Federal Flood Risk Management Standard (FFRMS) Interim Flood Mapping Data Development Methodology

April 2024

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Table of Contents

Acknowledgments

Drafting of this document was led by the Federal Emergency Management Agency (FEMA) and FEMA's Production and Technical Services contractors.

Additional Review

The National Climate Task Force Flood Resilience Interagency Working Group (IWG)[1] and the Flood Resilience IWG Science Subgroup[2] led a series of reviews on the Interim Methodology Report (Interim Report) to ensure the mapping data development methodology underlying the Federal Flood Standard Support Tool is robust and well documented.

Agency Expert Review

In January 2024, Federal agency experts from the IWG were given a two-week period to review draft versions of: (1) the Federal Flood Standard Support Tool website; and (2) the Interim Report. The agency experts submitted feedback to NOAA and FEMA on both deliverables and modifications were made as appropriate.

IWG Science Subgroup Review

The IWG Science Subgroup subsequently conducted a technical review of the Interim Report. The technical reviewassessed the clarity of the data underlying the Interim Report, how well the Interim Report and the Federal Flood Standard Support Tool and website explained and described how data are determined to best available, actionable and available for CISA, the explanation of data limitations, how conflicts in flood elevation were addressed in the documented methods, and what areas might be available for future research.

Representatives from DOE, HHS, HUD, NOAA, and the OSTP drafted the technical review of FEMA's methodology report. The review suggested some clarifications but ultimately found FEMA's Interim Report to sufficiently describe the methods used to create flood mapping data to support the CISA (where data are available), FVA, and 0.2PFA approaches for areas across the United States that have effective FEMA FIRMs.

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[1] Launched in August 2021, the Flood Resilience Interagency Working Group (IWG) under the National Climate Task Force is part of the Administration's whole-of-government approach to building flood resilience. The IWG was formed in response to Executive Order (EO) 14030 on Climate-Related Financial Risk, which reinstated EO 13690 and, in doing so, reestablished the FFRMS. The Flood Resilience IWG is co-led by the Council on Environmental Quality (CEQ), the Office of Management and Budget (OMB), and the Department of Homeland Security (DHS) Federal Emergency Management Agency (FEMA) to coordinate Federal agencies' implementation of FFRMS and other flood-related priorities.

[2] In October 2021, the Flood Resilience IWG convened an FFRMS Science Subgroup to review and update the best-available, actionable science and guidance underpinning the standard, and to facilitate development and delivery of science-based implementation resources that support consistent application of the standard by Federal agencies and non-Federal partners.

Based on the IWG Science Subgroup’s technical review, FEMA made additional edits to the Interim Report. Specifically, FEMA added clarifications regarding the estimation of water levels in locations subject to both coastal and riverine hazards; where the simplified CISA data were produced and identifying the simplified nature of the data development; addressing data limitations in areas which experience both coastal and riverine flooding; providing additional documentation on the use of cross-sections and digital elevation models (DEMS).

FFRMS Interim Methodology Report

1.1. Overview

Executive Order (EO) 13690, *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input* (2015)[3], establishes a Federal Flood Risk Management Standard (FFRMS) so that agencies take action to enhance the nation's resilience to current and future flooding. EO 13690 and the associated FFRMS amended and built upon EO 11988, *Floodplain Management* (1977), that requires agencies to take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values of floodplains. EO 13690 was revoked in 2017 but reinstated on May 20, 2021, through EO 14030, *Climate-Related Financial Risk*, clarifying that the FFRMS and the guidelines for floodplain management under EO 11988 remain in effect.

The FFRMS applies to "federally funded projects" defined as "actions where Federal funds are used for new construction, substantial improvement, or to address substantial damage to structures and facilities." Additionally, individual Federal agencies may further define the programs or actions considered to be federally funded projects for applying the FFRMS. Agencies must select from the following several different approaches to establish the FFRMS floodplain:

1. **Climate-Informed Science Approach (CISA)**[4] – The elevation and flood hazard area (i.e., vertical flood elevation and expanded corresponding horizontal floodplain) that result from using the best available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding based on climate science.
2. **Freeboard Value Approach (FVA)** – The elevation and flood hazard area that result from adding an additional 2 feet to the Base Flood Elevation (BFE; also known as the elevation of the 1% annual chance flood or 100-year flood elevation) for non-critical actions, and by adding an additional 3 feet to the BFE for critical actions.
3. **0.2% Annual-Chance (500-year) Flood Approach (0.2PFA)** – The area subject to flooding by the 0.2% annual-chance flood (also known as the 500-year flood).
4. The elevation and flood hazard area that results from using any other method identified in an update to the FFRMS.

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[3] EO 14030, Climate-Related Financial Risk (2021), reinstated EO 13690.

[4] The FFRMS and the 2015 Guidelines for Implementing Executive Order 11988, Floodplain Management, and Executive Order 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input identify CISA as the preferred FFRMS approach when climate science and future conditions data are available and actionable. Where data are not available or actionable for CISA, FVA and 0.2PFA are acceptable approaches.

WHAT IS THIS DOCUMENT?

The Interim Methodology Report was designed to summarize the methodology processes and procedures followed by FEMA to create digital flood elevations and extents that can be used within the Federal Flood Standard Support Tool (FFSST).) The tool is designed to implement simplified CISA (where applicable), FVA, and 0.2PFA approaches. The methodology processes and procedures summarized within this document use as a basis the hydrologic and hydraulic model-basedbased, digital flood hazard datasets that have gone through a full public comment and appeal period and are published as part of FEMA's Flood Insurance Rate Maps. This document provides a resource that Federal agencies and their non-federal partners (including potential federal grant recipients) may use to understand the process and procedures followed by FEMA in data development of the freeboard mapping data and 0.2PFA data.

The data produced are water surface elevation (WSEL) rasters at the county (or county-equivalent) level:

- Freeboard WSEL rasters for +0, +1, +2-, and +3-foot elevations for all riverine areas, in the continental US as well as Puerto Rico and the US Virgin Islands (USVI), (where digital effective FEMA floodplain data exists).
- Freeboard WSEL rasters for +0 through +10-foot elevations for coastal areas on the Atlantic and Gulf Coasts, to support a simplified CISA application utilizing NOAA Sea Level Rise projections [5] within the FFSST.
- 0.2% annual chance flood WSEL rasters where effective FEMA data include 0.2% annual chance flood elevations.

A key component of the data development is the distinct separation between the datasets developed for use in the FVA and the datasets developed for use within simplified CISA. For coastal areas considered within the simplified CISA application (Atlantic and Gulf), the coastal data is processed fully independently and is separated from the rest of the county based on the extent of the coastal Stillwater Elevation that is produced as part of the FIRM. For the FVA approach, the elevation data published on the FIRM is used as the base data. Even in areas where these two things may overlap, the WSEL rasters are computed independently. Base Flood Elevations (BFEs) published on the FIRMs and used as the base data for all Freeboard Mapping Data may, in some transition zone areas, contain components from both riverine and coastal sources. These are computed using FEMA's standard

[5] 2022 Sea Level Rise Technical Report (noaa.gov); The Sea Level Rise Technical Report provides the most up-to-date sea level rise projections available for all U.S. states and territories. This multi-agency effort, representing the first update since 2017, offers projections out to the year 2150 and information to help communities assess potential changes in average tide heights and height-specific threshold frequencies as they strive to adapt to sea level rise.

approach, documented within the county FIS and the Combined Coastal and Riverine Floodplain guidance document (FEMA, 2020)[6].

Quality Control and Assurances are discussed in Section 1.3.3.

WHO IS THE AUDIENCE FOR THIS DOCUMENT?

This document is intended for Federal agencies and/or their partners to understand the methods that FEMA utilized to create flood hazard mapping information that supports the implementation of FFRMS.

This document assumes 1) an intermediate level of floodplain management knowledge and 2) some familiarity with reading and interpreting FEMA Flood Insurance Rate Maps (FIRMs) and associated online mapping and data, including Flood Insurance Studies (FISs). For more information on FEMA mapping, consult the following resources:

- How to Read a FEMA FIRM Tutorial
- Coastal flood mapping basics (coastal hazards and mapping elements unique to coastal areas).

LIMITATIONS OF THIS DOCUMENT

The data development effort described herein does not address methods for determining sea level rise. The science and simplifications associated with a simplified CISA approach are documented within the FFRMS Job Aid[7]. This simplified CISA method suggests adding localized sea-level rise elevation data to the BFE to determine the FFRMS floodplain. For coastal settings, apply the simplified CISA to actions along low-lying coastal shorelines on the Atlantic and Gulf Coasts. The data development effort described herein is only designed to document the development of the FFRMS elevations and horizontal extents of this simplified approach, the Freeboard elevations andper extents, and 0.2% values and extents, where applicable. These data are then implemented within the FFSST[8], which is not the focus of this Interim Report.

