdwatching, photography, and interpretation, will change, and access to portions may be entirely lost. Saltwater intrusion is already killing trees and turning tidal marsh into open water in the refuge, and seawater threatens structures and archeological sites at both locations.[9]
- **Increased drought and wildfire can be expected throughout the United States, with particularly notable impacts on western trails and recreation areas**. The Pacific Crest Trail (PCT) runs approximately 2,650 miles from Mexico to Canada through California, Oregon, and Washington. Many portions of the PCT have been closed due to fires. Periods of extreme heat and dryness are increasing, the fire season is expanding, and it threatens more smoke and closures of portions of the trail.[10]
- **Warming temperatures are reducing snow accumulation nationwide, shortening seasons for snow sports and impacting trail construction and maintenance.** In the northeast, the vernal window, or transition period, from winter to spring is expected to grow by 2100 to be two to four weeks longer, which has significant ecological impacts[11] and has also shortened ski seasons. In Vermont, cross country ski center operators have to pay increased attention to trail elevation, insulation (such as with straw), and preventing standing water in low spots, among other issues.[12]

These are just a few of the many climate impacts that can be expected. This Guide attempts to address the primary concerns for each trail type listed above with key planning, construction, and maintenance considerations.

Linkages to Other Federal Efforts

This Guide is one of many Federal efforts addressing climate change in transportation and recreation contexts. The following is a brief list of programs and initiatives that relate to trail planning and design:

- National Park Service Climate Change Response Program (CCRP)[13]
- National Park Service Rivers, Trails, and Conservation Assistance Program (RTCA) Climate Change Adaptation Technical Assistance[14]
- Northern Institute of Applied Climate Science (NIACS) Adaptation Workbook for Recreation[15]
- USDA Forest Service Climate Change Resource Center: Recreation[16]

Audience

The Guide is oriented toward trail and transportation planners, designers, managers, maintenance workers, and advocates. Guide content is relevant for staff at local, regional, State, and Federal agencies, plus their contractors, constituents, and stakeholders. Content may also be relevant for nonprofits that fund, develop, or maintain trails. While many of the recommendations in the Guide involve resources, low-cost or creative considerations and strategies are highlighted where possible.

Organization of Guidebook

This Guide will help readers understand, plan, and design trail projects within a framework of resilience. The Guide illustrates considerations from the big picture down to design details. However, given the number of resources that are available for trail design in all different settings, the Guide is not a general trail design guide. The content of the Guide is as follows:

Chapter 1: Introduction and Context discusses the purpose of the guidebook, including background and context, trail types and uses, components of a trail, related Federal efforts, and audience. The role of trails in climate mitigation and adaptation is also discussed.

Chapter 2: Planning and Implementation covers tools and documents, tips for integrating resilience into trail planning, partnerships and community coordination, and funding. This chapter also highlights equity in trail planning and design, through discussion of topics such as inclusive planning processes, community partnerships, social resilience, and public health.

Chapter 3: Evaluating Vulnerability describes event types and risk factors, such as geologic events, severe storms, flooding, climate pattern changes, wildfire, and heat. The basics of vulnerability assessments are discussed along with assessment methodology and low-cost assessment methods.

Chapter 4: Design and Engineering for Resilience provides detailed design guidance on several topics: siting, grading, drainage, materials, natural infrastructure, structures, and construction access and staging.

Chapter 5: Emergency Response Planning discusses the role of trails in emergency response and trails as evacuation routes. Emergency operations and management guidance is also provided.

Chapter 6: Management and Maintenance details practices to improve climate resilience, visitor use management, and how to overcome land management conflicts.

Chapter 7: Conclusion wraps up the discussion of all previous material and offers suggestions for future study.

Chapter 8: Case Studies covers key take-aways and lessons learned from interviews with trail managers, planners, and designers who have worked to adapt their local trails to climate impacts. These case studies include trail planning and design strategies to address climate impacts across a wide range of geographies, contexts, and trail types.

1.2. The Role of Trails in Climate Mitigation and Adaptation

This section provides an overview of key considerations for using trails as a means of mitigating and adapting to climate change. For implementable design strategies, see Chapter 4: Design and Engineering for Resilience.

Climate Mitigation and Adaptation

Climate mitigation refers to interventions that reduce greenhouse gas emissions, such as shifting travel away from single occupant vehicles, or enhance carbon sinks that absorb carbon dioxide from the atmosphere.

Climate adaptation refers to the process of adjustment to actual or expected climate and its effects, in order to reduce harm or exploit beneficial opportunities.

Adaptive capacity refers to the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

See Glossary and Acronyms for a complete list of key terms.

Trails for Mitigation

Trails can help mitigate climate change by reducing motor vehicle dependency and accompanying greenhouse gas (GHG) emissions. According to the Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2020), transportation is the largest source of GHG emissions in the U.S., accounting for 27.2 percent of total GHG emissions in 2020. The majority of GHG emissions from transportation are carbon dioxide (CO_2) emissions, with 92.1 percent of total CO_2 emissions in 2020 caused by fossil fuel combustion. The largest fossil fuel emissions contributor in transportation is passenger vehicles.[17]

Trails can mitigate this issue when they are integrated into local and regional transportation networks (see PBIC's info brief on Advancing Trails to Support Multimodal Networks for more information).[18] Trails that connect people to where they need to go can help shift trips to travel modes with lower CO_2 emissions. Trail corridors can also incorporate natural infrastructure and vegetation, particularly trees, to sequester and store carbon. This topic is addressed in Section 1.1: Natural Infrastructure.

Trails in recreation areas, such as hiking and mountain bike trails or Off Highway Vehicle (OHV) trails, generally do not function as an alternative to motor vehicle travel, and OHVs emit CO_2 while in use. However, the transition from gas-powered to electric OHVs is expected to accelerate across the globe over the next several years. The global market size for electric OHVs was $707.6 million in 2021 and is forecasted to reach $3,845.3 million in 2030 with the largest share of the market in North America. The rise of electric OHVs is in part due to their reduced noise and tailpipe emissions.[19] Furthermore, these trails are often located on protected lands with vegetation that serves as large carbon sinks. The management of the landscape surrounding trails is key to preserving recreational areas as climate change mitigators. See management considerations in Section 6.2: Management.

Another consideration when thinking about trails and climate mitigation is emissions from trail construction and maintenance. For instance, urban trails can be designed with largely low- or no-mow landscapes that

can also serve as habitat for insects and birds. Strategies for lower emission construction are provided in Section 4.6: Construction Access and Staging, and maintenance strategies are provided in Section: 6.1: Maintenance.

Areas for Additional Research

Assessing the lifecycle of trail materials and construction and maintenance equipment could clarify the relationships between trails and emissions. Additional research would also be helpful to help quantify the potential that different trail types possess to attract a greater diversity of users to walk, bike, and roll for transportation, which will impact vehicle miles travelled (VMT) reduction goals.

Trails for Adaptation

Trails should also be designed to be adaptable so that they remain functional as popularity increases and environmental conditions change over the long-term. This entails attention to siting, grading, drainage, and materials, among other factors. This Guide provides design and engineering considerations for adapting all different trail types to the impacts of increasingly extreme weather and other effects of climate change (see Section 3.1: Event Types and Risk Factors for more information).

It is also essential to consider trail adaptability not only in terms of the trail itself, but also in terms of how trails help communities and regions adapt to climate change impacts. Trails and trail corridors can be used as physical protection from extreme weather events. For example, trails can serve as flood protection for surrounding areas, whether by being built on top of berms or by functioning as floodable corridors. Trails corridors can function as fire breaks or for fire vehicle access in wildfire prone areas. Trails also play a role in adaptive transportation networks when they can be used for travel within or between places in which people live and work.

Adaptive Transportation Networks

Transportation systems are diversifying at all scales, with infrastructure that supports active transportation and micromobility expanding rapidly across urban and rural areas. Accompanying that diversification is the increased focus on trails as safe, comfortable infrastructure that separates people walking and biking from roadways and motor vehicles. Trails are increasingly used to connect between and within population centers, often following rail corridors or utility easements.

Thus, trails present opportunities for:

- Low-conflict and low-time delay connections for people walking, biking, and rolling;
- Redundancy with roadway systems and alternate evacuation routes, whether within a municipality or regionally; and
- Emergency evacuation for pedestrians and bicyclists, and/or emergency vehicle access and operations when roadways are congested with motor vehicle traffic or as alternatives to closed roadways.

The Oak Leaf Trail in Milwaukee, WI is a multiuse trail system with over 135 miles of mostly paved paths connecting throughout the metropolitan area. Main “branch lines” run in different directions around the area and meet several smaller municipal trails. The extent of the trail network allows people to substitute active transportation in place of driving for daily travel and can provide means for travel and first responder operations during emergencies.[20]

For trails to function as part of adaptive transportation networks, it is necessary to understand the points of vulnerability both for trails and their local and regional context. Section 3.2: How to Evaluate Vulnerability

covers formal and low-cost, informal methods for conducting vulnerability assessments as well as a range of potential hazards and vulnerability risks. Beyond the aforementioned design strategies, emergency management and response planning come to the fore along with protocols and methods for communication before, during, and after hazardous events. These are addressed in Chapter 5: Emergency Response Planning.

2. Planning and Implementation

This chapter describes how to make climate-conscious decisions at every step of the trail planning process. Resilience can be integrated into both new and existing trail projects.

A key component of trail planning and implementation is understanding how they impact communities. This chapter also explains strategies for ensuring equity in planning, design, and usability so that the social, economic, and health benefits of trail systems are distributed fairly.

Figure 2: An asphalt trail along Lake Kittamaqundi in Columbia, MD (Photo: Toole Design)

2.1. Planning for Resilient Trails

This section provides guidance on how to plan for resilience for different trail types (i.e., multiuse paths, natural-surface recreational trails, etc.). It also contains information on how a range of planning processes can consider climate resilience.

Basic Planning and Implementation Process

Table 1 below depicts the typical steps to plan and implement a trail.[21] Some steps are iterative – for example, involving public agencies and community support is key throughout the process. While the process may differ based on the trail type there are common and consistent elements worth noting.

Decisions should be documented throughout the planning and implementation process. Trail projects are most successful when there is a planning document that answers the most pressing questions, for example how the project will be built, which constituents it will serve, how it will be funded, and more. Key documents may include a trail feasibility study, trail system master plan, and a management and maintenance plan.

Table 1: Typical steps to plan and implement a trail

STEPS	ACTIONS
Organizing	• Build support with public agencies • Coordinate with metropolitan and statewide planning • Build community support • Develop project goals that incorporate climate resilience • Practice inclusive engagement
Land acquisition	• Identify the general area of the trail (may include park lands or public right-of-way, and may involve rail banking) and ensure it is possible to construct at the proposed location
Site assessment	• Analyze environmental constraints and relevant climate hazards • Conduct climate vulnerability assessment • Analyze soil type and quality • Consider how to distribute the benefits of the trail to underserved communities
Planning	• Determine trail user type • Identify trail alignment(s) that avoid sensitive ecosystems • Develop feasibility study
Funding	• Collaborate with public and private entities to fund the project (for either further planning or design and construction) • Apply for grant funding • Prioritize projects that support climate resilience

Design	Consider the following: • Surface material, Wayfinding, Lighting, Landscaping, Natural infrastructure, Drainage structures, Grading, Crossings, Bridges, Tunnels and underpasses, Trailheads, Maintenance access
Construction	• Obtain permits • Consider water quality protection measures • Develop erosion control plans • Restore disturbed soil • Minimize transporting nonnative invasive species
Maintenance and management	• Conduct inspection • Develop management and maintenance plan • Coordinate staff, other agencies, and volunteers • Manage visitor use and improve user experience • Engage trail users through programming and science education opportunities

Integrating Resilience into Trail Planning

No matter where an agency is in the development of a trail network or what the scope of the work may be, there are opportunities for integrating climate resilience into the planning and design process:

Creating project goals. Planning for climate resilience can start at the beginning of the trail project when it is integrated into the project vision and goals. Climate resilience goals can be adopted alongside typical transportation and recreation goals for a trail. The Town of Sturbridge, Massachusetts developed a 2022 Trail Sustainability Plan with a goal that states: "Achieving harmony between human trail use and environmental sustainability is possible through sound building practices, careful monitoring of changing conditions, and prudent management decisions. The town should strive to take every measure within reach to mitigate harm to the region's ecology, and when that harm cannot be mitigated through sound trail design and use guidelines, limiting human access should be considered."[22]

Considering who the trail will and should serve and aligning the route accordingly. Once planning and design work has begun for a particular trail connection, identifying the alignment is critical to the success and resilience of the trail. Considerations should include access to common destinations, links to the overall trail network, and property ownership.

Alignments that serve communities with limited transportation options should be prioritized, especially if these communities currently lack access to green space or may be disproportionally burdened by the effects of climate change. While climate change affects all people, some demographic groups are and will be more severely impacted. Protecting and providing resources to these groups can help to address uneven impacts.

There are several Federal tools available to identify communities that are disproportionately impacted. The Transportation Disadvantage Census Tracts is the most common tool to determine level of disadvantage according to DOT's Justice40 definition. EJScreen, a national mapping tool by the EPA, combines socio-economic and environmental exposure data to areas with high burdens, as well as where populations may

Example of Community-Based Trail Prioritization

In 2019, Portland, Oregon's Metro organization made a goal of providing opportunities for people to connect with nature close to home, earmarking $10 million in bond funds to complete portions of the region's trail network.

Figure 3: Regional trail needs versus available bond funds

In order to prioritize these funds, Metro worked closely with the community to develop a prioritization tool that ranks potential projects by assessing the degree to which they connect equity focused areas to destinations, improve access to nature, and provide an alternative to high-crash streets. Another major goal for Metro is to decrease greenhouse gas emissions that contribute to climate change by shifting more trips from driving to walking, biking, and transit. Metro used its regional transportation model to estimate the transportation potential of each potential trail connection.

Figure 4: Visualization of trail user volumes

be particularly vulnerable to the negative health effects to those exposures. Finally, the CDC's Social Vulnerability Index provides databases to help emergency response planners and public health officials identify and map communities that will most likely need support before, during, and after a hazardous event. There are also many State and local level tools such as the Washington Environmental Health Disparities Map that include different factors.

It is important to keep in mind the limitations of any equity measure. Each census tract has between 1,200 and 8,000 people[23] which makes some level of aggregation bias inevitable. Individuals also move between census tracts and may have ties to particular geographies that are different from those where they live. In addition, the incorporation of geographic equity measures into the prioritization framework is not a substitute for a needs assessment that identifies barriers faced by underserved individuals or groups in accessing trails, regardless of where they reside.

Designing for resilience and environmental health. It is important to consider how grading requirements may contribute to erosion, which creates potentially dangerous conditions on and near the trail. For wildlife, erosion leads to loss of habitat, and pollution and sedimentation in bodies of water disrupts aquatic life. Routing on steep grades may negatively impact sensitive plant species or habitat. Other climate-related hazards, such as flooding, rockslides, avalanches, and wildfires may be minimized or avoided with careful alignment consideration. The integration of natural infrastructure into the trail alignment can mitigate some of these issues and even yield environmental co-benefits. Other considerations may include existing environmental protections, such as the National Environmental Policy Act, National Historic Preservation Act, or Endangered Species Act.

Prioritizing trails that boost climate resilience. To prioritize limited funding and implementation resources, many cities, counties, metropolitan

planning organizations, and regional trail coalitions engage in planning processes to decide which trail projects should be prioritized for implementation. Prioritization is often based on factors such as equity, connectivity, and access. Climate resilience can also be used as a factor for prioritization. For example, trails used heavily for transportation may be prioritized for upgrades, including fortification against potential climate related threats. This is particularly relevant when these trails serve communities with lower rates of vehicle access or ownership. Trails may also be prioritized for construction based on their usefulness as part of emergency response or evacuation scenarios. As noted previously, prioritization may also be weighted towards neighborhoods that are more vulnerable to the effects of climate change.

Building support for trail implementation. Successful trail projects are built on support from public agency leadership and staff that will be tasked with planning and implementing the project, and from advocacy or nonprofit organizations that can assist with a variety of tasks including advocacy, public outreach, funding, and management. To build support, trail champions should create a compelling case that includes the benefits of the trail. This is a key time to share the anticipated impacts on the natural environment and the value of planning for climate resilience. Explaining how climate resilience is being planned for can demonstrate the longevity of the project in the face of changing climate conditions.

Trail Redesign or Reconstruction. Reconstructing or rerouting a trail presents an opportunity to integrate sustainable practices that may have not been implemented before. This may include choosing an alternative surface material, relocating part of a trail, or integrating drainage solutions. See Chapter 4 for design and engineering considerations.

Integrating Trails into Other Planning Efforts

Trail projects can be paired with other transportation, resilience, restoration, and emergency management plans to maximize opportunities to make a community more resilient to climate change. Climate-related events may create opportunities to incorporate trail projects into disaster recovery.

If an agency is developing a climate action plan, trail resilience projects can be incorporated as a strategy to reduce greenhouse gases by encouraging active transportation. The City of Watsonville, California's Climate Action and Adaptation Plan includes updating its trails master plan as an immediate action item to reduce the city's transportation emissions.[25]

Trails can also be leveraged as a resource in emergency response and evacuation planning. Looking outside the lens of climate change, trails offer a valuable redundant transportation network. When a transit system shuts down due to a system failure or worker strike, or if roads are closed for repairs, community events, or civil unrest, trails offer an alternative means for transportation. Pairing trails with shared micromobility programs can further enhance a community's resilience to breakpoints in the transportation network. Providing redundancy is a foundational component to resilience for climate change and beyond. See Chapter 6 for more information.

Trails as Redundant Transportation Networks: ATV Trails in Vermont

In 2011 Tropical Storm Irene caused floods that damaged roadway bridges throughout Vermont. Residents used ATVs on trails to move people and supplies to and from isolated communities. Following the initial response effort, local officials decided to create trails more accommodating of ATV use to support future disaster response needs.[24]

Partnerships and Community Coordination

One aspect of a resilient trail is community support from a diverse group of stakeholders that can serve as advocates and stewards. State and local agencies, nongovernmental organizations, businesses, and volunteers can be included to collectively envision, fund, construct, and manage a trail system. Proactive coordination yields better plans and designs and can also help avoid unexpected costs associated with post-construction retrofits or lawsuits if trails are designed incorrectly.

Climate resilience can be integrated into trail planning by partnering with groups with similar goals. Climate change advocacy groups often integrate trails into their work. For example, Western Resource Advocates is an organization dedicated to addressing the effects of climate change on the western U.S.'s environment and economy, and its work includes connecting people to natural lands while at the same time protecting those lands.[26] Conservation land trusts, interested in preserving open space, may attract donors with the promise of a trail through their lands.[27] The Land Trust of North Alabama works to preserve the natural state of lands in its care, and over 70 miles of trail are open for public recreation.[28] Teachers may also be interested in using trails for environmental education and demonstrating youth involvement can attract funding.

Community support groups can take on many different forms and functions based on the size and complexity of the community and project(s) being supported. The most common are:

- **Public agency supported advisory boards and committees.** Public agencies typically form advisory boards to obtain ongoing public input at various stages in planning and/or implementing project(s). Hosting an advisory board is an excellent way to thoughtfully plan and maintain a trail while also building support for agency policies, programs, projects, and funding. Creating and running an effective advisory board involves a thoughtful, purposeful, and informed strategy. Further, inviting local scientists, researchers, advocates, or other climate experts can help emphasize resilience.
- **Public agency supported nonprofit organizations.** Many successful community support groups are independent nonprofits that are partly funded by a public agency. This structure is an excellent way to ensure long-term sustainability of a project but involves significant upfront effort, funding, and public support. These groups often have sophisticated organizational structures and significant corporate or public agency support.
- **Coalitions.** Coalition groups bring together the public, private, and nonprofit sector to support trail development. Often, these coalitions span several jurisdictions, and their work impacts many different interest groups. This type of group can be useful to build support for more contentious projects and to coordinate trail planning and long-term sustainability at the regional level.
- **"Friends of" nonprofit groups.** "Friends of" groups are typically the most common and locally focused type of support group. These groups are usually started by neighbors or concerned people who coalesce around the common goal of supporting a particular trail or trail system.
- Throughout the collaboration process, groups should consider how to maximize community benefits and ensure they are distributed equitably. Refer to Section 2.2 for more information.

Evolving Shorelines

Figure 5: Plan for improvements on the Mill Valley-Sausalito Path. (Image: Marin County Parks)

Like elsewhere in the Bay Area, Bothin Marsh (Mill Valley, California) is threatened by sea level rise and has frequent flooding events. The Mill Valley-Sausalito Path, which runs along the marsh, is in poor condition after repeated flooding. National, State, and local land managers and a conservation nonprofit are collaborating to improve the conditions of the marsh while maintaining the trail experience. Three proposed conceptual options were presented to the public for comment and reviewed by technical experts. The favored approach is to route part of the trail to higher ground at the perimeter of the marsh. The new segment of the trail would be elevated to accommodate 3.5 feet of sea level rise, and extensive wetland restoration would improve habitat and marsh resilience. [29, 30]

Funding

An analysis of current and future trail projects that align with funding opportunities can broaden opportunities for the planning, design, construction, and on-going maintenance of more resilient trails and those that can provide emergency management functions. The funding landscape for trails is continuously changing, and relevant funding for trail projects varies greatly based on the location and project type.

Federal surface transportation funds can be used for trail planning, design, construction, and maintenance. They typically involve matching funds from the recipient. FHWA provides a table of potential Federal Department of Transportation Pedestrian and Bicycle Funding Opportunities by project type. Relevant Federal funding programs administered through the States include:

- Carbon Reduction Program: Aims to reduce transportation related emissions. Planning, design, and construction of trails for nonmotorized transportation are eligible.
- Surface Transportation Block Grant (FHWA): provides flexible funding to address State and local transportation needs.
- Transportation Alternatives Set-Aside (FHWA): Provides funding for a variety of smaller-scale transportation projects including recreational trails. March 2022 Implementation Guidance clarifies that climate and extreme weather resilience elements that make transportation systems more reliable are eligible for TA Set-Aside funding.
- Congestion Mitigation and Air Quality Improvement Program: supports State- and locally selected transportation projects that reduce mobile source emissions.
- Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program: provides funds for resilience improvements.

- Recreational Trails Program (FHWA): Funds recreational and transportation trails and related facilities for both nonmotorized and motorized uses.

The Department of Transportation also has discretionary programs such as:

- Safe Streets and Roads for All (SS4A) Grant Program: Trails are eligible if the separation of users from the existing road network is identified in an existing, eligible Action Plan as a safety need.
- Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grant Program
- Reconnecting Communities Pilot Program: The RCP Notice of Funding Opportunity (NOFO) states "the variety of transformative solutions to knit communities back together can include linear parks and trails." The Inflation Reduction Act created a related Neighborhood Access and Equity grant program that includes eligibility for multiuse paths that support community connectivity.
- Thriving Communities Program provides technical tools and organizational capacity to enable communities and neighborhoods to thrive.

Other Federal agency programs include:

- Building Resilient Infrastructure and Communities (BRIC) annual grant program (FEMA)
- Rivers, Trails, and Conservation Assistance Program, National Park Service (NPS): Provides direct technical assistance rather than funding.
- Land and Water Conservation Fund, NPS
- The National Forest System Trail Stewardship Partner Funding Program for trails on National Forests and Grasslands (USFS and National Wilderness Stewardship Alliance)
- Forest Service Legacy Road and Trail Remediation Program: Supports resilient trails by taking into account foreseeable changes in weather and hydrology when decommissioning unauthorized and previously closed trails; converting National Forest System roads to trails where appropriate; and otherwise carrying out trails projects to improve resilience to extreme weather events, flooding, or other natural disasters. The program ensures that trails are adequate for supporting emergency operations, such as evacuation routes during wildfires, floods, and other natural disasters.

Many Federal grant programs require the grantee to provide a match to cover a percentage of the project's total cost. Typically, other Federal funds cannot be used as match for a Federal grant. However new legislation, such as the Infrastructure Investment and Jobs Act, do include provisions to reduce cost sharing burdens and allow Federal resilience funds to be combined.

There are two types of matches, cash and in-kind, and each grant will vary on what types are accepted. A cash match is either general revenue funds from the grantee organization, cash donations from non-Federal third parties, or funds from a non-Federal grant. An in-kind match is derived from the monetary value of noncash contributions that support the project. Examples of in-kind matches for trails projects may include volunteer hours, equipment, or material donations.

Trail projects can also be funded by a variety of State and local programs, often in the departments of health, environmental protection, parks and recreation, or transportation. Private grants often provide the most flexibility for funding. Partnerships with businesses and clubs are another viable option for both funding and volunteer support. Presenting a diverse set of funding opportunities for trail management that do not rely solely on tax dollars can help build a framework for dialogue between governments and community members.

Bundling trails into large-budget Transportation Improvement Program projects is another strategy for securing trail project funding. These high-dollar projects can typically absorb the costs of trail construction and often stand to benefit from their inclusion. Including trails within larger roadway

projects can benefit the project's overall environmental documentation by showing improved air quality outcomes when a subset of the intended users is bicycling, walking, or rolling as opposed to driving a gas-powered vehicle. Bundling these projects also makes more efficient use of equipment and material procurement and offers potential for creative on-site recycling opportunities.

Finally, nontraditional funding sources, including stormwater management benefits, environmental agencies, or other sources can also help support trail projects that deliver a wider range of social, economic, and environmental benefits.

Innovative Financing: Stormwater Credit Trading Programs

Municipal separate storm sewer system (MS4) permits allow public entities to discharge pollutants from public stormwater systems to waters of the United States. The permits require that discharge pollutants be reduced to the maximum extent practicable, and permittees can meet some or all of their reduction obligations by trading credits generated through other sources where pollution control costs are lower.[31]

The "other sources" may include stormwater management corridors with potential for trail development, as evidenced by the Gambles Mill Eco-Corridor in Richmond, Virginia (a case study in this Guide). The project was focused on stream restoration for pollutant load reduction, and a 0.5-mile multiuse path was incorporated within the stormwater corridor as a recreational and educational amenity for the University of Richmond. The City of Richmond funded the project by purchasing MS4 credits from Resource Environmental Solutions.

Emergency Response and Management Specific Funding

Planning for future design and maintenance costs and aligning these costs with potential funding sources can help to mitigate the infrastructure impacts and financial burden of disaster recovery. Recognizing trails as valuable resources for emergency response and evacuation can serve as a framework for a funding plan with a diverse set of sources, which provides the opportunity for a higher success rate, as well as a more sustainable stream of funding for future projects. Some potential funding sources that provide comprehensive disaster preparedness and response are managed by the Department of Transportation (DOT), U.S. Department of Homeland Security (DHS) and its Federal Emergency Management Agency (FEMA), U.S. Department of Housing and Urban Development (HUD), and the U.S. Department of Commerce (DOC).

The majority of funding provided by the DOT can be used to restore community networks to pre-disaster conditions. The Federal-aid Highway Emergency Relief Program (ER), Federal Transit Administration (FTA), and the Federal Railroad Administration (FRA) offer grants and direct loans that assist agencies in recovery from major disasters through the DOT.

The grants provided by DHS and FEMA offer supplemental Federal disaster grants that can be used for debris removal along trails, emergency protective measures, and publicly owned facilities that have been damaged through disasters. Provided by DHS through FEMA, the Hazard Mitigation Grant Program (HMGP) provides funding for eligible mitigation measures reduce losses in the wake of a major disaster. Authorized under Section 404 of the Stafford Act, the HMGP's goal is to reduce or eliminate threats from future disasters in communities. Using this grant for emergency response and management within trail systems aligns with the mission statement of HMGP by providing a long-term solution to specific risks.

Other potential FEMA grants include Building Resilient Infrastructure and Communities and the Pre-Disaster Mitigation (PDM) Grant Program.

Two grants provided by HUD to improve economic resilience are the Community Development Block Grant (CDBG) and HUD Disaster Recovery Assistance. The Disaster Recovery Assistance offers more flexible CDBG recovery grants to assist locations responding and recuperating from Presidentially declared disasters specifically in low-income areas. The allocated CDBG Disaster Recovery Assistance funds are applied to long-term needs such as purchasing disaster-prone land and improving the emergency response for disaster communities and victims.

Other programs that can help build resilience or recover transportation networks are found under the DOC through the Economic Development Administration (EDA). Two of the seven programs within EDA are specific to transportation improvements following a disaster, the Public Works and Economic Development Program and Economic Adjustment Assistance Program. Both programs directly or indirectly improve or expand upon existing networks while creating employment opportunities and can respond flexibly to economic recovery issues and challenges faced by U.S. regions and communities. However, a majority of these grants require a Presidentially declared disaster.

There are also more specific local and State funding sources that can be applied to annual maintenance or trail enhancements such as the Caltrans Active Transportation Program (ATP). The Caltrans ATP is a competitive statewide program in California that encourages increased use of active modes of multimodal transportation. The ATP is a funding source for the development of community-wide bike, pedestrian, safe routes to schools, or active transportation plans in disadvantaged communities. Funding comes from existing Federal funding sources, such as the ones listed above, and State transportation programs that amplify the ATP mission and can expand Emergency Response and Management. The programs included are the following:

- Transportation Alternatives Program
- Bicycle Transportation Account
- State Safe Routes to Schools

Another new potential funding source is the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Formula Program and Discretionary Grant Program, managed by FHWA. These programs fund projects designed to make transportation more resilient to current and future weather events, natural disasters, and changing conditions. Eligible projects include planning activities, resilience improvements, community resilience and evacuation routes, and at-risk coastal infrastructure. PROTECT funds can be used to support the incremental cost of making transportation assets more resilient.

2.2. Pursuing Equity in Trail Planning and Design

This section provides guidance on how to consider trail facilities and their accompanying benefits from an equity perspective.

Historically underserved communities, including but not limited to low-income, people of color, people with physical or intellectual disabilities, seniors, and people with limited English proficiency, may:

- **Lack access to trails where they live** due to historic inequities in infrastructure investment and development.[32] Transportation costs, lack of transit connections to trails, and park fees can also be barriers to access in recreational areas.
- **Feel unwelcome, uncomfortable, or unsafe** due to racial profiling and stereotyping, a lack of visibly diverse populations in rural parks, legacies of racism in how recreational spaces were founded and managed, or imagery and language in marketing materials that prioritize particular types of users. For instance, websites for shared use paths often feature white, thin, able bodied bicyclists with expensive equipment and specialized gear rather than families of color, people with disabilities, and people with varied body types.
- **Be prevented from using trails** due to physical barriers or poorly maintained surfaces. An example is people using wheelchairs or other mobility devices, who cannot easily use earth or stone dust paths due to ruts and potholes. Barriers intended to prevent motor vehicle access on trails, such as gates, can also inadvertently keep people in wheelchairs or mobility devices off trails when designed or installed poorly.

Trails and Displacement

It is also crucial to note the role that trail development has played in the purposeful displacement of low-income and minority populations. Historically, the development of public open spaces has at times depended on the forced removal of people from their homes; this was famously the case with the displacement of Seneca Village, a predominantly African-American community, for the development of Central Park.[33] In cities today, trail development can lead to green gentrification, where increased demand for housing next to trails and green space amenities leads to higher property values, taxes, and rents that force long-term low-income residents to move out. Moreover, a 2019 study found that new greenway parks with active transportation components, such as the 606 Trail in Chicago or the BeltLine in Atlanta, contribute more to green gentrification than the development of other types of parks, such as small-scale neighborhood parks.[34]

Equity in Transportation

Equity in transportation seeks fairness in mobility and access based on the needs of a variety of individuals and communities.[35] An equitable transportation system is one where all individuals and communities have the access and mobility that they need. Equity does not mean equality, where everyone is given the same resources and access. Rather, equity recognizes historic disparities in treatment, considers the circumstances impacting communities' mobility and connectivity needs, and uses this information to determine the measures needed to develop fair, just, and impartial processes and outcomes. For example, infrastructure for walking and bicycling is disproportionately absent from Black and Hispanic neighborhoods,[36,37] and Black and Hispanic neighborhoods have lower quality sidewalks with more obstructions and accessibility issues.[38,39] This has many implications for trails, as detailed below.

