NCHRP 20-59(53): FLOODCAST

A FRAMEWORK FOR ENHANCED FLOOD EVENT DECISION MAKING FOR TRASPORTATION RESILIENCE

PRACTITIONER GUIDEBOOK

Prepared for the
The National Cooperative Highway Research Program (NCHRP)
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ACRONYMS

AHPS	Advanced Hydrologic Prediction Service
API	Application programming interface
DOT	Department of Transportation
FEMA	Federal Emergency Management Agency
GIS	Geographic information system
GIS-T	Geographic information system for transportation
NCHRP	National Cooperative Highway Research Program
NFHL	National Flood Hazard Layer
NFIE	National Flood Interoperability Experiment
NHC	National Hurricane Center
NHD	National Hydrography Dataset
NWM	National Water Model
NWS	National Weather Service
OGC	Open Geospatial Consortium
SMS	Short Message Service
USGS	United States Geological Survey
WMS	Web Map Service

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FOREWORD

This report develops a proposed strategic framework and data architecture for enhanced flood event decision making tailored for transportation system use. This framework can be used to help a wide variety of users that are involved in transportation and emergency management understand and acquire available data, tools, and methods within the context of a flexible, scalable framework producing actionable data. The research team conducted an extensive review of existing tools, methods, data, and models for flood event decision support and hazard mitigation to identify practitioner needs and address persistent data, usage, and practical shortcomings with respect to existing tools and models available to practitioners. The various data elements identified by the research team were used to develop a prototype tool that provides granular, spatially explicit weather, climate, hydrologic, and hydraulic data that can be integrated with transportation asset information to support state DOT flood response and hazard mitigation decision making. The prototype tool demonstrates how the proposed framework can be applied to ingesting and distributing information corresponding to data availability and high-priority practitioner needs.

Flooding has a significant, damaging impact on our nation's transportation infrastructure. Transportation systems are complex systems composed of spatially distributed networks with interactions both within and outside the network. Seemingly isolated flood-related vulnerabilities can therefore have ramifications for the wider transportation network. System-level vulnerabilities become increasingly difficult to diagram and understand when systems combining physical infrastructure, computers, and human decision-makers come into play. Depending on the degree of asset connectivity, failure of one asset can affect a number of other assets as well as overall system function. Before the event, addressing system-level vulnerabilities can improve the overall resilience of the transportation network; after an event, pinpointing the source of failures can enable faster recovery.

Although there are data, tools, and models available to forecast weather and climate conditions, in many states, these tools have not yet been appreciably integrated with state DOT asset data to carry out flood planning, risk management, mitigation, preparedness operations, and emergency response activities. Data coverage, spatial resolution, and interoperability issues are key barriers to building a flexible, scalable, and interoperable information network that enables decision support in the transportation space. The current information environment is missing the standards and organization needed to assemble data from multiple partners and provide end users with relevant input to critical decisions. There is also a need to combine the available technologies and data sets into a suite of tools and methods that can be easily used by DOT decision makers and are optimized for the transportation agency workflows during the planning, response and recovery phases of a flood event.

Under NCHRP Project 20-59(53), "FloodCast", a research team led by Dewberry Consultants, LLC developed a strategic framework and prototype tool for enhanced flood event decision making. Intended for transportation practitioners, this report describes the best ways to efficiently leverage existing data sources, acquire and use data from new and innovative technologies, and develop a flexible and scalable framework to use in flood event planning, preparedness and emergency management. This report also documents the development of a prototype model implementing the framework.

The primary function of this project is to provide a proof-of-concept to the industry, recognizing that future implementation would be customized to each DOT's existing capacities, data and processes. Prototype capabilities and a plan for building out a full system will be described. This research effort will lay a groundwork for the development of a comprehensive and coordinated decision-support system for transportation practitioners, and the prototype tool developed for NCHRP 29-50(53) will be used to demonstrate currently available technologies and how they might interface with preparedness, response and recovery activities, thus prompting further refinement of the tool for flood event decision making. This project is the initial step in producing actionable flood forecasting information and tools for DOTs nationwide.

SUMMARY

FloodCast: Framework for Enhanced Flood Event Decision Making for Transportation Resilience

Project Overview

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. In response to this idea, a FloodCast project was initiated by the National Cooperative Highway Research Program (NCHRP), with support from multiple American Association of State Highway and Transportation Officials and Transportation Research Board (TRB) committees.

NCHRP Project 20-59(53) was undertaken to develop a data architecture, framework and prototype tool for addressing practitioners' needs based on available data and tools. The Dewberry research team identified numerous resources (tools, methods, data, and models) that can help support flood forecasting for the state transportation agency context. Many of these tools can be readily integrated into a framework to support DOTs in planning for, responding to, and operating during floods. Others require modification before being integrated into a flood forecasting, or "floodcasting" framework. The research team developed an architecture and framework for those ready-to-use and easily modified tools. The research team also documented high-priority research requiring additional resources, detailing the level of effort and scope to address the gaps.

Interoperability – the ability of different information technology systems and software applications to communicate, exchange data and use the information that has been exchanged – is a fundamental consideration of this project and was the organizing principal of the prototype tool. Nationwide, activities such as the National Flood Interoperability Experiment, now incorporated in the National Water Model, are ongoing, with the objective of developing approaches to producing integrated climate, hydrologic, and hydraulic data intended to support floodcasting. Once widely available, these models will ease the burden of disseminating flood forecasting data into actionable information (such as translating precipitation forecast into stream discharge), but as of this report, a stable dissemination portal for these products does not yet exist. The research team structured the data architecture and framework to anticipate updates such as the National Water Model (NWM) outputs and other local datasets that support floodcasting.

This final report is intended to help state and local DOTs, and other transportation practitioners make sense of existing data and tools applicable to flood response and hazard mitigation. The report details the development process of the prototype FloodCast tool to demonstrate the value of high quality forecast data coupled with tools to support effective operational and emergency response by transportation practitioners. Elements of the FloodCast prototype are intended to support pre-disaster hazard mitigation and preparedness, emergency response, and post disaster recovery. With respect to preparedness, the tool has elements such as event summarization, so that during debriefing and planning, agencies are able to look at past events and understand what they might want to change with respect to planning and emergency response. Reviewing past events can also help agencies explore types of mitigation activities to pursue in future. With respect to operations and emergency response, the FloodCast prototype incorporates elements of the Federal Emergency Management Agency's (FEMA) Situation Reporting (SitRep) standards with the objective of facilitating interactions with emergency managers and emergency response services. With respect to post-disaster recovery, the FloodCast prototype includes elements of Federal Highway Administration (FHWA) and FEMA infrastructure damage reporting to enable application for post-disaster reimbursement and recovery funds. The prototype tool will help state DOTs, federal agencies, universities, and other transportation authorities and private entities, understand and plan to contribute to the information environment so that they can act on information in a meaningful time frame to reduce losses.

Scope and Products

NCHRP Project 20-59(53) was designed to start development of a framework and prototype tool that will: 1) leverage best practices from communities across the country that are delivering early warning information in 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, and 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.

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 products of the framework and prototype tool includes:

- Thorough, reference-quality documentation on the state of practice, including both practitioner-identified and expert-identified data needs. This document is the Technical Memorandum, which is included in Appendix A of this report.
- An accessible go-to guidebook to help practitioners understand and acquire available data, tools, and methods within the context of a flexible, scalable framework producing actionable data.
- A prototype tool demonstrating how a flexible, scalable framework can be applied to digesting and distributing information corresponding to data availability and high-priority practitioner needs, as documented in Chapter 5 of this report.

FloodCast is a prototype floodcasting project demonstrating the value of high quality forecast data coupled with tools to support effective operational and emergency response by transportation practitioners. By showing forecast data, predicted floodplains, and estimates of affected transportation assets, decision-makers are able to receive timely intelligence with which to respond to forecasted or ongoing flood events. Incident tracking and summary tools provide streamlined workflows, centralized tracking, and rapid synthesis of flood event analytics to facilitate post-disaster recovery activities and post-disaster grant applications or hazard mitigation. While riverine flooding is highlighted in the FloodCast prototype, both coastal and riverine flooding can be considered, making FloodCast flexible enough to be used nationwide. While in a prototype state, FloodCast's support for planning, operations, response and recovery has the potential to significantly amplify the reach of DOT staff during demanding flood response scenarios.

Future of FloodCast

For the prototype, the research team drafted initial requirements analysis based on the project problem statement, assessing potential uses of existing and soon-to-be released data sets and technologies. The resulting prototype demonstrates a number of optimal capabilities. In development of the framework and prototype tool, the research team also 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.

In order to build a maximally useful, fully realized FloodCast program, there is a need to perform a more comprehensive incorporation of the community of practice's full set of requirements. The prototype likely embodies some requirements that are in strong alignment with DOT needs and others that require some degree of adjustment. Because it is critical to maintain momentum for the FloodCast project, the research team will continue to engage with State DOTs to build a mature FloodCast program and determine how this framework fits into DOTs existing capacities. In order to reap the full benefits of this work, the research team recommends that the FloodCast project's next steps focus on requirements gathering, specifications, and data standards. These are discussed in more detail in Chapter 6 of this report.

Chapter 1 INTRODUCTION

1.1 Research Problem Statement and Objectives

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. Many state DOTs have a bridge flood monitoring program for structures that are susceptible to bridge scour. Additionally, most states have access to inundation mapping, however, significant gaps often exist between available inundation maps and vulnerable areas. Although there are tools and data available to forecast weather and climate conditions, in many states, these tools have not yet been appreciably integrated with state DOT asset data to carry out flood planning, risk management, mitigation, operations, and emergency response activities.

Research is needed to combine the available technologies and data sets into a suite of tools and methods for use by decision makers at DOTs. Such research is intended to support DOTs in hazard mitigation planning as well as operational and emergency management during flood events. In sum, these methods can be applied to flood prediction and warning for enhanced flood event decision making and situational awareness for transportation resilience by harnessing available processes, tools, and hydrometeorology network capabilities.

The objectives of this research are to develop a strategic framework and a prototype tool for enhanced flood event decision making. The framework and tool should help state DOTs plan, manage risks, mitigate hazards, and respond to flood and flash flood events. Given the varying sources, resolutions and spatial coverage in available data and tools, the framework design should be flexible and scalable to accommodate the available data sets and allow users to easily share both data and products with other users, thereby fostering collaboration across government organizations and, potentially other sectors.

1.2 Research Approach

This research was undertaken in two major phases. In Phase I, 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 developed recommendations for further research that can be carried out within the project timeframe and in work subsequent to this project.

In Phase II, the research team started by closing any necessary gaps in the research conducted in Phase I, ensuring that there was a sound, defensible platform for the work performed in Phase II. Subsequently, the research designed and developed the FloodCast prototype tool. Phase II also developed recommendations for next steps to build a fully mature FloodCast program, which will be used as a basis for developing the Phase III work plan.

Phase I and Phase II work for this study occurred in seven primary tasks. For each task, a team member was assigned as that task's lead. Task leads were responsible for the oversight of all work completed within the task. Study research analysts were assigned to tasks based on their expertise. The research work program had the following tasks:

1.2.1 *Phase I Tasks*

- ***Task 1, Prepare Technical Memorandum:*** The study team investigated existing tools, methods, data, and models for flood event decision support and hazard mitigation through a comprehensive literature review and focused on known data and tools that are currently employed. The team reviewed:
    - Publications by various transportation and emergency management organizations,
    - Relevant academic theses and dissertations in addition to materials listed in section E of the NCHRP 20-59(53) RFP,
    - Materials known to the research team through extensive work in natural hazard mitigation as well as vulnerability and risk assessment

  Task 1 efforts are discussed further in Chapter 3.

- ***Task 2, Gap Analysis****:* Building on the results of Task 1, the research team prepared a technical memorandum summarizing three categories: a) needs satisfied by available resources; b) needs requiring modification to available resources; and c) needs requiring new resources. Practitioner needs identified in Task 1 were treated as business requirements, which were then matched against the capabilities of available data and tools. Also, identify outstanding practitioner-identified needs not met by existing resources and classify into categories b) or c) as appropriate. Task 2 efforts are discussed further in Chapter 3.

- ***Task 3, Develop a Framework and Architecture:*** the research team developed a recommended framework and architecture to organize tools, methods, and data for practitioner use. Task 3 efforts are discussed further in Chapter 4.

- ***Task 4, Develop Recommendations to Close Gaps:*** Using the input gathered in the preceding tasks, the research team developed a suite of recommendations that address stakeholder needs and are widely accessible to the community of practitioners. Solutions consider such issues as: interoperability; data storage and archiving requirements; communication processes for submission of data; quality control and standardization of data submissions; and distribution of data to the community of practitioners in an accessible format. Recommended improvements were broken into two categories: improvements that can be carried out in Phase II, versus those requiring additional resources. Task 4 efforts are discussed further in Chapter 4.

