NCHRP 20-59(53): FLOODCAST

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

Data Standards and Specifications

Prepared for

The National Highway Cooperative Research Program

Transportation Research Board

of

The National Academies

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April 2018

CONTENTS

1 INTRODUCTION

This technical memorandum documents the data standards and specifications that were developed for the National Cooperative Highway Research Program (NCHRP) Project 20-59(52), "A Framework for Enhanced Flood Event Decision Making for Transportation Resilience", or FloodCast. The FloodCast prototype is a proof of concept, designed to show the benefit of bringing key data elements together to support Department of Transportation (DOT) flood emergency response activities. The data elements referred to are produced by a variety of entities (e.g. federal, state, local, etc.) across a variety of domains e.g. meteorology, hydrology, asset management, etc.).

The FloodCast Requirements Analysis performed previously revealed that the majority of State DOTs are not aware of the importance of and need for developing data standards or and specifications prior to data dissemination and sharing. To complicate the matter, many DOTs use multiple systems for flood forecasting and response (e.g. 511, asset management systems, etc.), none of which are interoperable with each other or with partnering agency systems. Because DOTs often use their own systems to manage their data and there are no guidelines as to how to collect, name and save the data, it is difficult to develop a common, overall operational picture before, during and after a flood event and even more difficult to move data in a timely manner to decision-makers.

Combining data from multiple sources is difficult, if not impossible, if data standards and specifications are not in place or if different groups are using different data standards and specifications. Data standards and specifications provide a set of requirements that must be met in order for the product to be maximally useful by the intended audience. For example, very high resolution accurate data is of no use to the decision-maker if it cannot be read by the software the decision-maker has access to during a flood event or if it requires significant manipulation prior to integrating with a commonly used web-based service or software. When used properly, data standards and specifications create rules by which data are described and recorded, ensuring data can be consumed by the majority of web platforms and GIS systems in use by decision-makers. Specifications take into account both client-defined requirements and the limitations in the data and technology available to meet the requirements. In other words, data standards and specifications standardization of this type is essential for communicating internally with field crews and collaborating across entities, especially at the local, state, or national level.

Standardization can significantly streamline the number of steps required when coupling models together and when integrating flood forecasting tools with emergency management, traffic notification, and other tools used by the transportation agency and cooperating entities. For optimal functionality, determining interoperability requirements and data standards for software are critical.

The objectives of the FloodCast data standards task were to:

1. Select or develop data standards for each of the FloodCast capability dimensions (illustrated in Figure 1 and described in Table 1). It is important to note that some of the FloodCast capability dimensions are ready for formal standards while others need more time to reach maturity.

2. Develop recommended specifications for how the FloodCast system should handle the range of data qualities and availabilities indicated by State DOTs while still meeting the needs of decision-makers.

Figure 1: FloodCast Elements

Table 1: FloodCast Capability Dimensions

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.
Hydrology and Hydraulics	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 and Information Transfer	Effective communication before, during and after a flood event requires dissemination of flood event information to multiple platforms (e.g. in-house, partner agencies, the public and traffic alert systems).
Incident Management	The incident management component of an operational flood forecasting system involves flood event incident tracking, storing, and reporting to facilitate early recovery, post-disaster grant application, and hazard mitigation.

2 APPROACH

2.1 Data Standards

The study team conducted a review of existing open data standards for each of the five FloodCast capability dimensions. For purposes of this report, "open" indicates all details needed for interoperability are present, the standard is freely available, and there is no requirement for the usage of proprietary software or tools. Open *standards* are distinct from open *data*: the format is freely available but the data is not, in accordance with security considerations.

The study team reviewed existing standards for applicability to FloodCast objectives. Based on this review, the study team either 1) selected appropriate standard(s), 2) developed a new standard, or 3) described ideal standards that could be developed.

Another aspect of open standards is that anyone can join the entity developing standards; and for this task, the FloodCast study team collaborated with the Open Geospatial Consortium (OGC) Hydrology Domain Working Group (Hydro DWG). In June 2017, members of the FloodCast study team attended the Hydro DWG's annual workshop at the National Water Center in Tuscaloosa, AL. The workshop kicked off the Environmental Linked Features Interoperability Experiment (ELFIE). The ELFIE brought together interested stakeholders who shared a common goal of developing a standard for linking hydrologic and related features to observational data about those features. The ability to encode documents containing links between and among monitoring sites and environmental domain features such as rivers or groundwater aquifers, in a common way, will enable automation and efficient interoperability of such linked information. The FloodCast study team presented the FloodCast prototype demonstration to ELFIE participants followed by a discussion of how FloodCast could be included as an "event-driven" use case in ELFIE. The study team contributed example FloodCast datasets (e.g. flood event, flood extents and depths, and transportation assets) to demonstrate the importance of establishing these data types as domain features.

