

TECHBRIEF



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Impacts of Wildfires on Highway Assets

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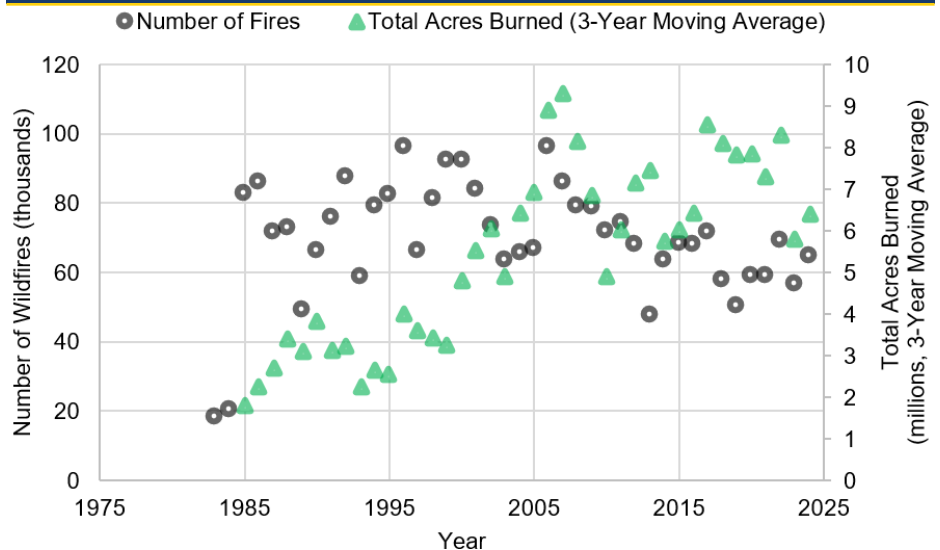
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BACKGROUND

Over the past several decades, the United States has seen a steady increase in the intensity and extent of wildfires, especially in the Western States. Figure 1 presents data on the number of wildfires and total acres burned in the United States between 1981 and 2021 (National Interagency Fire Center (NIFC) n.d.). While the number of wildfires shows a relatively constant trend, the total acres burned over a 3-yr period shows a steady increase. According to recent data, the largest and most destructive wildfires have mostly occurred since 2000 (Legislative Analyst's Office 2020).

Wildfires cost agencies and the public billions of dollars in economic loss due to property damage, environmental damage, fire suppression efforts, cleanup efforts, and litigation (Congressional Budget Office (CBO) 2022). Specific to transportation infrastructure, wildfires have destroyed or caused extensive damage to roads, bridges, and drainage structures. In several cases, State and local agencies have been forced to close roads and highways, sometimes for extended periods. Detours from these closures can be lengthy, and existing pavements on the detour routes may not be adequately designed or in adequate condition to handle the volume and weight of additional loadings. A secondary hazard is postfire flooding. Wildfires leave areas vulnerable to decreased vegetation, decreased soil infiltration capacity and

Figure 1. Graph. Total number of wildfires per year and acres burned per 3-yr period in the United States (NIFC n.d.).



Source: FHWA (National Interagency Fire Center n.d.).

stability, and the potential for hydrophobic layers—all of which increase flooding potential. It is not uncommon for the aftereffects of wildfires to result in 1,000-yr floods within the first 1 to 2 yr after a wildfire when combined with high-intensity rain (Fraser, Chester, and Underwood 2020).

Federal, State, and local agencies alike are increasingly recognizing the effect of wildfires on pavement and roadway infrastructure. Much has been learned in the past several years regarding the impacts of wildfire events on infrastructure assets as well as the planning, management, and recovery needs for those assets. The purposes of this TechBrief are to accomplish the following:

- Document the current state of knowledge on the direct and indirect impacts of wildfires on pavement systems based on a comprehensive literature review.
- Summarize lessons learned from interviews conducted with local, State, and Federal agencies on their experiences in dealing with the impacts of wildfires.
- Identify knowledge gaps and research needs.

