Virginia Coastal Resilience Master Plan, Phase II

Appendix B - Impact Assessment Methodology

December 13, 2024 | Dewberry Contract No. E194-89627

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Acronyms and Abbreviations

AAD	Average Annualized Depth
AAL	Average Annualized Loss
ACS	U.S. Census Bureau's American Community Survey
ADT	Average Daily Traffic
AEP	Annual Exceedance Probability
ALF	Annual Likelihood of Flooding
BCAR	Benefit Cost Analysis Re-engineering
BCA	Benefit-Cost Analysis
C	Coastal
C-CAP	Coastal Change Analysis Program
CPFRA	Coastal Probabilistic Flood Risk Assessment
CRMP	Coastal Resilience Master Plan
DCR	Virginia Department of Recreation and Conservation
DDF	Depth-Damage Functions
E	Exposure
ES	Event-Specific
FEMA	Federal Emergency Management Agency
F	Fluvial
Hazus-MH	Hazus Multi-Hazard
HIFLD	Homeland Infrastructure Foundation-Level Data
HUC	Hydrologic Unit Code
MF	Multi-Frequency
MHW	mean high water
MHWS	mean high water spring
MLW	mean low water
MTR	mean tidal range
NFHL	National Flood Hazard Layer
NNBF	natural and nature-based features
NOAA	National Oceanic and Atmospheric Administration

OSM	OpenStreetMap
P	Pluvial
R	Risk
SACS	South Atlantic Coastal Study
SFHA	Special Flood Hazard Areas
SLR	sea level rise
SWEL	Stillwater Elevation
TAC	Technical Advisory Committee
TB	Threshold-Based
USACE	U.S. Army Corps of Engineers
V	Vulnerability
VGIN	Virginia Geographic Information Network
VIMS	Virginia Institute of Marine Science

A. Introduction

A.1 DOCUMENT OBJECTIVES

This document provides a technical overview of the approach and methods used to assess potential flooding impacts in Phase II of the Virginia Coastal Resilience Master Plan (CRMP). Phase II of the CRMP builds on the approach and methods of Phase I (Dewberry, 2021), with an expanded set of flood hazards, updated asset data sources, and refined impact metric calculation methods. The impact assessment produces quantitative data that characterizes how Virginia's people and landscape will be affected by flood hazards, now and into the future, accounting for sea level rise (SLR) and shifting precipitation regimes. The impact assessment incorporates the hazard data from the Phase I coastal hazard framework, the Phase II pluvial hazard framework, and Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas (SFHA). The impact assessment uses these sets of hazard data and results from the asset data gathering effort to produce information that decision-makers can leverage to address flood risk.

A.2 BACKGROUND

The Virginia Department of Recreation and Conservation (DCR) published the first iteration (Phase I) of the CRMP in 2021, with support from Dewberry. Phase II of the CRMP builds on and updates the data, methods, and outputs from Phase I. Key updates include expanding the suite of flood hazards considered to include fluvial (riverine) and pluvial (rainfall-driven) flood hazards and an additional planning horizon for coastal flood hazard events.

A.2.i Scenarios and Hazard Information

DCR defined five planning scenarios for the Phase II effort, considering the planning horizon, and relative climate projections (Table 1). Current and future conditions are broken out into these scenarios to help planners and decision-makers prepare for a range of possible future conditions while recognizing the uncertainty that exists in climate forecasts. The planning scenarios were developed specifically for the Coastal Resilience Master Plan with guidance from expert stakeholders, using widely accepted data sources. The planning scenarios are based on the best available data to forecast increasing coastal flood hazards and precipitation.

Note: The scenarios were originally established for Phase II in the context of risk tolerances; however, this was pivoted to the scenario names in rows 1 and 2 of Table 1 as the Phase II overall plan document was finalized. This report retains the original risk tolerance nomenclature (rows 1 and 3) and readers should use Table 1 to cross-reference the scenario nomenclature. In the risk-tolerance context, a low risk tolerance is aligned with planning for greater flood risk, while a moderate risk tolerance relates to a less extreme flood risk scenario.

Coastal flood hazard data was consistent with Phase I for 2020, 2040, 2060, and 2080 and expanded to include sea level rise projections for the 2100 time horizon. Within each time horizon, multiple tidal conditions and storm events were modeled. Based on best available SLR trends, Phase II updated how the SLR increments were associated with planning scenarios for analysis and presentation, relating these sea level rise scenarios to near-future and far-future planning horizons and risk tolerances, as shown in Table 1.

Pluvial and fluvial flood hazards were new to Phase II, and this analysis calculated impact metrics for these flood hazards based on hazard data availability. Pluvial flood hazard modeling was conducted as part of the CRMP Phase II effort. The approach included a wide range of rainfall conditions that were modeled over 1,830 sub-basins using the USACE HEC-RAS version 6.1 software. DCR in consultation with the Technical Advisory Committee (TAC) selected the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) Program projected intensity-duration-frequency curves to model future precipitation conditions. The model outputs were leveraged to create derivative products for a variety of recurrence intervals aligning with the planning scenarios.

Fluvial flood hazard data in this assessment was based on the effective one-percent Annual Exceedance Probability (1% AEP) riverine flood event as depicted in FEMA's SFHA from the National Flood Hazard Layer (NFHL). This data has been processed to only show fluvial, not coastal, components of the SFHA. Note that due to the limited data available for fluvial flood hazard scenarios, this analysis only calculated fluvial impact metrics based on the 1% AEP event and not multiple recurrence intervals. Additionally, unlike coastal and pluvial hazard data which include flood depths, fluvial impact metrics only considered the extent of the SFHA and not flood depth of the event that it represents. Separate from this task, a case study was performed in three select Hydrologic Unit Code (HUC) watersheds (Great Wicomico-Piankatank, Lower Rappahannock, and Mattaponi) using the full impact assessment methodology applied to multi-frequency fluvial data, as applicable, to understand the value that data may add to future iterations of the CRMP. The Fluvial Multi-Frequency Impacts Case Study Report is presented as Addendum B to this document.

Table 1: Scenarios used in the presentation of impact assessment results.

CRMP Planning Scenario Name:	Baseline	Near Future		Far Future	
Projection:		Moderate	High	Moderate	High
Risk Tolerance Name Used in Impact Assessment :	*Present*	*Moderate*	*Low*	*Moderate*	*Low*
Planning Horizon:	Present-Day (2000-2020)	Near Future (2030-2060)		Far Future (2060-2100)	
Coastal Sources	CRMP Phase 1 modeling, using NOAA and FEMA water level data and the NOAA 2017 Intermediate-High relative sea level rise scenario				
	2020 Conditions	2040 Projections	2060 Projections	2060 Projections	2080 Projections
Rainfall-Driven Sources	NOAA Atlas-14 precipitation estimates with MARISA RCP 4.5 change factors				
	No Change Factor	2020-2070 50th Percentile	2020-2070 90th Percentile	2050-2100 50th Percentile	2050-2100 90th Percentile
Riverine Sources	FEMA National Flood Hazard Layer filtered to riverine flooding.				

A.2.ii Asset Data and Analysis

Phase II updates and expands on asset data used in Phase I, including the addition of new critical facilities, transportation assets, and natural infrastructure, and land use information (See Section D for list of data sources). With the expanded suite of flood hazards and updated asset data, the impact metrics in this assessment included key metrics calculated in Phase I, with a broader range of flood hazard inputs and additional metrics to support evaluating flood hazards impacts on newly included asset data types (see Section B.3).

B. Approach

B.1 OVERVIEW

The CRMP impact assessment employs a structured yet flexible mixed-methods framework for producing metrics to describe the level of impact flooding is expected to have across Virginia's coastal region. These quantitative metrics can be paired with qualitative analysis to strengthen findings, reduce uncertainties, and provide a more complete picture of current and evolving flood impacts. Using this framework, the impact assessment evaluates three types of data as inputs (hazards, assets, and context) to produce the three levels of progressively-detailed quantitative metrics: exposure, vulnerability, and risk.

The following sections overview the impact assessment technical approach through a presentation of proposed metrics and methods for calculating them. Each calculated metric is defined in Section C.2 and their calculation methods are detailed in Section C.2. Raw quantitative assessment results are captured in the Asset-Specific Impacts and Geographic Impact Summary Tables outlined in Section C.4.

B.2 DATA INPUTS

Inputs to the impact assessment includes data related to hazards, assets, and context, described below:

Hazards – Hazards are the potential occurrence of a physical event or trend that may threaten our social, built, and ecological environments. The flood hazard data from the Coastal Flood Hazard Framework, Pluvial Flood Hazard Framework, and Fluvial FEMA SFHA were key inputs into the impact assessment. Resulting event-driven flood exposure and depth scenarios represent where and how often flooding may occur and how severe the flood hazard may be at a particular location.

Assets – Assets are physical components or resources of value that may be directly affected by the hazard. Assets considered for this assessment include buildings, roadways, and other built infrastructure, and land areas with cultural, recreational, agricultural, or ecological value. The location, characteristics, and value of a given asset inform our understanding of the types of consequences that may occur due to its flooding.

Context – Context informs our understanding of how flooding challenges differ by region, locality, neighborhood, and individual, and the varying capacity to address them. Qualitative and quantitative information relating to Virginia's coastal areas' history, demographics, and community characteristics drive our understanding of how impacts may accrue amongst populations and communities across the Commonwealth.

Outputs of the assessment include quantitative asset-specific impacts, and impacts summarized over geographic areas of interest. Those output data can then be further manipulated for scoring, ranking, and comparative presentation.

B.3 IMPACT METRICS

B.3.i Organizational Framework

This section presents a consolidated list of all of the quantitative metrics that produced in the impact assessment, summarized in Table 2 through Table 4. To further understand and describe these metrics, they are classified by category, level, type, and hazard, as introduced below.

Category – Metrics in the impact assessment are organized into three overarching categories based on the concept behind the calculation performed: Binary Exposure, Depth of Flooding, and Extent of Flooding.

Level – The impact assessment approach enables a progressively detailed evaluation dependent on the availability and quality of data. As noted in Figure 1 below, three overarching levels of assessment were executed: exposure, vulnerability, and risk.

A quantitative estimate of risk is possible where accurate asset location, key characteristics related to asset sensitivity to flooding, and asset value data are available. Where no such information is available, the impacts may be described in narrative format. Thus, impact metric results are presented through a range of progressively data-intensive metrics introduced below and further described in Section C.2. In the set of tables below, metric level is indicated as either Exposure (E), Vulnerability (V), or Risk (R).

- **Exposure** – The likelihood and degree (e.g., flood depth) to which an asset – or population or system associated with the asset – will be physically exposed to flooding. For this assessment, the flood exposure for a given asset is a factor of its location and the hazard present at that location.
- **Vulnerability** – A measure of the degree to which an asset – or population or system associated with the asset – is likely to be adversely affected by the hazard. For a vulnerability assessment, physical exposure is enhanced by understanding the asset's susceptibility, or sensitivity, and adaptive capacity. Sensitivity measures an asset's innate susceptibility to harm, and adaptive capacity captures the asset's ability to adjust to a new situation or cope with the consequences of a hazard event.
- **Risk** – The estimated value of direct and indirect consequences associated with the functional disruption of the asset – or population or system associated with the asset. For this assessment, the risk is quantified in economic terms. It incorporates probable losses associated with direct damages to the asset.

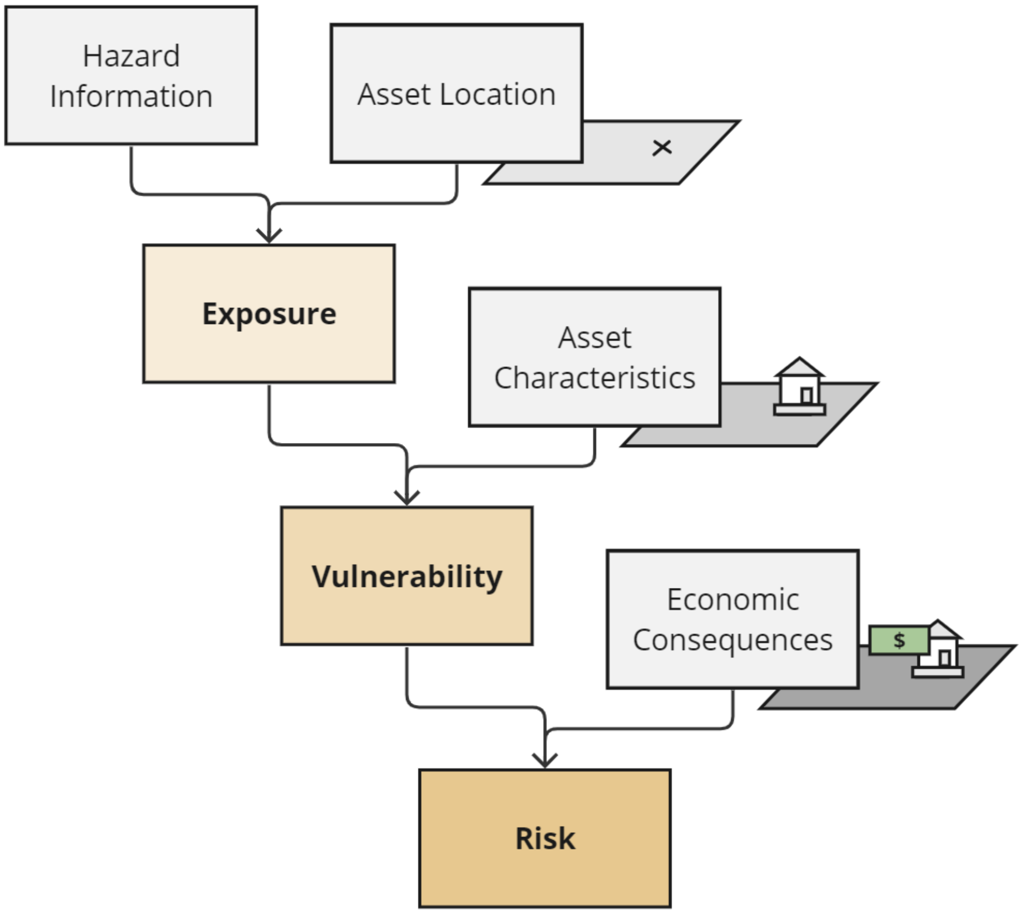

Figure 1. Asset information required to describe impacts with varying levels of detail.

All impacts that revolve around discrete and identifiable assets have exposure statistics, but the degree to which vulnerability and risk are quantified depends on asset-specific and hazard-specific data available. As shown in Figure 2 and described below, hazard-specific data varies based on whether the flood data source is coastal, pluvial, or fluvial, and impact metrics produced may be based on individual events or aggregated across events.

Hazard – Due to the varying nature of flood hazard information available, not all metrics are calculated for all flood hazard types.

- Coastal flooding conditions considered for this analysis include the tidal boundaries of mean low water (MLW), mean high water (MHW), and 1.5 times mean tidal range (1.5xMTR); and coastal storm surge events with an AEP of 50%, 20% 10%, 4%, 2%, 1% and 0.2% (i.e., recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years). Coastal flood conditions were assessed across five SLR conditions, representing the current and future time horizons.
- Pluvial (rainfall-driven) flood conditions follow a similar framework as coastal flood events, with the same recurrence intervals used as the coastal flooding

analysis, but with the newer planning scenario framing of time horizons (present, short-term, long-term) and risk tolerance (present, moderate, and low). The pluvial scenarios also consider multiple storm duration hours (2-, 6-, and 24-hour storms) and the storm with the highest maximum depth for each asset was used for analysis.

- Fluvial (riverine) flooding was not modeled for the CRMP, and so impacts related to this type of flooding are limited to an assessment of whether or not assets are within FEMA's riverine SFHA.

The Flood Hazard Data Development Report (Appendix A) provides more detail on hazard data development and products referenced in this assessment. Additionally, terms used to describe flood hazard scenarios in this report are presented or labeled differently in the CRMP Phase II Plan. The "Risk Tolerance" row in Table 1 shows how planning scenarios are described in this report and how that cross-walks to the data sources described above.

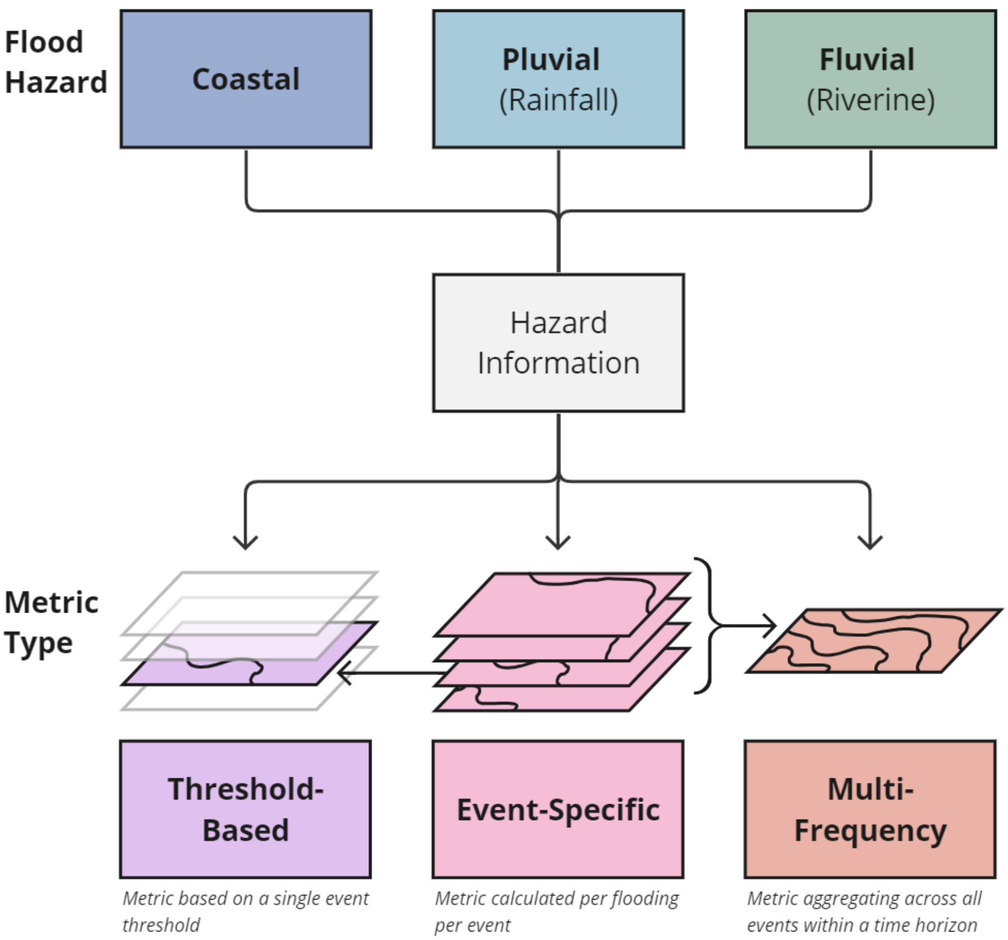

Figure 2. Flood hazard information sources and impact metric types.

In the tables below, which flood hazard type is relevant to each metric is indicated as either Coastal (C), Pluvial (P), and/or Fluvial (F).

Type – Some metrics are event-specific (e.g., depth of flooding per event), while others represent multi-frequency calculations that aggregate impacts across events with a given time horizon (e.g., average annualized depth of flooding). Additionally, other metrics use a threshold (such as MHW) to estimate changes across time horizon (e.g., land lost). In the tables below, this metric type is indicated as either Event-Specific (ES), Multi-Frequency (MF), or Threshold-Based (TB).

This impact assessment results in a set of asset-specific impact metrics presented in Asset-Specific Impact tables, as well as aggregated summaries of those impacts over designated areas of interest presented in Geographic Impact Summary tables. A breakdown of which metrics appear in which tables and across which asset types is presented in Section C.4.

B.3.ii Binary Exposure

Whether or not an asset is exposed to any amount of flood waters during a flood event provides the most foundational view of flood exposure. Key metrics related to this binary (in or out) depiction of flood exposure are summarized in Table 2 below and Figure 3 shows conceptually how these metrics build off each other. The process for calculating these metrics is described in Section C.2.i.

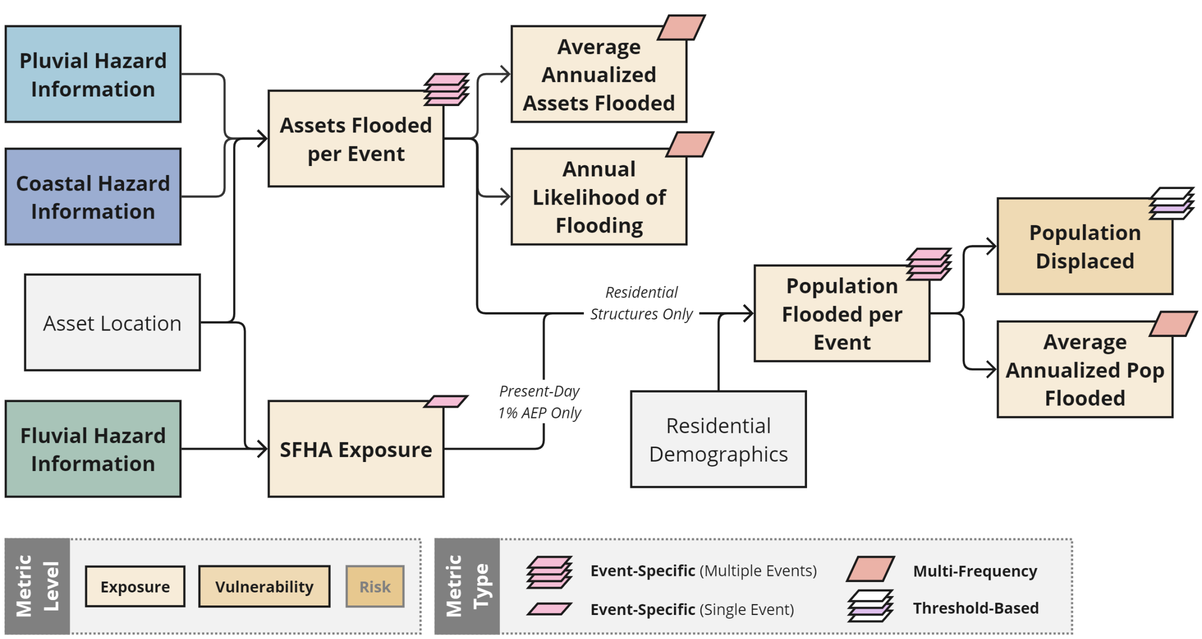

Figure 3. Conceptual illustration of the binary exposure metrics calculation flow.

Table 2. Binary exposure metrics with relevant definition, units, level, type, and hazard.

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD		
Annual Likelihood of Flooding	The probability that any amount of flooding will occur at a location in a given year for a given time horizon.	percent	E	MF	C	P	
Minimum Recurrence Interval	The highest-frequency event (expressed as a return period in years) or tidal condition that would expose the asset.	number	E	MF	C	P	
SFHA Exposure	The binary determination of whether or not an asset is within FEMA's present-day SFHA.	Y/N	E	ES	F		
Assets Flooded Per Event	The number of assets of a certain type exposed to flooding for each modeled flood event within a given geography of interest.	asset count	E	ES	C	P	F*
Percent of Assets Flooded per Event	The portion of assets of a certain type exposed to flooding for each modeled flood event within a given geography of interest.	percent	E	ES	C	P	F*
Average Annualized Assets Flooded	The probability-weighted average number of assets flooded in a given year across all events within a given time horizon and geography of interest.	asset count	E	MF	C	P	
Average Annualized Assets Flooded Percent	The probability-weighted average number of assets flooded in a given year across all events within a given time horizon and geography of interest divided by the number of assets within the geography (whether or not they are exposed to flooding).	percent	E	MF	C	P	
Population Flooded per Event	The estimated number of people living in flood-exposed residential buildings for each modeled flood event.	pop count	E	ES	C	P	F*
Percent of Population Flooded per Event	The estimated portion of people living in flood-exposed residential buildings for each modeled flood event.	percent	E	ES	C	P	F*
Population Displaced	The estimated number of people exposed to MHW for a given time horizon.**	pop count	V	TB	C		
Average Annualized Population Flooded	The probability-weighted average people exposed to flooding in a given year	pop count	E	MF	C	P	

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD	
	across all events within a given time horizon.					

Levels: Exposure (E), Vulnerability (V), and Risk (R)
Types: Event-Specific (ES), Multi-Frequency (MF), and Threshold-Based (TB)
Hazards: Coastal (C), Pluvial (P), and Fluvial (F)
* Metric calculated for the present-day 1% AEP only.
** Metric not independently reported but can be extracted from event-specific data.

B.3.iii Depth of Flooding

Flood depth is a component of asset exposure, but for assets where their sensitivity to impact can be directly tied to flood depth, this can lead to measurements of vulnerability and risk. Most notably, for building assets, damage and loss metrics reflect direct damages to the structures and contents of buildings from a flood event (calculated using assigned industry standard depth-damage functions). The six metrics related to the depth of flooding are summarized in Table 3 below and Figure 4 shows conceptually how these metrics build off each other. The process for calculating them are described in Section C.2.ii.