As an outcome of our involvement with ELFIE, new domain feature types, specific to FloodCast were established. The feature types can be adapted to other similar applications that depict flooding and flooding related risks to transportation systems. Each feature type has relations established with transportation assets data to facilitate flood event analytics. For example, a relational attribute within the flood inundation extent polygon linking to all of the assets that are within (i.e. "threatened" status) or near (i.e. "monitor" status) the flooding. A demonstration video shown to the attendees of the 106th OGC Technical Committee meeting in Orléans, France in March 2018, showcased the important data elements, feature types and relations in FloodCast.

Other FloodCast elements not considered within the scope of ELFIE required additional research. For example, while participating in ELFIE helped us with aspects of data standards for meteorology, H&H, and incident management elements of FloodCast, the team still needed to research other relevant data standards such as the HY_Features, Water ML, and WMO's meteorological/climatological data standards. Throughout this research process, the team recognizes there are some elements within FloodCast which might not be mature enough yet for development of data standards.

2.2 Data Specifications

The data specifications developed for FloodCast provide guidance on how the FloodCast system should handle State DOT requirements given known data limitations. The research team compared known data limitations that were documented during the FloodCast Literature Review against requirements gathered from State DOTs during the FloodCast requirements analysis task to develop specific FloodCast data specifications. For example, common data limitations with respect to asset data include characteristics crucial to estimating flood impact, such as missing elevation or discharge capacity. Topography, which is essential to estimating flood depth, is also anticipated to have quality issues. While many states are gathering or already have produced high resolution LiDAR for part or all of the State, access to quality topographic data is not universal and holdings may vary in resolution, quality and currency. Additional data limitations and options for handling them were explored during the specifications drafting process.

3 METEOROLOGY

3.1 Quantitative Precipitation Forecasts

Numerous scientific and computing advances over the recent years have paved the way for atmospheric models to produce more reliable quantitative precipitation forecasts (QPF). Overall, there is higher confidence in short-term forecasting, with uncertainty increasing as lead time increases. To better quantify uncertainty, the QPF from multiple models and initialization times (which are all equally probable) can be combined to create an "ensemble". One key benefit provided by a QPF ensemble is the ability to create a probabilistic forecast. Combined with pre-established exceedance thresholds (e.g. 1 inch per hour, 3 inches in 24 hours), a QPF ensemble allows a decision-maker to quantify the likelihood and severity of possible flooding. The lead time provided by QPF can range from short-term (an hour) to long-term (multiple days), with both sides of the spectrum having value for decision-makers.

3.1.1 Short-term forecasts

Short-term forecasts include both the immediate and short-term threat (up to two days). As a forecast for heavy rainfall becomes more certain for a given area, higher spatiotemporal resolution is needed. Likewise, the data needs to be updated as often as possible and the QPF issue time needs to be stated. Hourly forecasts help assess the areas with the highest potential flood threat and also capture the changing nature of the heavy rainfall event as it unfolds. For many high impact flood events such as Hurricane Harvey, the January 2018 California flooding, the 2013 Colorado Front Range flood, and Hurricane Sandy, the placement and timing of heavy rainfall was well forecasted down to a county level up to 36 hours in advance.

The NOAA Weather Prediction Center (WPC) produces high-resolution short-term deterministic and probabilistic QPF in 6-hour accumulations out to 72 hours twice daily. These are used as guidance for River Forecast Centers (RFCs) and Weather Forecast Offices (WFOs). Alternatively, the High-Resolution Rapid

Refresh (HRRR) model from the National Centers for Environmental Prediction (NCEP) provides very high-resolution 15-minute QPF out to 18 hours, with hourly updates. A combination of WPC and HRRR QPF products provide a high-resolution snapshot of heavy rainfall potential that will, in most cases, have enough accuracy to be of utility for decision-makers.

3.1.2 Medium-term forecasts

Medium-range forecast (3-7 days) increases lead-time, allowing decision-makers time to plan, collect, and allocate resources. They also inform decision-makers of the duration of an event, which becomes important when flood conditions last for several days. The WPC produces 24-hour QPF out to seven days and is updated twice daily. Although the medium-range forecasts contain more uncertainty in space and time, they can still be used as a flood "outlook". Often times, the forecast of a high-impact rainfall event will gradually trend towards a certain spatial direction or a faster/slower onset time, which can be used to anticipate the eventual outcome. Interestingly, some high-impact events such as Hurricane Sandy had very accurate forecasts with up to 7 days of lead time.

3.1.3 Antecedent Rainfall

Antecedent rainfall is very useful for flood forecasting. If there are saturated soils, there will likely be increased runoff. The Multi-Radar Multi-Sensor (MRMS) integrates several meteorological tools such as radar, surface and satellite observations to generate a quantitative precipitation estimate (QPE). This product can create QPE as far back as 72-hours with a time step between 1 and 24 hours. As an event is occurring, the hourly QPE files are updated ~2 hours after occurrence. Paired with short-term and medium-term QPFs, QPE can provide a snapshot of flood prone regions, which has value for decision-makers.

