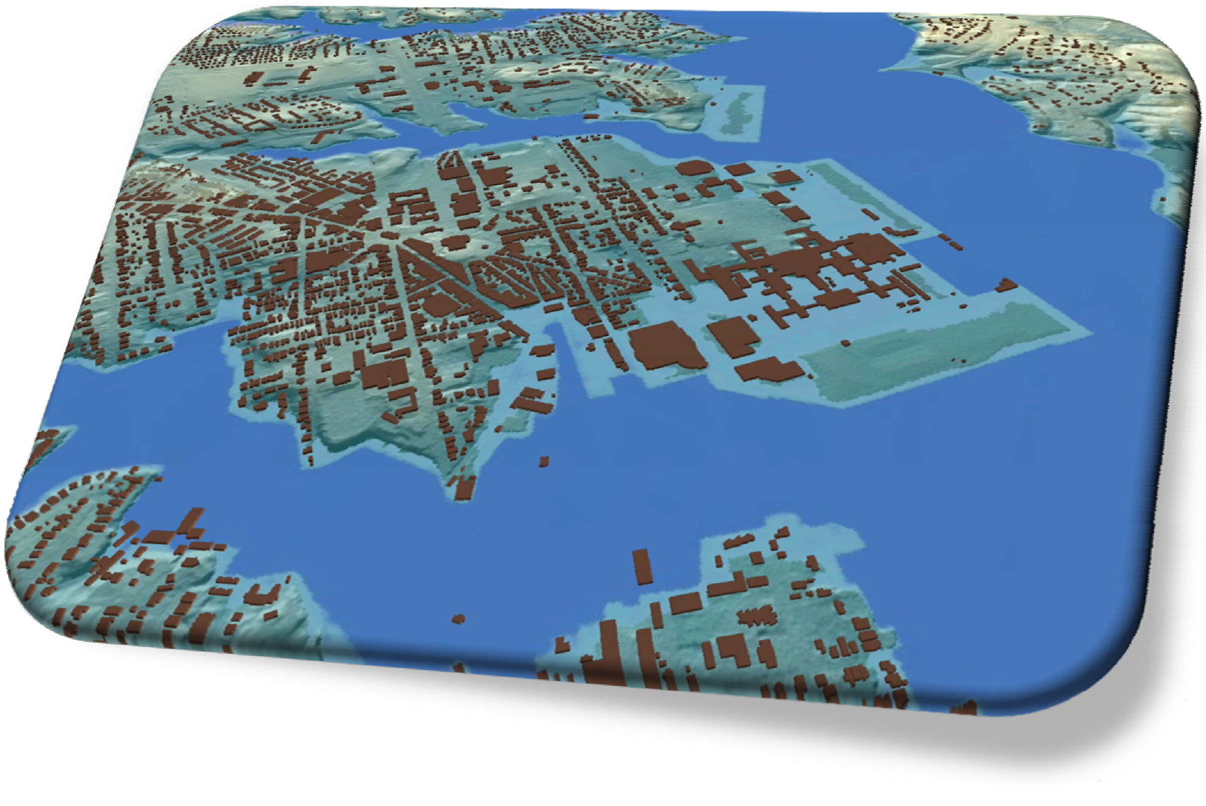
Community Adaptation to Sea-Level Rise and Inundation (CASI)

Permanent Inundation and Coastal Flood Hazard and Risk Analysis



April 13, 2012

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1. Overview

This report describes the procedures applied to generate hazard and risk data in support of the Community Adaptation to Sea-Level Rise and Inundation (CASI) study, sponsored by Mid-Atlantic Sea Grant. The study was intended to advance research into how the combination of deliberative polling and local impacts data visualization could increase public engagement in evaluation of policy responses to sea level rise. Anne Arundel County, Maryland was selected for the study location.

To support visualization of hazard and risk to the potential impacts of sea level rise (SLR), Dewberry completed an exposure and risk analysis to both permanent inundation and coastal flooding. This assessment was completed at the building level for the identified SLR scenarios. Summaries of impacts were generated at the building, "neighborhood" (defined as U.S. Census Block Groups) and county levels. The hierarchy was intended to give the individual contextual information across a wide range of geography. Specific details as to methods applied to generate the supporting data for the viewer follow:

2. Sea Level Rise Scenarios

The CASI study proposed to produce sea level hazard information at four future time slices, including 2025, 2050, 2075, and 2100. Early in the study process, the study team coordinated with the Maryland Department of Natural Resources (MDDNR) and Anne Arundel County on scenario selection. An initial agreement was reached to keep projections used for CASI at or below SLR scenarios established by MDDNR and Anne Arundel County.

