2050 Long-Range Transportation Plan

ADOT

Resilience Improvement Plan Primer



Connecting Arizona. Better Lives Through Better Transportation.

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1 Introduction

Resilience is the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability to:

- Resist or withstand impacts from weather events and natural hazards;
- Reduce the magnitude or duration of impacts of a disruptive weather event or natural hazards; and
- Have absorptive capacity, adaptive capacity, and recoverability to decrease project vulnerability to weather events or other natural hazards[1]

The Arizona Department of Transportation (ADOT) is actively incorporating resilience into transportation planning, engineering, and design. To improve the understanding of resilience needs across Arizona's state transportation system, ADOT is developing a Resilience Improvement Plan (RIP). The RIP will demonstrate a systemic approach to transportation system resilience. A systemic approach means considering risk across transportation modes, regions, and critical interdependent sectors while also addressing interdependencies for both the user (e.g., key multimodal connections) and assets (e.g., power supply for facilities, pumping stations, etc.).[2] The RIP will also include a risk assessment of transportation systems, including their individual assets, to current and future weather events and natural hazards. Therefore, the RIP will evaluate how weather events and natural hazards, exacerbated by climate change, may impact Arizona's state transportation system and their users. The benefits of the RIP are shown in **Figure 1**.

Figure 1. Benefits of Developing a Resilience Improvement Plan.

The RIP will summarize ADOT's work to assess the risks to the statewide transportation system and provide additional insights into how phenomena, such as climate change, may exacerbate these events and can lead to subsequent impacts. The RIP will also describe ADOT's extensive resilience program development, including resilience-based investment decision-making, project review and development, and resilience data management, connecting the RIP to the state's transportation investment plans.

1.1 RIP & LRTP Relationship

Incorporating the RIP into the state Long Range Transportation Plan (LRTP) aligns the state's long-term transportation investment plans with identified climate hazards to ensure that the investments are safeguarded against future climate-related events and that investments are designed to address high-risk areas, where appropriate. Moreover, the current LRTP is a policy-based document, and as such, resilience is integrated throughout to embed existing policies, procedures, and plans that ADOT has developed around climate resilience.

Similar to the LRTP, the RIP looks as the systemwide state transportation assets while focusing on systems under the direct responsibility of ADOT and considering interdependencies with other systems such as transit and active transportation. The RIP will also utilize a time horizon consistent with the available climate science information, which is often until the end of the century. This is also consistent with the LRTP's 25-year time horizon.

2 Resilience Work To-Date

2.1 Policy and Planning

Though ADOT has not yet adopted a state resilience policy, they have adopted the resilience definition of the Federal Highway Administration (FHWA) as outlined in Order 5520.[3] ADOT has conducted several climate hazard-focused risk assessments over the past 10 years, each varying in scope, scale, and analytical approach as resources and guidance have evolved. The three primary risk assessment efforts developed by ADOT during this period are the 2013 Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona, the 2015 Extreme Weather Vulnerability Assessment, and the 2020 Asset Management, Extreme Weather, and Proxy Indicators Pilot Project.

The 2013 Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona generated recommendations to enhance ADOT's resilience, flexibility, and responsiveness to the effects of climate change. This work identified key individuals within ADOT with decision-making authority relevant to climate change adaptation incorporation in planning, design, and operations, reviewed literature and best practices for climate adaptation in the desert Southwest, developed a research agenda for ADOT to further understand the impacts of climate change on the agency, and identified key areas for future research.

The 2015 Extreme Weather Vulnerability Assessment, developed as part of the FHWA Climate Change Resilience Pilot Program, assessed the vulnerability of transportation infrastructure to extreme weather in Arizona, including hazards like extreme heat, heavy precipitation, flooding, and landslides. This assessment focused on the Interstate corridor connecting Nogales, Tucson, Phoenix, and Flagstaff (I-19, I-10, and I-17). The project team integrated climate data, transportation asset data, and land cover data into a Geographic Information System (GIS) database and analyzed the potential change in existing transportation-related vulnerabilities over the next century.

The 2020 Asset Management, Extreme Weather, and Proxy Indicators Pilot Project introduced the concept of Lifecycle Planning, a process to estimate the cost of managing an asset over its expected lifespan, minimizing cost and preserving or improving the condition. The assessment focused on extreme weather and climate stressors, targeting four prioritized asset classes (i.e., bridges, culverts, pavement, and roadside vegetation/stabilization) and emphasizing the use of GIS as a tool to advance scientific evidence-driven decision-making within transportation systems management and integration into the asset management process. ADOT developed a GIS Resilience Database as part of this project to compile existing locations subject to natural hazard and weather-related risks. Over 500 locations of concern that experience natural hazard and weather-related risks were identified, such as overtopping at low water crossings, dust storms, flooding, rockfall, wildfires, erosion, and slope failures.