3.2 FloodCast Data Standards and Specifications for Meteorology

Raw QPF data, such as that from the NCEP HRRR model, are typically in a raster-type Gridded Binary (GRIB2) format. GRIB2 allows for efficient storage of multi-dimensional data (e.g. time, latitude, longitude, and in the case of an ensemble, the ensemble member) and also contains metadata to make note of model resolution, projection/grid type, initialization time, forecast valid time and QPF accumulation increment. QPF from the WPC comes in vector format (e.g. ESRI shapefile or Google kmz) where each feature comes with its own metadata. In order for hydrometeorological products to be correctly interpreted in different locations, timing of the products are expressed in Coordinated Universal Time (UTC). Midnight (0000 UTC) starts the 24-hour clock at the zero meridian. It is typical for a capital "Z" to follow any forecast time to indicate the unit is UTC. The metadata of all hydrometeorological products contain the initialization time, time of transmission and valid period.

3.3 Visualization

3.3.1 Raster data

For raster type format such as the HRRR model raw QPF data, visualization methods can be cumbersome due to the need to carry along substantial amount of information. One approach to overcome this is to develop static images, such as the PNG format, and then loop these images. However, one limitation of this approach is the inability to easily zoom in, since a separate PNG is required for each zoom level. A better approach is to convert the raster data into vector data (see 4.3.2) using GIS tools such as those available in open-source *python* or *R* software. To do this, the only user input required is the setting of contour levels that are then "polygonized" into objects.

3.3.2 Vector data

Visualization of vector QPF data, such as that from the WPC, can be done using many platforms such as QGIS, Esri's ArcGIS online, or Mapbox. The only user input required is the choice of colorscales and base maps, which can both significantly influence the effectiveness of the visualization. Typical color scales for QPF data are called "rainbows". A variety of different color tables can be found from the NCL software site.

4 HYDROLOGY & HYDRAULICS

During the FloodCast Requirements Analysis, DOTs across the nation expressed the need for more efficient prediction of expected timing, magnitude, and location of flooding, as well as anticipated impacts on infrastructure, particularly for locations without monitoring gages. To demonstrate how this requirement could be realized, the FloodCast prototype simulates flood inundation extents based on Advanced Hydrologic Prediction Service (AHPS) river age forecasts for various National Weather Service (NWS)-defined flood stages.

For the FloodCast H&H data standards and specifications component, the research team explored ongoing efforts for developing flood extent and depth predictions at locations with and without monitoring gages. The National Water Model (NWM), an experimental product developed by NOAA's Office of Water Prediction (OWP), provides access to predicted streamflow at ~2.7 million locations nationwide on a real-time basis. However, in order for the NWM output to be useful for DOTs, the streamflow forecasts need to be converted to either water depth and/or inundation extents. There is currently no agreed upon method for doing this conversion. As efforts to develop forecasted inundation extent and depth products advance, data standards for these products will be critical to ensure interoperability with flood forecasting decision-support systems.

4.1 Existing H&H Data Standards

Some types of H&H data in the FloodCast framework have existing data standards or data models. For example:

- **HY_Features** is a common reference to hydrologic features such as watersheds, streams and rivers.
- **WaterML2** (Water Markup Language) provides a systematic way to access water information from point observation sites.
- **RiverML** (River Markup Language) is a proposed language to standardize the description of river hydrology and hydraulic characteristics (e.g., river channel and floodplain geometry, flow characteristics) for use in web applications. River ML is a joint effort involving Consortium of

Universities for the Advancement of Hydrologic Science, Inc.'s (CUAHSI) HydroShare development team, the OGC Hydrology DWG, and the developer community.

4.2 FloodCast Data Standards and Specifications for H&H

The FloodCast data standards and the specifications were developed as part of our contribution to ELFIE. The data standards are built upon open source formats. At the core of framework is a flood event triggered by a large precipitation event (henceforth referred simply as the "event"). This event causes flooding in a flooding source like a river or stream in a watershed. The watershed is a "catchment realization" of the event. The watershed and stream are interlinked features with the event. At different times during the event, we have various inundation extents modeled. These inundation extents are captured in a "FloodExtent" feature type which in turn links the assets within the extent. Each inundation extent is also associated with a depth of flooding which is captured in a "FloodDepth" feature type. Figure 2 shows the various links and data types that were established as part of the ELFIE process.