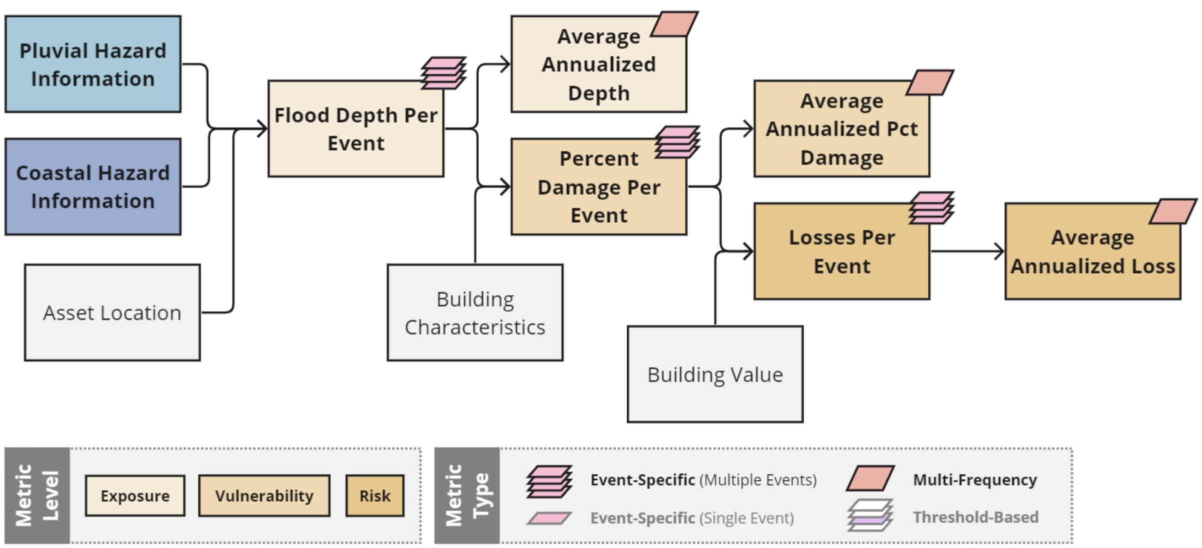

Figure 4. Conceptual illustration of the depth and damage metrics calculation flow.

Table 3. Depth of flooding metrics with relevant definition, units, level, type, and hazard.

METRIC	DEFINITION	UNITS	LEVEL		TYPE	HAZARD	
Maximum Flood Depth per Event	The maximum depth of flooding an asset is exposed to for each modeled flood event.	feet	E	V	ES	C	P
Average Annualized Depth	The probability-weighted average of flood depth across all events within a given time horizon.	feet	E	V	MF	C	P
Total Percent Damage per Event	The estimated dollar value of structure and content losses due to flood damage across all buildings in the geography divided by the total structure and content replacement value for all buildings (whether or not they are exposed to flooding).	percent	V		ES	C	P
Structure Percent Damage per Event	The estimated dollar value of structure losses due to flood damage across all buildings in the geography divided by the total structure replacement value for all buildings (whether or not they are exposed to flooding).	percent	V		ES	C	P
Content Percent Damage per Event	The estimated dollar value of content losses due to flood damage across all buildings in the geography divided by the total content replacement value for all buildings (whether or not they are exposed to flooding).	percent	V		ES	C	P
Average Annualized Total Percent Damage	The probability-weighted average of event-specific structure and content losses across all events within a given time horizon divided by the total replacement value of all buildings within the geography (whether or not they are exposed to flooding).	percent	V		MF	C	P
Average Annualized Structure Percent Damage	The probability-weighted average of event-specific structure damages (as a percent of replacement value) across all events within a given time horizon.	percent	V		MF	C	P
Average Annualized Content Percent Damage	The probability-weighted average of event-specific content damages (as a percent of replacement value) across all events within a given time horizon.	percent	V		MF	C	P

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD	
Total Losses per Event	The estimated dollar value of structure and content losses due to flood damage across all buildings in the geography.	dollars	R	ES	C	P
Structure Losses per Event	The estimated dollar value of structure losses due to flood damage, based on flood depth and building characteristics for each modeled flood event.	dollars	R	ES	C	P
Content Losses per Event	The estimated dollar value of content losses due to flood damage, based on flood depth and building characteristics for each modeled flood event.	dollars	R	ES	C	P
Average Annualized Total Loss	The probability-weighted average of event-specific structure and content losses across all events within a given time horizon.	dollars	R	MF	C	P
Average Annualized Structure Loss	The probability-weighted average of event-specific structure losses across all events within a given time horizon.	dollars	R	MF	C	P
Average Annualized Content Loss	The probability-weighted average of event-specific content losses across all events within a given time horizon.	dollars	R	MF	C	P

Levels: Exposure (E), Vulnerability (V), and Risk (R)
Types: Event-Specific (ES), Multi-Frequency (MF), and Threshold-Based (TB)
Hazards: Coastal (C) and Pluvial (P)

B.3.iv Extent of Flooding

Although many assets considered in the CRMP are site-specific points, some assets are represented by lines, polygons, or gridded raster data where length or area flooded across various event conditions can be used to capture measures of exposure, vulnerability, and risk. This includes assets like roads, military facilities, tribally owned land, conserved lands, and recreational areas. For these assets, the extent of flooding is used to estimate the damage and disruption likely to be caused by flood events. Note for non-raster data, metrics are calculated at the level of individual assets (features), which can be summarized across asset types to calculate total lengths or areas exposed within an area of interest. However, for raster data where discrete assets are not identifiable, metrics are only calculated in aggregate in geographic summaries.

Healthy ecosystems are resilient to major storm events, but likely to be impacted by long-term changes in tidal conditions due to rising sea levels. Examining changes in frequent and periodic flood conditions (MLW, MHW, and 1.5xMTR) can help determine natural areas most vulnerable to increased flooding from climate change. These natural areas provide ecosystem services (direct or indirect contributions that ecosystems make to the environment and human populations), which can be quantified in dollar values and used to estimate the risk posed by SLR in these areas. Coastal hazard conditions were used to calculate these metrics given the prominent influence of tidal conditions. Changing fluvial and pluvial hazard conditions will also likely affect existing natural infrastructure through processes such as increased erosion, changing salinity, and turbidity; however, quantifying fluvial and pluvial impacts on natural infrastructure is beyond the scope of this assessment.

Metrics related to length-based and area-based flood exposure, including impacts to natural areas that provide ecosystem services, are summarized in Table 4 below and Figure 5 shows conceptually how these metrics build off each other. The processes for calculating them are described in Section C.2.

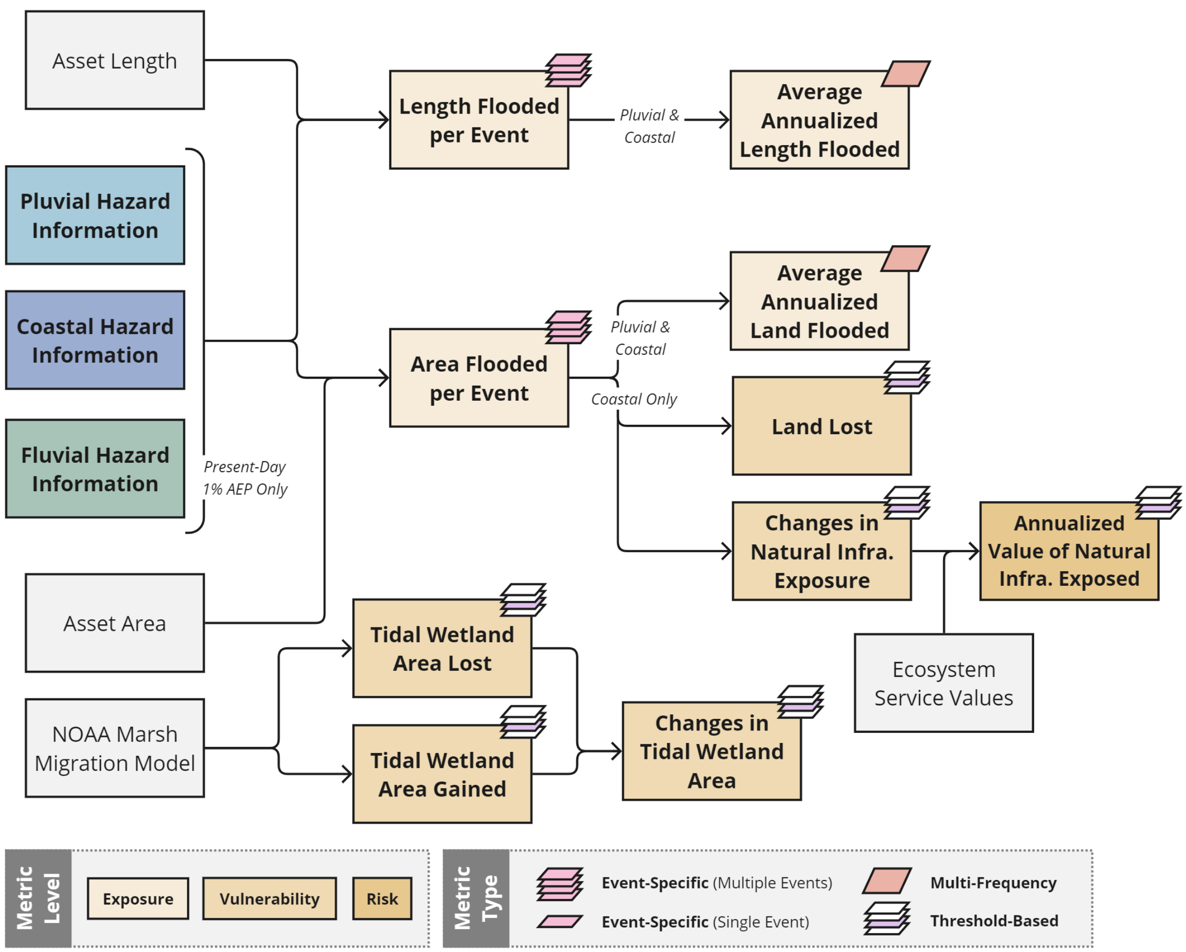

Figure 5. Conceptual illustration of the extent of flooding metrics calculation flow.

Table 4. Extent of flooding metrics with relevant definition, units, level, type, and hazard.

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD		
Total Length Flooded per Event	The total length of a linear-based asset that is covered by any depth of floodwaters for each modeled flood event.	feet	E	ES	C	P	F*
Land Length Flooded per Event	The land length (defined as above 2020 MHW) in feet of a linear-based asset that is covered by any depth of floodwaters for each modeled flood event.	feet	E	ES	C	P	F*
Percent of Total Length Flooded per Event	The portion of a linear-based asset that is covered by any depth of floodwaters for each modeled flood event.	percent	E	ES	C	P	F*
Percent of Land Length Flooded per Event	The portion (above 2020 MHW) of a linear-based asset that is covered by any depth of floodwaters for each modeled flood event.	percent	E	ES	C	P	F*
Average Annualized Total Length Flooded	The probability-weighted average of linear feet flooded across all events within a time horizon.	feet	E	MF	C	P	
Average Annualized Land Length Flooded	The probability-weighted average of linear feet flooded above 2020 MHW across all events within a time horizon.	feet	E	MF	C	P	
Total Area Flooded per Event	The total area in square feet of an area-based asset that is covered by any depth of floodwaters for each modeled flood event.	square feet/acres	E	ES	C	P	F*
Land Area Flooded per Event	The land area (defined as above 2020 MHW) in square feet of a polygon-based asset that is covered by any depth of floodwaters for each modeled flood event.	square feet/acres	E	ES	C	P	F*
Percent of Total Area Flooded per Event	The portion of an area-based asset that is covered by any depth of floodwaters for each modeled flood event.	percent	E	ES	C	P	F*
Percent of Land Area Flooded per Event	The portion (above 2020 MHW) of an area-based asset that is covered by	percent	E	ES	C	P	F*

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD	
	any depth of floodwaters for each modeled flood event.					
Average Annualized Total Area Flooded	The probability-weighted average of total area flooded across all events within a time horizon.	square feet/acres	E	MF	C	P
Average Annualized Land Area Flooded	The probability-weighted average of square feet flooded above 2020 MHW across all events within a time horizon.	square feet/acres	E	MF	C	P
Land Lost	The projected changes in the acreage of area-based assets' land area for a given time horizon relative to 2020 MHW baseline.**	acres	V	TB	C	
Changes in Natural Infrastructure Flood Exposure	The projected changes in the acreage of all natural infrastructure areas for a given time horizon based on selected exposure zones using MLW, MHW, and 1.5xMTR thresholds.	acres	V	TB	C	
Tidal Wetland Area Lost	The projected loss in tidal wetland acreage for a given time horizon within the extent of current (2020) wetland based on the NOAA Marsh Migration model thresholds for wetland class transitions.	acres	V	TB	C	
Tidal Wetland Area Gained	The projected gain in tidal wetland acreage outside the extent of current (2020) wetland for a given time horizon based on the NOAA Marsh Migration model thresholds for wetland class transitions.	acres	V	TB	C	
Total Change in Tidal Wetland Area	The projected total change in tidal wetland acreage for a given time horizon relative to current (2020) conditions based on the NOAA Marsh Migration model thresholds for wetland class transitions. This accounts for tidal wetland loss and potential tidal wetland gain through wetland migration.	acres	V	TB	C	
Annualized Value of Natural Infrastructure	The dollar value of ecosystem services for natural infrastructure exposed to flooding based on selected exposure	dollars	R	TB	C	

METRIC	DEFINITION	UNITS	LEVEL	TYPE	HAZARD
Exposed to Flooding	zones in a given year within a given time horizon.				

Levels: Exposure (E), Vulnerability (V), and Risk (R)
Types: Event-Specific (ES), Multi-Frequency (MF), and Threshold-Based (TB)
Hazards: Coastal (C), Pluvial (P), and Fluvial (F)
* Metric calculated for the present-day 1% AEP only.

** Metric not independently reported but can be extracted from event-specific data.

B.4 ADDITIONAL ANALYSES

Additional analyses were performed leveraging the data, methods, and results from the overall impact assessment as described in the body of this report. The methods and results from these analysis may be found in the appendices of this document. These include:

Case Study of Multifrequency Fluvial Flood Hazard Data: Although the overall Impact Assessment was limited by single-frequency (1% AEP) riverine flood data, a case study was completed to examine the potential differences if multi-frequency riverine data were available (as is the case for coastal and pluvial hazards). The case study was performed in three HUC watersheds (Great Wicomico-Piankatank, Lower Rappahannock, and Mattaponi) using the full impact assessment methodology. Limitations of the study included only including a small subset of mostly rural areas, limited recurrence intervals as compared to coastal and pluvial flood risk data, and that it was limited to existing conditions fluvial flood risk data. Findings from this effort supported recommendations to expand multi-frequency fluvial modeling across the entire CRMP study area and incorporate flood depth data to better evaluate asset vulnerability and damage potential. The full results, including key findings and recommendations are provided in the Fluvial Multi-Frequency Impacts Case Study Report (Addendum B to this report).

Expanded Economic Impacts: Using Average Annualized Losses (AALs) developed through the Impact Assessment, Old Dominion University (ODU) estimated the total economic impact, including direct, indirect, and induced impacts, across various localities. The economic impacts were further aggregated by Planning District Commissions (PDCs) to assess regional flood risks. The loss estimates and estimates of economic impact are in 2024 dollars.

ODU employed Bureau of Economic Analysis Regional Input-Output Modeling System (RIMS II) multipliers directly comparable with the North American Industry Classification System (NAICS) used for localities included in the CRMP study area. The economic impact multipliers were mapped to the building occupancy classes employed in the CRMP Impact Assessment. AALs produced by the CRMP Impact Assessment by occupancy and region were used in combination with the multipliers to estimate the impact of coastal flooding and rainfall-driven flooding on economic output, compensation, and value added. The estimates of economic impact were aggregated by study region to obtain the final projections of the impact in 2024 dollars. Coastal, pluvial, and combined estimates were provided at PDC and CRMP study area geographies. As the study periods were discrete events expressed in 2024 dollars using 2020 building stocks, the results were not discounted into present value. The full methodology and results are documented in a separate Expanded Economic Impact Analysis Report.

Tax Base Impacts: The Tax Base Impacts Assessment sought assessed potential real estate tax revenue loss from projected future land inundation, and the possible increase in the tax base to offset these losses. The analysis encompassed the 57-county CRMP study area using methods modeled after prior work by Climate Central (2022).

First, the area of each property parcel impacted by Mean High Water (MHW) inundation extents at each time horizon from the CRMP (2020, 2040, 2060, 2080) was determined. Next, the analysis identified if buildings on the exposed properties were also impacted. If no buildings were impacted, the land value reduction was proportional to the parcel area submerged during that tidal scenario, and property tax was re-calculated accordingly using effective tax rates. If buildings were impacted, it was assumed that the property was no longer usable, land and property values were set to zero, which resulted in zero property tax amount. Impacts were analyzed on a raw basis and then baselined to the 2020 results. Dollar value impacts presented in this report are calculated as changes in impacts from the 2020 modeled results. However, changes to effective tax rates are calculated as net tax rate increases to cover all lost revenue for that time horizon (i.e., not baselined to the 2020 results). The full methodology and results are documented in a separate Tax Base Impacts Report.

C. Methods

C.1 ASSET DATA PREPARATION

Accurate and complete data is the essential foundation for executing a reliable analysis. The study team took multiple steps to prepare asset data for analysis, including a detailed source review, data cleaning, and merging.

C.1.i Data Source Review

The project team consulted with numerous external experts to source and review asset data. Information on data sources and requests for feedback were presented to the Coastal Resilience Technical Advisory Committee and its Project Prioritization Subcommittee, the VDEM Critical Infrastructure Working Group, and the EPA Region III Regional Tribal Operations Committee. Additionally, the project team directly consulted with experts and data owners regarding their best available datasets. Entities that provided data and/or consulted on appropriate data sources and uses included:

- Department of Conservation and Recreation/Natural Heritage
- Department of Environmental Quality (DEQ)/Coastal Zone Management
- Department of General Services
- Department of Historic Resources
- Department of Housing and Community Development

- Department of Rail and Public Transit
- DEQ Office of Pollution Response & Emergency Preparedness
- US Navy Region Mid-Atlantic
- Virginia Department of Emergency Management
- Virginia Department of Health
- Virginia Department of Transportation
- Virginia Institute of Marine Science

Detailed evaluation of proposed asset data included documenting information related to the asset data source and considerations related to relevancy, quality, and database integration. Data reviewers used an online database form to input fields including date last updated, relevant attributes, potential overlap with other sources, and concerns to flag or discuss. Data from the forms are maintained in an online Airtable database that can be updated as new sources or information arise. Screenshots of the review survey are shown below in Figure 6.

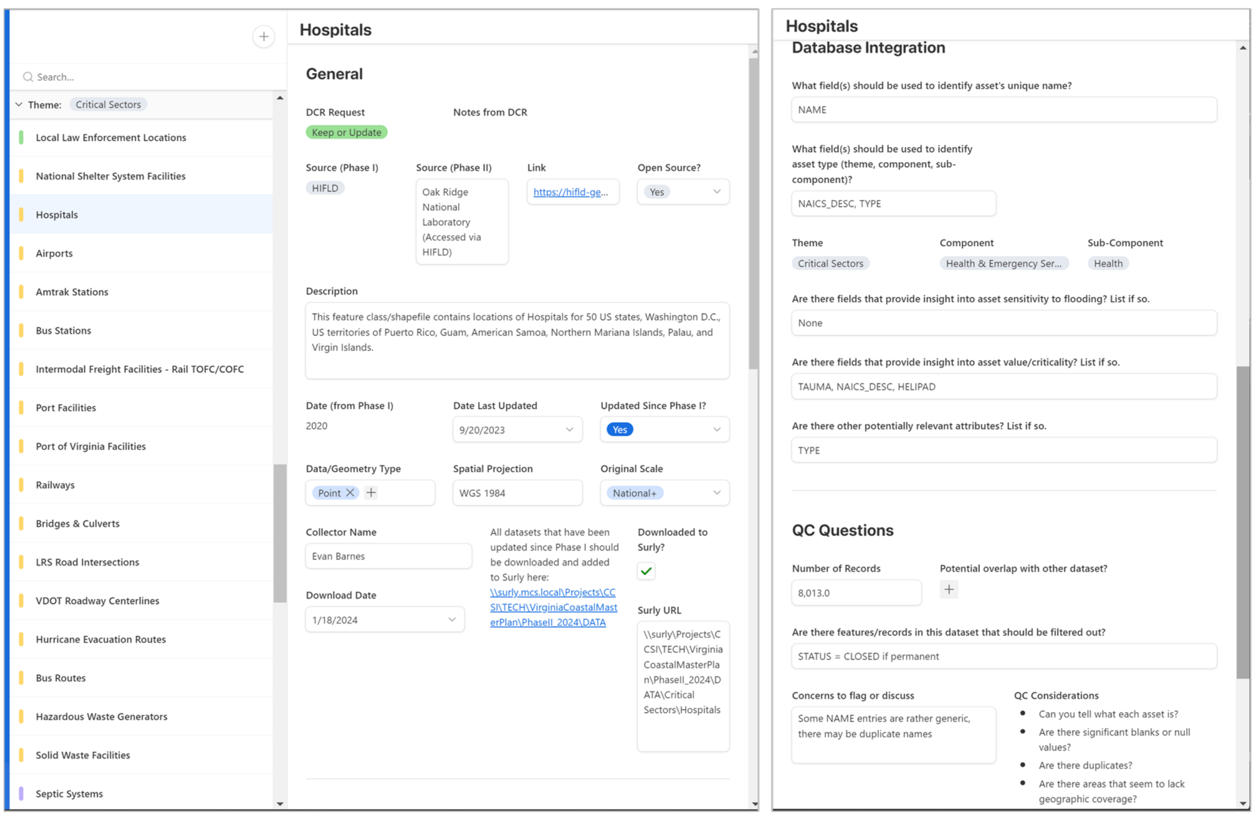

Figure 6. Screenshots of the online database form used by data review team to document data sources and flag analysis and quality concerns.

Reviewers were prompted to flag concerns including significant blanks, null values, duplications, and lack of geographic coverage. Additionally, datasets were cross-checked for overlap with other sources. Concerns were flagged and minor issues were addressed if feasible, but due to the timeline of this study, no base asset data was created or significantly improved. Large deficiencies in data were noted in the data documentation to aid the Commonwealth in future data improvement efforts.

C.1.ii General Asset Data Standardization and Cleaning

To bring data into a consistent format, information from individual data sources was extracted to identify unique asset identifiers, names, and typology information in a consistent and integrated format. To ensure both consistency in data formatting and traceability for the provenance of data in use, an automated process was used to reproject spatial information to a common analytical projection system and metadata concerning the initial download as well as the database transfer were collected and stored alongside the data. Additionally, the following steps were taken to support quality control processes:

- Assets exposed to MLW in 2020 were assumed to be water-based assets and flagged for potential exclusion.
- Assets suspected to be duplications across and within source datasets were flagged for further examination and potential exclusion.
- Asset source, name, and type information was retained so that sorting and rule-based exclusions can be applied at a later stage of the analysis. This includes the removal of ancillary data that are not important to the assessment.

C.1.iii Roadway Asset Data Preparation

Linear roadway assets were broken up into segments as a factor of the input data, with each segment then treated as a discrete asset. These linear features were also converted to a polygon by buffering with a default width of 40 feet, to capture a more realistic view of flood exposure for these assets. Roads are assessed as both linear assets (providing length of roadway exposure in feet) as well as an area-based asset (providing area exposed to flooding) and a broader picture of potential impacts. To provide context to roadway segments, the following attributes are also included for additional context and classification:

- Category (i.e., Hurricane Evacuation Routes, Primary, Secondary, Street)
- Average Daily Traffic (ADT)

C.1.iv Building Dataset Creation

Additional steps were taken to prepare building dataset to maximize coverage and accuracy for risk assessment.

Refine Building Inventory – The building inventory is a combined dataset. The primary source of building footprint and parcel data for this effort is the Lightbox SmartParcels data (dated July 2023 and sourced through Homeland Infrastructure Foundation-Level Data (HIFLD) Secure). The latest Virginia Geographic Information Network (VGIN) building footprint data (last updated January 2024) was used to supplement building footprints with attribute data being provided from the Phase I dataset where available. Preliminary analysis identified about 79,000 buildings to be integrated into the LightBox SmartParcels data before the below exclusions were integrated. For Phase II, those 79,000 building footprints were overlaid against the latest VGIN building footprint data to identify the additional buildings to be integrated. The attributes from the Phase I data were transferred over to the latest VGIN data before integration. More information about Phase I building sources can be found in Section 3.1.2 of the Phase I Appendix E: Impact Assessment Methodology Report (Dewberry, 2021).

From this combined dataset, the building footprints were excluded from analysis for the following reasons:

- Occupancy type (vacant or undefined designations)
- Area (less than 500 square feet)
- Buildings in 2020 MLW floodplain

The combined building data represents a best available dataset. However, buildings are inevitably going to still be missing from this merged data set, particularly in areas with new development.

Attribute Relevant Data – In order to prepare structures for damage and loss assessments described in Section C.2.ii, several critical attributes must be assigned to each building: occupancy type, foundation type, number of stories, building area, building replacement value, year of construction, and first floor height. First-floor height is the height, in feet, of the top of the first floor above ground level. The building area is the area of building footprint in square feet. The number of stories is the number of occupiable stories. Occupancy type describes the building's use or function and is typically represented by general use classes defined in the Hazus Multi-Hazard (Hazus-MH) loss estimation model framework (FEMA, 2020). Additionally, information on structure value is needed to translate building damages into economic losses.

Occupancy type, foundation type, and number of stories were attributed to each building through the LightBox building, parcel, and associated tax assessment data. Building area was calculated in PostgreSQL, based on the building footprint polygonal geometry, as the building area field included in the LightBox building, parcel, and associated tax assessment data was not found to be accurate data based on geospatial investigation by the study team. First-floor height utilized Phase I locally sourced data were available from Virginia Beach, Norfolk, Newport News, and the HRPDC. Around 74,000 building first floor heights utilized this locally sourced data. The remaining buildings had first floor height attributed through Hazus assumptions based on foundation type shown in Table 5 (FEMA, 2022). Building replacement value was calculated using empirical relations between building area multiplied by the number of stories, occupancy type, and cost per square foot associated with the occupancy type as defined by Hazus. Content replacement value was calculated as a proportion of the calculated building replacement value using the default content percentage in Hazus. A list of occupancy types and valuation rates is included in Table 8 in Section C.2.ii. For additional information on the Hazus approach to utilizing replacement values to estimate damages from flood hazard events, please see the FEMA "Guidance for Flood Risk Analysis and Mapping" report (FEMA, 2020).