IMPACT OF WILDFIRES ON PAVEMENT MATERIALS AND TRANSPORTATION INFRASTRUCTURE

Wildfires have direct impacts on pavements and other transportation infrastructure, such as burn scars on the pavement surface, melted culvert pipes, burned traffic signals, guardrails, signage,

fencing, and bridges. However, most of the damage to pavement and other infrastructure are indirect effects resulting from increased heavy truck traffic loadings from detoured traffic, fire suppression vehicles, and postfire cleanup efforts. Additionally, postfire flooding can result in debris flow, resulting in clogged or damaged drainage systems, as well as loss of pavement structural capacity due to inundated unbound layers and subgrade (Signore 2020; Fraser, Chester, and Underwood 2020). The following sections further describe these impacts.

Pavements and Materials

With respect to pavements, wildfires can potentially affect their serviceability in any or all of the following ways:

- Direct impacts:
 - Surface damage during the fire event, which could lead to melted pavement, potholes, raveling, and delamination (as shown in figure 2).
 - Strength loss, shrinkage, and cracking of pavement materials due to exposure to extreme temperatures.
- Indirect impacts:
 - Structural damage to the pavement because of the increase in both the number and weight of the heavy truck traffic loadings from detoured traffic, fire suppression vehicles, postfire cleanup operations, and rebuilding activities.

Figure 2. Photo. Examples of fire-scorched pavement surfaces.



A. Delamination.



B. Raveling.

- Potential damage due to postfire flooding (e.g., complete washout and debris flow, loss of structural capacity due to inundated unbound layers and subgrade).
- Pavement damage because of clogged or damaged drainage systems (e.g., clogged culverts).

Asphalt Materials

During a fire event, asphalt materials can become mechanically unstable and emit harmful gases (Androjić and Dimter 2022). In tunnels or underground garages lacking ventilation, these conditions can lead to compromised safety for exposed personnel. Physical-chemical material changes during fire exposure include inflammability, flame spread rate, ability to generate toxic smoke, and thermal power (Rimac, Simun, and Dimter 2014). Temperatures during wildfires can often exceed 2,000 °F (Keirn, Burks, and Zappell 2019); in extreme conditions, wildfires have the potential to reach 2,200 °F (Office of Communications and Publishing (OCAP) 2024). Asphalt binders can easily catch on fire at temperatures between 802 and 986 °F (Keirn, Burks, and Zappell 2019). Typical changes in roadway temperatures range from 37 °F to 566 °F within 5 h of ignition of a wildfire, depending on specific location along the roadway and fuel conditions (Barzegar and Wen 2023). Within 5 minutes of the beginning of heating, the asphalt binder can emit toxic gases, including carbon

monoxide, carbon dioxide, and sulfur dioxide; inhaling these gases can lead to suffocation, and they are also carcinogenic. Aggregates in the asphalt mixture, while still present, can separate from the binder, making the asphalt mixture mechanically unstable (Noumowe 2003).

Fire damage to asphalt materials is most severe in tunnels, where the fire is enclosed and can break down the stability of the asphalt mixture and produce toxic fumes. However, fire impacts on asphalt pavements can be found outside of tunnels as well. During wildfires, asphalt roadways do not generally undergo combustion due to two main reasons. First, aggregates, fillers, and air (generally noncombustible materials) comprise approximately 90 percent of the asphalt concrete mixture by volume. Second, the ignition temperature of asphalt binder is between 880 and 1,060 °F (California Department of Transportation (Caltrans) 2003), significantly higher than the mix temperatures typically reached. However, the typical roadway temperatures of up to 566 °F during wildfire events are likely to melt the binder (Barzegar and Wen 2023). Fire also can arise from other sources (such as stalled or abandoned cars), which can lead to roadway damage. For example, during the 2018 Camp Fire near Paradise, CA, vehicles left on or next to the road became ignition sources for the fire, producing extreme heat (Mattox 2020). This event resulted in substantial damage to the asphalt surface, as shown in figure 3.

Figure 3. Photo. Damage to asphalt pavement due to Camp Fire (National Institute of Standards and Technology 2023).



Source: Technical Discussion 041 from National Institute of Standards and Technology Report.