The basis of all data development under this effort includes FEMA effective FIRMs and BFEsBFE that are digitally available and model-based.sed Some FEMA regulatory flood maps (e.g., effective FIRMs) may not reflect current conditions on the ground (for example, they may be more than 10 years old and/or lie in areas that have experienced substantial land use changes). Details regarding the underlying FIRM and FIS data are best obtained from those sources, which are available on FEMA's Map Service Center. Although the methodology developed and used to generate the underlying data

[6] December 2020- Guidance for Flood Risk Analysis and Mapping – Combined Coastal and Riverine Floodplain

[7] Federal Flood Risk Management Standard (FFRMS) Floodplain Determination Job Aid

[8] Note that the simplified CISA approach utilized in the FFSST uses more precise ground and water surface elevations (decimals) compared to the simplified CISA application in the Job Aid (whole foot).

that is described within this document is consistent with the 2015 revised Guidelines for Implementing EO 11988[9], it does not describe the only methods to develop FFRMS floodplains. Agencies may develop other methods to identify the FFRMS floodplain consistent with the approaches identified in the EOs and the FFRMS.

LIMITATIONS OF DATA AVAILABILITY

Where no FIRM is available, as stated in EO 11988, "the agency shall make a determination of the location of the floodplain based on the best-available information."[10] Users may need to rely on other resources, including flood hazard data from other Federal sources or from state, tribal, territorial, or local government sources to identify the flood elevations used to identify the FFRMS floodplain. Users should first reference individual Agency rules.

DECISION FACTORS FOR THE APPROACH

Several decisions regarding this data development effort were made at the initiation of the project in consultation with decision makers and Federalfederal FFRMS stakeholders. Decisions are required to ensure that resources are prioritized in data development. These decisions do not preclude changes or future augmentation, decided in consultation with decision makers and FFRMS stakeholders.

- Raster outputs:
  - All FFRMS freeboard datasets are being developed in raster format only. To produce vector data, similar to what is shown in the FEMA National Flood Hazard Layer (NFHL), requires more detailed labor and would not meet the requirements of a tool designed to output specific freeboard elevations.
- 0.2%-annual-chance flood elevations:
  - Where FEMA digital FIRM data includes digital, model-based 0.2%-annual-chance flood elevations within the NFHL, that information is being utilized to create raster datasets to represent the 0.2%-annual-chance elevations and floodplain.
  - Where FEMA digital FIRM data does not include 0.2%-annual-chance flood elevations within the NFHL, a vector dataset was created showing the extent of the 0.2%-annual-chance floodplain using mapped flooding extents shown on the effective FIRM. Elevations associated with these extents may be available from the underlying model data, however, in consultation with decision makers, the effort required to generate these data was not prioritized at this point in the data development process.

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[9] https://www.fema.gov/sites/default/files/documents/fema_implementing-guidelines-EO11988-13690_10082015.pdf

[10] Executive Order 11988, Section 2(a)(1)

  - In coastal flood hazard areas, 0.2%-annual-chance flood hazards shown on FEMA FIRMs do not include the assessment of wave effects in the extent of the flood hazard mapping. In consultation with decision makers and FFRMS stakeholders, additional development of wave data associated with the 0.2%-annual-chance flood hazards was not prioritized at this point in the data development process.

- Digital Effective FIRMs:

  - To ensure project efficiency and to provide the most consistent dataset possible, FFRMS freeboard and 0.2%-annual-chance mapping data was only developed in areas where digital effective FIRMs exist. FEMA is constantly updating flood hazard information across the country and have data in various stages of development in many areas beyond the geographic extents of existing FIRMs, as well as in some areas where FIRMs already exist. However, utilizing datasets that have gone through a full public comment and appeal period as the basis for this effort was prioritized in consultation with decision makers and FFRMS stakeholders.

- Coastal/riverine flood hazard transition:

  - Digitally effective FIRM data includes areas where both riverine and coastal hazards exist[11]. The freeboard values generated to support the FVA approach, therefore include these areas implicitly as these datasets were constructed for each county using digital effective FIRM data. No modifications to these areas or methods were applied.

  - Freeboard values in coastal areas that are used to support a simplified CISA approach were generated independently and were based on digital effective FIRM data that was spatially limited to coastal areas, as defined by the extents of coastal SWEL data.

Overlapping of these datasets occurs in many instances, and the use of these datasets is determined within the implementation of the flood support tool.

1.2. Basic Concepts of Methodology

The FFRMS recognizes that numerous factors, such as climate change and other future land use changes, may increase the likelihood of future floods exceeding the currently mapped base flood elevation. Changes in flood events may make a wider land area vulnerable to flooding (see Figure 1). For example, in most densely populated areas of the U.S., FEMA identifies and maps the BFE ((also known as the 1%-annual-chance flood elevation) and the associated area inundated with that flood elevation. Figure 1 displays the Water Surface Elevation, or BFE if sourced from the NFHL, as the top of the dark blue area. The BFE, based on modeling of the existing conditions at the time of the engineering study, is the primary elevation depicted on the FIRM, and forms the basis for current

[11] December 2020- Guidance for Flood Risk Analysis and Mapping – Combined Coastal and Riverine Floodplain

minimum floodplain management standards. The FFRMS flood elevation, using simplified CISA[12], FVA, or 0.2PFApfa, will bebe higher than the BFE; see "vertical extent" in Figure 1. A higher elevation means that more dry land would be inundated; see "horizontal extent" in Figure 1. The methodology outlined in the following sections describes details on the data and processes applied to generate both the vertical and horizontal footprints for the data developed in support of FFRMS methods.

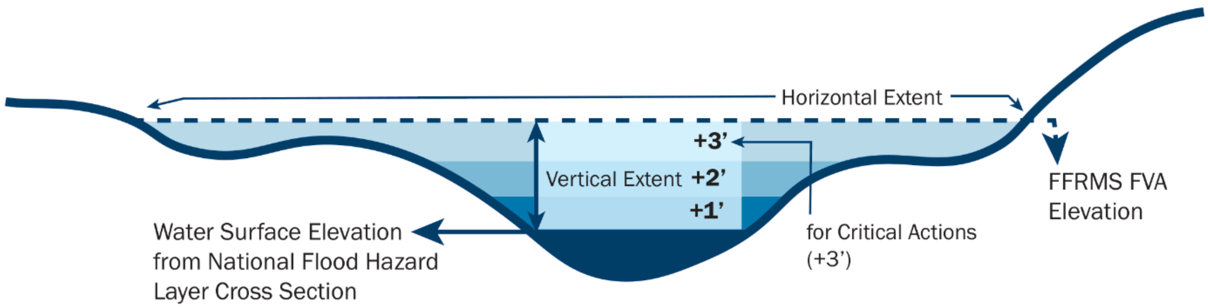

Figure 1: FFRMS Freeboard Value Approach Data Development, Horizontal and Vertical Extents

[12] While direct application of the Climate Informed Science Approach in some areas of the United States could result in a water surface elevation that is lower than the BFE, the 2015 revised Guidelines for Implementing EO 11988 require using the BFE as the minimum.

The methods describe include the processing of data resulting from riverine cross-sections or coastal models. Figures 2a-2c visually show the general process of how the FFRMS floodplains are created by a linear interpolation applied between two riverine cross sections from the NFHL. More details on these processes are described in later sections.

