NCHRP 20-59(53): FLOODCAST

A Framework for Enhanced Flood Event Decision Making for Transportation Resilience

INTERIM REPORT

Prepared for

The National Cooperative Highway Research Program

Transportation Research Board

of

The National Academies

Dewberry
Venner Consulting

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INTERIM REPORT

1 INTRODUCTION

This is the interim report for the National Cooperative Highway Research Program (NCHRP) Project 20-59(53), "A Framework for Enhanced Flood Event Decision Making for Transportation Resilience." The report summarizes the previous tasks in the project:

- Technical Memorandum describing existing tools, methods, data, and models for flood event planning, response, and operations
- Gap analysis and prioritized list of practitioner needs versus capability of existing resources to meet those needs
- A framework and architecture to organize existing resources
- Recommendations for further research that can be carried out:
    - Within the project timeframe
    - In work subsequent to this project

Chapter 2 summarizes practitioner needs and research gaps. Chapter 3 discusses needs versus available tools, methods, and data and updates the work plan for Phase II of this project. Chapter 4 proposes a scope of work for additional research to follow this project. Chapter 5 provides a brief summary of proposed products and research. The Technical Memorandum and a sorted, graded list of resources are included in the appendices.

2 PRIORITIZED LIST OF PRACTITIONER NEEDS

In the Technical Memorandum, a number of unmet flood forecasting needs were identified based on Department of Transportation (DOT) interviews, literature reviews, and the proceedings of the 2015 Annual Transportation Research Board meeting. These findings are summarized in brief below. These gaps are the basis for developing recommendations for Phase II of this project, which is discussed in more detail in the following sections.

2.1 Major Gaps

Forecast

- Very-short term events and flash flooding are harder to predict and manage
- Inundation estimates are more common and easier to produce at gaged, populous locations and relatively uncommon at ungaged locations

Assets and Base Data

- Data limitations: DOT asset databases may be incomplete, not entirely in geographic information system (GIS) format, with partial or no topology enforcement
- DOTs assets may affect or contain assets (e.g., tunnels) owned by other entities or vice versa
- Connectivity and dependency between assets and other systems (e.g., power) are not typically mapped
- Fragility characteristics related to flooding, even elevation, are not always recorded or known
- Spatial coverage of national stream and tidal gages can be sparse in some areas, and could be supplemented with other sensors, such as BridgeWatch® systems and Road Weather Information System (RWIS) or ALERT gages
- Even some of the most advanced flood systems (e.g., Iowa) are not well-integrated with asset maps or traffic models (although the Iowa Flood Information System does show real-time traffic conditions)

Comm.

- Internal: DOT heads-up displays are not typically predictive; they tend to show things like the current weather report as opposed to potential threats
- Outgoing: Communication is not typically integrated (one system/one touch) or automated
- Incoming: Data from field teams, public crowdsourcing (damage/incidents) are not typically processed or posted real-time (internally, to work planning task lists, or to 511 sites)

2.2 High-Priority Requirements

The gap analysis in Section 2.1 can be refined to the following list of high-priority requirements:

1. Threat assessment support: Models, data, or tools that produce reasonable estimates of flood extent and depth that can be cross-referenced against asset data (elevation, depth-damage curves) to make an actionable threat assessment
2. Data dissemination to multiple platforms:
    a. Support for communicating with decision-making personnel via automated early warnings, interagency collaboration, and personnel working in the field
    b. Support for integrating information from cooperating entities, such as power utilities with information about blackouts
    c. Easy integration with traffic alert systems
    d. Two-way communication with the public, focused on obtaining and responding (where appropriate) to real-time crowdsourced situational updates, through social media
3. Data interoperability, storage, and archival: Protocols, database design, and querying functionality to support floodcasting, grant applications, lessons learned and debriefings, and mitigation prioritization

It is currently possible to achieve many of these objectives with standard tools, methodology, and data or modifications thereof, although some may require new approaches. Major feasibility considerations are outlined in Chapter 3.

3 CURRENT CAPABILITIES, MODIFICATIONS, AND RESEARCH AND DEVELOPMENT NEEDS

Table 1 reflects the priorities enumerated in the previous section, broken out to a more granular level of detail and scored according to feasibility.

- "Currently satisfied" indicates that high-quality, national data of adequate spatial resolution and refresh rate for local planning is currently available to support the need.
- "Can be satisfied with minor modification" represents a range of needs for which data and tools exist, but either:
    - Achieve only partial national coverage
    - Achieve full national coverage but have suboptimal resolution, or
    - Can be obtained through standardized guidelines, but have significant heterogeneities between states and may require significant local scale input or cooperation.
- "Will require new approaches" indicates that the necessary data and tools to meet this need are not yet available or require further refinement.

Each point in the table is discussed in more detail below, summarizing the research in the previous Technical Memorandum and adding additional insights.

Table 1. Suitability of current tools and methods to meet DOT information needs

	Needs	Currently satisfied	Can be satisfied with minor modification	Will require new approaches
	Threat assessment support			
1	Long-term and mid-term weather forecasts	x		
2	Flash flood forecasts		x	
3	Forecasted timing, extent, depth at gaged locations		x	
4	Forecasted timing, extent, depth at ungaged locations			x
5	Basic impact threat assessment for well-characterized assets with elevation information		x	
6	Detailed impact threat assessment using fragility curves for each asset			x
7	System model defining relationships between transportation assets and external dependencies			x
8	Analytical capabilities to map and anticipate system level problems and cascading failures due to flooding			x
	Data dissemination to multiple platforms			
9	In-house communication		x	
10	External communication with field crews		x	
11	External communication with partner agencies		x	
12	External communication with other relevant entities (e.g., power utilities)		x	
13	External communication with the public		x	
14	Smooth integration with traffic alert systems			x

	Needs	Currently satisfied	Can be satisfied with minor modification	Will require new approaches
	Data storage and archival			
15	Data storage and archival protocol to support grant applications, lessons learned/debriefings and mitigation prioritization		x	

3.1 Currently Satisfied

- **Long-term and mid-term weather forecasts.** Numerous National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) products are readily available (as shown in the accompanying Technical Memorandum's Appendix B. Resources Table) and of appropriate resolution and refresh rate for long-term and mid-term forecasts as well as short-term/real-time verification. Further, many of these resources are readily available through application programming interfaces (APIs) and Web Map Services (WMSs).

