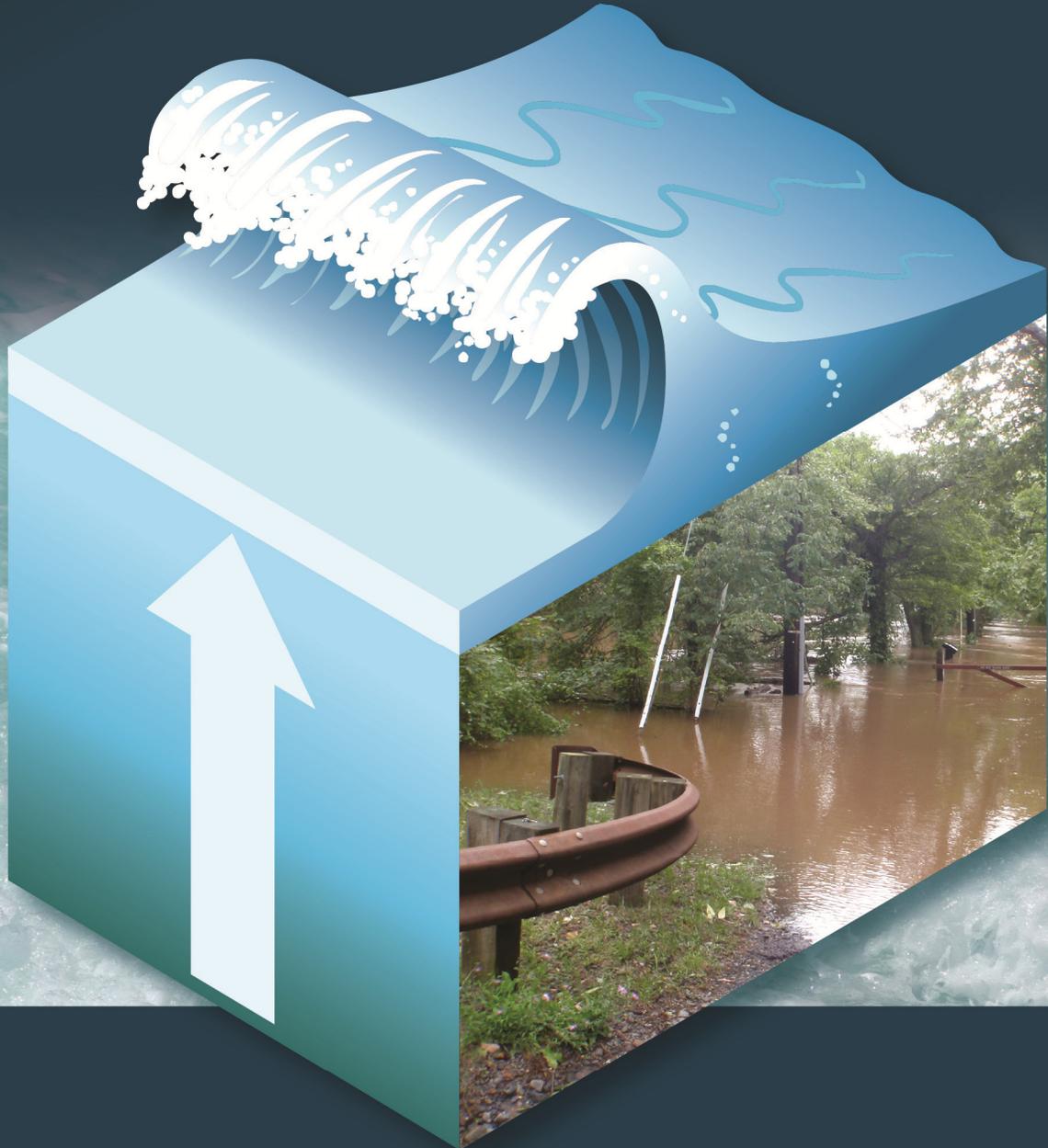


Delaware Flood Risk Adaptation Map: Methods, Assumptions and Limitations

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URS

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Acronyms and Abbreviations

BF E	Base Flood Elevation
DEM	digital elevation model
DNREC	Delaware Department of Natural Resources and Environmental Control
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FRAM	Flood Risk Adaptation Map
GIS	geographic information system
NAVD88	North American Vertical Datum of 1988
RMSEz	Vertical Root Mean Square Error
SLR	sea level rise
URS	URS Group, Inc.