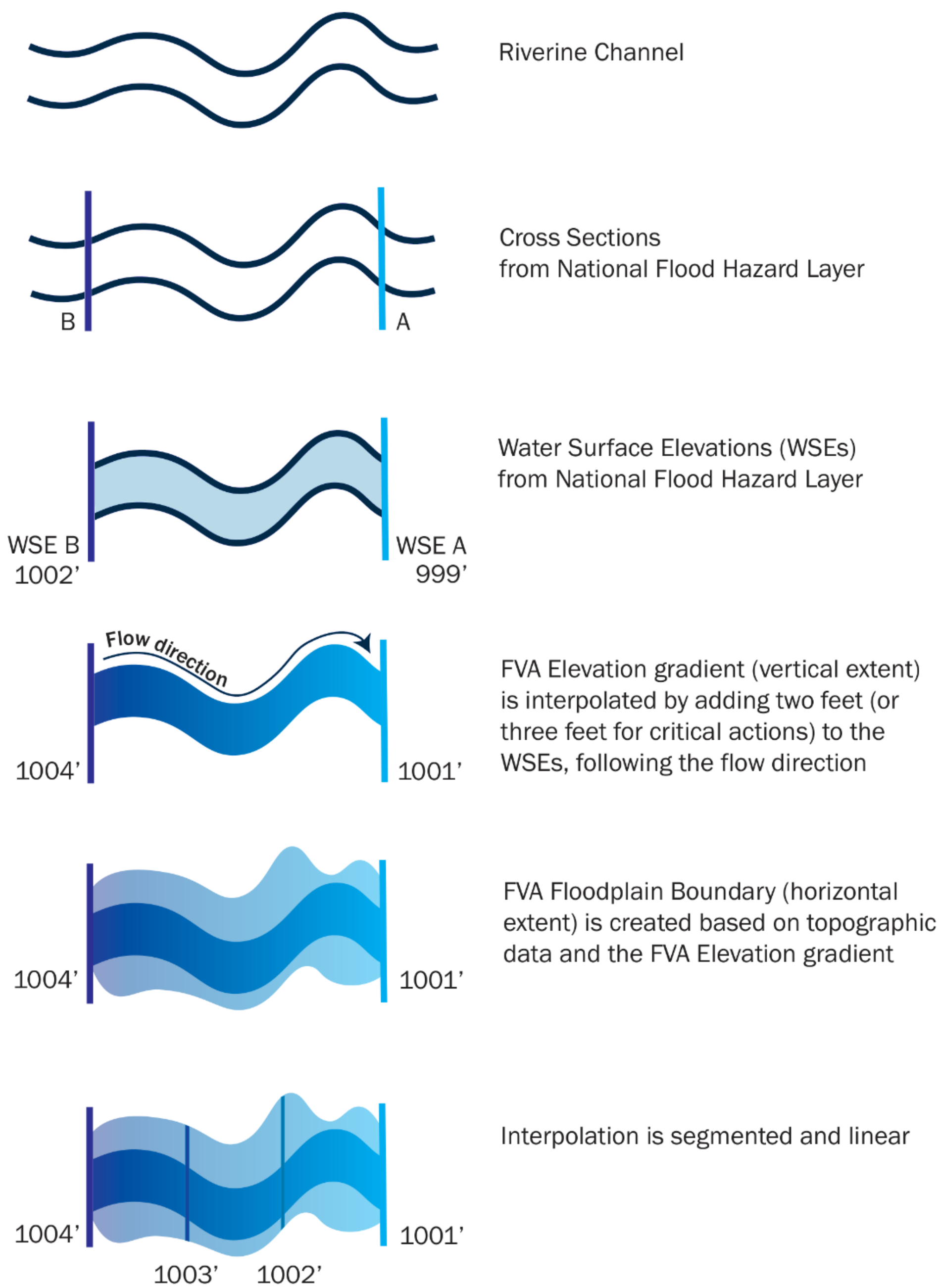

Figure 2a: The FFRMS floodplain is created by a linear interpolation applied between two cross sections from the National Flood Hazard Layer.

Figure 2b shows how the interpolation process of FFRMS freeboard data is consistent between cross sections as the river channel continues.

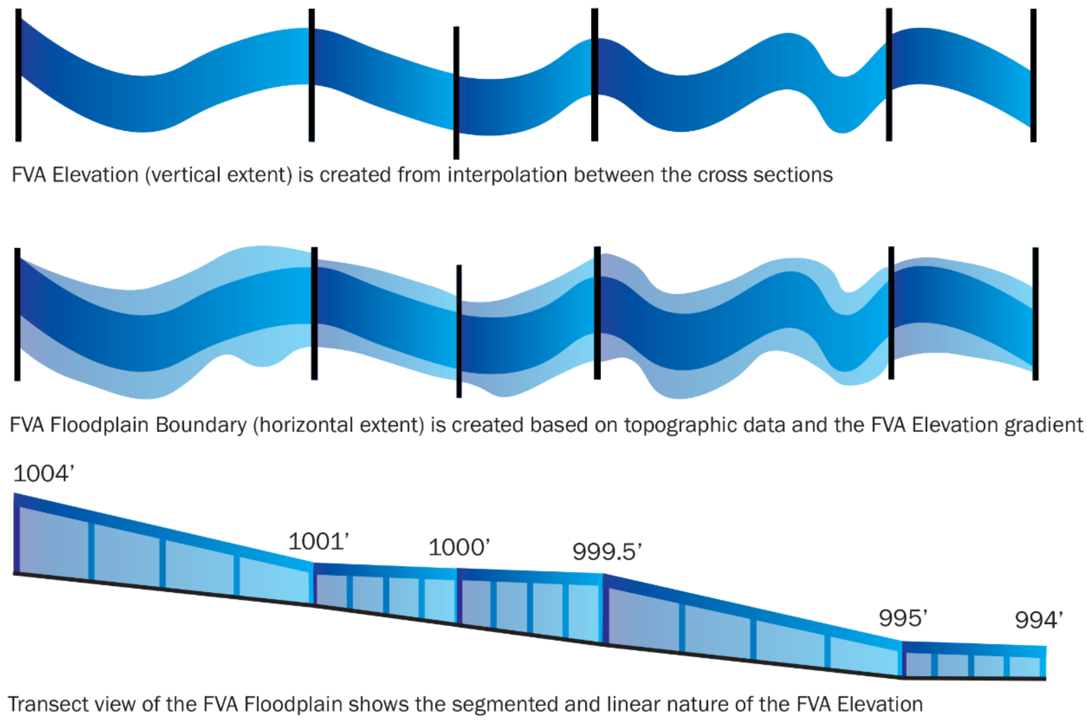

Figure 2b: Interpolation is consistent between cross sections as the river channel continues.

Figure 2c shows plan view and transect view of the FVA floodplain showing the segmented and linear nature of the FVA Elevation.

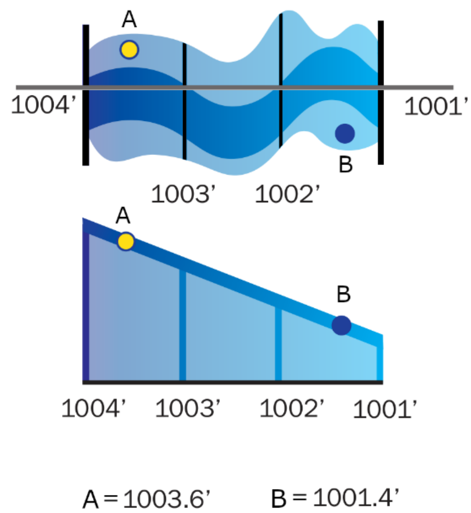

Figure 2c: Determining FFRMS Elevations

1.3. Methodology of FFRMS Floodplain Mapping

FFRMS INPUT DATA SOURCES

FEMA utilizes two primary data sources for developing FFRMS data: USGS’s The National Map (TNM) for terrain and FEMA’s National Flood Hazard Layer (NFHL) for regulatory water surface elevations. The TNM and NFHL datasets were produced and underwent quality control under Federal efforts independent of the FFRMS methodology described in this document. Both datasets are well documented, and the documentation associated with each can provide useful and complementary information.

TNM terrain elevation data resolution consists mainly of 1m, 3m, and 10m digital elevation models (DEM). A DEM represents elevation values over a topographic surface, referenced to a common vertical datum. Each cell within a DEM has a single elevation value. Much of the US is covered by 1m and 3m DEM data, particularly in developed areas. However, rural and/or high relief terrain areas of the United States may be covered by 10m DEM data.

To produce consistent and accurate FFRMS data across the US, 3m DEM resolution was selected as the terrain resolution to be used when available. Where only 10m DEM data exists, FFRMS data was produced at the 10m resolution, and an area of interest (AOI) polygon was added depicting the extent of that mapped area with a user note indicating that 10m DEM data was used to produce the FFRMS data. 1m DEM data was re-sampled to a 3m DEM resolution to produce consistent FFRMS data for consistency. Areas where 1m DEM data was re-sampled are not specifically noted through an AOI. Figure 3 below shows the terrain and FFRMS Freeboard raster attribution.

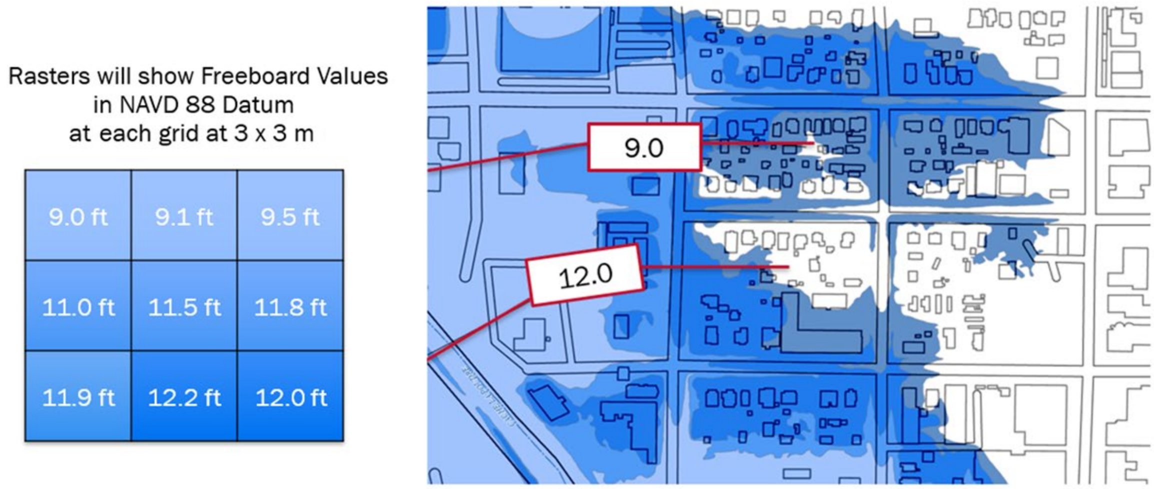

Figure 3: FFRMS Freeboard Raster Attribution. Freeboard grids of 0 to +3 feet shown in light to dark blue in grid at left, and in map at right. Cross-sections with WSELs also shown on map.

