Arizona Department of Transportation / United States Geological Survey
Partnering Project
Federal Highway Administration Funding Justification

Goal

Adopt and implement a process improvement framework utilizing the United States Geological Survey (USGS) advancements in modeling, tools and platforms that would directly and meaningfully contribute to expediting and improving Arizona Department of Transportation (ADOT) project planning, design and delivery especially as they relate to incidents of flood, hydraulic related failure and extreme weather events.

Funding Request

To actively engage the USGS Arizona Water Science Center personnel and USGS advancements in modeling, tools and platforms that would directly and meaningfully contribute to expediting and improving ADOT's scoping, planning, and project development through various means especially as they relate to incidents of flood, hydraulic related failure and extreme weather events in connection with new bridge design, evaluating existing bridges for scour potential, and developing countermeasure; NEPA jurisdictional and wetland delineation expediting and streamlining efforts; response to a growing extreme weather regulatory orders and regulations. This would be including, but not limited to, meetings, field visits, conference calls, video teleconferencing, and electronic correspondence.

Relevant Guidance

Interagency Guidance: Transportation Funding for Federal Agency Coordination Associated with Environmental Streamlining Activities (March 2006 revision)
"[W]here a proposal is to fund activities that are not project-specific, such as process improvement . . . the criteria relating to environmental review time limits will be deemed satisfied so long as the efforts are designed to produce a reduction to produce a reduction. A baseline of current activities and the associated times would be helpful in the project explanation" p.4

Relevant Regulation (see additional RRs end of proposal)

SAFETEA-LU, Section 6002
Codified in Subchapter I of chapter 1 of Title 23 USC section 139
Specifically, Section 139(j), (2) *Activities for which funds may be provided under paragraph (1) include transportation planning activities that precede the initiation of the environmental review process.*

MAP-21
23 U.S.C. 119(e)(1), MAP-21 § 1106
Each State is required to develop a risk-based asset management plan (TAMP) for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system.

23 U.S.C. 119(e)(3) (MAP-21 § 1106) requires the Secretary to encourage States to include all infrastructure assets within the highway right-of-way.

23 U.S.C. 119(d)(2)(K) (MAP-21 § 1106) and 133(b)(24) (MAP-21 § 1108) costs associated with development of a risk-based asset management plan are eligible for Federal funding. Specifically, these

costs are eligible for both National Highway Performance Program (NHPP) and Surface Transportation Program (STP) funds.

2014 ADOT/USGS Partnering Project History
This effort stems from an original encounter with the USGS AZ Director and Assistant Director at ADOT's scientific stakeholder meeting in connection with FHWA's extreme weather and climate pilot project. There was mutual realization that ADOT may be underutilizing the low cost or free services available from USGS and that USGS was remiss in not having an updated relationship with ADOT. Our initial scoping/KO meeting for assessing the viability of a partnering project was May 7, 2014. A subsequent exploratory partnering meeting was conducted on September 2, 2014 with the wider group listed below (ADOT and USGS presentations attached). An initial framework was identified and a summary was forwarded to the ADOT State Engineer Jennifer Toth for review. Full support was given from the State Engineer's Office to further this effort and an October 7, 2014 meeting was conducted to begin to narrow ADOT needs and USGS services.

Exploratory Team

James Leenhouts	Director, USGS Arizona Water Science Center
Chris Smith	Assistant Director, USGS Arizona Water Science Center
Alissa Coes	Hydrologist/QW Specialist, USGS Arizona Water Science Center
Stephen Wiele	Research Hydrologist/SW Specialist USGS Arizona Water Science Center
Ken Akoh-Arrey	Chief Drainage Engineer, Manager ADOT
Alicia Urban	Senior Drainage Engineer, ADOT
Julia Manfredi	Senior Water Quality Analyst ADOT
Steven Olmsted	Environmental Planner/Extreme Weather & INVEST Grants/TAMP
Emily Lester	Environmental Planner/Biologist/INVEST Grant
Itty P. Itty	Section Leader – Bridge Hydraulics
Ken Fossum	USGS Tempe acting field office chief
Wendy Terlizzi	Water Quality section manager

Key Observations/Entry Points for partnering and collaboration
Please see the attached September 2, 2014 Meeting Minutes

What did ADOT Identify in 2014 from this exploratory effort?
ADOT has identified one approach that could measurably contribute to geographic-specific bridge design, evaluating existing bridges for scour potential and develop countermeasure designs as it relates to flood, hydraulic related failure and extreme weather events would be to adopt and implement a process improvement framework utilizing USGS advancements in modeling, tools and platforms. This partnership was not only identified as meaningfully way to expedite the design, project delivery and National Environmental Policy Act (NEPA) processes, but also as a new and novel approach to cost savings in connection with the NEPA Army Corps of Engineer's 404 permitting preliminary Jurisdictional Delineation (PJD) work. (see Conclusion section).

