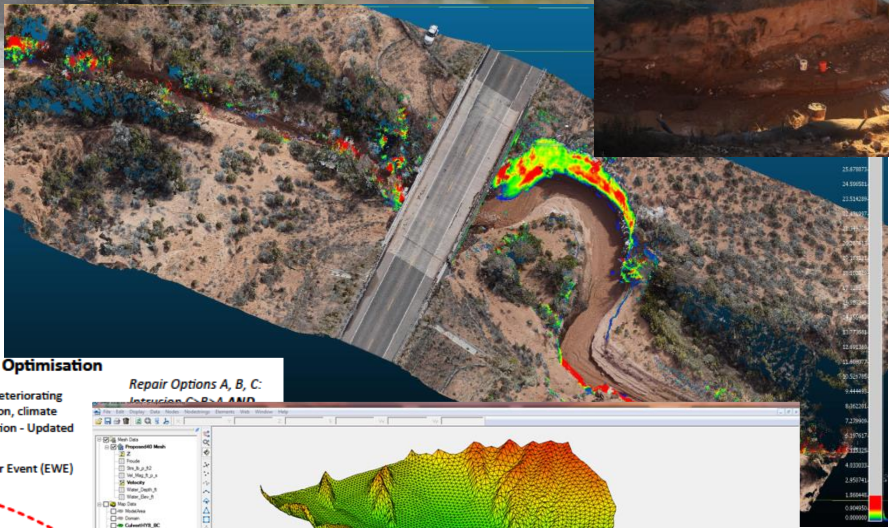
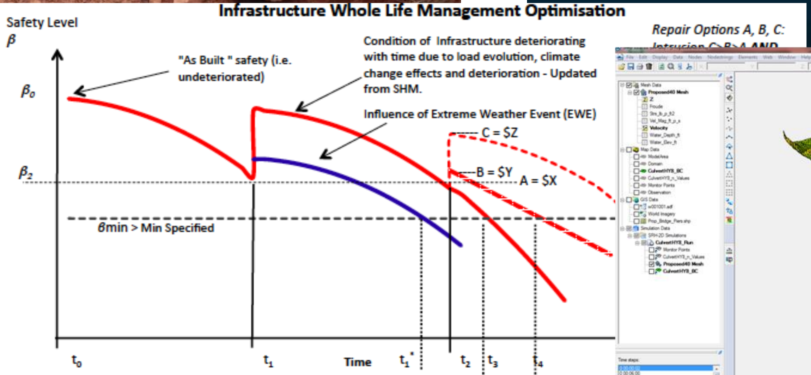
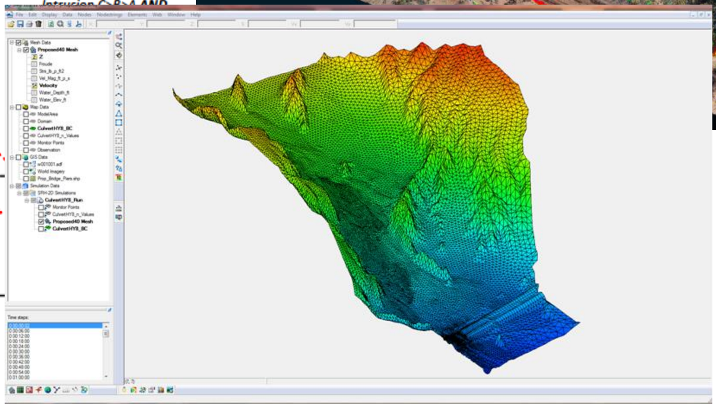
Arizona DOT Infrastructure Resilience
Risk & Resilience in TAMPs
Asset Management, Extreme Weather, and Climate Trends
Blending Risk/Science/Technology/Engineering







Steven Olmsted

Arizona DOT

Environmental Planning

TRB 12th National Conference on Transportation Asset Management

July 17, 2018

ADOT

Arizona DOT Resilience Program

How is ADOT bringing EX W & Climate risk into asset management planning?

