FRA Climate and Sustainability

Rail Resiliency

Resiliency Planning

U.S. Department of Transportation

Federal Railroad Administration

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THE NEED FOR RESILIENCY PLANNING

Climate change and extreme weather events increase risk to the safety, effectiveness, equity, and sustainability of our transportation infrastructure and the communities it serves (NOAA, 2024). The rail industry is vulnerable to extreme weather events and must address the issue of infrastructure resiliency. Adverse conditions, such as excessive heat, flooding, sea level rise, tornadoes, hurricanes, and wildfires are exacerbated by climate change and threaten the safety and reliability of the rail network (NOAA, 2024).

The Federal Railroad Administration (FRA) manages billions in taxpayer funding to develop and support a safe and efficient rail network, and has initiated several research efforts to provide resiliency information to rail owners and operators. This document introduces the threats to the rail network, provides tools and resources such as Climate Mapping for Resilience and Adaptation (CMRA), summarizes a recent weather-oriented FRA Safety Advisory, and provides a case study of experiences in Maine to highlight issues faced by the rail industry.

Ultimately, the management of the rail network and rail assets is the responsibility of the owners of those networks. However, FRA can play a role in providing training, promoting safety, identifying threats, and building awareness of vulnerabilities caused by extreme weather events, including developing research and tools for the rail community. The success of these efforts relies on coordination with the owners of rail assets and the ability of different parties to work together where cooperation provides asset management and protection benefits.

WHAT IS RESILIENCY PLANNING?

Resiliency planning is an essential part of ensuring the **reliability**, **safety**, and **continuity** of railroad operations.

Resiliency planning refers to a system's ability to prevent, absorb, recover from, and adapt to disruptions caused by hazards or natural disasters in a timely and efficient manner[i].

The principles of resiliency planning are to proactively:

- Identify risks and vulnerabilities in infrastructure systems;
- Assess climate risk to understand a system's survivability during a disruptive event while implementing mitigation measures, and;
- Develop procedures that enhance the response and recovery time after a disruptive event has occurred.

It is important in the early stages of project planning to allocate adequate funding up front for risk and resilience analysis as part of the project lifecycle process. This allows for more reliable infrastructure in the long term. Thinking of the additional up-front costs can help mitigate damage from future hazards or natural disasters and generate significant benefits in lower repair and maintenance costs over the lifetime of an infrastructure system.

CURRENT CHALLENGES FACING THE RAILROAD INDUSTRY

The railroad industry encounters a multitude of hazards and threats that can disrupt operations and present significant challenges to **reliability**, **safety**, and **continuity**; these include:

Natural Disasters: *Hurricanes, floods, wildfires, earthquakes, sea level rise, and severe storms can damage railroad infrastructure, including tracks, bridges, and signals, leading to service disruptions and delays.*

Infrastructure Failures: *Aging infrastructure, inadequate maintenance, and insufficient investment in upgrades can result in equipment failures, track defects, and other issues that disrupt railroad operations and pose safety risks.*

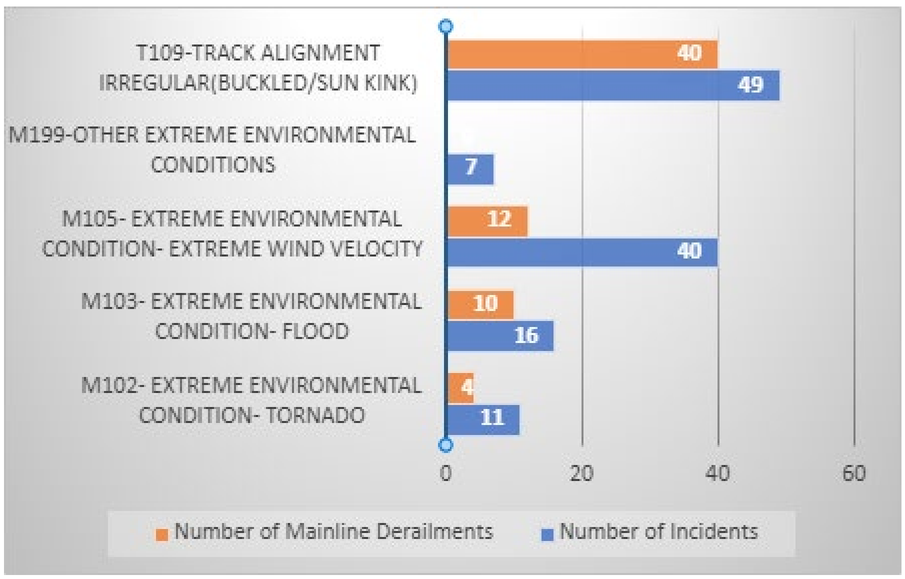


***Figure 1: Number of Accident Cause Codes with Weather Identified*[1]**

Figure 1 shows the proportion of incidents caused by various extreme weather conditions and the prevalence of each cause. Figure 2 offers insight into the economic impact of rail accidents due to extreme weather and track issues, highlighting the potential for decreased average costs with increased frequencies. Together, this type of data can provide comprehensive insight into both the financial and operational aspects of rail system resilience to extreme weather events.

