Transportation Research Board Webinar
The National Academies of Sciences
Measuring Resiliency – Tools for Analyzing Resilient Transportation Systems

Steven Olmsted – Arizona Department of Transportation – March 2021

Agency Resilience

Critical Transportation Infrastructure Protection

State

- Arizona State Emergency Response and Recovery Plan (SERRP)
- Planning Branch – AZ Department of Emergency and Military Affairs

ADOT

- Emergency Preparedness Management

https://azdot.gov/business/highway-maintenance/emergency-preparedness-management

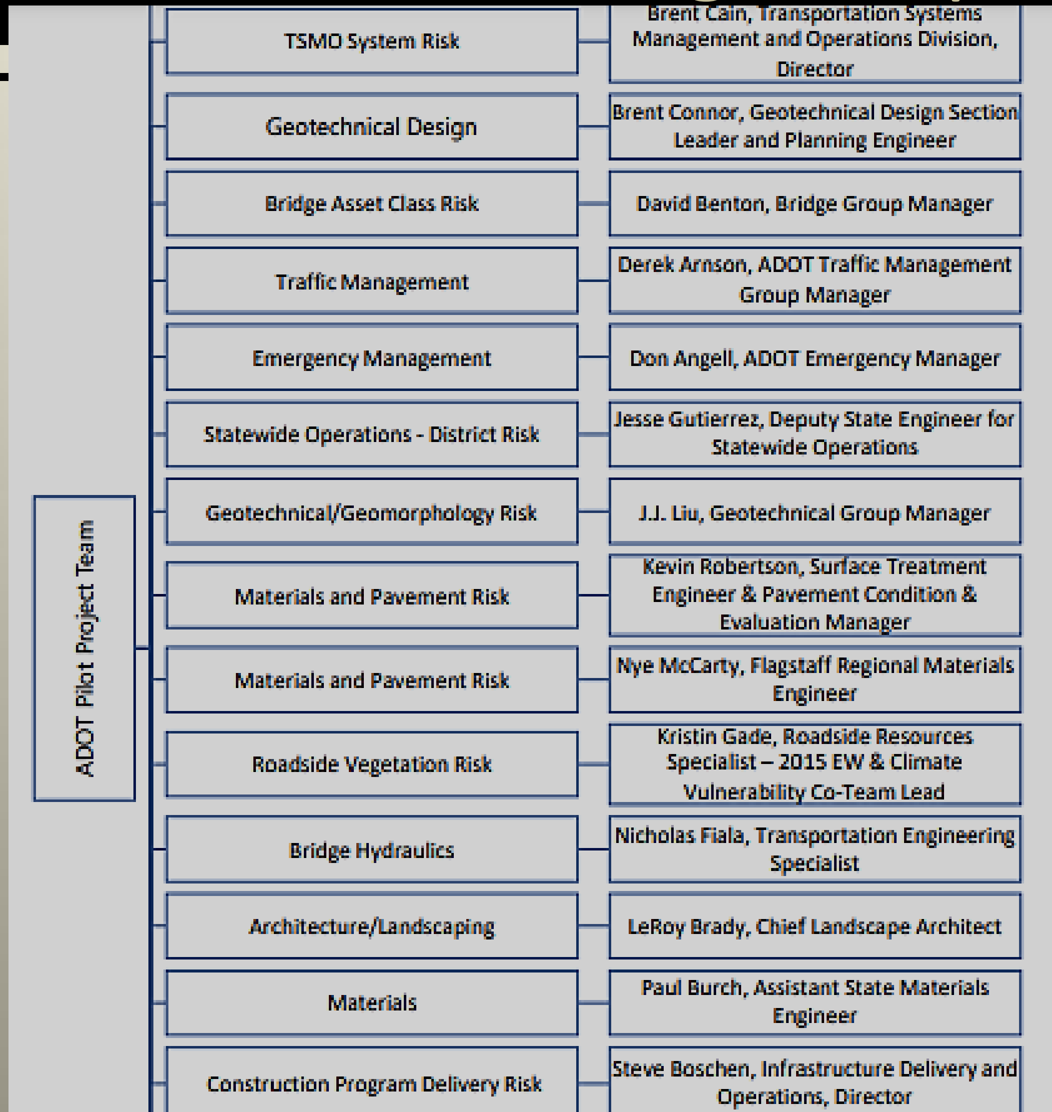
- Business Continuity - pandemic - Director's Office revamp
- Roadway - Incident Response Unit
- Physical, chemical, biological – dedicated Emergency Manager
- Road Weather AZ 511 app / ADOT Alerts app
- Cyber - IT Security Risk Management & Compliance team
- Transportation Infrastructure - Weather & Natural Hazard

Transportation Infrastructure Resilience

FHWA 5520 - anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions

Program Definition - The management of assets (bridges, culverts, pavement, and roadside vegetation/stabilization) in relation to the extreme weather-climate risks of; intense precipitation, system flooding, wildfires, wildfire-induced floods, drought-related dust storms, rockfall incidents, slope failures, and measurable climate trends (especially as it relates to precipitation and direct effects of increased surface temperatures); by regions or specific segments, emphasized as critical to contribute to the safety of the traveling public, improve weather and natural hazard risk management, and improve the long term life cycle planning of transportation infrastructure.

Internal Working Group



Eligible Risks Inventory

- Intense Precipitation
- System Flooding
- Wildfires
- Wildfire-Induced Floods
- Drought-Related Dust Storms
- Rockfall Incidents
- Slope Failures
- Increased Surface Temperatures

Impacts Narrative

There is currently a multitude of natural hazard and weather related stressors present in Arizona, but they can largely be separated into two categories: extreme heat and extreme precipitation.

The negative impacts of extreme heat include: pavement deformation, shorter pavement construction windows, heat-related worker safety issues, and public safety during lengthy delays. Extreme heat can also lead to an increase in dust storms, due to a decrease in vegetation coverage on soil, as well as contributing to an increased number of wildfires. Areas affected by wildfires may see increases of runoff to levels that the current drainage system cannot handle. On the other hand, extreme heat has the benefit of reducing the amount of freeze-thaw impacts to pavements and a reduced amount of snow removal.

Impacts Narrative - continued

Precipitation levels are expected to remain consistent for the near future. However, if precipitation levels rise, the existing drainage and pump stations in the state may become overwhelmed. Another impact of oversaturated soils includes the increased likelihood of rock falls, subsidence, and landslides. Lower number of precipitation events but a higher intensity is a concern. This scenario can heavily impact rural and urban areas alike for safety and economic development.

Resilience Financial Decision Making Steps (1)

A critical part of ADOT's TAMP financial plan is the agency's investment strategy. A major contributor to that investment strategy is the identification of ways to maintain the asset categories by using risk-based lifecycle planning strategies. One of the fundamental ways in which an Agency can begin to sort and prioritize risk is through the use of the TAMP required risk register. Inherently, there are regulations, constraints, and existing commitments on available funding sources. Once ADOT considers all the asset needs against available resources, making room for extreme weather and measurable long-term climate (EX W & C) trend mitigation strategies is difficult.

