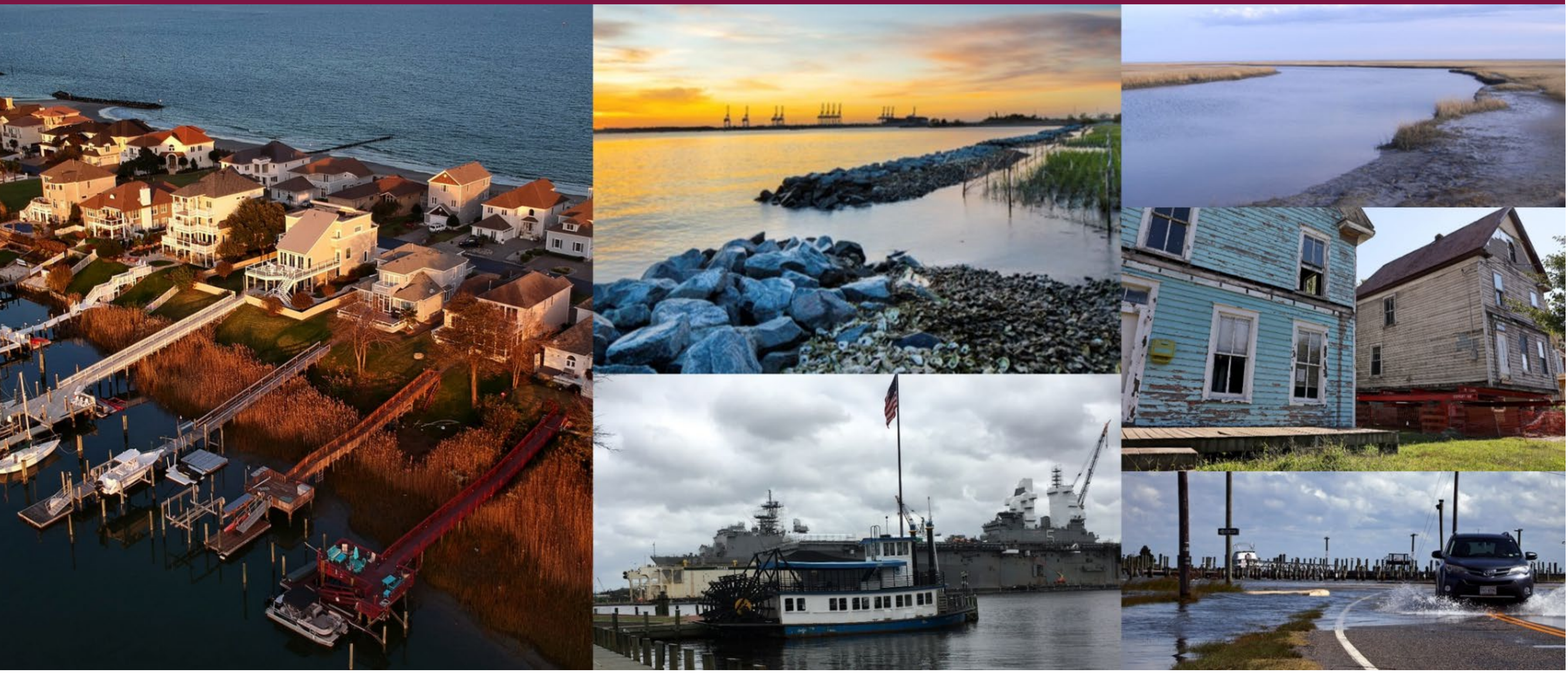
VIRGINIA COASTAL RESILIENCE MASTER PLAN

Task 4: Impact Assessment Methodology

OCTOBER 27, 2021



FINAL REPORT

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Contents

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AAD	Average Annualized Depth
AAL	Average Annualized Losses
ACS	American Community Survey
AEP	Annual Exceedance Probability
ALF	Annual Likelihood of Flooding
AOI	Area of Interest
ATSDR	Agency for Toxic Substances and Disease Registry
AWS	Amazon Web Service
BCAR	Benefit-Cost Re-analysis
C-CAP	Coastal Change Analysis Program (C-CAP)
CDC	Center for Disease Control and Prevention
CISA	Cybersecurity & Infrastructure Security Agency
CityGML	City Geography Markup Language
CPFRA	Coastal Probabilistic Flood Risk Analysis
CRMP	Coastal Resilience Master Plan
DCR	Virginia Department of Conservation and Recreation
DDF	Depth Damage Function
DEQ	Virginia Department of Environmental Quality
EJSCREEN	Environmental Justice Screening and Mapping Tool (EPA)
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FFE	First Floor Elevation
GDAL	Geospatial Data Abstraction Library
GDP	Gross Domestic Product
HIFLD	Department of Homeland Security - Homeland Infrastructure Foundation-Level Data
HVRI	University of South Carolina Hazards and Vulnerability Research Institute
LAG	Lowest Adjacent Grade
MHW	Mean High Water
MLW	Mean Low Water
MTL	Mean Tide Level
NOAA	National Oceanic and Atmospheric Administration
ODU	Old Dominion University
OSM	Open Street Map
SAV	Submerged Aquatic Vegetation
SLAMM	Sea Level Rise Affecting Marshes Model
SLR	Sea Level Rise
SoVI	Social Vulnerability Index (HRVI)
SVI	Social Vulnerability Index (CDC)
USACE	U.S. Army Corps of Engineers

VDH	Virginia Department of Health
VDOAV	Virginia Department of Aviation
VDOT	Virginia Department of Transportation
VEDP	Virginia Economic Development Partnership
VGIN	Virginia Geographic Information Network
VIMS	Virginia Institute for Marine Sciences
VRT	Virtual Format (GDAL)
WMS	Web Map Service

1. INTRODUCTION

1.1. OBJECTIVE

The purpose of this document is to provide a technical overview of the impact assessment approach and methods used to identify and evaluate strategies for coastal resilience in the Virginia Coastal Resilience Master Plan (CRMP). The impact assessment produces quantitative data that characterizes how Virginia's people and landscape will be affected by coastal hazards, now and into the future, accounting for sea level rise (SLR). The CRMP includes eight coastal Planning District Commissions and Regional Commissions. The impact assessment incorporates the coastal flood hazard modeling from the Coastal Hazard Framework, data gathering results, and informs risk summarization and resilience project evaluation.

While the study area is subject to other flood hazards such as rainfall-driven (pluvial) flooding, riverine flooding, and other geomorphic hazards such as shoreline erosion and subsidence, these processes, while drivers of risk in all, or portions of the study area, were not included in the first iteration of the Virginia CRMP. These limitations are acknowledged and accepted. Future iterations of the CRMP will expand the hazards considered, including evaluation of cascading impacts from joint occurrence of these complicated natural processes.

1.2. BACKGROUND

The Virginia Coastal Resilience Master Plan Framework lays out the core principles of the Commonwealth's approach to coastal adaptation and protection and how the Commonwealth developed and began to implement Virginia's first Coastal Resilience Master Plan in 2021. The Study Conceptual Model, illustrated in Figure 1, was established to identify the analytical approach to the CRMP and the CRMP Framework goals.

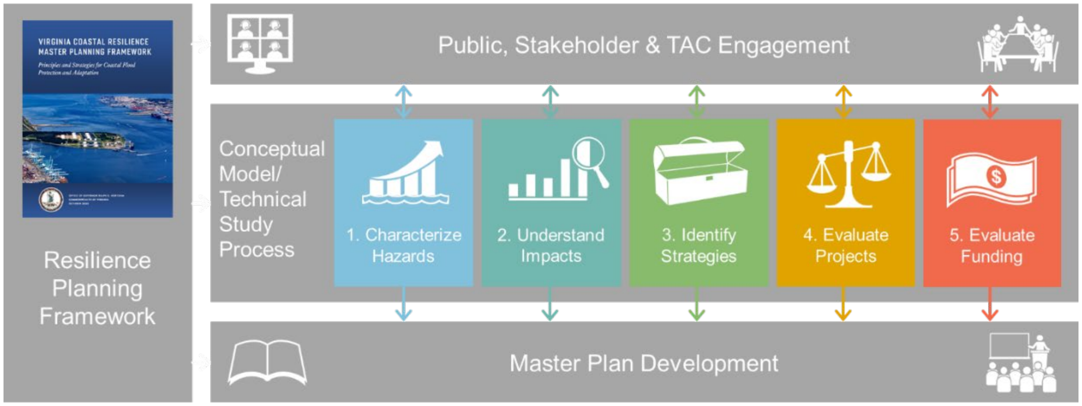


Figure 1: Study Conceptual Model alignment with the CRMP Framework and consensus-built outcomes to inform the CRMP development.

The foundation of the CRMP analysis is the Coastal Hazard Framework, which completes Step 1 in the Study Conceptual Model. The Coastal Hazard Framework identifies and characterizes the various components of the coastal flood hazard through the production of flood extents and depths for existing conditions and future condition SLR scenarios. The outputs provide the ability to characterize the vulnerability of Virginia's coast from a range of events.

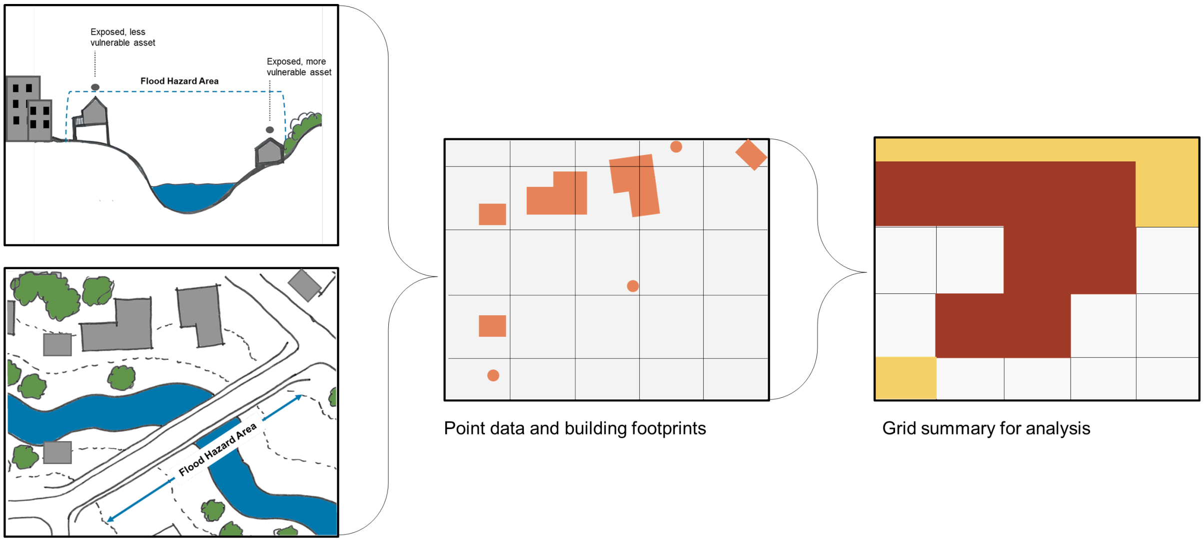
The coastal flood hazard assessment will serve as the input to the impact assessment where a range of impact types will be evaluated. This impact assessment methodology documents the process for identifying, examining, and assessing the coastal flood risks and impacts used for the CRMP effort. This effort provides a current baseline assessment of impacts on existing coastal assets and conditions, in three thematic areas: **Community Resources, Natural Infrastructure, and Critical Sectors**. Community context is also included in the assessment to identify and understand the impacts of coastal flood hazards on underserved communities. In addition to current conditions, the assessment also considers future SLR scenarios and the impacts on this baseline. The impact assessment process results in an analysis that provides the Risk Summarization Dashboard and Master Plan Document input and informs the relative evaluation of resilience projects for the CRMP.

1.3. UNCERTAINTY IN FLOOD IMPACT ASSESSMENTS

A significant challenge in performing a flood hazard impact assessment is understanding the uncertainties that exist at every stage of the process and deciding how to incorporate those uncertainties into subsequent decisions and evaluations.

Flood hazard models simplify multiple, complex hydrologic processes that depend on the use of multiple assumptions, incomplete datasets, and imperfect models. These factors lead to uncertainty in the water levels and the spatial extent of flooding.

There are also considerable uncertainties in impact assessments. For example, building characteristics and infrastructure variations cannot be captured using a single damage function. However, it is impractical to create accurate damage functions for each home or business that might be affected at a regional scale. The inability to characterize building or infrastructure level flood impacts can then translate into errors in estimated impacts. Figure 2 is an illustration of this limitation. In Section 2.3, Figure 5 also highlights a limitation in aligning asset data with building footprints to improve the impact assessment.



Point data and building footprints

Grid summary for analysis

Data rich flood maps including building characteristics

Figure 2: Illustration of the uncertainties and limitations in flood impact assessments. Impacts are less specific without key attributes like structure foundation type, e.g. slab on grade or elevated, and first floor elevation. For example, a critical sector asset data limitation is the absence of bridge deck information, which enables site-specific vulnerability evaluation.

Although uncertainty cannot be eliminated, these limitations and the inherent uncertainty in the impact assessment are considered throughout the CRMP, the strategy identification, project evaluation and highlighted throughout this methodology document.

1.3.1. NOTABLE APPROACHES AND METHODOLOGY

In order to limit uncertainty and provide the most complete information possible, several methods were employed. Including:

Using mixed-methods and diverse datasets – The impact assessment employs both qualitative, narrative descriptions of impacts in addition to semi-quantitative and quantitative impact assessment methods to characterize the impacts of exacerbating coastal hazards. Balancing quantitative methods with qualitative descriptions provides a more comprehensive picture of flood impacts and bridges some of the gaps left after obtaining and using best available data.

In addition, a diverse array of data sources was included in the asset characterization to provide a robust assessment, measure social vulnerability, and consider natural infrastructure. For example, to quantify social vulnerability, the impact assessment uses variables established in the Social Vulnerability Index (SVI) developed by the Centers for Disease Control and Prevention and the Agency for Toxic Substances and

Disease Registry.[1] This index uses census data on race and ethnicity, income, education, age, disability status, language ability, vehicle access, and housing type.

Employed nontraditional flood loss estimation software to support more nimble and customized depth-damage curves (DDFs) – The Impact assessment used the Go-Consequences Loss Analysis software, recently developed by the USACE's Hydrologic Engineering Center, for flood loss estimation. Go-Consequences is highly efficient, customizable, and partially mitigates the uncertainty with DDF selection. A more detailed description is in Section 3.2.4.

Accounted for variations in population density through characterization of the built environment - Developing a spatial representation of buildings in the study area and attributing those buildings with information relevant to their value, structural attributes, and occupancy is critical for evaluating flood risk. A building footprint dataset was developed using a combination of state, local, and third-party data to model these assets. Population and demographics from ACS were statistically attributed to the building footprints providing an alternative to distributing the population uniformly through a census block. While a model, this approach tries to account for variations in population distribution and density at a high resolution. More information about this approach is in Section 3.2.2.

1.3.2. LIMITATIONS AND OPPORTUNITIES FOR FURTHER DEVELOPMENT

Limitations with the methodologies employed are discussed in more detail throughout Section 3. However, there are several general impact assessment limitations and opportunities for further development to consider.

Consideration of Additional Hazards - The study area is subject to other flood hazards, from riverine, rainfall-runoff, and groundwater, as well as erosion. These processes are the drivers of additional risk in certain areas of the state. Additionally, the impact assessment does not consider coastal erosion, shoreline, or geomorphic changes. These limitations are acknowledged and accepted for the first iteration of the Virginia CRMP. Future iterations of the CRMP will improve the evaluation of the potential consequences of individual and combined occurrences of these complicated processes.

Data Updates and Refinements – Future iterations of the impact assessment can be improved by leveraging more detailed, complete, or recent data sets. For example, the current analyses utilize 2018 ACS data for all current and future time horizons, but this is likely an underestimate of future population exposure and displacement. The 2020 Census data showed, in aggregate, that Virginia grew by almost 8% in population since 2010. Further, assessing future demographic impacts and

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[1] CDC SVI 2010 Documentation, Updated 2020. Available here: https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/pdf/SVI2018Documentation-H.pdf

population displacement metrics should include future population estimates such as the EPA's Integrated Climate and Land Use Scenarios, which provide population projections at a county level into 2100.[2]

Additionally, data to support metrics related to Community Resources and the community context is currently limited. This element of the Impact assessment could be supplemented with additional data and findings acquired through surveys and outreach conducted for the CRMP. Additionally, VEDP Opportunity Zones data could be included in future iterations of the CRMP.

Additional Analytical Opportunities – In future iterations of the CRMP, opportunities for further advancement and refinement of datasets and analytical processes will be explored and implemented. For example, data with more structural attributes and characteristics could provide additional detail for vulnerability analysis. Additionally, a longer period of stakeholder engagement could support a more nuanced understanding of asset criticality – at a community, regional, and Commonwealth level. An adaptive capacity assessment could also be considered in future iterations of the CRMP.

Expanding tribal engagement and understanding of cultural resources – There is an opportunity for future analysis to further consider culturally significant places and associated historically marginalized populations and their impacts from coastal hazards. A starting point for such an evaluation may be the identification of the number and portion of designated historic places associated with historically marginalized populations within the Commonwealth. Future iterations of the CRMP can engage tribes to better understand culturally important sites, accompanying privacy considerations, and represent all state and federally recognized tribal lands.

Market Values for Ecosystem Services – Improved impacts associated with loss of coastal habitat can be captured by quantifying the ecosystem services lost. Several existing approaches and sources for valuation of ecosystem services were reviewed. However, given the insufficient research or case study evidence to formulate a defensible, Virginia-specific approach at this time, an alternative approach was employed for this iteration while future iterations may consider this more comprehensively.

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[2] U.S. Environmental Protection Agency. (2020). Fourth National Climate Assessment: Integrated Climate and Land Use Scenarios. Retrieved from https://www.epa.gov/gcx/iclus-fourth-national-climate-assessment.

2. APPROACH

2.1. OVERVIEW

The impact assessment employs a structured yet flexible mixed-methods framework involving qualitative and quantitative data to strengthen findings, reduce uncertainties, and provide a more complete picture of current and evolving coastal flood impacts.

Using a mixed-methods approach, the impact assessment evaluates three types of data as an input:

- **Hazards**
- **Assets**
- **Context**

To produce the following four levels of analysis or outputs for the CRMP:

- **Narrative**
- **Exposure**
- **Vulnerability**
- **Risk**

Figure 3: Overview of the impact assessment approach.