Formalize an ADOT Resilience Program - October 2015

Facilitate ADOT's engineering/technical capability to manage risk and long term asset management strategies - the assets (bridges, culverts, pavement, and roadside vegetation/stabilization) in relation to the extreme weather-climate risk 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

AASHTO TERI Database idea #884 October 2013
https://environment.transportation.org/teri_database/idea_details.aspx?rid=884
Became NCHRP 25-25, Task 94, *Integrating Extreme Weather into Transportation Asset Management Plans*
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3723

ADOT

FHWA / ADOT Asset Management Project

And through the continuous improvement adoption of Life Cycle Planning (LCP)

Overarching EX W & Climate LCP Drivers

- 23 U.S.C. 119, 101(a)(2), 150(a) & (b)(2); 23 CFR Part 667; Order 5520
- All other relevant Asset Management Rule items
- Arizona Management System (AMS LEAN initiatives)
- Guidance on Using a Life Cycle Planning Process to Support Asset Management (2017)
- Guidance on Incorporating Risk Management into Transportation Asset Management Plans (2017)

Arizona DOT specific LCP Drivers

- Execution of grant related tasks, TAMP Agency Risk Register, Resilience Program Risk Register, State Transportation Improvement Plan, ADOT 5-yr Construction Program, Climate Engineering Assessment for Transportation Assets (CEA-TA), Arizona DOT Influence Model - Surface Transportation System Resilience to Climate & Extreme Weather Events

ADOT

Life Cycle Plan

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.

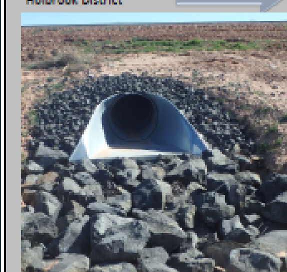
WHY IS MOVING TO A PROBABILISTIC APPROACH EVEN NEEDED?

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*

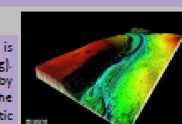
An economic analysis for the CEA-TA process would consist of using a probabilistic approach to life cycle cost analysis. The life cycle cost of an infrastructure asset such as a roadway or bridge, is the total cost to an agency throughout the asset's useful life. This includes the planning, design, construction, 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.

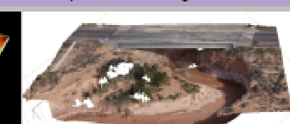
Resilience Program
Economic Analysis Pilot
US 191 MP 436 to Chinle
PROJECT NO. 191 AP 436 H8676 01 C
FEDERAL AID NO. STP-191-E(214)T
Apache County
Holbrook District



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

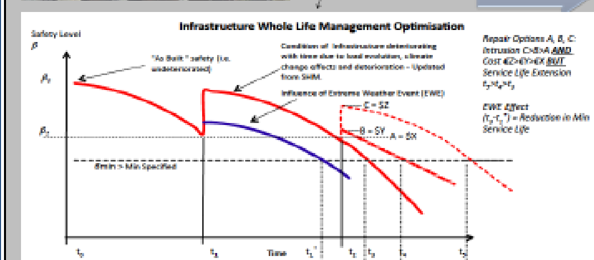




Define limits of simulation runs that incorporates latest science/engineering - *Policy*

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.