The ADOT Transportation Asset Management Plan (TAMP) includes detailed consideration of risk and risk management. The applied framework includes five components, namely: (i) Establish Context, (ii) Risk Identification, (iii) Risk Analysis, (iv) Risk Evaluation, and (v) Manage Risks. Risk types considered include Agency, Financial, Program, Asset, Project, and Activity. Risk registers are maintained whereby the likelihood and impact of various risks are considered and ranked. The TAMP proposes mitigation actions in the case of these high priority risks, which include extreme weather.

ADOT has developed many resilience planning tools, such as:

- A resilience financial hierarchy model;
- A planning/screening tool;
- An end-to-end engineering process tool; and
- A climate influence model.

In addition to these efforts, the 2018 Arizona State Hazard Mitigation Plan (HMP) set a goal to increase resilience throughout Arizona by reducing the vulnerability of people and property to natural and human-caused hazards. The plan identified critical facilities and infrastructure categories, including transportation networks. Other critical facilities and infrastructure categories evaluated included communications infrastructure, electrical power systems, gas and oil facilities, water supply systems, government services, and emergency services, which depend on the reliability and availability of transportation services.

Transportation systems evaluated in the HMP include:

- Interstates, US or state highways, and major local arterial roadways;
- Railways, rail yards, and train depots;
- Airports; and
- Major bridges, culverts, and storm drains that protect transportation infrastructure.

The HMP identified several transportation network vulnerabilities:

- Several ADOT-operated and -maintained freeways, highways, and state routes are located within dam and levee failure inundation zones.
- Drainage facilities (bridges, culverts, and channels) constructed within the ADOT roadways are not expected to have the capacity for handling the magnitude of flows associated with dam failure.
- Activation of a fissure intersecting property, facilities, and infrastructure can result in damage to transportation corridors (roadways and railroads) through cracking of drive surfaces, collapse of subterranean trenches, and rail separation or misalignment, which can lead to accidents or travel disruption.
- The majority of ADOT roadway corridors in the rural areas are designed to handle at least a 2% annual exceedance probability flood (50-year event), which means a 1% annual

exceedance probability flood (100-year event) may overtop or exceed the constructed drainage facilities.

- Transportation infrastructure is potentially most at risk from landslides.
- When a vital transportation corridor is blocked or damaged, the costs to the local jurisdiction can be significant.
    - Some transportation routes in Arizona are not easily detoured and alternative roads, if available, may take hours longer.
    - This impacts remote communities in particular where road damage can disrupt local services in the delivery of goods, interrupt employment, and impede access to health, educational, and social services.
- In the case of a wildfire, travel may be affected by damaged transportation routes, no traffic control resulting from power outages, and blocked routes due to downed trees and/or power poles.

2.2 Capital Programming and Investments

The Planning to Programming (P2P) Guidebook is another key entry point for resilience at ADOT. The Guidebook connects the LRTP to the Five-Year Construction Program. There are several technical working groups involved in the call-for-project, including a working group for geohazards. Resilience can also be flagged through the Technical Score Criteria. Specifically, the P2P Guidebook Section 7.0 District Score section heavily weighs resilience factors, which acts as a "resilience project prioritization trigger because the final decision on what project to pursue comes with visiting the sites and getting on the ground District input from the folks that know that specific location and the weather and natural hazard issue."[4]

In June 2023, the Arizona State Transportation Board approved the 2024-2028 5-Year Construction Program, which included more than $9 billion in transportation investments and committed $2.6 billion to upgrade pavement conditions across the state.

ADOT has established resilience metrics which are driven and tracked through resilience building software tools considering dollars spent, number of screened activities, asset types, State Route vs. Interstate, resilience cost-benefit analysis, total lane mile assessed for resilience, number of structures assessed for resilience, and more. For example, metrics are employed in the economic justification for project building. ADOT has, to date, completed ten resilience building efforts. For example, 24-hour precipitation design threshold and scour critical status were selected as sensitivity metrics in the TAMP and the Extreme Weather and Proxy Indicators Pilot Project.

3 Climate Hazards—Risks to ADOT

Arizona faces a variety of climate hazards (see **Figure 2**). The climate hazards discussed in this section include flooding, extreme heat, landslides, wildfires, and drought. In addition, earthquakes are discussed as a natural hazard. Although earthquakes are not climate hazards, they are relevant to transportation infrastructure and pose a hazard to transportation assets. The following hazard descriptions include a summary of the hazard, significant events in the state, and impacts on transportation infrastructure.

Figure 2. Natural Hazards affecting Arizona Transportation Infrastructure.

