

Trails and Resilience: Review of the Role of Trails in Climate Resilience and Emergency Response

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Image source: Volpe Center



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1. Introduction

Trails are often overlooked as elements of essential infrastructure for a resilient transportation system.¹ In emergencies where other transportation facilities are shut down or inaccessible, people may use trails to get where they need to go. Trails can also provide critical access in emergencies for people without access to a car or transit service. Trails for both motorized and nonmotorized use can provide access for search and rescue, fighting wildfires, or other emergency response operations. The increase in trail use during the COVID-19 pandemic has also demonstrated the importance of trails for improving health and wellbeing during public health emergencies.

At the same time, many trails are located along rivers, in coastal areas, in forests, or along slopes, and are therefore particularly vulnerable to impacts from climate change and extreme weather, such as floods, wildfires, and erosion. To better respond to such impacts, trails can be designed, planned, and maintained to be resilient to natural hazards. Designing trails to be resilient to climate change has many benefits, including lower maintenance and repair costs and better access during emergencies and after severe weather. Trails can also enhance the resilience of surrounding communities by providing ecosystem services (e.g., stormwater management). Many trail designers note that well-designed, sustainably built trails are also more accessible for people with disabilities.^{2,3}

The [Infrastructure Investment and Jobs Act \(IIJA\) \(Public Law 117-58, or Bipartisan Infrastructure Law\)](#) provides considerable resources through programs and funding sources to improve transportation infrastructure resilience, including investments to improve trails:

- The [Transportation Alternatives \(TA\) Set-Aside](#) from the Surface Transportation Block Grant (STBG) Program provides funding for a variety of smaller-scale transportation projects including recreational trails. The [March 2022 Implementation](#)

Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions ([FHWA Order 5520](#)). The Bipartisan Infrastructure Law (2021) codified the definition of resilience in [23 U.S.C. 101\(a\)\(24\)](#): “The term ‘resilience’, with respect to a project, means a project with the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability—
(A)(i) to resist hazards or withstand impacts from weather events and natural disasters; or
(ii) to reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster on a project; and
(B) to have the absorptive capacity, adaptive capacity, and recoverability to decrease project vulnerability to weather events or other natural disasters.”

¹ This white paper uses the term *trail* to refer to all types of trails, including shared use paths for transportation use, paved and natural surface trails, and trails for both motorized and nonmotorized use. The white paper does not cover water-based trails.

² In this white paper, *accessible* and *accessibility* are used both in a general sense (as in access for pedestrians, bicyclists, equestrians, off-highway vehicle users, or any other trail users) and to refer to pedestrian accessibility for people with disabilities.

³ American Trails Resource Library

[Guidance](#) clarifies that climate and extreme weather resilience elements that make transportation systems more reliable are eligible for TA Set-Aside funding.

- The [Recreational Trails Program](#) (RTP) provides funding for recreational trails and trail-related facilities for both nonmotorized and motorized recreational trail uses (see box on the following page).
- The [Carbon Reduction Program](#) aims to reduce transportation emissions through the development of State carbon reduction strategies and by funding projects designed to reduce transportation emissions. Construction, planning, and design of on-road and off-road trail facilities for pedestrians, bicyclists, and other nonmotorized forms of transportation are eligible activities under this program.
- The [Safe Streets and Roads for All \(SS4A\) Grant Program](#) funds regional, local, and Tribal initiatives through grants to prevent roadway deaths and serious injuries. The [Eligible and Ineligible Implementation Grant Projects factsheet](#) explains that projects building offroad bicyclist and pedestrian facilities, including trails, are eligible if the separation of mode users from the existing road network is identified in an existing, eligible Action Plan as a safety need.
- The [Reconnecting Communities Pilot Program \(RCP\)](#) supports planning, capital construction, and technical assistance to equitably and safely restore community connectivity through the removal, retrofit, mitigation, or replacement of eligible transportation infrastructure facilities that create barriers to mobility, access, or economic development. 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.
- The [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.
- Other programs that may fund trails include the [National Scenic Byways Program](#), which supports programs along designated scenic byways, and the Active Transportation Infrastructure Investment Program, which supports active transportation networks and active transportation spines, including trails. These programs are subject to annual appropriations.

FHWA published a [funding opportunity matrix](#) identifying potential eligibility for pedestrian and bicycle activities and projects under numerous U.S. Department of Transportation surface transportation funding programs. The resource identifies eligibilities for the following trail-relevant projects: recreational and transportation trails, trail bridges, trail construction and maintenance equipment, trail/highway crossings and intersections, and trail facilities/amenities.

Recreational Trails Program

The FHWA [Recreational Trails Program](#) (RTP) provides funding to States to develop and maintain recreational trails and trail-related facilities for both nonmotorized and motorized recreational trail uses. Each State manages its own program.

This white paper considers all trail types eligible under the RTP, including trails for the following nonmotorized and motorized trail activities:

- Pedestrian activities, including wheelchair use;
- Skating or skateboarding;
- Equestrian activities, including carriage driving;
- Nonmotorized snow trail activities, including skiing;
- Bicycling or use of other human powered vehicles;
- Aquatic or water activities; and
- Motorized vehicular activities, including all-terrain vehicle riding, motorcycling, snowmobiling, use of off-road light trucks, or use of other off-road motorized vehicles.

However, despite new and expanded trails funding opportunities, existing resources for practitioners on climate resilience and emergency response typically do not specifically address the trail context. Trail projects differ in important ways from roadway projects, including different design guidelines, materials, maintenance practices, and user groups. In addition, trails typically have lower project budgets and are often maintained by nonprofits and volunteers, making in-depth climate vulnerability analyses infeasible in many cases.

Similarly, existing resources for trail planners, designers, and managers do not always address climate change or emergency response. For example, trail design guidelines may have information about context sensitive trail design, but not about how climate conditions are likely to change over the decades that the trail will be in use, or how to adapt maintenance practices for more severe weather.

To address this gap, the Volpe National Transportation Systems Center (Volpe Center), in support of the Federal Highway Administration's (FHWA) Recreational Trails Program, conducted a literature review on resilience and emergency response on trails. The project team also conducted eight interviews with national trail organizations to inform the development of this report. The Appendix provides the interview questions and list of interviewees.

This research seeks to answer two key questions, illustrated by the green overlaps in Figure 1:

- To what extent do existing resources for trail planners, designers, and managers address climate change and emergency response?
- To what extent does transportation-sector climate resilience and emergency response research address the trail context?

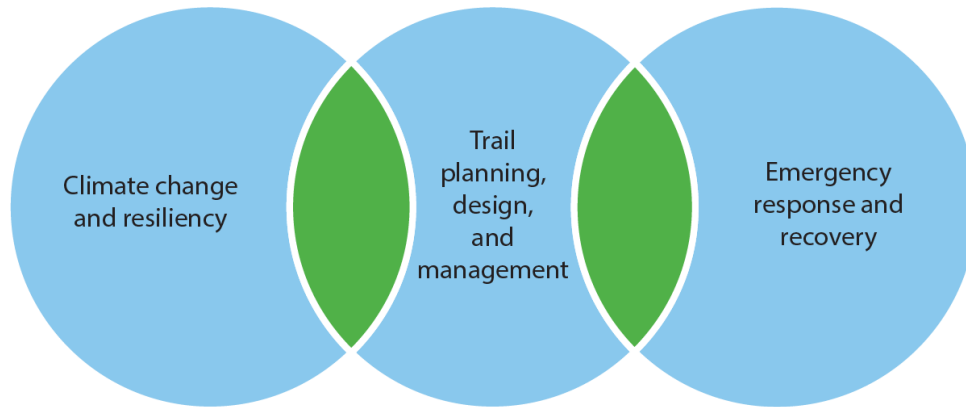


Figure 1. Research Focus

This white paper summarizes these research findings. Based on the literature review and interviews, the Volpe Center also identified areas for future research to advance trail resilience.

This white paper includes the following sections:

- **Vulnerability and Resilience to Natural Hazards:** This section explores research on the vulnerability of trails to natural hazards, designing trails to be resilient to climate change and related extreme weather events, and ways in which trails can influence regional resilience. Further research could investigate techniques to create resilient trails, and strategies to incorporate trails into larger resilience-focused efforts.
- **Disaster and Emergency Response:** This topic investigates how trails can serve as evacuation routes, trail design for emergency vehicle access, and the relationship between trails and search and rescue. Further research could look at how trails can serve as redundant transportation infrastructure to enable more effective emergency and disaster response and recovery.
- **Use of Trails During Public Health Emergencies:** This section explores initial outcomes from trail use during the COVID-19 pandemic in terms of trail usage, management strategies, and benefits of trails for mental and physical health as well as part of essential transportation networks. Future research could investigate how these lessons learned could be applied to the concept of trail resilience more broadly.

Trail planners, designers, and managers across the country are integrating resilience and emergency response considerations into how trails are designed, built, and managed; call-out boxes throughout this report highlight several of these efforts.

2. Vulnerability and Resilience to Natural Hazards and Climate Change

Trails are vulnerable to the impacts of climate change, including the increasing frequency and severity of extreme weather events. Existing research explores the ways in which various natural hazards can increase the vulnerability of trails. Less research is available on how these vulnerabilities impact trails, and how trail management and maintenance practices may contribute to these vulnerabilities.

In an internal FHWA review of State bicycle and pedestrian plans (October 2021 through March 2022), 24 FHWA Divisions responded that State plans addressed climate resilience, emissions reduction, or energy use. However, not all these States provided details about how their plans specifically address climate or resilience.

In terms of resilience to natural hazards and climate change, the considerations for trails are twofold. First, trails can be designed and constructed to increase the resilience of the trails themselves. Second, trails can increase the resilience of their surrounding areas by incorporating green infrastructure components and conserving the surrounding natural environment to provide ecological benefits. Research regarding both considerations has focused on transportation infrastructure more broadly, rather than on trails specifically. Future research could explore resilience concerns of trails and develop resources to guide trail designers, planners, and managers in how to approach these opportunities.