Concrete Materials

Concrete can be a more attractive material for use in areas likely to be impacted by wildfires because it is a poor conductor of heat and has increased fire resistance compared to asphalt. However, considerable damage to concrete is possible when exposed to fire. Understanding the heating history of concrete exposed to fire can help determine if a concrete structure and its components are structurally sound. This evaluation typically begins with visual observation of color change, cracking, and spalling (Georgali and Tsakiridis 2005). Table 1 lists the impact of high temperature on concrete color and other possible physical effects associated with exposure to high temperature.

While these temperature–strength relationships found through laboratory testing are useful (Georgali and Tsakiridis 2005), studies that focus on the structural integrity of concrete pavements after a wildfire event are not well-documented. Devices, such as the rebound hammer (ASTM International (ASTM) 2018) can be used to evaluate the extent of fire damage on concrete by comparing the measurements performed on sound concrete and concrete exposed to fire.

Soil

Wildfire events often result in surface issues, such as soil erosion and slope instability. These issues can potentially lead to loss of human life, property damage, reduction in mobility, and damage to transportation infrastructure (Arizona Department of Transportation (ADOT) 2020). Material may directly block roadways, and hillslope material can move into stream channels and overwhelm culverts, leading to prolonged road closures. Additionally,

potential changes in soil productivity and increased sedimentation may have consequences on food production, water quality, recreational and aesthetic uses, and other ecosystem services provided by the soil (Jain et al. 2012). Geogrids are commonly used to mechanically stabilize and reinforce weak subgrade soils (Tutumluer, Huang, and Bian 2009). However, since geogrids are typically made of polymeric materials, they can potentially burn and melt during wildfires if exposed to high temperatures.

Debris Flow

Extreme wildfire events followed by precipitation can cause debris flow, endangering downslope infrastructure. Excess water and debris flow increase the likelihood of functional or structural failure of transportation infrastructure elements, including culverts, bridges, and drainage systems. Burned areas are susceptible to flooding due to decreased vegetation, decreased soil infiltration capacity and stability, and possible hydrophobic layers (or water-repelling soil conditions) due to extreme heat (DeBano 1981).

Bridges

Bridges are vital components of a transportation network because they provide transportation connectivity to safely cross features, such as waterways, railways, roadways, and other obstructions. However, high-temperature fires can threaten structural bridge members and lead to collapse (Garlock et al. 2011). Additionally, no common design standards or codes related to fire protection of bridges currently exist (Refai 2020). Figure 4 shows the remains of a burned timber bridge that collapsed during the Dixie Fire in Plumas National Forest, CA, in 2021.

Table 1. Visual evidence of temperature to which concrete has been heated based on Georgali and Tsakiridis (2005).

Concrete Color	Concrete Color Temperature Range	Trigger Temperature for Physical Effect	Possible Physical Effects
Black or gray to buff	1,110–1,740 °F	1,650 °F	Powdered, light colored, dehydrated
		1,470 °F	Spalling, exposing <25 percent reinforcing bars
Pink to red	570–1,110 °F	1,070 °F	Popouts over chert or quartz aggregate particles
		1,020 °F	Deep cracks
Normal	100–570 °F	570 °F	Surface crazing
		100 °F	None

Figure 4. Photos. Remains of a fire-damaged timber bridge in Plumas National Forest.



A. Timber substructure elements with signs of severe fire damage.



B. Recovered steel girder with intact cross bracing.

Source: FHWA.

Culverts

Wildfires impact culverts in several ways. Firstly, polyvinyl chloride (PVC) and high-density polyethylene (HDPE) pipes are prone to melting during wildfires due to miniature fires that ignite inside open-ended culverts from low-flying embers (Mattox 2020). This direct impact from wildfires was reported by several transportation agencies interviewed as part of this study.^{1,2} When culverts are completely burned, there is risk of collapse, threatening the integrity of the roadway above (figure 5). Beyond the direct effects, an indirect wildfire impact on culverts occurs from postfire flooding and debris flow, which can overwhelm culverts and other drainage structures.

Zhao et al. (1998) documented the fire resistance of various types of pipes:

- Concrete: Generally higher fire resistance than other material types.
- Corrugated steel: Most coatings used for corrosion protection are flammable.

- HDPE: Flammable.
- PVC: Flammable with lower flammability rating than HDPE.