The exposure, vulnerability, and risk assessments are all based on quantitative and semi-quantitative methods, detailed in Section 3. The results are captured in the Asset and Summarization Tables. The narrative analysis accompanying the impact metric results is qualitative and discussed in the Master Plan document.

While methods vary based on data availability and asset-level information, the following sections overview the impact assessment approach through a presentation of notable attributes and limitations and chief components, proposed metrics, and organizational structure.

2.2. TYPES OF DATA

To assess impacts, three main types of data are utilized as inputs: hazards, assets, and context, as presented in Figure 4 and described below:

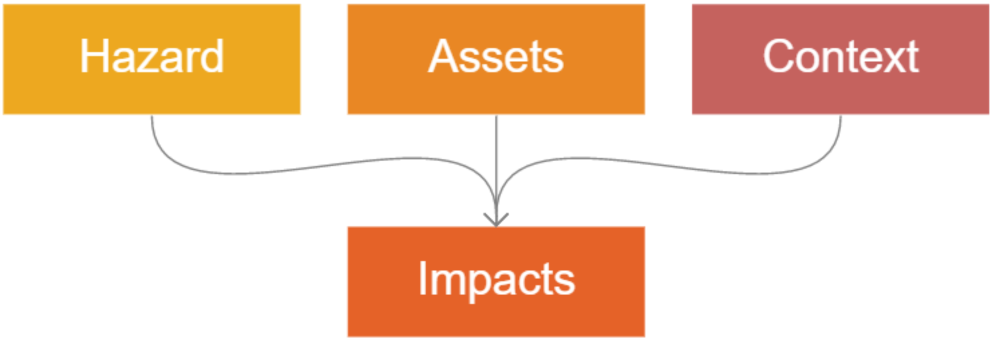

Figure 4: Generalized inputs used to determine impacts.

Hazards – Hazards are the potential occurrence of a physical event or trend that may threaten our social, built, and ecological environments. The coastal flood hazard data produced through the Coastal Flood Hazard Framework is a key input into the impact assessment. Resulting event-driven inundation 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 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 – As stated in the Framework, coastal flooding "challenges differ by region, locality, neighborhood, and individual, as does the 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.

2.3. METRICS

Location intelligence and asset-specific impact threshold information guide the selection of metrics to describe hazard impacts. For example, in the absence of state- or local-scale data about the location and impact thresholds of important commercial manufacturing or agricultural facilities in the study area, the decision was made to focus on counting exposure to the hazard using best available information about these facilities, rather than producing quantitative estimates of risk. Figure 5 illustrates an example, where the point data source provides information about the asset (a critical manufacturing facility) while the actual building footprints are unattributed. Although the study parcel dataset could be used to assign the point attributes to the largest building, by area, on the parcel, the team declined to do that since the point data has significant spatial fidelity limitations and can asset points were found on roads and undeveloped areas, requiring further analysis or adjustment to not lose the information.

Figure 5: Example of challenge in aligning assets to building footprints. The selected point from the DHS Homeland Infrastructure Foundation-Level Data (HIFLD) represents a critical manufacturing facility, however only a manual assignment of the point to the facility's footprint, impossible to accomplish due to current time constraints, would have yielded an accurate location and thus a valid risk assessment.

On the other hand, for assets where it was possible to more accurately estimate relevant impact thresholds such as flood depths at which the asset was disrupted, damaged or destroyed, the impact assessment advanced through a quantitative estimate of risk, in the form of direct and indirect economic losses, such as residential structures.

Fundamentally, the CRMP impact assessment approach enables a progressively detailed evaluation dependent on the availability and quality of data. As noted in Figure 6 below, four overarching types of assessments have been executed. A quantitative estimate of risk was possible where accurate asset location, key characteristics, and asset value were available. Where no such information was available, the impact assessment may be captured in narrative format. Thus, impact metric results are presented through narrative-based descriptions and progressively data-intensive metrics introduced below and further described in Section 3.2.

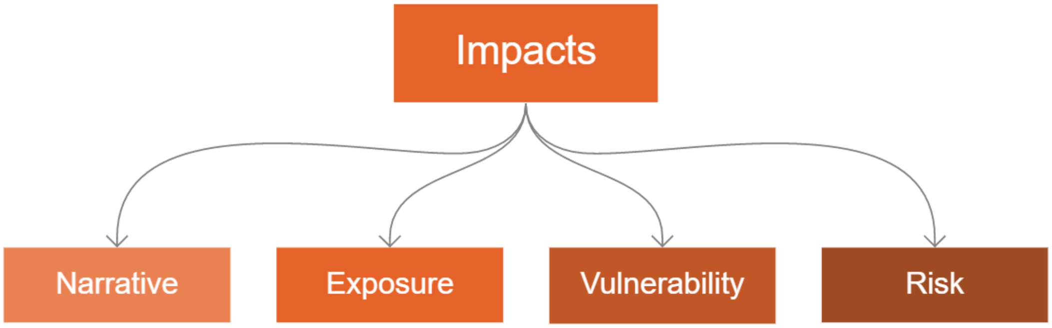

Figure 6: Four levels of impact assessment results.

Exposure – The likelihood and degree to which an asset, population or system 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. Exposure is captured using metrics like the annual likelihood of flooding (ALF), land lost, and Annualized Inundated Acres.

Vulnerability – A measure of the degree to which an asset, 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. Vulnerability is captured in metrics like average annualized depth (AAD), habitat loss, and residential population displacement.

Risk - The estimated value of direct and indirect consequences associated with the functional disruption of the asset, population, or system. For this assessment, the risk is quantified in economic terms. It incorporates probable losses associated with direct damages to the asset. Risk is captured in metrics like averaged annualized loss (AAL).

ADAPTIVE CAPACITY

Understanding and assessing adaptive capacity, or the ability of an asset or system to adjust to a hazard or cope with a change, provides additional context in a vulnerability assessment. The Coastal Hazard Framework accounts for adaptive capacity through asset damage functions or when additional insight into structural attributes was available to represent the adaptive capacity (i.e., structures on piers). Where local resolution data was provided or built environment representations were validated manually, for example, through Google Street View, adaptive capacity was incorporated. However, an adaptive capacity assessment was not applied to all sectors and can be considered in future iterations of the CRMP.

All impacts that revolve around discrete and identifiable assets will have exposure statistics, and the degree to which vulnerability and risk is quantified depends on asset-specific available data, as illustrated in Figure 7 below.

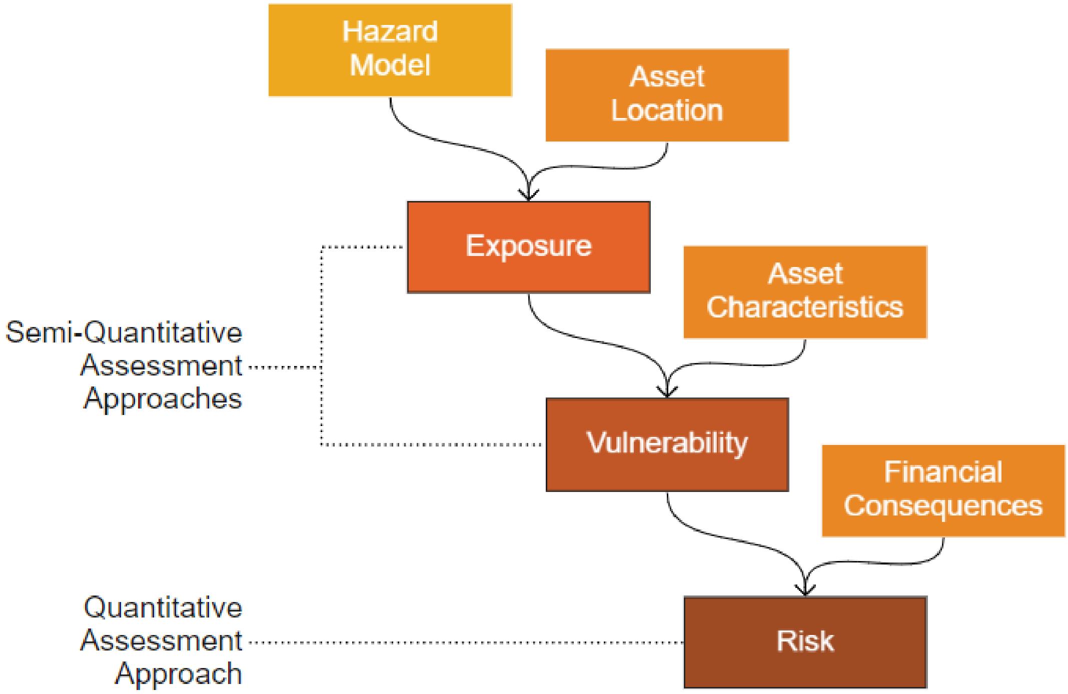

Figure 7: Asset information required to describe impacts with varying levels of detail.

2.4. THEMES, COMPONENTS, AND SUBCOMPONENTS

The impact assessment approach examines three thematic areas to understand the consequences of coastal hazards on assets. The three asset-based themes are: **Community Resources, Critical Sectors, and Natural Infrastructure**. The community context is also considered in the approach. Along with each asset-based theme is a summary of how, and to what extent, exposure, vulnerability, and risk are considered for each component and the sub-components that make up each type.

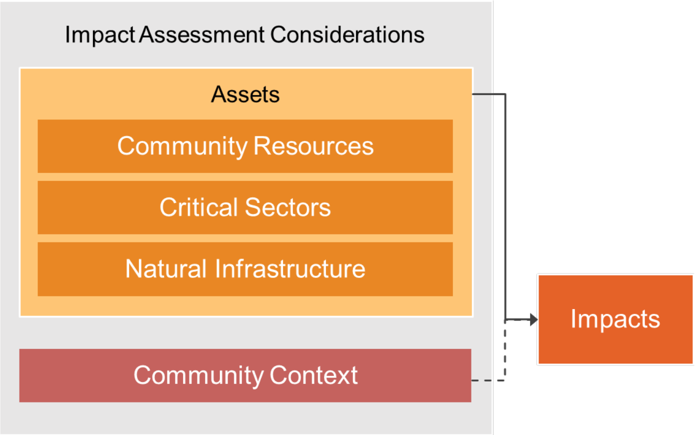

Figure 8: Asset-based themes are examined in the impact assessment in addition to the community context.

Note that while the asset-based and contextual information is presented separately in the impact assessment for quantitative purposes, the two concepts are integrated into the narrative of the Master Plan Document.

2.4.1. COMMUNITY RESOURCES

The Community Resources theme considers impacts to the physical assets that contribute to coastal Virginia's unique economy and social environment. It includes three components described below. The impact types for each sub-component are outlined in Table 1.

- **Businesses and Employers** – Structures and areas used to procure, process, manufacture and/or exchange goods and services. Impacts quantified include flood-induced damages to commercial buildings.
- **Residential Neighborhoods** – Areas that are primarily occupied by residential housing. Impacts quantified include the flooding of residential homes and displacement of residential populations.
- **Tribal Resources** – Areas that contain lands currently inhabited by federally recognized Native American tribes. Impacts quantified include the flooding and loss of tribal lands.

Table 1: Component types and sub-component types quantified within the Community Resources theme.

COMPONENT	SUB-COMPONENT	ASSET	EXPOSURE	VULNERABILITY	RISK
Businesses & Employers	Agricultural Lands	Agricultural Parcels	X		
	Public & Commercial Structures	Agricultural Structures	X	X	X
		Commercial Structures	X	X	X
		Educational Structures	X	X	X
		Industrial Structures	X	X	X
		Religious Structures	X	X	X
Residential Neighborhoods	Residential Displacement	Displaced Populations (Displaced)	X	X	
	Residential Exposure	Residential Population (Exposed)	X	X	
	Residential Structures	Residential Structures	X	X	X
Tribal Resources	Tribal-Owned Lands	Tribal-Owned Land (Inundated)	X		
		Tribal-Owned Land (Lost)	X	X	

2.4.2. CRITICAL SECTORS

The Critical Sectors theme considers impacts to assets, systems, and networks vital to state, regional, and national activities. If disrupted, damaged, or destroyed, Critical Sector impacts would have debilitating effects on the economy, public health and safety, and/or security.[3]

The assets and systems considered under the Critical Sectors theme were identified using the Cybersecurity & Infrastructure Security Agency (CISA) framework for critical infrastructure sectors. The CISA framework outlines 14 critical sectors whose assets, systems, and networks are vital enough that their destruction or incapacitation would debilitate the economy, public health and safety, security, or any combination thereof. Several of these sectors were combined for this analysis, while those considered not relevant to coastal resilience in Virginia were not included.

The Critical Sector theme includes nine components, described below. Impact types are outlined for each component in Table 2.

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[3] Adapted from the Cybersecurity & Infrastructure Security Agency's definition of Critical Infrastructure Sectors. Available here: https://www.cisa.gov/critical-infrastructure-sectors

- **Commercial & Manufacturing**– Privately-owned sites that are essential to economic activity and transactions, including the production, processing, storage, and distribution of goods and services.
- **Communications** – Assets and networks that facilitate the distribution of information via radio, telephone, television, and the internet.
- **Defense Industry** – Areas and sites occupied by military installations that directly support military operations, research, product development, and other specialized services related to Department of Defense business and military requirements.
- **Energy** – Assets, facilities and networks that process, store, and distribute fuel, or generate power.
- **Food Production** – Assets that facilitate the production, processing, manufacture, storage, and distribution of food, including farms, and food manufacturing facilities.
- **Health & Emergency Services** – Facilities and systems that deliver medical care, treatment, and services to people, and deliver services that prepare for and respond to unexpected incidents that have the potential to create adverse impacts.
- **Transportation** – Assets, facilities, and networks that facilitate the movement of people and goods by road, rail, air, water, and pipelines.
- **Government Facilities** – Both publicly- and privately-owned buildings that facilitate the provision of government services, including education facilities.
- **Water, Waste and Wastewater** – Facilities and systems that store, transport, treat, recycle, and/or dispose of human-contaminated water and unwanted materials.

Table 2: Component types and sub-component types quantified within the Critical Sectors theme.

COMPONENT	SUB-COMPONENT	ASSET	EXPOSURE	VULNERABILITY	RISK
Commercial & Manufacturing	Commercial	Commercial Buildings	X		
		Commercial Parcels	X		
	Manufacturing	Biological Products Manufacturing Facilities	X		
		Chemical Manufacturing Facilities	X		
		General Manufacturing Facilities	X		
		Nitrogenous Fertilizing Plants	X		
		Pharmaceutical Preparation Manufacturing Plants	X		
		Food Production Facilities	X		
Communications	Broadband Internet	Broadband Radio Service and Educational Broadband Service Transmitters	X		
	Phone, Radio, and TV	AM Transmissions Towers	X		
		Cellular Towers	X		
		FM Transmissions Towers	X		
		Land Mobile Broadcast Towers	X		
		Land Mobile Commercial Transmission Towers	X		
		Microwave Service Towers	X		
		Paging Transmission Towers	X		
		TV Analog Transmitters	X		
Defense Industry	Defense	Department of Defense Sites Points (Public)	X		
		Department of Defense Federal Lands	X	X	
		National Security Government Military Facilities	X		
Energy	Electricity	Electric Generating Units	X		
		Electric Substations	X		
		Power Plants	X		
	Oil & Biofuel	Petroleum Ports	X		
		Petroleum Registered Tank Facilities	X		
		Petroleum Release Sites	X		
		Petroleum Terminals	X		
Government Facilities	Education Facilities	Child Care Centers	X		
		Colleges and Universities	X		
		Private Schools (Pre-K to 12th)	X		
		Public Schools (K to 12th)	X		
		Federal Bureau of Investigation (FBI) Offices	X		

COMPONENT	SUB-COMPONENT	ASSET	EXPOSURE	VULNERABILITY	RISK
	Federal Government Facilities	General Services Administration (GSA) Owned or Leased Properties	X		
		National Guard Readiness Centers	X		
		Space Research and Technology Facilities	X		
		U.S. Army Corps of Engineers (USACE) Offices	X		
	State and Local Government Facilities	Courthouses	X		
		Major State Government Buildings	X		
Health & Emergency Services	Emergency Services	Emergency Medical Service Stations	X		
		Fire Stations	X		
		Local Emergency Operations Centers	X		
		Local Law Enforcement Locations	X		
	Health	Hospitals	X		
Transportation	Airports	Airports	X		
	Freight, Ports, and Shipping Facilities	Amtrak Stations	X		
		DHL Facilities	X		
		FedEx Facilities	X		
		Intermodal Freight Facilities - Rail TOFC/COFC	X		
		Port Facilities	X		
		Port of Virginia Facilities	X		
		Private Non-Retail Shipping Facilities	X		
		Railways	X		
		UPS Facilities	X		
		U.S. Postal Service (USPS) Post Offices	X		
		U.S. Postal Service (USPS) Processing Centers	X		
	Roads	Bridges & Culverts	X		
		LRS Road Intersections	X		
		VDOT Roadways	X	X	
Water, Waste & Wastewater	Waste	Hazardous Waste Generators	X		
		Solid Waste Facilities	X		
	Wastewater	Biosolid Areas	X		
		Septic Systems	X		
		Wastewater Treatment Facilities	X		
	Water	Drinking Water Wells	X		

DATA LIMITATIONS IN THE CRITICAL SECTOR

Criticality is considered a binary threshold for this assessment, with assets, either included or excluded from the analysis. Future iterations could expand upon the understanding of criticality to consider varying levels of value and importance, which would be incorporated through additional data, analysis, and stakeholder input. Additionally, improved risk quantification for built environment assets, such as critical sector assets, would likely require:

1. Connecting state or local-scale facility point data to local-scale building footprint information to ensure credible hazard and loss information informs the risk assessment. Figure 5 illustrates an example of the challenges in this process.
2. Adding additional attribute information such as structure design characteristics. For example, the lowest elevation or first-floor elevation can provide insight into how high the water must become before an asset is damaged.
3. Understanding the assets' value, or criticality, to the Commonwealth, region, and any national economic, public health, safety, and security activities of significance. This information, in part, could be obtained through in-depth stakeholder consultations.
4.

Without asset characteristic data, this impact assessment can identify flood depth at an asset location but cannot quantitatively assess the risk beyond exposure. The exception to this is roadways which are assumed to be ground-level. With this assumption, roadway vulnerability can be assessed by equating higher flood depth with higher impacts. Even so, some roads may be elevated, and bridge elevations were unavailable. All roadways crossing 2020 mean low water (MLW) were removed from the analysis products to address this limitation.

2.4.3. NATURAL INFRASTRUCTURE

The Natural Infrastructure theme considers impacts to natural coastal and aquatic environments that provide fish and wildlife habitat, water quality and flood reduction benefits, and numerous ecosystem services to the surrounding region. It includes five component types, described below. Impact types are outlined for each component in Table 3.

