

CHAPTER 4

Case Examples of Integrated Flood Prediction and Response Systems

Introduction

The information in the following sections was derived from detailed interviews with individuals from seven states selected to serve as case examples (Idaho, Iowa, New York, North Carolina, South Carolina, Texas, and Washington). The list of interviewees is provided in Appendix D. This chapter generally addresses the following four topic areas with each agency: (a) flood monitoring, (b) flood prediction, (c) flood warning and emergency response systems, and (d) observed successful practices and gaps in addressing synthesis topics. The original scope of this synthesis was to conduct in-depth interviews with six state DOTs, but ultimately the number of DOTs interviewed included seven states as it would provide broader and diverse aspects.

A number of criteria were used to select the states to serve as case examples. First, the states that indicated that their DOT views the state integrated system for flood prediction and response as successful—ascertained through either the literature review or the survey—were identified. A further criterion applied was whether the state DOT indicated it has an effective and successful system for each topical area (e.g., flood monitoring, flood prediction, flood warning and response system). In addition, geographic and physiographic distribution, differing flood causes and types, different types of land cover and development, and population densities were also considered. Consideration was also given to states that highlighted particular strengths in their approach to flood management. Ultimately, these factors resulted in a diverse group of states facing a range of challenges and practicing innovative solutions. Table 29 and Figure 48 summarize the selected states along with their notable features considered for the selection. Because of the continually evolving nature of the data collection and information technology fields, it should be noted that the information in this chapter will require frequent updating in the future.

Idaho

Background

In the state of Idaho, river flooding and surface and overland flooding are major types of observed flooding. These flooding events are typically caused by rain on snowpack, speeding the rate at which it melts. Approximately 90% of flooding is the result of rain on snow in December or spring months. Roadway inundation and culverts blocked by debris are Idaho's biggest concern during flooding, while most of Idaho's state bridges are designed for scour.

Following the recommendations of the Hydraulic Engineering Circular 18 in 1991 and AASHTO in 1992, the Idaho Transportation Department (ITD) formed the multidisciplinary Scour Committee in the early 1990s. The Scour Committee is the longest-running committee at ITD; members typically meet monthly. The Scour Committee members maintain a Scour Review spreadsheet containing committee decisions from about the past 12 years. Consistency of the

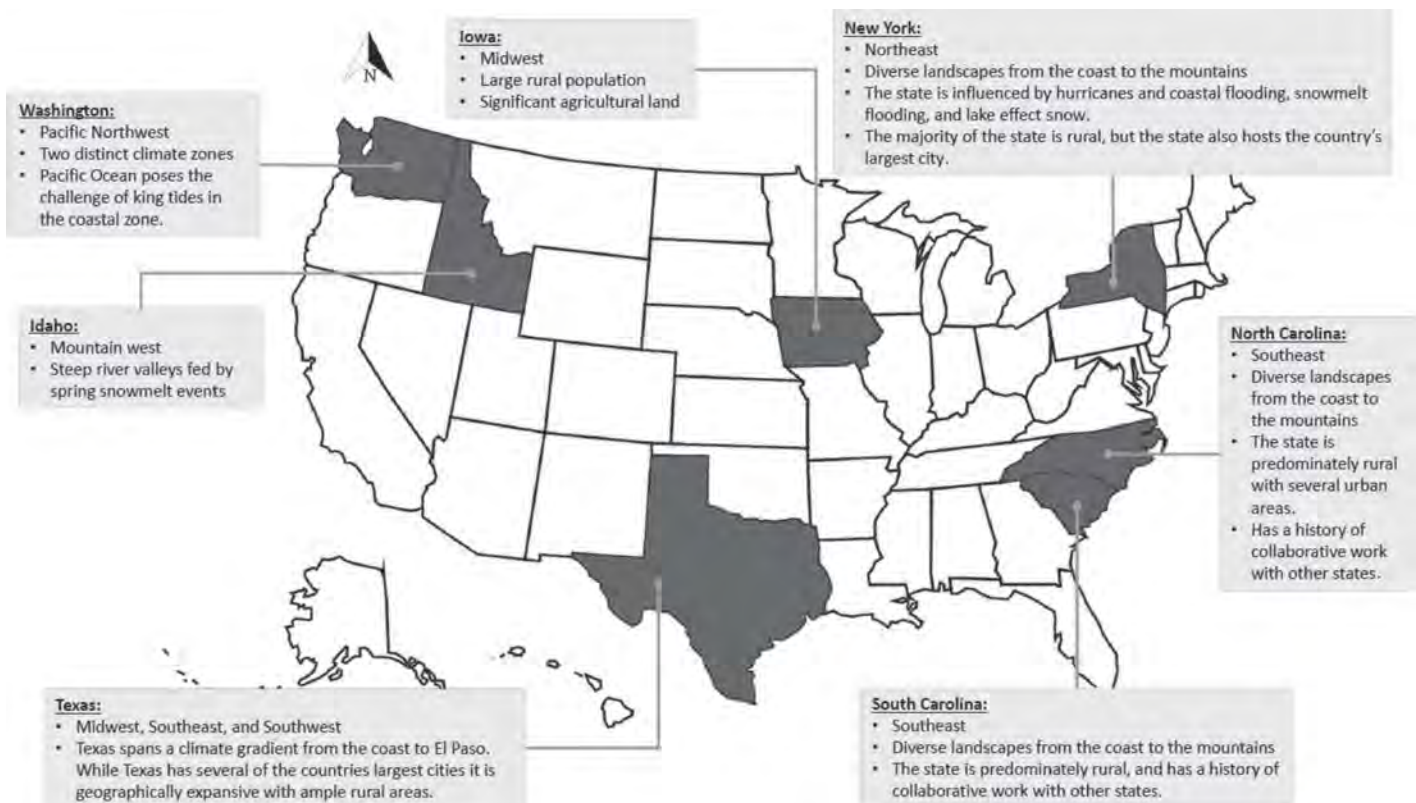
Table 29. Reported flood types and causes of case example states.

State	Flood type	Flood cause
Idaho	River flooding, surface/overland flooding	Heavy rain events, snowmelt
Iowa	River flooding	Heavy rain events, snowmelt
New York	Coastal flooding, river flooding, surface/overland flooding	Storm surge, tidal flooding due to sea level rise, heavy rain events, snowmelt
North Carolina	Coastal flooding, river flooding, surface/overland flooding	Storm surge, tidal flooding due to sea level rise, king tides, heavy rain, riverine
South Carolina	Coastal flooding, river flooding, surface/overland flooding	Storm surge, king tides, heavy rain
Texas	Coastal flooding, river flooding, surface/overland flooding	Storm surge, heavy rain events
Washington	Coastal flooding, river flooding, surface/overland flooding, stream flooding	Storm surge, tidal flooding due to sea level rise, king tides, heavy rain, snowmelt, private ponds fail and cause downstream flooding

membership has allowed for lengthy institutional knowledge that has benefited the committee's programs and contributed to its success. This committee also spans several different sections to make up a multidisciplinary team that helps disseminate information. Members include a bridge asset management engineer, geotechnical engineer, hydraulics engineer, structural engineer, and technical engineer.

Flood Monitoring

Key attributes to ITD's flood monitoring include active management of BridgeWatch and a long-standing committee with a wealth of knowledge. BridgeWatch is used mainly for bridge monitoring and has been used by the Scour Committee since the early 2000s. In some instances, ITD monitors culverts and roadway inundation using BridgeWatch. Culverts and roadway inundation are managed by maintenance personnel. Supplemental BridgeWatch reports

**Figure 48. Location of state DOTs that were selected as case example states.**

(Appendix F) are written each time an alert is generated by USGS gages (streamflow), the SNODAS system (snowmelt), or NERAD (rainfall).

Figure 49 shows an example supplemental BridgeWatch report for Bridge 19260 over Sand Creek. It highlights the date of the event, work accomplished, recommendations, site conditions (substructure, channel, notes, weather), and signature of the person who wrote the report. The intent of supplemental BridgeWatch reports is to track events and scour observed to improve alert thresholds and improve the reliability of the system.

This supplemental BridgeWatch report also highlights the alert that was generated because the system reported 0.84 inches of rainfall, which exceeds the threshold of 0.83 inches. However, this alert was incorrect because only 0.34 inches of rain fell that day. The report then indicated that this faulty alert likely came from a larger rainfall prediction from NEXRAD and the small drainage basin attributes. Another supplemental BridgeWatch report in Figure 50 shows that the alert was generated by a USGS gage, part of the National Water Information System, indicating that the streamflow exceeded the threshold.

Idaho also maintains the Idaho Manual for Bridge Evaluation (IMBE), which ensures that bridges are correctly evaluated. For instance, the IMBE includes the procedures for coding new bridges, training requirements, determining the risk of unknown foundation bridges, and other quality review procedures. The IMBE acts as a supplemental document to the 2011 AASHTO Manual for Bridge Evaluation specifically for Idaho (Appendix E).

ITD has invested substantially in research on active scour measurements during an event. A previous research program with the University of Idaho investigated a thermal device for measuring real-time bridge scour. This device offered a low-cost and simple method to continuously monitor elevation changes in the streambed using temperature change differentials from in-sediment and in-stream waters. This study showed that the technology was viable. However, the scope of this project was limited, collecting data at only three sites. ITD is now collaborating with USGS to develop instruments that can be rapidly deployed to measure scour during high-flow events.

Flood Prediction

Idaho does little flood prediction because the nature of flooding in the state is rain on snow events. Idaho does little seasonal flood prediction. This type of flooding is difficult to predict; therefore, systems are more reactionary than predictive. ITD focuses on real-time, day-to-day management of scour on bridges.

Active management of the BridgeWatch system led ITD to review the accuracy of its data inputs. The SNOTEL system gave false predictions and was replaced with the more accurate SNODAS system. SNODAS measures the snowpack and water equivalency every 24 hours and can measure loss to predict potential water in the drainage basin. BridgeWatch incorporates SNODAS and uses USGS input and NEXRAD data.

Flood Warning

ITD uses BridgeWatch to generate flood warnings at bridges. ITD attributes the regularly updated inputs of the BridgeWatch system as being key to its state's success in flood warning. Although this program has been helpful, it requires a lot of upkeep and evaluation to ensure that alerts are actionable.

Response System

USGS alerts are most accurate for streamflow; the rainfall and snowmelt alerts often do not lead to high flows at bridges but are an important secondary system for areas without USGS gages.

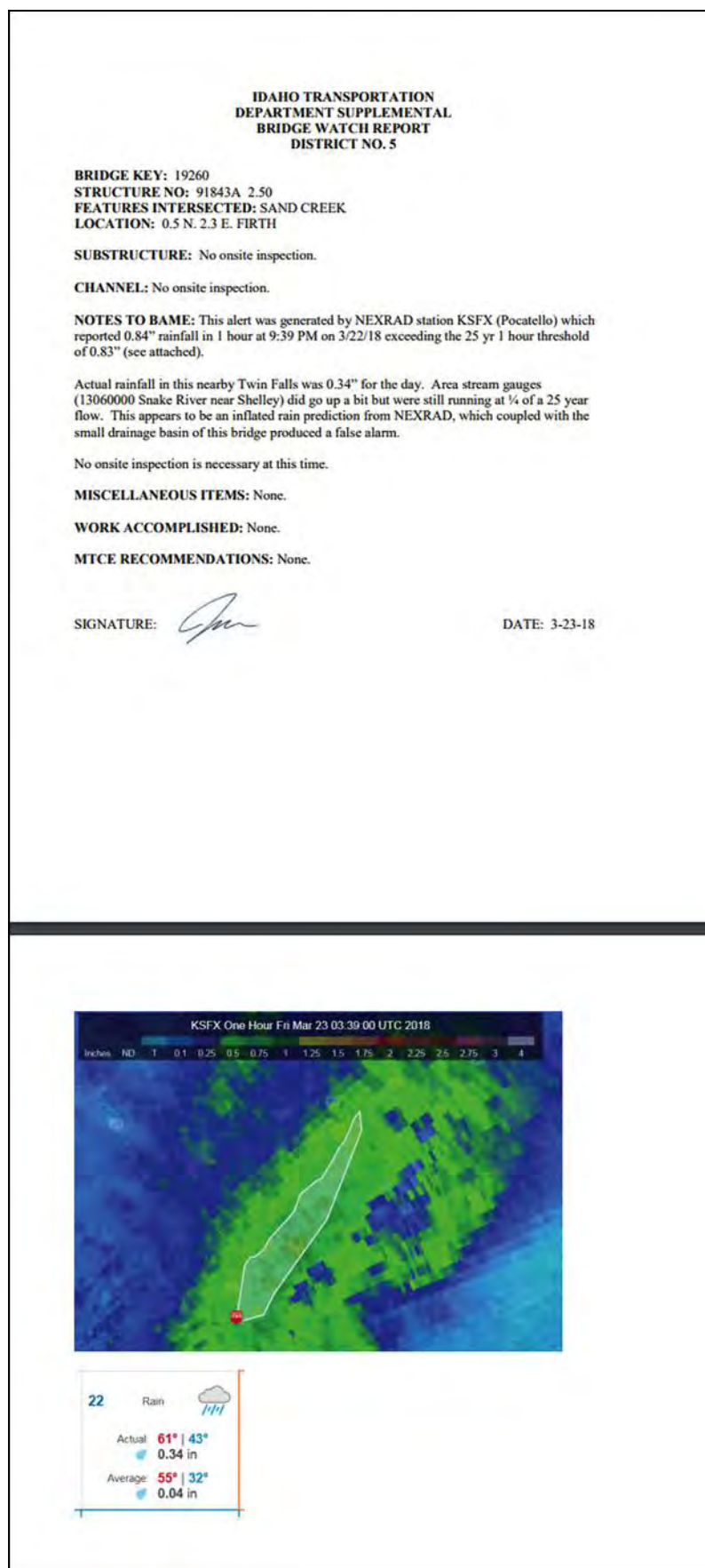


Figure 49. Supplemental BridgeWatch report for Bridge 19260.

