An Arizona Department of Transportation - United States Geological Survey Pilot Project Blending Science and Engineering - Laguna Creek Bridge Bank Protection

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ABSTRACT

Laguna Creek Bridge Scour Remediation, State Project Number H8913 01C, Federal Aid No. 160-B(205)T, is a scour remediation project on the existing Laguna Creek Bridge located in Arizona Department of Transportation's (ADOT) Northeast District. Laguna Creek Bridge is located on United States (US) Route 160, Tuba City-Four Corner Monument Highway, MP 420.1, over Laguna Creek in Apache County, Arizona. The bridge is within the boundaries of the Navajo Nation Reservation. This site is approximately twenty-five (25) miles east of the Town of Kayenta, Arizona. This project was administered by ADOT, who maintains the facility. The project scope consisted of installation of riprap gabion spur-dikes upstream and downstream of the existing structure and along the bridge abutments, in an effort to mitigate scour, provide bank protection, and reduce channel meandering at the bridge.

The original bridge structure was constructed in 1961 by the United States Department of Interior. In 1984 the original bridge was retrofitted with barriers. During the period from 2004 to 2008, bridge inspections identified excessive scour at both of the pier locations. In 2012 a replacement bridge was constructed just to the south of the previously existing bridge structure. Bridge abutments repairs and countermeasures were recommended, but were found to be insufficient to address the current problem. Since then, inspection efforts have continued to identify and monitor the accelerating meandering of the wash and subsequent undercutting of the abutment fill. The goal of the project was to provide protection of the existing bridge and roadway against the effects of local scour and severe channel meandering just upstream and downstream of the bridge crossing.

In 2015 ADOT set out to develop a Statewide Stormwater Modeling program. The effort was designed to centralize the Agency's response to system wide water issues, introduce next generation science and engineering modeling techniques (2-D hydrological and 3-D visualization), advance risk-science-technology-engineering development goals, and launch the Arizona DOT Resilience Program. The United States Geological Survey (USGS) Arizona Water Science group was key to the new program and supplies ADOT direct (real-time) storm monitoring and data collection, indirect (post-storm event monitoring and data collection), and next generation hardware/software and surface water flow data collection capabilities. This partnering effort would contribute to expediting and improving ADOT's efforts in planning and responding to incidents of flood, over-topping, system hotspots, hydraulic-related failure, and extreme weather events in connection with **1)** NEPA jurisdictional and wetland delineation and streamlining **2)** Highway stormwater runoff management **3)** Evaluating scour potential and countermeasure development at water crossings **4)** Drainage structure siting, design and construction **5)** Response to Federal extreme weather regulatory activities.

The first of six pilot efforts to address different types of water exposure on ADOT's highway system were initiated in 2016. The Laguna Creek project was identified as the main pilot to test a suite of USGS next generation technologies as they relate to transportation infrastructure - LiDAR, UAS (drone), Rapid Deployment Streamgage, Non-Contact Velocity Sensors, Video Camera and Particle Tracking Data Collection, 3-D Land Surface Models.

BANK PROTECTION PROJECT

US 160 is classified as a Rural Principal Arterial Highway in ADOT's Functional Classification Map. It is located in the Federal Highway Administration (FHWA) National Highway System. The original Laguna Creek Bridge (# 705) was constructed in 1961. This bridge was replaced in 2012 (# 20001) with a single-span bridge, however, abutment bank protection was not included in the project. Since completion of the bridge construction, Laguna Creek has meandered resulting in a significant amount of undercutting of the fill slopes adjacent to the bridge abutments. The work under this Scoping Letter is to analyze the existing bridge conditions and provide scour remediation alternatives to prevent further erosion and protect the bridge abutments and approaches.

A listing of the original and subsequent construction projects that incorporated all or part of the project segment are listed below:

Project No.	Begin MP	End MP	Project Description	Year
AU I(28)	420.1	420.1	Laguna Creek Bridge # 705	1961
F-064-1(3)	420.1	420.1	Barrier Retrofit	1984
			Pavement Preservation	2004
U-160-A-202	311.46	470.83	Corridor Feasibility Study	2007
160 AP 420 H7571 01C	420.04	420.24	Laguna Creek Bridge # 20001	2012

Figure 1. Project Hydraulic Report Final

Site Conditions

Laguna Creek originates at Tsegi Canyon and flows northeast. Soil in the watershed is fine grained and susceptible to sediment transport at relatively low velocities. The US160 crossing is characterized by a meandering vertical bank channel (unstable). Laguna Wash has the potential to adversely impact the US 160 structure at the following three locations: 1) Abutment #1, 2) Abutment #2, and 3) the approach roadway west of the structure. The following aerial photograph shows the existing channel and the historic scarring due to previous migrations of the wash (old oxbows).