1%-Annual-Chance Event (or) 100-Year Flood Event: A flood event that has a 1 percent chance of being met or exceeded during any year.

Base Flood Elevation (1 percent elevation): The hazard elevation that has a 1 percent chance of being met or exceeded during any year. The hazard can include both stillwater and waves.

“Bathtub” Methodology: A method for representing sea level rise (SLR) that assumes the effects of sea level can be directly added to existing data instead of using non-linear models to calculate predicted changes.

Dune: A sandy ridge adjacent to a sandy beach characterized by steep sides and vegetation. The first line of defense from storm surge and waves.

Floodplain Boundary: A delineation of the probable limit of flooding defined where the flood elevation is equal to the ground elevation.

Flood Insurance Rate Map (FIRM): The regulatory map of a community on which FEMA delineates special flood hazard areas and the risk zones applicable to the community.

Flood Insurance Study (FIS): A study that contains the compilation and presentation of flood risk data for specific watercourses, lakes, and coastal flood hazard areas within a community.

Overtopping: The phenomena of flood waters exceeding the height of a structure or land feature, allowing water to enter the area behind the feature.

Runup: The uprush of water that occurs when a wave encounters a barrier. Barriers can be naturally occurring, such as a steep ground slope, or man-made, such as a seawall.

Stillwater: The water elevation reached when storm surge, tide, and wave setup are combined, not including the inland wave height.

Storm Surge: The mass of water, in excess of normal tides, pushed ashore by a storm system approaching the shoreline.

Wave Height: The vertical dimension of a wave measured from the trough to the crest that contributes to the Base Flood Elevation.

Wave Setup: A super-elevation of the water level above the storm surge caused by waves travelling toward the shoreline.

Zone AE: FEMA FIRM flood zone indicating an area that is predicted to be inundated by the 1 percent annual chance storm accompanied by the base flood elevation. These areas have a wave height less than 3 feet.

Zone VE: FEMA FIRM flood zone indicating an area that is predicted to be inundated by the 1 percent annual chance storm accompanied by the base flood elevation. These areas have a wave height exceeding 3 feet or are located seaward of the heel of Primary Frontal Dunes.

Zone AO: FEMA FIRM flood zone indicating an area prone to flooding from shallow (i.e., less than 3 feet deep) sheet flow.

Zone Break: Lines on a map separating areas with different hazard levels or zone types.

SECTION 1: INTRODUCTION

The Delaware Department of Natural Resources and Environmental Control (DNREC) contracted URS Group, Inc. (URS) to create a geospatial data set that can be used to consider the potential impacts of flooding and sea level rise (SLR) in the planning of state projects in Delaware. This project was precipitated by Section 5 of Governor Markell's Executive Order 41 (State of Delaware, September 2013): *Preparing Delaware for Emerging Climate Impacts and Seizing Economic Opportunities from Reducing Emissions*, which directed DNREC to develop maps illustrating areas impacted by the combined risk of flooding and SLR.

The resulting Delaware Flood Risk Adaptation Map (FRAM) was created under the direction of DNREC and the Executive Order 41 Flood Avoidance Workgroup using the methods described in Section Two: Methodology. The target end users of the FRAM and associated data are state agencies, though the data will be available to any entity within the state who wishes to consider the combined impact of flooding and SLR during planning, design, construction, and mitigation activities. The data are available both as digital map data in a single statewide geographic information system (GIS) layer and as three different county-wide GIS layers. The data are identical in both the statewide and countywide coverages.

