A Regional Approach to Applying First Floor Elevation Data to Coastal Flooding Vulnerability Assessments in Hampton Roads

WR20-03 | November 2020
Grant #NA19NOS4190163 | Task 84

Hampton Roads PDC Planning District Commission
Virginia Coastal Zone Management Program

HAMPTON ROADS PLANNING DISTRICT COMMISSION

CHESAPEAKE
Steven Best
Debbie Ritter
Ella Ward
Christopher Price
Robert Geis

FRANKLIN
Frank Rabil
Amanda Jarratt

GLOUCESTER COUNTY
Phillip Bazzani
Brent Fedors

HAMPTON
Steve Brown
Donnie Tuck
Mary Bunting

ISLE OF WIGHT COUNTY
William McCarty
Randy Keaton, Treasurer

JAMES CITY COUNTY
Michael Hipple
Scott Stevens

NEWPORT NEWS
David Jenkins, Vice-Chair
McKinley Price
Cynthia Rohlf

NORFOLK
Kenneth Alexander
Courtney Doyle
Mamie Johnson
Andria McClellan, Chair
Larry “Chip” Filer

POQUOSON
Eugene Hunt
Randall Wheeler

PORTSMOUTH
John Rowe
LaVoris Pace

SMITHFIELD
Carter Williams
Michael Stallings

SOUTHAMPTON COUNTY
William Gillette
Michael Johnson

SUFFOLK
Leroy Bennett
Albert Moor

SURRY COUNTY
Robert Elliott
Melissa Rollins

VIRGINIA BEACH
Robert Dyer
Barbara Henley
Louis Jones
Guy Tower
Rosemary Wilson
Sabrina Wooten
Patrick Duhaney

WILLIAMSBURG
Douglas Pons
Andrew Trivette

YORK COUNTY
Sheila Noll
Neil Morgan

Robert A. Crum, Jr., Executive Director / Secretary

A Regional Approach to Applying First Floor Elevation Data to Coastal Flooding Vulnerability Assessments in Hampton Roads

This report was funded, in part, by the Virginia Coastal Zone Management Program
at the Virginia Department of Environmental Quality through
Grant #NA19NOS4190163 of the U.S Department of Commerce,
National Oceanic and Atmospheric Administration,
under the Coastal Zone Management Act of 1972, as amended.

The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S Department of Commerce, NOAA or any of its subagencies.

Federal financial assistance to this project amounted to $31,624,
approximately 50% of the total cost.

Preparation of this report was included in the HRPDC Unified Planning Work Program for FY2019-2020, approved by the Commission on May 16, 2019, and in the HRPDC FY2020 Extension Work Program, approved by the Commission on May 21, 2020.

Prepared by the staff of the
Hampton Roads Planning District Commission

NOVEMBER 2020

REPORT DOCUMENTATION

TITLE:
A Regional Approach to Applying First Floor Elevation Data to Coastal Flooding Vulnerability Assessments in Hampton Roads

REPORT DATE
November 2020

GRANT/SPONSORING AGENCY
DEQ/NOAA/LOCAL FUNDS

AUTHOR:
Ashley M. Gordon
Coastal Analyst
Email: agordon@hrpdcva.gov

ORGANIZATION NAME, ADDRESS AND TELEPHONE
Hampton Roads Planning District Commission
723 Woodlake Drive
Chesapeake, Virginia 23320
(757) 420-8300
http://www.hrpdcva.gov

ABSTRACT

This report documents the third of three phases of the Hampton Roads Planning District Commission's first floor elevation initiative. In this phase, first floor elevation (FFE) estimation methods and vulnerability assessment approaches evaluated in the first and second phase were expanded to support a regional analysis. To develop a regional first floor height (FFH) database, a suite of methods was applied in the following order of preference: (1) elevation certificate data/field survey data, (2) predictive model estimates, (3) stair counting, and (4) Hazus default estimates. The database was used in vulnerability assessments for the 1% annual chance flood with an additional 1.5ft and 3ft of sea level rise. Estimated building losses increased by more than double with 1.5ft sea level rise and by nearly six times the initial baseline for 3ft of sea level rise. Elevation certificates and survey data were critical to both this and other modeling efforts. This report recommends that localities maintain digital copies of elevation certificates to assist with floodplain management, vulnerability assessments, and opportunities to earn credit through the Community Rating System. The regional FFE database is designed to be adaptive and continued research and coordination across the Hampton Roads region will support coastal resiliency planning efforts.

ACKNOWLEDGEMENTS

This report was funded, in part, by the Virginia Coastal Zone Management Program at the Virginia Department of Environmental Quality through Grant # NA19NOS4190163 from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended. The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its sub-agencies.

This report was prepared by the Hampton Roads Planning District Commission (HRPDC) staff in cooperation with its member localities. Preparation of this report was included in the HRPDC Unified Work Program for FY2019-2020, approved by the Commission on May 16, 2019, and in the HRPDC FY2020 Extension Work Program, approved by the Commission on May 21, 2020.

Virginia Coastal Zone
MANAGEMENT PROGRAM

Table of Contents

Glossary of Acronyms

Term	*Acronym*	*Definition*
Base Flood Elevation	BFE	Elevation of surface water corresponding with the 1% annual chance flood (FEMA, 2020a).
First Floor Elevation	FFE	Elevation of a structure's first finished floor elevation, recorded in feet relative to the vertical datum.
First Floor Height	FFH	Height of first floor above the ground elevation (calculated as FFE – LAG), reported in feet.
Flood Assessment Structure Tool	FAST	FEMA Natural Hazards Risk Assessment Program open-source tool that analyzes site-specific flood losses (NHRAP – Hazus, 2020).
Flood Insurance Rate Map	FIRM	Official map delineating the flood zones within a community (FEMA, 2020b).
Hampton Roads Hazard Mitigation Plan	HMP	2017 regional hazard mitigation plan including flooding vulnerability analysis for Hampton Roads.
Lowest Adjacent Grade	LAG	Lowest land elevation adjacent to the structure, recorded in feet relative to the vertical datum.
Single-Family Residential Structure	RES1	Single-family residential structures with one or multiple stories. RES1 represents the code used by the FEMA Hazus software (FEMA Mitigation Division, 2017).
Special Flood Hazard Area	SFHA	Area corresponding to the 100-year, or 1% annual chance, flood event and where the National Flood Insurance Program regulations must be enforced (FEMA, 2020d).
User-Defined Facilities	UDF	Individual structure inventory with attributes compatible for input to FEMA's Hazus software (FEMA Mitigation Division, 2017).

Executive Summary

As the Hampton Roads region of southeastern Virginia continues to experience recurrent flooding, vulnerability assessments provide critical insights to inform local flood mitigation efforts. A key data set for assessing structural flood vulnerability is building finished first floor elevation (FFE). By comparing building FFEs to anticipated flood water levels, the depth of water within a structure can be determined and converted into dollar losses. Within the Hampton Roads region, elevation certificates are the primary source of FFE data; however, elevation certificates are available for approximately only 7% of residential structures in the Special Flood Hazard Area (SFHA). To address the FFE data gap, the Hampton Roads Planning District Commission (HRPDC) has undertaken a three-year effort to develop FFE data for application in flooding vulnerability assessments. This report documents the third year of the regional FFE effort.

During the first phase of the regional FFE data initiative, digital elevation certificates were collected from local governments to develop a geospatial database of elevation certificate data. This database, available on the HRPDC's regional GIS portal HRGEO.org, provides FFE measurements in a format that can readily be applied in flooding vulnerability assessments and spatial analysis. To estimate FFE for structures without elevation certificates, a predictive modeling approach was piloted in Chesapeake, Hampton, and York County (Gordon and McFarlane, 2019; Gordon, 2020). The models for each pilot community used building attributes, including foundation type and year built, and land elevation data to inform first floor height (FFE – lowest adjacent grade) predictions for residential structures in each community's SFHA, or the 1% annual chance floodplain (Gordon and McFarlane, 2019; Gordon, 2020). The first floor height (FFH) estimates were then applied in a flooding vulnerability assessment, which identified that changing FFH by less than a foot can increase or decrease flood damage estimates by hundreds of structures and millions of dollars (Gordon, 2020).

The HRPDC built upon this modeling approach and vulnerability assessments in the three pilot communities to produce the regional scale analysis documented in this report. The primary objectives included: (1) updating and expanding the online elevation certificate spatial database to include additional Hampton Roads localities, (2) developing a regional FFE database for single-family, residential structures that includes elevation certificate data, model predictions, and alternative FFE estimation methods, (3) applying the regional FFE database in a flooding vulnerability assessment that accounts for sea level rise, and (4) synthesizing results from the multi-year effort to inform recommended data management and data development methods.

First Floor Elevation Data Collection, Assessment, and Analysis

The regional elevation certificate GIS database was updated to include new elevation certificates completed since the previous 2019 data call, additional elevation certificates recently scanned by the city of Norfolk, and the complete inventory of Gloucester County elevation certificates. The elevation certificate inventory now includes approximately 4,000 elevation certificates from 12 Hampton Roads localities (HRGEO, 2020a). To develop FFH estimates for structures without an existing value in the SFHA, a suite of estimation methods was applied in the following order of preference: (1) predictive model estimates, (2) stair counting, and (3) Hazus default estimates. Newport News, Norfolk, and Virginia Beach had additional data sources available respectively from Old Dominion University, the U.S. Army Corp of Engineers, and Dewberry. The regional FFH database is focused on single-family residential structures and contains nearly 34,000 buildings from thirteen different Hampton Roads localities. Attributes required for the flooding vulnerability assessment were also recorded in the database, including building area, number of stories, foundation type, and estimated replacement cost.

Regional Coastal Hazard Vulnerability Assessment

The FFH estimates developed for the single-family residential structures within the SFHA were used in the following flooding scenarios: (1) 1% annual chance flood, (2) 1.5ft of sea level rise plus the 1% annual chance flood, (3) 3ft of sea level rise plus the 1% annual chance flood. For the 1% annual chance flood, both the custom-developed FFH estimates and FFH estimates based on Hazus default reference tables were applied. In agreement with the conclusions of the pilot community vulnerability assessment results, the regional scale vulnerability analysis supports that building damage estimates are highly sensitive to the FFH input. The regional custom FFH building damage estimate was only $1.3 million greater than the default FFH building damage estimate. However, the differences in individual localities were as large as $36.6 million. The overall difference in damage appears lower at the regional scale because the default FFH estimates do not always result in higher flood damage estimates for individual localities. The total absolute difference in damage between the custom and default FFH results across all localities is $122.5 million. Under the sea level rise scenarios, the estimated building losses increased with sea level rise for all localities. When accounting for 1.5ft of sea level rise, the overall estimated damages increased by more than double, and with 3ft of sea level rise, the total estimated damages were nearly six times the initial baseline damage estimate.

Recommended Practices for Data Management and Development

The multi-year regional FFE effort has provided insight into approaches for organizing and applying elevation certificate data and developing FFE estimates. Localities should maintain digital copies of elevation certificates to support earning credit in the National Flood Insurance Program's Community Rating System (CRS). The Hampton Roads elevation certificate inventory, hosted on HRGEO.org, can support localities in earning credit for two activities under the CRS (WEB3 under Activity 350 and AMD13 under Activity 440). In addition to the HRPDC inventory, interested localities could also host elevation certificate information on their local websites or GIS portals. Following the example of the Florida Division of Emergency Management, a streamlined approach of collecting elevation certificates and joining them to structure locations in GIS could be coordinated at the regional or state-level for long-term database management. When developing FFE inventories, existing survey data and building attribute data should be evaluated in addition to elevation certificates. As observed with the development of the HRPDC regional structure inventory, a combination of various methodologies, including predictive statistical modeling and imagery-based stair counting, can be applied. When determining what FFE estimation approaches may be suitable, tradeoffs between time, cost, required level of expertise, and data availability for each methodology should be considered.

Conclusions and Next Steps

Through the multi-year regional FFE initiative, various estimation methods and applications of FFE/FFH data in coastal flooding vulnerability assessments have been evaluated. Accurate FFH data is critical in developing flooding vulnerability assessments that influence long-term community planning decisions. By comparing building FFHs to anticipated flood water levels, the depth of water within a structure can be converted into dollar losses using depth-damage functions. These damage estimates are highly sensitive to the FFH input. The lessons learned through the regional FFE effort will serve as a resource for the upcoming Hampton Roads Hazard Mitigation Plan update, which is expected to be completed by April 2022. The regional FFE database is designed to be adaptive and continued research and coordination across the Hampton Roads region to improve FFE data will support coastal resiliency planning efforts.

I. Introduction

Coastal communities experience recurrent flooding resulting from precipitation events, high tide, and storm surge. Recurrent flooding within the Hampton Roads region of southeastern Virginia is predicted to become worse over planning horizons spanning at least the next 20-50 years, with sea level rise being a contributing factor (Mitchell et al., 2013). By 2040, approximately 127 square miles of present-day land area (including wetlands) and 78 miles of roadway are estimated to be flooded by sea level rise within Hampton Roads under the National Oceanic and Atmospheric Agency (NOAA) 2017 Intermediate-High scenario (CCRFR, 2020). To address this flood risk, Hampton Roads localities are actively developing and implementing projects to improve coastal resiliency, including over $1.2 billion in proposed projects (HRGEO, 2020b).

To support regional sea level rise adaptation, the Hampton Roads Planning District Commission[1] (HRPDC) adopted a resolution encouraging local governments within the region to adopt policies incorporating sea level rise into planning and engineering decisions (HRPDC, 2018a). The approved sea level rise planning policy recommends the following relative sea level rise scenarios, referenced to current mean higher high water (MHHW): (1) 1.5ft above MHHW for near-term decisions (2018-2050), 3ft above current MHHW for mid-term decisions (2050-2080), and (3) 4.5 ft above MHHW for long-term decisions (2080-2100) (HRPDC, 2018b). For individual projects, the policy recommends selecting a sea level rise scenario based on risk tolerance and associated costs (HRPDC, 2018b). While accounting for sea level rise in project design increases current project costs, these higher standards will likely result in future cost savings by reducing flood damage.

Flooding vulnerability assessments help inform flood mitigation project design by identifying areas with the greatest flood risk in the community. A critical data set for assessing structural flood vulnerability is building finished first floor elevation (FFE). For a given flooding scenario, the number of structures likely to experience damage is determined by comparing building FFEs to anticipated flood water levels. The depth of water within a structure can be converted into dollar losses using depth-damage functions, which relate flood depth to a percent of the structure's total replacement cost. Depth-damage functions vary based on the occupancy type of the structure, number of stories, and presence of a basement (FEMA Mitigation Division, 2017). Additional building attributes, including

[1] The Hampton Roads region includes seventeen localities in southeastern Virginia: Chesapeake, Franklin, Gloucester County, Hampton, Isle of Wight County, James City County, Newport News, Norfolk, Poquoson, Portsmouth, Southampton County, Suffolk, Surry County, Town of Smithfield, Virginia Beach, Williamsburg, and York County.

foundation type, also support flooding vulnerability assessments. For example, given two structures at the same location and land elevation, a structure with a slab-on-grade foundation would be more likely to experience flood damage than a structure with a crawlspace foundation because the FFE of the slab structure is lower (Figure 1).