The Maryland Commission on Climate Change Scientific and Technical Working Group provided estimates of RSLR by the end of the century (MDDNR, 2008). Projections were derived from the 2007 IPCC global SLR projections and combined with regional land subsidence magnitudes. The values, presented as "conservative", include estimates from 1-1.3 ft by 2050 to 2.7-3.4 ft by 2100. Published scenarios distributed by MDDNR are limited to time slices of 2050 and 2100. Coordination was been undertaken with MDDNR request supporting data were available for the 2025 and 2075 time slices. MDDNR replied that they did not have the data, and it was suggested that CASI reconstruct projections from the IPCC data for those two SRES emissions scenarios (B1 and A2). This option was investigated, however, it was noted that the SLR scenarios presented by MDDNR report include contributions by accelerated ice melt scenarios. Available documentation did not provide sufficient information to reconstruct the needed information to develop scenarios at 2025 and 2075.

An alternative method was pursued founded on the U.S. Army Corps of Engineers (USACE) Engineering Circular 1165-2-212 (USACE 2011) “Sea-Level Change Considerations for Civil Works Programs.” The USACE document provides a clearly documented process to establish future sea level conditions that is directly repeatable by various end-users. The methodology utilizes the modified National Research Council (NRC) SLR projections from 1987. Although these curves may be considered dated, they provide similar values to current projections, having a “low”, “medium”, and “high” curves that result in 0.5, 1.0, and 1.5 m of SLR by 2100, respectively. The guidance includes a Microsoft Excel worksheet that the user can enter the local, long-term observed change rate for sea level and the desired date to return projected conditions. Use of local, gage-based rates for SLR projections includes subsidence, as the gages are attached to land at the local locations. As such, gage-based rates include both vertical land movements and change in sea level; this is defined as a relative sea level change.

There are high levels of uncertainty associated with projections of future climate, and in turn the projection of future sea level. Uncertainties in climate models include greenhouse gas emissions scenarios and contribution of ice melt to sea level. We therefore analyzed hazards for three levels of sea-level rise, including projection of historical trends, low acceleration, and moderate acceleration. Projection of historical levels at each time was calculated using the observed historical rate of sea level rise at the Annapolis National Oceanic and Atmospheric Administration (NOAA) tide gage (3.4 mm/yr, NOAA 2011) and extrapolated from today (2012) to the given years. The low and moderate SLR acceleration scenarios were estimated using Modified NRC-I and –II curves from the USACE guidance. This approach allows a scenario of moderate acceleration that is consistent with guidance from MDDNR, and a low acceleration scenario that provides for a middle ground between the MDDNR scenarios and the extrapolated historical trend. The final scenarios are shown in Figure 1, values are reported in Table 1, and MDDNR scenarios are shown in Table 2.

TABLE 1. VALUES FOR SLR SCENARIOS FOR EACH SLR CURVE AND TIME SLICE, RELATIVE TO 2012 IN UNITS OF FEET.

Scenario/Year	2012	2025	2050	2075	2100
Historical Trend	0.0	0.1	0.4	0.7	1.0
Low Acceleration	0.0	0.2	0.7	1.3	1.9
Moderate Acceleration	0.0	0.3	1.1	2.2	3.5

TABLE 2. MDDNR SLR SCENARIOS, RELATIVE TO 2008 IN UNITS OF FEET.