3.2 Can Be Satisfied with Minor Modifications

- **Flash flood forecasts.** The dynamics contributing to flash floods are often so small-scale and complex that missing or underpredicting flash flooding is still common even with the most sophisticated tools and methods. Existing NWS flash flood guidance estimates a range of times and locations at the county level, which is useful, but defining the timing, location, and extent of flash flooding at a finer level is needed to support operational decision-making.
- **Forecasted timing, extent, and depth at gaged locations**. Some NWS and National Flood Hazard Layer (NFHL) products exist to support this objective at riverine locations, although spatial coverage is limited. National Hurricane Center (NHC) products for storm surge estimates are also available, but vertical resolution is poor. It is possible to automate existing flood mapping techniques to produce event-specific inundation extents, but computation requirements are likely to be a complicating factor and feasibility must be considered further to evaluate the possibility of producing actionable statewide inundation estimates. Additionally, run times for flash flooding-type events at the state level may exceed the rate at which flooding occurs, which is suboptimal for response.

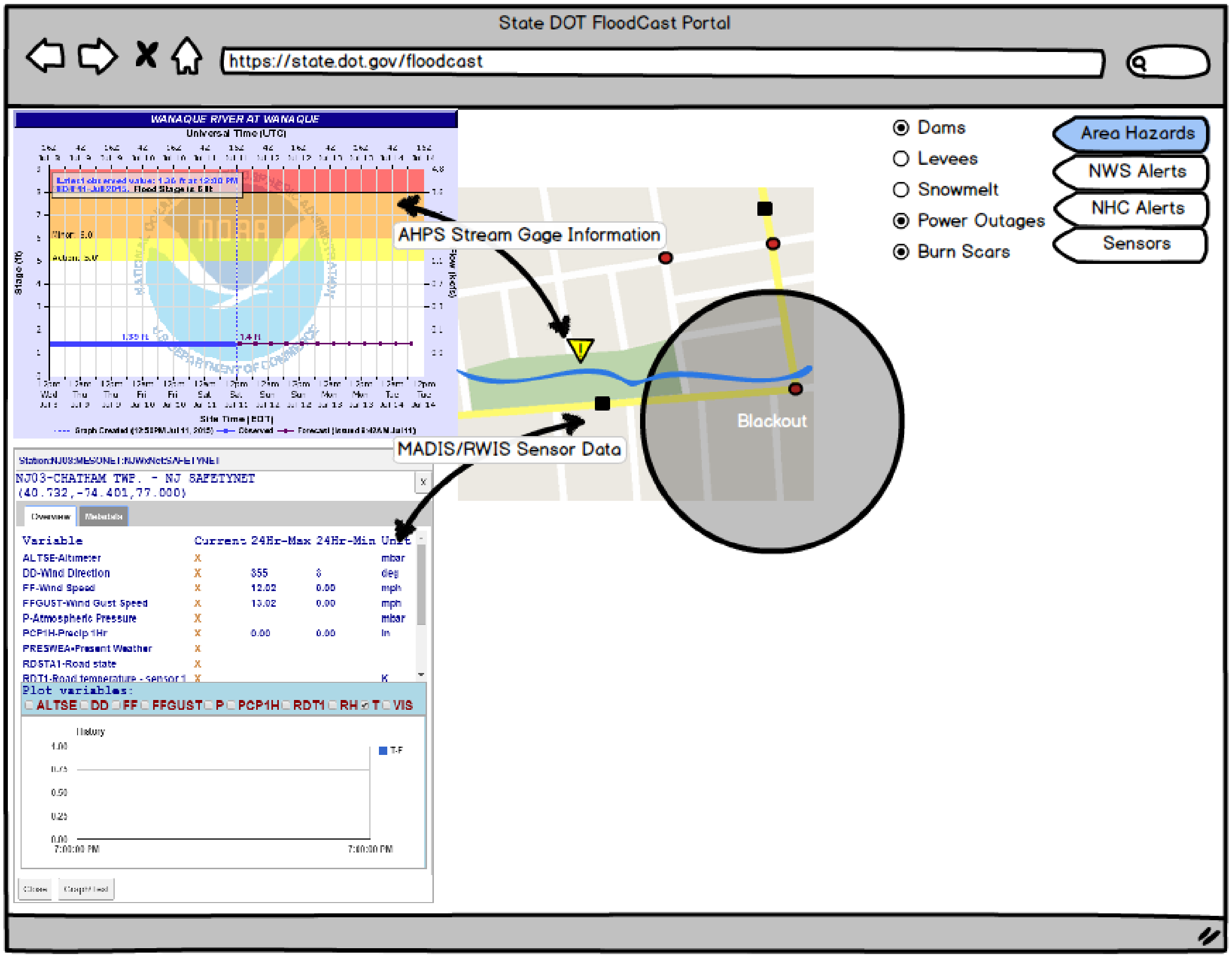

Figure 1. Notional wireframe. Forecast and sensor data as well as information from cooperating entities (e.g., power companies) can be collected as part of a single heads-up display.

- **Basic impact threat assessment for well-characterized assets with elevation information.** A robust GIS-based asset management system is critical to the success of floodcasting efforts, and many DOTs are working toward that goal. The guidelines described in NCHRP Report 800 are useful, and the data model described in NCHRP 20-27 is part of the standard for roadway GIS. However, attribution assets with elevation data (e.g., road centerline, bridge deck) are necessary to any rigorous flood risk analysis and planning. As discussed in the Technical Memorandum, remote and mobile sensing technologies are an avenue through which to accomplish this. It is critical that elevation attribution be added to existing data models defining GISs for transportation (GIS-Ts) for asset management.
- **In-house communication.** Smooth operations and response during flood events requires adequate lead time, and automated messaging will help meet this need. Short Message Service (SMS)-based and Internet-dependent text message functionalities based on geospatial information are examples of technologies that can be employed for flood hazard alerts and warnings, and existing Federal Emergency Management Agency (FEMA) Wireless Emergency Alerts and NWS alerts can also be used.