To conduct flooding vulnerability assessments, the Federal Emergency Management Agency (FEMA) Hazus software applies a suite of depth-damage functions to estimate losses from various flooding scenarios (FEMA Mitigation Division, 2017). As part of the 2017 Hampton Roads Hazard Mitigation Plan (HMP), a FEMA Hazus flooding analysis was conducted at the individual structure level (HMP, 2017). While the individual structure inventory incorporated available local assessor data, the FFE values were based on reference tables provided in the Hazus flood technical manual (HMP, 2017). FFE data was not widely available or easily accessible in the Hampton Roads region at the time the flooding analysis was completed. To address this data gap, the HRPDC has been working on a multi-year effort to develop FFE data.

The primary source of FFE data within the Hampton Roads region is FEMA elevation certificates. An elevation certificate is completed by a licensed surveyor and provides building elevation information to ensure development complies with the community floodplain management ordinance (FEMA NFIP, 2020). By determining the FFE relative to the Base Flood Elevation (BFE), elevation certificates can also help homeowners reduce their flood insurance premium (Figure 1). Flood insurance premium calculations account for the elevation of the first floor relative to the BFE for structure's built after a

Figure 1: Illustration from a FEMA Fact Sheet (2018) based on a minimum NFIP deductible and $250,000 building coverage only for a single-family, one-story structure in Zone AE. The house on the left represents a structure with slab-on-grade foundation, and the house in the middle and right are elevated on a crawlspace with flood vents.

community's first Flood Insurance Rate Map (FIRM) is adopted (FEMA Federal Insurance and Mitigation Administration, 2015). For example, the annual premium for a single-family, one-story structure in the high-risk AE flood zone is $1,500 lower if the structure is built 3ft above the BFE rather than at the BFE. (Figure 1, FEMA 2018b). While several thousand elevation certificates exist across the Hampton Roads region, this information is generally available only as a paper or digital PDF copy of the certificate.

The first goal of the HRPDC regional FFE initiative was to develop a geospatial database with information from elevation certificates recorded. This would provide a searchable database to easily identify properties with elevation certificates and convert elevation certificate measurements to a format that could be readily applied in flooding vulnerability assessments. HRPDC staff collected elevation certificates from local governments, recorded the measurements, and joined the data with building footprints and parcels in GIS (Gordon and McFarlane, 2019). The elevation certificate database was initially published on the regional GIS portal, HRGEO.org, in February 2019 and has since been updated. The current inventory now includes over 4,000 elevation certificates from 12 Hampton Roads localities (HRGEO, 2020a).

Based on the current regional elevation certificate inventory, approximately only 7% of residential structures in the SFHA (1% annual chance floodplain) have an elevation certificate. The second goal of the HRPDC regional FFE initiative was to apply the elevation certificate database to develop predictive statistical models to estimate FFE for structures without elevation certificates. The predictive modeling approach, referred to as Random Forest analysis, was piloted in three communities: Chesapeake, Hampton, and York County (Gordon and McFarlane, 2019; Gordon, 2020). The models for each pilot community used building attributes, including foundation type and year built, and land elevation data to predict building FFH (Gordon and McFarlane, 2019; Gordon, 2020). FFH is the difference between the building FFE and lowest adjacent grade, and was selected as the model output to account for differences in vertical datums between elevation certificates. Foundation type was identified as the more important attribute in model development across all pilot communities (Gordon and McFarlane, 2019; Gordon, 2020). The models were applied to estimate FFH for residential structures in each community's SFHA.

Following the development of the FFH estimates for the three pilot communities, the third goal of the HRPDC regional FFE initiative was to evaluate the sensitivity of flooding damage estimates to changes in FFH values through different flooding vulnerability assessment methods. Within each pilot community, three flooding vulnerability assessment approaches were applied: (1) a census block scale analysis with default Hazus data, (2) an individual structure level analysis with default Hazus FFH values, and (3) an individual structure level analysis with custom Hazus FFH values, including elevation certificate data and model predictions (Gordon, 2020). The individual structure analysis was determined to be more accurate than the census block approach because the census block analysis includes assumptions about structure locations and foundation types that inflated flood damage estimates (Gordon, 2020). The results of the individual structure level analysis indicated that damage estimates are highly sensitive to the FFH input (Gordon, 2020). Changing FFH by less than a foot can increase or decrease flood damage estimates by hundreds of structures and millions of dollars (Gordon, 2020).

Building upon the work of the previous two years, this report documents the third phase of the HRPDC regional FFE initiative. The four main objectives of this phase were as follows: (1) update and expand the online elevation certificate spatial database to include additional Hampton Roads localities, (2) develop a regional FFE database for single-family, residential structures that includes elevation certificate data, model predictions, and alternative FFE estimation methods, (3) apply the regional FFE database in a flooding vulnerability assessment that accounts for sea level rise, and (4) synthesize results from the multi-year effort to inform recommended data management and data development practices. The analyses supporting these objectives are detailed in the following report sections:

(1) *First Floor Elevation Data Collection, Assessment, and Analysis* – Provides an overview of the elevation certificate inventory update, the development of multiple predictive models, and various data sources that were integrated to develop the regional single-family residential FFE database.

(2) *Regional Coastal Hazard Vulnerability Assessment* – Describes the vulnerability assessment methods and results for the 1% annual chance flood, as well as an additional 1.5ft and 3ft of sea level rise.

(3) *Recommended Practices for Data Management and Development* – Documents elevation certificate data management practices and related opportunities for earning credit through the FEMA National Flood Insurance Program's Community Rating System and describes related first floor elevation data development efforts across the Hampton Roads region.

(4) *Conclusions and Next Steps* – Reviews key findings of the multi-year regional FFE effort and recommends actions for future improvement of the FFE database and flooding vulnerability assessment applications.

II. First Floor Elevation Data Collection, Assessment, and Analysis

Regional Elevation Certificate Database Update

While elevation certificates are the primary source of FFE data across the Hampton Roads region, elevation certificates are not available for all structures within the SFHA. Elevation certificates must be completed by a licensed surveyor on an individual structure basis and can thus be costly in terms of both time and money. The regional elevation certificate database was launched on the regional GIS portal, HRGEO.org, to develop a database of structures with elevation certificates. As of October 2019, the inventory contained information from 2,569 elevation certificates representing 11 localities (Gordon, 2020). To maintain the regional elevation certificate inventory, HRPDC staff collected new digital copies of elevation certificates, including an additional locality, Gloucester County (Table 1). Norfolk had also recently scanned elevation certificates copies, dating from 1994-2015, that were included in the update (Table 1).

Table 1: Total elevation certificates added by locality for the 2020 database update. All elevation certificates are based on finished construction.

Locality	Total Elevation Certificates	Elevation Certificates Added in 2020
Chesapeake	658	22
Franklin	172	3
Gloucester County	678	678
Hampton	700	12
James City County	195	9
Newport News	7	1
Norfolk[2]	776	655
Portsmouth	107	17
Southampton County	33	0
Suffolk	3	0
Virginia Beach	238	39
York County	442	10
TOTAL	4,009	1,446

[2] Approximately 200 additional elevation certificates from 2015-present are currently available for Norfolk and will be included in future data updates.

Support for updating the database was provided by the Center for Geospatial Science, Education, and Analytics at Old Dominion University (ODU), with specific contributions by Manuel Solano (ODU) to the Gloucester County and Norfolk data development. The remaining 10 localities included provided elevation certificates that were completed since the 2019 database update (Table 1). The elevation certificate inventory is approximately 88% residential structures. Elevation certificates for accessory structures, additions, and non-residential building types are also included. Figure 2 displays the locations of all elevation certificates included in the inventory (HRGEO, 2020a).

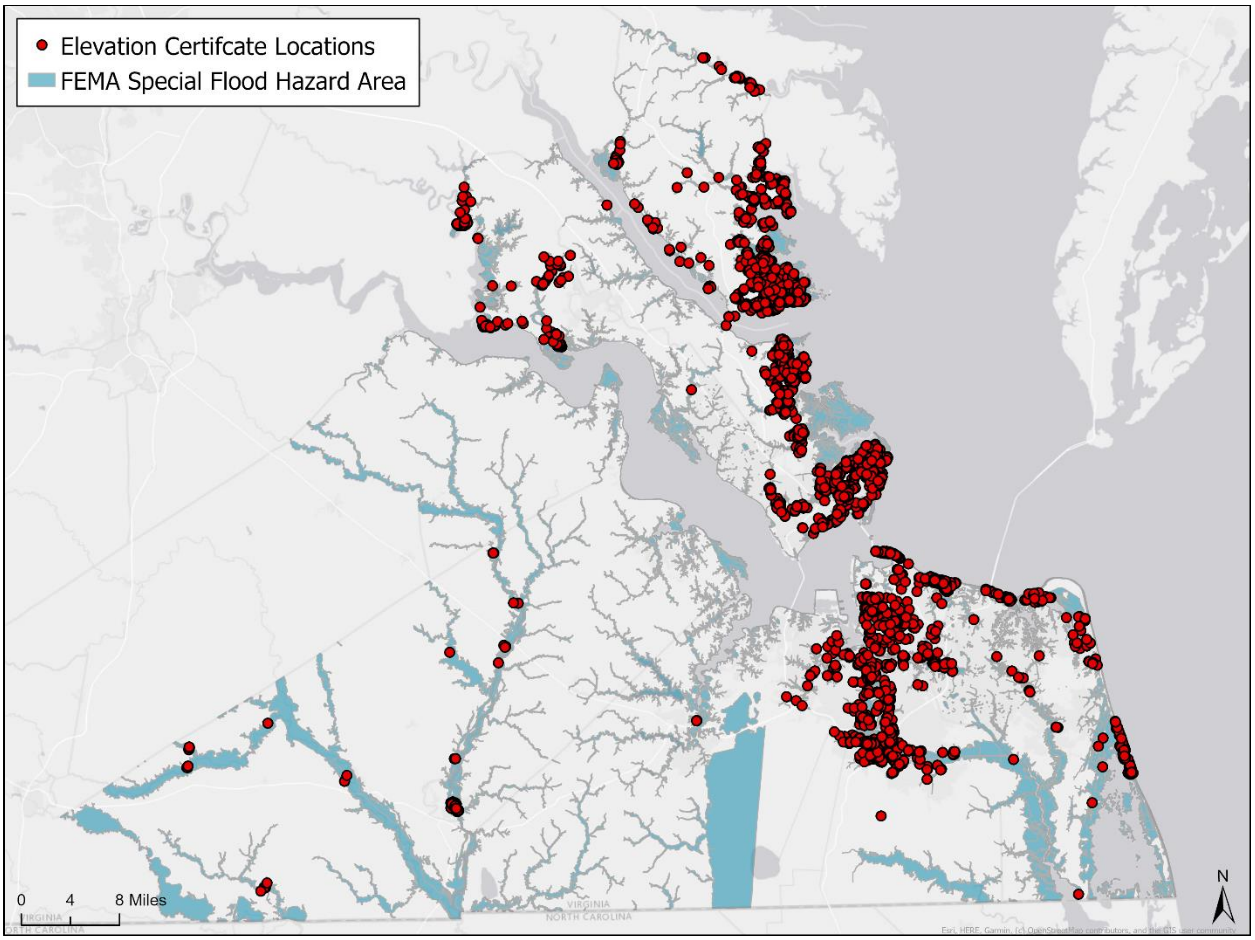


Figure 2: Distribution of elevation certificate locations in the HRGEO.org database. 4,009 features covering 12 localities are included. The FEMA Special Flood Hazard Area is displayed for reference.

Four separate GIS layers of elevation certificate information are available: (1) parcel polygons with elevation measurements reported in the original vertical datum (NGVD 1929 or NAVD 1988), (2) parcel polygons with elevation measurements converted to NAVD 1988, (3) building footprints with elevation measurements reported in the original vertical datum, and (4) building footprints with elevation measurements converted to NAVD 1988. NOAA's NGS Coordinate Conversion and Transformation Tool

(NCAT) tool was used to convert new elevation certificate measurements recorded in NGVD 1929 to NAVD 1988 (NGS, 2019).[3]

Regional Structure Inventory Development

To support a regional flooding vulnerability assessment, a database of single-family residential structures located in the SFHA was developed. Given that the regional elevation certificate inventory is predominantly residential structures, single-family residential structures were selected as the focus. The database was restricted to the SFHA because the majority of elevation certificates (85%) were located in the SFHA and the FEMA 1% annual chance flood depth grids applied in the analysis correspond with the SFHA boundaries. Within the Hampton Roads region, it is estimated there are nearly 34,000 single-family residential structures in the SFHA. To develop FFH values for each structure, a suite of methods was applied in the following order of preference: (1) elevation certificate data/field survey data, (2) predictive model estimates, (3) stair counting, and (4) Hazus default estimates. Additional data sources were available for Newport News, Norfolk, and Virginia Beach respectively from Old Dominion University, the U.S. Army Corp of Engineers, and Dewberry. The FFH values from these additional data sources were used unless an elevation certificate was available. The "First Floor Elevation Estimation Methods" section of the *Recommended Practices for Data Management and Development* chapter in this report provides details about these data sources. Franklin and Southampton County were not included in the flooding vulnerability assessment because FEMA coastal flood depth grids were not available. Additionally, no structures within Williamsburg intersected the coastal flood depth grid for James City County.

Predictive Modeling

A predictive modeling approach, referred to as Random Forest analysis, was previously evaluated in three pilot communities (Chesapeake, Hampton, and York County) in earlier phases of the regional FFE initiative. The Random Forest modeling approach generates and averages hundreds of regression trees based on building attributes to produce FFH estimates (Liaw and Wiener, 2002). FFH is the difference between the building FFE and lowest adjacent grade, and was selected as the model output to account for differences in vertical datums between elevation certificates. All Random Forest models were developed in Esri ArcGIS Pro software using the Forest-based Classification and Regression

[3] Previously the VERTCON v2.1 tool was used to identify conversion factors. This software has been superseded and replaced by the NCAT software. Within NCAT, an updated version of VERTCON (3.0) is applied for orthometric height transformations.

tool in the Spatial Statistics toolbox (Esri, 2020a). This modeling approach is best suited for sample sizes that include several hundred features (Esri, 2020b).

Nearly 700 elevation certificates for Gloucester County were added in the most recent elevation certificate database update. This provided a sufficient sample to develop a Random Forest model that estimates building FFH within the locality. Following the methodology established in the pilot communities, the predictor variables included in the model, listed in order of importance, were as follows: (1) foundation type, (2) digital elevation model (DEM) value, (3) total property value, (4) year built, (5) difference in grade, and (6) current flood zone. As observed in the pilot communities, foundation type was the most important predictor variable, accounting for 54% of variable importance. The Gloucester County foundation code scheme included the following foundation types: (1) crawlspace, (2) slab, (3) piers, and (4) full enclosure. When comparing the model estimates to elevation certificate values withheld from the model as testing data (20% of sample), the absolute average error was 1.06 ft (Table 2). This represents a 30.3% reduction in error relative to using Hazus default FFH values (absolute average error of 1.52ft).