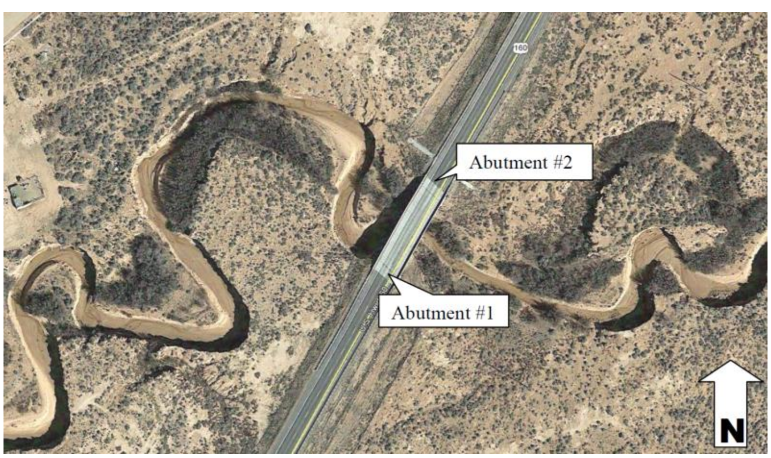

Figure 2. Aerial SR 160 Laguna Creek Bridge

Drainage Conditions

A Hydraulics Report for Laguna Creek Bridge was completed in May 2011 by ADOT Bridge Group, Bridge Hydraulic Section (TRACS No. 160 NA H 7571 01C). According to this report, the total watershed area for Laguna Creek Bridge is 848 square miles. Discharge and water surface elevation are summarized below. The proposed bridge required 1 foot of freeboard for the 50-year storm. The bridge soffit elevation is 4973.67.

Storm Event	Discharge (cfs)	Water Surface Elevation	Freeboard Height (ft) (Constructed)
Q50	6,895	4969.79	3.88
Q100	10,826	4973.20	0.47
Q500	23,370	4979.67	-6.00

Figure 3. Project Hydraulic Report Final

Proposed Improvements

In order to protect the existing bridge it is recommended that guide banks be constructed to direct storm water through the structure. The guide banks will be constrained by limited rights-of-way (200' to the north of US 160 centerline and 100' south of US 160 centerline). The area of disturbance (excavation limits) may not extend outside of the rights-of-way and the proposed improvements may not adversely impact the cultural site adjacent to the structure. Team members evaluated several alternatives for the guide banks including: cement stabilized alluvium (CSA), ADOT standard rail bank protection, gabion mattress, gabion basket, grouted rip rap, rip rap, and sheet pile bank protection.

Design Alternatives

Seven (7) design alternatives for Laguna Creek Bridge bank protection were evaluated in this Scoping Letter. The preferred alternative was determined to be gabion baskets (Alternative 1) due to the smaller area of disturbance, constructability, long-term bank protection and lower cost relative to the other alternatives. Below is a description of four (4) of the alternatives. The preliminary configuration of Alternative 1, Gabion Baskets is shown below

Alternative 1: Gabion Baskets

Description:

This alternative consists of 3' x 3' x 6' gabion baskets, filled with 4" to 8" nominal rock that will be placed around the perimeter of the bridge abutments and approaches to prevent lateral stream migration and bank protection.

Conclusion:

The preferred alternative was determined to be gabion baskets. The use of gabions baskets reduces the disturbance area, is constructible based on the site constraints, and is the most cost effective of all of the alternatives considered in this scoping letter. Gabion baskets have the advantage of being constructible beneath the existing bridge, requiring only a small section of concrete infill at the top of the new gabion wall where vertical clearance beneath the existing bridge is less than approximately 5’. Rock suppliers have been located in southern Utah and in the Phoenix area.

Alternative 2: Driven Sheet Pile Bank Protection

Description:

This alternative consists of driving a continuous wall of sheet piling to the required scour elevation plus the required embedment depth for the piling. Various pile sizes were considered. Due to the height of material required to be retained by the piling, large pile sections such as AZ-24 and larger are required. It is also necessary to construct a 3- tiered wall system with the back rows acting as buried tie-back walls. For the segment of protection directly below the bridge there is insufficient vertical clearance to drive piling, so a separate type of wall such as gabion baskets or a CSA wall would need to be constructed and connected to the sheet piles outside of the bridge limits.