ASTM is considering the development of a guide for resilience-based design of culvert and storm drainpipes exposed to wildfire events (<https://www.astm.org/workitem-wk77797>) (ASTM 2025).

Other Infrastructure Assets

Wildfires can have lasting impacts on other key transportation infrastructure assets, such as signs, signals, and guardrails. During the 2020 Oregon wildfires, for example, temperatures increased to the point where metal signs were warped, and the wooden ties holding up guardrails vaporized (Ross 2020). Damage to guardrails, signage, and fencing are direct impacts noted by several agencies (figure 6). One agency observed an entire traffic signal and its underground wiring destroyed by a wildfire.³

¹Virtual interview conducted with U.S. Forest Service staff in California and Utah on May 9, 2023.

²Virtual interview conducted with Paradise town manager on August 30, 2023.

³Virtual interview conducted with Paradise town manager on August 30, 2023.

Figure 5. Photo. Collapsed culvert after Camp Fire (Mattox 2020).



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Figure 6. Damage to signs and guardrails due to 2020 Oregon wildfires (Creative Commons n.d.).



A. Sign damaged by wildfire.



B. Guardrail post destruction.

Source: Oregon DOT (ODOT).

POSTFIRE ACTIVITIES

Impact of Response and Recovery Activities on Pavement Performance

Damage from debris removal and reconstruction often threatens the structural integrity of pavements. In fact, fire-related damage to pavements often occurs postfire due to increased heavy truck traffic used for debris removal and reconstruction. For example, after the Camp Fire, more than 3.66 million tons of ash, debris, metal, concrete, and contaminated soil were removed over a 9-mo period.

Additionally, trees deemed hazardous were removed immediately following the fire, adding more heavy traffic to the roads (Mattox 2020).

Postfire Pavement Condition Evaluation

Burn scars occurring during wildfire events, combined with debris removal following a fire, often lead to extensive structural damage to pavements. Presently, published studies on assessing pavement structural damage after a wildfire are limited. However, Mattox (2020), in discussing the Camp Fire, offers two approaches to assessing pavement

damage: (1) the theoretical equivalent single-axle load (ESAL) method and (2) surface inspection based on the pavement condition index (PCI) methodology. These approaches are described in the following sections and may need to be used together when assessing fire-related damage to pavements.

ESAL Method

The theoretical ESAL method is based on the American Association of State Highway and Transportation Officials (AASHTO) 1993 *Design Guide for Pavement Structures*, specifically appendix D, which focuses on converting mixed traffic to ESALs for pavement design (AASHTO 1993). The ESAL method does not depend on measurement of visible distresses but instead considers the increase in traffic weights and volumes to determine how much life was lost due to fire-related traffic. A simplified application of this approach is to determine the pavement fire damage as the ratio of the fire-related ESALs to the design ESALs. The ratio is then multiplied by the replacement cost to determine the damage value (Signore 2020). A simple example of the ESAL method is illustrated in table 2.

Based on the example illustrated in table 2, the damage value because of the fire-related traffic is \$80,000, and this value is regardless of any visible distress increase observed.

The ESAL method has limitations because it may not capture immediate (visible) damage to a pavement surface. This damage could include raveling, rutting, and age-related cracking. A visual pavement assessment may be needed to identify obvious areas of fire-related damage (e.g., melted, raveled pavement).

PCI Method

The PCI procedure based on the ASTM (2020) D6433 standard is a commonly used approach to visually assess pavement surface condition, providing engineers with a consistent, objective, and repeatable method to represent the overall pavement condition. The PCI scale ranges from a value of 0 (representing a pavement in failed condition) to a value of 100 (representing a pavement with no distress). In general, pavements with PCIs greater than 70 are candidates for routine maintenance and restoration activities. Pavements with PCIs between 40 and 70 may benefit most from major rehabilitation (such as an overlay), and pavements with PCIs below 40 are typically candidates for reconstruction. Since the PCI rating is a numerical measure of the existing condition of the pavement based on the distresses observed on the pavement surface, the results provide an indication of the structural integrity and functional capabilities of the pavement. However, it is important to remember that the PCI is only an indirect indicator of the overall condition of the pavement since only the surface of the pavement is examined; thus, the structural load-carrying capabilities of the pavement are not directly measured. Nevertheless, the PCI does provide an objective basis for determining maintenance and rehabilitation needs and establishing priorities in consideration of fiscal constraints.