The second set of input data is the Base Flood Elevation (BFE) data derived from the NFHL. NFHL water surface elevations at riverine cross-sections were extracted from digitally effective model-baseddata, including digital effective Letters of Map Revision (LOMR) data within the NFHL. NFHL model-basedbaseddata contain the required water surface elevation data from modeled stream cross -section lines and static BFE polygons. Figures 2a-2c in the prior section shows how the FFRMS floodplains are created by a linear interpolation applied between two cross sections from the NFHL. Static BFEs were also used for coastal analysis. NFHL data may be downloaded from https://www.fema.gov/flood-maps/national-flood-hazard-layer.

Additionally, FEMA's Mapping Information Platform (MIP) repository was used to supplement data acquisition where NFHL data did not contain the water surface elevation data. Specifically, the MIP was used when the effective NFHL data did not include cross sections or water surface elevation values needed to produce FVA rasters.

TNM terrain elevation and NFHL water surface elevation data were then used to create freeboard flood hazard mapping.

The overall process of the FFRMS Flood Mapping workflow is shown in Figure 4 below.

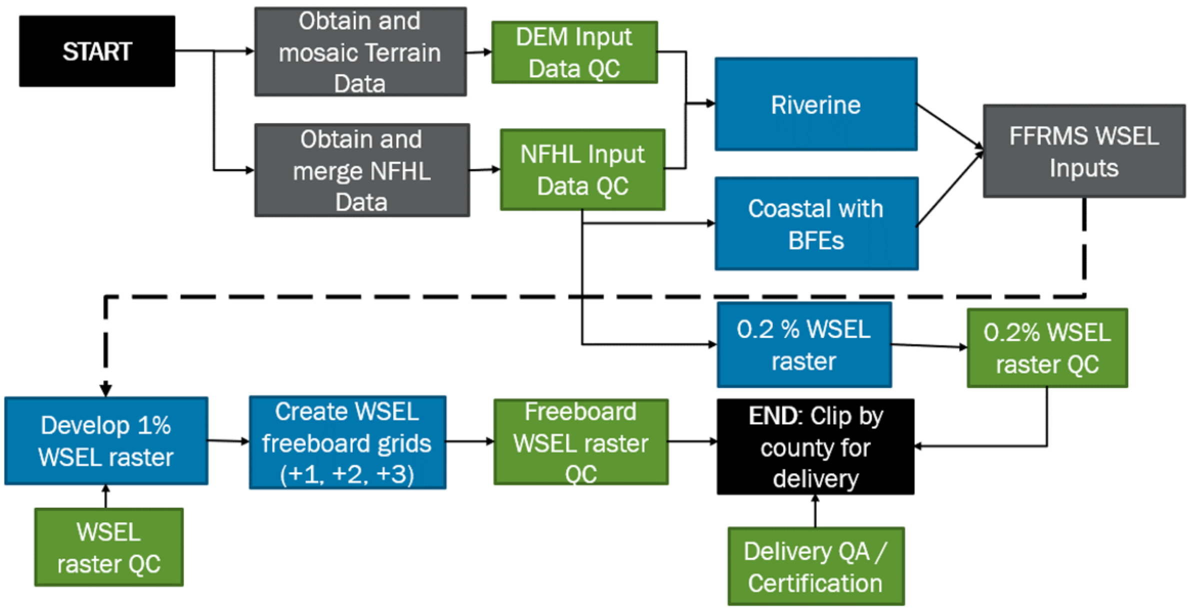

Figure 4: FFRMS Flood Mapping Workflow

FREEBOARD VALUE APPROACH MAPPING

Riverine

Mapping freeboard WSEL rasters to support the FVA approach utilizes the same floodplain delineation approach that is used in the production of regulatory NFHL mapping and relies on streamlines, cross-sections, static BFEs and terrain data. These rasters are produced across all counties and may include areas with both riverine cross-sections and static BFEs. A Triangulated Irregular Network (TIN) is created from the water surface elevation values of all cross-sections, which TIN is then converted to a raster of the same resolution as the terrain DEM. The arithmetic difference between the WSEL raster and the terrain raster is computed. Any raster cells with a negative difference are eliminated from the difference raster. Each cell in this difference raster represents the depth of flooding. In regulatory floodplain mapping, this raster is typically converted to a polygon that represents a floodplain of a certain frequency or magnitude 1%-annual-chance flood (100-year flood). This process is not a new calculation of the mapped elevation but is the standard procedure for creation of floodplain extents for already approved modeling.

The starting water surface elevations to which the freeboard value is added are effective BFEs that have been through due process and have been adopted by the appropriate jurisdiction. No new calculations or analysis of flood hazard have been performed for this effort. The corresponding effective FIS may be consulted for additional information about the engineering analysis methods used in development of the BFEs.

The freeboard mapping methodology utilizes the water surface elevation values of the 1%-annual-chance flood from cross-sections and areas of static flooding and adds whole foot increments from 1 to 3 feet. The increased freeboard water surface elevations are then used with the same TIN mapping process as described above. In some cases, the original cross section extents may not contain the increased horizontal extent of the freeboard floodplain. In this case, cross section extents need to be revised so the full floodplain is captured in the mapping. As general practice, the cross section was not revised within the effective floodplain. Revisions were made beyond the effective floodplain extent. Additionally, cross sections were only extended to the watershed boundary of the corresponding flooding source. In some instances, the cross sections were extended to the watershed boundary, but the elevation of the terrain at the boundary was lower than the freeboard value WSEL. In those cases, an AOI polygon was added along the boundary with a user note saying that the freeboard mapping overflows the watershed at this location.

In addition to the 1-3 foot freeboards, the 1%- and 0.2%-annual-chance (if available) water surface elevations were mapped and may be used for comparison and decision making. Figure 5 is an example of riverine Freeboard Value Approach mapping with cross sections.

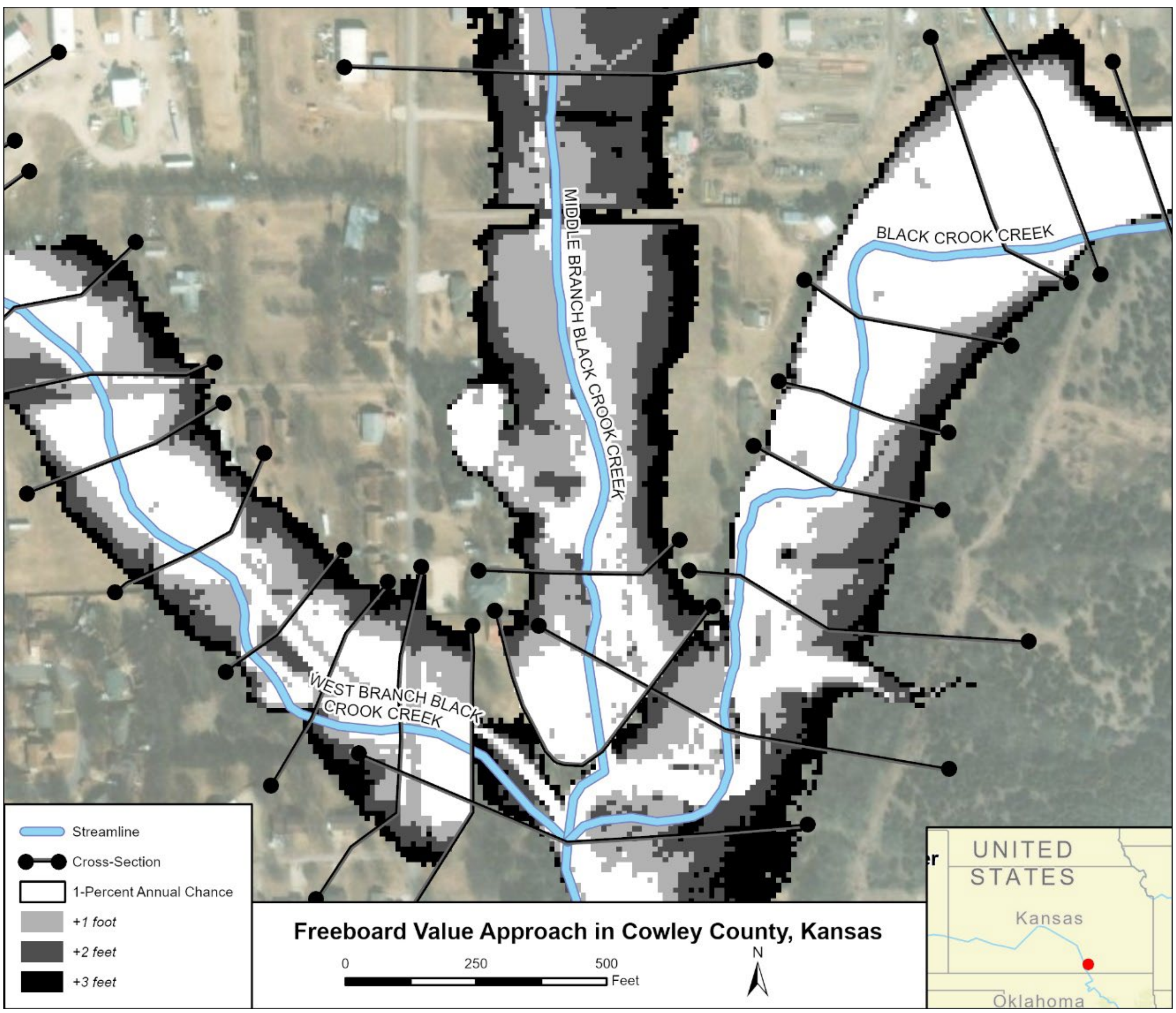

Figure 5: Freeboard Value Approach mapped results (riverine area example).