- ***Task 5, Prepared Interim Report****:* The research team produced an interim report detailing the work performed to date, primary research findings, methodologies developed, and results achieved to date and is included in Appendix B of this report. This report was delivered for review in advance of an interim panel meeting, held in October 2015. The interim report also discussed the remaining study tasks to be performed. In addition to the report, the research team develop a Phase II work plan, which was discussed and finalized following the interim panel meeting. The interim meeting results are discussed further in Chapter 5.

1.2.2 *Phase II Tasks*

- ***Task 6, Carry Out Phase II Work Plan:*** Upon final approval of the Phase II work plan by NCHRP, the research team set out to address the research tasks identified by the Phase II work plan. The research team started by closing any necessary gaps in the research conducted in Phase I, principally through development of mock-ups for the prototype. Beyond closing any research gaps, the team set out to develop a strategic framework and prototype tool for enhanced flood event decision making. Task 6 efforts are discussed further in Chapters 5 and 6.

- *Task 7, Provide Guidebook and Document Framework Prototype Development and Evalution:* The research team developed a stand-alone document providing guidance for practitioners on methods and technologies, including case studies vignettes. This document will be based on the results of Tasks 1 and 2 and will represent the current state of practice. The content of the two technical memoranda produced in Tasks 1 and 2 will form the backbone of the document. The guidance document will be practitioner-focused, organized according to application and with an emphasis on using the resources listed to produce actionable information. Guidance on acquiring the tools, methods, and data will be provided (i.e. links to data sources and tool downloads). This final report is the product of Task 7.

1.3 Contents of Report

This report summarizes the results of Tasks 1 through 7, in addition to describing a plan to build out a mature FloodCast system. It is organized in the following sections:

- Chapter 1 presents the introduction, research objectives, and research approach.
- Chapter 2 provides a high-level view of real-time flood forecasting and decision-support requirements for transportation practitioners based on a comprehensive literature review, providing a context for development of the data architecture, framework, and prototype FloodCast tool.
- Chapter 3 identifies and priorities practitioner and expert-identified requirements in light of current capabilities, potential modification, and research and development needs.
- Chapter 4 describes the prototype tool development process.
- Chapter 5 discusses present capabilities of the FloodCast prototype tool, illustrated using examples of this technology.
- Chapter 6 describes initial prototype evaluation activities.
- Chapter 7 discusses the future of the FloodCast system, providing recommended next steps to maintain the momentum of this important research.
- Appendix A is the Technical Memorandum produced in Phase I (Task 1).
- Appendix B is the Interim Report produced in Phase I (Task 5).
- Appendix C provides copies of FEMA’s Site Inspection forms suitable for FEMA’s Public Assistant grant process.
- Appendix D includes the SitRep XML schema from FEMA’s IPAWS.
- Appendix E is the NOAA Partnered Guidelines for the Development of Advanced Hydrologic Prediction Service Flood Inundation Mapping.

Chapter 2 CURRENT PRACTICE REVIEW

During the Phase I literature review, the research team reviewed a broad range of materials. A variety of topics were included in the review, such as:

- Roadway sensors and the national MADIS network.
- Advances in the areas of meteorology and climatology.
- Transportation and flood risks.
- DOT emergency management responsibilities.
- The state of the practice for DOTs concerning real-time flood response.

Materials such as academic literature, industry research, and transportation-related publications (e.g. FHWA, AASHTO and NCHRP) were consulted. In addition, information was collected during the FloodCast workshop track at the 2015 TRB Annual Meeting which was organized by the research team. Tools, methods, and data were a central focus of this work. From these efforts, the research team was also able to gain an understanding of the needs of DOTs, other infrastructure owners, and the public, as well as what is possible from a technical standpoint. This research revealed barriers and opportunities to incorporate more data into the FloodCast prototype in light of the many flooding issues for transportation. Real-time DOT concerns during flood conditions are illustrated in Figure 1.

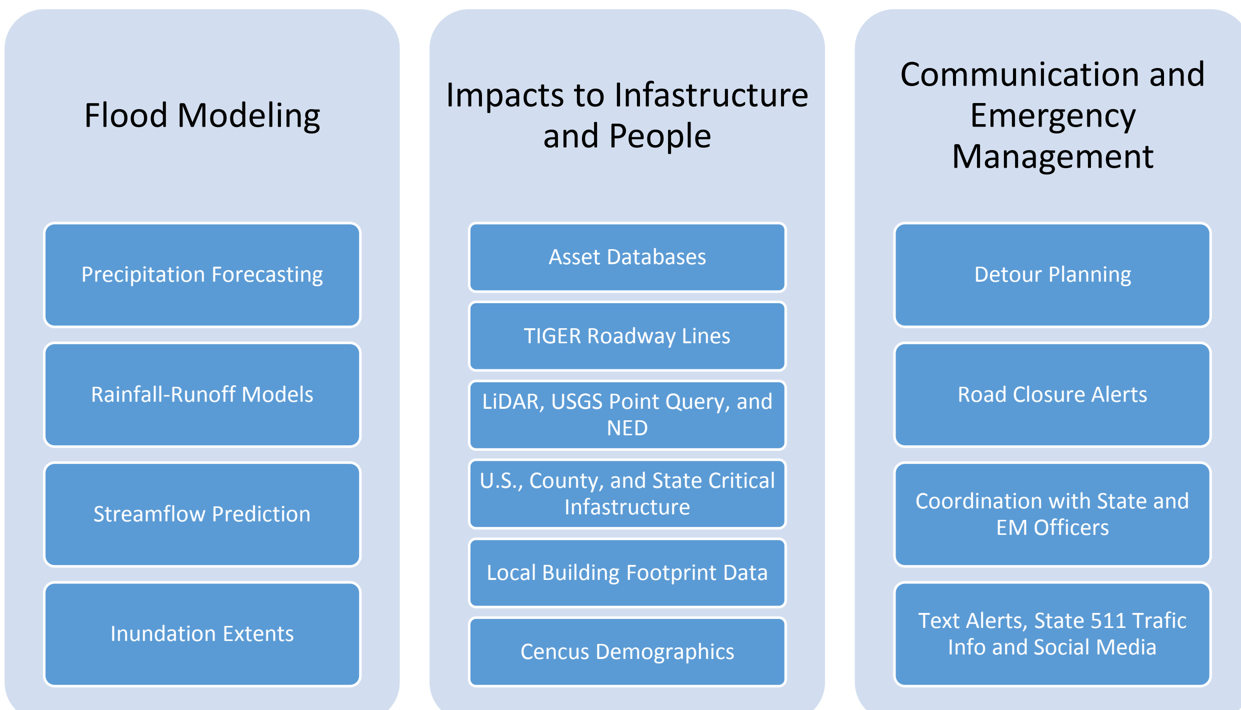


Figure 1: Real-time DOT information needs during flood conditions include flood modeling, impacts to infrastructure and people, and emergency management.

The Technical Memorandum included in Appendix A of this report summarizes the literature review described above, focusing on the idea that timely flood forecasting information can help DOTs before, during and after a flood event. A sorted, graded list of resources identified during the literature review is provided in the Technical Memorandum's Appendix B.

Key lessons learned during the course of the Phase I research included:

- Before an event, DOTs can use forecasts to anticipate staffing and operational needs. Precipitation forecasts with medium resolution and outlooks of approximately one week (e.g. NOAA's Quantitative Precipitation Forecast Maps; approx. 25 km resolution) can be used as a "distant early warning system" for longer-term, day-long or multi-day flood events. Precipitation forecasts with higher resolution and outlooks of 24, 18, 12, and 6 hours (e.g. the national Digital Forecast Database, approx. 5 km resolution) can be used to prepare for flash flood conditions and to revise and update earlier forecasts
- Forecasts can be translated into flood extents using detailed elevation data from local and national sources; this information can supplement DOT's existing GIS-based asset data. During an event, geospatial tools can be used to update flood extents, identify vulnerable populations, mark road closures, plan detours, assess impacts to emergency management and evacuation efforts, and to take note of incidents that will be examined during debriefing. These tools can also be used to communicate with emergency managers and the public through techniques like automatic alerts and integration with state 511 traffic websites, Google Maps, and other platforms.
- After an event, forecasts can be compared to actual impacts, incidents can be reviewed, and damage to infrastructure can be tracked. This information can be used in multiple ways, including improving operations and emergency response during flood conditions as well as mitigation planning.

The Technical Memorandum also makes note of general themes that were considered during the Gap Analysis phase of the project, which in turn drove the refinement of the conceptual model (Figure 2). 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.

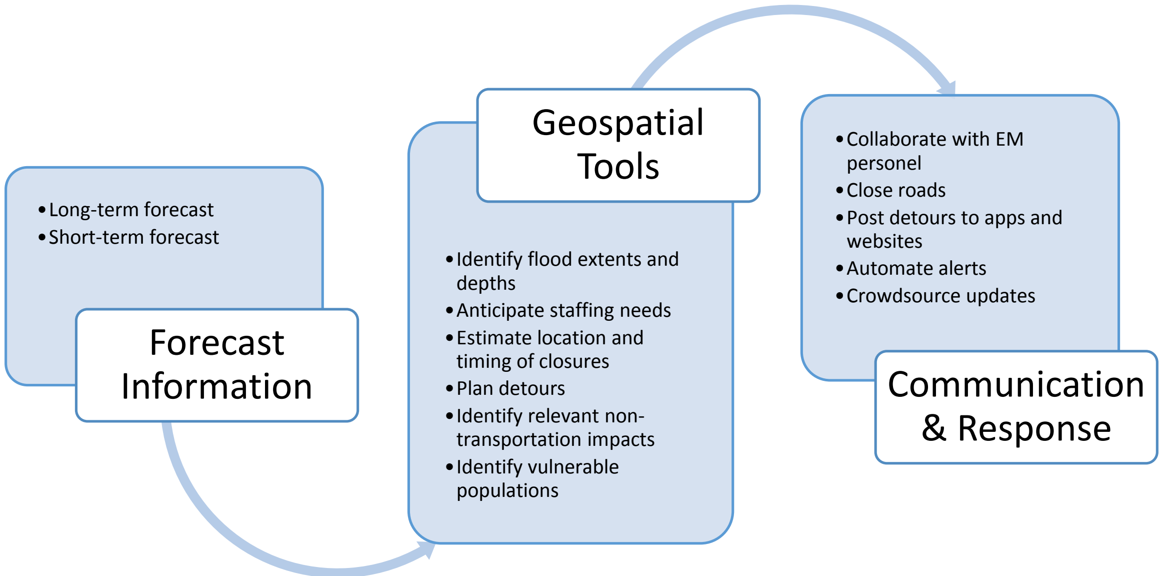


Figure 2: Tool conceptual model. It is possible to couple models for forecasts, flooding, and transportation assets to estimate, plan for, and communicate flood impacts. Given the current state of the science and available data and tools, a template tool can be developed to support many of these functions for most states. The tool could be designed so that records for a flood event could then be saved and used for future flood response or mitigation activities.

From an emergency management perspective, understanding whether there may be impacts to freight routes or designated evacuation routes is important, as is being able to assess impacts to critical infrastructure outside the road network. Infrastructure owners do not typically have tools that answer critical infrastructure inquiries such as the following:

- Will flooding impact access to hospital facilities, fire and rescue, police, etc.?
- Does flooding hinder access to shelters (e.g. stadiums or schools) or emergency management staging areas?
- Are power substations likely to be impacted, and what are the implications for signals, dynamic message boards, communication, etc.?

Finally, one-click or automated communication tools are essential for DOT and infrastructure owners as well as the public. Multi-media integration across the most commonly used platforms including mapping applications is highly desirable: it has become almost axiomatic that every year, some drivers will ignore detour warnings in favor of the route shown on their smartphone. Additionally, crowd-sourcing can provide valuable real-time updates to flood extents, incidents, and other information.

Chapter 3 GAPS AND OPPORTUNITIES FOR FLOODCAST

3.1 Gap Analysis

In the Technical Memorandum, a number of unmet forecasting needs were identified based on DOT interviews, the previously- described literature review of existing resources (e.g. tools, methods, data, and models), and the proceedings of the 2015 Annual Transportation Research Board (TRB) meeting. The reserach team treated identified practitioner needs as collected business requirements and reviewed these gaps in light of current capabilities, potential modifications, and research and development needs.