- **Aquatic Habitat** – Shallow tidal water supports essential habitats for estuarine flora and fauna along thousands of miles of Virginia's shoreline. These habitats also help to add frictional resistance to slow down the velocity of floodwaters. As sea levels rise, submerged aquatic vegetation (SAV) beds and oyster reefs' habitat zones will be restricted by water depth and can potentially migrate landward given suitable conditions.
- **Beaches & Dunes –** Beaches and dunes can provide a buffer zone that protects upland areas during flood events. They can dampen and absorb the energy from a wave before it reaches upland development, especially if dune systems have healthy vegetation. Beaches and dunes also provide habitats for many different coastal animals, including sea turtles, crabs, and shorebirds. They can improve local water quality by filtering nutrients and pollutants.
- **Tidal Habitat** – The Commonwealth's coastal areas boast an expansive network of tidal wetlands along the shorelines of bays and rivers. Spanning more than 190,000 acres across Virginia, tidal wetlands provide an essential first line of defense during tidal and storm events by reducing wave energy along the shoreline. They also filter nutrients and pollutants and provide habitat and food for various species important to conservation.
- **Upland Habitat** – Upland habitat includes non-tidal marsh, wooded areas, and scrub-shrub habitat. Non-tidal marsh includes wetland from the National Wetlands Inventory located on lands generally less than 10 feet in elevation in the coastal zone not mapped as Tidal Marsh in the CCRM Tidal Marsh Inventory. Upland wooded areas are located on lands generally less than 10 feet in land elevation covered trees greater than 20 feet tall, including land cover classes 'Forest' and 'Trees' within the VGIN Virginia Land Cover Dataset (2016). Upland scrub-shrub habitat includes areas on lands generally less than 10 feet in land elevation covered by woody vegetation with stems generally less than 20 feet tall.
- **Recreational Areas –** Public conservation lands include state, federal, and locally managed lands.

Table 3: Components types and sub-component types quantified within the Natural Infrastructure theme.

COMPONENT	SUB-COMPONENT	ASSET	EXPOSURE	VULNERABILITY	RISK
Aquatic Habitat	Oyster Habitat	Oyster Habitat	X	X	
	SAV Habitat	SAV Habitat	X	X	
Beaches & Dunes	Beaches & Dunes	Beaches & Dunes	X		
Tidal Habitat	Wetland Habitat Loss	Marsh Habitat	X	X	
	Wetland Migration Prevention	Marsh Migration Conflicts	X	X	
Upland Habitat	Non-Tidal Marsh	Non-Tidal Marsh Habitat	X		
	Upland Wooded Areas and Scrub-Shrub	Upland Wooded Areas and Scrub-Shrub	X		
Recreational Areas	Public Parks and Wildlife	Public Parks and Wildlife Areas	X		

2.4.4. CONSIDERING THE COMMUNITY CONTEXT

Community context focuses on identifying communities—either demographically or geographically defined—that have been systemically disenfranchised from educational opportunities, participation in civic decision-making, and access to capital and inter-generational wealth building.[4] While this is not a hazard-informed impact type, this context plays an important role in furthering the CRMP guiding principles and objectives to center social equity and justice in creating a more resilient coast for all Virginians. This context provides a quantitative backing for methodologically prioritizing projects and actions that serve these groups.

- **Social Vulnerability** – Populations that experience the adverse impacts of coastal hazards more acutely than other groups due to disparities of health, income, and access to services that may be related to race or ethnicity, socioeconomic status, language, or other innate characteristics.
- **Jurisdictional Resources & Capacity** – Jurisdictional areas (cities, towns, tribes, and unincorporated counties) that suffer from a relative lack of financial resources and technical capacity relative to other areas. It is assumed that these cross-jurisdictional inequities are largely a result of historic and present disadvantages that reduce a community's capacity for resilience planning and project implementation.

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[4] Adapted from EO 13985. Available here: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/

3. METHODS

3.1. DATA INPUTS

3.1.1. HAZARD ANALYSIS

Although areas within the eight coastal planning regions are subject to coastal, rainfall, and riverine flood hazards, **only coastal flood hazards** are addressed in this iteration of the CRMP.

The Coastal Hazard Framework task established the coastal flood hazard components, including a range of low to high spatially variable water elevations, including daily tides, frequent storm conditions, and hurricane-driven storm surge. The effort leveraged the best available statewide information for water level and publicly available regional land elevation and bathymetric data. To produce flood depth and extent data, two tidal and seven storm surge frequency events in addition to a regulatory elevation were modeled, including:

- Mean low water (MLW)
- Mean high water (MHW)
- The limit of the Virginia Wetland Boards and Tidal Wetlands Act (defined as 1.5 times the mean tidal range, above MLW)
- 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% annual exceedance probability (AEP) with a range of low- to high- coastal flood conditions (2-, 5-, 10-, 25-, 50-, 100-, 500-year recurrence intervals),

Statewide representations of the flood hazard data were developed for each of the time horizons identified in the CRMP Framework: 2020, 2040, 2060, and 2080. The 2020 horizon represents a baseline or current condition, and SLR was incorporated based on the current interagency **Federal Intermediate-High** sea level rise projection.[5]

For each of the nine hazard frequency events and the regulatory elevation described above, the following data products were developed:

- Spatially-variable water surface (with and without estimated local wave heights);
- Spatially-variable flood depths (with and without estimated local wave heights);

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[5] Sweet et. al. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083.

- Cleaned and smoothed flood extents.

COASTAL HAZARD FRAMEWORK

The foundation of the CRMP analysis is the Coastal Hazard Framework, which completes Step 1 in the Study Conceptual Model. The Coastal Hazard Framework identifies and characterizes the various components of the coastal flood hazard through the production of flood extents and depths for existing conditions and future condition SLR scenarios. Future activities are planned to add representation of rainfall, riverine, compound flood factors, coastal erosion, shoreline, and geomorphic change to ensure a more holistic evaluation of the hazards facing the coastal planning regions of the Commonwealth.

More details on the development and production of these products can be found in the Coastal Hazard Framework Technical Memorandum.

These data serve as the inputs to the impact assessment and characterize the changing hazard in illuminating ways. Figure 9 illustrates the change in the likelihood of flooding for a particular building as a series of flood hazard curves. Viewing the hazard data output like this offers the opportunity to see how an asset's threshold depth, for example, the height of the first floor, becomes more likely to occur over time, appreciably adding to the structure's risk. The development of these products is essential to understanding how physiographic conditions and SLR estimates shape the nature of the hazard, directly informing the assessment of exposure, vulnerability, and risk.

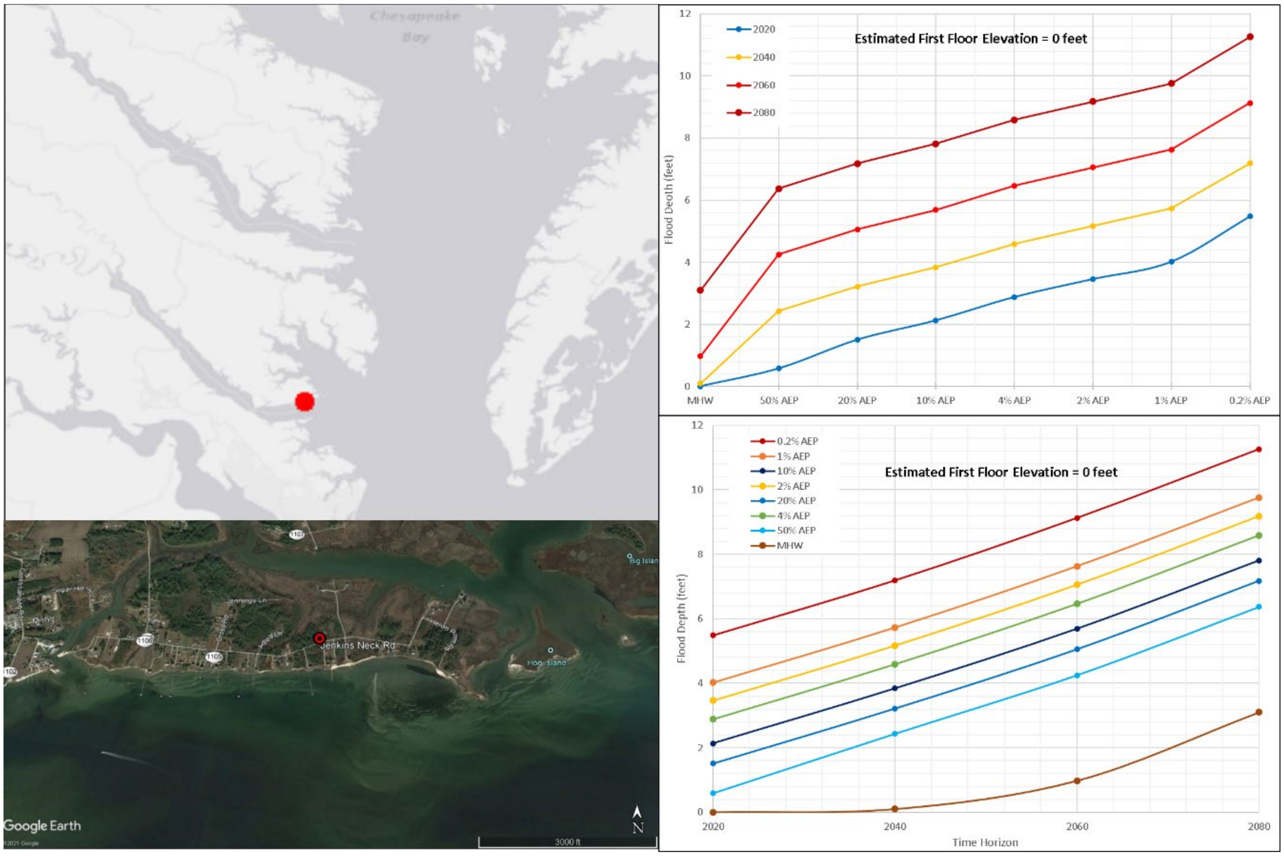

Figure 9: Hazard curves across time horizons. ***.*** *Example residential structure wherein (top right) the change in frequency between 2020 and 2060 for an event with depth of 4', for example, goes from a rare 1% AEP event in the 2020s to a 50% AEP event in the 2060s.*

3.1.2. ASSET DATASETS

The following section outlines the datasets used to characterize the components and sub-components within each theme— Community Resources, Critical Sectors, and Natural Infrastructure. A table is presented for each theme identifying which datasets were used to represent the array of asset types.

To model these assets, the team began by constructing a best available building footprint dataset based on the buildings that fell within the 0.2% AEP 2080 time horizon extent. This represented approximately 275,000 structures with more than an estimated 500 square feet of interior area. Using this base set of information, the team collected, derived, or developed key building attributes needed to calculate loss estimates.

In Figure 10 below, the origin of building footprint sources used in the impact assessment are presented.

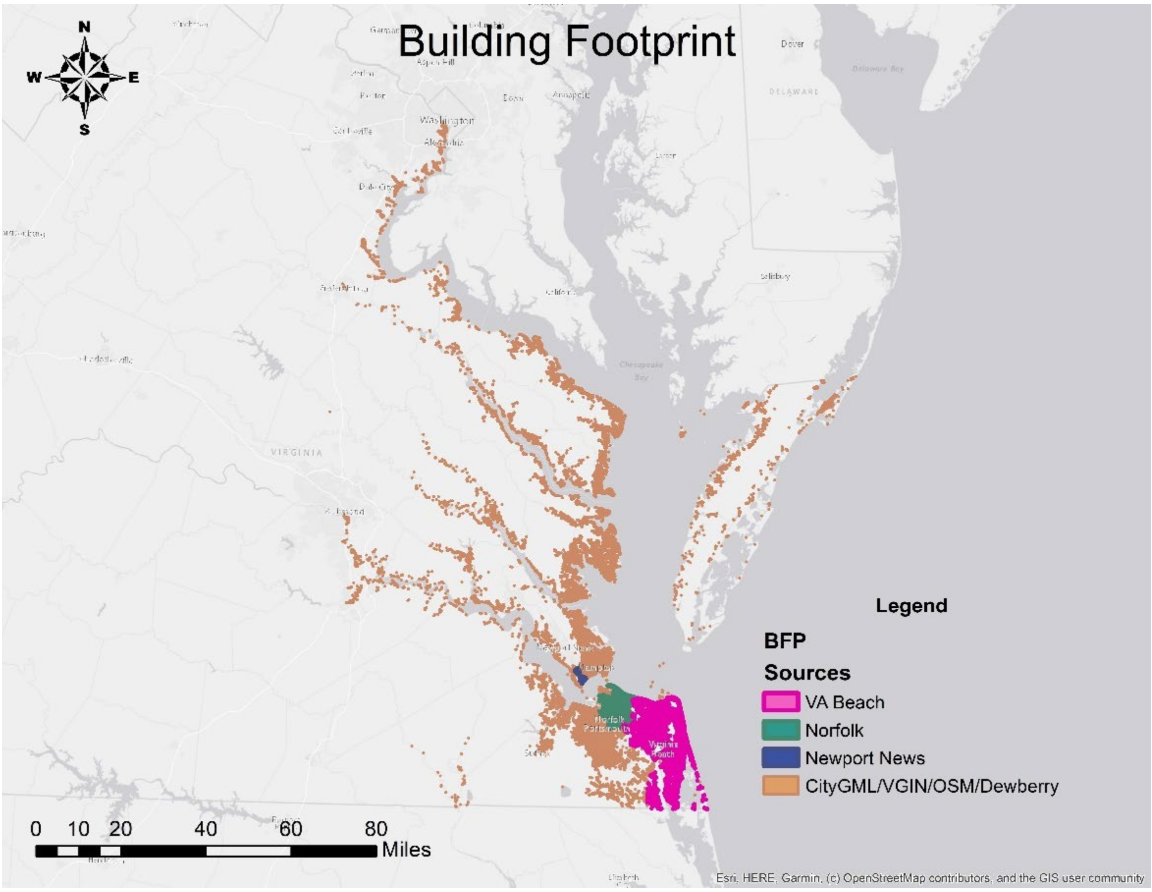

Figure 10: Sources of building footprints and key attributes in the study area.

PREFERRED ATTRIBUTES FOR BUILDING FOOTPRINT DATA

Developing a standard set of attributed parcel data at the county level could help support future impact assessments. These types of datasets are typically developed through information collected as a part of routine tax assessment efforts. The most important attribute for parcel data is building occupancy, which can also be modeled based on land use type. Other essential and highly desirable attributes for loss estimation at a building-level scale include address, building type, first-floor elevation, foundation type, number of stories, livable area, year built, and building value. The availability of more detailed attributes enables a more detailed assessment and improved modeling.

To attribute the essential set of information to the building footprints, the team used the sources and attribute fields listed in Table 4.

To assess the number of residents exposed and/or displaced, census population data was allocated to building footprints, a process detailed in Section 3.2.2

Table 4: Data sources and attributes used for the building footprint dataset development.

ASSET	**SOURCE (S)**	**DATE**	**DESCRIPTION**	DATA ATTRIBUTES								
				Occupancy	Land Use	Foundation Type	# of Stories	Area	Year Built	LAG	FFE	Building Type
Virginia Beach Buildings	City of VB	2019	Building footprint information attributed with parameters needed to calculate flood loss.	**X**		**X**	**X**	**X**	**X**	**X**	**X**	
Norfolk Buildings	USACE	--	The City of Norfolk provided building footprints developed by the USACE Norfolk District.			**X**	**X**	**X**	**X**	**X**	**X**	**X**
Newport News Buildings	ODU	--	This dataset was developed by Old Dominion University (ODU) and obtained from ODU.			**X**	**X**	**X**	**X**	**X**	**X**	**X**
Hampton Roads Planning District Commission (HRPDC)	HRPDC	2020	Multiple datasets combined by HRPDC to provide data points representing single-family residential buildings in the current Special Flood Hazard Area were provided.	**X**		**X**	**X**	**X**	**X**	**X**	**X**	
Combined datasets for CRMP study area	Light Box	2021	Using these datasets, the Dewberry team combined county parcel data and 3rd party parcel data, Google Street View, and aerial imagery, to extract relevant building characteristics for loss calculation.		**X**	**X**	**X**	**X**	**X**			**X**
	VGIN Buildings	2021										
	CityGML Buildings	2019										
	Open Street Map (OSM)	2021										

3.1.2.1. *Community Resources Datasets*

Community Resources datasets in Table 5 outlines the datasets used to represent the three components in the **Community Resources** theme: businesses and employers (commercial, industrial, educational, agricultural, religious, and non-profit owned facilities), residential neighborhoods, and tribal resources.

Historic resources were reviewed and considered using the National Park Service's National Register of Historic Places, including specific sites and districts of significance. However, they were not included as scoring criteria for project evaluation.

Tribal resources were determined based on the boundaries of tribal reservations and statistical areas. Future iterations of the CRMP will need to engage tribes to understand culturally important sites better, accompanying privacy considerations, and represent all state and federally recognized tribal lands.

Table 5: Community Resources datasets.

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNITS	TYPE	DATE	SOURCE
Businesses & Employers	Agricultural Lands	Agricultural Parcels	Annualized Inundated Acres	Acres	Parcel	2021	Lightbox
	Public & Commercial Structures	Agricultural Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Agricultural Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Agricultural Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Commercial Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Commercial Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Commercial Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Educational Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNITS	TYPE	DATE	SOURCE
		Educational Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Educational Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Industrial Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Industrial Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Industrial Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Religious Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Religious Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Religious Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
Residential Neighborhoods	Residential Displacement	Residential Structures (Pop Displaced)	Population Displacement	People	Polygon	2018	ACS
	Residential Exposure	Residential Structures (Pop Exposed)	Population Displacement	People	Polygon	2018	ACS
	Residential Structures	Residential Structures (Content Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
		Residential Structures (Exposure)	ALF	%	Polygon	--	Multiple Sources*
		Residential Structures (Structure Damages)	AAL	Dollars	Polygon	--	Multiple Sources*
Tribal Resources	Tribal-Owned Lands	Tribal-Owned Land (Inundated)	Annualized Inundated Acres	Acres	Polygon	2020	Census Bureau

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNITS	TYPE	DATE	SOURCE
		Tribal-Owned Land (Lost)	Land Lost	Acres	Polygon	2020	Census Bureau
*Data is from Dewberry, Old Dominion University (ODU), USACE, Hampton Roads PDC, OpenStreetMap, CityGML and Lightbox and is described in Table 4.							