Conclusion:

Sheet piles were eliminated due to high cost, difficulty of construction, and large area of disturbance.

Alternative 3: Cement Stabilized Alluvium (CSA)

Description:

This alternative constructs a compacted cementitious soil fill to create a hardened surface layer that will prevent stream lateral migration and erosion due to scour.

Conclusion:

CSA was determined not to be practical due to the limited space to operate large grading and compaction equipment beneath the existing bridge. The area of disturbance exceeded the rights-of-way limit due to the flatter side slopes required for typical CSA construction. This alternative is also the highest cost of the three constructible alternatives considered for the site.

Alternative 4: Rail Bank Projection

Description:

This alternative uses ADOT standard Rail Bank Protection constructed around the perimeter of the bridge abutments in a configuration similar to the Gabion basket bank protection alternative.

Conclusion:

Rail bank projection is eliminated because the existing standard is not capable of providing more than 10’ of vertical projection above existing grade. The vertical face requiring protection adjacent to the bridge abutments exceeds 20’ in most locations. Rail bank protection is not constructible beneath the bridge due to insufficient vertical clearances.

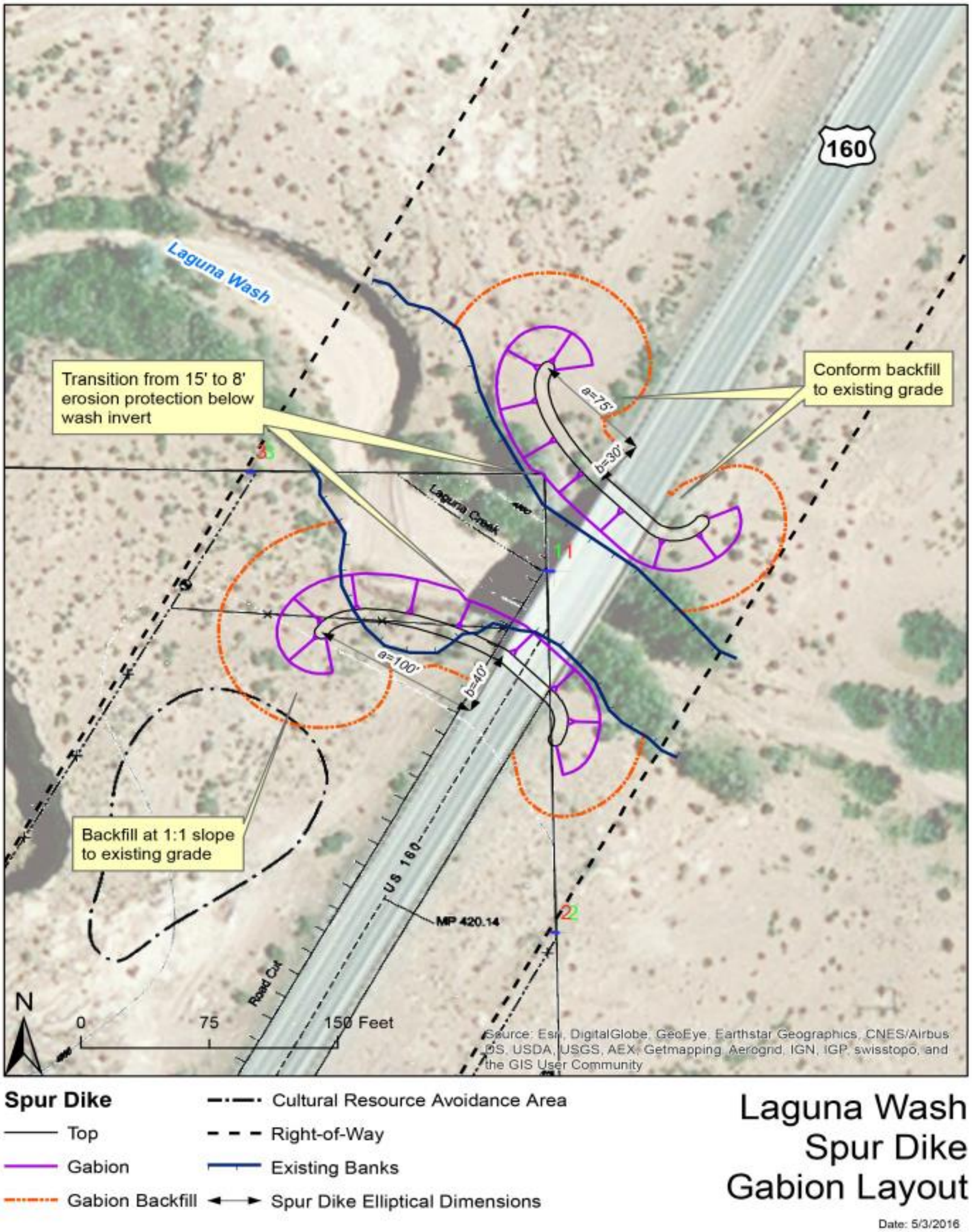

Figure 4. Project Design Overview

Figure 5. Looking downstream approaching the structure (notice the floating fence – upper right)

Figure 6. Looking downstream from the structure

Integration of USGS Technology for Future Design

Due to the emergency nature of this project the preliminary scoping was based largely on hydraulic and geotechnical information obtained for the design of the replacement bridge (#20001). In large part this is typical for many scour design projects; limited information is available in the preliminary design stage when key decisions are made that impact the project construction costs, durability, and long term maintenance costs.

The availability of real-time information has many beneficial impacts. The USGS information allows planners and designers to view current channel configurations as well as to look at time lapse information for comparison. On the Laguna Creek project our team was able to compare current stream velocity and path with prior survey data and hydraulic studies for confirmation of our assumptions of the long-term channel movement in the vicinity of the bridge. It will now be possible to monitor the channel behavior with the bank protection in place to improve our understanding of the protections long-term performance and potential refinements for future designs. The velocity vector and flow limits data can be used to verify 1-D hydraulic models as well as calibrate or verify 2-D hydraulic models early in the design process. This will enable designers to progress more quickly through the design process while enhancing their confidence in the results.

The availability of this information is valuable to owners and agencies in several ways. The topographic and stream flow data can be obtained using drone-mounted photogrammetry. This enables information to be cost effectively obtained over large areas and streamlines or eliminates the permitting process required to obtain traditional field survey and stream flow data outside of existing Right of Way limits. Software is available that allows this data to be transformed into renderings that allow a quick visual interpretation of the site characteristics to facilitate coordination among diversified staff and agencies.