In contending with flood, hydraulic related failure and extreme weather events, the immediate adverse impacts on roadway operations and maintenance and the subsequent pressures that materialize back to a given assets structural design, making the necessary decision during each of these phases is critical. In order to identify the best us of resources, maximize that structural design decision making and expedite delivery in a fiscally constrained era; closing gaps, reducing margins for error, replacing assumptions and limitations with numerical and computing accuracy and reducing or eliminating subjectivity and error where possible would measurably contribute to new bridge design, evaluating existing bridges for scour potential, and develop countermeasure designs. In addition, the issues related to flood, hydraulic related failure and extreme weather event are operationally critical considering the increasing materials costs, environmental concerns, and the public demand for safe passable roads. Thirdly, all these issues are further compounded by:

- Emergency response reporting
- Infrastructure health reporting
- Agency wide assets reaching end of life
- MAP-21/Transportation Asset Management Planning (TAMP) requirements
- Resource prioritization requirements
- Streamlining and accelerated project delivery expectations
- MPO, COG, LPA project administration and cost control responsibilities

ADOT identified the erratic and abrupt nature of flood, hydraulic-related failure and extreme weather impacts on maintenance and operations and asset design as an excellent entry point to cope with new external threats, develop a strategic and systematic process for continuous improvement and respond to many of the issues referenced above. Specifically, identifying repeatable processes that address these sudden and unpredictable events would allow a ADOT to further their preservation and replacement life cycle projection activities, incorporate cost effective and defensible strategies and supplement their Moving Ahead for Progress in the 21st Century (MAP-21) risk-based TAMP rulemaking requirements.

Justification

State DOTs have relied on several forecasting strategies and techniques to gain insight into incidents of flood, hydraulic related failure and extreme weather events. The forecasting methods range from those based on sound scientific principles to those rooted in weaker doctrine and extraneous numerical modeling. The more recognized modeling techniques include persistence forecasts – conditions remain unchanged, analog – blend historical data, statistical – good for one dimensional, and numerical forecasting. Numerical modeling's advantage is that has the potential to simulate the evolution of a condition over a specified period - A computer representation of a prototype condition.

Numerical forecasting for the weather has been around for over 50-years. The advent of high resolution, real-time modeling and the advances computing power and observation networks has made numerical modeling a very capable approach to improving a series of ADOT's activities such as scoping, planning, and project development through various means especially as they relate to incidents of flood, hydraulic related failure and extreme weather events in connection with new bridge design, evaluating existing bridges for scour potential, and developing countermeasure. The time is right to incorporate a host of modeling and computer analysis to upgrade how ADOT addresses the management of new bridge design, evaluating existing bridges for scour potential, and development of countermeasure designs. A brief discussion follows on the areas that in the past had a certain level of guess work involved or where the effort simply defaulted to the given 25, 50, 100 year design parameters.

One-Dimensional Versus Two-Dimensional Modeling [1]

One-dimensional modeling requires that variables (velocity, depth, etc.) change predominantly in one defined direction, x, along the channel. Because channels are rarely straight, the computational direction is along the channel centerline. Two-dimensional models compute the horizontal velocity components (Vx and Vy) or, alternatively, velocity vector magnitude and direction throughout the model domain. Therefore, two-dimensional models avoid many assumptions required by one-dimensional models, especially for the natural, compound channels (free-surface bridge flow channel with floodplains) that make up the vast majority of bridge crossings over water. The advantages of two-dimensional modeling include a significant improvement in calculating hydraulic variables at bridges. Therefore **FHWA has a strong preference for the use of two-dimensional models** over one-dimensional models for complex waterway and/or complex bridge hydraulic analyses. Two-dimensional models generally provide more accurate representations of:

- Flow distribution
- Velocity distribution
- Water Surface Elevation
- Backwater
- Velocity magnitude
- Velocity direction
- Flow depth
- Shear stress

Although this list is general, these variables are essential information for new bridge design, evaluating existing bridges for scour potential, and countermeasure design. The Federal Emergency Management Agency (FEMA) also depends on numerical hydraulic models of extreme events to determine flood hazards.