If pre- and postfire PCI data are available, the change in PCI may result in a change in an agency's maintenance strategies and costs. The difference in costs between pre- and postfire treatment costs can be used to calculate the fire damage cost. For example, if the recommended treatment prior to the

Table 2. ESAL method example (based on Signore 2020).

Steps	Example
Step 1: Estimate design traffic for pavement subjected to fire-related traffic	Estimated design traffic = 400,000 ESALs
Step 2: Estimate replacement value of pavement	Pavement replacement value = \$800,000
Step 3: Estimate fire-related traffic	Fire-related traffic = 40,000 ESALs
Step 4: Calculate fire damage ratio	Fire damage ratio = $(40,000/400,000) = 10\%$
Step 5: Calculate damage value	Damage value = $10\% \times \$800,000 = \$80,000$

fire costs \$3 per yd², and the appropriate treatment strategy after the fire is expected to cost \$8 per yd², the fire-related damage for a 10,000-yd² pavement area would amount to \$50,000 (($\$8 - \3) \times 10,000 yd²). If there is no PCI change, the impact of fire on the current pavement maintenance treatment is \$0 (Signore 2020).

Again, the PCI method has limitations because it only captures the visible distress at the surface. It is also a metric that combines distresses associated with loading (e.g., fatigue cracking, rutting) and environmental conditions (e.g., transverse cracking). Theoretically, the same PCI value can be calculated with different combinations of these distresses; thus, any changes in visible load-related distresses should be considered along with changes in PCI (pre- and postfire). Furthermore, the expected annual change in PCI (without a fire event) has to be considered, as some level of annual deterioration is expected.

Approaches to Repair Damage

Postfire repair begins with hauling out debris. This removal process can include fallen trees blocking roadways, debris from damaged roadway assets (e.g., guardrails, signage, fencing, bridges, culverts), adjacent damaged or uprooted trees, materials from debris flow, and other types of debris. Once the roadway is cleared and no longer hazardous, a visual assessment is often performed to determine whether the road can be reopened or if additional repair activities are needed prior to opening to traffic. The pavement repair approach depends on the type and severity of pavement distresses and the level of funding available. Due to funding constraints, agencies have primarily focused on performing localized repairs, such as spot patching, localized asphalt concrete mill and fill, and full-depth reclamation treatments.

During fires, culvert and bridge components are often melted or burned beyond repair, and replacement is the only solution. If possible, PVC and HDPE culvert

pipes and timber bridges should be replaced with less flammable materials, such as concrete and steel.

Debris flow may wash out unbound material in and around culverts, leading to collapse and potentially compromising the roadway above. In such cases, the roadway may need localized reconstruction and replacement or repairs to the culvert to address structural issues. Debris clogging culverts will also need to be removed. Other burned roadway assets, including guardrails, signage, and fencing, should also be replaced.

The amount of funding needed to address damage from wildfires depends on numerous factors, including the following (Signore 2020):

- Extent and severity of damage.
- Type of road(s) (classification, pavement type, thickness, etc.).
- Layout of road(s) and locations of fire damage.
- Nature of fire response traffic patterns and durations.
- Type of trucks loading the pavement.

AGENCY LESSONS LEARNED IN WILDFIRE RESPONSE

To learn more about how agencies have dealt with wildfire impacts on roadway and transportation infrastructures, the research team conducted interviews with the following entities:

- U.S. Forest Service (regions 4 and 5).⁴
- Town of Paradise.⁵
- New Mexico DOT.⁶
- Government of Alberta, Canada, Transportation and Economic Corridors, Peace Region.⁷
- ADOT.⁸
- Washington State DOT.⁹

⁴Virtual interview conducted with U.S. Forest Service staff in California and Utah on May 9, 2023.

⁵Virtual interview conducted with Paradise town manager on August 30, 2023.

⁶Virtual interview conducted with New Mexico DOT staff on September 1, 2023.

⁷Virtual interview conducted with Province of Alberta provincial pavement engineering director, regional director, and city operations manager on October 30, 2023.

⁸Virtual interview conducted with Arizona DOT staff on November 6, 2023.