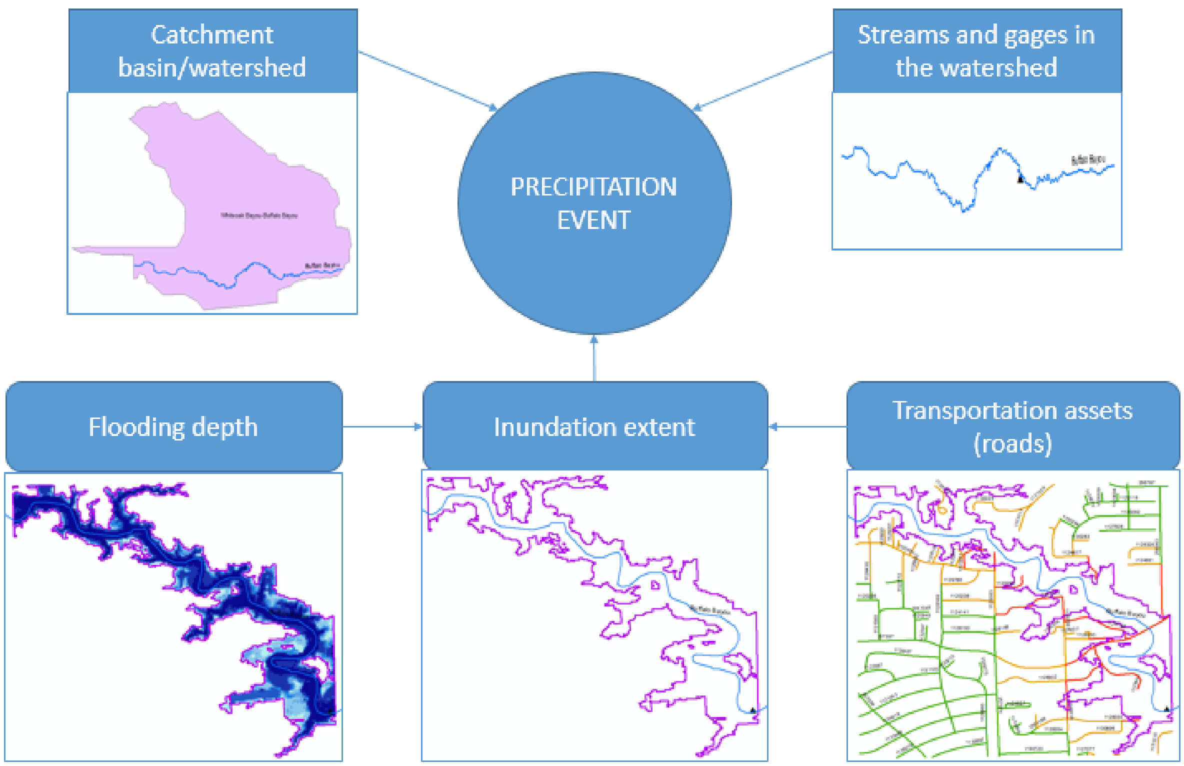

Figure 2: Illustration of FloodCast relational features within the ELFIE context.

The various domain feature types and the relations established will be captured in the ELFIE engineering report that is due in May 2018. Figure 3 shows the various feature types and the relations used for the FloodCast system and their descriptions. JSON-LD (JSON-linked data) format context files were produced for the FloodCast feature types. The format can be easily consumed in other applications for universal interoperability. The FloodCast JSON-LD content are listed in the ELFIE wiki and GitHub repository which can be accessed by clicking here. The watershed, streams, gages that are part of FloodCast's hydrologic component are captured as part of the HY_Features standard.

Feature Type	RDF encoding?	Comment
fc:FloodEvent	No	Feature representing the spatial coverage of a flood event.
fc:FloodExtent	No	Feature representing the inundation extent (i.e. floodplain)
fc:FloodDepth	No	Feature representing the inundation depth of a floodplain (i.e. depth grid)
fc:TransportationAssets	No	Feature representing the transportation-related assets like bridge, culverts, roads etc.

Relation	Feature Type (domain)	Feature Type (range)	RDF encoding?	Comment
fc:AssetsThreatened	fc:FloodExtent	fc:AssetsThreatened	No	Associated assets that are threatened based on proximity to the flood inundation extent
fc:AssetsMonitored	fc:FloodExtent	fc:AssetsMonitored	No	Associated assets that require monitoring based proximity to the flood inundation extent

Figure 3: FloodCast feature types and data relationships added to the ELFIE context.

While methods for generating real-time flood inundation depth and extents products advance, DOTs still need to maintain or improve their H&H capabilities to enable effective flood event decision-making. Therefore, a recommended specification for the H&H component is for the FloodCast system to utilize the best available source of H&H data. In some areas, the AHPS flood inundation extents may be the best available source of data while in other locations, DOTs may have their own flood extent and depth inundation libraries based on historical flood events. Eventually, when there is an authoritative approach for providing real-time inundation forecasts, the FloodCast specification will be updated to reflect the preferred data sources.

