Impacts of Climate Change on Idaho's Infrastructure

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Key Points

- Idaho's infrastructure likely will be impacted by climate change and climate change-related weather events.
- Infrastructure systems – including those in Idaho – are both internally, within a system (e.g., stormwater management), and externally, across systems (e.g., transportation and energy), connected. Weather-related disruptions in one system often cascade into other systems, which can greatly increase economic impacts of a disruption.
- Since infrastructure systems are internally and externally connected, the integrity of the entire infrastructure system is determined by the strength of the most vulnerable link.
- In the short-term, climate change impacts on infrastructure in Idaho will mostly be in the form of an increase in disruptions caused by weather-related events, such as avalanches, floods, landslides, and wildfires.
- Utilizing models that take into account future climate conditions, infrastructure managers can rethink facilities, operations, and maintenance practices on a longer-term scale.
- It is difficult to quantify economic consequences, since they are dependent on the location and duration of the disruption in infrastructure. That said, economic impacts can be significant.[1]

1. Introduction

Infrastructure consists of the basic facilities and networks that are needed for a functioning economy. In Idaho, this includes road and rail systems, information and communication networks, energy networks, water and wastewater facilities, and air and seaports.[2] Infrastructure is not only essential for communities to function, the quality and reliability of infrastructure systems also factor into corporate location decisions.

Infrastructure usually requires large investments in assets that are designed to operate over the long-term. Bridges have a typical design life of 50-60 years and hydropower dams and large geotechnical structures are designed for up to 100 years of use (McKinsey, 2020). Infrastructure systems often comprise geographically extensive interdependent networks; disruptions in one system often affect other systems. As a consequence, when infrastructure systems are compromised, cumulative losses are often substantial and disproportionately large. In Idaho, a mudslide and consequent closure of one road can (often for days

[1]Ada County's 2017 Hazard Mitigation Plan provides some cost estimates for a variety of events (Ada County, 2017).
[2] For the purposes of this assessment, the focus is infrastructure networks and does not include hospitals and educational institutions.

and even weeks) disrupt traffic flows in a larger region and impede emergency response and freight movement, as well as movement of residents and visitors. Similarly, a major wildfire can close roads, and with very limited redundance in Idaho's road system, can lead to significant disruptions in the movement of people and products. One of the largest infrastructure impacts connected to climate change may be on the electrical energy supply, as evidenced by the recent events in Texas and central California.

Idaho's infrastructure can be envisioned as a system of interconnected networks consisting of high intensity nodes and connecting links (described in more detail in Section 3). The high intensity nodes, typically in urban areas, are complex and relatively resilient, with some built in redundancy and rerouting opportunities. The links are much more vulnerable, with limited redundancy and rerouting opportunities. In the case of a closure on Idaho Highway 55 between Boise and McCall, there is only one other connection between the two cities, through Interstate 84 and U.S. Highway 95, a route that adds about 50 miles to the trip. The nature of Idaho's roadway network system, with limited redundancy, means that local incidents not only have systemwide effects, they also can lead to significant disruptions in local and/or regional transportation of people, goods, and services. In addition, different infrastructure systems often use the same links that connect the different nodes, such as the main power transmission line along Idaho Highway 55, which means that different infrastructure systems can be impacted by the same climate-related event.

With respect to planning for infrastructure within the context of climate change, it is important to plan for (1) an increase in the frequency of weather-related events, (2) climate extremes, and (3) a slowly changing climate baseline.

2. General Infrastructure Impacts

The general perception of climate change on infrastructure is its impact on flooding of low-lying coastal areas. However, climate change can and has had significant impacts on infrastructure in inland states, including Idaho.

Climate change is altering the magnitude and frequency of environmental disruptions, such as wildfires and seasonal flooding of rivers, which can have significant impacts on the usability and integrity of infrastructure systems. As well, the direct impacts of climate change can include the weakening of the structural integrity of bridges and pavements, weakening of embankments, and damage to pavement and runways. All of these impacts can apply to Idaho.

Recent events in Idaho, such as the March 2021 8-day closure of Idaho Highway 55 near Smiths Ferry and the April 2019 closure just north of the Banks Lowman Road, illustrate the vulnerability of Idaho's road infrastructure and the immediate consequences of weather-related localized incidents.

Many of the infrastructure systems throughout the U.S. are outdated (Schaper, 2021). In its 2021 Report Card for America's Infrastructure, the American Society of Civil Engineers (ASCE) scored America's infrastructure with a C-. In their latest state report, ASCE (2018) gave Idaho an overall infrastructure score of C-. Idaho's bridges received a score of D; bridges are a major component of the highway transportation system.

A changing climate, including more extreme weather events, means that design criteria for infrastructure systems likely are outdated. Humphrey (2008) found that present design models of infrastructure may be operating outside of tolerance levels (Humphrey, 2008). For instance, Rosenberg et al. (2009) showed that stormwater infrastructure design in Washington state has been based on mid-20th century rainfall records and may not be representative of future scenarios associated with short- and long-term climatic change. Design of future infrastructure systems should integrate future climate models, rather than basing decisions on historic weather trends.

As mentioned earlier, climate change is likely to threaten infrastructure performance in two fundamentally different ways. First, short-term and acutely, through extreme weather events and related incidents. These kinds of events can lead to serious, sudden interruptions and are difficult to predict and/or prevent. The second way is chronically, through sustained incremental changes. These changes are easier to predict and changes in design parameters, routine maintenance, and operations can minimize interruptions from occurring (Wilbanks and Fernandez, 2014).

3. Interconnectedness of Infrastructure Systems

Figure 1 shows the interconnectedness of infrastructure systems—a disruption in one system can often lead to (temporary) disruptions in other systems. This applies to infrastructure broadly, including infrastructure in Idaho. For example, extreme weather events, such as a flood, have not only a potential impact on infrastructure systems directly, but also through the cascading effects of disruptions in other infrastructure systems. Studies of infrastructure interactions became more prevalent in the early 2000s and focused on the threat of intentional attacks on infrastructure systems (O'Rourke et al., 2003; Mendonça and Wallace, 2006). More recently, research has focused on the cascading disruptions caused by natural hazards (Hasan and Foliente, 2015; Pescaroli and Alexander, 2016; Mitsova et al., 2020).

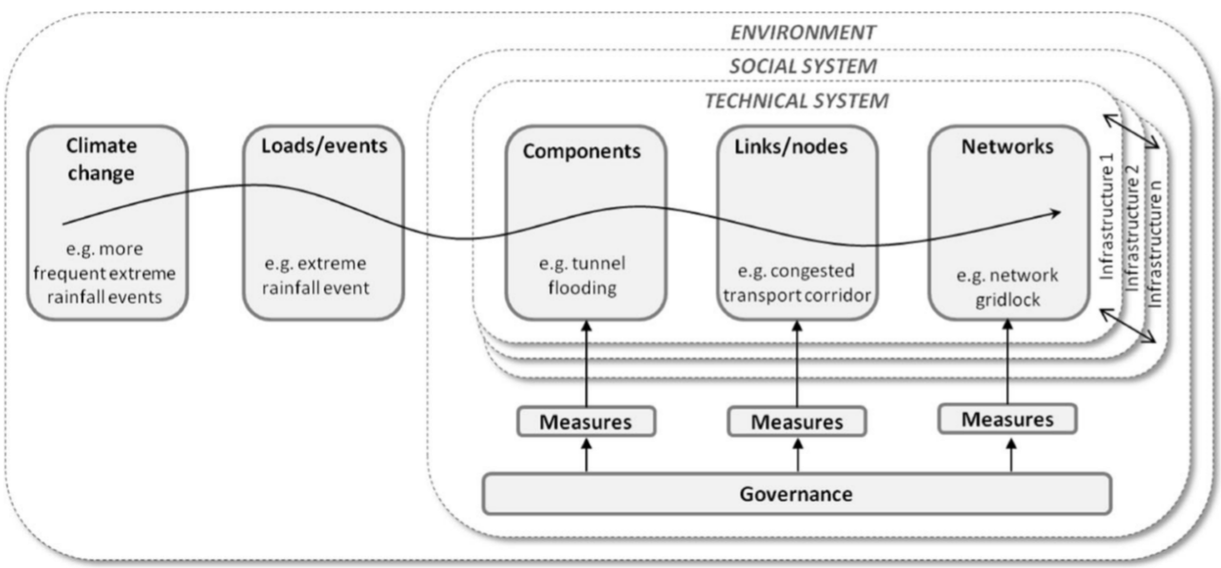

Figure 1: Infrastructure climate-impact model proposed by Bolinger et al. (2014).

