DEVELOPING AN INUNDATION MAP STANDARD FOR THE U.S. ARMY CORPS OF ENGINEERS

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INTRODUCTION

Inundation maps are used to estimate flooding from multiple sources. FEMA uses inundation maps to determine flood insurance rates in the U.S., emergency action plan inundation maps are used to prepare for potential disasters surrounding dam projects across the country. Inundation maps may seem simple but require a complex combination of hydrologic data, hydraulic modeling, and engineering knowledge to produce accurate estimations of flooding for a given scenario. Modern inundation mapping utilizes computer modeling paired with GIS mapping technology to present the data in many mediums. Historically paper inundation maps were the exclusive available product of inundation estimation efforts. Today, multiple stakeholders using various levels of technology require the data to be distributed in many different formats. Technology has changed the way we generate inundation data and the ways the data is consumed. These changes have spurred an effort within the Army Corps of Engineers to update the standards for inundation modeling and mapping.

The Modeling, Mapping and Consequences production center (MMC) has been created to support the U.S. Army Corps of Engineers (USACE) Institute for Water Resources (IWR) Risk Management Center (RMC) in the production of hydrologic and hydraulic (H&H) models, economic consequence models and analysis, and flood inundation map production. The RMC is the agency responsible for updating USACE guidance and policy and the MMC is playing a critical role in defining the direction of modern policy. The MMC has been tasked with testing and developing new standards for inundation modeling, mapping and consequence estimation. These efforts are in direct support of the Critical Infrastructure Protection and Resilience (CIPR) program within the USACE Office of Homeland Security (OHS) and the USACE Dam Safety program within USACE Engineering and Construction (EC).

This paper will focus on the progression to a national inundation mapping standard as developed by the MMC. During the time since the MMC was formed, the requirements and formats used for USACE inundation modeling and mapping have been debated and defined by the many stakeholders in the MMC project. We'll begin by describing the MMC Production Center framework, look at the requirements driving the MMC inundation mapping efforts, and lay the groundwork for discussing the development of a mapping standard.

The MMC was formed as a virtual Project Delivery Team (PDT) comprised of USACE employees from around the country. The Program is lead by a project management team based out of Vicksburg, MS. There are approximately 70-80 engineers, geographers and economists from around the country that have committed at least half their time over the next two years to

MMC efforts. The functional areas of the MMC are lead by technical leads based in Vicksburg, MS, Tulsa, OK - Modeling, Kansas City, MO – Mapping, and Huntington, WV – Consequences. A central set of requirements were developed for the MMC to follow regardless of the specific stakeholder. Developing scalable models that support the estimation of inundation areas and consequences for dam failure and non-failure flooding scenarios over a broad range of loading conditions and operation parameters is the core requirement of the modeling portion of the MMC. Tabulation of consequence data using those models that support the national infrastructure protection priority development using a risk-based framework drives the consequences portion of the MMC. Development of mapping products that clearly communicate the location of potential inundation areas, critical facilities and communities at risk drive the mapping portion of the MMC. Requirements specific to the individual stakeholder also drive decisions and work-flow within the MMC. These individual requirements are responsible for the range of mapping products that are being produced for MMC studies.

MMC PRODUCTS

The goal of the MMC Production Center is to provide USACE stakeholders with standardized H&H models, mapping products, and consequence estimates for all of the dams owned and operated by USACE. These products are designed to specifically address the requirements set by the CIPR and Dam Safety programs, but are being developed with the intent to meet future needs both internal and potentially external to USACE.

H&H unsteady flow models developed using either the Hydrologic Engineering Center (HEC) River Analysis System (HEC-RAS) or Flo-2D that support the estimation of inundation areas over a range of conditions for both failure and non-fail scenarios. These models incorporate real-world flow estimation and use structure operation parameters directly out of the guidance developed for the individual dam when it was built. The models are developed on an expedited schedule and are subsequently built to a lower level of detail than would be used for a fine scale model. The models allow for more detailed study in the future because they can be enhanced by adding more detailed geometric data and by finely tuning the model parameters. Models developed are used to estimate the flooding extents for a standard set of scenarios that are required by Dam Safety and CIPR. These estimations are then used in the consequence modeling and mapping efforts. A report detailing the modeling efforts procedures and results accompanies the model data deliverable as well.