3.1.2.2. *Critical Sectors Datasets*

Critical Sectors include assets, systems, and networks vital to everyday functions, and if damaged or destroyed, would have debilitating effects on the economy, public health, and safety, and/or security. The impact assessment examines nine asset types, informed by the CISA framework. Table 6 below outlines the datasets used to characterize the sub-components, each of which is made up of multiple assets. For dataset description information, see the Data Catalog. For example, roads, railways, airports, freights and shipping, and pipelines are assets that, if affected by flooding, would impact transportation in coastal Virginia. The impact assessment leverages data primarily from Virginia government agencies and the Homeland Infrastructure Foundation-Level Data (HIFLD) Open Data portal. HIFLD Homeland Security Infrastructure Program (HSIP) Gold data were used to improve representation over HIFLD Open, where a more complete coverage was available. Building footprint and parcel information were acquired using LightBox and OpenStreetMap (OSM) data.

Table 6: Critical Sectors datasets.

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNIT	DATA TYPE	DATE	SOURCE
Commercial & Manufacturing	Commercial	Commercial Buildings	ALF	%	Area	--	Multiple Sources*
		Commercial Parcels	ALF	%	Area	2021	Lightbox
	Manufacturing	Biological Products Manufacturing Facilities	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
		Chemical Manufacturing Facilities	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
		General Manufacturing Facilities	ALF	%	Points	2021	HIFLD
		Nitrogenous Fertilizing Plants	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
		Pharmaceutical Preparation	ALF	%	Points	2015	HIFLD – HSIP Gold 2015

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNIT	DATA TYPE	DATE	SOURCE
		Manufacturing Plants					
		Food Production Facilities	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
Communications	Broadband Internet	Broadband Radio Service and Educational Broadband Service Transmitters	ALF	%	Points	2017	HIFLD
	Phone, Radio, and TV	AM Transmissions Towers	ALF	%	Points	2018	HIFLD
		Cellular Towers	ALF	%	Points	2021	HIFLD
		FM Transmissions Towers	ALF	%	Points	2018	HIFLD
		Land Mobile Broadcast Towers	ALF	%	Points	2018	HIFLD
		Land Mobile Commercial Transmission Towers	ALF	%	Points	2018	HIFLD
		Microwave Service Towers	ALF	%	Points	2021	HIFLD
		Paging Transmission Towers	ALF	%	Points	2018	HIFLD
		TV Analog Transmitters	ALF	%	Points	2018	HIFLD
Defense Industry	Defense	Department of Defense Sites Points (Public)	ALF	%	Points	2021	HIFLD
		Department of Defense Federal Lands (Lost)	Land Lost	Acres	Polygon	2021	ESRI
		Department of Defense Federal Lands (Inundated)	Annualized Inundated Acres	Acres	Polygon	2021	ESRI
		National Security Government Military Facilities	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
Energy	Electricity	Electric Generating Units	ALF	%	Points	2015	HIFLD – HSIP Gold 2015

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNIT	DATA TYPE	DATE	SOURCE
		Electric Substations	ALF	%	Points	2020	HIFLD
		Power Plants	ALF	%	Points	2019	HIFLD
	Oil & Biofuel	Petroleum Ports	ALF	%	Points	2019	HIFLD
		Petroleum Registered Tank Facilities	ALF	%	Points	2021	DEQ
		Petroleum Release Sites	ALF	%	Points	2021	DEQ
		Petroleum Terminals	ALF	%	Points	2020	HIFLD
Government Facilities	Education Facilities	Child Care Centers	ALF	%	Points	2020	HIFLD
		Colleges and Universities	ALF	%	Points	2020	HIFLD
		Private Schools (Pre-K to 12th)	ALF	%	Points	2020	HIFLD
		Public Schools (K to 12th)	ALF	%	Points	2020	HIFLD
	Federal Government Facilities	Federal Bureau of Investigation (FBI) Offices	ALF	%	Points	2014	HIFLD – HSIP Gold 2015
		General Services Administration (GSA) Owned or Leased Properties	ALF	%	Points	2007	HIFLD – HSIP Gold 2015
		National Guard Readiness Centers	ALF	%	Points	2014	HIFLD – HSIP Gold 2015
		Space Research and Technology Facilities	ALF	%	Points	2015	HIFLD – HSIP Gold 2015
		U.S. Army Corps of Engineers (USACE) Offices	ALF	%	Points	2014	HIFLD – HSIP Gold 2015
	State and Local Government Facilities	Courthouses	ALF	%	Points	2019	HIFLD
		Major State Government Buildings	ALF	%	Points	2019	HIFLD
Health & Emergency Services	Emergency Services	Emergency Medical Service Stations	ALF	%	Points	2019	HIFLD
		Fire Stations	ALF	%	Points	2020	HIFLD
		Local Emergency Operations Centers	ALF	%	Points	2021	HIFLD
		Local Law Enforcement Locations	ALF	%	Points	2021	HIFLD

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNIT	DATA TYPE	DATE	SOURCE
	Health	Hospitals	ALF	%	Points	2021	VDH
Transportation	Airports	Airports	ALF	%	Points	2021	FAA
	Freight, Ports, and Shipping Facilities	Amtrak Stations	ALF	%	Points	2020	HIFLD
		DHL Facilities	ALF	%	Points	2017	HIFLD
		FedEx Facilities	ALF	%	Points	2017	HIFLD
		Intermodal Freight Facilities - Rail TOFC/COFC	ALF	%	Points	2020	HIFLD
		Port Facilities	ALF	%	Points	2020	HIFLD
		Port of Virginia Facilities	ALF	%	Points	2020	VEDP
		Private Non-Retail Shipping Facilities	ALF	%	Points	2017	HIFLD
		Railways	ALF	%	Line	2020	VGIN
		UPS Facilities	ALF	%	Points	2017	HIFLD
		U.S. Postal Service (USPS) Post Offices	ALF	%	Points	2014	HIFLD – HSIP Gold 2015
		U.S. Postal Service (USPS) Processing Centers	ALF	%	Points	2014	HIFLD – HSIP Gold 2015
	Roads	Bridges & Culverts	ALF	%	Points	2014	VDOT
		LRS Road Intersections	ALF	%	Points	2021	VDOT
		VGIN Roadway Centerlines (Depth and Exposure)	AAD, ALF	Segments, Miles, %	Lines	2021	VDOT
Water, Waste & Wastewater	Waste	Hazardous Waste Generators	ALF	%	Points	2020	DEQ
		Solid Waste Facilities	ALF	%	Points	2020	DEQ
	Wastewater	Biosolid Areas	ALF	%	Multi-polygon	2021	DEQ
		Septic Systems	ALF	%	Points	--	VDH
		Wastewater Treatment Facilities	ALF	%	Points	2021	DEQ
	Water	Drinking Water Wells	ALF	%	Points	--	VDH
*Data is from Dewberry, Old Dominion University (ODU), USACE, Hampton Roads PDC, OpenStreetMap, CityGML and Lightbox and is described in Table 4.							

3.1.2.3. *Natural Infrastructure Datasets*

Natural Infrastructure includes natural coastal and aquatic environments that provide fish and wildlife habitat, water quality, flood reduction, recreational benefits, and numerous ecosystem services to the surrounding region. It includes five components: aquatic habitat, beaches and dunes, tidal habitat, , upland habitats, and recreational areas.

Table 7 outlines the datasets used to identify the component types. NOAA land cover data identified coastal habitats with specific classification for types of marshland. Aquatic habitats were determined using VIMS aerial survey data that identifies the distribution of submerged aquatic vegetation.

Table 7: Natural Infrastructure datasets.

COMPONENT	SUB-COMPONENT	ASSET	METRIC	UNIT	DATA TYPE	DATE	SOURCE
Aquatic Habitat	Oyster Habitat	Oyster Habitat	Habitat Lost	Acres	Polygon	2019	VIMS
	SAV Habitat	SAV Habitat	Habitat Lost	Acres	Polygon	2020	VIMS
Beaches & Dunes	Beaches & Dunes	Beaches & Dunes	Land Lost	Acres	Polygon	2021	VIMS
Tidal Habitat	Wetland Habitat Loss	Marsh Habitat	Habitat Lost	Acres	Raster	2020	NOAA
	Wetland Migration Prevention	Marsh Migration Conflicts	Habitat Endangered	Acres	Raster	2020	NOAA
Upland Habitat	Non-Tidal Marsh	Non-Tidal Marsh Habitat	Land Lost	Acres	Polygon	2020	VIMS
	Upland Wooded Areas and Scrub-Shrub	Upland Wooded Areas and Scrub-Shrub	Land Lost	Acres	Polygon	2021	VIMS
Recreational Areas	Public Parks and Wildlife	Public Parks and Wildlife Areas	Land Lost	Acres	Polygon	2020	DCR

3.1.3. COMMUNITY CONTEXT DATASETS

The following section outlines the datasets used to characterize the community context to understand the impacts on underserved communities better.

Underserved communities refer to communities that have been systemically disenfranchised from educational opportunities, participation in civic decision making and access to capital and inter-generational wealth building. Underserved communities are characterized by social vulnerability and jurisdictional capacity and resources.[6] Table 8 outlines the datasets used to identify such communities.

The impact assessment uses the Centers for Disease Control and Prevention and Agency for Toxic Substances and Disease Registry's Social Vulnerability Index (CDC/ATSDR SVI) to assess social vulnerability. This index leverages Census data on demographics, household composition, and socioeconomic status. The impact assessment uses these variables, acquired from the 2014-18 American Community Survey (ACS) at the Census Block Group level. To assess jurisdictional capacity, or the available resources and capacity at a jurisdiction's disposal, the CRMP uses the Fiscal Stress Index framework, developed by the Virginia Department of Housing and Community Development's (DHCD) Commission on Local Government (CLG).

Table 8: Datasets informing the community context.

COMPONENT	SUB-COMPONENT	DATASET	DATA TYPE	DATE	SOURCE
Social Vulnerability	Household Composition & Disability	Age and Sex	Table	2014-2018	U.S. Census Bureau ACS
		Population Under 18 Years			
		Disability Status			
		Single-Parent Households			
		Sex by Age: Race/Ethnicity			
	Minority Status & Language	Ability to Speak English for Population Over 5 Years			
	Socioeconomic Status	Educational Attainment			
		Per Capita Income in the Past 12 Months			
		Poverty Status in the Past 12 Months			
		Unemployment			
	Housing Type & Transportation	Group Quarters Population			
		Selected Housing Characteristics			
Jurisdictional Capacity and Resources	Community Capacity	DHCD Fiscal Stress Index 2018	Table	2018	DHCD

3.2. METRICS CALCULATIONS

The tables presented in Section 2.4 summarize impact types for each asset type. Descriptions of how each impact type is calculated, using the datasets outlined in Section 3.1, are provided in the following section.

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[6] Note – Data to support the jurisdictional capacity and resources analysis is limited for the moment. As part of study outreach efforts and surveys, communities will be asked to self-assess their capacity, which can be included and used to supplement GDP for future iterations. This consideration is discussed in more detail in Section 3.2.12.

3.2.1. ASSETS EXPOSED TO FLOODING

Annual likelihood of flooding (ALF) is a metric for exposure. It describes the probability that any amount of flooding will occur at a location in a given year for a given time horizon. The calculation considers the annual probability of an event occurring and the extent of the floodplain associated with that event across multiple event scenarios. ALF helps to account for the relative variation in hazard exposure between assets in flood-prone areas. This metric is particularly useful for summarizing exposure for built assets for vulnerability and when data needed to calculate risk is not available or easily calculable. Figure 11 below illustrates the inputs, key processes, and results related to this calculation.

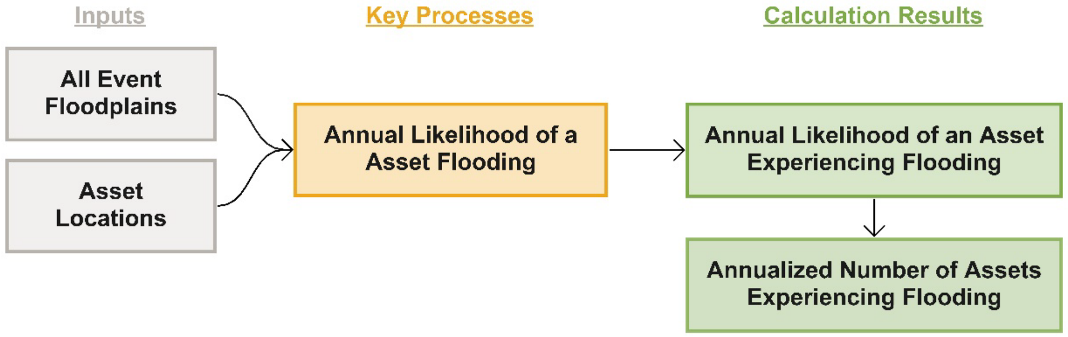

Figure 11: Summary of key inputs, processes, and results for calculating assets exposed to flooding.

Approximating Annual Likelihood of Flooding – 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. **Building-Floodplain Intersection** – Structure data from all sources described in Section 3.1.2 are intersected with all the extents of the modeled flood events, outlined in Section 3.1.1, to identify whether or not the structure is inside or outside of the floodplain for each time horizon.
2. **Impact Threshold Frequency** – For each time horizon, the highest frequency flood (the flood with the lowest return interval and highest annual exceedance probability) that intersects with the asset is identified. This event is considered the threshold for the asset experiencing flooding.
3. **Annual Likelihood of Flooding** – The AEP of the identified smallest frequency flood is used to estimate the ALF for a given structure. For example:
    - If a structure, is in the 2-year floodplain (and by default all lower frequency floodplains) but not in a higher frequency floodplain, it is estimated to have an 50% ALF.

- If a structure is in the 500-year floodplain but no others, it is estimated to have a 0.2% ALF.

ALF can be summed across assets to summarize total hazard exposure of an asset type across a geography. 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.

FLOOD RISK COMMUNICATION

Flood risk terms such as the 100-year flood may lead to the common misconception that flooding is likely once a century when in reality there is an appreciable chance of flooding every year. It may also falsely suggest that if a community is at risk of a 100-year flood, they are exempt from other flood risks such as a 50-year or 20-year flood. Communicating the annual likelihood of flooding can help support risk awareness.

3.2.2. POPULATION EXPOSED TO FLOODING

Population exposure captures the approximate likelihood that a resident will experience flooding to their home in a given year. It is calculated for each time horizon by estimating the population associated with each residential structure and calculating the annual likelihood of that structure experiencing flooding. This process helps to account for the relative variation in hazard exposure between people living in flood-prone areas. Figure 12 below illustrates the inputs, key processes, and results to calculate population exposure.

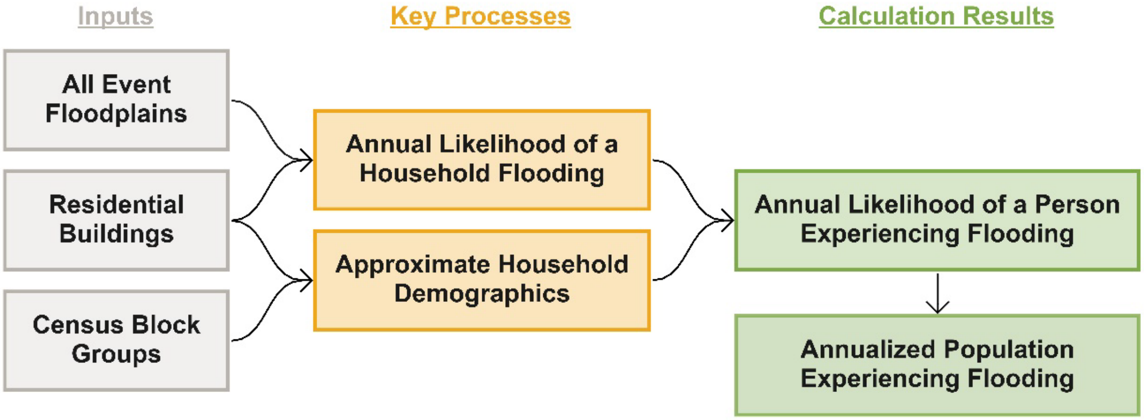

Figure 12: Summary of key inputs, processes, and results for calculating population exposed to flooding.

Annual Likelihood of Flooding – ALF describes the probability that any amount of flooding will occur at a location in a given year for a given time horizon. The calculation considers the annual probability of an event occurring and the extent of the floodplain associated with that event across multiple event scenarios and is described in Section 3.2.1.

Approximation of Household Demographics – Population and demographics from ACS are statistically attributed to building footprints. This is an alternative approach to distributing population uniformly through a census block that accounts for population distribution and density variations. Mapping the population to the building footprints facilitates more agile and geographic-specific population and demographic aggregation when working with geometries outside census block boundaries (such as floodplains and project boundaries). While this process is highly useful for statistical modeling at an aggregated scale, these estimates should not be used to assess impacts to individual structures and residents. The process to do this calculation is described below.

1. **Source Data Aggregation** – Building-level data from multiple sources are combined to create a comprehensive building layer, as illustrated in Figure 15.
2. **Land-Use Attribution** – Land-use information for the buildings is extracted from the parcel data.
3. **Type Classification** – Each building is categorized as residential or non-residential based on the land-use type of the parcel.
4. **Demographic Attribution** – The centroids of the residential building are intersected with 2018 census block groups. The ACS demographics reported for each census block group are then proportionally allocated to the residential buildings. The proportioning equally distributed demographic composition based on the living square footage reported in the parcel data. Where that attribute was not available, this was based on the building footprint area. The building data did not attribute residential structures as second homes, as such, the distribution assumes that all residential structures are occupied by ACS demographics in the census block group. Larger footprints received a bigger share of the census block population. Care was taken to verify that the total population allocated to buildings matched with the total reported in ACS. 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.
    a. The best available residential buildings layer was created by combining the data from Virginia Beach, Norfolk, CityGML, VGIN, and OSM datasets. From this building layer, only residential buildings were identified as the primary areas of population in each census block group.
    b. Additionally, residential non-vacant parcels without building footprints were identified. For those parcels, their centroids were used as

representative points to be considered for the population. For statistical purposes, each building in the parcel area was assumed to be 2,000 square feet.

c. In populated census blocks with no residential buildings or parcels available, the population was distributed to all the buildings in the census block group, regardless of occupancy type.

d. In populated census block groups where no building footprints were available, the parcel centroids were used as representative points to be considered for the population. Each building in the parcel area was assumed to be 2,000 square feet.

When summarizing population exposure to a geography, 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.

While the population exposure impact metric focuses on population counts and is unrelated to demographic characteristics, population exposure can also be broken down by race/ethnicity or other relevant categories in subsequent analyses.