FRA safety data covering the years 2012 to 2021, highlight the cost of railway accidents caused by extreme weather conditions (FRA, 2023). These accidents are classified under two cause codes: M103 (Extreme Environmental Condition – Flood) and T002 (Washouts/Rain/Slide/etc.). The cost of these accidents ranged from $1 million to over $1.2 million per event.

[1] FRA'S *Safety Advisory 2023-07* recommendations.

Figure 2[2] represents FRA safety data interpreted by MxV Rail[3]. These data show the number of annual derailments along with the corresponding average costs for accidents categorized under M103 and T002. Many incidents do not result in derailment. For example, weather events such as the accumulation of snow and ice may cause delays due to the speed restrictions, but do not typically lead to derailment. Consequently, the data provided only account for a fraction of actual incidents and causes for each of the mentioned accident codes. Additionally, many track washouts are discovered before a train derails. These costs are not reported to FRA and include direct costs (like repair) and indirect costs (like loss of use).

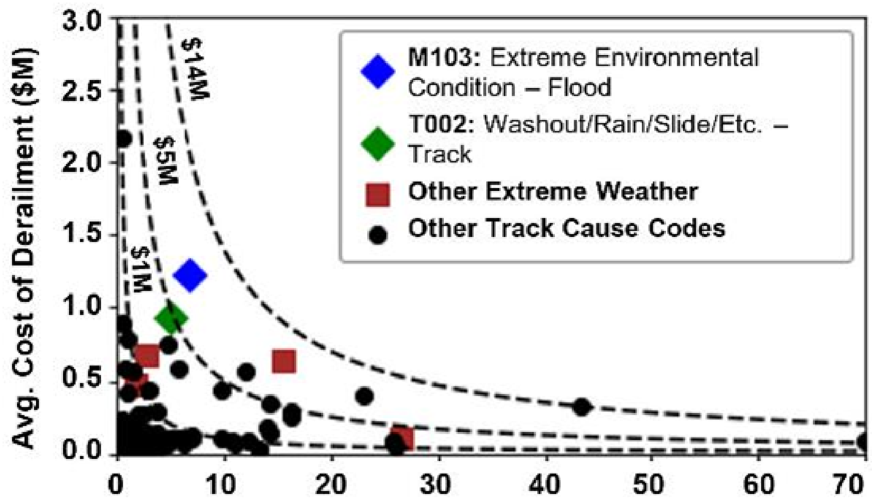


Figure 2: Extreme Event Accident Cause Codes[4]