Economic and life-loss estimations are produced using modeling software and economic research. The software used to estimate economic and life losses is the HEC Flow Impact Analysis (HEC-FIA) software which incorporates a version of the LifeSim life-loss model. This software uses the modeling output from HEC-RAS and Census data to estimate the number of structures and people affected by the inundation. Structure counts, attributes, and locations are estimated using Census block data and tabulated by a specified impact area, usually at the county level. The model also uses a modified version of the LifeSim model to estimate the number of lives lost during the specific scenario. The H&H modeling team is responsible for developing the base HEC-FIA model and supplying it to the economists in the consequence team to refine and report the results.

The H&H modeling results are also used in the mapping products of the MMC. Basic inundation maps have evolved into a number of inundation mapping products that are developed for use on many platforms to meet stakeholder needs. The standard mapping products developed by the MMC map production team include; Google Earth Keyhole Markup Language (KMZ) files for use in the desktop Google Earth software, PDF format inundation map atlases developed using both street-map and aerial photo backgrounds for digital distribution and use as well as publication for use in Emergency Action Plans (EAPs), and online web mapping services for viewing the data as it is developed through the life cycle of the MMC studies. The foundation of the mapping products is a standard Geographic Information Systems (GIS) database consolidating the model results and supporting the production of all of the mapping products. The paper/pdf map atlases are only one of the products generated by the MMC map production team, each of the products fills a unique need for the MMC stakeholders. The following is a summary of the development of the MMC inundation atlas product.

MMC MAP PRODUCT DEVELOPMENT

The process of developing a standard presentation for the mapping products generated by MMC studies began by analyzing the existing formats and presentation methods currently being used for inundation mapping. Existing EAP mapping within USACE are generally formatted to an 11” by 17” page size in order to be included in EAP report binders. These maps are indexed along the stream below the specific dam project. The inundation estimates used in the existing maps vary based on the age of the maps and the district responsible for developing the maps. Scales and styles vary across USACE based again on the age and source of the mapping. When looking at ongoing inundation mapping efforts, the prime example of inundation mapping in the United States is the FEMA Digital Flood Insurance Rate Mapping (DFIRM) efforts that have been taking place to update the government flood insurance rate maps that define areas where flood insurance is mandated, and sets the rating classifications for such areas based on the likelihood of flooding. These maps are developed in county level series with scales that vary depending on the population density of the area but are generally presented using the standard 1:24,000 scale. The DFIRM map format is based on a large format template making each panel a stand-alone map document. One of the key differences between the DFIRM modeling and mapping effort and the MMC modeling and mapping effort is that DFIRM modeling uses steady-state H&H modeling, depicting ranges of flows corresponding with the estimated likelihood of the flow while MMC modeling is unsteady, using a varying input hydrograph over time. When the MMC mapping effort began, the DFIRM style map panel approach was adopted by the MMC.

When defining a format for mapping products and designing the dissemination methods for those products and the data they rely on, we must understand how the data is developed and what uses are appropriate for that data. As mentioned earlier, the primary modeling system used for MMC studies is the HEC-RAS modeling suite. This model is what is described as a one-dimensional hydraulic model, meaning that water is assumed to move in only one direction in relation to the model geometry. When the model is constructed, cross sections depicting the topography of the river channel and surrounding over-bank area are digitized so that they are perpendicular to the flow of water. The model interpolates the behavior of the underlying ground surface between cross sections and estimates the water elevation at a specified time interval for each cross section in the model. There are other geometric entities that store modeled water elevation values such as storage areas, but the cross sections are the primary tool in this model. The model data is then brought into a Geographic Information System (GIS) and the inundation can be generated by plotting the modeled water surface elevations against existing digital elevation model (DEM) data. The variables in this process that can affect the accuracy of the output inundation extents are the level of detail in the geometry that goes into the model, i.e. – the number and layout of the cross sections, the level of detail used to define the underlying topography for each of the cross sections, and the resolution and accuracy of the DEM used to generate the inundation data after modeling is completed. Understanding the source data is important when deciding on what scale is appropriate for the display of the data and what level of manual editing of the data is required.

