Project No. _____

NCHRP 20-59(53): FLOODCAST

A Framework for Enhanced Flood Event Decision-Making for Transportation Resilience

Final Report

Prepared for

The National Cooperative Highway Research Program

Transportation Research Board

of

The National Academies of Sciences, Engineering, and Medicine

Dewberry
Venner Consulting

July 2018

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DISCLAIMER

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CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Flooding has a significant, damaging impact on transportation systems and its users. Many lives have been lost when cars are swept away by flood waters and drivers are unable to escape their vehicles in time. In 2012, the California Department of Transportation (Caltrans) identified the need for a flood alert system that would allow Caltrans to proactively monitor, assess, and respond to flood-related disasters and associated hazards in real time. This system would focus on providing bridge and infrastructure management during destructive flood conditions in order to predict infrastructure failure. Caltrans called the system they desired "FloodCast," similar to Caltrans's current ShakeCast system for early situational awareness of earthquake impacts. This concept was presented at the Transportation Research Board (TRB) in workshop form in January 2015. The proposed system would integrate multiple sources of data and provide automated notifications to various audiences. Emergency response and state transportation agencies often lack the integration of real-time forecast information into their asset management and communications systems to expeditiously close roads, bridges, tunnels, etc. and prevent human loss of life.

In response to this idea, NCHRP initiated the FloodCast project with support from multiple American Association of State Highway and Transportation Officials (AASHTO) and TRB committees. The project is overseen by a panel led by officials from CalTrans and Delaware Department of Transportation (DOT) and comprised of representatives from AASHTO, National Oceanic and Atmospheric Administration (NOAA), United States Geological Survey (USGS), research universities, and private consulting firms. The research team, led by Dewberry, developed the FloodCast data architecture and framework with the following objectives:

1. Leverage best practices from communities across the country that are delivering early warning information regarding impacts to transportation systems.
2. Identify, from a global perspective, potential users and sources for the data and information streams needed to produce the desired flood situational awareness.
3. Advance research in the areas of meteorological forecasting, sensor telemetry, hydrologic/hydraulic modeling, hazard identification, asset management, and risk mitigation.
4. Identify near term improvements to the current state of systems, data, and tools, while ensuring delivery of a framework that anticipates the evolution of that state.

With respect to the last objective, the concepts of practicality, scalability, and interoperability were key themes throughout the FloodCast project. The FloodCast framework was designed to be useful for a wide range of transportation practitioners with varying backgrounds. In development of the framework and prototype system, the research team determined how a nationwide, distributed network of weather data, hydrologic data, and transportation asset specific information can be woven into a practical, scalable, and flexible decision support system. NCHRP 20-59(53) has provided a framework and prototype tool that serves as a stepping stone toward developing a fully mature flood event decision-support system.

This report provides a summary of the FloodCast project by describing the project approach and delineating principal findings. The FloodCast project resulted in numerous deliverables intended to build flood forecasting and response capabilities for State DOTs. The primary purpose of this report is to summarize the outcomes of the FloodCast project and make these products discoverable to the larger community. All of the FloodCast products are available on the FloodCast.Info webpage.

2 SCOPE AND PRODUCTS

The scope of this project was twofold: first, to identify tools, methods, and models to support forecasting, operations, and response activities, and second, to support pre- and post-event mitigation planning and risk reduction in the context of transportation decision-making. The outcomes of the FloodCast project include:

- FloodCast Literature Review Technical Memorandum (July 2015)
- FloodCast Interim Report (July 2015)
- FloodCast Practitioner Guidebook (October 2016)
- FloodCast Prototype Tool (2017)
- FloodCast Prototype Demo (2017)
- FloodCast Capability Maturity Model Report (February 2017)
- FloodCast Capability Maturity Model Excel Tool (February 2017)
- FloodCast Requirements Analysis (May 2017)
- FloodCast Data Standards and Specifications Report (April 2018)
- FloodCast Example Dataset in Environmental Linked Features Interoperability Experiment (ELFIE)
- FloodCast ELFIE Use Case Demo

3 APPROACH

This project was undertaken in three main phases, illustrated in Figure 1. In Phase 1, the research team:

- Researched and documented existing resources for flood event planning, response, and operations relevant to the transportation context;
- Conducted a gap analysis and prioritized practitioner needs versus capability of existing resources to meet those needs;
- Developed a framework and architecture to organize existing resources; and
- Delivered recommendations for further research that can be carried out within the project timeframe and in work subsequent to this project.