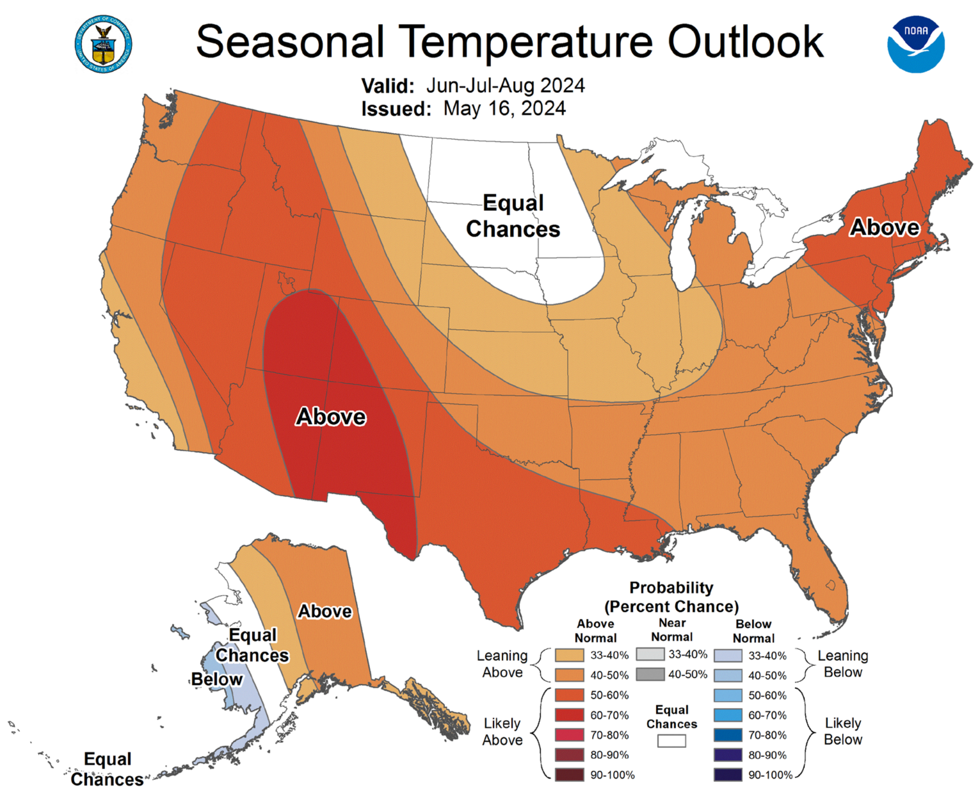
[2]Federal Railroad Administration, Office of Safety Analysis. https://safetydata.fra.dot.gov/OfficeofSafety/publicsite/on_the_fly_download.aspx.
[3] Transportation Technology Center, INC DBA MxV Rail, is a subsidiary of the Association of American Railroads, which conducts rail equipment testing and training for member railroads.
[4] S. Wilk and S. Galvan-Nunez, "Climatic Impacts on Railroad Infrastructure," *Technology Digest* TD23-015 (2023). AAR/MxV Rail. https://www.mxvrail.com/technology-digest/climatic-impacts-on-railroad-infrastructure/.

KEY RISKS AND THREATS

Extreme weather events, such as hurricanes, floods, and severe storms, in addition to sea level rise, pose immediate and disruptive threats to rail infrastructure, potentially causing extensive damage to track, bridges, and signaling systems, undermining their stability and increasing maintenance costs. Further, the rise in average temperatures presents a risk to the integrity of track infrastructure and contributes to the heightened probability of wildfires, which can destroy rail right-of-way and surrounding ecosystems. These environmental threats directly and indirectly impact human health, affecting both the workforce and the broader communities that depend on rail services.

Next, we will provide an overview of key risk areas, highlighting their potential impacts and providing essential information for the industry's forward-looking planning and resilience-building effort.

HEAT / TEMPERATURE



Credit: National Weather Service Three Month Outlooks

Heat waves have become more frequent in the United States since the 1960s, whereas extreme cold temperatures and cold waves have become less frequent. Recent record-setting warm years are projected to become common for the United States as annual average temperatures continue to rise. Railway infrastructure is greatly impacted by heat and temperature, posing a significant challenge for railway system engineers and maintenance teams.

What Aspects of Railroad Infrastructure Are Affected?

