NCHRP 20-59(53): FLOODCAST

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

Floodcasting Capability Maturity Framework Technical Memorandum

Prepared for

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CONTENTS

1 INTRODUCTION

This technical memorandum documents the research team's approach for creating a Capability Maturity Model (CMM) framework that facilitates DOT self-assessment and identifies activities and products State Departments of Transportation (DOTs) may need in order to reach their desired levels of flood forecasting capability or "level up" to the point where they can fully participate in an operational FloodCast program. We are transmitting this memorandum along with the tool itself for NCHRP review and comment.

CMM frameworks can help define the key data, technologies and practices required to effectively achieve an objective. Originally developed to improve software development processes, CMMs have been applied to address other process or system improvements. Broadly defined, "maturity modeling is the process of establishing a graduated path for improvement of an organization's data program governance activities (policies, standards, assignment of responsibilities, etc.), and then applying the framework to assess both where an organization is and where it needs to go" (AASHTO 2011). CMMs for a given objective are often organized into capability dimensions with tiers indicating levels of maturity towards that objective. Tiers can then be used by interested entities to identify a pathway toward improving capabilities along each dimension.

1.1 Existing CMM Frameworks and Tools

In order to develop a well-informed and useful flood forecasting framework, the research team explored existing CMM frameworks and tools. The capability maturity framework (CMF) concept emerged from the from the Strategic Highway Research Program 2 (SHRP2) L01 and L06 projects intended to provide a process-driven approach to improve Transportation Systems Management and Operations (TSM&O) (FHWA 2016). Building on SHRP2 results, AASHTO continued development of the capability maturity concept and published the AASHTO Transportation Systems Management and Operations (TSM&O) guidance. This web-based self-assessment guidance is designed to help State DOTs develop action plans to improve their TSM&O capabilities.

The Federal Highway Administration (FHWA) leveraged AASHTO's TSM&O guidance by developing additional frameworks allowing agencies to self-identify their current and desired levels of capability and focus on strategies to advance levels of maturity within specific TSM&O program areas (see Table 1).

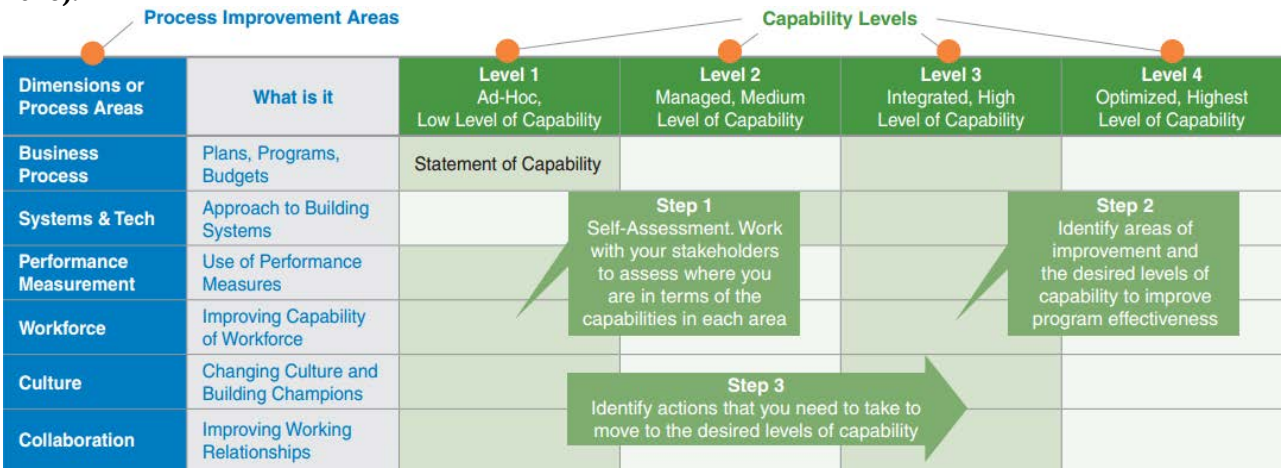
Table 1: FHWA Frameworks for TSM&O program areas.