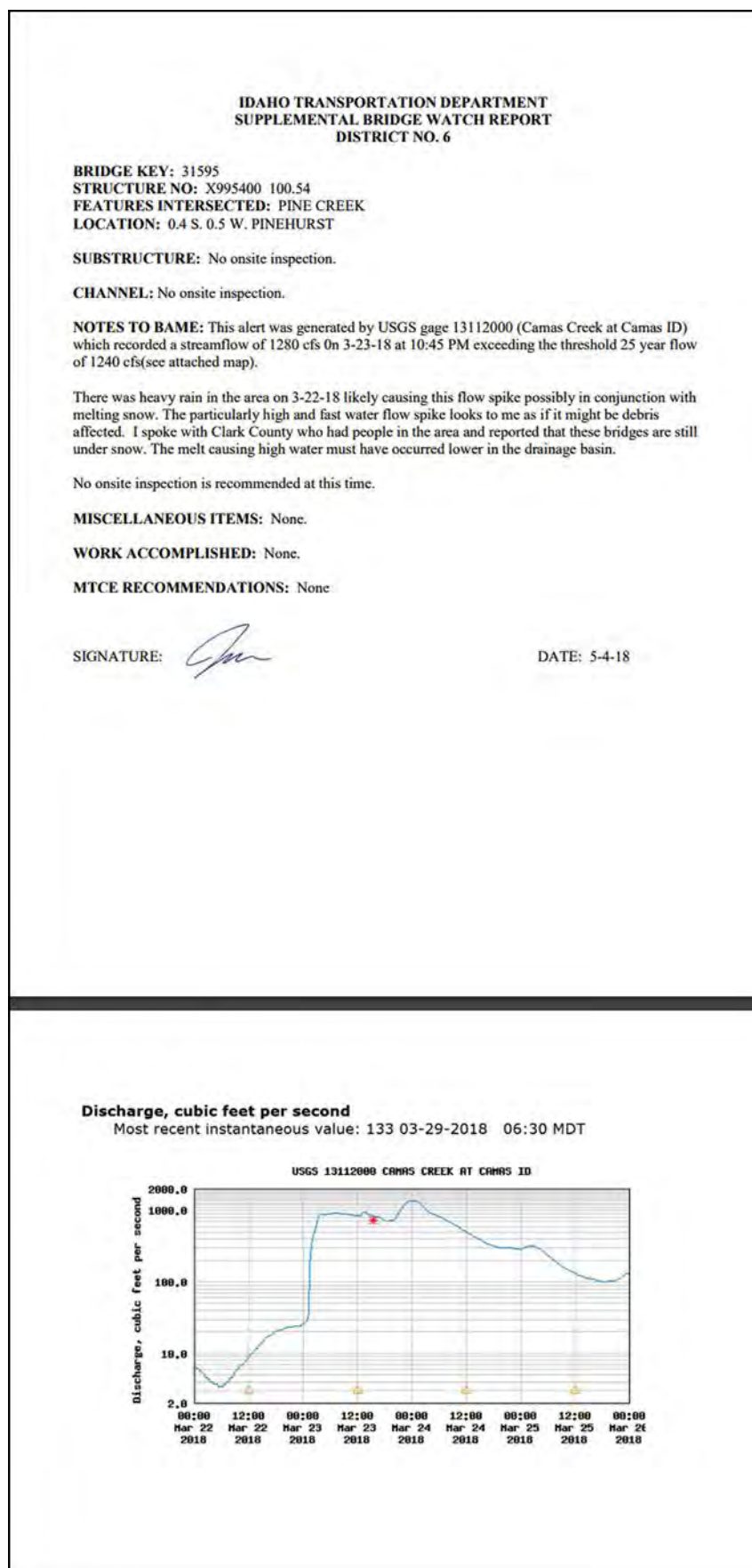


Figure 50. Supplemental BridgeWatch report for Bridge 31595.

As a result, alerts are first evaluated by the Bridge Asset Management section. If necessary, inspectors or local maintenance personnel are sent out to take photographs and make observations that will be used along with plans and historical information to assess the current safety of the bridge. If temporary closure is necessary, ITD communicates that information to the public through its communications department and the 511 website.

Addressing Challenges

ITD has identified several flood challenges and gaps within its flood monitoring, prediction, warning, and response methods. For flood monitoring, ITD explained the difficulty of relating its measurements from data sources to critical scour depths at a bridge. The current equations relating water flow to scour depth are conservative and almost always overpredict scour when compared with real scour observations. ITD also explained that when high-water events occur, it has great difficulty measuring scour on a typical bridge because of the velocity of water and debris often trapped against the piers. As water recedes, scour holes typically fill back up, making a maximum scour measurement nearly impossible using normal low-water inspection methods. The lack of accurate predictive scour equations and challenges in measuring scour during an event make decision making that properly balances safety and mobility difficult. To address this problem, ITD has implemented several research projects aimed at providing real-time scour depths to improve active management.

Currently, there are not enough active USGS stream gages to adequately monitor flooding at all bridges in the state. Existing gages might be in the basin, but not at the bridge. A \$0.5 million project with USGS intends to deploy gages rapidly, and ITD also uses private gages. It is difficult to predict flood events driven by rain on snow and snowmelt. The day-to-day nature of this flooding is challenging to monitor and predict. For flood response, too many BridgeWatch system alerts report a 25-year rainfall or snowmelt event that does not lead to high flows, or high flows that do not lead to scour. Therefore, these alerts need a lot of calibration.

Summary

The most successful practices within ITD are the Scour Committee and BridgeWatch. The ITD Scour Committee is composed of a diverse group of engineering disciplines. The range of experiences and fields within the committee offers unique insights into Idaho's scour problem. Membership within the committee has also been consistent since its formation. The span of this committee also promotes the dissemination of information throughout the DOT. This committee's success is also due to support from upper management. Moreover, BridgeWatch is considered a successful practice within the state because the BridgeWatch inputs are regularly updated and its outputs regularly monitored.

ITD suggests that other states share information because the more information shared, the better. It also suggests that other states form committees similar to ITD's Scour Committee. Another suggestion is to keep systems like BridgeWatch up-to-date because these monitoring systems are dynamic and require updates. ITD emphasized how critical real-time data are to effective flood monitoring.

Iowa

Background

In the state of Iowa, river flooding (e.g., overtopping banks) is the major type of observed flooding. This type of flooding is caused by heavy rains and snowmelt. Iowa's topography

consists of gently rolling plains of rich, deep topsoil. Roughly two-thirds of the state falls within the Mississippi River watershed.

Iowa DOT has been successful in incorporating BridgeWatch and the Iowa Flood Information System (IFIS) for providing real-time monitoring of weather-related data and automated alerts when infrastructure becomes vulnerable to flooding. Implementation of FHWA's Plans of Action (POAs) for scour critical bridges prompted the purchase of BridgeWatch to provide maintenance personnel with real-time monitoring and alerts of potential flooding at scour critical bridge sites. In addition, major flooding in 2008 resulted in the Iowa legislature's creating the Iowa Flood Center, which resulted in a real-time flood forecasting model to determine potential flooding along any stream within the state of Iowa. This approach has created ways to mitigate future flooding in Iowa and provide monitoring of potential flooding over frequently overtopped highway locations.

All programming and major design work are centralized at Iowa DOT. Districts handle maintenance and operation of the transportation system. Communication between districts is through a constant emergency operations hub system.

Flood Monitoring

The Bridge Bureau's hydraulic staff is responsible for flood monitoring, and the preliminary bridge supervisor oversees the monitoring and implementation of POAs through the BridgeWatch program. This system collects data from NWS's Doppler radar and federal and non-federal stream gages and compares the data with rainfall and stage thresholds that could impact infrastructure (bridge scour and roadway overtopping). Along with bridges, BridgeWatch monitors potential highway inundation and culverts. For small basins with frequent inundation, flood sensors developed by the Iowa Flood Center have been added (sensors read water surface elevation every 15 minutes and are monitored by the BridgeWatch program). Images, gage and point data, and staff inspections are collected for flood monitoring support. Data are stored in a repository that is accessed by users with BridgeWatch account privileges.

BridgeWatch was noted as a successful flood monitoring system for Iowa DOT. The automated alerts from BridgeWatch eliminate the human element in determining which bridges and highways could be impacted by flooding. Sometimes, the conservative thresholds have led to false positives and resulted in complacency for inspection and reporting when an alert has been issued. All scour critical bridges are now protected with countermeasures that have significantly reduced the risks and allowed Iowa's scour critical bridges to remain open during a flood.

Flood Prediction

The Iowa DOT Bridge Bureau is responsible for using BridgeWatch and hydrologic/hydraulic models to predict potential impacts on Iowa's transportation system. The hydrologic/hydraulic models used, HEC-RAS (one-dimensional) and TUFLOW (two-dimensional), predict the flood elevations and vulnerability of bridges and roadways during flood events. Iowa DOT's flood prediction model (BridgeWatch) is on an external platform, developed and managed by external consultants. Iowa DOT uses BridgeWatch to monitor weather-related data sources and compares them with infrastructure thresholds to provide a proactive warning for potential bridge and highway impacts due to flooding. Iowa DOT has been using two-dimensional modeling since 2010 to provide more accurate information related to the impacts to its highway infrastructure.

The flood prediction model incorporates precipitation (15-minute input) and stream stage and discharge data. Federal gage data and Iowa Flood Center sensor data (gage data and topographic data) are used by the flood prediction model.

The Iowa Flood Center uses IFIS (Appendix E) to provide real-time flood monitoring and forecasting, as well as inundation maps to assess impacts to communities from flooding due to NEXRAD rainfall, USGS gages, and Iowa Flood Center sensors. The Iowa Flood Center's hydrologic model is similar to the National Water Model currently under development through the National Water Center. IFIS is an interactive map for the public to view flood conditions, forecasts, inundation maps, and other flood-related information. Figure 51 shows IFIS with an overlay of precipitation forecast, river gage location, and river gage data.

Flood Warning

Flood warnings are issued by the National Weather Service, not Iowa DOT. Iowa DOT uses NWS NEXRAD radar for formal warnings and IFIS as another flood management tool. It was highlighted that the Flood Center's IFIS flood warning system is important as it is another "incident/layer" to alert the public. The DOT noted that its flood warning system is effective because of the warnings of the BridgeWatch system and IFIS. BridgeWatch provides a text message to district maintenance personnel and to Iowa DOT's 24/7 Traffic Operation Center.

Response System

The Emergency Management Office of Iowa DOT is responsible for flood response and is overseen by the director of the Operations Division. Other agencies involved in dealing with major flood events include the state police, state Emergency Management Agency, Governor's Office, FEMA, National Guard, and local government. In response to a flood event, Iowa DOT

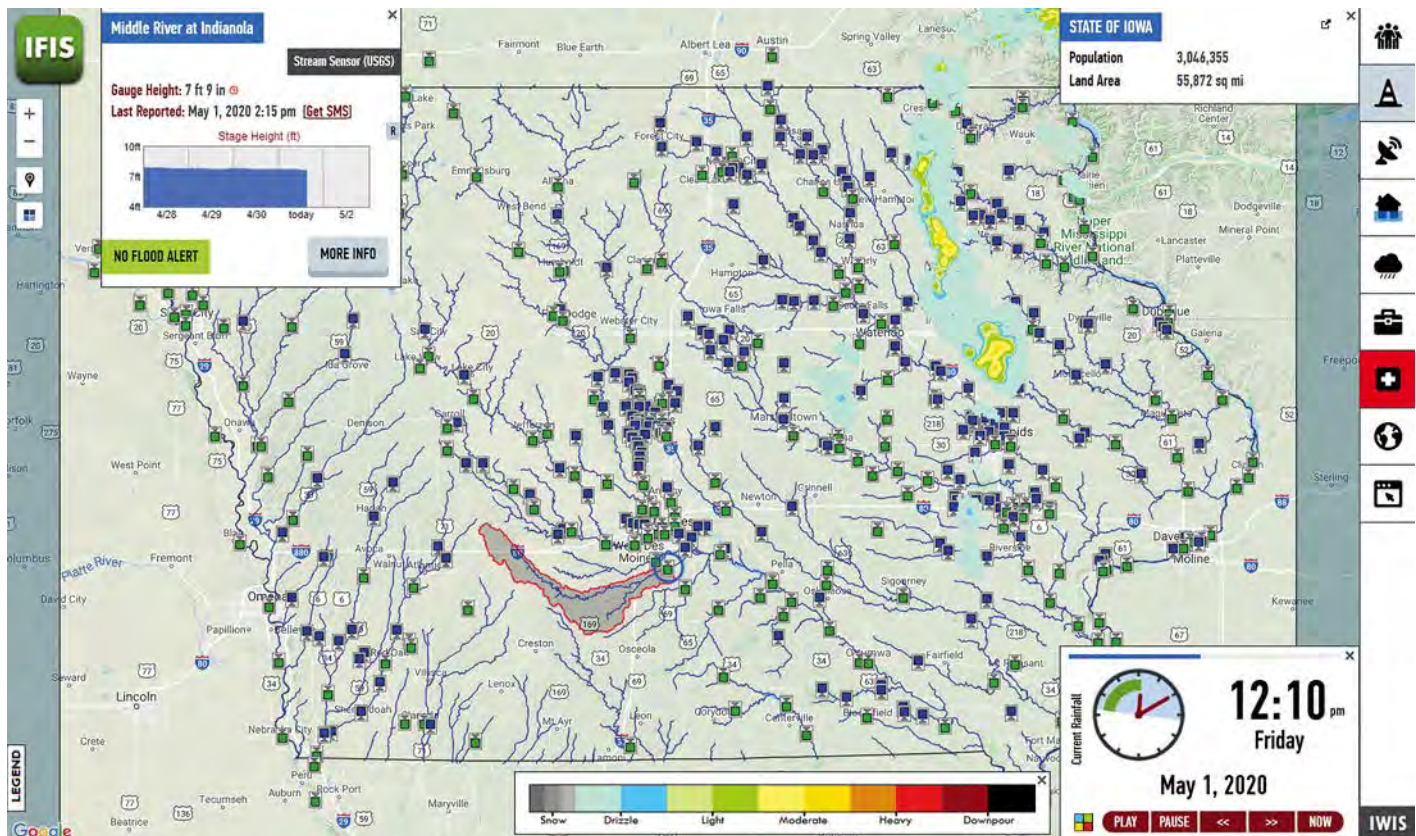


Figure 51. Screenshot of Iowa Flood Center's Iowa Flood Information System.

communicates internally through an email list, emergency management center, and conference calls. When working with other state agencies, it was noted that collaboration between districts, design, and emergency operations is a practice providing a common line of communication and decision making regarding flood events.

Iowa DOT has operation procedures and guidance for a flood response. Iowa has POAs for every scour critical bridge in the state and bridge-specific plans for closure. The DOT developed “Bridge Scour Management Plan—Standard Provisions” (Appendix F) to document standard procedures for inspecting and monitoring scour critical bridges during a flood. FHWA has published Hydraulic Engineering Circular, *Bridge Scour and Stream Instability Countermeasures* (volume 1) (2009), which provides some guidance for developing POAs. When a bridge is inspected, “Bridge Scour Management Plan—Standard Provisions” (presented in Appendix F) reports specific bridge inspection requirements, plan information, monitoring schedules, monitoring procedures, and critical streambed elevations. “ScourWatch Data,” now referred to as BridgeWatch (presented in Appendix F) reports the comments of Iowa DOT contacts and alerts for a bridge, gage data, and rainfall data.