The primary map product developed by the MMC is the inundation map atlas. This series of maps is designed so that it can stand alone as a publication or be appended to an emergency action plan. The design of the inundation map atlas evolved over time as the MMC program has matured. The first generation design of the MMC inundation maps were based on a DFIRM-like template. This product was based on a 26” by 36” map panel. Six key pieces make up the MMC inundation maps:

- Title block
- Legend
- Notes to users and disclaimer information
- Location/Index map
- Inundation map
- Profile graph

All six elements were incorporated into a single sheet for the 26” by 36” format map panels. This allowed each map panel to act as a stand-alone product that could be used individually without the remainder of the map series. The autonomy gained by generating self-contained products competed with the costs of the maps physical size. A large format map panel could not easily be incorporated into emergency action plan documents. Ease of use in the field of large format map panels was also called into question. The MMC proposed moving to an 11” by 17” format map book similar to the existing EAP map format. The six elements still needed to be presented in the map product, but going to a map atlas style product meant that there would be much less redundant information presented to the end user. Both formats were presented to the MMC stakeholders and the decision was made to move to the smaller format map atlas.

As mentioned earlier, either map format requires the six key pieces of information to be complete. Each piece presents the final end-user with a set of information used to relay the information gleaned from the H&H modeling effort to the map user. Some of these key map elements are standard cartographic conventions required for any successful map product. Others are unique data display tools formulated for the MMC specifically. Each element will be addressed individually below. Changes to the design of individual elements over the evolution of the MMC inundation atlas will be addressed along with any issues faced during the design and early implementation phases. Figures 1 and 2 display the MMC mapping products in both the large format and 11” by 17” format. Each element is called out and will be described below.