Understanding and Assessing Trail Vulnerability

Key Findings

Significant research exists on assessing the vulnerability of transportation infrastructure to climate change and incorporating climate resilience into planning and project design. The [4th National Climate Assessment](#) describes the risks the transportation sector faces from extreme weather events and rising temperatures, and how these risks are likely to affect urban and rural transportation networks.⁴ The FHWA [Vulnerability Assessment and Adaptation Framework](#) provides a process for transportation agencies to assess the vulnerability of transportation infrastructure and systems to extreme weather and effects of climate change, and to integrate climate adaptation considerations into transportation decisionmaking.⁵ FHWA also has tools to help agencies assess vulnerability, such as the [Climate Data Processing Tool \(CMIP\)](#) that uses climate projections to generate temperature and precipitation statistics at the local level for transportation planners. [Other FHWA resources](#) address incorporating climate resilience considerations into transportation planning, project development, and asset management. FHWA's National Highway Institute offers the course, [Addressing Climate Resilience in Highway Project Development and Preliminary Design](#). The [U.S. Department of Transportation's website](#) highlights climate action among the priorities of the Department, which summarizes the objective and strategies from the Department's [Strategic Plan FY 2022-2026](#). However, none of these documents or resources specifically consider trails.

⁴ Jacobs et al., 2018

⁵ FHWA, 2017b

In addition, a 2022 National Cooperative Highway Research Program [project](#) involves developing a guidebook and toolkit for State departments of transportation (DOTs) and metropolitan planning organizations (MPOs) to incorporate uncertainty, including uncertainty related to climate change, into long-range transportation planning.

Specific to trails, existing research also examines the many ways in which trails are vulnerable to the impacts of climate change, including to the increasing occurrence and severity of extreme weather events. Trails are particularly vulnerable to changes in precipitation and streamflow, as well as sea level rise. This vulnerability is often due to their location on slopes or along water, and can be more severe for natural surface trails. Changes in precipitation, streamflow, and sea level can increase the potential for erosion, landslides, washouts, and flooding.^{6,7,8,9,10,11} More wildfire activity due to increased temperatures and changes in precipitation and wind patterns can also impact trails in vegetated environments.^{12,13,14} Forested areas may also experience more tree mortality from an increasing presence of insects and/or disease, increased temperatures, and more extreme storms, which can lead to downed or at-risk trees damaging trails or creating unsafe conditions for trail users.^{15,16} Longer warm and dry seasons could increase trail visitation over longer periods of time each year, resulting in more wear and tear to the physical infrastructure of the trail.¹⁷ The Adaptation Workbook by the Northern Institute of Applied Climate Science includes a section on adaptation strategies and approaches for recreation, which directly addresses trails.¹⁸



Figure 2. The Cowboy Trail runs 195 miles across northern Nebraska, following the old Chicago & Northwestern rail route from Norfolk in the east to Valentine in the west. In 2019, the trail flooded, causing serious damage, including one 100-foot-long section washed out by water. Image source: [Outdoor Nebraska Magazine](#)

⁶ Beiler and Miller, 2019

⁷ Binder et al., 2017

⁸ Furniss and Howe, 2016

⁹ Beiler and Miller, 2019

¹⁰ Tomczyk et al., 2016

¹¹ U.S. Forest Service and U.S. Department of Transportation Volpe Center, 2018

¹² Binder et al., 2017

¹³ Furniss and Howe, 2016

¹⁴ U.S. Forest Service and U.S. Department of Transportation Volpe Center, 2018

¹⁵ Binder et al., 2017

¹⁶ U.S. Forest Service and U.S. Department of Transportation Volpe Center, 2018

¹⁷ Binder et al., 2017

¹⁸ Northern Institute of Applied Climate Science

There is limited research on the outcomes from specific vulnerabilities and the implications for trail users and managers. The outcomes that the literature discusses include:

- Impacts to trail visitors, such as reconsideration of trail locations,¹⁹ blocked visitor access to trails,^{20,21} and impacts on visitor safety.²²
- Increased expenses from damaged infrastructure and/or more frequent required maintenance.^{23,24}

In a study on the effects of intense rainfall in a Polish national park, Tomczyk, White, and Ewertowski (2016) note that, “Adverse impacts on trails may be limited to some extent by appropriate management activities, such as planning, robust construction, and regular maintenance.”²⁵ While trails may be more vulnerable to the climatic factors described above due to natural features such as their proximity to water, number of stream crossings, and unstable slopes, research shows that they are also more vulnerable due to human factors including little or no regular maintenance and high use without concomitant maintenance.^{26,27,28} The U.S. Forest Service’s [*Transportation Resiliency Guidebook*](#) (2018) also highlights the importance of maintenance and management, especially in terms of how infrastructure is upgraded over time to consider the vulnerability and sensitivity of assets to climate change. Although existing research recognizes the importance of maintenance and management, trail managers already face a backlog of trail maintenance and staffing challenges for this maintenance. Volunteers play a crucial role in trail maintenance, but staffing and expertise is needed to manage volunteers.²⁹ Another component to preparedness for extreme weather events and subsequent maintenance is to ensure detour or other temporary wayfinding signs are stored in a safe location and ready to use.

Research Gaps

Although there is research on the vulnerability of trails to climate change, as noted above, this research generally identifies trails as one example of infrastructure affected by natural hazards and does not focus on trails specifically. There is a lack of research and resources on how the assessment and management of trail vulnerabilities differ from that of other types of infrastructure, as well as on trail-specific vulnerability concerns.

More research is needed to understand how and to what extent MPOs and local agencies are using vulnerability and risk information to program and prioritize funding for future trail projects. Such research would inform development of data sources and methods to integrate resiliency into trail project decision making.

¹⁹ Binder et al., 2017

²⁰ Binder et al., 2017

²¹ Tomczyk et al., 2016

²² Tomczyk et al., 2016

²³ Binder et al., 2017

²⁴ Tomczyk et al., 2016

²⁵ Tomczyk et al., 2016, pp. 157

²⁶ Furniss and Howe, 2016

²⁷ Tomczyk et al., 2016

²⁸ U.S. Forest Service and U.S. Department of Transportation Volpe Center, 2018

²⁹ M. Passo, personal communication, March 25, 2021

In terms of specific vulnerabilities, future research could focus on the vulnerability of trails to wildfires, particularly on the role the vegetation along the trail may play as fuel for wildfires in urban and semiurban areas. In geographic areas at risk from wildfires, trail designers, planners, and managers will benefit from understanding how trail design and vegetation can be adapted to reduce trail vulnerabilities to the frequency and/or severity of wildfire events.

Additionally, given the recognition that maintenance and management play an important role in reducing trails' vulnerability to extreme weather, future research could address how those practices should change, now and in the future, to ensure trails' resilience to increasing and shifting natural hazards. Future research could identify the specific and necessary strategies to reduce the vulnerability of trails through maintenance and management, within different types of landscapes, and in response to different types of natural hazards. Additionally, these strategies could consider how trail managers will fund and staff this increase in maintenance and management, including the role of volunteers. Future research could also seek to understand and quantify the current backlog of maintenance on trails across the country to prioritize resources and plan for future increases in maintenance needs. Federal land management agencies have documented their maintenance backlogs, but it is unclear how many miles of trails State, county, and local governments manage, how many of those miles need additional maintenance, and to what extent the backlog is caused by the increasing vulnerability of trails.³⁰ The Department of the Interior, in partnership with other agencies, has launched the [America the Beautiful initiative](#) to help conserve, connect, and restore the public lands and waters of the United States. Future research can help to understand the impact of this new initiative, as well as the funding available under the [Great American Outdoors Act](#), to manage the maintenance backlog on Federal lands.

Additional research on how to manage and maintain trails to ensure their future resilience is particularly important given their importance as a draw for economic and tourist activity, especially in rural areas.³¹

Design Considerations around Climate Change

Key Findings

The way trails are designed and constructed significantly affects their resilience to natural hazards, particularly as climate change intensifies and related extreme weather events remain uncertain. Designing and implementing resilient trails requires expertise from multiple disciplines, including engineering, landscape architecture, planning, and construction.^{32, 33} Most trail guidelines are found within guidance documents developed by State DOTs, public land management agencies and organizations, landscape architecture organizations or firms, and trail building organizations or firms. Because trails include a variety of trail types (e.g., paved multiuse trails, engineered unpaved surface trails, natural surface trails), design guidelines are typically specific to a certain subset of trails. While State DOT guidelines focus on paved or natural surface shared use paths for bicyclists and pedestrians, guidelines from land management agencies and trail building organizations tend to focus on single-track hiking trails, mountain

³⁰ M. Passo, personal communication, March 25, 2021

³¹ American Trails, *Trails Make Economic Sense*

³² Berth, 2021

³³ Headrick, personal communication, April 6, 2021

biking trails, equestrian, off-highway vehicle, and other natural surface trails. Both paved and unpaved trails should consider erosion and resilience at water crossings. Where a trail crosses a body of water, designers should ensure the crossing can handle flows from storm events; culverts and bridges should be sized appropriately, or they can back up, washing out nearby trail infrastructure. Design guidelines for trails offer recommendations for cross sections, geometry, amenities, materials, and more. Trail guidelines typically only address planning for climate change indirectly. Existing guidelines cover two key areas of resilience: erosion and heat/sun exposure.

Paved and natural surface trails have distinct advantages and disadvantages that affect their resilience to the impacts of climate change; most trail design documents reference surface type and its impact on trail erosion and degradation over time. Paved trails are typically multiuse trails and urban or suburban walking trails. The American Association of State Highway Transportation Officials (AASHTO) notes in the [Guide for the Development of Bicycle Facilities](#) that unpaved paths are suggested for use only in rural areas, further explaining that unpaved paths are not appropriate for high use trails. This AASHTO guide prescribes planning, design, and maintenance guidelines for multiuse trails, bike lanes, and other bicycle facilities; a facility's compliance to this guidance impacts its eligibility for Federal funding. AASHTO also explains that natural surface trails are more vulnerable to flooding and drainage problems, and recommends limiting grading on unpaved trails to three percent to reduce erosion.³⁴

Some guides for unpaved recreational trails recommend “the half rule” (trail grade should be no more than half the sideslope grade) or the 10-percent guideline (keep the grade below 10 percent).³⁵ [Trail accessibility guidelines](#) under the Architectural Barriers Act allow grades up to 5 percent, with limited exceptions for steeper grades for short distances ([ABA Section 1017.7](#)).