In response to the flood of 2008, the Iowa Flood Center at the University of Iowa and the Iowa Department of Natural Resources have established a map—Iowa Draft Flood Hazard Products—for 85 counties declared presidential disasters. The map is a part of the Iowa Statewide Floodplain Mapping Project. The Iowa Draft Flood Hazard Products is a color map of flood hazard areas with 1% annual chance (100-year) and 0.2% annual chance (500-year) across the state of Iowa. Figure 52 shows the flood mapping of water bodies in the Des Moines area.

Addressing Challenges

A highlighted challenge of flood prediction by Iowa DOT includes communication and feedback from other districts. Proper and timely feedback from maintenance on the alerts is needed to assess the proper use of thresholds. Whenever the preliminary bridge supervisor and district get an alert, the district needs to convey the high-water elevation to assess the viability of the threshold. The preliminary bridge supervisor can adjust this measure to reduce false positive flood alerts, and this change requires feedback. Some districts are poor at providing feedback.

Another major challenge is integrating the real-time data with other agencies to provide automated warnings for other flood-vulnerable infrastructure. Iowa DOT hopes that the National Water Model can help integrate data with other agencies for providing warnings for other infrastructure. Furthermore, Iowa DOT would like a wider use of BridgeWatch (beyond DOT infrastructure) to benefit other infrastructure and other flood-prone areas outside Iowa DOT’s responsibility because it could protect assets and structures. Iowa DOT has notified other entities—such as Iowa Homeland Security, county emergency managers, and other agencies—of the importance and efficiency of the BridgeWatch system functions.

Iowa DOT wants to take the next step with BridgeWatch. The common linear referencing system is a good GIS system that shows potential flooding sites on a map. The DOT wants to expand the system to become a more management-friendly tool that can visually show red, yellow, or green stage “traffic light” visual coding to indicate the potential impact on infrastructure. Iowa DOT is currently working toward this goal and wants the real-time flood monitoring capabilities to be broader based and applicable to others.

Summary

Iowa DOT has demonstrated a dedication to improving its emergency flood monitoring and prediction. In response to FHWA POAs for scour critical bridges, Iowa DOT has successfully

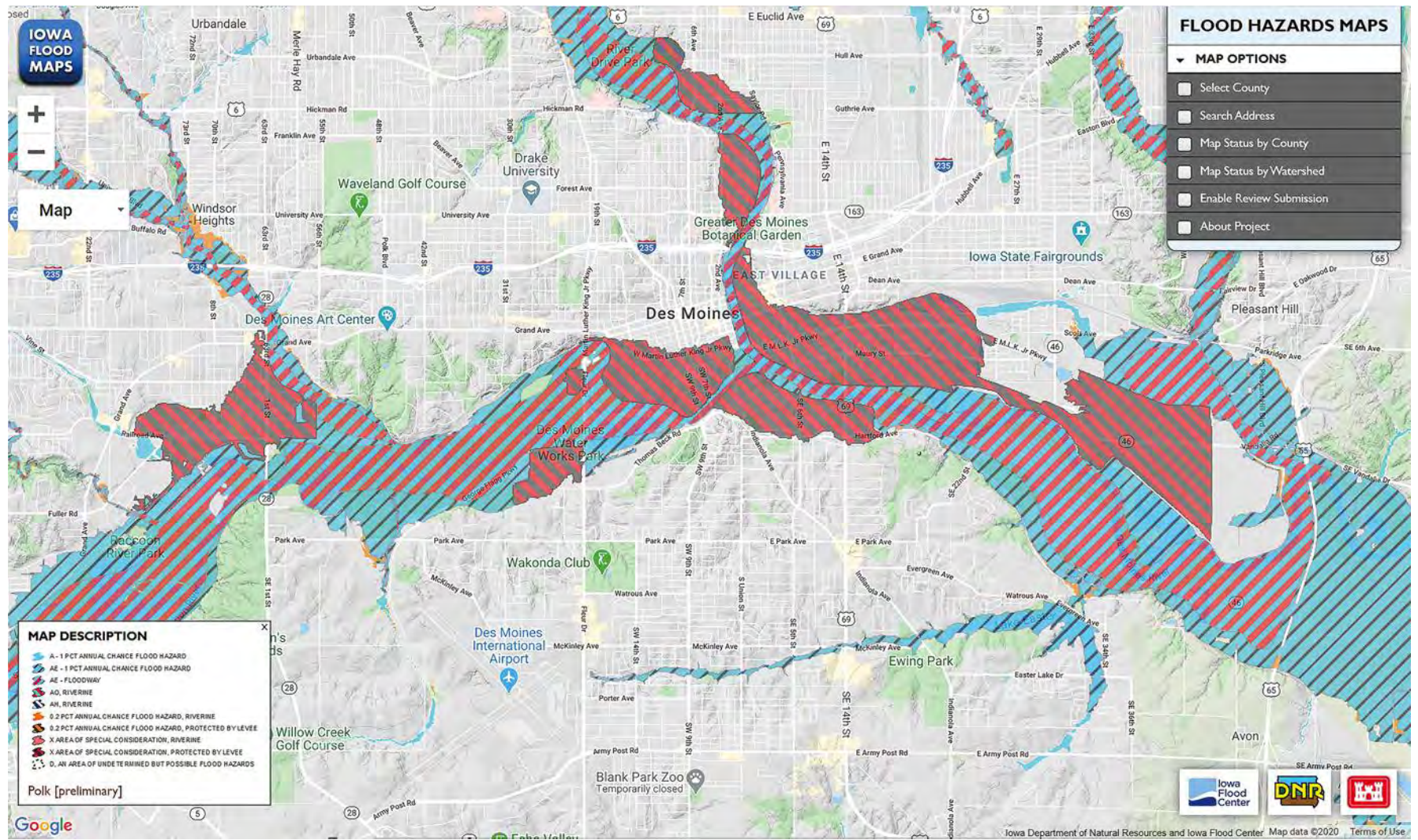


Figure 52. Screenshot of Iowa Draft Flood Hazard Products map.

implemented BridgeWatch. The program has eliminated the human element for determining when flooding is severe enough to warrant inspection of infrastructure by monitoring weather-related assets and comparing those inputs with rainfall and stage thresholds for highway overtopping and scour critical bridges. The data collected have allowed for successful flood predication modeling and implementation of FHWA POAs. Iowa DOT recognizes that the challenges are improving communication and feedback and integrating BridgeWatch and real-time weather-related data with other agencies. Iowa DOT notes that it would like to leverage real-time capabilities and automated alerts to enhance public safety. By focusing resources where flooding will occur, unwarranted inspections of bridges or monitoring of roadway sites will be eliminated, better allocating resources and saving public costs. Furthermore, Iowa DOT has found success with the prediction of floods by the Iowa Flood Center and information shared in the Iowa Flood Information System.

New York

Background

New York State is located in the northeastern United States and has a diverse landscape of mountains, coastline, plateaus, and lowlands. The state experiences river flooding, surface and overland flooding, and some coastal flooding. These types of flooding are caused by heavy rain, snowmelt, storm surge, and sea level rise and land subsidence.

In 1987, New York State experienced the Schoharie Creek Bridge failure, which was the impetus for incorporating scour into all new bridge designs nationwide. In 1990, in direct response to this event, the Bridge Safety Assurance Unit was formed. The New York State Department of Transportation (NYSDOT) works closely with USGS for flood prediction. Because the geology, hydrology, and hydraulics (i.e., groundwater and backwater) are substantially different for Long Island than for the rest of the state, USGS is currently working on addressing flood prediction for Long Island for NYSDOT.

New York State has a Statewide Transportation Information and Coordination Center (STICC) located in NYSDOT's main office. STICC is part of the Office of Traffic, Safety, and Mobility. This office is where NYSDOT plans for emergency (e.g., hurricanes, blizzards) response and where supplies, equipment, and manpower are procured and distributed. NYSDOT has more than 20 hydraulic engineers who are distributed across 11 different regions and the main office. These hydraulic engineers work closely with one another and with state maintenance engineers.

Flood Monitoring

In 1990, NYSDOT created a bridge flood watch and inspection list from a hydraulic vulnerability assessment. NYSDOT ranked all statewide bridges on the basis of their vulnerability to scour failure. These rankings are updated if the bridge is replaced. The rankings may also change if the regional hydraulic engineer determines that a change is warranted. A change is triggered by either routine biannual inspections or frequent visits by the regional hydraulic engineer. These changes in ratings may lead to the design of countermeasures.

This program is managed by maintenance personnel in all counties of the state. The program relies heavily on the institutional knowledge of the county-based maintenance specialists, who are familiar with the bridges in their area. When NWS sends a text or email flood warning for a particular county, a maintenance team is sent out to observe the condition of the bridges on their list that are vulnerable to scour. The field teams check the bridges to see whether they have met certain thresholds (i.e., high-water markings on the bridge) and to watch for signs of failure.

A bridge will be closed if it is deemed unsafe by meeting critical thresholds during a flood watch. In the event a bridge is closed, the team will conduct a post-flood inspection of the bridge before it is reopened by a licensed professional engineer.

Flood Prediction

NYSDOT has a close relationship with USGS that dates back 40 to 50 years. NYSDOT uses USGS's StreamStats for flow predictions. USGS in Troy, New York, has developed regression equations specifically for New York State within the national StreamStats program, which are a more precise fit to New York State than the general StreamStats approach. Data from gages were used to develop regression equations for NY StreamStats, a program to determine predicted peak flows specific to the state. If a large flooding event occurs, USGS can obtain recurrence intervals for New York State to calibrate hydraulic models of rivers and streams. USGS renews the regression equations about every 10 years. The new bridge substructures are designed to withstand StreamStats-predicted 100- and 500-year flood events. Current state regression equations do not cover Long Island because of the need to account for different geology and hydraulics (i.e., groundwater and coastal backwater). USGS is now in the process of determining regression equations for Long Island for NYSDOT.

StreamStats is used more than 90% of the time. When StreamStats is not applicable, NYSDOT uses stream gage data (where available), FEMA flows, or other methods. NYSDOT always validates which flows should be used by checking the history and alternate methods and always makes sure that the method and the use of the data are checked for quality control.

USGS developed Future StreamStats as an estimate for future flows. Future StreamStats uses the existing regression equations paired with the predicted future rainfall intensity data. This tool does not have the accuracy to be used for prediction of site-specific future flows and should not be used for design; NYSDOT used Future StreamStats to best estimate trends for future flows. Generally, the trends show a 20% increase in future flows for eastern New York State and a 10% increase for western New York State. To account for future resiliency or climate change, this general approximation of change is paired with the current NYSDOT StreamStats outputs to project the flows for new designs.

Flood Warning

NYSDOT has a hydraulic vulnerability program that ranks bridges on the basis of certain factors like scour. Based on this list, the findings are mapped with NWS warnings to identify points of risk. NYSDOT is currently reviewing its Hydraulic Vulnerability Manual to see whether any changes are warranted. NYSDOT's San Diego Domestic Scan presentation (Appendix F) provides insight into its hydraulic vulnerability procedures, shown in Figures 53 and 54.

NYSDOT is developing an Upstate New York Flood Warning System that will use precipitation and stream gages (existing and newly installed) and weather forecasts. This flood warning system will address three watersheds that have a recurring flooding problem in 27 counties in Upstate New York. The new system will allow for more precise flood warnings, including time to peak water levels. Projected flood inundation produced from this system will be available through an online mapping system (Dewberry and Venner Consulting 2015).

Addressing Challenges

NYSDOT receives countywide flood warnings through the NWS. New York's weather is highly variable across the state due to micro-climates. As a result, only part of a county may be experiencing flooding, whereas other parts of the county are unaffected. NYSDOT still conducts a quick inspection of all bridges on the list if a warning is received.

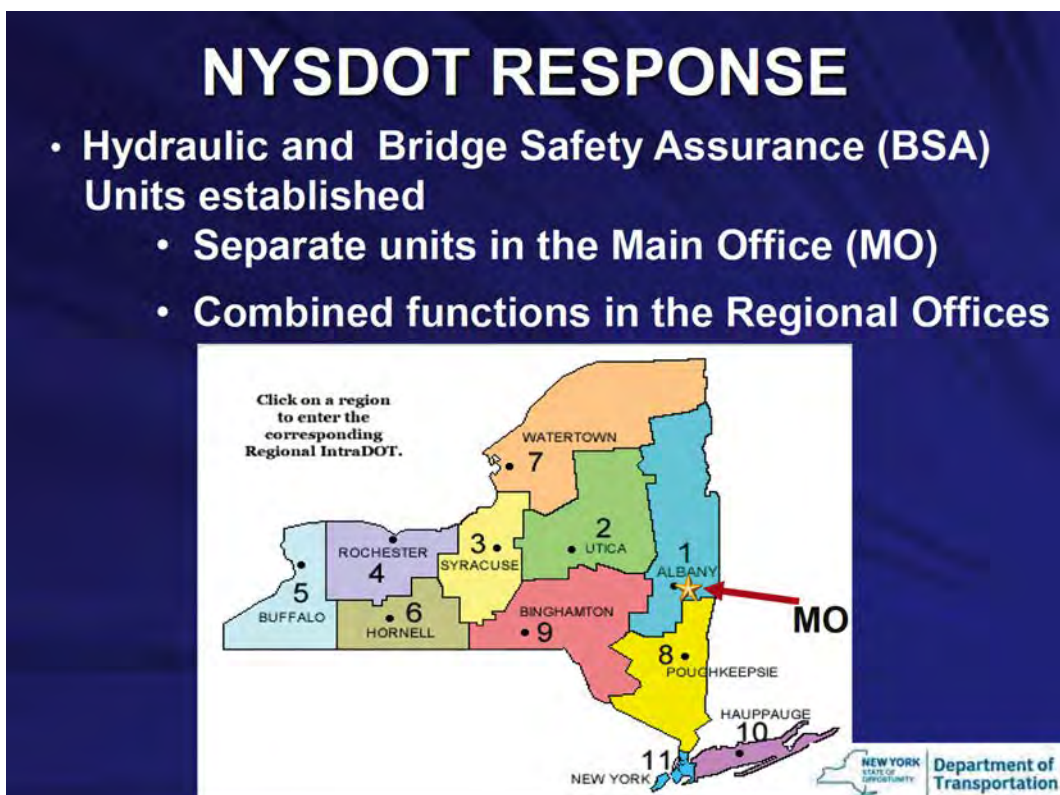


Figure 53. NYSDOT response.