⁹Virtual interview conducted with Washington DOT staff on January 31, 2024.

- Independent researcher from the University of Colorado, involved in the investigation of postfire impacts of pavement overload after the Marshall Fire in Colorado in 2021.¹⁰
- Lahaina, HI: Hawaii Asphalt Paving Association.¹¹

Following are the main lessons learned from the interviews:

- Direct impacts of wildfires on pavements are generally limited and localized. Agencies noted that the direct impacts of wildfires on pavements (e.g., pavement damage because of burned asphalt) are mainly due to abandoned vehicles left on the road that become fuel sources for the fire.^{12,13} Based on limited coring conducted after the Marshall Fire in burned areas beneath vehicles, Senseney (2024) reported that the asphalt appeared to have sustained heat-related damage to a depth of approximately 2.5 to 3.5 inches below the pavement surface; this damage needed the removal of up to 4 inches of asphalt

before the placement of an overlay. Figure 7 shows an example of a severely burned area during the Marshall Fire and a core extracted from the burned location.

- Burned asphalt pavement areas are more susceptible to cracking and raveling. Asphalt pavement surfaces that have experienced high temperatures during wildfires are likely to experience accelerated cracking and raveling (Mattox 2020). Several burn scars on Skyway Road in Paradise exhibited raveling and cracking within 2 yr after the Camp Fire (figure 8). Note the raveling and cracking in figure 8 does not extend past the burn scar into other pavement that was likely exposed to excess heat but did not have a fuel source (e.g., an abandoned car) parked directly over it.
- Indirect impacts from wildfires tend to cause most of the damage to pavements and other transportation infrastructure. The main indirect impacts are due to postfire flooding, debris

Figure 7. Photos. Severely burned pavement after Marshall Fire.



A. Burned pavement from car.

B. Burned core.

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¹⁰Virtual interview conducted with University of Colorado, Boulder independent researcher studying Marshall Fire on January 30, 2023.

¹¹Virtual interview conducted with Lahaina, HI Hawaii Asphalt Paving Association staff on January 30, 2024.

¹²Virtual interview conducted with Province of Alberta provincial pavement engineering director, regional director, and city operations manager on October 30, 2023.

¹³Virtual interview conducted with University of Colorado, Boulder independent researcher studying Marshall Fire on January 30, 2023.

Figure 8. Photo. Cracking and raveling in burned area on Skyway Road in Paradise.



Source: FHWA.

flow, and pavement overloading from response and recovery traffic. NMDOT noted that chip seal roads incurred the most damage due to overloading since these roads are not structurally designed to handle heavier loading and increased traffic volumes.¹⁴ The Town of Paradise indicated that cracking and rutting quantities (based on pavement condition data collected) had significantly increased on many routes after the fire due to debris removal traffic and other clean-up and rebuilding efforts.¹⁵ Most U.S. Forest Service roads are relatively thin (less than 2 inches) bituminous surface treatments on existing grade.¹⁶ These pavements have experienced washouts due to postfire flooding in areas with unsupported shoulders (figure 9) and are prone to further damage from timber hauling traffic (figure 10) and other hydrologic events that may occur after wildfire.

- Culverts and other drainage structures, such as drop inlets, catch basins, and ditches, have to be cleaned after fire events, as they are often clogged with debris (figure 11 and figure 12). It is important to inspect and clean all main drainage structures to ensure effective water flow

and minimize water on the roads. After fires, drainage structures may need greater frequency of inspection and maintenance due to higher potential for landscape erosion.

- Trash racks placed in strategic locations can limit damage to roads. Placement of trash racks in expected downstream flow areas can prevent debris that can clog culverts and potentially make roads impassable.¹⁷ Figure 13 shows a wooden trash rack structure in Plumas National Forest.
- Geogrids and geotextiles can provide stability to road surfaces. The U.S. Forest Service personnel indicated the use of geogrids and geotextiles beneath the bituminous surface treatment layer helped in preventing complete washouts of the road surface after flooding events in certain areas.¹⁸
- Effective communication and coordination among all involved agencies are vital to successful fire management and disaster response efforts. By fostering relationships and maintaining open lines of communication (between multiple agencies, such as county maintenance units, fire departments, emergency

¹⁴Virtual interview conducted with NMDOT staff on September 1, 2023.