Coastal data to support the simplified CISA approach

Coastal freeboard WSEL rasters to support a simplified CISA approach are generated using a simple, incremental fill approach to analyze the potential effects of increases to the water surface elevation. This ensured no additional models or calculations would be performed. The Freeboard Value Approach analysis for coastal areas to support the simplified CISA approach does not tie in with the riverine and is processed independently, though it will overlap.

The coastal freeboard WSEL raster methodology assumes the use of the coastal static BFE values from the NFHL flood hazard areas as the water surface. To create an expanded surface, these water surface values are collected at uniformly spaced points along the boundary of the effective coastal 1%-annual-chance flood mapping and expanded inland utilizing Thiessen polygons. After converting the Thiessen polygons to a raster matching the spatial resolution of the terrain DEM, the difference between the water surface elevation raster and the terrain is computed. Areas where the water surface raster value is higher than the terrain raster value indicate the area of flooding. Each subsequent freeboard value is mapped independently in whole foot increments utilizing the prior, lower freeboard value boundary of flooding to establish an expanded surface. For the Great Lakes and Pacific coasts (including Pacific Islands), the analysis is performed up to a three (3) foot increase in water surface. For the Atlantic (including Puerto Rico and the United States Virgin Islands) and Gulf coasts, the analysis is performed up to a ten (10) foot increase in water surface as shown in Figure 6. The application of freeboard values (up to 10 feet) to existing FEMA flood hazard information works well to approximate CISA on the Atlantic, Gulf, and Caribbean coasts. Due to the predominant United States Pacific coast (including Pacific Islands) shoreline geography, simple application of freeboard values does not serve as appropriate of a proxy for understanding the change in flood hazards due to CISA SLR projections, as much of these areas have BFEs that reflect wave runup, which is highly sensitive to geometry and wave heights. For the Great Lakes, recent CISA projections[13] using updated methods of lake levels for the next several decades generally show water levels staying within 3 feet of existing elevations and freeboard analysis was performed up to that level which is consistent with the methodology described in Section 1.3.2.

Coastal modeling includes unique situations that are accounted for independently from the standard methods of the freeboard analysis. Scenarios, where water surface elevations are only increased within the area of effective mapping of NFHL flood hazard zones, include Coastal AH zones (shallow flooding areas) not based on topographic mapping, Coastal AE zones not based on topographic mapping, and Primary Frontal Dunes (PFD). Coastal AO (areas at risk of wave overtopping a dune or bluff) flood hazard zone flood depths are excluded from the water surface but will include freeboard analysis by any expansion of adjacent water surface values. Wave runup areas and overtopping scenarios are handled by establishing water surface elevations from nearby Static BFEs or limiting expansion to the extent of the effective mapping. Each of these unique scenarios will be covered by

[13] Federal Flood Risk Management Standard Climate-Informed Science Approach (CISA) State of the Science Report A Report by the Federal Flood Risk Management Standard (FFRMS) Science Subgroup of the Flood Resilience Interagency Working Group of the NATIONAL CLIMATE TASK FORCE, March 2023

an AOI (area of interest) polygon stating the aspects of the analysis that will require further information.

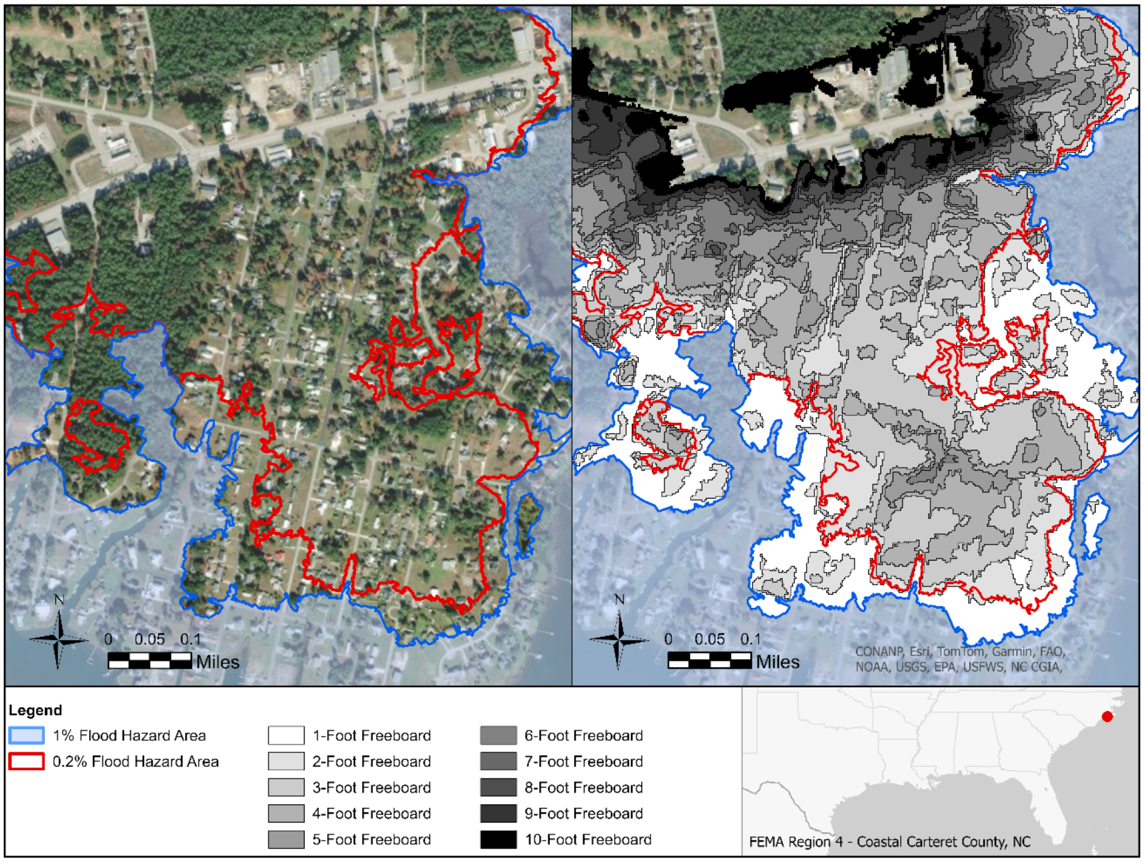

Figure 6: Freeboard Value Approach extents mapped results (coastal area example) mapped in comparison to effective 1% and 0.2% Flood Hazard Area boundaries.

FFRMS OUTPUT DATA QUALITY CONTROL AND ASSURANCE

The FFRMS data produced has similarities to other non-regulatory flood risk data produced for FEMA's Risk Mapping, Assessment, and Planning (Risk MAP) program. Due to the similarity, FEMA's checklist for non-regulatory Flood Risk Products (FRP) was leveraged to develop the FFRMS Quality Checklist. Many of the same raster quality checks were utilized for the FFRMS rasters. The raster quality checks consist of raster properties (e.g., projection, cell size, etc.) and floodplain extents and elevation values. The FFRMS raster values are checked to ensure that each recurring freeboard value (+0, +1, +2, +3, and up to +10 for coastal) or modeled value (1%-, 0.2%-annual-chance) is greater than the previous value. A similar check is performed to ensure the extents for the recurring freeboard values (+0, +1, +2, +3, and up to +10 for coastal) or modeled value (1%-, 0.2%-annual-chance) is greater than the previous. For the +0 freeboard or 1%-annual chance raster, there is a quality check to verify that the raster values match within 0.5 ft of the cross-section value. The passing threshold is 90% for the raster values. Additionally, the FFRMS Quality Checklist has checks for Areas of Interest (AOI) and data attribute naming. Below are some of the quality compliance checks:

Terrain Data (Input Data)

- Does terrain data cover the watershed footprint relevant to the scope?
- Are vertical and horizontal datum and coordinate systems documented and consistent with project definition?

Digital Flood Hazard Information (Input Data)

- Does the digital data have the required WSEL parameters (1%, 0.2%)?
- Do cross-sections intersect only 1 stream?
- Does the cross-section intersect the floodplain boundary an even number of times?
- Are the cross-sections representing geospatially independent lines (i.e., there aren't any intersections with other cross-section lines)?
- Do cross-sections only intersect riverine floodplains?
- Are complex areas documented and consistent across teams?
- Is the floodplain and WSEL information continuous across political boundaries?