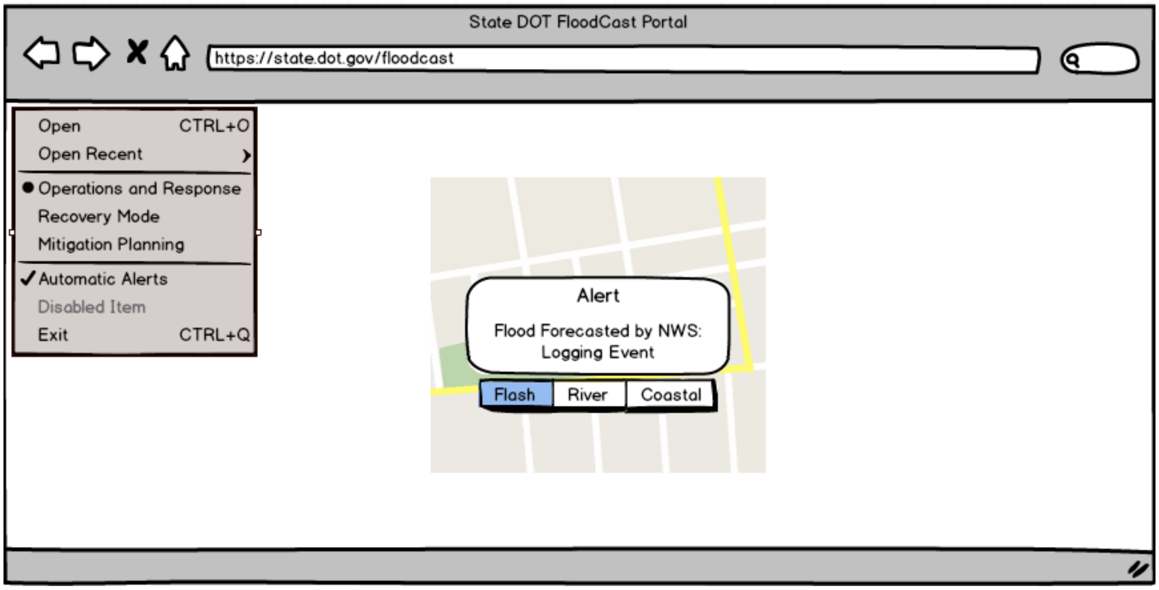

Figure 2. Notional wireframe. Automated alerts to DOT personnel involved in emergency management and response functions, based on various forecast products.

- **External communication with DOT field crews**. The technologies listed above may be enlisted, and tablet and smart phone applications used for data collection in the field can likely interface with floodcasting tools. Custom tailoring to account for unique systems, use cases, and work flows at each DOT would be required in many of these situations, although data standardization efforts could ease this problem.

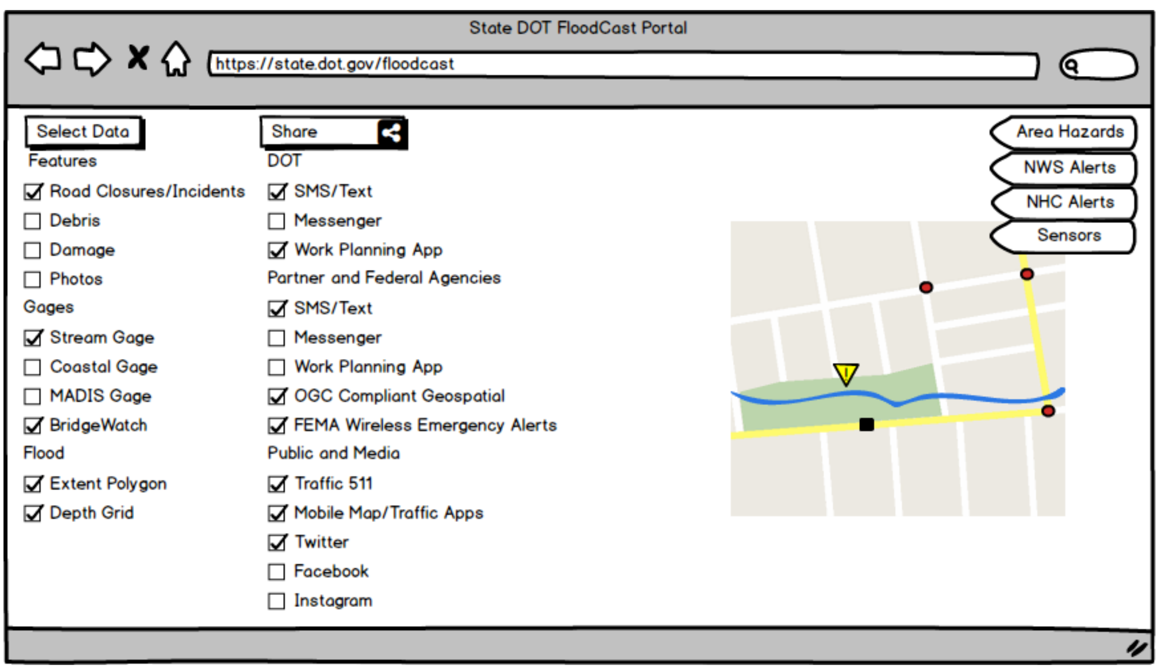

Figure 3. Notional wireframe. Planned and actual road closures along with geo-tagged photos can be a useful part of response, recovery, and mitigation.

- **Other external communication.** Unique features of various systems may require some customization, but reliance on Open Geospatial Consortium (OGC) compliance for geospatial data dissemination and the use of native APIs for the dissemination of alerts to social media and mobile applications is feasible. Streamlined messaging functionality across platforms and toward different audiences is desirable. Audiences may include:
    - Partner agencies
    - Other relevant entities (e.g., power utilities)
    - The public
    - Traffic alert systems