3.1 Flooding

Flooding is the most common and costly hazard that affects Arizona. The state experiences three main types of seasonal atmospheric conditions leading to heavy rainfall and significant flood events: tropical storm remnants, winter rains, and summer monsoon storms. These events can lead to multiple types of flooding: riverine, shallow sheet flow, distributary flow, alluvial fans, and post-fire flooding. It is uncertain how climate change will impact extreme precipitation and flood frequency and intensity in the future in Arizona. This is an active area of scientific research.

Since February 1966, a state or federal disaster has been declared in Arizona as a result of flooding incidents more than 130 times, more than any other category of hazard.[5] In July 2017, a flash flood swept through Ellison Creek within the area burned in the Highline fire that same year, killing 10 people.[6] In July 2022, heavy rain fell throughout south-central Arizona. Apache Junction was inundated with runoff from nearby mountains, causing multiple road closures and road damage across the city (see **Figure 3**).[7]

Figure 3. Flooding in Apache Junction in in July, 2022. Source: National Weather Service

The majority of ADOT roadway corridors in rural areas are designed to handle at least a 2% annual exceedance probability flood (50-year event), which means a 1% annual exceedance probability flood (100-year event) may overtop or exceed the constructed drainage facilities. There are numerous drainage facilities (e.g., bridges, culverts, and channels) constructed within ADOT roadways. Typical impacts include erosion of roadway embankments and pavements, culvert failures, and potential bridge failures.

3.2 Extreme Heat

Extreme heat occurs when temperatures rise above average temperature conditions. The most intense extreme heat events, heat waves, occur over several consecutive days. Extreme high temperatures occur in Arizona on a regular basis, but the highest threat typically occurs during the summer months of June to August when the monsoon season brings more moisture and humidity, raising the heat index (the combination of air temperature and humidity, often causing the temperature to feel hotter to humans). Extreme heat is anticipated to continue increasing in intensity, frequency, and duration in Arizona as climate change progresses. Phoenix has the hottest climate of all major US cities.[8] As an already significant hazard in the state historically, future conditions are projected to become increasingly dangerous and severe.

In 2020, Phoenix experienced a record 145 consecutive days above 100°F and 53 days above 110°F. More recently, in the summer of 2023, Phoenix experienced 31 consecutive days with high temperatures at or above 110°F. In July of 2023, the average monthly temperature in Phoenix was 102.7°F, the highest of any US city ever recorded. As of September 2023, nearly 200 people have died in Maricopa County due to heat-related illnesses.[9] These conditions are particularly dangerous for maintenance crews and outdoor workers.

Direct impacts of extreme heat on buildings and structures are generally limited to long-term, maintenance related issues like material degradation and expansion/contraction related movement. Extremely hot temperatures can soften asphalt-based pavements to the point of severe damage potential by heavy trucks and equipment. Improperly spaced rails can buckle due to heat expansion. Extremely hot temperatures can also ground airplanes due to the lack of air density required to generate the appropriate lift. Heat-generating mechanical equipment that is cooled by air can be pushed beyond operational temperatures and possibly fail or seize if not shut down in time. Heat-related illnesses like heatstroke, heat exhaustion, and heat syncope can cause negative health impacts on people, especially outdoor workers that are exposed to the heat, oftentimes without shade or cooling.

3.3 Landslides

Landslides, or downslope movements of soil, rock, and organic material, typically result from disturbances in the natural stability of a slope. They frequently accompany heavy rainfall or earthquakes and occur most commonly in mountainous areas. Landslides are complex events and the conditions leading to a landslide include a multitude of variables. Changes in storms, precipitation patterns, and drought conditions can lead to conditions favorable to the development of wildfires and landslides, and as such, the likelihood of landslide conditions may change in the future. This is an active area of scientific research.

There has only been one state disaster declaration in Arizona for a landslide event in 2010 that covered State Highway 87 in a large mudslide, causing a closure of the road for several days. This landslide was preceded by extreme winter rainfall in the area earlier in the month. In the summer of 2006, extreme precipitation caused approximately 1,000 debris flows to occur in four mountain ranges in southern Arizona. Repairs for infrastructure destroyed in Sabino Canyon near Tucson cost more than $1.5 million.[10]

Transportation infrastructure is potentially most at risk from landslides. Structures and buildings that are located within the path of a landslide typically sustain severe damage, if not complete destruction. Culverts and bridges receiving debris flows can be filled with dirt, cobbles, and boulders, rendering them ineffective. When a vital transportation corridor is blocked or damaged, the costs to the local jurisdiction can be significant. Some transportation routes in Arizona are not easily detoured, and alternative roads, if available, may take hours longer. This impacts remote communities in particular where road damage can disrupt local services in the delivery of goods, interrupt employment, and impede access to health, educational, and social services.