Resilience Financial Decision Making Steps (2)

Even in light of those difficulties, ADOT prioritized conducting EX W & Climate vulnerability assessments, developing a Resilience Program, conducting extreme weather event modeling and engineering analysis, working with climate models, and begin resilience building.

In concert with using lifecycle planning to support asset management decision making and incorporating risk management into TAMP reporting, an Agency needs a formal financial process to consider extreme weather and climate in financial decision making.

Resilience Financial Decision Making Steps (3)

- Assessment of - Agency/SEO /5-yr Construction Program/Divisions/Districts
- Screen through - Resilience Program
- Looking for - All historical actions and known locations to catalogue (GIS)
- Identified by - Design/Construction/Operations/Maintenance
- Financially justified with - Resilience Investment Economic Analysis (RinVEA)
- Programmed using - Financial tool box
- Support garnered - Decision maker consensus

Resilience Financial Decision Making Steps (4)

- Funding confirmed - Project Resource Board, Project Management, Project Finance
- Resilience Scope of Work developed blending Risk/Science/Technology/Engineering
- Funded projects commences
- System resilience advances
- Lessons learned gained
- Feedback loop to TAM Program Manager and Resilience Program Manager
- Feedback loop to methodology - Risk/Science/Technology/Engineering

Resilience Investment Economic Analysis (RinVEA)

A need for a process to assess cost viability and develop a tool to integrate extreme weather and climate justification into asset management and financial decision making. It amounts to a:

- CBA (total systems / sustainability centric)
- Project Justification
- Resilience Investment

Agency Chinle, AZ project photos

Investment Decision Tools

Resilience Investment Economic Analysis (RinVEA)

The main objectives of the RinVEA is to conduct basic economic analysis (CBA Analysis) that included the following basic parameters:

- Protect the new $5.2M roadway investment
- Address severe erosional and drainage issues that has led to a 25%-100% degradation at sixty-one (61) of the eighty-six (86) CMP drainage structures
- Address drainage excavation, barrow and slope stabilization issues at those structures and severely compromised stormwater management capabilities along this segment of SR 191
- Comply with and proactively address expected regulatory actions on stormwater management, FHWA Order 5520, Presidential Executive Order on Federal Flood Risk Management, and MAP21 asset preservation performance requirements
- Upgrade ADOT's application of risk-based assessment modeling at the asset class, project development, and localized hydrological event level
- Further ensure use of SR 191 in the remote far northwest of Arizona and a main Apache County connector between SR 264 and US 160 in the advent of an extreme weather event

Resilience Building Tracking

Project Number	Rt.	System Location	Resilience Work Completed	Project Cost	Resilience & Financial Decision-Making Outcome
Resilience Building Project #1	SR 191	Chinle, AZ	31 Drainage Structures Rehab	$6m	Roadway and embankment now protected to the 50-year storm event
Resilience Building Project #2	SR 160	Laguna Creek Bridge	Gabion basket bank protection	$1m	Bridge now protected to the 500-yr storm event - Tribal Partner - key corridor
Resilience Building Project #3	SR 95	Fortuna Wash Bridge	Bridge replace	$9.3m	Bridge now protected against Fortuna Wash floodwaters flowing over the road, secured the $500m in area economic impact, reduced/eliminated considerable detour
Resilience Building Project #4	I-8	Foothills Blvd to Dome Valley	Roadway deterioration and clogged and corroded drainage structures due to storm events and aging repaired	$14m	Vulnerable NHS asset improved - Access for City of Yuma, Yuma Port of Entry, State of California, Yuma International Airport, USMC Air Station Yuma, Barry M. Goldwater Air Force Base, Port of San Luis SR 95, MP .01 Mexico Border
Resilience Building Project #5	I-17	New River Bridges Structures - N and S	Concrete floor approximately 3 feet below the channel bed underneath the bridges. Cutoff walls at both upstream (approximately 4 feet deep) and downstream (approximately 6 feet deep)	$2m	Vulnerable NHS asset improved Maricopa County and its 4.2m residents
Resilience Building Project #6,7,8 underway					
Resilience #9,10 identified entering design					
Resilience Operating Project #1 (TSMO)	Phx		Pump Station Optimization Tool for operators and capital investment	$200K	Developing predictive model of probability of pumping station failure. Variable examples: season, condition, manufacturing date, date of last repair, size, sufficiency of capacity, precipitation magnitude, and manufacturer type.

Asset Management

Asset Management Risk Register - 25
Weather/Natural Hazard Risks – 6 (links to 6 other)
Agency – Extreme Weather Trends
Asset – Flooding, Scour, Pump Stations
Asset – Landslide/Slope Failure
Asset – Rockfall
Asset – Culvert Failure
Activity – Redundant Routes

Table 6-1 Risk Type

Risk Type	Affect
Agency Risk	Risk to the agency that affects the implementation of the strategic goals of the asset management plan. Examples include changes in leadership, legislative actions, unfunded mandates and the ability to convey the importance of asset management to decision-makers and the public.
Financial Risk	Affect the availability of adequate funding or accurate prediction of future funding needed to implement the TAMP. Examples include inflation, unexpected funding shortfalls, solvency of the Highway Trust Fund, financial markets, interest rate increases and inaccurate predictions in financial plans.
Program Risk	Affect the ability to deliver a program of projects in a timely manner and meet performance targets. Risks may include the inability to effectively manage data, the loss of institutional knowledge via attrition, competing spending priorities, inaccurate cost-estimates and construction/materials price volatility.
Asset Risk	Affect individual assets, such as structural deterioration, extreme weather and obsolescence. Assets risks include flooding, landslides, hazardous materials spills, collisions with bridge elements and assets that do not meet current design standards.
Project Risk	Associated with projects to restore or replace individual assets. An example of a project risk is the impacts associated with lengthy construction detours in areas where redundant, alternative routes don't exist. Project delivery risks include delays caused by environmental, utilities, right-of-way, geotechnical, procurement, scope creep and inter-governmental agreements.
Activity Risk	Associated activities like routine maintenance, including slow or inadequate response to damaged assets (e.g., pothole or guard rail repair) or extreme weather events (e.g., clearing blocked drainage structures, repairing scour weakened bridge foundations or risks to workers such as heat, fires, etc.).