In Phase 2, the research team started by closing any necessary gaps in the research conducted in Phase 1, ensuring that there was a sound, defensible platform for the work performed in Phase 2. Subsequently, the research team designed and developed the FloodCast prototype system along with a practitioner guidebook on best practices for producing actionable information based on available resources.

Lastly, during Phase 3 of this work, the research team:

- Developed a Capability Maturity Model (CMM) to help State DOTs define the key data, technologies and practices required to effectively achieve floodcasting progress over time;
- Performed a Requirements Analysis to identify, from a State DOT perspective, the capabilities a flood forecasting and response platform should have to support State DOT response, recovery, and mitigation activities; and
- Identified data standards and specifications that would ensure an interoperable and scalable framework.

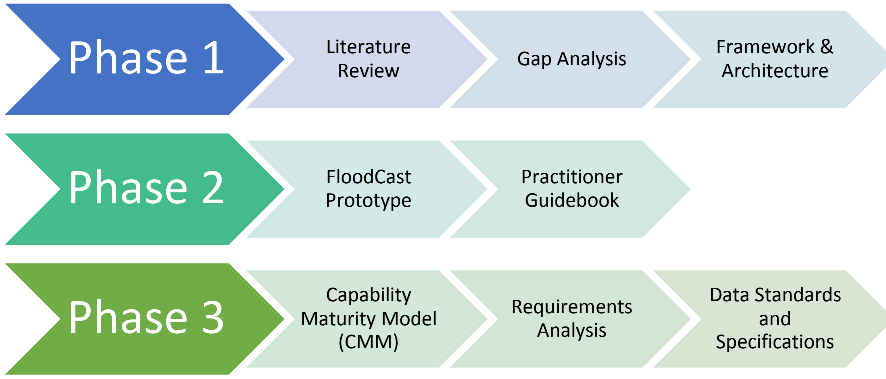

Figure 1: FloodCast project phases.

4 KEY FINDINGS

4.1 Phase 1

The primary objective of the first phase of the FloodCast project was to identify resources, tools, and technology that could be leveraged to build capability within State DOTs. The FloodCast Literature Review Technical Memorandum (July 2015) identifies numerous available resources to support flood forecasting, response and recovery. Many of these resources can be readily integrated into a framework to support State DOTs in planning for, responding to and operating during floods. Other resources require modification before being integrated into a floodcasting framework. The study team also identified a number of unmet practitioner needs based on literature review and information interviews with State DOTs. The identified practitioner needs were collected as unmet business requirements and these gaps were reviewed in light of current capabilities, potential modifications to existing data, and research and development needs. The FloodCast Interim Report (July 2015) provides a prioritized list of practitioner needs, describes current capabilities, modifications and research and development needs, and provides recommendations for further research.

Generally speaking, many DOTs are interested in tools to assist with flood conditions, but while most states are engaged in flood mapping at various levels of detail, few DOTs have mature models that can help estimate flood impacts to the transportation network using atmospheric forecasts. There is also interest in integrating flood forecasting tools with tools that will support emergency management and communication functions. One important gap is the single-asset, single-issue focus of the most common transportation decision-making systems. Flood events are typically comprised as a family of incidents, impacting multiple assets at once that might be interconnected. Enhanced flood event decision-making hinges on a system's ability to forecast how any given flood event might impact all assets within the projected flood extent, thus enabling more streamlined and coordinated response activities.

The results of the Phase 1 research culminated in a list of five (5) key elements that would need to be included in a robust flood forecasting and response framework (illustrated in Figure 2).