Element 800 – SCOUR

This element is used to evaluate the loss of the material next to and under a substructure (Unit = ft)

Condition	Condition State 1	Condition State 2	Condition State 3	Condition State 4
	GOOD	FAIR	POOR	SEVERE
Scour (6000)	None	Exists within tolerable limits or has been arrested with effective countermeasures.	Exists that exceeds tolerable limits but is less than the critical limits determined by scour evaluation but does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.

Figure 54. Element 800—Scour.

Other challenges include predicting flood conditions in coastal backwater zones (e.g., Long Island). These areas are subject to storm surges, sea level rise, and land subsidence. NYSDOT considers sea level rise when planning coastal bridges but is sometimes unable to fully incorporate sea level rise into its work because of limitations from existing infrastructure. In these cases, the maximum design possible is used. Additionally, backwater hydraulics are a modeling challenge, as discussed earlier.

Following Community Risk and Resiliency Act (CRRA) regulations, signed in 2014, NYSDOT used Future StreamStats to develop trends to predict future flows using existing StreamStats and projections of future rainfall intensity. The state is currently reviewing the Hydraulic Vulnerability Manual to see whether any updates are needed.

Summary

To maintain safe bridges during flooding events, New York State uses hydraulic vulnerability assessments, flood warnings, flood watches, and post-flood inspection programs. After CRRA guidance was established to consider climate change for future designs, NYSDOT used StreamStats with the current state regression equations in combination with a multiplier developed from trends obtained from Future StreamStats to obtain future flows for new designs. The design policy for bridges is to design for 2 feet of freeboard for the future Q50 water surface elevation and to pass the future Q100 water surface elevation. Substructures are designed to withstand the future Q100 flow and are checked for the future Q500 flow. For coastal bridges, New York State considers future sea level rise and maximizes the opening as limited by existing infrastructure. USGS is currently working on developing regression equations for Long Island because of the difference in geology and groundwater present on Long Island.

North Carolina

Background

North Carolina is located on the southeastern coast of the United States. In North Carolina, coastal flooding, river flooding (e.g., overtopping banks), and surface and overland flooding (e.g., due to poor drainage) are major types of observed flooding. Some of the causes of flooding include storm surges, sea level rise and land subsidence, king tides, heavy rain, and riverbank overtopping.

Recently, North Carolina has experienced multiple major storms, including Hurricane Floyd (1999), Hurricane Matthew (2016), and Hurricane Florence (2018). These events have been catalysts for many changes and improvements made to strengthen North Carolina's flood management and response. North Carolina Department of Transportation's (NCDOT) Central Technical Services units support their state's 14 division offices. NCDOT owns and maintains more than 80,000 miles of roads statewide, including most major municipal routes (nearly all roads in North Carolina, except major city roads).

Flood Monitoring

NCDOT has a strong Research and Development Unit that coordinates research with multiple university research teams on topics that are pertinent to NCDOT's interests. The following are examples of recent research that has been completed, is currently underway, or is starting soon:

- A flood abatement assessment for Neuse River basin, including flood mitigation prioritization studies for Windsor, Goldsboro, Smithfield, and Kinston
- A study to advance the use of artificial intelligence to improve efficiencies in processing terrestrial LiDAR and bathymetric sonar data for hydraulic structures

- Numerical computational fluid dynamics (Delft3D) hydraulic modeling to assess bridge scour
- Evaluation of two-dimensional hydraulics models to improve scour predictions and countermeasures, including fiberoptic scour monitoring technology use
- Predictions of roadway washout locations during extreme rainfall events based on forecasted rainfall, hydrologic/hydraulic modeling, and machine learning algorithms to predict washout locations and develop a network of safe routes within a watershed.

NCDOT's Hydraulics staff is actively involved in AASHTO and TRB committees related to hydraulics, hydrology, and stormwater management. NCDOT has a relationship with the State Climate Office at North Carolina State University, which has developed a Multi-Frequency Precipitation Estimator application that the DOT Hydraulics staff uses for design and analysis on DOT projects.

The floodplain management data—produced by the North Carolina Emergency Management (NCEM) Flood Risk Information System (FRIS) (Appendix E)—are used statewide by more than 650 municipalities and various state agencies, including NCDOT. All FEMA flood insurance data are available to North Carolina citizens through public access via this NCEM FRIS web application. This system is an all-digital data system that has enabled a streamlined FEMA National Flood Insurance Program (NFIP) compliance review and approval process for NCDOT projects statewide. The North Carolina Floodplain Mapping Program (NCFMP) and NCDOT entered into an MOA (Appendix F) in 2008 to bring NCDOT into compliance with FEMA NFIP regulations. All project submittals and correspondence are entirely digital in the FRIS system. Private engineering firms that are contracted to NCDOT and NCEM use FRIS for all flood data needed for flood studies. As the largest “developer” in the state, NCDOT provides current data on an ongoing basis for all DOT projects statewide that are affecting FEMA-regulated special flood hazard areas. This method improves the quality of the FRIS flood data.

The Flood Inundation Mapping and Alert Network (Appendix E) for emergency preparedness and response in extreme events provides critical statewide information for first responders and recovery efforts. This real-time flood mapping system has one of the most robust surface transportation flood warning systems in the United States (Dewberry and Venner Consulting 2015). The FIMAN-T application—the transportation-specific version of FIMAN—is currently in development and will leverage FIMAN's success to provide a similar enhancement to NCDOT's operational emergency preparedness and response capabilities. NCDOT is working to incorporate a coastal surge component into the FIMAN-T system.

Flood Prediction

NCDOT relies on FRIS and FIMAN/FIMAN-T for flood prediction model development and management. These systems are developed and maintained for NCEM by both in-house staff and external consultants. NCEM does not regard the FIMAN/FIMAN-T system as a flood prediction model because that role is seen as belonging to the National Weather Service. NCEM is careful to avoid public release of flood prediction information that might be inconsistent with that provided by NWS. However, some limited predictive functionality is available to the extent that some gages in the FIMAN system are associated with the Southeast River Forecast Center that provides limited forecast data regarding expected peak flow time and stage. NCEM is currently exploring the use of the National Water Model for future predictive analysis. Unmanned aerial vehicles (UAVs) are not currently used in prediction, but research into their use is underway. NCDOT has used UAVs to capture high-water information following recent major hurricanes. NCDOT's Photogrammetry Unit is currently assisting its Hydraulics Unit by digitizing high-water mark data from these events, which will be used for future reference in flood modeling studies.

Flood Warning

NCDOT recently launched the BridgeWatch application, which it expects to use internally for flood warning, among other things. Initially, NCDOT will need to determine the appropriate optimal thresholds from both stream gage data and precipitation forecasts to trigger alerts to provide effective flood warning for bridges in the state. Over time, with ongoing use of the BridgeWatch system, NCDOT Hydraulics expects this tool to be a valuable asset for flood warning, operational awareness, emergency response, and risk assessment.

Response System

North Carolina lost 740 structures in Hurricane Matthew. To facilitate recovery efforts, NCEM worked with NCDOT and FEMA for approvals for replacements of flood-damaged emergency structures to reopen the roads quickly. During Hurricane Florence, a representative from the NCDOT Hydraulics Unit went to the Emergency Response Center to coordinate with NCEM regarding resources that were available for NCDOT. In the Hydraulics Unit, a temporary “war room” was set up that comprised NCDOT’s internal staff and on-call consultants. These consultants had expertise in emergency flood response. The goal of this temporary “war room” was to provide effective and efficient information to assist the secretary of NCDOT with recovery and response efforts, and to provide information for public briefings.

This experience resulted in the realization that the state’s GIS layer of road networks lacked elevation data. In response, NCEM created a LiDAR model of North Carolina’s roadway network with elevation data. This model has allowed NCDOT to develop algorithms that use the intersection of flood inundation layers with the road elevation data to show when roadways are flooded. NCDOT funds positions at NCEM to provide support during extreme events. These job positions focus on NCDOT interests. In an effort to leverage a successful inter-agency relationship between NCEM and NCDOT, NCDOT has established and funded two positions within NCEM—one engineer and one GIS specialist—to facilitate and support NCDOT interests. This support includes ongoing FEMA NFIP regulatory compliance for NCDOT projects and, in emergencies, providing effective emergency preparedness and response capabilities.

The North Carolina Floodplain Mapping Program, which is under NCEM, is a designated Cooperating Technical Partner for FEMA. NCFMP was established in 1999 because of a flood mapping gap that was realized following Hurricane Floyd. NCFMP became a Cooperating Technical Partner with FEMA in 2000 and began remapping North Carolina’s regulatory flood insurance maps. NCFMP coordinates with more than 650 individual municipalities in North Carolina. This program helps NCDOT by having to coordinate with only one state agency rather than with each individual municipality affected by DOT projects with respect to FEMA NFIP compliance approvals. This program also helps ensure that FEMA staff is not overwhelmed and helps keep NCEM strong.

Addressing Challenges

The backwater zone in coastal estuaries is a major challenge for NCDOT because this is the most complex area to model. NCDOT is working on a component within FIMAN-T to take the coastal surge ADCIRC (advanced circulation) model data provided by the Coastal Emergency Risks Assessment (CERA) application and process them to correlate with detailed terrain models from statewide LiDAR data. These data then intersect with road network elevation data to estimate flood inundation on coastal area roadways that cannot be evaluated by riverine hydraulic inundation models.

In the case of flood monitoring, FIMAN-T is only applicable where stage gages are present. The system can only be used where inundation maps are developed. This factor makes effective

growth of the FIMAN-T system for the whole state of North Carolina difficult, so NCDOT plans to use virtual gages in the future. Virtual gages would involve the future modeling of rain on grid for multiple rain events or having the capability to run models in cloud computing applications before the event. It is hoped that these processes will provide valuable information for prediction as virtual gages. This information will be combined with observations to increase awareness and to build artificial intelligence into the system.

NCDOT has difficulties in tracking hydraulics on smaller river systems. NCDOT also has difficulties with maintaining and installing gages and is currently investigating its specific gage needs. NCDOT aims to optimize its gage network and increase coverage to fill in gaps across the state.

NCDOT needs more sophisticated modeling in coastal areas for flood prediction. NCDOT needs a better predictive model, because NCDOT currently relies on limited predictive model data from other agencies, such as the Southeast River Forecast Center, which only use data from stream gages on certain large rivers in North Carolina. It would likely be better to have state-wide predictive data tied to the National Weather Model from NWS. Also, the current FIMAN/FIMAN-T flood inundation libraries are based on one-dimensional hydraulic models, which are not as detailed and accurate as two-dimensional hydraulic models. These two-dimensional models are becoming more widely used for hydraulic analyses. In the future, NCDOT anticipates using two-dimensional HEC-RAS hydraulic models that are currently being developed by NCEM to help provide more efficient and accurate flood inundation models statewide to evaluate smaller watersheds within the larger river basins.

Additionally, working to maintain stream gages through partnerships will be an ongoing challenge as NCDOT grows its statewide stream gage network. A number of state and federal agencies and private interests benefit from and become increasingly dependent on a reliable and robust statewide stream gage network. NCDOT and NCEM hope to leverage resources through partnerships with other state and federal agencies and private interests to fund and maintain this valuable resource.

Summary

NCDOT has a close relationship with NCEM, TRB, AASHTO, FEMA, and numerous universities, which has helped develop and maintain its state's strong flood management and response systems. NCEM FRIS allows NCDOT's FEMA NFIP process to become more streamlined, as all project submittals and correspondence are entirely digital. FIMAN-T, the transportation-specific version of FIMAN, is currently in development. One of FIMAN-T's ultimate goals is to create operational models to predict flooding.

NCDOT currently relies on FRIS and FIMAN/FIMAN-T for flood prediction model development and management. NCDOT aims to develop a more sophisticated model for coastal areas in the future because these areas prove to be difficult to assess. Additionally, NCEM is exploring the use of the NWM for future predictive analysis. For flood warning, NCDOT is at an early stage of using BridgeWatch and is working to determine appropriate alert thresholds for the state.

NCDOT works with NCEM and FEMA on recovery efforts. NCEM's NCFMP provides simplified coordination so that NCDOT needs to coordinate with only one agency with respect to FEMA NFIP compliance approvals for DOT projects. NCDOT-funded job positions at NCEM create increased support during extreme events and ongoing routine support to facilitate FEMA NFIP approvals for NCDOT project delivery.

NCDOT experiences challenges in modeling backwater zones and needs more sophisticated modeling in coastal areas. Virtual gages are being explored to assist with flood monitoring

efforts. NCDOT hopes to optimize its gages and to increase gage coverage throughout North Carolina to fill in gaps across the state. NCDOT wants to develop a better predictive model so it does not need to rely on other agencies for predictive modeling needs.

South Carolina

Background

Located on the southeastern coast of the United States, the state of South Carolina experiences coastal flooding, river flooding (e.g., overtopping banks), and surface and overland flooding (e.g., due to poor drainage). Some of the causes for such flooding include storm surge, king tides, and heavy rain. South Carolina experienced major storms between 2015 and 2018, such as Hurricane Matthew (2016) and Hurricane Florence (2018). These flood events resulted in South Carolina DOT (SCDOT) improving coordination with other state and federal agencies. Figures 55 and 56 contain a visualization of how SCDOT investigated Hurricane Matthew and Hurricane Florence, respectively, through rainfall maps, which help SCDOT with flood predictions. These maps are usually produced post-storm.