Although Newport News had a limited sample of only 7 elevation certificates, a robust sample of FFHs were collected by Old Dominion University using a laser inclinometer (Allen, 2019). ODU measured approximately 1,700 FFHs in Newport News to support a geostatistical modeling effort.[4] Since the ODU model is currently under development, HRPDC staff used the ODU FFH measurements to develop a predictive Random Forest model for the remaining 34% of structures in the Newport News SFHA. The same suite of predictor variables applied in the Gloucester County model were applied in the Newport News model, with foundation type again ranking as the most important predictor variable (29% of variable importance). Although basement, piers, crawlspace, and slab foundation types are available in the Newport News database, only crawlspace and slab structures were included in the model given that few structures (9 structures) of basement and pier foundation type required FFH estimation in the SFHA. The absolute average error was 0.42 ft when comparing the model estimates to the testing data measurements (Table 2). This represents a 59.6% reduction in error relative to the Hazus default FFH values (absolute average error of 1.04ft).

[4] Additional details regarding the methodology are provided under "Old Dominion University" in the "First Floor Elevation Estimation Methods" section of the *Recommended Practices for Data Management and Development* chapter of this report.

Individual locality models offer the advantage of using local foundation schemes and the range of FFH estimates specific to that locality. However, there was not a large enough sample of elevation certificates available to develop individual models for each of the remaining localities in the region. Thus, the elevation certificate data was compiled to create a multi-jurisdictional model that covers localities with more limited samples of elevation certificates. In order to build a regional model, the foundation type codes were standardized across localities. Since most localities have crawlspace and slab foundation data available, these two foundation types were selected for the regional model. Individual locality codes that represent these structure types were re-classified as "Crawlspace" or "Slab". The following localities with elevation certificate data were included in the regional model[5]: (1) Chesapeake, (2) Gloucester County, (3) Hampton, (4) James City County, (5) Portsmouth, (6) York County. The same suite of predictor variables from the individual locality models was applied in the regional model, with the addition of locality name as a predictor variable. The regional model absolute average error was 0.72ft (Table 2). This represents a 20.9% decrease in error from the Hazus default values (average absolute error of 0.91 ft). Since local models had been developed for Chesapeake, Gloucester County, Hampton, and York County, the regional model predictions were only applied to structures in James City County and Portsmouth.

Table 2 compares the five local models to the regional model. It is important to note that while some local models have higher error values than the regional model, a greater range of FFH values was considered in several local models. For example, the Gloucester County model has an absolute average error of 1ft, but includes structures elevated on piers and structures with a full enclosure below the living space. This creates a range of possible FFH values from 0-11ft, while the regional model estimates only encompass a range of 0-6ft.

[5] Newport News data were not included in the regional model given the FFH estimates were based on a different field sampling technique from the other localities. Norfolk and Virginia Beach were not included in the model because existing FFH databases were available.

Table 2: Comparison of predictive Random Forest models used to develop the regional residential structure inventory.

Model Results	*Chesapeake*	*Gloucester County*	*Hampton*	*Newport News*	*York County*	*Regional Model*
% of Variation Explained [6]	69.5%	72.0%	62.0%	37.0%	74.5%	56.3%
MSE (RMSE ft)	0.47 (0.69 ft)	2.50 (1.58 ft)	1.03 (1.02 ft)	0.330 (0.574 ft)	2.02 (1.42 ft)	1.10 ft (1.05 ft)
Absolute Average Error (ft)	0.45 ft	1.06 ft	0.80 ft	0.42 ft	0.83 ft	0.72 ft
Most Important Predictor (% Importance)	Foundation (53%)	Foundation (54%)	Foundation (38%)	Foundation (29%)	Foundation (52%)	Foundation (28%)
% Reduction in Error Relative to Hazus default values	19.6%	30.3%	4.8%	59.6%	33.6%	20.9%

[6] The percent pf variation explained and the mean squared error (MSE) indicate the ability of the model to accurately predict FFH based on the observed values in the training dataset (Esri, 2020b). These are Out of Bag statistics that are calculated iteratively and averaged based on random subsets of data (Esri, 2020b). The higher the percent of variation explained and the lower the MSE, the better the model performance. Root mean square error (RMSE) is the square-root of the MSE and is reported in the linear unit of the response variable.

Additional Estimation Methods

Stair counting and Hazus default reference tables are additional methods for estimating FFH. These methods were applied where the Random Forest modeling approach was not applicable or not needed due to existing data. For Isle of Wight County, Poquoson, Suffolk, and Surry County, only stair counting or Hazus default reference tables were used to estimate FFH. These estimation approaches were also used for structures in other localities where the model could not be applied, including structures with foundation types excluded from the model or structures missing year-built information.

To estimate FFH through stair counting, a standard height of 7.5 in (0.625ft) was applied to each stair (Needham and McIntyre, 2018). The count of stairs was obtained using either Google Street View imagery or photos from online locality property information portals (Figure 3). Given that the FFH is relative to the lowest adjacent grade when using elevation certificate data, an adjustment factor was applied to correct for the location of the stairs relative to the lowest adjacent grade (LAG):

FFH = (Number of stairs *0.625 ft) + (Ground elevation of stairs – LAG)

Figure 3*:* Illustration of stair counting approach for estimating FFH. The count of 7 stairs equals a FFH of 4.4ft. The land elevation difference between the bottom of the stairs and lowest adjacent grade would be added to produce the final FFH estimate. Image from City of Hampton Property Information Parcel Viewer (2017).

When a clear view of a structure's stairs was not available, the FFH estimate was based on Hazus reference tables, which provide standard FFH estimates based on foundation type, year built, and flood zone. A complete list of Hazus reference table values is available in Appendix A. Table 3 provides a summary of the methodologies used to estimate FFH for single-family residential structures (RES1) within each of the Hampton Roads localities included in the coastal flood hazard vulnerability assessment.

It is important to note that the Hazus structure inventory developed for the Hampton Roads HMP was used for the city of Poquoson (HMP, 2017). This database uses the Hazus default FFH estimates for all structures. The default FFH values were not adjusted as part of this analysis because HRPDC staff are currently coordinating with Poquoson staff to scan and record the complete elevation certificate inventory for the city. The Poquoson inventory likely includes over 1,000 elevation certificates, and the Hazus default estimates can be replaced with Poquoson elevation certificate values when the data is recorded. These additional elevation certificates will likely be included in future HRGEO elevation certificate updates.

Table 3: Methods used to develop FFH estimates for the single-family residential (RES1) FFH inventory for each locality.

Locality[7]	*Number of RES1 Structures*	*Elevation Certificates*	*Predictive Model*	*Elevation Adjusted Stair Estimation*	*Hazus Default*	*Other Data Source*
Chesapeake	4,524	9%	90%	<1%	---	---
Gloucester County	1,676	32%	62%	2%	4%	---
Hampton	7,107	7%	92%	1%	<1%	---
Isle of Wight County[8]	133	---	---	47%	53%	---
James City County	407	23%	70%	4%	3%	---
Newport News[9]	761	< 1%	34%	1 %	<1 %	64%
Norfolk[10]	4,940	8%	---	<1%	<1%	91%
Poquoson[11]	2,847	---	---	---	100%	---
Portsmouth	2,996	2%	97%	<1%	---	---
Suffolk	211	1%	---	54%	45%	
Surry County[12]	36	---	---	61%	39%	---
Virginia Beach[13]	6,449	2%	---	<1%	<1%	97%
York County	1,634	20%	78%	1%	1%	---
Total Inventory	33,721	7%	49%	1%	10%	33%

[7] Franklin, Southampton County, and Williamsburg did not have any structures which intersected the coastal flood depth grids.
[8] Isle of Wight County data includes the Town of Smithfield.
[9] The additional data source for Newport News was FFH estimates collected by Old Dominion University using a laser inclinometer.
[10] The additional data source for Norfolk was the structure inventory developed by the U.S. Army Corps of Engineers in 2016.
[11] The Hazus default values were provided as part of the structure inventory for the Hampton Roads HMP.
[12] An additional 27 structures were present in the SFHA but were excluded from the analysis because of missing building attributes.
[13] The additional data source for Virginia Beach was the structure inventory developed by Dewberry in 2016.

Attributes for Coastal Flooding Vulnerability Assessment

In addition to FFH, several other building attributes are required as inputs for a coastal flooding vulnerability assessment when applying the FEMA Hazus methodology. Table 4 illustrates the additional required attributes and sources of this information. For Norfolk and Virginia Beach, these attributes were provided in the database respectively created by U.S. Army Corps of Engineers and Dewberry.

Table 4: Required building attributes for FEMA Hazus analysis at the individual structure level.

Attribute	Description	Source
Occupancy Class	Hazus occupancy class code	Classified based on local assessor data
Building Cost	Replacement cost	Calculated using square footage from assessor data and R.S. Means values
Building Area	Square footage of structure	Local assessor data; estimated in GIS using building footprint if unavailable
Number of Stories	Number of stories rounded up to nearest whole number	Local assessor data
Foundation Type	Corresponding Hazus foundation type reported as an integer	Classified based on local assessor data

Replacement cost was calculated based on square footage and R.S. Means, or dollar per square foot values. This approach is based on the Hazus valuation parameter tables, which provide R.S. Means values for single-family residential structures by number of stories and census block income ratio ranges (FEMA Mitigation Division, 2017). Appendix B describes the methodology and reference values for calculating replacement cost. It is important to note that the Hazus R.S. Means reference tables were updated since the previous phase two pilot community analysis, and thus the replacement cost estimates for structures within Chesapeake, Hampton, and York County have been adjusted from the previous analysis (FEMA Risk MAP CDS, 2019).

III. Regional Coastal Hazard Vulnerability Assessment

Vulnerability Assessment Methods

As part of the second phase of the regional FFE initiative, flooding vulnerability assessments were conducted within the pilot communities of Chesapeake, Hampton, and York County. To compare damage estimates between different scales of analysis, the flooding vulnerability assessments were completed at both the census block and individual structure level scale for the 1% annual chance flood event. The census block analysis resulted in flooding damage estimates that were over three times as large as the flood damage estimates at the individual structure scale. The substantially higher damage estimates resulting from the census block analysis are likely the result of differences in foundation type and structure location. A higher number of basement and slab foundation types were observed in the default Hazus census block database than in the pilot communities, and the census block scale analysis assumes equal distribution of structures within developed areas. Given the advantages of applying local assessor data and precise structure locations, the individual structure level analysis was selected for the regional approach.

The FEMA Hazus program has developed an open-source tool, referred to as the Flood Assessment Structure Tool (FAST), that streamlines the Hazus flood damage assessment methodology for an individual structure level analysis (FEMA NHRAP-Hazus, 2020). To apply the tool, the user must supply a depth grid and structure inventory, referred to as User-Defined Facilities (UDF) (FEMA NHRAP-Hazus, 2019). The regional FFH database of approximately 34,000 structures was used as the UDF inventory in the Hazus FAST tool for the following flooding scenarios: (1) 1% annual chance flood, (2) 1% annual chance flood plus 1.5ft of sea level rise, and (3) 1% annual chance flood plus 3ft of sea level rise. Structures located within the VE flood zone were run separately from other buildings in the SFHA. The FAST tool offers unique depth damage functions for "coastal V" structures, which includes the VE flood zone. The riverine depth damage functions were applied for all other structures in the SFHA. A latitude and longitude value must be provided for each structure in the UDF inventory. The point location for the analysis corresponded with the location of the structure's LAG, which was determined by selecting the minimum DEM value for each building footprint outline (Esri, 2019).[14]

[14] For the city of Newport News, the ODU field measurements were based on average grade; therefore, building centroids were used for the lat/lon measurements rather than the lowest adjacent grade.

As part of the non-regulatory FEMA Flood Risk Mapping, Assessment, and Planning (MAP) products, 1% annual chance flood depth grids were available for each Hampton Roads community, with the exception of Franklin and Southampton County (FEMA, 2020c). The Flood Risk MAP products provide additional information beyond the FEMA regulatory FIRMs to improve community knowledge of flood risk (FEMA, 2020c). For the FEMA 1% annual chance flood scenario, damage estimates were produced using two different FFH scenarios: (1) custom FFHs based on elevation certificate data, model predictions, and additional local data sources, and (2) default FFHs based on Hazus default reference tables (provided in Appendix A). Previously in all three pilot communities, damage estimates were lower when custom FFH estimates were applied rather than Hazus default values. This comparison was repeated at the regional scale to determine if this pattern is consistent across localities.

The 1.5ft and 3ft sea level rise scenarios selected for this analysis correspond with the present-2050 and 2050-2080 planning horizons in the Hampton Roads Sea Level Rise Planning Policy and Approach (HRPDC, 2018b). The depth grids applied for the sea level rise scenarios were developed by HRPDC staff using storm surge scenarios produced by the U.S. Army Corps of Engineers for the North Atlantic Coast Comprehensive Study (USACE, 2015), and the FEMA Region III Storm Surge Study (FEMA, 2013). Given the sea level rise scenario depth grids were generated using a different DEM than the one used in the FEMA Flood Risk MAP products, the UDF analysis was run using a 1% annual chance depth grid created with the same DEM used for the sea level rise scenarios. This established baseline damage estimates for comparing changes with sea level rise. An outline of all scenarios applied is illustrated in Figure 4.

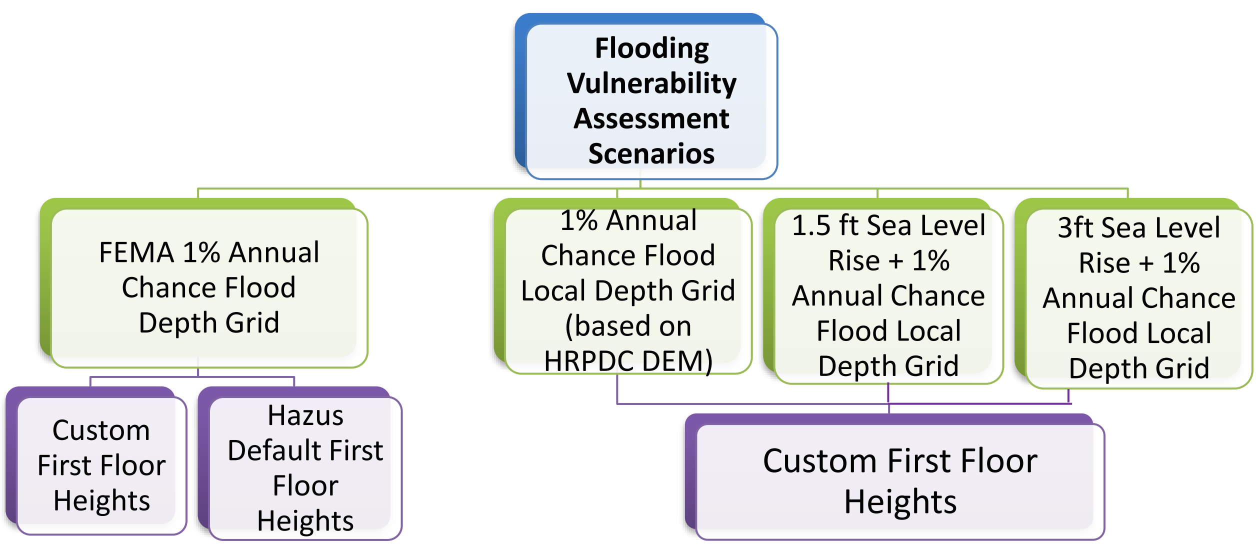


Figure 4: Combinations of depth grids (green highlighted boxes) and first floor height values (purple highlighted boxes) applied in the regional coastal flooding vulnerability assessment.