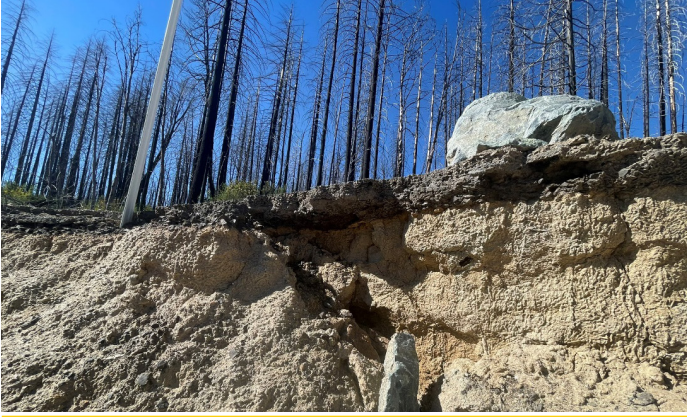
¹⁵Virtual interview conducted with Paradise town manager on August 30, 2023.

¹⁶Virtual interview conducted with U.S. Forest Service staff in California and Utah on May 9, 2023.

¹⁷Field visit with Paradise staff on October 17, 2025.

¹⁸Virtual interview conducted with U.S. Forest Service staff in California and Utah on May 9, 2023.

Figure 9. Photo. Washout due to postfire flooding on a U.S. Forest Service Road in Plumas National Forest.



Source: FHWA.

Figure 10. Photo. Timber-hauling truck on U.S. Forest Service Road in Plumas National Forest.



Source: FHWA.

Figure 11. Photo. Clogged culvert.



Source: FHWA.

Figure 12. Photo. Clogged drop inlet.



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Figure 13. Photo. Trash racks to catch debris in downstream flow area in Plumas National Forest.



Source: FHWA.

services, and forestry departments) before disasters occur, agencies can better prepare and respond to emergencies. These relationships ultimately save lives and minimize the impact of fires and other disasters.

- Use of proactive measures can minimize damage. Agencies suggested various proactive measures that could be employed to minimize damage caused by wildfires and associated impacts.^{19,20} These measures include applying fire retardants to guardrails, reducing tree and fuel density (by removing deadfall, underbrush, and other flammable debris), enhancing evacuation routes (with improved route designation, increased structural capacity, public communication, etc.), eliminating dead-end streets by creating an interconnected network of roadways, and burying utilities underground.
- Improved coordination among funding authorities is needed to ensure an efficient system to facilitate effective funding allocation for infrastructure rehabilitation efforts. All the agencies participating in the interviews (see footnotes 4–13 on page 8–9) emphasized the need for better coordination among funding authorities (e.g., Federal Emergency Management Agency, Federal Highway Administration) to streamline the funding process and ensure agencies receive the financial support needed for infrastructure rebuilding efforts in a timely manner; ideally, this funding should include the consideration of both direct and indirect impacts of damage caused by wildfires. Current regulations for non-Federal aid and Federal aid routes are found in the Code of Federal Regulations (CFR) (CFR 2024a; CFR 2024b).

STRATEGIES TO IMPROVE HIGHWAY INFRASTRUCTURE RESILIENCE

The following actions can be taken to help improve the resilience of pavements to wildfire events:

- Establish prefire baseline conditions and periodically monitor key pavement performance indicators: To determine the damaging impacts of wildfires on pavements, an important first step is to periodically monitor pavement performance indicators to help evaluate pre- and postfire

performance and establish the damaging impacts that can be attributed to wildfires and postfire response and recovery events. Standardized methodologies, such as the PCI method (as described in the ASTM (2020) D6433 standard) can be used to document distress types, severities, and extents (Signore 2020). Implementing a pavement management system, flagging high-risk fire routes, designating potential fire suppression and evacuation routes, and identifying areas of repeated damage can help agencies better manage these routes within the pavement network.