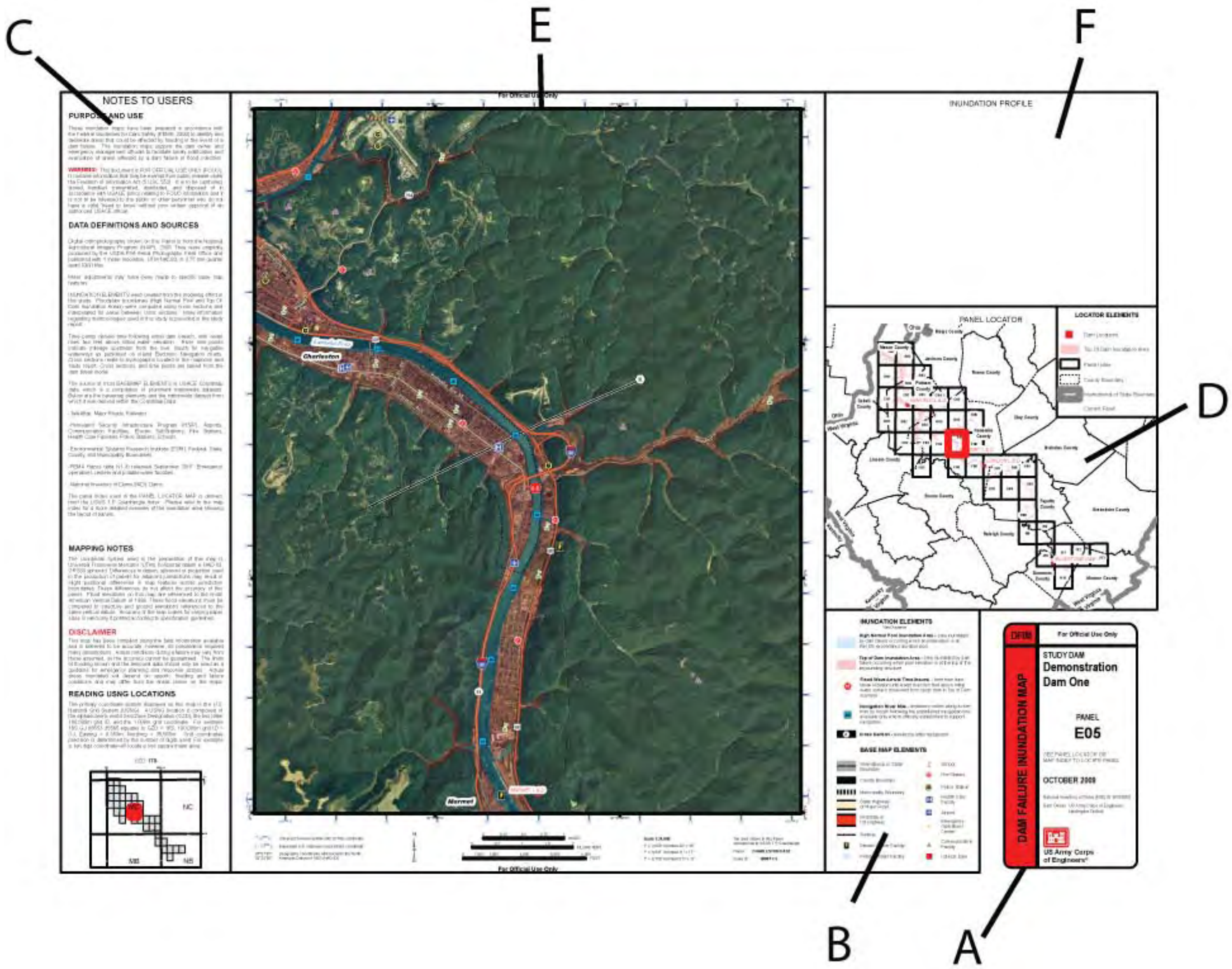

Figure 1 Large Format Inundation Map Example

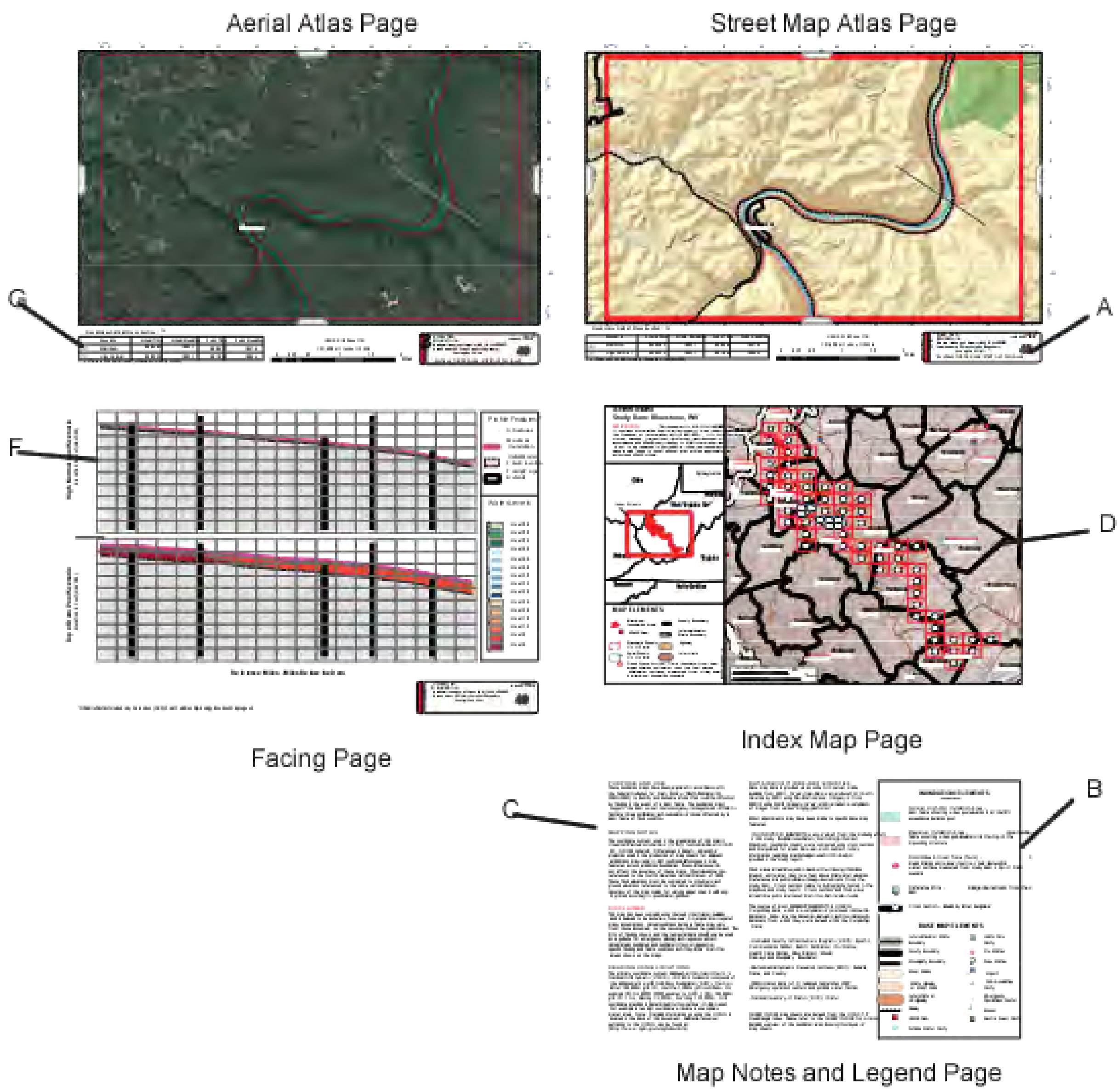

Figure 2 Inundation Atlas Examples

The title block is standard on many mapping products developed throughout USACE cartography. Title blocks are called out as part A in figures 1 and 2. The blocks purpose is to convey information about what the intended use and scope of the mapping product is. The information contained in the title block has changed little over the evolution of the inundation atlas. Information such as the NIDID of the study dam and the USGS quad ID for the individual panel or sheet are displayed. The inundation atlas employs a title block on each page describing the contents of the individual map sheet as well as an atlas title page displaying the study dam information for the atlas. The legend is also a standard map element, providing the user reference to how each of the data layers display in the map. Legends have not changed over the development of the inundation atlas. Legends are called out as part B in figures 1 and 2.

On each of the original large format inundation maps, the left portion of the map page was used for the notes to users and disclaimer information. This text gives the users a summary of the intended use of the product, lists the data sources used for the map, and includes legal disclaimer language cautioning users of the maps. The content of these notes have not changed substantially over the development of the products, but the way they are included in the final product has. Each panel of the large format maps were developed to act individually, thus each contained a copy of these map notes. The small-format atlases were designed as a single unit, so this information is included with the legend on a single page in the front of the atlas publication. The notes to users are called out as part C in figures 1 and 2.

Most maps require a location or index map to give the user a reference to the broader geographic context of the maps they are looking at. Each large format panel contained a copy of the location map showing surrounding states and major transportation features. Like the notes to users, this information was redundant if used on every page, so for the inundation atlas, this information was moved to a single page in the front of the publication. The location/index map is called out as part D in figures 1 and 2.

While the previous map elements changed little besides their location within the publication, the inundation map itself and the profile graph portions of the product have seen much change over the development cycle of this product. As called out as part E in figure 1, the inundation map portion of the large-format map product were designed to display two inundation scenarios over aerial photography with road network and critical infrastructure point location information. Specific changes to the format of the inundation map are outlined in table 1 below.