Results: 1% Annual Chance Flood Scenario

Across all thirteen cities and counties included in the regional flooding assessment, there were 30,212 RES1 structures that intersected the FEMA 1% annual chance flood depth grid with an estimated total exposure value of $8.4 billion. Nearly half (43.9%) of all RES1 structures experienced flood damage under the custom FFH scenario, totaling $354.6 million in estimated flood losses. When replacing the custom FFH estimates with Hazus default FFH estimates, nearly half (43.5%) of all RES1 structures also experienced damage, totaling $353.3 million in estimated flood losses. While previously in the pilot communities the default FFH estimates resulted in higher damage estimates than the custom FFH estimates, at the regional scale, the default FFH estimates produced lower damage estimates by $1.3 million (0.4%).

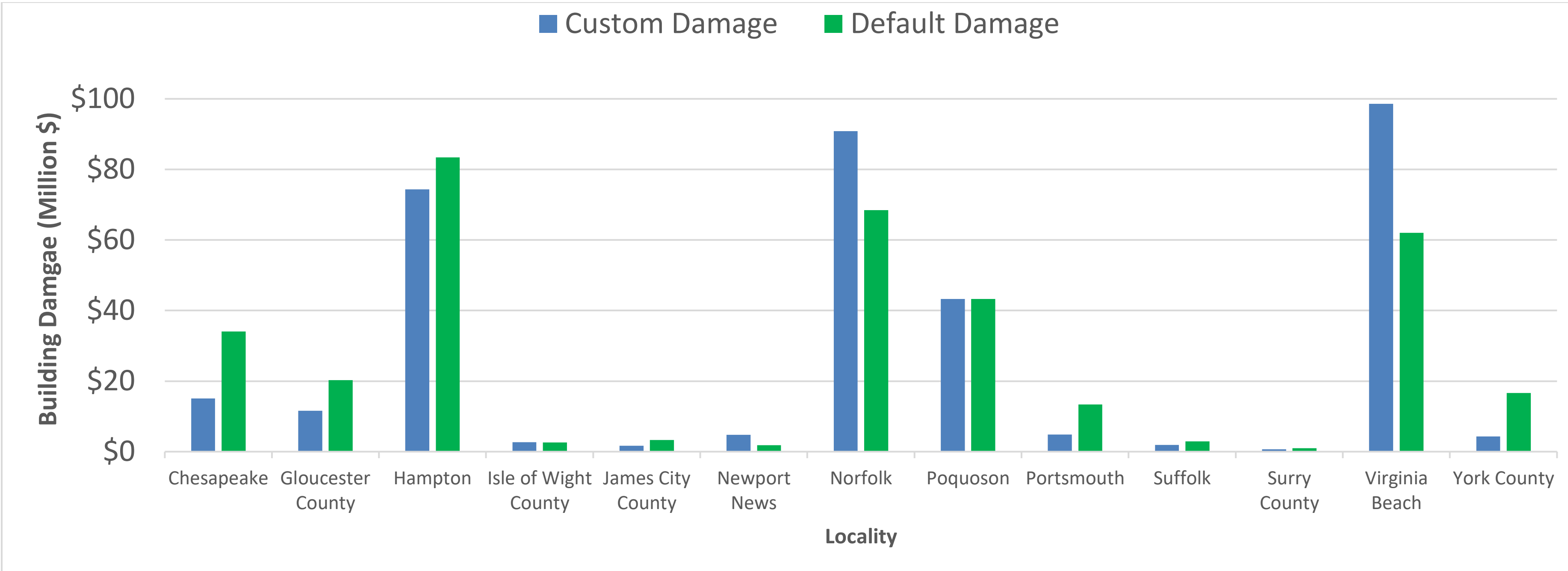
To investigate differences between elevation certificate data and the Hazus default FFH estimates, damages were compared for only structures where elevation certificates were available. Within the regional FFH inventory, elevation certificates were available for approximately 7% of structures. Across all 8 localities where a sufficient number of elevation certificates were available for comparison, the estimated damages were higher when the default FFH values were applied (Table 5). The default FFH values increased the damage estimates between 28% and 127% (Table 5). This indicates that the default FFH values tend to underestimate the FFH reported on the elevation certificate, and consequently overestimate the damage. It is important note that while the default FFH values overestimate FFH for this sub-set of data, the elevation certificate sample is skewed to more recent construction, with 70% of structures being built after a community's first FIRM. Therefore, the default FFH values may not overestimate FFH as consistently for older structures built pre-FIRM.

Table 5: Comparison of estimated building losses using Hazus default FFH estimates and elevation certificate FFH values. The difference is calculated as default building losses – elevation certificate building losses, and the percent change indicates the increase in estimated damages relative to the elevation certificate building losses.

Locality[15]	Default First Floor Height	Elevation Certificate First Floor Height	Difference (% Change)
Chesapeake (n=433)	$4,811,254	$3,337,416	$1,473,838 (44%)
Gloucester County (n=531)	$4,949,846	$3,514,020	$1,435,826 (41%)
Hampton (n=470)	$7,995,962	$6,234,693	$1,761,269 (28%)
James City County (n=93)	$863,031	$529,454	$333,576 (63%)
Norfolk (n=403)	$5,070,990	$3,082,551	$1,988,438 (65%)
Portsmouth (n=63)	$566,198	$289,857	$276,341 (95%)
Virginia Beach (n=153)	$2,581,646	$1,456,467	$1,125,179 (77%)
York County (n=331)	$2,714,018	$1,195,096	$1,518,922 (127%)

Figure 5 compares the estimated damages under the custom and default FFH scenarios by locality. For 8 of the 13 communities, the estimated damages were higher under the default scenario. The estimated damages did not change for Poquoson because only default FFH values were available. Within Newport News, Norfolk, and Virginia Beach, larger damage estimates were reported under the custom FFH scenario than the default FFH scenario. This is primarily attributed to crawlspace structures that had a lower FFH estimate than the Hazus default value. For Newport News, the largest increase in damages resulted from crawlspace structures where the Old Dominion University laser inclinometer FFH measurement was lower than the Hazus default value. Within Norfolk, partial crawlspace structures were treated as slab in the U.S. Army Corps of Engineers database and assigned a FFH value of 0.5ft. This resulted in higher damage estimates than the default FFH scenario, where these structures were assigned crawlspace FFH values. For Virginia Beach, the largest increase in damage is attributed to crawlspace structures where the Dewberry regression model predicted custom FFH lower than the default FFH value. In comparison, the elevation certificate based-Random Forest modeling approach tends to produce higher FFH estimates than the Hazus default FFH methods, resulting in overall lower damage estimates

[15] Isle of Wight County, Newport News, Poquoson, Suffolk, and Surry County were excluded from this table because there were not enough elevation certificates available for a meaningful comparison.



Figure/Table 5: Comparison of flooding damage estimates in millions of dollars using default and custom FFH values for the 1% annual chance flood event.

	Chesapeake	Gloucester County	Hampton	Isle of Wight County	James City County	Newport News	Norfolk	Poquoson	Portsmouth	Suffolk	Surry County	Virginia Beach	York County	**Total**
Custom Damage	$15.1	$11.6	$74.4	$2.7	$1.7	$4.7	$90.8	$43.3	$4.8	$1.9	$0.7	$98.6	$4.3	**$354.6**
Default Damage	$34.1	$20.3	$83.4	$2.6	$3.3	$1.9	$68.4	$43.3	$13.4	$2.9	$1.0	$62.0	$16.7	**$353.3**
|Difference|	$19.0	$8.7	$9.0	$0.1	$1.6	$2.8	$22.4	0	$8.6	$1.0	$0.3	$36.6	$12.4	**$122.5**
Percent Change	125.7%	75.0%	12.2%	-3.1%	99.8%	-60.7%	-24.7%	0.0%	178.3%	53.7%	49.0%	-37.1%	285.9%	**-0.4%**

The percent of building damage was classified as substantial (>49%), moderate (15-49%), low (<15%), or no damage. The substantial and moderate ranges are defined in the Hampton Roads Hazard Mitigation Plan (HMP, 2017). While 44% of all structures experienced flood damage, the percent of building damage per individual structure tended to be less than 15%. Approximately 36% of all structures included in the analysis experienced a low level of flood damage, 8% experienced a moderate level of damage, and less than 1% experienced substantial damage (Figure 6). This pattern was also observed in each individual community, where at least half of damaged structures had a low level of flood damage (with the exception of Surry County which had more moderately damaged structures) (Figure 7). Hampton (4,015 structures), Virginia Beach (3,009 structures), and Norfolk (2,700 structures) experienced the greatest number of damaged structures (Figure 7). The distribution of damaged structures classified by level of damage is displayed in Figure 8. A heat map of the structures weighted by total dollar losses illustrates the highest density of losses occurring in Hampton, Poquoson, Norfolk, and the northern portion of Virginia Beach (Figure 8).

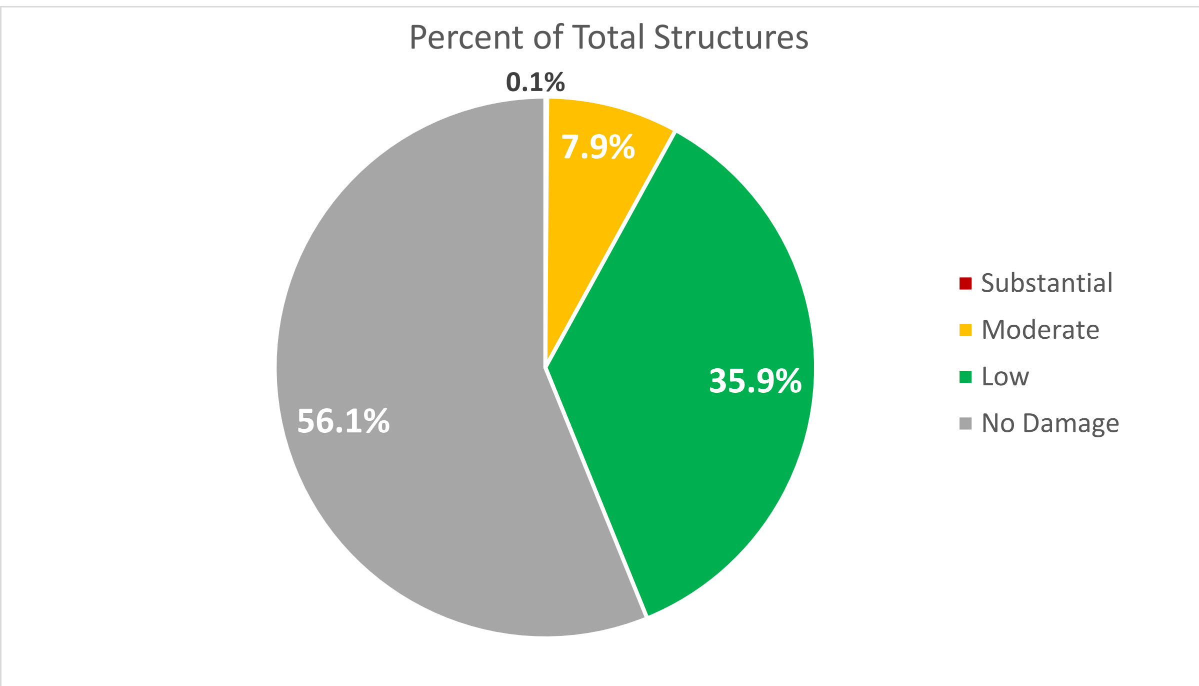


Figure 6: Percent of structures experiencing substantial, moderate, low, or no damage from the 1% annual chance flood event using custom first floor height estimates derived from local data.

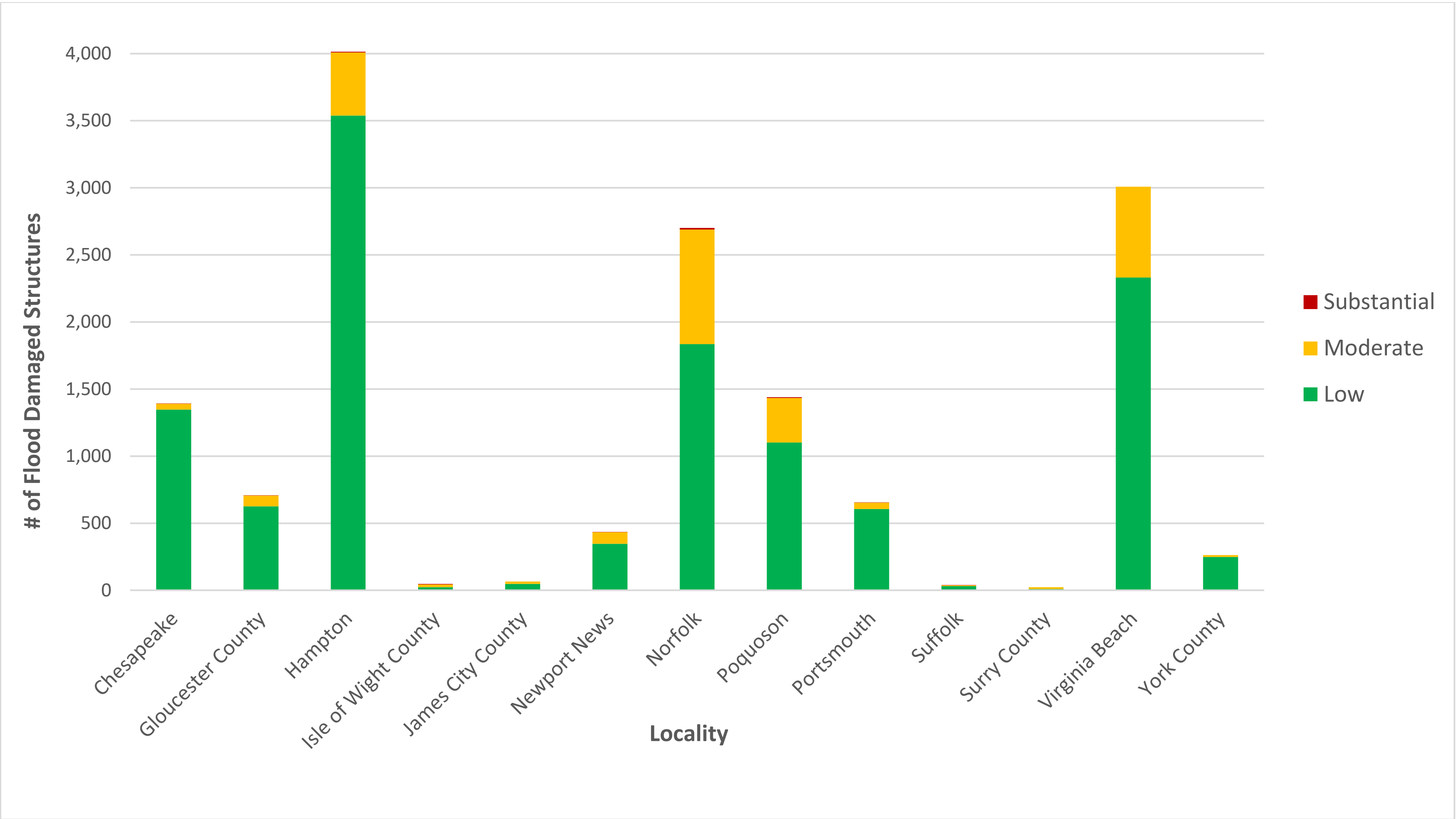


Figure 7: Number of structures experiencing substantial, moderate, or low damage from the 1% annual chance flood event using custom first floor height estimates derived from local data.