This information also adds value for construction cost control. In a typical design-to-construction cycle the topographic survey data is obtained as early in the design process as possible. The construction project is then bid against the plans, specifications, and estimates which are based on the original survey. It is often the case that stream migration, erosion or infill, and changes in accessibility occur in the time period between the design survey and the construction project award. These items can become change orders during construction as well as result in delays for design changes to be produced. While not currently implemented, it should be possible to utilize this hydraulic data to improve construction cost estimating and to mitigate potential delays and funding shortfalls due to naturally occurring shifts in channel profiles.

ADOT RESILIENCE PROGRAM

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 continues to be cost prohibitive, new and novel approaches to life cycle costing and long term planning become paramount. In addition, the management of these infrastructure systems has now evolved from a decentralized, project based focus to one that now encompasses enterprise wide endeavors [1]. Three areas of concern for state DOTs and the main catalyst for developing an ADOT Resilience Program involved how to:

- Centralize to one operating area the unknown, erratic, and abrupt incidents of stormwater and its contributors of flooding (overflow of water that submerges land), overtopping (rise over or above the top), system hotspots (roadway flood prone history), hydraulic-related failures (structure failure mechanisms)
- Introduce extreme weather adaptation to agency and engineering design processes and establish transportation asset sensitivity to extreme weather
- Handle scientifically-informed climate data downscaling as it relates to transportation systems and development of an ADOT Climate Engineering Assessment for Transportation Assets (CEA-TA)

Flood Event - State of the Practice

Flooding, and the effects and impacts of flooding along transportation corridors, has caused billions of dollars of damage and countless deaths. Technology currently exists to accurately pinpoint those areas along a transportation corridor that are susceptible to flooding. “Although there are tools . . . they have not yet been integrated to provide sufficient planning and prediction information required by state DOTs to carry out flood planning, risk management, mitigation, operations and emergency response activities.” Further research is needed to translate the available technologies into a suite of tools and methods for use by decision makers [2].

The largest hurdles for state DOTs in connection with flooding and risk assessment tends to be the shortage of an end-to-end framework that addresses planning, risk management, hazard mitigation, maintenance repairs, and life cycle projecting. This is particularly true when an event or emergency has extensive cascading impacts. The main avenue to finding a solution is to develop an approach that could funnel all these issues to one place for proper analysis within the state DOT utilizing current technology, tools, and partnerships that could benefit the DOTs [3].