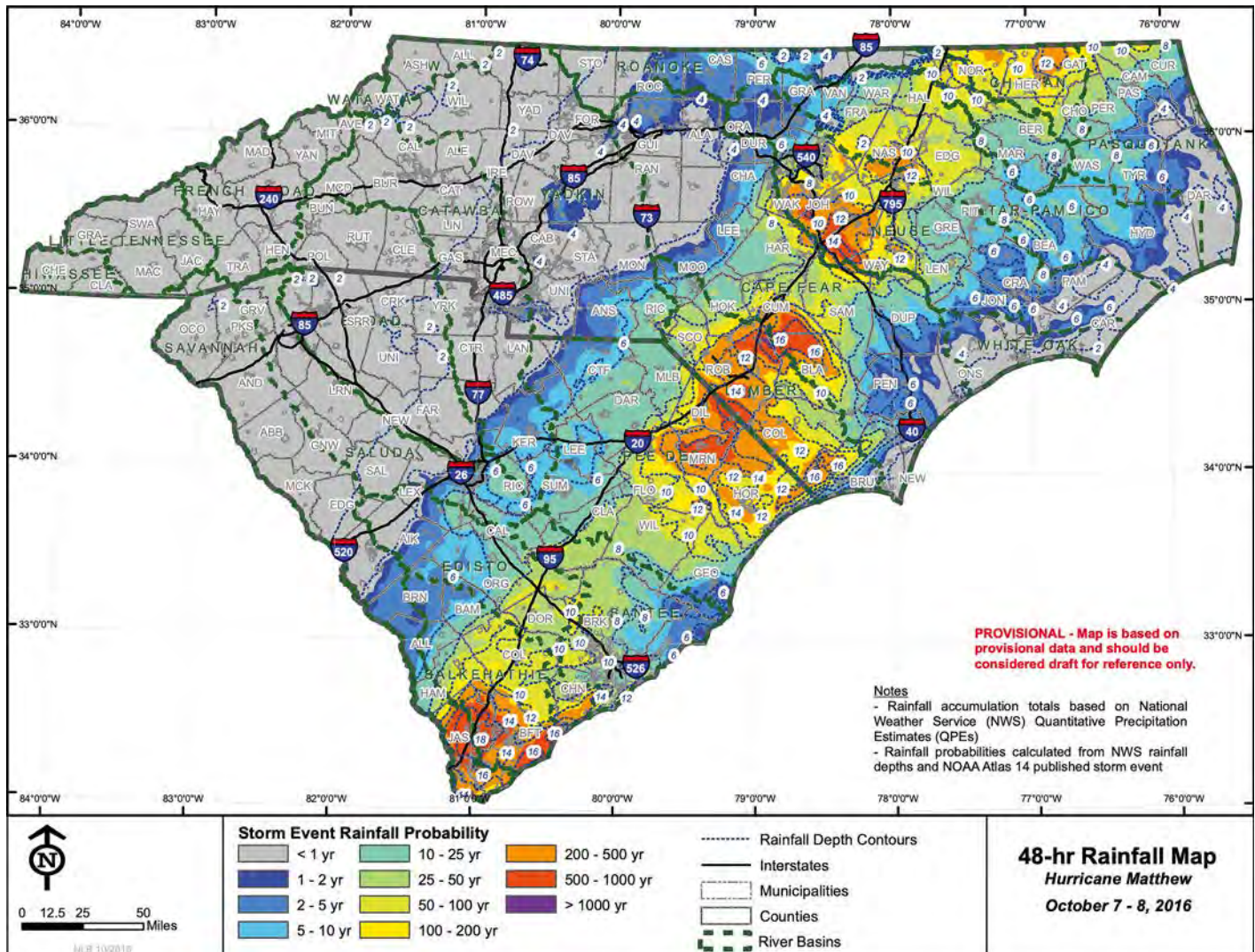


Figure 55. Hurricane Matthew 48-hour rainfall map.

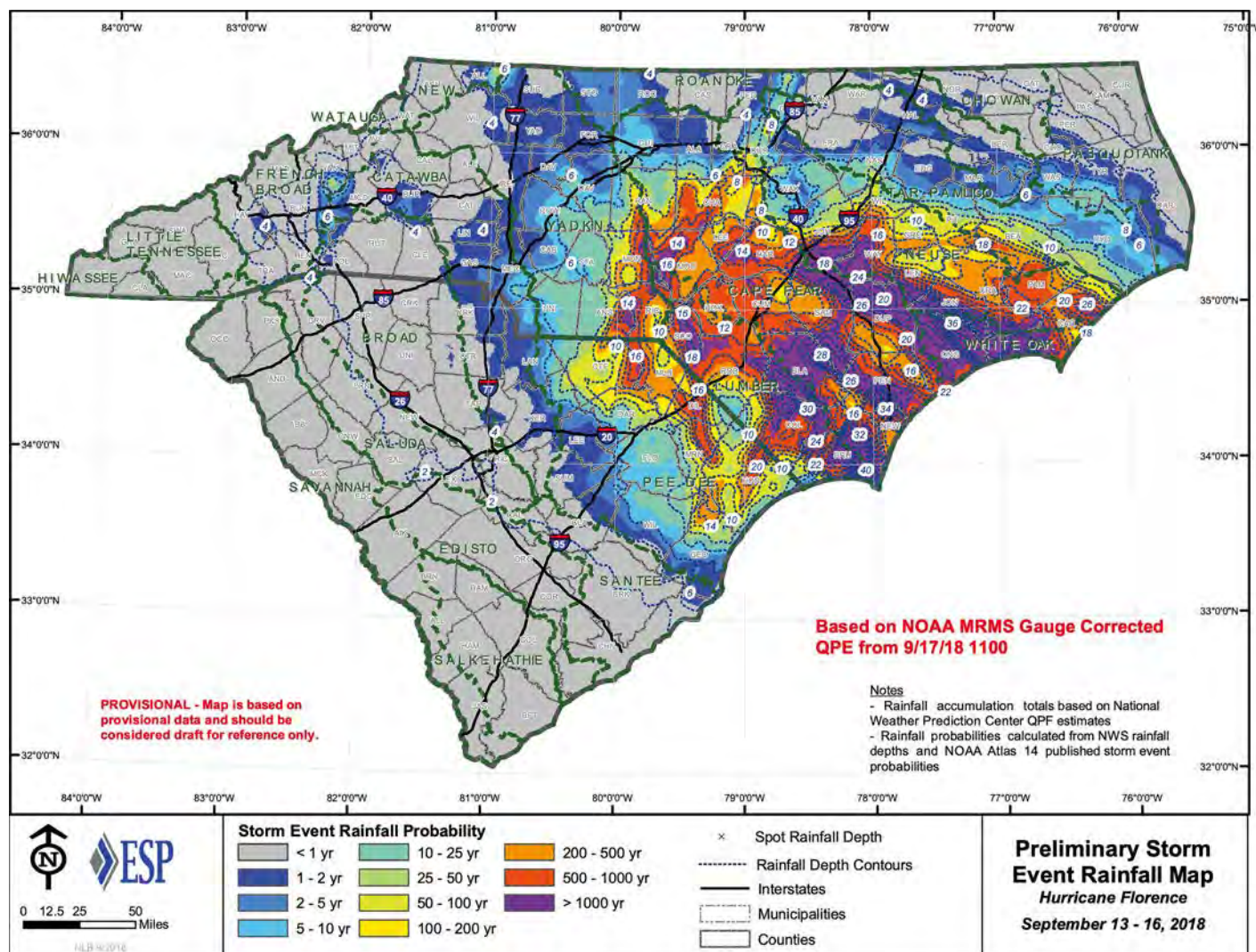


Figure 56. Hurricane Florence preliminary storm event rainfall map.

SCDOT is centralized with all preconstruction activities conducted within its headquarters. For flood response, SCDOT works at the state level with the South Carolina Emergency Management Division, other state agencies, and the National Guard. It coordinates with FHWA on recovery efforts. SCDOT also works on flood predictions with its Department of Natural Resources (SCDNR), whose main focus is on community-level flooding. SCDOT and USGS have a strong record of collaboration, because USGS owns and operates most of the state's gages. These collaborative efforts contribute greatly to the success of SCDOT's integrated flood systems.

Flood Monitoring

A long-term effort is currently underway to develop a South Carolina Flood Inundation Mapping (SCFIM) program. SCDOT plans to work with SCDNR to develop the application and website to help address extreme climate and flooding issues. The SCFIM application will also be helpful in sharing data and communication. At the time of this synthesis development, this program was not yet operational, but it will be accessible to both public and private users.

SCDOT has developed flood monitoring spreadsheets that integrate NWS, SCDNR, and SCDOT predictions; monitoring data; and high-water marks. This spreadsheet is shared internally

in the form of a graph, which can be used in reports. Figures 57 and 58 present example graphs on the flood monitoring spreadsheets.

SCDOT uses USGS's StreamStats, river cams, and BridgeWatch for flood monitoring. Coordinating with USGS, SCDOT has customized StreamStats to show SCDOT bridges and roadway information. SCDOT is currently working to add enhancements. SCDOT also plans to use National Weather Service outputs in the future and does not use the National Water Model at this time.

SCDOT has an Excel database containing Resiliency Survey information. This spreadsheet integrates resiliency along corridors with structure features, including stream crossings, bridge low chords, and bridge elevations (east and west). The spreadsheet contains visual locations of the recorded data, which makes it easier to locate these points in the field. Figures 59 and 60 show, respectively, a portion of the Resiliency Survey spreadsheet (Appendix F) and images for the U.S. 501 Resiliency Corridor Survey.

Flood Prediction

SCDNR uses a two-dimensional model for inundation modeling. Documentation for the model is currently under development. The model uses recurrence intervals and rainfall from

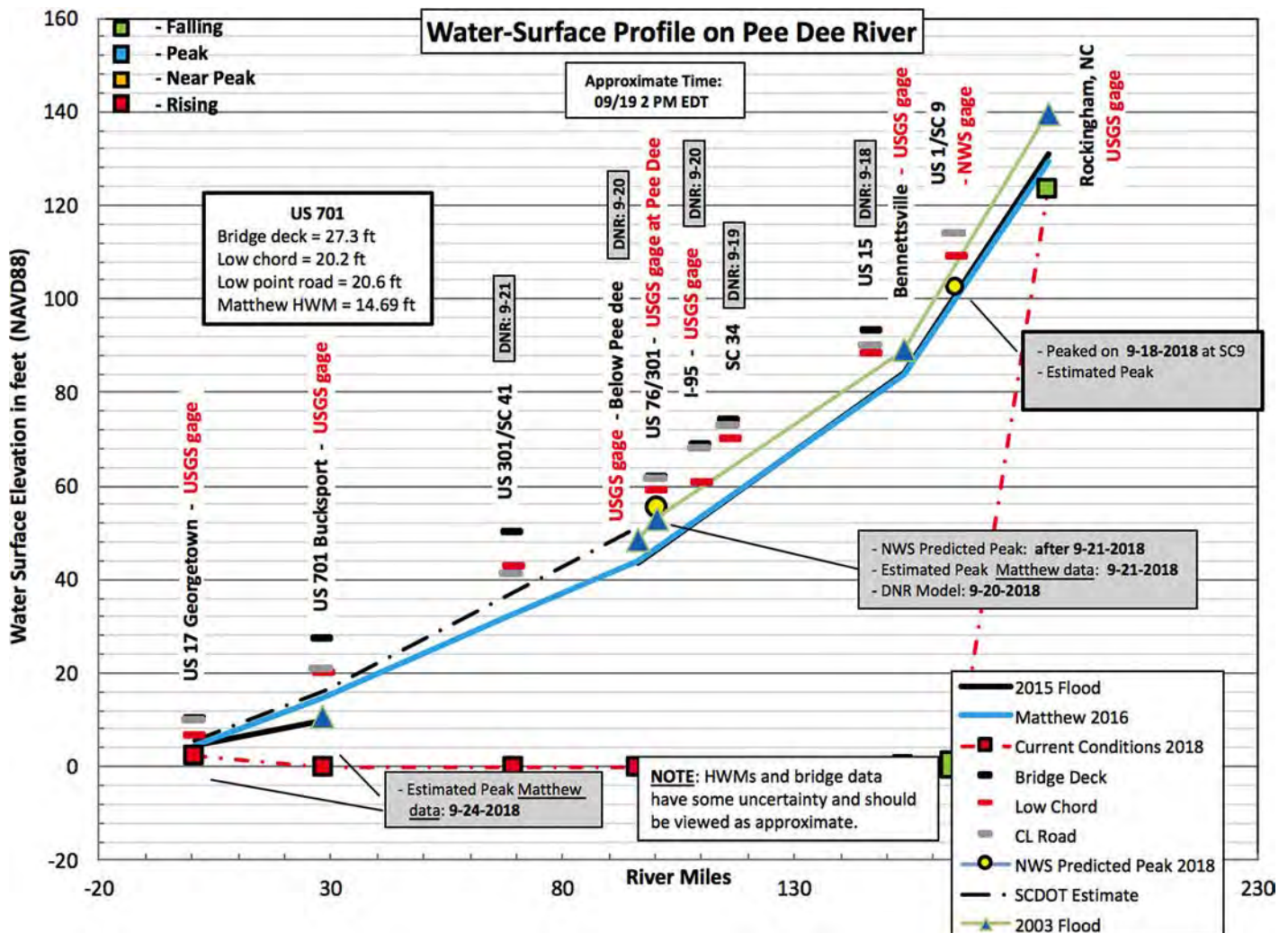


Figure 57. Sample water-surface profile on September 19.