The International Mountain Bicycling Association (IMBA), which focuses on natural surface mountain biking trails, notes that natural resource geospatial data including soil type, elevation, slope, ground cover, and hydrology should be used to carefully design an unpaved trail to minimize erosion and reduce potential impacts; however, IMBA also notes that if a trail minimizes erosion but does not meet the desires of users, it cannot be considered truly sustainable.³⁶ IMBA identifies a triple bottom line of sustainable trails, with environmental, social, and economic components. Related to trail sustainability and resilience, IMBA has also conducted a study on impacts associated with mountain bikes and electric mountain bikes on natural surface trails, finding that both trail use types result in relatively low soil displacement and erosion.³⁷

As climate change accelerates, trails and trail users in warmer climates may face elevated risks from heat and sun exposure. Few documents provide specific direction for trail designers in these areas. The Maricopa Association of Governments' [Pedestrian Area Policies and Design](#)

³⁴ AASHTO, 2012

³⁵ FHWA and U.S. Forest Service, 2017

³⁶ IMBA, 2017

³⁷ IMBA, 2016

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.³⁸ Trail designers can also consider the cost and impact of artificial shade structures and natural shade structures (e.g., trees), although guidelines do not recommend frequency or type of structures. 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).

Research Gaps

Trail design guidelines generally do not address resilience and climate change directly, and tend to be siloed depending on trail type and professional specialization (e.g., engineering, trail construction, landscape architecture). Additionally, guidelines and research exist on how roadways should be designed to address climate change, but this research has not yet been integrated with trail-specific resources. New trail-focused resources could bridge the gaps across interrelated professional disciplines.

As extreme temperatures and weather events continue to intensify across the U.S., research is needed to investigate shade and heat as they pertain to trail use. Techniques for measuring shaded areas will support trail designers and managers in addition to public lands managers in efforts to create safe and comfortable trails. Further research can investigate whether recommended shade percentages are appropriate, and how to decide when natural or built shade structures should be installed. Also pertaining to heat management, research can examine what pavement types and color are best to reduce the intensity of heat for trail users, including vulnerable trail users like elderly folks, young children, and pets; while some research identifies that lighter pavement reflects heat to users, other practices have used light-colored pavement as a cooling mechanism.³⁹ Trail design guidelines could also be revised to include ideal surface types for flood-prone areas, beyond the general understanding that paved trails are less prone to erosion than unpaved trails. Finally, technologies like Lidar⁴⁰ and drones could play a role in trail planning and design; further research could establish how these tools can effectively support trail design and construction while also increasing trail resilience.⁴¹

Another consideration that needs to be further studied are the risks associated with e-bike batteries during use on trails. Given the devastation of wildfires, if battery combustion were to occur in a natural area it could pose a significant hazard not only to wildlife and natural resources, but also to the health and safety of surrounding populations. Further research needs to be done to better understand the probability of a combustion and the possible scenarios of one occurring within forested environments.

³⁸ Maricopa Association of Governments, 2005

³⁹ Erell et. al., 2013

⁴⁰ According to the National Oceanic and Atmospheric Administration, Lidar, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system — generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

⁴¹ American Trails (producer). 2020. *Technology in Trail Building and Planning: Drones and LiDAR* [webinar].

Project Highlights: Heat and Wildfire

- The [Bear Creek Greenway](#) is a 20-mile paved multiuse trail that links the cities of Ashland, Talent, Phoenix, Medford, and Central Point in Oregon. The Greenway provides a separated route from cars, and provides Rogue Valley residents and visitors opportunities for exercise and general recreation, as well as bird watching and wildlife viewing. The trail is vulnerable to wildfire due to its vegetation structure and in 2020 was partially closed due to extensive damage from the Almeda Fire. Plans are in place to reshape the corridor to reduce future wildfire advances, while still using vegetation to protect the stream from erosion and provide wildlife habitat.



Figure 3. Burned bridge along the Bear Creek Greenway from the Almeda Fire. Image source: [Jackson County Emergency Management](#)

- [CV Link](#) in Coachella Valley in California is a 50-mile trail that links the Salton Sea to the western edge of Palm Springs. This trail has significant shading structures to accommodate intense sunlight and high temperatures.



Figure 4. Shade structures along CV Link in Coachella Valley, California. Image source: [Alta Planning & Design](#)

Project Highlights: Heat and Wildfire (Continued)

- The [Trust for Public Land](#) is turning over 900 linear miles of alleys in Los Angeles, California into safe, green, community spaces using light colored paving to reduce heat, lights and signage for pedestrians, and native plants to green and beautify the neighborhood.

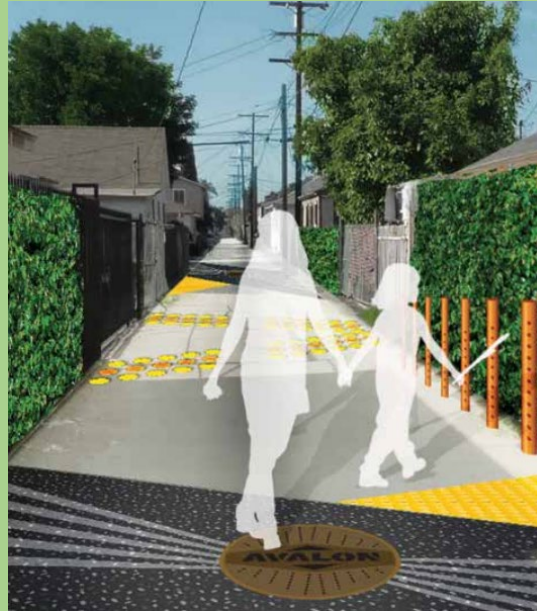


Figure 5. Rendering of Avalon Green Alley Network Demonstration Project. Image source: [Trust for Public Land](#)

The Impact of Trails on Regional Resilience

Key Findings

In addition to designing trails to be resilient to climate change, trails can be planned, designed, managed, and maintained to increase the resilience of their surroundings, including through the provision of ecosystem services. The U.S. Department of Agriculture defines ecosystem services as benefits people obtain from ecosystems.⁴² Trails can facilitate ecosystem services when they incorporate natural⁴³ or green infrastructure,⁴⁴ such as rain gardens, bioswales, and detention and retention ponds, all of which can help capture and store water for stormwater management, flood reduction, and water quality improvement (see Figure 5). By incorporating green infrastructure,

⁴² Ecosystem services are often divided into four categories, including provisioning services, regulating services, supporting services, and cultural services.

⁴³ [23 U.S.C. 101\(a\)\(17\)](#) defines natural infrastructure as infrastructure that uses, restores, or emulates natural ecological processes.

⁴⁴ Section 502 of the U.S. Clean Water Act defines green infrastructure as the range of measures that use plant or soil systems, pervious pavement or surfaces, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspire water and reduce flows to sewer systems or to surface waters.

trails can help improve stormwater management, including by intervening in, capturing, filtering, and treating runoff.^{45,46}



Figure 6. Examples of green infrastructure. Image source: [Environmental Protection Agency](#)

Trails have also been shown to support the development of linear green infrastructure, which can promote other types of ecosystem services and ecological benefits, such as habitat conservation, habitat connectivity, a reduction of the urban heat island effect, and carbon capture and nutrient cycling. For example, a study on coastal community resilience and trail planning notes that trails can connect wetlands and habitats and, in waterfront locations, create a vegetated linear shore buffer that protects from floods, storm surges, and coastal erosion^{47,48} Additionally, research on trails along waterways found that in urban and suburban areas in particular, trails can preserve vegetation while also serving as a source of wildlife connectivity and habitat.⁴⁹

FHWA has highlighted many of these ecological benefits in case studies of multimodal projects that provide resilience and green infrastructure benefits, particularly stormwater management and flood mitigation.⁵⁰ Additionally, a Vermont Agency of Transportation project looked at the potential for trails that have been converted from rail lines and are located along rivers to be lowered to their original floodplain elevation. The study found that this modification, as explored

⁴⁵ Myers, 2013

⁴⁶ Parfenova and Boswell, 2014

⁴⁷ Parfenova and Boswell, 2014

⁴⁸ FHWA published *Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide* that covers many solutions to help prevent erosion and protect against storm surge for coastal highways, which could also be relevant for coastal trail systems.

⁴⁹ Livingston and Myers, 2010

⁵⁰ Cohn et al., 2018

through the example of the Lamoille Valley Rail Trails in Vermont, can help to restore floodplain function, dissipate floodwaters, and reduce inundation and erosion hazards to downstream communities and infrastructure. It also found that some of these projects could help to achieve reductions in pollutant discharges from impervious surfaces. However, the authors also note that enhanced flooding of sites along the rail trail has led to increased maintenance expenses and challenges for recreational use, so there is a need to balance recreational goals alongside flood resilience and water quality goals.⁵¹



Figure 7. Lamoille Valley Rail Trail crossing a former railroad bridge in Johnson, Vermont. Image source: [Vermont Community Newspaper Group, Andrew Martin](#)

Research on the potential environmental and resilience-related benefits of trails primarily focuses on greenway planning rather than general trail planning.⁵² Greenways were historically designed, as noted in Maryland’s definition of greenways, as “natural corridors set aside to connect larger areas of open space and to provide for the conservation of natural resources, protection of habitat, movement of plants and animals, and to offer opportunities for linear recreation, active transportation, and nature study.”⁵³ However, greenways today are often built with more of an emphasis on economic and recreational benefits.⁵⁴ A study of recent greenway and trail conference presentations found that greenways and trails addressed many goals, such as recreation, economic development, health, transportation, and equity. However, few

⁵¹ Underwood et al., 2020

⁵² In practice the term greenway is often used interchangeably with trail or shared use path, but not all trails are developed as greenways to include the ecological benefits that are generally associated with greenways.