Bolinger et al. (2014) suggested an infrastructure model that recognizes the interconnectedness of infrastructure systems, both internally, as well as with one another. Each system consists of connected components and links or nodes that together form the infrastructure network. Within this model, different infrastructure systems come together in either specific components, links and nodes, or a combination of the two. Therefore, disruptions in one infrastructure system often have ripple effects that impact other systems. A local power outage caused by a malfunctioning substation (a component) in the electric infrastructure can have impacts on the road infrastructure through traffic lights that need electricity from that substation to function. Similarly, different infrastructure systems can share links, whereas a climate-related event could disrupt multiple infrastructure systems simultaneously. For instance, a major mudslide could take out a section of a road, collapse an overhead powerline, and flood a residential area. The impact of a disruption to an infrastructure system can vary from a temporary local inconvenience with minimal consequences to a major regional event with cascading effects and extended major disruptions in multiple infrastructure systems with impacts on many aspects of life.

4. Governance of Infrastructure Systems

One of the challenges with addressing disruptions in Idaho's infrastructure systems is that infrastructure systems are built, maintained, and managed by a multitude of different public and private entities. Road infrastructure is built and maintained by the public sector. However, only 20% of Idaho's road system is the responsibility of the Idaho Transportation Department (ITD); the rest consists of local roads that are managed by counties, cities, highway districts, and metropolitan planning organizations (MPOs) (see Figure 2). Electric power in Idaho is supplied by three investor-owned utilities and 23 municipal and rural electric cooperative utilities (Idaho Office of Energy and Mineral Resources (OEMR), 2021). Broadband infrastructure in Idaho is almost entirely owned and operated by private companies. Similarly, railroad in Idaho is predominantly privately owned. Given the internal and external interconnectedness of these systems, the potential for disruption-related cascading effects and governance and management challenges is considerable.

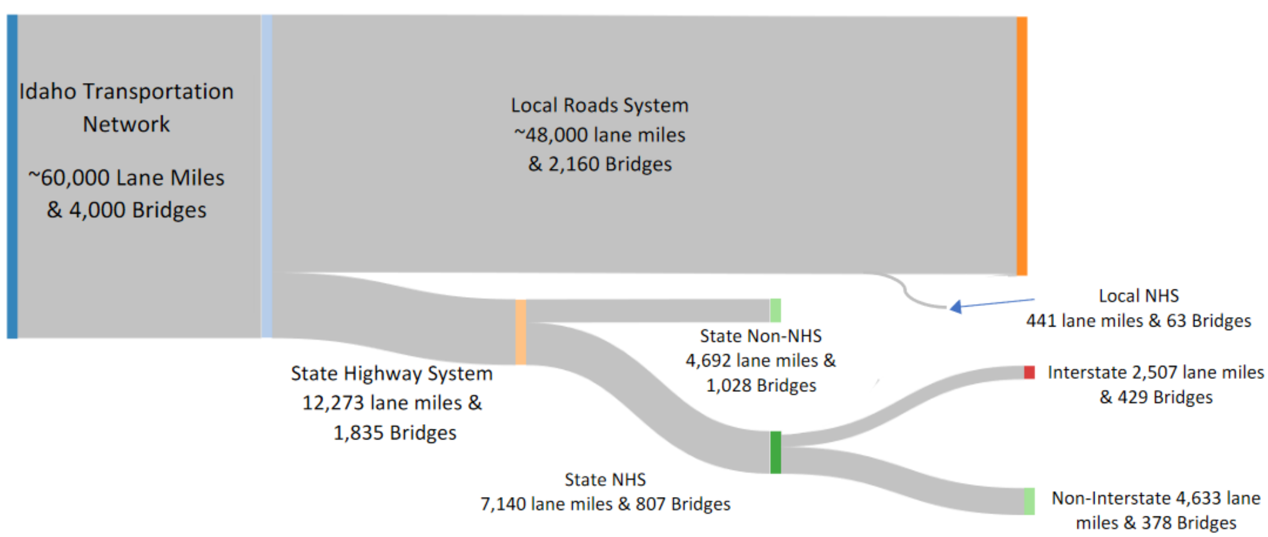

Figure 2. Idaho transportation network asset classes (ITD, 2019). National Highway System abbreviated NHS.

5. Idaho's Major Infrastructure Systems and Facilities

Roads

As shown in Figure 2, Idaho has 60,000+ lane miles of roads in the state. The majority of roads are part of the local road system, with just over 12,000 lane miles part of the State Highway System (Figure 2). Although the State Highway System accounts for 20% of all lane miles in Idaho, it carries 55% of Idaho's total vehicle miles of travel (ITD, 2019). This road system transports 650,000 residents to work each day and 221 million tons of freight, worth $80.5 billion, each year (ITD, 2020).

Commodities are an important part of the Idaho economy and often are transported by heavy trucks, which put additional strain on Idaho's roads. The condition of Idaho's road surfaces is split nearly equally between the categories of good and fair (Figure 3). Forestry, agriculture, and mining all rely on local road networks.