Asset Management Tools

Risk Rating Scale

		Consequence (C)				
Likelihood(L)		1	2	3	4	5
Level	Descriptor	Negligible	Minor	Major	Critical	Catastrophic
1	Low	1	2	3	4	5
2	Medium Low	2	4	6	8	10
3	Medium	3	6	9	12	15
4	Medium High	4	8	12	16	20
5	High	5	10	15	20	25

Agency Action Process

Agency Action	Description
Prevention	Vulnerability and risk assessments; Hardening of structures and materials; Detection and monitoring; Asset management techniques; Resiliency Plans
Response	Training; Emergency response guidelines; Practice drills; Alternative service strategies
Recovery	Alternative routing; Fast contracting and project initiation; Staff allocation plans
Investigation (Root-cause)	Engineering studies; Probabilistic analysis; Service planning reviews
Learning	After action reports; Research; Performance assessments

CEA-TA

A Climate Engineering Assessment for Transportation Assets (CEA-TA)
Incorporating Probabilistic Analysis into Extreme Weather and Climate Change Design Engineering

Steven Olmsted, Arizona Department of Transportation; Alan O'Connor, Trinity College Dublin; Constantine Samaras, Carnegie Mellon University;
Beatriz Martinez-Pastor, Trinity College Dublin; Lauren Cook, Carnegie Mellon University

Abstract

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. As fiscal constraint for the development and rehabilitation of such structures remains; and endless retrofitting continues to be cost prohibitive; new and novel approaches to long term planning and project development, engineering design, and life cycle assessment are paramount. The management of these infrastructure systems has now evolved from a decentralized, project-based focus, to one that now encompasses enterprise wide endeavors – administration, technology adoption, planning, design, construction, operations and maintenance. In addition, the expansion of risk analysis for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems. At the 2015 Transportation Research Board (TRB) Annual Meeting, Session 197: *Mainstreaming Climate Change and Extreme Weather Resilience into Transportation*, the Arizona Department of Transportation (ADOT) introduced the challenge ahead for public entities to coordinate a host of known and unknown extreme weather and climate change issues. That challenge – Continue considering the balance between predictable asset deterioration curves, the sudden and unpredictable nature of extreme weather events and long term climate trends, new models for risk assessment and life cycle cost analysis, and appropriate adaptation strategies. This multiple part challenge necessitated a new end-to-end engineering approach to incorporate such current and future risks. At the 2016 Annual Meeting ADOT submitted a paper representing the core of that new approach – a Resilience Program and an ADOT/United States Geological Survey Partnership. That paper was graciously recognized as a best paper by the TRB Special Task Force on Climate Change and Energy. In the spirit of continuing that forward progress – this paper presents the remaining parts needed to develop a new end-to-end engineering-based asset adaption process – a structured sequence to incorporate extreme weather and climate change adaptation into the design engineering process. The paper benefits from preeminent researchers in the two integral, and practice ready, remaining parts – probabilistic modeling for engineering design and infrastructure system design life cycle outcomes for extreme weather and climate change in a transportation engineering setting.

Arizona DOT Resilience Program

Transportation infrastructure is a complex system of assets required to deliver a myriad of services and functions. The expansion of risk development for extreme weather management and climate change adaptation has complicated the long term delivery of these complex transportation systems.
In order to develop an innovative approach, the first step was to create a system process that allowed for a shift from a deterministic preset design parameter and/or frequency basis, statistical risk of failure, and historic project and programs budgeting focus – i.e. extreme events not considered – to a probabilistic analysis approach that inputs additional data, vulnerabilities, and considerations not previously considered. In 2015 and 2016 ADOT focused on linking scientific evidence-driven data capture with the design engineering processes through the development of a partnership with the United States Geological Society (USGS). Extensive 2-D/3-D engineered modeling underway.

(CEA-TA) – A Structured Sequence

Identify EX W & CC project and program candidates - *Vulnerability Assessment*

2015 FHWA Pilot Project - The study examined baseline (historical) and potential future extreme weather conditions, focusing on temperature and precipitation variables. Two future analysis periods were selected: 2025 to 2055 (referred to subsequently as 2040, the median year), which reflects the time horizon of ongoing long-range planning efforts, and 2065 to 2095 (2080), roughly associated with the expected design lifespans of some critical infrastructure types, such as bridges. To provide a long term baseline against which to compare the projections, the team also examined temperature and precipitation observations from 1950 through 1999. The report was issued by FHWA in the Spring of 2016.

WHY IS MOVING TO A PROBABILISTIC APPROACH EVEN NEEDED?

This question could cover pages and pages. The short answer is easy. In addition to sustainable transportation attributes, there is growing consensus that if transportation systems are going to incorporate extreme weather and climate change, consideration must be developed that account for hydrometeorology/climatology, hydrology, hydraulics, and hydrodynamics. Since all these areas continue to adopt advanced mathematical modeling approaches, it is therefore logical that transportation systems and projects develop also incorporate these progressions.

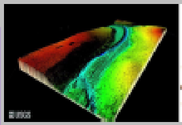
Develop economic analysis process - *Justification*

An economic analysis for the CEA-TA process would consist of using a probabilistic approach to life cycle cost analysis. The life cycle cost of an infrastructure asset such as a roadway or bridge, is the total cost to an agency throughout the asset's useful life. This includes the planning, design, construction, maintenance and decommissioning phases of infrastructure delivery. State DOTs typically initially approach this process without considering risk and uncertainty that future conditions will be different from the past, and assume a uniform distribution of annual maintenance costs and major reinvestment intervals. Long-lived infrastructure must perform under future climate conditions and climate-influenced usage that deviates from the historical data now populating infrastructure economic analysis and asset management models. Climate change impacts, such as sea-level rise, storm surges, changes in precipitation, hotter temperatures, and others are potential vectors of infrastructure failure and should be taken into consideration in infrastructure economic analysis and asset management models.

Resilience Program
Economic Analysis Pilot
US 191 MP 436 to Chinle
PROJECT NO. 191 AP 436 H8676 01 C
FEDERAL AID NO. STP-191-E(214)T
Apache County
Holbrook District

Design probabilistic modeling approach to produce an array of results - *Quality Control*

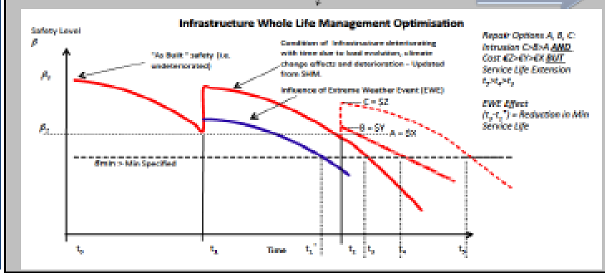
Optimize operation and maintenance of an increasingly aging stock, which is subjected to evolving loads (e.g. both live loading and climate induced loading). In response to this challenge the past decade has seen increased interest by infrastructure owners and managers in the use of probabilistic methods for the assessment/management of their assets. Employed once a deterministic assessment has rendered a repair/rehabilitate/replace now scenario



Define limits of simulation runs that incorporates latest science/engineering - *Policy*