3.2.3. POPULATION DISPLACED

Residential population displacement is a vulnerability metric that captures the projected changes in residential population due to extreme flood hazards for a given time horizon relative to a 2020 baseline of population.

DISPLACEMENT LIMITATIONS

For this assessment, residents are considered displaced from their home and neighborhood if their household is permanently inundated or experiences daily flooding due to tides. This metric is not precise and does not consider population growth for future time horizons or that some coastal residential buildings are secondary or rental properties. However, this metric is helpful for identifying displacement hotspots.

The process to calculate residential displacement includes two parts: approximation of household demographics and identification of uninhabitable structures for each time horizon. Figure 13 below illustrates the inputs, key processes, and results to calculate expected population displacement.

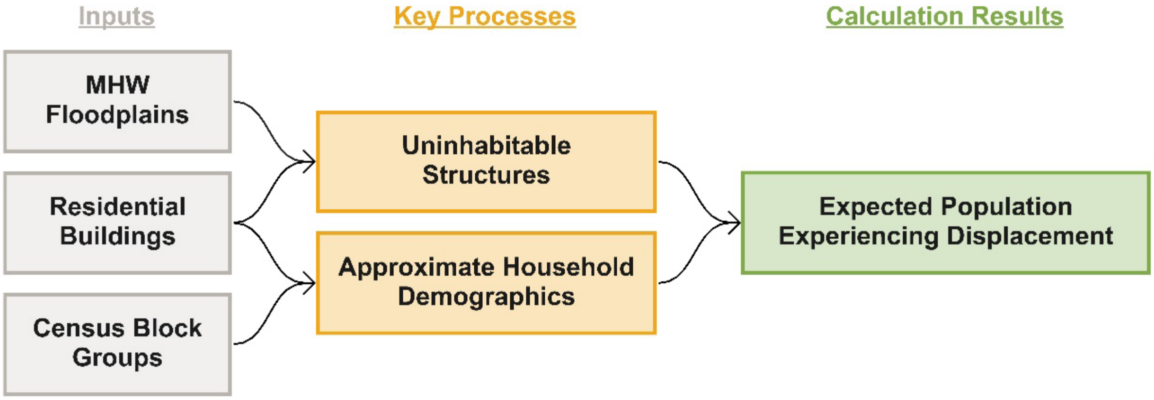

Figure 13: Summary of key inputs, processes, and results for calculating population displaced.

Identification of Uninhabitable Structures – Land is considered fully inundated, and therefore effectively "lost," if it falls within the MHW floodplain. All structures on this land are therefore considered uninhabitable. Uninhabitable structures are identified for each time horizon by intersecting structure data from all sources described in Section 3.1.2 with the extent of the MHW floodplain for the given time horizon.

Approximation of Household Demographics –This process involves using the structure-level demographic information described in Section 3.2.2. For this analysis, residents associated with the uninhabitable structures are considered displaced.

3.2.4. STRUCTURE DAMAGES

Average annualized loss (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, the USACE, and the flood insurance industry, among others. Flood loss for an individual structure is calculated for each included flood event probability (here, the 50%, 20%, 10%, 4%, 2%, 1%, and 0.2% annual exceedance conditions), the event's associated flood depth and wave height, and structure attributes (e.g., Figure 14). This approach highlights that repetitive, high-frequency flooding damages are comparable to very infrequent extreme events with catastrophic losses. AAL from individual structure analysis can inform structure-level flood mitigation and be aggregated into larger geographic units to inform resilience planning by identifying "hot spots" of flood loss. Figure 14 below illustrates the inputs, key processes, and results to calculate structure damages.

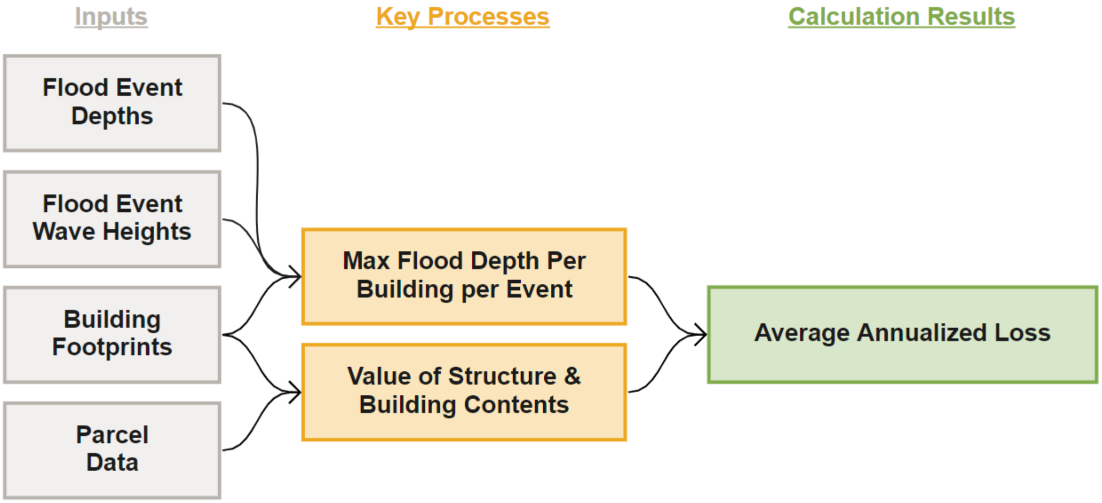

Figure 14: Summary of key inputs, processes, and results for calculating structure damages.

The process for preparing the required data and calculating AAL is described in the following steps and illustrated in Figure 15:

1. Develop a spatial representation of buildings.
2. Attribute buildings with information relevant to their value, structural attributes, and flood susceptibility (e.g., first-floor height) from parcel data.
3. Develop flood hazard information at a variety of flood frequencies.

For each flood frequency:

4. Identify the specific hazard (i.e., flood depth) at each building.
5. Identify the wave height at each building.
6. Relate flood depth to building damage using depth-damage functions.
7. Calculate loss as a function of damage and value.

Annualize the losses:

Annualize losses at each building as a function of the individual event probabilities and the loss incurred by each event.

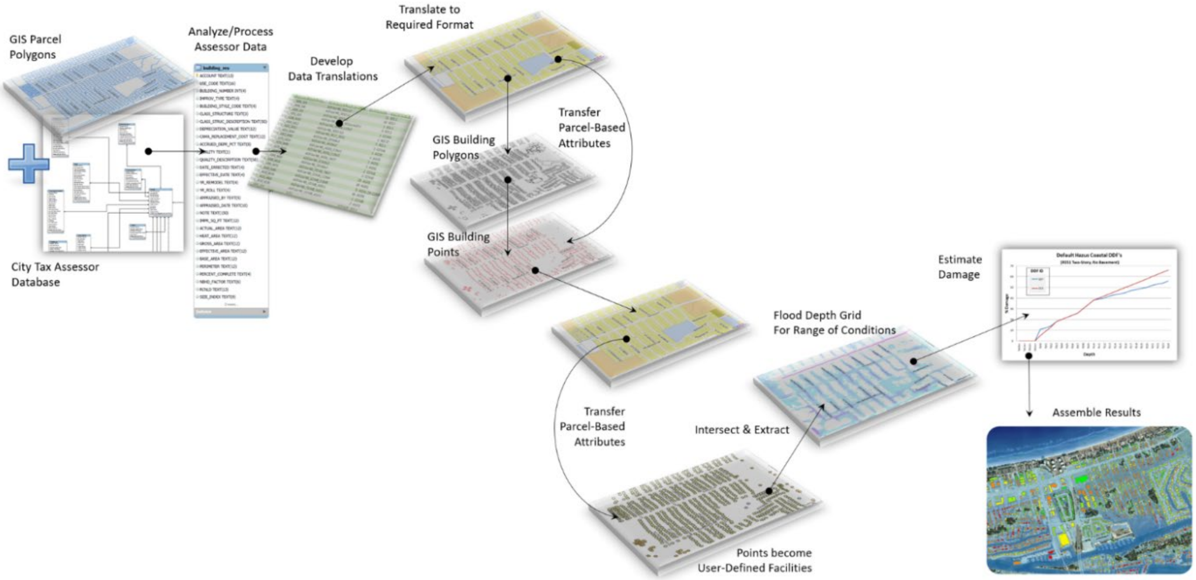

Figure 15: Building-level flood loss analysis steps.

The FEMA Hazus flood risk estimation approach is a common approach for estimating flood-generated damages and associated losses. The Hazus Multi-Hazard (MH) software integrates many of the needed steps into a single process. However, the software imposes time and data constraints that do not make its use ideal for the scale of the CRMP's geography and multiple time horizons. Other alternatives were evaluated to address this challenge, including Hazus-FAST, a Python implementation of Hazus developed by the Oregon Department of Geology and Mineral Industries, and the Go-Consequences Loss Analysis software, recently developed by the USACE's Hydrologic Engineering Center. The Go-Consequences software was selected for use in the CRMP.

BENEFITS OF GO-CONSEQUENCE SOFTWARE

Go-Consequences is 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.[7] Go-Consequences offers significant efficiency over Hazus in that it separates the compilation of input data and the loss calculations. The software is ideal for application in the CRMP, as the Coastal Hazard Framework and impact assessment leverage cloud computing for analytical support, and rapid data compilation is possible through custom scripting. As with Hazus-MH, Go-Consequences calculates structural and contents loss based on building occupancy types and their respective depth-damage curves (DDFs). While selecting the appropriate DDF for loss analysis of each building occupancy type can be informed by various factors, it is largely informed by expert judgment.

In contrast to Hazus-MH, Go-Consequences provides tools for sampling DDF with uncertainty to express the uncertainty in damage for a given occupancy type conditioned on the damage driving parameter (usually depth). This capability can be turned off for deterministic analysis depending upon the study's design, so Go-Consequences provides a more flexible platform and customization. This approach partially mitigates the uncertainty with DDF selection and application and is highly suitable for applications such as the CRMP.

Building attributes relevant to impact assessment – Several critical attributes to impact assessment must be assigned to each building: occupancy, foundation type, number of stories, and first floor height. First-floor height is the height, in feet, of the top of the first floor above ground level. The number of stories is the number of occupiable stories. Occupancy describes the building's use or function and is typically represented by general use classes defined in the Hazus-MH loss estimation model framework. See Table 9 for a list of the occupancy types considered.

Depth Damage Functions (DDF) – 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) and the building design (foundation type,

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[7] https://github.com/USACE/go-consequences/wiki

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. As previously mentioned, 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 depth-damage functions as part of ongoing research and development for **Coastal Probabilistic Flood Risk Assessment (CPFRA)**. The CPFRA curves were collaboratively developed and reviewed by a group of flood loss experts across FEMA's Production and Technical Services contractors. Although the CPFRA DDFs have not yet been broadly disseminated, they have been socialized to the Hazus user group and the USACE and were recently applied in FEMA's *Building Codes Save: A Nationwide Study of Loss Prevention*[8]. There are two distinct improvements of the CPFRA suite over existing DDFs:

    1. CPFRA curves were developed by examining existing FEMA, USACE, and international data to address shortcomings, differences, and varying definitions of reference elevations.

    2. CPFRA DDFs offer multiple graduated damage functions to reflect different wave environments, graduating from saltwater inundation, inundation with moderate wave conditions (wave heights from 1 to 2.9 ft), and inundation with high hazard wave conditions (wave heights greater than 3 feet).

- **Mobile Homes and Multi-Family Residential Structures –** The Go-Consequences software default DDFs are used 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.

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[8] Federal Emergency Management Agency (2020). Building Codes Save: A Nationwide Study. Retrieved from https://www.fema.gov/emergency-managers/risk-management/building-science/building-codes-save-study

- **All Building Occupancy Classes (except Single Family, Mobile Homes, and Multi-Family Residential Structures) –** The CRMP risk analysis uses the default DDFs in Go-Consequences. 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 (SACCS, Will Lehman, USACE, per comm.). Go-Consequences provided multiple DDFs for all structure types, as noted in Table 9, 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 Homes, 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 will better reflect 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 for planning purposes. Despite their developmental status, these DDFs are derived from existing data, have been internally peer-reviewed, 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 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 depth-damage functions that are paired with the building DDFs. However, the Single-Family Residential building DDFs sourced from the FEMA CPFRA suite do not come paired with Contents DDFs, so suitable matches were pulled from the USACE Galveston and the FEMA BCAR DDF libraries.

Estimate Damage – For each probabilistic flood hazard, the Total Flood Depth and Wave Height Above Stillwater Elevation (SWEL) is extracted at each building. Each Wave Height Above Stillwater Elevation is translated into a Breaking Wave Height as,

Breaking Wave Height = Wave Height Above SWEL / 0.7,

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

Depth Above First Floor = Total Flood Depth – First Floor Height.

For each different hazard, every building is assigned a Building and Contents DDF based on the building occupancy or other building attributes, including Breaking Wave Height. Each building will then have seven Breaking Wave Heights, seven Depths Above First Floor, and seven DDFs corresponding to the seven AEP hazards, outlined in Section 3.1.1. The Go-Consequences software will then relate each Depth Above First Floor to a Building Percent Damage using the defined Depth Damage Function to provide seven damage calculations for each building.

Monetary loss for both building and contents are calculated for each hazard and building as,

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

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

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

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

Average Annualized Loss – After losses are calculated for each hazard, the building AAL can be calculated following the HAZUS-MH method.[9] The hazard frequencies are paired with the consequent building losses sorted by frequency (ascending) to determine AAL.

From each sorted pair, i, the structure's AAL is 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.

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[9] HAZUS-MH Technical Manual, Flood Model, 14-38. Retrieved at https://www.fema.gov/sites/default/files/2020-09/fema_hazus_flood-model_technical-manual_2.1.pdf.

ESTIMATING BUILDING AND CONTENT VALUES

"The approach for estimating building replacement costs followed the Hazus Flood Model Technical Manual(DHS/FEMA 2006), which provides standard cost per square ft values for different occupancy types. Adjustments were made to update these values to the most recently available consumer price index (CPI) following the FEMA Modeling Task Force (MOTF) approach." For the cost per square feet by occupancy type, see Table 9.

Source: Hazus-MH Technical Manual

Table 9: Structure occupancy type and cost classifications for loss calculations.

OCCUPANCY	COST/FT2 (FEMA BCA2018 /ENR 2021)	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	
COM6	419.08	Hospital	Single	
COM7	301.27	Medical Office/Clinic	Multiple	
COM8	279.64	Entertainment & Recreation	Multiple	
COM9	209.73	Theaters	Multiple	

OCCUPANCY	COST/FT2 (FEMA BCA2018 /ENR 2021)	DESCRIPTION	MULTIPLE OR SINGLE DDFS PROVIDED BY GO-CONSEQUENCES	DDF USED BY CRMP
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	

3.2.5. DEPTH OF FLOODING

Depth of flooding captures vulnerability for impacts where depth directly relates to an asset's ability to function and provide service, such as roadways. The calculation considers the annual probability of an event occurring and the depth of flooding associated with that event at a specific location across multiple event scenarios. Figure 16 illustrates the inputs, key processes, and results to calculate the depth of flooding.

DEPTH OF FLOODING LIMITATION

The depth of the flooding metric in the CRMP is used only to summarize roadway impacts but can be applied to other asset types in future iterations.

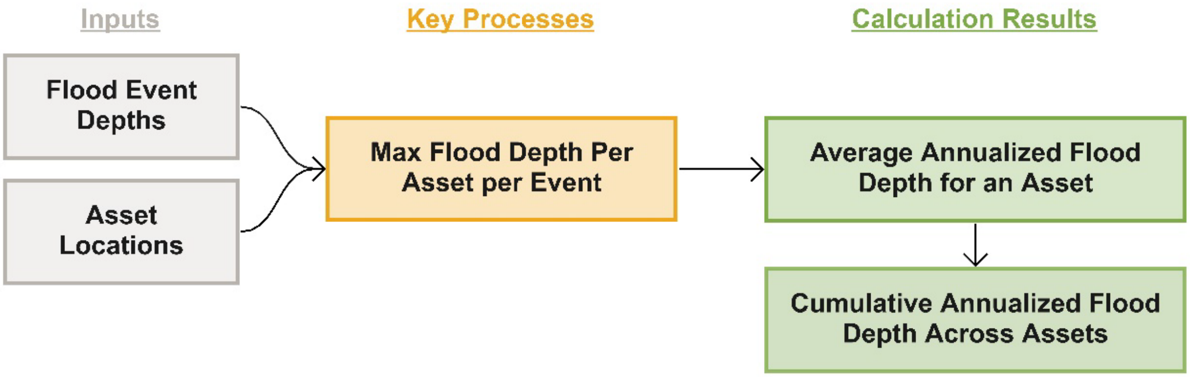

Figure 16: Summary of key inputs, processes, and results for calculating depth of flooding.

The process for calculating average annualized depth for a point, line, or area feature is described below:

1. **Conversion** – If the feature is a line, the line is converted into a polygon by buffering. Roads are buffered by the road surface width.
2. **Depth Extraction** – Extract maximum coastal flood depths at each asset point or polygon for 2, 5, 10, 25-, 50-, 100-, and 500-year return periods and four time horizons.
3. **Probability Weighting** – Calculate the probability weights for the 2, 5, 10, 25-, 50-, 100-, and 500-year return periods, using the equation:

   $$W_n = RI_n - RI_{n+1}$$

   Where W_n = Weight for return interval **n,** RI_n = Inverse Return Interval n, and RI_{n+1} = Inverse Return Interval n+1.
4. **Average Annualized Depth Summarization** – Average annualized depth (AAD) for each point or polygon is computed by the sum product of the average flood depth and probability weights. The AAD at each point and polygon is calculated for all four-time horizons 2020, 2040, 2060, and 2080.
5. **Summarizing AAD** – When summarizing AAD to a geography, the resultant value is the expected cumulative depth of flooding across all assets for a given year. This process helps to account for the relative variation in hazard exposure between assets in flood-prone areas.

3.2.6. LOSS OF LAND

Loss of land, or land lost, is a vulnerability metric that captures the projected changes in the acreage of land area for a given time horizon relative to a 2020 baseline. This metric is particularly useful for summarizing impacts when the land has unique value, such as tribal reservations and agricultural areas. Figure 17 illustrates the inputs, key processes, and results in calculating the loss of land.