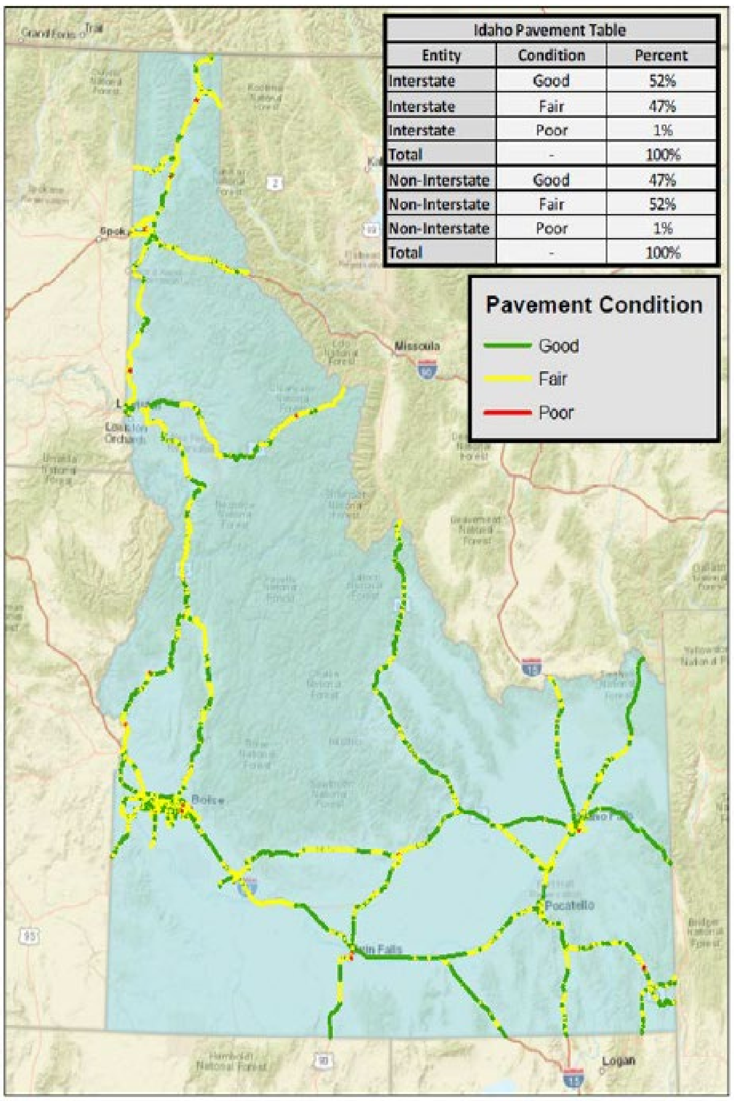

Figure 3: Condition assessment of Idaho's road surfaces (ITD, 2019).

Bridges

In a study of the impacts of climate change on bridges, Neumann et al. (2015) concluded that depending on the climate scenario, between 24% and 61% of all bridges in the Pacific Northwest hydrologic region (Oregon, Washington, and Idaho) are at risk from increased peak streamflow/river flow runoff by 2100. Idaho has a total of about 4,000 bridges, with 5.9 million square feet of bridge deck in the local system and 11.9 million square feet in the state system. Among these bridges, 6% are in poor condition, 19% are in fair condition, and 75% are in good condition. According to ITD's 2020 Annual Report, 964 out of the 1,800 state system bridges will have exceeded their design lifespan (50-60 years) by 2021.

Water transportation

While this report will not delve into impacts to water transportation, it is important to note that Idaho has the farthest inland seaport east of the west coast. The Port of Lewiston serves as a key hub for movement of Idaho's and regional agricultural and forest products—as well as other goods—to Portland for distribution to national and international markets.

Air transportation

Idaho has seven commercial airports and 37 public-use airports (Idaho Department of Commerce (IDC), 2021). The commercial airports are mostly in the southern part of the state–Boise, Idaho Falls, McCall, Pocatello, Sun Valley, and Twin Falls. In addition, the Mountain Home Air Force Base is located in the southern part of Idaho. The only commercial airport north of McCall is in Lewiston. The Pullman-Moscow Regional Airport, located in Pullman, Washington, is a commercial airport less than four miles west of the Idaho border, adjacent to two land-grant universities and their communities. The air transportation infrastructure network includes airports and ground facilities, the air traffic control system, and the planes that carry passengers and freight.

Rail transportation

Idaho's rail system consists of more than 1,900 miles of railroad tracks, moving more than 100 million metric tons of freight each year (IDC, 2021). According to ITD's 2017 freight plan, 12% of the freight moved in Idaho was moved by rail. The only passenger train stop is in Sandpoint; the rest of the railroad system is used for freight. Figure 4 shows the location of Idaho's rail infrastructure, as well as airports that move freight.

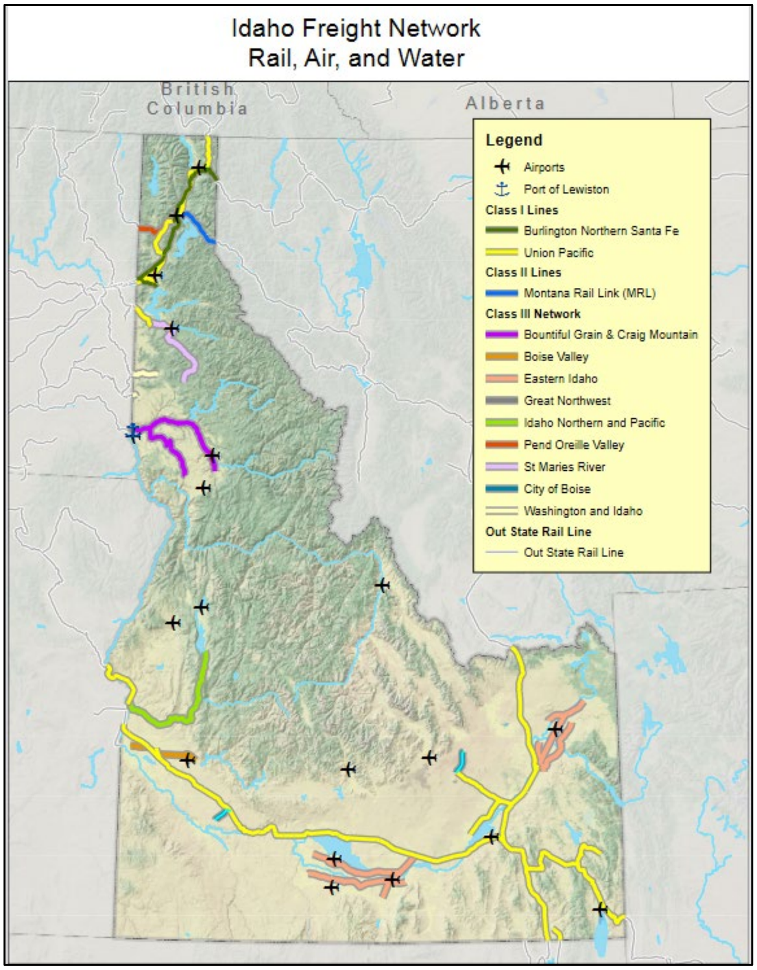

Figure 4: Idaho freight network (ITD, 2017).

<u>*Water and wastewater infrastructure*</u>

Idaho has approximately 1,960 public water systems consisting of pipes, plants, and pumps that work together to deliver clean water to the state's homes and businesses. The Idaho Department of Environmental Quality (IDEQ) regulates the planning, design, and operation of wastewater collection and treatment facilities to protect public health and the environment (IDEQ, 2021). Municipal and industrial wastewater system designs must be reviewed and approved by IDEQ prior to construction and also must be constructed and operated in compliance with the permit issued by IDEQ (IDEQ, 2021). Some systems also require a licensed operator to oversee the operation and maintenance of the system (IDEQ, 2021). Idaho's wastewater infrastructure is owned, operated, and maintained by a host of private and public entities, including local municipalities, businesses, nonprofit organizations, and homeowners' associations. In 2021, IDEQ became the permitting authority for stormwater permits in Idaho; previously, the authority was held by the U.S. EPA (IDEQ, 2021b). Stormwater, excess water from precipitation and snowmelt, runs off the land and hard surfaces and often collects pollutants along the way. Local, state, and federal agencies, as well as businesses, industries, and landowners, share responsibility for stormwater management (IDEQ, 2021b). Stormwater permits are required for stormwater discharge and often are general permits that cover runoff from construction projects, industrial facilities, and municipal separate storm sewer systems (IDEQ, 2021b).

Communications infrastructure

The vast majority of communications infrastructure is deployed by the private sector and providers typically do not publish details on their infrastructure (Anderson et al., 2020). This is case for Idaho, leaving limited information on communications infrastructure specific to this state.

Electric power infrastructure[3]

Electrical energy is supplied to Idaho consumers by several service providers (Figure 5). Broadly, energy-related infrastructure consists of electric power generating facilities and electric power transmission (and distribution). For more on Idaho's energy systems, please see the assessment's [Energy Report].