WSEL Rasters

- Rasters should be calculated and compared, so that the 1%-annual-chance (+0) WSEL raster (used as the basis for +1, +2, +3 WSEL rasters) has 90% of its WSEL QC points within a vertical tolerance of +/- 0.5 ft. WSEL. QC Points will be located at the confluence of profile baselines and where cross-sections used in the analysis cross profile baselines.
- Do 1% and +1, +2, and +3 feet have areas that are each equal to or larger than the previous lower elevation delineation?
- Do recreated WSEL rasters follow the same pattern as above, for vertical elevation values. For example, the 1% +1 foot should not have any elevation values greater than the 1% +2-foot WSEL raster, etc.

FFRMS DATA PRODUCED

The following data are produced for each riverine and coastal county: Shapefiles, Rasters, Geodatabases, Metadata, and QC Checklists. Below is a list of items that are withincounty produced data. The geodatabases will be produced for county study areas and contain polygon documentation feature classes and raster datasets for the +0, +1, +2, and +3 freeboard scenarios and where applicable, the 0.2%-annual-chance effective values for riverine areas, and +0 to +10 freeboard scenarios for coastal areas. Additional supporting file directories per county study area also contain AOI polygons and relevant existing supporting data. The FFRMS Geodatabases and shapefiles will be used to support the public facing FFSST.

1D/2D Riverine

- Geodatabases
- Rasters (+0, +1, +2, and +3 freeboard rasters and where applicable 0.2%-annual-chance WSEL raster)
- Shapefiles (AOI polygons and effective 0.2%-annual-chance polygon)
- FFRMS QC Checklist
- Metadata

Coastal

- Geodatabases
- Rasters (+0 to +10 freeboard rasters and where applicable 0.2%-annual-chance WSEL raster)
- Shapefiles (AOI polygons and effective 0.2%-annual-chance polygon)
- FFRMS QC Checklist
- Metadata

1.4. Challenges and Solutions

CONSISTENT NATIONWIDE DATA SET

Part of the FFRMS product development process was the creation of a standardized data model for FFRMS spatial and tabular datasets to make the final data products consistent and easier to use by stakeholders. FEMA consulted NOAA in the development of this approach to align data requirements within the FFRMS FFSST. Ultimately, the FFRMS data ultimately produced during this project will be delivered to NOAA for inclusion in a nationwide FFRMS dataset. Therefore, data consistency is paramount and begins with consistent data sources and ends with a unified data deliverable schema.

Consistent and Standardized Data Sources

Consistent and standardized terrain and flood hazard data sources were crucial for producing a nationwide dataset. Terrain data was sourced from USGS's TNM. This aligned quality levels, resolution, format, and properties such as datums consistently across the United States. Using terrain data from a single source with a few exceptions for U.S. Island territories maintained uniformity in methods for data production, minimized the need for data manipulations, and upheld data integrity. While terrain data of better resolution or quality may be available from local or state sources, USGS's TNM provides the most consistent and standardized source for nationwide terrain data.

FEMA's NFHL is the only nationwide dataset that contains the necessary flood hazard data for applying the FFRMS approach outlined in this document. While other datasets may offer more detailed or updated flood hazard data, none of them have nationwide coverage or adhere to a standardized format. Therefore, NHFL data was used to effectively develop nationwide and consistent FFRMS data.

FFRMS Database Schema Development

The FEMA Flood Risk Products Working Group (FRPWG) developed an Esri File Geodatabase and deliverable folder structure to provide end users with consistent and well-documented FFRMS data. Figure 8 displays the attribute details for six feature classes within the FFRMS geodatabase schema.From left to right and top to bottom, the six feature classes are labeled as S_FFRMS_Proj_Ar, S_FFRMS_Ar, S_Raster_QC_Pt, S_EFF_0_2pct_Ar, L_Source_Cit, and S_AOI_Ar. Each feature class includes attribute fields which have labels such as FIPs, political name, LIDAR_Date. It should be noted that the S_Eff_0_2pct_Ar feature class does not contain attribute fields. Additionally, a standard metadata XML template was developed that leveraged the existing NFHL and FEMA Data Capture Standard (DCS) metadata profiles as a base template for creating a new FFRMS metadata profile.

Dataset	Field	Description
S_FFRMS_Proj_Ar	FIPS	(STCO)
	POL_NAME1	(POLITICAL NAME)
	EFF_DATE	(EFFECTIVE DATE OF SFHA)
	PROD_DATE	(DATE OF FFRMS PRODUCTION)
	LIDAR_DATE	(DATE OF LiDAR ACQUISTION)
	CASE_NO	(MIP CASE NO)
	PROJECTION	
	PROJ_ZONE	
	PROJ_UNIT	
	NOTES	
	SOURCE_CIT	
S_FFRMS_Ar	FIPS	(STCO)
	POL_NAME1	(POLITICAL NAME)
	FFRMS_AVL	(FFRMS AVAILABLE (Yes/No))
S_Raster_QC_Pt	FIPS	(STCO)
	POL_NAME1	(POLITICAL NAME)
	WTR_NM	(STREAM NAME)
	FRBD_RP	(FREEBOARD/RETURN PERIOD)
	ELEV DIFF	(has to be 1/2 ft or lower)
	NOTES	
	SOURCE_CIT	
S_Eff_0_2pct_Ar		

Dataset	Field	Description
L_Source_Cit	SOURCE_CIT	
	CID	
	CITATION	
	PUBLISHER	
	TITLE	
	AUTHOR	
	PUB_PLACE	
	PUB_DATE	
	WEBLINK	
	MEDIA	
	CASE_NO	
	MIP CASE NO	
	VERSION_ID	
S_AOI_Ar	AOI_ID	
	FIPS	(STCO)
	POL_NAME1	
	AOI_TYP	(data collection/terrain/mapping)
	AOI_ISSUE	(Domains issue - Major/Minor)
	AOI_INFO	(Description of why) (256 char)
	NOTES	(256 char)

Figure 8: Data Schema of FFRMS GIS Datasets

Areas Of Interest (AOI) Naming Convention

There are a number of areas across the country where freeboard interpolation of existing FEMA flood hazard data is not straightforward and would require significant additional analysis and/or engineering judgment to determine FFRMS floodplains. For these areas, the S_AOI_Ar dataset was developed. Standing for “Areas of Interest”, this polygon-based GIS dataset is part of the standard FFRMS data schema.

The intent is to capture as much information as possible about areas of interest, but also to create a consistent and easy to understand dataset that provides stakeholders with the information required to make meaningful decisions based on the specific AOI. Standard domain values and AOI categories were created for the AOI dataset. These categories and domain values are meant to capture as many of the likely AOI scenarios that could be encountered in the NFHL when developing freeboard mapping products to support the implementation of the FFRMS. While these values will not capture everything, the schema allows for unique issues to be documented alongside more standard AOI data types. Table 1 shows a comprehensive list of the AOI categories (Data Collection, Terrain, Coastal, and Riverine) along with their associated AOI Types that are used to explain each scenario.

Table 1: AOI Categories and Domain Types

AOI Category	AOI Type
Data Collection	MIP search undertaken - Data found
	MIP search undertaken - Data not found
	Remaining Zone AE 1D Miles
	Can/cannot produce data
	Mapping Data
	Other
	LOMR
Terrain	anything that's 10M or greater
	Insufficient data or No data
	Other
Coastal	DEM resolution transition
	Topography issue
	Wave runup area
	AO area
	AH area
	PFD area
	FVA Complex Engineering Area
	Levee
	Areas around dams and spillways
	Shows unrealistic results where FFRMS can't be used AOI made from NFHL
	Topography overtopped at watershed boundary of mapped flooding source
	WSE error/discrepancies
	Other
Riverine	DEM resolution transition
	FVA Complex Engineering Area
	Levee

AOI Category	AOI Type
	Mismatch effective WSEL elevations (including backwater)
	AO Area
	AH Area
	Shows unrealistic results where FFRMS can't be used AOI made from NFHL
	Topography overtopped at watershed boundary of mapped flooding source
	WSE error/discrepancies
	Other

DATA CHALLENGES

Coastal Flood Hazard Challenges

In areas where wave runup is unwarranted for flooding that abuts Primary Frontal Dunes, coastal engineering subject matter experts are needed to help determine the areas to be removed from the freeboard mapping and included in the AOI. Globally across these datasets, freeboard mapping outside the boundary of the effective Special Flood Hazard Area (SFHA) was clipped and the highest level of freeboard mapping was used to generate an AOI.

Levees

To align with the objectives of a consistent and standardized national approach, leveed areas from the National Levee Database (NLD) were utilized as the authoritative dataset for AOI generation. This leveed area dataset was selected because FEMA and USACE worked together to develop this national dataset for all levees in the NLD. The NLD is a dynamic database that is continually updated, so the number of levee systems and their associated data changes over time as new information is provided to FEMA and/or USACE. As such, there may be discrepancies between the number and location of levee alignments in the NFHL as compared to those in the NLD. In cases where a levee was identified in the NFHL and not in the NLD, an AOI was not generated. This is primarily because FEMA recognizes that the NFHL may identify levee alignments where FEMA and USACE have since determined they do not exist or the feature does not meet the definition of a levee. This levee information will be removed from the FIRMs and the NFHL at such time when FEMA updates the SFHA in those areas.