Scenario/Year	2050	2100
Lower*	1.0	2.7
Higher*	1.3	3.4

*include accelerated melting

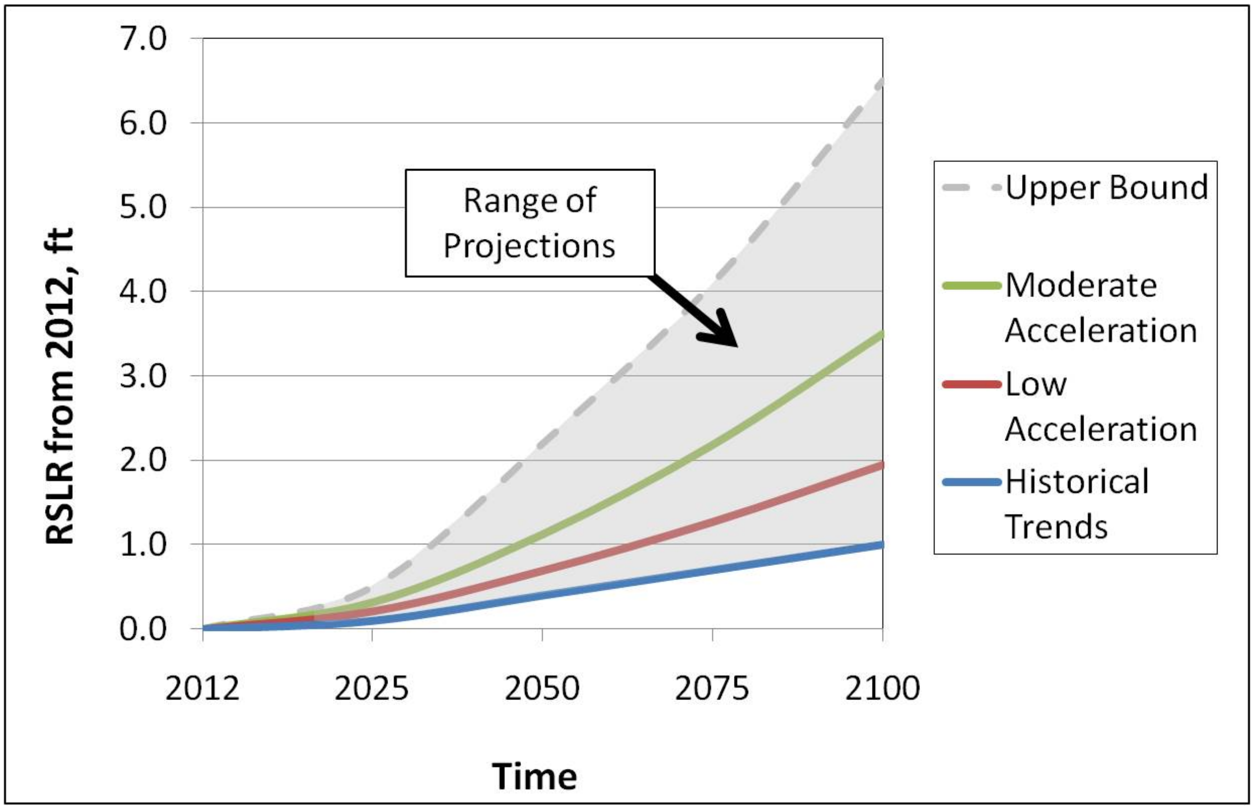


FIGURE 1. SLR SCENARIOS SELECTED FOR ANALYSIS INCLUDE REPRESENTATION OF HISTORICAL TRENDS, A LOW ACCELERATION, AND MODERATE ACCELERATION. THE UPPER BOUND REFLECTS PHYSICAL LIMITS ON THE GLACIOLOGICAL RESPONSE TO PROJECTED FUTURE TEMPERATURE INCREASES AS DISCUSSED BY PFEFFER (2008).

TABLE 3. POTENTIAL SCENARIOS WERE REVISED IN CONSIDERATION OF TOPOGRAPHIC ACCURACY AND STUDY NEEDS.

Original	Simplified
0	0
0.1	0.3
0.2	
0.3	
0.4	
0.7	0.7
1.1	1.0
1.3	1.3
1.9	1.9
2.2	2.2
3.5	3.5

3. Inundation and Coastal Flooding Assessment

The study was focused on evaluating exposure and risk to both permanent inundation and episodic coastal flooding. Each of these processes is discussed in further detail below.

3.1. Permanent Inundation

Permanent inundation was defined as areas having elevations less than the mean higher high water datum (MHHW) tidal datum. MHHW is defined by NOAA as the "The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch." In practice, elevations below this datum are typically "wetted" or "near-wetted" by tides on a daily basis by the higher high tide. For reference, MHHW is approximately 0.7 ft above mean sea level at Annapolis.

A base, "present day" MHHW surface was established using the NOAA VDatum software, which provided for a continuous, spatially variable value across the county geography. The surface was created by first establishing a regular point grid over the study area. The point grid was then input into the VDatum software to return the MHHW elevation relative to NAVD88, the datum of the topographic base. The base coverage output from VDatum was limited to "water" areas, and did not intersect the topographic at the MHHW elevation. This was corrected by extrapolating the coverage until intersection was consistently achieved throughout the county. The point coverage was then converted into a base MHHW surface elevation model.