5 ASSET MANAGEMENT

Most State DOT's have started to embark on Transportation Asset Management Plans (TAMP), many of which have already improved infrastructure management at several agencies nationwide. Using their State TAMP as a guide, agencies will be able to thoroughly analyze life-cycle costs, evaluate risks and develop mitigation strategies, establish asset condition performance measures and targets, and develop investment strategies. The TAMP also serves as an accountability and communication tool and will inform established capital and operations planning efforts. Establishing an Asset Data Registry is the first step in developing a TAMP, however data mining the entire DOT's infrastructure could be time consuming and cost prohibitive. For this reason DOT's tend to develop TAMP with readily available asset data and establish a framework such that the new data is updated periodically as it becomes available.

Transportation asset data is a critical component of the FloodCast framework. State DOTs need to understand potential vulnerabilities for both individual assets and the transportation system as a whole well in advance of a flood event. As identified in the NCHRP FloodCast requirements analysis report, most DOTs have some sort of asset management system. In fact, the Moving Ahead for Progress in the 21st Century Act (MAP-21) requires DOTs to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and performance of the system that typically involves developing an asset registry. However, the absence or lack of enforcement of data standards have resulted the following issues for many DOT asset management systems:

- Do not include all transportation assets and only show DOT-owned assets.
- Are not completely in GIS format or a format that can be easily shared.
- Do not include information about asset fragility and vulnerability to flood conditions.
- Do not have or only have partial topology enforcement.
- Are missing asset elevation attributes.

To obtain sufficient information to support flood hazard impact analysis, it is likely that many DOTs will need to supplement their in-house data with other sources such as GIS files from local, county, and private stakeholders. Agencies have found that disparate systems for data collection can make it very difficult to combine the data into a centralized, state-wide system. Some agencies deal with these issues by creating their own data management plans and standards. However, the majority of DOTs would benefit from standardizing symbology and format, and establishing a set of attributes to ensure consistency among DOT-published data. Furthermore, State DOTs wishing to participate in operational flood forecasting would be able to use open data standards during the procurement process to ensure collected data would be maximally useful in the FloodCast framework.

5.1 Existing Asset Data Management Best Practices and Standards

The FloodCast study team performed a literature review of existing best practices and data standards for transportation asset data. There are several best practice/guidance resources available for State DOTs to use to address some of the asset data issues outlined above. For example, the FHWA with support from the

Volpe Center developed a guidance in 2012 entitled Best Practices in Geographic Information Systems-Based Transportation Asset Management. The guidance document acknowledges that GIS-based asset management systems are affected by several data standards issues and offers potential best practices based on interviews with several State DOTs from across the U.S. such as:

- A comprehensive and consistent data inventory for assets. Agencies do not necessarily need exhaustive data for every type of asset so the selection should be strategic and purposeful.
- A consistent linear referencing system and/or asset identification system so that assets are uniquely identified and clearly located regardless of who collects and enters data.
- Agencies may need to explore a number of different data collection methods (manual methods and surveys, GPS-enabled handheld devices (e.g. tablets and smartphones), sensors and cameras, automated asset data collection vehicles, aircraft surveillance) to obtain specific asset attributes.
- Asset management databases should be stored in a non-propriety shareable format. Specifically, a GIS format or a format that can be easily converted to a GIS format.

Some additional guidance on developing more robust asset management systems using GIS for transportation (or GIS-T) include:

- **NCHRP 20-27(2) (1997): Development of System and Application Architectures for Geographic Information Systems in Transportation and NCHRP 20-27(3) (2001)** Guidelines for the Implementation of Multimodal Transportation Location Referencing Systems. This project set the Location Referencing System standard for US DOTs and was simplified and codified in ISO IS 19148:2012.
- **NCHRP 20-47 (2003): Quality and Accuracy of Position Data in Transportation.** Discusses and suggests a data error model to evaluate the quality and possible ramifications of positional error inaccuracies introduced to data during acquisition, processing, transformation, and visualization.
- **NCHRP 08-87 (2015): Successful Practices in GIS-Based Asset Management** Provides examples of successful integration of GIS and asset management systems and uses, such as for data collection, communication, work planning, and disaster recovery. NCHRP 08-87 found that state DOT GIS data, overall, tends to be more complete for roads, followed by bridges, tunnels and culverts. Location data for signals, signs, guard rail, DOT-owned electrical infrastructure, sensors/instrumentation, and building facilities are also useful, as is hazard data (e.g., Colorado DOT rockfall data). Geospatial asset information tends to show location data, but is often lacking in other information that can help characterize vulnerability, such as elevation attributes, age, and condition.
- **Asset Management Data Collection for Supporting Decision Processes (FHWA 2009)** This report is a review of State DOTs data collection policies, standards and practices. Broadly speaking, the review found that data collection requirements can be categorized in the following three groups: 1) Location – actual location of the asset as denoted using a linear referencing system or geographic coordinates, 2) Physical Attributes – description of the considered asset,

which can include material type, size, length, etc., and 3) Condition – condition assessment data can be different from one asset category to another according to the set performance criteria.