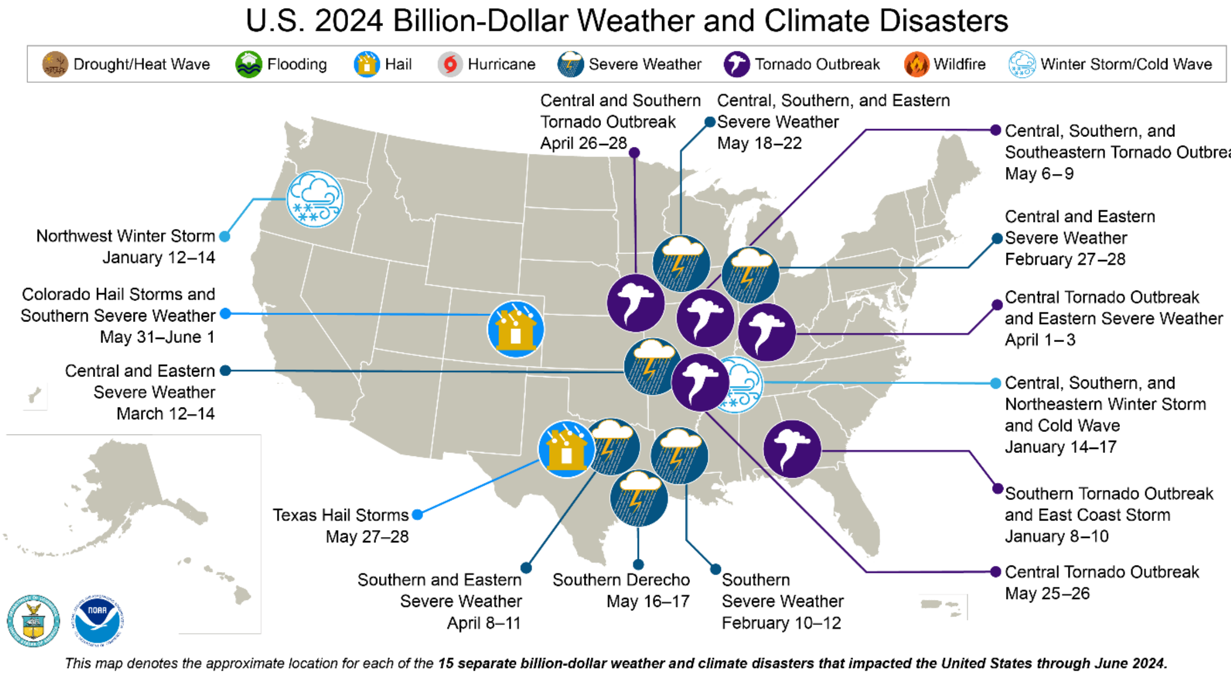
1. **Track Expansion:** The expansion limitations of steel used in the construction of track can lead to rail buckling. This phenomenon results in unwanted misalignment in rail lines and adverse effects on overall rail infrastructure.
2. **Material Degradation:** Railroad components such as ties (sleepers), fastening systems, and other structural elements can degrade faster due to high temperatures. This can affect wooden ties, which can dry out and become more vulnerable to wear and decay. Synthetic or composite materials used in ties and other components can also lose durability and elasticity when exposed to prolonged heat.
3. **Signal Systems:** Heat can affect the performance of electronic components, leading to malfunctions in signals, switches, and monitoring systems that are crucial for safe rail operations.
4. **Human Health:** Heat exposure adversely impacts railroad workers, both directly and indirectly influencing their health, safety, productivity, and overall working conditions.[5] The risk of heat-related illnesses for railroad workers includes heat exhaustion, heat stroke, dehydration, sunburns, and skin cancer.

Frequency of Heat Events:
From 1901 to 2016, the contiguous United States experienced a noteworthy increase in temperature, with a rise of 1.8°F (1.0°C) (National Climate Assessment, 2017, Executive Summary). Looking ahead to the next few decades (2021-2050), projections indicate that the average temperature in the United States is expected to climb approximately 2.5°F compared with the recent past (average from 1976-2005), despite the range of potential climate scenarios.

On average, the heat wave season in 50 major cities has become longer by 49 days compared with the 1960s. Out of these 50 cities, 46 have experienced a significant increase in the number of heat waves from the 1960s to the 2020s.

[55] As of publication, the Occupational Safety and Health Administration is drafting rules for heat exposure for workers.

EXTREME WEATHER EVENTS



Credit: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters

Extreme weather events pose challenges to railroad infrastructure. These events include hurricanes, floods, blizzards, wildfires, and other severe weather. The nature of these events and the impacts depend on the severity of the weather.

What Aspects of Railroad Infrastructure Are Affected?

1. **Tracks and Ballast:** Heavy rains and flooding can wash away ballast, causing tracks to sink, shift, or become uneven, which can derail trains. Debris carried by high winds can obstruct tracks and damage infrastructure.
2. **Bridges and Culverts:** Flooding can undermine bridge foundations through scour (removing sediment from around the foundations) or by depositing debris that blocks water flow, potentially leading to structural failures.
3. **Signal Systems:** High winds can damage overhead lines and other critical components. Floodwater can damage the electronic components of these systems, leading to signal failures and disrupting the ability to safely manage train movement. Snow and ice can obstruct switches and signals, disrupt electrical systems for track circuits, and increase derailment risk by obscuring tracks or causing ice accumulation.
4. **Railroad Embankments:** Many railroads are built on raised embankments to keep tracks dry. However, these structures can erode or be breached by floodwaters, undermining the tracks above.

Frequency of Extreme Events:
Between 1980 and 2024, 187 severe storms, 44 flooding events, 31 drought events, 62 tropical cyclone events, 22 wildfire events, 22 winter storm events, and 9 freeze events, each causing at least $1 billion in damages, have affected the United States (CPI-adjusted) (NOAA, 2024).

According to NOAA, the United States has seen a significant increase in the frequency of heavy rainfall events over the last few decades. NOAA predicted that from May 2023 to April 2024[ii] the coastal United States would experience between four to nine high-tide flood days—an increase from last year's prediction of three to seven days and about three times as many as typically occurred in 2000.