State DOTs generally utilize some form of flood frequency analysis to evaluate a given asset. Design and response standards may not provide enough flexibility to unusual or extreme weather occurrences. Certain assets may not require any special treatment, as available data and standard design guidelines offer acceptable levels of mitigation. This is particularly true when the asset is either at the largest, most monitored level, or is very small and maintenance oriented. Issues arise when a non-monitored asset is overwhelmed, and when the best representations of probability-distribution of floods equal to or longer than 2-years, no longer applies. The range for the confidence limits of that distribution is relatively tight, because in general the fifty (50) largest floods are used to establish the best fit line for the asset [4].

Overtopping and System Hotspots – State of the Practice

NCHRP Synthesis 20-05 (46-16) completed in late 2016 with the objective to produce “a state of the practice report on how the transportation community is protecting roadways and mitigating damage from inundation and overtopping. The report documented ‘the mechanics of damage to the embankment and pavement, analysis tools available, and design and maintenance practices for embankment protection. The synthesis considered the inundation-only condition of pavements and subgrades” [5]. The immediate risk of overtopping and inundation (an overwhelming abundance) is an indication of how crucial that particular segment of roadway within the system is to moving traffic. Determining how quickly that route can be up and running again is essential to an efficiently functioning transportation system. In rural parts of Arizona it is common to use vertical curves and to take advantage of natural low flow areas to address the roadway prism drainage needs. To clarify, roadway overtopping generally begins when the headwaters rise to the elevation of the roadway (as seen in Figure 7 below). The overtopping will usually occur at the low point of a sag vertical curve on the roadway.

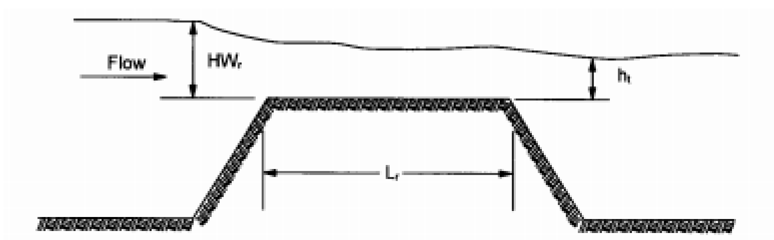

Figure 7. ADOT Cross Section

Hydraulic-Related Failure - State of the Practice

Current industry practice looks to develop a “risk and reliability-based methodology” that can be utilized to better link scour depth estimates to probability at the crossing of rivers, washes, streams, and transportation assets. In addition, state DOTs need an approach for determining a target or range of reliability for the service life of that asset that is consistent and reasonable for the design load and resistance factors [3].

Event uncertainty makes identifying probability from a limited number of flood events and linking a range of reliability from those events challenging. The probability of exceeding a design-scour-depth over the service life of a bridge additionally has a low likelihood. Hydraulic parameters such as roughness coefficient, channel energy, and critical shear stress also contain uncertainties. Inputs in hydraulic models estimate flood elevations and velocities. Uncertainties in the estimates will translate to uncertainties in resulting calculations.

Changes in the wash structure over time such as upstream and downstream impacts, surface water and groundwater wash-instability magnification effects (as seen in Figure 8 below) drought, vegetation, bank erosion and sediment transfer are all factors which inject additional uncertainty. Supplementary data to more efficiently depict activity in the area is needed to limit the amount of uncertainty in the estimates. A way to limit the uncertainty of all these conditions and factors is the utilization of measured data such as high water marks, discharge measurements, broad system sensors, water surface effects, and new usages of historical data. Attempting to establish a repeatable process to address hydraulic-related failure and assessing hydraulic, geomorphic, vegetation, construction, and maintenance impacts from those failures is specific to the FHWA asset management MAP-21 guidance.