⁵³ Myers, 2013, pp. 145

⁵⁴ Myers, 2013

presentations focused on conservation.⁵⁵ The study's literature review also suggests that urban greenway planning theory and practice is moving away from solely focusing on greenways for their ecological benefits, and towards the incorporation of recreation and active transportation features.⁵⁶

Existing literature on trails explores the various challenges with planning, building, and managing trails as green infrastructure. For example, public support is necessary to create a trail system with the size and connectivity necessary to provide many ecosystem benefits; at the same time, overused or disruptive recreation elements can detract from environmental benefits.⁵⁷ Trails can also provide opportunities for public education through interpretative materials that explain the environmental or ecological benefits of the green infrastructure.⁵⁸ In identifying trail priorities, trail managers should consider and balance competing recreational and conservation priorities.

A study on flood-resilient green infrastructure revealed that regulatory and statutory procedures can make it difficult to use disaster funding to incorporate elements with ecological benefits.⁵⁹ Using the example of the Lafitte Greenway in New Orleans, the study showed that the Federal Emergency Management Agency's (FEMA) [Hazard Mitigation Grant Program](#) did not provide funding for the trail project to incorporate stormwater management components because, using benefit-cost project calculations at the time, the agency determined that "there is not enough documentable, historical evidence to demonstrate a sufficient reduction in either future Federal flood insurance claims and/or property damage from a hundred-year storm event."⁶⁰ Regardless, the Lafitte Greenway incorporates green infrastructure elements, including over 500 trees, bioswales that can collectively hold up to 1.45 million gallons of water above ground, pervious⁶¹ pavement, and bioretention cells.⁶²

⁵⁵ Lynch, 2019

⁵⁶ Lynch, 2019, pp. 49

⁵⁷ Lynch, 2019

⁵⁸ National Recreation and Park Association

⁵⁹ Fields et al., 2016

⁶⁰ Fields et al., 2016, pp. 317

⁶¹ Pervious pavers or pavement allow water to percolate through the surface.

⁶² Friends of Lafitte Greenway



Figure 8. Example bioswale along the Lafitte Greenway in New Orleans, Louisiana. Image source: [Friends of Lafitte Greenway](#)

In this study on the Lafitte Greenway, Fields et al. (2016) note that while post-Superstorm Sandy Federal policy changes have been promising in terms of climate adaptation investment opportunities, the statutory and regulatory particulars of disaster funding can be difficult to apply to green infrastructure solutions.⁶³ However, there are potential opportunities for exploring creative options to finance trails as green infrastructure, as evidenced in the Environmental Protection Agency (EPA) webinar, [Financing Green Infrastructure: Best Practices From the Clean Water State Revolving Fund](#), which also covered the EPA's new Sewer Overflow and Stormwater Reuse Municipal Grant Program. Both programs work to support a wide range of green infrastructure projects at all levels. During the webinar, PENNVEST, Pennsylvania's CWSRF, noted that they funded a trail to implement management practices for green infrastructure to improve trail stabilization and reduce sedimentation and erosion.⁶⁴ Additionally, a study on the overlap between conservation and recreation planning notes that, since funding for conservation and for recreation development is often limited, trails can provide an opportunity for integrating recreation and conservation planning to make funding go further and extend infrastructure benefits.⁶⁵

Research Gaps

Most existing literature focuses on the resilience benefits of greenways, but not all trails are designed or planned within a greenway framework. Therefore, additional research could focus on trails generally and how they can incorporate green infrastructure and the conservation of their

⁶³ Fields et al., 2016

⁶⁴ Environmental Protection Agency, 2021

⁶⁵ Courtenay and Lookingbill, 2014

surrounding natural environment to provide ecological benefits. This future research may consider the range of local and regional geological, hydrological, and ecological considerations that will drive the planning and design of trails. Trail planners, designers, and managers could benefit from a direct application of greenway planning best practices and lessons learned to trails generally that may not be designed and planned with conservation and ecological resilience as goals.

In terms of the challenges of incorporating green infrastructure into trails as part of a resilience strategy, future research could identify ways that trail construction and maintenance qualify for funding related to the inclusion of green infrastructure and conservation practices for ecological benefits. Some trail corridors may be appropriate for habitat connectivity or animal migration. Finally, as the purpose and goals of trails evolve to include resilience, additional research could explore the balance between recreational goals and ecological goals as climate change intensifies to assist trail planners and managers in meeting both needs. New research, literature, and resources on these topics could help to empower trail planners, designers, and managers to create and maintain trails that provide ecosystem services and increase the resilience of their surroundings, while also providing recreation opportunities.

Project Highlights: Stormwater and Flooding Management

- The [South Tar Greenway](#) in Greenville, North Carolina is located in a small city within a generally rural State. The trail was partially constructed on FEMA buyout properties, beginning in 2008, after homes were destroyed by flooding. This path now uses otherwise unusable land to create connection over five miles of paved trails.
- [Sam Houston National Forest](#) in Texas has had several 100-year floods since 2015, which washed out a multiuse path. This required recreational trails staff at the Forest to reevaluate where the trail was located and redesign the trail system. Much of the previous access has reopened. The National Forest is reassessing its management practices due to changing conditions.
- The [Houston Bayous Greenway](#) is a trail system in Houston, Texas designed to withstand flood inundations during storms, with some sections designed to flood during the storm event to help control the excess water. Initially begun in 2014, when the network is completed, it will include over 150 miles of trails along 3,000 acres of green space.
- The [New Jersey Highlands Rail Trail](#) in Passaic County, New Jersey will use pervious asphalt as a way of meeting stormwater mitigation requirements from the New Jersey Department of Environmental Protection. This will be New Jersey DOT's first trail using this material, which also accommodates access for service vehicles.
- The Albuquerque Metropolitan Arroyo Flood Control Authority built the [Hahn Arroyo](#) segment of the Paseo del Nordeste Trail in Albuquerque, New Mexico in the 1970s. The path is in a drainage area and its construction required developers to weigh the benefits and risks of allowing drainage to flow through streets as opposed to constructing a separate channel. A balance of water flows through a channel and the neighborhood streets.

Project Highlights: Stormwater and Flooding Management (Continued)

- The [Providence Riverwalk Resilience Project](#) will use RAISE funding received in 2022 to make improvements to the Riverwalk to address more frequent and severe flooding caused by sea-level rise. The project will replace a flooded pedestrian tunnel with a new bike/pedestrian bridge and raise the new shared use path and Riverwalk above future flood elevations.
- [Prison Hill Recreation Area](#) in Carson City, Nevada is a municipally owned off-highway vehicle (OHV) area, originally granted through a 2010 conservation easement. The 2,000-acre park has 980 acres open to OHVs. The Bureau of Land Management transferred ownership of the property to Carson City, and the city has since endeavored to more actively manage the property to accommodate changing trends in OHV recreation over the last several decades. Carson City has focused on developing sustainable trails with effective drainage that reduces sedimentation into local waterways and private property. For example, the city has closed some paths without adequate drainage and has restored or enhanced other trails with lead off ditches and check dams to improve drainage.



Figure 9. OHVs in Prison Hill Recreation Area in Carson City, Nevada. Image source: [Travel Nevada](#)

Project Highlights: Stormwater and Flooding Management (Continued)

- The Vermont Recreational Trails Program awarded a grant to the [White River Partnership](#) in 2021 to develop a river access trail and trailhead parking area in Stockbridge, Vermont. This new development is at the former Gaysville Campground, which was washed out during Tropical Storm Irene in 2011 and resulted in a FEMA buyout.
- Included in the Campus Master Plan in 2011 and built adjacent to the Little Westham Creek, the [Eco Corridor](#) on the University of Richmond’s campus in Richmond, Virginia includes four key components: construction of a multiuse recreational trail, removal of invasive plants, management of stormwater, and restoration of Little Westham Creek.

3. Disaster and Emergency Response

The nexus of trails and emergency management can be broadly conceived of in two general categories: managing emergencies on trails and using trails to support broader emergency response and recovery. Generally, there is a body of knowledge regarding the former topic, but there is a gap in theory and practice regarding how trails can serve as redundant transportation infrastructure to enable more effective emergency and/or disaster response and recovery for incidents occurring outside of wilderness or recreational areas in which trail networks exist.

In an internal FHWA review of State bicycle and pedestrian plans (October 2021 through March 2022), two FHWA Divisions responded that State plans address emergency response. Florida’s plan was coordinated with other plans, including emergency medical services. Kansas noted that while its plan does not include cargo bikes, it supports use of cargo bikes for emergency services. FHWA could encourage Statewide bicycle and/or pedestrian plans to consider emergency response.

The National Off-Highway Vehicle Conservation Council (NOHVCC) provides basic guidance⁶⁶ for trail managers about emergency management for off-highway vehicle (OHV) trails, covering such topics as effective trail mapping to facilitate emergency response, emergency closure of trails, emergency communications and planning, and emergency vehicle access needs. While there are not similar overarching emergency management resources for other types of trails, this guidance is potentially applicable in non-OHV trail contexts.

Existing resources on emergency response typically do not specifically address the trail context. The FHWA Disaster/Emergency Transportation Operations (ETO) program coordinates work with local, State, and Federal officials to address special movement coordination operations, particularly for evacuations during catastrophic events. The FHWA Office of Operations provides several [publications](#) related to ETO. FHWA conducted an [Assessment of State of the Practice and State of the Art in Evacuation Transportation Management](#), identifying best practices and lessons learned regarding transportation aspects of emergency management.⁶⁷ FHWA resources generally focus on privately owned vehicles on highways and address

⁶⁶ Dufourd, 2015

⁶⁷ FHWA, 2006

transportation emergency management needs for both events with advance warning and for “no-notice” events.