The Interim Report, included in Appendix B of this report, summarizes the research approach and results of the gap analysis, including a list of high-priority requirements which include:

1. Threat assessment support;
2. Data dissemination to multiple platforms, and;
3. Data interoperability, storage, and archival.

Refer to Table 1 in Appendix B for a list of practitioner needs for each of these high-priority requirements. The research team scored the high-priority requirements according to the following feasiblity categories: *1) currently satisifed and ready-to-use, 2) can be satisfied with minor modification, or 3) will require new approaches.* Many of the high-priority requirements can be readily integrated into a framework to support DOTs in planning for, responsidng to, and operating during floods. The research team developed an architecutre and framework for those ready-to-use and easily modified tools, which is disussed in the following chapter (Chapter 4). Other requirements necessitate modification before being integrated into a Floodcasting framework. At a high-level, the research team identified the following findings to serve as a basis for identifying opportunities for FloodCast to close gaps:

- Standardized national data sources exist for flood forecasting, but should be supplemented by high resolution, local products.
- Significant gaps often exist for forecasing riverine flood extents and depths as well as GIS-transportation assets.
- Data frameworks should emphasize stable, web-based, standards-based storage and exploration of data.
- Major improvements in riverine (NWM) and coastal storm surge inundation products are possible.

There are current research advances taking place to address some of the above high-priority research needs, such as NWM forecast-based discharge estimates for streams. Together, Phase II products (Chapter 5 and 6) and subsequent research will incorporate effective information into a single framework to support transportation flood casting needs. The framework and architecture developed in Chapter 5 was built to anticipate updates from both the NWM and local datasets.

Chapter 4 FLOODCAST PROTOTYPE SYSTEM DEVELOPMENT

This chapter describes both the process used to develop the proof-of-concept system for a FloodCast program and the work products of the effort.

4.1 FloodCast System Development Options

The literature review, gap analysis, and practitioner input gathered by the research team were the basis for developing work plan options that could be accomplished in Phase II of the project. The research team presented four options outlined in the following table for further development of the FloodCast program to the Study Panel on October 1, 2015.

FloodCast System Development Options	Description of Development Option
A	Develop specifications, data standards and format for the key data components of FloodCast.
B	Undertake detailed requirements analysis for FloodCast, based on a maturity model for DOT capabilities.
C*	Prototype for particular location (sub-state level) with coastal and riverine exposure.
D	Requirements analysis plus specifications for select components of item A.

These options were developed by the team to address key needs for FloodCast program development while aligning withthe remaining resources available for the project. Ultimately, the Study Panel chose the prototype option "C*" – developing a protoype for a particular location with coastal and riverine exposure. The prototype simulates a recent flood event responsible for numerous transportation impacts. San Diego County, south of Los Angeles, was chosen as a case study location for the FloodCast prototype. Data availability, dense population and heavy precipitation over land subject to recent drought conditions made the area a good candidate for demonstratring the usefuleness of the FloodCast tool. Subsequently, the research team developed the proof-of-concept system to demonstrate the framework, which will be discussed in the following section.

4.2 FloodCast System Framework and Architecture

The research team developed a recommended framework and architecture to organize tools, methods, and data for practitioner use identified in the preceding tasks. Appendix B of this report provides an overview of the system and components for the FloodCast prototype, including the functional goals, functional requirements, system limitations, safety constraints, and major assumptions.

Interoperability: the extent to which systems can communicate, exchange data, and use that shared data.

Interoperability was a fundamental consideration in this project and was the organizing principle in the FloodCast prototype development to meet the high-priority requirements identified in Chapter 3: threat assessment support; data dissemination to multiple platforms, and; data interoperability, storage, and archive. To achieve the first objective, threat assessment support, the research team's developers selected from the tools graded A and B in the Technical Memorandum's Appendix B Resources List, with preference for those available through stable web mapping services. To do so, the study team developed a stable, standards-based geospatial framework to consume the information necessary to produce a threat assessment and to disseminate the results of that analysis to other platforms and audiences (objective 2). The third objective, data storage and archival, required design of a geodatabase, which also supports the other two objectives. These development tasks are illustrated in Figure 3.

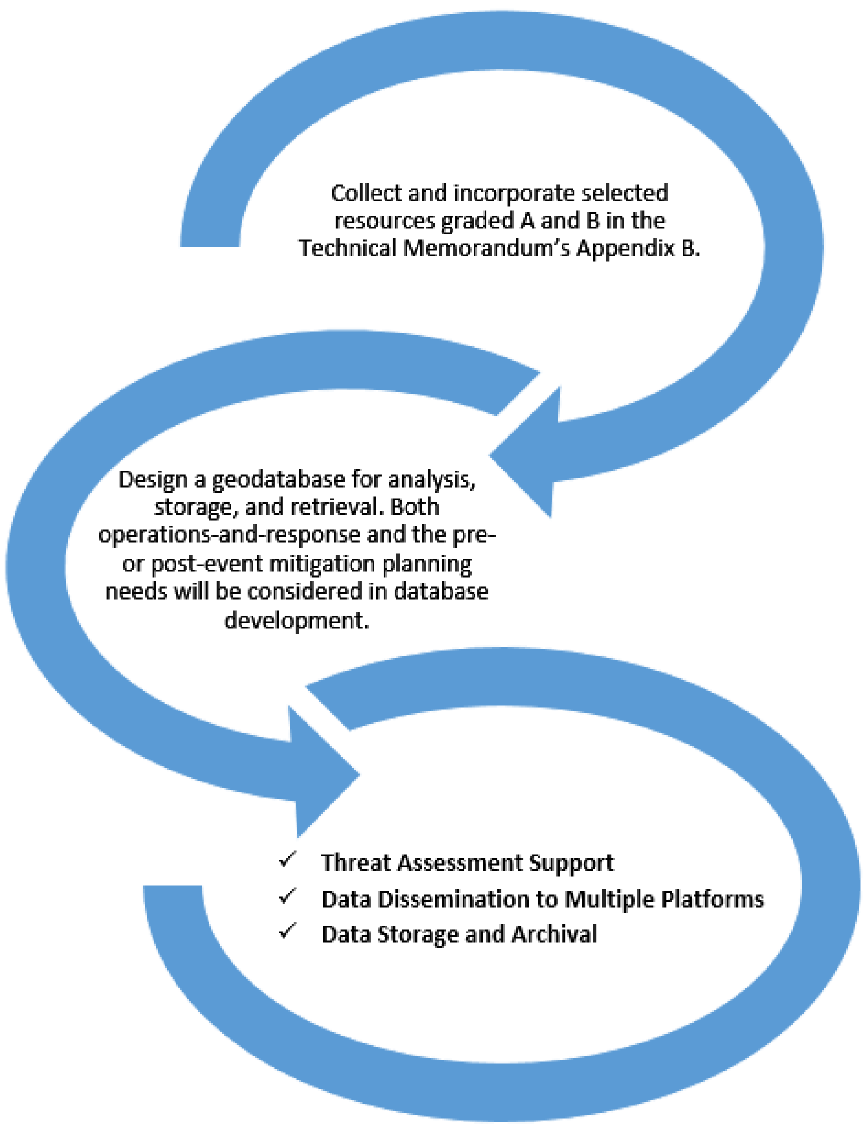


Figure 3: Illustration representing the workflow of the development tasks implemented to achieve the three high-priority requirements.

4.3 FloodCast Prototype Technical Framework

The research team's overall goal for the FloodCast system was to develop a web-based platform with ingestion, dissemination, and storage capabilities that incorporates existing data to support flood response and mitigation activities and real-time geospatial analysis capacities. The development team used OpenLayers version 2.13, Leaflet version 0.7, and other JavaScript libraries to develop the prototype graphical user interface (GUI) for the web application. Table 1 provides descriptions and links to this software.

Table 1: Software used to create the FloodCast prototype web-based platform.

JavaScript Libraries	Description	Link(s) to Software
OpenLayers 2.13	Architecture mapping framework for basemaps and geoprocessing tools for visualization and analysis	• http://openlayers.org/two/
Leaflet version 0.7		• http://leafletjs.com/index.html
jQuery 2.1.4	Extends JavaScript functionality	• https://jquery.com/
D3.js v.3	A powerful library for making custom data visualizations	• https://d3js.org/
Bootstrap 4.6.1	Layout template	• http://getbootstrap.com/
Ext JS 3.2.1	JavaScript application framework	• http://docs.sencha.com/extjs/3.4.0/

Chapter 5 FLOODCAST PROTOTYPE SYSTEM FUNCTIONALITIES

The FloodCast prototype demonstrates the value of high quality forecast data coupled with dissemination tools to support effective operational and emergency response by transportation practitioners. By showing forecast data, predicted floodplains, and estimates of affected transportation assets, decision-makers can receive timely intelligence with which to respond to forecasted or ongoing flood events. Incident tracking and summary tools provide streamlined workflows during both the response and recovery phases of the event. Rapid synthesis of flood event analytics also facilitate post-disaster grant applications or hazard mitigation. While riverine flooding is highlighted in this example, both coastal and riverine flooding can be considered, making FloodCast flexible enough to be used nationwide. While still in prototype mode, the support FloodCast can provide for planning, operations, response and recovery has the potential to significantly reduce disruptions and increase system resilience during demanding flood response scenarios.

This chapter highlights the present system functionalities of the prototype tool, illustrated using examples of the technology currently being employed. This chapter is organized as a tour of the FloodCast prototype system, first introducing the Login and Register page and user roles, followed by a demonstration of the capabilities of each of the following modules incorporated into the system.

- Forecasting
- Flood Extents & Stage-Discharge Predictions
- Emergency Management and Operations (EM & Ops)
- Incident Reporting and Damage Estimates
- Communication

This chapter also describes the suite of products that were considered for each module, the products that were actually incorporated into the FloodCast prototype system, and the research team's vision of what products would need to be incorporated to build a maximally useful, fully realized FloodCast program. It should be noted that some of the resources incorporated into the FloodCast prototype are "real" (i.e. ready-to-use) while other products were simulated and serve as placeholders until anticipated forecasting or other data products become available.

5.1 Login and Register

The Registration page prompts new users to create a username and password, provide a phone number or e-mail address for receiving automated alerts, and specify a geographic area and associated zip codes of interest (Figure 4). Existing users can use the Login page to provide login credentials (Figure 5). If a valid username and login is provided, then the user is directed to the appropriate next page based on their user role. If an invalid username or password is provided, the user is notified and prompted to try again. The system will only allow the user to access or modify information according to their user role.