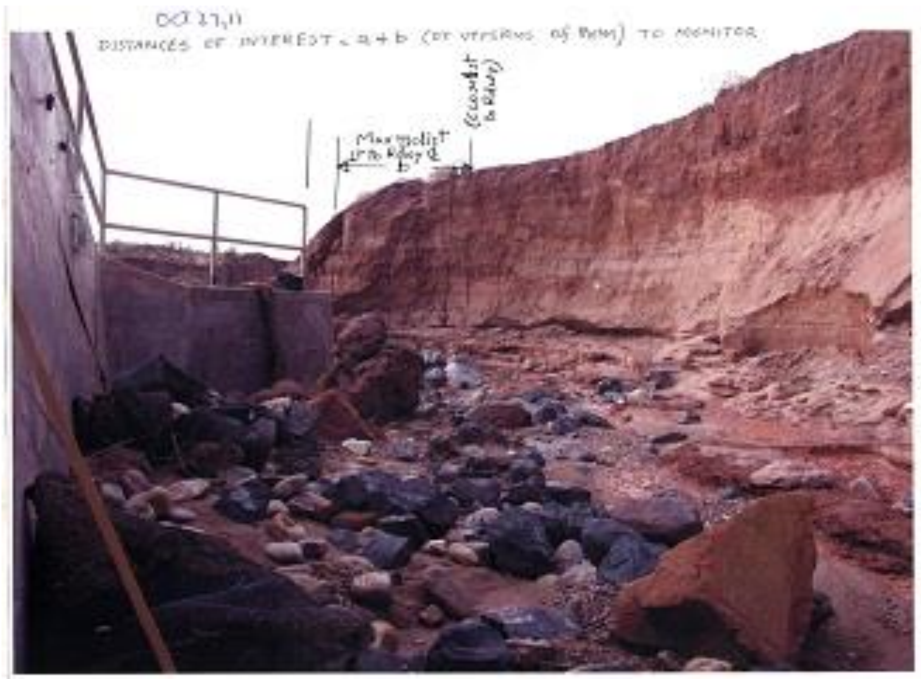

Figure 8. Hydraulic-related failure monitoring due to ground water, channel energy, and altered flow

In addition, FHWA guidance directs federally funded projects to incorporate risk into bridge scour analyses and project development. It dictates that design efforts for new bridge foundations should withstand "the effects of scour caused by hydraulic conditions from floods larger than the design flood" [3].

Extreme Weather - State of the Practice

FHWA's climate change and extreme weather vulnerability assessment pilot projects collected a wide geographic sampling of vulnerabilities in the transportation asset universe. Establishing transportation asset sensitivity to extreme weather can contribute to a systematic approach to programming adaptive capacity strategies and asset life cycle prioritization. These vulnerability assessments gather data on assets, identify characteristics and sensitivities, analyze historical weather data, determine a usable climate projection model, and through this iterative process develop a vulnerability framework [6,7,8].

Integrating risks based on the severity or consequence of an extreme weather impact and determining the probability or likelihood it would occur to a specific asset at some point now or many decades forward is challenging. But, even low likelihood risk assessment modeling using historic, current, or 2050 / 2100 climate projection can allow state DOTs to categorize assets by a low, moderate, or high rating. "The integrated risk is often represented by a two-dimensional matrix that classifies risks into three categories (low, moderate, high) based on the combined effects of their likelihood and consequence. An example matrix risk rating matrix used by the San Francisco Pilot" is provided in Figure 8 below [7]. Risk application within the context of this paper refers to the additional analysis undertaken to put a variety of determined flows into a context of likelihood or future recurrence interval in relation to historic peak-flow discharge.

		Consequence				
		1	2	3	4	5
Likelihood	1	2	3	4	5	6
	2	3	4	5	6	7
	3	4	5	6	7	8
	4	5	6	7	8	9
	5	6	7	8	9	10
Risk	Low		Moderate		High	

Unacceptable, major disruption likely; priority management attention required.

Moderate Risk (Orange)

Some disruption; additional management attention may be needed.

Low Risk (Green)

Minimum impact; minimum oversight needed to ensure risk remains low.

Figure 9. Risk Rating Matrix

Resilience Building – ADOT State of the Practice

The reality of a changing climate means that transportation and planning agencies need to understand the potential effects of changes in temperature, storm activity, and precipitation patterns on the transportation infrastructure and services they manage. These changes can result in increased heat waves, droughts, storm activity, early snowmelt, wildfires, and other impacts that could pose new challenges for ADOT. The goal of the 2014 *Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona* study was to establish a path for ADOT to continue working toward being more resilient, flexible, and responsive to the effects of global climate change. The study identified, key individuals within ADOT with decision making authority relevant in incorporating climate change adaptation in planning, design, and operations, framed relevant literature and best practices for climate change adaptation as relevant to 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 further research on climate change adaptation for ADOT's statewide transportation system beyond the scope of the initial study [8 - P.5].