Table 5. Hazus First Floor Height Assumptions (FEMA, 2022)

Foundation Type	Default First Floor Height (feet)
Pile	7
Pier	5
Solid Wall	7
Basement/Yard	4
Crawlspace	3
Fill	2
Slab on Grade	1

To determine occupancy type based on the HIFLD Secure tax assessment data, the fields use_code_std_lps, use_code_muni, and use_code_std_desc_lps were used to crosswalk Hazus designated occupancy type for each building. Addendum A to this report shows the determined relationships between these attributes and Hazus designated occupancy types.

Additional attribute data that can be utilized for analyzing and classification of the buildings in this dataset also include: Lowest Adjacent Grade (the lowest point of the ground level immediately next to a building), Highest Adjacent Grade (the highest natural elevation of the ground surface), Owner Occupied (Yes/No), Assessed Land Value ($), Assessed Improved Value ($).[1] Furthermore, additional land ownership data collected was used to designate whether a building was on tribal-owned or federally-owned lands and the relevant owning entity.

C.1.v Approximation of Household Demographics

Population counts from the US Census Bureau's American Community Survey (ACS) was statistically attributed to individual residential building footprints (using 2020 block group boundaries and 5-year ACS estimates from 2021 TIGER data). This is an alternative

[1] If data was missing or unavailable, null values were reported.

approach to distributing population uniformly through a census block and has the benefit of accounting for population distribution and density variations. Mapping the population to the building footprints facilitates geographic-specific population and demographic aggregation for working with geometries that do not coincide with census block boundaries (such as HUCs and project boundaries). While this process is highly useful for statistical modeling at an aggregated scale, these estimates should not be used to report impacts to individual structures and residents. It is recommended that the resulting raw values be shared and reported out at a minimum geographic scale of a census block group. The process to do this calculation is described below.

- **Source Data Aggregation** – Building-level data from multiple sources were combined to create a comprehensive building layer, as described above in Section C.1.iv.
  - **Land-Use Attribution** – Land-use information for the buildings was extracted from the parcel data.
  - **Type Classification** – Each building was categorized as residential or non-residential based on the land-use type of the parcel.

  Population Attribution – In order to use the ACS demographics data, each residential building footprint was associated one-to-one with a census block group based on building centroids. Population counts reported for each census block group were then proportionally allocated to the residential buildings using a simplified volumetric approach[2] (Murayama, 2009; Pajares, Muñoz Nieto, Meng, & Wulfhorst, 2021) using the number of stories multiplied by footprint area for area-weighted population allocation. In order to account for every person in the census block group, a set of rules was devised based on the data available in each census block group. These rules were incrementally applied in each census block in the order shown in the list below.
  - Only residential buildings were identified as the primary areas of population in each census block group. Residential buildings were identified as anything with a residential-based land use type.
  - In populated census block groups with no residential buildings or parcels available, the population was distributed to all the buildings in the census block group, regardless of occupancy type. An example for this case would be prisons. Generally, prisons are the only buildings in a census block reporting population. Since prisons are considered Government or Tax-exempt occupancy buildings,

[2] This differs from phase 1 where an areametric approach was used where larger footprints received a bigger share of the census block group population. The proportioning method distributes demographic composition based on the living square footage reported in the parcel data. Where square footage was not available, the building footprint area was used.

they are not included in population distribution. In such blocks, population was distributed to all the buildings regardless of occupancy type.

In addition to population counts, demographic information related to social vulnerability (e.g., race, income, education, employment, etc.) was pulled at the census tract level and paired with all residential building footprints. These should not be presented at the building-level, but were associated with estimated population counts and rolled up to various summary geographies using a population-weighted average approach. Due to the imprecise statistical methods implored, it is not recommended that these demographic variables are reported directly, but instead can be used for qualitative analysis and showing relatively high or low presence or estimated flood exposure of certain demographic groups. Demographic variables referenced in the CRMP are listed in Table 6.

Table 6. Demographic ACS Variables that align with the CDC's 23 SVI components. (Centers for Disease Control and Prevention and Agency for Toxic Substances and Disease Registry, 2022)

SVI Theme	SVI Variable	ACS Variables
Socioeconomic	No Health Insurance	Estimated percentage uninsured in the total civilian noninstitutionalized population.
Socioeconomic	Civilian Unemployment	Estimated unemployment rate.
Socioeconomic	Below 150% Poverty	Estimated percentage of persons below 150% poverty.
Socioeconomic	No High School Diploma	Estimated percentage of persons with no high school diploma (age 25+).
Socioeconomic	Housing Cost Burden	Estimated percentage of housing cost-burdened occupied housing units with annual income less than $75,000 (30%+ of income spent on housing costs).
Household	Single-Parent Households	Estimated percentage of single-parent households with children under 18 estimate.
Household	Limited English Language Proficiency	Estimated percentage of persons (age 5+) who speak English "less than well."
Household	Civilian with a Disability	Estimated percentage of civilian noninstitutionalized population with a disability.
Household	Aged 65 and older	Estimated percentage of persons aged 65 and older.
Household	Aged 17 and younger	Estimated percentage of persons aged 17 and younger.

SVI Theme	SVI Variable	ACS Variables
Racial & Ethnic	Total Minority	Estimated percentage minority (non-white) persons. This includes Hispanic or Latino (of any race), Black and African American, American Indian and Alaska Native, Asian, Native Hawaiian and Other Pacific Islander, Two or More Races, Other Races.
Racial & Ethnic	Hispanic or Latino	Estimated percentage of Hispanic or Latino persons.
Racial & Ethnic	Black or African American	Estimated percentage of Black/African American (not Hispanic or Latino) persons.
Racial & Ethnic	Asian	Estimated percentage of Asian (not Hispanic or Latino) persons.
Racial & Ethnic	American Indian or Alaska Native	Estimated percentage of American Indian or Alaska Native (not Hispanic or Latino) persons.
Racial & Ethnic	Native Hawaiian or Pacific Islander	Estimated percentage of Native Hawaiian or Other Pacific Islander (not Hispanic or Latino) persons.
Racial & Ethnic	Other Races	Estimated percentage of some other race (not Hispanic or Latino) persons.
Racial & Ethnic	Two or More Races	Estimated percentage of two or more races (not Hispanic or Latino) persons.
Housing	No Vehicle	Estimated percentage of households with no vehicle available.
Housing	Multi-Unit Structures	Estimated percentage of housing in structures with 10 or more units.
Housing	Mobile Homes	Estimated percentage of mobile homes.
Housing	Group Quarters	Estimated percentage of persons in group quarters.
Housing	Crowding	Estimated percentage of occupied housing units with more people than rooms.
Housing	No Internet	Estimated percentage of households without an internet subscription.

C.2 KEY METRIC CALCULATIONS AND PROCESSES

The following sections provide more details on the calculation methods and processes behind the impact metrics introduced in Section B.3.

C.2.i Binary Exposure

Annual Likelihood of Flooding (ALF) – When multi-frequency hazard data is available (coastal and pluvial hazards), ALF describes the probability that any amount of flooding will occur at a location in a given year for a given time horizon. ALF considers the annual probability of an event occurring and the extent of the floodplain associated with that event. This calculation includes the following steps:

1. **Asset-Floodplain Intersection** – All discrete assets from all sources were intersected with all the extents of the modeled flood events to identify whether or not the asset was inside or outside of the floodplain for each event frequency and time horizon. If a building footprint, area-based asset, or linear asset was partially in the floodplain, it was considered exposed by this metric.
2. **Impact Threshold Frequency** – For each time horizon, the highest-frequency flood (the flood with the lowest return interval and highest AEP) that intersects with the asset was identified. This event was considered the threshold for the asset experiencing flooding. Assets exposed to tidal flooding (MHW) were assumed to have a 100% ALF.
3. **Annual Likelihood of Flooding** – The AEP of the identified most-frequent flood event was used to estimate the ALF for a given structure. For example, if a structure was in the 20% AEP floodplain (and by default the floodplains of all less-frequent flood events) but not the 50% AEP floodplain, it was estimated to have an 20% ALF.

SFHA Exposure – The SFHA data used in this impact assessment was a spatial extent reflecting the extent of the present-day 1% AEP fluvial (riverine) flood. Similar to the process described in calculating ALF, all buildings, point-based assets, area-based assets, and linear assets were compared to this extent to determine whether they or inside or outside of the SFHA.

Assets Flooded per Event – For coastal and pluvial hazards, assets were analyzed for exposure to flooding for any given event frequency. If the asset had a depth greater than 0 ft for each AEP, the asset was deemed to be "exposed". All assets deemed as "exposed" were counted and summarized for all assets of the same type within a geography of interest.

For fluvial, SFHA-exposed assets of the same type were counted to summarize the number of assets in the SFHA within a given geography of interest.

Note if a linear or area-based asset is partially flooded, this exposure should not be reported in terms of length of area. For example, if a 1,000 ft roadway is partially exposed (10 feet of exposure), reporting 1,000 ft of roadway infrastructure exposure is not appropriate. Instead, it would be appropriate to report that 1,000 ft of roadway service is impacted due to partial roadway infrastructure flooding.

Percent of Assets Flooded per Event – The count of flooded assets were compared to the total number of assets of the same type within a geography of interest in order to develop a percent of assets flooded for any given event frequency.

Average Annualized Assets Flooded – For each event frequency, assets exposed were summed with a weight given to each event type based on its ALF. This was then summarized by asset type across a geography of interest for a given time horizon. Mathematically, this is the same as taking the metric average across all assets and multiplying it by the number of assets in a given geographic boundary. The resultant value is the average annualized number of flooded assets or the expected number of assets flooded each year.

Population Flooded per Event – This metric provides an estimate of the number of people living in flood-exposed residential buildings for each modeled flood event. Population estimates were attributed to each residential building footprint using the method described in Section C.1.v and exposure was derived from the building's calculated ALF. While the population exposure impact metric focuses on population counts and was unrelated to demographic characteristics, population exposure can also be broken down by race/ethnicity or other relevant categories in subsequent analyses.

Percent of Population Flooded per Event – The estimated number of residents exposed to flooding was compared to the total number of residents within a geography of interest by building type in order to develop a percent of population flooded for any given event frequency.

Population Displaced – For this assessment, buildings that fall within the MHW floodplain were considered uninhabitable and so this metric captures an estimated count of residents living in buildings with an ALF of 100%. This metric is an approximation of a much more complex process that involves individual decision-making about what level of flooding would trigger decisions to relocate—while others are studying these triggers, a more detailed analysis is outside of the scope of this plan. It also does not consider population growth for future time horizons or that some coastal residential buildings are secondary homes or vacation rental properties. Note this metric is not reported separately but can be extracted from event-specific summary data.

Average Annualized Population Flooded – When summarizing population exposure to a geography of interest, the ALF at a residential structure was used as a weight applied to each resident. Mathematically, this is the same as taking the average ALF across all residents and multiplying it by the number of residents. The resultant value is the average annualized number of people experiencing flooding, or the statistically expected number of people whose homes are flooded in a given year.

C.2.ii Depth of Flooding

Maximum Flood Depth per Event – The depth of flooding is the difference between water surface elevation and ground elevation at the location of the asset, measured in feet. For linear- or polygon-based assets, this metric focuses on the maximum flood depth experienced across the length or perimeter of the asset during any given flood event and time horizon. First floor height was added to ground elevation to determine depth in structure for buildings. Flood depth was only calculated for coastal and pluvial flood hazards. When summarizing across a geographic area, counts of assets by bucketed flood depths (e.g., Assets Flooded 0 to 1 ft, Assets Flooded 1to 2 ft, etc.) could be a useful future analysis for certain asset type.

Average Annualized Depth (AAD) – The probability-weighted average of flood depth for a given asset across events was calculated by computing the sum product of the maximum flood depth and probability weights assigned to each modeled flood event within a time horizon. Probability weights for each modeled event AEP were calculated using the following equation:

$$Weight_n = AEP_n - AEP_{n+1}$$

If summarizing AAD to a geography of interest, the resultant value would be the expected cumulative depth of flooding across all assets for a given year. This metric can be challenging to communicate but can help to account for the relative variation in hazard exposure between assets in flood-prone areas.

Table 7. Weights Utilized by Event Type

Event Type	Recurrence Interval	Weight
MHW	1	0.5
2	2	0.3
5	5	0.1
10	10	0.06
25	25	0.02
50	50	0.01
100	100	0.008
500	500	0.002

Percent Damage per Event – The level of damage a building (both structure and contents) is likely to experience can be estimated based on modeled relationships between flood depth and building damage, using best-available information about a building's characteristics. Building damages were calculated using the U.S. Army Corps of Engineers' (USACE) Go-Consequences, a flood loss estimation software written and optimized for use in a cloud computing environment to estimate flood loss over large geographies and/or flood conditions. Go-Consequences calculates structural and contents loss based on building occupancy types and their respective depth-damage functions (DDFs). While selecting the appropriate DDF for loss analysis of each building occupancy type can be informed by various factors, it was largely informed by expert judgment.

Building DDFs relate the flood depth above the first floor of a building to structural and contents damages and expected economic loss. The relationship between flood depth and damage is dependent on several factors, particularly the building use or functionality (occupancy type) and the building design (foundation type, number of stories, height of first floor above ground). Often, building design is inferred by occupancy type and no other information is needed to assign a DDF. However, in single and multi-family residential buildings, which represent a large variety of building designs in a variety of environments, other building attributes can be incorporated into the DDF assignment process to provide a DDF better tailored to building design.

The USACE and FEMA have developed a wide variety of DDFs for different building types, different geographic regions, and different types of flood hazards (freshwater, saltwater, waves, etc.). The USACE Go-Consequences software provides a default suite of DDFs sourced from the USACE Galveston DDF library for all Hazus occupancy types. The library provides multiple possible curves for a given occupancy, in such cases, the software adopts the average of the curves. Where multiple curves are not assigned, the library provides a single curve for a given occupancy, and the software adopts the curve. The following describes the DDFs used for each structure type.

- **Single Family Structures** – FEMA has recently developed an improved suite of DDFs as part of ongoing research and development for Coastal Probabilistic Flood Risk Assessment (CPFRA). Following the methodology employed in Phase I, the FEMA CPFRA curves were applied again in Phase II.
- **Mobile Homes and Multi-Family Residential Structures –** The Go-Consequences software default DDFs are used for both inland (including pluvial) conditions and coastal conditions when breaking wave conditions are less than 1.5 feet. However, when breaking wave conditions exceed 1.5 feet (i.e., the area of moderate wave action, or coastal high hazard zone, as defined by FEMA), the FEMA Benefit Cost Analysis Re-engineering (BCAR) DDF library is used, which appropriately considers the enhanced damage effects caused by large waves.
- **All Other Building Occupancy Classes –** Default DDFs in Go-Consequences were used for buildings with occupancy classes other than single family, mobile homes, and multi-family residential for both inland and coastal conditions. These pre-selected DDFs were reviewed by a subject matter expert in loss analysis and post-disaster damage assessments and were deemed appropriate for use in coastal Virginia. It should be noted that the USACE is currently applying Go-Consequences with an adaptation of the DDF library developed by FEMA for coastal damages across the southeastern coast as part of the South Atlantic Coastal Study (SACS) (Will Lehman, USACE, per comm.). Go-Consequences provided multiple DDFs for all structure types, as noted in Table 8, except for *Group Housing*, *Nursing Homes*, *Banks*, *Hospitals*, *Parking Garages*, *Industrial High Technology Factories*, *Churches/Non-profit*, and *College/University* occupancy types.

For *Single Family*, *Mobile Home*s, and *Multi-Family* residential structures occupancy types, additional DDF libraries provide a more nuanced view of the relationship between flood depth and damage based on details of building design and specific hazard conditions not considered by the Go-Consequences default DDF library.

This graduated approach is especially applicable to the CRMP. It better reflects changing risk and loss to residential structures as SLR increases flood depths and allows for greater wave heights and increased inland propagation of wave action. Used as a package, these DDFs represent a range of similar building designs and hazard variables for single-family homes and are deemed suitable by FEMA for planning purposes. Despite their developmental status, these DDFs are derived from existing data and are considered the best available product for single-family coastal buildings. The Go-Consequences code was modified to assign the correct DDF to each building for each hazard type (inland and coastal), and for each flood level, based on building attributes such as the number of stories and foundation type, as well as breaking wave height. Damages to building contents are determined using a separate set of *Contents* DDFs that are paired with the building DDFs.

Flood damages for an individual building were calculated for each event AEP, based on the event's associated flood hazard type, flood depth and possible wave height, and structure attributes. For each event, the *Total Flood Depth* and, in coastal conditions, *Wave Height Above Stillwater Elevation (SWEL)* was extracted at each building. In riverine or pluvial conditions, wave height was set to 0, while in coastal conditions, each *Wave Height Above SWEL* was translated into a *Breaking Wave Height* as,

$$\textit{Breaking Wave Height} = \textit{Wave Height Above SWEL} / 0.7,$$

and each *Total Flood Depth* was translated to *Depths Above First Floor* by subtracting the building's *First Floor Height* from each *Total Flood Depth* as,

$$\textit{Depth Above First Floor} = \textit{Total Flood Depth} - \textit{First Floor Height}.$$

For each different hazard, every building was assigned a *Building* and *Contents* DDF based on the building occupancy or other building attributes, including *Breaking Wave Height* in applicable coastal situations. Each building then have event-specific *Breaking Wave Heights*, *Depths Above First Floor*, and DDFs corresponding to the AEP hazards. The Go-Consequences software then relates each *Depth Above First Floor* to a *Building Percent Damage* using the defined DDF to provide event-specific damage calculations for each building. Estimated damages to a building's structure and contents were calculated separately but can be combined for simplicity in presentation.

Losses per Event – Monetary loss for both building and contents were calculated for each hazard and building as:

$$\textit{Buildings Loss}_{hazard} = \textit{building damage}_{hazard} * \textit{building replacement value}, \text{ and}$$

$$\textit{Contents Loss}_{hazard} = \textit{contents damage}_{hazard} * \textit{contents value}.$$

Total Loss is the sum of building and contents losses for each event and building,

$$\textit{Total Loss}_{hazard} = \textit{Buildings Loss}_{hazard} + \textit{Contents Loss}_{hazard}.$$

Building replacement value was calculated as a factor of building footprint square footage multiplied by the number of stories. Table 8 details how occupancy types are aligned with values and DDFs.

Other, indirect losses can be incurred from the displacement of people from the structures and broader economic impacts of the damage and disruption but those were not captured in this effort.

Table 8. Structure occupancy type and cost classifications from FEMA/Hazus used for coastal damage calculations.

Occupancy	Cost/ft^2	Description	Multiple or single DDFs provided by go-consequences	DDF used by CRMP
RES 1- STORIES 1	150.09	SINGLE-FAMILY DWELLING	MULTIPLE	FEMA CPFRA
RES 1- STORIES 2	156.24			
RES 1- STORIES 3	160.53			
RES 1- STORIES 4	145.42			
RES2	52.39	Mobile Home	Multiple	Default when breaking wave < 1.5 feet FEMA BCAR when breaking wave > 1.5 feet
RES3A	141.95	Multi-Family Dwelling - Duplex	Multiple	
RES3B	124.79	Multi-Family Dwelling - 3 to 4 Units	Multiple	
RES3C	224.08	Multi-Family Dwelling - 5 to 9 Units	Multiple	
RES3D	210.75	Multi-Family Dwelling - 10 to 19 Units	Multiple	
RES3E	230.45	Multi-Family Dwelling - 20 to 49 Units	Multiple	
RES3F	217.03	Multi-Family Dwelling > 50+ Units	Multiple	
COM1	136.83	Retail Trade	Multiple	Default
COM2	132.88	Wholesale Trade	Multiple	
COM3	161.37	Personal and Repairs Services	Multiple	
COM4	218.79	Business/Professional/Technical Services	Multiple	
COM5	317.05	Depository Institutions	Single	

Occupancy	Cost/ft2	Description	Multiple or single DDFs provided by go-consequences	DDF used by CRMP
COM6	419.08	Hospital	Single	
COM7	301.27	Medical Office/Clinic	Multiple	
COM8	279.64	Entertainment & Recreation	Multiple	
COM9	209.73	Theaters	Multiple	
COM10	95.15	Parking Garages (Not Parking Lots)	Single	
IND1	162.76	Heavy Industrial	Multiple	
IND2	132.88	Light Industrial	Multiple	
IND3	258.12	Food/Drugs/Chemicals	Multiple	
IND4	258.12	Metal/Minerals Processing	Multiple	
IND5	258.12	High Technology	Single	
IND6	132.88	Construction (Facilities and Offices)	Multiple	
RES4	236.49	Temporary Lodging	Multiple	
RES5	254.52	Institutional Dormitory	Single	
RES6	258.46	Nursing Home	Single	
AGR1	132.88	Agriculture	Multiple	
REL1	223.92	Church/Membership Organizations	Single	
GOV1	171.68	Government, General Services	Multiple	
GOV2	291.91	Government, Emergency Response	Multiple	
EDU1	217.09	K-12 Schools/Libraries	Multiple	
EDU2	241.74	Colleges/Universities	Single	

Average Annualized Loss (AAL) – AAL is a risk metric that captures the expected flood loss for any given year over a broad period of time, based on an individual structure's exposure to a range of flood elevations and their associated annual probabilities. AAL is a flood loss industry standard for evaluating flood risk, employed by FEMA, USACE, and the flood insurance industry, among others. AAL is expressed in dollars and can be particularly helpful for comparing the costs and benefits of risk mitigation actions.

After losses were calculated for each hazard, the building AAL can be calculated following the Hazus-MH method. The hazard frequencies were paired with the consequent building losses sorted by frequency (ascending) to determine AAL.

From each sorted pair, *i*, the structure's AAL was calculated as,

$$AAL = \sum_{i=1}^{n-1}\left((F_i - F_{i+1}) * \frac{(L_i + L_{i+1})}{2}\right) + (F_n * L_n)$$

where **n**=number of Hazards, **Fi** = ith Frequency, and **Li** = ith Loss. The formula used for AAL calculation was derived from FEMA's Guidance for Flood Risk Analysis and Mapping (FEMA, 2020).

Average Annualized Percent Damage – When aggregating across event conditions within a given time horizon, event-specific percent damages were translated into *Average Annualized Percent Damages*. This metric represents the probability-weighted average across event-specific building damages (structure and content) across all events within a given time horizon. This can be derived by applying the probability weighting function (described above) to event-specific damages, similar to the AAD or AAL calculations. It is also the same as dividing a building's AAL by its value (or total AAL in a geography of interest by the total value of buildings exposed) in order to get a normalized perception of vulnerability and risk that is based on structure values. Using damages (rather than losses) to visualize or evaluate flood risks can help to serve equity objectives and counteract the tendency to see higher-value buildings as presenting greater risk than lower-value buildings.

C.2.iii Extent of Flooding

Total Length Flooded per Event – For linear assets, the extent of their exposure was calculated as the length in linear feet that intersect with the floodplain extents for each event condition. For fluvial (riverine) flood hazards, length exposed was calculated only to the present-day 1% AEP.

Land Length Flooded per Event – For linear assets, the extent of their exposure was calculated as the length, above the 2020 MHW, in linear feet that intersect with the floodplain extents for each event condition. For fluvial (riverine) flood hazards, land length exposed was calculated only to the present-day 1% AEP.

Percent of Total Length Flooded per Event – Length in feet of flood exposure was translated into a percent value based on the total length of the asset, to convey the portion of the asset that intersects with a given floodplain for any given event frequency.

Percent of Land Length Flooded per Event – Length in feet of flood exposure was translated into a percent value based on the land length of the asset (defined as length above 2020 MHW), to convey the portion of the asset that intersects with a given floodplain for any given event frequency.

Average Annualized Total Length Flooded – The probability-weighted average of linear flood extents per asset feature across events was calculated by computing the sum product of flooded lengths and probability weights assigned to each modeled flood event within a time horizon. This leverages the probability weight function described above and resultants in the statistically expected cumulative extent of flooding across all assets for a given year.

Average Annualized Land Length Flooded – The probability-weighted average of linear flood extents per asset feature across events was calculated by computing the sum product of flooded lengths, above the 2020 MHW, and probability weights assigned to each modeled flood event within a time horizon. This leverages the probability weight function described above and resultants in the statistically expected cumulative extent of flooding across all assets for a given year.

Total Area Flooded per Event – For assets that cover a significant amount of land area (i.e., a raster or non-building polygon), exposure was calculated as the area that intersects with the floodplain extents for each event condition.

For fluvial (riverine) flood hazard, flood exposure to the present-day 1% AEP event was calculated as the area that intersects with the SFHA boundary.

Land Area Flooded per Event – For assets that cover a significant amount of land area (i.e., a raster or non-building polygon), exposure was calculated as the area, above the 2020 MHW, that intersects with the floodplain extents for each event condition. To account for area-based assets that cross over bodies of water, all flood inundation was considered relative to a 2020 MHW baseline.

For fluvial (riverine) flood hazard, flood exposure to the present-day 1% AEP event was calculated as the area that intersects with the SFHA boundary.

Percent of Total Area Flooded per Event – Area of flood exposure was translated into a percent value based on the total area of the asset, to convey the portion of the asset that intersects with a given floodplain for any given event frequency. Percent values will also be calculated within a geography of interest, based on the total area exposure of a certain asset type.

Percent of Land Area Flooded per Event – Area of flood exposure was translated into a percent value based on the land area of the asset (defined as area above the 2020 MHW), to convey the portion of the asset that intersects with a given floodplain for any given event frequency. Percent values was also calculated within a geography of interest, based on the total area exposure of a certain asset type.

Average Annualized Total Area Flooded – The probability-weighted average of area-based flood extents per asset feature across events was calculated by computing the sum product of flooded area and probability weights assigned to each modeled flood event within a time horizon. This leverages the probability weight function described above and resultants in the statistically expected cumulative extent of flooding across all assets for a given year.

Average Annualized Land Area Flooded – The probability-weighted average of area-based flood extents per asset feature across events was calculated by computing the sum product of flooded land, above the 2020 MHW, and probability weights assigned to each modeled flood event within a time horizon. This leverages the probability weight function described above and resultants in the statistically expected cumulative extent of flooding across all assets for a given year.