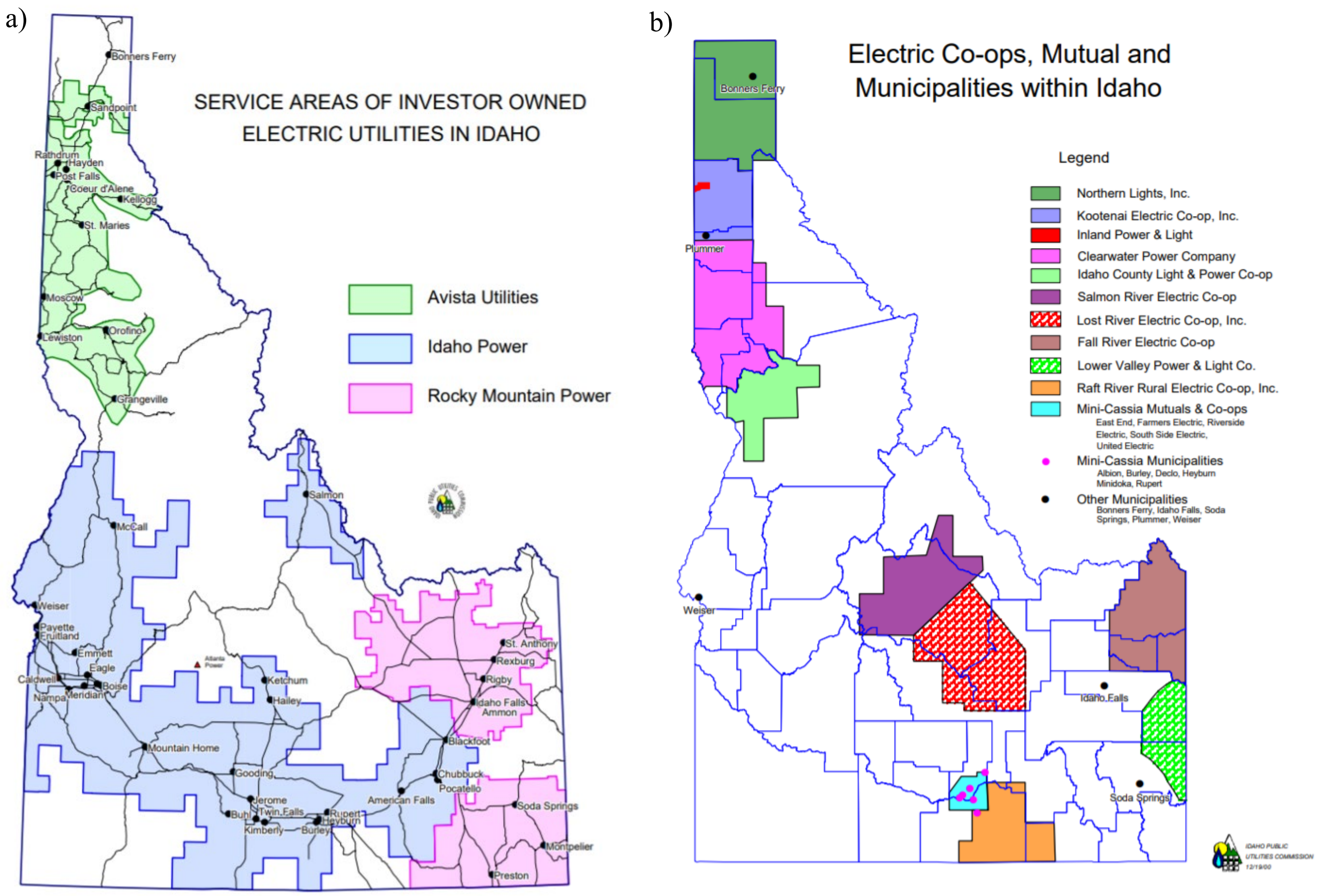

Figure 5. Service territories for a) Idaho investor-owned electric utilities (IOUs) and b) Idaho municipalities and rural electric cooperative utilities (OEMR, 2021).

6. Short-term Impacts on Infrastructure

Weather-related events are expected to rise in frequency and intensity, which will increase costs to respond to and repair infrastructure damage (Melillo et al., 2014). To reduce economic impacts, an

[3] This report addresses electric power infrastructure, not other aspects of energy infrastructure.

immediate response to weather-related events often is required and likely will become more important with increases in weather-related event frequency and intensity.

For instance, increases in the occurrence of wildfires can lead to disruptions in the transportation network and power supply, which consequently can impact the communications network. The overall economic impact of a wildfire that affects critical infrastructure therefore extends well beyond the cost to fight the fire and repair the damage; it also includes indirect costs associated with lost economic activities that were either halted or delayed.

Impacts of weather-related events in Idaho

A review by the Idaho Office of Emergency Management of major federal disaster and emergency declarations in Idaho between 1956 and 2017 shows that floods were a component of 21 disasters (45%), wildfires a component of 18 disasters (39%), severe storms a component of 10 disasters (21%), and landslides and mudslides a component of three disasters (6%) (Idaho Office of Emergency Management, 2020). Below are descriptions of the major weather-related events that are projected to increase with climate change. A table summarizing the impacts from these events to Idaho's major infrastructure is provided below (Table 1).

Avalanches

More near-freezing events can potentially increase the frequency of avalanches through their effect on snowpack stability. Infrastructure at higher elevations in Idaho, such as mountain roads, ski resorts, and cabin communities, might experience more snow avalanches due to more frequent and intense snowfall in these areas and possibly also due to more available snow. Another facilitating condition for avalanches might be more rain-on-snow (ROS) events, since more winter precipitation likely will fall as rain and rainfall events are becoming more intense in Idaho. As with landslides, avalanches can impact road and railway infrastructure systems, electric power transmission lines, and communication transmission lines and can severely damage road infrastructure, making entire areas inaccessible due to road closures.

Flooding

One of the changes in precipitation patterns that is expected to impact Idaho is an increase in frequency and magnitude of ROS events. Changes in the intensity and/or frequency of ROS events will impact intensity and/or frequency of flooding events. The frequency and intensity also can have a significant impact on the loads of contaminants in rivers and streams, in turn impacting water and wastewater treatment facilities. Flooding has the potential to impact almost all major infrastructure systems in Idaho. For more information and details on flooding, please see the assessment's Water Report.

Heat

As described in the assessment's Climate Report, "increased temperatures and increased overall atmospheric moisture are projected to dramatically increase the number of days with elevated heat index values across Idaho. The heat index – which incorporates a combination of air temperature and relative humidity – is used by the National Weather Service and health information services across the country to assess heat-related impacts. While Idaho has rarely seen heat indices exceeding 100˚F despite daytime highs topping the century mark, the Snake River Valley could see more frequent days where the heat index exceeds 100˚F by the mid-21st century" (also see Dahl et al., 2019). Heat has the potential to impact many infrastructure systems in Idaho. For example, heat can degrade road surfaces and soften asphalt, damage bridges, cause delays in air and rail travel, increase algae in water systems, and increase resistance and sag in overhead electric power lines.

Landslides

Landslides include a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors. Among the contributing factors: (1) erosion by rivers, (2) rock and soil slopes weakened through saturation by snowmelt and/or heavy rains, (3) earthquakes that create stresses and lead to slope failure, and (4) excess weight from rain/snow accumulation, rock/ore stockpiling, waste piles, and/or man-made structures (USGS, 2017). Road and railway infrastructure systems, electric power transmission lines, and communication transmission lines can be impacted by landslides. Landslides can severely damage infrastructure and make entire areas inaccessible due to road closures, as has been seen in Idaho. As recently as July 2020, a rockslide closed almost all north-south Idaho traffic for several days.