Flooding Scenario: 1% Annual Chance Flood

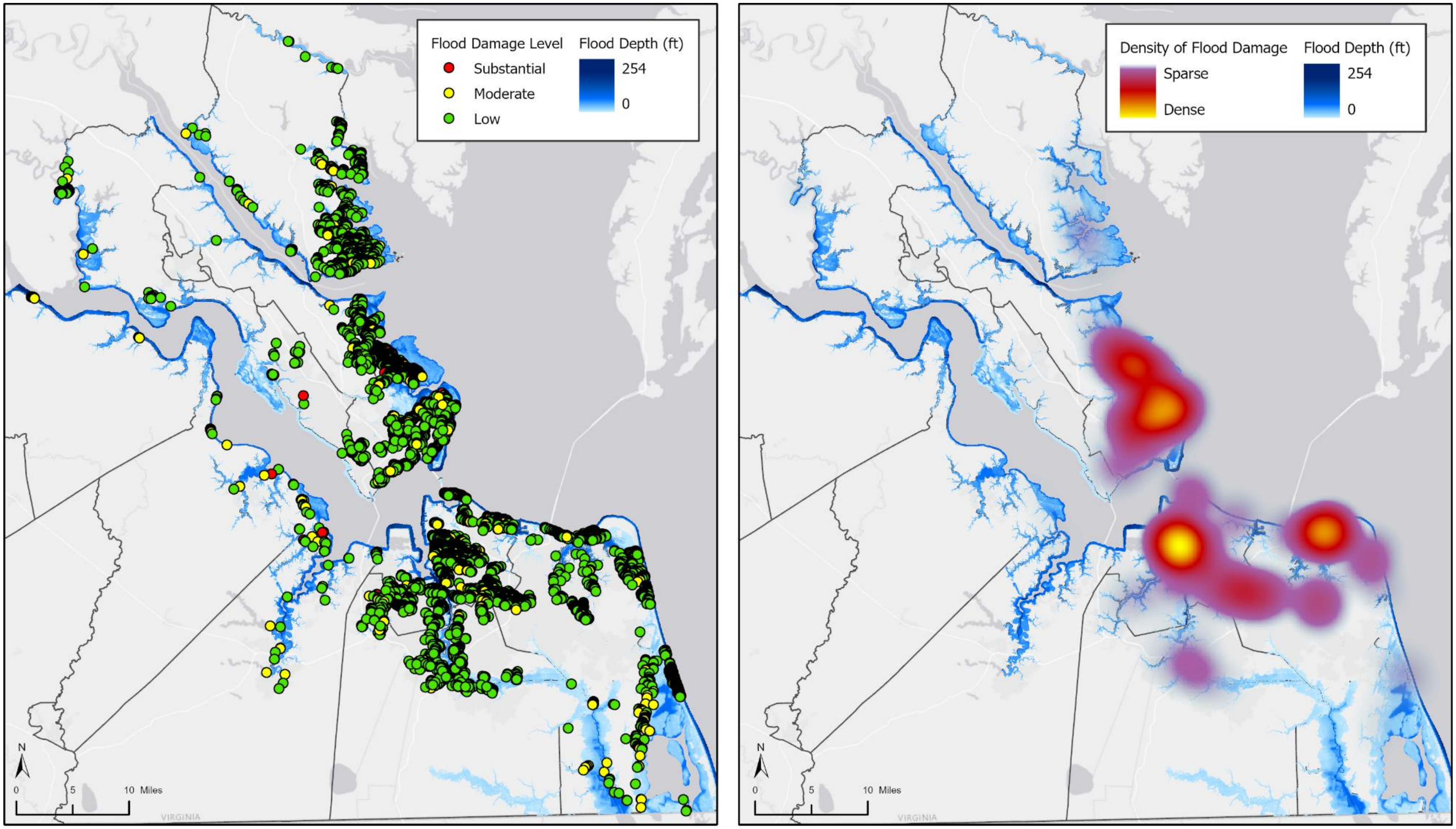


Figure 8: Distribution of individual structures experiencing flood damage under the 1% annual chance flood event across the Hampton Roads region. The heat map displays the density of damaged structures weighted by the value of loss in dollars.

Results: Sea Level Rise Scenarios

The baseline 1% annual chance flood scenario, developed using the same DEM as the sea level rise scenario depth grids, resulted in approximately 28,121 structures intersecting the depth grid, with a total exposure value of $7.8 billion. There were 2,091 fewer structures exposed to flooding using the local flood depth grid rather than the FEMA Flood Risk MAP product depth grid. The custom FFH estimates including local elevation certificate data were applied for the local flood depth grid and sea level rise analysis. The estimated building losses for the local flood depth grid analysis were also $49.6 million lower than under the FEMA flood depth grid scenario. The estimated building losses under the local flood depth grid were $305.0 million (Figure 9). When accounting for 1.5ft of sea level rise, the estimated damages increased by more than double to $865.8 million (Figure 9). For 3ft of sea level rise, the total estimated damages were $1.7 billion, nearly six times as high as the initial baseline damage estimate (Figure 9).

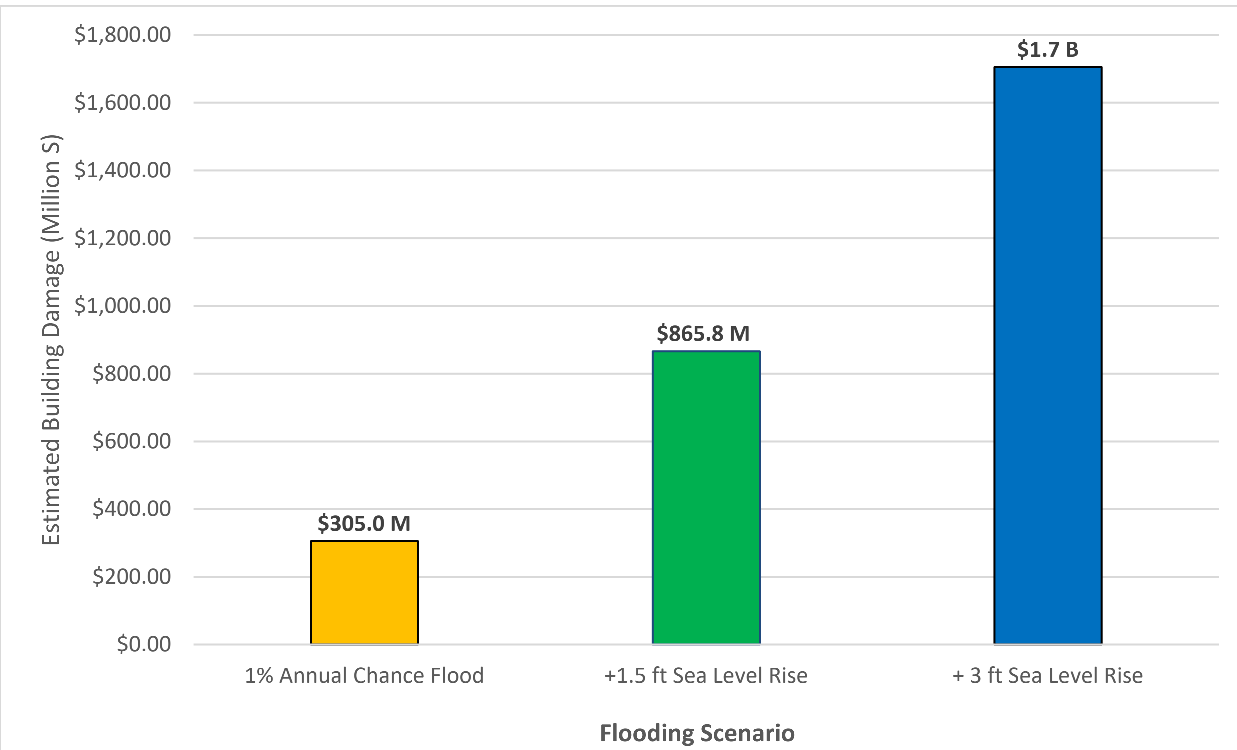


Figure 9: Estimated building losses in millions of dollars for the 1% annual chance flood using the local depth grid, 1.5 ft of sea level rise in addition to the 1% annual chance flood, and 3ft of sea level rise in addition to the 1% annual chance flood. Custom FFH values derived from local data were used.

The total estimated building losses from 3ft of sea level rise ranged from $1.3M (Surry County) to $326.3M (Hampton) (Table 6). Across all localities, the estimated building losses increased with sea level rise. The rate of increase in building losses and the relative number of structures damaged as a result of sea level rise varied by community.

Table 6: Comparison of estimated building damages in millions of dollars for the 1% annual chance flood using the local depth grid, 1.5 ft of sea level rise in addition to the 1% annual chance flood, and 3ft of sea level rise in addition to the 1% annual chance flood. Custom FFH values derived from local data were used.

Locality	1% Annual Chance Flood (Million $)	+1.5 ft Sea Level Rise (Million $)	+ 3ft Sea Level Rise (Million $)
Chesapeake	$33.3	$127.4	$234.4
Gloucester County	$5.4	$20.8	$57.5
Hampton	$43.8	$157.1	$326.3
Isle of Wight County	$1.4	$2.1	$3.7
James City County	$1.6	$5.5	$16.0
Newport News	$3.7	$9.0	$18.1
Norfolk	$95.4	$192.5	$314.5
Poquoson	$46.8	$131.4	$256.9
Portsmouth	$5.4	$29.7	$83.1
Suffolk	$0.7	$2.0	$4.2
Surry County	$0.4	$0.8	$1.3
Virginia Beach	$63.5	$162.9	$313.7
York County	$3.4	$24.7	$75.7
TOTAL	**$305.0**	**$865.8**	**$1,705.4**

Figure 10 illustrates the number of structures experiencing flood damage under each scenario as a percent of total structures damaged across all three flooding scenarios. For example, in Chesapeake, 50% of structures that experienced flood damage across all three scenarios were initially damaged under the 1% annual chance flood event (Figure 10). York County experienced the greatest overall relative increase in damage as a result of sea level rise because only 22% of structures were initially damaged under the 1% annual flood scenario (Figure 10); however, in terms of estimated total dollar loss, York County ranked 7th of out 13 localities (Table 6).

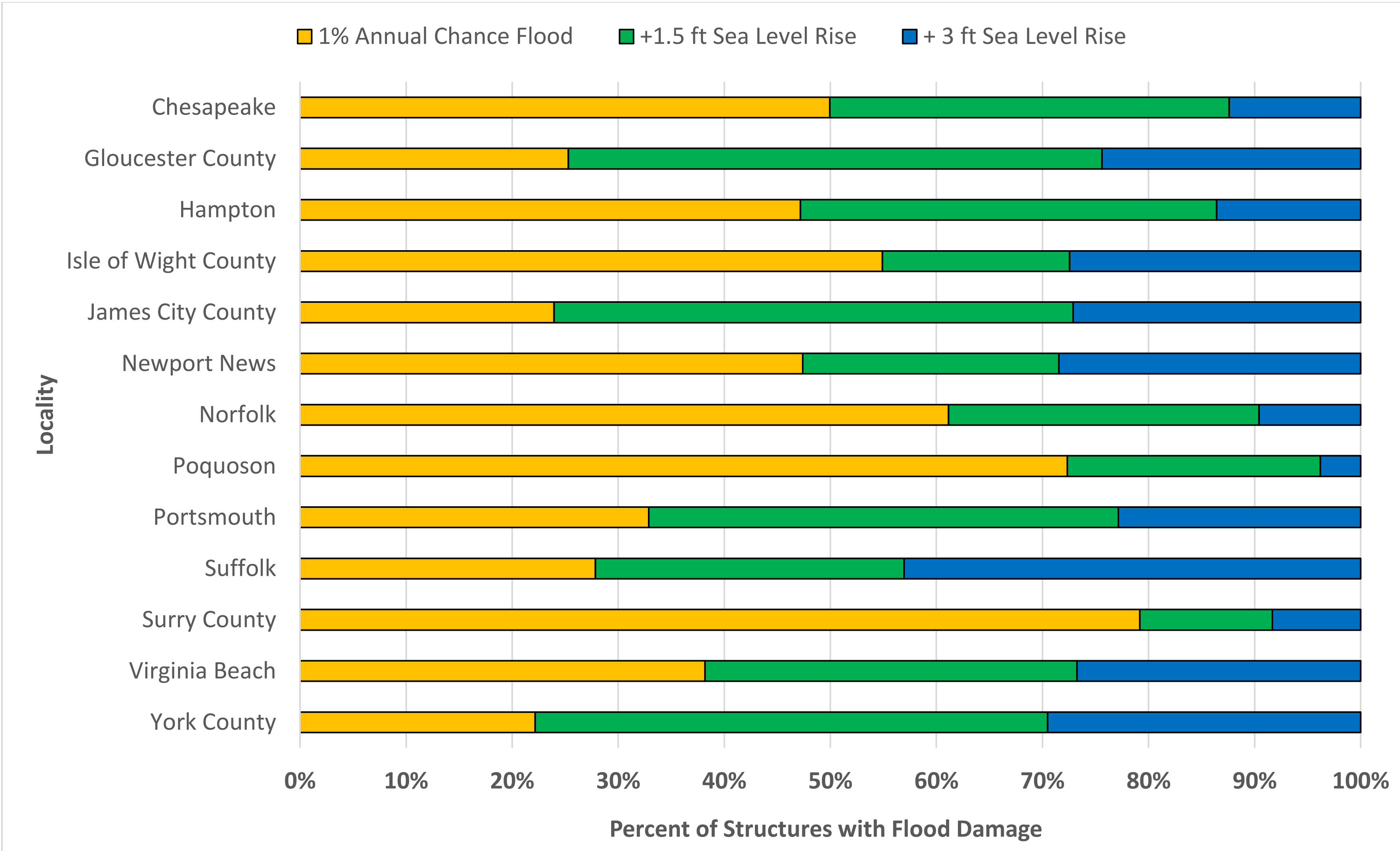


Figure 10: A comparison of the number of structures experiencing flood damage under each scenario as a percent of total structures damaged across all three scenarios in each locality. Custom FFH derived from local data were used.

In addition to changes in total estimated building damage with sea level rise, changes in the level of building damage were also observed. The percent of building damage was classified into the following categories: substantial (>49%), moderate (15-49%), low (<15%), or no damage (HMP, 2017). Sea level rise substantially increases the number of structures experiencing damage. With the 1% annual chance flood alone, 57.1% of structures are not damaged. With an additional 1.5ft of sea level rise, 23.7% of structures are not damaged, and with 3ft of sea level rise, only 8.4% of structures are not damaged (Figure 11). Furthermore, there was a shift in the level of damage structures experienced. In the baseline scenario, only 6.8% of structures experienced moderate damage (Figure 11). However, in the 3ft sea level rise scenario, over half (55.2%) of structures experienced a moderate level of damage (Figure 11).