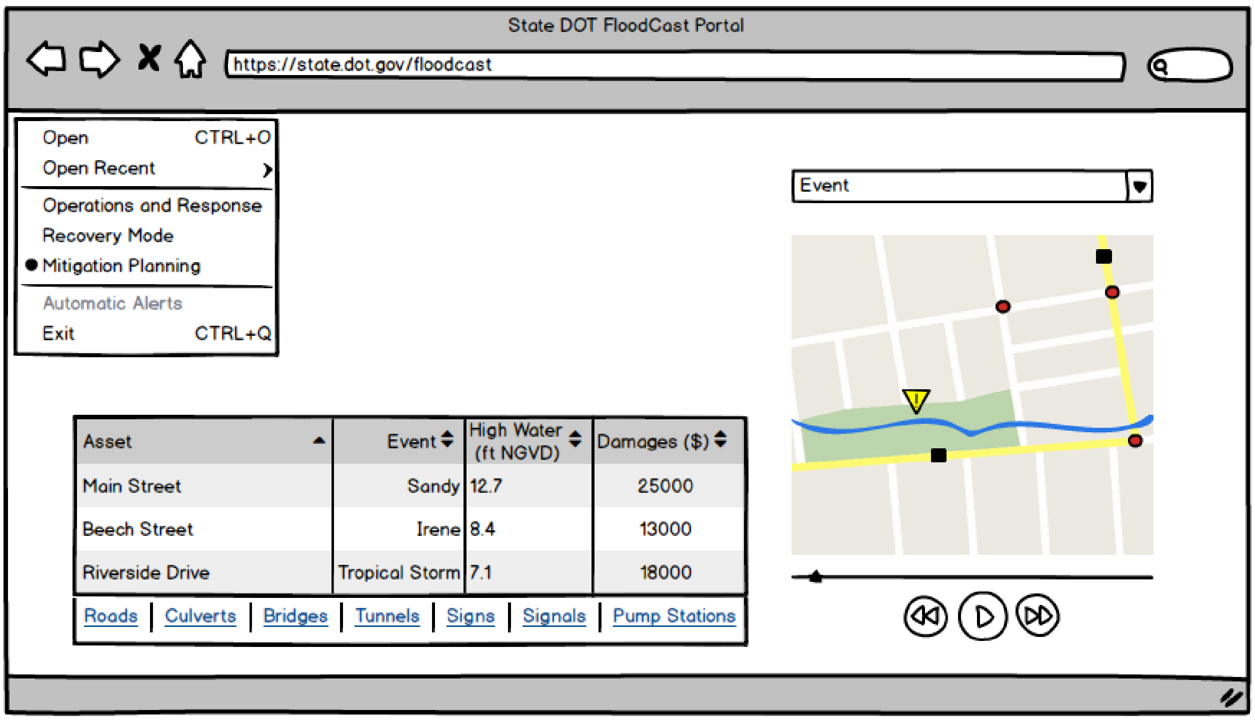

Figure 4. Notional wireframe. Given the important of multi-platform media as an information source, it is desirable for DOTs to share geospatial and text-format data with various audiences at regular intervals.

- **Data storage and archival protocol to support floodcasting, grant applications, lessons learned/debriefings, and mitigation prioritization**. A geospatial database can be designed to capture relevant details from events, including modeled flood extents, field information, and damage estimates. The database can be developed to support queries related to mitigation, climate adaptation, and capital investment planning. NCHRP Report 754 includes a case study of the Louisiana Department of Transportation and Development, showing GIS use for flood planning, response, and cooperation with emergency management, which is particularly relevant. As noted in the Technical Memorandum, the New York State DOT also has some excellent examples of capital planning based on hazard vulnerability rankings assigned to different asset classes.

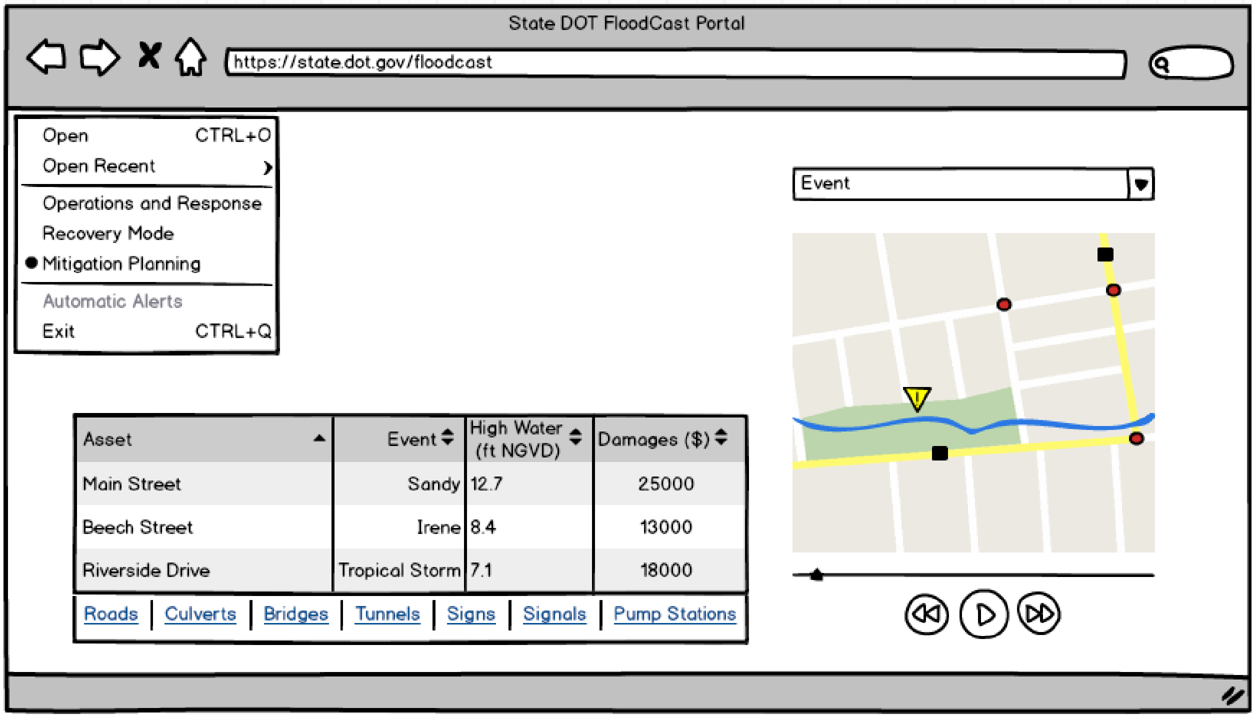

Figure 5. Notional wireframe. Mitigation planning and the grant application process benefit from detailed records of past events, including damages and high water marks. The ability to review past events can also improve operations and response.

3.3 Will Require New Approaches

- **Forecasted timing, extent, and depth at ungaged locations.** Certain states, e.g., Iowa, have existing models to at least develop discharges, if not inundation extents, based on forecasts statewide, but the computational requirements are significant. Participants in the National Flood Interoperability Experiment (NFIE) (discussed in more depth in the Technical Memorandum) are working on approaches to develop and provide nationwide streamflow estimates for all National Hydrography Dataset (NHD) stream segments based on downscaled results from NWS WRF-Hydro and European Center for Mid-Range Forecast ensemble models. Once widely available, these models will ease the burden of translating precipitation forecast into stream discharge, but as of this writing, a stable dissemination portal for these products does not yet exist.
- **Detailed impact threat assessment using fragility curves for each asset.** Fragility curves, such as depth-damage curves for buildings and roads, may be adapted from FEMA Hazus databases. Damage estimates could therefore be produced for forecasted or actual flooding for use in planning. However, some asset types may not be well represented by existing databases, and damage estimates are often linked to flood return interval rather than stage, which may be somewhat unwieldy for users. Existing methods likely require some adaptation for efficient use in the transportation planning process. See also NCHRP Report 777 for a brief discussion of the possible utility of Hazus for this purpose.
- **System model defining relationships between transportation assets and external dependencies.** This step would build on a GIS-based asset management database by defining and quantifying interactions and relationships between transportation system components, moving beyond road network analysis to capture interactions from signals, power outages, etc. Manually mapping these interactions is time consuming and benefits from expert knowledge to identify and quantify system behavior.