The Idaho Geological Survey (IGS) recently released an Idaho Landslide Inventory Database, sponsored by ITD, that can assist emergency managers and planners with identifying particular areas of concern (University of Idaho, 2021). These areas can be a focus when planning for hazard mitigation. As noted by IGS, understanding landslides can be essential for reducing risks and avoiding costly consequences (IGS, n.d.).

Wildfires

Wildfires are increasing in number and intensity across the west (Spracken et al., 2009). It is projected that forests of the Northwest and Rocky Mountains, including those in Idaho, likely will experience more than a 75% and 175% increase, respectively, in burned area by mid-century under a moderate-warming scenario (RCP4.5)[4] (Spracklen et al., 2009). Wildfires can directly damage infrastructure, including bridges, roads, communications infrastructure, electric power infrastructure, and water infrastructure. Infrastructure remains threatened even after a wildfire is extinguished by debris flow, erosion, flooding, and water contamination (Neary and Jackson, 2019).

[4] Representative Concentration Pathway (RCP)4.5 is a moderate-warming scenario. Mid-century projections are less sensitive to choice of RCP; differences between RCP4.5 and RCP8.5 are most important for late century projections. Additional detail available in the assessment's Climate Report.

	Communications			Energy		Transportation			Water	
	Wireless infrastructure	Fixed infrastructure	Data centers	Transmission and distribution lines	Substations	Airports	Rail	Roads	Potable water treatment systems	Wastewater treatment systems
Avalanches	no	minimal	no	yes	no	no	yes	yes	no	no
Heat	minimal	minimal	yes	yes	minimal	minimal	minimal	minimal	no	minimal
Landslides/ Mudslides	minimal	minimal	no	yes	no	no	yes	yes	no	no
Riverine and fluvial flooding	minimal	yes	yes	minimal	minimal	no	yes	yes	yes	yes
Storm events[5]	yes	yes	no	yes	yes	minimal	minimal	minimal	minimal	minimal
Wildfires	yes	yes	no	yes	yes	minimal	minimal	yes	no	minimal

Table 1: Risk posed by exposure to climate-related events for selected infrastructure systems, applied to Idaho (adapted from McKinsey, 2020).

7. Long-term Impacts on Infrastructure

With respect to impacts on infrastructure in Idaho, it is important to recognize the different effects of increased weather-related events, such as wildfires and mudslides, and long-term, sustained climate change, such as drought. Long-term, sustained climate change will lead to the need for updated design criteria for infrastructure systems, different maintenance protocols, system hardening and reconfiguration (including redundancies), and stakeholder engagement. This would require a significant long-term investment in infrastructure, but could lead to a more resilient infrastructure system as part of the "normal" update and replacement strategy. Table 2 provides a summary of some of the expected short- and long-term economic impacts of climate change on infrastructure in Idaho.

[5] The National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI; https://www.ncdc.noaa.gov/stormevents/) defines storm events as:

a. The occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce;
b. Rare, unusual, weather phenomena that generate media attention, such as snow flurries in south Florida or the San Diego coastal area; and
c. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event.

Increase in maximum temperatures/Extreme heat events	Seasonal shift in temperatures	Extreme precipitation events, increased streamflow	More frequent droughts	More frequent wildfires
Direct Impacts				
• Asphalt cracking • Asphalt aging • Asphalt softening • Railway buckling • Catenary wire sag • Concrete pavement blowups • Failed expansion joints • Increased road surface degradation due to extreme heat	• Increased damage from freeze-thaw cycles • Increased frequency of landslides/mudslides and avalanches • Infiltration drainage systems not able to handle runoff due to increasing frost depth	• Increased frequency of landslides/mudslides • Flooding • Flooding of water and wastewater facilities and debris blockage • Overloading of drainage systems • Roadway washouts • Bridge scour/washout • Increased roadway prism erosion	• Increase of debris in stormwater management system • Changes to the environment surrounding bridges and other water-related infrastructure	• Damaged and destroyed structures • Damaged and destroyed energy infrastructure • Increased debris and contamination in stormwater and water management systems
Direct Economic Impacts				
• Increased cost of maintenance • Increased cost of materials	• Increased cost of maintenance • Cost of repair of infrastructure system • Cost of stabilizing slopes	• Redesign of stormwater management system • Blowouts and additional maintenance of drainage systems • Cost of repair for damage to water and wastewater facilities • Disruption to water and wastewater treatment facilities • Repair of roadways and bridges	• Redesign of stormwater management system	• Increased cost to repair and rebuild structures • Converting to underground energy and communication lines • Temporary interruption of electrical energy • Inspection and repair/replacement costs for assets damaged by smoke exposure • Replacement costs for assets damaged by wildfire • Loss of livelihoods in impacted communities
Indirect Economic Impacts				
• Delays in movement of goods, services, and people caused by repairs • Temporary interruption of rail and flights due to extreme heat	• Delays in movement of goods, services, and people caused by repairs	• Major disruption of movement of goods and people • Flooding of surrounding buildings from localized flooding	• Decrease in streamflow impacts to hydropower production • Increased risk of wildfires/damage to electric power and communications infrastructure	• Increasing cost to insure structures in wildfire prone areas • Loss of livelihoods in impacted communities • Delays in movement of goods and people during wildfire • Potential major disruption after wildfire

Table 2: Short- and long-term economic impacts on infrastructure in Idaho due to climate-related events (based on Wilbanks and Fernandez, 2014; U.S. DOE, 2016; Silicon Valley 2.0).

Potential long-term impacts on Idaho's infrastructure

Increasing temperature, variable precipitation, and decreasing snowpack, along with increasing frequency in extreme weather events, will lead to long-term impacts on Idaho's infrastructure. While there is a dearth of Idaho-specific data and information on these impacts, the studies described below represent applicable findings for Idaho infrastructure.

Potential long-term impacts on Idaho's road infrastructure

Extreme maximum temperature and prolonged-duration heat waves can lead to premature deterioration and failure of the roadway infrastructure. Temperature increases have the potential to reduce the life of asphalt road pavements through softening, buckling, and traffic-related rutting.

In Idaho, warmer winters will likely lead to less snow and ice on roadways, but may increase the incidence of slippery roads and freeze-thaw conditions, creating frost heaves and potholes on road and bridge surfaces that increase maintenance costs. Studies suggest that rutting and cracking of pavement will be exacerbated by climate change and that maintenance, rehabilitation, and/or reconstruction of roadways will be required earlier in the design life (Mills et al., 2006). Potential road adaptation cost estimates vary greatly, $140-$475 per lane mile (Chinowsky, 2013) to $3,000-$4,000 per lane mile (Larsen et al., 2008).[6]

The change in range of maximum and minimum temperatures due to climate change likely will result in both positive and negative impacts on highway operations and maintenance. Warmer winters should bring reductions in snow and ice removal costs, lessen adverse environmental impacts from the use of salt and other chemicals on roads and bridges, extend the construction season, and reduce winter hazards. On the other hand, with warmer winter temperatures, greater vehicle load restrictions may be required to minimize damage to roadways if they begin to settle and/or lose bearing capacity during the spring thaw cycles. With the expected earlier onset of seasonal warming, the period of springtime load restrictions might be reduced in some areas, but are likely to expand in others areas that have shorter winters and longer freeze-thaw seasons.

Potential long-term impacts on Idaho's bridge infrastructure

In a review of close to 70 research studies, Nasr et al. (2020) identified potential impacts of climate change on bridges, three of which are relevant to Idaho:

1. Accelerated material degradation.
2. Damage to bridge pavements due to accelerated heat and freeze-thaw cycles.
3. Higher scour rates due to increased peak flow.