Numerical Stability

Model accuracy can be defined as how well the numerical solution matches the true solution. Accuracy depends upon the assumptions and limitations of the model (i.e., one-dimensional model with a single water surface verses a two-dimensional model). It also depends upon the accuracy of the (1) geometric data, cross section data, Manning n values, bridges and culverts; (2) flow data and boundary conditions; and (3) the numerical accuracy of the solution scheme.

Computing Scour

Each of the types of scour relies on hydraulic variables as input to the scour calculations. These variables include velocity, depth, discharge, flow width, unit discharge, and flow direction. The quality and accuracy of hydraulic modeling directly impact the accuracy of scour calculations. **If model geometry is inaccurate**, bank stations are not correctly or consistently defined, Manning n values are not accurate, or model assumptions are violated, then the poor quality of the hydraulic input data used in scour **calculations can result in unreasonable and incorrect scour estimates**.

[1] Reference
Hydraulic Design of Safe Bridges. Section 4.2.1, No. FHWA-HIF-12-018, Hydraulic Design Series Number 7, April 2012.

Revetments and Vegetation

Channel bank revetments and vegetation are the most common type of lateral stream instability and bank erosion countermeasure. Revetments are placed directly on the channel bank and include riprap, articulating concrete blocks, various types of mattresses, and may be used in combination with vegetation. Hydraulic modeling of revetments and vegetation includes adjusting geometry to represent earthwork and assigning representative values of Manning n for the countermeasure material.

Error Potentiality [2]

Accounting for the high sediment mobility and flashy floods in Arid West ephemeral and intermittent streams is just one of the challenges involved in developing a stage–discharge relationship. . . . Indirect measurements are less accurate than direct measurements as they result in errors associated with calculation techniques. **At best, indirect discharge measurements are within 15% of the actual Discharge**[3]. Indirect errors occur during slope–area, slope–conveyance, and step–backwater computations. Slope–area and slope–conveyance computations involve calculating the discharge post flood by identifying high water mark indicators, determining the maximum stage, surveying the channel, and estimating a Manning's n, the channel hydraulic roughness coefficient. **The uncertainties with these indirect measurements relate to the underlying assumption that the conditions present post-flood are the same as those that existed prior to and during the flood event**. However, conditions frequently change in sandy ephemeral streams, and the reliability of these methods is questionable.

The two highlighted areas are specific activities relative to this partnering proposal. The combination of high end modeling and computing power has allowed the USGS to begin the process of solving many of the previous recognized indirect errors. Secondly, the USGS staff would be able to conduct real-time event measurements at ADOT's assets thus further eliminating many underlying assumptions.

NCHRP REPORT 761 Summary[4]

Current practice for determining the total scour prism at a bridge crossing involves the calculation of the various individual scour components (e.g., pier scour, abutment scour, contraction scour, and long-term channel changes). Then, using the principle of superposition, these individual components are considered to be purely additive and the total scour prism is then drawn as a single cumulative line for various frequency flood events (e.g., 50-year, 100-year, and 500-year flood events). The scour equations are generally understood to be conservative in nature and, with the exception of the contraction scour equations, have been developed as envelope curves for use in design. This approach does not provide an indication of the uncertainty involved in the computation of any of the individual components. Uncertainties in hydrologic and hydraulic models and the resulting uncertainty of relevant inputs (e.g., design discharge, velocity, depth, and flow distribution between the main channel and the floodplain) to the scour calculations will all have a significant influence when evaluating the risk associated with scour

[2] Ordinary High Flows and the Stage–Discharge Relationship in the Arid West Region Publication ERDC/CRREL TR-11-12. Katherine E. Curtis, Robert W. Lichvar, and Lindsey E. Dixon July 2011. U.S. Army Corps of Engineers.

[3] Tillery, A. C., J. V. Phillips, and J. P. Capesius. 2001. Water Resources Investigations Report 00-4224. Tuscon, AZ: U.S. Geological Survey and Flood Control District of Maricopa County.

[4] NCHRP REPORT 761 - Reference Guide for Applying Risk and Reliability-Based Approaches for Bridge Scour Prediction, 2013.

prediction**. A widespread belief within the bridge engineering community is that unaccounted-for biases, together with input parameter and hydraulic modeling uncertainty, lead to overly conservative estimates of scour depths. The perception is that this results in design and construction of costly and unnecessarily deep foundations.**

Conclusion – Increasing Accuracy[5]

The accuracy of modeling depends in part on the quality of the observations and on the process of data assimilation. To improve modeling dynamics the model must know the state of the conditions before, during and after events. By having most of the inputs in the model data assimilation numerical forecasting can deliver what can be referred to as a "first guess." If the initial conditions used in the model contain significant errors, the errors can magnify by the extent of the observed data. This in turn can encourage the continued design input usage of standard given 25, 50, 100 year parameters. Therefore, the addition of real-time data, computing power, numerical modeling and improved GIS can now allow for better initial condition inputs and superior prediction reliability.