For the Mid-Atlantic, 9 to 15 high-tide flood days were predicted, an almost 350 percent increase since the year 2000. Along the western Gulf, 7 to 14 days are predicted, an almost 350 percent increase since the year 2000.

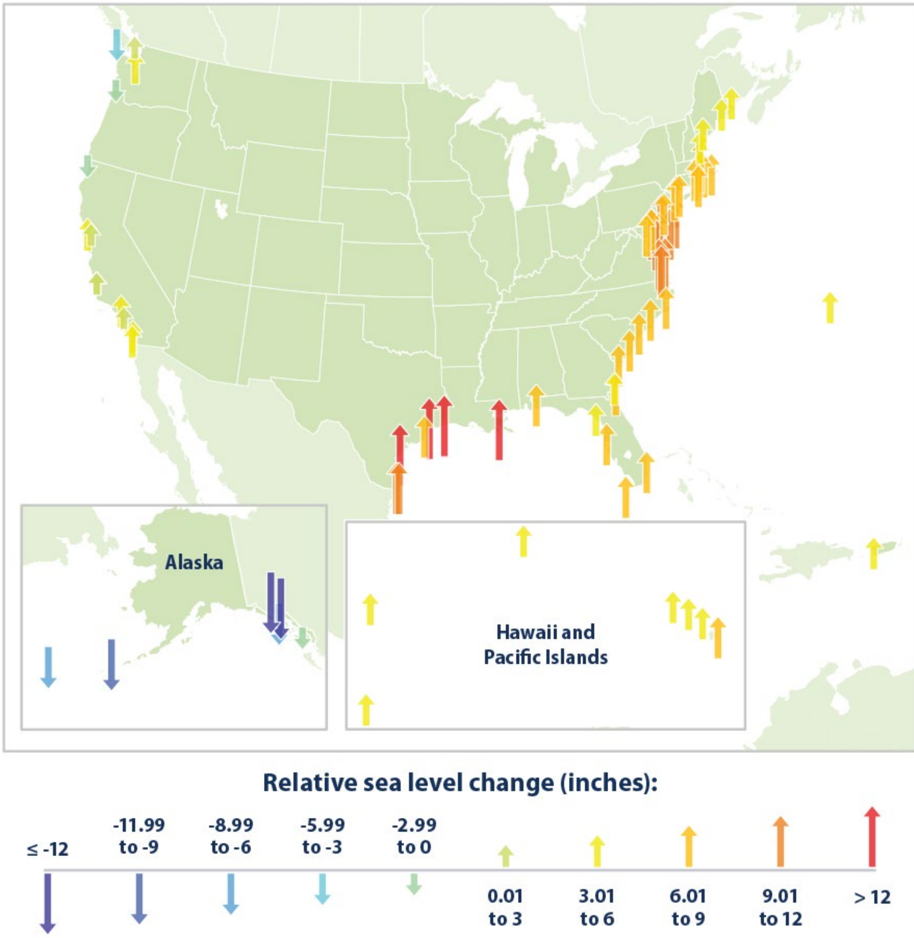
For the Pacific Northwest, 4 to 11 high-tide flood days were predicted—an approximately 150 percent increase from the year 2000. For the Pacific Southwest, one to five days are predicted, an almost 100 percent increase since 2000.

NOAA predicts that as sea levels continue to rise, our coastal communities will experience more frequent high-tide flooding—a national average of 45 to 85 days per year by 2050.

> *"Communities across the country are seeing more and more high-tide flooding, with damaging effects to transportation systems and infrastructure — particularly in our most underserved communities."*
>
> *– Jainey Bavishi, Assistant Secretary for Oceans and Atmosphere and NOAA Deputy Administrator.*

SEA LEVEL RISE

U.S. Sea Level Trend Map



Credit: EPA Relative Sea Level Change Along U.S. Coasts, 1960–2023[iii]

Sea level rise caused by global warming is a complex issue that affects infrastructure, natural resources, and urban planning. As sea levels rise, coastal and low-lying areas are increasingly at risk. This poses a significant threat to railroad infrastructure, which is often located in these vulnerable zones due to historic development patterns and the need to connect ports and coastal cities. The impacts of sea level rise on railroad infrastructure can be broadly categorized as physical damages, operational disruptions, and economic implications.

What Aspects of Railroad Infrastructure Are Affected?

1. **Erosion of Rail Embankments:** Rising sea levels have the potential to cause erosion of track bed and embankments, which can significantly impact their structural integrity.
2. **Coastal Rail Networks:** When coastal rail networks are damaged or lost, it can result in significant economic disruptions that affect local businesses, tourism, and the broader economy. This

underscores the critical importance of maintaining and safeguarding these networks.