TSM&O Program	Capability Maturity Framework Scope	Targeted Stakeholders	Tool Link
Planned Special Events	Framework assesses current capabilities with respect to planned special events management. Managing travel for planned special events involves advanced operations planning, stakeholder coordination and partnerships, developing multi-agency transportation management plans, raising awareness of general public and event patrons of potential travel impacts, and coordinating agency services and resource sharing.	• Planned special event coordinators or managers • Selected group of event planners • Law enforcement representatives • Traffic managers in the region	https://ops.fhwa.dot.gov/tsmoframeworktool/tool/pse/index.htm
Road Weather Management	Framework assesses the institutional capacity of an agency or a region to respond to adverse weather conditions from both a maintenance and operations perspective.	• Agency maintenance staff • Agency operations staff • Meteorologists • Emergency operations managers	https://ops.fhwa.dot.gov/tsmoframeworktool/tool/rwm/index.htm

Traffic Incident Management	Framework assesses the capability to detect, respond to and clear traffic incidents so that traffic flow may be restored as safely and quickly as possible.	• Traffic Incident Management program and other managers in the region • Representatives from transportation, law enforcement, fire/rescue, emergency medical services, towing and recovery, and all other responder or TIM committee disciplines	https://atri.checkboxonline.com/TIM-SA-2015.aspx
Traffic Management	Framework assesses the capability to efficiently manage the movement of traffic on streets and highways and includes corridor management approaches.	• City and state traffic managers in the region • Selected group of traffic operators • Metropolitan Planning Organization representatives • Law enforcement representatives • Transit operators	https://ops.fhwa.dot.gov/tsmoframeworktool/tool/traffic_mgmt/index.htm
Traffic Signal Management	Framework assesses the agency capability to support effective signal operations management by building on various existing resources available for this topic including the guidance provided in "Improving Traffic Signal Management and Operations: A Basic Service Model".	• Traffic engineers involved in signal design and operations • Transit agencies and operators • Emergency personnel • Traffic and emergency operations staff	https://ops.fhwa.dot.gov/tsmoframeworktool/tool/tssc/index.htm
Work Zone Management	Framework assesses the capability for effective work zone traffic management including assessing work zone impacts and implementing strategies for minimizing or mitigating the impacts.	• Work zone traffic managers • Maintenance staff • Traffic operations managers • Construction staff • Project planning and design staff	https://ops.fhwa.dot.gov/tsmoframeworktool/tool/wzm/index.htm

All of the TSM&O programs assess capability across the same six dimensions: Business Processes; Systems and Technology; Culture; Organization and Workforce; Performance Measurement; and Collaboration; and across the same four capability levels (from Level 1, low-level to Level 4, optimized high-level) (see Figure 1).

Figure 1: Capability Maturity Framework Process Overview (illustration obtained from FHWA 2016).



Attributes (i.e. descriptors of capability) within each of the Dimension-Level combinations and the recommended actions to increase capabilities across the desired process area are unique to each TSM&O program. For example, Figures 2 and 3 show attributes across the Business Process dimension for the Road Weather Management and Traffic Management maturity frameworks, respectively.

Figure 2: Business Process dimension attributes within the Road Weather Management Capability Maturity Framework.

Dimension	Level 1	Level 2	Level 3	Level 4
 BUSINESS PROCESSES	Agencies are constrained by annual funding limitations and inability to make long-term capital or operational improvements. At this level, agencies have difficulties in scaling up responses to conditions due to significant differences and inconsistencies between processes based on jurisdiction. There are no formal procedures/requirements in place for weather management. Policy and programmatic capabilities to implement response strategies are not aligned limiting the options of the agency.	There is some dedicated funding available for multi-year programs and improvements and agencies are starting to see allocation of funds to invest in road weather technology, systems and tools. However, funding is variable and subject to reallocation to other priorities. Generally, documented policies allow agency to ramp up adequately for major events and formal procedures/requirements (like warning system activation thresholds, maintenance plan/strategy, route maps, operator guides, policy guidelines) are starting to emerge and becoming available throughout the agency.	Funding for road weather management is part of regional planning process and dedicated funds with flexibility are available as part of a multi-year program for agencies at this level. Resource sharing processes and procedures in place to maximize response capabilities in accordance to the scale of the event between jurisdictions of an agency. Overall, existing policies allow for a full range of appropriate advisory, control and treatment strategies.	Funding is tied to a multi-year strategic roadmap for road weather for agencies at this level. Agencies are likely to have a strategic plan includes consideration on future needs incorporating medium-term and long-term changes to climate, technology and reinvestment in systems plan that includes recovery and resiliency of systems to extreme weather. Agencies also demonstrate common process and procedures allow greater integration into other aspects of the agency like construction, transit operations.