Within the wider topic of flood, hydraulic-related failure and extreme weather impacts significant aspects of bridge hydraulic design including: regulatory topics, specific approaches for bridge hydraulic modeling, hydraulic model selection, bridge design impacts on scour and stream instability, and sediment transport are seen by ADOT as key drivers to measurably improving and directly and meaningfully contributing to expediting and improving Arizona Department of Transportation (ADOT) project planning, design and delivery thru improved quantitative data.

ADOT respectfully request the authorization to use federal funds to further develop the Arizona Department of Transportation / United States Geological Survey Partnering Project. ADOT has identified at least the following four criteria that would directly and meaningfully contribute to expediting and improving Arizona Department of Transportation (ADOT) project planning, design and delivery.

- Actively engage the USGS Arizona Water Science Center personnel and USGS advancements enhance the missing hydraulic data specifically through better modeling of channel roughness (Manning's n) where USGS gaging activity would directly benefit ADOT assets. Verified n values reduce or eliminate the subjectivity and error associated with choosing n values based on visual assessments of the modeled reaches. Models incorporating verified n values are more accurate, reliable, and defensible. **Outcome**: Improved design and life cycle costing, quicker, more accurate scour critical prediction, defensible MAP-21 asset management reporting.

- Actively engage the USGS Arizona Water Science Center personnel and USGS advancements to provide real-time event measurement and analysis data during flood, hydraulic-related failure and extreme weather events. **Outcome:** Improved design and life cycle costing, quicker, more accurate scour critical prediction, defensible MAP-21 asset management reporting.

[5] Petty, K.R., 2009. Advances in Models, Sensors, Tools, and Platforms to Improve Maintenance Operations. Transportation Research News.

- Actively engage the USGS Arizona Water Science Center personnel and USGS advancements with part of a proposed ADOT Environmental Planning Group's NEPA submittal requirements project in connection with the Army Corps of Engineers wash jurisdictional delineation and wetland delineation. The new approach would be to generate the needed data and aerials required for the delineations using a combination of the USGS next gen Stream Stats tool and yet to be determined 2-D hydraulic modeling tool. **Outcome:** Verify if an inhouse desktop generated delineation can match the accuracy/certainty of a consultant led field visit/desktop delineation. If viable it could eliminate most consultant led NEPA delineation work (20-30 per year avg) and expedite the delineation process and subsequent related documentation activities.

- Improved and meaningful Flood Plain, Army Corps, USGS, ADOT coordination on project development and weather event activities. **Outcome:** Crosscutting benefits of streamlined and specific utilization of statewide stream gages and flood warning gages in conjunction with USGS StreamStat analytics for more accurate data. Thus increasing the accuracy and usage of regional gages for transportation specific needs, leading to expedited decisions making and related life cycle costing.

Additional Relevant Regulations

https://www.fema.gov/federal-flood-risk-management-standard-ffrms

An Introduction to the Federal Flood Risk Management Standard ("Standard")

To improve the nation's resilience to flooding and better prepare the nation for the impacts of climate change, the President's Climate Action Plan (June 2013) directs federal agencies to take the appropriate actions to reduce risk to federal investments, specifically to "update their flood-risk reduction standards."

To further the Climate Action Plan, the President released the Executive Order, *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*, and the Standard.

Between 1980 and 2013, the United States suffered more than $260 billion in flood-related damages. On average, more people die annually from flooding than any other natural hazard. Further, the costs borne by the Federal government are more than any other hazard. Flooding accounts for approximately 85% of all disaster declarations. With climate change, we anticipate that flooding risks will increase over time. In fact, the National Climate Assessment (May 2014) projects that extreme weather events, such as severe flooding, will persist throughout the 21^{st} century. That damage can be particularly severe to our infrastructure, including our buildings, roads, ports, industrial facilities, and even our coastal military installations.

The new federal flood risk standard requires all future federal investments in and affecting floodplains to meet the level of resilience as established by the Standard. For example, this includes where federal funds are used to build new structures and facilities or to rebuild those that have been damaged.