Impacts

ADOT

Impacts

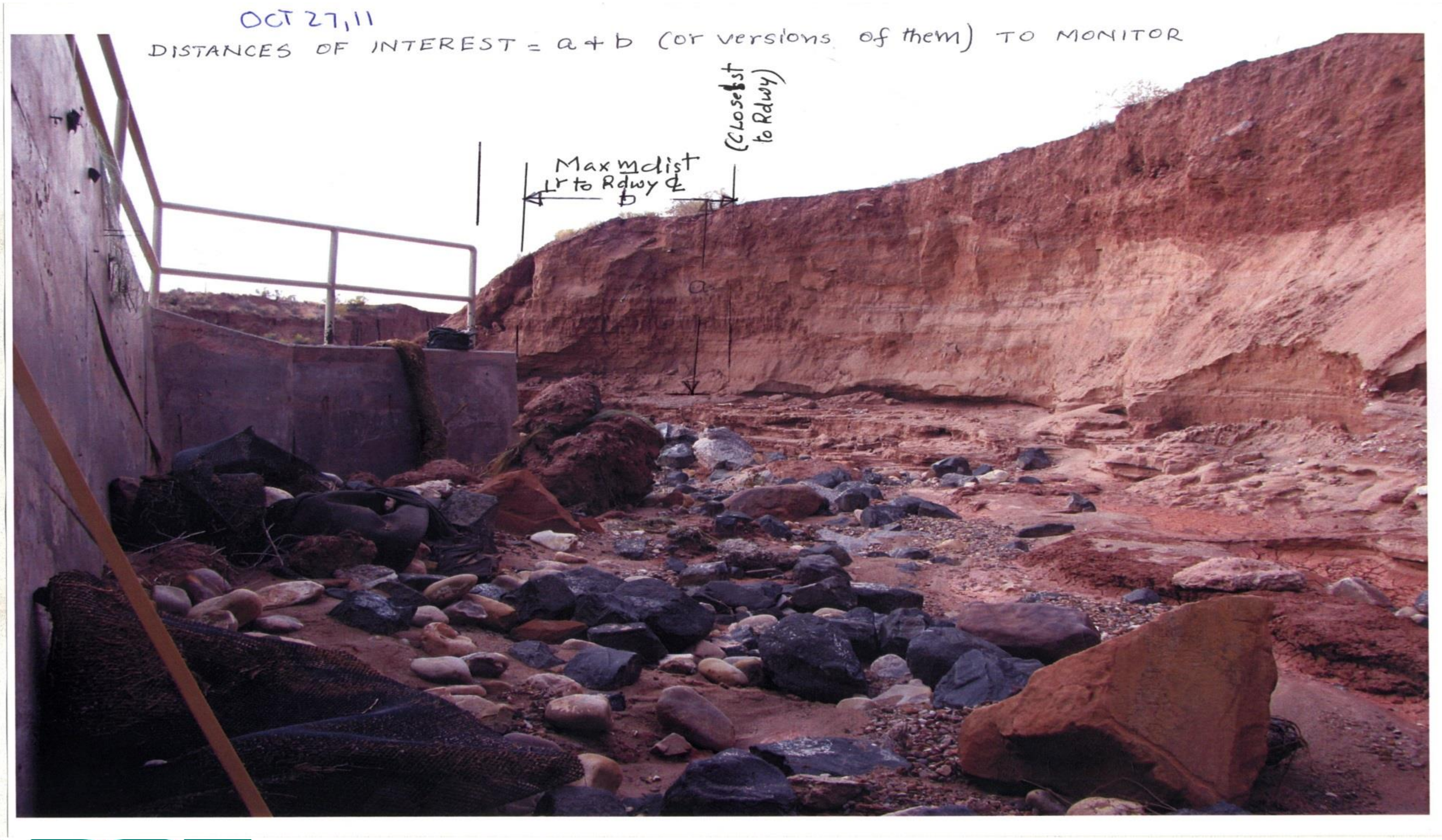
Impacts

Impacts

ADOT

Impacts

Impacts



OCT 27, 11
DISTANCES OF INTEREST = a + b (or versions of them) TO MONITOR
(Closest to Rdwy)
Max m dist Lr to Rdwy ℄
b
a

Impacts

Impacts

ADOT

Impacts

W
RAIN ON THE WAY?
AZ - CA - NV
MOISTURE BEING PULLED NORTH
T'STORM CHANCES INCREASE
HEAVY RAIN & FLASH FLOODING POSSIBLE
SEATTLE
BILLINGS
DENVER
LAS VEGAS
LOS ANGELES
PHOENIX
DALLAS
L
1
1
1
1
NORBERT