Federal Guidance

To confront the inequities described above, trail development should start and end with equitable and inclusionary planning and design processes, which are guided at the Federal level. Title VI of the Civil Rights Act of 1964 prohibits discrimination or denial of participation in or benefits from any USDOT program or activity on the grounds of race, color, or national origin. In accordance with this law, each agency must ensure that all programs or activities receiving Federal financial aid that affect human health and environment do not use criteria, methods, or practices that discriminate. The following Executive Orders also establish approaches to equity:

- **Executive Order (EO) 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (1994).** EO 12898 directs Federal agencies to address disproportionately high and adverse human health or environmental effects on low-income or minority populations resulting from their programs, policies, and activities. The EO also directs agencies to develop environmental justice strategies, which are described in more detail below.
- **Executive Order 13985, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government (2021).** EO 13985 seeks to advance equity through various efforts at the Federal level, including assessing and developing plans to overcome barriers.
- **In response to EO 13985, USDOT created an Equity Action Plan** that describes drivers of inequity and focuses on actions to pursue equity in the areas of Wealth Creation, Power of Community, Interventions, and Expanding Access. Many of the performance indicators and actions listed in the plan have been incorporated into this chapter.

Environmental Justice

As defined by the Environmental Protection Agency (EPA) and USDOT, "Environmental Justice (EJ) is the fair treatment and meaningful involvement of all people, regardless of race, ethnicity, income, national origin, or educational level with respect to the development, implementation and enforcement of environmental laws, regulations and policies." Federal agencies and entities receiving Federal grant funding must consider environmental justice in their programs and in their activities under the National Environmental Policy Act (NEPA). Several States have also built on EO 12898 and adopted their own EJ policies, many as tie-ins to State NEPA law, climate, or other policy. Whether pursuing Federal funds, by State mandate, or as a matter of ethical best practice, the following are basic actions that trail planners should take for their projects:

- Review either EPA EJSCREEN or State EJ GIS data to determine whether a trail or trail network will run through EJ communities.
- Research how climate change impacts are disproportionately affecting different communities at the local level and look for ways to address inequalities through trails projects. Climate change effects have been shown to disproportionately affect disadvantaged groups through increases in exposure to adverse effects and susceptibility to damage caused by climate change and through a decrease in the groups' ability to cope and recover from damage suffered.[40]
- Review State thresholds requiring environmental review to determine whether trail projects may adversely affect EJ communities. This may particularly relate to tree removal or addition of impervious pavement.
- Follow all guidance and policies initiated by a proposed trail project, including creating and implementing a plan for meaningful engagement of EJ communities who may be adversely affected.

- Consider whether community partnerships could be incorporated into a trails project. These partnerships can build capacity around a trail project while raising community resilience by strengthening social infrastructure. Successful community partnerships ensure that people are compensated for the time and expertise they bring to the project.

It is the task of all trail planners and advocates to pursue environmental justice and equity in trail planning and design whether legally mandated or not. The next sections highlight ways to pursue equity through all projects.

Inclusive Planning Processes

No matter the scope of the project, trail planning should treat public involvement as a process rather than an event. Planners and designers should expect to learn from the community at the beginning of a project and engage with the community during each phase of a project to gather feedback. It is important to practice inclusive engagement, which means that people who have traditionally been underrepresented in the trail planning process should be directly engaged throughout the life of a project and have decision-making power in the project.

Inclusionary planning begins by acknowledging both the past and present social, economic, and demographic context in which a trail or trail network is to be located and by seeking to understand issues as described by community leaders and advocates, rather than solely relying on written information and data. Planners also need to respect and value the views of community members for whom trail planning is not a priority. Other infrastructure needs or issues beyond mobility such as poverty, unemployment, housing, police violence, and crime, may take precedent.

Inclusive trail planning processes will:

- Create inclusive project teams by actively incorporating community representatives as stakeholders with decision-making power and/or as engagement leaders who drive project processes. See the following section on Community Partnerships and Leaders for more information.
- Seek active participation in trail planning, programming, and management by a spectrum of people who extend across all ages, abilities, and identities. Consolidate engagements, when possible, to avoid overburdening participants.
- Determine outreach goals and methods based on project context. What are the existing community planning process to build on? What are the intersecting issues, such as housing and public health?
- Meet people where they are by showing up at existing community meetings and events rather than expecting them to take time out of their lives to attend project-specific public meetings. When meetings are needed, consider hosting them at locations convenient to underserved communities and providing childcare and food for participants.
- Develop short-term, low-cost initiatives as part of projects that create immediate change.
- Follow-through on promises made.

See the Inclusionary Trail Planning Toolkit by the Pennsylvania Environmental Council for detailed recommendations and case studies on developing inclusive planning processes around trail projects. USDOT's Promising Practices for Meaningful Public Involvement in Transportation Decision-Making also includes useful guidance on seeking full representation from the community and incorporating feedback into a project. Other resources for inclusive trail planning include:

- The New Majority: Pedaling Towards Equity, The League of American Bicyclists and The Sierra Club
- Circuit Trails: Equity of Access to Trails: Market Research Conducted Fall 2020

Community Partnerships and Leaders

Trails are not isolated infrastructure, even if located in remote areas. They are influenced by the communities in which they are located and the people they serve, and likewise, trails also exert an impact and influence on the community.

Defining Community

The term "community" can vary in meaning. It may refer to people who live in specific neighborhoods adjacent to a planned or existing urban trail corridor or to people who live in the town(s) that abut a large, rural recreation area.

Resilient trails demand social, economic, and caretaking investment, so it is important to cultivate partnerships with the community that will endure beyond the life of any single project. Consider the following strategies:

- Seek partnerships with civic groups, grassroots organizers, nonprofits, businesses, arts councils or sports teams, among others. Leverage the relationships among individuals and groups to reach more people and address needs.
- Provide mutual support to partners and help them develop their own capacity by providing resources or connections. This mutual support can help build and sustain relationships and cultivate community leaders who will drive social investment in and stewardship of trails for the long-term.
- Compensate community members for their assistance and time, particularly when asking for participation across multiple events or meetings.

Community Feedback

Inclusive planning processes include community engagement throughout the life of a project, from identifying issues to refining plans and designs respond to community needs and values. Community feedback should not be sought to "check a box" but rather to truly influence the direction of a project.

It is best to set goals and be transparent about why feedback is being sought and what will be done with the information provided. This can be accomplished by making other people's feedback accessible for public viewing, taking into account privacy requirements or desires for anonymity. Be honest about limitations and demonstrate the ways in which community feedback is incorporated into the project.

Community feedback can also help trail planners and designers understand climate impacts and how to address them. For example, adjacent residents and trail users may have an intimate, firsthand understanding of issues like drainage and erosion. They see where water ponds for days after a heavy rain or where sediment is washed into storm drains, presenting an opportunity to refine trail design or maintenance protocols.

Equity in Trail Planning Outcomes

In pursuing the fair distribution of resources, the aim for high-level trail planning should be to enhance access to trails where they are needed most. Regional and local trail prioritization plans, active transportation plans, capital improvement programs, and other planning initiatives should include underserved communities, their connectivity needs, and level of access to open space and trails in prioritization tools and rankings. Examples of tools and methodologies include:

- Portland Metro Trails Prioritization Tool
- Reconnecting Milwaukee: A BikeAble Study of Opportunity, Equity and Connectivity
- ESRI's Racial Equity GIS Hub
- Minneapolis Park and Recreation Board's Equity-based Criteria for Regional Park and Trail Capital Project Scheduling
- Capital Trails Coalition's Equity Foundation for Priority Projects

Data Sources and Criteria

Successfully incorporating equity into trail planning involves collecting and interpreting qualitative and quantitative data. Trail planners should understand patterns in community conditions that reflect historic and present-day inequities. Spatial data can be particularly helpful in identifying trends and patterns. Trail planners may choose to develop equity metrics using racial, economic, and other criteria to prioritize trail projects. For example, the Minneapolis Park and Recreation Board has used equity-based criteria for prioritizing park and trail projects since 2017. Its process assesses community characteristics including racially concentrated areas of poverty, access, and neighborhood safety, as well as asset characteristics of historic investment, use intensity, accessibility considerations, natural resource conditions, and trail quality. The characteristics are weighted and combined to help ensure that the board prioritizes projects with a focus on racial and economic equity.[41]

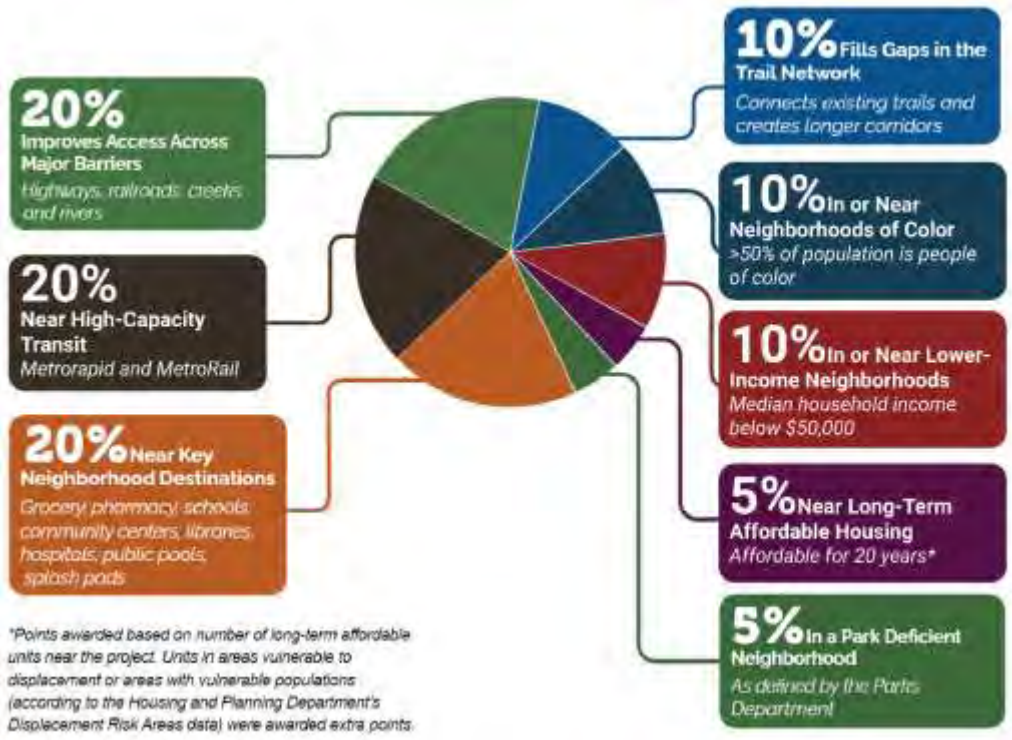

Figure 6. Equity-based Trail Prioritization Criteria (Source: Austin Urban Trails Program)

Equity in Design

Once a trail design project has been initiated, designers should look for ways to promote equity both as part of the engagement process and in the physical design of the trail corridor or area. Too often, trails are designed to serve limited groups of users, and amenities are chosen solely based on their aesthetics and costs. Across all types of trails, multiple opportunities exist to expand people's experience through inclusive design. Consider:

- Grading trails and selecting and locating amenities such as seating and bike racks to support people with limited mobility.
- Providing design treatments that assist in navigation or greater interaction with spaces for people with low vision or blindness.
- Designing more intentionally for women. Consult resources on designing spaces that feel secure and support women's recreational and social needs. Collaborate with female hiking, running, or bicycling groups.
- Providing skate zones, pump tracks, parking for e-scooters or e-bikes, or other space and amenities that meet the needs of a wide array of users for trails in populated areas
- Seek opportunities for accessible loops in areas with a network of trails

Also consider equity in the design of marketing materials, signage, art, and websites. Consider:

- Is artwork along the trail welcoming and inclusive?
- Is the trail marketed toward a wide spectrum of ages, body types, family types, abilities, races, and ethnicities?
- How are children incorporated into the planning and design?
- How can symbols or graphics be used in place of words to communicate to those for whom English is not a primary language?

See Section 4.1 for more information on designing for equity.

Equity in Usability and Access

Elements of trail planning and design determine what groups are able to use and benefit from trails. Below are some considerations for improving trail access and usability for all:

- Find ways to offer free or inexpensive options if trails require fees or equipment rental for certain uses. Consider partnering with organizations to provide free or reduced prices.
- Plan for transportation network connectivity that allows families and individuals to access trails without use of a personal vehicle. Consider public transit options or shuttle services that can reduce car dependency.
- Plan trailheads for locations that are accessible by neighborhoods within a locally defined time or distance.

Trails as Part of Social Resilience and Public Health

Social and community resilience is the capacity of individuals, groups, communities, and systems to anticipate, absorb, respond to, and overcome chronic stresses and acute shocks. Social resilience has taken on greater importance as climate change increases the frequency and severity of disasters and extreme weather events that can disrupt infrastructure and social services. Although social resilience is not the primary topic of this guidebook, trails can play an important role. Examples are noted below:

- Trails can serve as part of an emergency response network.
- Trails can be community assets – places to gather and socialize.
- Trails support public health, which is closely tied to resilience.
- Trails should be viewed as part of, not independent from, communities.

See the FHWA's Health in Transportation page for additional information on incorporating public health considerations into transportation planning processes.

Additional Resources

- FHWA, Transportation Planning Capacity Building. Transportation Planning Process Briefing Book.
- FHWA. (2016). Pursuing Equity in Pedestrian and Bicycle Planning.
- Rails to Trails Conservancy. Equitable Practices in Trail Planning.
- Centers for Disease Control and Prevention. (2013). A Practitioner's Guide for Advancing Health Equity. Section 4-3: Trails and Pathways to Enhance Recreation and Active Transportation.

3. Evaluating Vulnerability

This chapter provides guidance on how to evaluate trails vulnerability to climate change and related extreme weather events. It also identifies the specific ways in which various climate trends and event types make trails vulnerable.

The acceleration of climate change has increased trails' exposure to destructive weather patterns and events around the globe. Different regions within the U.S. have increased risk factors associated with geography. For example, 57 percent of Philadelphia's off-street trail mileage is projected to be unusable by 2100 due to sea level rise.[42] Parts of the country that are prone to wildfire are seeing increasingly widespread destruction, including negative impacts to trails. In 2021, the Pony Express National Historic Trail incurred severe damage along 20 miles from the Caldor Fire, which burned 221,835 acres in California.[43] Other destructive weather-related events, such as flooding, are occurring nationwide.

Climate change is also impacting different trail types differently, and this often depends on the uses for which they were originally designed. Cross-country ski trails, such as the Methow Trails in northern Washington, are delaying trail opening dates due to lack of snow.[44] Hiking trails in the Mountain West are seeing more days with poor air quality due to wildfire and hazards following wildfire when standing dead trees, known as snags, precariously line the trail corridor.[45]

Figure 7: The Shoreline Trail at Coyote Hills Regional Park, Fremont, CA (Photo: Toole Design)

3.1. Event Types and Risk Factors

This section considers the growing body of research on climate change's impacts to trails. It emphasizes understanding climate change-related trends and events in a local area and provides guidance for considering the risk to and impact on trail infrastructure.

Evaluating Climate Impacts

The impacts to trails from severe weather and other events driven by climate change can be grouped into three categories:

- **Physical impacts**. Storms, flooding, fires, heat, and geological events can all result in physical damage to trail infrastructure. This damage can result in trail conditions that are dangerous to users (e.g., uneven surfaces and failing structures) and surrounding ecosystems (e.g., erosion).
- **Economic impacts**. The economic impacts of extreme climate events include the costs of repairing and rebuilding trail infrastructure as well as the impacts to the communities that use them.
- **Trail user impacts**. Climate change is changing annual weather trends, resulting in changes to user behavior and participation. Trail users may change the time of day or season they are out on the trail. Other factors like duration of trail use or selection of electric-assist bicycles and devices may also be affected.

Each of the following climate events results in some combination of these impacts. An evaluation of risk should consider each impact area.

Severe Storm Events

Severe storms come in many forms, including hurricanes, thunderstorms, straight line winds, ice, blizzards, tornado-producing storms, and rain-on-snow events. These storm events have the capacity to cause devastation, including loss of life and costly destruction of infrastructure. Data from the National Oceanic and Atmospheric Administration (NOAA) shows that billion-dollar natural disasters are occurring more frequently in the U.S.[46]

Damage to trails resulting from severe and frequent storm events can include washouts, flooding, erosion, sedimentation, and destruction of trail infrastructure such as bridges and culverts.[47,48,49,50] Severe storms can also cause wind impacts in forested areas that make the trail impassable with downed trees or leave hazardous standing dead trees.[51]

Flooding

Flooding is associated with several storm events and conditions that are occurring more frequently and severely with climate change. Riverine flooding occurs when rivers and streams exceed the capacity of their natural or constructed channels and overflow onto adjacent lands. The FHWA report on Highways in the River Environment offers further information on riverine flooding and discusses strategies for projecting flood frequency using rainfall/runoff modeling and statistical methods.[52] Flooding frequently affects trails that run parallel to rivers and streams and causes damage to trail tread, bridges, and culverts. Debris flows carried by floodwaters can be particularly harmful to structures that are not built to accommodate passage of large branches and other detritus. Trails adjacent to rivers and streams affected by flooding may also be at risk for washouts or undercutting, where floodwaters erode away the trail surface or the earth that supports it.

Saturated soils can also contribute to flooding and affect trails that run through areas with low water tables. More frequent and extreme rainfall events are particularly problematic for trails through low-lying areas. In 2018, a series of rainstorms in Montgomery County, Maryland forced the closure of more than 150 miles of trails[53] due to the wet conditions. Saturation makes trails further susceptible to erosion and

encourages trail users to walk outside of the trail tread. Trail corridors can become widened or braided when enough users bypass sections of flooding. This inadvertent trail widening can lead to impacts to natural resources along the trail corridor.

Sea level rise is threatening many shoreline trails and associated infrastructure. The effects of sea level rise on coastal infrastructure include increased flooding and more vulnerability during storms. Intrusion of saltwater into drinking water supplies is another hazard associated with coastal flooding. Further detail about the impacts of coastal water level fluctuations associated with climate change can be found in the FHWA Highways in the Coastal Environment report.[54] Theodore Roosevelt Island showcases the impacts sea level rise is anticipated to have on trails. The island is a national memorial managed by the National Park Service and located in the Potomac River in Washington, D.C. Although the memorial structures located in the interior of the island are at a high enough elevation to avoid increased flooding, sea level rise will force walkways and bridges to be rebuilt in order to maintain access to the memorial.[55]

An indirect hazard associated with climate changes is failure of water conveyance structures, such as dams. Decades-old dams are not suited to handle the more frequent extreme rainfall events and saturated grounds associated with climate change. In February 2017, heavy mountain runoff linked to climate change caused a near-failure of an emergency spillway and severe damage to the main spillway at the Oroville Dam in California. The repairs cost over $1 billion and nearly 200,000 people were evacuated as a precaution.[56] Dam failures may threaten the many trails located around dams and reservoirs including those that are part of the required recreation plan for the more than 2,500 dams[57] licensed by the Federal Energy Regulatory Commission (FERC).[58]

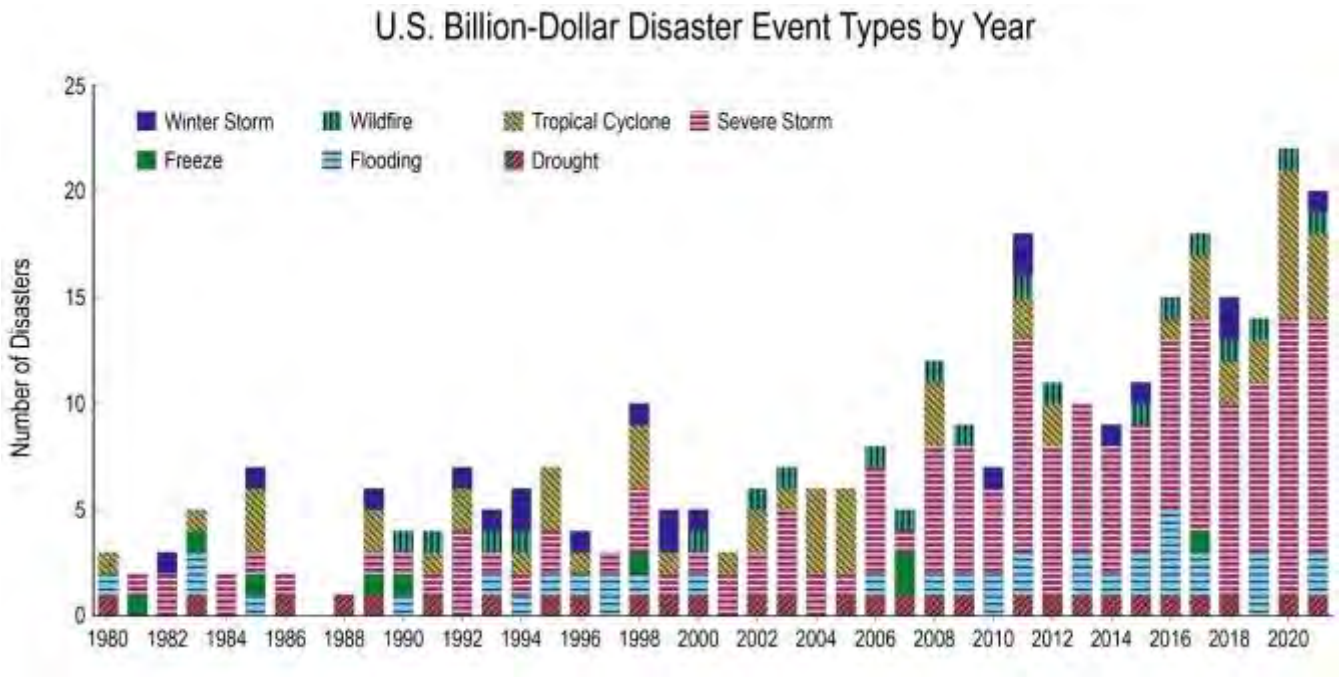

Figure 8: Billion-dollar natural disasters are increasingly common in the United States. Adjusted for inflation (Consumer Price Index) (Source: adapted from NOAA National Centers for Environmental Information (NCEI). Billion-Dollar Weather and Climate Di

Lasting Damage

It takes years for some trails to recover from severe storm impacts. West Lake Trail in Everglades National Park was reopened in March of 2022 after sustaining heavy damage from Hurricane Irma in 2017. The trail was closed since February of 2021 for repair. Park staff used innovative design and construction techniques to protect the wetlands and mangrove forest while also preparing for future sea level rise and increased storm intensity. The boardwalk, which suffered the most severe damage, was raised by one to two feet and flow-through decking was installed to better accommodate storm surge uplift.[59]

Figure 9. Hurricane Irma damage to West Lake Trail (2017) (Photo: NPS)

Wildfire

Climate change's impact on wildfire season length, area burned, and frequency is already apparent. In 2020, 10.1 million acres were burned by wildfire, the second-most acreage affected since 1960.[60] Increased temperatures and drought are both contributing to increased severity and extent of wildfires.[61] Wildfire impacts trails in many ways. While fires are burning, there is the obvious immediate danger to trail users, and smoke can impact air quality thousands of miles away.[62] Wildfire can cause severe damage to trail surfaces and structures (such as bridges). The 2021 Knoll Fire damaged several trail structures and forced a lengthy closure of a section of the popular McKenzie River Trail on the Willamette National Forest in Oregon.[63]

Wildfires also leave trails susceptible to severe erosion in rainstorms. Without vegetation to hold soils in place, trail corridors are vulnerable to washouts. This was the case for trails within the Angeles National Forest that suffered damage from flooding caused by rainfall that extinguished the Station Fire in 2009.[64] Trail corridors can also be left with downed trees and hazardous standing dead trees following wildfire.[65] Snags are particularly problematic along busy sections of trail, trail waysides, and adjacent day-use areas and campgrounds. Wildfires can also have widespread effects that impact trails outside of burn areas including air and water quality reduction.

Heat

Longer stretches of hot weather and more frequent extreme heat events may have a negative effect on trail infrastructure. At high temperatures, trails paved with asphalt or concrete are at increased risk of deformation. Asphalt softens when it gets hot and will age faster at high temperatures, and concrete can buckle. Buckling can be exacerbated by pavement designs that have insufficient expansion joints between slabs or if debris accumulates in the joints due to lack of maintenance.[66] For more in depth information about temperature and moisture changes' effects on pavement systems, see FHWA's Synthesis of Approaches for Addressing Resilience in Project Development report and associated studies conducted in Texas (TEACR Pavement Shrink-Swell) and Alabama (GC2 Pavement). See Section 4.4: Materials for more information on temperature's effects on asphalt and concrete trails.

Hotter temperatures also affect trail users.[67] In addition to higher risk of heat-related illness, many people may simply choose not to use trails. A study conducted on the Ann and Roy Butler Hike-and-Bike Trail in Austin, Texas estimated the association between temperature and trail counts. Pedestrians were more likely to use the trail between 45° and 85°F with peak use at 63°F, while bicyclists were more likely to use the trail between 59° and 91°F with peak

use at 81°F.[68] Weather projections for intermediate- and high- emissions climate change scenarios were then used to predict future trail use trends. By 2041-2060, a net decrease in trail use was estimated for pedestrians (-4.5 to -6.6%) and cyclists (-1.1 to -1.6%). By 2081-2100, trail use is estimated to decrease further: -7.5 to -16% for pedestrians and -1.9 to -4.5% for bicyclists.[69] These results suggest that trails in hotter climates may have reduced ability to provide comfortable options for transportation and physical activity in the hottest months of the year.

Often correlated with heat, drought decreases availability of drinking water sources along hiking trails and can have consequences for long distance hikers as well as wildlife and forest health.[70]

Trees and Vegetation Stress Factors

Changes to plant communities are at the heart of climate change impacts to trails. Trees and vegetation serve important ecological functions in both urban and rural trail settings, in addition to the benefits they offer trail users. In urban areas, trees and vegetation provide shade, aesthetic benefits, and visual buffers. In natural settings, such as streams and rivers, trees and vegetation along trails support ecological functions, habitat, and biodiversity. For example, greenways can serve as natural floodplains that improve water quality and reduce the impacts of flooding.[71] For an example of greenways serving as floodplains, see the Bear Creek Greenway case study.

Trees and vegetation along trails also prevent soil erosion during wind and rainfall, can reduce and filter stormwater runoff and pollutants (both agricultural and road), and retain soil moisture, which has a direct correlation with plant health and diversity.

Changes in the Earth's temperature affect the availability of water critical for plant health and reproduction and can alter growing seasons.[72] As hardiness zones shift with a changing climate, vegetation and tree selection and management along trails becomes more challenging.

Changes to vegetation and loss of habitat result in "range expansion and contraction," which affects availability of food and breeding patterns for insects, birds, and animals. This in turn results in geographical or altitudinal shifts of plant and wildlife communities, upsetting ecological balance and biodiversity.

These stresses also make trees and vegetation vulnerable to die off, diseases, and pests, not to mention storm damage, resulting in more frequent and intensive trail management needs.[73,74]

Insects and Disease

Many climate change-induced trends create prime conditions for insect outbreaks and diseases, affecting trails and trail users, as described above.

Forest Health

Forests already weakened by changing climate and/or overly-dense conditions are more susceptible to insects and disease.[75],[76] Higher winter temperatures and extended droughts increase the vigor of some insect species or may allow the insect to produce more generations than under colder conditions, resulting in rapid population increases. In the western US, bark beetles killed trees across 50 million acres from 2010-2018.[77] Western pine beetles killed 129 million trees in California following an outbreak brought on by the 2011-2016 drought. The Southern pine beetle also contributes to extensive tree mortality in the eastern part of the country, and its habitat is extending to the northeast because of warming winters.[78]

Fungal diseases are expected to have greater effects due to climate change, especially pathogens that prey on stressed vegetation. For example, eastern white pine is more susceptible to disease due to increasing temperatures and precipitation in New England.[79] Understanding both lifecycles and optimal conditions for pests and pathogens, as well as forest

management history or lack of management, can help to identify areas that are at high risk for these hazards.

Tree and forest health matter in both urban and backcountry trail settings. Trees can provide valuable shade and improve aesthetics along trails in all settings. Shaded surfaces may be 20-45° cooler than the peak temperatures of unshaded materials.[80] In urban settings, the loss of shade and benefits to scenery can dramatically affect the trail experience. As temperatures continue to rise and pest and disease risks change, it will be increasingly important to plan for tree maintenance along urban trails. Proper tree care is important not only for aesthetics but also for mitigating risks associated with dead and dying trees that pose a hazard to trail users.

These consequences also occur in backcountry trail settings and present a significant hazard to manage along forested trail corridors. Following impacts from bark beetles, for example, the USDA Forest Service contracted the removal of hazard trees along at least 88.5 miles of trails on the Arapaho and Roosevelt, Medicine Bow-Routt, and White River National Forests.[81]

Human Health

Climate change is also benefiting insects that pose a health risk to trail users who, through outdoor activity on trails, are exposed to disease-carrying insects. Warmer temperatures and environmental changes have allowed several tick species to expand north. Tick-borne diseases, including Lyme disease and Anaplasmosis, are predicted to become more common in Canada. Increased temperatures prolong the survival and activity period of ticks and widens the season when people are outdoors and may be exposed to ticks.[82]

Mosquito-borne illnesses are also likely to increase in prevalence as well as changes in where people are exposed to different species of mosquito. For example, the yellow fever mosquito (Aedes aegypti) and the tiger mosquito (Aedes albopictus), which transmits dengue, chikungunya, and Zika to humans, may thrive in parts of Canada and Northern Europe in the future.[83] West Nile Virus and Equine Encephalitis are mosquito-borne diseases that may be of particular concern for equestrians. Both viruses can infect humans and horses (but are not passed between humans and horses).[84]

It is important to highlight the reality that populations and individuals who have to spend long periods of time outdoors due to lack of housing or occupation type, will experience greater exposure to climate change-induced increases in insect-borne diseases. Without assistance, many of these populations will also lack access to protective sprays or clothing that are recommended as mitigation.

Climate Pattern Changes

Many climate change impacts are not measured by events but rather in trends and changes to seasonal patterns. Although sometimes less apparent, these changes can have major impacts to trails. One of the most impactful trends of climate change for trails is the projected shorter winters with less snow. This trend will put pressure on all snow-based trail uses including skiing, snowmobiling, dogsledding, and snowshoeing.[85] Communities in New England and the upper Midwest are likely to bear the economic brunt of this climate shift[86] as relatively fewer high elevation alternatives are available compared to the Mountain West. A 2018 analysis by the Climate Impact Lab shows that some of the most popular ski towns in the U.S. will see the number of days at or below freezing decline by up to a month within the next 20 years.[87]

Climate pattern changes are not only affecting winter. Researchers at the University of New Hampshire have found that the shift from winter to spring, known as the vernal window or 'mud season' for many northern trail users, could be two to four weeks longer.[88] This extension of the winter to spring transition could mean longer periods of time when natural-surface trails are wet and unsuitable or highly susceptible to damage from hiking, bicycling, OHV, or equestrian use.

Another perspective to consider is how climate change, particularly the shift in seasons and precipitation patterns, will impact trail user participation. A 2018 report published in The Journal of Park and Recreation Administration notes that climate change will impact participation differently based on geographic area and activity. Snowmobiling, cross-country skiing, and snowshoeing were found to be most negatively impacted by climate change. While horseback riding days-of-participation could see negative climate impacts, it was found that horseback riding on trails may see an overall increase in participation.[89] When seasons with preferable conditions are shortened, crowding may become an issue.[90]

Geologic Events

A geologic hazard can include landslides, rockfall, and debris flow and can damage or destroy property or cause loss of life.[91] Many geologic hazards are linked to climate change and are predicted to occur more frequently. The FHWA Synthesis of Approaches for Addressing Resilience in Project Development report offers detailed insight on geohazards associated with climate change and impacts to infrastructure.[92] NASA's Landslide Hazard Assessment for Situational Awareness (LHASA) Model and Landslide Susceptibility Map are available for download and viewing, and this information can provide insight into an area's risk level.[93]

Landslides often occur after wildfire, when slopes are left denuded of trees and vegetation that would normally hold soil and rocks in place.[94] This type of geologic hazard is complex, and after a fire, it can typically take one to three years for vegetation to reestablish and stabilize the slope.[95]

Rockfall, which is the free or bounding fall of rock debris down steep slopes[96], has also been shown to increase in frequency with rising temperatures. This is because rising air temperatures are melting permafrost, which helps glue rocks in place at higher elevations.[97] This phenomenon may especially impact the safety of high elevation trails.