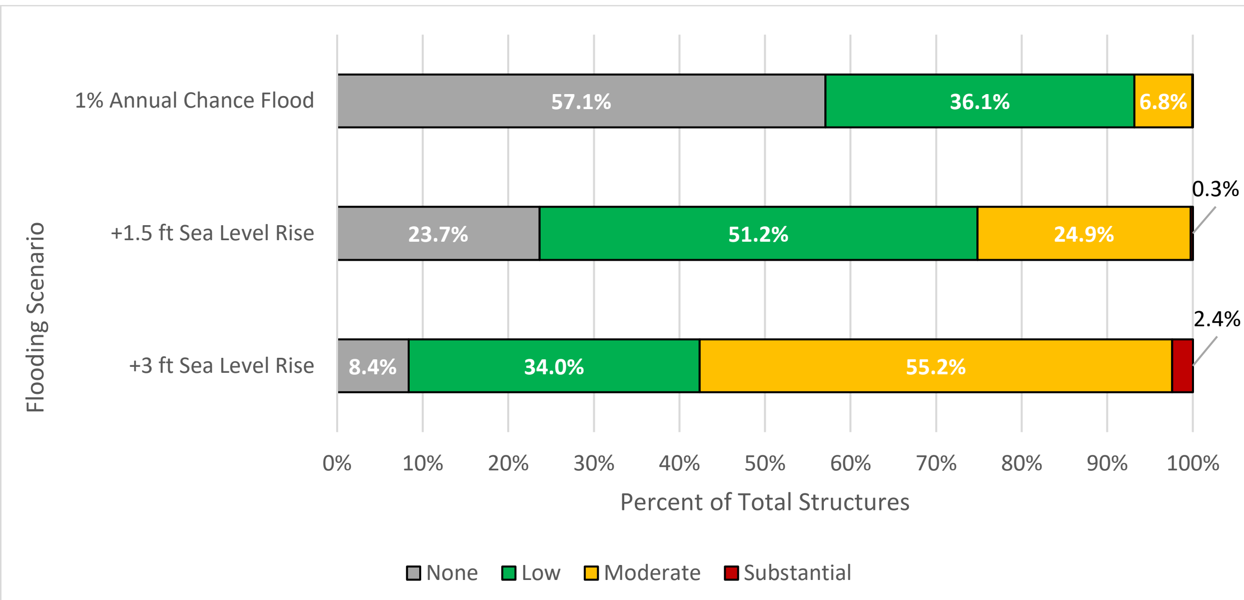


Figure 11: Percent of total structures experiencing substantial, moderate, low, or no damage from the 1% annual chance flood event plus an additional 1.5ft and 3ft of sea level rise. Custom first floor height estimates derived from local data were used.

The distribution of damaged structures classified by level of damage is displayed in Figure 12 for the 1.5ft sea level rise scenario and in Figure 13 for the 3ft sea level rise scenario. A heat map of the structures weighted by total losses illustrates the highest density of losses occur in Hampton, Poquoson, Chesapeake, Norfolk, Portsmouth, and Virginia Beach under both sea level rise scenarios (Figures 12 and 13). Additional damage hot spots begin to emerge in Gloucester County and along the southern coastline in Virginia Beach under the 3ft sea level rise scenario (Figure 13).

Flooding Scenario: 1% Annual Chance Flood with 1.5 ft Sea Level Rise

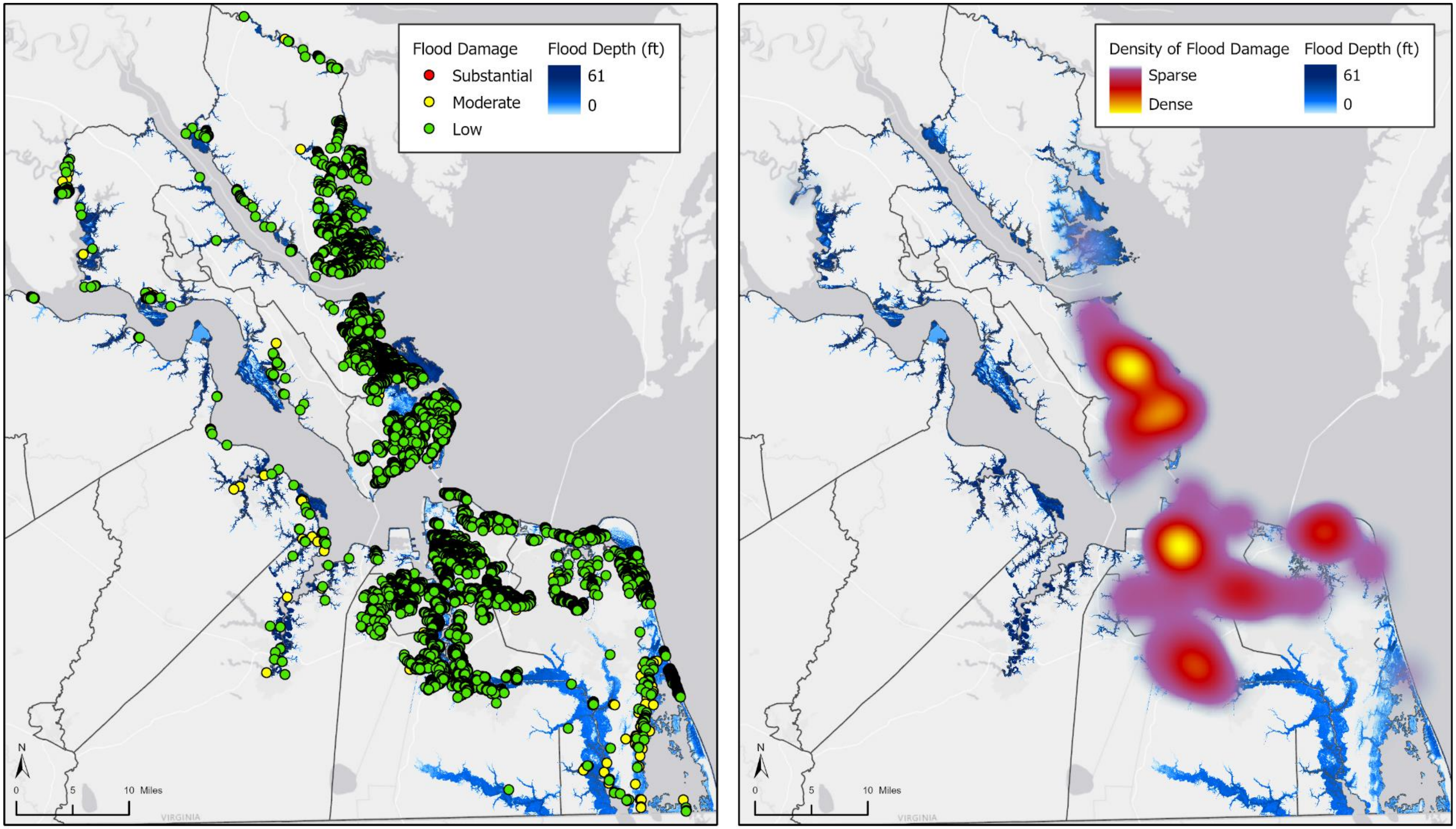


Figure 12: Distribution of individual structures experiencing flood damage under the 1% annual chance flood event plus 1.5ft of sea level rise across the Hampton Roads region. The heat map displays the density of damaged structures weighted by the value of loss in dollars.

Flooding Scenario: 1% Annual Chance Flood with 3 ft Sea Level Rise

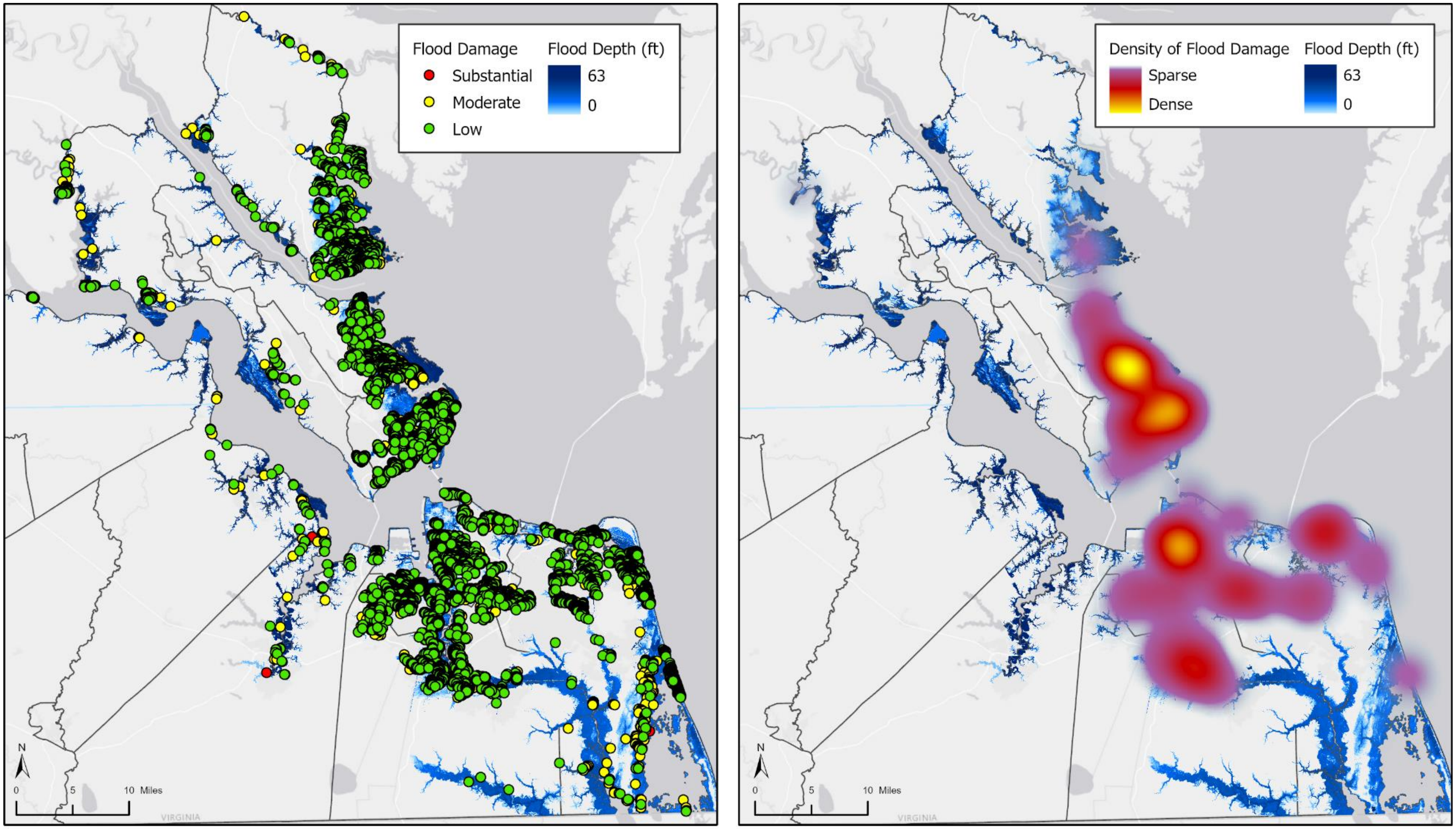


Figure 13*:* Distribution of individual structures experiencing flood damage under the 1% annual chance flood event plus 3ft of sea level rise across the Hampton Roads region. The heat map displays the density of damaged structures weighted by the value of loss in dollars.

Comparisons and Limitations

While the overall custom FFH building damage estimate was only $1.3 million greater than the default FFH building damage estimate (Table 7), the differences in individual localities were as large as $36.6 million. The overall difference in damage appears lower at the regional scale because the default FFH estimates do not always result in higher flood damage estimates for individual localities. The total absolute difference in damage between the custom and default FFH results across all localities is $122.5 million. In agreement with the conclusions of the pilot community vulnerability assessment results, locality building damage estimates are highly sensitive to the FFH input.

In localities where elevation certificates were available and used to inform predictive models, the FFH estimates tended to be higher, and therefore, the damage estimates were lower than when using the Hazus default values. Given that elevation certificates are generally more common for recent construction, the Hazus default FFH values may not overestimate FFH consistently for older structures-built pre-FIRM. Integrating additional survey data or Google Street view stair counting estimates for pre-FIRM structures would likely improve predictive model performance for these structure types.

When comparing the local depth grid for the 1% annual chance flood to the FEMA Flood Risk MAP product depth grid, the FEMA depth grid resulted in a larger damage estimate by $49.6 million (Table 7). Considering both depth grid scenarios, the total estimated building damage for RES1 structures in the SFHA likely ranges from $305 to $354 million. The building damage estimate when using the Hazus default FFH values ($353) also falls within this range.

Table 7: Comparison of estimated total building damages across the Hampton Roads region resulting from the 1% annual chance flood plus 1.5ft and 3ft sea level rise. Estimates are reported in millions (M) or billions (B) of dollars.

Flooding Scenario	Custom First Floor Height Total Building Damage	Default First Floor Height Total Building Damage
1% Annual Chance Flood – FEMA Depth Grid	$354.6 M	$353.3 M
1% Annual Chance Flood – Local Depth Grid	$305.0 M	---
+ 1.5 ft Sea Level Rise	$865.8 M	---
+3 ff Sea Level Rise	$1.7 B	---

While the damage estimates were lower for the 1% annual chance flood depth grid based on the HRPDC DEM, there are inconsistences in coverage between the two depth grids. Within the local depth grid, several areas have been identified that are tidally connected but currently excluded from the depth grid. Further enhancements to the local flood depth grid to incorporate these additional tidally connected areas will help improve damage estimates. It is also important to note that only points in the current SFHA were considered in this analysis. Additional structures outside of the SFHA impacted by sea level rise were not accounted for, and future analysis could expand the database to incorporate these additional residential structures. For the sea level rise analysis, emphasis should be placed on the relative increases in damage estimates as a result of sea level rise, rather than the exact building loss dollar estimate.

Additional limitations in the analysis existed for Franklin, Southampton County, and Poquoson. Given that the depth grids are based on storm surge scenarios associated with the 1% annual chance flood event, inland floodplains that do not have a static BFE were not included in the depth grids. Therefore, Franklin and Southampton County were excluded from the flooding vulnerability assessment. The FEMA Hazus program has developed recommended methodologies for developing depth grids based on local FIRM transects (FEMA, 2018a). By adapting this methodology to the Hampton Roads region, additional flood depth grids can be developed to address these existing gaps. For Poquoson, it is important to note that the damage estimates resulting from using the Hauzs default FFH values likely overestimate the expected damage because many home elevations have been completed. Over 1,000 elevation certificates are available for Poquoson, and HRPDC staff has been coordinating with the city to convert paper copies into a digital PDF format for future data entry. Upon entering the elevation certificate data into GIS, the revised FFH estimates can be applied in a vulnerability assessment to develop more accurate building damage estimates.