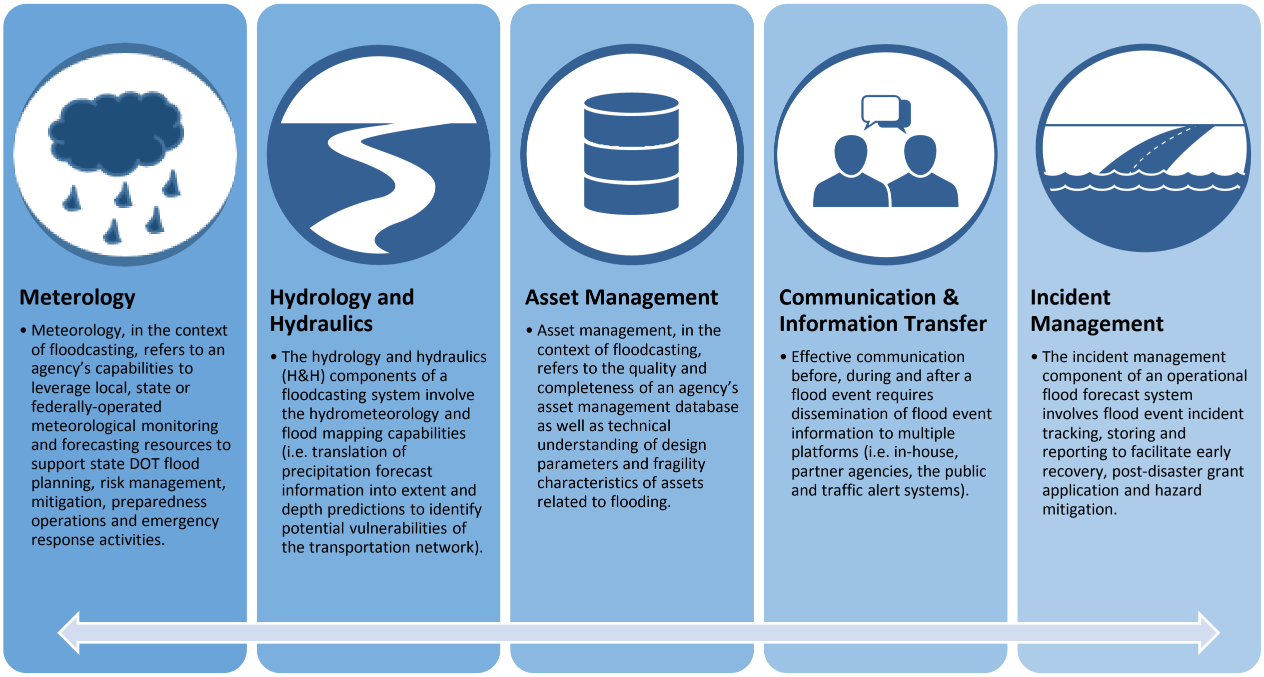

Figure 2: Key elements of a robust flood forecasting and response framework.

4.2 Phase 2

During Phase 2, The study team developed a prototype FloodCast system to help demonstrate a number of possible flood forecasting and response capabilities by incorporating the five key elements illustrated in Phase 1. The FloodCast prototype is a web-based platform that combines high quality forecast data with dissemination tools to support effective emergency response by transportation practitioners, schematically illustrated in Figure 3. By delivering forecast data, predicted floodplains, and analytics of affected transportation assets, decision-makers can receive timely intelligence to better respond to forecasted and ongoing flood events.

The FloodCast Practitioner Guidebook (October 2016) documents the FloodCast prototype system development along with its current system functionalities. This report is intended to help state and local DOTs, and other transportation practitioners understand existing data and tools applicable to flood response and hazard mitigation. Outlining the development process and functionalities of the FloodCast prototype demonstrates how a flexible, scalable framework can be applied to digesting and distributing information corresponding to data availability and high-priority practitioner needs.