- **Analytical capabilities to map and anticipate system level problems and cascading failures due to flooding.** Complex systems models, particularly network-based models, have been increasingly used over the past decade to model interactions between infrastructure systems. However, this work is nascent, does not typically account for feedbacks, and has not been successfully piloted for state level transportation network.
- **Smooth integration with traffic alert systems.** Again, unique features of various systems may require some customization, but reliance on OGC compliance for geospatial data dissemination and the use of native APIs for the dissemination of alerts to social media and mobile applications is feasible.

3.4 Recommended Phasing of Priority Requirements

A number of the items listed in Sections 3.1 and 3.2 can be accomplished in Phase II of this project. The study team recommends that Phase II tasks focus on the following development tasks:

1. Developing protocols to ingest key products identified in the accompanying Technical Memorandum's Appendix B. Resources List, as well as protocols and standards allowing DOTs to supplement national datasets with local, more complete or higher resolution products where available. With respect to the latter, the team proposes developing standards for attributing GIS-Ts with elevation data and other key asset characteristics. The team will also evaluate Advanced Hydrologic Prediction Service (AHPS) and USGS Flood Inundation Mapping standards for the development and use of flood hazard information in floodcasting systems.
2. Creating a stable web platform and geodatabase for analysis, storage, and retrieval. Both operations-and-response and the pre- or post-event mitigation planning needs will be considered in database development.
3. Transforming data and analysis products into formats suitable for dissemination. The prototype will prioritize the export of geospatial transportation data with operational significance (e.g., road closures) in an OGC-compliant format, but depending on time and resources, can also consider vehicle traffic, Hazus, SMS-hazard notifications, and social media.

3.5 Framework and Architecture

Interoperability is a fundamental consideration in this project and is the organizing principal in the Phase II prototype development to meet the goals listed in Section 2.2. To achieve the first objective, threat assessment support, the study team's developers will incorporate the tools graded A and B in the Technical Memorandum's Appendix B. Resources List. To do so, the study team will develop 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. The third objective, data storage and archival, will require the design of a geodatabase, which will also support the other two objectives.

An overview of the estimated schedule to accomplish these items is shown below.

Task	2015				2016				
	S	O	N	D	J	F	M	A	M
1. Data Model									
2. System Architecture Design									
3. Implementation									
4. Beta Testing									
5. User Acceptance									
6. Project Closeout									

3.5.1 Architecture, Framework, and Metamodel

An overview of the system and components of the proposed Phase II prototype follows. This overview includes the functional goals, high-level requirements, limitations, and major assumptions. As noted in the previous section, the study team is prioritizing a stable, 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 capabilities. The primary function of the deliverable application will be to provide a proof of concept to the industry, recognizing that future implementation would be DOT-specific. Diagrams modeling an operations and response-focused module as well as a mitigation-focused module follow.

Functional goals:

- Design system that brings flood forecasting information, DOT operational and emergency management considerations, and mitigation planning support together in one place.
- Provide a model for flood decision-support usable by most state transportation agencies focusing on preservation of life and preventing damage to assets.
- Integrates with state traffic advisory systems and state emergency management platforms by providing OGC-compliant export functionalities.
- Uses accessible products that are familiar to DOTs, such as common ESRI and open source GIS tools.

Functional requirements:

- This model will provide alerts for any precipitation events within county or more granular boundaries where flash flood guidance, river forecasts, or NWS AHPS action stage conditions are met or exceeded and transportation assets will be affected.
- Updates incorporating new forecast data, asset data, and field/sensor verification will be possible.
- Time-stamped incident tracking will be supported: flood location, estimated depth, population impacted, assets impacted.
- The event database will serve as a centralized location for post-event field data collection and damage assessment.
- Assumptions: County or better granularity is a meaningful resolution for flood prediction. Only currently available (e.g., AHPS) information will be used to show flood prediction and to perform impact analysis to the asset and neighborhood level.

System limitations:

- FloodCast provides no advisories against events that occur at less than the data refresh rate.
- FloodCast only provides advisories when the system is on and advisory functionality is enabled.
- FloodCast cannot provide advisories where terrain, asset, or other critical data are missing, and advisories are limited by the quality of that data.
- FloodCast accounts for flooding due to precipitation falling as rain and will not consider storm surge, snowmelt, water main breakage, dam breach, or other sources of flooding.
- During power outage, FloodCast functionality is limited by power availability and battery backups.
- FloodCast cannot provide advisories if forecast source is offline.

Safety constraints:

- FloodCast advisories do not supersede established DOT workplace safety policies.
- FloodCast advisories are estimates and do not take the place of sensor and field verification.
- FloodCast displays can be minimized so as not to disrupt in emergency situations involving life safety.
- Assumption: The minimization feature will only be used when heads-up display would interfere with life-safety related activities.