Percent Average Annualized Total Area Flooded – Average annualized land area of flood exposure was translated into a percent value based on the total land area of the asset, to convey the portion of the asset that intersects with a given floodplain for each modeled flooded event within a time horizon above the 2020 MHW. Percent values was also calculated within a geography of interest, based on the total average annualized land area exposure of a certain asset type.

Percent Average Annualized Total Land Flooded – Average annualized total area of flood exposure was translated into a percent value based on the total area of the asset, to convey the portion of the asset that intersects with a given floodplain for each modeled flooded event within a time horizon. Percent values was also calculated within a geography of interest, based on the total average annualized area exposure of a certain asset type.

Land Lost – For this assessment, the land was considered fully inundated and therefore effectively "lost" if it falls within the MHW floodplain. As sea levels rise, the MHW floodplains expand and areas newly covered by this tidal condition were considered lost to permanent daily inundation. Change in land area, calculated in acres, was found by subtracting the non-inundated land area associated with a given time horizon from the baseline condition land area (landward of 2020 MHW) in the geography of interest. Because tidal inundation is specific to coastal flooding, this metric can only be calculated for coastal flood hazard. While this metric is not explicitly presented in the data outputs, it can be derived from the coastal threshold-based geographic impact summary tables, which compare coastal flood exposure for each future planning horizon to present (2020) MHW conditions.

Changes in Natural Infrastructure Flood Exposure – The natural infrastructure analysis enhanced the framework from Phase I by incorporating new data sources and new metrics of natural infrastructure vulnerability and risk. The complete list of data sources used to represent natural infrastructure is presented in Table 9.

Select data sources were used in a baseline assessment of natural infrastructure across the entire coastal zone. The Chesapeake Conservancy land use/land cover data was selected for the baseline assessment because it provides sufficient detail to estimate the value in average annualized dollars of natural infrastructure and continuous coverage for the Chesapeake Bay watershed. While this covers most of the Virginia coastal zone, a portion spanning five localities (Greensville County, Southampton County, Sussex County, City of Emporia, and City of Franklin) in the southwest region of the coastal zone was excluded. The Virginia State Land Cover data provided coverage for this area. The Virginia Institute of Marine Sciences (VIMS) Natural and Nature-Based Features (NNBF) data was also used in the baseline assessment to identify beach and dune features, which were not easily distinguished in the land use/land cover data.

As noted in Section 2.3.4 Extent of Flooding, for non-raster data, metrics were calculated at the level of individual assets (features). Natural infrastructure features assessed for asset-specific impacts include DCR Conservation Lands, DCR Predicted Suitable Habitat for Sensitive Species, the VIMS NNBFs, and the ConserveVirginia Agricultural and Forested Conservation Priority Areas, Natural Habitat and Ecosystem Diversity Conservation Priority Areas, and Protected Landscapes Resilience Conservation Priority Areas. Summaries of area flood exposure were produced for geographies of interest (i.e. acres of predicted suitable habitat for sensitive species exposed to future MLW within a given watershed).

Table 9. Natural infrastructure assets and supporting data sources.

Natural Infrastructure Assets	Data Source	Used in Baseline Assessment
Beaches, Breakwater, Dune, Emergent Wetland, Forested Wetland, Marsh Sill, Oyster Sill, Scrub-Shrub, Scrub-Shrub Wetland, Tidal Marsh, and Wooded	Virginia Institute of Marine Sciences NNBF	Yes
Land Use/Land Cover (upland forest, scrub-shrub, non-tidal wetlands, cropland, etc.)	Chesapeake Conservancy Land Use/Land Cover Data	Yes
Land Cover	Virginia State Land Cover Dataset	Yes
Tidal wetlands*	NOAA Marsh Migration Model	No
Conservation Lands	DCR	No
Predicted Suitable Habitat for Sensitive Species	DCR	No
Natural Habitat and Ecosystem Diversity Conservation Priority Areas	ConserveVirginia	No
Protected Landscapes Resilience Conservation Priority Areas	ConserveVirginia	No
Agricultural and Forested Conservation Priority Areas	ConserveVirginia	No

*Changes in tidal wetland area were calculated using the NOAA Marsh Migration model thresholds.

As sea levels rise relative to the landscape, today's upland areas will become more frequently inundated. These areas will be subject to changing environmental conditions associated with this tidal inundation, resulting in alterations to asset characteristics as natural ecosystems respond. For example, this changes in natural infrastructure flood exposure metric may be useful for anticipating locations of potential species or crop loss due to saltwater intrusion. The acreage of natural infrastructure within different flood exposure zones was calculated under present and future conditions. The flood exposure zones represent areas that are projected to be lost to flooding (MLW) or experience daily (MHW) to periodic (1.5xMTR) flood exposure. The boundary of 1.5xMTR was selected for alignment with Virginia's legal boundaries for the extent of tidal wetlands, which is defined as those areas between MLW and 1.5xMTR. These discrete calculations, as shown in Table 10, allow for different combinations of flood exposure to be assessed based on the threshold and relative baseline of interest. In the context of Table 10, upland refers to area landward of the MLW to 1.5xMTR flood extent. For example, the following calculations could be completed for natural infrastructure based on the combination of different exposure zones:

- Total area of natural infrastructure exposed to future MLW
- Total area of natural infrastructure exposed to future MHW
- Total area of natural infrastructure exposed to future 1.5xMTR

Table 10. Exposure zone conversion calculations for natural infrastructure analysis

Exposure Zones	Exposure Zone Conversion Calculations
Exposed to future MLW	Current MLW area exposed to future MLW
	Current MHW area exposed to future MLW
	Current 1.5xMTR area exposed to future MLW
	Current upland area exposed to future MLW
Exposed to future MHW	Current MHW area exposed to future MHW
	Current 1.5xMTR area exposed to future MHW
	Current upland area exposed to future MHW
Exposed to future 1.5xMTR	Current 1.5xMTR area exposed to future 1.5xMTR
	Current upland area exposed to future 1.5xMTR
Not exposed to future MLW, MHW, or 1.5xMTR	Current upland area remaining as upland

It is important to note that tidal wetlands were not included in the changes in natural infrastructure flood exposure metric due to complex factors, including coastal geomorphology and development pressures. The following section describes the approach used to calculate changes in tidal wetland area.

Tidal Wetland Area Lost – Changes in tidal wetland area were calculated using National Oceanic and Atmospheric Administration (NOAA) Marsh Migration data created in 2016. NOAA's marsh migration mapping was selected because it was the only readily available statewide coverage of a coastal land cover change model that aligned with the CRMP SLR scenarios. This data source was also used to calculate loss of tidal wetland habitat in Phase I. The NOAA analysis classifies wetlands based on NOAA's Coastal Change Analysis Program (C-CAP), which provides inventories of coastal intertidal areas, wetlands, and adjacent uplands. The NOAA marsh migration analysis land cover classes have a 10-meter resolution and are based on the C-CAP data that reflects conditions mapped in the 2005 to 2006 timeframe. While NOAA is currently phasing in the next generation of high-resolution land cover data for the nation's coastal areas at 1-meter resolution, the initial next generation NOAA C-CAP Phase I data products only include impervious, canopy, and water classifications, and did not provide sufficient details for a tidal wetland acreage loss analysis.

The NOAA methodology assumes that specific wetland types exist within an established tidal elevation range based on an accepted understanding of what types of vegetation can exist given varying frequency and time of inundation, as well as salinity impacts from such inundation (NOAA Office for Coastal Management, 2017). The NOAA methodology assumes areas between Mean Tide Level and MHW as suitable for salt marsh, and areas between MHW and mean high water spring (MHWS) tide as suitable for brackish/transitional marsh. MHWS represents an upward shift in the MHW based on the highest tide levels in the spring. The marsh mapping results are available in half-foot increments of net sea level change from 0 to 10 feet. To calculate changes in tidal wetland area, representative water levels that align with the 0.5-foot increment data from NOAA were selected. As shown in Table 11, water values were selected for alignment with the CRMP scenario water level ranges.

Table 11. CRMP scenario alignment with NOAA marsh migration mapping outputs

Year	CRMP Scenario Ranges (ft)	Nearest 0.5-foot Increment from NOAA (ft)
2040	1.6 to 1.8	1.5
2060	2.8 to 3.0	3.0
2080	4.4 to 4.8	4.5
2100	6.3 to 6.9	6.5

In addition to marsh migration landward, marshes also can experience vertical accretion through the buildup of organic and inorganic matter. While the NOAA Marsh Migration data is relatable to different water levels based on specific marsh accretion rates, marsh accretion was not directly included in the marsh model response. Accretion rate data is limited and highly variable between marshes in coastal Virginia, presenting challenges in selecting a single marsh accretion rate value for the coastal zone. Therefore, marsh accretion was not included in the marsh migration analysis. It is important to note this may result in an overestimation of marsh loss given that some marshes may persist longer.

To calculate tidal wetland area lost, current marsh (salt marsh and brackish/transitional marsh) extent was compared with future open water conditions as defined in the NOAA data and the area of existing marsh converted to open water was calculated. For example, an area designated as salt marsh under present day conditions that is represented as open water under 1.5ft sea level rise conditions was considered tidal wetland area lost.

Tidal Wetland Area Gained – Tidal wetland area gained was calculated as the projected acreage of tidal wetland under future conditions that is outside of the extent of current tidal wetlands. For example, an area designated as upland under present day conditions that is represented as saltwater marsh under 1.5ft sea level rise conditions would be considered wetland area gained.

Total Change in Tidal Wetland Area – The total change in tidal wetland area used the tidal wetland area gained and tidal wetland area lost calculations above as follows:

Total Change in Tidal Wetland Acreage = Total Tidal Wetland Area Gained - Total Acres of Tidal Wetland Lost.

Annualized Value of Natural Infrastructure Exposed to Flooding – The benefits provided by natural infrastructure, known as ecosystem services, can be appraised in dollars and used to translate potential loss into risk values for communication and comparison. Current FEMA Benefit-Cost Analysis (BCA) Guidance provides FEMA ecosystem services values, as shown in Table 12.

To determine the value of ecosystem services, the natural infrastructure data sources to be used in the CRMP Phase II analysis were cross-walked with the 2022 proposed FEMA BCA guidance ecosystem service categories, as shown in Table 13, Table 15, and Table 16. The value calculations were based on the area calculations derived from the changes in natural infrastructure metric. Natural infrastructure features within other exposure zones landward of MLW were considered areas where ecosystem services could be threatened by daily or periodic tidal flooding. Natural infrastructure areas in the selected exposure zones were multiplied by the FEMA BCA ecosystem service value to estimate the annualized value of ecosystem services. The Conservation Lands, Predicted Suitable Habitat for Sensitive Species, Natural Habitat and Ecosystem Diversity, and Protected Landscapes datasets were not included in the annualized value of natural infrastructure exposed to flooding analysis because there were no natural feature assets within these datasets that can be directly aligned with FEMA BCA ecosystem service classifications.

Table 12. FEMA BCA Guidance ecosystem service values

2022 Proposed Values	
Land Cover Category	**Value (2021 USD/acre/year)**
Forest	12,589
Urban Green Open Space	15,541
Rural Green Open Space	10,632
Riparian	37,199
Coastal Wetland	8,955
Inland Wetland	8,171
Coral Reefs	7,120
Shellfish Reefs	2,757
Beaches and Dunes	300,649

The Chesapeake Conservancy land use/land cover data and Virginia State Land Cover data were cross walked with the FEMA as shown in Table 13 and Table 14, respectively. For the baseline assessment of the annualized value of natural infrastructure across the coastal zone, the Chesapeake Conservancy land use/land cover data served as the primary dataset. The Virginia State Land Cover valuation was only used in the five counties within the coastal master planning region which the Chesapeake Conservancy land use/land cover data does not cover.

The VIMS NNBF data is better suited for beach and dune analysis given there is not a direct land use/land cover category that correlates with this natural infrastructure type. Within the VIMS NNBF dataset, *Beach* and *Dune* were separated into two different categories that can be combined to crosswalk with the *Beaches and Dunes* BCA classification.

In the FEMA BCA Guidance (2022), green open space is further refined to rural or urban classification for valuation. The FEMA BCA Guidance defines urban based on the criteria specified in the U.S. Census Bureau's 2010 Census Urban and Rural Classification and Urban Area Criteria. The Census criteria for defining Urban Areas was updated in the 2020 Census data. Therefore, the 2020 Census Urban Areas data was used to distinguish areas as rural or urban for the corresponding classification as *Rural or Urban Green Space.* Land use/land cover classifications that do not represent natural infrastructure, such as *Impervious Structures*, *Impervious Roads*, and *Other Impervious*, were not assigned natural infrastructure values (Chesapeake Conservancy, 2022).

Table 13. Alignment of Chesapeake Conservancy land use/land cover classification with FEMA BCA ecosystem services classification

Chesapeake Conservancy Land Use/ Land Cover Classification	BCA Ecosystem Services Classification	Value (USD/acre/year)
Forest	Forest	$12,589/acre/year
Riverine Wetlands Forest	Inland Wetland	$8,171/acre/year
Terrene Wetlands Forest	Inland Wetland	$8,171/acre/year
Tidal Wetlands Forest	Coastal Wetland	$8,955/acre/year
Harvested Forest Barren	Urban Green Open Space	$15,541/acre/year
	Rural Green Open Space	$10,632/acre/year
Harvested Forest Herbaceous	Urban Green Open Space	$15,541/acre/year
	Rural Green Open Space	$10,632/acre/year
Natural Succession Barren	Urban Green Open Space	$15,541/acre/year
	Rural Green Open Space	$10,632/acre/year
Natural Succession Herbaceous	Urban Green Open Space	$15,541/acre/year
	Rural Green Open Space	$10,632/acre/year
Natural Succession Scrub/Shrub	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Suspended Succession Barren	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Suspended Succession Herbaceous	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Suspended Succession Scrub/Shrub	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Tree Canopy over Turf Grass	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Riverine Wetlands Barren	Inland Wetland	$8,171/acre/year
Riverine Wetlands Herbaceous	Inland Wetland	$8,171/acre/year
Riverine Wetlands Scrub/Shrub	Inland Wetland	$8,171/acre/year
Terrene Wetlands Barren	Inland Wetland	$8,171/acre/year

Chesapeake Conservancy Land Use/ Land Cover Classification	BCA Ecosystem Services Classification	Value (USD/acre/year)
Terrene Wetlands Herbaceous	Inland Wetland	$8,171/acre/year
Terrene Wetlands Scrub/Shrub	Inland Wetland	$8,171/acre/year
Tidal Wetlands Barren	Coastal Wetland	$8,955/acre/year
Tidal Wetlands Herbaceous	Coastal Wetland	$8,955/acre/year
Tidal Wetlands Scrub/Shrub	Coastal Wetland	$8,955/acre/year

Table 14. Alignment of Virginia State Land Cover classification with FEMA BCA ecosystem services classification.

Chesapeake Conservancy Land Use/ Land Cover Classification	BCA Ecosystem Services Classification	Value (USD/acre/year)
Forest	Forest	$12,589/acre/year
Tree	Forest	$12,589/acre/year
Shrub/Scrub	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
Harvested/Disturbed	Rural Green Open Space	$10,632/acre/year
	Urban Green Open Space	$15,541/acre/year
TurfGrass	Rural Green Open Space	$10,632/acre/year
	Rural Green Open Space	$10,632/acre/year
NWI/Other (wetlands)	Inland Wetland	$8,171/acre/year

The changes in tidal wetland area calculated based on the NOAA Marsh Migration data were used to estimate the value ecosystem services for tidal wetlands. The values representing tidal wetlands from the NOAA Marsh Migration Classification were cross-walked with the BCA ecosystem service classification values as shown in Table 15. The area of tidal wetland lost was used to calculate the potential loss of marsh ecosystem services, while the area of tidal wetland gained was used to calculate the value of the ecosystem services of new marsh. The total change in tidal wetland area was used to assess changes in the total value of tidal wetland ecosystem services between different sea level rise scenarios.

Table 15. Alignment of NOAA marsh migration classification with FEMA BCA ecosystem services classification

NOAA Marsh Migration Classification	BCA Ecosystem Services Classification	Value (USD/acre/year)
Salt Marsh	Coastal Wetland	$8,955/acre/year
Brackish/Transitional Marsh	Coastal Wetland	$8,955/acre/year
Open Water	n/a	n/a

The ConserveVA datasets include only high priority unprotected lands. While natural infrastructure classifications in the Agriculture and Forestry ConserveVA data layer can be cross walked with the FEMA BCA ecosystem service categories, it is important to note that the resulting values represent the value of high priority unprotected lands, rather than a complete representation of these natural infrastructure categories. These values were provided in addition to the ecosystem services values calculated based on the land cover, beaches and dunes, and tidal wetlands.

In the ConserveVA datasets, *Agriculture and Forestry* is broken down into two classifications as shown in Table 16. *Forest* can be easily cross-walked to the BCA classification of *Forest*. *Agriculture* is, for the most part, open space in rural areas, and can be cross-walked to *Rural Green Open Space*. The Natural Habitat and Ecosystem Diversity dataset and Protected Landscape Resilience dataset were not directly used for this analysis as there are no natural feature classification within the dataset.

Table 16. Alignment of ConserveVA classifications with FEMA BCA ecosystem services classification.

ConserveVA Classification	BCA Ecosystem Services Classification	Value (USD/acre/year)
Agriculture and Forestry: Forest	Forest	$12,589/acre/year
Agriculture and Forestry: Agriculture	Rural Green Open Space	$10,632/acre/year
Natural Habitat and Ecosystem Diversity	n/a	n/a
Protected Landscapes Resilience	n/a	n/a

C.3 INTEGRATING CONTEXTUAL DATA

To complement asset data and metrics, contextual datasets were integrated into the database alongside asset information and summarized across geographic areas of interest (reference grid cells, census block groups, counties, towns, and HUC12s). Contextual data is all data that does not describe discrete assets of value (such as complementary modeled indices), even if the subject of the dataset it aligns with a specific asset-based theme.

In Phase I this focused on social vulnerability and community capacity. In Phase II, demographic data relating to social vulnerability was pulled directly from ACS using Census's API (described in Section C.1.v), but in order to ensure alignment with CFPF and other statewide efforts, the social vulnerability theme scores from DCR's Virginia Social Vulnerability Block Groups 2020 (Virginia DCR, 2023) were leveraged directly for this effort, rather re-calculating these values independently as done in Phase I. The demographic estimates and block group social vulnerability scores were attributed to residential footprints for summarization across different geographies of interest as described in C.1.v. This data can then be used for multi-variant analyses and visualizations within geographic areas of interest. For example, in Phase I, a combined view of social vulnerability and Average Annualized Land Inundated for each populated reference grid cell was presented using bi-variant mapping (using a two dimensional axis) to highlight areas with both high social vulnerability and high flood exposure.

In Phase II, the suite of contextual datasets integrated into the database and analysis was expanded to include Conservation Vision's watershed impact model, development vulnerability model, aquatic recreational access needs model, and terrestrial recreational access needs model. These indices cover the entirety of the study area and were summarized based on categorical counts or area-based averages for geographies of interest (as described in Section 3.4.3).

C.4 STRUCTURE OF RESULTS

Data ingested and produced is stored in multiple sets of tables outlined in this section and illustrated in Figure 7. Tables pertaining to the same asset or geography are linkable through unique identifiers.

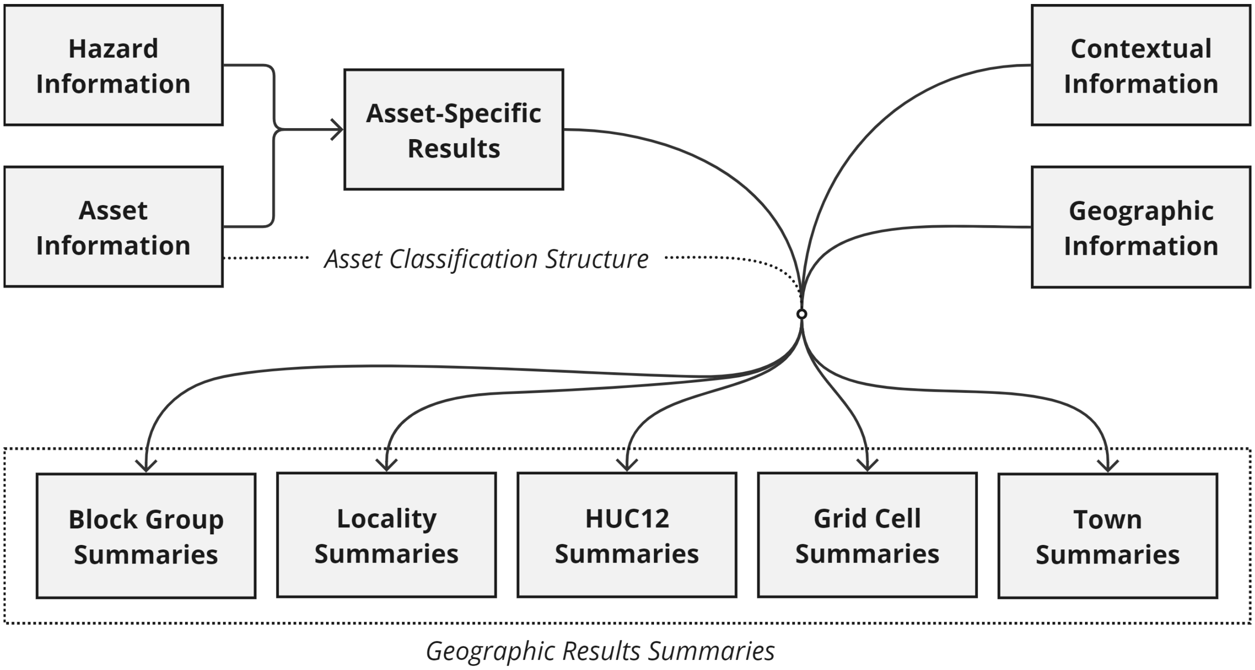

Figure 7. Graphic representation of the types of tables stored in the CRMP database and how they connect.

C.4.i Asset-Specific Impacts

As described in the calculation processes of Section C.2, hazard and asset information were leveraged for asset-specific impact metrics, which are stored in a set of asset-level impact results tables organized by asset and analysis type. There are also linkable asset detail tables with contextual information related to asset name and type for use in categorization, outlined in Table 17 (these include all assets, not just ones with flood exposure). Organization structure and key table attributes (i.e., columns) for all produced asset-specific results tables are outlined in Table 18. Same as in Section B.3, the results tables below indicate metric type as either Event-Specific (ES), Multi-Frequency (MF), or Threshold-Based (TB). Additionally, separate tables were produced for impacts related to different flood hazards, and which flood hazard type is relevant to each metric is indicated as either Coastal (C), Pluvial (P), and/or Fluvial (F).

Table 17. Organization of asset detail tables and attributes.

Asset Data	Table Attributes/Columns
Building Footprints	Building ID, Source, Source ID, Occupancy Type, Owner Occupied, Foundation Type, Number of Stories, First Floor Height, Building Footprint Square Footage, Volumetric Square Footage (Building Footprint Square Footage x Number of Stories), Year of Construction, Assessed Land Value, Assessed Improvement Value, Building Replacement Value, Content Replacement Value, Lowest Adjacent Grade, Highest Adjacent Grade, Population, Land Ownership Tribal (Yes or No), Basement Type, ID Field, Grid ID, CBG ID, Town ID, HUC12 ID, County ID, ESRI Database Federal Land Ownership, Chesapeake Bay Program Federal Land Ownership, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Protected
Point Assets	Asset ID, Name, Name Field(s), Type, Type Field, Sub-Type, Sub-Type Field, Source, Source ID, Grid ID, CBG ID, Town ID, HUC12 ID, County ID, Additional Type Field(s), ID Field, Exposed to MLW, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Excluded, Protected
Area-Based Assets	Asset ID, Name, Name Field(s), Type, Type Field, Sub-Type, Sub-Type Field, Source, Source ID, Area in Square Feet, Ecosystem Service Value (in Natural Infrastructure Polygon table only), Grid ID, CBG ID, Town ID, HUC12 ID, County ID, Additional Type Field(s), ID Field, Exposed to MLW, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Excluded, Protected
Linear Assets	Asset ID, Name, Name Field(s),Type, Type Field, Sub-Type, Sub-Type Field, Source, Source ID, Length in Feet, Grid ID, CBG ID, Town ID, HUC12 ID, County ID, Additional Type Field(s), ID Field, Exposed to MLW, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Excluded, Protected, ADT (for roadway assets only)

Table 18. Organization of asset-specific impact tables and attributes.