The effective flood hazard data within the NFHL was used as-is to develop freeboard and 0.2PFA WSEL rasters in areas impacted by levees. The FFRMS approach to levees is consistent and refrains from manipulating model-based data. NFHL cross-sections, covering the floodplain boundary (or up to the levee), may be extended, if necessary, up to a limit of +3 ft areas. The approach does not involve additional engineering analysis for leveed areas.

To overcome challenges in applying a consistent and standardized FFRMS approach to levees, a process was developed to address four anticipated levee scenarios. Descriptions of each scenario and process are listed below. For each scenario the AOI is consistent and was applied from the NLD leveed area.

- **Scenario 1: Non-accredited levee with full cross sections.**

Freeboard data development will interpolate between NHFL cross sections using the with-levee BFE values.

- Scenario 2: Non-accredited levee with split cross sections.

Cross sections span the valley but are split, with different WSEL values on the riverside and the landside of the levee (Figure 9). Freeboard data is developed by interpolating between both the riverside and the landside cross section WSEL values. The AOI generated from NLD may not cover the area of WSEL change between the riverside and landside of the levee, and differences may be more prominent along curved levee features.

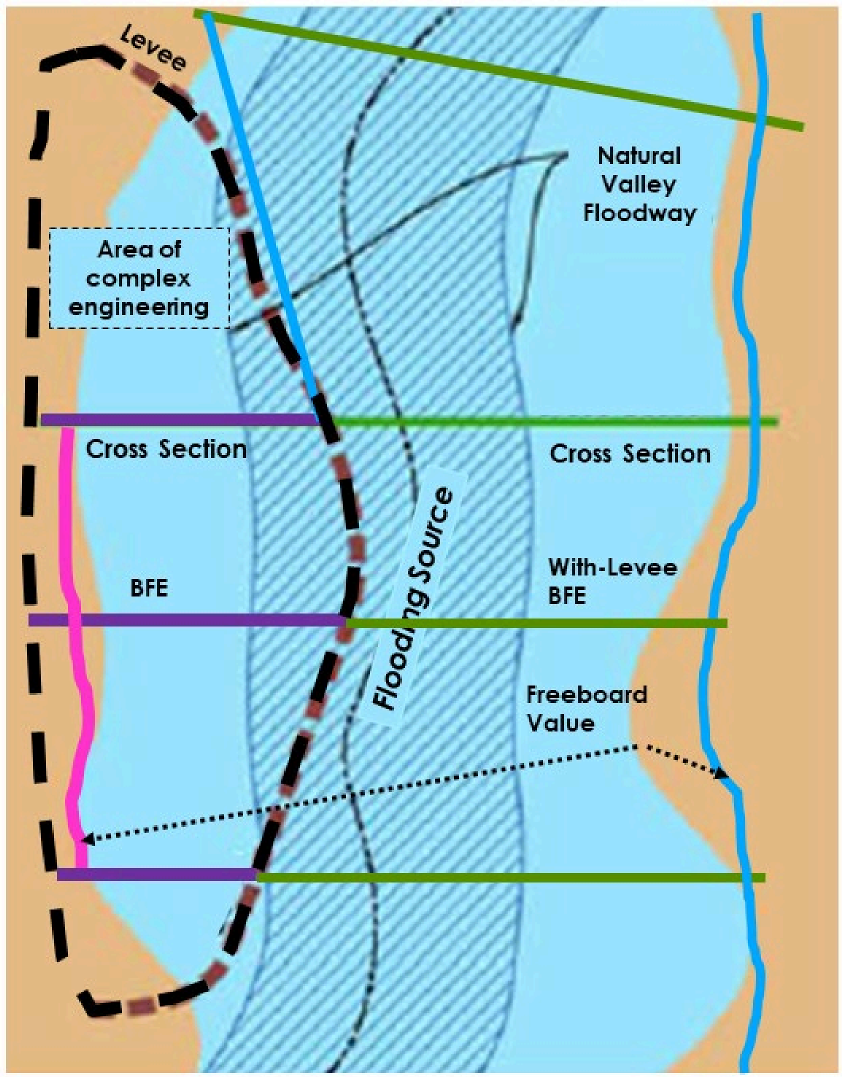

Figure 9: Non-accredited levee with modeled cross sections

- Scenario 3: Accredited or Provisionally Accredited Levee (PAL) with full cross sections.

Freeboard data is developed by interpolating between cross section features using the with-levee BFE. Any interior drainage SFHA on the landside of the levee is disregarded during freeboard data development as shown in Figure 10.

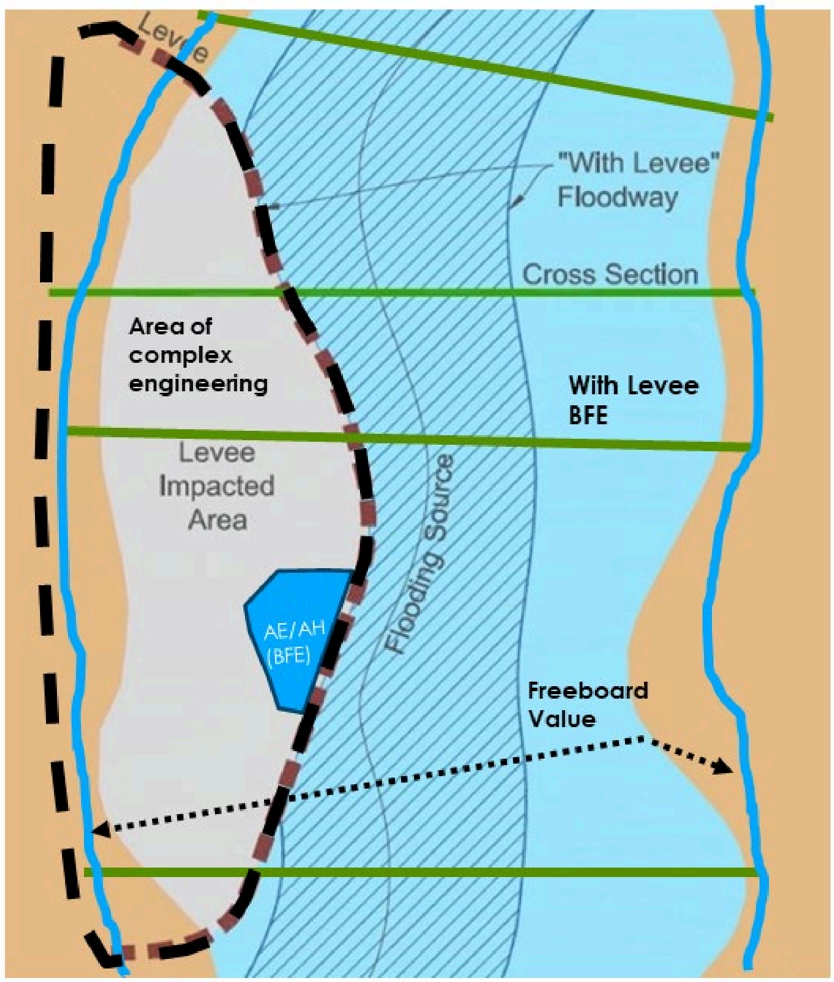

Figure 10: Accredited or PAL levee with full cross sections

- **Scenario 4: Accredited or PAL Levee with short cross sections.**

NHFL cross sections are extended as shown in Figure 11 across the levee. Freeboard data is developed by interpolating between cross sections based on riverside (with-levee) BFE values. Any interior drainage SFHA on the landside of the levee is disregarded during freeboard data development.