Additionally, changes in rainfall patterns, namely frequent high-intensity rainfall events that are concentrated in a few months of the year, are anticipated to trigger more landslides.[98]

Tsunamis are a geologic hazard not typically associated with climate change, but there is a link between warming temperatures and certain types of tsunamis. The current risk of a tsunami within the Barry Arm Fjord in southern Alaska illustrates this connection. As the Barry Glacier has retreated, previously supported slopes are now exposed and susceptible to landslide. If a slope were to fail and flow into the adjacent Barry Arm Fjord, it could generate a tsunami. This would mean major risk for nearby tourists, fishers, and the town of Whittier and its coastline trails and campground.[99] Sea level rise associated with climate change will further exacerbate the effects of tsunamis.[100] Modeling of sea level rise and tsunamis shows that Southern California, particularly the Port of Los Angeles and Long Beach, will be increasingly vulnerable to inundation and strong currents from tsunamis.[101]

Snowmobile, ski, and snowshoe trails in mountainous regions are also seeing a growing risk for avalanches. Climate change and avalanches are connected in several ways:

- Increased moisture in the atmosphere fuels extreme snowstorms, resulting in bigger avalanches.
- As temperatures rise, layers of snow are more likely to collapse and slide.
- Snow layers are destabilized by more rain-on-snow events.[102]

Regional Impacts

Climate change impacts trails around the U.S. differently, depending on region. A summary of a few of the primary impacts by geographic region are listed below:

- **In the Northeast**: rising temperatures, longer growing seasons, less winter precipitation or snow, earlier peak river flows.
- **In the Southeast**: decreased precipitation, fewer freezes, shorter growing seasons.
- **In the Southwest and Great Plains**: more heat waves, severe drought, declining water resources.
- **In the Northwest**: earlier snowmelt, leading to flooding, and at the same time, reduced summer stream flows, more frequent and intense wildfires and subsequent erosion.
- **The West**: more heat waves, severe drought, declining water resources, more frequent and intense wildfires and subsequent erosion.
- **In coastal areas**: sea level rise, higher water temperatures, ocean acidification. [103]
- **In Alaska**: reduced snowpack and seasonal disruptions, melting sea ice and loss of a permafrost, and more frequent and intense wildfires.[104]
- **In Hawaii and Puerto Rico**: warming seas, sea level rise, and more intense rain and tropical storms, as well as drought.[105]

3.2. How to Evaluate Vulnerability

This section provides guidance for assessing how vulnerable a given trail is to climate change-related impacts.

Basics of Vulnerability Assessments

Assessing trail vulnerability can be very similar to assessing infrastructure vulnerability in the broader transportation sector. Using FHWA's Vulnerability Assessment and Adaptation Framework, 3rd Edition,[106] a trail's vulnerability to climate change and extreme weather can be seen as a function of a trail's or trail network's exposure, sensitivity, and adaptive capacity::

- **Exposure** depends on whether a trail or trail network is located in an area experiencing direct effects of climate variability and extreme weather events.
- **Sensitivity** refers to how the trail or trail network responds to or is affected by climate stressors.
- **Adaptive capacity** is the trail or trail network's ability to adjust, repair, or flexibly respond to damage caused by existing climate variability or future climate impacts.

FHWA also has tools to help agencies assess vulnerability, such as the Climate Data Processing Tool, which uses climate projections to generate temperature and precipitation statistics at the local level for transportation planners.

Risk

Risk is another key consideration that should be incorporated when assessing vulnerability. The FHWA Vulnerability Assessment and Adaptation Framework notes that, "Risk is a measure that considers both the probability that [a trail] will experience a particular impact and the severity or consequence of the impact." (FHWA Vulnerability Assessment and Adaptation Framework).

Risk-based decision-making tools are growing in popularity and are frequently used for predicting the likelihood of wildfire occurrence, spread, and associated consequences. For example, the Wildland Fire Decision Support System is based on risk management principles.[107] The concept of risk assessments designed for wildfire management and planning may be adapted for trails and may best be used when assessing specific hazards.

Risk assessments are a scientific approach to quantifying risk.[108] They typically make use of quantitative geospatial data but can also take a more qualitative approach, which is frequently done for assessing risks associated with job hazards. Risk assessments look at likelihood of a hazard occurring, intensity of the hazard, and the susceptibility of "highly valued resources and assets" in this case, a trail or trail network.[109]

Figure 10. The three building blocks of assessing wildfire risk (Scott, J.H., Thompson, M.P., and Calkin, D.E. (2013). A Wildfire Risk Assessment Framework for Land and Resource Management. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-315.)

Assessment Methodology

Vulnerability assessments for trails are a more recent concept and as such, there are fewer available best practice examples. That said, the following are principles and considerations that can be used to develop an assessment process and adapted as appropriate.

Articulate Objectives and Define Study Scope. It is important to identify the goals of a vulnerability assessment to understand the types of data and inputs needed. Will the assessment be used to evaluate an area for new trail construction? Identifying key agencies, organizations, statistics, projections, and other data needed for the assessment is also critical for determining scope and feasibility. Determining area boundaries and components of a trail to include in an assessment will help ensure the process stays within a manageable scope. Is the focus on infrastructure investments that are most susceptible to damage from hazards? Is the assessment covering one trail or a network of trails within a park or across an entire city?

Obtain Data for the Vulnerability Assessment. Establishing types of hazards that the assessment will take into consideration may involve coordination across disciplines within an organization or may necessitate reaching out to local professionals in natural resources or climate science fields. An area may have one very obvious hazard, such as wildfire, which has a clear increase in likelihood with climate change. However, there may be linked hazards, such as erosion or dead standing trees along the trail corridor, which occur after an initial event has taken place. Taking a longer perspective than currently evident hazards is important due to the dynamic nature of climate change. Using climate change projection models to anticipate hazards and trends that may not yet be evident is one way of planning for the future.

Resilience Framework for Trails and Recreation Planning

Mariposa County, CA developed its first parks and recreation plan on a resilience framework that also identifies opportunities for investments to support climate change adaptation and mitigation. The Recreation and Resiliency Master Plan examines acute shocks and continual stressors affecting the county, including wildfires, climate change, heat, drought, and floods. The plan includes specific climate projections for the North Sierra region over the next 30 to 80 years, including temperature changes, precipitation, heat wave events, snowpack, and wildfire risk. The plan also identifies broad actions that can be taken to improve the resilience of park system infrastructure.

Figure 11: Climate Projections from Recreation and Resilience Master Plan (Credit: Mariposa County)

The plan also integrates wildfire planning and practices into recreation, making it clear how recreation goals often align with goals of the county's wildfire risk reduction projects. This integration project encourages recreation decision-makers to consider wildfire in planning efforts and site design.[110]

The Northern Institute of Applied Climate Science offers a map of climate change impacts for the United States. The impact statements presented in the tool are summarized from published reports and give insight at the regional level for temperature, precipitation, and storm event trends.[111]

The U.S. Climate Resilience Toolkit, an inter-agency initiative managed by NOAA's Climate Program Office, offers numerous tools for resilience planning. The Climate Explorer offers climate maps, graphs, and charts for extreme events for every county.[112]

There are additional hazard-specific projection tools such as NOAA's Sea Level Rise Viewer. This interactive map allows users to see community-level impacts of coastal flooding and sea level rise (up to 10 feet above average high tides).[113]

San Francisco Bay Trail Risk Assessment and Adaptation Prioritization Plan

The East Bay Regional Park District developed the SF Bay Trail Risk Assessment and Adaptation Prioritization Plan in 2022 to understand the future climate change effects anticipated along the East Bay shoreline and help the Park District prioritize nature-based adaptation projects that will benefit the community and the broader region. The plan examines the East Bay area across multiple scales. The full East Bay shoreline along both Alameda and Contra Costa counties was studied to identify the top at-risk zones and develop a risk assessment. The plan then looks at several prototype sites to illustrate potential adaptation strategies and approaches that could be applied in multiple locations across the region.[114]

Although not accounting for climate change projections at this time, FEMA's National Risk Index provides index scores and ratings at the county level for numerous hazard types, including ice storms, wildfire, and riverine flooding. This tool may be a helpful starting point to develop a baseline understanding of hazards in a project area. The map also offers layers for social vulnerability and community resilience, which are important considerations that are reflected in the Risk Index score. [115]

Assess Vulnerability. Examining the current status of trail infrastructure and the surrounding landscape and community through the lens of a particular event is the basis behind determining sensitivity. In a given scenario, how susceptible would trail infrastructure, such as tread, bridges, and culverts, be to damage? Would the landscape being considered for a new trail project be severely impacted? How would different populations within the community fare? What are the demographics of people using and depending on the trail for transportation? People who are negatively impacted by socioeconomic inequities, including many people of color, are disproportionately affected by climate change impacts.[116]

It is also helpful to determine the likelihood and degree of exposure a trail has to a particular hazard. Looking at individual trails (if analyzing a network), segments, or infrastructure components such as bridges will provide a more detailed look at how likely certain parts of a trail are to see damage from an event. An exposure analysis will involve different data based on the hazard. Surrounding vegetation, slope, and aspect should considered for wildfire risk exposure,[117] while floodplain and streamflow should be considered for flood risk exposure.

Prioritize Adaptation Options. After determining sensitivity and exposure levels for a trail or trail network, trail segments and components should be prioritized for mitigation measures. The following are some factors that may be weighed in prioritization:

- Equity considerations regarding which populations the trail serves
- Sensitivity of trail infrastructure
- Exposure to hazardous conditions
- Critical connectivity provided by the trail

- Cultural or historical significance

It is possible that one segment of trail tread is particularly vulnerable to erosion from riverine flooding, and that becomes the priority area for mitigations. In other instances, large sections of trail or even an entire network may be highly susceptible to a hazard. In those cases, it may be prudent to prioritize a key community connection, core segment of trail, or a costly infrastructure investment, such as bridges. Prioritizing trail assets will help with developing and phasing mitigation projects.

Incorporate Assessment Results into Decision Making. Phasing implementation of mitigation projects can make the process more manageable when funding and other resources are not in infinite supply. It can also allow some mitigation techniques to be tested out before being applied at larger scales. See the Katy Trail Case Study for an example of where Missouri State Parks is sequentially replacing old railroad bridges with single-span steel bridges.

Informal and low-cost means of evaluating vulnerability

Methods used to evaluate vulnerability can involve a wide range of time, funding, and coordination across professionals in different fields. When local funds and/or time are limited, there are techniques for informally evaluating vulnerability and options for requesting assistance.

Starting with existing planning documents for the municipality or county, such as hazard mitigation plans or wildfire protection plans, can be a good way to find summarized information about the known hazards in an area. State departments of transportation may have valuable climate data across various subdepartments that could be requested for use on trails projects. Larger cities may have climate adaptation plans that include projections for the locality. It can also be helpful to review other projects that are occurring or have recently been completed in the area. Data associated with climate change vulnerability that is collected for larger infrastructure projects, like roadways, may be able to be repurposed for adjacent or nearby trails.

Finding the expertise to conduct or lead a vulnerability assessment can also be a challenge. Partnering with a local college or university may be a lower-cost way to tap into some of the climate science that may be needed for an assessment.

The following hazard screening tools have been developed to assist communities with climate change risk assessments:

- Climate Change Risk Assessment Guidance and Screening Template (C40 Cities Climate Leadership Group)
- Climate Risk Screening and Management Tool for Project Design (United States Agency for International Development)
- Climate Mapping for Resilience and Adaptation (US Global Change Research Program)

Resilience Improvement Plans

The Bipartisan Infrastructure Law (2021) established the PROTECT Formula Program and Discretionary Grants to help make surface transportation more resilient to natural hazards, including climate change, sea level rise, flooding, extreme weather events, and other natural disasters through support of planning activities, resilience improvements, community resilience and evacuation routes, and at-risk costal infrastructure. The PROTECT Formula Program requires each State to use at least 2 percent of its apportioned funding each fiscal year for specified types of resilience-related planning activities, such as developing a Resilience Improvement Plan; resilience planning, predesign, design, or the development of data tools, including vulnerability assessments; technical capacity-building; or evacuation planning and preparation. [§11405; 23 U.S.C. 176(c)(2) and (d)(3)]. Developing a Resilience Improvement Plan involves conducting a risk-based vulnerability assessment, which may be used to identify a list of priority projects.

Under the PROTECT Discretionary Grant Program, States and metropolitan planning organizations can submit applications to develop Resilience Improvement Plans. A broader set of eligible applicants (including local governments) can submit applications for Planning Grants, which can include resilience planning, predesign, design, development of data tools, vulnerability assessments, technical capacity building, etc. See the Notice of Funding Opportunity: https://www.fhwa.dot.gov/environment/protect/discretionary/.

4. Design and Engineering for Resilience

This chapter provides guidance for designing trails so that they are resilient in the face of extreme climate events, and so that they preserve, create, and/or enhance natural habitat function through thoughtful siting, grading, and material selection.

The trail design process should also be considered a means for addressing environmental wrongs and pursuing justice for communities of color. The trail should be an inclusive place, developed through inclusive design processes, to be truly sustainable and relevant for the long-term. See Section 2.2 for more guidance on equitable trail design.

Figure 12: Pedestrians, cyclists, and micromobility users sharing a trail in Columbus, Ohio (Photo: Toole Design)

Chapter Topics

There are five sections in this chapter. Note that each includes strategies for designing trails to need minimal maintenance. The sections are as follows:

- **Siting, Grading, and Drainage.** Accounting for sensitive ecosystems and hydrology to create trail systems that are both long-lasting and preserve natural conditions.
- **Natural Infrastructure.** Pairing trails with natural infrastructure projects to enhance ecological function and provide means for climate change adaptation.
- **Materials.** Selecting materials for different trail functions and user types, as well as for amenities such as site furnishings and signs.
- **Structures.** Placing and designing culverts, bridges, boardwalks, and other structures, as well as amenities like benches, restrooms, and water fountains.
- **Construction Access and Staging.** Considerations when constructing a trail, including how to protect water quality, mitigate erosion, control nonnative species, and reduce construction emissions.

4.1. Resilient Trail Design Principles

The following principles should be used to design for resilience and a quality user experience:

When building a new trail, do it right the first time. Trail construction can leave a lasting impact on the landscape. Properly siting, aligning, and building trails helps prevent future maintenance issues and the need to rebuild.[118]

Site trails to respond to their setting and with change in mind. Trail design should account for local context and be adaptable to changing conditions. Understanding relevant land use plans can help with aligning the trail with future destinations of interest, and to ensure the trail does not conflict with planned development. It is also important to understand potential long-term changes, such as new developments, demographic changes, or trails programming that will increase demand for trail access. In contexts where space allows, opt for trail alignments without extreme constraints. Ideally, the location of the trail should allow for flexibility, which enables the trail to be rerouted to new destinations or away from hazards.

Design for anticipated users. Trails for mountain bikers are designed differently than trails for casual pedestrians and bicyclists. Elements such as surface material, grade, and trail width will vary based on who will be using the trail.

Design for anticipated use volumes. A trail should be wide enough to accommodate existing use and anticipated future use. Properly sized trails encourage users to stay on the path. Even when widening trails is feasible, it is better to avoid the need for future widening through proper planning initially.

Design for equity. Refer to the guidance on the following page, as well as Section 2.2.

Design to preserve nature and to conserve natural resources. Trails, especially those that are highly traveled, can threaten surrounding ecosystems. Sustainable trails minimize environmental impact while ensuring access for human use. A low-impact approach to trail design recognizes the ecological and hydrological functions of the natural landscape and attempts to maintain the site's functions by protecting and enhancing natural processes.[119] This includes protecting natural water flows, minimizing soil compaction and erosion, and avoiding sensitive areas. Sustainable trail design considers the potential effects of trail lighting and makes use of dark sky outdoor lighting.

Design for drainage. Excess surface water flows are one of the greatest threats to a trail and its environment. During storm events, trails may intercept surface water flows resulting in ponding and erosion. On wet or muddy trails, users often opt to travel on the sides of the trail, which damages adjacent vegetation and increases soil compaction, erosion, and sedimentation of streams. In addition to siting trails away from primary drainage paths, grading and the use of best management practices for stormwater will support proper drainage. As storms and flooding become more frequent and intense, drainage and erosion prevention measures should withstand high volumes of surface water flows.

Design for heat and drought. Climate change is contributing to longer periods of warmer temperatures and heat waves. It is crucial to incorporate strategies that will reduce the extent of paved surfaces and provide shade along the trail for the welfare of trail users. Tree species should be selected carefully to be regionally-appropriate and resilient.

Account for long-term maintenance and replacement costs. Maintenance is critical for safety, comfort, and accessibility. Maintenance impacts people's perceptions about how a trail is valued and whether it feels safe. Maintenance responsibilities and costs should be addressed in the planning and design phases.

Design for Equity

Designing trails to accommodate the needs of a variety of users and abilities makes trails more equitable. Using design principles such as lighting on urban trails and improved visibility can help improve personal comfort and sense of security for all trail users.[120] Collaborating with organized user groups such as Black running groups, women's cycling clubs, or LGBTQ outdoors groups can help trail designers and managers address specific concerns for those that may be at higher risk for harassment or threats to personal safety. The following is a brief list of groups to consider when designing for equity. Proactively work with these groups to ensure their needs are reflected in the trail design.

Table 2. Design Considerations for Equitable Trails

User Group	Design Consideration
Older Adults; Wheelchair and Walking Aid Users	• Firm, stable, and nonslippery trail surfaces. • Cross-slopes of less than two percent. • Longer pedestrian signal cycles, shorter crossing distances, and median refuge islands. • Trailhead facilities, which include parking areas, restrooms, and visitor centers should be compliant with appropriate accessibility guidelines under the Americans with Disabilities Act (ADA) (or the Architectural Barriers Act (ABA) for Federal lands). • Provide benches and rest areas at regular intervals. • Don't use barriers (such as gates and bollards), and tight switchbacks unless absolutely necessary. Gates and bollards may pose crash hazard risks. If used, ensure navigability for people who use mobility devices, cargo and recumbent bikes, and bikes with trailers.

People who are Blind or have Low Vision [121]	• Consider how to communicate trail routes and other information with a variety of cues.
	  o Visual cues, such as signs and pathway markings, should include contrasting colors and large, sans-serif text.
	  o Tactile cues, such as changes in surface texture, are used to indicate changes in the pedestrian route, such as approaching a crossing.
	  o Audible cues, such as audible messaging, provide navigational information.
	• Application of cues should be consistent and should comply with accessibility guidelines and Federal, State, and local accessibility requirements (where applicable).
	  o Accessibility guidelines for paved, multiuse trails are different from those for natural-surface, recreational trails
	• Accommodations for service animals.

People who are Deaf or Hard of Hearing	• Clear sight distances. • Highly visible pedestrian signals and markings.
People with Low English Proficiency	• Signs with pictures, universal symbols, and colors, rather than text
Youth	• Consider how trails can be designed to improve access to youth destinations, such as schools, parks, daycare facilities, and community centers. • Include signs that provide age-inclusive learning opportunities for environmental education.
People with Safety and Security Concerns	• Consider the personal comfort and safety for all trail users by using Crime Prevention Through Environmental Design (CPTED) design principles such as lighting and improved visibility. • Collaborate with groups who may have safety and security concerns.
People of Color	• Consider how views on law enforcement may extend to park rangers. Ranger uniform and protective gear may bring discomfort to trail users who are people of color.[122] • Collaborating with advocacy groups and residents to determine: o How spaces can be designed to serve their needs, whether regarding amenities or features that will make people feel secure and represented. o What stories special spaces should tell and how spaces could be designed to promote art, storytelling, and civic engagement.

4.2. Siting, Grading, and Drainage

This section contains guidance on choosing overall trail locations as well as designing trails to work with the landscape.

Siting

When siting a trail, consider the context. Trails should be carefully integrated into the landscape and sited with change in mind. Changing environmental conditions may require parts of the trail to be rerouted, and locations with extreme constraints may not have this flexibility.

Some trails rely on conditions for a certain user experience. Consider what conditions are needed or expected and anticipate how climate change may affect these conditions. For example, snowmobile, cross-country ski, and snowshoe trails may need to be at higher elevation and/or may not be appropriate over wetlands that no longer freeze consistently.

Storm and Flooding Events

Determine goals for how a trail should function during storm and flooding events. Trails may need to be serviceable during emergencies, so the trail should be sited to avoid floodwater. Other trails may be floodable to capture water from surrounding areas. Strategic trail siting can also provide protection of surrounding areas with berms or dikes.

Sensitive Environmental Areas

Avoid or minimize stream, wetland, and associated buffer crossings as well as siting in or near other critical areas and natural resources. Rivers, streams, and wetlands are valuable ecosystems, and nearby trail development may negatively impact their quality and functions. In addition, these features are typically protected at local, State, or Federal levels, depending on their roles in the local ecosystem, and will require environmental documentation, permits, and potentially mitigation for impacts. The EPA recommends implementing a 50-foot buffer around wetlands and streams when siting campsites, parking lots, or other built trail facilities; consult local requirements for definitive guidance.[123]

In the case that a stream crossing is unavoidable, site the crossing with an understanding of seasonal flow and stream channel movement. Stream crossings are most ideal at riffle areas (shallow, fast moving areas where rocks tend to break the surface) instead of at pools or meanders, as riffles are relatively stable and have the coarsest substrate.[124] Trails through wetlands should be carefully scrutinized. These areas are highly sensitive but are valuable for tourism and science education. A combination of natural surface trails and boardwalks may be appropriate through wetlands. Consider how the soil structure and water level will support boardwalks, and avoid deep, unconsolidated soils which are likely to flood. Bolting each boardwalk section to pilings or tethering each section with cables can help to address potential flood damages. Refer to Common Questions: Constructing Wetland Boardwalks and Trails for more planning and design guidance.

In areas that have high biodiversity or are populated by rare or endangered species, trails should be routed around the edge, rather than through the center.[125] Trails should also avoid seasonal nesting areas. A buffer around these sensitive habitats can help protect these areas from trail construction or trail users.

Paved Trails

Pedestrian accessibility guidelines limit cross slopes to a maximum of 2 percent for shared use paths to maintain positive drainage. A cross slope closer of 1 to 1.5 percent is recommended as this is more comfortable for pedestrians while still conveying surface drainage and allowing for construction tolerances.

Cross slope transitions, such as where trails cross roadways, should be gradual and comfortable for the path user. A minimum transition length of 5 feet for each 1 percent change in cross slope should be used. For more information on shared use trail design, see the American Association of State Highway and Transportation Officials (AASHTO) Guide for the Development of Bicycle Facilities.

Shared use paths must be accessible. The Access Board's Accessibility Guidelines for the Public Right-of-Way provide guidelines to ensure that shared use paths are accessible to and usable by individuals with disabilities.[126] The guidelines include paths in the public right-of-way that follow the roadway and function as sidewalks, commonly referred to as sidepaths.

See Section 4.4 for more information on materials for paved trails.

Natural Surface Trails

In contrast to trails with paved or otherwise engineered surfaces, most natural surface trails are primarily used for recreation rather than transportation. Natural surface trails can and should be made accessible whenever possible. The Architectural Barriers Act Accessibility Standards provides guidelines for accessible recreational facilities including trails (Section 1017) and outdoor recreation access routes (Section 1016). Although these guidelines are required only for projects constructed or altered by Federal agencies or by non-Federal entities constructing facilities on Federal land on behalf of Federal agencies, the guidelines provide best practices for natural surface trails. In general, recreational trails should follow the natural contours of the topography; this helps to blend in with the landscape. The trail should run predominantly perpendicular to the cross-slope. While general guidelines exist, site-specific analysis should be conducted to understand the exact conditions, including soil type, annual rainfall, types and number of users, and difficulty level.

The International Mountain Bicycling Association's five guidelines for grading are noted below:

1. **The Half Rule**: A trail's running grade should not exceed half of the grade of the side slope that the trail traverses.
2. **The Ten Percent Average Guideline**: An average trail grade of 10 percent or less is most sustainable. Shorter sections may be steeper, though they should adhere to the Half Rule.
3. **Maximum Sustainable Trail Grades**: The maximum grade is the steepest allowable grade based on the site's characteristics. The maximum grade is usually around 15 to 20 percent.
4. **Grade Reversals**: A trail should regularly climb and descend to shed water. A trail should have grade reversals every 20 to 50 feet.
5. **Outslope**: An outslope (the cross-sectional grade of the trail) of 5 percent is recommended for natural surface trails when necessary for drainage.

For additional guidance on the design of natural surface trails, see the USFS Trail Construction and Maintenance Notebook (currently under revision as of the writing of this guidebook) and the International Mountain Bicycling Association's Trail Solutions guide.

Grading and Drainage

Grading relates to setting the horizontal and vertical grade of a trail to fit within the landscape for trail user comfort and sustainability over time. When done properly, it can prevent soil erosion and slow stormwater runoff. Grading can also create a pleasant

user experience. Trails with straight lines can be monotonous, but trails with gentle curves and grade reversals provide variety, and brief descents allow users to catch their breath.

Grade requirements depend on the type of trail and intended users. Accessible trails are often sustainable trails since accessible slopes typically avoid fall lines.

As people walk or roll along a trail, uncompacted soil can loosen, and be washed away, disrupting the surrounding environment and eroding the trail tread. Grading the various slopes of the trail forces water to cross the trail perpendicular to the path of travel, rather than along it. Careful grading also prevents water from gaining velocity, and instead encourages dissipation and infiltration of stormwater.

In general, the prior guidelines for grading help to manage drainage. An outsloped trail, or a trail with an outside edge that is lower than the inside edge, is key to prevent water from being captured on a trail. The exact slope varies depending on trail conditions, but 5 percent is recommended. For natural surface recreational trails, outslopes of 5 percent meet accessibility guidelines, and outslopes exceeding 5 percent may be exempted through the Condition for Exception 1.[127] Grade reversals are also essential to force water to drain off of the trail.

Drainage outlets to catchment areas may be placed strategically to accommodate excess flows of water.[128] Above stairs or the bottom end of switchbacks are key locations to redirect water flow. Drains should have a wide mouth and a 15 percent outslope to gently guide water. While all catchment areas will fill in with sediment and leaves, allowing water to follow the path of least resistance off a trail will minimize debris accumulation. Drains should be consistently monitored and reestablished at least twice a year.

It is important to avoid areas with completely flat terrain where possible, as water will collect in the lowest places, leading to mud or erosion. If the trail travels along a body of water or a low-lying area, consider an overall raised elevation along waterways to ensure water drains off the tread.

Water bars, which are long rocks or logs installed across the tread, are commonly used to direct water. However, water bars should be avoided because they are not accessible and they easily collect sediment or debris, which eventually negate the utility of the water bar.

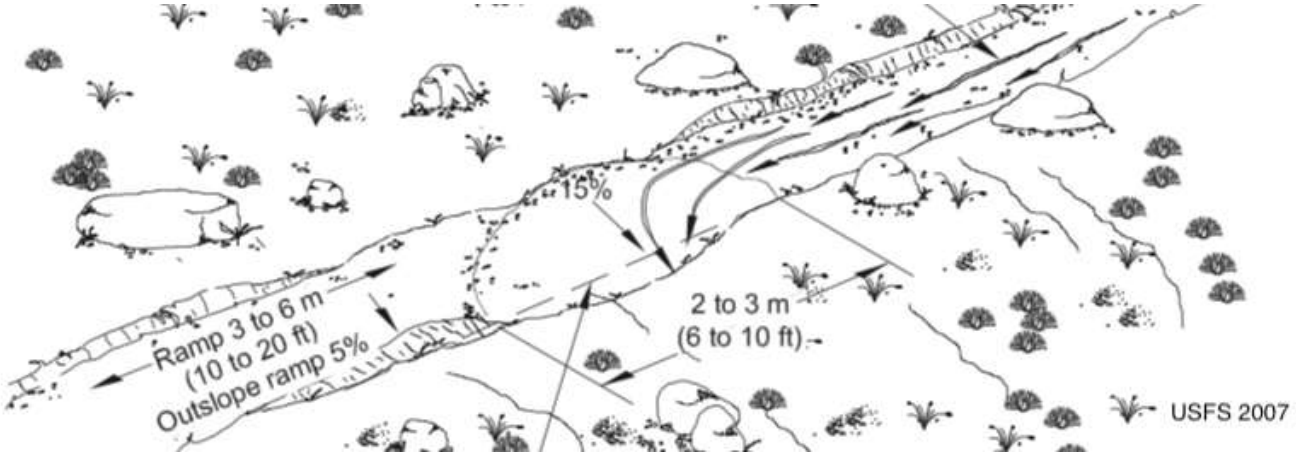

Figure 13. Drainage outlets direct water off steep sections of trail. (Source: Trail Construction and Maintenance Notebook, USDA 2007)

Soil Type and Capacity for Drainage

Soil type will influence the stability and drainage of a trail. While soil can be classified by feel and visual assessment, the USDA NRCS Soil Survey can be used to assess local soil conditions. The best soil type for trails is a mixture of sand, silt, and clay, also known as loam. This combination can hold its shape while allowing water to drain away. Trails built on clays, deep loam, and other soils tend to drain slowly should be avoided. In some arid environments, ideal soil conditions are those with high rock content.[129]

Trail slope should be based on the type of soil. The International Mountain Bicycling Association recommends the following maximum grades by soil type: 5 percent for sandy or fragile soils, 10 percent for loamy or mixed textures, and 15 percent for rocky or durable soils.

All soils should be compacted on the trail tread to improve the load support and reduce the permeability of the soil. Compacted soil reduces the likelihood of the trail becoming cupped and forming a berm. These conditions trap water and encourage erosion. However, compaction can negatively affect adjacent trees by limiting access to water and oxygen; additional soil or mulch on the trail tread can help to protect the tree.[130]

4.3. Natural Infrastructure

This section explores the relationship between trails and their surrounding ecosystems. It introduces natural infrastructure as a concept and discusses how it can be paired with trails as part of a climate mitigation and adaptation strategy.

Ecological Landscapes

Trails, particularly those located in natural settings, can protect and preserve ecological, cultural, and historic landscapes.[131] Trails are also often part of the ecosystem itself, and those sited in natural environments experience the effects of climate-induced changes to biodiversity.

Biodiversity refers to the variation among living organisms at all levels of the ecosystem.[132] Healthy ecosystems rely on a wide range of animals, plants, and microorganisms to function and thrive.

Climate change-related impacts to ecological landscapes are unfolding over time, affecting trails and trail users directly and indirectly. Biodiversity is threatened by human-induced changes to land use, habitat degradation, landscape fragmentation, pollutants, and invasive species. Changing growing seasons and precipitation patterns are impacting health and resilience in plant, animal, and insect communities.

Trails can be designed to bolster ecosystem health and biodiversity. By incorporating landscaping and/or avoiding fragmentation and disturbance of vulnerable plan communities and habitat areas, trail corridors can offer benefits such as reducing the urban heat island effect, capturing carbon, storing and filtering stormwater, and enhancing habitat and wildlife corridors.[133,134] Another approach to maximizing benefits to surrounding ecosystems is to pair trails with natural infrastructure.