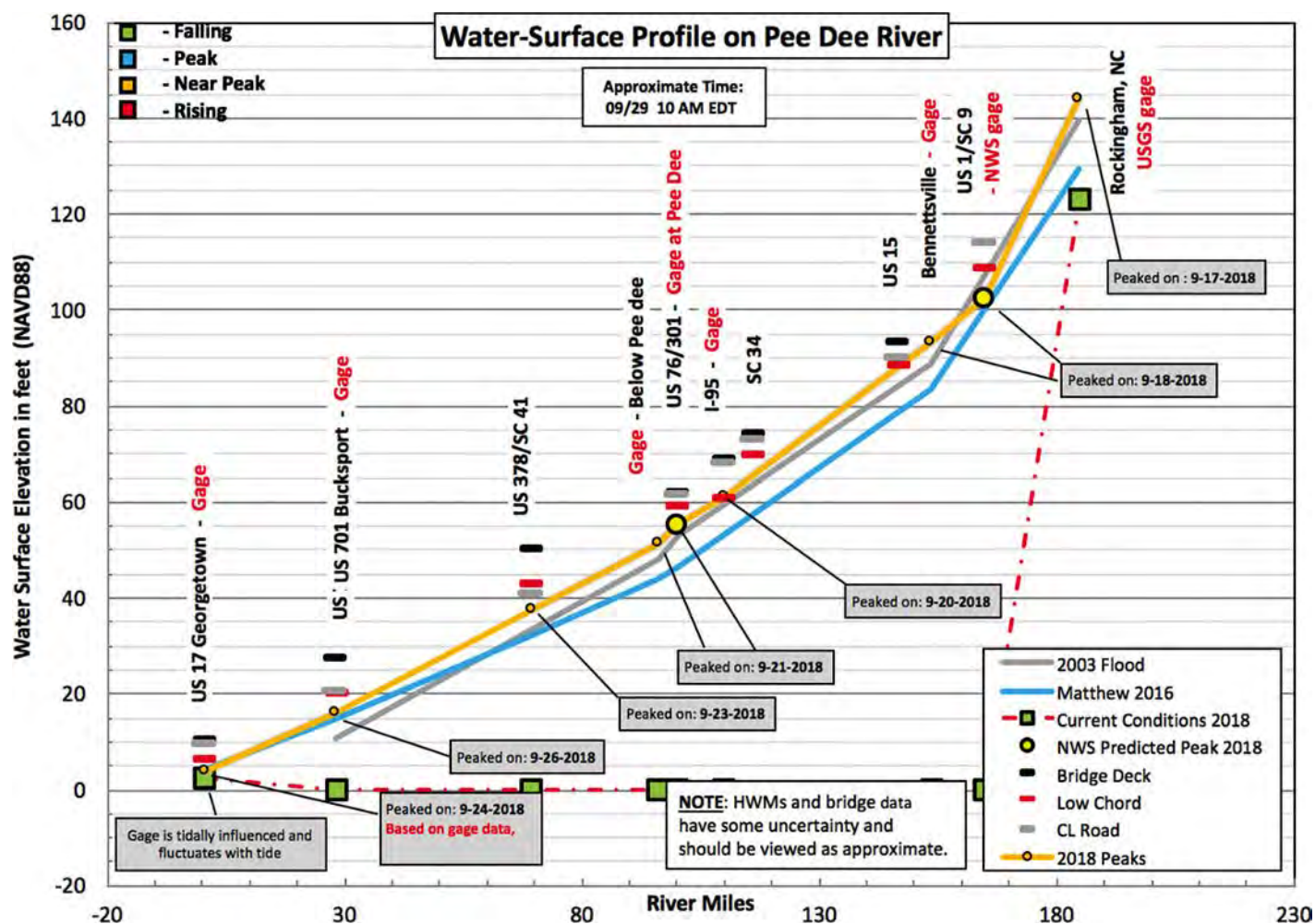


Figure 58. Sample water-surface profile on September 29.

actual events and applies the Unit Hydrograph Method of the Natural Resources Conservation Service. SCDOT is in discussions with SCDNR on using the Unit Hydrograph Method, which allows for weighted peak rate factors and rainfall durations of less than 24 hours. SCDOT also uses surface modeling systems with SRH-2D for two-dimensional modeling, which is an FHWA graphical user interface for several hydraulic models.

Flooding events in 2015, 2016, and 2018 have helped improve SCDOT's coordination with other federal and state agencies. This better coordination is important because it has improved communication on flood monitoring and prediction between agencies. SCDOT collaborates with USGS on funding for USGS gages and in pre- and post-event communications. SCDOT works closely with SCDNR despite operating with different missions. SCDNR's mission is community-level flooding, whereas SCDOT focuses on transportation, lifelines, preservation of open evacuation routes, and its monitoring system. SCDOT also collaborates with the National Guard and other state agencies while working toward its mission.

SCDOT decided to move forward with the BridgeWatch program after Georgia DOT shared its system during Hurricane Florence in 2018. The initial phase of BridgeWatch for SCDOT focused on bridges that are scour critical, evacuation routes, interstates, and important crossings. SCDOT is working toward fully deploying BridgeWatch for all bridges. BridgeWatch allows SCDOT to view rainfall, storm surge flow, and hurricane tracking in a geospatial format. This ability allows SCDOT to see its bridge locations along with the data. The program allows

US-501 RESILIENCY CORRIDOR SURVEY												
Number	MP	Details	Structure Number	Asset Number	Stream Crossing	Bridge Low Chord (ft)	Begin Bridge C.L. Elev.(ft) West	End Bridge C.L. Elev.(ft) East	Begin Bridge Right West Edge(ft)	Begin Bridge Left West Edge(ft)	End Bridge Right East Edge(ft)	End Bridge Left East Edge(ft)
			US-501		(34) MARION DIST 5	NAVD 88 Datum						
1	20.52		3420050130600	560	BACK SWAMP	43.43	45.50	45.29	45.19	45.26	44.99	45.05
2	20.514		3420050110600	6543	BACK SWAMP	43.55	45.66	45.70	45.27	45.14	45.26	45.15
3	22.047		3420050130700	561	LITTLE PEE DEE SWP -1	43.38	45.25	45.35	44.94	45.00	45.03	45.10
4	22.05		3420050110700	6544	LITTLE PEE DEE SWP -1	43.56	45.55	45.56	45.14	45.06	45.17	45.09
5	22.388		3420050130800	562	LITTLE PEE DEE SWP -2	43.53	45.29	45.44	45.03	45.09	45.12	45.22
6	22.391		3420050110800	6545	LITTLE PEE DEE SWP -2	43.31	45.35	45.42	44.92	44.84	44.95	44.86
7	22.661		3420050130900	563	LITTLE PEE DEE SWP -3	43.65	45.49	45.41	45.18	45.24	45.12	45.20
8	22.663		3420050110900	6546	LITTLE PEE DEE SWP -3	43.15	45.36	45.43	44.97	44.85	44.88	44.77
9	23.199		3420050131000	564	LITTLE PEE DEE SWP -4	43.43	45.28	45.72	44.98	45.05	45.41	45.49
10	23.201		3420050111000	6547	LITTLE PEE DEE SWP -4	43.61	45.64	45.60	45.23	45.09	45.22	45.11
11	23.38		3420050131100	565	LITTLE PEE DEE SWP -5	43.92	45.81	45.80	45.51	45.56	45.50	45.59
12	23.38		3420050111100	6548	LITTLE PEE DEE SWP -5	43.53	45.52	44.45	45.07	44.94	45.08	44.98
			US-501		(26) HORRY DIST 5	NAVD 88 Datum						
13	0.004		2620050130100	546	LITTLE PEE DEE RIVER	43.10	45.80	44.89	45.49	45.56	44.58	44.64
14	0.004		2620050110100	6512	LITTLE PEE DEE RIVER	43.43	45.43	45.46	45.03	44.92	45.03	44.91
15	20.741	STRUCTURE	2620050105200	2753	US-501 BYP. - WACCAMAW RIVER	24.09	28.20	27.99	27.86	27.78	27.54	27.53
16	1.922		2620050103100	793	US-501 BUSINESS - WACCAMAW RIVER	23.35	31.26	25.41	31.49	31.04	25.40	25.34
17	2.5		2620050103200	794	US-501 BUSINESS - WACCAMAW BACKWATER #1	16.01	17.92	17.92	17.65	17.66	17.66	17.63
18	2.904		2620050103300	795	US-501 BUSINESS - WACCAMAW BACKWATER #2	16.09	18.02	18.03	17.77	17.77	17.76	17.77

Figure 59. U.S. 501 Resiliency Survey data.

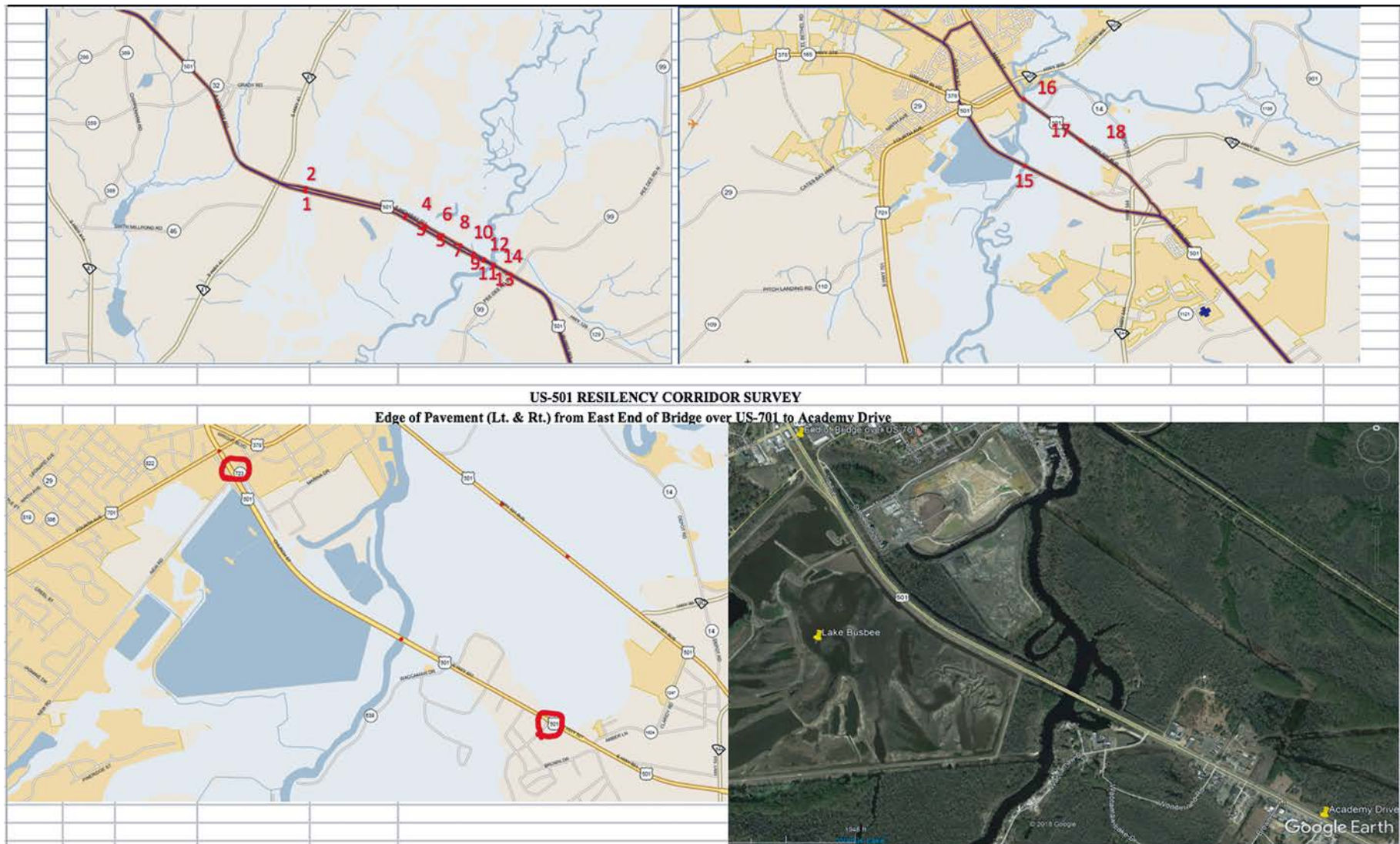


Figure 60. U.S. 501 Resiliency Survey visuals.

SCDOT to set thresholds for predicted rainfall, actual rainfall, predicted surge, and flows at structures. This capability allows SCDOT to monitor the system and flag locations that could have issues. BridgeWatch is working on adding CERA outputs for tidal surge, rainfall maps from historical events, Plans of Action for scour critical bridges, and data collection.

SCDOT also uses NWS, SCDNR, and its own predictions in an Excel spreadsheet for planning and operations. This approach has been a great success for coordinating event operations. Experience has helped SCDOT manage different types of flooding, allowing it to use previous events to help guide predictions of flooding. SCDOT has found that using similar events to predict current floods has improved the accuracy of its predictions. This is the most accurate method of the methods and predictions SCDOT has used.

SCDOT is developing a GIS database for high-water marks. This is being done through digitizing information previously stored in paper files from historic flood events. This method of prediction by water surface elevation is particularly useful in backwater areas of the state, where other models fail to accurately predict flooding.

Flood Warning

SCDOT uses BridgeWatch for flood warning by monitoring more than 1,600 structures. This program helps with rainfall prediction, hurricane tracking, structure notes, flood alerts, USGS gage flow, and scour critical thresholds. Using BridgeWatch will improve communication and data sharing within SCDOT. SCDOT notes that BridgeWatch allows it to bring in a lot of spatial information as GIS files. BridgeWatch has given SCDOT a good platform to monitor and manage its bridges over water.

Key attributes contributing to SCDOT's success in addressing flooding issues include USGS's improving its websites during events by making all of the information available on one site. NWS is also working on its own website and models to improve prediction. SCDOT and USGS have worked together to develop the Rapid Deployment Gage Network and the Real-Time Scour Monitoring Program. This effort has allowed SCDOT and USGS to extend USGS gage monitoring to sites of concern. This system has allowed SCDOT to select sites for USGS to preinstall brackets for gages and to build gages that are dedicated for SCDOT use. SCDOT and USGS work together to determine where to locate the rapid deployment gages (RDGs). The Real-Time Scour Monitoring Program includes sonar sensors, river cams, and gages at multiple locations around the state. SCDOT has found USGS's river cams to be an effective tool for monitoring important sites. SCDOT stresses the importance of working with field personnel to help decimate information on current conditions and model validation. Developing monitoring and prediction spreadsheets can also help improve the communication of information with upper management and decision makers and across the agency.

SCDOT recommends sharing data and improving relationships with other divisions in order to foster communication. SCDOT noted how these relationships can also be developed and improved by sharing how its work can be mutually beneficial. Each state has its own different experiences and great practices that would benefit others through sharing. Communication between divisions has strengthened through working together during multiple events. SCDOT has noted that this trend in its relationships with USGS and SCDNR has improved over the years.

Response System

SCDOT response efforts start before an event begins and involve all units within the agency. The precursors to an event, storm, or flooding in another state are monitored by the Hydraulic Design Support Office (HDSO) using information from the National Hurricane Center, NWS Advanced Hydrologic Prediction Service, USGS, CERA, SCDNR, and experience from previous

events. Coordination meetings are held with all units involved in preplanning, monitoring, evacuation support and traffic counterflow, and response. This approach allows SCDOT to pre-position assets and develop response plans. USGS is contacted by HDSO to determine locations for RDG deployments. Road Data Services monitors roadway-related data and develops mapping products. Personnel from other units volunteer to work in the Customer Service Center to help provide customers with prompt and professional assistance related to the event. Procurement works with other units on emergency-related items.

Monitoring efforts continue until the event has ended. Monitoring involves HDSO's developing predictions, reviewing predictions from other agencies, reviewing gaging and other types of data, and communicating the information to other units within SCDOT. Part of this effort involves developing water surface profiles, shown in Figures 57 and 58, to communicate current conditions and their comparison to historic conditions on affected rivers. Maintenance forces with help from other units—including the Construction and State Highway Emergency Program—work to determine locations that should be closed to traffic and that need repair. Traffic helps develop detour routes for closures. The GIS/Mapping Section of Road Data Services works with other units to develop and maintain GIS products related to the event to help with internal communication.