3. **Bridges and Tunnels:** Increased flooding can cause bridge support to weaken through scour, where water erodes sediment around it. The increased hydrostatic pressures caused by sea level rise can increase the risk of flooding. Consequently, tunnels located near or below sea level are at higher risk of flooding.

Frequency of Sea Level Rise:
A sea level rise study[6] completed in 2016 indicated a 100-year storm surge, which is expected to begin occurring every 3 to 20 years, could cost billions of dollars in direct damage from one foot of sea level rise.

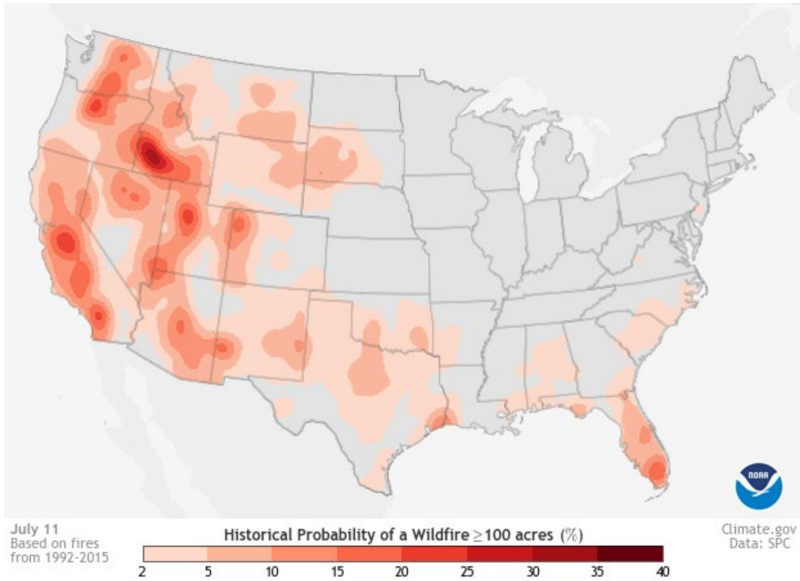
As more water enters the ocean through melting glacier runoff and thawing permafrost, as well as thermal expansion of water under direct heating, sea level rise will threaten coastal infrastructure.

The average global sea level rise has been 8 to 9 inches (21 to 24 centimeters) since 1880.

- In 2022, the average global sea level set a record high—4 inches above 1993 levels.
- The rate of global sea level rise is accelerating. It has more than doubled from 0.06 inches per year throughout most of the twentieth century to 0.14 inches per year from 2006–2015.
- In many locations along the U.S. coastline, the rate of local sea level rise is greater than the global average due to land processes like erosion, oil and groundwater pumping, and subsidence.

[6]Beatriz Azevedo de Almeida and Ali Mostafavi, "Resilience of Infrastructure Systems to Sea-Level Rise in Coastal Areas: Impacts, Adaptation Measures, and Implementation Challenges." *Sustainability* (2016 8(11)), 1115. https://www.mdpi.com/2071-1050/8/11/1115.

WILDFIRES



Credit: NOAA Climate Maps and Data[iv]

Wildfires pose a growing risk to railroad infrastructure. This threat is influenced by climate change, land management practices, and human activities. The impact of wildfires on railroads can be direct, resulting in physical damage to infrastructure, or indirect, causing disruptions in operations, economic losses, and safety concerns.

What Aspects of Railroad Infrastructure Are Affected?

1. **Tracks:** Wildfires can generate intense heat that may damage railroad tracks because high temperatures can cause the rails to warp. Additionally, heat from wildfires can cause the ties to deteriorate, especially wooden ties. Even concrete ties and ballast can be weakened by the intense heat from wildfires.
2. **Operations:** Wildfires can disrupt rail services, causing delays and cancellations for both passengers and freight, which result in logistical and economic impacts.
3. **Vegetation Loss:** The loss of vegetation from wildfires can lead to an increased risk of erosion, heightening the risk of flooding and mudslides, especially in hilly or mountainous regions.
4. **Human Health:** Smoke from wildfires can significantly reduce visibility, which poses risks to train operations. Additionally, air quality issues can affect the health of rail workers and passengers, particularly those with pre-existing respiratory conditions.

Frequency of Wildfires:
According to research, climate change is causing warmer, drier weather conditions, which in turn lead to longer and more severe fire seasons. Climate change has contributed to the increased aridity of forest fuels during the fire season, resulting in a decrease in the moisture content of fuels by over half in western U.S. forests between 1979 to 2015, and a doubling of the area burned by forest fires from 1984 to 2015.