- **Best Practices in GIS-Based Transportation Asset Management (FHWA 2012)**
  This report provides background on GIS and asset management, describes how public agencies have been integrating the two, and identifies benefits and challenges to doing so.

With respect to transportation-related data standards and specifications, there have been a number of efforts. NHRP Project 20-64 (2007) includes a comprehensive review of XML-based transportation data standards. In recent years, XML (eXtensible Markup Language) has become a well-accepted method for data exchange across platforms and applications. XML data structures, known as *schemas* provide a mechanism to develop and adopt common formats for data exchange, thereby allowing separate information systems to communicate. NCHRP Project 20-64 found that while significant progress has been made, particularly in the area of geographic data, the transportation arena is still at a relatively early stage of development and adoption. Several standards of relevance to the FloodCast project are included in Table 2.

Table 2

Schema/Standard	Content	Developer/Participants
TransXML (Transportation Extensible Markup Language)	XML-based data model developed to store transportation-related information including geometric roadway design, bridge design and analysis, construction progress, crash reports, highway information safety analysis.	NCRHP
CityGML (City Geography Markup Language)	Open data model developed for the storage and exchange of virtual three-dimensional city models.	NCRHP
InfraGML (Infrastructure Geography Markup Language)	Proposed standard that is still in the public comment period as of this writing. This standard is being developed with the intent of facilitating integration with TransXML and CityGML. The intent is to create a markup language to describe land parcels and the built environment, starting with: alignment/roads, survey, land parcels, and modules for other areas with identified needs such as pipe networks.	NCRHP
LandXML	Focus is the exchange of civil design information including raw and reduced surveying data, surface data, parcel data, and 3D road model.	Derived from earlier ASCII-based Engineering and Surveying-Exchange (EAS-E) initiative
GML (Geographic Markup Language)	A comprehensive XML schema for encoding both spatial and non-spatial geographic information. Feature-centric model, defining abstractions of real-world phenomenon (e.g., roads) with properties having names, values, and types.	OGC
XGDF XML	The ISO TC204 (ITS) GDF standard supports location-based services, with a current focus on car navigation systems. Data model includes features (e.g., roadway, structures, and railways), relationships between features,	ISO TC204 (Intelligent Transportation Systems)

Schema/Standard	Content	Developer/Participants
	and attributes of features or relationships. Includes roadway features, other transport modes, area features. Focus of attributes is on navigation needs.	
Geospatial One-Stop	As part of the National Spatial Data Infrastructure, the Geospatial One-Stop (GOS) data content standard formalizes how geographic information in any of seven themes can be represented for transfer between government agencies. The transportation theme includes modes of road, rail, transit, air, and navigable water. The road mode of the transportation theme is consistent with constructs found in GDF. It includes the ISO 19133 linear referencing clause	Federal Geographic Data Committee. Modeling teams had representatives from government, industry, and academia. The U.S. Department of Transportation Bureau of Transportation Statistics led the transportation theme model development.
ISO 19113	Linear Referencing data standard. Provides a standard, generalized content format for specifying a location, applicable to most any linear referencing method.	International Organization for Standardization (ISO) Technical Committee TC211 (Geographic information/Geomatics)
AASHTOWare – TSIMS	The goal of TSIMS is to develop a uniform approach to management of traffic safety information. Guidelines are being developed, so that any vendor or agency can interface existing systems with it.	AASHTO/FHWA
OGC Testbed-11 Symbology Mediation (2015)	Explores symbology used in the emergency management context. The report found that despite the large number of initiatives to develop standardized symbology sets, most of the initiatives have failed to become widely accepted and applied mapping symbol standards. Testbed 11 offers two new ontologies: the SPARQL Extensions Ontology and Semantic Mapping Ontology, designed to be more lightweight and flexible.	OGC
National Information Exchange Model (NIEM)	The NIEM model defines agreed-upon terms, definitions, relationships and formats-independent of how information is stored in individual systems- for data exchange. The NIEM model consists of two related vocabularies: core elements that are commonly agreed to by all the communities who use NIEM, and community-specific elements that align to individual NIEM domains. The infrastructure protection and emergency management domains offer promise for the FloodCast objective. Furthermore, NIEM developed geospatial exchange capabilities that leverage GML standards established by the OGC. By combining NIEM with GML, users benefit from shared access to the common operating data and services used within these geospatial systems.	Department of Homeland Security (DHS), U.S. Department of Justice (DOJ), U.S. Department of Health and Human Services, and U.S. Department of Defense (DOD)

5.2 FloodCast Data Standards and Specifications for Asset Management

The efforts listed in Table 2 address the data standards issues expressed by DOTs. For the purposes of supporting the FloodCast framework, the following requirements are recommended:

- The FloodCast framework should follow the OGC Testbed-11 symbology recommendations for mapping symbol standards.
- DOT asset management systems should utilize the linear referencing standards outlined in ISO 19133 for all linear referencing.