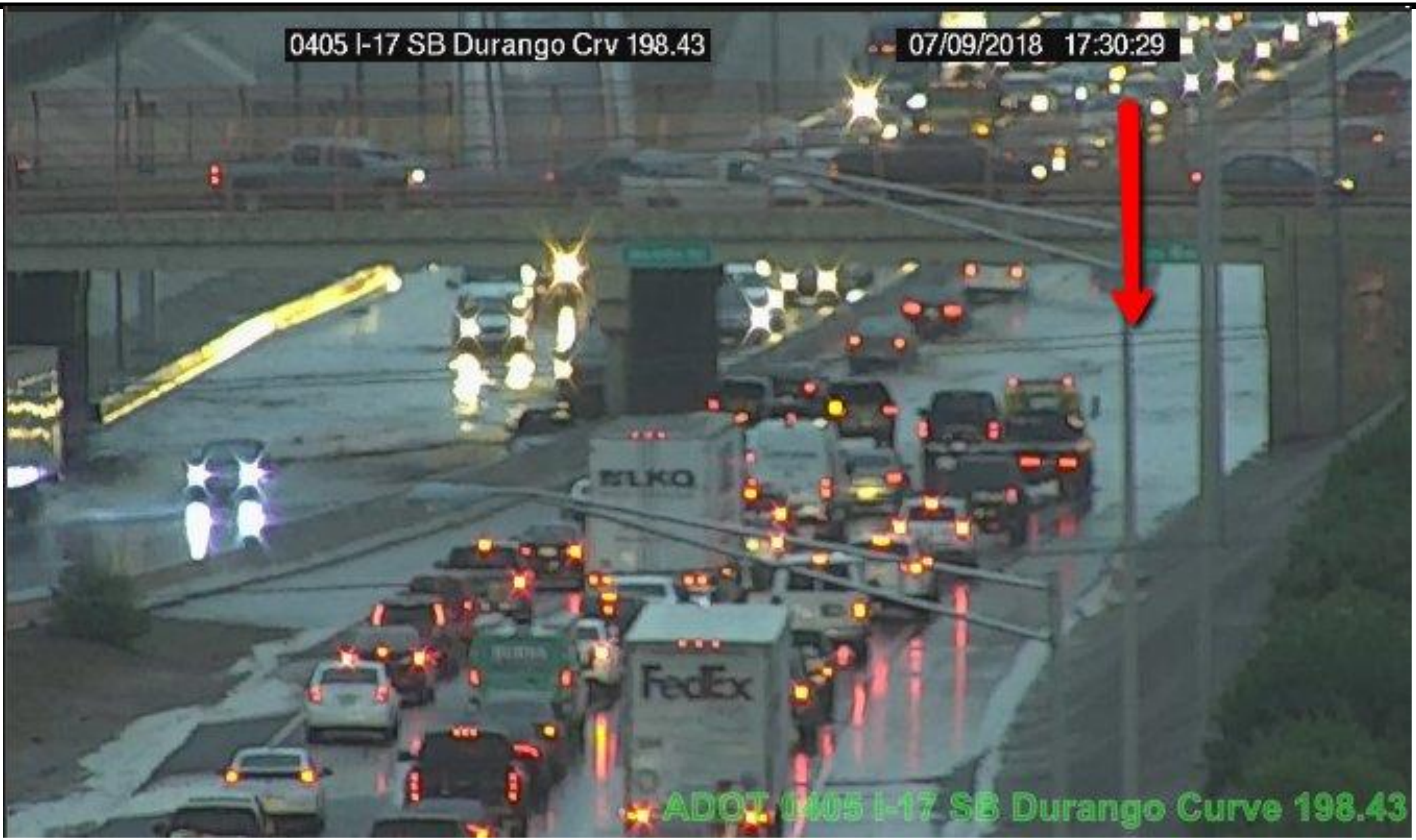
Impacts


HOV 2+ ONLY
EXITS 143 A-B
17
60
Flagstaff
I-10 TRUCK ROUTE
2 MILES
EXIT 141
35th Ave
3/4 MILE

Impacts


EXIT 42
Pima Rd
90th St
EXIT ONLY
ADOT 0666 L-101 NB S of 90th st 043.05

Impacts


0405 I-17 SB Durango Crv 198.43
07/09/2018 17:30:29
FedEx
ADOT 0405 I-17 SB Durango Curve 198.43

Link EX W & Climate to AM - Proposed Methodology

Phase 1

ADOT / FHWA
2018 Asset Management – Infrastructure Resilience

Phase 2

Phase 3

- Identify key stressors and their associated weather-related risk - Identify vulnerable assets
- Identify impacts-ADOT system

ADOT / FHWA
2015 Vulnerability Assessment

- Compile data – GIS Resilience Database - systematically record known locations and resilience building actions
- Identify case study area(s)
  - Identify root cause during different stages of asset lifecycle (creation, maintenance, preservation, rehabilitation/reconstruction)
  - Identify direct modeling or proxy indicator approach
  - Identify mitigation strategies / decision trees, including adaptation options and selection criteria driven initially through (Mobility, Safety, Asset preservation, Asset performance)
- Develop / Incorporate a new whole life cost asset class methodology into decision making and TAM reporting

ADOT

Link to AM - Proposed Methodology

Root Cause Screening - TOC reports and/or known system risks/climate data

Direct - Design probabilistic modeling approach to produce an array of results
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.

Proxy Indicators – An indirect measure or sign that approximates or represents a phenomenon in the absence of a direct measure or sign.