Extreme heat also can increase the stress levels in steel in bridges through restrained thermal expansion in beam pockets and movement of bridge joints and paved surfaces. One study found that across various road types and climate impacts, proactive adaptation to protect roads against climate change-related impacts is projected to decrease costs over the century by 98% under climate scenario RCP8.5 (high-warming) and 83% under climate scenario RCP4.5 (moderate-warming) (EPA, 2017).

Potential long-term impacts on Idaho's air transportation infrastructure

Warming temperatures and possible increases in temperature extremes will affect airport ground facilities—runways and taxiways in particular—in much the same way that they are expected to affect roads (Coffel et al., 2017). Further, the wide-open spaces at airports make them more vulnerable to wind, rain, and snow events. Runways and taxiways are vulnerable to changes in precipitation and airport

[6] These estimates are for 2025 and were generated in the late 2000s/early 2010s.

drainage systems can be overwhelmed, leading to flooding. Aircraft are less efficient in hot weather, as there is less lift. Aircraft lift is a concern at high-altitude airports. If runways are not of sufficient length for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced and flights may be delayed and/or canceled. Increases in extreme heat could result in payload restrictions and flight cancellations, as was seen in 2017 and 2021 (Worland, 2021). A study by Karl and Anderson (2007) estimated summer cargo loss (June-August for the Denver and Phoenix airports) for a single Boeing 747 of about 17% and 9%, respectively, by 2030 because of the effects of increased temperature and water vapor.

With warmer temperatures, airports may benefit from reductions in the cost of snow and ice removal and lower environmental impacts of salt and chemical use. The need to de-ice airplanes also may be reduced.

Potential long-term impacts on Idaho's rail infrastructure

According to a study by Rosetti (2003) the impact of weather events on railroad infrastructure in the U.S. has been minimal, with the exception of the occasional development of heat kinks during temperature extremes, which can lead to train derailment. Railroads are impacted by winter storms and climate-related events, such as floods, mudslides, avalanches, and wildfire, all of which are expected to increase in Idaho. Blockage of railroads by mud, rockslides, and avalanches can cause significant delays and, due to a lack of redundancy in the rail system, can lead to significant detours (Rosetti, 2003). Increased heat and excessive precipitation can lead to increased system delays as a result of slow down orders. According to Lovett et al (2017), "slow down orders are a major concern for heavy-haul freight railroads because they reduce capacity and increase costs." For the most part, the impacts to rail infrastructure will be short-term. The long-term vulnerability of the railway system is due to the very limited flexibility of infrastructure and operations in the event of disturbances (Climate Adapt, 2021).

Potential long-term impacts on Idaho's water and wastewater infrastructure

Climate change can impact both source and receiving water quality (EPA, 2021b). As water temperatures increase, the quality of water for drinking water changes (EPA, 2021a), which impacts the way operators run water treatment plants. For example, changes in dissolved oxygen content in the water change the applied chemical treatment process (Zouboulis and Tolkou, 2014). Increased water temperature also creates more opportunities for problems like cyanotoxin (blue-green algae) outbreaks, which can range from difficult to impossible to treat. Additionally, other plant-related growth in response to increased heat can result in more algae-clogging intake filters (EPA, 2021a). Summer streamflow is projected to decline in Idaho; this could lead to water levels falling below intakes for water treatment plants (EPA, 2021a). The potential for contaminants in water can increase during drought conditions and lower summer streamflow when pollutants are concentrated due to limited dilution capacity of receiving water (EPA, 2021b). Existing water treatment systems may not be able to discharge water without modifications to existing treatment processes or the adoption of additional treatment technologies to ensure that water quality standards are met (EPA, 2021b).

Increases in extreme precipitation and ROS events can increase stormwater runoff and overwhelm the design capacity of municipal stormwater management systems (EPA, 2021b). This can lead to backups and localized flooding and the potential for contaminants, such as sediment, pesticides, fertilizer, oil, garbage, debris, bacteria, and/or viruses, to get into local waterways. Floods cause significant issues at both water and wastewater treatment facilities. Wastewater treatment plants often release treated flow back to rivers. If the river floods, wastewater treatment plants can be submerged, resulting in damaged equipment and raw sewage released to the river. Another challenge water treatment plants face relates to their intake systems—any system with an intake in the river is vulnerable to raging waters and debris (large trees, etc.) that can flow downriver during a precipitation event (Singh and Tiwari, 2019; EPA, 2021).

Potential long-term impacts on Idaho's communication infrastructure

Unfortunately, there is relatively little research on the impacts of climate change on communication infrastructure in Idaho and elsewhere in the U.S., but it is clear that communication infrastructure is vulnerable to climate-related events, such as wildfires. Any deployed communications assets, such as cellular communication towers or above-ground data transmission lines that are located in the direct path of wildfires, are at risk of structural and functional damage. However, in a study on the impact of wildfire on cellular communication infrastructure, Anderson et al. (2020) found that disruption of cell service in the majority of cases was not related to damage to the cellular infrastructure; rather, due to disruptions in the electric power infrastructure. Underground, buried transmission lines, such as copper and fiber optic cables, are also at risk for impacts associated with increasing extreme weather events. Often, these buried assets are in the highway right-of-way. If highways are damaged due to increasing landslides, mudslides, and flooding, then these broadband communication assets can be damaged.

Potential long-term impacts on Idaho's electric power infrastructure

Climate change has different impacts on each of the dimensions of electric power infrastructure. Energy generation and demand are addressed in the assessment's Energy Report. The long-term impacts to Idaho's power infrastructure described here focus on electric power transmission and distribution. With respect to the functioning of the transmission and distribution system, higher temperature extremes are expected to increase resistance and sag in overhead lines and drought may reduce the capacity of underground cables (Rademaekers et al., 2011). More important are disruptions in the transmission and distribution system caused by an increase of extreme weather and weather-related events, such as wildfires, as well the potential role of transmission igniting fires. A 2013 report by the U.S. Department of Energy lists severe weather as the leading cause of electric power outages in the U.S. (U.S. DOE, 2013). Electric power outages can have significant direct economic impacts. Examples of these costs are presented in Table 3.

Interruption Cost	Interruption Duration					
	Momentary	30 Minutes	1 Hour	4 Hours	8 Hours	16 Hours
Medium and Large C&I (Over 50,000 Annual kWh)						
Cost per Event	$12,952	$15,241	$17,804	$39,458	$84,083	$165,482
Cost per Average kW	$15.9	$18.7	$21.8	$48.4	$103.2	$203.0
Cost per Unserved kWh	$190.7	$37.4	$21.8	$12.1	$12.9	$12.7
Small C&I (Under 50,000 Annual kWh)						
Cost per Event	$412	$520	$647	$1,880	$4,690	$9,055
Cost per Average kW	$187.9	$237.0	$295.0	$857.1	$2,138.1	$4,128.3
Cost per Unserved kWh	$2,254.6	$474.1	$295.0	$214.3	$267.3	$258.0
Residential						
Cost per Event	$3.9	$4.5	$5.1	$9.5	$17.2	$32.4
Cost per Average kW	$2.6	$2.9	$3.3	$6.2	$11.3	$21.2
Cost per Unserved kWh	$30.9	$5.9	$3.3	$1.6	$1.4	$1.3

Table 3: Estimated cost per event (source: U.S. DOE, 2016)

8. Summary

Effective operation of Idaho's infrastructure systems is essential for Idaho's residents and Idaho's economy. This report has outlined some of the potential short- and long-term impacts on Idaho's infrastructure systems connected to climate change based on existing literature.