1.1 TECHNICAL BACKGROUND

The State of Delaware is utilizing three planning scenarios for SLR analyses (DNREC, December 2009), low, intermediate, and high, as shown in Figure 1. Due to funding constraints, only one of these three scenarios could be mapped in combination with the existing floodplain maps. DNREC and the Executive Order 41 Flood Avoidance Workgroup identified the *intermediate* 1.0-meter (3.3-feet) SLR scenario as the most appropriate for use in the Delaware FRAM because it represents both the *intermediate* SLR scenario in the year 2100 and can be utilized to approximate the *high* SLR scenario by 2080.

Although the state SLR scenarios are in meters, data in the FEMA Flood Insurance Studies (FISs) of Delaware's three counties as well as the LiDAR and digital elevation model (DEM) data are reported in feet. Because the FRAMs are based upon the FISs, and to avoid putting decimal numbers as flood elevations on the maps, the 1.0-meter intermediate SLR value for the year 2100 was rounded to 3 feet.

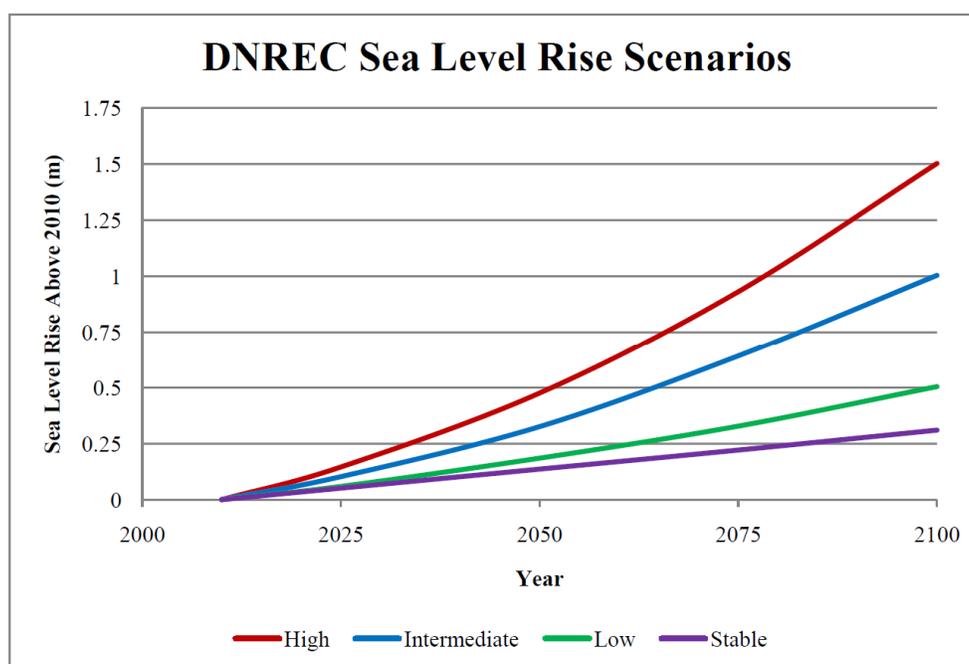


Figure 1: SLR prediction curves developed by DNREC in the December 2009 paper, *Recommended Sea Level Rise Scenarios for Delaware*

1.2 FLOOD MAP PRODUCTS

A number of different flood and SLR information products are mentioned in this report, and understanding the intended use of each data set or map is important. For the purposes of this report, applicable data products are described below:

- FIS & FIRM:** Regulatory data produced by FEMA for the determination of flood insurance rates. The FIRM geographically depicts the varying 1%-annual-chance flood hazards and the Flood Insurance Study provides supporting documentation. These products are useful when considering present-day storm events and their implications on flood insurance.
- FRAM:** The Delaware Flood Risk Adaptation Map (FRAM) is the product associated with this document. Created primarily for use by state agencies for facilities management, construction, and planning purposes. The FRAM describes the 1%-annual-chance coastal hazard from stillwater and waves plus an additional 3 feet of SLR. This map is useful when considering future storm events in addition to SLR.
- Delaware SLR Inundation Maps:** Delaware's sea level rise inundation maps depict the extent of inundation due to sea level rise using a bathtub model. These maps are not regulatory; however, they are useful for planning purposes when considering the impacts of SLR on daily water levels.