The FHWA Emergency Relief (ER) Program is funded through the Highway Trust Fund and can be used for the repair or reconstruction of Federal-aid highways and roads on Federal lands which have suffered serious damage as a result of natural disasters or catastrophic failures from an external cause. FHWA [publishes](#) policy, guidance, and other ER Program information, including an [Emergency Relief Manual](#), which provides guidance to assist States in applying for ER funds and making damage assessments, detailed inspections, and eligibility determinations.⁶⁸ States and Federal land management agencies can incorporate resilience into projects funded through the ER Program if the resilience feature makes the project consistent with current standards, or if the State DOT demonstrates that the resilience feature is economically justified to prevent future recurring damage.⁶⁹

In addition, FEMA supports State and local [hazard mitigation planning](#) by providing information and guidance, technical assistance, capacity building, and financial support.

Section 11505 of IIA requires that the U.S. Department of Transportation carry out a study to determine the utility of incorporating the use of bicycles into the disaster preparedness and disaster response plans of local communities. The study includes a vulnerability assessment of active transportation infrastructure and considers evacuation, first responder access, and search and rescue.

Trails as Evacuation Routes

Key Findings

Researchers have evaluated pedestrian evacuation in urban areas due to catastrophic events (e.g., the September 11, 2001 terrorist attacks),^{70,71} making several recommendations regarding trails:

- Include walking paths in assessments and designations of priority pedestrian evacuation routes;
- Develop complete off-street shared use path and trail networks; and
- Provide sufficient nonmotorized access and capacity at “gateways” (i.e., major bridges and highway connections) through, among other methods, shorefront trails.

In 2007, FHWA released a report titled [Managing Pedestrians During Evacuation of Metropolitan Areas](#), which focused on the necessary activities to ensure safe and effective movement of pedestrians while minimizing their impact on vehicular movement during urban evacuations due to no-notice events. The report found that largescale pedestrian evacuations in urban centers are rare given the extent of car ownership in the U.S.

⁶⁸ FHWA, 2013

⁶⁹ FHWA, 2019

⁷⁰ Ercolano, 2008

⁷¹ Ercolano, 2009

The study recommends three approaches to pedestrian evacuation management in these settings, the choice of which depends on the strategic objectives of the evacuation:

- Designate and manage separate evacuation corridors for outbound vehicles and for pedestrians;
- Provide dedicated evacuation transit hubs at the outer perimeter of the evacuation zone to which evacuees can walk; and
- Provide “bus bridges” from where large numbers of people exit buildings to designated points at the perimeter of the area being evacuated, where people disembark and walk or take regular transit to their destination.

The study does not focus on the use of trails, but does note a few relevant points:

- During wildfire evacuations, people may not consider evacuating using paths, even when it may be faster than driving; and
- Emergency managers do not give bicycle paths sufficient consideration as alternative options for pedestrian evacuation.

Pedestrian evacuation considerations are particularly important for certain populations, including those without access to personal vehicles, people with disabilities, and others in traditionally underserved communities. The FHWA report, [*Routes to Effective Evacuation Planning Primer Series: Evacuating Populations with Special Needs*](#), briefly addresses pedestrian evacuation needs, but focuses on longer-distance, vehicle-based evacuation planning and operations.

Modeling and simulation of evacuation during natural disaster events (e.g., tsunamis, storm surge, wildfires, and earthquakes) has been applied extensively to roadway networks for vehicle-based evacuations. In many cases, evacuation modeling has also been applied to pedestrian movement through road networks in various disaster contexts. Researchers in the United Kingdom developed a pedestrian evacuation simulation sophisticated enough to incorporate how people may use open space, like parks and plazas (but not trails), to avoid hazards.⁷²

Some tsunami evacuation plans consider pedestrian routes and infrastructure, particularly in the Pacific Northwest where these hazards are more common. For example, a study analyzed pedestrian evacuation times in Crescent City, California⁷³ and an evacuation plan for the Marine Science Center in Newport, Oregon discussed use of pedestrian routes.⁷⁴ A study⁷⁵ modeling pedestrian evacuation during tsunami events in three coastal communities in Washington State suggested ways trails could be modified to better serve evacuation purposes. 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 that trail modifications should consider the demographics of evacuees, such as

⁷² Veeraswamy et al., 2018

⁷³ Graehl, 2011

⁷⁴ Hunter-Zaworski, 2011

⁷⁵ Wood et al., 2016

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).⁷⁶

Research Gaps

There is not significant research about using trails as evacuation routes. Best practices could be identified regarding trail design and management to support evacuations during different natural and human-caused disaster scenarios. Further research could also consider how micromobility (e.g., bikeshare, e-scooters) can be accommodated on trails⁷⁷ in emergency situations.

Models of evacuation in urban settings do not always include the pedestrian mode, and those that do^{78,79,80,81,82,83} may not include nonroad routes that pedestrians may use.⁸⁴ Evacuation models may be improved by including trails (not just roads) in urban and nonurban contexts.

Project Highlights: Trails Supporting Evacuation Needs

- During the [Hurricane Sandy disaster response](#), bicycle and pedestrian networks in New York, New York provided critical redundancy and saw increased use for essential trips while the subway system was flooded.
- The [New River Trail State Park](#), a 57-mile linear park that follows an abandoned railroad right-of-way in southwest Virginia, is managed by the Virginia Department of Conservation and Recreation. When the New River floods, a portion of the New River Trail State Park can be used by motor vehicles for evacuations and emergency response.

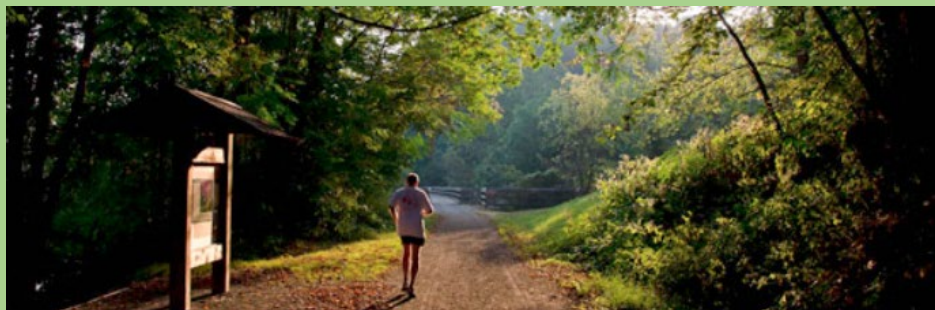


Figure 10. New River Trail State Park.

Image source: [Virginia Department of Conservation and Recreation](#)

⁷⁶ IMBA, personal communication, March 24, 2021

⁷⁷ Rails to Trails Conservancy, 2019

⁷⁸ Zhang et al., 2016

⁷⁹ Bernardini et al., 2017

⁸⁰ D’Orazio et al., 2014

⁸¹ Takagi et al., 2016

⁸² Wood et al., 2018

⁸³ Wang and Jia, 2021

⁸⁴ Shiwakoti et al., 2013

Project Highlights: Trails Supporting Evacuation Needs (Continued)

- Berkeley, California 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.
- The [Topsail Island Bridge](#) in North Carolina connecting Surf City to the mainland is the main evacuation route for the island. This bridge represents one of the few evacuation routes with a multiuse path. It also has shoulders in each direction marked for bicycle use, which can provide additional emergency or hurricane evacuation capacity for vehicles.



Figure 11. Rendering of the Topsail Island Bridge.
Image source: [North Carolina Department of Transportation](#)

- Portland, Oregon 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.

Trail Design Considerations around Emergency Vehicle Access

Key Findings

Generally, trails should be designed with consideration of emergency vehicle access, particularly when multiuse paths are separate from roadways.⁸⁵ AASHTO, State DOTs, and local transportation agencies have developed a significant amount of design guidance around emergency vehicle access for paved multiuse paths. Example management plans, studies, and design guidelines recommend the following more specific design features or considerations for emergency vehicle access to trails:

- Use thicker pavement to reduce likelihood of damage from the weight of motor vehicles;^{86,87,88}
- Paths should typically have a minimum 10 feet of vertical clearance (8 feet in constrained scenarios);^{89,90,91}

⁸⁵ Seifert and Lind, 2018

⁸⁶ Seifert and Lind, 2018

⁸⁷ Hawaii DOT, 2013

⁸⁸ Washington DOT, 2020

⁸⁹ AASHTO, 2012

⁹⁰ Toronto Transportation Services Parks, Forestry, and Recreation, 2015

⁹¹ Minnesota DOT, 2020

- Paths should be a minimum 10 feet wide (8 feet in constrained scenarios);^{92,93,94}
- Path tunnels should be a minimum 14 feet wide;⁹⁵ and
- Path bridges should be a minimum 12 feet wide.⁹⁶

Several design approaches aim to limit access to trails only to authorized emergency vehicles, including removable barriers⁹⁷ and gates.⁹⁸ However, the preferred method for restricting unauthorized vehicle access to trails is to divide the path into two sections with low landscaping that emergency vehicles can drive over (see Figure 11). These “splitter islands” avoid the installation of bollards, which can be a safety hazard for cyclists.⁹⁹ All of these design features still allow nonmotorized access to trails.