3.2. Coastal Flooding

Coastal flooding was defined as areas having elevations less than the 1.0% annual chance flood as defined by the Federal Emergency Management Agency (FEMA). The 1% annual chance floodplain is defined as the area that will be inundated by the flood event having a 1% chance of flooding of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. This area defines the Special Flood Hazard Area (SFHA) that is delineated on Federal Emergency Management Agency Flood Insurance Rate Maps.

The base coastal floodplain was established in the 2011 restudy of storm surge elevations throughout FEMA Region III, which encompasses Delaware, Maryland and Virginia. Data were provided by FEMA in a point coverage limited to the statistical analysis footprint of the study. In a similar fashion to the MHHW data, the surge data were extrapolated to ensure that the coverage was extended outside of the floodplain boundary and provide for an accurate delineation. Base surfaces were also created for the 0.2, 2% and 10% frequencies to facilitate evaluation of flood probabilities.

3.3. Implementation of SLR Conditions

Changes to inundation and coastal flooding were estimated by increasing the present day base surface elevations by the projected changes to sea level for each scenario. Implementation was accomplished by the method of linear superposition, which entails simple addition of the scenario to the base surface. For example, to achieve a scenario of 0.7 ft above present day condition, 0.7 ft was added to the permanent inundation and flood water surface elevation models.

3.4. Inundation and Coastal Flood Exposure

Inundation and coastal flooding extents were established for each scenario by intersecting the scenario surfaces with the topographic elevation model. The process resulted in raw polygon coverage representing the exposed area. These coverages were post-processed to remove small artifacts, hydraulically unconnected areas, and to smooth boundary edges. Post-processing involved both an automated process to address small scale features, followed by a visual keep/discard review of larger areas of disconnected flooding. The area of each polygon was calculated from feature geometry in ArcGIS. Depth grids were established by subtracting the topographic surface from the water surface and clipping extents to the respective flood coverage. Finally, wave height grids were calculated using the following relationship between stillwater depth, maximum breaking wave height, and flood depth (FEMA 2011a):

$$H = 1.55\, d_s$$

where H is the depth of water including wave height, measured at the wave crest, and d_s is the stillwater flood depth (1% annual chance surge elevation).

Probability or percent chance of flooding in a 30-year period was calculated to show the potential for flood impacts at a given building within a 30-year period of time, equivalent to the standard home mortgage. For each scenario, this value was calculated for all buildings within the 0.2% annual chance flood extent. The value was calculated by first determining the percent annual chance of flooding for each building by utilizing the 0.2, 1%, 2%, and 10% water surface elevations provided by FEMA, then interpolating the log-linear relationship between the associated flood elevations and the ground elevation within the 0.2% chance floodplain. The 30-yr probability was then calculated using the following relationship (FEMA 2011b):

$$P_{30} = 1 - (1-p)^n$$

where P_{30} is the 30-year probability of flooding, p is the percent annual chance of flooding, and n is the time period in years.

In summary, the following inundation and flood exposure products were created for each scenario:

- MHHW Surface Elevation Model
- MHHW permanent inundation polygon
- Surface Elevation Models for the 0.2, 1%, 2%, and 10% flood elevations
- 1% annual chance coastal flooding polygon
- Depth Grids for the 0.2, 1%, 2%, and 10% flood elevations
- Depth of flooding with wave height grid for the 1% flood elevation
- Annual chance and 30-yr probability of flooding grids

4. Building Damage Assessment

For each scenario, building exposure to inundation and/or coastal flood impacts was evaluated by intersecting the permanent inundation and coastal flood extents with countywide building footprint data (see Data Sources for more information). If the inundation of flood layer intersected the building footprint, the building was respectively attributed as inundated or flooded for that scenario. Buildings attributed as inundated were assumed to become inhabitable and were attributed as lost for the respective and successive scenarios. Buildings attributed as flooded were attributed with the site-specific 1% flood depth with wave height and then evaluated for flood-induced damage.