What is Natural Infrastructure

Natural infrastructure, first officially defined in the 2022 Bipartisan Infrastructure Law, uses, restores, or emulates natural ecological processes. This type of infrastructure can be created by natural physical, geological, biological, or chemical processes, or it can be created by human design, engineering, and construction. Natural infrastructure involves the use of natural features, such as plants and soil appropriate to the region, to manage stormwater and runoff, attenuate flooding and storm surges, or achieve other related purposes.[135] The terms “green infrastructure” and “nature-based solutions” are often used interchangeably. These infrastructures differ from gray infrastructure, which includes systems like underground pipes, where water is sent off-site.

Natural Infrastructure Definitions

“Nature provides effective solutions for minimizing coastal flooding, erosion, and runoff, as do man-made systems that mimic natural processes – known as natural infrastructure. Examples include mangroves and wetlands, oyster reefs, and sand dunes; permeable pavement and driveways; green roofs; and natural areas incorporated into city designs.” (NOAA Office for Coastal Management)

“Natural infrastructure is an area or system that is either naturally occurring or naturalized and then intentionally managed to provide multiple benefits for the environment and human well-being.” (International Institute for Sustainable Development)

Natural infrastructure applies at a range of scales, whether on an area basis through open spaces and wetlands, or down to small streetscape or residential treatments, such as bioswales, rain gardens, and rain

barrels. Natural infrastructure may also be connected to gray, as, in urban spaces with limited areas for infiltration, it is often necessary to send the remainder of stormwater to pipe systems once natural infrastructure is at capacity. Natural infrastructure can complete one or more of the following tasks:

- **Capture Volume**. High volumes of runoff are disruptive to both grey infrastructure and local bodies of water. Natural infrastructure captures a significant proportion of the runoff.[136]
- **Reduce Peak Flows**. Natural infrastructure is often implemented to reduce flooding. Peak flows, or the maximum amount of runoff during a storm, can overwhelm stormwater systems. Natural infrastructure can reduce peak flow by capturing water before it reaches grey infrastructure and allowing it to infiltrate.
- **Manage Storm Surge**. In coastal situations, natural infrastructure can be used to reduce the velocity of storm surges. Systems such as vegetated berms can help dampen the effects of storm surge and protect coastal infrastructure.
- **Filter Pollutants**. Stormwater carries pollutants, such as pathogens, nutrients, and sediments. By reducing the amount of runoff, natural infrastructure prevents pollutants from reaching waterways and endangering ecosystems. Vegetation also absorbs and filters particulate pollutants. Thus, natural infrastructure improves overall water quality.[137]

Natural infrastructure can mitigate or reduce carbon emissions, as vegetation also sequesters and stores carbon. Natural infrastructure also assists in climate change adaptation as it increases the capacity of drainage systems to handle storm events. On the latter point, it is necessary to think about natural infrastructure in broad terms, where planted slopes, bioswales, retention areas, floodable corridors, wetlands, and other infrastructure are sized to capture increased stormwater flows. Natural infrastructure at the micro level, such as a small rain garden, is helpful but not capable of driving systemic adaptation.

Low Impact Development

Low impact development (LID) integrates stormwater management into site design. LID emphasizes understanding local hydrology and developing in less sensitive areas, eventually aiming to reduce maintenance needs and costs. LID design objectives are to:[138]

- Develop a site plan that reflects natural hydrology.
- Minimize impervious surfaces.
- Treat stormwater in numerous small, decentralized structures.
- Use natural topography for drainageways and storage areas.
- Preserve portions of the site in undisturbed, natural conditions.
- Lengthen travel paths to increase time of concentration and attenuate peak rates.
- Use “end of pipe” treatment structures only for quantity or rate controls of large storms.

Stream Restoration

Natural infrastructure includes streams and stream networks. Whether in urban or rural landscapes, trails often run parallel to or cross streams, and it is vital that trail design maintain or enhance stream function. Stream restoration projects are increasingly common throughout the U.S. Municipalities are daylighting streams that had historically been forced underground, and many streams are restored to address erosion and lack of floodable capacity. The following are examples of stream restoration projects tied to trails:

- The eroding bank of the Caffrey Run Stream in Annapolis, Maryland threatened aquatic life and the structural integrity of a trail bridge in Quiet Waters Park. In 2022, Arundel Rivers Federation stabilized the stream bank and planted over 1,500 trees to reduce the erosive effects of future storm events.[139]

- Wissahickon Creek, in Pennsylvania, had long been classified as an impaired stream due to excessive nutrients and sediments. The creek experienced frequent rain events and flooding due to development in the watershed. The Wissahickon Headwaters Stream and Riparian Restoration Project was completed in 2020 significantly improved both the riparian habitat and the safety of the nearby trail network. The project was made possible through strong public-private partnerships.[140]
- Genetta Park, located on a brownfield site in Montgomery, Alabama, serves as a gateway for the Selma to Montgomery National Historic Trail. In the 1960s, the Genetta Park stream was channelized underground, leading to extensive impervious surfaces and runoff. The EPA and Alabama Department of Environmental Management opened the stream up in 2009 and worked to restore it to its natural state. Other natural infrastructure was implemented to filter pollutants in stormwater.[141]

Carbon Sinks

Forests, wetlands, and grasslands are all powerful carbon sinks. Despite occupying just 5-8 percent of the Earth's land, wetlands store a disproportionate amount of the global soil carbon. About 20-30 percent of the global soil carbon is in freshwater wetlands. The limited oxygen in wetland soils slow decomposition, thus leading wetlands to have a high accumulation of carbon.[142]

As extreme heat waves, droughts, and wildfires threaten tree mortality in more arid climates, the resilience of grasslands point to these environments being increasingly valuable carbon sinks.[143]

Pairing Trails with Natural Infrastructure

Trails can be built into natural infrastructure, as shown in the Gambles Mill Eco Corridor and Grand Forks Greenway case studies. Spaces such as floodable corridors can be appropriate host sites for trail corridors when trails can be designed to withstand flooding. Natural infrastructure can also beautify trail corridors by adding native plants or water elements in the case of rain gardens or retention ponds. Trails can also present opportunities for public education on the benefits of natural infrastructure through interpretive materials.[144]

Trails can also receive protective benefits from natural infrastructure. Parts of the Bay Trail in San Francisco are at risk for inundation with sea-level rise and loss of tidal marshes and mudflats. Eel grass plantings and oyster reef structures have been identified as a tactic for providing wave attenuation and encouraging sediment retention for tidal marshes to protect the trail.[145] The FHWA Nature-Based Solutions for Coastal Highway Resilience Guide offers additional information on natural infrastructure that could be adapted to protect trails.

Planning trails within larger natural infrastructure projects can present a way to secure funding. High-cost natural infrastructure projects with far-reaching benefits are likely to have large budgets that may be able to easily absorb trail project costs. For more examples of projects that incorporate natural infrastructure into trail projects, see FHWA Case Studies in Realizing Co-Benefits of Multimodal Roadway Design and Gray and Green Infrastructure.

4.4. Materials

This section describes climate-related considerations for the materials used in trail construction. As research continues to progress and product information becomes more transparent, readers are encouraged to consider the origins of materials and whether using recycled materials may be beneficial for reducing carbon footprint of construction.

Surface Materials

The selection of trail surfacing material is typically based on trail function and user needs, cost and maintenance considerations, availability of materials, and sustainability. Climate change adds complexity to the selection of trail surfacing. Rising temperatures, extreme weather conditions and events like high summer temperatures, and flooding can take a toll on trail surfacing, reducing durability, life expectancy, and increasing maintenance and replacement costs.

Hard Surface Materials

Concrete and asphalt surfacing are the most durable trail surface materials, but even these materials can be vulnerable to climate change-related weather events and conditions.

Sustainable Pavements

Sustainable pavement refers to technologies and practices that are intended to address economic, environmental, or social issues. An important starting point to development sustainable pavement is using practices and technologies that reduce embodied carbon. A sustainable approach to paving trails can also be consistent with resilience when the technologies focus on preserving and restoring surrounding ecosystems and preservation, maintenance, and rehabilitation are most relevant to resilience.[146] Examples include pavements that are flexible or cooling; essentially any technologies that are climate-adaptive by reducing the potential for degradation, damage, and reduce maintenance costs.

Heat, Temperature, and Ultraviolet Radiation

Temperature is a major factor along trails both for the integrity of paving materials and user comfort. Heat island area areas where infrastructure such as building, roads, and trails, absorb and reemit the sun's heat, creating pockets of higher temperatures relative to outlying areas.[147] Heat islands have been found to be inequitably dispersed throughout cities with higher temperatures occurring more frequently in neighborhoods with low-income and with higher populations of people of color than in adjacent neighborhoods in the same city.[148] Planting shade trees, typically absent in heat islands, is a primary method for reducing the heat island effect, benefitting both trail users and pavement surfaces.

Hard surfaces absorb heat, which raises not only the thermal surface temperature of the material but also the temperature of the surrounding area (ambient heat). This translates to reduced thermal comfort for trail users, especially pedestrians, and the ambient heat can dry out soil and stress nearby plants.[149] High heat can also break down the trail surfacing material. Pavement's ability to reflect the sun is measured through the solar reflective index (SRI). Materials that are lighter in color, like concrete, have a higher SRI value. Asphalt has a much lower SRI due to its dark coloring and thus responds differently to the effects of high temperatures.

In the case of asphalt, intense and prolonged ultraviolet (UV) radiation from the sun can cause oxidation, a chemical reaction that reduces the binding oils that hold together the aggregate, thereby compromising the structural integrity of the asphalt. The material becomes lighter in color, is less elastic and more brittle, and thus becomes prone to cracks,

buckling, potholes, and without repair, ultimately failure. Cracks can allow water to infiltrate into the asphalt, and when water remains and temperatures drop, ice can expand cracks and infiltrate the base layer and subgrade causing significant structural damage. High temperature can also soften the surface of the asphalt to the point where tracking can occur, a condition where the softened asphalt sticks to shoes and tires. These issues increase trail maintenance efforts and costs and can damage bikes.

Concrete's ability to reflect rather than absorb UV radiation means that it is more resistant to damage from UV radiation and high temperatures, especially lighter concrete. However, concrete is vulnerable to compressive stress as a result of temperature swings; thermal cracking can occur when concrete temperatures are over 10 degrees Fahrenheit higher than the daily high or low temperatures. More extreme temperatures swings pose a hazard to concrete if it is not designed to withstand such changes.

Heat Mitigation

For existing asphalt surfaces, regular maintenance and responsive repair are key to maintaining the integrity of asphalt trail surfaces in higher temperatures.[150] Additional measures include adding shade trees nearby to lower surface temperatures and using heat-reflective coatings to increase reflectivity and cool the material and radiant heat. These materials include pigment along with polymer and other additives to bind the material to the asphalt and are thermochromic, changing color in response to temperatures. The coatings can reduce the skid resistance of asphalt; however, this can be mitigated with additives.[151] Such coatings can significantly improve the durability of asphalt. Thermal resistant asphalt mixtures can help improve durability to heat while also reducing the temperature of asphalt surfaces.[152]

Permeable pavements, which can include asphalt, concrete, and pavers, can lower surface temperatures as well, through the evaporation of water that seeps into the pores of the pavement. Permeable pavements must be cleared of sediment to keep pores open.[153]

Hard-surface materials are ideally installed within a certain temperature range: 50-90 degrees Fahrenheit for asphalt[154] and 40-60 degrees Fahrenheit for concrete.[155] High temperatures can thus affect the installation of concrete and asphalt, limiting times they can be laid or poured, causing the materials to cure too quickly, unevenly, or interrupting the chemical reactions that occur as the materials harden.

Reducing Heat Risk for Trail Users

Climate change may result in trail users in warmer climates facing elevated risks from heat and sun exposure. There is little design guidance on this topic. The Maricopa Association of Governments' Pedestrian Area Policies and Design Guidelines recommends three levels of shade coverage, with 50 percent shade coverage as a minimum safe standard and up to 75 percent as an ideal for gathering spaces and areas with many elderly pedestrians. These recommendations are suitable for comparably dry climates—in more damp environments too much shade can make some trail surfaces slippery if they don't dry quickly enough. Shade structures and tree cover may be eligible under some Federal funding programs or initiatives to mitigate urban heat islands and heat impacts of infrastructure, such as the Healthy Streets program (subject to appropriations).[156]

Moisture

With climate change also comes an increase in moisture, through more frequent and severe storms, extreme flooding, storm surges, early snowmelt, and high humidity. Climate scientists explain that as the world warms, atmospheric moisture increases, and when that moisture condenses, it releases heat or energy in the form of heavier storms.[157]

Water is one of the most damaging elements to paving. Intense rainfall, flooding and standing water, and high humidity can impact both the placement and curing of hard-surface material as well as its lifespan.

The surface of asphalt itself, being naturally porous, makes it particularly vulnerable to damage from excessive moisture. Asphalt naturally deteriorates over time, and water can accelerate that breakdown. As described above, when the surface of the asphalt is compromised, excess moisture can gather in cracks, potholes, and puddles and seep more deeply into the material. Over time, the moisture causes raveling, where the aggregate materials separate from the binder materials, exposing and degrading the layers underneath. Permeable pavements can be effective for dealing with areas that experience excessive moisture. See 4.2 Siting, Grading, and Drainage and 1.1 Natural Infrastructure for further discussion of techniques for managing runoff along trails.

Concrete is better able to withstand the shrinking and swelling of soils from heat and flood events. Concrete is innately water resistant, but excessive water, such as during flood events, can collect underneath it, moving and cracking concrete slabs. When installing concrete trail surfacing, best practices for mitigating flooding impacts include understanding the load carrying characteristics of native soil, providing additional drainage structures, and ensuring proper subgrade compaction, adequate pavement thickness and pavement compaction. In addition, reinforcing the trail edges, for example the 18-to-36-inch turndowns used on the Houston Bayou Greenways, protect the underside of trails from being washed out by flooding.

Natural-Surface Materials

Natural-surface trails are constructed with materials such as crushed stone (e.g., decomposed granite, cinder or rock dust), self-compacting aggregates (crusher fines), and geosynthetics. While natural-surface trail materials are generally compacted in place or manufactured to hold together, they are ultimately porous materials that can be disturbed, damaged, or degraded by events like flooding.

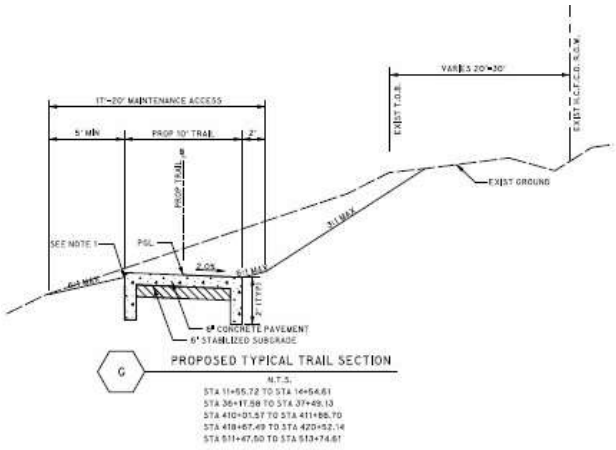

Figure 14: Detail of a double turndown trail profile (Source: Houston Parks Board)

The effects of excessive wetness and flooding on natural-surface trails include eroded edging that breaks down the surface, pitting and potholes, washboarding, and loosening of the material. These effects not only degrade trail user safety but can also create negative impacts to the surrounding landscape and habit. Flooding can also create soil erosion adjacent to the trail, expose roots and lead to vegetation damage and loss. Flood damage can also alter natural overland drainage flows, contributing to sediment loading and siltation downstream.[158] Natural-surface trails may not be the best choice for areas with longer winters or seasonal precipitation, or even certain soil types (e.g., clay).[159]

Limiting grading on natural-surface trails to three percent can help prevent erosion.[160] Tackifiers and chemical-based soil stabilizers can also be used to prevent erosion from climate change exacerbated rainfall, wind, and snowmelt. These chemicals are typically used for short-term applications, such post-construction until vegetation roots can be established to hold soils in place but could also be used strategically in areas with persistent erosion problems.[161]

In particularly wet or vulnerable areas, natural-surface trails can also be hardened through armoring the

tread or turnpiking. Hardening is achieved by excavating the natural-surface materials, placing concrete blocks, filling with loamy or gravel soil, and then covering the area with natural-surface material. Turnpiking uses concrete, wood, or large rocks, to armor the trails edge, which is then backfilled with gravel and dressed with crushed stone.

Amenities Materials

The selection of materials for trail amenities, such as furnishings and signs, are based on several factors – durability, cost effectiveness, aesthetics, as well as context and local character.

Sustainable sourcing, transport of materials, energy emissions and lifecycle considerations of materials are gaining importance amongst many designers.[162] With the potential for climate change impacts, trail designers and managers should also consider materials that can withstand the impacts of higher temperatures, fire, flooding, and other kinds of landscape changes.

For example, wooden benches and wooden handrails on pedestrian bridges not only deteriorate over time, but they are also vulnerable to damage by wildfire. Wood treated with bio-based liquids and heat can be more durable. Recycled poly lumber or plastic wood (high-density polyethylene material), which include UV inhibitors, are a durable alternative for many similar applications and are typically used with other materials like steel for support as recycled poly can sag under its own weight. Recycled poly lumber and plastic wood do not absorb moisture, so they are resistant to rot, salt, and acids. However, the materials are vulnerable to damage from fire, which should be taken into consideration for areas that are at high risk of wildfire.

Steel benches and picnic tables that are powder coated (treated with a colored steel topcoat) or that have thick thermoplastic coatings (typically 25-300 mils), are durable materials that can withstand UV radiation as well as fire. However, steel is not corrosion resistant. Stainless steel and hot-dip galvanized steel, which creates a tightly bonded alloy coating, are both corrosion-resistant. Finally, aluminum, though lighter and not as strong, is a better choice in wet and coastal environments where corrosion is an issue.

In addition to resilience to climate change impacts, it is important to consider how materials and amenities choices impact users. Metal site furnishings, bridges, and structures can get very hot to the touch in intense sun. Shading metal site furnishings, particularly play features, is recommended and can be achieved with trees or shade structures. Similar to asphalt, plastics and wood can all be engineered to reflect heat, either through color or reflectivity.[163]

Shaded benches, restrooms, and water fountains are key elements for improving people's experience and protecting public health on trails. Exercising in warmer climates is more physically demanding, requiring the body to use more energy and water. Accordingly, providing shaded benches can help people and pets rest out of the sun, while water fountains and bottle filling stations help ensure that trail users avoid dehydration and heatstroke. Dogs are more susceptible to heatstroke and dehydration than humans, so drinking facilities can be added for them as well.164 Providing restroom facilities in conjunction with water fountains can ensure people are not dissuaded from hydrating properly and that users feel comfortable spending time on a trail. Pet waste stations are another important feature to consider including to help keep trails clean.

Some landscapes may demand adaptable designs to accommodate changes over time. For example, it is sensible to choose a style of footing (foundation) for wayfinding and interpretive signs that can be raised up or relocated in shifting sand dune landscapes.

Utilities

Both underground and overhead utility lines are often located within trails corridors, out of convenience and for economic reasons. Utility impacts from extreme

weather can occur, not only limiting access for trail users but potentially creating hazardous conditions, such as downed power lines. In some situations, utilities may be put underground to address adverse weather conditions. When co-located with utilities, trails may provide access for the repair of utilities or even be used to provide emergency water sources for firefighting.

4.5. Structures

This section provides guidance on the structures that are often needed along trails when the landscape alone cannot support the trail tread. Often one of the costliest components to construct and maintain, trail structures need to be well designed to withstand storm events. By designing structures to withstand more frequent and extreme storm events, trail managers can protect their investments and preserve trail functionality.

Culverts

Culverts are structures embedded into the trail corridor that allow for passage of water underneath the trail tread. Most modern culverts are made of concrete, corrugated metal, or a high-density polyethylene plastic. Increased flow rates, higher volumes of runoff, sedimentation, and larger debris flows from more frequent and severe storms all threaten to overwhelm and clog culverts. Many older trails were constructed with culverts that are undersized for today's flow rates. The shape and frequency of culverts along a trail can also impact functionality and effect surrounding natural resources. The following are considerations for culverts when constructing or rehabilitating a trail:

- When possible, work with hydrologic (rainfall and runoff) and hydraulic (flow velocity) data and projections over the service life of the asset to properly size culverts for modern-day and future storm events.
- Consider the style of culvert used. Older styles like box culverts or traditional cylindrical styles can present barriers to aquatic organisms. Bottomless arch or three-sided culverts are constructed without a floor. This configuration preserves the natural streambed and helps facilitate aquatic organism passage by eliminating vertical barriers.
- Calculate the frequency at which culverts should be placed along a trail. An insufficient number of culverts creates a higher risk for overflow.
- Maintain culverts by keeping them free of debris so they remain functional. See Section 6.1: Maintenance for more information.
- Use alternative means of getting water off the trail, such as grading or routing the trail away from wet areas.

In some scenarios, alternatives to culverts may be a better option. Culverts have the disadvantage of concentrating stormwater flows, which can worsen erosion and lead to bigger problems when they become clogged. Grade reversals, or dips, are a surface level technique of moving water off the trail that do not carry risks of overflow or clogging[165]. See Section 4.2: Siting, Grading, and Drainage for more information.

Bridges

Bridges are frequently the costliest components of a trail corridor. Similar to culverts, higher peak flow rates, larger debris flows, and more severe storm events are posing greater risks to bridges. Several design and placement considerations can help bolster bridges' resilience:

Siting the Crossing

- Site bridge crossings along straight stretches of the stream when possible.[166]
- Locate a crossing site with characteristics conducive for bridges including stable soils and slopes. Avoid areas that are vulnerable to channel degradation, shifting, aggradations, or excessive scour.[167]
- Select a narrow section of the stream channel to reduce the structure length.[168]
- Avoid siting the bridge in a low point of a sag curve where both approaches slope down

towards the bridge. This situation causes bridges to collect debris, water, or ice.[169]

Higher, Longer Bridges

Bridges are being built higher and longer to account for more extreme and frequent flooding events. The Winooski River footbridge, completed in 2015 as part of a relocation along the Long Trail in Vermont, is a 224-foot suspension bridge that exemplifies this needed trend in bridge construction.[170] The Green Mountain Club, the founder and a nonprofit maintainer of the Long Trail, notes the Winooski River footbridge design and other innovative tactics as strategies for trail management responses to climate change.[171]

Designing and Positioning the Structure

- When possible, use stream bank surveys and flow models to determine appropriate bridge spans.
- Bridges should be designed to withstand a 100-year flood at a minimum. Plan for ample clearance under the bridge to allow for higher stream flows, debris, or floating ice to pass freely.[172] Single-span bridge designs will allow for better passage of debris flows during and following storm events.
- Design bridges to have a slight running grade, around two percent, to allow water to shed off the decking.[173]
- Locate bridge substructures outside of stream channels to avoid erosion, damage, and rot caused by higher flow volumes.[174]
- When selecting an abutment design, opt for materials and designs that are durable and can be situated above the stream channel. Concrete is typically very long lasting, fire resistant, and can be made resistant to spalling in cold weather conditions when it is air-entrained.[175]
- Select bridge materials that are resistant to rot, corrosion, and weathering such as steel, concrete, aluminum, or preservative-treated wood. Wood should be from a naturally rot resistant species, such as cedar or black locust, or pressure treated. Pressure treatment with Alkaline Copper Quaternary (ACQ) offers a more environmentally friendly option without the use of arsenic or chromium. However, because ACQ has a corrosive effect on metal, nails, fasteners, and other hardware need to be selected carefully. Steel should be specified as galvanized, painted, or weathering (corten).[176]
- Specify concrete used for bridges in areas that are subject to freeze-thaw cycles as as air-entrained.[177]
- Select decking material carefully to ensure that it is rot resistant and maintains structural integrity. Composite decking has been found to be more subject to issues of warping, delamination, and mold and mildew growth than traditional wood decking. When used in cool, wet climates, composites can make for a very slippery surface.[178] Finishes such as gritty paint or other textured applications can be used to reduce slipping.
- Consult sustainable wood certification programs, such as Forest Stewardship Council when sourcing wood for decking.

Boardwalk

Like bridges, boardwalks can be a focal point along a trail corridor, allowing trail users to more closely observe and interact with aquatic environments. More frequent freeze-thaw cycles, severe storms, and higher flood levels make boardwalks increasingly susceptible to damage in light of climate change. Boardwalks may need to be used more frequently where soils are saturated for longer periods of time or on winter trails where wet areas fail to freeze over in colder months. Many of the considerations for bridge design, such as decking material selection, also apply to boardwalks. The following principles can be factored into boardwalk design to improve structure resilience:

- Make use of applicable modeling for sea level rise, floodplain changes, and predicted affects to tides to determine the necessary height of the boardwalk.
- For wet areas that will not experience much water level fluctuation such as areas with subsurface ground water flow, consider puncheon as an alternative to boardwalk. Puncheon is similar to boardwalk but sits no more than two feet off the ground and does not need a railing.[179]
- Consider floating deck or tethered designs that allow for wide fluctuations in water depths.
- When working in sensitive environments, consider using alternative footings such as helical piles or pin footings to reduce ground disturbance. Helical piles are also appropriate for structurally weak or saturated soils.[180]

Crib Walls and Retaining Walls

Both forms of retaining walls, crib walls are built into the side of a slope to create support for the trail tread, while retaining walls hold back and stabilize a cut slope on a side of a trail.

Retaining structures are typically constructed from rock, wood, or concrete. Retaining walls can be used

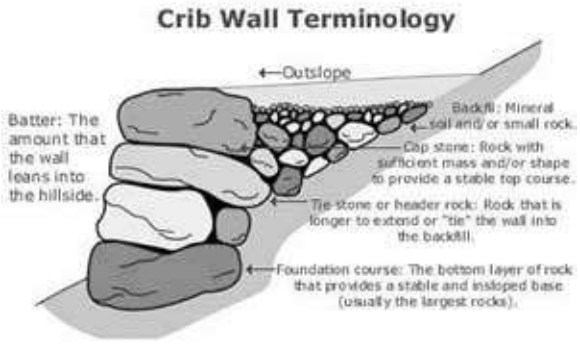

Figure 15. Crib Wall. Source: Hesselbarth, W., Vachowski, B., and Davies, M.A. (2004). Trail Construction and Maintenance Notebook. USDA Forest Service and Federal Highway Administration.

to reduce impacts to sensitive natural or cultural resources by minimizing the amount of excavation needed to establish the trail bed.[181] Climate change effects, including more instances of saturated soils and freeze thaw cycles, should be considered in the design of walls. Careful selection of materials that can withstand these turbulent conditions and building above the mean high water level or above the floodplain when possible will provide more hospitable conditions for the structure. Keeping foundation footings out of the floodway is another technique to improve resilience of the structure.

Helical Piles and Pin Footings

Helical piles are foundational support for structures such as boardwalks that have steel screw threads or helical bearing plates at the base. The shape of the pile is similar to a screw, so it can be driven deep into soils with the use of a hydraulic system, avoiding the need for significant excavation. The shape of helical piles allows them to bear heavy loads and resist tension.

Figure 16. Helical pile installation for an Appalachian Trail boardwalk crossing of the Great Swamp near Pawling, NY. (Photo: Teatown Trails)

Pin footings are foundational support for structures that distribute load into bearing pins. Bearing pins are short piles that can easily be driven into soil rather than requiring excavation.

Designing retaining structures to have adequate drainage is increasingly important for areas experiencing wetter climate conditions. Porous fill material should be used behind the wall to reduce pressure and weight that would otherwise be exerted on the wall from saturated soils. Weepholes or perforated pipe systems that convey water out from behind the wall are key design features, as is grading along the top of the structure so water does not pool and saturate soils behind the wall.

Impermanent Designs

Sometimes an environment can become too harsh to sustainably host certain trail structures. Continuing to rebuild trail structures after sequential storm events is a costly and unsustainable practice. If trails cannot be relocated to avoid the need for structures, temporary structures may be an appropriate alternative. For example, portable piers or floating docks may offer seasonal uses to continue and can be relocated during times of higher storm risk.[182]

4.6. Trail Construction

This section addresses trail construction considerations that relate directly to climate change impacts. It complements the trail design strategies provided in the previous sections, and it focuses on four key aspects of construction:

1. Construction Methods and Equipment
2. Water Quality Protection and Erosion Control
3. Protecting Soil Quality
4. Control of Nonnative Invasive Species

As climate change makes natural systems more sensitive and susceptible to disruption, construction has the potential to create longer-term impacts to the resilience of trails, through soil health, drainage, and plant and animal health. This makes careful trail construction practices increasingly important. Consulting natural resource professionals during trail planning and prior to construction will provide the best chance at avoiding negative environmental outcomes.

Construction Methods and Equipment

As covered in Section 4.4, trails should be constructed using materials that can withstand a range of climate change impacts, in order to reduce maintenance and thus disturbance.

During the construction phase, there are significant opportunities to reduce the embodied carbon of the project:

- Source materials locally to reduce transportation emissions and costs through shorter trips.
- Use recycled content or salvaged materials, or reuse materials that exist on-site.
- Practice soil banking, which has become an increasingly popular strategy in which soil is reused from other local projects or from the same project. Excavated soil is stored for later use rather than disposed, saving transportation and material costs.[183]
- Select lower emission construction and maintenance equipment, including manual and electric equipment where feasible

Sustainable construction methods and equipment are critical for both reducing climate change in general and reducing the possibility of creating or contributing problems. There are several excellent sources for this information, including Building Green and the Institute of Sustainable Infrastructure.

Water Quality Protection and Erosion Control

The Clean Water Act addresses water pollution by regulating activities that can discharge pollutants into U.S. water bodies. Under this Federal act, the National Pollution Discharge Elimination System (NPDES) permit program, managed by the Environmental Project Agency, regulates how activities like construction. It is anticipated that stormwater and erosion control regulations will become more restrictive or specific in response to climate change.[184,185] In the meantime, The EPA's Climate Change Adaptation Resource Center offers information and tools for addressing these impacts to increase resilience.

NPDES compliance requires Stormwater Pollution Prevention Plans (SWPPPs) for trail projects that disturb over an acre. SWPPPs include erosion control treatments, which are not only best management practice for trail construction but are a required element of construction plans for some jurisdictions. Erosion control best management practices include the placement of temporary barriers to capture sediment, like straw or hay or rock mulch, hydro mulch, fiber or geotextile matrices, wattles, hay bales, and filter fences to and limit soil erosion and sedimentation of nearby water bodies. These materials can also be deployed in response to climate change related events, for example in advance of flooding, to prevent

mudslides where there has been a loss of vegetation to hold soils in place, post wildfire or large-scale tree die-off.

Permitting

Depending on the location of the trail project and State laws, certain permits may need to be obtained prior to construction. Trail construction activities that take place within or adjacent to brooks, streams, rivers, or wetlands should be checked with State regulatory offices to see what permits are required.

Protecting Soil Quality

Healthy soil is critical to plant health and stable soils are critical to ecosystem health. During trail construction, soil quality can be damaged by disturbance and heavy equipment, leading to erosion but also vegetation loss and soil compaction, which reduces water infiltration, drainage, and makes for difficult rooting conditions to plants and trees. Trails should be built when precipitation and water levels are low, and soils are less saturated to minimize damage to soil quality.

It is critical to ensure that any native soils that are disturbed are restored or replaced to their original content, structure and function (e.g. topsoil is reused as topsoil; and that topsoil and other high-value soils are not removed from a site at all). Best practices also include establishing a soil management plan and banning the use of harvested peat or peat moss, which releases greenhouse gases, as a soil amendment. Trail construction impacts to soil related to climate change will vary by region. For example, with northern climates experiencing longer vernal windows[186], trail construction seasons may need to be narrowed to avoid impacting sensitive, saturated soils. Certain trail construction activities may be able to take place over frozen ground, such as staging materials or structures with heavy equipment. The route that heavy machinery takes to access trail construction sites may need to be altered to avoid sensitive areas. When sensitive soils cannot be avoided, erosion control matting may be an option to preserve soils within equipment access paths. In addition, smaller-scaled equipment, like trail sized excavators and dozers should be used to reduce the footprint of trail construction.