ASSET DATA	TYPE	TABLE ATTRIBUTES/COLUMNS	C	P	F
Building Footprints	ES	Building ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Maximum Flood Depth per Event in Feet, Structure Percent Damage per Event, Content Percent Damage per Event, Structure Losses per Event, Content Losses per Event	✓	✓	
	MF	Building ID, Time Horizon, Risk Tolerance (Pluvial only), Annual Likelihood of Flood, Minimum Recurrence Interval, Average Annualized Content Loss Percent, Average Annualized Structure Loss, Percent, Average Annualized Content Loss, Average Annualized Structure Loss	✓	✓	
	ES	Building ID, SFHA Exposure			✓
Point-Based Assets	ES	Asset ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Maximum Flood Depth	✓	✓	
	MF	Asset ID, Time Horizon, Risk Tolerance (Pluvial only), Annual Likelihood of Flooding, Minimum Recurrence Interval, Average Annualized Depth, Within 1.5xMTR	✓	✓	
	ES	Asset ID, SFHA Exposure			✓
Linear Assets	ES	Asset ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Maximum Flood Depth, Total Length Flooded per Event in Feet, MHW Length Flooded per Event in Feet, Land Length Flooded per Event in Feet, Total Asset Length in Feet, Land Length of Asset in Feet, Percent of Total Length Flooded per Event, Percent of Land Length Flooded per Event	✓	✓	
	MF	Asset ID, Time Horizon, Risk Tolerance (Pluvial only), Annual Likelihood of Flooding, Minimum Recurrence Interval, Average Annualized Total Length Flooded, Average Annualized Land Length Flooded, Average Annualized Depth	✓	✓	
	ES	Asset ID, SFHA Exposure, SFHA Length Flooded in Feet, MHW Length Flooded in Feet, Land Length Flooded in Feet, Total Asset Length in Feet, Land Length of Asset in Feet, Percent of Total Length Flooded, Percent of Land Length Flooded			✓
Area-Based Assets	ES	Asset ID, Time Horizon, Event Type, Risk Tolerance (Pluvial Only), Maximum Depth in Feet, Total Area Flooded per Event in Square Feet, MHW Area Flooded per Event in Square Feet, Land Area Flooded per Event in Square Feet, Total Asset Area in Square Feet, Land Area of Asset in Square Feet, Percent of Total Area Flooded per Event, Percent of Land Area Flooded per Event	✓	✓	
	MF	Asset ID, Time Horizon, Risk Tolerance (Pluvial only), Annual Likelihood of Flooding, Minimum Recurrence Interval, Average Annualized Total Area Flooded in Square Feet, Average	✓	✓	

ASSET DATA	TYPE	TABLE ATTRIBUTES/COLUMNS	C	P	F
		Annualized Land Area Flooded in Square Feet, Average Annualized Depth, Within 1.5xMTR			
	TB	Asset ID, Time Horizon, Zone Present, Zone Future, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Converted Area in Square Feet, Converted Area in Acres, Total Area in Square Feet, Total Area in Acres, Percent of Converted Area, Converted Ecosystem Service Value, Total Ecosystem Service Value, FEMA Ecosystem Service Classification	✓		
	ES	Asset ID, SFHA Exposure, SFHA Area Flooded in Square Feet, MHW Area Flooded in Square Feet, Land Area Flooded in Square Feet, Total Asset Area in Square Feet, Land Area of Asset in Square Feet, Percent of Total Area Flooded, Percent of Land Area Flooded			✓

Raster data, such as land cover data, describes the location of critical natural infrastructure and other relevant features but is not classified as discrete assets. The results of raster-based analyses are presented in the geographic summary tables described below, but not in an asset-specific format.

C.4.ii Geographic Impact Summaries

Asset impact data was also geographically aggregated across pre-determined geographies of interest to support mapping, comparison, and additional analysis. Impact results data across designated five designated summary levels, with summary level 1 as the most general categorization of the asset (built infrastructure, human infrastructure, community resources, etc.) and summary level 5 as the most specific categorization of the asset (e.g., for land use land cover, it has summary level 5 categories such as turf grass, riverine wetlands forest, natural succession barren, etc.). Results across summary levels were aggregated and summarized across multiple geographic units:

- **Census-designated boundaries** – Census block groups, which can be rolled-up into Census tracts, localities and planning districts. In addition to block groups. summary tables for counties/localities were also produced separately for easy analysis and visualization.
- **Town boundaries** – Virginia town boundaries, which do not neatly align with census block group boundaries.
- **Watershed Hydrologic Unit Codes (HUCs)** – HUC 12s, which can be rolled-up into HUC 10s and HUC 8s.
- **Reference Grid Cells** – A custom reference grid with a tiling schema of 1,375 ft x 1,375 ft

(43.4 acres), which creates a mesh of 290,000 grid cells to cover the study area.[3]

Note some metrics are not suitable for all summarization scales. Historic resources data is sensitive and should not be shown publicly at the reference grid cell or other geography less than ~250 acres. Specific population and demographic estimates are also less likely to be accurate at the sub-tract level. More details on data sensitivity and sharing limitations is provided in section D.1 Data Sensitivity.

The varying geographic size of census-based or HUC-based boundaries can make aggregation across those geography types harder for comparison, and so data can be normalized by a consistent total if used for comparison (i.e., divide raw values by land area or asset count, producing metrics like average annualized assets flooded per acre or average annualized percent of assets flooded). Alternatively, the grid cells with a consistent geographic size present a standard unit for accurate cross-jurisdictional analysis and comparison.

There are also linkable geography detail tables with contextual information related to geography name. Organization structure and key table attributes (i.e., columns) for all produced geographic impact summary tables are outlined in Table 19. Note that in order to aggregate results across assets, a classification structure was developed to group assets of the same type.

Average annualized land flooded and total land area exposed per event can be readily derived from the land use land cover geographic impact summary tables. However, it is important to note that water is a classification within the land use land cover tables as defined by the Chesapeake Conservancy based on current conditions, as opposed to 2020 MHW as used in some metric calculations. Contextual data is also summarized at each of the geographic units to facilitate integrated application and comparison as described in Section Integrating Contextual Data C.3.

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[3] The flood hazard model has a tiling schema that is 55,000 ft x 55,000 ft, and so the reference grid cells were designed as fractions of those tiles. In the Phase I assessment, four alternative reference grid cell sizes were explored but only the 1,375 ft x 1,375 ft one (the smallest option) was found most useful and is therefore the sole focus of Phase II.

Table 19. Organization of geographic summary impact tables and attributes.

ASSET DATA	TYPE	UNITS	C	P	F
Building Footprints	ES	AOI ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Structures Flooded per Event, Total Structures, Percent of Structures Flooded per Event, Percent Structure Loss per Event, Percent Content Loss per Event, Percent Total Loss per Event, Structure Loss per Event, Content Loss per Event, Total Loss per Event, Population Exposed per Event, Total Population, Percent of Population Exposed per Event, Structure Replacement Value Exposed per Event, Content Replacement Value Exposed per Event	✓	✓	
	MF	AOI ID, Time Horizon, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Annualized Structures Flooded, Total Structures, Percent Average Annualized Structures Flooded, Average Annualized Loss, Total Structure Value, Percent Average Annualized Loss, Total Population, Average Annualized Population Exposed, Percent Average Annualized Population Exposed	✓	✓	
	ES	AOI ID, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Structures in SFHA, Total Structures, Percent of Structures in SFHA, Population Exposed, Total Population, Percent of Population Exposed			✓
Point-Based Assets	ES	AOI ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets Flooded per Event, Total Assets, Percent of Assets Flooded	✓	✓	
	MF	AOI ID, Time Horizon, Risk Tolerance (Pluvial Only),), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Average Annualized Assets Flooded, Total Assets, Percent Average Annualized Assets Flooded, Average Annualized Depth	✓	✓	
	ES	AOI ID, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets in SFHA, Total Assets, Percent of Assets in SFHA			✓
Linear Assets	ES	AOI ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets Flooded per Event, Total Assets, Percent of Assets Flooded per Event, Total Length Flooded per Event, Land Length Flooded per Event, Total	✓	✓	

ASSET DATA	TYPE	UNITS	C	P	F
		Length, Land Length, Percent of Total Length Flooded per Event, Percent of Land Length Flooded per Event			
	MF	AOI ID, Time Horizon, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Annualized Assets Flooded, Total Assets, Percent Average Annualized Assets Flooded, Average Annualized Total Length Flooded, Average Annualized Land Length Flooded, Total Length, Land Length, Percent Average Annualized Total Length Flooded, Percent Average Annualized Land Length Flooded, Average Annualized Depth	✓	✓	
	ES	AOI ID, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets in SFHA, Total Assets, Percent of Assets in SFHA, Total Length, Land Length, Total Length in SFHA, Land Length in SFHA, Percent of Total Length in SFHA, Percent of Land Length in SFHA			✓
Area-Based Assets	ES	AOI ID, Time Horizon, Event Type, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets Flooded Per Event, Total Assets, Percent of Assets Flooded per Event, Total Area Flooded per Event*, Land Area Flooded per Event*, Total Area*, Land Area*, Percent of Total Area Flooded per Event, Percent of Land Area Flooded per Event, Ecosystem Service Value Rate**, Ecosystem Service Value Flooded per Event**, Total Ecosystem Service Value**, FEMA Ecosystem Service Classification**	✓	✓	
	MF	AOI ID, Time Horizon, Risk Tolerance (Pluvial only), Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Average Annualized Assets Flooded, Total Assets, Percent Average Annualized Assets Flooded, Average Annualized Total Area Flooded*, Average Annualized Land Area Flooded*, Total Area*, Land Area*, Percent Average Annualized Total Area Flooded, Percent Average Annualized Land Area Flooded, Ecosystem Service Value Rate**, Average Annualized Ecosystem Service Value Flooded**, Total Ecosystem Service Value**, FEMA Ecosystem Service Classification**	✓	✓	
	TB**	AOI ID, Time Horizon, Zone Present, Zone Future, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Converted Area in Square Feet, Converted Area in Acres, Total Area in Square Feet, Total Area in Acres, Percent of Converted Area, Ecosystem Service Value Rate, Converted Ecosystem Service Value, Total Ecosystem Service Value, FEMA Ecosystem Service Classification	✓		

ASSET DATA	TYPE	UNITS	C	P	F
	ES	AOI ID, Summary Level 1, Summary Level 2, Summary Level 3, Summary Level 4, Summary Level 5, Assets in SFHA, Total Assets, Percent of Assets in SFHA, Total Area*, Land Area*, Total Area in SFHA*, Land Area in SFHA*, Percent of Total Area in SFHA, Percent of Land Area in SFHA, Ecosystem Service Value Rate**, Ecosystem Service Value Flooded**, Total Ecosystem Service Value**, FEMA Ecosystem Service Classification**			✓

**For Natural Infrastructure Polygon Geographic Impact Summary Tables, area calculations were done in both square feet and acres for application in the calculation of total ecosystem service value and flooded ecosystem service value which use acres as the unit of measurement (dollars/acre/year)*

***Only applies to Natural Infrastructure Polygon Geographic Impact Summary Tables.*

C.4.iii Context Summaries

The suite of natural infrastructure related contextual datasets integrated into the database and analysis includes Conservation Vision's watershed impact model, development vulnerability model, aquatic recreational access needs model, and terrestrial recreational access needs model. The development vulnerability model and aquatic and terrestrial recreational access models are categorical indices; therefore, they were summarized as counts of raster values by category within the geography of interest. The watershed impact model is a numerical index and average values were presented within a given geography. The organization structure and key attributes are listed in Table 20.

Table 20. Organization of Context Summary Tables

Development Vulnerability Model	AOI ID, Class Value, Total Count, Total Area, Class Area, Percent of Class Area
Watershed Impact Model	AOI ID, Average impact Value
Aquatic Recreational Access Model	AOI ID, Class Value, Total Count, Total Area, Class Area, Percent of Class Area
Terrestrial Recreational Access Model	AOI ID, Class Value, Total Count, Total Area, Class Area, Percent of Class Area

C.4.iv Demographic Summaries

Demographic information from ACS data (sourced from CDC/ATSDR Social Vulnerability Index) and Virginia's Social Vulnerability Index was statistically attributed to individual residential building footprints (using 2020 block group boundaries and 5-year ACS estimates from 2021 TIGER data) as mentioned above in Section C.1.v. Demographic summary tables were then created for each geography of interest. The organization structure and key attributes are listed below in Table 21.

Table 21. Organization of Demographic Summary Tables.

Demographics	AOI ID, Percent Persons Below 150% Poverty, Unemployment Rate, Percent Cost-Burdened Occupied Housing Units, Percent of Persons with No High School Diploma, Percent Uninsured, Percent Age 65 and Older, Percent Age 17 and Younger, Percent with Disability, Percent of Single-parent Households with Children Under 18, Percent of Population That Speaks English "Less than Well", Percent Minority Persons, Percent of Housing Structures with 10 or More Units, Percent of Mobile Homes, Percent of Housing Units with More People than Rooms, Percent of Households with No Vehicle, Percent in Group Quarters, Percent of Households with No Internet, Percent Black/African American, Percent Hispanic/Latino, Percent Asian, Percent American Indian/Alaska Native, Percent Native Hawaiian/Other Pacific Islander, Percent Two or More Races, Percent Other Race, Theme 1, Theme 2, Theme 3, Theme 4, Themes.

C.5 QUALITY CONTROL CHECKS

Results data were reviewed by various members of the CRMP team and rule-based methods for additional data sorting and cleaning as described in Section C.1.ii can be applied as needed. Typical checks that were run on resultant tables included:

- All values within reason for a given factor
- Values remain constant and/or scale as expected
- No unexpected duplication of assets or values
- Geographic map trends are reasonable and as expected
- Geographic coverage of data and metrics are complete as expected

Additionally, produced metrics were run through a monotonicity check, which is a test to ensure that impact metric values were increasing as hazard conditions increase, both over specific events and time horizons. If any results were found that don't follow this pattern, it is an indication that there is something awry about the hazard data or functions and steps were taken to correct any errors.

Histograms were developed to assess the distribution of depth values for each scenario and identified significant outliers. An anomaly was identified in the HEC-RAS pluvial modeling software used in this analysis in two cells at one location in the study area which impacted 6 polygon assets and 2 linear assets, attributing outlier depth values to each of them. The pluvial depths for these assets were nullified and excluded from the analysis.

C.6 AGGREGATION AND SCORING OPTIONS

Each asset type's impact and context metrics vary in units, scale, and calculation method. To facilitate impact aggregation and comparison across impact types, all aggregated metrics used in the summarization layers can be converted to scores on any scale, such as 0-10. This conversion involves normalizing cumulative impact values for a specific asset type or category relative to all other geographic areas of interest. These asset-specific impact scores can then be combined to generate impact scores by impact type and theme for use in various applications.

For each unit summarization for scoring (i.e., asset-level, grid cell, census tract, locality, HUC 12), scores would be calculated using the following process:

- **Convert to Impact Type Scores** – Starting with raw asset-level or summarized impact metrics (described above), values can be normalized to a standard range. This redistribution of values leads to a single impact type score for each impact type, regardless of metric units and scale. Normalization of raw values ranging from *Range_min* to *Range_max* can be calculated using the following formula:

$$X' = 10 * [(X - Range\_min) / (Range\_max - Range\_min)]$$

Ranges should consider raw values across all time horizons. When components have multiple sub-components with scores calculated using different methods (e.g., transportation roadways and facilities), the component score can be calculated through averaging across components.

- **Generate Impact Theme Scores** – Average impact type scores across themes for each geographic unit of interest and time horizon, applying weighting criteria across impact types or components if desired.
- **Calculate Relative Ranking** – The range and distribution of raw scores will vary between categories, which can make it difficult to use raw scores alone for mapping and prioritization. To avoid the undue influence of outliers, raw scores can be converted relative rankings based on a variety of potential methods, including percentile, quintile, and k-means clustering.

D. Data Catalog

Below is a list of data sources leveraged for this analysis, including their source and date last updated. More details about sources reviewed and assessed are provided separately.

Table 22. List of data sources used in the analysis.

INPUT DATASET	SOURCE	DATE
Assets		
Above Ground LNG Storage Facilities	Homeland Infrastructure Foundation-Level Database (HIFLD), original source unclear	12/15/2022
Airports	United States Department of Transportation, Federal Aviation Administration-Aeronautical Information Services (Accessed via ArcGIS Hub)	11/30/2023
AM Transmissions Towers	Federal Communications Commission Licensing Database (accessed via HIFLD)	5/7/2022
Amtrak Stations	Virginia Department of Rail & Public Transportation (DRPT)	3/15/2024
Bridges & Culverts	Virginia Department of Transportation (VDOT)	1/19/2024
Broadband Radio Service and Educational Broadband Service Transmitters	Federal Communications Commission (accessed via HIFLD)	11/23/2021
Bus Routes	Virginia Department of Rail & Public Transportation (DRPT)	3/1/2024
Bus Stations	Virginia Department of Rail & Public Transportation (DRPT)	3/1/2024
Cellular Towers	Federal Communications Commission (accessed via HIFLD)	6/1/2022
Child Care Facilities	Virginia Department of Social Services (accessed via HIFLD)	12/8/2022
Conservation Lands	Virginia Department of Conservation and Recreation (DCR)	11/1/2023
Conservation Priority Area: Agriculture and Forestry	DCR Agriculture and Forestry (ConserveVA)	11/18/2021
Conservation Priority Area: Natural Habitat and Ecosystem Diversity	Natural Habitat and Ecosystem Diversity Exposure (ConserveVA); Virginia Department of Conservation and Recreation (DCR)	11/18/2021
Conservation Priority Areas: Protected Landscapes Resilience	DCR Protected Landscapes Resilience (ConserveVA)	11/18/2021
Dams	Virginia Department of Conservation and Recreation (DCR)	2/12/2024

INPUT DATASET	SOURCE	DATE
Emergency Medical Service Stations	Homeland Infrastructure Foundation-Level Database (HIFLD), original source unclear	6/1/2022
Emergency Operations Centers	Virginia Department of Emergency Management (VDEM)	10/1/2023
EPA Toxic Substance Control Act Facilities	United States Environmental Protection Agency (EPA)	3/11/2024
FDIC Insured Banks	Federal Deposit Insurance Corporation (accessed via HIFLD)	5/17/2022
Federal Real Property Public Dataset	U.S. General Services Administration	10/25/2023
Federally-Owned Land (Chesapeake Bay Program's Federal Facilities Workgroup)	Chesapeake Bay Program's Federal Facilities Workgroup	1/1/2017
Federally-Owned Land (ESRI)	BLM, DoD, USFS, USFWS, NPS, PADUS 2.1 (accessed via ESRI)	7/7/2023
Fire Stations	U.S. Geological Survey, National Geospatial Technical Operations Center (Accessed via HIFLD)	10/22/2023
FM Transmissions Towers	Federal Communications Commission (accessed via HIFLD)	9/18/2018
General Manufacturing Facilities	Industrial PinPointer database of manufacturing companies (accessed via HIFLD)	7/3/2023
Hazardous Waste Generators	U.S. Environmental Protection Agency (EPA) (accessed via VGIN)	11/18/2020
Higher Education Facilities	National Center for Education Statistics (accessed via HIFLD)	12/7/2022
Historic Resources (Historically significant and potentially historically significant properties)	Virginia Department of Historic Resources	2/15/2024
Hospitals	Oak Ridge National Laboratory (Accessed via HIFLD)	9/20/2023
Hurricane Evacuation Routes	Virginia Department of Transportation (VDOT)	9/20/2023
Industry-Specific Manufacturing	HIFLD Secure	3/15/2024
Land Cover Data	Virginia State Land Cover	1/1/2016
Land Use/Land Cover data	Chesapeake Conservancy	1/1/2018

INPUT DATASET	SOURCE	DATE
Land Mobile Broadcast Towers	Federal Communications Commission (accessed via HIFLD)	9/18/2021
Land Mobile Commercial Transmission Towers	Federal Communications Commission Licensing Database (accessed via HIFLD)	11/23/2021
Land Use Data	Chesapeake Conservancy	1/1/2018
Local Law Enforcement Facilities	Oak Ridge National Laboratory (Accessed via HIFLD)	2/1/2021
Major State Government Buildings	Technigraphics Inc. (accessed via HIFLD)	10/19/2021
Microwave Service Towers	Federal Communications Commission (accessed via HIFLD)	8/23/2022
National Shelter System Facilities	Federal Emergency Management Agency (FEMA) (accessed via HIFLD)	7/3/2023
Natural and Nature-Based Features	Virginia Institute of Marine Science (VIMS)	1/1/2021
Natural Gas Receipt Delivery Points	Oak Ridge National Laboratory (accessed via HIFLD)	12/11/2023
NOAA Marsh Migration	National Oceanic and Atmospheric Administration	5/30/2023
Paging Transmission Towers	Federal Communications Commission Licensing Database (accessed via HIFLD)	9/18/2021
Petroleum Ports	Federal Communications Commission (accessed via HIFLD)	1/8/2022
Petroleum Registered Tank Facilities	Virginia Department of Environmental Quality (DEQ)	1/9/2024
Petroleum Terminals	Federal Communications Commission (accessed via HIFLD)	4/5/2022
Port of Virginia Facilities	Virginia Economic Development Partnership (VEDP)	10/22/2022
Power Plants	Oak Ridge National Laboratory (accessed via HIFLD)	9/21/2023
Predicted Suitable Habitat for Sensitive Species	High-resolution Predicted Suitable Habitat Summary (non-public dataset); Virginia Department of Conservation and Recreation (DCR)	12/5/2023
Private Schools	National Center for Education Statistics (accessed via HIFLD)	10/4/2023
Public Refrigerated Warehouses	The International Association of Refrigerated Warehouses (accessed via HIFLD)	7/5/2023

INPUT DATASET	SOURCE	DATE
Public Schools	National Center for Education Statistics (accessed via HIFLD)	12/7/2022
Public Water Supply	Virginia Department of Health (VDH)	7/14/2016
Railroad Crossings	Virginia Department of Rail and Public Transportation (DRPT)	5/1/2020
Railways	Virginia Department of Rail & Public Transportation (DRPT)	3/15/2024
Road Intersections	Virginia Department of Transportation (VDOT)	3/22/2023
Roadway Centerlines	Virginia Geographic Information Network (VGIN); Virginia Department of Transportation (VDOT)	1/12/2024
Septic Systems	Virginia Department of Health (VDH)	2021
Solid Waste Facilities	Virginia Department of Environmental Quality (DEQ)	7/12/2023
State Building Inventory	Virginia Department of General Services (DGS)	9/1/2023
Structures (Lightbox/HIFLD)	Lightbox/HSIN (accessed via HIFLD Secure)	7/15/2023
Structures (Phase I Supplemental)	Composite from CRMP Phase I (Sources including ODU, USACE, HRPDC, OSM, CityGML, and Dewberry)	2021
Substations	HIFLD Secure	7/20/2023
Supplemental Colleges	National Center for Education Statistics (accessed via HIFLD)	12/7/2022
TV Analog Transmitters	Federal Communications Commission (accessed via HIFLD)	12/16/2021
U.S. Army Corps of Engineers (USACE) Offices	USACE (accessed via HIFLD)	12/18/2023
VDOT Average Daily Traffic (ADT)	Virginia Department of Transportation (VDOT)	2/3/2024
VDOT LRS Map Package	Virginia Department of Transportation (VDOT)	3/11/2024
VGIN Building Footprint Data (Phase I)	Virginia Geographic Information Network	2021
Wastewater Treatment Facilities	United States Environmental Protection Agency (EPA) (accessed via HIFLD)	4/17/2022
Context		
Development Vulnerability Model	Virginia Department of Conservation and Recreation (DCR)	6/16/2022

INPUT DATASET	SOURCE	DATE
Nature Based Recreational Access Model	Virginia Department of Conservation and Recreation (DCR)	7/1/2021
Population Demographics	American Community Survey (ACS), Census Bureau (from 2021 TIGER data)	7/20/2023
Social Vulnerability Index	Virginia Department of Conservation and Recreation (DCR)	10/18/2023
Watershed Impact Model	Virginia Department of Conservation and Recreation (DCR)	6/7/2022
Hazards		
Coastal Flood Events	Dewberry	2021
Pluvial Flood Events	Dewberry	2024
Riverine SFHA	Federal Emergency Management Agency (FEMA)	2024
Geographies		
Census Block Groups	American Community Survey (ACS)	10/12/2021
Census Urban Areas	2020 Census	1/1/2023
HUC12 Boundaries	United States Geological Survey (USGS)	12/27/2023
Reference Grid Cells	Dewberry	2021
Towns	Virginia Administration Boundaries Workshop community (via VGIN)	1/12/2024

D.1 DATA SENSITIVITY

Some datasets listed in the data catalog and included in analysis have specific sensitivities or sharing restrictions that limit the potential for publicly dissemination. Sensitivity notes and sharing restrictions are described below:

- **Emergency Operations Centers** – Data on locations of individual emergency operations centers is provided by VDEM and should not be publicly disseminated due to its potentially sensitive nature.
- **Historic Resources** – The locations of archaeological sites should not be distributed no precise spatial mapping products will be made that disclose precise locations. Data should not be shown at a resolution higher than what is shown on the Cultural Preservation Index on the DCR website https://vanhde.org/content/map (individual hexagons are ~250 acres in size).

- **Hurricane Evacuation Routes** – This data is produced, owned, and managed by VDOT - Office of Safety, Security, and Emergency Management (SSEM). Please coordinate with SSEM if this data is to be used or altered for the creation of derivative work products, linked to various technology solutions, or to support other efforts outside of expected tasks in support of hurricane evacuation.
- **Industry-Specific Manufacturing** - Data obtained through HIFLD Secure and should not be publicly disseminated due to its potentially sensitive nature.
- **Predicted Suitable Habitat for Sensitive Species** – Non-public dataset from Natural Heritage. Licensee shall take reasonable precautions to ensure the security of species locations.
- **Public Water Supply** – This data includes Surface Water Intakes, Wells and Springs. Individual site locations are not to be disclosed or distributed.
- **Structures (Lightbox/HIFLD)** – Data from HIFLD Secure. License states: Accessible in support of Homeland Security, Homeland Defense, Emergency Preparedness, Response and Recovery Missions by United States Federal Government agencies as well as state, territorial, tribal and local government agencies. Includes the right to access, use, copy, modify, reproduce, release, perform, display, prepare derivative products, and distribute to mission partners. Derivative products created from the dataset may be publicly releasable to mission partners.
- **Substations** - Data obtained through HIFLD Secure and should not be publicly disseminated due to its potentially sensitive nature.

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Addendum A - Occupancy Type Classifications

Lightbox SmartParcel use code crosswalk to HAZUS occupancy code.