Figure 3: Example of the Business Process dimension attributes within the Traffic Management Capability Maturity Framework.

Dimension	Level 1	Level 2	Level 3	Level 4
 BUSINESS PROCESSES	Traffic management development and deployment processes are agency specific and ad hoc.	Agencies implement a nominally systematic approach to traffic management to address immediate concerns. Traffic management approaches are operator driven and either static or based on time of day.	Traffic management development and deployment processes are standardized and have a more system-wide approach that is well documented.	Development and deployment processes related to traffic management are streamlined across an entire region, and agencies have a continuous improvement process for traffic management.

2 FLOODCAST CAPABILITY MATURITY FRAMEWORK

This section describes the critical parts of the FloodCast CMM framework and specific actions state DOTs can utilize to advance their levels of maturity.

While the Road Weather Management (RWM) framework has some relevance to the flood forecasting decision-support effort, it focuses on assessing the capacity of an agency to respond to adverse weather conditions. While effective response is a critical piece to achieving flood hazard resilience, preparation and recovery are also key processes that need to be considered. Furthermore, as identified in NCHRP 20-59(53) Technical Memorandum #1, a robust flood forecasting decision-support system must address key gaps with

respect to practices, technologies and data holdings necessary to participate in operational flood forecasting. The research team built upon the RWM to develop a CMM framework to provide a structured approach to review these practices, technologies and data holdings necessary to enhance flood-event decision making.

2.1 The Key Dimensions of Capability

The research team identified five critical capability maturity dimensions that reflect a State DOT's ability to participate in an operational FloodCast program. They are shown in Figure 4 and defined in Table 2.

Figure 4: Key Dimensions of Capability.

Table 2: Key Dimensions of Capability Descriptions.

Dimension	Description
Meteorology	Meteorology, in the context of floodcasting, refers to an agency's capabilities to leverage local, state or federally-operated meteorological monitoring and forecasting resources to support state DOT flood planning, risk management, mitigation, preparedness operations and emergency response activities.
H&H	The hydrology and hydraulics (H&H) components of a floodcasting system involve the hydrometeorology and flood mapping capabilities (i.e. translation of precipitation forecast information into extent and depth predictions to identify potential vulnerabilities of the transportation network).
Asset Management	Asset management, in the context of floodcasting, refers to the quality and completeness of an agency's asset management database as well as technical understanding of design parameters and fragility characteristics of assets related to flooding.
Communication & Information Transfer	Effective communication before, during and after a flood event requires dissemination of flood event information to multiple platforms (i.e. in-house, partner agencies, the public and traffic alert systems).
Incident Management	The incident management component of an operational flood forecast system involves flood event incident tracking, storing and reporting to facilitate early recovery, post-disaster grant application and hazard mitigation.

2.2 The Four Levels of Capability

The original CMM developed by the Software Engineering Institute in 1984 identifies five levels of maturity (Table 3). Most of the maturity models building from this original CMM suggest maturity scales with four to six discrete steps that vary in complexity, focus and comprehensiveness (AASHTO 2011).

Consistent with AASHTO's TSM&O guidance and the FHWA CMFs, the research team defined four distinct levels of capability for each of the dimensions with assignment in the lowest tier indicating limited capabilities in developing and disseminating floodcasting data/information along that dimension while the highest tier indicates participation and good alignment with the effective practices identified in NCHRP 20-59(53) Technical Memorandum #1.