Dryland areas, such as the west and southwest, feature biological soil crust (biocrusts), which stabilize the soil and resist erosion, increase soil fertility, and maintain water, amongst other benefits. Biocrusts are vulnerable to climate change effects similar to those of physical disturbance, resulting in degraded soil conditions, which can stress plants and lead to erosion.[187] Disturbance from construction activities can further alter these communities. Research indicates that the best practice for restoring disturbed soils is to contract to have replacement biocrusts grown offsite to restore damage areas.[188]

In dryer landscapes, trail construction can also create fugitive dust, a condition in which particulate matter is lifted by construction activities or wind.[189] Dust control measures include minimizing soil disturbance and removal of vegetative cover, providing materials and treatments to cover the soil, creating wind barriers with fences or vegetation, and lastly, dampening soil.

Control of Nonnative Invasive Species

Both climate change and construction-related disturbances, which remove vegetation, loosen soil, and disturb habits, can create opportunities for nonnative invasive species (NNIS) to establish and upset native biodiversity. NNIS can be spread inadvertently by construction equipment, vehicles, tools, and even construction workers' boots and clothing. To minimize transporting NNIS, the following best practices should be carried out:

- Minimize the creation of new access roads to avoid disturbance, using existing roads where possible.
- Avoid spreading seed or plant materials from infested areas.

- Clean construction equipment of debris, plants, insects, and diseases from moving from infested to noninfested areas.
- Ensure materials like mulch, topsoil, and travel are free from NNIS.
- Allow natural revegetation where possible, otherwise revegetate as quickly as possible using native seeds or noninvasive cover crops or annuals.[190]

4.7. Design Strategies for Emergency Response and Evacuation

Trails can also play a valuable role in providing access for emergency response vehicles and personnel and for evacuations in areas where roadway infrastructure may be limited or disrupted. Developing and using trail design strategies that address environmental context and geography is important to allow trails to function effectively in emergency scenarios. See Chapter 5 for more information on trails and emergency response planning.

Emergency Access

Identifying pedestrian trails along highly trafficked routes into town or city centers enables prioritization of the most appropriate trails to use for emergency vehicle ingress and egress. Multiuse trails provide multimodal transportation alternatives that promote safety, connectivity, and health benefits, while also increasing potential capacity and routes with connections to community lifeline services, such as food stores, shelters, and hospitals.

The following trail attributes should be considered when using trails for emergency access and response:[191]

- Trail width:
  - Minimum of 10-foot width[192]
  - Minimum 14-foot tunnel width[193]
  - Minimum 12-foot bridge width[194]
- Vertical Clearance: Minimum 10-foot (8-foot in constrained scenarios)[195]
- Surface: Thicker pavement to reduce potential damage from heavy vehicles[196,197,198]
- Wayfinding signage
- 911 linkages
- Call boxes
- Solar powered charging stations
- Access management
- Patrols by police and volunteers

Barriers and Bollards

Barriers such as bollards, gates, and fences are sometimes used to restrict unauthorized use. In some scenarios, these barriers are a necessary step to minimize significant damage that can occur to the trail tread and surrounding sensitive natural environments. However, due to safety risks and accessibility issues, they should not be used along trails unless absolutely necessary. Bollards can present a hazard to trail users, specifically higher speed users such as bicyclists or snowmobilers.

The primary goal of barriers, to restrict unauthorized (typically motorized) uses, is often left unmet. Barrier layouts that permit bicycles simply cannot exclude single-track motor vehicles such as dirt bikes, motorcycles, or mopeds. Furthermore, determined motorists often find or create a way around the barrier. In circumstances where accidental unauthorized use by vehicles is a concern, the preferred method for restricting access is to divide the trail into two sections with a low, vegetated center island designed to allow emergency and maintenance vehicles to enter the shared use path, if needed, by straddling the island and passing over the landscaping.[199]

If bollards, gates, fences, or other barriers must be used, such as in instances where there is a history of unauthorized used and other mechanisms have failed, the following principles from FHWA's Recreational Trails Program guidance on Bollards, Gates, and Other Barriers should be followed. Barriers should:

- Not restrict access for people with disabilities (ABA, Rehabilitation Act, and ADA).
- Be easily visible, especially in low light conditions. Section 9C.03 of the Manual on Uniform Traffic Control Devices (MUTCD) *requires* retroreflectorization of any obstruction in the traveled way of a shared-use path. This includes posts along the edge of a path (within a path's "shoulder"). In addition, MUTCD Figure 9C-2 defines a diamond-shaped marking that should be

used around bollards or other obstructions within a path.

- Have sufficient sight distance to allow users to adjust speed. This is especially important on paths that have traffic calming features such as curves or landscaping near the bollards. Insufficient sight distance increases the likelihood that bollards will be dangerous hazards.
- Permit passage, without dismounting, for adult tricycles, bicycles towing trailers, and tandem bicycles. All users legally permitted to use the facility should be accommodated; failure to do so increases the likelihood that the bollards will be dangerous hazards.[200]

Trail Construction and Materials

As discussed in Chapter 4, the construction or reconstruction or redesign of a trail is an opportunity to integrate sustainable materials and build a more resilient trail system. Designing a trail to withstand extreme conditions and growing climate hazards involves careful consideration regarding materiality and surface width. The CV Link in Coachella Valley, California used a hierarchy of surface material to indicate primary and secondary trail widths. The primary trail surface is concrete set at 14 feet wide and 8 inches thick to accommodate all modes of transportation. The secondary trail is aligned with decomposed granite running adjacent to the trail for walking and running.

Using two materials to create a wider trail reduces the conflict between emergency motor vehicles and pedestrians. Material selection is also important when considering the use of trails in an emergency scenario. Considerations for material selection can include longevity, environmental stress, and desired capacity to withstand heavy vehicles used in emergency response. In the case study of CV Link, concrete was chosen over asphalt because it is a more stable surface over time, and in such a high-heat environment asphalt would become brittle. Analyzing the climate where a paved trail might be implemented is essential for maintenance and management.

Interconnected Trail System

When designing and implementing trail systems, it is more beneficial for emergency access if they interconnect with other trails. Trail system interconnectivity is a key element in a successful emergency evacuation, and also provides redundancy of access points and routes. Trails may interconnect with other trails or road systems, potentially providing both short and long connections within and between communities. Examples of interconnected trail systems at various scales include:

National Scenic Trails. These are trails of outstanding recreation opportunity and extend for hundreds of miles. The trailways traverse terrain that connects communities, landmarks, and public lands primarily through nonmotorized continuous trails.[201]

Regional or State level long-distance trails. These are trails that can be traversed through different States, jurisdictions, and townships. An example is the Mountain-to-Sea-Trail (MST) in North Carolina, which is an interconnected trail system spanning over 1,100 miles. The MST runs along the east-west length of the State, connecting hikers and backpackers to the different ecoregions found between the mountains and sea. The most western edge of the trail connects to a National Scenic Trail, the Appalachian Trail an expansive long-distance trail stretching from Georgia to Maine.

Urbanized Greenways. Greenways typically include paved infrastructure within more urban environments. Urban greenways can have positive impacts on the social, economic, and environmental fabric of a community. The Indianapolis Cultural Trail (8 miles) and the Atlanta BeltLine (22 miles) are two examples of urbanized greenways that provide networks for communities while preserving and improving ecological functions.

Varying Hazards and Unique Conditions

There are unique conditions and potential natural hazards that might compromise trail routes and should be considered when integrating trails into emergency access and response plans.

Table 3 builds on the hazards identified in 3.1 Event Types

Hazard	Impacts
Rockfall and Landslides	Direct or indirect impacts to homes, vehicles, infrastructure, people, and roadway and trail closures. This can result in injury or traffic hazards due to over-steepened land, disturbed hillsides or mountainsides, and undercut land.
Wildfire	Air quality reduction, increased pollution from soot and ash, pollutants in the water system, property damage, loss of habitat and ecosystem functions.
Sea Level Rise, Storm Surge, Coastal Erosion, Coastal Flooding	Frequent road closures, reduced stormwater drainage capacity, infrastructure damage, intrusion of saltwater to drinking water and impacts to water quality
Pluvial and Fluvial Flooding	Interruption in public and economic services, reduced stormwater drainage capacity, infrastructure and property damage, personal injury

and Risk Factors and summarizes the impacts each hazard may have in an emergency situation.

Table 3: Hazards and impacts for consideration in trail emergency response planning

Hazard	Impacts
Rockfall and Landslides	Direct or indirect impacts to homes, vehicles, infrastructure, people, and roadway and trail closures. This can result in injury or traffic hazards due to over-steepened land, disturbed hillsides or mountainsides, and undercut land.
Wildfire	Air quality reduction, increased pollution from soot and ash, pollutants in the water system, property damage, loss of habitat and ecosystem functions.
Sea Level Rise, Storm Surge, Coastal Erosion, Coastal Flooding	Frequent road closures, reduced stormwater drainage capacity, infrastructure damage, intrusion of saltwater to drinking water and impacts to water quality
Pluvial and Fluvial Flooding	Interruption in public and economic services, reduced stormwater drainage capacity, infrastructure and property damage, personal injury

5. Emergency Response Planning

In widespread and severe incidents, lifeline services can be disrupted for many weeks or months. These disruptions can be extensive and have cascading consequences. Trails can play a critical role in mitigating the harm of such disasters. For example, the Mount Vernon Trail facilitated the evacuation of the Pentagon following the terrorist attacks of September 11th, 2001.

This chapter provides high-level guidance for integrating emergency responsiveness into trail planning, design, management, and maintenance. It explores the role trails play in emergency response and preparedness for hazards, disasters, and other events.

Trails can provide a redundant network of routes for evacuation, rescue, or other emergency response operations; this is true relative to both events occurring on or near trails and for communities adjacent to trails. Evacuation plans that include trails can better prepare communities for emergency response and rapid recovery, and many communities, especially those in the west where there is a high risk of wildfire, do include trails in evacuation plans.

Emergency preparedness is addressed at the Federal level by the Federal Emergency Management Agency (FEMA), at the State level by State emergency management entities, and at the local level by county and local emergency management offices. In reality, myriad agencies and partners often work together to prepare for emergencies.

FEMA recommends that the best strategy for emergency preparedness is an all-hazard approach, which means defining which disasters and hazards can affect an area. This guidebook focuses on planning for climate related disasters and emergencies, but this chapter also addresses other human-related hazards such as terrorism, cyber-attacks, or other events that may result in disruptions to transportation and other infrastructure.

5.1. Trails in the Context of Emergency Management

Trails play a critical role in in emergency management, which is the approach communities take to make themselves less vulnerable to and more able to cope with disasters.

In 2019, FEMA formalized the National Response Framework, which includes a toolkit to help jurisdictions, the public, nongovernmental organizations, and businesses continue functioning in the face of disaster.[202] This framework sets a strategy for integrating government and private sector response efforts, providing guidance for taking full advantage of the emergency support functions that trails can provide.

The framework specifically addresses how trails can provide access to community lifelines, which are government and business functions or services that are essential to human health, safety, and economic security. FEMA's community lifelines substructure and associated toolkit can help communities identify, sustain, and effectively leverage available resources during a catastrophe.

Figure 17: The FEMA Community Lifelines Icons

Section 11505 of the Infrastructure Investment and Jobs Act requires that the U.S. Department of Transportation carry out a study to determine the utility of incorporating bicycle use into local communities' disaster preparedness and response plans. The study includes a vulnerability assessment of active transportation infrastructure and considers evacuation, first responder access, and search and rescue.[203]

An incident response that prioritizes focus on community lifelines can help maintain essential services and save lives after disasters. Interconnected trail systems support community lifelines by providing vital access to shelters, hospitals and other services during and after emergencies.[204]

5.2. Planning for Trails as Emergency Response Routes

This section provides guidance for planning potential trail routes and access points to help ensure both that trails function as part of a network and that trails are designed with emergency response team use in mind. Chapter 4 discusses trail design strategies for resilience as well as emergency response.

Emergency Response Planning

For trails to best function as part of a network of emergency response routes, they should be integrated into emergency response plans. This involves ongoing coordination between State, regional, and local officials that considers new trail developments, trends in trail use, and emerging threats related to climate change. Planning trail access points with emergency response personnel can help decrease emergency response times and improve trails' utility as ingress/egress routes.

Search and Rescue (SAR)

SAR operations are initiated when people become lost, often while using natural-surface trail networks. Trails are often used for SAR operations. ATVs are often used for SAR operations to handle rough terrain and to transport injured persons.[205] Research has found that ATVs can reduce response times for SAR personnel, and recommends that practitioners 1) document trail network accessibility by ATVs and 2) in areas with high demand for SAR services, upgrade trails to improve ATV access.[206] SAR needs on trails have increased in recent years and climate change may be exacerbating risks for trail users, increasing demands for SAR services.[207]

Evacuation Planning

Evacuation planning is necessary to enable large numbers of people to leave an area in a limited time frame, which is critical for climate-related emergences like fire or flooding. Trails can provide a redundant network for people to evacuate from an area in the event that other routes are blocked by crashes, downed trees, flooding, fire, or other hazards.

When a large-scale emergency or imminent threat emerges, transportation agencies—in partnership with public safety officials—typically have two objectives:

1. Minimize the time it takes to get emergency responders to the scene
2. Maximize the proportion of the affected population moved away from danger without being subjected to other risks such as traffic crashes

Events, such as the terrorist attacks of September 11th, 2001, and the evacuation of New Orleans during Hurricane Katrina, revealed the need to think about how to manage large volumes of people walking during urban evacuations.[208] These considerations are important not only because urban areas must be ready for large numbers of people to evacuate on foot, but also because, in some circumstances, walking may be the most efficient means to get the largest number of people out of harm's way.[209] Due to roadway congestion, researchers at the University of Minnesota found that, for evacuation volumes greater than 5,000 per square mile, evacuation by walking is generally faster than driving.[210]

During such events, it is important to create and manage separate evacuation corridors for outbound vehicles and pedestrians. In urban areas, multiuse trails may be used as key corridors for the evacuation of people walking, bicycling, or rolling. Examples of trails and multimodal networks playing a role in evacuation include:

- **In New York, NY** during Hurricane Sandy, bicycle and pedestrian networks provided critical redundancy and saw increased use for essential trips while subway tunnels were flooded[211]
- **Berkeley, CA** used a FEMA Fire Prevention and Safety grant to fund pedestrian pathway improvements in neighborhoods, including adding concrete steps and handrails, to improve access for evacuating residents and emergency responders during wildfires.[212]
- **Portland, OR** incorporated active transportation into the city's emergency response plans by identifying Bike Emergency Transportation Routes. Planners noted the resilience value of bicycles' ability to travel on unimproved and spontaneous paths in emergencies.[213]

Outside of dense urban areas, trails may serve as supplemental routes for emergency vehicle traffic. In these contexts, trails should be designed to withstand heavy use by vehicles such as fire trucks and ambulances and be integrated into the overall street network with many potential access points.

Trails that do not need to support emergency vehicle traffic can offer safe ingress/egress routes for pedestrians and bicyclists without potential conflicts with vehicles during an emergency.

Tsunami Evacuation Plans

Some tsunami evacuation plans consider pedestrian routes and infrastructure, particularly in the Pacific Northwest. For example, a study analyzed pedestrian evacuation times in Crescent City, CA[214] and an evacuation plan for the Marine Science Center in Newport, OR discussed use of pedestrian routes.[215] A study modeling pedestrian evacuation during tsunami events in three coastal communities in Washington State suggested ways trails could be modified to better serve evacuation purposes.[216] The study's recommendations included rerouting trails to align with evacuation corridors, paving trails, constructing steps on trails with steep terrain, building trail bridges over water obstacles, and expanding trail networks to improve connectivity to evacuation assembly areas. The study also recommended trail modifications that consider the demographics of evacuees, such as determining whether ramps or stairs on a trail may be more appropriate for older users. However, these mitigation strategies are not appropriate in all trail contexts (e.g., stairs would be inappropriate on a mountain bike trail).[217]

Geographic Variation

Trails run through varying geographies, which necessitate unique emergency response strategies. When planning trail systems, it is important to consider the array of potential conditions and the modes of transportation that may be used on the trails. Certain geographies present unique conditions and hazards that warrant special consideration for emergency planning and response:

- **Upland and mountainous areas**. Lack of visibility due to fog, steep terrain, landslides, and rock falls may result in roadway and trail closures.
- **Lowland and coastal areas**. Frequent road closures due to flooding; intrusion of saltwater into drinking water.
- **Dry areas prone to fire hazards**. Hazardous air quality and decreased visibility due to smoke.
- **Highly urbanized areas**. Heavily trafficked evacuation routes; people without access to a motor vehicle; exposure to hazardous materials; complex infrastructure systems.

5.3. Emergency Operations and Management

This section includes guidance on ensuring that trails are best suited to support emergency response. It provides an overview of modern data use tools to ensure that responses are equitable.

Being prepared to quickly respond with detailed emergency procedures and trained professionals is critical to mitigate negative impacts.[218] Creating clear and comprehensive emergency operation plans and ensuring communications remain uninterrupted for each unique condition and geography type is critical to the health and safety of trail users.

Planning for emergency response should include multiple technological elements that ensure communications are maintained in the event of an emergency, such as solar-power charging stations or the practice of carrying extra radio batteries and mobile charging blocks for phones. One example to consider is that the National Park Service currently manages emergencies by phone and radio in order to provide redundancies in communication that are not dependent on one network. Dispatchers are certified as both Public Safety Telecommunicators and Emergency Medical Dispatchers.[219]

In many areas where the network of marked trails has organically grown over time, new connectors and segments can lead to trail distance and directional markers that confuse those responding to trail incidents.[220] A unified system of trail markers, each tied to a particular access protocol, can help provide emergency responders with accurate information and reduce response times (see case study 8.5: Houston Bayous Greenways, “911 discs” for an example).

The National Off-Highway Vehicle Conservation Council provides guidance for trail managers about emergency management for OHV trails, covering topics such as effective trail mapping to facilitate emergency response, emergency closure of trails, emergency communications and planning, and emergency vehicle access needs.[221] While similar overarching emergency management resources for other types of trails is limited, this guidance may be applicable in non-OHV trail contexts.[222]

Management Using Monitoring and Data

Collecting and analyzing data on trail use, incidents, and search and rescue operations is essential to understanding and responding to user behavior and potential incidents. Technologies such as heat mapping software or behavior mapping techniques can help prioritize where emergency response and planning should be focused along trails. Behavior mapping software tools can also be used to observe and record behaviors in a particular setting and time. Such tools can visualize data and create more detailed maps of popular destinations, heavily trafficked trails, and reoccurring trail issues to aid in trail planning, including where redundant connections may be needed or where users can be rerouted.

Customer Relationship Management

Developing a Customer Relationship Management (CRM) system can improve emergency response management by providing timely information to trail users. A CRM system may also provide data to trail managers to inform project prioritization and support requests for additional trail funding. Finally, a well-managed CRM system can help create a more transparent and accountable relationship between trail managers and trail users and improve user experience.

Figures 12-15 show a seasonal hiker heatmap on the Appalachian trail according to an interactive online ESRI heat map published by Raincrow.[223] Developing an emergency management plan according to existing user behavior can aid decisions about the allocation of resources and investments, such as where signage and access points should be located.

Figure 18: Appalachian Trail Usage: Spring (Map credit: Raincrow)

Figure 19: Appalachian Trail Usage: Summer (Map credit: Raincrow)

Figure 20: Appalachian Trail Usage: Fall (Map credit: Raincrow)

Figure 21: Appalachian Trail Usage: Winter (Map credit: Raincrow)

Equity in Emergency Response

Equity in trail planning and design is addressed in Section 2.2. However, equity is also a key consideration with respect emergency response and management. The needs of vulnerable populations are not homogenous, but individuals with access and functional needs have the highest mortality rates during emergencies and disasters.[224] Guidelines to strengthen equitable trail emergency response include:

- **Evacuation Planning for Vulnerable Populations**. Evacuation Plans must account for people who cannot drive or do not have access to a vehicle. Depending on the context, some of these people may be able to walk, bike, or roll their way to safety. Others—including people with certain disabilities—will require transportation and other evacuation assistance regardless of context. Local governments should consider pre-identifying these individuals through the creation of disaster assistance registries, identifying designated pick-up locations, and creating multimodal or pedestrian evacuation plans.[225]
- **Universal Design Standards.** Provide an emergency response that is inclusive to all user groups. Universal design can be integrated into emergency response by incorporating multiple language translations within trail signage and incorporating virtual platforms that are accessible to all user groups.
- **Trail Access.** Trail access is important issue for trail planning and development more broadly but it also critical to emergency response planning. Public transportation links should be considered as part of trail access.
- **Funding Allocation.** Funding should support all efforts of emergency management and systematically connect communities within the local or regional context of the planning area. Funds should also be distributed in a way that supports community members of all abilities.

6. Maintenance and Management

This chapter addresses trail management and maintenance in the context of climate mitigation and adaptation. It makes the case for the importance of management and maintenance to ensure a safe and enjoyable experience for users and to preserve the long-term sustainability of trails. It covers construction techniques that can reduce maintenance burdens as well as maintenance techniques to improve climate resilience and reduce emissions. It provides guidance on management strategies to encourage responsible use and make trails more accessible to a greater diversity of users. Finally, it discusses how to plan the management of trails in the context of changing climate patterns, extreme weather events, and the potential land management conflicts that these changes may create.

Figure 22: Slope stabilization along the Houston Bayou Greenways (Photo: Houston Parks Board)

6.1. Maintenance

This section provides guidance on maintaining trails, including a focus on how maintenance can lessen the impact of climate-related events as well consideration of how to minimize the environmental impact of maintenance practices.

Basic maintenance is a major challenge for many agencies and land managers. While there are many funding sources for trail planning, design, and construction, relatively few grants will fund ongoing maintenance work. This has contributed to a major backlog of maintenance on trails across the country.

The Importance of Maintenance

Routine maintenance is crucial to ensuring the longevity, sustainability, and safety of trails, and to provide a quality user experience. In the absence of regular maintenance, trails can quickly become unsafe and even inaccessible for many users, particularly for people with disabilities, micromobility users, and families with young children or elders.

For the purposes of this guidebook, maintenance is defined as inspecting, preserving, repairing, and restoring an active transportation facility and keeping it in condition for safe, convenient, and accessible use. Maintenance includes repairing surface defects and changes in level (e.g., heaving) as well as snow or ice, debris, and vegetation removal. Maintenance can also include keeping railings, lighting, and other trail amenities in working order. For information on the breadth of maintenance practices for walking and bicycling facilities, refer to the FHWA Guide for Maintaining Pedestrian Facilities (update forthcoming).

For many trails, particularly those located in areas prone to flooding, wildfires, landslides, and extreme heat, climate change will exacerbate existing maintenance challenges. For trail managers, this increases the importance and frequency of routine maintenance.[226,227] Identifying and addressing issues such as blocked culverts, eroded subgrade, or outdated signage improves the resilience of trails, decreasing the likelihood of more severe impacts in the event of a climate-related disaster.

The maintenance of shared use paths is typically performed by local governments, although State governments, homeowner associations, and other groups may also be involved. Natural-surface trails are generally maintained by public land managers and/or volunteer groups. In either case, maintenance involves a significant ongoing investment of time and resources.

Construction Techniques to Reduce Maintenance Burden

The best way to maintain a trail is to build it to be durable. Trail damage can frequently be avoided or mitigated by using quality materials and proper construction techniques that consider the underlying soils, seasonal conditions, surrounding vegetation, and local hydrology. These construction techniques are discussed in Chapter 4.

Maintenance Practices to Improve Climate Resilience

Maintenance practices have major implications for a trail's resilience to climate related impacts such as fire and flooding. The following maintenance practices are particularly important to a trail's overall climate resilience:

Inspection. Regular inspection is critical to promptly identify, document, and resolve potential issues. The Minnesota Local Technical Assistance Program

provides a sample Paved Trail Inspections Checklist as part of its Management and Maintenance Workshop. Inspection allows trail managers to identify issues before they become a problem, helping to avoid more expensive repairs down the line. Whenever feasible, issues should be addressed as they are identified during inspection. Inspection and documentation can also reduce potential liability when an accident occurs on the trail. Inspection should also include periodic ongoing monitoring of biological diversity and resilience indicators.

Vegetation Management for Wildfire Prevention. Wildfires such as the Almeda Fire in Jackson County, Oregon (see Section 1.1: Bear Creek Greenway Case Study) have made it increasingly clear that vegetation management makes the difference between a trail corridor that serves as a fire break and one that facilitates the rapid spread of wildfire. Certain kinds of vegetation, such as grasses, blackberries, juniper, and scotch broom are highly flammable, enabling fire to move quickly across the ground and climb into the tree canopy. Vegetation management in fire-prone areas can be used to create firebreaks and/or shaded fuel breaks along trail corridors.[228,229] Firebreaks are areas cleared of all vegetation to eliminate fuel sources for fire. Shaded fuel breaks are areas where trees are thinned and pruned but enough of the crown canopy is retained to create a less favorable microclimate for surface fires.[230] Additional research is needed to understand how trail design and vegetation management can be adapted to reduce vulnerability to wildfires.

Trail Surface Maintenance. Climate change presents additional challenges for the maintenance of trail surfaces. For paved trails, extreme heat may result in damage to trail surfaces (see Section 3.1: Event Types and Risk Factors). Asphalt surfaces in particular may become soft and deform in extreme heat. Cracking also becomes a risk when asphalt expands during periods of very high daytime temperatures and then contracts quickly with nighttime lows. Techniques for preserving asphalt trail surfaces in light of hotter temperatures, include additives used in installation that reduce thermal distortion (see Section 4.4: Materials) and maintaining a shaded corridor along the trail to keep surface temperatures lower.

Concrete trails can experience expansion and buckling in extremely hot weather. Maintaining clean control joints is particularly important during hot weather to ensure debris does not inhibit slab expansion.

Shaded Fuel Breaks

Using vegetation to shade a trail corridor may be in conflict with fuel management goals in areas prone to wildfire. However, a canopy of mature trees can also help suppress the growth of underbrush by creating a shaded fuel break.

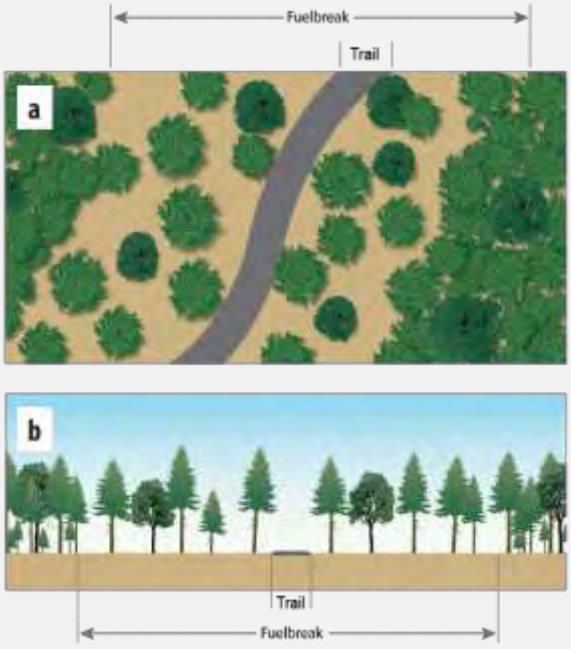

Figure 23: Shaded fuel break plan and section view. Adapted from the Oregon State University Extension publication Reducing Fire Risk on Your Forest Property (PNW 618).

Structure Maintenance. Bridges, boardwalks, culverts, and retaining walls are trail structures that benefit from regular inspections and maintenance to avoid a buildup of issues that can result in structure failure. Abutments, posts, beams, and decking should be regularly examined and repaired when issues arise. Accumulation of debris in scuppers along bridges and boardwalks can accelerate deck rot. Obstructions underneath structures can cause damaging jams when met with debris flows from storms. Keeping structures in good condition will give them the best chance of survival during a climate-related disaster.

Drainage Maintenance. Drainage structures, such as culverts, are needed when trails disrupt natural sheet drainage patterns. Maintaining drainage features can help minimize path erosion and negative environmental impacts. This is becoming increasingly necessary as climate change increases the air's capacity for water vapor, which in turn increases the frequency of extreme rainfall events. These events elevate the risk of flooding, particularly in urban areas with a high proportion of land area covered with impervious surfaces. Periodic maintenance of trail drainage systems, swales, and culverts can prevent catastrophic damage to the trail when heavy rainfall and flooding events occur. This work is primarily carried out manually with the use of rakes and shovels but may also include power washing and other forms of silt removal.

Natural-surface trails include additional types of drainage structures, such as waterbars, reinforced grade dips, checkdams, and turnpikes. Waterbars are one of the most failed structures on natural-surface trails as sediment build-up can render them useless for drainage. See the USFS Trail Construction and Maintenance Notebook for guidance on the construction and upkeep of these features.

Reducing Maintenance-Related Emissions

There are several trail maintenance activities that contribute to greenhouse gas emissions, including mowing, resurfacing, and inspection. In each case, there are strategies that may be used to mitigate or reduce the climate impacts of these activities:

Mowing. In many areas, trails are flanked by strips of grass on either side and requiring regular mowing, at least during the summer months. Winter trails used for snowmobiling, skiing, or snowshoeing often have a grass base that necessitates mowing, or the use of a brush hog rotary mower pulled behind a tractor. Most mowing equipment is gasoline powered and produces greenhouse gas emissions. Mowers with two-stroke engines are particularly harmful because of the higher levels of volatile organic compounds (VOCs) released due to incomplete combustion. These emissions can be reduced by installing vegetation that does not require mowing, decreasing width of mowed area on either side of trails, reducing the frequency of mowing, and using less polluting types of mowing equipment such as those using four-stroke or electric engines.

Resurfacing. There is limited research on mitigating the emissions associated with pavement management. Resurfacing intervals should be balanced to maintain a sufficiently smooth trail surface while minimizing the costs and emissions associated with resurfacing. A variety of techniques can be used to prolong the life of pavement without requiring a full resurfacing. On-site recycling and local sourcing of materials also play a role. See the FHWA Guide for Maintaining Pedestrian Facilities (update forthcoming) for more information.

Inspection. Many trail managers use trucks or other large, gas-powered vehicles to conduct inspection. The use of electric utility vehicles or cargo bicycles should be considered where feasible to reduce the

greenhouse gas emissions associated with trail inspection. Drones may also be used to complete some inspection tasks. Drones may reduce costs and emissions but come with their own set of challenges.

See the Volpe Center White Paper on Small Unmanned Aircraft and the U.S. Forest Service for more information.

6.2. Management

This section provides guidance for managing trails, which is critical for user safety and security as well as the protection of natural and cultural resources. Management also encompasses financial planning and administration, programming and education, volunteer coordination, and visitor use management, including the mitigation of conflicts between competing uses.

Climate change presents additional challenges for the management of trail systems. Changes to seasonal patterns can shift, narrow, or widen windows of high trail use times.[231] Climate change is also creating new conditions that may make some areas unsuitable for certain trail uses. Trail managers should be able to respond to these novel weather patterns and be able to alert the public about adverse conditions or trail closures that result from extreme weather events.

Visitor Use Management

Visitor use management is fundamental to maximizing the benefits of trails for users while maintaining desired resource conditions and user experiences.[232] Desirable times to be out on the trail may shift from time of year, as happens with longer summers, to time of day, as occurs with hotter mid-day temperatures. Trail managers may need to adapt by modifying staffing times and maintenance activities.

Climate change will likely result in more instances where conditions on trails are poor, or closures are necessary to protect public health and safety and/or trail infrastructure. Weather conditions can also impact safety for pets on trails. In addition to providing clear information on where pets are allowed and where leashes are required, it can also be helpful to remind and educate owners about pets and heat-related illness risk.

Communicating conditions and closures with the public is critical. Trail managers can use websites, listservs, social media, or text alert sign-ups to share notifications and updates with the public. When multiple organizations are involved with managing a trail, it is important to clarify which entity has the jurisdiction and responsibility to make the call on closures.