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
10		MISCELLANEOUS (GENERAL)		DNU - no specific usage
11		PIPELINE OR RIGHT-OF-WAY		DNU - no specific usage
13		ROAD (RIGHT-OF-WAY)		DNU - no specific usage
17		LEASEHOLD RIGHTS (MISC.)		DNU - no specific usage
22		EASEMENT (MISC.)		DNU - no specific usage
24		COMMON AREA (MISC.)		DNU - no specific usage
27		PARCELS WITH IMPROVEMENTS, USE NOT SPECIFIED		DNU - no specific usage
1000		RESIDENTIAL (GENERAL) (SINGLE)	RES1	
1001		SINGLE FAMILY RESIDENTIAL	RES1	
1002		TOWNHOUSE (RESIDENTIAL)	RES1	
1004		CONDOMINIUM UNIT (RESIDENTIAL)	RES1	"unit" implies a single residence
1005		COOPERATIVE UNIT (RESIDENTIAL)	RES1	"unit" implies a single residence
1006		MOBILE/MANUFACTURED HOME (REGARDLESS OF LAND OWNER	RES2	
1007		ROW HOUSE (RESIDENTIAL)	RES1	
1008		RURAL/AGRICULTURAL RESIDENCE	RES1	
1009		PLANNED UNIT DEVELOPMENT (PUD) (RESIDENTIAL)		DNU - future usage
1010		RESIDENTIAL COMMON AREA (CONDO/PUD/ETC.)	COM8	
1011		TIMESHARE (RESIDENTIAL)	RES1	
1012		SEASONAL, CABIN, VACATION RESIDENCE	RES1	
1013		BUNGALOW (RESIDENTIAL)	RES1	
1015		MISC RESIDENTIAL IMPROVEMENT	COM8	
1016		MODULAR/PRE-FABRICATED HOMES	RES2	
1100	*	RESIDENTIAL INCOME (GENERAL) (MULTI-FAMILY)	RES3B	default
	210		RES3C	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
	310		RES3C	
	340		RES3C	
	355		RES3C	
	396		RES3C	
	409		RES4	
1101		DUPLEX (2 UNITS, ANY COMBINATION)	RES3A	
1102		TRIPLEX (3 UNITS, ANY COMBINATION)	RES3B	
1103		QUADRUPLEX (4 UNITS, ANY COMBINATION)	RES3B	
1104		APARTMENT HOUSE (5+ UNITS)	RES3C	
1105		APARTMENT HOUSE (100+ UNITS)	RES3F	
1106		GARDEN APT, COURT APT (5+ UNITS)	RES3C	
1107		HIGHRISE APARTMENTS	RES3E	
1108		BOARDING HOUSE, ROOMING HOUSE, APT HOTEL, TRANSIEN	RES4	
1109		MOBILE HOME PARK, TRAILER PARK	RES2	
1110	*	MULTI-FAMILY DWELLINGS	RES3B	default
	305		RES3D	
	306		RES3E	
	376		RES3E	
1111		FRATERNITY HOUSE, SORORITY HOUSE	RES5	
1112	*	APARTMENTS (GENERIC)	RES3B	default
	13		RES3D	
	401		RES3C	
	402		RES3C	
	403		RES3E	
	404		RES3E	
	405		RES3F	
	406		RES3F	
1113		DORMITORY, GROUP QUARTERS (RESIDENTIAL)	RES5	
1114		RESIDENTIAL CONDOMINIUM DEVELOPMENT		DNU - future usage
1124		CONDOMINIUM BUILDING (RESIDENTIAL)	RES3B	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
1901		RESIDENTIAL PARKING GARAGE	COM10	
1999		SINGLE FAMILY RESIDENTIAL (ASSUMED)	RES1	
2000	*	COMMERCIAL (GENERAL)	COM1	default
	13		AGR1	
	300		RES3B	
	369		COM3	
	439		COM8	
	C470		COM3	
	C471		COM3	
2001	*	RETAIL STORES	COM1	default
	4		COM3	
	520		COM3	
	E529		COM8	
	I315		COM8	
2002		STORE (MULTI-STORY)	COM1	
2003		STORE/OFFICE (MIXED USE)	COM4	munic codes look office
2004		DEPARTMENT STORE	COM1	
2005		DEPARTMENT STORE (MULTI-STORY)	COM1	
2006		GROCERY, SUPERMARKET	COM1	
2007		REGIONAL: SHOPPING CENTER, MALL (W/ANCHOR)	COM1	
2008		COMMUNITY: SHOPPING PLAZA, SHOPPING CENTER	COM1	
2009		NEIGHBORHOOD: SHOPPING CENTER, STRIP CENTER	COM1	
2010		SHOPPING CENTER COMMON AREA (PARKING, ETC.)	COM1	
2011		VETERINARY, ANIMAL HOSPITAL	AGR1	
2012		RESTAURANT	COM8	
2013		FAST FOOD RESTAURANT / DRIVE-THRU	COM8	
2014		TAKE-OUT RESTAURANT	COM8	
2015		BAKERY	COM8	
2016		BAR, TAVERN	COM8	
2018		CONVENIENCE STORE	COM1	
2019		CONVENIENCE STORE (W/FUEL PUMP)	COM1	
2020		SERVICE STATION (FULL SERVICE)	COM1	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
2021		SERVICE STATION W/CONVENIENCE STORE	COM1	
2022		TRUCK STOP (FUEL AND DINER)	COM1	
2023		VEHICLE RENTALS, VEHICLE SALES	COM3	
2024		AUTO REPAIR (& RELATED), GARAGE	COM3	
2025		CAR WASH	COM3	
2026		DRY CLEANER, LAUNDRY SERVICE	COM3	
2027		SERVICE SHOP (TV, RADIO, ELECTRIC, PLUMBING)	COM3	
2028		FLORIST, NURSERY, GREENHOUSE (RETAIL/WHOLESALE)	COM1	
2029		WHOLESALE OUTLET, DISCOUNT STORE	COM2	
2030		PRINTER/DELIVERY - RETAIL (KINKOS, UPS, FEDEX, ETC	COM3	
2031		MINI-WAREHOUSE, SELF-STORAGE	COM3	
2032		DAY CARE, PRE-SCHOOL (COMMERCIAL)	COM3	
2033		MOTEL	RES4	
2034		HOTEL	RES4	
2035		PARKING GARAGE, PARKING STRUCTURE	COM10	
2036		PARKING LOT	COM10	
2037		FUNERAL HOME, MORTUARY (COMMERCIAL)	COM3	
2039		HOTEL-RESORT	RES4	
2040		HOTEL/MOTEL	RES4	
2041		GAS STATION	COM1	
2042		RETAIL/RESIDENTIAL (MIXED USE)	COM1	mixed use - default to LPS category COM; munic codes look retail
2043		COMMERCIAL BUILDING, MAIL ORDER, SHOW ROOM	COM2	
2044		COMMERCIAL/OFFICE/RESIDENTIAL (MIXED USE)	COM3	mixed use - default to LPS category COM; munic codes look service
2045		APPLIANCE STORE (BEST BUY, HH GREGG)	COM1	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
2046		KENNEL	AGR1	
2047		LAUNDROMAT	COM3	
2048		NIGHTCLUB / COCKTAIL LOUNGE	COM8	
2050		FARM SUPPLY & EQUIPMENT (RETAIL)	COM1	
2051		HOME IMPROVEMENT, GARDEN CENTER (HOME DEPOT, LOWE'	COM1	
2052		COMMERCIAL CONDOMINIUM (NOT OFFICES)	COM1	
2053		DRUG STORE / PHARMACY (CVS, WALGREENS)	COM1	
2054		BED & BREAKFAST	RES4	
2058		CAR WASH - AUTOMATED	COM3	
3000		COMMERCIAL OFFICE (GENERAL)	COM4	
3001		PROFESSIONAL BLDG	COM4	
3003		OFFICE BLDG (GENERAL)	COM4	
3004		OFFICE BLDG (MULTI-STORY)	COM4	
3005		DENTAL BLDG	COM6	
3006		MEDICAL BLDG/CLINIC	COM6	
3007		FINANCIAL BLDG	COM5	
3008		CONDOMINIUM OFFICES	COM4	
3009		SKYSCRAPER/HIGHRISE (COMMERCIAL OFFICES)	COM4	
3010		COMMERCIAL/INDUSTRIAL (MIXED USE)	COM3	
3011		COMMON AREA (COMMERCIAL)	COM1	
4000		RECREATIONAL/ENTERTAINMENT (GENERAL)	COM8	
4001		RECREATION CENTER	COM8	
4002		PUBLIC SWIMMING POOL	COM8	
4003		BOAT SLIPS, MARINA, YACHT CLUB	COM8	
4004		BOWLING ALLEY	COM8	
4006		SKATING RINK, ICE SKATING, ROLLER SKATING	COM8	
4007		CLUBS, LODGES, PROFESSIONAL ASSOCIATIONS	REL1	
4008	*	MUSEUMS, LIBRARY, ART GALLERY	EDU1	default to library; exceptions = museum
	45		COM8	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
	458		COM8	
	496		COM8	
	619		COM8	
	629		COM8	
	740		COM8	
	E481		COM8	
	MUSEUM		COM8	
4009		COUNTRY CLUB	COM8	
4011		ARENAS, CONVENTION CENTER	COM8	
4012		AUDITORIUMS	COM9	
4015		GYM, HEALTH SPA	COM8	
4018		CAMPGROUND, RV PARK	COM8	
4020		THEATER	COM9	
4025		OUTDOOR RECREATION: BEACH, MOUNTAIN, DESERT	COM8	
4027		PARK, PLAYGROUND, PICNIC AREA	COM8	
4028		GOLF COURSE	COM8	
4029		RACQUET COURT, TENNIS COURT	COM8	
4030		ZOO	COM8	
5000		INDUSTRIAL (GENERAL)	IND1	
5001		MANUFACTURING (LIGHT)	IND2	
5002		LIGHT INDUSTRIAL	IND2	
5003		WAREHOUSE (INDUSTRIAL)	IND6	
5004		STORAGE YARD, OPEN STORAGE	IND6	
5005		FOOD PACKING, PACKING PLANT	IND3	
5007		FOOD PROCESSING	IND3	
5009		COMMUNICATIONS	IND5	
5010		CONDOMINIUMS (INDUSTRIAL)	IND2	
5011		R&D FACILITY, LABORATORY, RESEARCH FACILITY	IND5	
5012		INDUSTRIAL PARK	IND1	
5015		LUMBER & WOOD PRODUCT MANUFACTURING (INCLUDING FUR	IND6	
5017		PRINTING & PUBLISHING	IND2	
5018		INDUSTRIAL LOFT BUILDING, LOFT BUILDING	IND2	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
5019		CONSTRUCTION/CONTRACTING SERVICES	IND6	
6000		HEAVY INDUSTRIAL (GENERAL)	IND1	
6002		DISTRIBUTION WAREHOUSE	IND6	
6003		MINING FACILITY (OIL; GAS; MINERAL, PRECIOUS METAL	IND4	
6004		STORAGE YARD	IND6	
6006		REFINERY, PETROLEUM PRODUCTS	IND4	
6007		MILL (FEED; GRAIN; PAPER; LUMBER; TEXTILE; PULP)	IND1	
6008		FACTORY (APPAREL, TEXTILE PRODUCTS, LEATHER, MEDIU	IND1	
6009		PROCESSING PLANT (MINERALS; CEMENT; ROCK; GRAVEL;	IND4	
6010		LUMBERYARD, BUILDING MATERIALS	IND6	
6011		SHIPYARD/STORAGE - BUILT OR REPAIRED (SEAGOING VES	IND1	
6013		WASTE DISPOSAL, SEWAGE (PROCESSING; DISPOSAL; STOR	IND6	
6014		QUARRIES (SAND; GRAVEL; ROCK)	IND4	
6015		HEAVY MANUFACTURING	IND1	
6017		WINERY	IND3	
6018		CHEMICAL	IND3	
6019		FOUNDRY, INDUSTRIAL PLANT (METAL; RUBBER; PLASTIC)	IND3	
6021		BULK STORAGE, TANKS (GASOLINE, FUEL, ETC.)	IND3	
6023		DUMP SITE	IND2	
6024		COLD STORAGE	IND3	
6500		TRANSPORTATION & COMMUNICATIONS (GENERAL)	IND6	
6501		AIRPORT & RELATED	IND1	
6502		RAILROAD & RELATED	IND1	
6503		FREEWAYS, STATE HWYS	IND6	
6504		ROADS, STREETS, BRIDGES	IND6	
6505		BUS TERMINAL	IND6	
6506		TELEGRAPH, TELEPHONE	IND6	
6507		RADIO OR TV STATION	IND6	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
6508		TRUCK TERMINAL (MOTOR FREIGHT)	IND1	
6510		HARBOR & MARINE TRANSPORTATION	IND1	
6511		MICROWAVE	IND6	
6512		COMMERCIAL AUTO TRANSPORTATION/STORAGE	IND6	
6514		CELLULAR	IND6	
7000		AGRICULTURAL / RURAL (GENERAL)	AGR1	
7001		FARM (IRRIGATED OR DRY)	AGR1	
7002		RANCH	AGR1	
7010		WILDLIFE (REFUGE)	AGR1	
7013		MISC. STRUCTURES - RANCH, FARM, FIXTURES	AGR1	
7017		HORTICULTURE, GROWING HOUSES, ORNAMENTAL (AGRICULT	AGR1	
7020		RESERVOIR, WATER SUPPLY	IND6	
7023		RURAL IMPROVED / NON-RESIDENTIAL	AGR1	
8000		VACANT LAND (GENERAL)		DNU - vacant
8001		RESIDENTIAL-VACANT LAND		DNU - vacant
8002		COMMERCIAL-VACANT LAND		DNU - vacant
8003		INDUSTRIAL-VACANT LAND		DNU - vacant
8004		PRIVATE PRESERVE, OPEN SPACE-VACANT LAND (FOREST L	DNU - vacant	
8005		INSTITUTIONAL-VACANT LAND		DNU - vacant
8006		GOVERNMENT-VACANT LAND		DNU - vacant
8007		MULTI-FAMILY-VACANT LAND		DNU - vacant
8008		RURAL/AGRICULTURAL-VACANT LAND		DNU - vacant
8010		RECREATIONAL-VACANT LAND		DNU - vacant
8011		WATER AREA (LAKES; RIVER; SHORE)-VACANT LAND		DNU - vacant
8017		VACANT LAND ï¿½ EXEMPT		DNU - vacant
8502		REGULATING DISTRICTS & ASSESSMENTS; TAX ABATEMENT	DNU - vacant	
8503		REDEVELOPMENT AGENCY OR ZONE		DNU - vacant

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
8504		CENTRALLY ASSESSED		DNU - vacant
9000		EXEMPT (FULL OR PARTIAL)		DNU - no specific usage
9100		INSTITUTIONAL (GENERAL)	GOV1	
9101		RELIGIOUS, CHURCH, WORSHIP (SYNAGOGUE, TEMPLE, PAR	REL1	
9102		PAROCHIAL SCHOOL, PRIVATE SCHOOL	EDU1	
9103		COLLEGE, UNIVERSITY, VOCATIONAL SCHOOL-PRIVATE	EDU2	
9104		HOSPITAL-PRIVATE	COM6	
9105		MEDICAL CLINIC	COM7	
9106		HOMES (RETIRED; HANDICAP, REST; CONVALESCENT; NURS	RES6	
9108		CEMETERY (EXEMPT)	COM3	
9109		CREMATORIUM, MORTUARY (EXEMPT)	COM3	
9110		CHARITABLE ORGANIZATION, FRATERNAL	REL1	
9111		RECREATIONAL NON-TAXABLE (CAMPS, BOY/GIRL SCOUTS)	COM8	
9112		PRIVATE UTILITY (ELECTRIC, WATER, GAS, NUCLEAR, SO	IND1	
9200		GOVERNMENTAL/PUBLIC USE (GENERAL)	GOV1	
9201		MILITARY (OFFICE; BASE; POST; PORT; RESERVE; WEAPO	GOV1	
9202		FOREST (PARK; RESERVE; RECREATION, CONSERVATION)	COM8	
9203		PUBLIC SCHOOL (ADMINISTRATION; CAMPUS; DORMS; INST	EDU1	
9204		COLLEGES, UNIVERSITY-PUBLIC	EDU2	
9205		POST OFFICE	GOV1	
9206		CULTURAL, HISTORICAL (MONUMENTS; HOMES; MUSEUMS; O	COM8	
9207		GOVT. ADMINISTRATIVE OFFICE (FEDERAL; STATE; LOCAL	GOV1	
9208		EMERGENCY (POLICE; FIRE; RESCUE; SHELTERS, ANIMAL	GOV2	
9209		OTHER EXEMPT PROPERTY		DNU - no specific usage
9210		CITY, MUNICIPAL, TOWN, VILLAGE OWNED (EXEMPT)	GOV1	

USE_CODE_STD_LPS	USE_CODE_MUNI	USE_CODE_STD_DESC_LPS	Occupancy	Notes
9211		COUNTY OWNED (EXEMPT)	GOV1	
9212		STATE OWNED (EXEMPT)	GOV1	
9213		FEDERAL PROPERTY (EXEMPT)	GOV1	
9214		PUBLIC HEALTH CARE FACILITY (EXEMPT)	COM6	
9215		COMMUNITY CENTER (EXEMPT)	COM8	
9216		PUBLIC UTILITY (ELECTRIC, WATER, GAS, NUCLEAR, SOL	IND1	
9217		WELFARE, SOCIAL SERVICE, LOW INCOME HOUSING (EXEMP	GOV1	
9218		CORRECTIONAL FACILITY, JAILS, PRISONS, INSANE ASYL	GOV1	
9219		HOSPITAL-PUBLIC	COM6	
9300		HISTORICAL-PRIVATE (GENERAL)	COM8	
9301		HISTORICAL RESIDENCE	COM8	
9305		HISTORICAL TRANSIENT LODGING (HOTEL/MOTEL)	COM8	
NA		NA		DNU - no specific usage

Addendum B - Fluvial Multi-Frequency Impacts Case Study Report

Virginia Coastal Resilience Master Plan, Phase II

Appendix B - Impact Assessment Methodology

Addendum B - Fluvial Multi-frequency Impacts Case Study

December 13, 2024 | Dewberry Contract No. E194-89627

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Acronyms and Abbreviations

AEP	Annual Exceedance Probability
CRMP	Coastal Resilience Master Plan
DCR	Virginia Department of Conservation and Recreation
HUC	Hydrologic Unit Code
PDC/RC	Planning District/Regional Commission
SFHA	Special Flood Hazard Area
TAC	Technical Advisory Committee

Executive Summary

The Virginia Department of Conservation and Recreation (DCR) initiated Phase II of the Coastal Resilience Master Plan (CRMP) to expand flood risk evaluations to include riverine (fluvial) flooding alongside existing coastal and rainfall-induced (pluvial) hazards. The assessment utilized multi-frequency fluvial flood data for three pilot areas, evaluating flood impacts at various recurrence intervals. Note that this pilot's limitations included that it was limited to a small subset of mostly rural areas, had limited recurrence intervals compared to coastal and pluvial flood risk data, and did not include any projected future changes in fluvial flood risk. Key findings highlight the need to include more diverse flood frequency data to capture the full scope of fluvial risk and inform better mitigation efforts.

KEY FINDINGS:

- Many buildings face a higher risk than represented by the 1% Annual Exceedance Probability (AEP) floodplain, with 79% of buildings in the 1% AEP floodplain also exposed to more frequent events like the 2% AEP (50-year) floodplain.
- Expanding the analysis to lower frequency events (e.g., 0.2% AEP) reveals significant additional exposure, though this represents a smaller fraction of overall financial risk than more frequent events.
- Including all evaluated frequencies significantly increases estimated annualized losses, from approximately $1M based on the 1% AEP floodplain alone to $5.7M when all five modeled frequencies are considered.
- Adding more fluvial frequencies does not drastically alter the broader flood risk landscape, as coastal and pluvial sources primarily impact most structures.
- The 1% AEP floodplain from FEMA's modeling aligns closely with the official Special Flood Hazard Area (SFHA), capturing 99% of buildings within the SFHA.
- Predominant Exposure in Natural Areas: Most fluvial flood exposure affects riverine wetlands and natural infrastructure, particularly in rural areas, though urbanized regions like Fredericksburg show greater developed land exposure.

RECOMMENDATIONS:

- Expand multi-frequency fluvial modeling across the entire CRMP study area to enhance the accuracy of fluvial flood risk assessments.
- Incorporate flood depth data in fluvial modeling to better evaluate asset vulnerability and damage potential.
- Add 50% and 20% AEP events to improve consistency and comparability with other flood hazard types.
- Include forward-looking climate scenarios to project future fluvial flood impacts, enhancing planning and mitigation strategies.
- Investigate overlaps between fluvial and pluvial flood trends to refine risk assessments.

These findings and recommendations underscore the importance of expanded and improved fluvial flood risk data to inform the CRMP and enhance coastal resilience efforts in Virginia.

A. Motivation

The Virginia Department of Conservation and Recreation (DCR) undertook the development of the first iteration (Phase I) of the Coastal Resilience Master Plan (CRMP) in 2021. Phase I focused on existing and future coastal flooding and associated projected impacts on the Commonwealth of Virginia's eight coastal Planning District/Regional Commissions (PDC/RCs).

At the conclusion of Phase I, DCR received feedback from both the study Technical Advisory Committee (TAC) and study stakeholders that the hazard framework should be expanded to include consideration of other hazards, with priorities for rainfall-induced (pluvial) and riverine (fluvial) flooding.

DCR has contracted with Dewberry to support specific tasks in Phase 2 of CRMP, including expanding the set of flood hazards evaluated to include riverine (fluvial) flooding. The CRMP Phase 2 evaluation of fluvial flooding is limited to the FEMA Special Flood Hazard Area (SFHA) extents (1% AEP). However, to understand how improved fluvial flood risk data changes the quantification of flood impacts, DCR additionally contracted with Dewberry to complete a case study of three pilot areas for which FEMA modeled multi-frequency depth grid fluvial data.

This technical memorandum is organized into the following sections:

- **Section 2: Methods** – describes the methods for assessment, including spatial context, flood frequencies evaluated, and metrics excluded from evaluation.
- **Section 3: Results** – presents key results and conclusions from evaluating the multi-frequency fluvial data in contrast to the SFHA fluvial boundaries.
- **Section 4: Recommendations** – discusses fluvial flood risk evaluation recommendations for DCR and future CRMP efforts.
- **Section 5: Limitations** – details limitations to the fluvial flood risk data evaluation presented in this technical memo, including notable differences in data between the pilot fluvial data and the coastal and pluvial data included in the impact assessment.

B. Methods

This case study evaluates flood impacts in three 8-digit Hydrologic Unit Codes (HUC8s) listed in Table 1, where multi-frequency fluvial hazard data was readily available from FEMA.

Table 1. HUC8 areas evaluated in the fluvial case study.

Community or HUC	Major River Basin	HUC8	Date	% of HUC in CRMP Study Area
Great Wicomico-Piankatank	Chesapeake Bay Coastal	02080102	10/06/2020	99.9
Lower Rappahannock	Rappahannock	02080104	10/06/2020	100
Mattaponi	York	02080105	12/23/2021	99.4

Raster data for flood extents and depths are available for five flood frequencies under present-day conditions. The flood frequencies available are:

- 0.2% AEP (500-year recurrence interval)
- 1% AEP (100-year)
- 2% (50-year)
- 4% (25-year), and
- 10% (10-year).

The extent of these floodplains in the study area is shown in Figure 1 below. Raster data relied upon in this case study are mosaicked depth grid products, as documented in Appendix B.

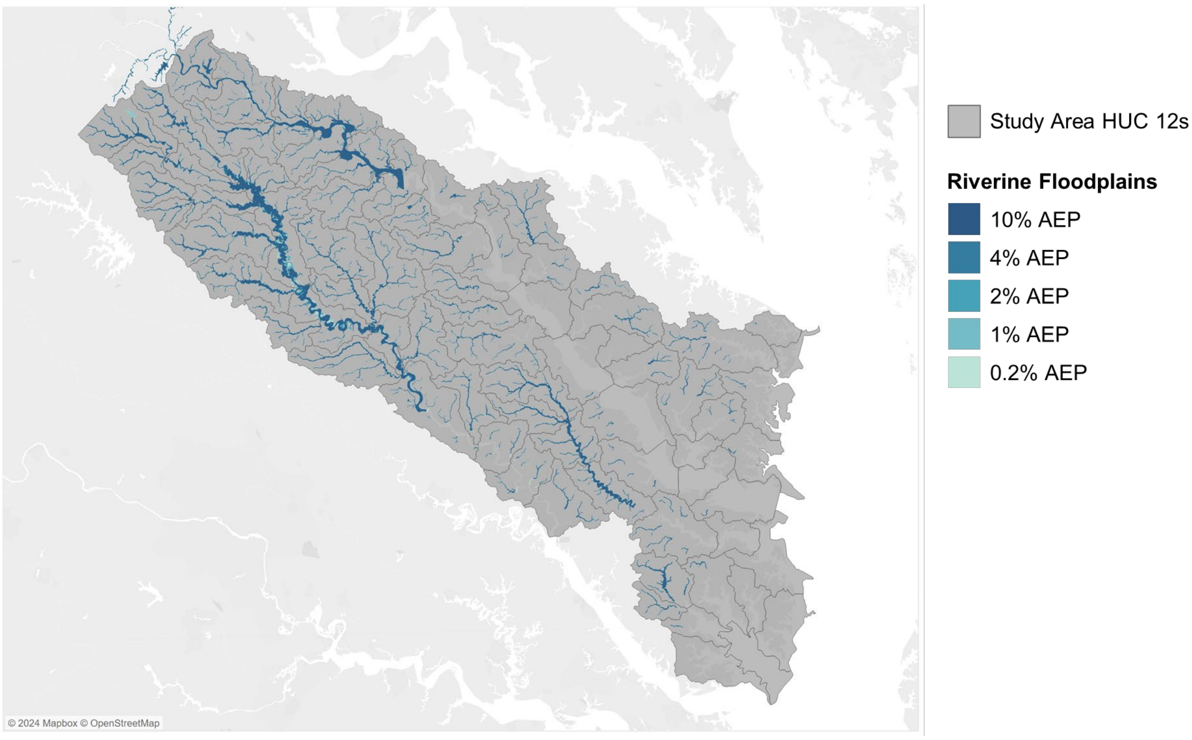

Figure 1. Riverine floodplains across flood frequencies (10-, 4-, 2-, 1-, and 0.2% AEPs) in study area.

This assessment relies on the standard metrics and asset categorizations developed in the overall impact assessment (see Methodology Documentation for additional details). The excluded assets and metrics are predominantly coastal-specific (e.g., coastal natural infrastructure assets and marsh migration metrics) and are listed in Table 2. The supporting data provided in this task includes the full suite of available asset types and metrics for the multi-frequency fluvial flood data and case study areas.