Table 1 Changes to the Inundation Maps

Map Element	**Large-Format Panel Design**	**11” by 17” Inundation Atlas Design**
Map Scale	1:24,000	1” = ½ Mile with detailed sheets at 1” = ¼ Mile
Base Map Data	Aerial Photography	Hillshaded Street Map series and Aerial Photography series
Road Data	Vector Data Layers	Raster Image imbedded with base data
Labels	Annotation	Combination of raster image imbedded with base data and annotation

The original map extents and scale were designed to mirror those used for the 1:24,000 USGS topographic map series. When moving to the 11” by 17” map format, the map extents had to be altered. Changing the scale to 1" = ½ Mile allowed the use of a standard engineering scale as well as allowing the maps to include some overlap while still staying close to the original scale and fitting on the new page size. Detailed sheets were implemented using a scale of 1" = ¼ Mile to show more detail in areas with higher population concentrations and more consequences.

Aerial photography from the National Agricultural Inventory Program (NAIP) obtained from the U.S. Geological Survey (USGS) was used as the original base map layer. This imagery was obtained from the USGS and local ESRI (Environmental Systems Research Institute) image services were developed to support map production. This was problematic however, because the amount of data that needed to be obtained surpassed the existing system capabilities for data storage and access. This problem was addressed by employing image services maintained and offered by the GIS software vendor ESRI. ESRI offers nationwide imagery and other base-data services at a substantial cost savings compared to maintaining local imagery. The ESRI base-data services also replaced the road network data and annotation development and maintenance costs. The MMC stakeholders decided that a street-map background similar to popular web-mapping applications was preferable to aerial photography. It was decided that the street-map background would become the standard base layer; however aerial photography would still be used to generate a companion product. Annotation layers were maintained and used for all labeling on the original map format. The cost to develop and maintain annotation for all feature types is substantial. Many of the layers including roads, counties and cities are labeled on the services we now use as the base data layer. These labels cannot be moved by the mapper, but any cartographic drawbacks were offset by the cost savings incurred by moving to pre-processed labeling. Some cities and counties still require annotation to be developed locally in order to make sure they are correctly labeled on each map sheet, but road labeling is exclusively obtained from the ESRI image service.