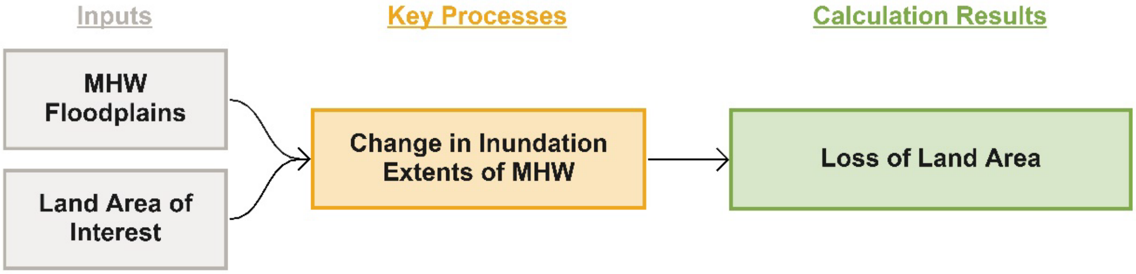

Figure 17: Summary of key inputs, processes, and results for calculating loss of land.

For this assessment, the land is considered fully inundated and therefore effectively "lost" if it falls within the MHW floodplain.

The process for calculating that is described below:

1. **Identification of Baseline Conditions** – Areas not inundated by the 2020 MHW floodplain are considered baseline land area that all subsequent time horizons are compared to.
2. **Non-Inundated Land Area** – Areas of interest are intersected with the 2040, 2060, and 2080 MHW floodplains to calculate the land area inside and outside the floodplain.
3. **Change in Land Area** – Change in land area, calculated in acres, is found by subtracting the non-inundated land area associated with a given time horizon from the baseline condition land area in the geography of interest.

A secondary risk metric, **Annualized Inundated Acres**, was calculated to highlight land loss impacts based on the AEP. This metric provides a measure of the land lost based on an asset's exposure to a range of flood elevations and their associated annual probabilities. It is calculated as a product of the land lost metric and the AEP. This approach highlights the varying impacts of flood event probabilities on land losses.

3.2.7. LOSS OF NATURAL BEACHES, DUNES, UPLAND, AND RECREATIONAL AREAS

Exposure of existing beaches and dunes, non-tidal wetland habitats, adjacent upland habitats, and public conservation lands (e.g., recreational areas) is estimated similarly to the loss of land metric. However, these areas are considered to be fully inundated if they fall within the future MLW floodplain.

LIMITATIONS OF LOSS OF NATURAL BEACHES APPROACH

This approach has several limitations, which could be addressed in future iterations of the CRMP. In reality, beaches and dune systems will respond to SLR in a much more dynamic way than represented in the current impact assessment. For example, beaches and dune systems can migrate landward similar to migrating marshes, given proper sediment supply and adequate room for retreat. These complex and dynamic processes were not accounted for in this assessment, and therefore likely overpredict the loss of these systems in response to SLR.

3.2.8. LOSS OF TIDAL WETLAND HABITAT

This vulnerability metric captures wetland habitat areas that are anticipated to be permanently lost to inundation as a result of the transition from tidal marsh to open water. Figure 18 below illustrates the inputs, key processes, and results in calculating the loss of wetland habitat.

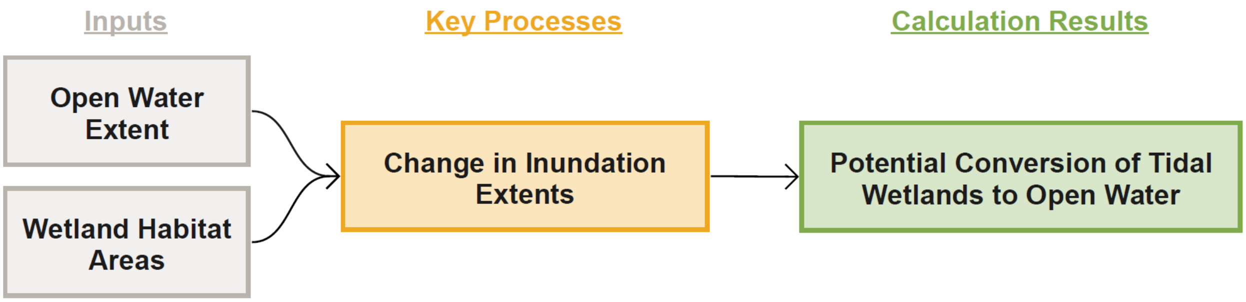

Figure 18: Summary of key inputs, processes, and results for calculating loss of wetland habitat.

Conversion of Wetlands to Open Water – Several existing landscape change models were reviewed to identify conversion areas, including Sea Level Rise Affecting Marshes Model (SLAMM) outputs, VIMS tidal marsh modeling outputs, and the National Oceanic and Atmospheric (NOAA) marsh migration mapping. NOAA's marsh mapping outputs were used because they were the only readily available statewide coverage of coastal land cover change modeling that closely aligned with CRMP SLR scenarios.

NOAA's marsh migration mapping is a modified bathtub approach that attempts to account for local and regional tidal variability and accretion.[10] The 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. As sea level rises, higher elevations will become more frequently inundated, allowing for marsh migration landward. At the same time, some lower-lying areas will be inundated so frequently that the marshes will no longer be able to thrive, becoming lost to open water.

LAND COVER CHANGE MODELING LIMITATIONS

The approach to mapping the conversion and loss of wetland habitat has several limitations. Firstly, it does not incorporate future changes in coastal geomorphology or account for development pressures. Modeling the response of tidal wetlands to sea level rise requires sophisticated calculations that consider multiple factors, including land slope, and sediment accretion, erosion, among others. However, simple land cover change models can identify areas that are vulnerable to habitat damage or loss.

The land cover change model assumes that specific types of wetlands can exist with a certain amount of water and salinity. As sea levels rise, low-lying wetlands may become inundated frequently enough that the ecosystem is effectively "lost" to open water. Wetlands at higher elevations may experience more frequent inundation but may be able to migrate landward.

Future iterations of the Master Plan will look to refine tidal marsh modeling by leveraging ongoing work by the University of Virginia Department of Environmental Sciences and using Commonwealth specific datasets, for example from the Virginia Institute of Marine Science (VIMS).

NOAA's marsh migration mapping provides baseline conditions and predicts future habitat coverage based on rising sea levels. The data is available in half-foot increments of

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[10] Note – Accretion is the vertical rise of the marsh's surface due to buildup of organic and inorganic matter. The amount of accretion is a result of sediment delivery and deposition dynamics that occur at an individual site. For purposes of the NOAA coast-wide marsh migration mapping, accretion is handled as a simple "flat" value across the study site and assumes no accretion (0 mm per year), leading to an overestimation of marsh loss. In reality, accretion rates are likely highly variable across habitat types and across individual geographies across coastal Virginia.

net sea level change from 0 to 10 feet. The process for calculating the potential conversion of tidal marsh to open water is described below:

1. **Scenario Selection** – Select the 0.5-foot increment that most closely aligns with the CRMP SLR Scenario (NOAA 2017 Intermediate-High), as shown in Table 10 below:

Table 10: 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

2. **Simplified Classification Schema** – Habitat types from the NOAA product represent a simplified version of NOAA's Regional Coastal Change Analysis Program (C-CAP) land cover classification schema, removing details in upland features to emphasize wetland areas. For purposes of this assessment, this schema was further simplified to focus only on tidal marshes and open water,[11] defined as follows:
    a. **Salt Marsh**: Includes all tidal wetland vegetation that occurs in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Salt marsh is assumed to exist between the meant tide level (MTL) and mean high water (MHW).
    b. **Brackish/Transitional Marsh**: Brackish, or transitional, the marsh is not a C-CAP class and is therefore not mapped within the current condition. However, NOAA included this class to highlight transition areas between salt and freshwater marsh, as identified based on the elevation-based rule that defines brackish/transitional marsh occupying the zone between MHW and the mean high water spring[12].

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[11] Note – While tidal freshwater marsh is vulnerable to sea level rise, this habitat type was not included in this assessment. Consultation with VIMS indicated that the C-CAP data does not accurately characterize location and extents of existing tidal freshwater marsh.

[12] NOAA. (2017). Office for Coastal Management. Detailed Method for Mapping Sea Level Rise Marsh Migration. Retrieved from https://coast.noaa.gov/data/digitalcoast/pdf/slr-marsh-migration-methods.pdf

    c. **Open Water**: Includes areas of open water, defined as having less than 25 percent cover of vegetation or soil.

3. **Intersections** – To represent the conversion of tidal marsh to open water, the future open water area was intersected with the existing tidal marsh area. For example, to map tidal marsh lost by 2060, the marsh area from 2040 would be interested with open water in 2060.
4. **Compute Land Coverage Conversion** – Area (in acres) of open water features in each time horizon (baseline, 2040, 2060, and 2080) was calculated, and the difference in the area was used to represent future changes in open water.

3.2.9. LOSS OF SUBMERGED AQUATIC VEGETATION (SAV) HABITAT

This vulnerability metric captures SAV habitat areas that are anticipated to be permanently lost due to deeper water levels. Figure 19 below illustrates the inputs, key processes, and results in calculating the loss of SAV habitat.

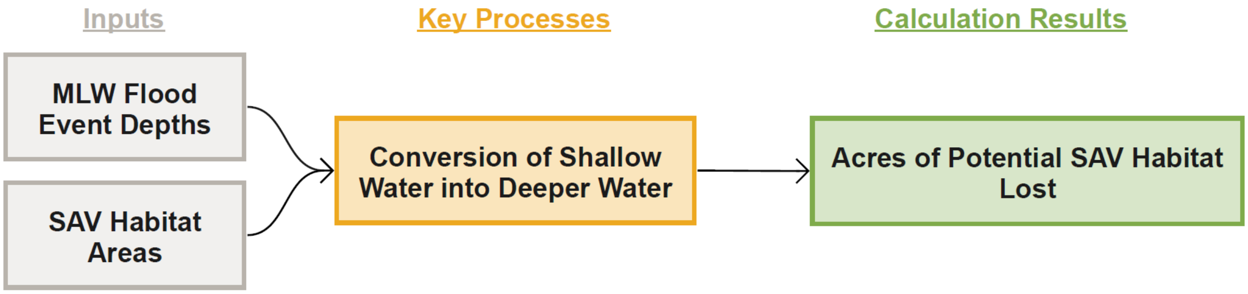

Figure 19: Summary of key inputs, processes, and results for calculating loss of SAV habitat.

Conversion of Shallow Water into Deeper Water – VIMS provided the study team with a composite of current potential SAV distribution, which represents a combination of the annual survey data from the SAV Program at VIMS from 2015 through 2019. A modified version of the VIMS methodology for evaluating shifts in currently existing submerged aquatic vegetation in responses to climate change[13] was leveraged for the analysis. The VIMS SAV habitat model assumes that SAV habitats with water depths greater than or equal to 2m are considered unsuitable for SAV survival. In alignment with this approach, the process for calculating acres of lost SAV habitat in response to sea level rise is described below:

1. **Extraction** – The area between 0 and 2m was extracted from the Mean Low Water (MLW) depth grids produced as part of the coastal flood hazard modeling.
2. **Intersections** – The 0 to 2m zone was intersected with the composite SAV

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[13] Bilkovic, D. M, et. al. (2009). Vulnerability of Shallow Tidal Water Habitats in Virginia to Climate Change. Retrieved from http://www.ccrm.vims.edu/research/climate_change/COASTALHABITATS_FinalReport.pdf.

coverage to produce coverages of lost SAV after sea level rise events.

3. **Acreage Calculations** – The area of potentially lost SAV habitat was calculated.

3.2.10. LOSS OF OYSTER HABITAT

This vulnerability metric captures oyster habitat areas that are anticipated to be permanently lost due to deeper water levels. Figure 20 below illustrates the inputs, key processes, and results in calculating the loss of oyster habitat.

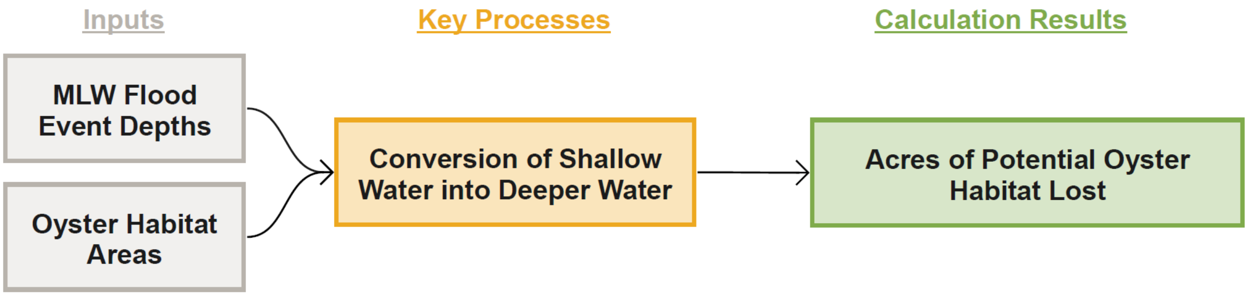

Figure 20: Summary of key inputs, processes, and results for calculating loss of oyster habitat.

Conversion of Shallow Water into Deeper Water – VIMS provided the study team with a dataset that delineates the location of oyster reefs, oyster sanctuaries, and oyster harvesting grounds. According to research compiled by the United States Department of Agriculture (USDA), the optimal water depth range for oyster reef habitat is between 0 and 3m[14]. Based on this threshold, water depths greater than or equal to 3m are considered unsuitable for oyster survival. The process for calculating acres of lost oyster habitat in response to sea level rise is described below:

1. **Extraction** – The area between 0 and 3m was extracted from the Mean Low Water (MLW) depth grids produced as part of the coastal flood hazard modeling.
2. **Intersections** – The 0 to 3m zone was intersected with the oyster habitat coverage to produce coverages of lost oyster habitat after sea level rise events.
3. **Acreage Calculations** – The area of potentially lost oyster habitat was calculated.

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[14] NRCS (2018). Eastern Oyster (Crassostrea virginica) Habitat Suitability. Retrieved from https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1466842&ext=pdf

FUTURE CONDITIONS IN OYSTER HABITAT

The approach for calculating oyster habitat loss is an approximation and has several limitations which could be addressed in future iterations of the CRMP, including accounting for changes in water temperature, salinity, and other factors.

3.2.11. SOCIAL VULNERABILITY

Social Vulnerability is a context metric that captures the degree to which a community exhibits certain social conditions—such as high poverty, low percentage of vehicle access, or crowded households—that may make a community more susceptible to human suffering and financial loss in the event of a disaster. Figure 21 below illustrates the inputs, key processes, and results in approximating social vulnerability.

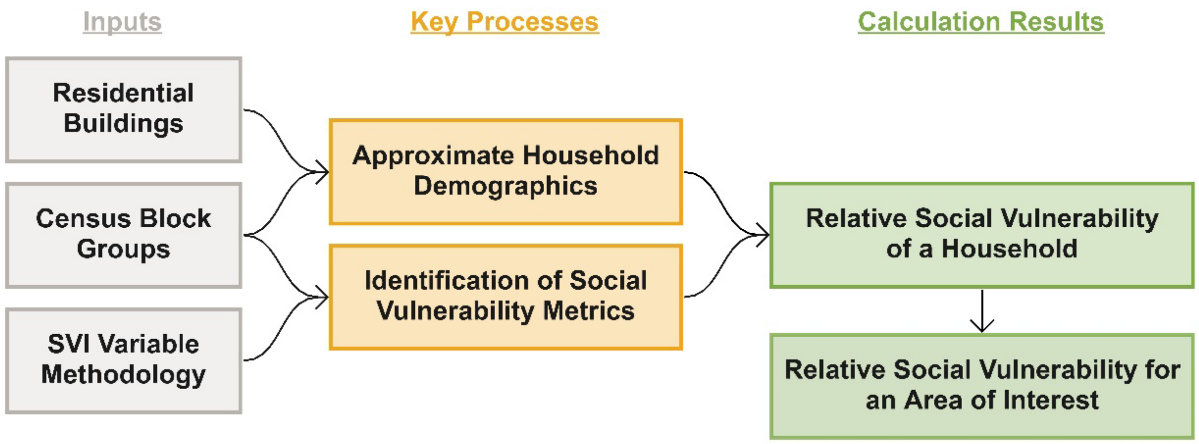

Figure 21: Summary of key inputs, processes, and results for calculating social vulnerability.

Several existing approaches and data sources to evaluate and quantify social vulnerability were reviewed, including:

- CDC/ATSDR Social Vulnerability Index (SVI)[15]
- HVRI's Social Vulnerability Index for the United States (SoVI®)[16]
- Demographic Indicators in EPA's Environmental Justice Screening and Mapping Tool

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[15] Centers for Disease Control and Prevention/ Agency for Toxic Substances and Disease Registry/ Geospatial Research, Analysis, and Services Program (2018). CDC/ATSDR Social Vulnerability Index. Retrieved from https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

[16] University of South Carolina, Hazards and Vulnerability Research Institute (2014). Retrieved from http://artsandsciences.sc.edu/geog/hvri/sovi%C2%AE-0

(EJSCREEN)[17]

- Virginia Social Vulnerability Index, AdaptVA Viewer[18]

A review of the available data considered the breadth, publication date, and precision of the source datasets and the thoroughness of the accompanying methodology documentation. The indices leverage many analogous and overlapping variables, leading to similar high and low social vulnerability areas.

The SVI approach was selected to inform the CRMP social vulnerability analysis, partly because it was deemed the most publicly accessible and replicable. It is also increasingly accepted as an application input for federal agency grant programs as a federal dataset.

The SVI is calculated at the census tract level, but it is used at multiple geographies and some custom geographies to summarize social vulnerability metrics for this project. Mapping SVI value at the tract level to the other geographies at different resolutions will not reflect a precise estimation of social vulnerability. For use in the CRMP, 2018 ACS variables identified in the SVI were applied to residential structures using the attribution method described in Section 3.2.1. Then the general SVI analytics approach was applied to custom geographies of interest.

3.2.12. JURISDICTIONAL RESOURCES & CAPACITY

Jurisdictional Resources and Capacity is a context metric that indicates a community's available financial resources and technical abilities. This factor may affect a community's ability to implement measures that prevent human suffering and financial losses in the event of a disaster.