The Federal Flood Risk Management Standard builds on work done by the Hurricane Sandy Rebuilding Task Force, which announced in April 2013 that all Sandy-related rebuilding projects funded by the Sandy Supplemental (Public Law 113-2) must meet a consistent flood risk reduction standard. The

Hurricane Sandy Rebuilding Strategy recommended that the federal government create a national flood risk standard for Federally-funded projects beyond the Sandy-affected region.
The Standard specifically requires agencies to consider current and future risk when taxpayer dollars are used to build or rebuild floodplains.
In implementing the Standard, federal agencies will be given the flexibility to select one of three approaches for establishing the flood elevation and hazard area they use in siting, design, and construction:

- Utilizing best-available, actionable data and methods that integrate current and future changes in flooding based on science,
- Two or three feet of elevation, depending on the criticality of the building, above the 100-year, or 1%-annual-chance, flood elevation, or
- 500-year, or 0.2%-annual-chance, flood elevation.

FHWA Issues Climate Change and Extreme Weather Resilience Order (attached)**.** FHWA Order 5520, *Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*, was signed on December 15, 2014 and states that it is FHWA policy to integrate consideration of climate and extreme weather risks into its planning, operations, policies and programs. Over the past decade FHWA has been a recognized leader in developing methods and tools to assist transportation agencies in assessing the vulnerabilities and risks of their transportation systems to the impacts of climate change and extreme weather. This new Order formalizes FHWA's commitment to this issue, guides the agencies' implementation of relevant MAP-21 provisions and recent Executive Orders, and identifies how the agency intends to continue to lead the transportation industry in making the nation's highways more resilient. In particular:

FHWA will integrate consideration of the risks of climate change and extreme weather event impacts and adaptation responses, into the delivery and stewardship of the Federal-aid and Federal Lands Highway programs by:

a. Encouraging State departments of transportation (DOT), metropolitan planning organizations (MPO), Federal land management agencies (FLMAs), tribal governments, and others to develop, prioritize, implement and evaluate risk-based and cost-effective strategies to minimize climate and extreme weather risks and protect critical infrastructure using the best available science, technology and information.

23 CFR Subpart A—Location and Hydraulic Design of Encroachments on Flood Plains § 650.115 Design standards

(a) The design selected for an encroachment shall be supported by analyses of design alternatives with consideration given to capital costs and risks, and to other economic, engineering, social, and environmental concerns. (1) Consideration of capital costs and risks shall include, as appropriate, a risk analysis or assessment which includes:
(i) The overtopping flood or the base flood, whichever is greater, or (ii) The greatest flood which must flow through the highway drainage structure(s), where overtopping is not practicable. The greatest flood used in the analysis is subject to state-of-the-art capability to estimate the exceedance probability.

Part 771—Environmental Impact and Related Procedures § 771.105 Policy.
. . . [relates to all environmental investigations, reviews, and consultations on a project] . . .

(b) Alternative courses of action should be evaluated and decisions be made in the best overall public interest based upon a balanced consideration of the need for safe and efficient transportation; of the social, economic, and environmental impacts of the proposed transportation improvement; and of national, State, and local environmental protection goals.

FHWA T5140.23 - Codified in 2005 in FHWA Regulations 23CFR650.313e.
All DOTs develop Plans of Action for implementing countermeasures and for inspecting the bridges frequently until such countermeasures were implemented.

A quandary faced by bridge owners in effectively complying with FHWA's Scour Program is determining the appropriate prioritization and level of effort. The risk & data utilization strategy assists bridge owners in establishing a process in managing bridges with known or potential deficiencies attributed to scour and provides the bridge owner a systematic means to prioritize and apply resources towards those bridges that could pose the greatest threat to public safety and/or disruption of vital services. The bridge owner may compare bridge importance and likelihood/consequence of failure (risk) against a suite of operational characteristics specific to the facility (data). Under the NBIP oversight process, any plan of corrective action relative to the Scour Program should look for opportunities to apply risk & data strategies.

Evaluating Scour at Bridges - Fifth Edition - April 2012
Publication No. FHWA-HIF-12-003
Hydraulic Engineering Circular No. 18
Data from the USACE, USGS, and other Federal and State agencies should be considered when evaluating long-term streambed variations – 5.1

Mueller (1996) compared 22 scour equations using field data collected by the USGS (Landers et al. 1999). He concluded that the HEC-18 (CSU) equation was good for design because it rarely under predicted measured scour depth. However, it frequently over-predicted the observed scour - 7.2