Projections indicate that a 1°C temperature increase in much of the western United States would increase the median burned area per year by as much as 600 percent in some types of forests. In the southeastern United States, modeling suggests an increased risk of wildfires and a longer fire season, with at least a 30 percent increase in the area burned by lightning-ignited wildfires by 2060 compared with 2011.

FRA'S SAFETY ADVISORY 2023-07 RECOMMENDATIONS

On November 24, 2023, FRA issued *Safety Advisory 2023–07: Review and Implement New Predictive Weather Modeling and Proactive Safety Processes Across the National Rail Network to Prevent Weather-Related Accidents and Incidents* (88 Fed. Reg. 82500). The purpose of the Safety Advisory is to reduce weather-related accidents/incidents and improve the efficiency of the national rail network during severe weather events. FRA issued recommendations that railroads review existing policies, procedures, and operating rules related to predicting, monitoring, communicating, training, and operating during severe weather conditions or after extreme weather events. FRA also recommended that railroads collaborate to develop best practices for using weather forecasting technologies, predictive weather models, and weather-related action plans throughout the industry.

In addition to *Safety Advisory 2023-07*, FRA has issued other weather-related safety advisories, including an advisory, issued in 1997, which focused on railbed flooding impacts, and another issued in 2012, which focused on safety issues from excessive heat and track buckling.

The *Safety Advisory 2023-07* provided six recommendations to the rail industry:

1. Railroads should evaluate their **communication** and **training** programs, rules, policies, and procedures related to severe weather and ensure those programs are adequate for promptly implementing weather-related action plans.
2. Railroads should **evaluate** and **assess** their weather forecasting policies and procedures; railroads should consider integrating weather forecasting policies and procedures (and the outcomes from those policies and procedures) into dispatch operations and determine whether those policies and procedures should be incorporated into positive train control systems.
3. Railroads should evaluate their operating infrastructure to **identify** critical and geographical elements susceptible to severe weather events.
4. Railroads should evaluate existing weather-related action plans and ensure that those plans detail the

necessary **proactive planning,** maintenance, communication, and other actions necessary to address the risks presented by severe weather conditions.

5. Railroads should establish standard operating **thresholds** to ensure their weather-related action plans adequately prepare for severe weather events.
6. Railroads should **work together** to develop summaries for using weather forecasting technologies, predictive weather models, and weather-related action plans throughout the industry.

These recommendations are especially pertinent given the changes in modern weather patterns caused by climate change.

BENEFITS OF RESILIENCY PLANNING

1. **Implementing resiliency planning for railroads helps to minimize disruptions during natural disasters, ensuring efficient movement of goods and delivery of services.**

   Disruptions to railroad operations can have significant impacts on different stakeholders, including:

Railroad Operations: Interruptions in service, delays, and cancellations can disrupt schedules, increase operating costs, impact railroad workers, and affect the efficiency of freight and passenger transportation.

Passengers: Delays and cancellations can inconvenience passengers, disrupt travel plans, and lead to dissatisfaction with rail services.

Freight: Interruptions to freight transportation can delay the delivery of goods, increase transportation costs, and disrupt supply chains, affecting businesses and industries that rely on rail transportation.

Economy: Disruptions to railroad operations can have ripple effects throughout the economy, leading to lost productivity, reduced economic output, and negative impacts on local and regional economies.

2. **Resiliency planning can identify risks and prompt strategies to mitigate them, improving safety for passengers and employees.**

3. **Implementing resiliency planning can increase railroad system efficiency, reliability, and lead to cost savings for companies, benefiting consumers.**

CASE STUDY: CPKC RAILROAD INCIDENT

FLOOD RISK MANAGEMENT AND INFRASTRUCTURE RESILIENCE

In April 2023, unexpected high temperatures in western Maine led to the rapid melting of snowpack, causing increased water volume in a tributary to the Moose River. Simultaneously, a beaver dam blocked a culvert under the Canadian Pacific (CP; now known as Canadian Pacific Kansas City, or CPKC)[v] Railroad-owned tracks in the region. The resultant floodwater washed out the culvert and damaged the track bed, culminating in a train derailment, staff injuries, and property damage.

Incident Overview: Contributing Factors

- Unforeseen high temperatures in western Maine triggered rapid snowmelt.
- Increased water volume in a tributary to the Moose River exacerbated by a blocked culvert due to a beaver dam.
- The flooded culvert washed out, damaging the CP Railroad tracks.