SECTION 2: METHODOLOGY

The approach to developing the FRAM and examples of mapping products are provided in this section.

2.1 EXISTING DATA

To utilize the best available data as a starting point for the FRAM analysis, the team collected data from the recently completed FISs in Delaware. The most recent coastal FIS for each county in the state is the FEMA Risk Mapping, Assessment, and Planning study that produced FIRMs in 2013. The FIRMs for Kent County became effective July 2014, and the FIRMs for New Castle and Sussex Counties are scheduled to become effective in 2015. The FIRMs for New Castle and Sussex Counties are currently published as preliminary FIRMs. The technical analyses and resulting water surface elevations are not expected to change for these counties prior to the maps becoming effective.

The studies that produced these FIRMs began with a high-fidelity, regional, two-dimensional storm surge model, which produced the 1%-annual-chance stillwater elevations across the entire study area. That information was entered into a series of one-dimensional models to compute overland wave hazards on a countywide basis. The combination of stillwater plus wave heights (or wave runup elevations, where they are applicable) yielded the regulatory Base Flood Elevations (BFEs) shown on the FIRMs (FEMA, May 2013; FEMA, August 2013; FEMA, July 2014).

The topographic Digital Elevation Models (DEMs) used for the FRAM are the same DEMs that were used for the FISs; they represent bare earth ground elevations collected by LiDAR in the year 2005 for Sussex County and 2007 for Kent and New Castle Counties. Vertical accuracy of LiDAR data is measured by the root-mean-square error in the z (vertical) direction (RMSEz). The RMSEz of the 2005 Sussex County LiDAR data is 10.2 centimeters, and the RMSEz of the 2007 Kent and New Castle Counties LiDAR data is 18.5 centimeters. All elevation data are referenced to North American Vertical Datum of 1988 (NAVD88).

2.2 SLR ADDITION TECHNIQUE

The FRAM uses a “bathtub” SLR addition technique, meaning the FRAM was created by adding a constant value of 3 feet to the 1%-annual-chance stillwater elevations and to the BFEs from the FIRMs. Three feet was first added to the 1%-annual-chance stillwater elevations to create the inundation extent and then three feet was added to the BFEs of the FIRMs to obtain the flood elevations on the FRAM.

More detailed SLR addition techniques were not conducted for this study because they require sophisticated computer models to determine the spatial variations in SLR caused by the many different forces controlling water levels. The bathtub technique is commonly used and is an economical method of considering SLR.

2.3 INUNDATION EXTENT

The FRAM analysis began by adding 3 feet of SLR to the 1%-annual-chance stillwater elevations from the FIS using the Raster Calculator tool in Esri ArcMap software. The spatial variation of 1%-annual-chance stillwater throughout Delaware, which is a feature of the high-fidelity storm surge modeling, is preserved in the resulting stillwater elevations plus 3 feet SLR raster data. The raster data was compared with a topographic DEM to determine those areas where the ground is lower than the stillwater plus 3 feet SLR, the limit of which defines the inundation extent of the 1%-annual-chance stillwater increased by 3 feet of SLR. Because the stillwater plus 3 feet of SLR is higher than the stillwater alone, the inundated area is also larger. From here on, the limit of inundation of the 1%-annual-chance stillwater plus 3 feet of SLR will be referred to as the FRAM floodplain boundary.

2.4 MAP ZONE DESIGNATIONS

Although the FRAM is derived from a regulatory map (FIRM), it is a planning tool, not a regulatory map. To avoid confusing its data with the FIRM designations, unique zone designations were adopted to describe the potential future flood hazards depicted on the FRAM. The zone designations are similar enough to capitalize on the familiarity that the end users may already have with the FEMA zones, but dissimilar enough to distinguish the two products.