In the short-term, climate change impacts will most likely consist of increased disruptions to infrastructure systems resulting from weather-related events. Given the internal and external connections of infrastructure systems, impacts of these weather-related events could have significant economic consequences.

Over the long-term, infrastructure managers may need to rethink their facilities, operations, and maintenance practices based on models that take into account future climate conditions. The Idaho National Laboratory (INL) is in the process of developing a guidebook focused on preparing Idaho's infrastructure for resiliency.[7] This guidebook will include Idaho-specific information regarding weather-related impacts on Idaho's infrastructure.

Table 4 provides a detailed summary of the short-term and long-term impacts of climate change on Idaho's infrastructure systems.

[7] https://inl.gov/article/inl-preparing-resiliency-guidebook-for-state-of-idaho/

Infrastructure sector	Climate/weather impact	Potential implications for infrastructure
Communication		
Wireless infrastructure	• Higher temperatures • Increased risk of subsidence • Increased risk of storm events • Increased/more intense precipitation	• Location/density of wireless masts may become sub-optimal as wireless transmission is dependent on temperature • Reduced stability of foundations and tower structures • Increased damage to above-ground transmission infrastructure • Possible reduced quality of wireless service
Copper and fiber optic cables	• Increased risk of flooding • Increased erosion and/or flooding	• Transport infrastructure (roads/bridges) affected, exposing cables and trunk routes • Increased damage to cables along road right-of-way due to flooding and land/mudslides
Energy		
Wind energy	• Potential changes in wind patterns	• Reduced efficiency and increased storm damage
Hydropower-based energy	• Changes in streamflow	• Reduced production
Electricity transmission and distribution	• Higher temperatures • Increased/more intense precipitation • Fluvial flooding • Potential higher winds • Increased wildfires	• Reduced capacity of network • Flood risk to substations • Storm damage to overhead power lines • Damage due to wildfires
Transportation		
Road	• Changes in precipitation • Wetter winters and drier summers • Higher temperatures	• Flood risk to roads • Increased scour of bridges • Increased instability of embankments • Increased damage to road surfaces • Increased degradation of road base due to precipitation events
Rail	• Changes in precipitation • Wetter winters and drier summers • Higher temperatures	• Flood risk to rail lines • Increased scour of bridges • Increased instability of embankments • Increased rail buckling • Increased delays due to slow down orders issued as a result of heat
Airports	• Changes in precipitation • Higher temperatures	• Flood risk to airports • Reduction in aircraft lift
Water		
Water supply, treatment, and infrastructure	• Changing precipitation patterns and drought • Increased/more intense precipitation • Higher temperatures	• Reduced security of water supply • Increased risk of fluvial flooding to water supply/treatment infrastructure • Water treatment processes affected
Wastewater collection, treatment, and disposal	• Changes in form of precipitation • Changing precipitation patterns and drought • Higher temperatures	• Inadequate capacity of sewage collection system • In lagoon systems, impacts on the treatment capacity of the biological systems

Table 4: Potential long- and short-term direct impacts of climate-related change on infrastructure (based on Climate Resilient Infrastructure: Preparing for a Changing Climate – UK, 2011).

References

Ada County. 2017. 2017 Ada County Multi-Hazard Mitigation Plan. Ada County, State of Idaho. https://adacounty.id.gov/emergencymanagement/mitigation/, accessed March 2021.

American Society of Civil Engineers (ASCE). 2021. *Report Card for America's Infrastructure.* https://infrastructurereportcard.org/, accessed November 2021.

ASCE. 2018. *Report Card for America's Infrastructure: Idaho 2018 Report.* https://infrastructurereportcard.org/state-item/idaho/, accessed November 2021.

Anderson, S., Barford, C., Barford, P. 2020. *Five Alarms: Assessing the Vulnerability of U.S. Cellular Communication Infrastructure to Wildfires*. In Proceedings of the ACM Internet Measurement Conference (IMC '20). Association for Computing Machinery, New York, NY, USA, 162–175. https://doi.org/10.1145/3419394.3423663

Bollinger, L. A., Bogmans, C. W. J., Chappin, E. J. L. et al. 2014. Climate Adaptation of Interconnected Infrastructures: A Framework for Supporting Governance. *Regional Environmental Change* 14, 919–931. https://doi.org/10.1007/s10113-013-0428-4

Coffel, E. D., Thompson, T. R., Horton, R. M. 2017. The Impacts of Rising Temperatures on Aircraft Takeoff Performance. *Climatic Change* 144, 381–388. https://doi.org/10.1007/s10584-017-20189

Chinowsky, P. S., Price, J. C., Neumann, J. E. 2013, Assessment of Climate Change Adaptation Costs for the U.S. Road Network. *Global Environmental Change* 23(4), 764-773, ISSN 0959-3780.

Climate Adapt, 2021. Operation and Construction Measures for Ensuring Climate-Resilient Railway Infrastructure. https://climate-adapt.eea.europa.eu/metadata/adaptation-options/operation-and-construction-measures-for-ensuring-climate-resilient-railway-infrastructure, accessed March 2021.

Climate Resilient Infrastructure: Preparing for a Changing Climate. 2011. Secretary of State for Environment, Food and Rural Affairs by Command of Her Majesty. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69269/climate-resilient-infrastructure-full.pdf, accessed November 2021.

Dahl, K., Licker, R., Abatzoglou, J. T., Declet-Barreto, J. 2019. Increased Frequency of and Population Exposure to Extreme Heat Index Days in the United States during the 21st Century. *Environmental Research Communications* 1(075002). https://doi.org/10.1088/2515-7620/ab27cf.

Environmental Protection Agency (EPA). 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001. https://www.epa.gov/sites/default/files/202103/documents/ciraii_technicalreportfornca4_finalwithupdates11062018.pdf, accessed May 2021.

Environmental Protection Agency (EPA). 2021a. Climate Impacts on Water Utilities. https://www.epa.gov/arc-x/climate-impacts-waterutilities, accessed November 2021.

Environmental Protection Agency (EPA). 2021b. Climate Adaption and Stormwater Runoff. https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff, accessed November 2021.

Hasan, S., Foliente, G. 2015. Modeling Infrastructure System Interdependencies and Socioeconomic Impacts of Failure in Extreme Events: Emerging R&D Challenges. Natural Hazards 78, 2143–2168. DOI:10.1007/s11069-015-1814-7

Humphrey, N. 2008. Potential Impacts of Climate Change on U.S. Transportation. TR News, Issue Number:256, Transportation Research Board. ISSN: 0738-6826

Idaho Department of Commerce (IDC). 2021. Infrastructure and Access to Market. https://commerce.idaho.gov/business-climate/infrastructure/, accessed March 2021.

Idaho Department of Environmental Quality (IDEQ). 2021. Wastewater. https://www.deq.idaho.gov/water-quality/wastewater/, accessed November 2021.