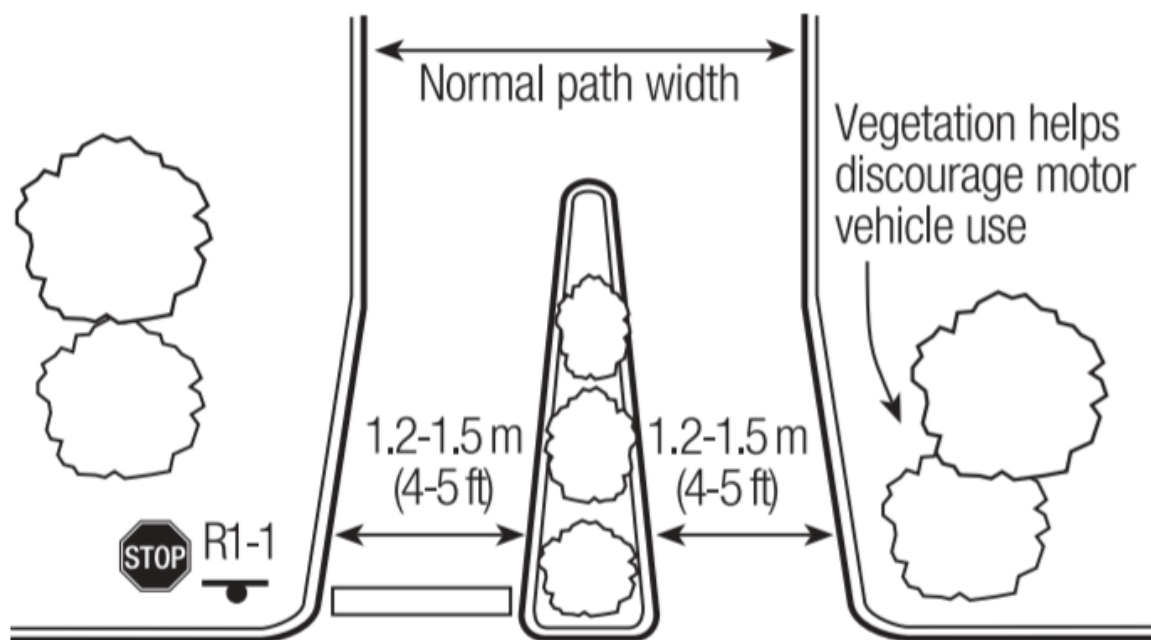


Figure 12. Diagram of splitter island feature low landscaping to restrict unauthorized vehicle access.
 Image source: [Vermont Department of Transportation](#).

Trails may also include reference location signs (i.e., mile markers) which provide visitors a way to identify the location of emergencies.¹⁰⁰ [Section 9B.24 of the Manual on Uniform Traffic Control Devices](#) provides guidance for the use of reference location signs on multiuse paths.

⁹² Ayers et al., 2012

⁹³ AASHTO, 2012

⁹⁴ Toronto Transportation Services Parks, Forestry, and Recreation, 2015

⁹⁵ Swindlehurst, 2006

⁹⁶ Hawaii DOT, 2013

⁹⁷ Swindlehurst, 2006

⁹⁸ Cathro Consulting Ltd. and B.A. Blackwell & Associates Ltd., 2016

⁹⁹ FHWA, 2017a, 2017c, 2018

¹⁰⁰ AASHTO, 2012

Trails can also support wildfire management activities, by providing access for ground crews using all-terrain vehicles (ATVs) and planning trail locations to act as fuel breaks.^{101,102}

Project Highlight: Trails as Redundant Transportation Networks

- 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.

Research Gaps

While there are example management plans and studies that address the topic of emergency vehicle access for trails, there is a lack of academic literature on the topic. Future research could address how trails can support emergency vehicle access not just for emergencies on a trail, but the feasibility and desirability of using trails as secondary transportation network for emergency vehicles. Another topic for potential further exploration is how to effectively apply wildfire management strategies to trail design (e.g., guidance on how to strategically locate trails to act as fire breaks).

Little design guidance exists about the frequency of trail access points for emergency vehicles. Future guidance could help clarify optimal access point spacing to improve emergency response times. Additional design guidance could address strategies for adapting existing trails to improve emergency vehicle access (e.g., balancing preservation and emergency access at historic bridges along paths).

Trails and Search and Rescue

Key Findings

Natural surface hiking, biking, and OHV trails can contribute to people becoming lost, may be used by lost persons, and are used by search and rescue (SAR) personnel during operations.

An analysis of search tactics found that, in 68 percent of SAR cases, hikers have become lost because of decision points on trails, including trail junctions, or confusing or poorly marked trails.¹⁰³ A review of SAR operations in Yosemite National Park found that 25 percent of individuals needing SAR services became lost from popular trails.¹⁰⁴

SAR research has established that lost people exhibit various behaviors as they attempt to reorient themselves, including “random traveling, direction traveling, route sampling, direction sampling, backtracking, using folk wisdom, and staying put.”¹⁰⁵ Research conducted in the U.S found that trails affect lost person behavior; for example, when finding a trail, missing persons

¹⁰¹ Cathro Consulting Ltd. and B.A. Blackwell & Associates Ltd., 2016

¹⁰² B.A. Blackwell & Associates Ltd., 2019

¹⁰³ Phillips et al., 2014

¹⁰⁴ Hung and Townes, 2007

¹⁰⁵ Lin and Goodrich, 2010

may abruptly change directions or momentarily stop moving to reorient themselves.¹⁰⁶ Lost people typically follow trails or “geographical paths of least resistance.”¹⁰⁷

SAR operations comprise three key activities: investigation, containment, and search. Investigation attempts to determine information helpful for defining the search area while the goal of containment is to limit how far a lost subject may travel. Trails are used by SAR personnel during operations; for example, SAR personnel may go to trailheads and trail junctions, among other strategic locations, as part of containment activities.¹⁰⁸

ATVs are often used for SAR operations to handle rough terrain and to transport injured persons.¹⁰⁹ Research has found that ATVs can effectively 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.¹¹⁰ More generally, OHV trails are more likely to be effective for SAR operations, since they are designed to handle vehicles and their networks reach farthest into wilderness areas, improving access for first responders.¹¹¹

Drones are an emerging technology with potential application to SAR. Relevant drone research has found that:

- Trails, viewed aerially from a drone flying over a wilderness area, can be used to help orient the drone during SAR¹¹²
- Drones can support SAR missions for particularly rugged or hazardous terrain¹¹³
- Machine learning can be applied to “train” a drone to identify and follow forest trails¹¹⁴

In addition to drones, other new technologies on OHVs, including Global Positioning System (GPS), satellite connectivity, and security locator systems, can facilitate more efficient SAR operations.¹¹⁵

SAR needs on trails have increased in recent years. Climate change may be exacerbating risks for trail users, increasing demands for SAR services. Studies^{116,117} of semi-permanent trails on sea ice along the Arctic coast in Nunavut, Canada have found that thinning ice increases hazards for indigenous peoples engaged in subsistence activities there, resulting in increasing SAR needs. The COVID-19 pandemic has drawn novice hikers into remote areas, straining SAR

¹⁰⁶ Goodrich et al., 2007

¹⁰⁷ Phillips et al., 2014

¹⁰⁸ Phillips et al., 2014

¹⁰⁹ GAO, 2010

¹¹⁰ Ciesa et al., 2014

¹¹¹ NOHVCC, personal communication, March 24, 2021

¹¹² Zhilenkov and Epifantsev, 2018

¹¹³ Tilburg, 2017

¹¹⁴ Giusti, 2015

¹¹⁵ NOHVCC, personal communication, March 24, 2021

¹¹⁶ Ford and Clark, 2019

¹¹⁷ Clark et al., 2016

personnel.¹¹⁸ More information on use of trails during public health emergencies is available in the Chapter 4 of this report.

Research Gaps

There is a lack of research regarding the role of trails in supporting drone staging or supply points for SAR. Future study may seek to address how drones can supplement or complement traditional SAR operations, investigate how drones may change how trails are used by SAR personnel during operations, and/or identify applications for using trails as supply points to support SAR efforts.

Increased standardization may improve how backcountry emergencies are reported and responded to by SAR personnel. Current practices vary from location to location, leading to confusion among visitors on how to reach emergency services. In general, development of quality maps and GPS data,¹¹⁹ as well as a comprehensive inventory of online trail mapping repositories, may help address this gap.

Project Highlight: Trails Supporting Search and Rescue

- The [New York-New Jersey Trail Conference](#) worked with superintendents at six New Jersey State Parks and Forests to implement changes to the trail networks to reduce the potential for visitors getting lost. These changes reconfigured the colors on existing trails to turn long, confusing, linear trails into simple, intuitive loop systems allowing hikers to confidently self-navigate and reducing burdens on first responders. These changes were crafted with the input of local SAR personnel, trail stewards, State Park and Forest superintendents, and volunteer leaders with local knowledge of the areas and their visitors.
- The New Jersey Region Bike Patrol identified that most trail maps are useful for hiking, but do not include all existing trails (e.g., social trails), so are less helpful for first responders conducting SAR operations. Crowdsourced maps like [Trailforks](#) fill those gaps.
- The State of Vermont and its Recreational Trails Program have supported development of the web-based mapping platform, [TrailFinder](#), as the public inventory of State- and local-managed trails. The database provides information, maps, directions, and conditions of managed trail networks throughout Vermont, and is useful not only to the public for recreational uses, but also for planners and emergency managers to plan SAR operations and identify alternative transportation routes for emergency ingress or egress.

¹¹⁸ Watkins, 2021

¹¹⁹ NOHVCC, personal communication, March 24, 2021

4. Use of Trails During Public Health Emergencies

The COVID-19 pandemic is linked to a significant increase in usage of trails for recreation and transportation. The limited existing academic research on this topic, in addition to many local news articles, point to a significant increase in trail usage during the COVID-19 pandemic that may signal increased usage beyond the end of the pandemic for both recreation and transportation. Trail managers had to quickly respond to this increase in use to manage short- and long-term outcomes, and to ensure the safety of users. Trail manager experiences from during the pandemic suggest a research need to learn from the impacts of this increased use and the outcomes of different management decisions to ensure that trails are resilient to future changes in use. This future resilience includes the maintenance of trails in response to increased use, as well as trail managers' ability to respond to any future public health emergencies that may impact the use of trails.