Management Coordination

Trail management involves coordination between State and local governments, local volunteer groups, and other stakeholders and nonprofits.[233] Strategic cooperation through public-private partnerships is an effective way to foster community relationships and allocate responsibility for trail segments for a more comprehensive maintenance plan. Creating diverse partnerships enables more stakeholders to be responsible for the routine upkeep of greenways and trails.

A good example of this is in East Grand Forks Minnesota, where the partnerships of local agencies with the Department of Natural Resources enables the comprehensive management of the greenway to prioritize accessibility, passive recreation opportunities, and active spaces.[234] In addition to management partnerships, building communication outlets with the public can keep them invested and informed on projects and management plans. Maintaining lines of communication during trail management also helps to keep trail users aware of maintenance issues, disruptions, or emergencies on the trail.

Trail Ranger Programs

In-person engagement with trail users can also yield a wide range of benefits in terms of trail stewardship, public safety, education, inclusivity, and maintenance. Some organizations have created trail ranger programs that organize paid staff or volunteers to

patrol trail networks, help trail users, and address minor maintenance issues. To meet goals around equity and inclusion, these programs should be designed to create a safe and welcoming trail experience for all users, with particular consideration for users who have historically been excluded from outdoor recreation opportunities.

Washington DC Trail Ranger Program

Figure 24: DC Trail Rangers (Photo: Washington Area Bicyclist Association)

The Washington DC Trail Ranger Program, run by the Washington Area Bicyclist Association and funded by the District Department of Transportation, employs full-time staff to provide a year-round, seven day a week trail presence on local trails. The Trail Rangers, hired from the local community, ride the trails using electric cargo bikes, addressing maintenance issues, fixing flat tires, providing directions, and ensuring that trails are clean and welcoming for all users.

Having a field team such as trail rangers also enables trail managers to respond to climate change and climate impacts in new ways, such as:

- Leading educational tours and events that highlight topics like climate change, ecology, and environmental justice;
- Distributing cold water and electrolyte beverages to users at risk of heat-related health issues on hot days.
- Identifying and reporting drainage and erosion issues;
- Conducting post-storm sweeps to address downed branches and other hazards; and
- Supporting people to use trails for transportation, reducing motor vehicle trips.

Mud Season Management

The early spring is a challenging time for the management of natural-surface trails. Snowmelt contributes to muddy trail surfaces and high stream flows. Trails see high rates of use as trails users are eager to enjoy the first warm days of spring. The combination of these factors results in a set of trail conditions often referred to as “mud season.”

Climate change is leading to warmer conditions and snowmelt earlier in the spring, resulting in a lengthening of the vernal window, the period of time between snow disappearing and vegetation budding.[235] These impacts will continue to lengthen the mud season for many trails, as well as the use season, making natural-surface trails more vulnerable to soil compaction and erosion. Soil compaction reduces the ability for vegetation to grow and for the ground to absorb water, increasing the potential for flooding and erosion.

Figure 25: The negative impacts of people hiking on muddy trails include erosion and soil compaction. (Photo: The Mountain Trails Foundation, Park City, UT)

Figure 26: Clear etiquette signage that explains the issue encourages responsible use. (Credit: The Mountain Trails Foundation, Park City, UT)

In order to reduce negative impacts to trails and other sensitive resources, natural-surface trail managers may need to employ new management techniques to keep users, particularly higher impact users like equestrians and OHVs, off of trails at certain times. These sorts of temporary trail closures involve extensive communication with users, using both on-site signage and other communication channels. Communication with users should explain the importance of closing trails during these times in order to preserve long-term sustainability and access.[236] In some instances, trail managers may need to patrol trails and/or partner with user clubs to ensure that these high impact uses are suspended.

Electric Mobility and Fire Risk

Electric bicycles, scooters, and other mobility devices have grown hugely in popularity, making biking and rolling more accessible to a greater diversity of users, increasing the number of people who use trails, and increasing the distance that users are able to travel. They have also introduced some new issues, such as increasing the speed differential between trail users, which can result in safety issues.

Another potential issue relates to the lithium-ion batteries that power these devices. When this type of battery is damaged, it can overheat, catch fire, or even explode. Resulting fires tend to burn very hot and can be difficult to extinguish. The risk of battery fires can be reduced by only purchasing devices that are listed by a nationally recognized testing lab and labeled as such. Only using charging equipment that comes with the device, discontinuing charging once the battery is full, and stopping use of the device if the battery is showing signs of damage are other ways to reduce battery fire risk.[237] Further research is needed to better understand the probability of a combustion and the possible scenarios of one occurring in a fire prone area.[238]

Planning for Extreme Weather Events

The ability to plan and prepare for extreme weather events depends greatly on available resources and time before the event occurs. Long-term planning for trail infrastructure in the form of vulnerability assessments or other means to measuring and mitigating risk is the best way to prepare in advance. See Chapter 3 for more information. Mitigation plans may help to identify any short-term actions to be taken to prepare for an imminent event. Preparatory actions may include clearing out drainage structures and securing trailside structures or signs that may be damaged in high winds.

Preparing staff and volunteers for the event and its aftermath is also critical. Safety should always be the priority and can be further built into the event response by developing and collectively reviewing risk assessments or job hazard analyses or the activities involved in clean up, such as chainsaw use. Building a safety culture in daily operations allows it to be carried into event response when risks are often higher.

Alerting the public about conditions leading up to and following a weather event is another way of preserving health and safety. When possible, trail managers should use communication tools such as website posts or email or text alert systems to notify trail users of conditions, closures, or repair work underway on the trails. Signs at trailheads or damaged sections of trail are also critical for communicating conditions with trail users. Trail managers should carefully consider whether to close trails for weather events. If trails can be properly prepared to provide safe passage, they should be left open to serve as additional transportation routes and even aid with ingress or egress during emergencies. However, if conditions along trails are dangerous, trail managers should close them to preserve the health and safety of the public.

Balancing Land Management Priorities

Trails are frequently located in vegetated corridors. In these areas, forest management should pursue carbon sequestration (best achieved by early successional or younger trees) and carbon storage (best achieved by mature trees) through species and age class diversification. Forest management can also help reduce the risk of extreme wildfire, which releases stored carbon back into the atmosphere. See the Vermont Department of Forests and Connecticut Forestry Division websites for examples of how States are managing forests for climate change.[239,240]

The scenery values of vegetated corridors should be balanced with land management goals for wildfire or forestry. Practices such as thinning or creating openings that can benefit an area in terms of resilience to wildfire or pest and disease can be viewed as unsightly when the vegetation treatment contrasts significantly with what is considered the valued scenic character of an area.

As climate change makes mitigating wildfire and forest pests and diseases even more crucial, it will become increasingly important for trail managers to work on ways to integrate mitigation techniques that preserve a scenic trail experience. One strategy is to develop adaptive management strategies for restoration based on based on projected climate change impacts by integrating climate change science into land management planning.[241]

Several Federal land management agencies have organized approaches for scenery management that may be adaptable to smaller scales, such as:

- National Park Service's Visual Resource Program
- USDA Forest Service's Scenery Management System[242]
- Bureau of Land Management's Visual Resource Management program

Managing scenery as a dynamic, long-term resource is another way of approaching vegetation management that may have immediate impacts to the trail experience. Choosing not to manage land around the trail corridor to preserve scenery in the short-term may, in some cases, lead to negative impacts for scenery down the road. More extreme wildfires with fuels buildup or tree mortality due to a single age class, disease, or pest infestation can have severe impacts to scenery.

7. Conclusion

This guide provides a foundation for understanding ways in which trails can be made more resilient and the role they can plan in meeting future challenges. Trails and trail networks present an array of possibilities for mitigating the impacts of climate change, fitting within larger transportation, ecological, and recreation systems to provide access to community lifelines. They will only become more critical as public investment increases and more networks are built.

While this guide, and the case studies that follow, present a collection of valuable current practice and research for practical use, it should be considered a starting point for this subject. As communities incorporate trails into their resilience and emergency management planning, best practices will emerge, and results will become more quantifiable. Intentional stakeholder outreach, information sharing, and collaboration will be necessary to bolster the roles that trails play.

To build on this guide, further study should address the following questions:

- How are different trail types impacted by climate change?
- How can technological advancements help monitor and understand these impacts?
- How can we better plan for emergency management during catastrophic events?
- How can trails be better leveraged as critical infrastructure in times of need?
- What was the longer-term effectiveness of the strategies implemented in the case studies?
- How are these resilience principles being implemented at scale?

Trails provide people with safe routes for active transportation, natural infrastructure, and opportunities to exercise and experience nature. They are a key element for making communities more resilient to the impacts of climate change and for emergency planning and response.

8. Case Studies

The case studies included in this chapter provide real-world examples of how trail planners, designers, and managers bringing creative approaches to their work to adapt to climate impacts and create more resilient trails. The case studies cover a wide breadth of geographies and contexts, each with unique environmental and management challenges. The icons in the top right corner of each section introduction correspond with the primary climate impacts and emergency response issues covered: fire, extreme heat, flooding, stormwater management, evacuation, and emergency response.

These case studies provide insight into how climate change is affecting trails today and the creative solutions being developed to adapt to those impacts. In addition to the design, implementation, and management strategies, they include funding strategies and lessons learned.

Figure 27: Gambles Mill Eco Corridor (Photo: RES (Resource Environmental Solutions))

8.1. Bear Creek Greenway

JACKSON COUNTY, OR

Figure 28: Restored segment of the Bear Creek Greenway (Photo: Jackson County)

Details

Managing Agency*:* Jackson County, Oregon, under the Bear Creek Greenway Joint Powers Authority.

Construction / Implementations Years: Constructed in segments beginning in 1973, completed in 2011.[243]

Uses: Walking and Biking

Trail Surface: Paved

Trail Length: 21 miles

Challenges and Objectives

This multiuse trail is located along the Bear Creek riparian corridor in the Rogue River Valley of southern Oregon. It parallels the area's two major transportation corridors, Interstate 5 and Highway 99, and links five cities, thus serving active transportation needs. In addition to transportation and recreation, the trail also supports passive recreation like bird watching and wildlife viewing.[244]

The Bear Creek Greenway was damaged in September 2020 by the Almeda fire. The fire burned 3,200 acres, destroyed 2,500 residences, 500 businesses, and damaged approximately 10 miles of the trail.

Caused by human activity, the fire occurred during the peak of Oregon's dry season, on a hot, windy day in a drought year. The trail, bordered by flammable, invasive blackberry and poison hemlock, allowed the fire to spread quickly along the ground and get into the canopy of the native riparian vegetation along the creek, primarily cottonwoods. The trail itself suffered limited damage; the trail's surface was damaged where trees fell but the bridges remained intact except for the wooden railings on them. However, the impact to the riparian corridor's natural resources was significant. The trail paved the way for fire to reach the heart of the riparian forest.

The largest impact to the trail and riparian corridor was to natural resources. Bear Creek is salmon-bearing, and salmon need shaded banks and clear, clean water. Bear Creek also feeds the Rogue River, the source of the area's drinking water. The loss of vegetation to hold the soil in place and retain water in the upcoming rainy season created the potential for soil, sediment, and ash to be flushed into the creek, catastrophically damaging water quality and habitat.

The managing agencies quickly mobilized to address the water quality impacts of the fire mere weeks before the rainy season started. Since the fire, local and regional governments, acknowledging that a warmer and drier climate means larger fires[245], have committed to more actively and effectively manage invasive vegetation along the corridor to suppress fuel and prevent future fires.

Management

The Bear Creek Greenway Joint Powers Agreement (JPA) was established in 2007 between the five cities and the County that manage the trail. The mission of the groups was to jointly provide for the consistent financial support, management, promotion, and maintenance of the greenway. The JPA established jurisdictional boundaries and created funding mechanism for staffing and both routine and major maintenance of the trail and 10 feet on either side of it."[246]

The trail was built to be accessible for maintenance vehicles, and all bridges are vehicle rated. This has allowed for both routine maintenance and more substantial interventions. General maintenance for the trail includes fog seal, shouldering, installation of trail counters, inspecting and repairing bridges, and managing vegetation.

Post-fire, the damage along the riparian trail corridor was mapped and prioritized for remedial seeding and treatments to hold the soil in place. Disaster response funding was obtained through the Federal Highway Administration and the Oregon Department of Transportation. A tiered response was developed. For high impact areas, Environmental Protection Agency contractors were hired to supervise and direct the restoration, particularly in wetland areas and irrigation intakes. Medium priority areas were addressed by contractors who installed straw wattles, jute mats, and sterile straw to hold the soil in place. Lower priority areas were addressed by volunteers (e.g. a high school cross-country team who used the trail), through aerial seeding, spreading of straw, and supplemental seeding.

It became clear to Jackson County, the trail manager, that more aggressively controlling the growth of invasive vegetation was key to fire avoidance and suppression. Jackson County conducted a survey post-fire and found that public sentiment was split between mowing invasive management and planting native understory. While vegetation management has always been part of the trail maintenance regime (limited to 10 feet on each side of the trail) Jackson County is now putting much more effort into "fuel management," reducing and eliminating invasive vegetation through cutting and applying herbicide on blackberries. It is also now working with nearby property owners to control vegetation that abuts the trail corridor. As a result of the fire, there is now a long-term

multidisciplinary management plan in place that includes fire, police, and natural resources staff.

In addition to this on-the-ground management of potential fuel supply, The Oregon Department of Forestry, has the power to declare off-path areas off-limits (especially fuel dense areas). Jackson County and the Bear Creek Greenway Foundation post rules, regulations, and closures through local media and social media.

Funding

Bear Creek Greenway Management Plan 2017-2022 laid out a budget for trail management recommendations with the exception of routine maintenance and staffing. The trail is divided into nine planning areas, based on location in relation to the jurisdictional boundaries. "The current JPA divides the responsibility for funding the $67,000 annual major maintenance contribution using a formula based on lane miles of trail and population. Staff updated the lane miles and population data, and contributions are weighted 90 percent based on population and 10 percent based on lane miles of trail."

Routine maintenance is funded by each of the nine planning areas. The five cities and the County spend an average of $4,000-$6,000 per mile annually for routine maintenance of the Bear Creek Greenway.

In 2021, Jackson County commissioners authorized an additional $457,000 for vegetation management post-fire.[247]

Results and Outcomes

Fires have continued to threaten the trail corridor during fire season, but these have been easier to control with more limited fuel supply.[248]

Lessons Learned

In reflecting on the initial devastation of the fire, acknowledgment of the high potential for futures fires, and subsequent planning actions, Jackson County provided the following tips for other trail managers:

- **Think beyond the trail**, as everything surrounding the trail can be impacted by natural disasters.
- **Develop a multidisciplinary management plan**, anchored by a formal agreement that includes fire, police, and natural resource staff to marshalling resources quickly and convening a coordinated management approach. The plan establishes roles and responsibilities which are essential to establishing communication channels and creating a culture of collaboration.
- **Establish a uniform governance and funding strategy** when multiple jurisdictions are involved.
- **Look to the community to help**. Groups that use the trail have a vested interest in its long-term health and success.

8.2. CV Link

Coachella Valley, CA

Figure 29: Shade structures and water fountains along the CV Link (Photo: CVAG)

Details

Managing Agency: Coachella Valley Association of Governments (CVAG)

Construction / Implementation Years: 2011 - present

Uses: Walk, Bike, and Low-Speed Electric Vehicles

Trail Surface: Concrete and Decomposed Granite

Trail Length: 40 miles

Challenges and Objectives

The CV Link is designed to provide a convenient, safe, high-capacity pathway through the Coachella Valley for pedestrians, bicyclists, and low-speed electric vehicles.[249]

The CV Link will ultimately span 40 miles through 6 cities and 3 Tribal jurisdictions. The trail will pass within one mile of over 52,000 jobs, 350 transit stops, 35 public schools and 850 acres of park land.[250]

During the summer months, average high temperatures in the Coachella Valley range from 103°F to 107°F and occasionally reach 120 °F. Climate models suggest the region will continue growing drier and hotter. Heat related illness was identified as one of the primary health related challenges in the Health Impact Assessment for the CV Link.[251]

The trail alignment follows the flood control channel for the Whitewater River. There are more than 100

property owners in the channel, including Federal and Tribal jurisdictions, golf courses, and homeowners' associations. Due to climate and environmental conditions, irrigation and water fountains were strategically placed along of the trail's length. This also limited the ability to plant trees that would shade the trail.

Low-speed electric vehicle use of the trail necessitated higher design standards from Caltrans and FHWA, including structural fencing wherever the concrete trail abuts a steep slope along the flood control channel.

Design and Implementation

The CV Link was designed to withstand use by heavy vehicles that service the flood control channel in addition to extreme heat conditions. The primary trail surface is concrete, eight inches thick and 14 feet wide. Unlike asphalt, which becomes brittle in the hot climate without regular automobile traffic, concrete provides a more stable surface over time. Where space allows, there is also a five to six-foot-wide decomposed granite path adjacent to the trail for walking and running.

The CV Link includes many bridges and undercrossings to reduce conflicts with motor vehicles. Additional armoring was needed at undercrossings to protect the bridge structures. These undercrossings, where the trail dips below the standard flood level, were the most expensive element of the project.

The CV Link includes shade structures at access points, located every one to two miles, and water fountains where feasible. The structures are angled and located to provide shade for the path in the late afternoons of summer when the heat is most intense.

Consideration was also given to the trail alignment and access points to ensure that services (e.g., hospitals, convenience stores) were readily accessible to trail users. Access points are spaced no more than two miles apart.

Figure 30: CV Link adjacent to the flood control channel (Photo: CVAG)

The trail includes solar lighting and distance markers to help users determine their location. Bollards were not included in the trail design to allow access for emergency response vehicles, and because bollards may create a safety hazard for users. The trail's location adjacent to the flood control channel also makes it a potentially useful access route in the event of a flood-related emergency.

Funding

Construction is estimated to cost approximately $100 million. The CV Link leveraged a diversity of funding sources including[252]:

- $18 million from the emission mitigation fund
- $20 million of CVAG transportation funds
- $21 million from the State Active Transportation Program[253]
- $10 million from Desert Healthcare District
- $13 million from Federal Congestion Mitigation and Air Quality Improvement Program funds
- Smaller amounts from the California Strategic Growth Council, County Parks, a bicycle transportation grant, developer fees, and a Caltrans environmental justice grant

Management

The Coachella Valley Water District, which manages the flood control channel, pays CVAG to collect garbage along the trail. Cities along the trail also help maintain some of the initial segments. Private parties have also opted into “Adopt-a-Mile” agreements along sections that fund routine upkeep.

Parts of the trail, such as undercrossings, may be closed during flood events for the safety of users.

Results and Outcomes

An economic impact study of the CV Link found that the project would yield $1.3 billion in benefits over a 25-year period, predominately from an increase in events and tourism.[254]

Lessons Learned

The CV Link, and the diversity of its funding sources, is a testament to the value of trails across a wide-ranging coalition of stakeholders. CV Link was promoted as more than a trail, appealing to a broad user base by including golf carts and other low speed electric vehicles and by minimizing conflicts with motor vehicles. It shows the potential for a productive relationship with a Water District and a maintenance model that provides consistency across diverse jurisdictions. Finally, it demonstrates that people will safely use and appreciate an urban trail even when temperatures climb well over 100 °F.

Future Plans

The CV Link is fully designed and funded. Right-of-way acquisition and construction is ongoing. By the end of the current construction contract, CVAG will have completed roughly half of the 40 miles planned.

Following the completion of the currently planned network, advocates such as the Friends of CV Link hope to see the CV Link extended north to Desert Hot Springs and south to the Salton Sea.

8.3. Gambles Mill Eco-Corridor

Richmond, VA

Figure 31: Gambles Mill Eco-Corridor (Photo: RES (Resource Environmental Solutions))

Details

Managing Agency: Resource Environmental Solutions (RES) on behalf of University of Richmond, VA

Construction / Implementation Years: March 2019 – March 2020

Uses: Walk, Bike

Trail Surface: Asphalt

Trail Length: 0.5 miles

Challenges and Objectives

This project marries trail building with stream restoration to resolve stormwater management challenges while strengthening campus and community active transportation connections. The project originated out of an informal public-private partnership between the University of Richmond, RES, and the City of Richmond, Virginia. The project included four key objectives:

Restore Little Westham Creek to manage stormwater and flooding from increased storm events within the stream floodplain. The main stream channel is part of an over 3 square mile urban watershed. Undersized pipes in the basin could not adequately manage flow from neighboring properties, and tributaries were incised to meet the elevation of the main channel. The channel, at 20 feet wide and a 4 to 6-feet-deep stream bank area, was oversized and significantly eroded. During routine storm events, the stream could not

breach into its wider floodplain due to the channel depth.

Reduce the amount of pollution, particularly phosphorus loads, and sediment traveling downstream to the James River. This is achieved by expanding the capacity of the stream to capture stormwater and filter pollutants with vegetation.

Reduce and manage invasive species. Use sustainable methods to remove nonnative invasive plant species.

Realign and pave. Create 0.5-mile multiuse trail where an obsolete road corridor with heavily deteriorated pavement was used as an informal walking path by community members. The constructed trail was meant to provide a fully accessible path for neighbors and university students while also supporting environmental education.

Design and Implementation

Stream restoration. RES created a smaller channel, 8 feet wide and 1 foot deep, to provide habitat. The agency restored the vegetated area around the channel so that a 40-60 feet wide, heavily vegetated floodplain captures 0.25 - 0.5 inches of rain. The team also constructed riffles, pools, and wood habitat structures along the channel, plus stone steps and pools along tributaries, to support fish habitat.

Plant management. Goats were brought in to browse out invasive species, reducing the need for herbicides and gas-powered equipment. Native herbaceous and woody species were seeded and planted across 3.68 acres.

Trail construction. Trail improvements were identified as a priority in the University's 2011 Campus Master Plan to increase connectivity with a fully accessible path for university staff and students and for residents in the surrounding community. Waterstreet Studio assisted the university in designing a 10-foot-wide trail that was welcoming to community on both ends, with spurs and sidewalks installed to support greater connectivity. The trail was aligned to allow for the creation of demonstration spaces and a rain garden. The trail was graded to solve any flooding issues and to bring it over a box culvert with which RES replaced a 36-inch pipe. The box was sized at 10 feet wide, with much higher capacity for storm events, and the team constructed stream habitat through the box. The trail is not lit for ecological reasons, but conduit was placed in case security becomes an issue in the future.

Funding

As a portion of the project, the extensive trail improvements cost over $500,000. The full project, which included the stream corridor work, focused on nutrient load reduction to meet municipal separate storm sewer system (MS4) permit credit requirements. The City of Richmond ultimately funded the project by purchasing the credits from RES. RES built and permitted the project and confirmed credit approval. The City provides funding each year to RES to maintain the stream corridor, and the University funds maintenance of the trail.

Management

RES monitors the corridor multiple times per year and maintains the stream and floodplain according to Army Corps of Engineers permit requirements. This work ensures that flooding and nutrient reduction capacity is maintained as the stream sees more increased storm events.

The trail was designed so that maintenance and emergency vehicles can travel its full length, including over the culvert. The trail functions as part of the broader campus transportation network. Staff from Waterstreet Studio and the University Landscape Services Department monitor the trail for maintenance.

Results and Outcomes

The project was intended to reduce total phosphorus loads by up to 1,440 pounds, assisting the City with

meeting its stormwater permit requirements. The floodplain is able to capture more rainwater, slow water velocity, and capture pollutants from more frequent storms. The restored stream has been observed to successfully manage stormwater. Rainfall has contributed as much as 3 feet of water into the floodplain without overtopping the floodplain or flooding the trail.

The trail was designed with the involvement of the community and is seen as a community asset and part of both neighborhood and campus active transportation networks. The trail was highly used during the COVID-19 pandemic.

University faculty have also developed several courses across many disciplines, including environmental science, economics, and English that integrate the eco-corridor into learning and research opportunities. Students benefit from being able to observe RES as staff monitor and maintain the stream corridor.

Lessons Learned

The Gambles Mill Eco-Corridor project was the result of close collaboration between public and private partners who brought different but complementary priorities to the table. Project designers were able to produce a space that responds to both community and environmental needs by openly engaging with community and stakeholders.

Future Plans

The Campus Master Plan laid out goals for integrating different types of gardens and planted walks into the trail and stream corridor, so opportunity exists to evolve some of the corridor spaces over time.

8.4. Greater Grand Forks Greenway

Grand Forks and East Grand Forks, MN

Figure 32: Gathering space along Greater Grand Forks Greenway (Photo: Visit Greater Grand Forks)

Details

Managing Agencies: City of Grand Forks, Grand Forks Park District, City of East Grand Forks, Minnesota Department of Natural Resources

Construction / Implementation Years: 2001 - 2007

Uses: Hike, Walk, Bike, X/C Ski, Snowmobile, Paddling (Red River Blueway)

Trail Surfaces: Asphalt, Natural Surface

Trail Length: 20+ miles

Challenges and Objectives

A 210-year flood event along the Red River in the spring of 1997 destroyed a large part of Grand Forks and East Grand Forks. Seventy-five percent of Grand Forks and 95 percent of East Grand Forks were inundated with water.[255] A congressional delegation from North Dakota successfully advocated for a greenway solution to the flooding rather than the original proposal of a bypass channel that would have involved buying out farmland.

The greenway concept was not initially supported by many at the local level. The predicted economic benefits were met with skepticism, but overall, the area now embraces the many benefits of the greenway including economic development, community programming, recreation, transportation, and stormwater management.

Design and Implementation

The U.S. Army Corps of Engineers developed a plan for a levee system along the Red River and Red Lake River systems that would protect the Greater Grand Forks region from future flooding. The land left within the floodplain was planned as a 2,200-acre greenway to benefit the community with recreation opportunities, ecological improvements, and economic growth.[256]

A floodwall with gated openings allows for accessibility standards for trails to be met and allows for access from adjacent neighborhoods.

Funding

A 50-50 cost share between the Federal government and the cities was established to fund the greenway project. The overall cost of the greenway and related flood mitigation infrastructure was $20 million.

The cities of Grand Forks and East Grand Forks and the Grand Forks Park District developed extensive programming for the trails and recreation spaces within the greenway to help fund maintenance of the trails and infrastructure. A few of the many events that take place along the greenway include the Extreme ND Iceman Triathlon, “Bikecicle” ice bike race, music festivals, and a farmers’ market.

Management

The management of the greenway is accomplished separately in the States of North Dakota and Minnesota. A Greenway Division within the City of Grand Forks Engineering Department was established in North Dakota, and East Grand Forks works in partnership with the Minnesota Department of Natural Resources to manage the greenway.

Mowing practices along the greenway have evolved and been reduced to prioritize accessible, active spaces while other more passive landscapes have been planted with wildflower mix.

The greenway has a communication system that alerts the public about current conditions and closures. Residents and visitors can sign up for email updates on the greenway’s webpage to be alerted about flooding and trail work as well as events and activities.

Results and Outcomes

The Red River floods annually as spring rains melt the winter ice pack. Several flood events that matched the 1997 water levels have occurred. The greenway has functioned successfully as designed and demands minimal clean-up of sedimentation along trails after the floods.

Lessons Learned

Greenways have an immense potential for positive impacts on adjacent communities. In addition to flood mitigation, the Greater Grand Fork Greenway has been a major factor behind economic development in the area including the opening of an outdoor gear store and a major call center.

Incorporating enough space to accommodate flood waters in the greenway footprint and designing infrastructure that can withstand flooding were two critical components of the greenway’s success.

8.5. Houston Bayou Greenways

Houston, TX

Figure 33: Two people riding bicycles along the Houston Bayou Greenway. (Photo: Houston Parks Board)

Details

Managing Agency: Houston Parks Board (HPB) nonprofit

Construction / Implementation Years: 2012 - present

Uses: Hike, Walk, Bike

Trail Surface: Concrete and Asphalt

Trail Length: 150+ miles

Challenges and Objectives

Between 2015 and 2020, the City of Houston experienced six major flooding events, including Hurricane Harvey, one of the most damaging natural disasters in U.S. history. Flood events that were believed to have less than a 2 percent chance of occurring in a given year have occurred annually. Impacts of the flooding events have been exacerbated further by the region's rapid urbanization. In response, the City of Houston and Harris County have invested extensively in preparing for the impacts of climate change, including flooding, tropical storms, and extreme heat.

Houston's 22 bayous, or waterways, which weave through the region on their way to Galveston Bay, are the defining feature of the City's landscape. The City's 2020 Resilient Houston Plan recognizes the importance of embracing the role of the bayous as "Houston's front yard" as part of the overall strategy

to improve physical, environmental, and economic resilience. The City and County's approach to managing the bayous includes removing structures from the floodway, expanding stormwater detention and infiltration, and developing trails that provide recreation, transportation, and community health benefits.

Local entities including the City of Houston, Harris County, and Texas DOT originally built 77 miles of trails along Houston's bayous. HPB is expanding those trails into a 150-mile trail network that connects all of Houston's major bayous. When the system is complete, 1.5 million Houstonians will live within 1.5 miles of the Bayou Greenways.

Design and Implementation

Houston Parks Board (HPB) has moved from asphalt to concrete trail construction. Concrete is better able to withstand the shrinking and swelling of soils from heat and flood events. Six-inch-thick concrete is used to support heavy maintenance equipment used by Harris County Flood Control District (HCFCD). Trails along the water's edge are also built with 18-to-36-inch turndowns on the edges of the trail, which protect the underside of trails from being washed out by flooding.

In addition to hardscaping design tactics, landscaping plays a role in flood mitigation as well. Plantings along the Greenways include native grasses with deeper root systems, which help to prevent erosion.

The Greenways are designed to be highly accessible for emergency responders. The maintenance ramps installed by HCFCD for channel maintenance have been incorporated into emergency response planning, enabling more rapid access along the length of the trail.

HPB is also installing metal "911 discs" embedded into the trail every quarter mile. The discs include point identifiers for trail users to communicate their exact location to emergency dispatchers. HPB provided

Figure 34: Graphic from Resilient Houston Plan (Credit: Resilient Houston)

dispatchers instructions for the best way to access each disc location. Signs are also being installed on all of the bridges that pass over the trail so that trail users know which street they are passing under.

Funding

Houston voters approved a $410 million bond proposal in 2012, including $100 million in funding for the Bayou Greenways linear parks and trails program. HPB leveraged this support to raise another $120 million from private, civic, and philanthropic partners, including $50 million from the Kinder Foundation.

HPB developed a long-term plan to fund maintenance and operations. There is an 80-year Economic Development agreement between the City of Houston and HPB to fund the maintenance program. The agreement includes an escalating maintenance budget to keep up with expansion and an annual 20 percent set-aside to cover the cost of clean-up and repair after major flood events. Maintenance funds remaining at

the end of each fiscal year are used to help fund capital costs associated with the long-term replacement and repair of trails, bridges, and other infrastructure.

Management

HPB maintains the trails and greenspaces, including mowing, litter and debris removal, graffiti abatement, conservation work, flood cleanup, and repair and replacement of amenities. During flood cleanup, clearing the trail surface is prioritized to make the trail usable for those who rely on it for transportation. HCFCD maintains the bayou channels and conducts mowing, channel improvements, and sink hole repair.

One downside to the shared management of the bayou greenways is that individual tasks such as mowing or litter removal can be divided between HPB and HCFCD for the same area. This division of work has the potential for inefficiency can result in public confusion about jurisdictional responsibilities and maintenance schedules. On the other hand, an advantage of the shared responsibility is that HPB can sometimes leverage larger HCFCD work to simultaneously build, repair, or upgrade trails.

Results and Outcomes

A study of the Bayou Greenways found that the network would yield annual benefits to the people of Houston conservatively valued at $90 million per year. This figure includes:

- $50 million improvement, equitably distributed, to Houstonians' physical and mental health
- $10 million improvement in Houston's environmental health
- $17.5 million benefit to Houston's economic health, by attracting workers, businesses, and retirees and increasing property values
- Since the program began in 2014, sections of the Bayous Greenway have weathered some of the worst floods in the City's history. Trails have been repeatedly submerged under 20-25 feet of floodwater without sustaining significant damage.