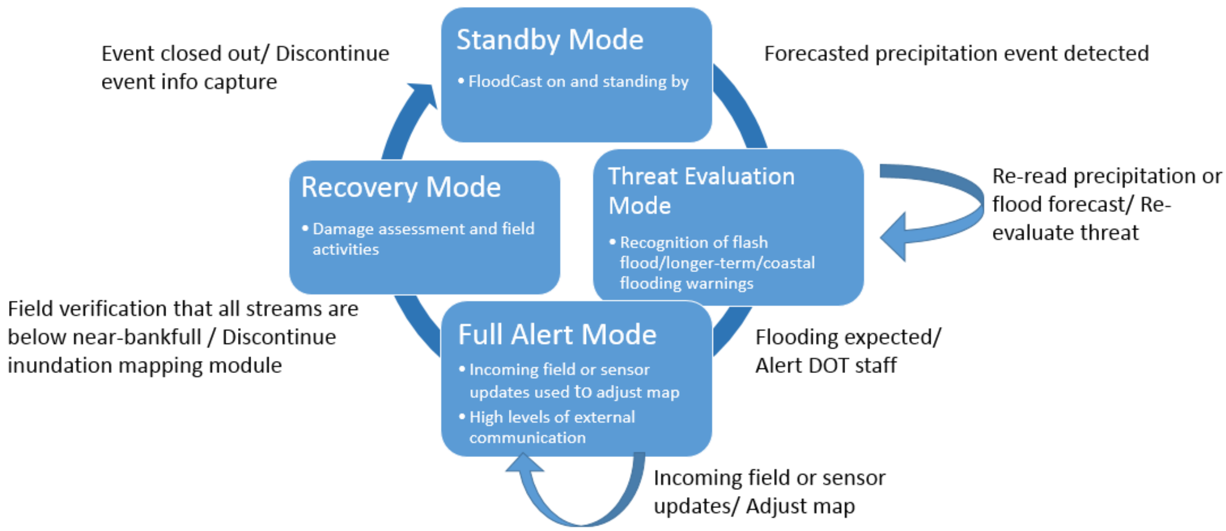

Figure 6. Phase II prototype functionalities desired to support operations/flood response.

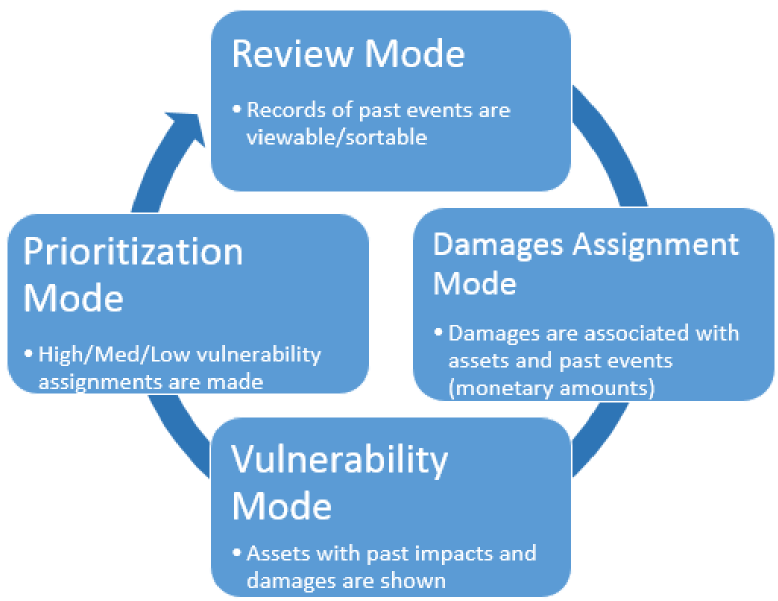

Figure 7. Phase II prototype functionalities desired to support mitigation planning.

3.5.2 Methodologies

Phase II priorities are constrained by implementation challenges. Implementation challenges are briefly noted in the following list. These challenges will inform the methodologies employed to develop the prototype. A variety of solutions, including open source tools, will be considered to address these challenges.

- **Varying data formats**. Data will be obtained from heterogeneous sources and in various formats. Tools with extract, transform, and load (ETL) functionality will be selected and used to store data in proper format.

99e_2015070221.tar	10.0 kB	7/2/15, 7:30:00 PM
99e_2015070309.tar	10.0 kB	7/3/15, 5:41:00 AM
99e_2015070321.tar	10.0 kB	7/3/15, 8:09:00 PM
99e_2015070409.tar	10.0 kB	7/4/15, 7:30:00 AM
99e_2015070421.tar	10.0 kB	7/4/15, 8:26:00 PM
EXCESSIVERAIN_Day1_latest.tar	10.0 kB	7/5/14, 1:02:00 AM
EXCESSIVERAIN_Day1_latest.zip	1.2 kB	7/5/14, 1:02:00 AM
EXCESSIVERAIN_Day2_latest.tar	10.0 kB	7/4/15, 8:21:00 PM
EXCESSIVERAIN_Day2_latest.zip	1.1 kB	7/4/15, 8:21:00 PM
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- **Not all desired data are universally available via APIs or WMS**. Data available through File Transfer Protocol (FTP) or other web formats will be accessed through subroutines developed by the study team.