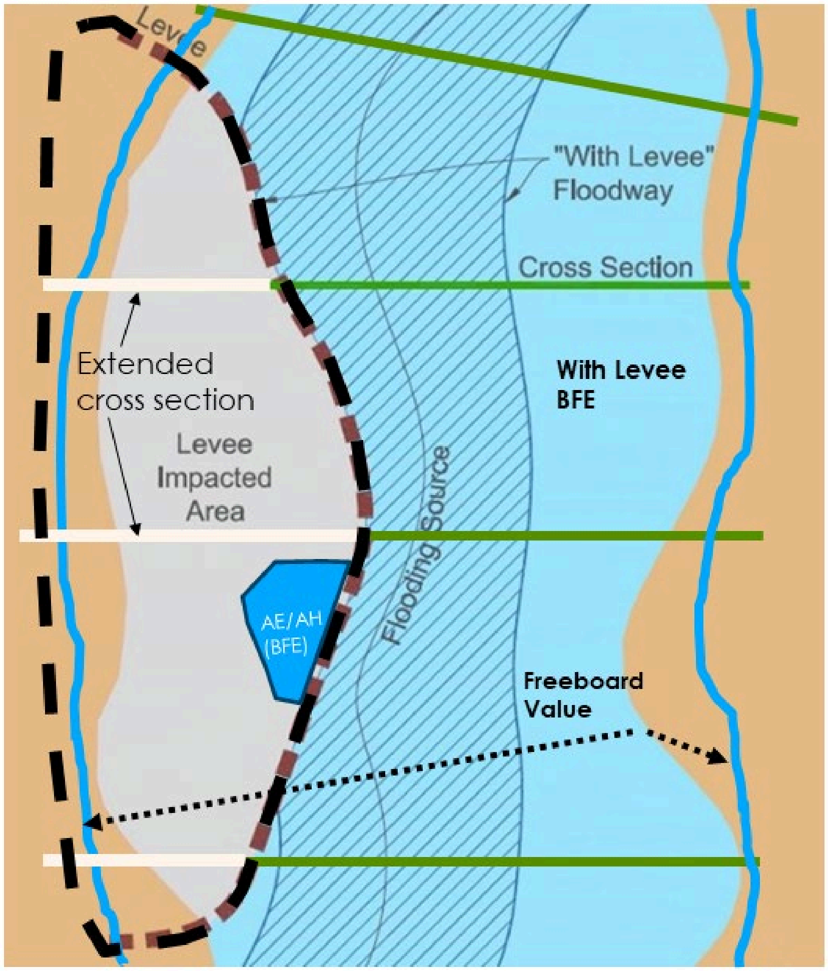

Figure 11: Accredited or PAL Levee with short cross sections

Spatial Projection and Datums

The vertical datum(s) used in the effective flood hazard data may differ from the vertical datum used in the base DEM from USGS or other approved sources. In some areas, such as Puerto Rico and Guam, a local vertical datum is used that does not conform to the National Vertical Datum of 1988 (NAVD88) standards. For areas where flood hazard data was referenced to a local vertical datum, such as the Puerto Rico Vertical Datum of 2002 (PRVD02), and a conversion factor does not exist to transform the data into NAVD88, the USGS DEM was downloaded from the National Oceanic and Atmospheric Administration's (NOAA) Digital Coast Data Access Viewer in the local projection and datums. For areas in the continental US, where the vertical datum of the effective flood hazard data differed from NAVD88, the WSELs were converted to NAVD88 to match the vertical datum of the USGS sourced DEM using the conversion factor listed in the effective or preliminary FIS report. The vertical datum conversion factor may vary across the area covered in an FIS. Typically, there is not a spatial depiction of where the differing conversion factors apply. Additionally, in some FIS reports, a unique conversion factor is noted as being used at each cross section.

Input Data Limitations with NFHL

Model-based flood hazard information is defined as the effective, digital flood information (WSELs, floodplain boundaries, BFE lines, static BFE coastal zones) housed within FEMA's NFHL database. Coordination was done amongst FEMA, NOAA, and FEMA's contractors to align the approach to data deficiencies and challenges to ensure consistent development of FFRMS mapping in Riverine and Coastal areas. In many areas, cross section lines with WSEL are insufficient to produce a WSEL raster, if available BFE lines were used to supplement cross sections. The approach was aligned to use all BFEs in any one reach between the gap in cross sections.

It was observed that differing coastal modeling techniques were used across neighboring counties. For example, some counties had static BFEs while other counties only had BFE lines. Additionally, some coastal regions had a data resolution issue where there was a significant drop off in the terrain along the coast, but the drop is not adequately captured in the current effective data. The terrain data often provided the needed resolution to capture the rapid transitions for the FFRMS process.

One of the most common challenges was regarding topography, where the DEM source or cell size of the terrain used to create the effective data was different than what was used to map the freeboard rasters. This resulted in a horizontal spatial difference between the mapped boundary of the effective 1% flood hazard boundary and the derived mapped boundary of the +0-ft freeboard raster. The +0-ft freeboard raster uses the same base flood elevation data as the effective 1% flood hazard but mapped over potentially different terrain data. This horizontal spatial extent difference, both where the +0-ft raster is horizontally greater or less than the mapped effective 1% boundary, is noted in the FFRMS data as an AOI for end users. Production of the +0-ft freeboard raster provided a baseline and option to mitigate potential impacts due to terrain used for FFRMS +1-, +2-, and +3-ft freeboard mapping data production.

There were instances where cross sections lines are duplicated and had different elevation values. The cross section with the most logical elevation value relative to up and down stream progression was selected and the other deleted.

Backwater fingers (unmapped channels or tributaries branching off from the main flooding source that typically have slower water flow, or stagnant areas) existing within the NHFL floodplain boundaries (see Figure 12). Often, cross sections are not extended past the boundary sufficiently to interpolate a WSEL raster and capture the backwater finger. In these areas, cross sections were manually extended out to encompass the finger and interpolate the WSEL values across the backwater finger.

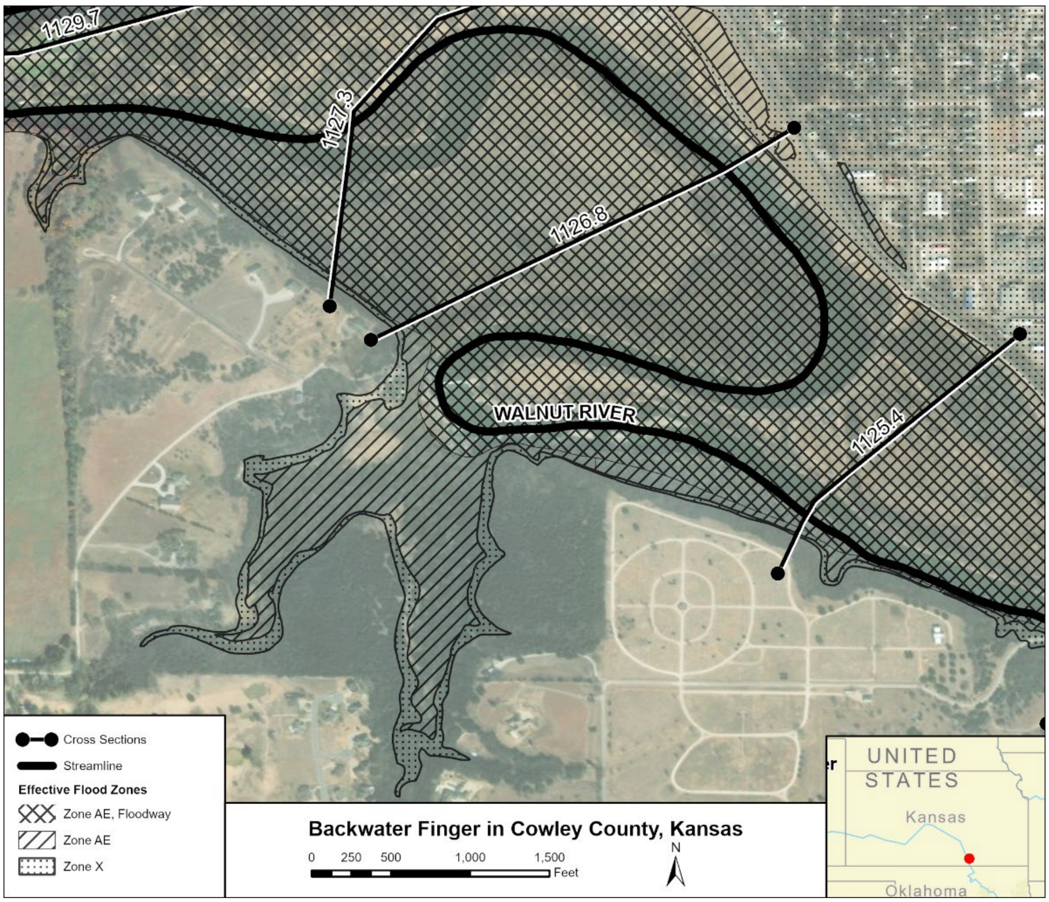

Figure 12: Example of backwater fingers existing within the NHFL floodplain boundaries.

In many counties across the country, the NFHL provides WSEL parameters for the 1%-annual-chance flood, but does not include information for the 0.2%-annual-chance flood in cross-section spatial files. If the 0.2%-annual-chance flood data was absent, then freeboard mapping could not be produced.

Appendix A: Acronym List

.02PFA	0.2%-Annual-Chance (500-year) Flood Approach
AOI	Area of Interest
BFE	Base Flood Elevation
CEQ	Council on Environmental Quality
CISA	Climate-Informed Science Approach
DCS	FEMA Data Capture Standard
DEM	Digital Elevation Model
DHS	Department of Homeland Security
DOE	Department of Energy
EO	Executive Order
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standard
FFSST	Federal Flood Standard Support Tool
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FRPWG	Flood Risk Products Working Group
FVA	Freeboard Value Approach
GIS	Geographic Information System
GSA	General Services Administration
HAG	Highest Adjacent Grade
HHS	Health and Human Services

HUD	Housing and Urban Development
IWG	Interagency Working Group
LAG	Lowest Adjacent Grade
LAMP	Levee Analysis and Mapping Procedure
LOMC	Letters of Map Change
MIP	Mapping Information Platform
MSC	Map Service Center
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NLD	National Levee Database
NOAA	National Oceanic And Atmospheric Administration
OMB	Office of Management and Budget
OPM	Office of Personnel Management
OSTP	Office of Science and Technology Policy
PAL	Provisionally Accredited Levee
PFD	Primary Frontal Dunes
SFHA	Special Flood Hazard Area
SLR	Sea-Level Rise
TIN	Triangulated Irregular Network
TNM	The National Map
U.S.	United States
USGS	United States Geological Survey
WSEL	Water Surface Elevation