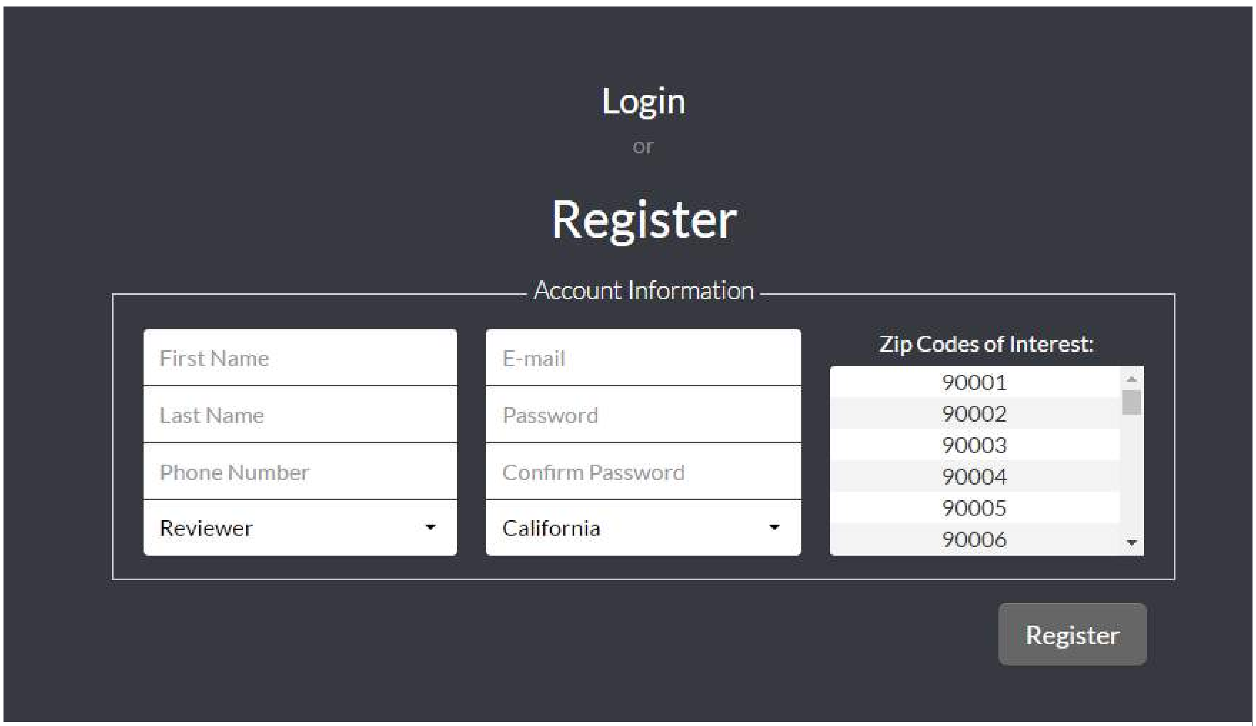
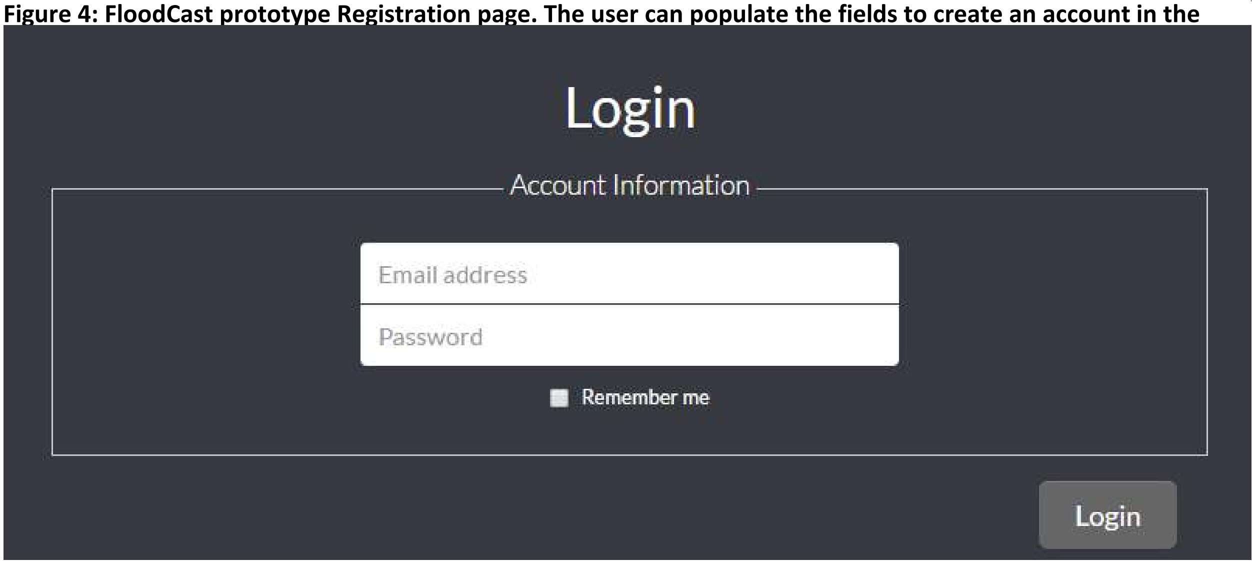


Figure 4: FloodCast prototype Registration page. The user can populate the fields to create an account in the



The research team defined user categories for the prototype tool (i.e. subscribers, reviewers, and administrators). Users of the system will experience different system functionalities:

Table 2: FloodCast prototype user categories and system functionalities.

User Role	Capabilities
Subscribers	Can choose to subscribe to receive flood warnings to user-specified devices (via email and/or SMS messaging); can also opt to unsubscribe.
Reviewers	Can view FloodCast through a web-based graphical user interface (GUI) and have the option to view everything in the subscriber role.
Administrators	Are able to add, modify, delete, and close out flood events, incidents, and damages to assets, print forms, and export to other applications; also have the option to view everything in the reviewer role.

5.2 Forecasting

This section describes forecasting products explored during prototype development, data incorporated into the FloodCast prototype, and a vision of what the forecasting module would include in a fully mature FloodCast tool.

As mentioned in Section 4.1, the research team developers used the San Diego County area as a case study for the prototype tool due to data availability and dense population. A number of factors made the January 2016 event a good candidate for the FloodCast prototype. First, during January 2016, San Diego accumulated 2+ inches of rainfall over two days over a large area of urban southern California--a relatively high amount of rainfall for the region. Second, the San Jacinto Mountains received over 25 inches of snowfall, which led to a significant quantity of forceful runoff. Lastly, as California has experienced one of the most severe long-term droughts on record, there was interest from the community to see how the dry ground would respond to the forecasted precipitation event.

Precipitation Forecasting Products

During Phase I of this project, the research team explored a number of existing resources (e.g. data, tools, and methods) for supporting the forecasting functionality of the FloodCast prototype. A full list of these resources, and their associated resource grades, are included in the Technical Memorandum's Appendix B Resource List (Table B1). These resources included a variety of hydrologic and meteorologic forecasting products such as flash flooding forecasts, precipitation forecasts, and storm surge forecasts.

To implement the prototype, the research team chose to focus the forecast module on precipitation forecasting. Before an event, DOTs can refer to depth estimates for expected rainfall as indicators of road passability. Visualizations for forecasted rainfall will also help DOTs estimate the location and timing of road closures and plan strategic detours. Additionally, this information can be used to anticipate staffing and operational needs.

From the suite of precipitation forecasting products available, the prototype developers incorporated NOAA's Quantitative Precipitation Forecasts (QPF) maps because this dataset can be used as a "distant early warning system" for day-long or multi-day flood events. Additionally, QPF have improved significantly over the past decade due to increased resolution in weather models, better incorporation of initial conditions as well as general improvement in our understanding of processes that produce rainfall.

The FloodCast prototype web application provides administrators and reviewers with system-generated visualizations of predicted extent and depth of rainfall in 2-hour time increments through the course of the precipitation event. By viewing precipitation forecast data and estimates of affected transportation assets, decision-makers are able to receive timely intelligence with which to respond to forecasted or ongoing flood events.

Figure 6 illustrates an event that began at 11:22 AM on Thursday, June 16, showing predicted hourly maximum precipitation 14 hours after the event began. Figure 7 illustrates a zoomed-in view of the same event at 12:38 PM on June 16, showing the predicted extent and depth of flooding 24 hours after the event originated.

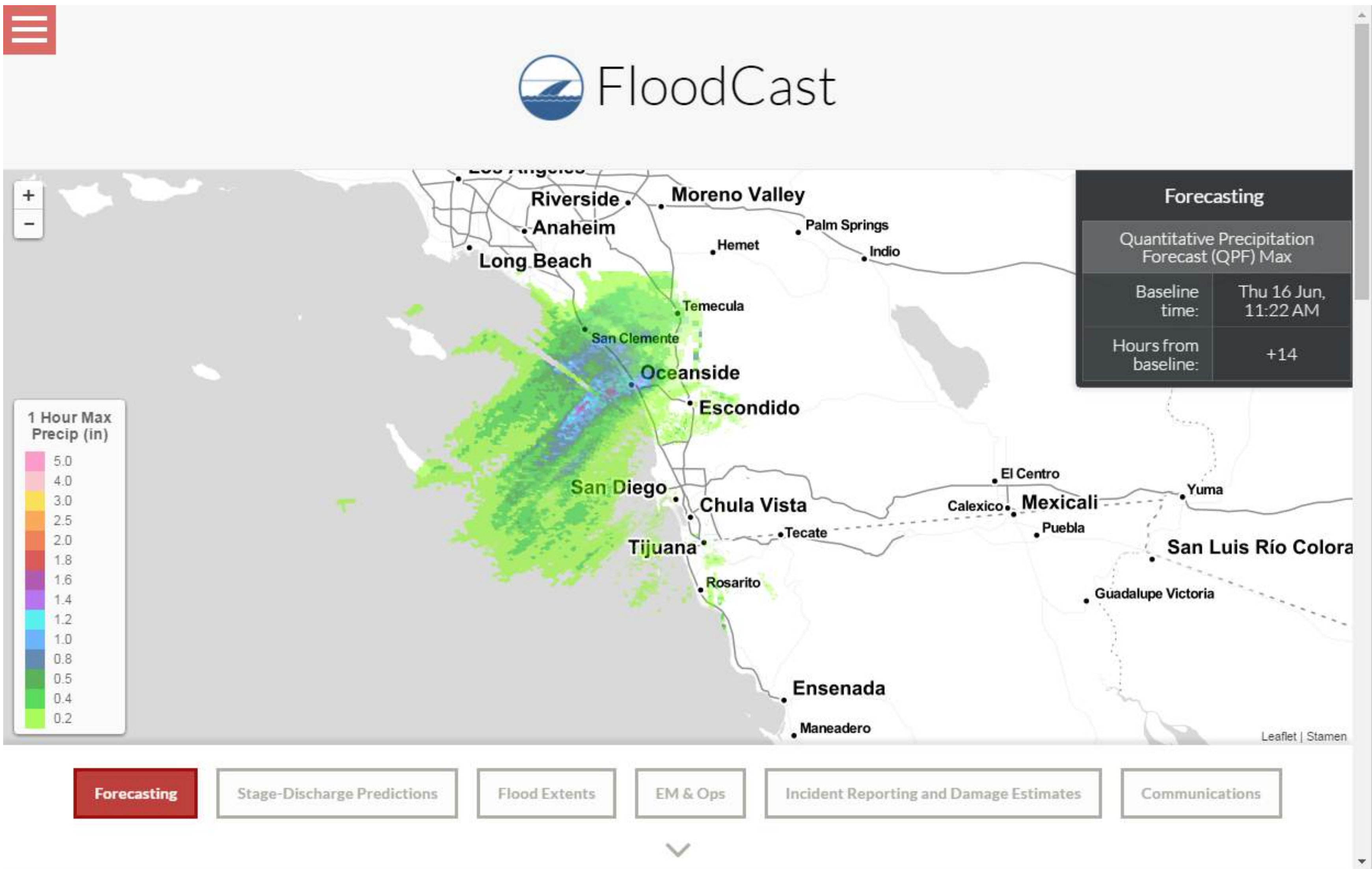


Figure 6: Example of a zoomed-out view of the FloodCast prototype's precipitation forecasting module. This module provides system-generated visualizations of predicted extent and depth of rainfall (in inches) over hourly time steps from the beginning of a precipitation event.

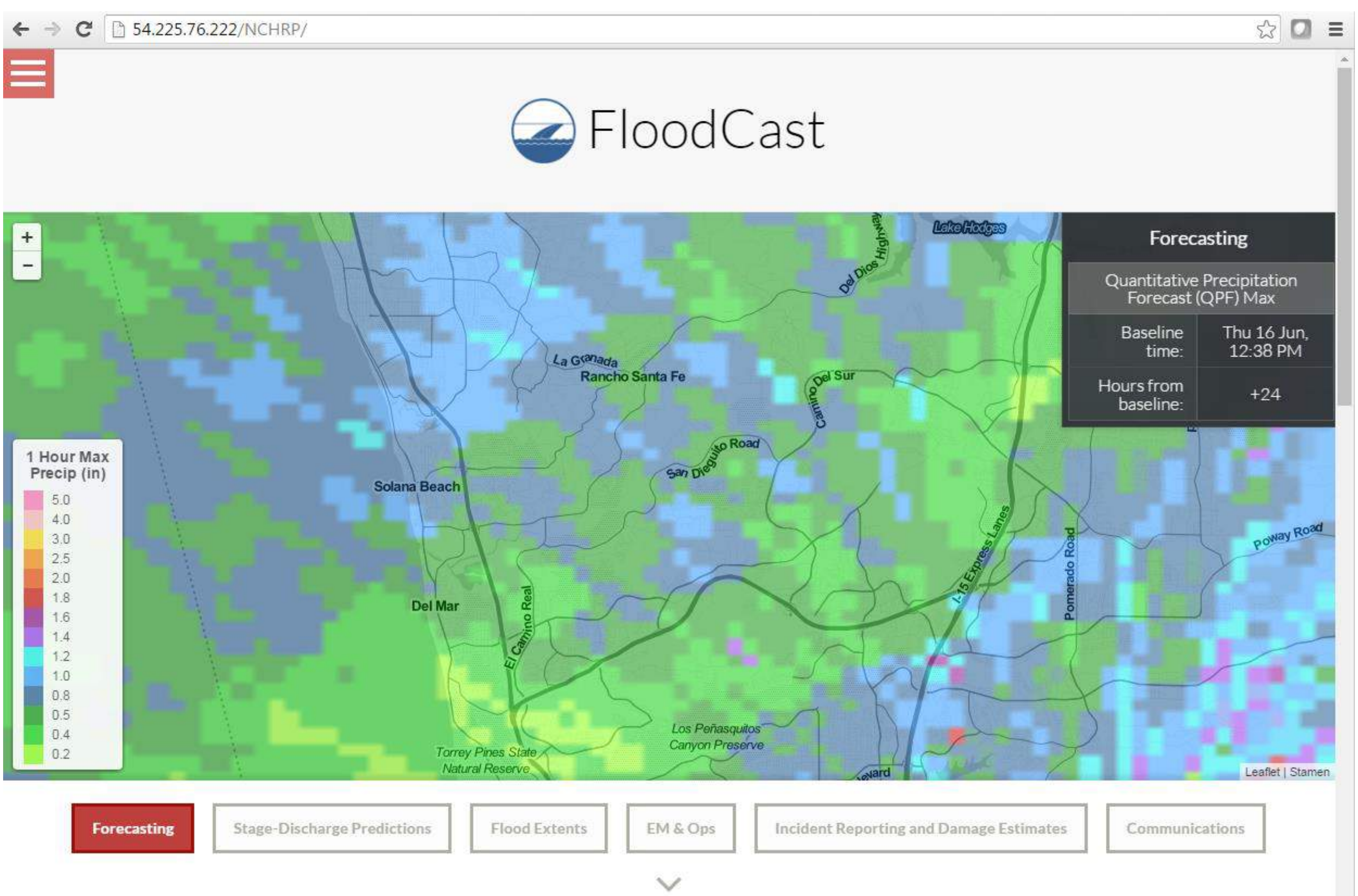


Figure 7: Example of a zoomed-in view of the FloodCast prototype's precipitation forecasting module. This module provides system-generated visualizations of predicted hourly maximum rainfall (in inches) over hourly increments from the beginning of a precipitation event.