The FRAM uses four zone designations, identified in the “Zone_Type” field of the GIS map data and summarized in Table 1. Flood hazard elevation data and flood depth data are found in the “Elevation” and “Depth” fields of the GIS map data, respectively, where they apply. Figure 2 can help the user differentiate between flood hazard elevation and flood hazard depth. The majority of the FRAM comprises *CE* zones, where a constant flood hazard elevation for each zone is specified. This elevation is unaffected by variations in the topographic elevation within the zone.

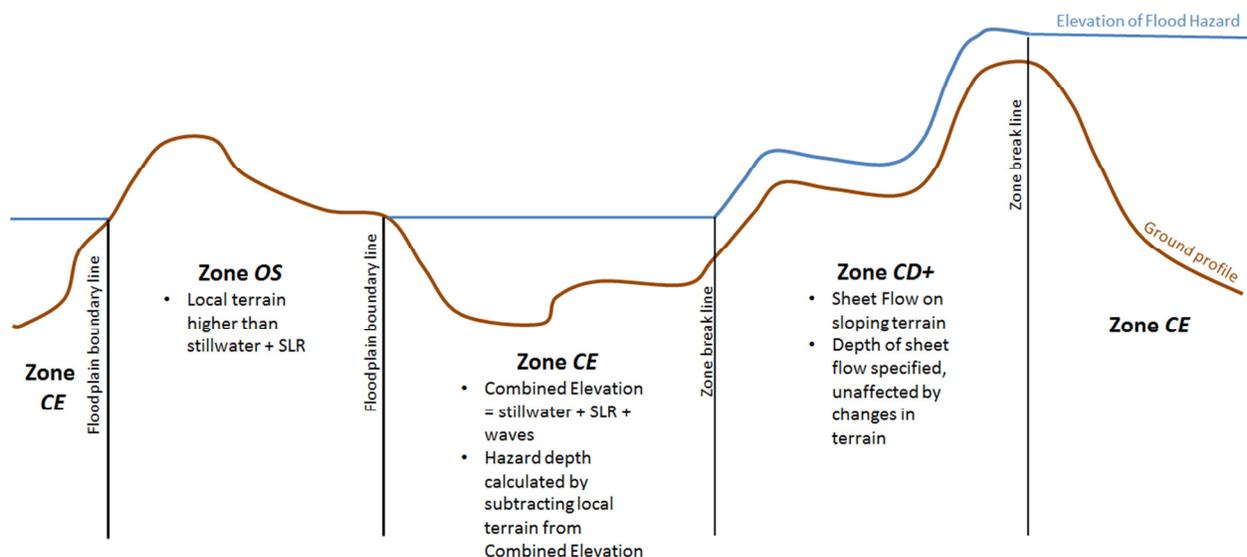


Figure 2: Sample ground profile showing traits of the different FRAM zones

On sloping terrains, where all the *CD+* zones exist in the FRAM, the *CD+* zone designation is used to represent sheet flow hazards, which are present because of the possibility of large ocean waves overtopping such features. Note that the *CD+* zones were converted from the *AO* zones on the FEMA FIRMs. Like the *AO* zones, the *CD+* zones exist in very limited areas of the State of Delaware, such as the landward side of dunes and structures. The “+” sign is used to emphasize the difference between a *CE* and a *CD+* zone. In *CD+* zones, a flood hazard depth is specified on the FRAM. As illustrated in Figure 2, the height of the flood hazard above the ground in a *CD+* zone is constant, as the sheet flow will follow the contours of the ground until it meets another flooding source. To compute the flood hazard elevation at specific locations, the user would add the elevation of the local ground (relative to NAVD88 datum) to the depth of the *CD+* zone.

The FRAM of an area just south of Indian River Inlet is shown in Figure 3 to provide context for the four zone designations described in and illustrated in Figure 2.