3.4 Wildfires

Wildfires are uncontrolled fires spreading through wildlands and/or urban interface areas, usually signaled by dense smoke that may fill the area immediately nearby or move higher into the atmosphere and spread for hundreds of miles. Wildfires can be caused by humans through arson or campfires or by natural events like lightning. Even small fires can threaten lives, infrastructure, and property. Long-term droughts raise the risk of wildfires, and the likelihood of wildfires will likely increase as climate change progresses.[11]

Wildfires burn thousands of acres in Arizona each year. According to the Southwest Coordination Center Historical Fire Data, between 2000 and 2015, Arizona averaged nearly 2,500 wildfires per year, burning more than 260,000 acres annually. More than half of the fires were human caused and another 45% were caused by lightning. In 2015, the Whitetail Fire burned for 30 days, costing fire management $2.8 million and ranking as the most significant fire monitored in the southwest during 2015. In 2013, the Yarnell Hill Fire, caused by lightning, grew rapidly, intensified by strong and erratic winds. Nineteen members of the Granite Mountain Hotshot Fire Crew lost their lives battling the severe fire.[12]

Structures, facilities, and above-ground infrastructure can be significantly damaged or destroyed by wildfires. The structural integrity of roads and bridges can be weakened by wildfires as well, rendering them unsafe for use. In addition, smoke and ash can cause health impacts and reduce visibility, causing dangerous travel conditions. Wooden poles can also be burned and the heat from a fire can warp metal on road signs.

3.5 Drought

Drought is a complex natural hazard and its impacts result from the interaction between a natural event (less precipitation than expected) and the demand people place on the water supply, which may include agricultural, municipal, industrial, and natural uses. Arizona is affected by drought conditions that extend beyond the state's borders and into the greater Colorado River watershed. Throughout the last half-century, groundwater has been extracted more rapidly than replenished, leading to a condition known as overdraft. Continued overdraft of the state's finite groundwater supplies will challenge the state's ability to ensure a secure water supply for the future. As climate change progresses, drought is anticipated to increase in intensity in Arizona due to higher temperatures, and potentially due to decreases in precipitation, although this is uncertain.[13]

As of October 2017, Arizona has experienced 22 droughts declared as drought disasters/emergencies by the Governor's Office and the Secretary of the US Department of Agriculture. The current drought began in 1995 and has persisted until now. The four wetter than normal years within that period have brought some relief but have not been enough to ameliorate the drought. A recent study of past droughts (A.D. 762-2005) in the southwest using tree ring data found that droughts in the past have lasted as long as 60 years, with reduced streamflow lasting an average of 25 years.[14]

Direct impacts of drought on the built environment are generally not measurable or significant for the normal drought cycles typical to the arid southwest. Travel patterns may be indirectly affected by drought due to changes in land use and potential population migration. Dust storms like haboobs can also cause significant traffic disruptions and delays as well as injuries and casualties from automotive accidents.

3.6 Earthquakes

Earthquakes, or ground shaking resulting from waves of energy released through the ground after tectonic plate movement at a fault, vary in size, depth, and type. When earthquakes occur, the waves generated travel through the ground and can cause ruptures, liquefaction, and widespread damage.

Even minor earthquakes can cause critical damage and loss of life. Earthquakes are not expected to change in intensity or frequency due to climate change.

Every year, hundreds of earthquakes occur in Arizona; however, most of these events are low magnitude earthquakes that are not felt by humans and do not produce damage. There has only ever been one state disaster declaration related to earthquakes in Arizona, resulting from the magnitude 6.6 Imperial Valley earthquake in 1979. Earthquakes occur most intensely in the southwestern and southeastern corners of the state, originating in southern California and Mexico, respectively.

Cascading events associated with moderate- to large-magnitude earthquakes are numerous, disparate, and potentially catastrophic. Examples include landslides, dam and levee failures, bridge failures, lifeline disruptions, road and rail transportation accidents, flood risk due to altered flow paths, fires, hazardous materials spills, and continuing seismicity due to aftershocks and activation of other fault systems. Damage to transportation corridors (roadways and railroads) can occur through cracking of drive surfaces, collapse of subterranean trenches, and rail separation or misalignment.

4 What's Next

As ADOT develops a formal RIP, much of the previously referenced work forms an excellent foundation which can be built upon. One of the RIP requirements is to have a comprehensive risk assessment that focuses on current and future climate events, including their likelihoods, impacts and consequences. The studies that have been conducted in the past are being gathered and assessed to compile past assessments and identify areas of opportunity for updated analysis.

Furthermore, as mentioned, aligning the RIP with the state's transportation investment plans will ensure that these investments consider resilience and can be expanded to include any additional investments that can increase transportation resilience. Therefore, another key step will be to build upon the previous project-level climate assessments and continue to holistically integrate risk into the project development and prioritization processes.