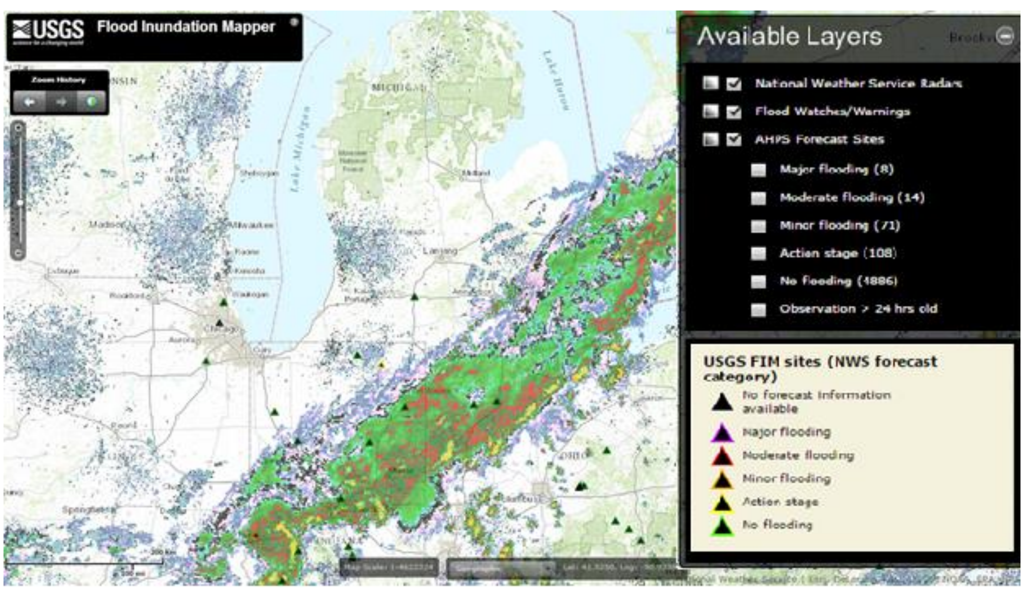
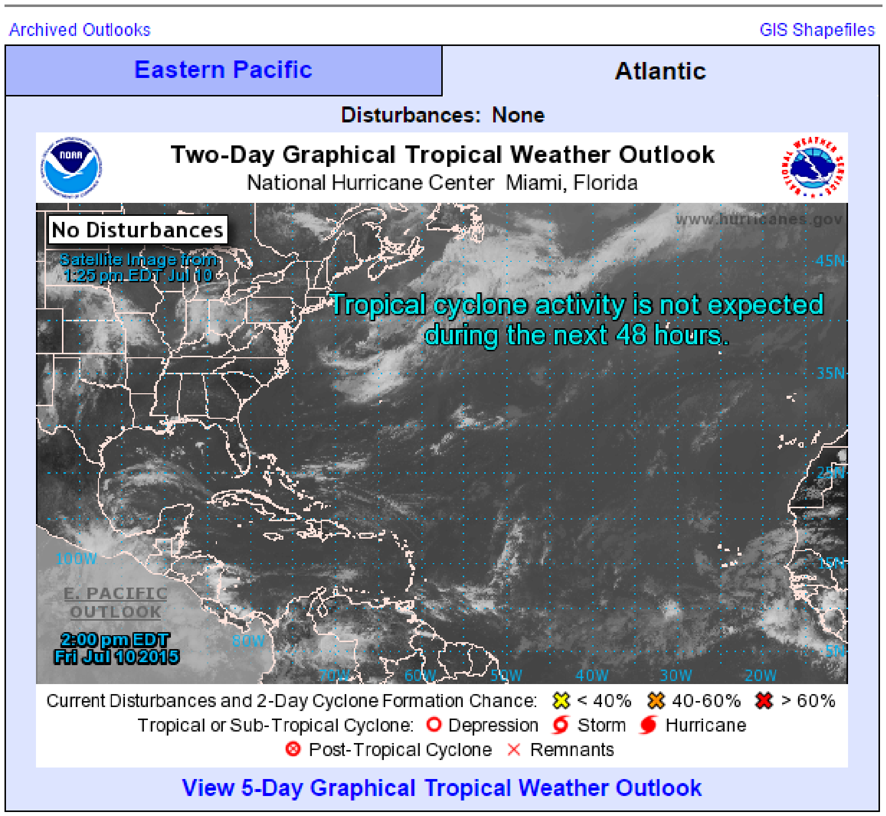


Figure 8. US Geological Survey (USGS) brings three useful flood impact datasets together in one location in its Flood Inundation Mapper.

- **Varying refresh rates between datasets, or manual updates triggered by external events for some datasets** (e.g., NHC data). For those datasets unavailable through WMS, data will be updated regularly using subroutines developed by the study team. The study team will also ensure that missing source data or access errors are handled with appropriate error or notification messages.

Atlantic 2-Day Graphical Tropical Weather Outlook



- **Incomplete spatial coverage for hazard datasets**, and insufficiently granular resolution (temporal, spatial, and/or vertical) of some readily available data products for local level decision making, e.g., AHPS inundation extents and depth grids and NHC storm surge estimates. Developing the data needed for real-time flood forecast prediction is an ongoing endeavor in the US. For the time being, the best available datasets, which are AHPS and NHC products, will be used, and NFHL extents will be used as a secondary source of flood extent estimates. Further work to close this significant data gap is discussed in Chapter 4.

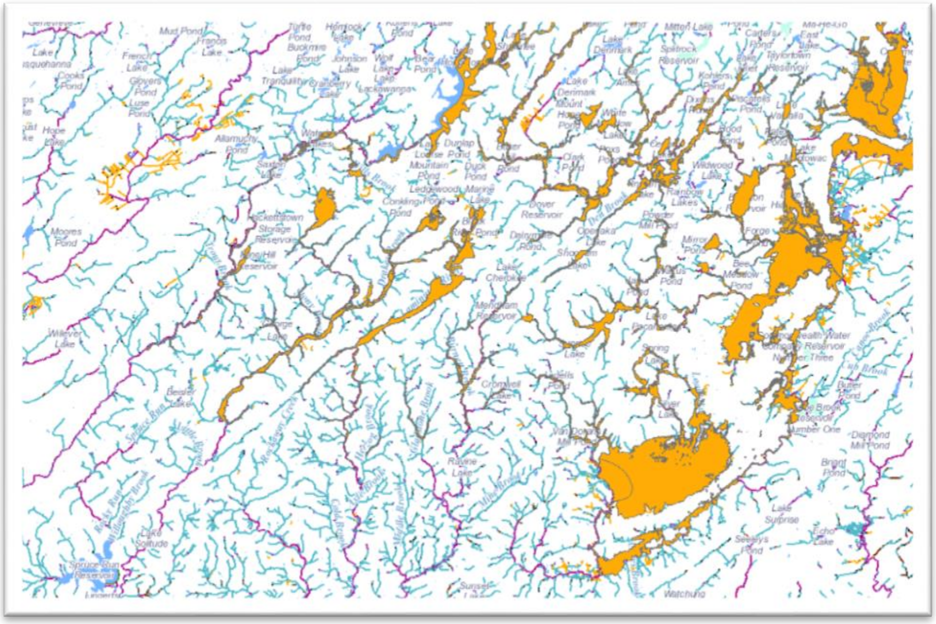


Figure 9. AHPS coverage in the US is not yet comprehensive. Areas in Bergen County, New Jersey, that have data showing flood extent and depth estimates for NWS AHPS flood stages are shown in orange. The NHD, which is a comprehensive network of the Nation's streams and water bodies, is shown in blue. This is a region of the US with dense AHPS coverage compared to the rest of the Nation.