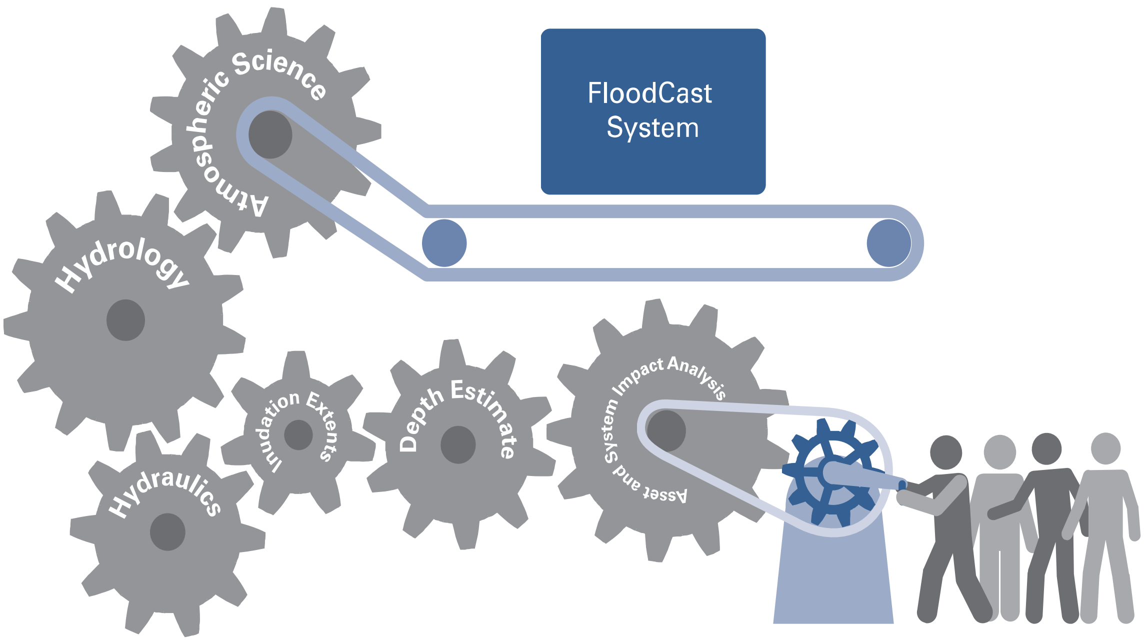

Figure 3: FloodCast prototype system components

4.3 Phase 3

The objective of Phase 3 was to further develop, inform and refine the FloodCast framework and prototype system. The research team first developed a CMM using the five key elements defined in Phase 1 (meteorology, hydrology and hydraulics, asset management, communication and information transfer and incident management) to help State DOTs define the key data, technologies and practices required to effectively achieve floodcasting over time. These CMM capability dimensions had tiers indicating levels of maturity with respect to each element. A CMM excel-based tool was developed to enable State DOTs to identify current maturity level as well as identify a pathway to improve capabilities along each dimension.

Next, the research team performed a detailed requirements analysis to identify, from a state DOT perspective, the essential capabilities a floodcasting platform should have to support their needs. During the requirements analysis, the study team collaborated with a number of State DOTs across the country (see Figure 4) with the goals of:

- Capturing a range of geographic regions with varying flood hazards;
- Involving appropriate staff with job responsibilities related to flood forecasting, response and recovery; and
- Engaging DOTs representing a mix of both basic and more mature practitioners with respect to the key dimensions of flood forecasting, response, and recovery.