Flood profile graphs are a visualization tool developed for the MMC mapping product. These graphs are generated to display the water surface elevation of the study stream at pre-defined time intervals for the portion of the stream shown in an individual map panel or sheet. The concept for the graphs was developed early on in the development of the MMC mapping products but a usable and producible format was developed specifically for the small-format maps.

Custom GIS tools were developed that allow the computer to ingest the data output from the hydraulic model along with information derived from other GIS layers to produce the graphs. The goal of the graphs is to show the timing of the inundation for an area that corresponds to the map sheet adjacent to the graph page in the inundation atlas. The profile graphs, or facing pages are called out as part F in figures 1 and 2. An example was not available for the large format example in figure 1; the location on the panel is called out. Adjustments to the display of the data and the format of the graph took place until the following standards were reached:

- Each flooding scenario displayed on the map will produce its own individual graph.
- Graphs will only be produced for sheets that contain river model centerline data.
- The graphs for a specific sheet will have the same vertical and horizontal scales.
- The river extent of the graph will contain the adjacent map sheet as well as data from a certain distance upstream and downstream of the active sheet.
- Points for critical infrastructure shown on the map in the vicinity of the inundation will also be shown on the graphs with identical symbology.
- Points representing the structure inventory used in consequence estimation will be included on the graphs to show where clustering of impacts might occur.

As a byproduct of the development of the profile graphs, timing information for both an estimation of the flood wave arrival and for the maximum inundation is calculated and displayed in the flood wave information table on the map sheet, called out as part G on figure 2.

LESSONS LEARNED

Developing an inundation map standard for USACE has proved to be a complex and time consuming process. The stakeholders in inundation modeling, mapping and consequences present a varied number of requirements that must all be addressed within a uniform product framework. The standard will no doubt change over time, and flexibility to allow this change has been built into the current standards. Decision points were reached during the process of developing the standard and have required substantial research and development efforts to address.

The quality of digital elevation models vary across the country. The standard base elevation dataset used for MMC projects is the 10m spatial resolution National Elevation Dataset (NED). This elevation dataset has proved sufficient for the level of detail required from the MMC modeling effort, but the sources of elevation data can vary from region to region. Light Detection and Ranging (LIDAR) technology is used to update the NED on the basis of availability and in those areas; the NED provides a good basis for modeling in these areas. There are areas of the country however, that have elevation data derived from old USGS topographic maps or similarly dated sources. These areas caused the MMC to re-consider the elevation data requirements for the program. The decision was made that the NED would be sufficient for the majority of the study areas, but an effort would be made to locate higher resolution data for many study areas. Processes have been developed that allow us to incorporate better elevation data into the modeling effort where available.

Another issue that we had to work through was the fact that much of the existing data surrounding the dam projects in USACE were developed using elevation values referencing the National Geodetic Vertical Datum of 1929 (NGVD29) but the standard for data developed in the Corps today is to use the North American Vertical Datum of 1988 (NAVD88). The conversion factor between datums varies across the country and can range from tenths of feet to tens of feet.

USACE developed software that can perform the conversion for X, Y, Z points anywhere in the continental United States; however this conversion software only works for point data. To give the modeling teams a way to update existing model elevations, the mapping team developed a raster dataset containing the vertical conversion factors on a 1 kilometer spatial resolution. Raster datasets were developed to both convert from and to each of the datums.

The primary lesson learned through developing the MMC mapping product is to know the user requirements of the products that are in design. The number of stakeholders and potential user bases for the MMC mapping products presented and still presents a challenge to the MMC development team. A substantial effort has to go into defining all of the potential roles that the mapping products may fill. Nut fully understanding the viewpoints of all of the stakeholders in a process like the MMC can result in the waste of a substantial amount of time and money.

CONCLUSION

Since the inception of the MMC within USACE in the fall of 2008, substantial progress has been made in the development of an inundation map standard for use throughout the USACE. By utilizing state-of-the-art technology and expertise from throughout the enterprise organizational structure, the MMC has been able to develop a suite of mapping products that fill the needs of the each of the programs stakeholders. The inundation atlas is the primary product that was developed by the MMC for this effort. Understanding the goals and requirements set forth and using an iterative design process, the MMC was able to provide a useful product to those who need it.