- Assess conditions immediately after a fire event: Impacts on the pavement should be assessed as quickly as practically feasible following a fire event using the following methods (Signore 2020):
 - Pavement Condition Survey: Manual or automated distress condition survey procedures may be used (ASTM (2020) D 6433). Ensuring that the pavement is free of debris prior to commencing the survey is crucial. For manual surveys, capturing photographs and video footage is essential to document the surface of the pavement and other features, such as drainage structures, slopes, and damage to other ancillary assets, including culverts, signs, and guardrails.
 - Structural Condition Evaluation: The structural integrity of the pavement should be assessed, ideally immediately postfire and then again post-debris removal. To assess the structural condition of a pavement using nondestructive test methods, such as falling weight deflectometer, knowing the pavement structure (layer types, thicknesses, and subgrade characterization) is vital. Additionally, information on fire-related traffic should be documented (e.g., truck weights, sizes, number of applications, start and end locations, and fire-response staging areas).
- Use fire-resistant materials: In fire-prone areas, the authors recommended that agencies consider using fire-resistant materials, such as concrete and steel, for culverts in place of HDPE, PVC, or corrugated metal pipes. For example, the Town of Paradise replaced all HDPE culverts

¹⁹Virtual interview conducted with Arizona DOT staff on November 6, 2023.

²⁰Virtual interview conducted with Paradise town manager on August 30, 2023.

with concrete after the Camp Fire (figure 14).²¹ Additionally, in areas prone to flooding, agencies may also consider increasing the capacity of the culverts and installing debris-capturing devices. Finally, agencies should also consider replacing wooden or plastic guardrail and sign components with metal components (e.g., steel, aluminum, or galvanized steel) to improve fire resistance.

- Improve evacuation plans. After the Camp Fire, Paradise received grant funding to develop a transportation master plan, which includes evacuation plans (Town of Paradise 2022). One key takeaway was that widened bike paths and center two-way turn lanes can be used as secondary evacuation assets to provide added capacity during an emergency event. This added capacity can be particularly effective in rural communities that do not have or have yet to build major highways. After the Camp Fire, the Town of Paradise removed raised medians along Skyway Road and replaced them with center two-way left-turn lanes (figure 15).

CONCLUSIONS

Wildfires can have detrimental impacts on roadways, both directly and indirectly. Direct impacts include physical damage caused by flames and heat to the pavement surface and other ancillary assets (such as culverts, guardrails, and signs) and reduction in mobility. Indirect impacts can include erosion, settlement, and structural damage to the pavement structure due to postfire flooding and debris flow, debris hauling, and other response and recovery efforts.

Wildfires can potentially shorten pavement serviceability in the following ways:

- Surface damage during the fire event itself can lead to melted pavement, potholes, raveling, and delamination.
- Structural damage to the pavement is caused by increased heavy truck loadings from fire suppression vehicles, postfire cleanup, and rebuilding activities.
- Strength loss, shrinkage, and cracking of pavement materials is caused by exposure to extreme temperatures.

Figure 14. Photo. Concrete culvert pipe in Paradise, replacing an HDPE pipe.



Source: FHWA.

Figure 15. Photo. Building Resiliency Center on Skyway Road in Paradise.



Source: FHWA.

²¹Virtual interview conducted with Paradise town manager on August 30, 2023.

- Pavement damage is possible from postfire flooding (e.g., complete washout and debris flow, loss of structural capacity due to inundated base layer).
- Fire-related debris and postfire flooding (e.g., inundated base layer, standing water on pavement surface, washout) may cause clogged and damaged drainage systems and further pavement damage.

The public agencies interviewed for this study (see footnotes 4–13 on page 8–9) indicated that the indirect impacts of wildfires tend to cause the most fire-related damage to pavements and other transportation infrastructure. The main indirect impacts derive from postfire flooding and debris flow and pavement overloading due to response and recovery traffic.

The impact of wildfires on pavement systems is a complex topic, as there are many factors that can contribute to pavement damage. Understanding and mitigating the impacts of wildfires on pavement systems is essential for ensuring the safety of road users and designing a more resilient transportation system. Determining the extent and details of the pavement damage caused by fires and associated response and recovery efforts can be challenging, particularly when the damage is not visible or if prefire pavement conditions are not documented. Therefore, routinely monitoring pavement condition and establishing pavement management programs in wildfire-prone areas is crucial.

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