Steps That Could Have Mitigated the Risk:

- Regular inspection and maintenance.
- Natural resources management.
- Updating culvert design and sizing.
- Investing in infrastructure upgrades.
- Installing a flood monitoring system.

Investigation and Regulatory Response:

- FRA investigated the incident.
- The investigation revealed that the combined effects of the beaver dam debris and heightened flooding—seven feet above normal levels—led to the washout.
- FRA issued a civil penalty to CP for failure to maintain the culvert, which contributed to the derailment.

Photo Credit: FRA Office of Railroad Safety

Outcome and Lessons Learned:

- Implementation of a larger culvert will improve the resilience of the CPKC railroad infrastructure against flooding events.
- Collaboration between CPKC, regulatory agencies, and scientific institutions facilitated informed decision making and proactive risk management.
  - CP collaborated with the United States Geological Survey (USGS) to assess flood risk and associated flood plains.
  - USGS provided data and tools to aid CP in understanding the flood risk and potential impacts on infrastructure.
- The incident underscored the importance of regularly monitoring and maintaining critical infrastructure to prevent disruptions and ensure safety.
- Lessons learned from this event can inform future infrastructure resilience strategies in areas prone to extreme weather events and natural hazards.

Conclusion:

The CP Railroad incident resulted from the combined effects of unusual weather and natural hazards. It exemplifies the critical need for proactive flood risk management and infrastructure resilience measures in mitigating the impact of natural disasters on transportation systems. Through collaborative efforts and informed decision making, CPKC and its partners addressed the vulnerabilities exposed by the incident, enhancing the safety and reliability of rail operations in flood-prone regions. This case study highlights the importance of integrating scientific expertise, regulatory oversight, and industry collaboration to build a resilient infrastructure capable of withstanding evolving environmental challenges.

RESOURCES & TOOLS

The tools and guides below are available to the public and States striving for resilience against climate impacts.

- Whole-of-government framework for climate services that highlights opportunities and challenges for both producers and users of climate information, tools, and resources.

  A Federal Framework and Action Plan for Climate Services

- View real-time statistics and maps documenting where people, property, and infrastructure may be exposed to hazards.

  Climate Mapping for Resilience and Adaptation (CMRA) overview

- The National Climate Assessment (NCA) summarizes the impacts of climate change on the United States, now and in the future. NCA released version five during the fall of 2023.

  Fourth National Climate Assessment (NCA4)

- The United Nation's IPCC provides Assessment Reports about the state of scientific, technical, and socioeconomic knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place.

  Intergovernmental Panel on Climate Change (IPCC)

- Resource for evaluating climate scenarios that provides an assessment of climate tools.

  Selecting Climate Information to Use in Climate Risk and Impact Assessments: Guide for Federal Agency Climate Adaptation Planners

- The USGS works in partnership with more than 1,885 Federal, regional, State, Tribal, and local agencies or organizations to maintain and manage a multipurpose network of stream gauges that monitor streamflow and (or) water level.

  USGS National Water Dashboard

- Overview of climate hazards and how you can protect vulnerable assets.

  U.S. Climate Resilience Toolkit

- NOAA' s Center for Environmental Information tracks wildfires with their monthly fires report.

  Track the Wildfire Season

- Often, the best source for local climate change information and impacts data is your State Department of Transportation.

  State Departments of Transportation

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NOTES

[i] According to the United Nations Office for Disaster Risk Reduction (UNDRR), building resilience in infrastructure systems is estimated to add just 3 percent to the total investment cost.
[ii] The Annual High Tide Flooding Outlook provides the number of high tide flooding days predicted for the coming meteorological year (May to April). Data is supplemented with decadal projections for the year 2050, sea level rise scenarios. There is currently no national annual data that is identified on the Annual High Tide Flooding Outlook: https://tidesandcurrents.noaa.gov/high-tide-flooding/annual-outlook.html.
[iii] This map shows cumulative changes in relative sea level from 1960 to 2023 at tide gauge stations along U.S. coasts. Relative sea level reflects changes in sea level as well as land elevation.
[iv] Historic Probability of Large Wildfire Map was produced by using daily fire records from the beginning of 1992 through the end of 2015. Meteorologists who specialize in predicting fire weather-plotted all fires of 100 acres or larger on a map. Grid lines on the map divide the entire area into rectangles—called grid cells—approximately 50 miles on a side. For every day of the year, scientists counted the number of years each grid cell contained at least one qualifying fire, and then divided by the total number of years.
[v] In reference to the case study, at the time of incident the company was known as CP railroad. The company is known now as CPKC.