For this assessment, Jurisdictional Resource and Capacity was measured using the Fiscal Stress Index developed by the Virginia Department of Housing and Community Development's (DHCD) Commission on Local Government (CLG). The fiscal stress is the aggregation of analyses on the comparative revenue capacity, revenue effort, and median household income for Virginia's cities and counties and indicates a locality's ability to generate additional local revenues from its current tax base relative to the rest of the Commonwealth.[19] It is assumed that these cross-jurisdictional inequities are largely a result

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[17] U.S. Environmental Protection Agency (n.d.). EJSCREEN: Environmental Justice Screening and Mapping Tool. Retrieved from https://www.epa.gov/ejscreen/overview-demographic-indicators-ejscreen

[18] Center for Coastal Resources Management and Virginia Institute of Marine Science (2017). AdaptVA Viewer: Virginia Social Vulnerability Index. Retrieved from http://cmap2.vims.edu/SocialVulnerability/Documents/Metadata_descriptions_for_the_SV_viewer.pdf

[19] Virginia Commission on Local Government, Report on Comparative Revenue Capacity, Revenue Effort, and Fiscal Stress of Virginia's Cities and Counties, FY 2018. Available here: https://www.dhcd.virginia.gov/sites/default/files/Docx/clg/fiscal-stress/fiscal-stress-report.pdf

of historic and present disadvantages that reduce a community’s capacity for resilience planning and project implementation.

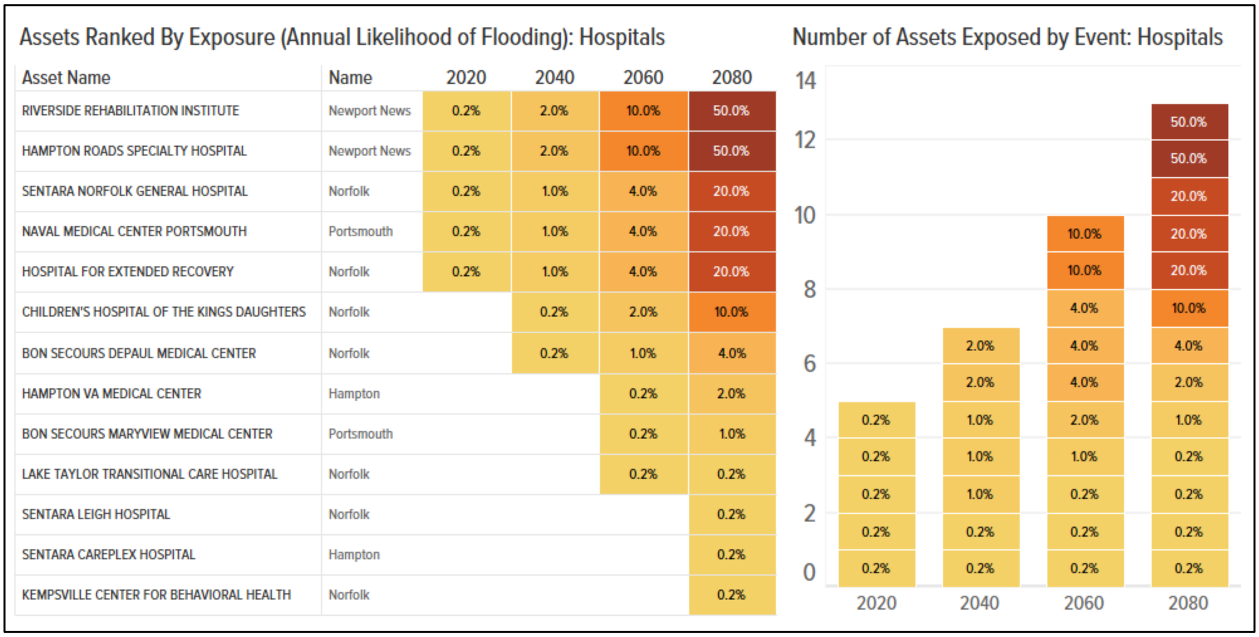
In the future, this metric could be supplemented with additional variables acquired through CRMP surveys and outreach efforts. Those variables may include binary thresholds, such as whether a jurisdiction reported voluntarily completing a resilience plan or participating in the Community Rating System. The inclusion of these variables depends on the timeline of future surveys and public outreach, as well as the quality of data received through these efforts.

3.3. RESULTS AND SUMMARIZATION

3.3.1. SPATIAL ANALYTICS FRAMEWORK

The primary results of the impact analysis will be in the form of impact-attributed Asset Tables and Summarization Tables.

Asset Tables – Most Impact metrics and relevant contextual information will be captured at the asset level. Point, line, and/or polygon layers for each asset type are joined with the relevant impact metrics used in the scoring and contextual analysis. This information will be used for project evaluation and other quantitative assessment. An example of the type of analytics that can be performed with a given asset table is provided in Figure 22.



Assets Ranked By Exposure (Annual Likelihood of Flooding): Hospitals

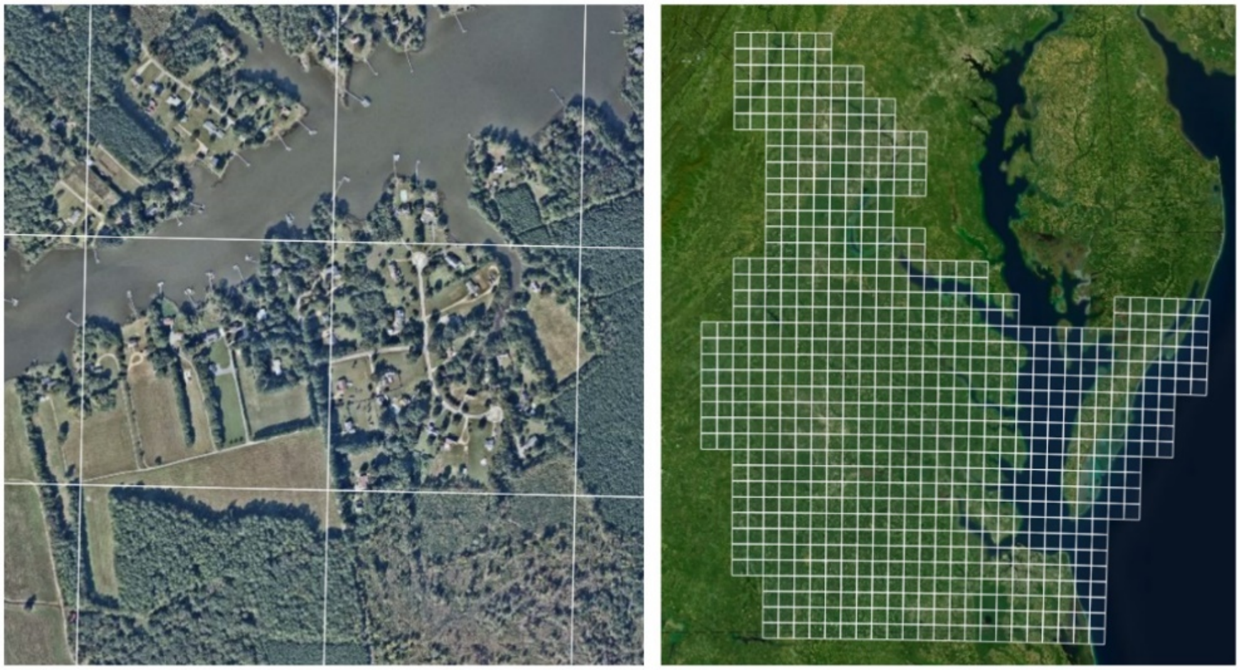
Asset Name	Name	2020	2040	2060	2080
RIVERSIDE REHABILITATION INSTITUTE	Newport News	0.2%	2.0%	10.0%	50.0%
HAMPTON ROADS SPECIALTY HOSPITAL	Newport News	0.2%	2.0%	10.0%	50.0%
SENTARA NORFOLK GENERAL HOSPITAL	Norfolk	0.2%	1.0%	4.0%	20.0%
NAVAL MEDICAL CENTER PORTSMOUTH	Portsmouth	0.2%	1.0%	4.0%	20.0%
HOSPITAL FOR EXTENDED RECOVERY	Norfolk	0.2%	1.0%	4.0%	20.0%
CHILDREN'S HOSPITAL OF THE KINGS DAUGHTERS	Norfolk		0.2%	2.0%	10.0%
BON SECOURS DEPAUL MEDICAL CENTER	Norfolk		0.2%	1.0%	4.0%
HAMPTON VA MEDICAL CENTER	Hampton			0.2%	2.0%
BON SECOURS MARYVIEW MEDICAL CENTER	Portsmouth			0.2%	1.0%
LAKE TAYLOR TRANSITIONAL CARE HOSPITAL	Norfolk			0.2%	0.2%
SENTARA LEIGH HOSPITAL	Norfolk				0.2%
SENTARA CAREPLEX HOSPITAL	Hampton				0.2%
KEMPSVILLE CENTER FOR BEHAVIORAL HEALTH	Norfolk				0.2%

Figure 22: Hospital exposure data derived from an asset table helps to compare impacts across events and/or facilities.

Summarization Tables – Assets' impact data will also be geographically aggregated across components and themes to support mapping, comparison, and gap analysis. Impact data will be aggregated and summarized across two main geography types:

- **Localities, Planning District/Regional Commissions, and Master Planning Regions.** These are widely used and understood jurisdictional boundaries, which have advantages for planning and communication. However, the wide variety of sizes and geometries of census block boundaries leads to challenges regarding standardized aggregation and comparison across units (people, structures, environmental features, etc.).
- **Gridded summarization:** A gridded summary facilitates a standardized framework for cross-jurisdictional analysis and comparison. Reference Grid Cells used in this analysis exist at four nested levels of detail, designed to align with the gridded boundaries of the flood hazard models. Grid-based summaries by theme will also allow for the quantitative identification of impact “hot spots” and facilitate a gap analysis to identify areas underserved by existing and proposed projects.

The flood hazard model has a tiling schema that is 55,000 ft x 55,000 ft, and so reference grid cells were designed as fractions of those tiles. **Reference Grid A is 1,375 ft x 1,375 ft per cell** and is the smallest, including 296,000 grid cells to cover the study area. This grid will be useful for examining the distribution of impacts within a smaller geographic area and identifying micro impact “hot spots.” **Reference Grid D is 27,500 ft × 27,500 ft per cell**, and the largest including 740 grid cells. This grid may be most useful for visualizing the distribution of impacts across all Coastal Virginia and summarizing impact data for public communication. **Reference Grid B is 6,875 ft × 6,875 ft per cell**, and **Reference Grid C is 13,750 ft × 13,750 ft per cell**.



Reference Grid A – Zoomed In

Reference Grid D – Full Extent

Figure 23: Examples of Reference Grid Scales, most useful for different scales of visualization.

In order to facilitate these summaries, point/line/polygon data will be pre-aggregated across the smallest reference grid and then rolled up as needed to any larger geography of interest. This pre-aggregation of the asset data into geospatial segments allows for quicker on-the-fly summaries and data analytics as data can be processed using tabular calculations rather than geospatial processing. Figure 24 illustrates how grid and census summaries are nested to facilitate faster analytical processes.

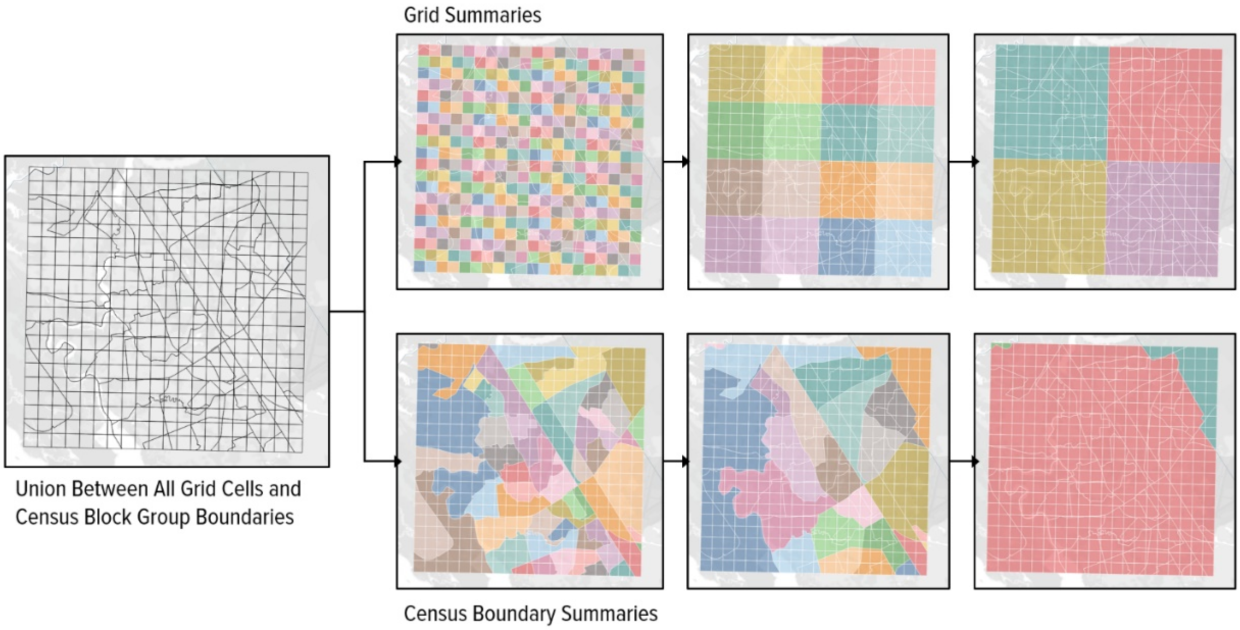
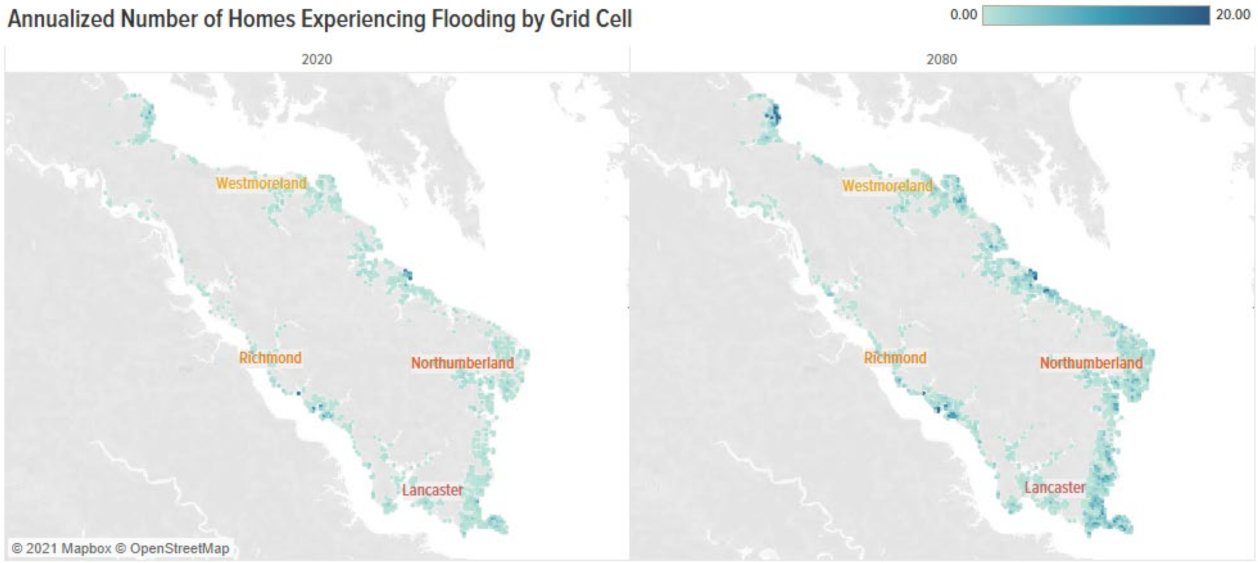


Figure 24: Illustration of how segmented geographic areas facilitate flexible data roll-up- either at CBG/county/PDC or standardized grid cells.

An example of the type of analytics that can be performed with a summarization table is provided in Figure 25.



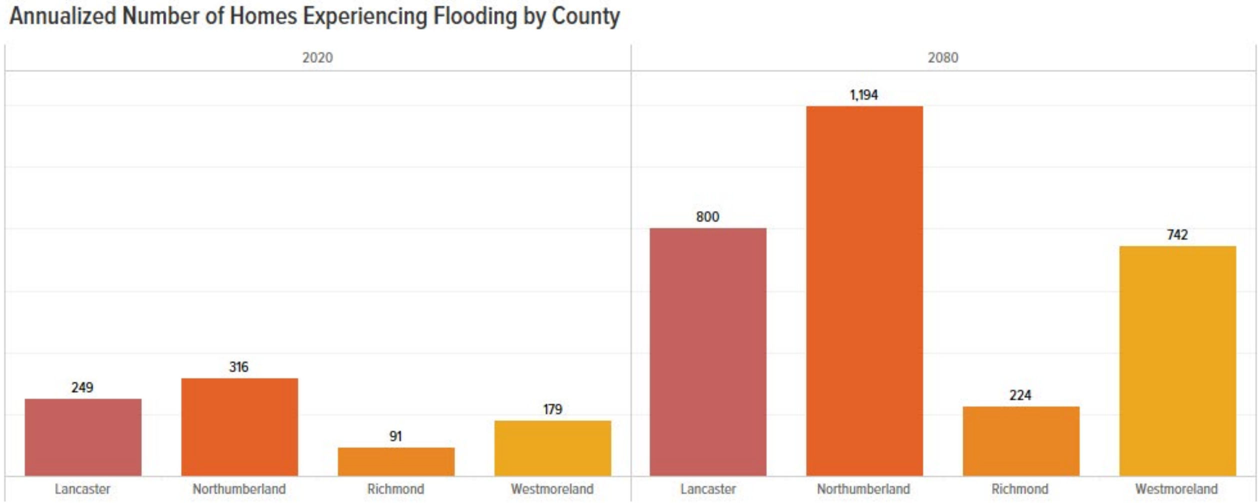


Figure 25: Annualized number of homes experiencing flooding in 2020 and 2080, summarized by grid cell and county across the counties of Lancaster, Northumberland, Richmond, and Westmoreland.

3.3.2. AGGREGATION & SCORING

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 between 0 and 10. This conversion involves normalizing cumulative impact values for a specific asset type 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 census boundary or grid cell, component and theme scores were calculated using the process described below:

1. **Calculate Impact Type Scores**
    a. **Impact Metric Calculation** – Calculate raw impact or context metric for each asset input layer across each planning horizon. Impact metrics will have different units, and reflect either exposure, vulnerability, or risk, depending on data available. Some impact types will have multiple components based on types of assets considered. The specific metric used for each impact type is described in Table 1, Table 2, and Table 3.
    b. **Aggregation by Geographic Unit** – Sum all raw impact metrics by type within the geographic unit (grid cell or census-based boundary) across each planning horizon.
    c. **Raw Value to Score Conversion** – Normalize values across geographic units to a range between 0 to 10. 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 score was calculated through averaging across components.