Table 1: Zone Designations Used in the FRAM

Designation Code (Zone_Type)	Code Description	Zone Description	Flood Elevation or Depth
CE	Combined Flood Hazard Elevation	Elevation of 1%-annual-chance stillwater + 3 feet SLR + possible wave conditions	Elevation in feet relative to NAVD88
CD+	Combined Flood Hazard Depth	Sheet flow depth due to wave runup and overtopping of dunes/structures	Depth of water above the local ground
OS	Outside of SLR Floodplain	Areas of high ground that are not shown as inundated by the analyses but may be completely surrounded by inundated land	N/A
Water	Open Water	Delaware Inland Bays, open water areas were not analyzed to determine hazard elevation	N/A

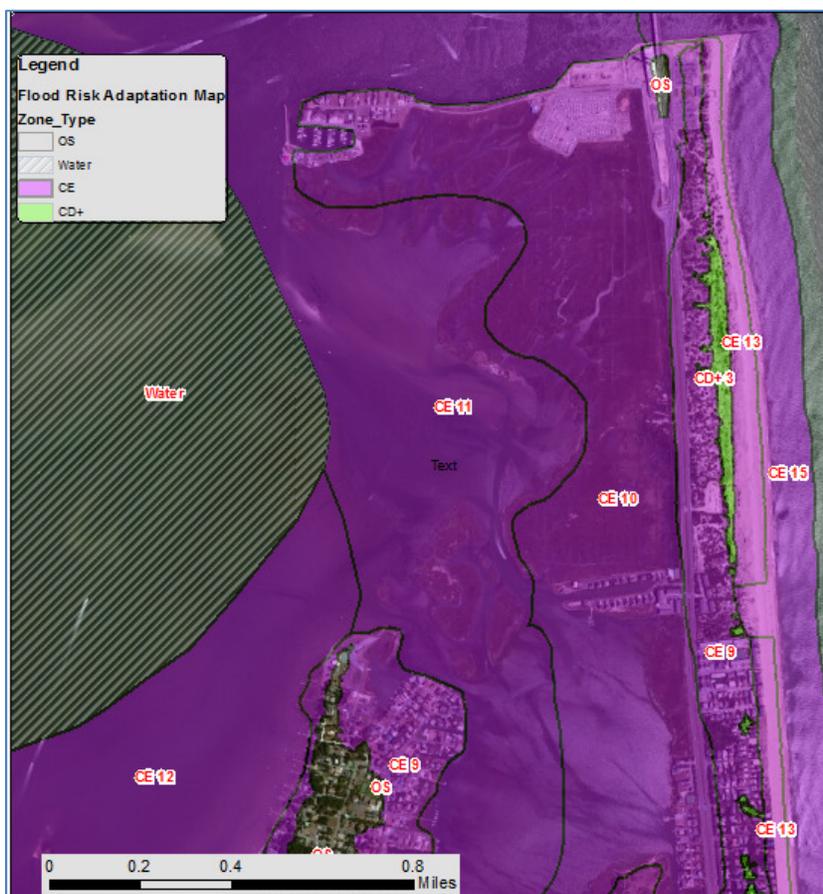


Figure 3: FRAM just south of Indian River Inlet with zone types labeled. Zone labels *CE* and *CD+* are followed by flood hazard elevations or depths, respectively.

2.5 COMBINED ELEVATION ZONES

Unlike the FIRM, the FRAM does not distinguish zones based on wave height; all zones wherein a flood hazard elevation is described are designated as *CE*, which is defined in Table 1. Section 3 of this report discusses the reasons why the FRAM does not show zones based on wave height.

2.5.1 FIRM Inundation Areas

The zone break lines separating zones of different hazard elevation in the FRAM are consistent with the FIRM, with the exception of a few minor, isolated changes to add clarity to the final product.

2.5.2 Expanded Inundation Areas

As mentioned in Section 2.3, the 1%-annual-chance stillwater plus 3 feet SLR (i.e., FRAM) resulted in a combined flooding plus sea level rise inundation area that is larger than that defined by the 1%-annual-chance floodplain boundary of the FIRM (i.e., regulatory map). To determine the combined SLR and flood hazard elevation in those expanded inundation areas of the FRAM,

depth-limited wave height analysis and topographic data determined the likely wave propagation and flow paths across the expanded inundation areas. Depth-limited wave height analysis is based on the wave theory that waves in shallow water reach a maximum height that is equal to 0.78 times the stillwater depth (FEMA, February 2007).