While some DOT asset management systems already contain the information necessary to perform flood impact analyses, there is still a gap **to develop a standard set of attributes and specific formats necessary to achieve FloodCast objectives.** In order for the FloodCast framework to effectively interface with the H&H data outputs (e.g. flood inundation extent and depth products), asset data needs to include specific attributes. Rather than using a data-centric approach to identify a FloodCast asset schema (i.e. what are all of the things about an asset that anyone would ever need to know?), the approach taken for this project was similar to the TransXML approach – a process-centric view (i.e. what information about an asset is required to evaluate asset failure to flood conditions?).

As identified during both the FloodCast Literature Review and Requirements Analysis, the asset vulnerability attribute can be difficult to characterize. A significant data limitation for flood impact analysis is whether DOTs have information about how assets within the transportation network are affected by heavy rainfall or flood conditions. Without this information, GIS-based analyses are limited to intersections which, at best, incorporate elevation data. To perform the intersection, any assets within the inundation boundary are considered impacted. This approach, impacted/not impacted, is very binary, whereas asset responses to hazard conditions often degrade along a continuum or stepwise based on factors such as elevation of key electrical components. Typically, TAMPs have a risk register where evaluating asset failure to flood conditions is defined based on proximity to the FEMA 100-year flood zones, a similar approach to the binary intersection analysis. However, the FloodCast vision hopes to move beyond this simplistic metric by developing asset fragility based vulnerability metrics across a wide range of potential operating conditions.

Vulnerability can be better assessed when detailed records of asset performance are available or can be inferred from design specifications, allowing the construction of fragility curves related to flood depth for a given asset. Fragility curves for floods show how an asset will function over the range of flood conditions the asset will be exposed to. Compared to the intersection or proximity analysis, depth-damage information provides a more accurate understanding of when assets are likely to fail. Loss estimation software such as FEMA's Hazus is a potential source of depth-damage curves for some transportation assets.

For purposes of the FloodCast framework, it is recommended that newly collected DOT asset data adhere to the format and attribute requirements provided in Table 3. Some DOTs have found it useful to provide field crews with data collector applications programed to follow specific data standards to ensure integrity and consistency of information gathered.

Table 3: Recommended FloodCast standard attribute requirements for DOT-owned shapefiles

Asset Type	Feature Type	Location	Vulnerability
Road	Polyline	LRS	Elevation Overtopping elevation
Bridge	Polyline	LRS	High cord elevation Low cord elevation
Culvert	Polyline	LRS	Culvert capacity
Tunnels	Polyline	LRS	Depth below the road level
Drainage systems	Polyline	LRS	Age of the system, approximate date of install.
Retaining Walls	Polyline	LRS	Condition assessments, LoF score
Building assets	Polygon		First floor elevation
Flood barriers and gates	Polyline	LRS	Condition assessment, CoF score
Pumps and pump stations	Point	Lat, Long (Decimal Degrees)	Resilience measures in place, such as secondary power supply sources on site.

6 COMMUNICATION & INFO TRANSFER

Effective communication during a flood event requires information transfer through a wide range of channels. Channels include traditional telecommunication (e.g. telephone, television, radio), social media, DOT and emergency management software, and innumerable sensors, some of which are static (e.g. stream gages, RWIS) and some of which are mobile (e.g. smartphones and tablets, Global Positioning System [GPS], aerial photogrammetry). DOT personnel, cooperating agencies; local, county, or national entities, and the public may be sending or receiving information at any given time. FloodCasting systems could be used to interface with widely available platforms (e.g. state 511 websites, Wireless Emergency Alerts, the FEMA Integrated Public Alert and Warning System (IPAWS) and geospatial services) to enhance flood event preparation, response, and recovery. Getting warnings out to the public early and through as many mediums as possible increases the chance that flood fatalities will be avoided.

The research team equipped the FloodCast prototype tool with automated alert capabilities to support both internal and external communication. The warning system capability allows users of the system to monitor the status, criticality, and passability of all assets within their affected municipality. When a flood event is triggered in the system, an automatic alert (either email or SMS text messaging) is sent out to subscribers of the system that includes the following information:

- forecasted flood event extent,
- predicted location and onset of flooding, and
- system-generated hyperlink to further information about the event (i.e. potentially threatened assets, criticality, passability etc.).

To achieve interoperability between the FloodCast system and other systems/information channels exchanging data during a flood event, the research team looked to the **Common Alerting Protocol (CAP)** developed by the **Organization for the Advancement of Structural Information (OASIS)** to meet FloodCast objectives. CAP provides an open, non-proprietary digital format for exchanging emergency alerts that allows a consistent alert message to be disseminated simultaneously over many different communications systems. The CAP format is compatible with emerging techniques, such as Web services, as well as existing formats including the Specific Area Message Encoding (SAME) used for the NOAA Weather Radio and the Emergency Alert System (EAS), while offering enhanced capabilities that include:

- flexible geographic targeting using latitude/longitude shapes and other geospatial representations in three dimensions,
- multilingual and multi-audience messaging,
- phased and delayed effective times and expirations,
- enhanced message update and cancellation features,
- template support for framing complete and effective warning messages,
- compatible with digital signature capability, and
- facility for digital images and audio.