Table 3: Five Levels of Maturity

Level	Key Characteristics
1	• Limited capabilities and participation in developing, maintaining, and disseminating flood forecasting data/information • Transportation system has minimal ability to respond to flooding and weather-related hazards
2	• Beginning to develop capabilities to allow for participation in operational flood forecasting • Key technology and core capacities under development, but limited ability to disseminate meteorological and hydrologic data to inform flood event decision making • Flood monitoring system not yet fully integrated into agency's existing operational framework
3	• On the verge of participating in advanced flood event forecasting and decision making • In the process of developing software and communication systems that incorporate hydrologic and meteorological information into agency's existing operational framework • Somewhat constrained by ability to invest resources in innovative research and new, possibly expensive technologies.
4	• Fairly advanced predictive weather and flood monitoring in place • Software and communication systems are corporate hydrologic and meteorological information into agency's existing operational framework • Data/technology limitations and model run times still pose limitations.

As noted in the RWM CMM User's Guide (FHWA 2016), "it is important to understand that levels of capability are not judgmental – they are simply an indication of the current capabilities of an agency". Many agencies taking the self-assessment today likely fall within different capability levels of each dimension. For example, an agency might be a Level 1 with respect to the Asset Management dimension, but a Level 3 in the Meteorology dimension. The overall intent of the CMM is to provide agencies with a method to identify strategies to increase the level of capability within each dimension.

2.3 General Strategies to Advance Levels of Maturity

Based on effective practices identified in NCHRP 20-59(53) Technical Memorandum #1, the research team created a general list of strategies needed to move up to the next level of capability for each dimensions. Actions define steps that an agency can take to advance levels:

- Level 1 to Level 2
- Level 2 to Level 3
- Level 3 to Level 4

The following series of illustrations show examples of actions that would help an agency advance across different levels and dimensions. A full list of actions for all dimensions and levels can be found in the Excel-based CMM tool (described in Section 3).

Meteorological Dimension	
Level 1 →	Level 2
• Become familiar with existing resources for precipitation forecasting (e.g., NOAA Quantitative Precipitation Forecast Maps, NOAA NEXRAD Radar, NWS flash flood guidance, etc.) • Identify existing staff or bring on new resource(s) with familiarity on precipitation forecasts • Develop an organizational approach for proactively monitoring flood conditions. • Identify real-time meteorological monitoring sources and become familiar with using these resources (e.g., rain gauges, Road Weather Information System stations, wind sensors, soil moisture sensors, etc.)	

H&H Dimension	
Level 2 →	Level 3
• Acquire high-quality topography suitable for flood mapping • Identify existing software or develop new system to visualize flood inundation extents • Develop protocol for using real-time national or state-H&H monitoring networks (such as USGS stream/rive gauges and NOAA tidal gauges) to anticipate and implement road closures throughout the state	

Asset Management Dimension	
Level 3 →	Level 4
• Develop fragility curves for assets that show how an asset will function over a range of flood depths. • Develop methodology for using fragility curves to produce damage estimates for forecasted or actual flooding. • Develop and enforce protocol for field personnel to report on potentially incorrect asset data information. • Asset database includes records of asset performance during past flood events • Obtain missing asset elevation data (via LiDAR techniques, remote sensing, deployment of survey crews, etc.) • Obtain information on infrastructure capacity (e.g., culvert capacity, drainage capacity, etc.) • Expand GIS-based asset database to include non-DOT assets. • Create map of asset network interconnectivity that includes potential failure pathways during a flood event to understand the vulnerabilities of individual assets within the larger transportation system. • Include location data for signals, signs, guard rail, DOT-owned electrical infrastructure, sensors/instrumentation, and building facilities in the asset database.	

3 CMM TOOL

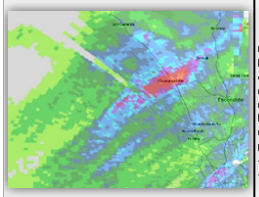
The floodcasting CMM framework is available as an Excel-based tool. The tool enables agency self-evaluation (Tab 1) and identification of related strategies for agency capability improvement (Tab 2).

Together, these provide a quick assessment of the key challenges facing the agency in improving the effectiveness of a floodcasting system.