Figure 4 shows the area around Silver Lake in Rehoboth Beach where the FRAM floodplain is larger and more continuous than the FIRM floodplain. The lines separating areas of different hazard elevation are unchanged where the two floodplains overlap, though they are extended to account for the wider FRAM floodplain. Also, notice that the combined flood hazard elevations in Figure 4 reveal the 3 feet of SLR that was added to the FIS BFE. These combined flood hazard elevations are composed of stillwater, SLR, and wave height in each respective zone.

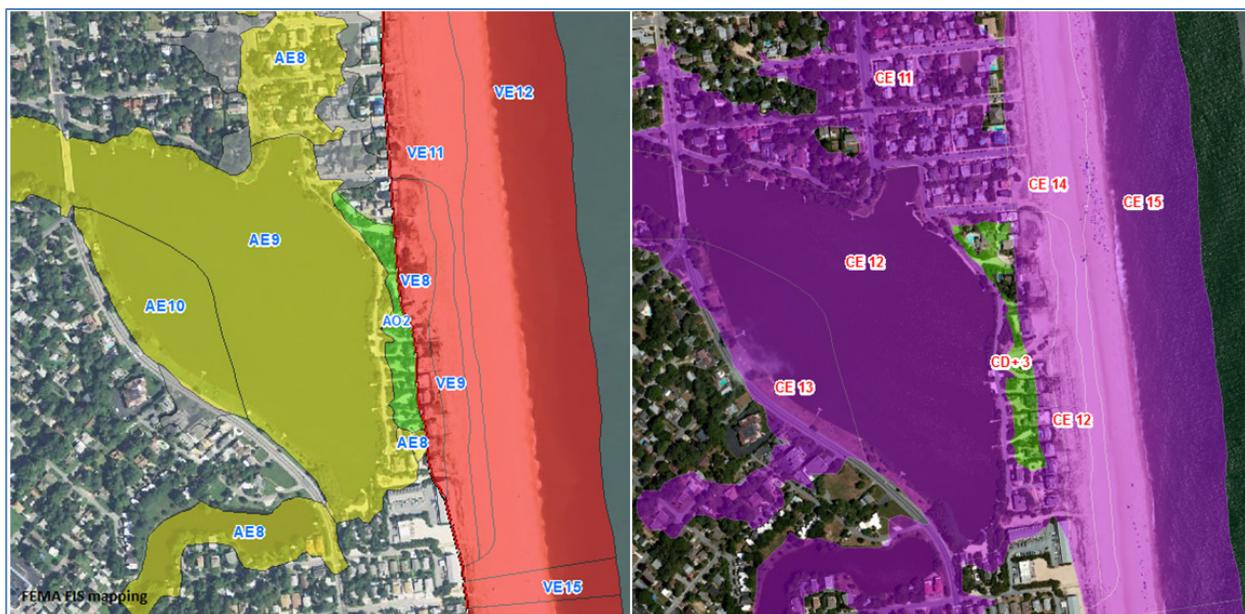


Figure 4: Left side: FIS polygons showing 1%-annual-chance inundation extent, with zone designation and flood hazard elevation (AE zones, VE zones) or depth (AO zone) in blue text inside each polygon area. Right side: FRAM showing expanded FRAM floodplain boundary, with zone designation and combined flood hazard elevation (CE zones) or depth (CD+ zone) in red text inside each polygon area.

2.6 COMBINED DEPTH ZONES

As introduced in Section 2.4, a special designation, “CD+” can be found on the FRAM in areas with sloping terrain, usually sand dunes, adjacent to the shoreline. The *CD+* zone is used because there is considerable uncertainty surrounding the performance of dunes during extreme storms, especially in light of the uncertainty of future conditions of dunes and beaches. To account for this uncertainty in the FIS study, sheet flow zones were mapped on the landward side of dunes or other high elevation features that are adjacent to the beach or could be subject to significant wave action during a storm. Wave runup and overtopping of these features could cause flood damage on relatively high ground. These sheet flow zones are labeled as *AO* on FEMA FIRMs.