Precipitation Forecasting: Vision for a Mature FloodCast Tool

For the prototype, the study team used currently available QPF products, but subsequent versions may benefit from the incorporation of new or emerging datasets with higher flood prediction accuracy. While QPF have improved significantly over the past decade, the majority of the improvement has occurred for light to moderate rainfall events, with smaller benefits seen for heavier events that cause the majority of floods. Furthermore, because floods are localized events, conventional “deterministic” QPF guidance has shortcomings. Deterministic guidance refers to one realization of QPF that is typically processed to show the “most likely” outcome. In reality, even the most likely outcome for a very rare event has high uncertainty even for short lead times. For example, Figure 8 shows that with a relatively short lead-time of about 21 hours, a “High” confidence equates to only about a 15% chance that a given locale within the High confidence area will experience flooding.

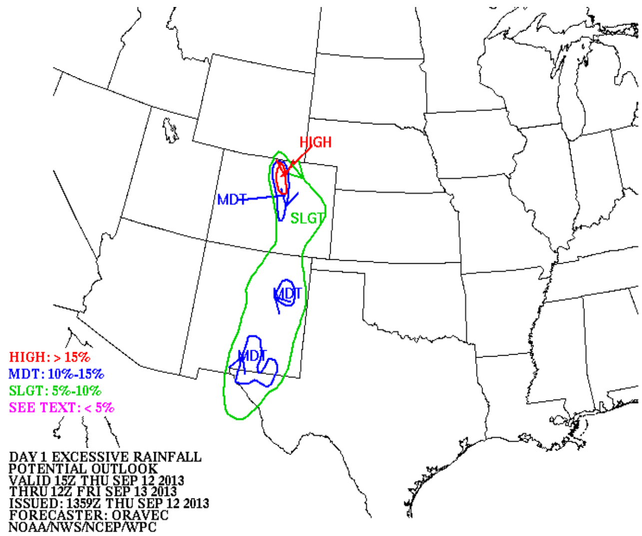


Figure 8: Day 1 Excessive Rainfall Potential Outlook from the Weather Prediction Center for the severe 2013 flooding event in north-central Colorado. (Source: Weather Prediction Center)

Probabilistic QPF (PQPF) can alleviate some of the above-mentioned challenges. The key power of PQPF lies in its ability to leverage the combination of equally realistic output from an ensemble of high-resolution weather models. This is especially useful for the 12-48 hour lead time range, at which high-resolution modeling (<= 4km) is computationally tangible and provides substantially added realism compared to the medium resolution (12 – 20km) modeling that is typically used for 3-7 day forecasts. The main benefit is a reduction in the miss rate of flooding events, particularly those that last longer than 1 hour. Furthermore, post-processing of raw PQPF guidance using historical-based bias correction can significantly boost the forecast reliability.

In summary, the research team envisions including PQPF in a mature FloodCast system, however these products are not yet available for consumption. One major barrier is that a stable dissemination portal for these products does not yet exist. Furthermore, there is still a need to develop protocols for how the information should be processed and disseminated so that it can be consumed in the most useful and meaningful way to inform enhanced flood event decision making.

5.3 Flood Extent Predictions & Stage-Discharge

This section describes flood forecasting products explored during prototype development, data incorporated into the FloodCast prototype, a vision of what the forecast-based flood extents module would include in a fully mature FloodCast tool.

Flood Forecasting Products

The research team explored a number of resources available for forecast-based riverine flood extents. Currently, the most comprehensive national geodatabase of flood inundation extents is the National Flood Insurance Program's (NFIP) National Flood Hazard Layer (NFHL). However, the NFHL shows inundation extents only for the low recurrence interval events with regulatory significance for the NFIP, mainly for the 100-year (1% annual chance) and 500-year (0.2% annual chance) events. Higher-frequency events that result in flooding are not represented in this dataset. Significant flooding can be caused by 50-, 25-, and even 10-year or more frequent events. Extents and depth grids for all NWS-defined flood stages are available at some locations through the Advanced Hydrologic Prediction Service (AHPS). Inundation maps are also available through the USGS Flood Inundation Mapping Program. Currently, however, the model development or calibration and flood mapping required to produce similar products for an entire state would be resource-intensive even with automation tools, because of gaps in coverage in the form of ungauged locations. As discussed in the Technical Memorandum, the Iowa Flood Information System is a model for how this can be done, but most states do not have statewide products at this time. Existing or evolving national-level datasets which will improve the coverage of flood mapping, such as ongoing NWM efforts as well as currently available national sources of flood inundation extents, are listed in Table 3.

Table 3: Sources of inundation extents explored for the flood forecasting module.

Inundation Extent Sources	Shows Inundation for	Coverage
NWS Advanced Hydrologic Prediction Service	NWS Flood Stages	Continental United States (CONUS) (partial coverage; ongoing)
FEMA National Flood Hazard Layer	100-year and 500-year event	National (partial coverage; ongoing)
National Water Model	Intended: Flood Stage Categories	CONUS (expected, 2016)

Data Incorporated

The research team evaluated Advanced Hydrologic Prediction Service (AHPS) and USGS Flood Inundation Mapping data for the development and use of flood hazard information in the FloodCast prototype. For the time being, the AHPS Open Geospatial Consortium (OGC) Web Services format is the most accessible national source for inundation and depth grid estimates for various flood stages. The AHPS is also currently useful because of its fluency within the emergency management context; many practitioners, both emergency managers and transportation practitioners are already familiar with the NWS flood stage categories and may use this information to make decisions about road passability and flood response activities.

For the FloodCast prototype, the tool developers incorporated AHPS data in addition to using FEMA's National Flood Hazard Layer (NHFL) as a secondary source of flood extent estimates to capture both low-recurrence events as well as more frequent events. To do so, the research team used the NFHL 100-year floodplain layer and USGS center streamline data to approximate flood stages, using aerial photographs for guidance and validation. As an example, the prototype demonstrates the results of this process using a stream gauge located at Chollas Creek in San Diego. An illustration of the forecast-based riverine flood extents for this particular gauge is provided in Figure 9. Figure 10 depicts the flood stage severity categories on the stage-discharge prediction graphic for the same gauge. The prototype will provide alerts to FloodCast users when the NWS AHPS action stage conditions are met or exceeded.

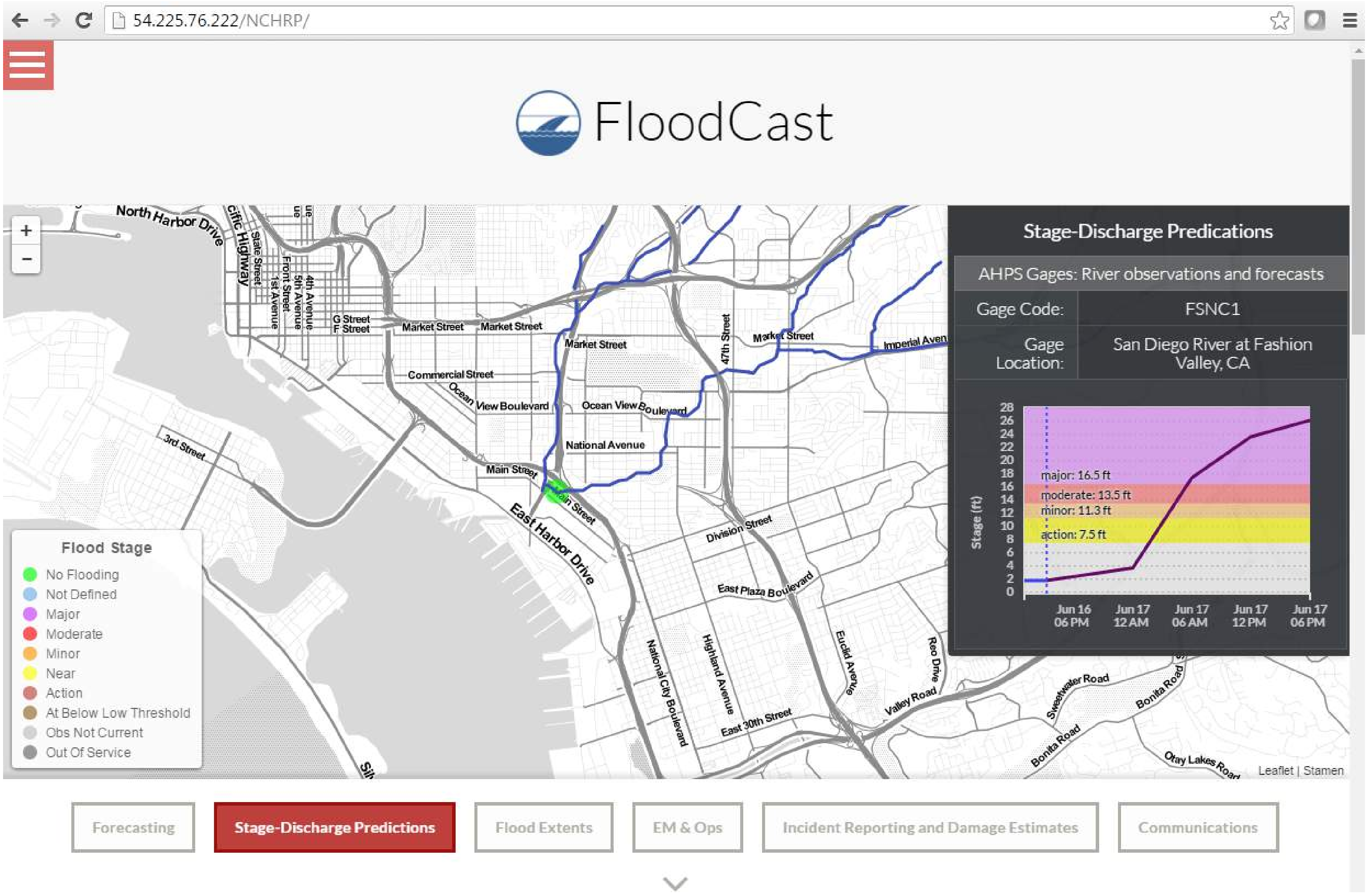


Figure 9: The Stage-Discharge predictions module showing the stage-discharge prediction curve for the Chollas Creek AHPS Gage.