GIS - Obtain and Finalize Data

Already Captured Data

- ADOT's USGS Data
  - Flood gauges
  - Wildfire
  - Drought
- Layers from ADOT's USGS Flood map
- Dust storm data (I-10 pilot)
- 5-yr program priority project information
- Bridges (including scour)
- Culvert

New 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
- Pavement

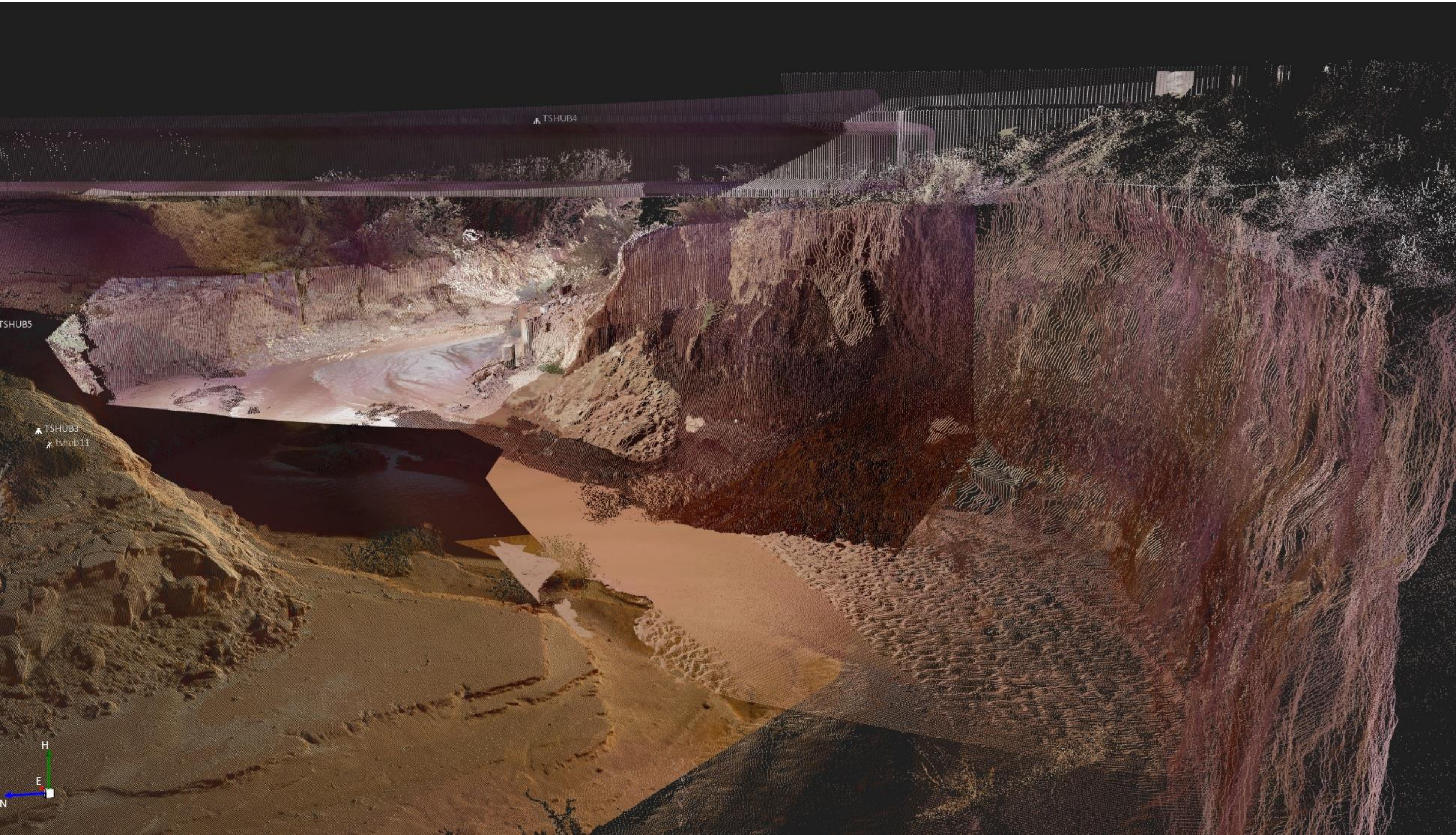
ADOT

Laguna Creek Bridge Bank Protection

ADOT

Laguna Creek Bridge Bank Protection

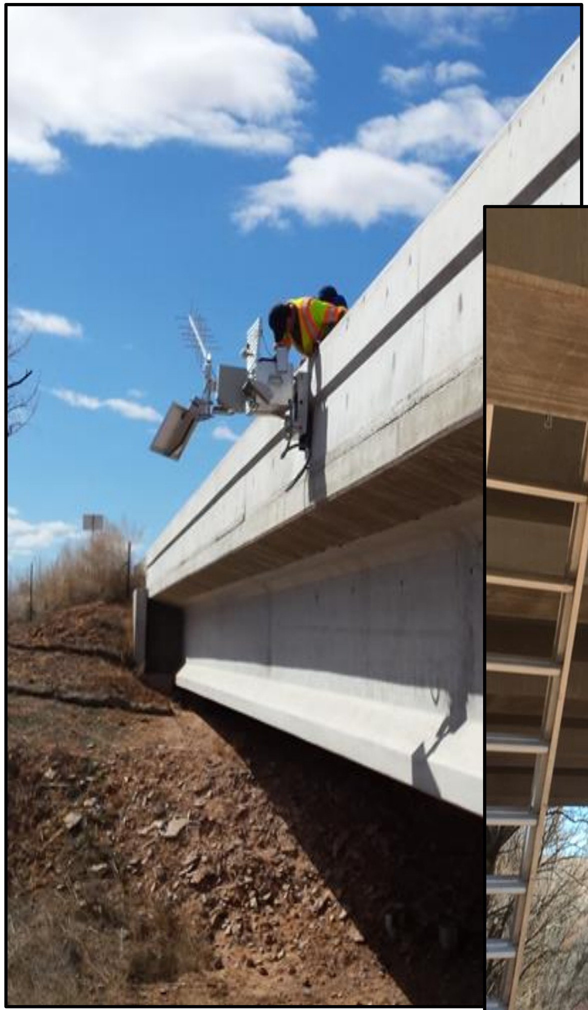
Laguna Creek Bridge (Ground based LiDAR project)



Reach Monitoring in Dynamic Channels
Understanding bank erosion and impacts to infrastructure