The FRAM adopts the same philosophy by assigning the label *CD+*, as defined in Table 1, and a flood depth of 3 feet in areas designated as susceptible to wave runup and overtopping. These zones are unique in that the flood hazard is defined as a depth over the ground; in the remainder of the dataset, flood hazards are defined as an elevation relative to NAVD88.

SECTION 3: ASSUMPTIONS AND LIMITATIONS

End users must always be mindful of uncertainties and assumptions when working with data such as the FRAM. Most importantly, users should remember that the FRAM floodplain boundaries were developed using a bathtub SLR addition technique with no new modeling and are for planning purposes only. The FRAM is not a substitute for site-specific surveys or studies, and many construction projects may warrant additional, more detailed investigation. As noted in Table 1, areas designated as Zone *OS* may be completely surrounded by inundated land; an *OS* designation for such areas should not be considered as a determination of invulnerability to future SLR.

3.1 HANGING CONDITIONS

An assumption to consider in using this data is that the data used will remain valid into the future. The FRAM data represent a snapshot of the conditions from a particular point in time. For example, the LiDAR used in FRAM development of Sussex County is 10 years old, yet it represents the best available topographic data for Sussex County. Further, an assumption was made that the 1%-annual-chance stillwater will not significantly change in the future. This assumption is valid for short projections into the future; however, an evolving storm climate or large-scale topographical changes could create uncertainty for long-term projections. Consistent with the DNREC Sea Level Rise Technical Workgroup's recommendation in its 2009 report, we recommend periodic review and update of the FRAM as new floodplain maps, SLR scenarios, and elevation data become available.

3.2 COASTAL DYNAMICS

A limitation of the FRAM relates to the dynamic nature of high-energy coastal locations that are subject to storm-induced shoreline and dune erosion, coupled with long-term chronic shoreline migration. The FRAM does not account for risk factors such as wave action, storm-induced shoreline erosion and long-term shoreline migration, which exist now and are likely to become more severe in the future as a result of higher sea levels relative to beaches and dunes.

3.3 HUMAN ACTIVITIES

Another limitation involves the management activities that are conducted in many vulnerable coastal areas, such as impoundments, dikes, beach nourishment, dune construction, and other erosion control structures. These coastal management strategies are assumed to continue into the future, and are not accounted for in the FRAM, which are based on 2005–2007 topography.

End users should bear in mind that increased stillwater depths due to SLR will lead to larger waves in some locations, especially adjacent to water bodies or other low-lying land where strong winds generate waves without impediment. Higher stillwater depths and larger waves are also expected to contribute to increased erosion of beaches and dunes. Because no new modeling was performed during development of the FRAM, potential higher waves are not accounted for; therefore, the combined flood elevation or depth is likely an underestimation of the actual hazard

Assumptions and Limitations

in some areas. The resulting map provides a valuable depiction of possible future conditions, but new modeling is required to precisely predict the wave conditions. End users should exercise appropriate caution when consulting combined flood hazard elevations from FRAM.

SECTION 4: DATA PRODUCTS

The Delaware FRAM consists of multiple pieces of electronically stored data. The data are customizable. As previously mentioned, the two main products are a set of geospatial polygons that cover the entire state and a set that covers each of the three counties individually. These products are delivered as Esri Feature Classes inside a Personal GeoDatabase. The metadata file associated with these polygons conforms to FGDC-STD-001-1998 standards. Digital raster data containing the combined stillwater elevations referenced above are also available through DNREC.

The units of the provided elevation and depth are feet and the elevation is relative to NAVD88.

SECTION 5: REFERENCES

- DNREC (Delaware Department of Natural Resources and Environmental Control). December 2009. *Recommended Sea Level Rise Scenarios for Delaware*. Dover, Delaware
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