Increased Usage of Trails for Recreation and Transportation

Key Findings

Although there is limited academic research on the impacts of the COVID-19 pandemic¹²⁰ on trails specifically, there is related early research on the increase in outdoor recreational activities during the pandemic. In one U.S.-based research study, the Leave No Trace Center for Outdoor Ethics and researchers from Pennsylvania State University sent surveys to its member email listserv in three phases in 2020: on April 9th, April 30th, and May 21st. They found a statistically significant increase in the number of days per week in which respondents participated in outdoor recreation between the three phases, as well as an increase in the distance traveled to participate in outdoor recreation.¹²¹

Outside of the U.S., the Norwegian Institute for Nature Research conducted a survey in Oslo and found a 291 percent increase in outdoor recreational activity relative to the three-year baseline average.¹²² They also found that activities were especially intensified in the urban periphery where “there is much more space to adhere to social distancing guidelines in the peri-urban areas, where there is easy access to walkways, bikeways, and forest roads, as well as marked and unmarked trails.”¹²³ Additionally, research on visitor monitoring in a peri-urban forest in Germany, which includes a network of long and straight forest roads used for recreation, found that visitation increased almost 140 percent. The monitoring also uncovered new visitors through increased web traffic and an increase in car license plates from other regions.¹²⁴

Boston University's Menino Survey of Mayors from 2020 surveyed 130 mayors from cities with 75,000 or more residents between June and August 2020 and included a special report on [Urban](#)

¹²⁰ For context in this section, the U.S. declared a public health emergency due to the COVID-19 outbreak on February 3rd, 2020. On March 11th, the World Health Organization declared COVID-19 a pandemic, and the U.S. declared a national emergency on March 13th, precipitating stay-at-home orders and closures across the country.

¹²¹ Rice et al., 2020

¹²² Venter et al., 2020

¹²³ Venter et al, 2020, pp. 6

¹²⁴ Derks et al., 2020

Parks and the Public Realm: Equity & Access in Post-COVID Cities.¹²⁵ The report notes that there was a large surge in park visitation in cities across the country in 2020. More importantly, the majority of those surveyed believed that residents would partake in outdoor recreational activities more frequently once an effective COVID-19 vaccine was available, with 76 percent responding that they think there would be an increase in visiting parks and green space, 62 percent for an increase in biking, and 70 percent for an increase in walking.¹²⁶ At the same time, 38 percent of those mayors surveyed responded that they expect to make or see a dramatic financial cut to parks and recreation (the second most commonly-noted category in relation to budget cuts).¹²⁷ However, recent research suggests that many States will rely on Federal funds distributed as part of the response to the COVID-19 pandemic, such as the Coronavirus Aid, Relief, and Economic Security Act and the American Rescue Plan, to invest in their outdoor recreation resources. For example, Michigan proposed investing \$250 million of the aid into the maintenance backlog at State parks, including trail infrastructure, and Indiana allocated \$60 million to a trail construction program.¹²⁸ Additionally, in the 2021 Menino Survey of Mayors' report on *Building Back Better*, 18% of the surveyed mayors who responded that they would use American Rescue Plan funds for "transformative things" identified transportation infrastructure as one of their primary uses. One mayor specifically referenced trails as a use of this funding.¹²⁹

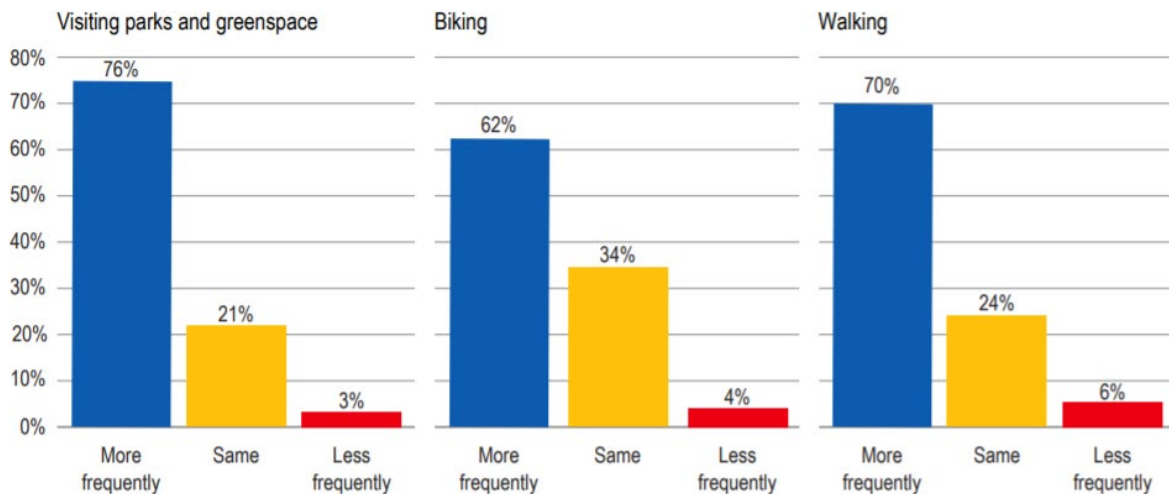


Figure 13. Responses from 130 mayors to: "Once an effective vaccine is available, do you believe that residents in your city will be doing the following with more, less, or the same frequency than they were just before COVID-19?" Image source: [2020 Menino Survey of Mayors](#)

¹²⁵ Lusk et al., 2021

¹²⁶ Lusk et al., 2021, pp. 12

¹²⁷ Lusk et al., 2021, pp. 16

¹²⁸ Brown, 2021

¹²⁹ Glick et al., 2021, pp.6

In addition to academic research, there is an abundance of news articles from across the U.S. that have focused on the growth in the usage of recreational facilities and trails during the pandemic.^{130,131,132,133,134,135,136} The Rails-to-Trails Conservancy has noted a surge in trail use in 2020, averaging nearly double that of 2019. Brandi Horton, the Conservancy’s Vice President of Communications noted that this is because, “People are discovering trails in their backyard. They are looking at a close-to-home outdoor space where they can be active. Trails have become essential for recreation and transportation.”¹³⁷ For example, the Lehigh Valley Planning Commission in Pennsylvania saw a 60 percent increase in use on paths and trails, for both recreation and for commuting,¹³⁸ and the city of New Orleans saw a 255 percent increase in riders using the Wisner Trail.¹³⁹ In addition, many National Parks saw visitation increase or remain constant during 2020 and 2021, especially at parks that attracted many local or regional visitors as people sought recreation opportunities close to home during the pandemic. For example, both [Great Smoky Mountains National Park](#) and [Indiana Dunes National Park](#) saw relatively constant visitation in 2020 compared to 2019, and a large increase in visitation in 2021.

Research Gaps

There is a general lack of academic research on the usage of trails during the COVID-19 pandemic due to the recent emergence of the research area. Future research could look at trends of trail usage during the COVID-19 pandemic, as well as to what extent those usage trends continue beyond the end of the pandemic. Research could also examine the management responses to heavy usage of trails in the short- and long-term, and any outcomes from these management decisions.

Trail Management

Key Findings

Many news articles focused on trail use during the COVID-19 pandemic emphasized that trails are both for exercise and recreation, as well as for essential travel and commuting.^{140,141,142,143,144} In order to keep trails open for all of these activities, while also maintaining a safe distance

¹³⁰ Abad, 2021

¹³¹ Brown, 2020

¹³² Eagle, 2021

¹³³ King, 2021

¹³⁴ Meeks, 2021

¹³⁵ Meyer, 2020

¹³⁶ Tate, 2020

¹³⁷ Tate, 2020

¹³⁸ Shortell, 2020

¹³⁹ Gibson, 2020

¹⁴⁰ City of Madison, 2020

¹⁴¹ Fucoloro, 2020

¹⁴² Shortell, 2020

¹⁴³ Thompson, 2020

¹⁴⁴ Trails and recreational facilities can also be used as locations for health-related outreach. For example, New Hampshire’s Department of Health and Human Services partnered with New Hampshire’s Department of Natural and Cultural Resources in August 2021 to offer vaccines at state parks via the state’s mobile vaccine van. Following vaccination at a state park, each individual received a complimentary entrance pass that could be used until the end of 2022.

between visitors, many trail managers implemented specific strategies, including volunteer or paid monitors to enforce distancing requirements,^{145,146} widening existing infrastructure,¹⁴⁷ limiting access to “Keep It Moving” activities (e.g., walking, jogging, biking),¹⁴⁸ and enforcing unidirectional traffic on trails.¹⁴⁹

The increased usage of trails during the COVID-19 pandemic contributed to various negative consequences to which trail managers have rapidly adapted. Colorado has been experiencing increased usage of their outdoor recreational facilities for many years due to population growth but saw that usage spike in 2020. For the public lands and trails in Colorado, this resulted in trail crowding, overflowing parking lots, and resource damage. This overuse led to some public lands instituting temporary management restrictions, including time-entry reservation systems.¹⁵⁰ As another example, the use of the Dartmouth Natural Resources Trust’s 40 miles of trails in Massachusetts was so heavy during the first few months of the pandemic that the Trust was forced to make emergency repairs to one of the trails. The trail became heavily compacted from overuse, so they had to add gravel.¹⁵¹ Lastly, the New York Times recently reported on the impact that increased exploration of the backcountry, including trail networks, “has strained the patchwork, volunteer-based search-and-rescue system in America’s West.”¹⁵²

Research Gaps

Future research could explore the direct connection to trails as critical infrastructure, for both transportation and recreation purposes, and compile resources on how trails can remain open during public health emergencies, considering safeguards and/or enforcement (e.g., trail monitors, limiting access to specific activities, and unidirectional access). To learn from the COVID-19 pandemic, future research could cover the outcomes of various trail management decisions and their consequences, as well as the effectiveness of the different decisions.

¹⁴⁵ March, 2020

¹⁴⁶ Ruiz, 2020

¹⁴⁷ City of Madison, 2020

¹⁴⁸ March, 2020

¹⁴⁹ Freeman and Eykelbosh, 2020

¹⁵⁰ Meyer, 2021

¹⁵¹ Brown, 2020

¹⁵² Watkins, 2021

Project Highlights: Managing Trail Use

- [King County Parks in Washington](#) offers 175 miles of regional trails (paved and unpaved) and 215 miles of backcountry trails. In March 2020, King County Parks [decided to close all of the county-run trails](#) except for access by essential workers for commuting purposes and by those accomplishing an essential task (e.g., grocery shopping, doctor appointment), until the governor allowed for the reopening of State recreational lands.
- The [Chicago Lakefront Trail](#) is an 18-mile paved shared use path along the western shore of Lake Michigan in Chicago, Illinois. During the COVID-19 pandemic, the City of Chicago [closed this trail for nearly three months and then reopened it with a limited schedule \(6 AM to 7 PM\)](#). In addition, the City limited access to "Keep It Moving" activities (walking, running, and biking) and hired Social Distancing Ambassadors to encourage visitors to comply with the rules.