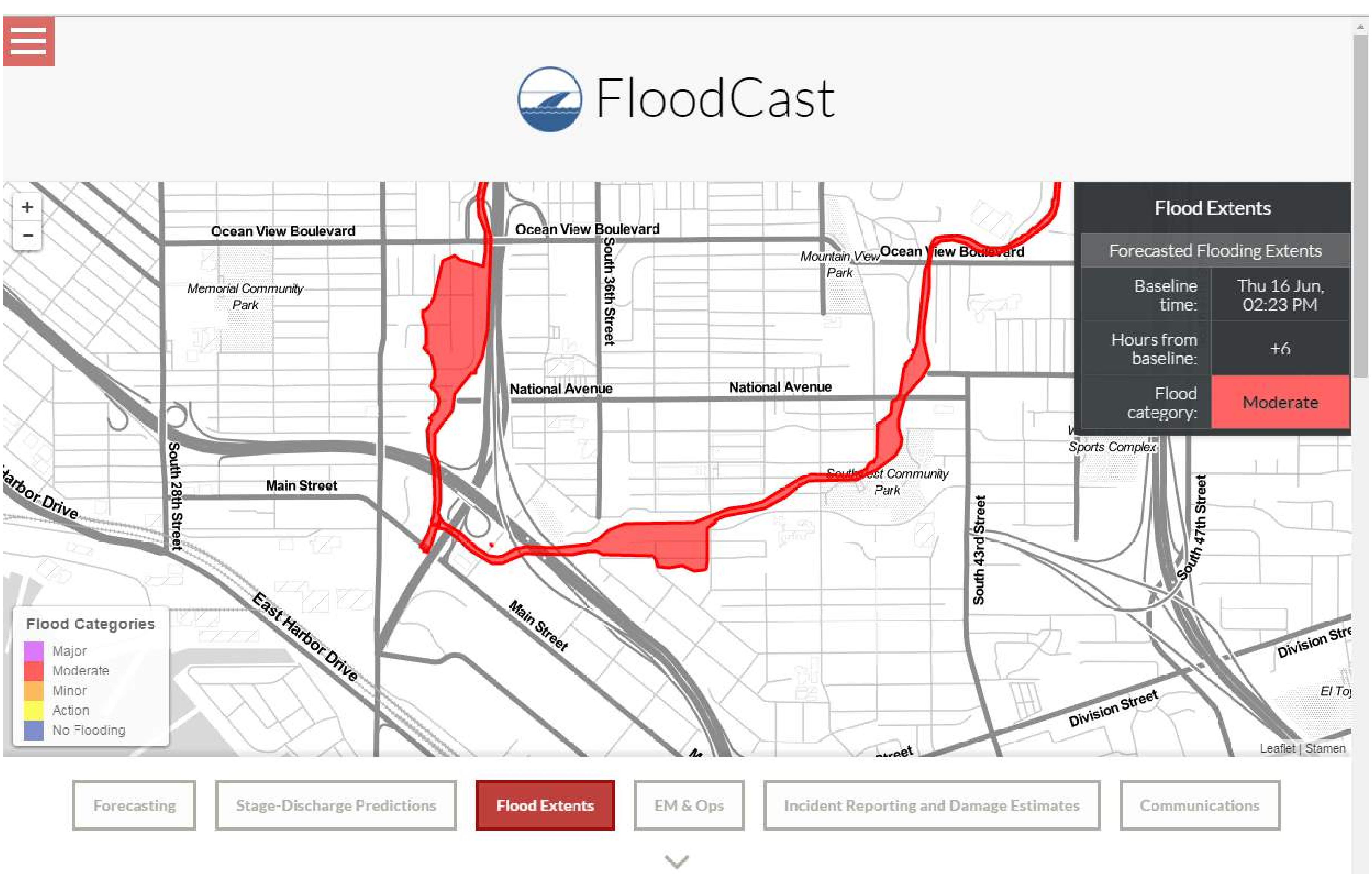


Figure 10: Forecast-based riverine flood extent for the Chollas Creek AHPS Gage. The tool predicts the flood severity category as “Moderate” after 6 hours from the baseline event.

Stage-Discharge Predictions: Vision for a Mature FloodCast Tool

While NWS AHPS is currently the best national source for inundation and depth grid estimates, it has spatial coverage limitations in terms of ungauged locations and currently does not include a future precipitation component. The National Water Model provNFIE participants are currently working on a standardized, national source of forecast-based stream discharge dataset that will be integrated into NWS AHPS within the next year. The research products will include forecast-based discharge estimates for all NHD stream segments by using USGS rating curves, resolving some of the issues with ungauged streams. Once widely available, these models will ease the burden of translating precipitation forecast into stream discharge, but for now, a stable dissemination portal for these products does not yet exist. The research team built the prototype system to ingest NFIE products once they become available.

5.4 Emergency Management and Emergency Transportation Operations

During threats or in response to actual or potential incidents, transportation agencies play a critical emergency management function. For example, transportation is classified as FEMA's Emergency Support Function (ESF) #1 because the ability to move emergency relief personnel and commodities, mitigate adverse economic impacts, and sustain transportation services depends on transportation system resilience during emergency situations. Transportation agencies play a coordinating role among public and private sector transportation stakeholders during flood events because of their ability to support prevention, preparedness, response, recovery, and mitigation activities.

The EM & Ops module of the FloodCast prototype displays the forecast-based riverine flood extents overlaid on critical transportation assets (Figure 11). For prototype purposes, only bridges are included in the display. In 2-hour increments from the baseline flood event, the system shows how the status of assets change as the flood event develops. For example, assets turn yellow to indicate that they are close to the flood extent and should be monitored, and assets turn red to indicate that they are located within the flood extent and are under threat of being damaged or destroyed. The EM & Ops view provides a wider lens of the status of all assets and incidents associated with a flood event, and allows emergency managers to organize and prioritize dispatch activities. For example, emergency managers may use this tool to identify closures and temporary detours needed when transportation assets are damaged, unavailable, or overwhelmed, as well as ranking and prioritizing repair and debris clearing activities for field crews.

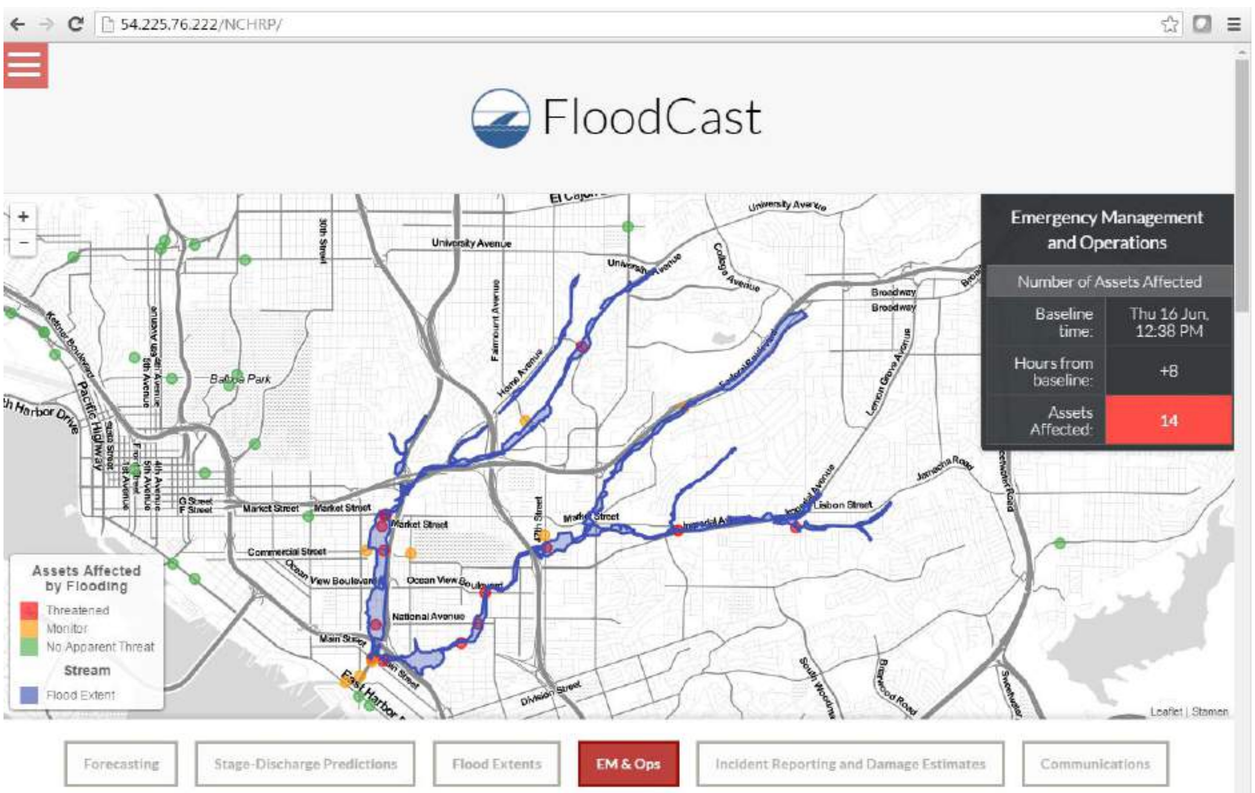


Figure 11: The Emergency Management and Operations module showing the number of assets forecasted to be affected 8 hours after a flood event that began at 12:38 on Thursday June 16.

5.5 Incident Reporting & Damage Estimates

Incident tracking and summary tools provide streamlined workflows, centralized tracking, and rapid synthesis of flood event analytics to facilitate both active flood event response as well as assist with post-disaster recovery and reimbursement activities. This section describes incident reporting and damage estimate products explored during prototype development, resources incorporated into the FloodCast prototype, and a vision of what the incident reporting and damage estimate module would include in a fully mature FloodCast tool.

Incident Reporting & Damage Estimate Resources

The research team explored a number of options to improve information exchange between disparate emergency response systems, especially as it relates to DOT's ability to participate in seamless information-sharing prior to, during, and in recovery from flood events. This tool uses FEMA's Emergency Data Exchange Language (EDXL) Standards Situation Reporting (SitReps), a standardized list of emergency management terminology and definitions made available in the cross-platform and easily accessible XML format.

Flood events in the tool can be either system-generated or user-generated, as administrator-level users have the capability to draw new events, view or modify existing events, or simulate events using the underlying models in the tool. In a fully mature FloodCast, system generated events will be created in response to precipitation events that cross a defined intensity and duration threshold. User-generated

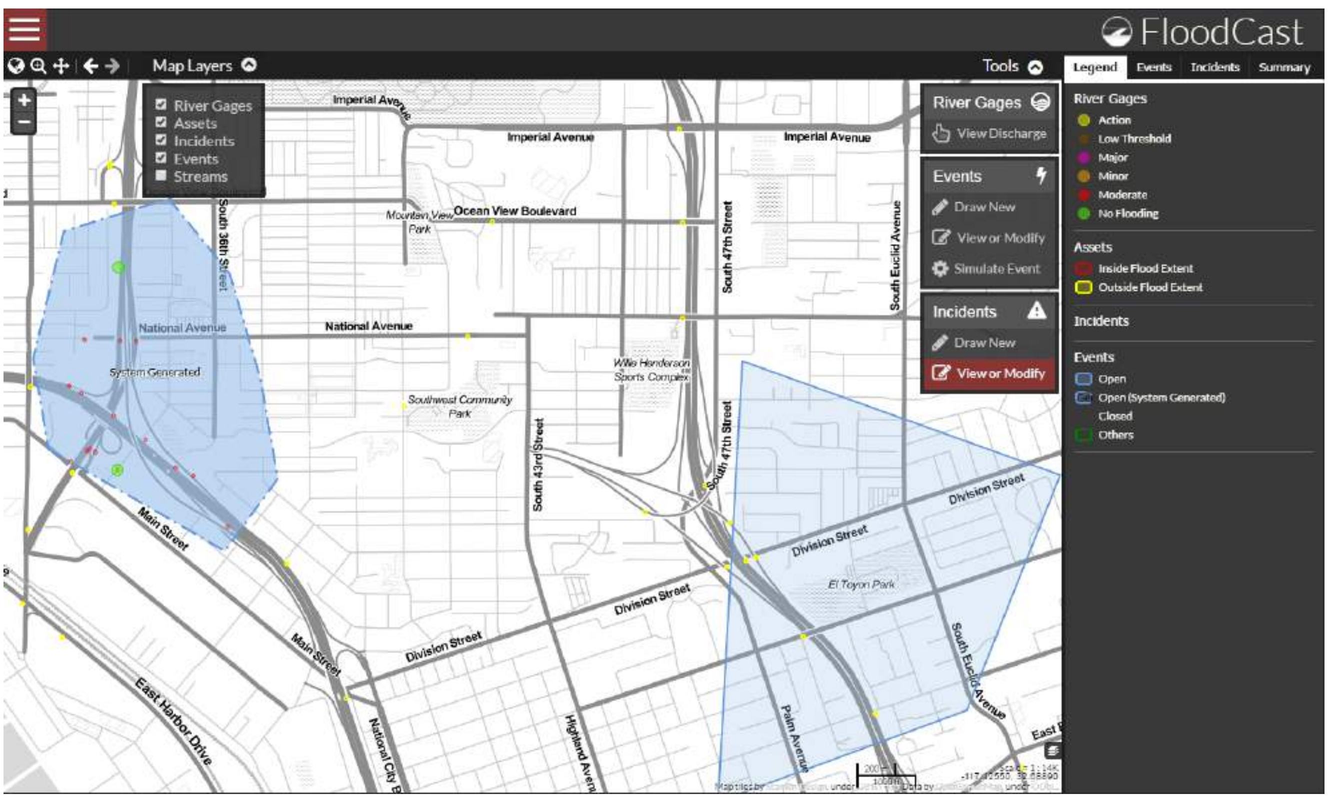


Figure 13: Administrator view of the Incident Reporting and Damage Estimate feature of the FloodCast prototype. Administrators have the capability of modifying existing events or simulating new flood events. Additionally, Administrators can modify or create new incidents and associate incidents with particular flood events.

events will be associated with signal that Events are classified as either open, open (system-generated), or closed. Figure 13 shows an example of a system-generated event on the left and an user-generated event to the right.