The post-event phase involves recovery efforts and data collection. Maintenance, Construction, Preconstruction, and Traffic work to determine recovery needs and cost. HDSO coordinates with USGS to collect high-water marks and with consultants to develop event-related rainfall maps and other data products. HDSO may collect high-water marks using its staff or data collected by Maintenance and Construction. HDSO makes post-event visits to affected bridges and roadways to examine the effects of the event and to gain insight for future events.

SCDOT collaborates with multiple state and federal agencies throughout all phases of the event. FHWA provides funding and helps develop plans to reopen routes after an event. In extreme conditions that impact a wide area across the state, the Office of Emergency Management and the Governor's Office will activate the Emergency Operations Center. The EOC will manage and coordinate resources, including the needs of local entities. The National Guard helps with evacuation and deploys measures to protect critical roadways from being closed by flooding.

Addressing Challenges

From the late 1910s until the 1980s and 1990s, communication and data sharing were more fluid between SCDOT divisions. The recent floods have shown the need to improve communication and data sharing across divisions. Initiatives within and across divisions are making progress both horizontally and vertically. Improving communication efforts on all fronts can ensure that no convolutions occur in the process.

As for flood prediction, tidal models affecting the backwater are difficult to develop because of a lack of information. These tidal models are also more costly. SCDOT is following North Carolina and Louisiana's lead in working with INTERA (a private consulting firm) on coastal modeling to predict wave effect on coastal bridges.

Another gap identified by SCDOT is the need for more states to be open to peer exchange opportunities. Such opportunities will allow states to share their own experiences and best practices with one another, so all states can benefit.

Summary

SCDOT is centralized with all preconstruction activities conducted in its headquarters. Since recent flood events, SCDOT has improved its communication with other agencies by sharing

data and working together during an event. SCDOT collaborates with USGS, SCDNR, FHWA, and other agencies but believes that there is always room to improve communication efforts. Gaining a deeper understanding of other agencies and the tools and data they use can be mutually beneficial. Communication can also be improved through platforms such as the development of flood monitoring and prediction spreadsheets.

The BridgeWatch program has allowed SCDOT to view its bridge locations in a geospatial format with event and rainfall prediction data. The program allows SCDOT to monitor its system and flag locations that may have issues or risks during an event. BridgeWatch also assists in hurricane tracking, USGS gage flow, structure notes, alerts, and scour critical thresholds. The program has allowed SCDOT to cut down on any necessary networks and file and data sharing while also letting it bring in a lot of GIS files. Cutting down on the hunt for information can help in times of crisis.

Texas

Background

In the state of Texas, coastal flooding, river flooding (e.g., overtopping banks), and surface and overland flooding (e.g., due to poor drainage) are common types of observed flooding. Causes of such flooding types include tropical storms and depressions, storm surges, and heavy rain. The geographic diversity of Texas includes the North Central Plains (central Texas), Great Plains (west-central Texas to the Panhandle), hilly region (west Texas), and the Gulf Coastal Plain (east Texas), all with different types of flood risks. Several watersheds run across the state, northwest to southeast. Over the past five years, Texas has been hit by major storms (Harvey and Imelda) causing major floods in the Houston District, Beaumont District, and central Texas (“Flash Flood Alley”), which includes major cities—Dallas, Fort Worth, Austin, and San Antonio.

The state consists of 25 Texas DOT (TxDOT) districts. All 25 districts in Texas are responsible for flood monitoring and flood response, working with the TxDOT Design Division’s Hydrology and Hydraulics Section when support is needed.

Flood Monitoring

The 25 TxDOT district offices are responsible for flood monitoring. Each district has a least one Maintenance Office per county. The District Maintenance Offices have teams that are responsible for flood staging and response. The District Maintenance Offices in each county are responsible for recording stage levels from visual and physical inspection. When a crossing or roadway is flooded or nearly overtopped, triggering the roadway to be closed, the information is added to the Highway Condition Reporting System (HCRS), which supplies the data for DriveTexas.org (Appendix E).

Each TxDOT district is responsible for its entries into HCRS. Each district has an HCRS coordinator and backup HCRS coordinator who maintain district personnel’s access and HCRS contacts within the district. TxDOT has more than 1,800 employees and contractors who have access to HCRS and can update conditions shown on DriveTexas.org.

Monitoring data are shared through a public online platform managed by TxDOT’s DriveTexas.org. The platform provides an interactive map for public users to inspect highway conditions, including current flood conditions. Flood information is uploaded throughout the day by each of the 25 districts. Figure 61 shows the DriveTexas.org interactive map and an updated flood condition report.

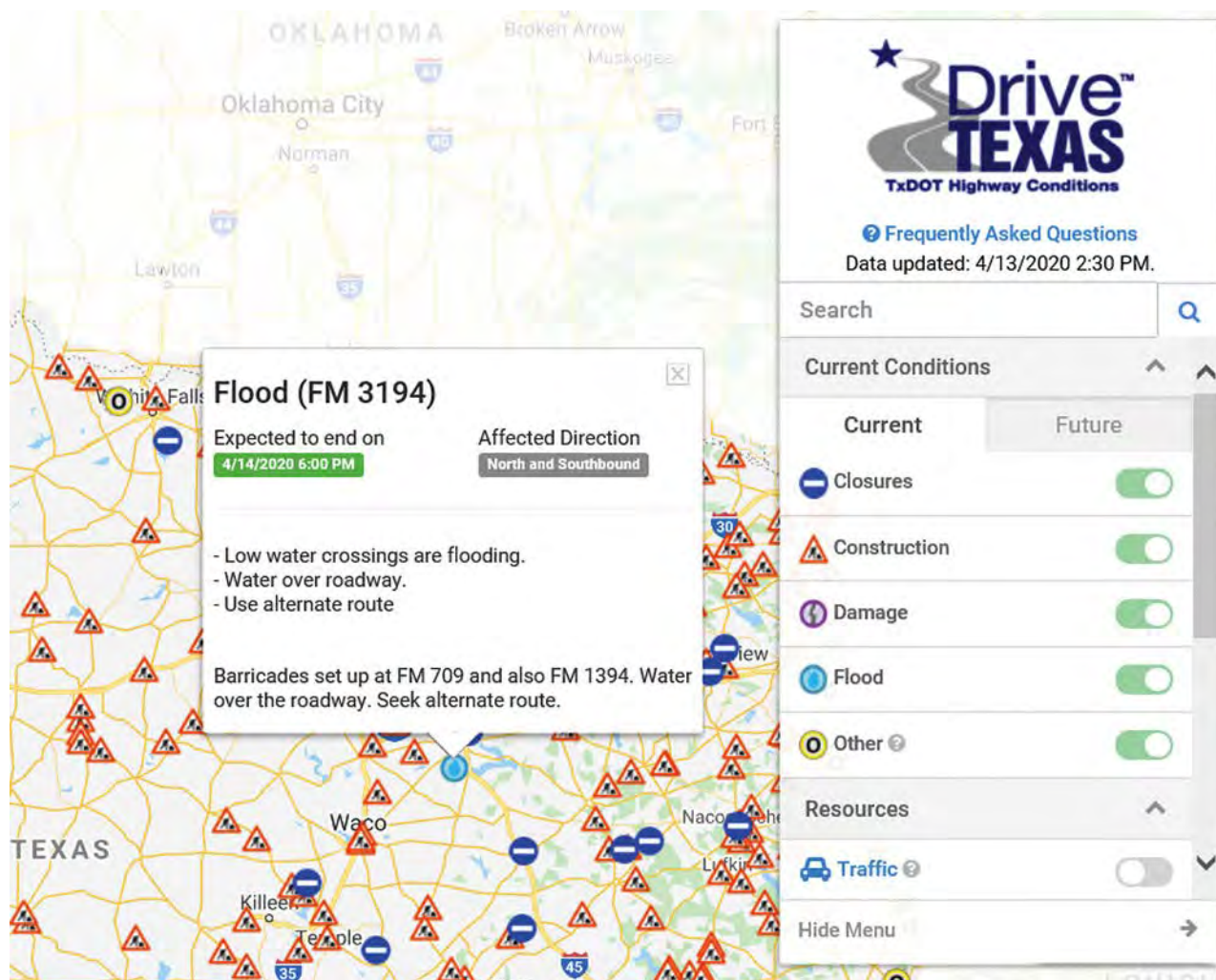


Figure 61. Example of flood update on DriveTexas.org.

TxDOT posts flood monitoring guidelines in an online platform. This webpage (Appendix E) has links to TxDOT Twitter feeds, winter travel guidelines, snowplow safety, flash flood guidelines, and hurricane guidelines.

Flood Prediction Research

TxDOT has recently completed a research project, “Streamflow Measurement at TxDOT Bridges” (Streamflow I), and has recently started a second research project, “Evaluate Improved Streamflow Measurement at TxDOT Bridges” (Streamflow II). The central goal of the two research projects is to strategically install a network of radar gage equipment on TxDOT bridges to supplement the USGS gage network used by the National Water Model. The NWM is a flood prediction model that was developed by the NOAA’s Office of Water Prediction. The NWM incorporates precipitation (one-hour timestep) and stream discharge observations to provide flood prediction on 2.7 million segments of the national stream network, as part of the weather forecasting system of the United States. The TxDOT research gage network will be used to validate the forecasted water levels and velocities. The first Streamflow Measurement research project was completed by the University of Texas at Austin under the leadership of Dr. David Maidment.

A presentation of “Streamflow Measurement at TxDOT Bridges” was prepared for TxDOT by the Center for Water and Environment at the University of Texas at Austin (Appendix F). Figure 62 shows a story map of UT-TxDOT radar gage sites for the TxDOT Streamflow Measurement System along the I-10 corridor with links to charts of battery charge, velocity, stage, and flow rate. TxDOT has also successfully installed 20 gages on 20 bridge crossings. Gages have been in operation for two years. Figure 63 shows a database of stream cross-sections.

The current flood prediction research, Streamflow II, is being completed by University of Texas and USGS. A total of 60 gages are proposed to be installed on Texas bridges. Streamflow II research will be completed in August 2023.

Success of the model is based on the type of information output, accuracy, and timing of information. TxDOT noted that a predictive model needs to give responders more time, even a few hours. TxDOT envisions that flood stage is presented relative to the low chord in an easy-to-read graphic showing a profile of the roadway and bridge with a calibrated vertical scale. An easy-to-read graphic shows the bridge and roadway profile relative to water surface elevation profiles for current conditions; short-range and medium-range predictions will be provided as an output. Districts can make decisions quickly when the information is laid out in this format. Additional information will be presented for velocity and discharge.

Flood Warning

TxDOT has not established flood warning guidelines, but there are threshold parameters (water surface elevation distance to low chord or edge of pavement) that districts apply to issue flood warnings or to determine when a roadway should be closed to traffic. Each district has its own emergency response team that also acts as a unit. Key attributes and factors leading to the success of the flood warning system are an accurate flood prediction system and accurate flood monitoring system.

Response System

The 25 TxDOT districts are responsible for flood response in coordination with the State Police, State Emergency Management Agency, Governor’s Office, Public Health, Department of Environmental Protection, Department of Water Resources (Bureau of Water), Department of Fish and Wildlife, FEMA, National Guard, and local government. TxDOT communicates internally through an internal emergency contact tree and Emergency Management Center. Other state agencies participate and communicate with the Response Command Center when flooding occurs.

Addressing Challenges

In Texas, with the increasing frequency of flooding events, there is an increase in the flood challenge response. A challenge for TxDOT is sharing, storing, and managing the flood-related data. Data need to be brought together and incorporated from counties, cities, and other agencies that have established gage networks and early warning systems. A common database system is needed. It was noted that TxDOT would like to incorporate gage data from other agencies in lieu of duplicating gaged reaches.

No culverts or storm sewers are in the central database. TxDOT sees a need for a central hydraulic database for flood resiliency assessment management and performance assessment (level of service). Additionally, a completed statewide inventory is needed that includes performance and flood risk assessments. This need is in response to a change in rainfall depths in Texas,

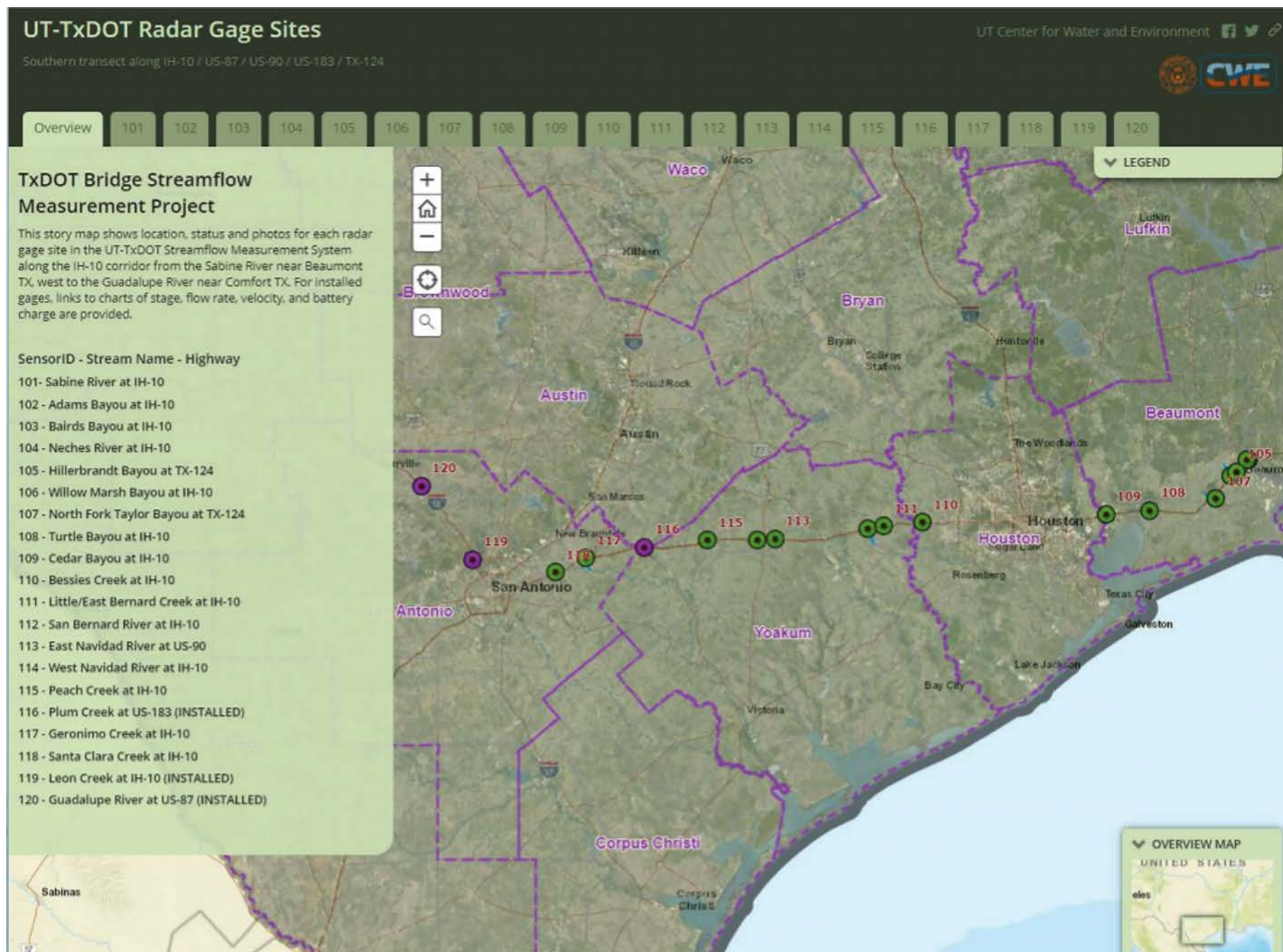


Figure 62. UT-TxDOT radar gage sites.