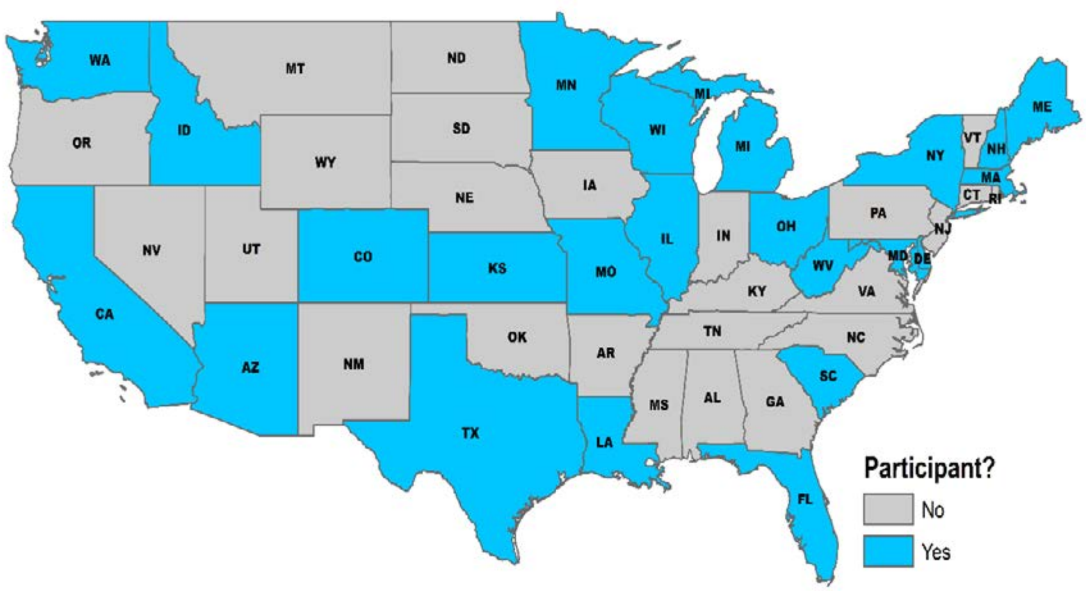

Figure 4: State DOT participation in the FloodCast Requirements Analysis

The research team provided demonstrations of the FloodCast prototype system (recording here) to facilitate discussion of DOT requirements. The FloodCast Requirements Analysis Report (May 2017) documents the approach and principal findings of the requirements gathering effort. Examples of concerns gathered from State DOTs and a summary of their needs follow:

- **Meteorology:** most State DOTs consult predictive weather forecasts for flood events most commonly from Nation Weather Service (NWS), NOAA, USGS, National Hurricane Center (NHC), and Federal Emergency Management Agency (FEMA). Data is gathered separately from each source. Time is then needed for creating an update rather than having one central system to store all weather and hydrologic data. **Need:** one central data collection system.

- **Hydrology and Hydraulics:** a few State DOTs use USGS rating curves or StreamStats program to estimate inundation extent and depth predictions for ungauged locations. **Need:** rapid translation of stream flow predictions to extent and depth predictions.
- **Asset Management:** many State DOTs have some sort of asset management system, but they can be limited or incomplete, not in a geospatial format, or the asset fragility information is questionable. **Need:** asset data in geospatial format with standardized key design attributes to support impact assessment.
- **Communications and Information Transfer:** many dispatch alert systems are rarely automated and occur during or post-event rather than delivering predictive information. **Need:** one-click automated communication tools to streamline internal and external dissemination efforts.
- **Incident Management:** agency staff have institutional knowledge of flood prone areas subject to loss. **Need:** a data system with flood prone areas identified allowing for rapid synthesis of all flood event analytics to facilitate both response and post-disaster recovery and reimbursement activities.

Building from the results of the requirements analysis, the study team began to identify data standards and specifications for FloodCast-relevant data elements with the following objectives:

- Review existing open data standards for each of the FloodCast capability dimensions. Based on this review, 1) select appropriate existing standards, 2) recommend a new standard for dimensions where standards did not exist or were not sufficient, or 3) describe ideal standards that could be developed. It is important to note that some of the FloodCast capability dimensions are ready for formal standards while others need more time to reach maturity.
- Develop recommended specifications for how the FloodCast system should handle the range of data qualities and availabilities indicated by State DOTs while still meeting the needs of decision-makers.

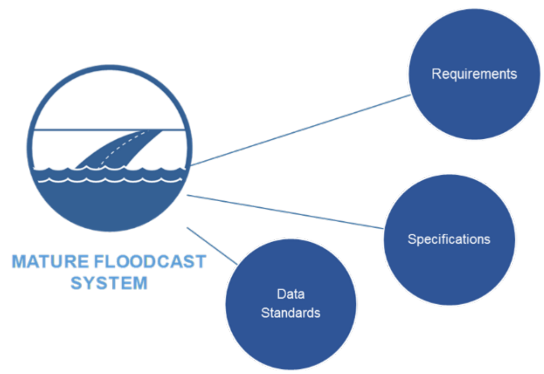

Figure 5: Mature FloodCast System components.