Flood events can affect one or many assets, and are typically comprised of families of incidents, especially when a flood event encompasses a large geographic area. For example, if there is a flood event that results in an interference with routes to hospitals, a bridge, culvert, and multiple roads might be affected. Figure 14 lists the incident types used in the FloodCast tool.

Incident Types

- ✓ Emergency management activity
- ✓ Vehicle crash
- ✓ Road closure
- ✓ Interference with evacuation point or route
- ✓ Interference with routes to critical infrastructure (e.g. hospitals)
- ✓ Partial damage to a transportation asset (including debris)
- ✓ Destroyed or incapacitated transportation asset
- ✓ Repairs that require traffic diversions
- ✓ Unspecified incidents

Figure 24: Incident Types used in the tool.

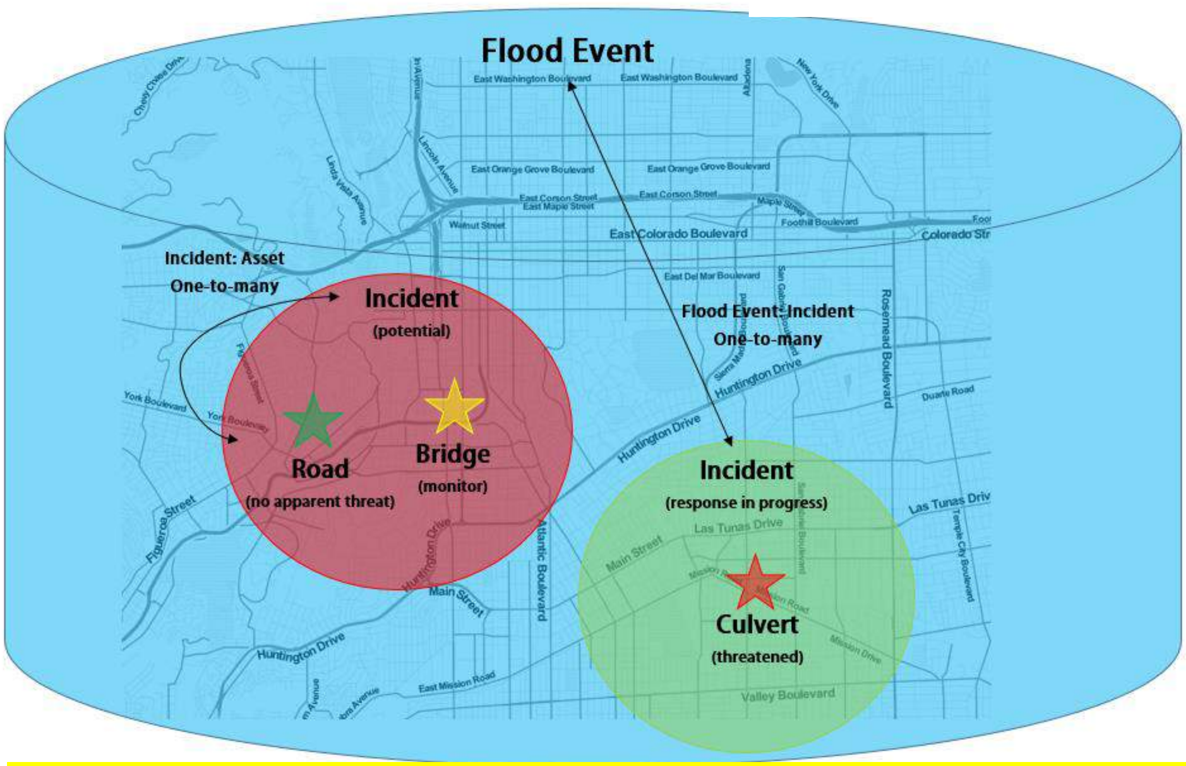


Figure 14: Schematic depiction of the relationship between flood events, incidents, and assets. The road, bridge and culvert are assets. Incidents comprise one or more assets. Flood events may contain records for one or more incidents, especially if the flood event spans a large geographic area.. I don't think this depiction is conveying the relationship between flood events, incidents and assets. Are the stars assets? Tried to clarify.

For system-generated and user-generated events, the system flags all assets that are located within the geographic area of the flood extent polygon and automatically classifies these assets as "Threatened" or "Monitor" depending on proximity to the floodplain. Once field crews arrive at the incident, they can conduct a reconnaisance of the affected assets and gather this information in the "Incident Report". The Incident Report allows the user to submit information about the incident, including the incident type, damage estimates, as well as the functionality of the asset. Functionality includes vehicle passability, which refines the NWS-defined flood categories for use in the transportation and response context. Passability categories are based on depth and typical vehicle profiles and include: 1) impassable, 2) passage of most large emergency vehicles, 2) cars/light EM vehicles might become displaced, 3) difficult for pedestrian, 4) shallow flooding, or 5) passable.

Once all relevant fields of the Indicent Report are completed, field crew members can either use a tablet interface to select "Confirm Incident" and add other dynamic updates of flood-related incidents, or field personnel can communicate internally to DOT decision makers to make updates. This information is also intended for sharing externally to coordinating stakeholders such as emergency managers. The study team acknowledges that the information needs of emergency managers may be somewhat different than those of transportation agencies, and in an effort to improve interoperability between DOTs and emergency managers, the research team integrated the relevant fields from FEMA's SitRep XML into the Incident Report. This feature enables users to adhere to FEMA reporting requirements by providing users with dropdown menus to select from FEMA standardized categories of incident information, such as "Incident Type", "Incident Status", and "Incident Date". The Incident Reporting section of the tool allows field crews to deliver status updates to decision makers during flood events, providing an understanding of the current situation, the operational picture, and current response activities and resources available to attend to the incident.

Workflow support during the recovery period is also important and includes different information than that needed for response activities. Information such as asset type, damaged elements, and damage estimates becomes essential for work planning as well as the reimbursement process, which may cover both emergency and permanent repairs. In the prototype tool, the study team developed a damage estimate feature, where field crews can submit a damage estimate form that specifies the major component of the asset that was damaged as well as a user-defined Total Estimated Damage ($). For example, if a flood event flags the Main Street bridge as "Threatened", dispatched field crews can assess the bridge and estimate that the total damage is $1,000,000 because the substructure, deck, and approaches were significantly impacted (Figure 15). These damage estimate forms facilitate flood event recovery and reimbursement because these form fields were adapted from the FEMA Public Assistance grant process and are also compatible with the information needs of the more commonly used FHWA Emergency Relief Program.

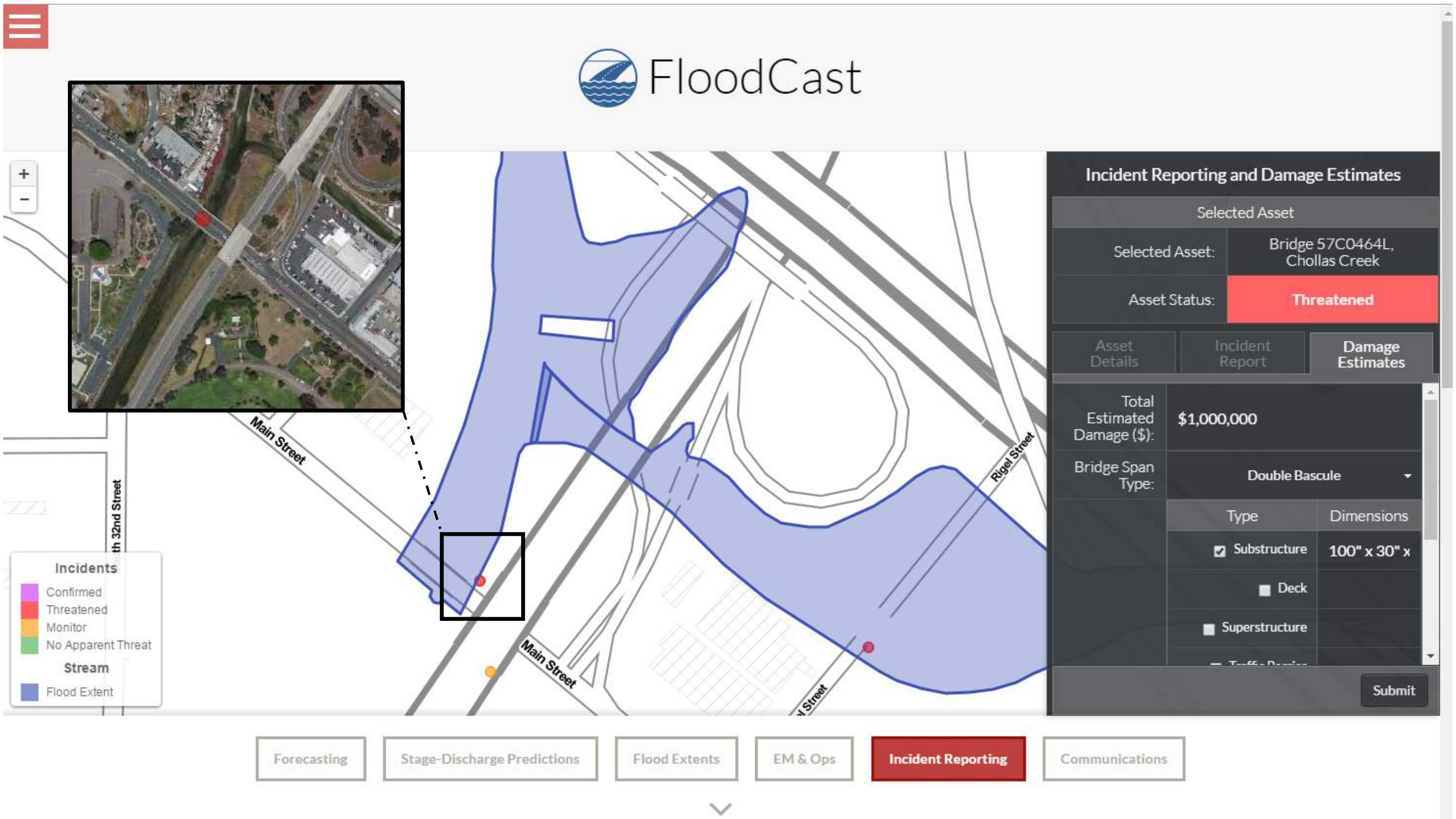


Figure 15: The Incident Reporting and Damage Estimate feature of the FloodCast prototype. This module shows users the status of incidents, and allows reviewers and administrators to confirm incidents after adding information to the incident report, as well as submit damage estimate forms that will facilitate the recovery and reimbursement process.

Incident Reporting and Damage Estimates: Vision for a Mature FloodCast Tool

For the full version of FloodCast, the research team envisions an enhanced exchange functionality. Key audiences are emergency managers and the public. For example, the SitRep XML feed could be provided to emergency managers to improve seamless incorporation of FloodCast-generated incident reports into emergency response systems. The information captured in FloodCast can also be used to develop a feed adhering to Waze's Closure and Incident Feed Specifications. In order to refine and expand the list of potential audiences for FloodCast information, the research team also plans on performing a more in-depth requirements analysis to understand additional reporting standards that would support emergency response and recovery.

5.6 Communication

The communication component is a key functionality of the FloodCast prototype, providing a means to deliver automatic alerts to all registered users of the system via e-mail or SMS message. The communications portion of the tool provides a warning system that allows users to monitor the status, criticality, and passability of all assets within their affected municipality.

Data Incorporated

In an effort to improve data dissemination to multiple platforms, the research team equipped the tool with capabilities to support communication with decision-making personnel via automated early warnings. Subscribers who have subscribed to events happening within their municipality will receive alerts via a user-specified device (email and/or SMS messaging) that include the following information (Figure 16):

- The geometry of the flood event;
- The predicted location and onset of flooding;
- System-generated hyperlink to further information about the event.