Climate models can provide insight into future conditions, projecting air temperature, precipitation, evapotranspiration, and other factors of interest to engineers, at various temporal and spatial resolutions. However, there is a considerable disparity in the outputs provided from climate models for impacts analyses and the inputs needed by engineers for planning and design. These discrepancies include mismatches in temporal and spatial scales, complicated data extraction and preparation requirements, sizeable model, data, and scenario uncertainties, and a lack of direction for the rigorous selection of models for use in different engineering applications.
Innovative change examples:

- Every Day Counts – 4 : Collaborative Hydraulics: Advancing to the Next Generation of Engineering (CHANGE)
- NCHRP 15-61 - Applying Climate Change Information to Hydrologic and Hydraulic Design of Transportation Infrastructure
- NCAR - *The Future Intensification of Hourly Precipitation Extremes* - Andreas F. Prein et al. December 2016
- LiDAR, UAS/UAV, 2-D water modeling, 3-D visualization and animation tools
- Translational organizations to provide rigorous standards for interpretation of climate data, development of a single, simplified user interface that accesses all downscaled data sources, and tools that automatically post-process data based on defined standards



Systematically record location and resilience efforts GIS/TAMP - *Risk Management*

ADOT has been systematically capturing data sets for extreme weather and climate change use through an extensive geographic information system (GIS) effort that will subsequently support ADOT's transportation asset management planning (TAMP). ADOT's studies showed concerns with the climate and extreme weather vulnerability of bridges, culverts, pavement, and roadside vegetation / stabilization. Legislation - Focus in MAP-21 on performance based management and risk-based asset management plans; Inclusion of "resilience" in FAST Act.

Develop life cycle models to monitor investment - *BCA/ROI*

Civil infrastructure systems are among the largest local, state and Federal investments, and these infrastructure systems are critical to U.S. economic, environmental and social outcomes. Yet longstanding underinvestment in infrastructure has resulted in the poor condition of much of U.S. infrastructure, with an estimated $3.6 trillion of re-investment needed by 2020. New methods for benefit cost analysis, return on investment studies, and major rehabilitation timeline analyses are needed that incorporate probabilistic approaches, and minimize regret by DOTs under a changing climate. The results of CEA-TA provides that method.

Acknowledgments

The completion of this project would not have possible without assistance from many stakeholders both within and outside ADOT that contributed to this effort. Specifically, the International Symposium - *Transportation Resilience: Adaptation to Climate Change and Extreme Weather Events*, June 16-17, 2016 at the European Commission in Brussels, Belgium that was the catalyst for the transatlantic partnering. The ADOT author wishes to acknowledge the efforts and support of: ADOT State Engineer's Office and ADOT Environmental Planning.

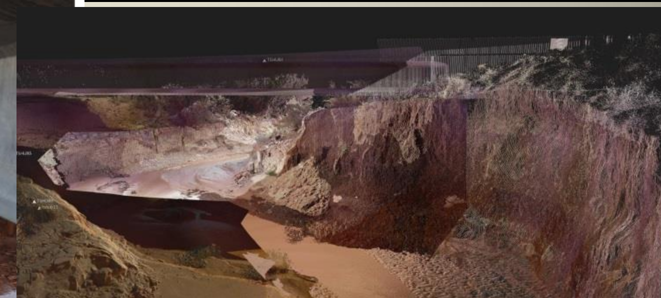
Engineering Tools

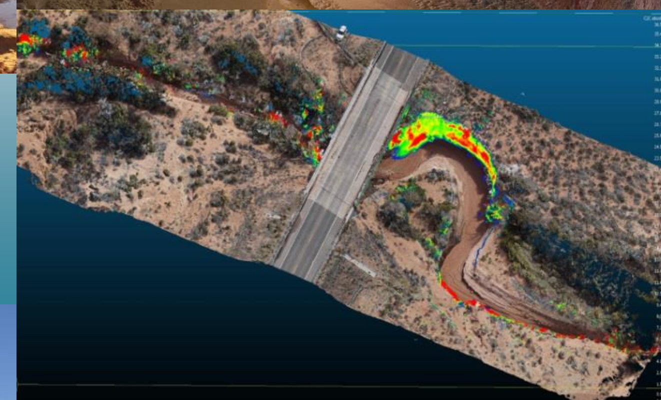
USGS Partnership - Reach Monitoring in Dynamic Channels

Understanding bank erosion and impacts to infrastructure

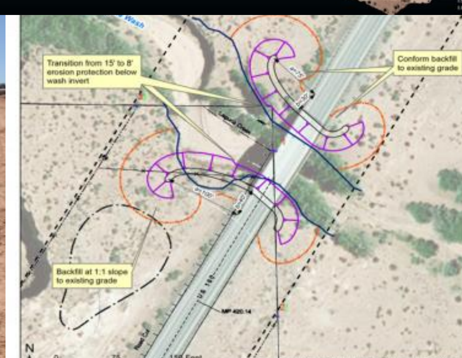
Laguna Creek Pilot Project Reach Monitoring:

- Rapid deployment stream gage
- Surface velocity radar sensor
- Particle tracking video cameras
- Indirect discharge measurements
- Repeat LiDAR scans of bridge structure and surrounding channel
- sUAS (drone) survey