Figure 4 illustrates the standard elements required for CAP alerts. The elements in bold are mandatory and are comprehensive of the information requirements for FloodCast warnings.

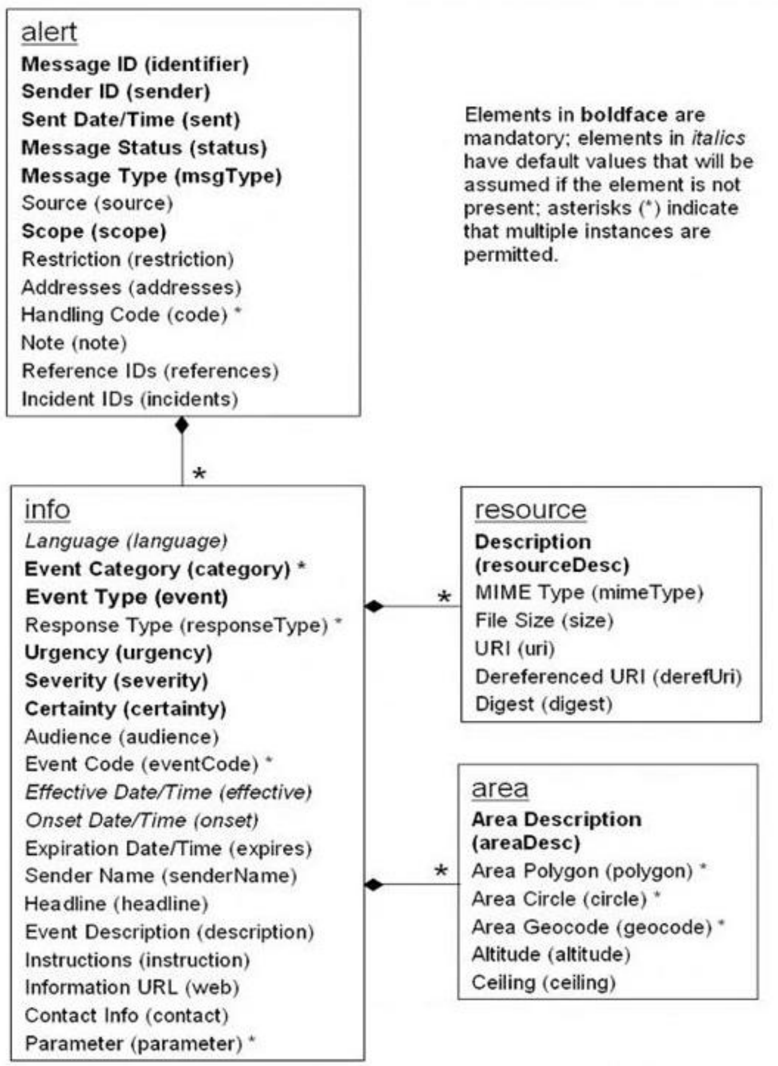

Figure 4: CAP's Document Object Model

Key benefits of using CAP standards for the FloodCast framework include the capability to include rich content such as photographs, maps, video and more as well as the ability to geographically target alerts to a defined warning area. Furthermore, as more systems are built or upgraded to CAP, a single alert can trigger a wide variety of public warning systems, thus increasing the likelihood that intended recipients receive the alert by one or more communication pathways.

8 INCIDENT MANAGEMENT

DOTs often share incident management data with partnering emergency management agencies before and during an event in order to both facilitate early recovery and to support after event applications for post-disaster grants. Therefore, in an effort to improve interoperability between DOTs and emergency managers, the research team integrated the relevant fields from FEMA's SitRep XML into the Incident Report module of the FloodCast system. This feature enables users to adhere to FEMA reporting requirements by providing users with dropdown menus to select from FEMA standardized categories of incident information, such as "Incident Type", "Incident Status", and "Incident Date".

Another element of the incident management data standards for FloodCast was supported by the study team's contribution to ELFIE. As described earlier in this report, ELFIE helped establish specific relational attribute fields for the different feature types. These standard relationships will enable improved flood event record keeping within the FloodCast system. Since the "Flood Event Feature" will have a date-time stamp, it will be easy to pull up that feature and see all related flood extents and impacted assets.

9 SUMMARY

The data standards and specifications for FloodCast were developed in alignment with existing data, DOT needs, and in support of DOT procurement so that state and local DOTs have a clear and efficient path forward for participating in FloodCast. The data standards in particular will be relevant for a wide variety of users that are involved in the transportation and emergency management communities of practice. Finally, the results of the research should be valuable to academic and other research institutes in identifying further areas for study.