Laguna Creek 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



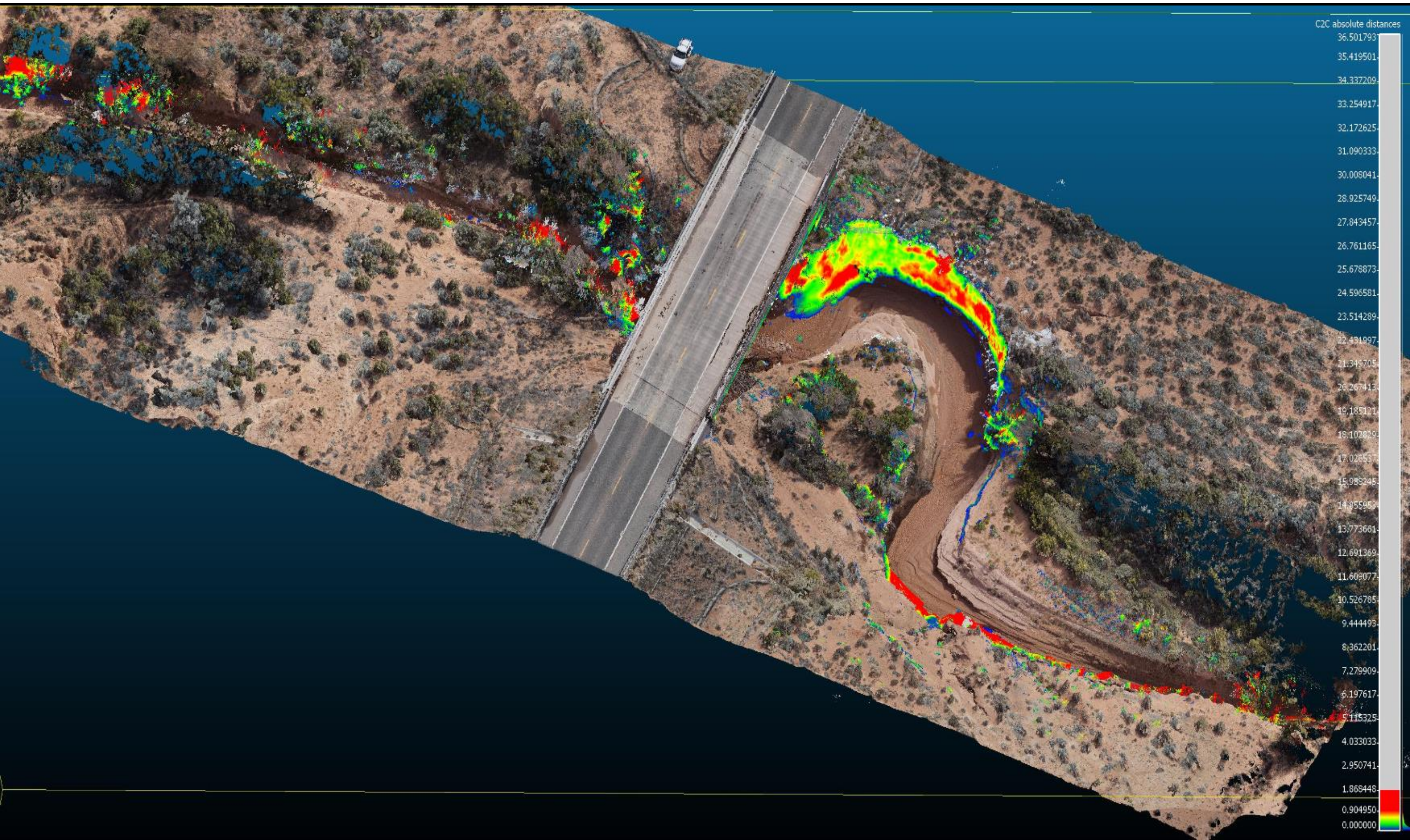
USGS

Reach Monitoring Products *Collecting data for the future*

- Discharge magnitude and frequency
- Velocity data
- High-res. aerial photographs
- Topographic models
- Post-wildfire data collection
- Maximum scour data
- Channel change data
- Vegetation change over time
- Vegetation density data
- Roughness values/drag coefficients
- Reach visualization

- Rating refinement
- 2D model calibration

3-D Erosion Change Detection Mapping



Laguna Creek Construction

ADOT

ADOT Resilience Project #2

November 2017 – State Route 160 Laguna Creek Bridge (Final grading and seeding)

Post Construction Monitoring

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

ADOT

North Carolina State

Shane Underwood – School of Civil, Construction, and Environmental Engineering
North Carolina State University – Climate Data Downscaling remainder of State(Pvmnt)

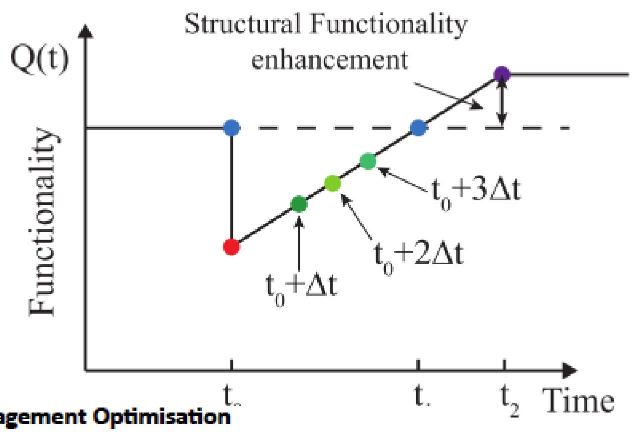
Modeling Center (or Group)	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1.0
Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1
Canadian Centre for Climate Modeling and Analysis	CCCMA	CanESM2
National Center for Atmospheric Research	NCAR	CCSM4
Community Earth System Model Contributors	NSF-DOE-NCAR	CESM1(BGC)
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CERFACS	CNRM-CM5
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-QCCCE	CSIRO-Mk3.6.0
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-ESM2G GFDL-ESM2M
Institute for Numerical Mathematics	INM	INM-CM4
Institute Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR IPSL-CM5A-MR
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies	MIROC	MIROC-ESM MIROC-ESM-CHEM MIROC5
Max Planck Institute for Meteorology	MPI-M	MPI-ESM-LR