Agency Dennehotso, AZ project photos



Geohazard Management Plan

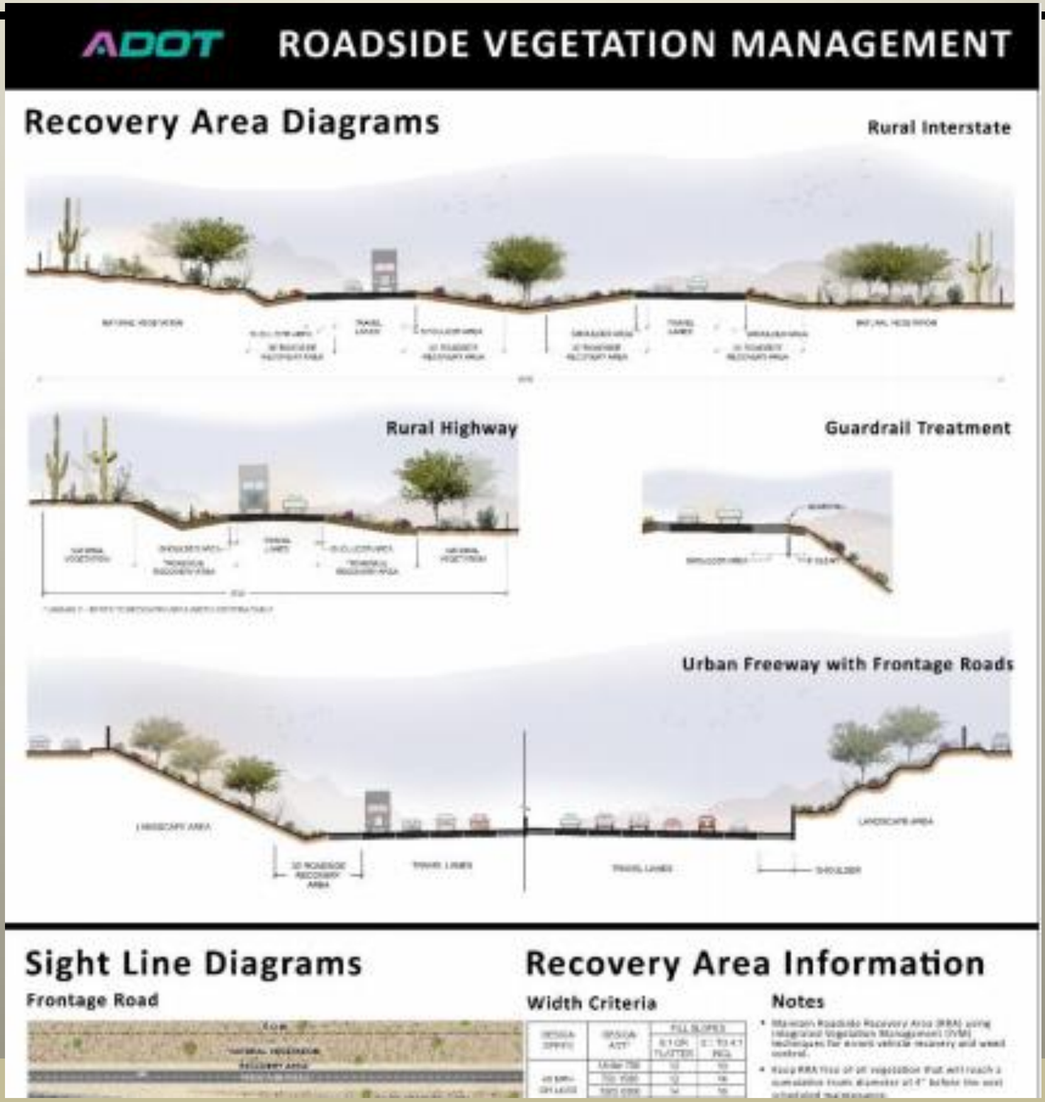
After experiencing significant impacts to mobility of the system due to geohazards in the analysis period of 2010 to 2015, ADOT has proactively managed many geohazards through preventative projects thought the Slope Management Subprogram. Geohazards such as landslides, rockfall, debris flow, sink holes, and heaving roadway subgrade have impacts to the maintenance, mobility and risk allocation in an asset management model.

Pavement Tool Box

The 2021 effort, already underway, will assess measurable climate trends against the impacts to ADOT's pavement asset class, surface treatments and materials, difficult to manage known freeze-thaw zones, and impacts to roadside vegetation/stabilization (biotic and seeding). All these have been framed to remain in the context of future asset management reporting for infrastructure health opportunities.

More specific to climate adaptation efforts

Roadside Vegetation / Stabilization



Resilience GIS Database

Data

- ADOT's USGS Data
- Drought & Wildfire
- Layers from ADOT's USGS Flood map
- Dust storm data (I-10 pilot)
- 5-yr program priority project information
- Bridges (including scour program)
- Culvert
- ADOT system base layers
- Geohazard locations
- Soils
- Live Feeds

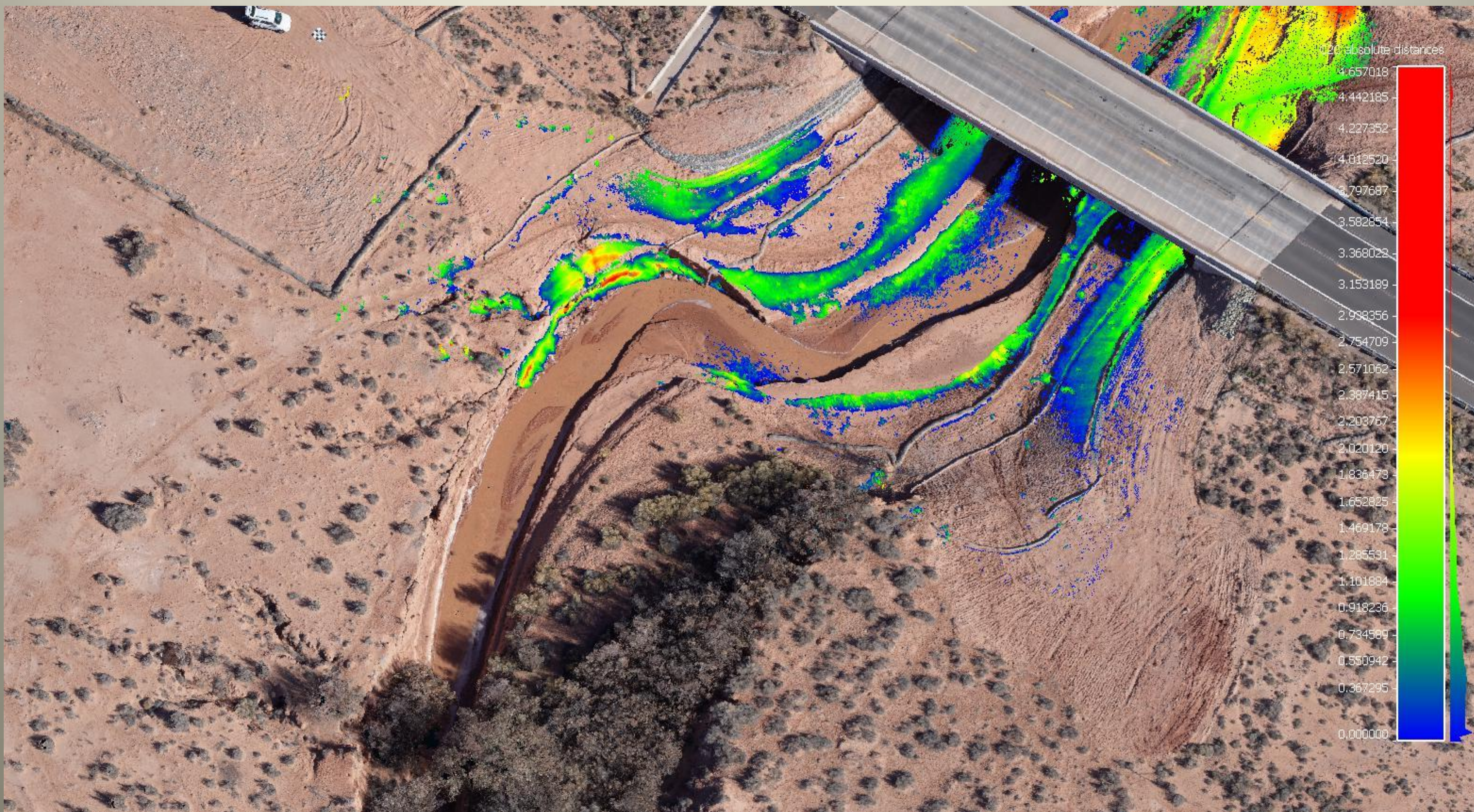
Data

- ADOT/USGS Project Work
- Resilience (Extreme Weather and Climate) Building
- Resilience Investment Economic Analysis assessment locations
- Climate Engineering Assessment for Transportation Asset (CEA-TA) locations
- Every Day Counts CHANGE 2-D modeling projects
- 2050 and 2100 climate data downscaling mapping
- Statewide drainage dashboard
- Weather event dashboards