The 2014 effort led ADOT to participate in the FHWA Climate Change Resilience Pilot program; the pilot effort assessed the vulnerability of ADOT-managed transportation infrastructure to Arizona-specific extreme weather. Long term, ADOT sought to develop a multi-stakeholder decision-making framework – including planning, asset management, design, construction, maintenance, and operations – to cost-effectively enhance the resilience of Arizona's transportation system to extreme weather risks. ADOT elected to focus on the Interstate corridor connecting Nogales, Tucson, Phoenix, and Flagstaff (I-19, I-10, and I-17). This corridor includes a variety of urban areas, landscapes, biotic communities, and climate zones which present a wide range of weather conditions applicable to much of Arizona. The project team examined climate-related stressors including extreme heat, freeze-thaw, extreme precipitation, wildfire, and considered the potential change in these risk factors as the century progresses.

As part of the pilot program, the study leveraged the FHWA Vulnerability Assessment Framework customizing it to fit the study's needs. The project team gathered information on potential extreme weather impacts, collected datasets for transportation facilities and land cover characteristics (e.g., watersheds, vegetation), as well as, integrated these datasets to perform a high-level assessment of potential infrastructure vulnerabilities. Each step of the process drew heavily on internal and external stakeholder input and feedback. This assessment qualitatively addresses the complex, often uncertain interactions between climate and extreme weather, land cover types, and transportation facilities—with an ultimate focus on potential risks to infrastructure by ADOT District. Preliminary results were presented in focus groups where ADOT regional staff provided feedback on the risk hypotheses developed through the desktop assessment. The results of the assessment were, organized first by District, then by stressor, and then further delineated by land cover types (e.g., desert) which are considered qualitative potential factors that could either alleviate or aggravate the impacts of extreme weather phenomena [9 – P. ES-1]

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This effort is in response to hydrological and hydraulic engineers need to address climate change and engineering dynamics. In addition, the research problem statement goes on to explain, in order to provide "hydraulics engineers with the tools needed to amend practice to account for climate change, output from climate models must be downscaled and modified to provide recommended changes to regional precipitation data for design events used by hydraulics engineers. Collaborative efforts between climate scientists, hydrologists, hydraulic engineers, and coastal engineers, are essential to producing these design inputs that are needed to amend hydraulic designs. Incorporating the results of climate models will have very large cost implications for future infrastructure. Overestimating the magnitude of peak flows suggested by climate models can result in costly over sizing of drainage infrastructure, while underestimating may leave infrastructure vulnerable and their resultant flooding impacts on surrounding lands and structures inadequately addressed" [10].

USGS PARTNERSHIP & LAGUNA CREEK PILOT PROJECT

Infrastructure in or near dryland river channels are susceptible to a variety of geomorphologic and hydrologic hazards caused by floodwaters. Historically, many dryland channels in northeastern Arizona were broad, shallow, and mainly un-vegetated. As a result, floodwaters in the past were conveyed slowly and gently through stream channels and surrounding floodplains at relatively low velocities and shallow flood depth. Today, many dryland channels have changed dramatically and have become largely incised into the floodplain, while the carved banks are being stabilized by vegetation, in many cases by nonnative tamarisk *(Tamarix ssp)*. The increase in bank stability may cause channels to incise deeper into floodplains, leading to narrower, less sinuous stream beds that can potentially convey floods at higher velocities. Additionally, channels in this region have the ability to convey and deposit large amounts of sediment, and sediment volumes may become larger as flood velocities increase. Ultimately, larger floods at higher velocities can erode the outside of channel bends where velocities are typically high, and deposit sediment on the inside of bends where velocities are naturally lower. This commonly causes channel migration, meander cutoff, and avulsion [11]. Prior studies have found that river channel instability in arid and semiarid regions and erosion caused by channel migration resulted in economic losses that were potentially five times greater than potential flood inundation losses [12]. However, potential channel migration is rarely accounted for in flood risk assessment [11].

Channel erosion and deposition have occurred at Laguna Creek at State Highway 160 bridge site. The channel is incised into the floodplain, the banks on the outside of bends are eroding, and clear evidence of past channel migration and meander cutoff can be seen just 250 feet downstream from the bridge structure. Additionally, any further erosion that occurs near the roadway may impact the transportation infrastructure. This erosion caused the Arizona Department of Transportation and the U.S. Geological Survey Arizona Water Science Center to deploy multiple sensors and use new technologies to collect many different types of data to help better understand the dynamic hydrologic conditions at the bridge site prior to construction efforts.