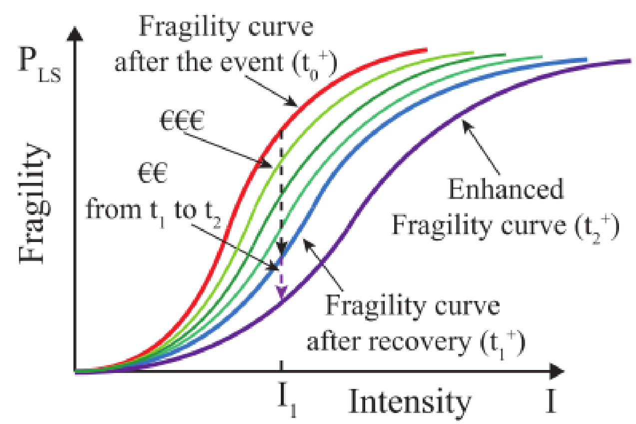
Trinity College Dublin

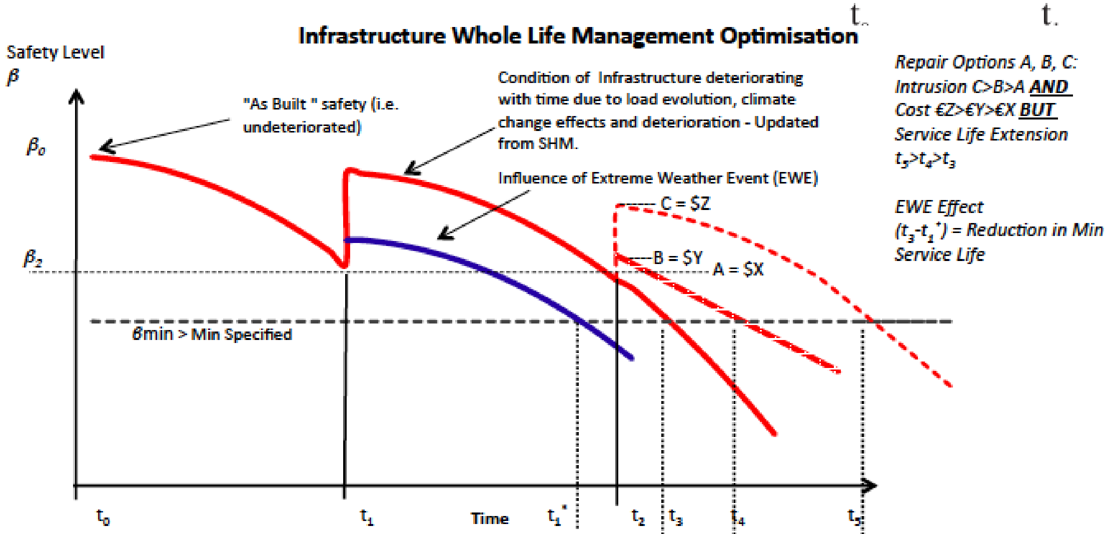
Alan O'Connor School of Engineering

Trinity College Dublin

Developing an asset class probabilistic engineering approach that assesses the stressors inherent to the built structure itself







Carnegie Mellon University

Constantine Samaras Department of Civil and Environmental Engineering
Carnegie Mellon University - Adjunct Senior Researcher, RAND Corporation

- Develop Economic Analysis Process
- Develop Life Cycle models to monitor investment
- Account for the differences in the deterioration model with new climate-informed asset management models

While different methods to quantify the economic impact of climate change for infrastructure can be found in the literature, none of these methods succeed in producing life cycle asset management plans that are robust to a wide variety of future climates. 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.

Part 667 - Developing a Process

- FHWA Emergency Relief Program (ERP) provides funds for the repair and reconstruction of highways and roads that have sustained serious damage from catastrophic failures or natural disasters, including extreme weather events. Since fiscal year 2012, Congress has appropriated approximately $5.7 billion to the ERP.
- MAP-21 and FAST Act National Highway Performance Program External - Asset Management Plan Final Rule
- 23 CFR Part 667 Periodic Evaluation of Facilities Repeatedly Requiring Repair and Reconstruction due to Emergency Events
- Statewide Evaluation §667.1 43 State DOTs shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events.
- Report No. ST2018014 - January 10, 2018 - Office of Inspector General - Improve Guidance on Infrastructure Resilience for Emergency Relief Projects and a Process To Track Related Improvements
- Statewide Evaluation §667.1 43 State DOTs shall conduct statewide evaluations to determine if there are reasonable alternatives to roads, highways, and bridges that have required repair and reconstruction activities on two or more occasions due to emergency events.

Part 667 - Developing a Process

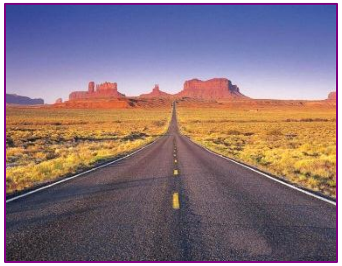
ADOT

Questions?

Steven Olmsted

Arizona Department of Transportation

solmsted@azdot.gov



ADOT