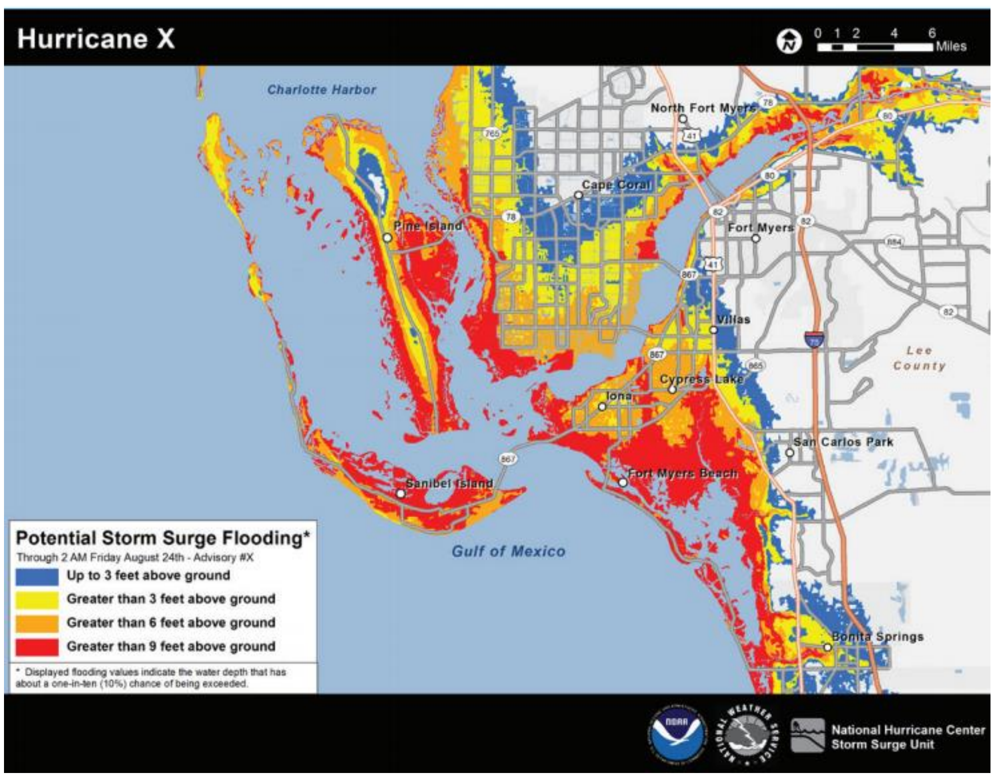


Figure 10. The best available national data is not always well suited to local level response and planning activities. The 3-foot increments shown in this NHC estimate illustrate this problem. Source: http://www.nhc.noaa.gov/surge/PotentialStormSurgeTipsem.pdf.

- **Incomplete transportation asset catalogues** and asset catalogues without elevation and fragility attributes. This issue is discussed in greater detail in the Technical Memorandum, and the study team believes this issue can be best handled using a standards-based approach incorporating elevation data into the GIS-T for asset management data model. The study team plans to engage with this issue during the prototyping process by incorporating an actual DOT's GIS data into the model.

4 RECOMMENDATIONS FOR FURTHER RESEARCH

In the previous section, the data challenge of obtaining comprehensive flood hazard information was noted. Spatial coverage of existing hazard datasets is limited for riverine applications, and NHC products may be of insufficient granular resolution for local level decision-making. The study team proposes working closely with NFIE participants to resolve these issues. The study team suggests focusing on the following tasks.

4.1 Forecast-Based Riverine Flood Extents and Depth Grids

NFIE participants are advancing research that will, within the next year, be integrated into NWS. The research products will include forecast-based discharge estimates for all NHD stream segments, resolving some of the issues with ungaged streams. While these products are not available through a federal agency's dissemination portal at this time, beta versions of the product may be available to the study team, which has a close relationship with several NFIE leaders. The study team is also composed of national experts in floodplain mapping with the following competencies:

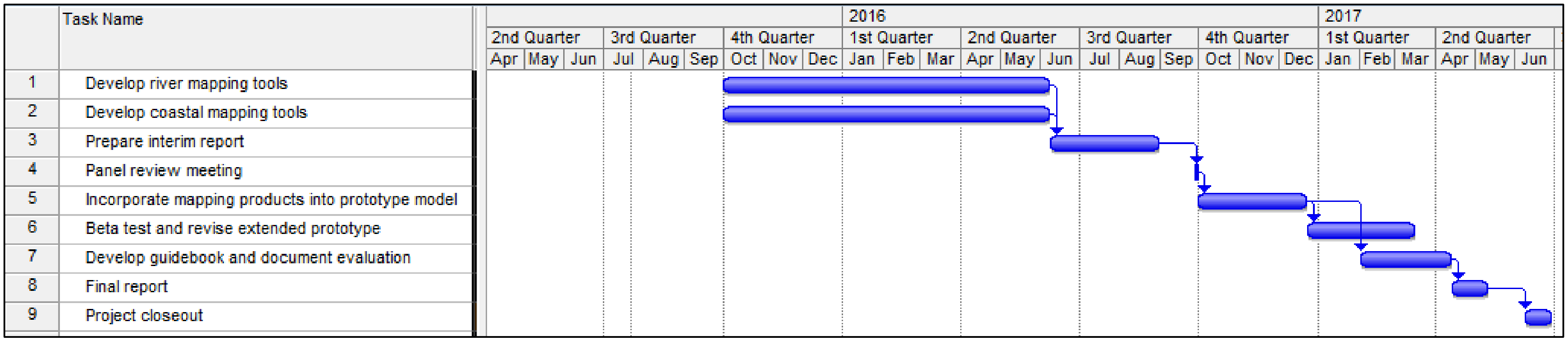
a. Contribution to the mapping standards and floodplain estimates for the NWS AHPS
b. Development of GIS-based mapping tools to increase mapping efficiency
c. Automation capabilities to develop floodplain extents and depth grids based on discharge estimates

The study team proposes using beta versions of the stream discharges to develop mapping automation tools and guidelines for replicating them, ensuring that DOTs will be able to take full advantage of nationwide, forecast-based stream discharge estimates once they do become available.

4.2 Higher Resolution Storm Surge Products

Study team members include former members of the NHC's storm surge modeling team, who are aware of the techniques needed to produce hurricane and extratropical storm surge products of sufficient resolution for local planning. Study team members would use the same approach as the NHC team, relying on the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model to produce a high-quality coastal inundation estimate. The study team proposes using these methods to develop coastal mapping tools that can produce real-time extent and depth estimates. These estimates will be granular enough for use by DOTs for operations and response during flooding caused by storm surge.

4.3 Workload Estimate



5 CONCLUSION

The work to date on this project has 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 floodcasting framework. An architecture and framework for those ready-to-use and easily modified tools are discussed in Chapter 3. High-priority research needing additional resources is described in Chapter 4. Together, Phase II products and subsequent research will incorporate effective information into a single framework to support transportation floodcasting needs, and the framework will be built to anticipate updates from both the NFIE and local datasets.

6 ABBREVIATIONS AND 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
NWS	National Weather Service
OGC	Open Geospatial Consortium
SMS	Short Message Service
USGS	United States Geological Survey
WMS	Web Map Service