3.1 Tab 1 (Self-Assessment)

The first excel tab presents the five critical capability maturity dimensions – as defined in the first column – needed to develop and maintain an effective floodcasting system. For evaluation purposes, four district levels of agency capability have been defined for each of the six dimensions. Users can select the cell that most closely reflects their agency's current capability level for each of the dimensions. Once users select their current capability level for each dimension, the tool will route them to actions to advance their capabilities (Tab 2), which is described in the next section.

Figure 5: Screenshot of FloodCast CMM Excel tool. Illustration shows Tab 1 (Self-Assessment).

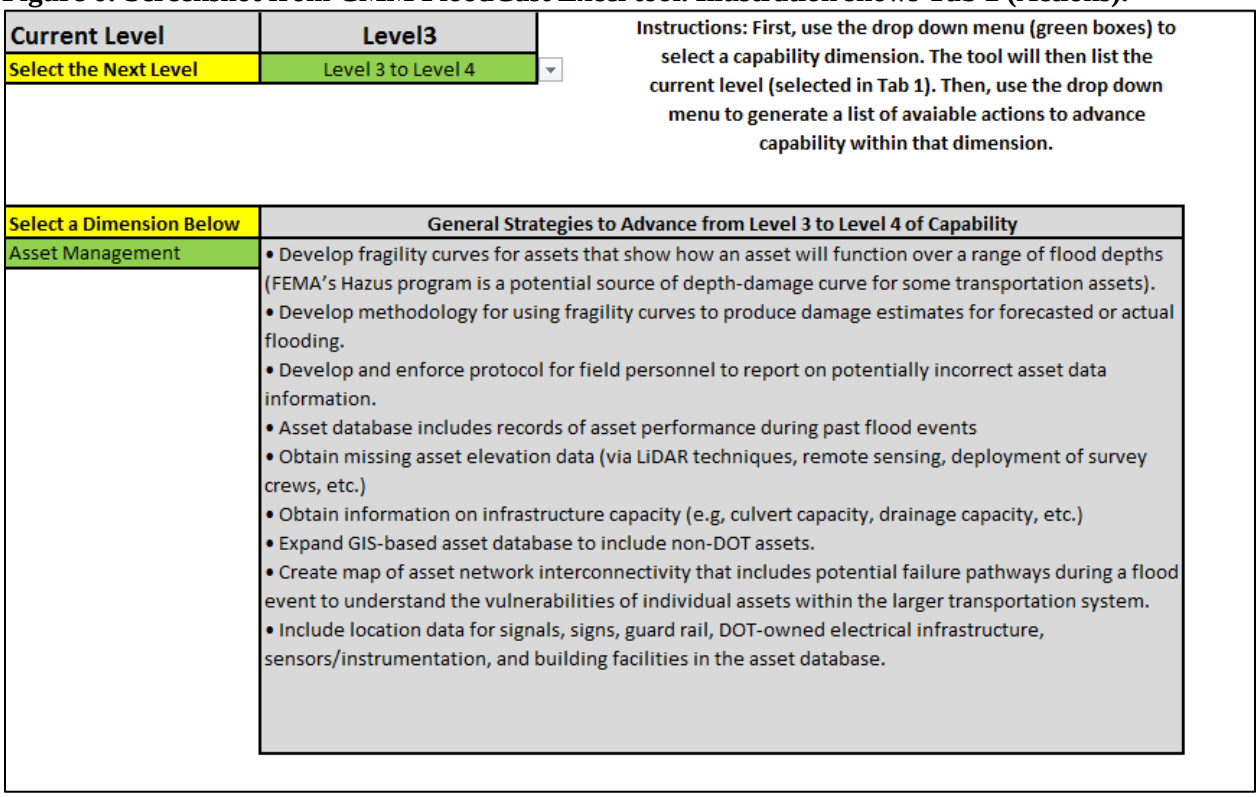
Welcome to the Floodcasting Capability Maturity Model (CMM) tool. This tool enables State DOT self-evaluation of current flood forecasting capabilities (Tab 1) and identification of related strategies for agency capability improvement (Tab 2). Instructions: For evaluation purposes, 4 distict levels of capability have been defined for each of the key dimensions of capability that reflect a State DOT's ability to participate in operational FloodCast program. In this tab, check the box that most closely reflects your agency's current capability level for each of the capability dimensions.		Limited capabilities and participation in developing, maintaining, and disseminating flood forecasting data/information; transportation system has minimal ability to respond to flooding and weather-related hazards	Beginning to develop capabilities to allow for participation in operational flood forecasting; key technology and core capacities under development, but limited ability to disseminate meterological and hydrologic data to inform flood event decision making; flood monitoring system not yet fully integrated into agency's existing operational framework.	On the verge of participating in advanced flood event forecasting and decision making; in the process of developing software and communication systems that incorporate hydrologic and meterologic information into agency's existing operational framework; somewhat constrained by ability to invest resources in innovative research and new, possibly expensive technologies.	Fairly advanced predictive weather and flood monitoring in place; software and communication systems are corporate hydrologic and meterologic information into agency's existing operational framework; data/technology limitations and model run times still pose limitations.
		Agencies at this level for flood event decision-making are likely to be/have:	Agencies at this level for flood event decision-making are likely to be/have:	Agencies at this level for flood event decision-making are likely to be/have:	Agencies at this level for flood event decision-making are likely to be/have:
Meteorological 	Capabilities to leverage local, state, or federally-operated meteorological monitoring and forecasting resources to support state DOT flood planning, risk management, mitigation, preparedness operations, and emergency response activities.	• Becomes aware of forecasted high rainfall events through television, online forecasts and general NWS alerts • Does not download or analyze weather data independently • Has limited or nonexistent real-time monitoring ○	• Tracks weather proactively using online forecasts, television and SMS weather alert services • Sometimes uses supplementary products from NOAA and NWS (e.g., when a hurricane is forecasted) • Real-time monitoring such as RWIS is nascent but has been initiated ◉	• Has a daily protocol for reviewing forecasts and planning agency response • Agency uses reliable, mid- and long-range forecasting products (such as NOAA QPF Forecast Maps) to increase amount of lead time to prepare and respond to rainfall flood events. • Consults the National Weather Service (NWS) flash flood guidance estimates • Some use of real-time data (e.g., rain gauges, radar, or sensors) to update forecast data, but temporal and spatial coverage and/or resolution limits use ○	• Agency leverages reliable, mid- and long-range forecasting products (such as NOAA QPF Forecast Maps or NWS meteorological forecasts) to increase amount of lead time for rainfall flood events and generate distant early warnings. • Is comfortable with identifying, downloading, analyzing, modifying, and exporting meteorological data as well as creating new map products • Supplements national meteorological datasets with local, more complete or higher resolution products where available (such as DOT maintained Road Weather Information System (RWIS) networks) • Meteorological monitoring network has high spatial and temporal resolution (for example, data is available every 5 minutes or less) and includes multiple meteorological variables • Agency invests in test beds and other research to continuously develop new technology capabilities of forecasting rainfall intensity (such as probabilistic QPF and innovative flood sensor technology) • Continuously focuses on locations throughout the state that require better meteorological monitoring/forecasts, due to adverse effects on local transportation-related infrastructure (either by developing relationships with existing monitoring stations or installing new gauges). • In addition to using existing NWS flash flood guidance estimates, agency is working with other agency and academic partners to actively developing new ways to forecast the timing, location, and extent of flash flooding at a finer scale. • Uses real-time meteorological monitoring data to confirm or adjust models, and comes from sources such as rain gages, radar, or sensors ○
Hydrology & Hydraulics 	Capabilities to use forecast information on the timing, extent, and depth of coastal and riverine flood events to identify potential vulnerabilities of the transportation network.	• Poor temporal resolution and spatial coverage of stream and tidal gauge data limits ability of agency to use this information in decision making • Lack of awareness or personnel to make use of available data, tools, and models used to forecast riverine and/or coastal flooding • For road closures prior to the event, the agency primarily uses permanent or temporary signage or rules of thumb ◉	• Uses forecasts that predict stream discharges, but do not uses visualizations of associated inundation extents • Has limited ability to flag potentially threatened assets • Spatial and temporal resolution of hydrologic monitoring network better, but does not cover entire land area and not all stations are available in real-time • Uses stream and tidal gages to anticipate and implement road closures where available ○	• Use forecasts that predict both stream discharges and riverine extents to visualize potentially threatened assets • Leverage real-time national and state-H&H monitoring networks (such as USGS stream/river gauges and NOAA tidal gauges • Has a consistent protocol in place to use stream and tidal gages to anticipate potential damage to infrastructure assets • Has a consistent protocol in place to use stream and tidal gages to anticipate and implement road closures throughout the road network ○	• Comfortable with identifying, downloading, analyzing, modifying, and exporting H&H (both riverine and coastal) data as well as creating new map products • Supplements national and state-H&H datasets (such as USGS stream/river gauges and NOAA tidal gauges) with local, more complete or higher resolution products where available • Uses forecasts that predict the timing, extent, and depth at both gaged and ungaged locations to visualize potentially threatened assets • System integrates flood advisory warnings from local NWS offices • Monitoring network includes elevation of water levels in hydrologic features to determine if a dam/water control structure may be overtopped • Uses real-time hydrologic monitoring data to confirm or adjust models, and comes from sources such stream/river/tidal gauges • Invests in research or innovative flood sensor technology (such as hydrologic monitoring stations at key transportation locations) • Meteorological monitoring network has high spatial and temporal resolution (for example, data is available every 5 minutes or less) and includes multiple variables on weather ○