2. **Generate Impact Theme Scores**
    a. **Impact Score Aggregation** – Impact scores were summed within the four Impact assessment themes for each geographic unit and time horizon.
    b. **Score Conversion** – Normalize values to generate an Impact Theme Score between 0 and 10 for geographic unit and time horizon. This score can be used to generate a choropleth “heat-map” and other analyses.
3. **Cluster Scores**

Geographic units will include both raw values and score conversions, so users will be able to view either or both as needed.

3.3.3. CONVERSION OF RAW SCORES TO RELATIVE RANKINGS

This impact assessment uses the best available data to calculate a raw impact score for several impact types (e.g., themes, components, sub-components). The raw impact score ranges from 0 to 10, with lower values indicating lower impacts and higher values indicating higher Impacts. A raw score of 0 is a “null” score, which indicates that data was insufficient to complete the impact calculation.

The range and distribution of raw scores vary significantly between categories, making it difficult to use raw scores alone to prioritize impact “hot spots” for adaptation planning . For example, in some categories, most of the raw scores are grouped between 0 and 3, so a raw score of 5 is a highly vulnerable outlier. In other categories, the raw scores are distributed more evenly from 0 to 10, so a raw score of 5 is not significantly vulnerable relative to its peers.

The raw scores were therefore used to calculate three additional “relative rankings” to better understand relative priority areas within each impact type, time horizon, and geographic area of interest. Three methods were used to calculate relative rankings: percentile rank, quintile rank, and clustered rank:

- **Percentile rank** is the percentage of scores within a given category that are lower than a given score. For example, a percentile rank of 50% indicates that half of all raw scores are less than the given score in its category. In identical scores, the percentile rank is the average of the percentile rank of the identical scores.
- **Quintile rank** is 1 if the percentile rank is 0% -20%, 2 if the percentile rank is 20%-40%, 3 if the percentile rank is 40%-60%, 4 if the percentile rank is 60%-80%, and 5 if the percentile rank is 80%-100%. In other words, the lowest one-fifth of raw scores within a given category are assigned a quintile rank of 1, the highest one-fifth are assigned a quintile rank of 5, and so forth for values in between.
- **Clustered rank** uses the k-means clustering algorithm to separate raw scores within a given category into the 5 most similar groups or “clusters” based on their value.[20] The cluster with the lowest raw scores is assigned a rank of 1, the next lowest a rank of 2, and so forth. The cluster with the highest raw scores is assigned a rank of 5 and is typically composed of a small number of high-scoring outliers. Therefore, the clustered rank can be especially useful for identifying vulnerability hot spots.

Each ranking was calculated three times: relative to the entire coastal region, relative to each planning district or regional commission, and relative to each locality. This adds flexibility to identify local and regional “hot spots” in addition to statewide “hotspots”.

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[20] The k-means clustering algorithm partitions the raw scores into 5 groups in a manner that minimizes within-cluster variances (i.e., squared Euclidian distances). K-means clustering (also known as natural breaks) is widely used for qualitative data analysis and relative risk categorization (e.g., FEMA’s National Risk Index). For computational details see Arthur and Vassilvitskii (2006). The clustering was implemented using the open source KMeans module in the Scikit Learn python package (link).

Rankings are also not calculated relative to each time horizon, but rather consider raw impact scores across all time horizons. This allows for the rankings to capture the ways relative impacts and "hotspots" grow over time as raw scores increase. For a given impact type, more 5s would be expected in 2080 than in 2020, and if impacts grow significantly over time, it is possible that no 5s would appear at all in 2020 or 2040 time horizon. Note that raw scores with a value of 0 (i.e., null scores) were assigned a percentile rank, quintile rank, and clustered rank of 0. They were excluded from the relative rankings.

3.3.4. DATA ACCESS

With the impact assessment completed, the CRMP will move towards risk summarization, empowering storytelling about the evolving coastal risk landscape in the Commonwealth. Specifically, data access will support the provision of the following capabilities:

- Tabular summaries of vulnerable populations, aggregated socio-demographically, geographically, and jurisdictionally.
- Tabular summaries of vulnerable critical infrastructure based on type, geography, and jurisdiction.
- Tabular summaries of vulnerable natural infrastructure based on type, geography, and jurisdiction.

Subsequent data publishing will occur through ArcGIS Web Services as well.

3.3.5. RESULTS DISCLAIMER

Note that the impact assessment's results are provisional and subject to change. Likewise, any summaries and interpretations based on the impact assessment results are also subject to change. Data sources and metrics may change in future iterations, depending on accuracy, resolution, and other attributes that affect processing and applications.

4. DATA CATALOG

COMMUNITY RESOURCES THEME

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
Businesses & Employers	Agricultural Lands	Agricultural Parcels	LightBox	2021	
	Public & Commercial Structures	Agricultural Structures (Content Damages)	Multiple Sources*	--	*Data was sourced from OpenStreetMap, CityGML, Lightbox, Old Dominion University (ODU), USACE, and Hampton Roads PDC, then compiled and enhanced in targeted locations by Dewberry in a process described in Table 4.
		Agricultural Structures (Exposure)	Multiple Sources*	--	
		Agricultural Structures (Structure Damages)	Multiple Sources*	--	
		Commercial Structures (Content Damages)	Multiple Sources*	--	
		Commercial Structures (Exposure)	Multiple Sources*	--	
		Commercial Structures (Structure Damages)	Multiple Sources*	--	
		Educational Structures (Content Damages)	Multiple Sources*	--	
		Educational Structures (Exposure)	Multiple Sources*	--	
		Educational Structures (Structure Damages)	Multiple Sources*	--	
		Industrial Structures (Content Damages)	Multiple Sources*	--	
		Industrial Structures (Exposure)	Multiple Sources*	--	

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
		Industrial Structures (Structure Damages)	Multiple Sources*	--	
		Religious Structures (Content Damages)	Multiple Sources*	--	
		Religious Structures (Exposure)	Multiple Sources*	--	
		Religious Structures (Structure Damages)	Multiple Sources*	--	
Residential Neighborhoods	Residential Displacement	Residential Structures (Pop Displaced)	ACS	2018	
	Residential Exposure	Residential Structures (Pop Exposed)	ACS	2018	
	Residential Structures	Residential Structures (Content Damages)	Multiple Sources*	--	
		Residential Structures (Exposure)	Multiple Sources*	--	
		Residential Structures (Structure Damages)	Multiple Sources*	--	
Tribal Resources	Tribal-Owned Lands	Tribal Owned Land (Lost)	Census Bureau	2020	
		Tribal-Owned Land (Inundated)	Census Bureau	2020	

CRITICAL SECTOR THEME

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
Commercial & Manufacturing	Commercial	Commercial Buildings	Multiple Sources*	--	*Data is from Dewberry, Old Dominion University (ODU), USACE, Hampton Roads PDC, OpenStreetMap, CityGML and Lightbox and is described in Table 4.
		Commercial Parcels	LightBox	2021	
	Manufacturing	Biological Products Manufacturing Facilities	HIFLD – HSIP Gold 2015	2015	
		Chemical Manufacturing Facilities	HIFLD – HSIP Gold 2015		
		General Manufacturing Facilities	HIFLD	2021	This dataset represents the entire Industrial PinPointer database of manufacturing companies.
		Nitrogenous Fertilizing Plants	HIFLD – HSIP Gold 2015		
		Pharmaceutical Preparation Manufacturing Plants	HIFLD – HSIP Gold 2015		
Communications	Broadband Internet	Broadband Radio Service and Educational Broadband Service Transmitters	HIFLD	2017	The Broadband Radio Service (BRS) is a commercial service. The Educational Broadband Service (EBS), formerly known as the Instructional Television Fixed Service (ITFS), is an educational service that has generally been used for the transmission of instructional material to accredited educational institutions and non-educational institutions.

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
	Phone, Radio, and TV	AM Transmissions Towers	HIFLD	2018	AM transmission tower locations as recorded by the Federal Communications Commission, extracted from the FCC Licensing Database.
		Cellular Towers	HIFLD	2021	This dataset represents cellular tower locations as recorded by the Federal Communications Commission
		FM Transmissions Towers	HIFLD	2018	This data represents FM transmission tower locations as recorded by the Federal Communications Commission.
		Land Mobile Broadcast Towers	HIFLD	2018	This dataset represents the Land Mobile Broadcast tower locations as recorded by the Federal Communications Commission.
		Land Mobile Commercial Transmission Towers	HIFLD	2018	This dataset represents Land Mobile Commercial transmission tower locations as recorded by the Federal Communications Commission, extracted from the FCC Licensing Database.
		Microwave Service Towers	HIFLD	2021	This dataset represents Microwave Service Towers, which is a part of a communications system that uses a beam of radio waves in the microwave frequency range to transmit video, audio, or data between two locations.
		Paging Transmission Towers	HIFLD	2018	Paging transmission tower locations as recorded by the Federal Communications Commission, extracted from the FCC Licensing Database.
		TV Analog Transmitters	HIFLD	2018	This dataset represents the locations of television analog station transmitters.

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
Defense Industry	Defense	Department of Defense Sites Points (Public)	HIFLD	2021	This geospatial dataset contains the authoritative point locations and (where available) boundaries of Department of Defense sites, commonly referred to as installations, ranges, training areas, bases, forts, camps, armories, centers, etc. These installations are, in many cases, comprised of several subordinate sites.
		Department of Defense Federal Land (Inundated)	ESRI	2021	These lands include over 30 million acres managed by the Department of Defense.
		Department of Defense Federal Land (Lost)	ESRI	2021	These lands include over 30 million acres managed by the Department of Defense.
		National Security Government Military Facilities	HIFLD – HSIP Gold 2015		
Energy	Electricity	Electric Generating Units	HIFLD – HSIP Gold 2015		
		Electric Substations	HIFLD	2020	This feature class/shapefile represents electric power substations primarily associated with electric power transmission.
		Power Plants	HIFLD	2020	This feature class/shapefile represents electric power plants.
	Oil & Biofuel	Petroleum Ports	HIFLD	2019	This feature class/shapefile represents Petroleum Ports. This includes ports in the 50 states and the District of Columbia that handle 200 or more short tons per year in total volume (import and export) of petroleum products (URL: http://www.eia.gov/maps/layer_info-m.cfm).

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
		Petroleum Registered Tank Facilities	DEQ	2021	The GIS layer shows AST/UST Tank Facilities registered with DEQ.
		Petroleum Release Sites	DEQ	2021	The GIS layer shows confirmed petroleum releases reported to DEQ.
		Petroleum Terminals	HIFLD	2020	This feature class/shapefile represents Petroleum Terminals.
Government Facilities	Education Facilities	Child Care Centers	HIFLD	2020	This feature class/shapefile contains locations of child day care centers for the 50 states of the USA, Washington D.C., and Puerto Rico.
		Colleges and Universities	HIFLD	2020	The Colleges and Universities feature class/shapefile is composed of all Post-Secondary Education facilities as defined by the Integrated Post-Secondary Education System (IPEDS, http://nces.ed.gov/ipeds/), National Center for Education Statistics (NCES, https://nces.ed.gov/), US Department of Education for the 2018-2019 school year.
		Private Schools (Pre-K to 12th)	HIFLD	2020	This Private Schools feature dataset is composed of private elementary and secondary education facilities in the United States as defined by the Private School Survey (PSS, https://nces.ed.gov/surveys/pss/), National Center for Education Statistics (NCES, https://nces.ed.gov), US Department of Education for the 2017-2018 school year.

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
		Public Schools (K to 12th)	HIFLD	2020	This Public Schools feature dataset is composed of all Public elementary and secondary education facilities in the United States as defined by the Common Core of Data (CCD, https://nces.ed.gov/ccd/), National Center for Education Statistics (NCES, https://nces.ed.gov), US Department of Education for the 2017-2018 school year.
	Federal Government Facilities	Federal Bureau of Investigation (FBI) Offices	HIFLD – HSIP Gold 2015		
		General Services Administration (GSA) Owned or Leased Properties	HIFLD – HSIP Gold 2015		
		National Guard Readiness Centers	HIFLD – HSIP Gold 2015		
		Space Research and Technology Facilities	HIFLD – HSIP Gold 2015		
		U.S. Army Corps of Engineers (USACE) Offices	HIFLD – HSIP Gold 2015		
	State and Local Government Facilities	Courthouses	HIFLD	2019	To document the spatial location and physical address of U.S. county courthouses, state supreme courthouses, and the Supreme Court of the United States for general cartographic representation purposes on USGS mapping products at a 1:24,000 scale.
		Major State Government Buildings[21]	HIFLD	2019	This dataset represents the locations of buildings or properties that are owned or leased by state level governments.

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[21] All state-owned buildings with known spatial information were assessed for exposure. Only Major Government Buildings from HIFLD are included in the reported outputs of this asset type.

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
Health & Emergency Services	Emergency Services	Emergency Medical Service Stations	HIFLD	2019	This dataset represents the EMS stations of any location where emergency medical service (EMS) personnel are stationed or based out of, or where equipment that such personnel use in carrying out their jobs is stored for ready use.
		Fire Stations	HIFLD	2020	To document the spatial location of fire stations in the U.S. for general cartographic purposes on USGS mapping products at 1:24,000 scale.
		Local Emergency Operations Centers	HIFLD	2021	HSIP Local Emergency Operations Centers in the United States "The physical location at which the coordination of information and resources to support domestic incident management activities normally takes place.
		Local Law Enforcement Locations	HIFLD	2021	This feature class/ shapefile contains law enforcement agencies as defined by the US Department of Justice - Bureau of Justice Statistics for the Homeland Infrastructure Foundation-Level Data (HIFLD) database.
	Health	Hospitals	HIFLD	2020	This feature class/shapefile contains locations of Hospitals for 50 US states, Washington D.C., US territories of Puerto Rico, Guam, American Samoa, Northern Mariana Islands, Palau, and Virgin Islands.
Transportation	Airports	Airports	FAA	2021	Airport locations.
	Freight, Ports, and Shipping Facilities	Amtrak Stations	HIFLD	2020	This dataset represents Amtrak intercity railroad passenger terminals in the United States and Canada.
		DHL Facilities	HIFLD	2017	This data set displays the physical locations of DHL facilities.

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
		FedEx Facilities	HIFLD	2017	This dataset displays the physical locations of FedEx facilities.
		Intermodal Freight Facilities - Rail TOFC/COFC	HIFLD	2020	The Major TOFC/COFC Rail Intermodal Facilities dataset is current as of December 10, 2018 and is part of the U.S. Department of Transportation (USDOT), Bureau of Transportation Statistics' (BTS) National Transportation Atlas Database (NTAD).
		Port Facilities	HIFLD	2020	This dataset represents port facilities and provides physical information on commercial facilities at U.S. coastal, Great Lakes and inland ports.
		Port of Virginia Facilities	VEDP	2020	This layer contains locations for all active Port of Virginia facilities. These facilities are all managed by the Virginia Port Authority.
		Private Non-Retail Shipping Facilities	HIFLD	2017	The companies represented in this dataset are involved in the parcel delivery / courier service business or the freight service provider business.
		Railways	VGIN	2020	The purpose of this data is to provide a geographic representation of the location of existing rail in Virginia.
		UPS Facilities	HIFLD	2017	This dataset represents the geospatial locations of United Parcel Service (UPS) facilities across the United States.
		U.S. Postal Service (USPS) Post Offices	HIFLD – HSIP Gold 2015	2015	
		U.S. Postal Service (USPS) Processing Centers	HIFLD – HSIP Gold 2015	2015	
	Roads	Bridges & Culverts	VDOT	2014	This feature class consists of point features which represent physical structures that

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
					Interstate, Primary, Secondary and Urban roads travel under or over on all Virginia Department of Transportation maintained roadways.
		LRS Road Intersections	VDOT	2021	This feature class consists of approximately 430,000 features representing roadway intersections throughout the State of Virginia.
		VDOT Roadway Centerlines (Exposure and Depth)	VGIN/VDOT	2021	
Water, Waste & Wastewater	Waste	Hazardous Waste Generators	DEQ	2020	The Resource Conservation and Recovery Act Information System (RCRAInfo) is EPA's comprehensive information system in support of the Resource Conservation and Recovery Act (RCRA) of 1976 and the Hazardous and Solid Waste Amendments (HSWA) of 1984. It tracks many types of information about generators, transporters, treaters, storers, and disposers of hazardous waste.
		Solid Waste Facilities	DEQ	2020	The GIS layer shows Solid Waste Facilities permitted with DEQ.
	Wastewater	Biosolid Areas	DEQ	2021	Boundary of permitted sites that includes one or more land application fields and may include setback areas or other areas not authorized for land application of biosolids and/or other residuals.
		Septic Systems	VDH	--	Septic system locations.
		Wastewater Treatment Facilities	DEQ	2021	Wastewater treatment facility locations.
	Water	Drinking Water Wells	COV	--	Drinking water well locations.

NATURAL INFRASTRUCTURE THEME

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
Aquatic Habitat	Oyster Habitat	Oyster Habitat	VIMS	2019	VIMS developed a coverage of oyster reef restoration sites in Virginia Portions of the Chesapeake Bay. This layer also presents oyster sanctuaries along Virginia's Eastern Shore and State and private oyster leasing grounds.
	SAV Habitat	SAV Habitat	VIMS	2020	The 2019 Chesapeake Bay SAV Coverage was mapped from digital multispectral imagery with a 25cm GSD to assess water quality in the Bay.
Beaches & Dunes	Beaches & Dunes	Beaches & Dunes	VIMS	2021	This dataset displays the physical coverage of existing beach and dune features, as delineated by the VIMS CCRM Shoreline Inventory.
Tidal Habitat	Wetland Habitat Loss	Marsh Habitat	NOAA	2020	These data were created as part of the National Oceanic and Atmospheric Administration Office for Coastal Management's efforts to map the potential distribution of each wetland type based on their

COMPONENT	SUB-COMPONENT	ASSET	SOURCE	DATE	DESCRIPTION
					elevation and how frequently they may be inundated under potential future SLR scenarios.
	Wetland Migration Prevention	Marsh Migration Conflicts	NOAA	2020	This dataset represents the areas that the NOAA marsh migration mapping intersects with areas of future development (using Coastal Change Analysis Program land cover data).
Upland Habitat	Non-Tidal Marsh	Non-Tidal Marsh Habitat	VIMS	2020	This dataset displays the physical coverage of non-tidal marsh located less than 10 feet in land elevation, including scrub-shrub wetlands, forested wetlands, and emergent wetlands.
	Upland Wooded Areas and Scrub-Shrub	Upland Wooded Areas and Scrub-Shrub	VIMS	2021	This dataset displays the physical coverage of upland wooded areas and upland scrub-shrub areas located less than 10 feet in land elevation.