Post Construction Monitoring Process

USGS Drone Data Capture – On-going Monitoring - Built Condition Wash Meander / Ox-bow

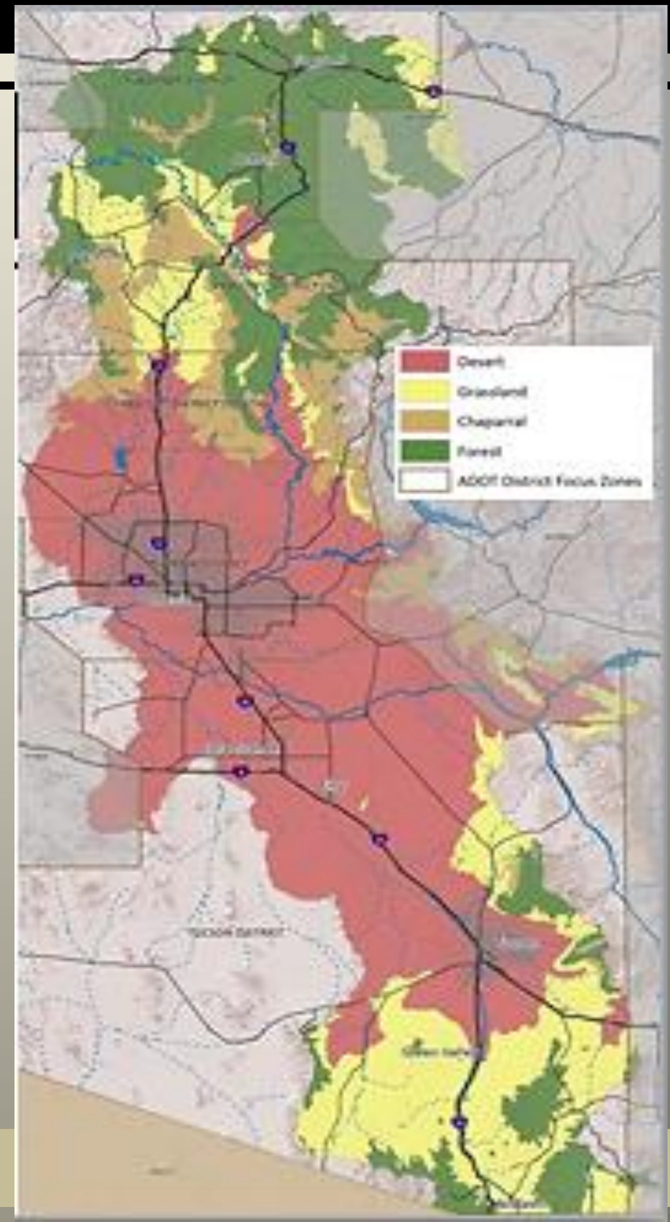
Post Construction Monitoring Process



2-D Erosion Change Detection Mapping

Develop Geographic Specific Climate Models

- Large, geographically diverse study area (over 30,000 square miles)
- High spatial resolution climate data desired
- Stressors included both average and extreme temperature and precipitation
- Helpful existing tools (e.g., FHWA CMIP Processer), but customization required
- Modest resources for collection and processing



Climate Data Selection

Parameter	Specification
Projections and Historical Data Source	Downscaled CMIP5 Bias Corrected Constructed Analogs (BCCA) daily projections with accompanying historical data
Emissions Pathway	Representative Concentration Pathway 8.5
Downscaled General Circulation Models (GCM)	NorESM1-M, HadGEM2-ES, CSIRO-MK3.6, CanESM2, MPI-ESM-LR, MPI-ESM-P, GFDL-ESM2M
Horizontal Spatial Resolution	1/8° (~7.5 mile or ~12km)
Temporal Resolution	Daily for 1950-2000 (backcastings from models in addition to historical data), 2025-2055, and 2065-2095
Model Outputs	Temperature (daily maximum and minimum) and precipitation (daily total)

Climate Output Metrics

Maximum 1-Day Precipitation Event (by time period)
100-/200-Year Maximum Precipitation Event using Generalized Extreme Value distribution
Minimum Annual Precipitation
Average Annual Precipitation
Average Number of Days Per Year in which Precipitation Exceeds Baseline Period's 99th-Percentile Precipitation Event
Average May-June-July-August Precipitation
Average Daily Maximum Temperature
Average Number of Days Per Year in which Temperature equals or exceeds 100 degrees
Average Number of Days Per Year in which Temperature equals or exceeds 110 degrees
Average Number of Days Per Year in which Temperature falls below or is equal to 32 degrees
Average Daily Minimum Temperature