3.2 Tab 2 (Actions)

The second tab presents the general strategies/actions needed to move up to the next level of capability for each dimensions. Users can select a dimension from a drop down menu, and the tool will show the user their current dimension and generate a list of actions to advance from the current level to the next for that dimension.

Agencies are encouraged to customize and prioritize actions as part of their planning efforts as it might not be realistic to take on the suite of available actions all at once.

Figure 6: Screenshot from CMM FloodCast Excel tool. Illustration shows Tab 2 (Actions).



Current Level	Level3	Instructions: First, use the drop down menu (green boxes) to select a capability dimension. The tool will then list the current level (selected in Tab 1). Then, use the drop down menu to generate a list of avaiable actions to advance capability within that dimension.
Select the Next Level	Level 3 to Level 4	

Select a Dimension Below	General Strategies to Advance from Level 3 to Level 4 of Capability
Asset Management	• Develop fragility curves for assets that show how an asset will function over a range of flood depths (FEMA's Hazus program is a potential source of depth-damage curve for some transportation assets). • Develop methodology for using fragility curves to produce damage estimates for forecasted or actual flooding. • Develop and enforce protocol for field personnel to report on potentially incorrect asset data information. • Asset database includes records of asset performance during past flood events • Obtain missing asset elevation data (via LiDAR techniques, remote sensing, deployment of survey crews, etc.) • Obtain information on infrastructure capacity (e.g, culvert capacity, drainage capacity, etc.) • Expand GIS-based asset database to include non-DOT assets. • Create map of asset network interconnectivity that includes potential failure pathways during a flood event to understand the vulnerabilities of individual assets within the larger transportation system. • Include location data for signals, signs, guard rail, DOT-owned electrical infrastructure, sensors/instrumentation, and building facilities in the asset database.