Table 2. Metrics Excluded

Metric	Definition	Reason for exclusion
SFHA Exposure	The binary determination of whether or not an asset is within FEMA's present-day SFHA.	Metric is specific to SFHA data
Population Displaced	The estimated number of people exposed to MHW for a given time horizon.	Threshold-based metric associated with inundation
Land Lost	The projected changes in the acreage of area-based assets' land area for a given time horizon relative to 2020 MHW baseline.	Threshold-based metric associated with inundation
Changes in Natural Infrastructure Flood Exposure	The projected changes in the acreage of all natural infrastructure areas for a given time horizon based on selected exposure zones using MLW, MHW, and 1.5xMTR thresholds.	Metric is specific to coastal flood hazard

Metric	Definition	Reason for exclusion
Tidal Wetland Area Lost	The projected loss in tidal wetland acreage for a given time horizon within the extent of current wetland based on the NOAA Marsh Migration model thresholds for wetland class transitions.	Metric specific to coastal flood hazard
Tidal Wetland Area Gained	The projected gain in tidal wetland acreage outside the extent of current wetland for a given time horizon based on the NOAA Marsh Migration model thresholds for wetland class transitions.	Metric is specific to coastal flood hazard
Total Change in Tidal Wetland Area	The projected total change in tidal wetland acreage for a given time horizon based on the NOAA Marsh Migration model thresholds for wetland class transitions. This accounts for tidal wetland loss and potential tidal wetland gain through wetland migration.	Metric is specific to coastal flood hazard
Annualized Value of Natural Infrastructure Lost	The dollar value of ecosystem services lost based on the area of natural infrastructure lost in a given year within a given time horizon.	Threshold-based metric associated with inundation

Resulting metrics are presented at the asset-specific level and summarized across each HUC 8. Additionally, the City of Fredericksburg is one of the only counties or towns within the study area that show the highest concentration of modeled fluvial flood exposure. Therefore, it is used as a more local case study to analyze results. Figure 2 shows the boundaries of HUC12s and localities within the study area, Highlighting Fredericksburg to the North.

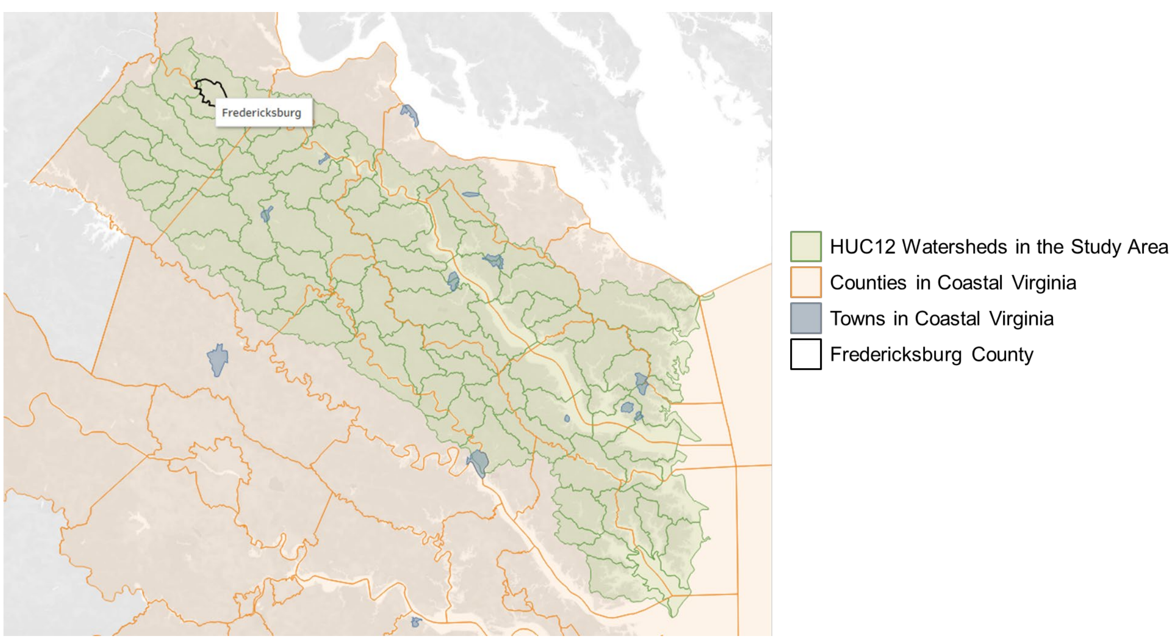

Figure 2. Study area for fluvial pilot study, including HUC12, county, and town geographies.

C. Results

This assessment aims to provide information on how improved fluvial flood risk data changes the quantification of flood impacts. This section demonstrates key findings from comparisons of asset fluvial exposure outputs from the multi-frequency flood risk data and the SFHA boundary data at the HUC8 level and for the case study municipality, Fredericksburg.

Note that the supporting data provided in this task includes the full suite of available asset types and metrics for the multi-frequency fluvial flood data and case study areas; the results presented in this section are intended to demonstrate key findings rather than a comprehensive evaluation of all flood risk metrics generated as part of this task. Additional figures showing results across the study area and in Fredericksburg are shown in Appendix A.

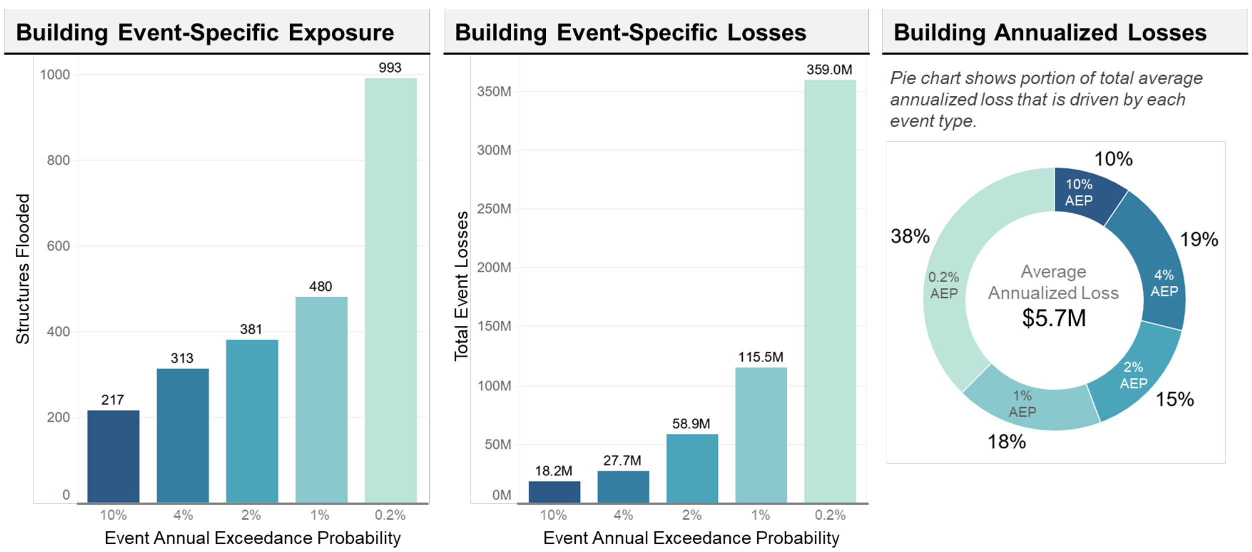

Figure 3. Building exposure and loss statistics within the pilot study area.

Key Finding 1: Considering higher frequency events highlights areas of increased asset exposure and risk. Most buildings within the one percent AEP floodplain have a much higher exposure than one percent AEP. Across the study area, 79 percent of buildings within the SFHA are also in the two percent AEP floodplain, and nearly half (about 45 percent) are within the 10 percent AEP floodplain. The risk posed to these buildings is likely under-represented and under-communicated when only considering their presence within the one percent AEP floodplain.

Key Finding 2: Considering lower frequency events shows that many more structures face some level of fluvial exposure and risk. About twice as many buildings are within the 0.2% AEP floodplain than within the one percent AEP floodplain, so the exposure of these buildings is also under-represented when only considering the extent of the one percent AEP floodplain. However, these structures represent only 11 percent of risk, so the majority of financial risk (in terms of AAL) is captured by driven by structures within the SFHA.

Key Finding 3: Considering the full spectrum of events leads to higher loss estimates, driven by both lower-frequency and higher-frequency events. Although high-frequency events impact fewer structures, in annualized loss estimates, higher-frequency events represent a large portion of total risk. Similarly, while a 0.2% AEP event is relatively infrequent, the scale and damage associated with such events also drive a notable portion of total risk. Annualized losses due to the one percent AEP floodplain alone would equate to around \$1M, but annualized losses considering the five extents modeled total to \$5.7M. Note that the 10 percent AEP event is also the highest frequency event considered within the modeling process, and higher risk might be measured if even higher-frequency events were modeled.

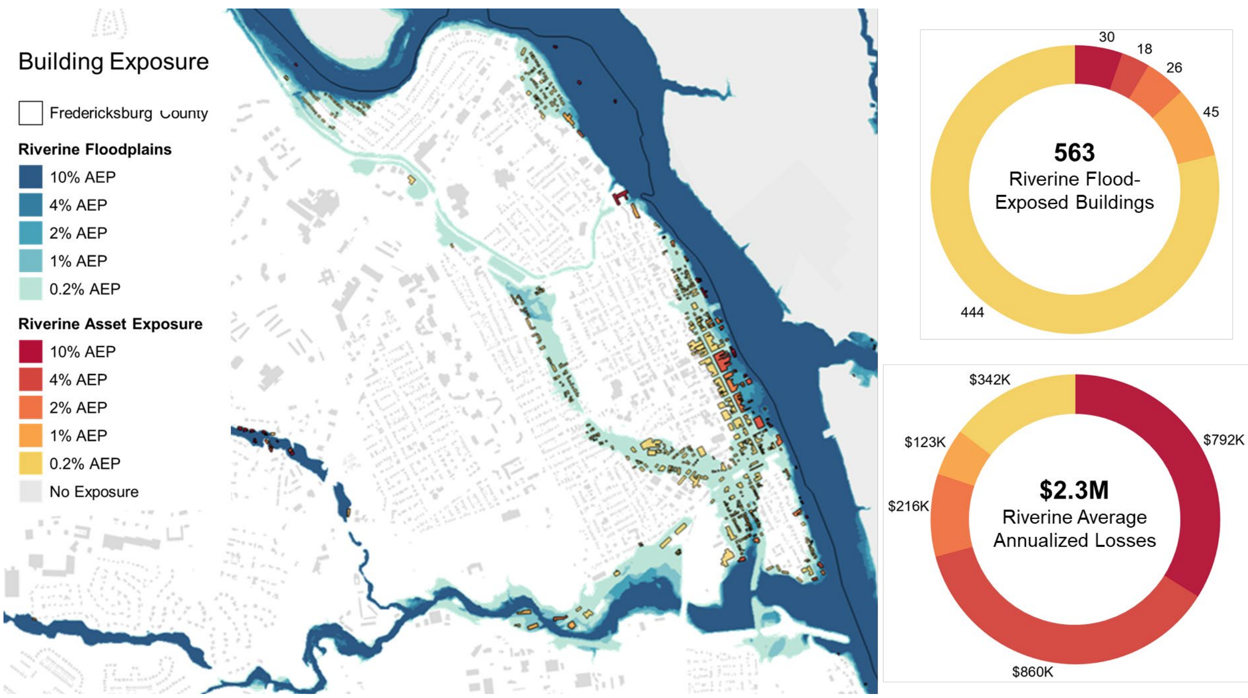

Figure 4. Building exposure highlight in Fredericksburg. The map on the left shows floodplains and exposed in the eastern side of Fredericksburg, where riverine impacts are concentrated. The top right pie chart shows the breakdown of exposed buildings by AEP exposure class. The bottom right pie chart shows the portion of AAL allocated to each building exposure class.

Of the 563 buildings with modeled fluvial exposure in Fredericksburg, 48 have an AEP of four percent or higher (i.e., are in the modeled 25-year or 10-year floodplain). These buildings represent less than 10 percent of buildings with fluvial flood exposure in Frederick but over 70 percent of the city's total fluvial risk (i.e., modeled average annualized loss). As illustrated in this case, having multi-frequency exposure data and loss modeling may help identify high-risk properties eligible for more serious mitigation interventions.

Additionally, 444 buildings have an exposure of less than one percent AEP but greater than 0.2% AEP. These are outside the SFHA but still have notable flood exposure. Together, they represent only 15 percent of Fredericksburg's total fluvial flood risk, showing that the SFHA captures most of the riverine-driven flood risk within the city.

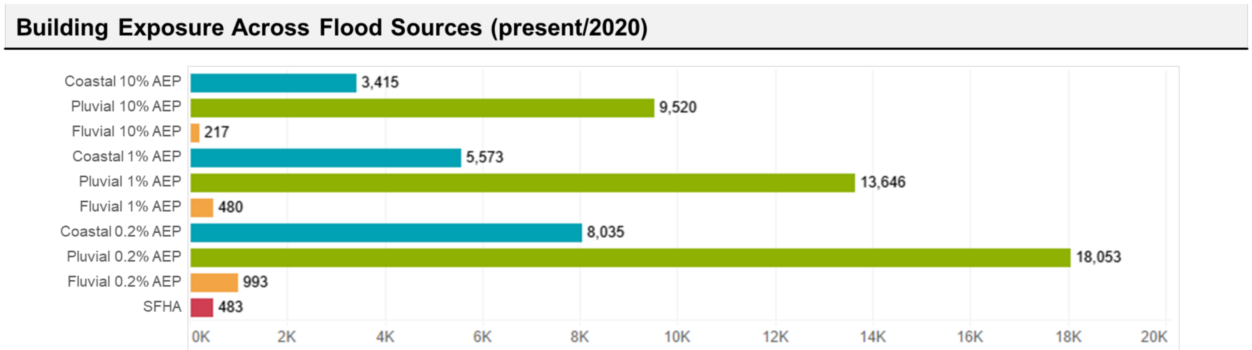

Figure 5. Comparison of building exposure counts across flood sources in the pilot study area.

Key Finding 4: Including more fluvial event frequencies may not significantly change the picture of the flood risk landscape across Coastal Virginia. Even with the inclusion of the 0.2% AEP event, the number of structures with fluvial hazard exposure within the study area represents only a small fraction compared to coastal and pluvial hazard sources.

Key Finding 5: In FEMA's non-regulatory products, the modeled one percent AEP floodplain is a "good match" for the SFHA, capturing 99 percent of buildings within the SFHA. The SFHA is a legal boundary used for federal regulation and is known to vary from other modeling products, but in this area, it seems fairly consistent with non-regulatory modeling from FEMA.

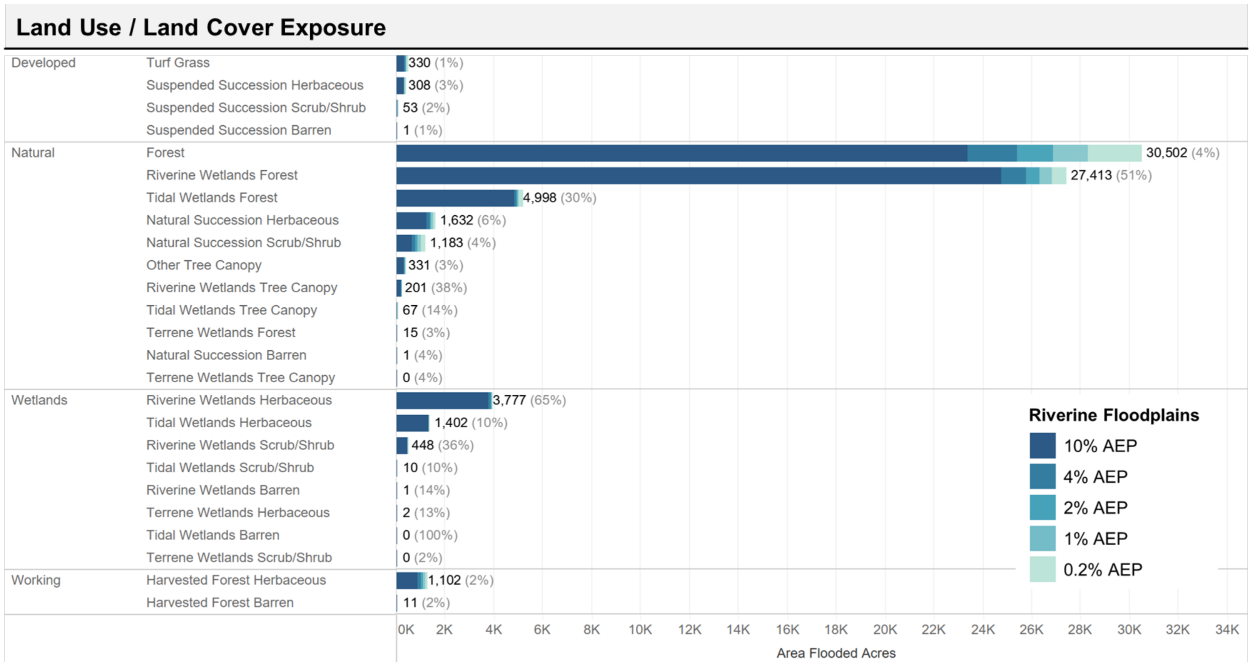

Figure 6. Land use / land cover exposure across riverine flood events throughout the pilot study area.

Key Finding 6: Within the study area, the majority of land exposed to fluvial sources is riverine wetlands and other natural infrastructure. Only a small fraction of the developed land area is exposed to fluvial flooding. This may be reflective of the study area being primarily rural as well as decades of riverine floodplain mapping and management practices that have incentivized lower development within the SFHA.

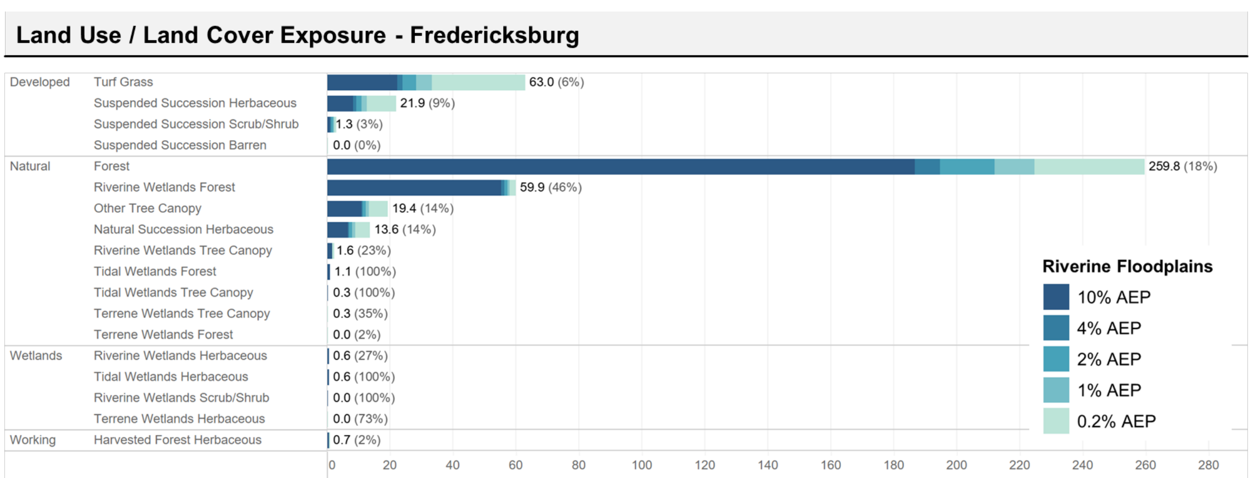

Figure 7. Land use / land cover exposure across events in Fredericksburg.

However, in Fredericksburg, where the area of interest is more urban, a more significant portion of the flood-exposed area was developed, particularly with exposure to 0.2% AEP event.

Overall trends are generally consistent across asset classes and types. A snapshot of exposure across asset classes and types is shown in Figure 8.

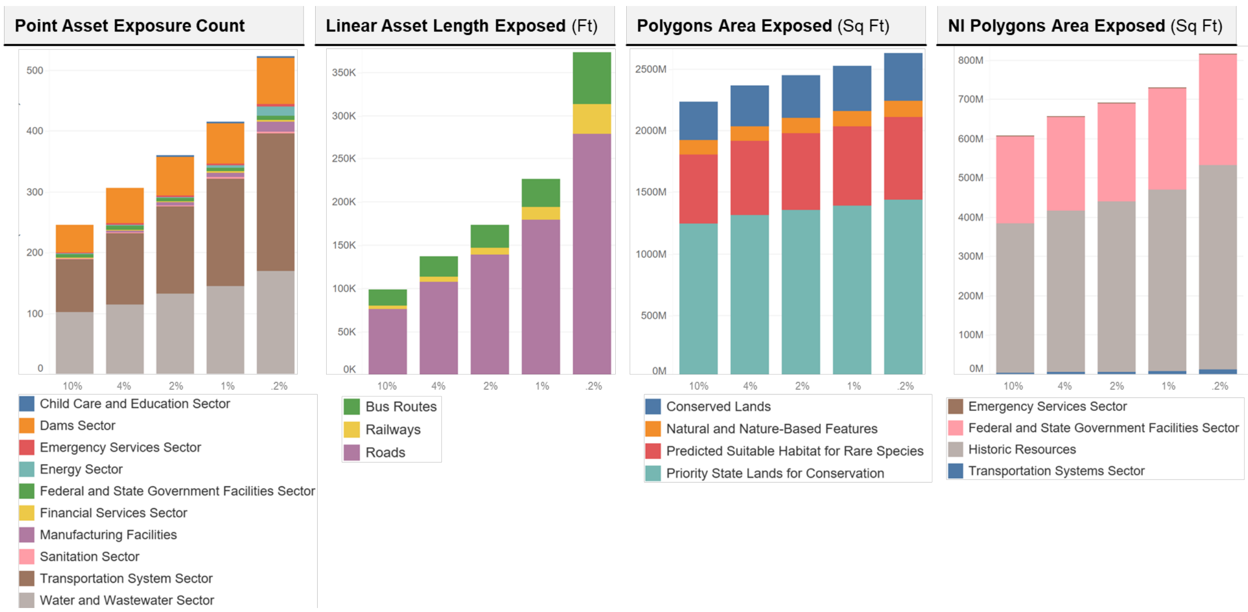

Figure 8. Exposure summaries by asset class and type.

D. Recommendations

Based on the evaluation of the multi-frequency fluvial data available for a subset of the HUC8s in the CRMP study area, this report makes the following recommendations:

- **Expand multi-frequency fluvial modeling to the entire CRMP study area;** doing so will significantly improve the quality of fluvial flood risk information in the CRMP.
- **Include flood depth information in fluvial modeling products,** which allows for estimations of vulnerability and risk to buildings and other assets. Leveraging only the current SFHA extent information limits the potential to assess potential damages or graduation within the floodplain.
- **Include the 50 and 20 percent AEP events in the suite of recurrence intervals modeled for fluvial flood hazards;** differing sets of recurrence intervals limit the comparability of fluvial flood hazards with coastal and pluvial flood hazards, as average annualized values are currently aggregated over different sets of recurrence intervals by flood hazard type.
- **Include forward-looking climate scenarios** to project changes in fluvial flood impacts. Both coastal and pluvial flood hazard information include climate projections and including projected fluvial hazards will improve the quality of information available for fluvial flood risk in the CRMP study area.

- **Explore overlaps between fluvial and pluvial trends.** Current modeling of pluvial and fluvial flood hazards likely overlap in identifying flood risk for areas and assets in the CRMP study area. Disentangling these flood hazard types will improve the quality of flood risk data. The combined flood hazard data products developed in a parallel effort help to accomplish this, but could be further analyzed to quantify the areas of overlap. This kind of analysis could be expanded to focus on asset impacts, not just hazard areas.

Note that FEMA's national flood mapping program has a *Future of Flood Risk Data* initiative that aims to provide graduated multi-frequency hazard and risk information nationwide and for both coastal and inland areas (encompassing both fluvial and pluvial sources). While the exact methods and pipelines behind this modeling process are still in development, it is likely that this information will help fill this gap within the next decade.

E. Limitations

The methods, results, and recommendations in this technical memo are intended to demonstrate the potential benefits of improved fluvial flood risk data in quantifying flood impacts. There are some notable limitations of the study of fluvial flood risk data presented in this memo:

- Data extents and source
- Range of recurrence intervals available
- Lack of forward-looking scenarios or projections.

E.1 DATA EXTENTS AND SOURCE

The data and results presented in this memo are provided by FEMA and not tailored to the CRMP study. Additionally, data is available only for a subset of the CRMP study area; only three HUC8 areas had readily available multi-frequency flood data. The inclusion of additional HUC8s within the CRMP study area would change summary results in the number of impacts and potentially the percentage of assets impacted. The three HUC8s evaluated in this memo are predominantly rural; if more urbanized areas are included in future evaluations, the estimated impacts of fluvial flooding may increase.

E.2 RANGE OF RECURRENCE INTERVALS AVAILABLE

The data available for this study includes five recurrence intervals (0.2, 1, 2, 4, and 10 percent AEP). Coastal and pluvial flood risk data included in the CRMP study are evaluated for a wider range of recurrence intervals, including the 50 and 20 percent AEP events. As a result, the average annualized impact metrics discussed in this memo and presented in the supporting data cannot be directly compared to average annualized impacts for coastal or pluvial impacts.

E.3 LACK OF FORWARD-LOOKING SCENARIOS OR PROJECTIONS

Unlike the coastal or pluvial flood data evaluated as part of the CRMP study, the fluvial data does not include forward-looking scenarios or projections. This lack of projected data is largely due to uncertainties in modeling future fluvial conditions associated with climate change. However, the lack of projected impacts limits the usefulness of fluvial flood risk data when attempting to estimate future impacts or improve upon planning scenarios to mitigate future flood risk.

F. References

Dewberry. Virginia Coastal Resilience Master Plan CO-8A: Pluvial Modeling (2023) https://vadcr-frp.s3.amazonaws.com/Pluvial_Pilot/VACRMP_Pluvial_ITM4_PilotResults.pdf

FEMA, 2023. FEMA Flood Map Service Center: Hazus. https://msc.fema.gov/portal/resources/hazus

FEMA 2020. Residential displacement. https://maps.coastalresilience.org/virginia/reports/FutureHabitatApp2018_FactSheet.pdf.