While this analysis focused on applying a single FFH estimate for each structure, alternative vulnerability assessment approaches can incorporate a range of likely FFH values for each structure. An approach developed by AECOM estimated flood damages given a range of FFH values, weighted by the probability of occurrence, for a given structure (Parson and Onufrychuck, 2019). This approach helps capture uncertainty associated with a single FFH estimate. The methodology was adapted to the Hampton Roads region and piloted in Hampton as part of the second phase of the regional FFE initiative. In the Hampton example, the probabilistic approach resulted in higher building loss estimates than using a single FFH value. Implementing this approach in other Hampton Roads communities could improve estimation of the possible range of building losses under various flooding scenarios. Further research is needed to identify the most appropriate scale of analysis (individual locality vs. multi-jurisdictional) and suitable foundation types for this approach based on available data.

IV. Recommended Practices for Data Management and Development

Elevation Certificate Data Management

The multi-year regional FFE effort has provided insight into approaches for organizing and applying elevation certificate data in both flooding vulnerability assessments and floodplain management. **It is recommended that localities maintain digital elevation certificate copies to support earning credit in the National Flood Insurance Program's Community Rating System (CRS).** The CRS is a program administered by FEMA that provides discounts on flood insurance premiums to the residents of participating communities (CRS, 2017). Localities are assigned a class from 1-10 that reflects the measures taken to reduce and mitigate flood damage beyond the minimum requirements for participation in the National Flood Insurance Program (CRS, 2017). Each CRS class corresponds with a discount on flood insurance premiums for residents of the community (CRS, 2017). Discounts increase in 5% intervals from Class 9 (5%) to Class 1 (45%) for polices in the SFHA (CRS, 2017). As a prerequisite for achieving a CRS Class 9 rating, the community must maintain FEMA elevation certificates for all new buildings and substantial improvements constructed in the SFHA following the community's CRS application (CRS, 2017). The community must also provide copies of the elevation certificates upon request (CRS, 2017). While the CRS program does not require the elevation certificate copies to be digital, there are several advantages to maintaining scanned elevation certificate copies.

Digital copies of elevation certificates are eligible for Flood Protection Website (WEB) credit under Activity 350, Flood Protection Information (CRS, 2017). WEB credit includes three sub-elements: (1) providing detailed information on flood protection messages associated with credited outreach projects, (2) publishing real-time water-level gage information, and (3) posting elevation certificates or data from elevation certificates (CRS, 2017). To achieve points for WEB3, the copies of elevation certificates, or a list of addresses for which elevation certificates are available, must be posted on the community's flood protection website (CRS, 2017). A maximum of 20 points is awarded if all available elevation certificate copies/addresses are available (CRS, 2017). If only a portion of the elevation certificates are available, the amount of points earned is adjusted proportionally (i.e. listing 50% of addresses would equal 10 points) (CRS, 2017).

Communities can also earn credit for providing access to building elevation data. Under Activity 440, Flood Data Maintenance, communities can earn points for providing additional map data (AMD) (CRS, 2017). In order to be eligible for AMD credit, a community must first display the SFHA boundaries, corporate limits, streets, and parcel or lot boundaries as part of the data system (CRS, 2017). Following this requirement, there are opportunities to earn points for 12 additional types of data (CRS, 2017). Under AMD13, 14 points are available for including building elevation data in a digital format (not just scanned copies of elevation certificates) (CRS, 2017). These points are prorated according to the percent of the inventory displayed, following the same calculation for the WEB3 activity of listing elevation certificate addresses online (CRS, 2017).

The Hampton Roads elevation certificate inventory, hosted on HRGEO.org, supports localities in earning credit for both WEB3 under Activity 350 and AMD13 under Activity 440. The elevation certificate parcels data provides a complete list of addresses for which elevation certificates are available within each participating locality. The list of addresses can be accessed as a spreadsheet or as GIS layers to support Activity 350. The elevation measurements from the certificates are also recorded in the GIS layers, providing the necessary information for Activity 440. To support keeping this inventory current, HRPDC staff plan to update this inventory annually. **It is recommended localities scan new elevation certificates as they become available and compile copies in a single computer folder. In addition to the HRPDC inventory, interested localities could host this information on their local websites or GIS portals.** For example, James City County includes PDF copies of elevation certificates by parcel on their public property viewer (James City County, 2020). This approach provides an opportunity to view elevation certificates, building details, and property assessment information in a central location.

The state of Florida has an exemplary approach to displaying and maintaining elevation certificate information. As of January 2017, surveyors are required to submit a copy of each elevation certificate, within 30 days of completion, to the Florida Division of Emergency Management (Land Surveying and Mapping, Florida Statute 472.0366, 2020). The elevation certificates are submitted through a geo-referenced form, and submissions are tracked through an online dashboard application (Florida Division of Emergency Management, 2020a and 2020c). Elevation certificate submissions can be viewed by the public through an interactive web map, which displays the location of the structure, reported base flood elevation, and a digital copy of the elevation certificate (Florida Division of

Emergency Management, 2020b). The statewide elevation certificate inventory contains over 100,000 elevation certificates, including both new elevation certificates collected through the online form and previously collected elevation certificates (Figure 14). **This streamlined approach of collecting and mapping elevation certificate data provides an example of long-term database management that could potentially be replicated in the Hampton Roads region or across Virginia.**

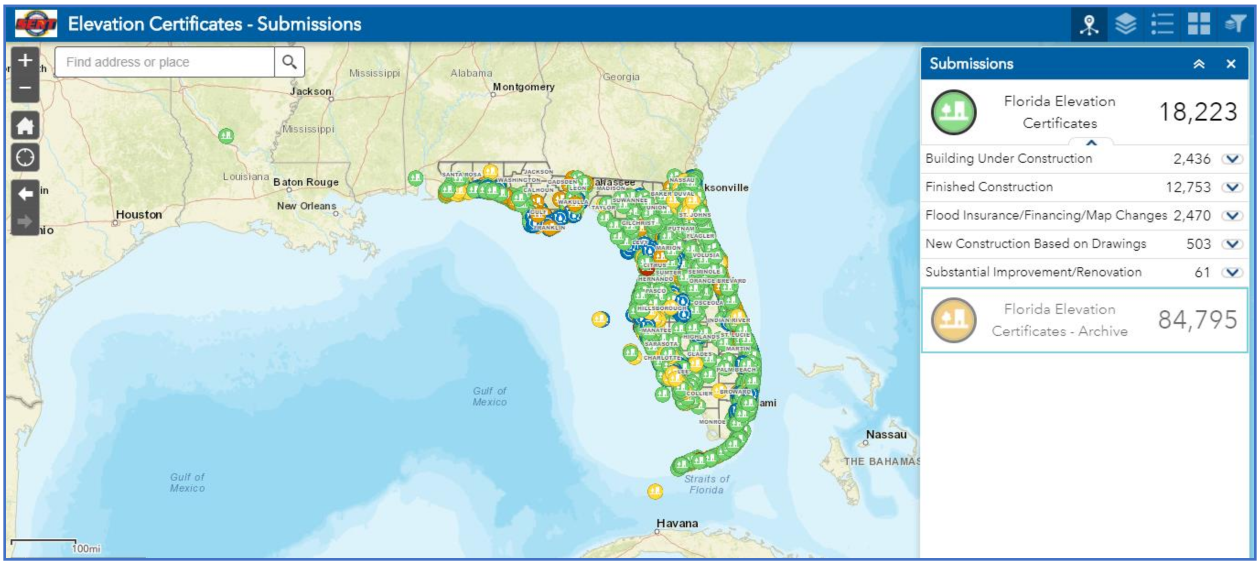


Figure 14: Image of the Florida Division of Emergency Management elevation certificate submission web application (Florida Division of Emergency Management, 2020b).

First Floor Elevation Estimation Methods

In addition to the HRPDC initiative to develop FFE data, there have been several other efforts in the Hampton Roads region to enhance FFE data. The following section describes the methodologies associated with the data development efforts lead by the U.S. Army Corps of Engineers, Old Dominion University, and Virginia Beach and the consulting firm Dewberry.

U.S. Army Corps of Engineers (USACE)

USACE has developed FFE databases for Norfolk and Portsmouth using a combination of available survey data, stair counting, and estimations based on floodplain regulations. Within each community, structures were classified as being built before or after the community's first FIRM. For pre-FIRM structures where FFE estimation was required, USACE applied a stair counting approach using Google Street View imagery and vehicle windshield surveys. The number of stairs leading to the entrance of each structure was recorded, and each stair was assumed to be approximately 0.5ft in height. Consideration was also given to the location of the stairs relative to the LAG when calculating

FFH. For post-FIRM structures, the FFE was assumed to be equivalent to the BFE plus additional freeboard required by the locality at the time of construction. The FFH was then calculated as the difference between the FFE and estimated lowest adjacent grade derived from a DEM.

The Norfolk USACE database was completed in 2016 and included in the HRPDC regional structure inventory for the flooding vulnerability assessment. Additional elevation certificates became accessible following the development of the USACE database, so FFH estimates were replaced with elevation certificate values where available prior to the flooding analysis. The Portsmouth database is being finalized and was not included in the HRPDC regional structure inventory.

Old Dominion University (ODU)

Through a collaborative effort between ODU, the Virginia Institute of Marine Science, the Commonwealth Center for Recurrent Flooding Resiliency (CCRFR), and the Virginia Department of Emergency Management, FFE data is being developed for the Salters Creek and Newmarket Creek areas of Newport News to support flooding vulnerability assessments (Allen, 2019). ODU is creating the FFE database using a combination of field data collection and predictive modeling (Allen, 2019). Because of the limited number of elevation certificates available for Newport News, additional field data collection was required to inform the modeling approach. FFE data was collected using a laser inclinometer for a random stratified sample of residential structures (Allen, 2019). The sample included approximately 1,700 buildings classified by flood zone, with priority given to structures in the SFHA and 0.2% annual chance floodplain (Allen, 2019). The field measurements were recorded in GIS, and the field measurements were included in the HRPDC regional structure inventory for application in the flooding vulnerability assessment.

ODU is applying the field data to develop geostatistical models, specifically Empirical Bayesian Kriging and Co-Kriging models (Allen, 2019). Kriging is a form of spatial interpolation that predicts values at unmeasured locations and quantifies uncertainty associated with the predictions (Esri, 2020). For the Co-Kriging approach, LiDAR-derived elevation and foundation type were used as predictor variables (Allen, 2019). The models create a surface of FFE values that can then be applied to individual building footprints (Allen, 2019). The FFE database is being developed in conjunction with high-resolution flood depth grids to support building-level damage assessments that could be integrated with the Virginia Integrated Flood Observing and Warning Systems (IFLOWs) for flood monitoring (VIMS, 2019).

Dewberry and the City of Virginia Beach

Virginia Beach and the consulting firm Dewberry recently completed a multi-year effort to develop strategies to respond to sea level rise and increased flooding (City of Virginia Beach, 2020). This comprehensive program, Sea Level Wise, included a flood risk analysis using FEMA's Hazus model to understand the impacts of existing and future flooding scenarios (City of Virginia Beach, 2020). To develop the required FFH input for the Hazus analysis, Dewberry applied a combination of observational data and predictive modeling (Dewberry, 2020). The sources of observational data included city permits and surveys previously collected by Risk Assessment, Mapping, and Planning Partners (RAMPP) and Kimley-Horn Associates (Dewberry, 2020). Given city permit data had the most robust sample size (~7,500 structures) with more than 10 times the amount of data from the other two data sources, it was used to develop predictive regression equations (Dewberry, 2020).

The explanatory variables used in the regression analysis included occupancy type, year the structure was built, foundation type, and difference between highest and lowest adjacent grade (Dewberry, 2020). The regression models produced estimates of FFH based on these attributes for structures where measurements were not available (Dewberry, 2020). The regression model produced a Root Mean Square Error (RMSE) of 1.23ft overall. When comparing the regression model predictions to observational data, the regression models produced a better estimate of FFH than Hazus default values 71% of the time (Dewberry, 2020). The resulting model FFH estimates were also added to the estimated LAG to produce a final FFE estimate. When compared to the additional survey data sources, the RMSE was 2.57ft and the mean absolute error was 0.94ft (Dewberry, 2020).

For the final FFH database, a tiered screening approach was applied in the following order: city permit, RAMPP/KHA survey data, regression equation, and Hazus default (Dewberry, 2020). The Dewberry FFH database was added to the HRPDC regional structure inventory. Given that the database was completed in 2016, the database was updated to account for new construction and elevation certificates before application in the HRPDC flooding vulnerability assessment.

Methods Comparison

When determining what FFE estimation approaches may appropriate for a given locality, it is important to evaluate tradeoffs between time, cost, required level of expertise and data for each methodology. Table 8 summarizes the various methodologies applied throughout Hampton Roads based on data, statistical knowledge, and time requirements. **When developing a local FFE database, it is**

recommended that the availability of existing survey data and building attribute data first be evaluated. Predictive methodologies are dependent on the availability of this information. In the absence of building attribute data, foundation type and number of stories can be estimated from Google Street View or local assessor imagery. The stair counting approach offers the advantage of minimal data requirements, but is more time consuming than a predictive modeling approach. While a modeling approach can quickly generate estimates for thousands of structures, it may require a significant amount of data preparation. The list of methodologies presented in Table 8 is not comprehensive, and additional data collection techniques, such as mobile-LiDAR, are also available. **As observed with the development of the HRPDC regional structure inventory, a combination of various methodologies can be applied to develop a local FFH database**.

Table 8: Comparison of data requirements, relative processing time, and technical qualifications needed for various first floor elevation estimation approaches.

Requirements	Dewberry Regression Modeling	HRPDC Random Forest Modeling	ODU Geostatistical Modeling	USACE Stair Counting	Hazus Default Reference Tables
Digital Elevation Model (DEM)	Yes	Yes	Yes	Yes (if adjusting for stair elevation)	No
Occupancy Type	Yes	Yes	No	No	No
Foundation Type	Yes	Yes	Yes (for Co-Kriging)	No	Yes
Year Built	Yes	Yes	No	No	Yes (Pre- or Post-FIRM)
Property Value	No	Yes	No	No	No
Survey Data	Yes	Yes	Yes	No	No
Image of Structure	No	No	No	Yes	No
Relative Processing Time	Thousands of structures can be estimated at once. Initial data prep can be time intensive.			Each structure must be reviewed individually.	Thousands of structures can be estimated at once. Adapting foundation codes can be time intensive.
Technical Qualifications	Requires knowledge of statistical modeling and GIS.			GIS only required to adjust for lowest adjacent grade.	May require knowledge of GIS to access building attributes.

V. Conclusions and Next Steps

The importance of accurate FFH estimates is underscored by the sensitivity of flooding vulnerability damage estimates to the FFH input. As noted in the pilot community vulnerability assessments and further analysis across Hampton Roads localities, changing FFH by less than a foot can alter flood damage by hundreds of structures and millions of dollars. When considering future sea level rise, the estimated flood losses increased by more than double with 1.5ft of sea level rise (present-2050 planning horizon) and increased by nearly six times the initial estimates with 3ft of sea level rise (2050-2080 planning horizon). Precise FFH data is critical to developing accurate vulnerability assessments that influence long-term community planning decisions.