Idaho Department of Environmental Quality (IDEQ). 2021b. Storm Water.

https://www.deq.idaho.gov/water-quality/wastewater/storm-water/, accessed November 2021.
Idaho Office of Emergency Management. 2020. State of Idaho Hazard Mitigation Plan; Building a More Resilient Idaho. https://ioem.idaho.gov/preparedness-and-protection/mitigation/state-hazard-mitigation-plan/, accessed November 2021.
Idaho Office of Energy and Mineral Resources (OMER). 2021. Utilities/Resources. https://oemr.idaho.gov/utilities/, accessed November 2021.
Idaho Office of Energy and Mineral Resources (OMER). 2021b. Idaho Energy Landscape. https://oemr.idaho.gov/wp-content/uploads/Idaho-Energy-Landscape-2021.pdf, accessed November 2021.
Idaho Transportation Department (ITD). 2020. Annual Report. https://apps.itd.idaho.gov/Apps/info/2020_Annual_Report.pdf, accessed November 2021.
Idaho Transportation Department (ITD). 2019. Transportation Asset Management Plan. https://itd.idaho.gov/wp-content/uploads/2019/06/ITD_TAMP.pdf, accessed November 2021.
Idaho Transportation Department (ITD). 2017. Idaho Transportation Department Statewide Freight Strategic Plan. Prepared by Cambridge Systematics Inc, Oakland, CA.
Mills, B., Tighe, S., Andrey, J., Huen, K., Parm, S. 2006. Climate Change and the Performance of Pavement Infrastructure in Southern Canada: Context and Case Study, 2006 IEEE EIC Climate Change Conference, 1-9. DOI: 10.1109/EICCCC.2006.277185.
Idaho Geological Survey (IGS). Landslides. https://www.idahogeology.org/geologic-hazards/landslides, accessed November 2021.
Karl, T. R., Anderson, D. M. 2007. Emerging Issues in Abrupt Climate Change, briefing (March 12, 2007).
Larsen, P. H., Goldsmith, S., Smith, O., Wilson, M. L., Strzepek, K., Chinowsky, P., Saylor, B. 2008. Estimating Future Costs for Alaska Public Infrastructure at Risk from Climate Change. Global Environmental Change 18(3), 42-457, https://doi.org/10.1016/j.gloenvcha.2008.03.005.
Lovett, A. H., Dick, C. T., Barkan, C. P. L. 2017. Predicting the Occurrence and Cost of Temporary Speed Restrictions on North American Freight Lines, Proceedings of the 11th International Heavy Haul Association Conference (IHHA 2017), Cape Town, South Africa, 2–6 September 2017.
McKinsey Global Institute. 2020 Climate Risk and Response: Physical Hazards and Socioeconomic Impacts: Will Infrastructure Bend or Break Under Climate Stress? https://www.mckinsey.com/business-functions/sustainability/our-insights/climate-risk-and-response-physical-hazards-and-socioeconomic-impacts, accessed March 2021.
Melillo, J. M., Richmond, T. C., Yohe, G. W. Eds. 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. *U.S. Global Change Research Program* 841. doi:10.7930/J0Z31WJ2.
Mendonça, D., Wallace. W. A. 2006. Impacts of the 2001 World Trade Center Attack on New York City Critical Infrastructures. *Journal of Infrastrcuture Systems* 12(4).
Mitsova, D., Sapat, A., Esnard, A-M, Lamadrid, A. 2020. Evaluating the Impact of Infrastructure Interdependencies on the Emergency Services Sector and Critical Support Functions Using an Expert Opinion Survey. *Journal of Infrastructure Systems* 26(2), 04020015, doi: https://ascelibrary.org/doi/10.1061/(ASCE)IS.1943-555X.0000548.
Nasr, A., Kjellström, E., Björnsson, I., Honfi, D., Ivanov, O. L., Johansson, J. 2020. Bridges in a Changing Climate: a Study of the Potential Impacts of Climate Change on Bridges and Their Possible Adaptations. *Structure and Infrastructure Engineering* 16(4), 738-749. DOI: 10.1080/15732479.2019.1670215
Neary, D. G., Leonard, J. M. 2019. Physical Vulnerabilities from Wildfires: Flames, Floods, and Debris Flows. In: Naser, H. (ed) Human Impact on the Environment. London, England: IntechOpen Limited. 17 p.
Neumann, J. E., Price, J., Chinowsky, P. 2015. Climate Change Risks to U.S. Infrastructure: Impacts on

Roads, Bridges, Coastal Development, and Urban Drainage. *Climatic Change* 131, 97–109. https://doi.org/10.1007/s10584-013-1037-4

O'Rourke, T. D. 2007. Critical Infrastructure, Interdependencies, and Resilience. *Engineering for the Threat of Natural Disasters* 31(1).

Pescaroli, G., Alexander, D. 2016. Critical Infrastructure, Panarchies and the Vulnerability Paths of Cascading Disasters. *Natural Hazards* 82, 175–192. https://doi.org/10.1007/s11069-016-2186-3

K. Rademaekers, van der Laan, J., Boeve, S., Lise, W. 2011. Investment Needs for Future Adaptation Measures in EU Nuclear Power Plants and Other Electricity Generation Technologies Due to Effects of Climate Change. European Commission Directorate-General for Energy. https://ec.europa.eu/energy/sites/ener/files/documents/2011_03_eur24769-en.pdf, accessed November 2021.

Rosenberg, E. A., Keys, P. W., Booth, D. B., Hartley, D., Burkey, J., Steinemann, A. C., Lettenmaier, D. P. 2009. Chapter 9 in The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington. doi:10.7915/CIG44Q7RD

Schaper, D. 2021. Potholes, Grid Failures, Aging Tunnels and Bridges: Infrastructure gets a C-. NPR. https://www.npr.org/2021/03/03/973054080/potholes-grid-failures-aging-tunnels-and-bridges-nations-infrastructure-gets-a-c_. accessed November 2021.

Silicon Valley 2.0: Climate Adaptation Guidebook. 2015. https://sustainability.sccgov.org/sites/g/files/exjcpb976/files/documents/1_150803_Final%20Guidebook_W_Appendices.pdf, accessed November 2021.

Singh S., Tiwari S. 2019. Climate Change, Water and Wastewater Treatment: Interrelationship and Consequences. In: Singh R., Kolok A., Bartelt-Hunt S. (eds) Water Conservation, Recycling and Reuse: Issues and Challenges. Springer, Singapore. https://doi.org/10.1007/978-981-13-3179-4_11

Spracklen, D. V., Mickley, J., Logan, J. A., Hudman, R. C., Yevich, R., Flannigan, M. D., Westerling. A. L. 2009. Impacts of Climate Change from 2000 to 2050 on Wildfire Activity and Carbonaceous Aerosol Concentrations in the Western United States. *Journal of Geophysical Research* 114(D20).

University of Idaho. 2021. New Idaho Landslide Inventory Database to Assist with Hazard Mitigation. https://www.uidaho.edu/news/news-articles/news-releases/2021-spring/062921-landslideinventorydatabase (June 29, 2021).

U.S. Department of Energy (U.S. DOE). 2013. Economic Benefits of Increasing Electric Grid Resilience to Weather Outages. Executive Office of the President. https://www.energy.gov/sites/default/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf accessed November 2021.

U.S. Department of Energy (U.S. DOE). 2016. Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning. Office of Energy Policy and Systems Analysis.

U.S. Geological Survey. 2017. Landslides 101. https://www.usgs.gov/natural-hazards/landslide hazards/science/landslides-101?qt-science_center_objects=0#qt-science_center_objects, accessed November 2021.

Wilbanks, T., Fernandez, S. J. 2014. Climate Change and Infrastructure, Urban Systems, and Vulnerabilities (National Climate Assessment Regional Technical Input Report Series). Washington, DC: Island Press.

Worland, J. 2021. It's More Than Just Rain and Snow. Climate Change Will Hit Air Travel in Surprising *Planning* Ways. Time. https://time.com/6075342/climate-change-air-travel/ (June 24, 2021).

Zouboulis A., Tolkou A. 2015. Effect of Climate Change in Wastewater Treatment Plants: Reviewing the Problems and Solutions. In: Shrestha S., Anal A., Salam P., Van der Valk M. (eds) Managing Water Resources under Climate Uncertainty. Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-319-10467-6_10