Lessons Learned

The funding and design strategies used by HPB could be used as an example for other agencies seeking to build trails along waterways where regular flooding is expected. The trails epitomize resilient infrastructure, providing facilities for sustainable transportation and recreation that can withstand severe flooding.

Other agencies could also look to the coordinated approach laid out in the Resilient Houston to invest in flood-prone neighborhoods without causing displacement. The Plan promotes a participatory, interagency planning process for community-driven change.

Future Plans

As of 2022, the Bayous Greenway network is nearly complete. HPB is now investing in Beyond the Bayous, a vision for expanding parks and greenways to communities that are not located near a bayou and providing a more equitable distribution of open space throughout the Houston area. The vision also includes higher quality linkages between habitat ecosystems as well as eight new regional connector corridors and twenty new potential "hub parks." Beyond the Bayous aims to create additional connections, leveraging linear open spaces such as tributaries, utility corridors, and other existing trail systems.

8.6. Katy Trail

Clinton to Machens, MO

Figure 35: Single span steel bridge along the Katy Trail (Photo: Missouri Department of Natural Resources)

Details

Managing Agency: Missouri State Parks

Reconstruction / Implementation Years: 2019-2022

Uses: Walk, Bike, Equestrian

Trail Surface: Crushed Limestone

Trail Length: 240 miles

Challenges and Objectives

The Katy Trail, which is the longest recreational rail trail in the US, includes a lengthy section along the Missouri River. Rail trails typically have the reputation of being “high and dry” because they are built on railroad grades. However, this section of the Katy Trail has seen more frequent flash flood events in recent years.

In late May and early June 2019, 100 miles of the trail along the Missouri River flooded and incurred significant damage. Damage was exacerbated by the slow recession of the flood waters. Railroad bridges along the trail that had bulkier support structures and lower clearances were destroyed by debris flows. As part of the trail rehabilitation, Missouri State Parks opted to include infrastructure capable of handling frequent flooding events.

Design and Implementation

Climate adaptation was incorporated into trail reconstruction following the 2019 flooding by installing infrastructure that would withstand flooding. Railroad bridges were replaced with single span steel bridges with higher clearance. Bridge designs incorporated modern stream flow data and culverts were upsized and added along the trail. Geotextile fabric was installed under the trail surface to help stabilize the trail tread during flooding.

Funding

Trail reconstruction funding came from the Federal Emergency Management Agency and Missouri State Parks' capital funds. The Parks, Soils, and Water Sales tax in the State of Missouri provides one-tenth of 1 percent to the State park system. This tax provides about three-fourths of the State parks' operations and development budget.

Management

Climate change has affected peak visitation times for the trail. More people are visiting in the spring and fall to avoid the heat of July and August. Missouri State Parks has updated staffing schedules and project implementation timelines to account for the change in peak visitation timing.

Missouri State Parks works closely with first responders to plan and prepare for emergency response. Highway patrol rangers provide a presence along the trail and respond to incidents, using railroad mile markers to find trail users' locations. The trail also has a GIS-based trail advisory system that can alert the public to closures, conditions, or construction along the trail.

Results and Outcomes

Flash flooding occurred on a section of the trail in June 2021. Although some damage was incurred, repairs were much faster than those needed after the 2019 flood.

Lessons Learned

Flooding will be an on-going challenge due to the trail's location along the Missouri River. Mitigating flooding will involve strategic upgrades of the trail's surfacing and infrastructure in areas prone to flooding.

8.7. New York-New Jersey Trail Conference

Greater Metropolitan New York

Figure 36: Ramapo Valley County Reservation map of updated loop hikes (Credit: New York-New Jersey Trail Conference)

Details

Managing Agency: New York-New Jersey Trail Conference

Construction / Implementation Years: Ongoing

Uses: Hike, Walk, Limited Bike

Trail Surface: Earth

Trail Length: 2,150+ miles in network

Challenges and Objectives

Natural area trail networks with extensive mileage and many route options can be confusing for hikers. As hiking grows in popularity, increasing numbers of inexperienced hikers are exploring the outdoors and many assume that all trails are loops. The New York-New Jersey Trail Conference is a volunteer-powered nonprofit that partners with land managers to build, protect, and promote public trails. The Trail Conference is rerouting and remarking trails to improve sustainability, introduce new loop options, and minimize lost hikers.

Design and Implementation

The Trail Conference works with local, State, and Federal land managers to maintain and improve trail networks. Most land managers are unable to collect comprehensive user data that would help guide project goal setting. Thus, while not representative of all hikers, the Trail Conference often uses Strava heat map data to learn what trails are the most or least used. Volunteers inspect trails they work on at least twice annually, and their feedback informs project priorities.

The Trail Conference uses heat map data, knowledge of user behavior, detailed maps of popular destinations, and recurring trail issues to determine where trails may necessitate rerouting. In addition to rerouting, the Trail Conference sometimes establishes new loop trails by changing the colors on existing blazes (paint or tags on trees to mark paths) and updating names and maps accordingly. This allows hikers to follow popular routes using a single color, rather than having to navigate multiple confusing intersections between different colors.[257] Blazing is relied upon more heavily than signage, as signage is prone to both vandalism and regular environmental damage. The Trail Conference has updated both its blazing and signage system to provide more information to trail users, including URLs to webpages with free maps (such as TheHighlandsTrail.org).

The Trail Conference has also worked to provide more equitable access to parks and trail by:

- Working only on public land that is free to access
- Prioritizing work on trails in close proximity to public transit
- Focusing on expanding the language in guides (LenapeTrail.org) to be more welcoming to new visitors
- Referring to “trail users” instead of “hikers” to serve a broader audience of casual walkers, trail runners, mountain bikers, and more

Where emergency response routes exist, the Trail Conference builds and maintains intersecting or co-aligned trails so as not to obstruct the emergency route.

Funding

Stable funding is limited, with awards from foundations and grants funding most significant projects. Examples include FHWA gas tax revenue dispersed through the Federal Recreational Trails Program and Consolidated Funding Application (CFA) grants, which can help fund engineering or professional trail construction.

Management

The Trail Conference does not provide emergency response or search and rescue services itself, though it does sometimes partner with local teams in project planning. The Trail Conference uses its website and social media to update trail users about events of concern, such as bear-related incidents or bridge and trail closures. Volunteers may also assist with marking or signing closed trails.

The larger management challenges the Trail Conference faces are sparse funding for critical staffing and overhead costs, time- and cost-intensive project engineering and permits, and a volunteer culture which seems to be moving away from the dedicated leadership roles which the organization relies on. Funding can be difficult to obtain for trail projects as material costs are high enough to rely on external funding, but the work of volunteers keeps costs down so much that projects are rarely eligible for larger infrastructure and transportation grants. Many grants do not pay for the critical staff time needed to navigate permitting and coordination processes, which means that staff support is limited, and less work can be done as a result.

Finally, the Trail Conference is increasingly asked to take on insurance and liability burdens with formal Memorandums of Understanding (MOUs) that would

indemnify the landowner while putting the Trail Conference at potential legal risk. This movement by land managers to place more liability on partner organizations can result in lengthy legal discussions, delaying projects months or even years.

Results and Outcomes

Local park managers and search and rescue teams have told Trail Conference staff that they have seen reductions in lost hikers in the wake of the organization's work to convert confusing trail networks into simpler routes blazed as intuitive loop hikes.

Future Plans

The Trail conference will continue to prioritize updating trail conditions, routes, and markings to prevent hikers from getting lost and to provide a more enjoyable experience

8.8. Paradise Multiuse Paths

Paradise, CA

Figure 37: Multiuse path paralleling Pentz Road adjacent to Paradise Ridge Elementary School (Photo: Town of Paradise)

Details

Managing Agency: Town of Paradise, California

Reconstruction / Implementation Years: 2022-Present

Uses: Walk, Bike

Trail Surface: Asphalt

Trail Length: 6 miles existing, 38+ miles planned

Challenges and Objectives

In November of 2018, the Camp Fire caused devastation across Butte County, California causing 85 fatalities and destroying nearly 95 percent of the Town of Paradise's buildings.[258] The fire resulted in $16.5 billion total losses.[259]

Prior to the fire, the Town received Active Transportation Program (ATP) Funds[260] through the California Department of Transportation (Caltrans) for the construction of a multiuse path that would provide access to an elementary school. Although the multiuse path near the school had yet to be constructed at the time of the fire, the 5.25-mile-long Yellowstone Kelly Heritage Trail, which bisects the Town and parallels Skyway, the major north-south road, served as an ad hoc evacuation and emergency response route. The series of events that took place

during the fire concerning traffic jams, crashes, and general lack of adequate ingress and egress routes highlighted the dire need for additional space and routes for evacuation as well as emergency vehicle access.

Design and Implementation

Following the fire, a long-term recovery plan was completed June 2019. The plan identified several emergency preparedness projects including an interconnected path system. Implementation of the path system along main ingress and egress routes in the Town is identified as a tier one priority. The paths focus not only on providing safety, connectivity, and health benefits associated with active transportation, but also on increasing potential capacity for first responders.[261]

The first path near the elementary school, funded through a prefire Caltrans ATP grant, was completed in May 2022. Through the development of its 2022 Transportation Master Plan, the Town identified additional multiuse paths as the key components of a comprehensive 43-mile network. Future pathways will include a minimum 10-foot-wide asphalt pathway with two-foot-wide shoulders. Trail construction will occur based upon funding availability and prioritization of critical routes.

Funding

The Town submitted a total of 17 projects which incorporate multiuse paths for consideration in disaster recovery funds available for the federally declared disaster 2018 California Wildfires. The recovery funds are provided through the Community Development Block Grant (CDBG) Program managed by the U.S. Department of Housing and Urban Development and administered by the California Department of Housing and Community Development. The Town also submitted the pathways for grant funding under Caltrans's ATP.

Management

The multiuse paths will be managed by the Town. Local fire and police departments are very supportive of the projects, which has helped to strengthen the working relationship between public works and emergency response. Due to the unpredictable nature of emergencies, the Town is not certain how the path network will be used in the event of another fire, but paths will provide additional asset and capacity for emergency responders, firefighters, or people evacuating by vehicle, bike, or foot.

The Town anticipates and allows for e-bike use along the paths. The hilly terrain and warm summer climate make e-bikes an appealing mode of transportation in the rebuilding community.

Results and Outcomes

The Town facilitated an evacuation scenario in 2022 that tested communication systems and on-the ground response for emergency personnel. The path along with to-be-constructed paths will likely be used in evacuation drills in the future.

Lessons Learned

Regional interagency coordination has opportunity for growth. Different jurisdictional authorities currently make emergency preparedness work across different government levels challenging, but recent progress and momentum has been built through the Town's Transportation Master Plan preparation process.

The recently built 0.5-mile pathway near the elementary school is eight feet wide, with accessible curb ramps that created unintentional pinch points. Although still functional for emergency ingress and egress, the pinch points may add some complexity for use by larger emergency vehicles. Future pathways

will be at least 10 feet wide with two-foot wide shoulders to better accommodate these uses.

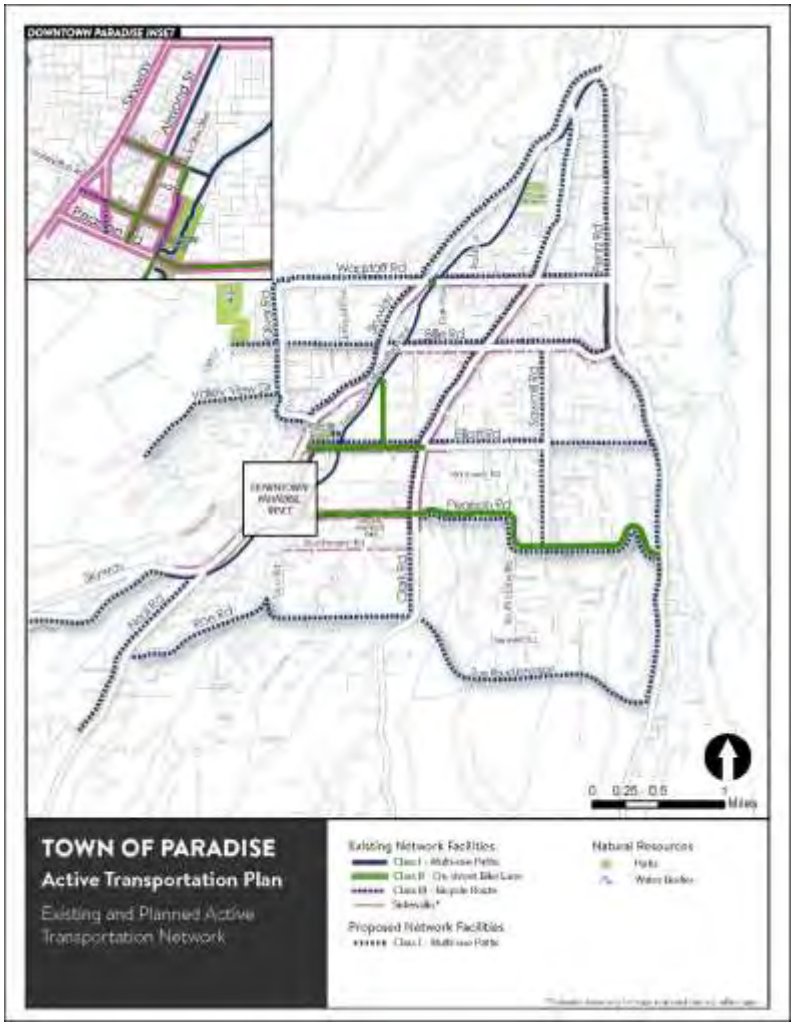

Figure 38: Paradise, CA Active Transportation Plan Network (Map credit: Town of Paradise)

8.9. Prison Hill Recreation Area

Carson City, NV

Figure 39: Single-track mountain bike trail at Prison Hill Recreation Area (Photo: Carson City Parks, Recreation and Open Space)

Details

Managing Agency: Carson City Parks, Recreation and Open Space Department

Construction / Implementation Years: 2015 - Present

Uses: Hike, Walk, Bike, Off-Highway Vehicle

Trail Surfaces: Natural Surface, Decomposed Granite

Recreation Area: 2,500 acres

Challenges and Objectives

The Prison Hill Recreation Area was conveyed to Carson City by the Bureau of Land Management in 2015. The conveyance included a conservation easement on the property which guides management practices, as well as a programmatic agreement regarding cultural resources and requirement for concurrence from the State Historic Preservation Office and consultation with the Washoe Tribe of Nevada and California prior to project development. A network of intentional and user-created trails, as well as undefined areas used by OHVs, was included with the land acquisition.

Increased frequency and severity of flooding events associated with climate change was causing severe erosion issues along trails. Carson City was particularly concerned with sedimentation in the Carson River, which runs adjacent to the recreation area.

The City was also concerned about the growing wildfire risk within the recreation area and in adjacent neighborhoods. Using the trails to provide fuel breaks and access for firefighters was an added objective of trail remediation and development.

Other environmental considerations included the 200+ bird species that seasonally live along the Carson River. Trails would need to be routed around the cottonwood galleries along the river to protect this important habitat area.

Design and Implementation

To address erosion issues, trails were rerouted away from sensitive areas and were reconstructed with sustainable grading and drainage features. With the help of a geomorphologist, managers were able to predict flows, potential for streambank erosion, and natural meanders that could impact trails along the river. Select trails along the river were decommissioned to reduce erosion and large rocks were used to further stabilize sections of streambank. Decommissioning trails along cottonwood groves also helped preserve quality habitat for birds.

The trails within the Prison Hill Recreation Area are part of a larger trail system connecting several low-income neighborhoods and schools. The recreation area offers opportunities for users of all abilities, including single track trails designed for adaptive mountain bikes.

Noteworthy design strategies of trail reconstruction included anticipating user behavior to reduce new user-created trails. For example, steps were constructed at switchbacks where people were likely to shortcut turns. Managers worked with the Carson City Fire Department's Wildland Fuels Management Division to design trails so they could serve as fuel breaks and provide access for firefighters.

Funding

The recreation area improvements have been funded by the City's Quality of Life Initiative, which is a quarter of one cent sales tax, 40 percent of which goes into the open space program for acquisition and maintenance. Funding has also come from the Southern Nevada Public Land Management Act which supports parks, trails, and natural area projects, from the federally funded Recreational Trails Program, and the Nevada Off-Highway Vehicle Program.

Management

Expense and labor needed for maintenance were considered in the selection of material for the accessible trail system. Decomposed granite is compacted on top of a road base to offer a firm and stable surface while keeping maintenance programmatically sustainable. Both road base and decomposed granite are stored on site which further reduces costs.

Prison Hill is upland sagebrush (unforested) and sees very high temperatures in the summer which has resulted in occurrences of heat-related illness. The City addresses the worsening heat effects of climate change by offering trails in more shaded areas in Carson City.

The trails serve as access for wildland firefighters responding to fire both within the recreation area and in adjacent neighborhoods. Trails also serve as emergency access to the Carson River, which is a dedicated aquatic trail.

Results and Outcomes

A 100-year rain event in November 2021 tested the trails' design, with successful results. Culverts and trail grading improvements allowed the trail tread to shed water rather than convey it and contribute to erosion. Trails have been used to respond to wildland fires, including an incident where water was air dropped by

helicopter directly onto a trail. The trail design and infrastructure performed well under the heavy load of water. Trails have also been used for search and rescue along the Carson River.

Lessons Learned

Some problematic legacy trails within the OHV area have proven challenging to decommission successfully. These trails still see unauthorized use despite attempts to close them. Managers are continuing to work with the OHV community to identify goals and provide sustainable recreation opportunities.

Implementing drainage improvements based on observations and professional knowledge has proven successful. Consolidating trail mileage to less sensitive areas has also helped reduce impacts

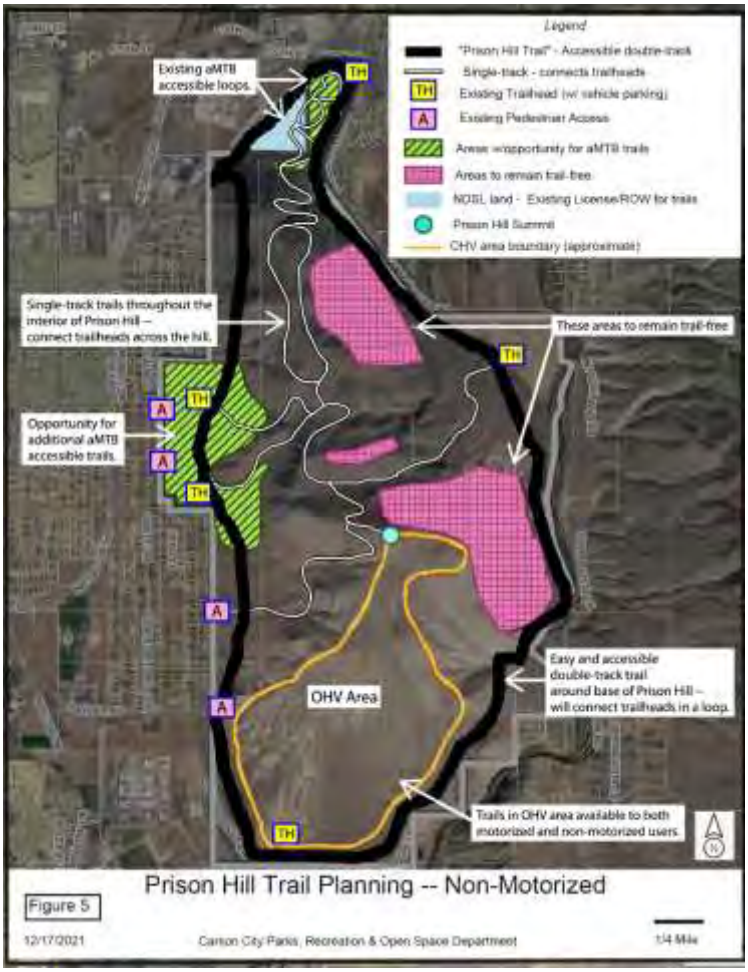

Figure 40: Prison Hill Nonmotorized Trail Plan (Map credit: Carson City Parks, Recreation and Open Space Department

9. Glossary and Acronyms

Term	Definition
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order 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. (IPCC)
Adaptive Capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. (IPCC)
Air pollution	Degradation of air quality with negative effects on human health or the natural or built environment due to the introduction, by natural processes or human activity, into the atmosphere of substances (gases, aerosols) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect. (IPCC)
Asphalt	A dark brown to black cement-like material containing bitumen as the predominant constituent. The definition includes crude asphalt and finished products such as cements, fluxes, the asphalt content of emulsions, and petroleum distillates blended with asphalt to make cutback asphalt. Asphalt is obtained by petroleum processing. (FHWA)
Capacity	A transportation facility's ability to accommodate a moving stream of people or vehicles in a given time period. (FHWA)
Carbon Dioxide (CO_2)	A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas and coal), of burning biomass, of land-use changes (LUC) and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a global warming potential (GWP) of 1. (IPCC)
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. (IPCC)
Climate Change	Climate change refers to a change in the state of the *climate* that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external *forcings* such as modulations of the solar cycles, volcanic eruptions and persistent *anthropogenic* changes in the composition of the *atmosphere* or in *land use*. (IPCC)
Climate Model	A numerical representation of the *climate system* based on the physical, chemical and biological properties of its components, their interactions and *feedback* processes, and accounting for some of its known properties. The climate system can be represented by models of varying complexity; that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such

Term	Definition
	aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parametrizations are involved. There is an evolution towards more complex models with interactive chemistry and biology. *Climate models* are applied as a research tool to study and simulate the *climate* and for operational purposes, including monthly, seasonal and interannual climate predictions. (IPCC)
Climate Projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission, concentration, or radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. (IPCC)
Commute	Regular travel between home and a fixed location (e.g., work, school). (FHWA)
Decarbonization	The process by which countries, individuals or other entities aim to achieve zero fossil carbon existence. Typically refers to a reduction of the carbon emissions associated with electricity, industry and transport. (IPCC)
Disadvantaged Communities	Communities that experience disproportionately high and adverse health, environmental, climate related, economic, and other cumulative impacts. (USDOT Equity Action Plan)
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. (IPCC)
Ecosystem services	Ecological processes or functions having monetary or nonmonetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or *biodiversity* maintenance, (2) provisioning services such as food or fiber, (3) regulating services such as climate regulation or *carbon sequestration*, and (4) cultural services such as tourism or spiritual and aesthetic appreciation. (IPCC)
Electric Bicycle (E-Bike)	A two- or three-wheeled cycle with fully operable pedals and an electric motor of less than 750 watts that provides propulsion assistance. (NPS Policy Memorandum 19-01)
Electric vehicle (EV)	A vehicle whose propulsion is powered fully or mostly by electricity. (IPCC)
Environmental Justice (EJ)	Environmental justice assures that services and benefits allow for meaningful participation and are fairly distributed to avoid discrimination. (FHWA)
Environmentally Sensitive Area	An area of environmental importance having natural resources which, if degraded, may lead to significant adverse, social, economic or ecological consequences. These could be areas in or adjacent to aquatic ecosystems, drinking water sources, unique or declining species habitat, and other similar sites. (FHWA)
Equality	A principle that ascribes equal worth to all human beings, including equal opportunities, rights, and obligations, irrespective of origins. (IPCC)

Term	Definition
Equity	Equity is the principle of fairness in burden sharing and is a basis for understanding how the impacts and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. It is often aligned with ideas of equality, fairness and justice and applied with respect to equity in the responsibility for, and distribution of, climate impacts and policies across society, generations, and gender, and in the sense of who participates and controls the processes of decision-making. (IPCC)
Extreme Weather Event	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season). (IPCC)
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods (occurring when the ground is over-saturated and/or drainage systems are over capacity), sewer floods, coastal floods, and glacial lake outburst floods. (IPCC)
Floodplain	The land area susceptible to being inundated by flood waters.
Grading	Shaping an area of land for the needs of a specific project. In the context of trails, the goals of grading are typically to ensure proper drainage and accessibility.
Greenhouse Gas (GHG)	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapor (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). (IPCC)
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. (IPCC)
Hydrology	The Earth science that considers the occurrence, distribution, and movement of water in the atmosphere, between the atmosphere and the Earth's surface, and in the Earth.
Impacts	The consequences of realized *risks* on natural and *human systems*, where risks result from the interactions of climate-related *hazards* (including *extreme weather and climate events*), *exposure*, and *vulnerability*. Impacts generally refer to effects on lives;

Term	Definition
	livelihoods; health and *well-being*; *ecosystems* and species; economic, social and cultural assets; services (including *ecosystem services*); and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial. (IPCC)
Infrastructure	A term connoting the physical underpinnings of society at large, including, but not limited to, roads, bridges, transit, waste systems, public housing, sidewalks, utility installations, parks, public buildings, and communications networks. In transportation planning, all the relevant elements of the environment in which a transportation system operates. (FHWA)
Justice	Justice is concerned with ensuring that people get what is due to them, setting out the moral or legal principles of *fairness* and *equity* in the way people are treated, often based on the *ethics* and values of society. (IPCC)
Land Use	Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, conservation and city dwelling). (IPCC)
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or service throughout its life cycle. (IPCC)
Low-Speed Electric Vehicle (LSEV)	A low-speed EV, also known as a neighborhood electric vehicle, is defined as a motor vehicle with four wheels, a gross vehicle weight rating of 3,000 pounds or less, and capable of achieving a minimum speed of 20 miles per hour (mph) and a maximum speed of 25 mph. (US Department of Energy)
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 (RE) technologies, waste minimization processes and public transport commuting practices. (IPCC)
Natural Infrastructure	Infrastructure that uses, restores, or emulates natural ecological processes and– (A) is created through the action of natural physical, geological, biological, and chemical processes over time; (B) is created by human design, engineering, and construction to emulate or act in concert with natural processes; or (C) involves the use of plants, soils, and other natural features, including through the creation, restoration, or preservation of vegetated areas using materials appropriate to the region to manage stormwater and runoff, to attenuate flooding and storm surges, and for other related purposes. (23 U.S.C. 101(a)(17)) Terms that are often used interchangeably include “green infrastructure” and “nature-based solutions.”
Off-Highway Vehicle (OHV)	An off-highway vehicle (OHV) is a motor vehicle capable of off-highway travel during winter or summer. OHVs include all-terrain vehicles (ATVs), four-wheelers, three-wheelers, dirt bikes, motorcycles, trail bikes, and snowmobiles. (USFS)
Overburdened communities	Minority, low-income, tribal, or Indigenous populations or geographic locations in the United States that potentially experience disproportionate environmental and/or safety harms and risks. This disproportionality can be a result of greater vulnerability to

Term	Definition
	environmental hazards, heightened safety risks, lack of opportunity for public participation, or other factors. (USDOT Equity Action Plan)
Resilience	The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. (FHWA Order 5520)
Right-of-Way	The land (usually a strip) acquired for or devoted to transportation purposes.
Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence. (IPCC)
Runoff	The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow or ice melt that does not evaporate or refreeze, and is not transpired. (IPCC)
Sensitive Area	See Environmentally Sensitive Area.
Superelevation	The amount by which the outer edge of a curve on a trail, road, or railroad is banked above the inner edge.
Sustainability	A dynamic process that guarantees the persistence of natural and *human systems* in an equitable manner. (IPCC)
Trail	All types of trails for recreation and transportation, including shared use paths, paved and natural surface trails, and trails for both motorized and nonmotorized use. (Volpe Center White Paper)
Transit-Oriented Development (TOD)	An approach to urban development that maximizes the amount of residential, business and leisure space within walking distance of efficient public transport, so as to enhance mobility of the public, the viability of public transport and the value of urban land in mutually supporting ways. (IPCC)
Turnpike	A rock or log-edged section of trail, constructed in successive layers of large fitted rock, smaller rock, then mineral soil, to lift the tread out of a wet area. (PCTA)
Vehicle Miles of Travel (VMT)	The number of miles traveled by vehicles in a given area over a given time period.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (IPCC)

Acronym	Meaning
ADA	Americans with Disabilities Act
CO_2	Carbon dioxide
EJ	Environmental justice
EV	Electric vehicle
FHWA	Federal Highway Administration
GHG	Greenhouse gas
LCA	Life cycle analysis
LSEV	Low speed electric vehicle
OHV	Off-highway vehicle
NPS	United States National Park Service
TOD	Transit-oriented development
USFS	United States Forest Service
VMT	Vehicle miles travelled
VOC	Volatile organic compounds

10.Endnotes

[1] United States Environmental Protection Agency (EPA). Climate Change Indicators: Weather and Climate.
[2] United States Department of Transportation. (2022). Equity Action Plan.
[3] Gould, K. A., and Lewis, T. L. (2018). From Green Gentrification to Resilience Gentrification: An Example from Brooklyn. *City & Community*, *17*(1), 12–15. https://doi.org/10.1111/cico.12283
[4] Jelks, N. O., Jennings, V., and Rigolon, A. (2021). Green Gentrification and Health: A Scoping Review. *International Journal of Environmental Research and Public Health*, *18*(3), 907. MDPI AG. http://dx.doi.org/10.3390/ijerph18030907
[5] Thomas, Adelle, and R. Haynes. (2020). Black Lives Matter: the link between climate change and racial justice. *The Climate Analytics Blog*.
[6] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[7] Ibid.
[8] Though water trails are increasingly popular, they are not included in the scope of this guide.
[9] Fleischer, Jodie. K. Leslie, T. Gibson, S. Jones, J. Upton, K. Van Baalen, A. Kopicki. (2021). Historic Harriet Tubman Sites at Risk of Rising Seas on Eastern Shore. *NBC Washington and Climate Central*.
[10] O'Brien, John P. and Marston, Brad. (Mar. 1, 2022). A Changing PCT: Climate change is already altering the trail experience. Pacific Crest Trail Association.
[11] Grogan, Danielle Sarah, E. Burakowski, and A. Contosta. (2020). Snowmelt control on spring hydrology declines as the vernal window lengthens. *Environmental Research Letters*. DOI: 10.1088/1748-9326/abbd00
[12] Sukiennik, Greg. (Dec. 1, 2021). For cross-country skiing centers, a warmer, wetter Vermont means an uncertain future. *Bennington Banner*.
[13] National Park Service. Climate Change Response Program.
[14] National Park Service, Rivers Trails, and Conservation Assistance Program. Climate Change Adaptation.
[15] Northern Institute of Applied Climate Science. Adaptation Workbook: Adaptation Strategies and Approaches for Recreation.
[16] U.S. Forest Service. Climate Change Resource Center: Recreation.
[17] EPA. (2022). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. U.S. Environmental Protection Agency, EPA 430-R-22-003.
[18] West, A., K. Brookshire, J. Ciabotti, M. Bryson, and D. Gelinne. (2022). Advancing Trails to Support Multimodal Networks. Pedestrian and Bicycle Information Center.
[19] Prescient & Strategic Intelligence. 2022. Electric ATV and UTV Market.
[20] Milwaukee County Parks. Oak Leaf Trail.
[21] Rails to Trails Conservancy. Trail Building Toolbox.
[22] Hendra, E., Marquis, A., McSulla, J. (2022). 2022 Trail Sustainability Plan. Town of Sturbridge, MA.
[23] United States Census Bureau. Glossary: Census Tract.
[24] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[25] City of Watsonville, CA. (Oct. 2021). Climate Action and Adaptation Plan.
[26] Western Resource Advocaces. Protecting the West's Lands.
[27] Ridley, Skye. (Oct. 1995). Using Partnerships and Cooperation to Get What You Need for Trails. Keynote Address to the Arizona State Trails Conference.
[28] Land Trust of Northern Alabama.
[29] Marin County Bicycle Coalition. (Nov. 5, 2021). Updates on the Mill Valley-Sausalito Pathway and Bothin Marshv.
[30] Marin County Parks. (Nov. 3, 2022). Design for sea level rise resilience at Bothin Marsh. Evolving Shorelines.