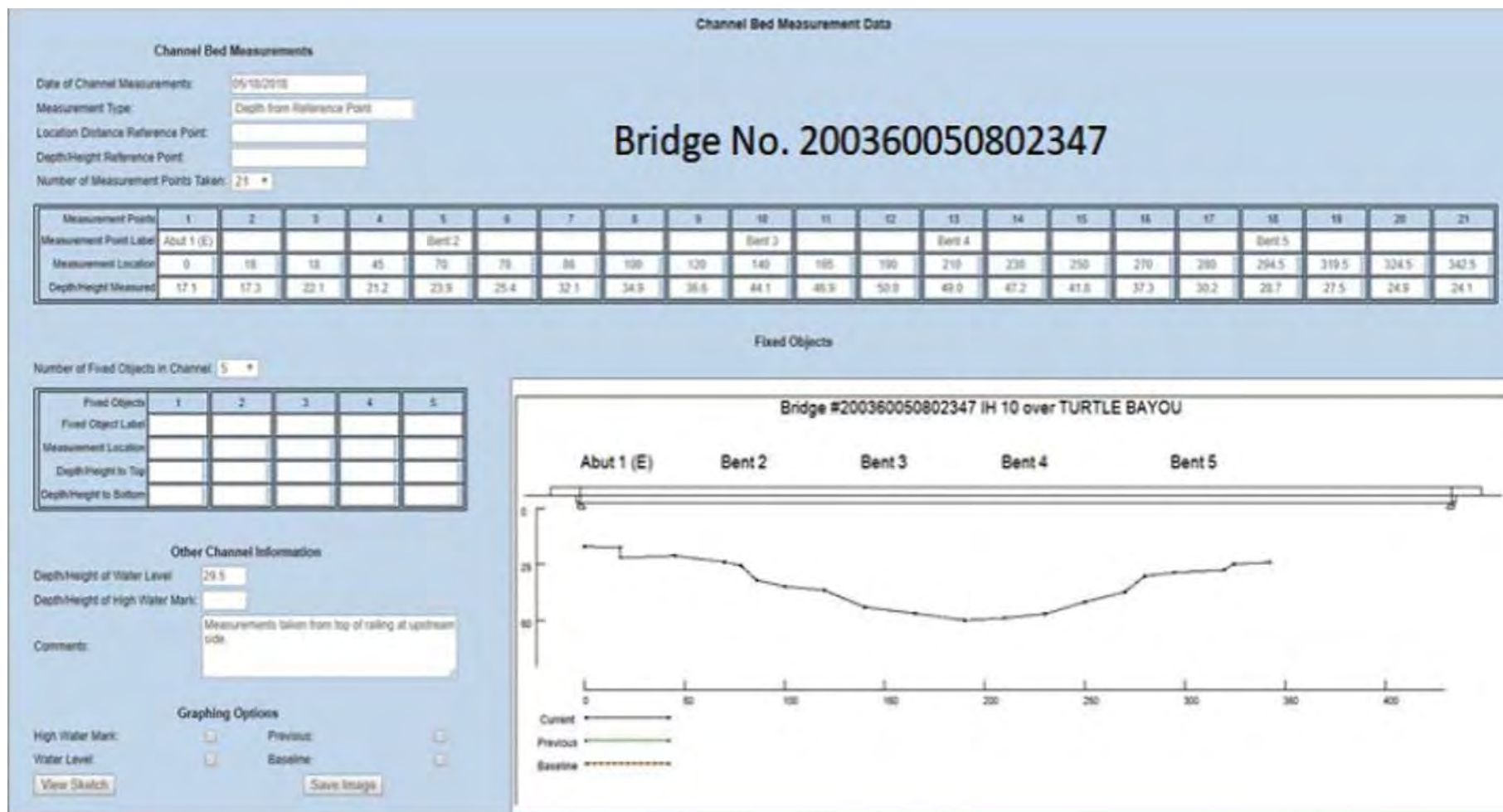


Figure 63. Channel bed measurement data.

as was published in NOAA's Atlas 14, and to recent extreme rainfall events. The updated rainfall depths published in Atlas 14 showed that a substantial increase in depths occurs in a band starting in Beaumont and crossing through central Texas (Austin and San Antonio). The Austin area has seen a change in the 100-year 24-hour depths that equate to the 500-year 24-hour depths previously published. TxDOT noted that it is currently difficult to establish a long-term trend in frequency looking forward. However, the increase in rainfall depths in parts of Texas, particularly during the extreme events, coupled with increased development, will likely cause more frequent overtopping of TxDOT facilities.

The statewide database flood risk tool can be leveraged to aid the NWM in Texas, because currently the NWM does not have transportation system survey data points showing low chords, roadway profiles at crossing, and so forth. TxDOT highlighted the need for a predicative model to have roadway elevations to reference and compare flood stage to determine when a roadway or bridge should be closed or reopened. Backwater issues can be a concern in Texas and therefore are a needed improvement in a predictive model. Optimal gage density for better prediction needs to be investigated.

Summary

TxDOT has demonstrated a well-coordinated effort in emergency flood management. With the aid of the TxDOT Traffic Safety Operations Division, Travel Information Division, and 25 districts, TxDOT can successfully input flood data into DriveTexas.org, constantly informing the public of flood conditions. TxDOT provides an API (application programming interface) data feed for emergency response agencies. This API is intended for emergency management organizations that respond to and assist in recovery from public emergencies and disasters. The data are provided to better coordinate and expedite these efforts, and to better ensure the emergency responders' safety. The state DOT is currently exploring improved predictive modeling based on methods from the National Water Model, which has some major flaws that need to be addressed, such as accuracy, data collection, and backwater prediction. Therefore, TxDOT is engaged in research that explores improving streamflow measurement at TxDOT bridges. The number of gages is being increased by incorporating other agencies' gages, as well as new gages. Thus, communication and collaboration with other agencies are key. A central database is warranted for improvement of flow measurement collection and storage, flood assessment management, and performance assessment (level of service).

Washington

Background

In the state of Washington, river flooding (e.g., overtopping banks) and coastal flooding are major types of observed flooding. The largest river flooding events are due to rain on snow. Coastal flooding is associated with storm surges during king tides. Coastal flooding is being exacerbated by sea level rise and land subsidence. Washington State DOT (WSDOT) noted that the major spring runoff or rain events that cause flooding issues do not occur every year, but flooding issues typically occur from October to spring. WSDOT headquarters communicates risks with districts, typically maintenance crews, to prevent likely flooding.

Washington has experienced substantial infrastructure and economic damages due to flood events in the past 15 years. Historically, WSDOT has taken a reactive approach to flooding; however, now the DOT does more monitoring. The regional maintenance environmental coordinator focuses on areas with ongoing maintenance activities. If a location is repaired three times within 10 years and the maintenance negatively affects aquatic fish habitats, a site is classified as a chronic environmental deficiency location and is assessed for more sustainable solutions. The

area maintenance crews also conduct drive-by assessments of locations to see whether erosion is present after big storms. In an emergency, maintenance personnel can take actions to respond. If warranted, the emergency may result in an emergency project.

WSDOT sees a need to improve certain components in its flood monitoring, prediction, and warning systems. The biggest challenge is climate prediction, which is an evolving science.

Flood Monitoring

WSDOT's Office of Emergency Management oversees flood monitoring in the state using USGS's National Water Information System. Tools to monitor flooding include federal stream gages and federal rain gages, because WSDOT does not operate its own gages. Remotely sensed data and UAV and UAS are also used for specific projects. The data are then collected as images, videos, bridge scour, and staff reports and stored in multiple databases. WSDOT focuses more on reacting to floods. If an emerging need is noticed, WSDOT personnel will go to the site and make an assessment. If the assessment proves that an emergency is present, WSDOT will then have information from the site assessment on what to do.

WSDOT dedicates a lot of asset management work that involves tracking for bridges and pavement. However, the DOT is working on all things water-related and has since expanded to all highway access. Its gages incorporate detailed attributes for maintenance personnel to pick up, like detailed pictures of how to assess a location. WSDOT and FHWA then filter those data using the terms "good," "fair," "poor," and "critical" so that critical ratings on any attribute can be found. It also allows the DOT to focus its time and effort on critical ratings. The gages are linked to a GIS database, and spatial data are collected on site using iPads.

WSDOT also has a distribution list for sending out information using the NWIS data within days of ramp-up. In case of potential flooding, WSDOT headquarters communicates with the region where the site is located and then maintenance crews can monitor the site and check for signs of peak arrival. If the location becomes an emergency, then the DOT will have a maintenance crew prepared to take action.

Flood Prediction

WSDOT Office of Emergency Management relies on NOAA and USGS gages to predict flooding peaks. The University of Washington's Climate Center produced a climate model that helps the DOT predict flows; however, it is difficult to use in mountainous and coastal regions. WSDOT does not use the National Water Model.

WSDOT addressed tidal flooding by tying it to climate science data from the University of Washington. On the basis of generated climate prediction data, WSDOT has added the flood height of king tides and two feet of sea level rise to design considerations.

Flood Warning

WSDOT attributes the success of its flood warning system to its monitoring system and shared access to maintenance spreadsheets, online highway tracking system, and WatchList. Maintenance areas are broken into six regions across the state and are tracked separately. Different maintenance areas have their own data spreadsheets and focus on significant events that require maintenance, such as bank protection or highway ditch regrading.

Response System

The WSDOT flood response system is a reactive approach rather than a proactive one. When an emergency occurs, the DOT implements an active approach in which information is sent out through a distribution list within a few days of the flood. The DOT communicates with the

maintenance crew within the region in which the site is located to ensure that the region is effectively monitoring it. The DOT works with the maintenance division within each area to track bridges, pavement, and all other highway aspects. This assessment incorporates overlapping terminology and details for inspection, such as culvert size and pictures, so the data are easier to filter for both engineering and maintenance. These infrastructure features are georeferenced on site. The infrastructure is then rated as “good,” “fine,” “poor,” or “critical.”

Addressing Challenges

WSDOT observes certain flood challenges and gaps within its flood monitoring, prediction, warning, and response methods. For flood monitoring, WSDOT explained that its communication preceding an emergency could use some work. Communication is more project specific and on the ground. The DOT commented that communication is likely tied to budget constraints. For flood prediction, WSDOT explained that it does not have a flood prediction model. Instead, its system currently follows a reactive approach to flooding rather than a proactive one. Flooding issues typically occur from October to spring, but it isn’t always clear where flooding will hit. This lack of a predictive model is likely due to budget constraints. The DOT uses current gage data and historical data in its analysis. Washington State Fish and Wildlife does have a web-based climate prediction tool that predicts flow data for up to year 2080. However, it is based on a grid system and is sometimes inaccurate. For flood warning, WSDOT struggles with managing its data so that the data and work do not overlap. The DOT explained that the goal is to have a system with live updates. That is why the maintenance crews go on site with iPads to input information directly into the database. However, these live inputs are not necessarily being used to their full potential. Also, the internal WatchList is in the form of a spreadsheet, which makes this live coordination clunky. Communication with maintenance may also need work because it is currently done through email and does not contain any live communication. Another challenge with the flood warning system is that the DOT cannot collect data on the highways that run into local areas. Its internal WatchList is a spreadsheet, which is clunky and not used to its full potential; coordination through some type of wide live system would be useful. For flood response, WSDOT explained that its reactive approach is not ideal because issues in the state need to be addressed before an emergency. The relational spatial database that the DOT uses for asset management has been hugely helpful. However, it is difficult to make the system proactive because the stormwater systems are complicated since outfall is the ocean (king tide, sea level rise, climate data).

Summary

WSDOT plans to make its system more proactive rather than reactive by incorporating climate predictions into its design criteria. The DOT also wants to improve its database management so that the content and ownership sharing are clearer. The DOT uses a statewide WatchList for critical flooding locations that are monitored by region-specific maintenance crews.

Observed benefits of its integrated system include overall safety enhancement, reduction in economic loss, improved and reliable relationships within state DOT offices, streamlined and collaborative inter-agency communication, and positive public feedback and trust.

Case Example Summary

The interviewees from the seven case example states consistently observed the following factors:

- The close relationship among the state DOT divisions (e.g., Hydraulics Design and Asset Management divisions), and between the state DOT and other state and federal offices (e.g., FEMA, Department of Natural Resources), is a key factor in successful flood prediction and response systems.

- A coordinated and updated asset inventory document that is accessible to the key state DOT staffs is a method applied to keep the state DOT informed.
- The advancements in technology—especially with GIS, data models, and sensors—has enabled both easier data collection and communication between stakeholders, and better coordinated model prediction efforts.
- Although observed gaps were different per state, improved real-time flood model predictions are needed, especially for backwater flow conditions and other hydrologically complex areas (i.e., snowmelt flooding or king tides).
- There is a need for further integration of developed BridgeWatch software into the state DOT's real-time monitoring system and an investigation to determine an optimal warning-level setting for a range of scenarios with BridgeWatch to minimize false alarms, because the degree of false alarms varies according to local hydrology and hydraulics.
- A close working relationship with USGS's gage program, particularly the RDGs, has proved helpful to several states.
- Data collection and sharing were a key issue for most states because issues of siloed data, data density, and data continuity pose many challenges.
- There is a need for consistent integrated database development, particularly for spatial data, to facilitate a better understanding of the flooding risks and impacts on the transportation infrastructure.
- There is a benefit in engaging partners (e.g., state and federal agencies, university transportation centers, companies) to coordinate and collaborate with state DOTs to accurately deliver flood models, scour detection, and flood-related data.