Highway Stormwater Pumps – Reliability Tool

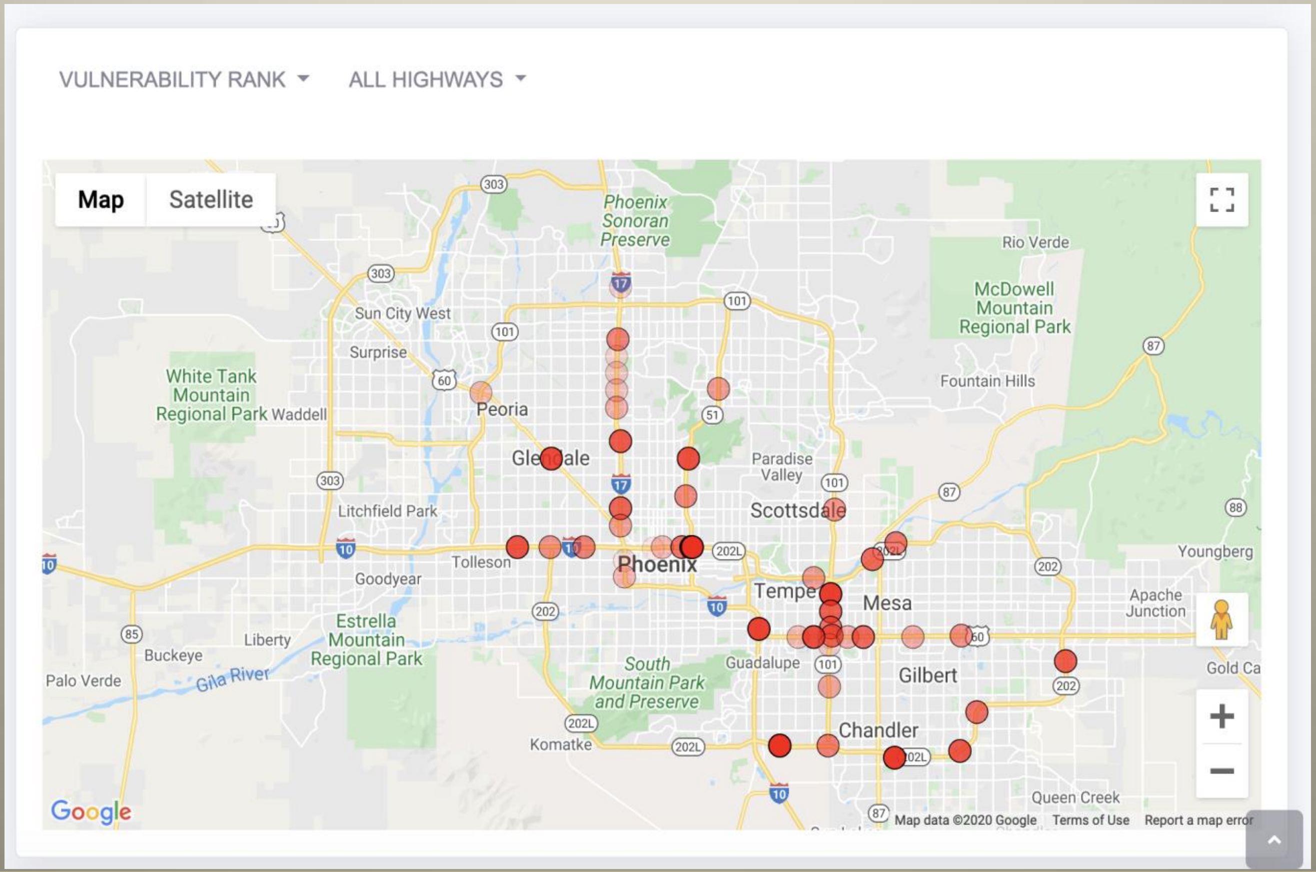
Increasing Accuracy

Pumping stations are critical hardware that must operate during the most extreme events to ensure roadway reliability. Yet little is known about the factors that contribute to pumping unit and station failure.

Developed a dynamic reliability analysis decision-support tool which considers individual pump component vulnerability, overall pump station vulnerability, and the risk of pump station failure (given vulnerability and traffic flow) to provide information to aid operators considering hardware and environmental conditions tin prioritizing maintenance and rehabilitation

Highway Stormwater Pumps – Reliability Tool

Prioritization Map Page: Ranking data is displayed visually on a geo-spatial map of pump stations in the Phoenix Metro area



Highway Stormwater Pumps – Reliability Tool

Statistical Model Description (E. Bondank)

Used description of which pump station component failed in the telemetry data, created a statistical model for each of the components to estimate their vulnerabilities.

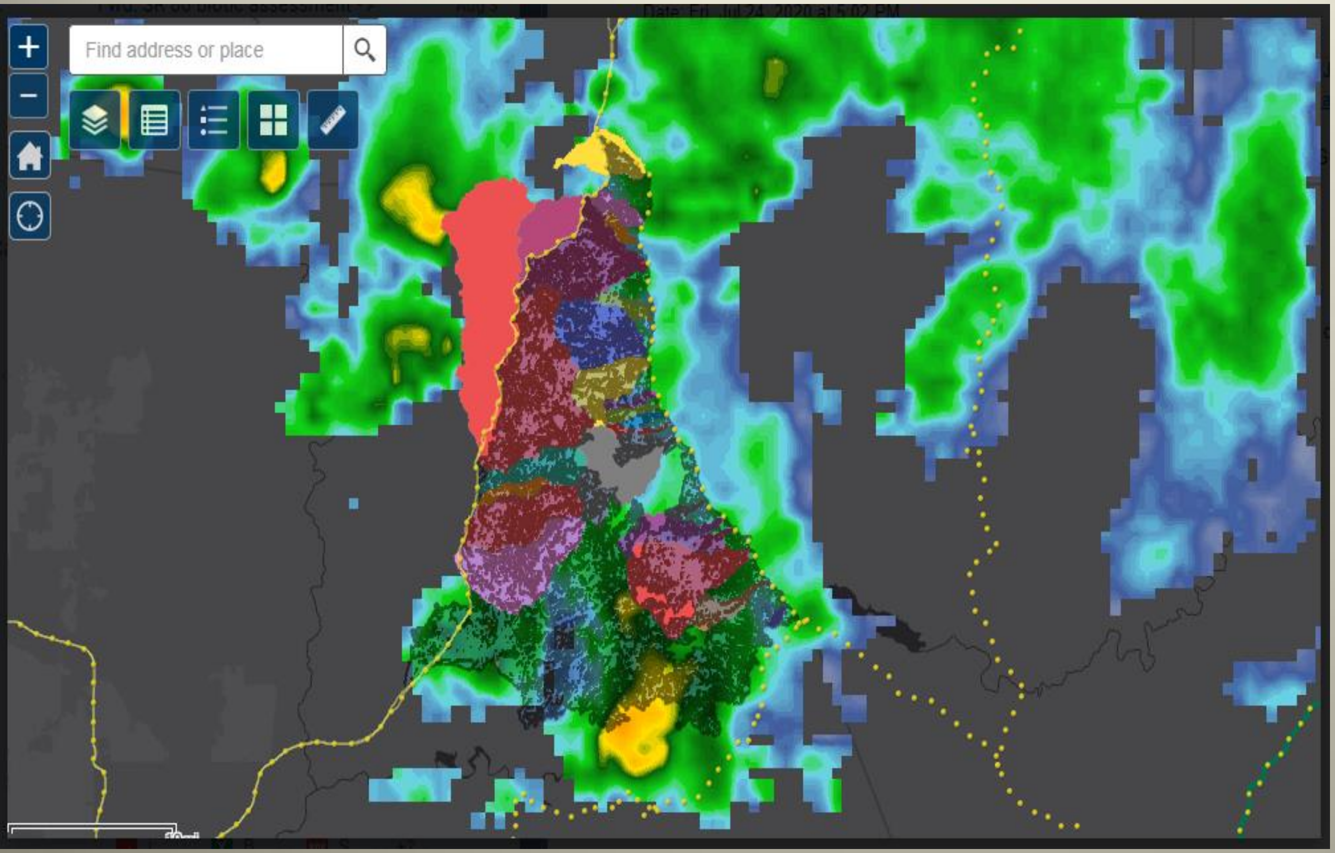
Used a form of non-linear statistical regression called a logistic model which can predict the probability of binary outcomes (such as pump failed or not failed). Transformed the data into panel data to assess for each rain event day, whether each pump station had a failed component.