Figure 16: illustrates an example of flood warning sent to user who has subscribed to receive alerts of flood events happening in their municipality.

Reviewers and administrators have the additional capability of viewing flood warnings on the FloodCast application. In the communications module, reviewers and administrators can view the same information as described above for subscriber flood warnings but can also view flood event summary reports (Figures 17 and 18). These reports, generated by administrators in the flood Event Summary view (Figure 18), include the information presented in the following table.

Table 4: Information included in a flood Event Summary report.

Incident Type	• **Road closure** • **Evacuation** • **Tree down** • **Standard vehicle** • **Bridge collapse** • **Building collapse**
Passability	• Impassable • Passable to most large emergency vehicles • Cars/light EM vehicles might become displaced • Difficult for pedestrians • Shallow flooding • Passable
Criticality	• 1 • 2 • 3
Urgency	• Immediate • Expected • Future • Past • Unknown

The communications system allows administrators to view detailed event summaries that includes a list of affected assets organized by asset type.

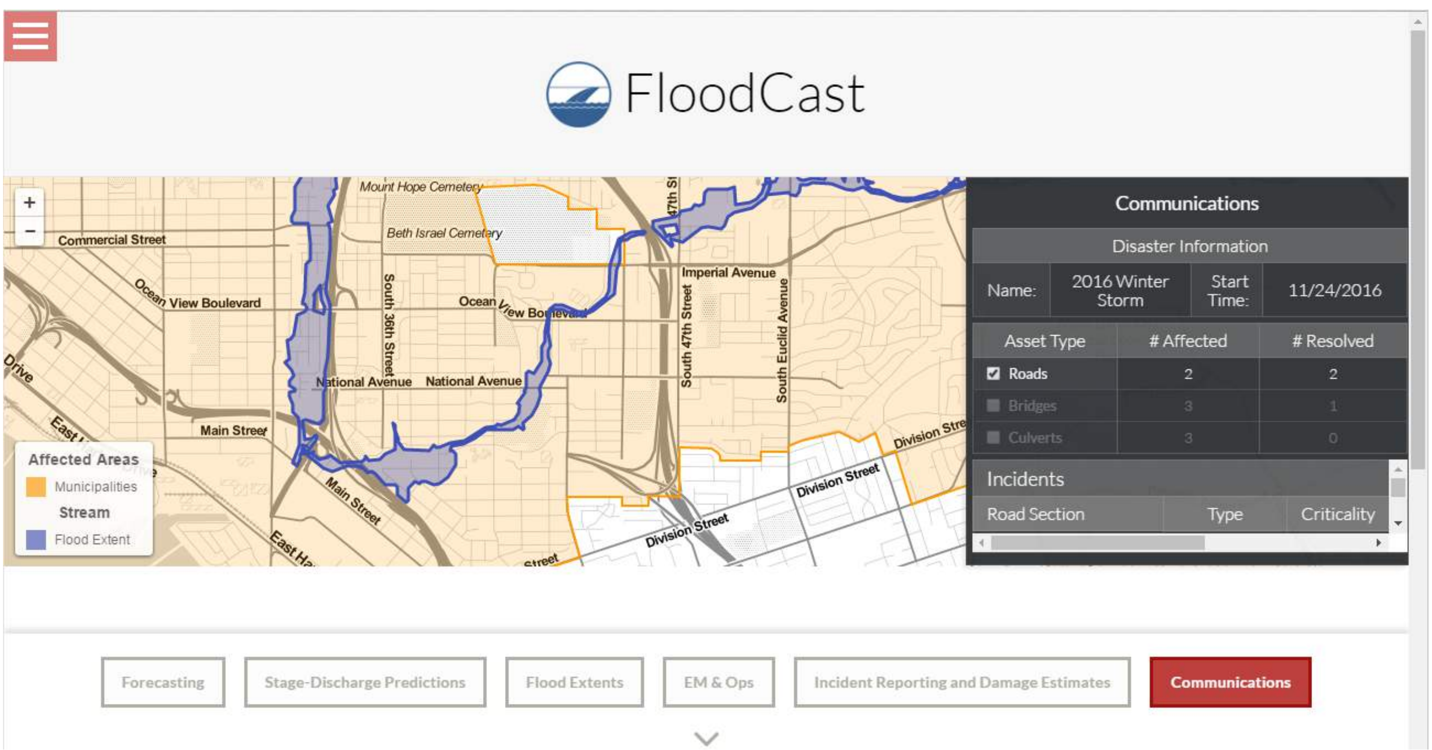


Figure 17:

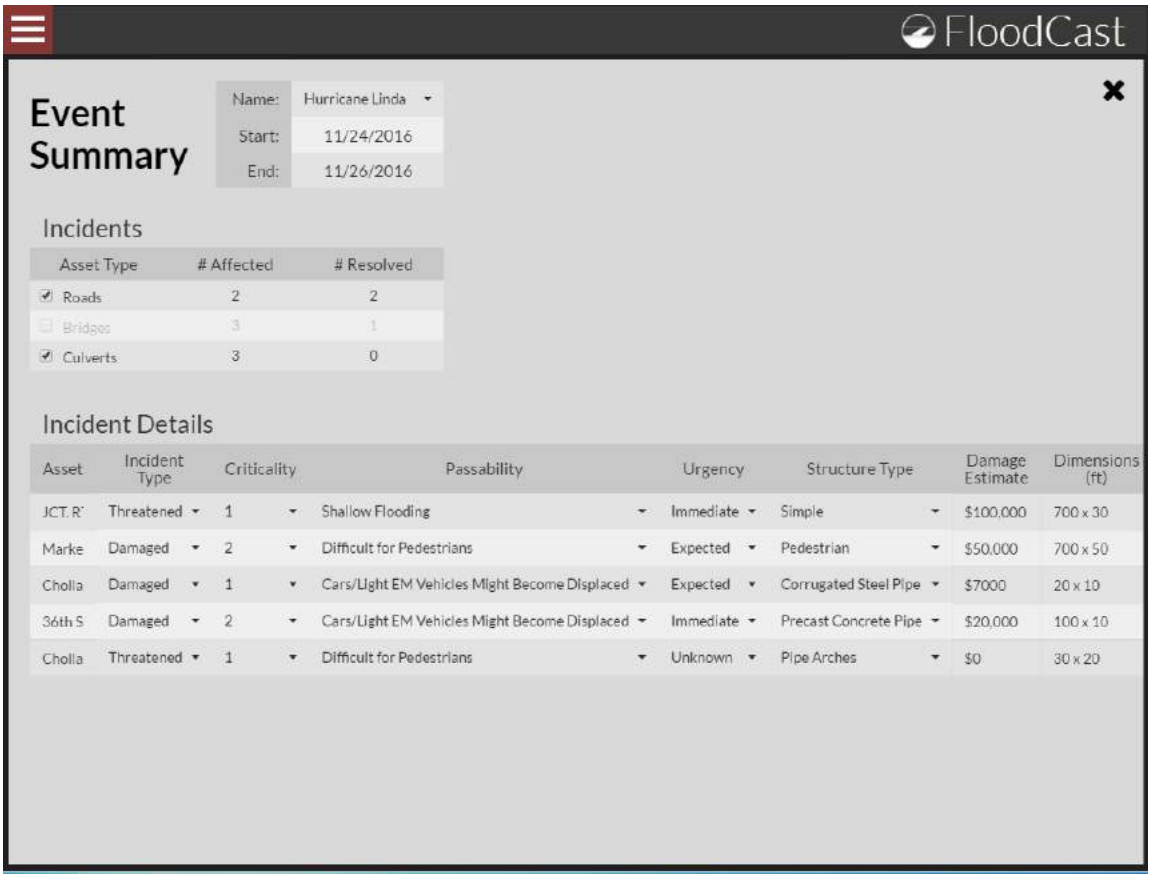


Figure 18: Administrator Event Summary form.

Communication: Vision for a Mature FloodCast Tool

The long-term vision for FloodCast is to have two-way communication to achieve the following objectives:

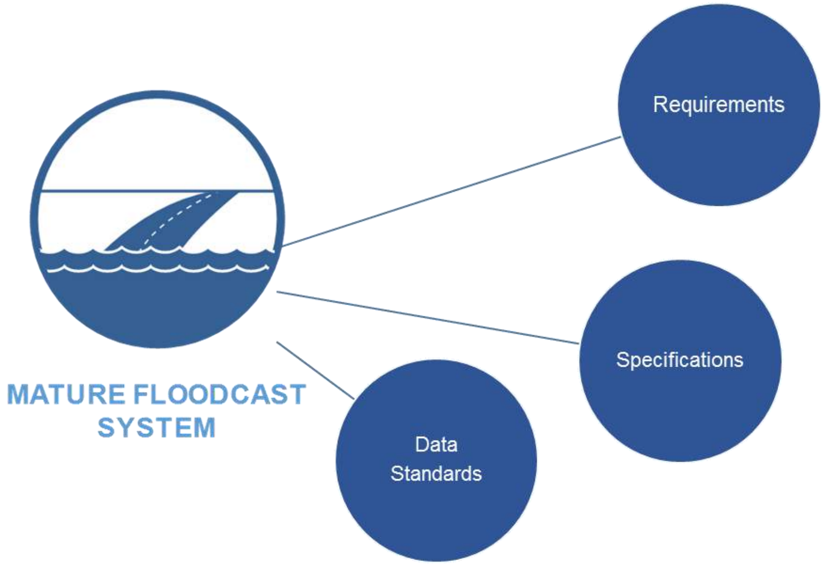
1. Facilitate data-driven decision making among public partners at the local, state and federal levels to enhance communication of emergency management decisions to downstream users; and
2. Enable dynamic updates from onsite personnel. These field updates should include the ability to submit updates from mobile devices.

Chapter 6 PROTOTYPE EVALAUTION

Upon completion of the system framework and prototype development described above, the research team prepared the prototype system for further testing and evaluation. Beta testing of the tool was performed by research team members who were not directly involved in the tool development and programming but contributed to developing the general content upon which the tool is based. The research team incorporated comments received from these tests into a revised version of the tool. The overall objective of the beta testing was to ensure the tool was capable of demonstration in order to spur conversation for building out the full system in Phase III of this project.

Chapter 7 FUTURE OF FLOODCAST

The scope and schedule of this project did not permit comprehensive incorporation of the community of practice's full set of needs. However, the framework and prototype development laid the groundwork for the development of an inclusive and coordinated decision-support system for transportation practitioners. In order to maintain momentum for the FloodCast project, the research team will continue to engage with State DOTs to build a maximally useful, fully-realized FloodCast program. In order to reap the full benefits of this work, the research team recommends that FloodCast project next steps focus on diving deeper into data standards, specifications and requirements.



The research team recommends that Phase III efforts focus on developing the following products:

- Thorough, detailed data standards that are developed with careful reference to DOT use cases and relevant processes and protocols. Data standards will be open, designed for maximum interoperability, and will be suitable for capturing key data during the preparation, response and recovery phases of a flood event. Data standardization will also be facilitated by developing a user-friendly tool which will check data prepared by DOTs or contractors for compliance with the data standards developed for FloodCast.

- A capability maturity model (CMM) outlining the steps needed for the development of a comprehensive and coordinated decision-support system for transportation practitioners. This CMM will serve as a roadmap for DOTs engaging with FloodCast.

- DOT-defined requirements and FloodCast specifications providing a comprehensive crosswalk between available data and use cases defined by the DOTs.

The first step to achieving the Phase III product objectives outlined above is further prototype evalaution and stakeholder outreach. While the prototype tool was tested internally by the research team, the prototype requires additional testing with appropriate stakeholders. Future prototype testing will evalaute the framework for completeness, consistency, and actionability. The research team proposes conducting web-based deomonstration workshops that describe the research in this report, demonstrates the functionality of the prototype system, and solicits input on the proposed functionality. This type of discussion will hopefully validate approaches used in the prototype, as well as raise additional questions and ideas that can be applied toward further research.

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Chapter 9 **APPENDIX**

APPENDIX A: TECHNICAL MEMORANDUM

APPENDIX B: INTERIM REPORT

APPENDIX C: FEMA SITE INSPECTION FORMS

APPENDIX D: SITREP XML SCHEMA FROM FEMA'S IPAWS

APPENDIX E: NOAA PARTNERED GUIDELINES FOR THE DEVELOPMENT OF ADVANCED HYDROLOGIC PREDICTION SERVICE FLOOD INUNDATION MAPPING