[31] National Association of Clean Water Agencies. (2018). MS4 Stormwater Permitting Guide.
[32] National Association of Clean Water Agencies. (2018). MS4 Stormwater Permitting Guide.
1). https://ehp.niehs.nih.gov/doi/10.1289/EHP7495
[33] The Central Park Conservancy. (2018). Before Central Park: The Story of Seneca Village. https://www.centralparknyc.org/articles/seneca-village#:~:text=The%20creation%20of%20Central%20Park&text=This%20was%20a%20common%20practice,that%20their%20land%20was%20undervalued.)
[34] Rigolon, A., and Németh, J. (2020). Green gentrification or 'just green enough': Do park location, size and function affect whether a place gentrifies or not? *Urban Studies*, 57(2), 402–420. https://doi.org/10.1177/0042098019849380
[35] Martens, K., Golub, A., and Robinson, G. (2012). A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States. *Transportation Research Part A: Policy and Practice*, *46*(4), 684–695. https://doi.org/10.1016/J.TRA.2012.01.004
[36] Barajas, Jesus. (2021). Biking where Black: Connecting transportation planning and infrastructure to disproportionate policing. *Transportation Research Part D: Transport and Environment*, 99, DOI: 10.1016/j.trd.2021.103027.
[37] Lee, Richard. I. N. Sener and S. N. Jones. (2017). Understanding the role of equity in active transportation planning in the United States, *Transport Reviews*, 37:2, 211-226, DOI: 10.1080/01441647.2016.1239660.
[38] Kelly, C. M., Schootman, M., Baker, E. A., Barnidge, E. K., and Lemes, A. (2007). The association of sidewalk walkability and physical disorder with area-level race and poverty. *Journal of Epidemiology and Community Health*, 61(11), 978–983. DOI: 10.1136/jech.2006.054775
[39] Rajaee, M, et al. (2021). Socioeconomic and racial disparities of sidewalk quality in a traditional rust belt city. *SSM Popul Health*, 16:100975. DOI: 10.1016/j.ssmph.2021.100975.
[40] Islam, N.S. and Winkel, J. (2017). Climate Change and Social Inequality. United National Department of Economic and Social Affairs.
[41] Minneapolis Park and Recreation Board. (2017). Criteria Based System for MPRB Regional Park and Trail Capital Project Scheduling.
[42] Oswald Beiler, M. R. and Miller, G. (2019). Sea-Level Rise Vulnerability Assessment of Bicycle and Trail Networks. *Journal of Transportation and Engineering: Part A Systems*. 145 (2). https://doi.org/10.1061/JTEPBS.0000214
[43] National Park Service. (2021). *Wildfire Destruction along the Pony Express NHT*. Pony Express National Historic Trail.
[44] Bellisle, Martha. (Jan. 18, 2022). Climate change makes the future of Nordic skiing uncertain. *AP News*.
[45] Larkin, Zacc. (Mar. 14, 2020). The Impact of Climate Change on Long Trails in the American West. *The Trek*.
[46] The White House. (Sept. 1, 2022). The Rising Costs of Extreme Weather Events.
[47] Bowman, J. and M. Orlousky. (2021). The A.T. and Climate Change: Reviewing the Basics. Appalachian Trail Conservancy.
[48] Binder, L. W., Morgan, H., and Siemann, D. (2017). Preparing Washington State Parks for Climate Impacts: A Climate Change Vulnerability Assessment for Washington State Parks. Washington State Parks and Recreation Commission and the University of Washington Climate Impacts Group.
[49] Furniss, M. J. and Howe, C. (2016, September). Regional-scale climate change vulnerability assessment for infrastructure in the national forests and grasslands of the Rocky Mountain Region. U.S. Forest Service.
[50] Tomczyk, A. M., White, P. C. L., and Ewetowski, M. W. (2016). Effects of extreme natural events on the provision of ecosystem services in a mountain environment: The importance of trail design in delivering system resilience and ecosystem service co-benefits. *Journal of Environmental Management, 166*, 156-167. https://doi.org/10.1016/j.jenvman.2015.10.016
[51] U.S. Forest Service and U.S. Department of Transportation Volpe Center. (2018). Addressing climate change impacts on U.S. Forest Service transportation assets.
[52] U.S. Department of Transportation Federal Highway Administration. (2016). Highways in the River Environment – Floodplains, Extreme Events, Risk, and Resilience. Hydraulic Engineering Circular No. 17, 2nd Edition
[53] Aubert, A. (2018). Saturated soil forces Montgomery County to close trails, sports fields. ABC7 News.

[54] U.S. Department of Transportation Federal Highway Administration. (2020). Highways in the Coastal Environment. Hydraulic Engineering Circular Number 25, Third Edition.
[55] National Park Service. Flooding Impacts in National Capital Area Parks.
[56] Fountain, H. (May 21, 2020). 'Expect More': Climate Change Raises Risk of Dam Failures. *New York Times*.
[57] Federal Energy Regulatory Commission. (2017). Hydropower Primer. P.1. Staff Report of the Office of Energy Projects, Federal Energy Regulatory Commission.
[58] Federal Energy Regulatory Commission, Division of Project Compliance and Administration. (1996). Recreation Development at Licensed Hydropower Projects.
[59] National Park Service. (2022). West Lake Trail has Reopened After Completed Repairs from Hurricane Damage.
[60] Hoover, K., and Hanson, L. A. (July 15, 2021). Wildfire statistics. Congressional Research Service.
[61] U.S. Environmental Protection Agency. (July 2022). Climate Change Indicators: Wildfires.
[62] Moore, A. (July 26, 2021). Ask an Expert: How Dangerous is Wildfire Smoke?. NC State University, College of Natural Resources News.
[63] KPIC. (Aug. 19, 2021). Wildfire Damage closes McKenzie River Trail from Blue Pool trailhead south to Deer Creek. Retrieved October 11, 2022.
[64] Miller, M. (Apr. 6, 2021). Closures, Floods, Erosion: The Wildfire Effect on Trails and Why it Probably Won't get Better Soon. *Singletracks*.
[65] U.S. Forest Service and U.S. Department of Transportation Volpe Center. (2018). Addressing climate change impacts on U.S. Forest Service transportation assets.
[66] Chiu, A. (July 20, 2022). With extreme heat, We can't build roads and railways as We used to. *Washington Post*.
[67] Koller, M., K. Garibay Garcia, S, Kime, W. Geiken, and S. Fearer. (2022). Hot Summer: The Impact of a Warming Climate of Climbing and Trail Sports. Protect Our Winters.
[68] Lanza, K., et al. (2022). Climate Change and Physical Activity: Ambient Temperature and Urban Trail Use in Texas. *Int J Biometeorol*. 2022; 66(8): 1575. https://doi.org/10.1007/s00484-022-02302-5
[69] Ibid.
[70] Bowman, J, M. Orlousky. (2021). The A.T. and Climate Change: Reviewing the Basics. Appalachian Trail Conservancy.
[71] Flink, C. Benefits of Greenways. Greenways, Inc.
[72] Ding, J. (Feb. 22, 2018). Linking Soil Moisture Variation and Abundance of Plants to Geomorphic Processes: A Generalized Model for Erosion-Uplifting Landscapes. JGR Biogeosciences, February 22, 2018.
[73] Gerety, Rowan Moore (Aug. 31, 2022). Heat, Water, Fire: How Climate Change Is Transforming the Pacific Crest Trail. *The New York Times*.
[74] Koller, M., K. Garibay Garcia, S, Kime, W. Geiken, and S. Fearer. (2022). Hot Summer: The Impact of a Warming Climate of Climbing and Trail Sports. Protect Our Winters.
[75] U.S. Forest Service and U.S. Department of Transportation Volpe Center. (2018). Addressing climate change impacts on U.S. Forest Service transportation assets.
[76] Binder, L. W., Morgan, H., and Siemann, D. (2017). Preparing Washington State Parks for Climate Impacts: A Climate Change Vulnerability Assessment for Washington State Parks. Washington State Parks and Recreation Commission and the University of Washington Climate Impacts Group.
[77] Jacobs, J.M., Culp, M., Cattaneo, L., Chinowsky, P., Choate, A., DesRoches, S., Douglass, S., and Miller, R. (2018). Transportation. In Reidmiller, D.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Lewis, K.L.M., Maycock, T.K., and Stewart, B.C. (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (pp. 479–511). U.S. Global Change Research Program, Washington, DC, USA.
[78] Ibid.
[79] Ibid.
[80] Akbari, H., D. Kurn, et al. (1997). Peak power and cooling energy savings of shade trees. *Energy and Buildings* 25:139–148.
[81] USDA Forest Service. Bark Beetle Management: Impact on Recreation.

[82] Bouchard, C., Dibernardo, A., Koffi, J., Wood, H., Leighton, P.A., Lindsay, L.R. (Apr. 4, 2019). N Increased Risk of Tick-borne Diseases with Climate and Environmental Changes. *Canada Communicable Disease Report*, 45(4), 83-89.
[83] Ryan, S.J., Carlson, C.J., Mordecai, E.A., Johnson, L.R. (2019). Global Expansion and Redistribution of *Aedes*-borne Virus Transmission Risk with Climate Change. *PLoS Neglected Tropical Diseases*.
[84] Michigan Department of Agriculture and Rural Development. West Nile Virus and Eastern Equine Encephalitis in Horses.
[85] O'Toole, et al. (2019). Climate Change Adaptation Strategies and Approaches for Outdoor Recreation. *Sustainability*. 11.
[86] Ibid.
[87] McCusker, K. and Hess, H. (Feb. 8, 2018). America's Shrinking Ski Season. *Climate Impact Lab*.
[88] University of New Hampshire (Nov. 2, 2020). Longer Mud Season, No Snow could alter Northeast U.S. rivers by 2100. *ScienceDaily*.
[89] Askew, A.E. and Bowker, J.M. (2018). Impacts of climate change on outdoor recreation participation: Outlook to 2060. *Journal of Park and Recreation Administration*. 36(2): 97-120. 24 p. https://doi.org/10.18666/JPRA-2018-V36-I2-8316.
[90] Albano, C.M., Angelo, C.L., Strauch, R.L., and Thurman, L.L. (2013). Potential Effects of Warming Climate on Visitor Use in Three Alaskan National Parks. *Park Science,* 30(1), 37-44.
[91] State of Alaska Department of Natural Resources Geological & Geophysical Surveys. Geologic Hazards.
[92] U.S. Department of Transportation Federal Highway Administration. (2017). Synthesis of Approaches for Addressing Resilience in Project Development.
[93] National Aeronautics and Space Administration (NASA). Landslide Team Projects.
[94] Palmer, Jane. (Nov. 23, 2020). A Slippery Slope: Could Climate Change Lead to More Landslides? *Eos*, 101. American Geophysical Union (AGU).
[95] Palmer, Jane. (Nov. 23, 2020). A Slippery Slope: Could Climate Change Lead to More Landslides? *Eos*, 101. American Geophysical Union (AGU).
[96] Luckman, B.H., (2013). Processes, Transport, Deposition, and Landforms: Rockfall. *Treatise on Geomorphology*. V7, 174-182. https://doi.org/10.1016/B978-0-12-374739-6.00162-7
[97] Palmer, Jane. (Nov. 23, 2020). A Slippery Slope: Could Climate Change Lead to More Landslides? *Eos*, 101. American Geophysical Union (AGU).
[98] Palmer, Jane. (Nov. 23, 2020). A Slippery Slope: Could Climate Change Lead to More Landslides? *Eos*, 101. American Geophysical Union (AGU).
[99] Palmer, Jane. (Nov. 23, 2020). A Slippery Slope: Could Climate Change Lead to More Landslides? *Eos*, 101. American Geophysical Union (AGU).
[100] Cunneen, J. (2022). 5 Ways Climate Change Increases the Threat of Tsunamis, From Collapsing Ice Shelves to Sea Level Rise. *The Conversation*.
[101] Kornei, Katherine. (2022). Rising Seas Boost Tsunami Impacts on Distant Shorelines. *Eos*.
[102] Berwyn, B. (2019). Avalanches Menace Colorado as Climate Change Raises the Risk. *Inside Climate News*.
[103] Jacobs, J.M., Culp, M., Cattaneo, L., Chinowsky, P., Choate, A., DesRoches, S., Douglass, S., and Miller, R. (2018). Transportation. In Reidmiller, D.R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Lewis, K.L.M., Maycock, T.K., and Stewart, B.C. (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (pp. 479–511). U.S. Global Change Research Program, Washington, DC, USA.
[104] Climate Reality Project. (2020). How is the Climate Crisis Affecting Alaska?
[105] State of Hawaii. Climate Change Impacts in Hawai'i. *State of Hawaii Climate Change Portal.*
[106] U.S. Department of Transportation Federal Highway Administration. (2018). Vulnerability Assessment and Adaptation Framework, 3rd Edition. Office of Planning, Environment, and Realty.
[107] Scott, J.H., Thompson, M.P., and Calkin, D.E. (2013). A Wildfire Risk Assessment Framework for Land and Resource Management. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-315.
[108] Granger Morgan, M. and Henrion, M. (1990). Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge University Press. Cambridge, 332 p.

[109] Scott, J.H., Thompson, M.P., and Calkin, D.E. (2013). A Wildfire Risk Assessment Framework for Land and Resource Management. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-315.
[110] Mariposa County. (2021). Mariposa County Recreation and Resiliency Master Plan.
[111]Northern Institute of Applied Climate Science. Explore Climate Impacts. Northern Institute of Applied Climate Science Adaptation Workbook Tool.
[112] United States Global Change Research Program. The Climate Explorer. Version 3.1. U.S. Climate Resilience Toolkit.
[113] National Oceanic and Atmospheric Administration. Sea Level Rise – Map Viewer.
[114] East Bay Regional Park District. (2022). SF Bay Trail Risk Assessment and Adaptation Prioritization Plan.
[115] Federal Emergency Management Association (FEMA). National Risk Index.
[116] Patnaik, A., Son, J., Feng, A. and Ade, C. (2020). Racial Disparities and Climate Change. Princeton Student Climate Initiative.
[117] Estes, B. L., E. E. Knapp, C. N. Skinner, J. D. Miller, and H. K. Preisler. (2017). Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. *Ecosphere* 8(5):e01794. 10.1002/ecs2.1794.
[118] Favro, John. Sustainable Trails: Doing it Right the First Time. American Trails.
[119] Vermont Green Infrastructure Initiative. Low Impact Development (LID) Fact Sheet, 2021. Watershed Management Division, Vermont Department of Environmental Conservation.
[120] Green City Partnerships. (2019). Best Management Practices for Crime Prevention Through Environmental Design in Natural Landscapes.
[121] Refer to the National Institute of Building Science's Design Guidelines for the Visual Environment and Planning and Montgomery County, Maryland's Designing Streets to be Safer and More Accessible for People with Vision Disabilities.
[122] Weber, J. and Sultana, S. Why Do So Few Minority People Visit National Parks? Visitation and the Accessibility of "America's Best Idea." *Annals of the Association of American Geographers*, Vol. 103(3), pp. 437–464. https://doi.org/10.1080/00045608.2012.689240
[123] National Park Service. (2012). Cuyahoga Valley National Park Sustainable Trail Guidelines.
[124] International Mountain Bicycling Association. (2004). Trail Solutions: IMBA's Guide to Building Sweet Singletrack.
[125] Bruggemann, J. and B. Giezentanner. Sustainable Trails: Pathways to Nature.
[126] U.S. Access Board. Public Right-of-Way Accessibility Guidelines.
[127] U.S. Access Board. Accessibility Standards for Federal Outdoor Developed Areas.
[128] Pisgah Conservancy. Trail Academy: Drainage.
[129] Bureau of Land Management (BLM), Kremmling Field Office. Criteria for Trail Placement, Control Points, and Layout. American Trails.
[130] Trailism. Soil Compaction.
[131] Connecticut Department of Energy and Environmental Protection. Benefits of Trails and Greenways.
[132] Trani, M.T., and Manley, P. (January 4, 2012). Biodiversity and Climate Change. U.S. Department of Agriculture, Forest Service, Climate Change Resource Center.
[133] Livingston, M. and Myers, D. (2010). Contributions of watercourse-associated greenways to green infrastructure: a comparison between two case studies in Arizona and Maryland, USA. *Proceedings of the Fabos Conference on Landscape and Greenway Planning, 3*(1), 161-168.
[134] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[135] Infrastructure Investment and Jobs Act, H.R. 3684, 117th Cong. (2021).
[136] National Association of City Transportation Officials (NACTO). Urban Street Stormwater Guide: Performance Measures for Ecology.
[137] EPA. Benefits of Green Infrastructure.
[138] Metropolitan Area Planning Council (MAPC). Fact Sheet: Low Impact Site Design.

[139] Arundel Rivers Federation. (Apr. 22, 2022). Caffrey Run Stream Restoration Project.
[140] Wissahickon Trails. (Sept. 1, 2022). Major In-Stream Restoration Project Completed at Wissahickon Creek Headwaters.
[141] EPA. (Sept. 2014). Genetta Park Stream Restoration Project.
[142] Nahlik, A., and M. Fennessy. (2016). Carbon storage in U.S. wetlands. *Nat Commun 7*, 13835. https://doi.org/10.1038/ncomms13835
[143] Dass, P.,Houlton, B, Wang, Y., and Warlind, D. (2018). Grasslands may be more reliable carbon sinks than forests in California. *Environmental Research Letters*, 13. 074027. 10.1088/1748-9326/aacb39
[144] National Recreation and Park Association. (N.D.). Resource Guide for Planning, Designing, and Implementing Green Infrastructure in Parks.
[145] East Bay Regional Park District. (2021). Bay Trail Risk Assessment and Adaptation Prioritization Plan. Appendix 3: Broad Guidance for Natural Systems and Bay Trail Adaptation to Sea-Level Rise.
[146] FHWA (FHWA-HIF-14-012). Pavement Sustainability Tech Brief.
[147] EPA. (Sept. 2022). Heat Islands.
[148] Ibid.
[149] Djekic, J., Djukic, A., Vukmirovic, M., Djekic, P., and Brankovic, M.D. (20180. Thermal comfort of pedestrian spaces and the influence of pavement materials on warming up during summer. *Energy and Buildings*, 159, 474-485.
[150] US Department of Transportation Federal Highway Administration. (2015). Climate Change Adaptations for Pavements.
[151] Gong, Z., Zhang, L., Wu, J., Xiu, Z., Wang, L., and Miao, Y. (2022). Review of regulation techniques of asphalt pavement high temperature for climate change adaptation. *Journal of Infrastructure Preservation and Resilience,* 3(9).
[152] Wang, J., Zhang, S., Guo, D., Xu, C., and Zhang, K. (2018). Study on Cooling Effect and Pavement Performance of Thermal-Resistant Asphalt Mixture. *Advances in Materials Science and Engineering.*
[153] Chen, J., Chu, R., Wang, H., Zhang, L., Chen, X., and Du, Y. (2019). Alleviating urban heat island effect using high-conductivity permeable concrete pavement. *Journal of Cleaner Production*, 237.
[154] Colorado Pavement Solutions. What Temperature Should Asphalt be Laid?
[155] Ibid.
[156] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[157] Climate Signals. Atmospheric Moisture Increase.
[158] Marion, J. (Feb. 2006). Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area. USGS Patuxent Wildlife Research Center, Cooperative Park Studies Unit. Virginia Tech Department of Forestry.
[159] Tony Boone. The Art of Building Crushed Stone Trails. *American Trails*.
[160] American Association of State Highway and Transportation Officials (AASHTO). (2012). Guide for the Development of Bicycle Facilities. Fourth Edition.
[161] Minnesota Pollution Control Agency. (July 2022). Erosion Preventions Practices. Minnesota Stormwater Manual.
[162] O'Neill, M. (July 2018). Designers vs. Climate Change. *Architectural Digest Pro*.
[163] Lim, X. (Dec. 31, 2019). The super-cool materials that send heat to space. *Nature*.
[164] DeFore, T. (Aug. 3, 2017). When Temperatures Rise, Keep Dogs Off the Trail. San Diego County News Center.
[165] USDA Forest Service. Increase Resilience of Stream Crossings, Culverts, and Bridges to Higher Peak Flows. Climate Change Resource Center.
[166] USDA Forest Service. (Mar. 2020). Sustainable Trail Bridge Design.
[167] Ibid.
[168] Ibid.
[169] Groenier, J. and Gubernick, R. (Jun. 2010). Locating Your Trail Bridges for Longevity. USDA Forest Service, Technology and Development Program.
[170] Debonis, M. (2019). Climate Change: Trail Management Strategies. Green Mountain Club.

[171] Dover, H. (June 12, 2015). Long Trail Footbridge (Finally) Opens to Hikers. *Burlington Free Press*.
[172] USDA Forest Service. (Mar. 2020). Sustainable Trail Bridge Design.
[173] Groenier, J. and Gubernick, R. (Jun. 2010). Locating Your Trail Bridges for Longevity. USDA Forest Service, Technology and Development Program.
[174] USDA Forest Service. (Mar. 2020). Sustainable Trail Bridge Design.
[175] California Department of Parks and Recreation. (2019). Trails Handbook: Ch. 16 Trail Bridges.
[176] USDA Forest Service. (Mar. 2020). Sustainable Trail Bridge Design.
[177] Ibid.
[178] California Department of Parks and Recreation. (2019). Trails Handbook: Ch. 15 Timber Planking, Puncheons, and Boardwalks.
[179] Ibid.
[180] Ibid.
[181] California Department of Parks and Recreation. (2019). Trails Handbook: Ch. 13: Retaining Structures.
[182] O'Toole, D., Brandt, L.A., Janowiak, M.K., Schmitt, K.M., Shannon, P.D., Leopold, P.R., Handler, S.D., Ontl, T.A., and Swanston, C.W. (2019). Climate Change Adaptation Strategies and Approaches for Outdoor Recreation. *Sustainability*, 11(7030).
[183] NYC Office of Environmental Remediation. Clean Soil Bank.
[184] Brzozowki, C. (Nov. 28, 2019). The Future is 2020. *Stormwater*.
[185] Stenlund, D. (Apr. 14, 2021). Erosion Prevention Practices for Winter Construction. International Erosion Control Association.
[186] Contosta AR, Adolph A, Burchsted D, Burakowski E, Green M, Guerra D, Albert M, Dibb J, Martin M, McDowell WH, Routhier M, Wake C, Whitaker R, Wollheim W. (Apr. 2017). A Longer Vernal Window: The Role of Winter Coldness and Snowpack in Driving Spring Transitions and Lags. Glob Chang Biol, 23(4), 1610-1625.
[187] Ferrenberg, S., Reed, S.C., Belnap, J. (Sept. 14, 2015). Climate change and physical disturbance cause similar community shift in biological soil crusts. *Proceedings of the National Academy of Sciences,* 112(39), 12116–12121.
[188] Faist, A., Tucker, C., C. Reed, S.C., et al. Operational Manual for Biocrust Restoration in Drylands. Canyonlands Research Center.
[189] Arizona Department of Environmental Quality.Fugitive Dust Prevention Tips.
[190] USDA Forest Service. (Aug. 2012). Non-native Invasive Species Best Management Practices.
[191] Paradise Multiuse Paths. (2022, August 08). Paradise, California, US.
[192] American Association of State Highway and Transportation Officials (AASHTO). (2012). Guide for the Development of Bicycle Facilities. Fourth Edition.
[193] Swindlehurst, J. (2006). Greenways and Trails Design Standards. Champaign County.
[194] Hawaii Department of Transportation (2013). Hawaii Pedestrian Toolbox.
[195] American Association of State Highway and Transportation Officials (AASHTO). (2012). Guide for the Development of Bicycle Facilities. Fourth Edition.
[196] Washington Department of Transportation (2020). Design Manual, Chapter 1515: Shared-Use Paths.
[197] Seifert, C. and Lind, S. (2018). Texas Bicycle Tourism Trails Study Final Report. Texas Department of Transportation.
[198] Hawaii Department of Transportation (2013). Hawaii Pedestrian Toolbox.
[199] American Association of State Highway and Transportation Officials (AASHTO). (2012). Guide for the Development of Bicycle Facilities. Fourth Edition.
[200] FHWA Recreational Trails Program. Bollards, Gates, and Other Barriers.
[201] National Park Service. (Oct. 2022). *National Scenic Trails*.
[202] FEMA. (2019). National Response Framework. Homeland Security.
[203] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.

[204] FEMA. (Nov., 2019). Community Lifelines. Retrieved from FEMA: https://www.fema.gov/fact-sheet/community-lifeline
[205] Government Accountability Office. (2010). All-Terrain Vehicles: How They Are Used, Crashes, and Sales of Adult-Sized Vehicles for Children's Use.
[206] Ciesa, M., Grigolato, S., and Cavalli, R. (2014). Analysis on vehicle and walking speeds of search and rescue ground crews in mountainous areas. *Journal of Outdoor Recreation and Tourism, 5–6,* 48-57. https://doi.org/10.1016/j.jort.2014.03.004
[207] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[208] Ercolano, J. (2008). Pedestrian disaster preparedness and emergency management of mass evacuations on foot: State-of-the-art and best practices. *Journal of Applied Security Research, 3*(3-4), 389-405. https://doi.org/10.1080/19361610801981068
[209] Bolton, Patricia. (2007). Managing Pedestrians during Evacuations of Metropolitan Areas. Battelle Human Factors Transportation Center. FHWA Report No. FHWA-HOP-07-066.
[210] NYSDOT Office of Integrated Modal Service. (February 13, 2008). Pedestrian Disaster Preparedness and Emergency Management of Mass Evacuations on Foot. Presentation to the Queens Hospital Center Emergency Management Committee's Conference on Emergency Preparedness.
[211] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[212] Ibid.
[213] Ibid.
[214] Graehl, N. (2011). Pedestrian Evacuation Time Analysis for Crescent City, CA. Del Norte Local Transportation Commission.
[215] Hunter-Zaworski, K. (2011). Tsunami Evacuation Plan. Hatfield Marine Science Center, Newport, OR.
[216] Wood, N., Jones, J., Peters, J., and Richards, K. (2018). Pedestrian evacuation modeling to reduce vehicle use for distant tsunami evacuations in Hawai'i. *International Journal of Disaster Risk Reduction, 28*, 271-283. https://doi.org/10.1016/j.ijdrr.2018.03.009
[217] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[218] TransMountain. (Oct. 28, 2022). Emergency Response Plans.
[219] National Park Service. National Park Service Careers: Visitor and Resource Protection. Retrieved October 31, 2022.
[220] Yang, K. (2020, September 23). Loop Trails Bring Safer, more Enjoyable Hiking. New York- New Jersey Trail Conference.
[221] Dufourd, D. (2015). Great trails: Providing quality OHV trails and experiences. National Off-Highway Vehicle Conservation Council.
[222] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[223] Raincrow. (2022). Visualizing Appalachian Trail Usage. Where Are The Hikers.
[224] Mace, Sharon, et. al. (2018). Planning considerations for persons with access and functional needs in a disaster-Part 2: evacuation and sheltering. *Am. J. Disaster Med*., 13 (3) (2018), pp. 195-206.
[225] Renne, John, and E. Mayorga. (2022). What has America learned Since Hurricane Katrina? Evaluating evacuation plans for carless and vulnerable populations in 50 large cities across the United States. *International Journal of Disaster Risk Reduction*. Volume 80.
[226] Tomczyk, A. M., White, P. C. L., and Ewetowski, M. W. (2016). Effects of extreme natural events on the provision of ecosystem services in a mountain environment: The importance of trail design in delivering system resilience and ecosystem service co-benefits. *Journal of Environmental Management, 166*, 156-167. https://doi.org/10.1016/j.jenvman.2015.10.016
[227] Binder, L. W., Morgan, H., and Siemann, D. (2017). Preparing Washington State Parks for Climate Impacts: A Climate Change Vulnerability Assessment for Washington State Parks. Washington State Parks and Recreation Commission and the University of Washington Climate Impacts Group.

[228] B.A. Blackwell & Associates Ltd. (2019). Community Wildfire Protection Plan Update. District of North Vancouver.
[229] Cathro Consulting Ltd. and B.A. Blackwell & Associates Ltd. (2016). Area I Community Wildfire Protection Plan Update. Regional District of Central Kootenay.
[230] Bennett, Max, et. al. (2017). Reducing Fire Risk on Your Forest Property. Oregon State University Extension.
[231] Binder, L. W., Morgan, H., and Siemann, D. (2017). Preparing Washington State Parks for Climate Impacts: A Climate Change Vulnerability Assessment for Washington State Parks. Washington State Parks and Recreation Commission and the University of Washington Climate Impacts Group.
[232] IVUMC (Interagency Visitor Use Management Council). (2019). Visitor Capacity Guidebook: Managing the Amounts and Types of Visitor Use to Achieve Desired Conditions. Lakewood, CO.
[233] City of Grand Forks and City of East Grand Forks. (2022, August). Greater Grand Forks Greenway.
[234] Ibid.
[235] Grogan. D.S. et al. (Nov. 30, 2020). Snowmelt control on spring hydrology declines as the vernal window lengthens. *Environmental Research Letters*, 15(11).
[236] For an example of effective communication with trail users around not using muddy trails, see this post from the Mitchell Lake Audobon Center.
[237] National Fire Protection Association. Safety with E-Bikes and E-Scooters.
[238] Davis, S., Z. McAlear, A. Plovnick, and A. Wilkerson. (2023). Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response. U.S. Department of Transportation, Volpe National Transportation Systems Center.
[239] Vermont Agency of Natural Resources, Department of Forests – Parks and Recreation. (2022). Managing Forest Carbon.
[240] Connecticut Department of Energy and Environmental Protection. (April 2022). Why Manage Forests in the Face of Climate Change.
[241] Trani, M.T., and Manley, P. (January 4, 2012). Biodiversity and Climate Change. U.S. Department of Agriculture, Forest Service, Climate Change Resource Center.
[242] USFS. (1995). Landscape Aesthetics: A Handbook for Scenery Management. Agriculture Handbook Number 701.
[243] Alta Planning + Design. Envision Bear Creek . Jackson County.
[244] Bear Creek Greenway Map and Brochure. Jackson County Parks.
[245] Max, B., Fitzgerald, S.A, Leavell, D., Berger, C. (Oct. 2018). Fire FAQs—Have the size and severity of forest wildfires increased in Oregon and across the West? Oregon State Extension Service.
[246] City of Pheonix, Oregon. Bear Creek Greenway Management Plan 2017-2022.
[247] Aldous, V. (Apr. 24, 2021). County Tackling Flammable Vegetation Along Bear Creek Greenway. *Mail Tribune*.
[248] King, J. (May 31, 2022). Medford Police Watching Bear Creek Greenway Closely as 2022 Fire Season Begins. *KOBI TV 5 Medford*.
[249] Low-Speed Electric Vehicles, which include golf carts, are regulated to a maximum speed of 25 mph.
[250] Human Impact Partners. (Dec. 2015). CV/Link: Connecting the Coachella Valley, Health Impact Assessment.
[251] Ibid.
[252] Downs, M. (2009). A Link to the Future. *Palm Springs Life*.
[253] The Caltrans ATP consolidates Federal and State transportation programs, including the Transportation Alternatives Program, Bicycle Transportation Account, and Safe Routes to School.
[254] Husing, J. (2012). Summary of the Economic Impact of the Parkway. *Friends of CV Link*.
[255] City of Grand Forks and City of East Grand Forks. (2001). Greenway Plan.
[256] Ibid.
[257] Yang, K. (Sept. 23, 2020). Loop Trails Bring Safer, more Enjoyable Hiking to NJ Parks. New York-New Jersey Trail Conference.
[258] McKay, J. (Nov. 18, 2020). After Campfire, Paradise, CA, Works on Long-Term Recovery. *Government Technology*.
[259] Reyes-Velarde, A. (Jan. 11, 2019). California's Camp fire was the costliest global disaster last year, insurance report shows. *Los Angeles Times*.
[260] The Caltrans ATP is funded in part through Federal Transportation Alternatives and Recreational Trails Program funds and through State funds.
[261]Town of Paradise. (June 2019). Long-Term Community Recovery Plan.