Figure 14. "Keep It Moving" Rules from Chicago Park District Image source: [StreetsBlog Chicago, Imelda March](#)

Trails for Physical and Mental Health

Key Findings

Although there is not yet academic research directly tying the importance of outdoor recreational spaces and trails during the COVID-19 pandemic to physical and mental health, many other sources recognize this connection.^{153,154,155} The National Collaborating Centre for Environmental Health published a report on [*COVID-19 and Outdoor Safety: Considerations for Use of Outdoor Recreational Spaces*](#). They note that outdoor recreational spaces contribute to social well-being, as well as physical and mental health but that, during a public health emergency, risks of community disease spread should also be considered. They conclude that “management of outdoor recreational spaces requires a thoughtful analysis to balance the needs of the population against the potential risks of community spread.”¹⁵⁶ If restrictions are needed, they emphasize looking for alternatives to full closures that allow managers to reduce risk while keeping spaces open to maximize distance and minimize interaction. Examples of this include unidirectional traffic on trails, or closing or removing certain features.^{157,158}

There are many examples from across the U.S. of trail managers deciding that the benefits of trails to physical and mental health merited maintaining them open during the COVID-19 pandemic. For example, the Chatham County Parks and Recreation Department in North Carolina decided to keep facilities, including trails, open during the stay-at-home order because of multiple benefits, including promoting physical and mental health, and physically-distanced social interactions.¹⁵⁹ Lee County in Florida voted in favor in April 2020 of opening some parks and trails, with the Commission Chairman specifically citing mental health as the primary issue at play in the decision.¹⁶⁰ Similarly, Athens-Clarke County in Georgia decided to reopen trails for public use in April 2020, specifically related to mental health and providing outdoor recreational opportunities.¹⁶¹

The East Coast Greenway Alliance recognized this issue in their recent letter to Congress advocating for a Greenway Stimulus, with signatures from more than 160 organizations, writing that, “People are using greenways and trails across the country more than ever as they strive to maintain their mental and physical health. Greenways have clearly gone from novelty to necessity.”¹⁶² Additionally, the Executive Director of the East Coast Greenway Alliance noted, “The COVID crisis has proven that greenways are essential paths to healing. They’re not just

¹⁵³ Abad, 2021

¹⁵⁴ Bonner, 2020

¹⁵⁵ Ruiz, 2020

¹⁵⁶ Freeman and Eykelbosh, 2020, pp. 1

¹⁵⁷ Freeman and Eykelbosh, 2020

¹⁵⁸ Jacob et al., 2020

¹⁵⁹ Horner, 2020

¹⁶⁰ Lauren, 2020

¹⁶¹ Grady Newsource, 2020

¹⁶² Wilson, 2020

paths to recreation; they've become necessary all over the country as sanctuaries of sanity, and havens of health."¹⁶³

Project Highlights: Maintaining Access to Trails

- The [Chatham County Parks and Recreation Department in North Carolina kept facilities, including trails, open](#) during the stay-at-home order because of multiple benefits, including physical and mental health, and community interaction.
- [Lee County in Florida voted in April 2020 to open some parks and trails](#). The Commission Chairman noted mental health as the primary reason.
- [Athens-Clarke County in Georgia reopened trails for public use](#) in April 2020, specifically citing mental health and the need to provide outdoor recreational opportunities.

Project Highlights: Expanding Access to Trails

- The [Capital City State Trail](#) is a 17-mile paved path connecting the suburbs and downtown of Madison, Wisconsin. Recognizing that the trail is a critical transportation link, the city [made trail improvements to widen path shoulders](#) in multiple locations in order to allow for adequate physical distancing.



Figure 15. Capital City State Trail
Image source: [TrailLink by Rails-to-Trails Conservancy](#)

¹⁶³ Wilson, 2020

Project Highlights: Expanding Access to Trails (Continued)

- The Lincoln National Forest and Village of Ruidoso in New Mexico created additional access to the [Grindstone Trail system](#) with a [new trailhead in Sawmill Canyon and six new miles of trail](#) for nonmotorized recreation that connected into the larger trail system. This expansion was specifically developed to help spread out visitors and create more distancing during the COVID-19 pandemic.



Figure 16. Sawmill Trail Improvement project to connect to the Grindstone Trail system in New Mexico
Image source: [Ruidoso News, Lincoln National Forest](#)

- The [Shelby County Commission in Alabama filed for a Recreational Trails Program grant](#) to expand trails across the county due to exceptional park usage during the COVID-19 pandemic and the need to create more physical distancing between visitors.
- [Cleveland Metroparks in Ohio closed several park roads](#) to expand existing space for bicycling, running, and hiking in the park. This created 20-foot-wide trails to encourage proper physical distancing between visitors.

Research Gaps

To learn from the COVID-19 pandemic, future research could cover the outcomes of various trail management decisions and their consequences. In relation to decisions to close and restrict access to trails, research could explore where that recreational activity moved and what alternatives commuters and others relying on the trail for essential transportation used. In cases of decisions to expand trail networks, research could explore whether trail planners and managers encountered less opposition than before the pandemic, and in what ways the planning and development process was different. Additionally, future research could expand on the COVID-19 pandemic to review how trails impact mental health in general.

5. Conclusion and Next Steps

In general, the research and interviews conducted for this white paper found that there is a lack of information on the topics of climate resilience and emergency response that is specifically geared towards trail planners, designers, and managers. There is also a lack of research on the usage of trails during the COVID-19 pandemic due to the recent emergence of the research area.

The section on **Vulnerability and Resilience to Natural Hazards** included research on the vulnerability of trails to natural hazards, designing trails to be resilient to climate change and related extreme weather events, and ways in which trails can influence community resilience. Future research could investigate techniques to design for, plan, and manage trails to be resilient to climate change, as well as strategies to incorporate trails into larger resilience-focused efforts. Research could also focus on innovative finance strategies to leverage existing funding for trail resilience.

The section on **Disaster and Emergency Response** investigated how trails can serve as evacuation routes, be designed to enable emergency vehicle access, and support search and rescue efforts. Further research could look at how trails can serve as redundant transportation infrastructure to enable more effective emergency/disaster response and recovery. More specifically, research could consider design strategies for emergency vehicle access and responding to emergencies on trails; planning for trails as evacuation routes; using trails for emergency access, search and rescue, or emergency staging; and management of trails during emergencies.

The section on **Use of Trails During Public Health Emergencies** explored initial outcomes of the COVID-19 pandemic, including trail use, management strategies, and benefits for mental and physical health, as well as role as part of essential transportation networks. Future research could explore the direct connection to trails as critical infrastructure, for both transportation and recreation purposes, and compile resources on how trails can stay open during public health emergencies, considering safeguards and and/or enforcement. Additional research could also investigate the extent to which trends of trail usage during the COVID-19 pandemic continue after the end of the public health emergency.

Given these identified research gaps, FHWA is developing a guidebook on trails as resilient infrastructure, with one section focused on climate resilience and one focused on emergency response, as follow-on work to this white paper. The guidebooks will provide actionable information to trail planners, designers, and managers on how trails can be designed to be both accessible for users and resilient to natural hazards, as well as how trails can be designed to support emergency response and recovery efforts. Additionally, they will help trail planners, designers, and managers identify strategies for improving infrastructure resilience and emergency response and preparedness on shared use paths and recreational trails. The guidebooks will include case studies that highlight effective trail design, planning, and management practices related to the topics of climate resilience, and emergency response and preparedness.

Trail designers, planners, and managers are faced with adapting to climate change, while also managing for increased use of trails and addressing growing critical maintenance backlogs. In responding to climate change, trail managers can help ensure that trails are designed, planned, and maintained to be resilient to natural hazards. In addition, trail managers can help increase the resilience of a trail's surroundings by incorporating green infrastructure and conserving the natural environment, thus providing important ecosystem services. Trails can also be designed and managed to support emergency response and preparedness operations, including search and rescue and fighting wildfires. Through the Recreational Trails Program, as well as other funding and technical assistance efforts, FHWA is providing resources and tools to assist trail managers in adapting to these challenges and maintaining trails as a critical piece of the transportation system.

Appendix: Interview Process

The project team conducted seven interviews with national trail organizations and other subject matter experts to inform the development of this report. Table 1 lists the interviewees and their affiliation. The interviews followed a semi-structured format, but generally covered the following questions:

- Has your organization seen changes in maintenance, management, and planning practices for trails in order to increase resilience to natural hazards, and prepare trails for climate change and future conditions?
 - Can you think of specific case studies/examples?
 - What are the most critical research gaps related to this topic?
 - What new developments does your organization see occurring related to this topic?
- Has your organization seen changes in maintenance, management, and planning practices for trails during emergencies for response and recovery?
 - Can you think of specific case studies/examples?
 - What are the most critical research gaps related to this topic?
 - What new developments does your organization see occurring related to this topic?
- What have been your organization’s main takeaways from the use of recreational trails during the COVID-19 pandemic?
 - Do you see the COVID-19 pandemic having a lasting effect on recreational trails? If so, how?

Table 1: List of Interviewees

Organization	Name
American Council of Snowmobile Associations	Christine Jourdain
American Trails	Mike Passo
East Coast Greenway Alliance	Niles Barnes
International Mountain Bicycling Association	Anthony Duncan Mike Repyak Shane Wilson
Greenman-Pedersen, Inc	Ron Headrick
National Off-Highway Vehicle Conservation Council	Mark Hildesheim Duane Taylor
Professional TrailBuilders Association	Aaryn Kay
Rails-to-Trails Conservancy	Kelly Pack Liz Thorstensen

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