The multi-year HRPDC FFE initiative investigated several methods for developing FFE/FFH estimates. There was not one estimation approach that was the most accurate or efficient across the Hampton Roads region. While the Random Forest modeling approach was the primary estimation method used in the initiative, it is dependent on the availability of a robust sample of elevation certificates or survey data that represents the community building stock. Elevation certificates are not as readily available for structures built before a community's first FIRM was adopted because they were not required for floodplain management compliance at that time. This results in lower confidence in Random Forest model FFH estimates for structures that were built pre-FIRM. Across all six Random Forest models described in this report, foundation type was the most important predictor variable. Local assessor codes are not consistent in the level of detail across Hampton Roads localities, and in some cases, a variety of foundation types are bundled under one code. Localities should consider adopting clear and consistent assessor foundation type codes to improve future modeling and vulnerability assessments.

Predictive modeling offers the advantage of quickly processing thousands of structures. However, it also requires a relatively large sample of data for model development and knowledge of statistics. In comparison, imagery-based stair counting requires minimal knowledge of building characteristics to estimate FFH, but requires significant time to review images for each structure. This illustrates the tradeoffs between time, data availability, and technical knowledge required for each approach. A robust methods assessment that includes additional methodologies not applied in this analysis, such as mobile LiDAR, would offer more insight into tradeoffs between cost and accuracy.

The regional FFE database developed through this initiative is designed to be an adaptive database. Additional elevation certificate or survey data can be integrated into the database as it becomes available. An immediate next step for the regional FFE database is to record information from Poquoson's elevation certificates. Given the robust sample of elevation certificates for Poquoson (likely over 1,000), the data could potentially be used to develop a predictive modeling approach for the locality or used to refine the regional FFH model. Continued collection of digital copies of elevation certificates by local governments will further support long-term database management and opportunities for localities to earn credit through the Community Rating System.

While the focus of this analysis was on building losses for single-family residential structures within the SFHA, comprehensive flooding vulnerability assessments also account for commercial and industrial properties, as well as building contents loss. The FEMA FAST tool applied in this analysis also produces contents loss estimates and is applicable to additional occupancy types. Future vulnerability assessments could include these aspects, as well as additional flooding scenarios. The lessons learned through the HRPDC regional FFE effort will serve as a resource for the upcoming Hampton Roads Hazard Mitigation Plan update, which is expected to be completed by April 2022. Continued research and coordination across the Hampton Roads region to develop more accurate FFE data will support coastal resiliency planning efforts and contribute to the advancement of the broader natural hazards analysis community.

VI. References

Allen, T. (2019, November). First Floor Elevation Analysis: VDEM FEMA HMP Research Update presentation. Old Dominion University.

City of Virginia Beach. (2020). Virginia Beach Sea Level Wise Adaptation Strategy. https://www.vbgov.com/government/departments/public-works/comp-sea-level-rise/Documents/20200330%20FullDocument%20(2).pdf

Commonwealth Center for Recurrent Flooding Resiliency (CCRFR). (2020). Future Sea Level and Recurrent Flooding Risk for Coastal Virginia. https://www.floodingresiliency.org/wp-content/uploads/2020/03/Future-Sea-Level-and-Recurrent-Flooding-Risk-for-Coastal-Virginia-Final-Version.pdf

Dewberry. (2020). Coastal Flooding and Economic Loss Analysis. https://www.vbgov.com/government/departments/public-works/comp-sea-level-rise/Documents/20200330_FloodRiskAnalysis_Final_%282%29.pdf

Esri. (2020a). ArcGIS Pro: Forest-based Classification and Regression. https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/forestbasedclassificationregression.htm

Esri. (2020b). How Forest-based Classification and Regression works. http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/how-forest-works.htm

Esri. (2019). How To: Create points representing the highest or lowest elevations within polygon features. https://support.esri.com/en/technical-article/000011761

FEMA. (2020a). Base Flood Elevation (BFE). https://www.fema.gov/node/404233

FEMA. (2020b). Flood Insurance Rate Map (FIRM). https://www.fema.gov/flood-maps/products-tools/products#

FEMA. (2020c). Risk MAP Flood Risk Products. https://www.fema.gov/flood-maps/tools-resources/risk-map/products

FEMA. (2020d). Special Flood Hazard Area. https://www.fema.gov/glossary/special-flood-hazard-area-sfha

FEMA (2018a). Guidance for Flood Risk Analysis and Mapping: Flood Depth and Analysis Grids. https://www.fema.gov/media-library-data/1523562952942-4c54fdae20779bb004857f1915236e6c/Flood_Depth_and_Analysis_Grids_Guidance_Feb_2018.pdf

FEMA. (2018b). If Your Home or Business Has Been Flooded, Build Back Safer and Stronger. https://www.fema.gov/media-library-data/1531251928965-e646d1b0e92038ab44410f2562061da0/Build_Back_Safer_and_Strong_Fact_Sheet_508.pdf

FEMA Federal Insurance and Mitigation Administration. (2015). Elevation Certificates: Who Needs Them and Why. https://www.fema.gov/media-library-data/1428941960043-a8f37b7e3af25f47396bbff04e7bf036/FEMA-HFIAA_ECFActSheet_040715.pdf

FEMA Mitigation Division. (2017). Multi-hazard Loss Estimation Methodology Flood Model Hazus-MH Technical Manual. https://www.fema.gov/hazus-mh-user-technical-manuals

FEMA National Flood Insurance Program (NFIP). (2020). Elevation Certificate and Instructions. https://www.fema.gov/glossary/elevation-certificate

FEMA National Flood Insurance Program Community Rating System Coordinators Manual (CRS). (2017). https://crsresources.org/manual/

FEMA Natural Hazards Risk Assessment Program - Hazus. (NHRAP - Hazus) (2020). Flood Assessment Structure Tool (FAST). https://github.com/nhrap-hazus/FAST

FEMA Region II Coastal Analysis and Mapping. (2013). Storm Surge Study. https://sites.google.com/site/r3coastal/home/storm-surge-study

FEMA Risk MAP CDS. (2019). Hazus 4.2.3 (Service Pack 3) User Release Notes. https://www.fema.gov/sites/default/files/2020-11/fema_hazus-4-2_sp3_user-release-notes.pdf

FEMA Risk Map CDS. (2016). Hazus 3.2 User Release Notes. https://www.fema.gov/media-library-data/1486406911383-78d7d706bc7995a20babc59d7976d692/Hazus_3.2_User_Release_Notes.pdf

Florida Division of Emergency Management. (2020a). Elevation certificate operations dashboard. https://floridadisaster.maps.arcgis.com/apps/opsdashboard/index.html#/36dcfb3279e0465e944178f4b4a37d0a

Florida Division of Emergency Management. (2020b). Elevation certificates submissions application. https://floridadisaster.maps.arcgis.com/apps/webappviewer/index.html?id=31af9cc082c442cea899fb955dc29d02

Florida Division of Emergency Management. (2020c). Elevation certificates web survey. https://maps.floridadisaster.org/portal/apps/GeoForm/index.html?appid=d5642b277af24b7191107524b390bada

Gordon, A.M. (2020). Applying First Floor Elevation Data to Flooding Vulnerability Assessments in Hampton Roads. https://www.hrpdcva.gov/library/view/1124/applying-first-floor-elevation-data-to-flooding-vulnerability-assessments-in-hampton-roads

Gordon, A.M. and McFarlane, B.J. (2019). Developing First Floor Elevation Data for Coastal Resilience Planning in Hampton Roads. https://www.hrpdcva.gov/library/view/932/developing-first-floor-elevation-data-for-coastal-resilience-planning-in-hampton-roads

Hampton Roads Geospatial Exchange Online (HRGEO). (2020a). Hampton Roads Elevation Certificates. http://www.hrgeo.org/datasets/hampton-roads-elevation-certificates

Hampton Roads Geospatial Exchange Online (HRGEO). (2020b). Hampton Roads Resilience Projects Dashboard.https://www.arcgis.com/apps/opsdashboard/index.html#/271ff8ba589540f494fc1770712cfea3

Hampton Roads Hazard Mitigation Plan (HMP) (2017).https://www.hrpdcva.gov/library/view/620/2017-hampton-roads-hazard-mitigation-plan-and-appendices/

Hampton Roads Planning District Commission (HRPDC) (2018a). Hampton Roads Planning District Commission Resolution 2018-01. https://www.hrpdcva.gov/library/view/823/2018_01-resolution-of-the-hampton-roads-planning-district-commission-encouraging-local-governments-in-hampton-roads-to-consider-adopting-policies-to-incorporate-sea-level-rise-into-planning-and-engineering-decisions

Hampton Roads Planning District Commission (HRPDC) (2018b). Proposed Sea Level Rise Planning Policy and Approach. https://www.hrpdcva.gov/uploads/docs/11_Attachment_Proposed%20Sea%20Level%20Rise%20Planning%20Policy%20and%20Approach%20100518.pdf

James City County. (2020). James City County Parcel Viewer. https://property.jamescitycountyva.gov/JamesCity/Account/Logon

Land Surveying and Mapping, Florida Statutes § 472.0366 (2020). http://www.leg.state.fl.us/statutes/index.cfm?mode=View%20Statutes&SubMenu=1&App_mode=Display_Statute&Search_String=elevation+certificate&URL=0400-0499/0472/Sections/0472.0366.html

Liaw, A. and Wiener, M. (2002). Classification and Regression by randomForest. R News. Vol. 2/3. https://www.r-project.org/doc/Rnews/Rnews_2002-3.pdf

Mitchell et al. (2013). Recurrent Flooding Study for Tidewater Virginia. http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf

Needham, H. and McIntyre N. (2018). Analyzing the Vulnerability of Buildings to Coastal Flooding in Galveston, Texas. City of Galveston and Galveston Historical Foundation.

NOAA National Geodetic Survey (NGS) (2019). VERTCON 3.0. https://geodesy.noaa.gov/VERTCON3/index.shtml

Parson, S., and Onufrychuk, M. (2019, May). Incorporating Uncertainty of First Floor Elevations into Flood Risk Assessment Modeling. AECOM. Presentation at the 2019 Association of State Floodplain Managers Annual National Conference, Cleveland, OH.

U.S. Army Corps of Engineers (USACE). (2015). North Atlantic Coast Comprehensive Study Report. https://www.nad.usace.army.mil/CompStudy/

Virginia Institute of Marine Science (VIMS). (2019), Center for Coastal Resources Management 2019 Annual Report. https://www.vims.edu/ccrm/_docs/annual-report/annualreport2019_final_042320.pdf

VII. Appendices

Appendix A: FEMA Hazus First Floor Height Reference Tables

The following table summarizes the Hazus default FFH values, reported in feet, by foundation type, flood zone, and FIRM-status. This table is adapted from FEMA's Multi-hazard Loss Estimation Methodology Flood Model Hazus-MH Technical Manual (Table 3.11 and Table 3.14, FEMA Mitigation Division, 2017).

Table 9: Hazus Default First Floor Height Values

Foundation Type	***Pre-Firm FFH***	***Post-FIRM FFH (Riverine)***	***Post-FIRM FFH (Coastal A zone)***	***Post-FIRM FFH (Coastal V zone)***
Pile	7	8	8	8
Pier/Post/Beam	5	6	6	8
Solid Wall	7	8	8	8
Basement/Garden Level	4	4	4	4
Crawlspace	3	4	4	4
Fill	2	2	2	2
Slab	1	1	1	1

Appendix B: Replacement Cost Calculation for Residential Structures

The structural replacement cost in Hazus is based on published R.S. Means Values for industry-standard cost-estimation (FEMA Mitigation Division, 2017). For single-family residential structures, socio-economic data from the Census is applied to identify construction classes and associated replacement cost models (FEMA Mitigation Division, 2017). Buildings are classified as Economy, Average, Custom, or Luxury based on the census block income ratio (I_K) as shown in Table 9.

Table 10: Income ratio ranges for selecting and weighting R.S. Means building classifications. Values correspond with the weight applied to the R.S. Means cost per square foot when calculating replacement cost. Adapted from Hazus Technical Manual (Table 14.5, pg 14-15. FEMA Mitigation Division, 2017).

Income Ratio (I_k)	Luxury	Custom	Average	Economy
$I_k < 0.5$				1
$0.5 \leq I_k < 0.85$			.25	.75
$0.85 \leq I_k < 1.25$		.25	.75	
$1.25 \leq I_k < 2.0$		1		
$I_k >= 2.0$	1			

The Hazus software includes reference tables for identifying R.S. Means values of cost per square foot. The R.S. Means values vary by construction classification, number of stories, and the presence of a basement (Table 10). These average national values are further adjusted by a regional factor provided in the Hazus software (Table 11).

Using values from the above reference tables, the structure replacement cost is calculated using the following formula (FEMA Risk Map CDS, 2016):

BLDG_SQFT * RS_Means * Reg_Factor

- BLDG_SQFT: Building Square Footage as reported in the assessor's database.
- RS_Means: 2018 RS Means Cost per square foot, weighted by income class for single-family residential structures.
- Reg_Factor: Regional adjustment factor for replacement cost calculation.

For example, the replacement cost for a 2,000 square foot, two-story, single-family residential, home with an income ratio between 0.85 and 1.25 located in Chesapeake would be calculated as follows:

2,000ft * ((141.49/ft * 0.25) + ($112.4/ft * 0.75)) * 0.95 = $227,378 replacement cost value.

Table 11: 2018 R.S. Means values representing cost per square foot for estimating structure replacement cost (FEMA Risk MAP CDS, 2019). Values copied from Hazus software reference tables.

Description	Height Class	Average Base Cost	Finished Basement Cost	Unfinished Basement Cost
Economy	1 story	84.03	25.5	8.8
Economy	2 story	90.11	14.35	5.8
Economy	3 story	90.11	14.35	5.8
Economy	Split level	83.59	14.35	5.8
Average	1 story	115.2	30.8	10.55
Average	2 story	112.4	19.75	6.9
Average	3 story	118.19	15.6	5.4
Average	Split level	104.01	19.75	6.9
Custom	1 story	143.55	50.4	19.5
Custom	2 story	141.49	28.95	11.65
Custom	3 story	147.21	21.05	8.65
Custom	Split level	131.78	28.95	11.65
Luxury	1 story	175.81	54.25	20.55
Luxury	2 story	168.8	31.75	12.55
Luxury	3 story	174.21	23.4	9.45
Luxury	Split level	156.91	31.75	12.55

Table 12: Regional location factors for adjusting R.S. Means values by community.

Locality	Regional Factor
Chesapeake	0.95
Gloucester County	1.03
Hampton	0.95
Isle of Wight County	0.95
James City County	1.03
Newport News	0.95
Norfolk	0.95
Poquoson	0.95
Portsmouth	0.87
Suffolk	0.95
Surry County	0.95
Virginia Beach	0.95
York County	0.96

For structures with a basement, an additive adjustment of additional cost per square foot of the structure is applied because the R.S. Means values do not consider basements in the base cost of the structure (FEMA Mitigation Division, 2017). For structures with a partial basement, the basement additional cost was only applied to the corresponding square footage (i.e. half of structure's square footage for a half basement foundation type). Unless otherwise specified in the assessor data, all basements were assumed to be unfinished. An additional adjustment can be made for structures with attached and detached garages. Given limited data on the type of garage in the assessor database and a different FFH for a garage compared to the main structure, garage replacement costs were not accounted for in this analysis.