FEMA. (n.d.). Coastal Hazards and Flood Mapping: A Visual Guide. https://www.fema.gov/sites/default/files/documents/fema_coastal-glossary.pdf

Appendix A: Supplemental Figures

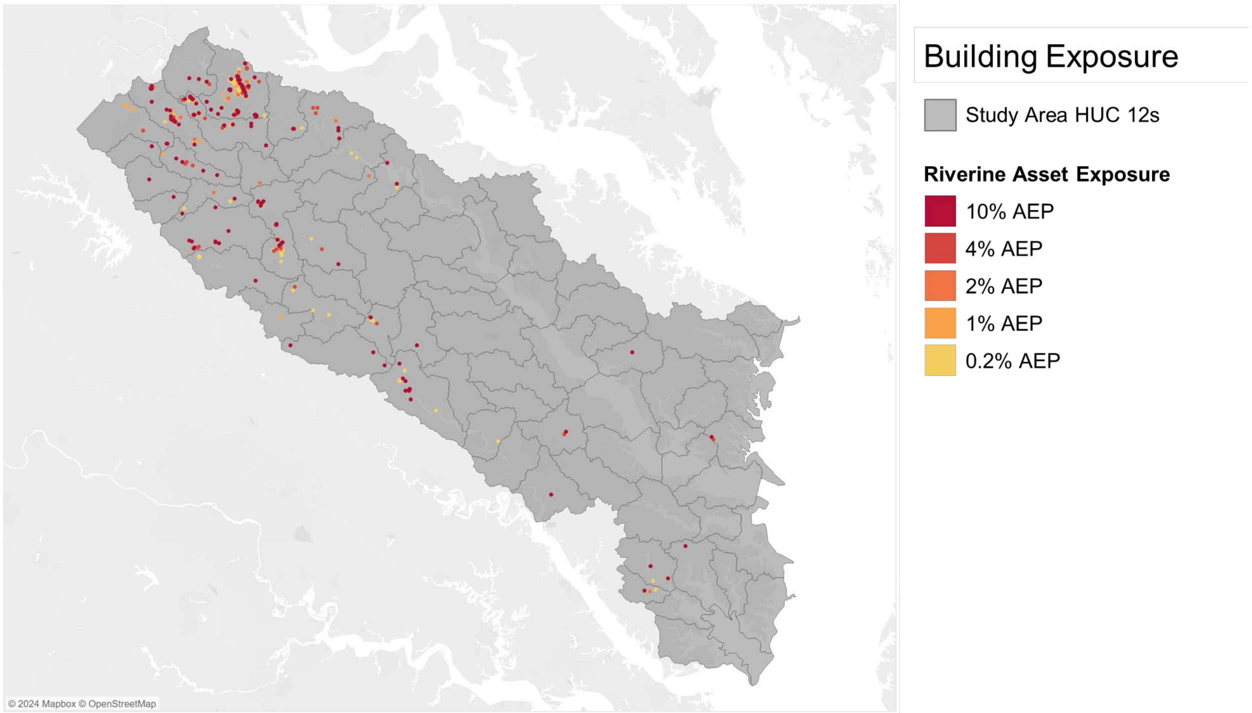

Figure 9. Building exposure across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in the fluvial pilot study area.

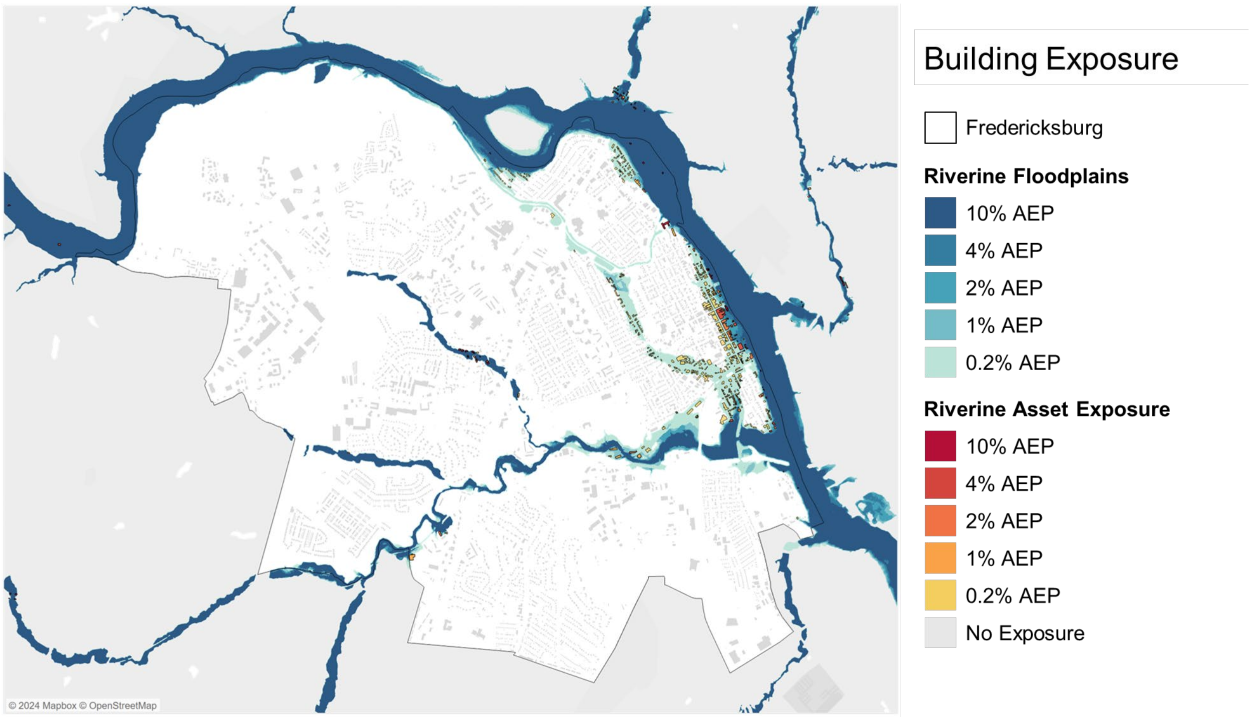

Figure 10. Building exposure and riverine floodplain extents across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in Fredericksburg.

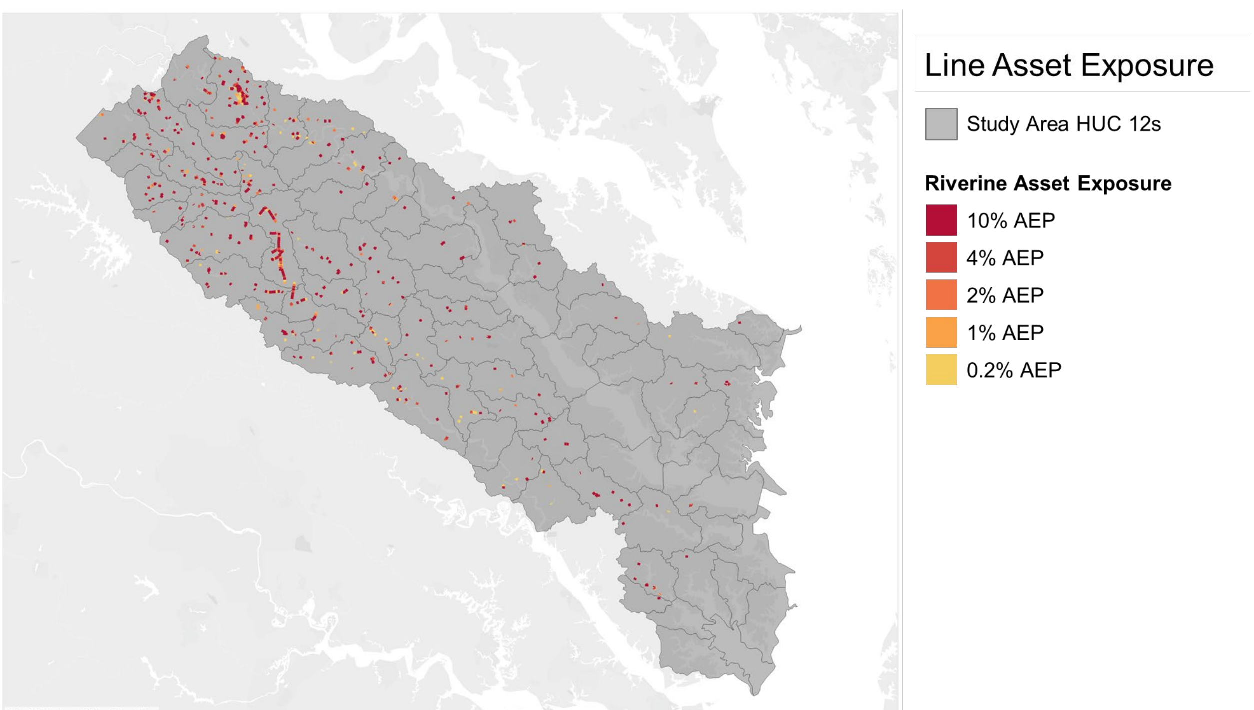

Figure 11. Line asset exposure across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in the fluvial pilot study area.

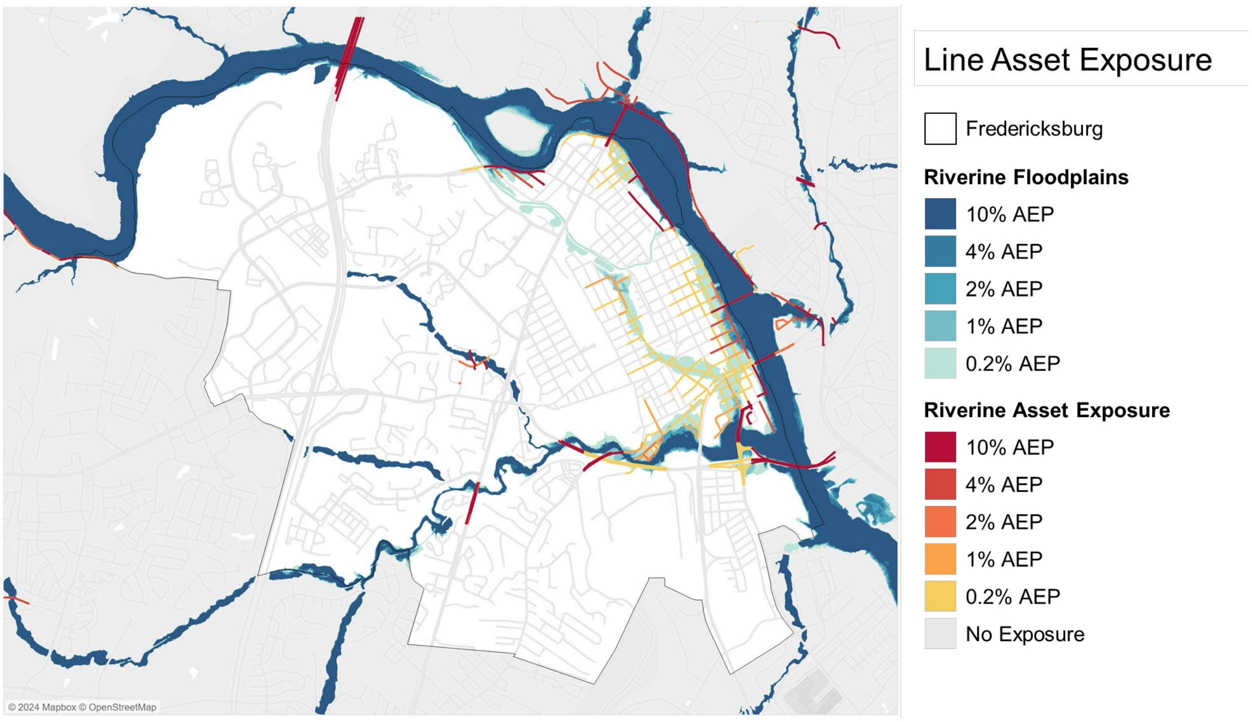

Figure 12. Line asset exposure and riverine floodplain extents across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in Fredericksburg.

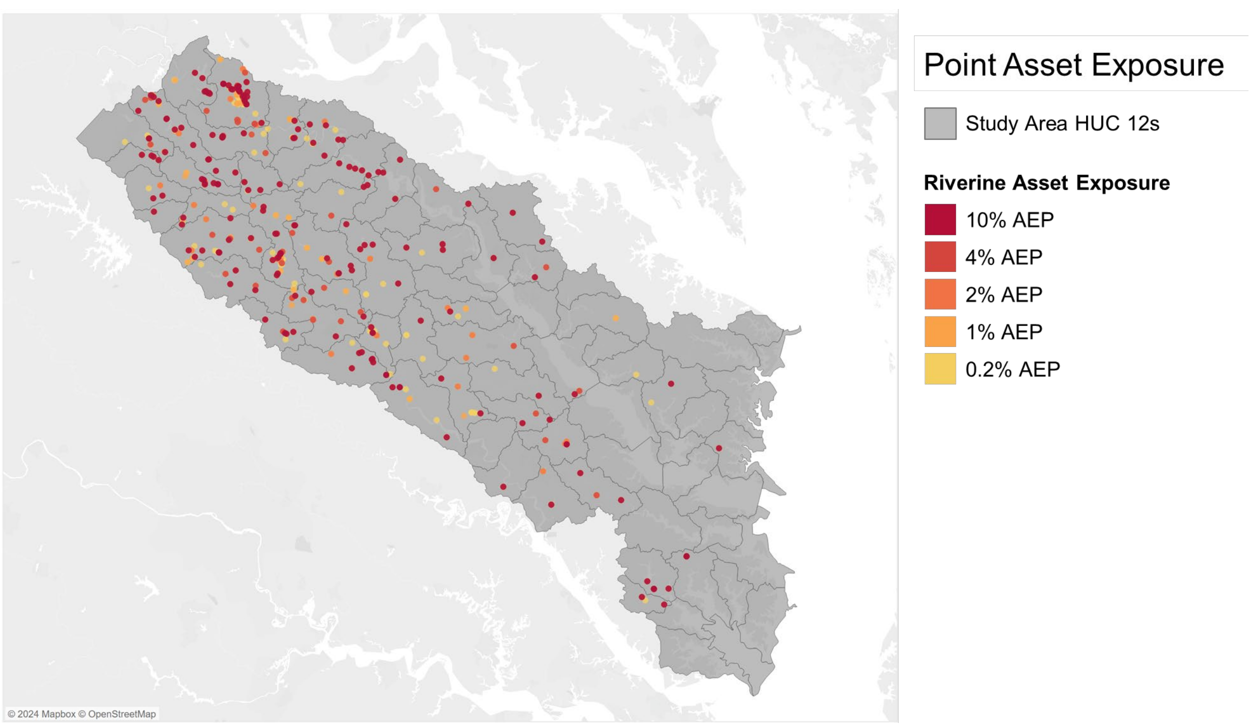

Figure 13. Point asset exposure across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in the fluvial pilot study area.

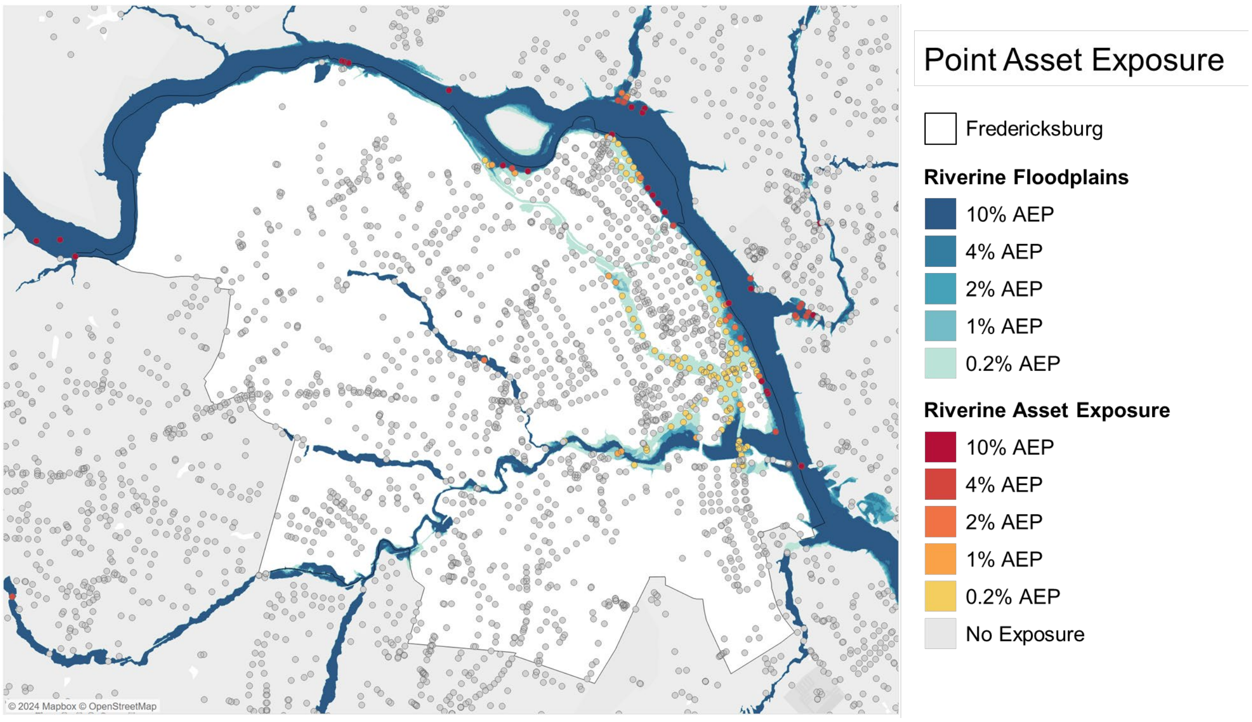

Figure 14. Point asset exposure and riverine floodplain extents across flood frequencies (10, 4, 2, 1, and 0.2% AEPs) in Fredericksburg.

Appendix B: Fluvial Depth Grid Coverage

Fluvial depth grids were received from DCR, reviewed, and merged for the study area. The process for creating fluvial depth grid coverage is summarized below.

SUMMARY

Compile riverine/fluvial water surface elevation (WSE) and depth grids (DG) for all riverine/fluvial flood zones for the portions of the HUC8 watershed boundaries 02080102, 02080103, 02080104, 02080105, that fall within the Virginia Coastal Resilience Master Plan (CRMP) study area.

DATA COLLECTION

Raster WSE and DG data representing the 0.2-, 1-, 2-, 4-, and 10-percent chance annual exceedance probability flood levels for the HUC8 regions 02080102, 02080103, 02080104, 02080105, Riverine SFHA flood zones from Task 8b3.

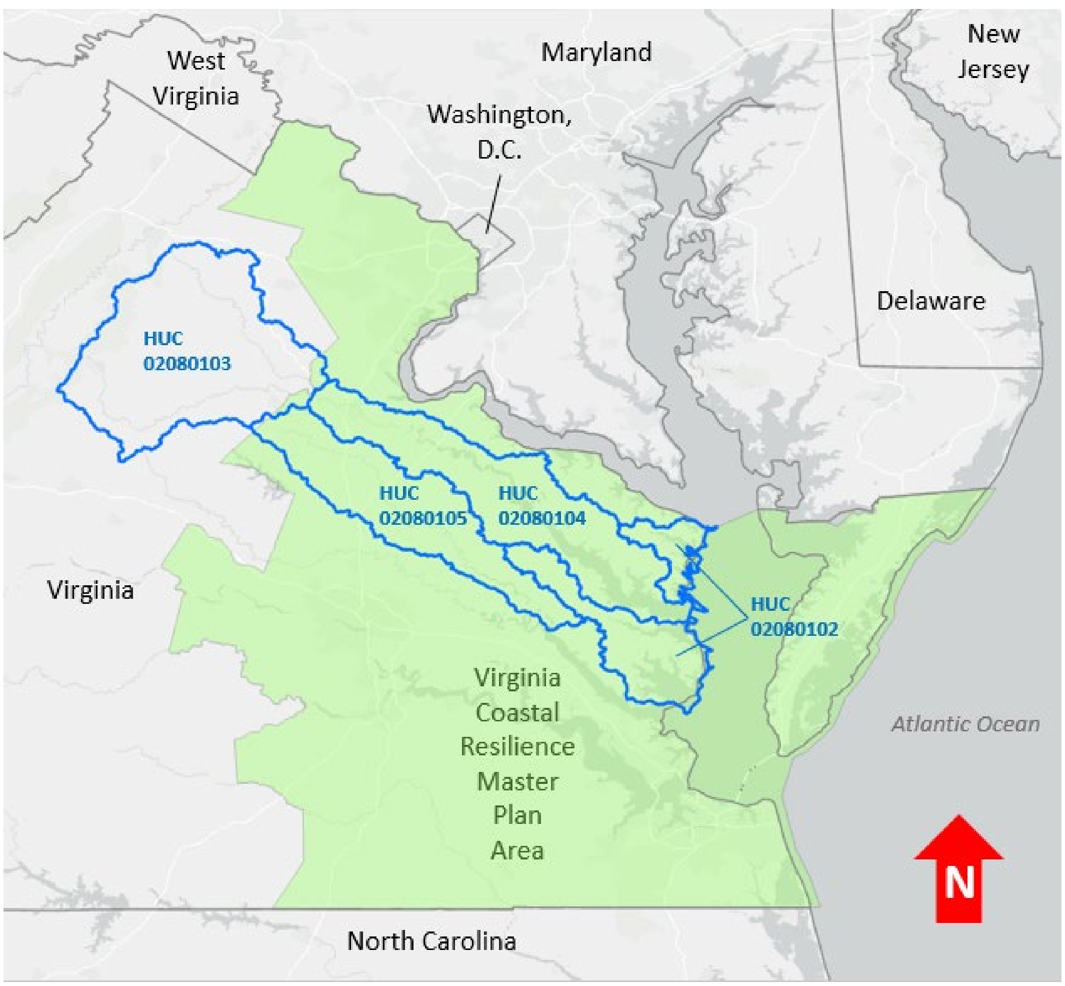

Figure 15. HUC locations and Coastal Master Plan Area.

DATA COMPLETENESS CHECK

Depth grids were visually scanned to locate areas where coverage did not match the extent of the riverine SFHA areas. Areas that have limited or no depth grid coverage are limited to the following stream segments:

Table 3. Areas with limited or no depth grid coverage.

HUC	Stream	Zone	Stream Area (sq feet)	DG Coverage
02080102	Conrad Pond/Wilton Creek	A	2,205,340	None
02080103	Thornton River @ Sperryville, from Fletcher Mill upstream to Beech Spring Hollow	AE	-	None
02080103	North Branch Thornton @ Sperryville, from Thornton River upstream to Piney River	AE	-	None
02080103	Hughes River @ Peola Mills, from Rt 231 bridge upstream to Rocky Run	AE	-	None
02080103	Rose River @ Syria, from Robinson River upstream to A zone	AE	-	None
02080103	Bowens Run @ Bealeton	AE	-	1% only
02080103	Marsh Run Trib @ Bealeton	AE	-	1% only
02080103	Craig Run @ Bealeton	AE	-	1% only
02080103	Confluence of Rappahannock River, Hubbard Run, Tinpot Run @ Remington	AE	-	10%, 2%, 1%, 0.2%
02080104	Sturgeon Creek, Woods Creek, and 2 Unnamed tribs of Rappahannock River @ Deltaville	A	1,075,654	None
02080104	Three unnamed tribs of Corrotoman River @ Kilmarnock	A	1,915,141	None
02080104	Unnamed trib of Robinson Creek @ Bethpage.	A	219,743	None
02080104	Three unnamed tribs of Lancaster Creek @ Simonson	A	1,756,106	None
02080104	Mill Branch @ Haynesville	A	1,396,127	None

HUC	Stream	Zone	Stream Area (sq feet)	DG Coverage
02080104	Pecks Creek @ Wellford	A	1,115,529	None
02080104	Jugs Creek @ Warsaw	A	1,863,718	None
02080104	Cliffs Creek and Garlands Creek @ Singerly	A	3,268,769	None
02080104	Unnamed trib of Troy Creek @ Leedstown	A	761,348	None
02080104	Bristol Mine Run @ Rollins Fork	A	343,387	None
02080104	Portobago Creek @ Daniel Corner	A	1,715,043	Incomplete coverage of 10%, 4% 2%, 1%, 0.2% depth grids
02080105	Unnamed trib of Aylett Pond @ Aylett Mill. Upstream of Fairwoods Rd	A	4,172,605	Incomplete coverage of 10%, 4% 2%, 1%, 0.2% depth grids

DATA INCONSISTENCY

Just below the confluence of the Rapidan and Rappahannock Rivers, HUC 02080103 transitions into HUC 02080104. At this boundary, some depth grid inconsistencies exist between one dataset and the other. These inconsistencies appear to be localized to the confluence and HUC boundary. The depth grids were sampled in two locations, and the differences are reported below.

While differences across the transition appear minimal (difference <= 1 ft), there are some large differences in this location's 1% depth grid. A preliminary investigation of the issue shows that the probable cause of these large discrepancies is processing issues in the HUC 02080103 portion of the 1% depth grid near the confluence.

Table 4. Test sites and associated depths.

Site	0.2% WSE	0.2% Depth	1% WSE	1% Depth	2% WSE	2% Depth	4% WSE	4% Depth	10% WSE	10% Depth
Site 1 Upstream	154.3	27.6	147.8	21.1	145.8	19.1	143.8	17.1	141.2	14.5
Site 1 Downstream	154.3	27.6	133.0	6.3	130.6	3.9	128.5	1.8	125.8	N/A
Site 2 Upstream	141.3	20.4	132.4	11.5	130.1	9.2	127.8	6.9	124.9	4.0
Site 2 Downstream	140.5	20.0	132.8	12.3	130.5	10.0	128.3	7.8	125.5	5.0

Depth grids from HUCs 02080102, 02080104, and 02080105 appear to be internally consistent, and there are no other riverine transition zones from one HUC to another.