4 USING THE FRAMEWORK AND TOOL

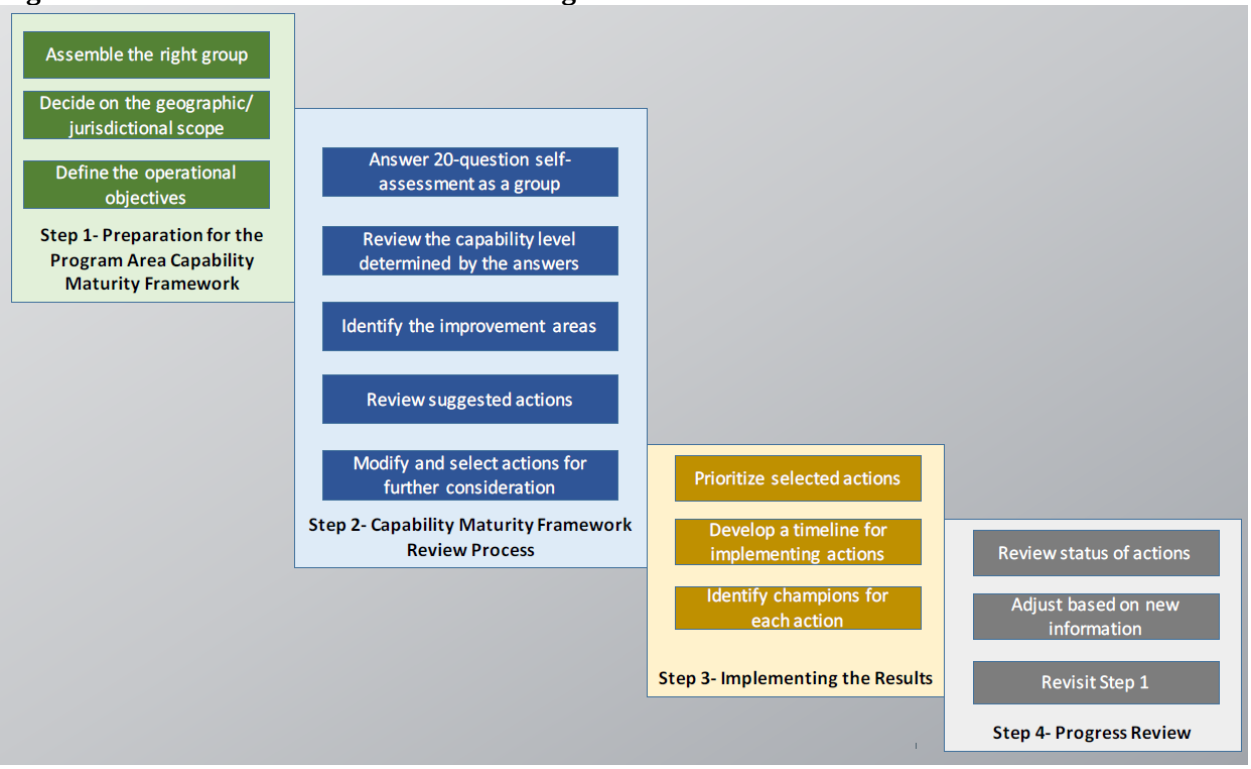
4.1 Who Should Use the Framework?

The requirements gathering effort of this project revealed that flood-event decision making is either handled at the State or district level. Differences in capabilities at the district level can be a challenge when striving for state level flood forecasting improvements. In cases where districts are responsible for flood-event decision making, it may be desirable for individual districts to complete the self-assessment at a workshop to facilitate collaboration.

4.2 How Should the Framework Be Used?

FHWA recommends the following 4-step process for using CMM frameworks (Figure 7). Step 1 and 2 in the figure would ideally be accomplished through an in-person workshop with State DOT staff responsible for flood preparation and response activities. The workshop should be scheduled to provide sufficient time to reach a consensus on the current capabilities across all dimensions and develop an initial list of prioritized actions.

Figure 7: FHWA Recommendations for Using CMM Frameworks.



In Step 3, State DOTs might be interested in convening future meetings where the identified actions will be further prioritized, championed and implemented. Once significant organizational change occurs (i.e., agency has advanced levels across all dimension), it might be desirable to revisit the tool to maintain momentum of floodcasting improvements.

5 NEXT STEPS AND RECOMMENDATIONS

The FloodCast CMM will be a preliminary step in further identifying the most pressing needs of state DOTs for establishing a mature FloodCast program. The overall intent of the tool is to provide agencies with a method to self-assess current capabilities and identify strategies focused on practices, technologies and data holdings to support DOTs in planning for, responding to and operating during floods.

It should be noted that flood forecasting is a rapidly evolving field. For example, the National Water Model (NWM), an experimental product developed by NOAA's Office of Water Prediction (OWP), is poised to revolutionize hydrologic prediction capabilities for streamflow. Expanding forecast locations from ~3,600 currently in operation to ~2.7 million nationwide, the NWM will provide unparalleled access to predicted streamflow on a real-time basis. Scientific advances such as this, once vetted and ready for dissemination, should be reflected in the attributes and actions of a floodcast CMM. While the developed CMM reflects the existing state of practice, the framework should remain flexible to anticipate significant improvements in practices, technologies and data used to make flood-event decisions.

6 REFERENCES

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