The logistic regression equation is shown in the equation. The predicted values are calculated using the cumulative probability distribution function of the standard logistic.

$$\mathrm{P(Failure = 1)} = \frac{1}{1 + e^{-z}}$$

2020 Arizona State University Metis Center Sustainable Infrastructure Award

Resilience GIS Database Event Dashboards



Bush Fire impacted
SR 87 & 188
195,000 Acres

Dashboard layers:

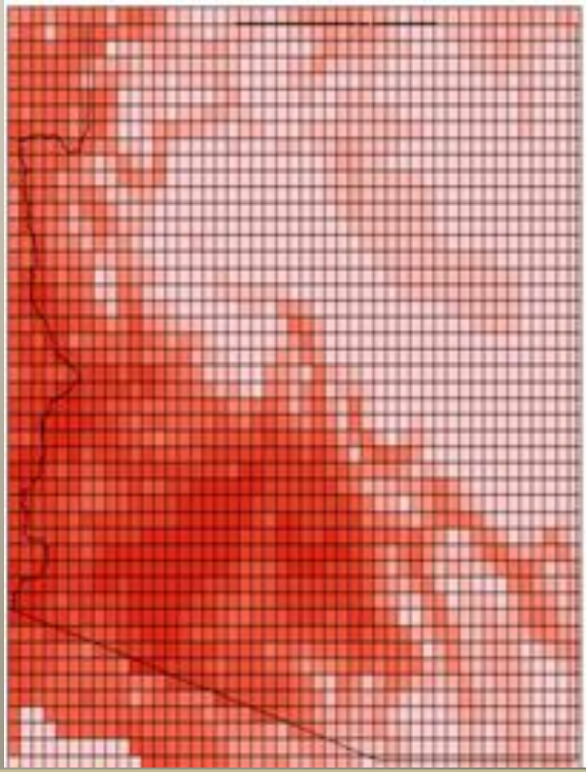
- Debris Flow
- Bush Burn Severity
- Bush Fire Watersheds
- Rain Gages
- Pressure Transducers
- Roads with Mile Posts
- Main Highways
- Scour Critical Bridges
- NOAA Radar live feed
- Watches, Warnings, Advisories live feed
- NDFD Precipitation live feed
- Active Hurricanes live feed

Climate Adaptation

- Arizona was laid out in 12 km x 12 km grid (total of 2680 grid elements)
- Grids are consistent with format of downscaled climate data from

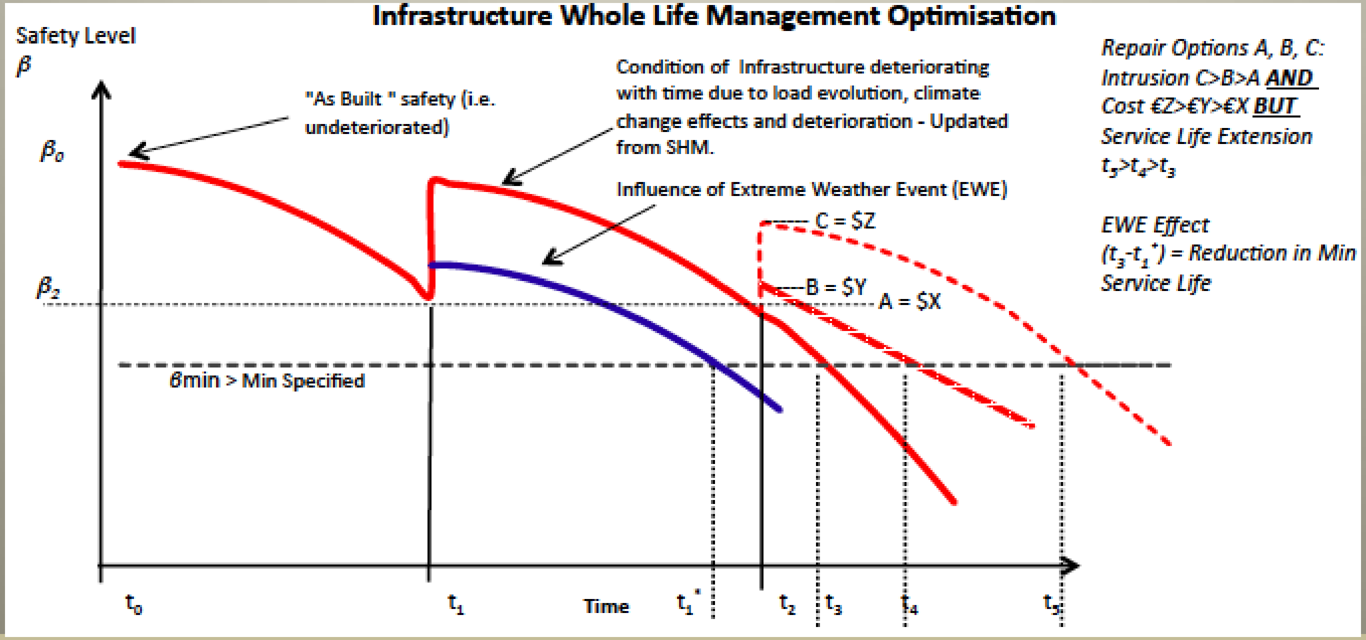
https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

- 19 climate models
- Considered two time periods
  - 2025-2055
  - 2065-2095
- 2021 Pavement binder and freeze thaw project
- Transportation will need 2125 climate data



Design Engineering Tool

Developing bridge asset class probabilistic engineering approach that assesses the stressors inherent to the built structure itself – live loading, extreme weather loading, climate induced loading using watershed, runoff data, topo, hydraulics, bridge design, and computation of the probability of failure at the considered limit state(s)



A. O'Connor

Tools Projects through 2021

Four Partnerships – Trinity College Dublin, Carnegie Mellon University, North Carolina State, and Texas Transportation Institute CAARTEH consortium:

- Finalize Resilience Performance Measures, Indicators, Metrics
- Further Economic Analysis Processes
- Further Life Cycle models to monitor resilience investment
- Account for the differences in the deterioration model with new climate-informed asset management models
- Customized intensity-duration-frequency (IDF) curves

Future Analysis Tools Needs

While different methods to quantify the economic impact of weather & natural hazard for infrastructure exist, advancing resilience tools for:

- Cost benefit analysis
- Return on investment
- Risk thresholds identification (fortify – rebuild – or absorb event risk)
- Identifying specific durability limit states
- Major rehabilitation timeline analyses
- Resilience bond adoption - Improved public agency awareness

are needed that incorporate probabilistic approaches, and minimize regret by DOTs under changing extremes and climates.