The effort started with the deployment of real time hydrologic data collection equipment to help form a baseline reference for the river conditions at the bridge. First, a rapid deployment streamgage was installed on the bridge structure. This gage contains equipment that measures river stage and surface velocity, which is telemetered to provide users with real time stream flow information on the web. The gage was also outfitted with two video cameras that are triggered to capture video once the river stage exceeds a predefined threshold. These cameras provide video of underneath the bridge and also the bend upstream of the bridge, which is the focus of this effort, and can provide insight to engineers by capturing video evidence of flows and recording potential erosional events on the banks. The video can also be analyzed with Large-Scale Particle Image Velocimetry (LSPIV) software to calculate and map the surface velocity of the flows upstream and downstream of the bridge. The LSPIV software is used to help calibrate and confirm the gage's velocity sensor along with computing the river discharge at the gage. All of the sensors were deployed over a year in advance of planned construction and provided a snapshot of the potential flow conditions at the Laguna Creek site.

The next objective included conducting an indirect measurement of discharge using evidence from the flow that increased the bank erosion near the upstream bridge abutment prior to gage installation. This indirect measurement resulted in a peak flow value of 1,300 cubic feet per second. This discharge was compared with the U.S. Geological Survey program StreamStats, which uses information from gages in the region to predict the flood flow frequency at ungaged watersheds using basin characteristics, in this case, watershed area. This method predicts the two year event to be 1,600 cubic feet per second [13]. In other words, a statistically common flow event of 1,300 cubic feet per second caused the bank erosion on the bank upstream from the bridge. After the gage's installation, an additional flow event occurred on September 30th, 2016, which provided another opportunity to conduct an indirect measurement of discharge. This event peaked at 1,270 cubic feet per second with a peak measured velocity under the bridge structure of six feet per second. Again, this event was less than the predicted two year flow event using StreamStats and continued to erode the bank next to the upstream bridge abutment.

Another interesting approach that the U.S. Geological Survey was able to utilize at the Laguna Creek site was the use of ground-based Light Detection and Ranging (LiDAR) scans in conjunction with photogrammetric surveys collected via small Unmanned Aerial Systems (sUAS or drones). These data collection techniques are used to collect high resolution point clouds, often under two centimeter resolution, to create three dimensional digital elevation models and high resolution orthoimagery. The use of the terrestrial LiDAR system is beneficial under structures and when very high resolution models are sought; the sUAS-based collection is best for efficiently collecting topographic data over large areas (miles) and areas that are difficult to survey using ground-based systems. These models can be collected before and after events to both visualize and measure land surface changes and can be especially important when trying to quantify erosional changes in stream channels. The land surface models can also be used in two dimensional hydraulic modeling software as well as LSPIV software to both confirm and predict different flow scenarios in the channel and around the bridge structure. Lastly, the high resolution orthoimagery can be used to visualize current conditions at the site and can be used to help inform decision making for the project. These technologies allow engineers to bring the site into the office and can be very useful in planning and scoping scenarios.

This collaborative effort conducted by the Arizona Department of Transportation and the U.S. Geological Survey was designed to provide snapshots of the potential hydrologic conditions at Laguna Creek at the Highway 160 bridge site. Collecting data during the year prior to construction provided a comprehensive data set including stream flow, river stage, surface velocity, video capture of flows, and high resolution digital elevation models and orthoimages. These data provide complete hydrologic monitoring that can be used by engineers and scientists alike to better understand the hydrologic and hydraulic conditions at the Laguna Creek site, and these data can be used to inform decision making for future construction efforts. These instruments will be left in place post-construction for continued data collection, and the data can be used to provide insight into the effectiveness of bank stability operations around the bridge structure.

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FIGURES

[1] Figure 1. Project Hydraulic Report Final. ADOT. 2016

[2] Figure 2. Aerial SR 160 Laguna Creek Bridge. ADOT. 2016

[3] Figure 3. Project Hydraulic Report Final. ADOT. 2016.

[4] Figure 4. Project Design Overview. ADOT. 2016

[5] Figure 5. Photo, USGS. 2016.

[6] Figure 10. Photo, USGS. 2016.

[7] Figure 7. ADOT Cross Section. Drainage Manual. 2016.

[8] Figure 8. Hydraulic-related failure monitoring due to ground water, channel energy, and altered flow. Photo ADOT. 2012.

[9] Figure 9. Risk Rating Matrix. ADOT. Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona. Report No. FHWA-AZ-13-696. 2014.