The study team collaborated with the Open Geospatial Consortium (OGC) Environmental Linked Features Interoperability Experiment (ELFIE) led by the Hydrology Domain Working Group (Hydro DWG) to ensure the data standards and specifications developed for FloodCast would be as open and widely accepted as possible. The Hydro DWG is a joint working group of the World Meteorological Organization (WMO) and the OGC. Within the ELFIE framework, new domain feature types specific to floodcasting were established (Figure 6); specifically, the "Flood Event" and the "Flood Extent". Each feature type within the ELFIE context has

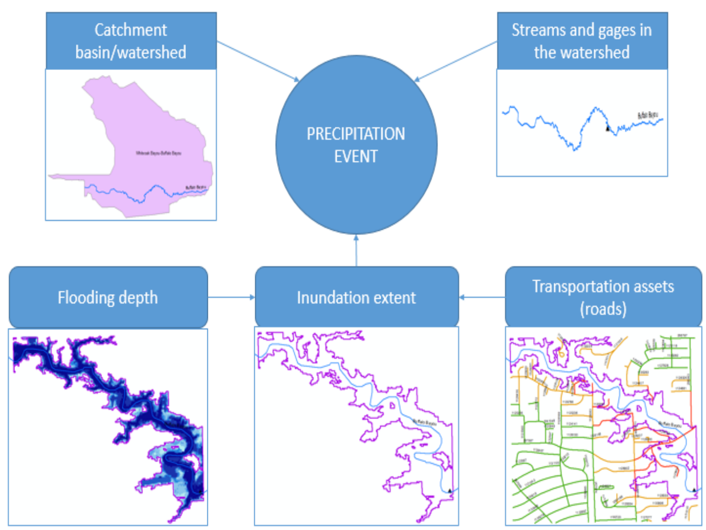

Figure 6: FloodCast features and relationships within the ELFIE context.

standard relationships established to show how flood forecasting data relates to transportation asset data. The study team developed a demonstration video in cooperation with the USGS, a Co-Chair lead of the Hydro DWG, showcasing the important data elements, feature types and relations in the FloodCast use case.

The research team also identified data standards for other FloodCast elements outside of the scope of ELFIE, especially for the elements identified as critical during the requirements analysis. For example, many State DOTs indicated that the asset vulnerability attribute (i.e., threshold at which an asset is impacted by a flood event) can be difficult to characterize. In fact, a significant data limitation for flood impact analysis is whether DOTs have information about how assets within the transportation network are affected by heavy rainfall or flood conditions. Therefore, the study team developed a standard set of attributes and specific formats for various DOT-owned assets necessary to achieve FloodCast objectives. The full set of data standards and specifications identified for this effort is summarized in the FloodCast Data Standards and Specifications Report (April 2018).

5 NEXT STEPS

During execution of Phase 1 through 3, the study team recognized the need for supplemental research related to this project and submitted a research problem statement to NCHRP. The problem statement, in summary, acknowledges that while many State DOTs are currently leveraging available data and technology to support flood event decision-making, a key data gap exists at locations along the stream networks without monitoring gauges. Access to this data would exponentially improve the effectiveness of state DOT flood forecasting, response and recovery efforts. The National Water Model (NWM), an experimental product developed by NOAA's Office of Water Prediction (OWM), provides access to observed and forecasted streamflow on a real-time basis over the entire continental United States, expanding forecast streamflow data from ~3,600 currently in operation to ~2.7 million locations nationwide. Despite the NWM's significant potential, key challenges currently prohibit its use at the operational level required by State DOTs:

1) The NWM's main output variable of use to DOTs is stream discharge, but this cannot be readily used for decision support in the current NWM format (i.e. streamflow forecasts). These variables need to be converted to either water depth and/or inundation extent. There is no agreed upon method for doing this conversion. How should one convert NWM streamflow data to water depth or inundation extent? This would make NWM relevant and useful for FloodCast and therefore, State DOTs for predicting likely flooding.
2) Although NWM results are presented at high resolution when compared to existing forecasts, it is yet to be validated and in some cases, is inconsistent in some geographic areas. Where can NWM output be used directly? Where does NWM output need post-processing to yield actionable information? Where should the output not be used until further improvements are made?

As the NWM offers promise to close many of the gaps identified during the FloodCast project, the next step for this work is determining how to deliver this capability to DOTs as soon as possible. Research focused on answering the above questions is the first step to achieving this objective.