Building value exposure was evaluated against the Maryland State Department of Planning “Md Property View” dataset for Anne Arundel County. This dataset had limitations in terms of the available parcel data being a raster base map, with vector points spatially located within each parcel. The Vector points did not have a common primary key value that facilitated a join relationship with the Anne Arundel building footprints. Additionally, the spatial location of the data point for each parcel was not correlated with the building location. Due to this limitation, attempts at performing spatial joins to achieve a one-to-one relationship with the building footprint data were unsuccessful. As a result of these limitations, an independent intersection of the Property View data against the inundation and coastal flood extents was necessary. Because a one-to-one relationship was not possible, total building footprint counts differ from Property View point counts. Given the constraints and scope of this study, the reported values derived from the Md Property View data provide an adequate representation of exposed property value for study purposes. Future efforts might consider investigating Improvement of this calculation through additional manual data manipulation techniques as well as monitoring for the availability of newer State, County and Community GIS datasets. It should be noted that several mitigation actions developed for the Maryland 2011 Hazard Mitigation Plan Update involve the update of the State's GIS datasets as well as close coordination of GIS professionals from each jurisdiction.

Potential damages in the event of a 1% annual chance flood were assessed by application depth damage functions (DDFs) sourced from the FEMA Benefit-Cost Analysis Re-Engineering (BCAR) Flood Module methodology (FEMA 2011a). The BCAR method was selected as the residential DDFs were recently updated to reflect post-storm damage assessments that have shown that homes near the coast are subject to severe damage from wave heights less than 3 feet, especially those not built on engineered pile foundations. DDFs in the 2011 BCAR update were updated to provide greater accuracy in predicting damage to residential structures subject to wave heights 1.5 ft or greater.

Selection of DDFs for building damage assessment was dependent of the available building attribute data. The Anne Arundel County building footprint layer lacked attribute data; however, limited attributes were available from the Maryland PropertyView dataset. Although the dataset lacked information of first floor elevation, differentiation was provided for structures with and without basements. These data were extracted and conflated into the study database. Due to a lack of specific information on first floor elevation, it was assumed that all structures were slab-on-grade construction. The basement/no basement attribute was used to select the appropriate curve from the BCAR DDF catalog. The selected DDFs were generalized into three categories:

Minor: Less than 25% damage is expected during a 1% annual chance flood, as defined by FEMA. Short term inundation is expected, water does not rise above the level of the bottom of the first flood of the structure. Common damage may include limited scour and erosion from low velocity floodwaters, with no noticeable cracking of masonry or displacement of foundation walls. Repairs expected to take 30 to 120 days.

Moderate: Structural damages are expected to in the range of 25-50% during a 1% annual chance flood, as defined by FEMA. Short term inundation is expected, water rises just above the first floor level. Common damage may include limited scouring or undermining of the foundation or footings, minor cracking from settlement, and/or heaving of the structural support systems. Some missing sections or open damage to portions of the wall structure, and damage to wall studs and sheathing from debris or hydrostatic pressure. Repairs expected to take 120 to 360 days.

Severe: Greater than 50% damage is expected during a 1% annual chance flood, as defined by FEMA. Long-term inundation is expected, with water up to and over 3-feet high from the bottom of the first floor level of the structure. Common damage includes cracking, displacement up to missing masonry and/or concrete foundation walls. Structure may become unstable due to foundation damage. Missing sections or open damage to significant portions of the wall structure is expected, with significant debris and or hydrostatic damage resulting in deformation or moderate to significant distortion of the structural frame. Repairs expected to take 540 to 720 days (structure lost).

Depth criteria were established the categories for each DDF, and then applied to the stored depth with wave height value for each exposed building to assign the appropriate damage category for each SLR scenario.

5. Composite Risk Analysis

The composite risk analysis metric was designed to provide an assessment of the relative degree of exposure to inundation and flood impacts across all scenarios. This assessment takes into account the number of times a building is subject to inundation, the scenarios that the structure is exposed to, as well as the severity of expected flood impacts. Scores were weighted by scenario and time slice, meaning that lower acceleration scenarios and earlier time slices received the highest scores – a reflection of their near term risk and greater need to adapt. Vice-versa, higher acceleration scenario and later time slices received the lowest scores, reflecting their long-term risk and lower need to adapt.

Scoring tables were established for occurrence and consequence. Occurrence scoring was separated into both permanent inundation and coastal flood exposure. The scores were then were decayed by scenario and time slice to give the highest score to the lowest scenario and nearest time slice and vice-versa. Scoring for permanent inundation and coastal flooding are presented in Table 4 and Table 5, respectively.

TABLE 4. INUNDATION OCCURRENCE SCORING TABLE

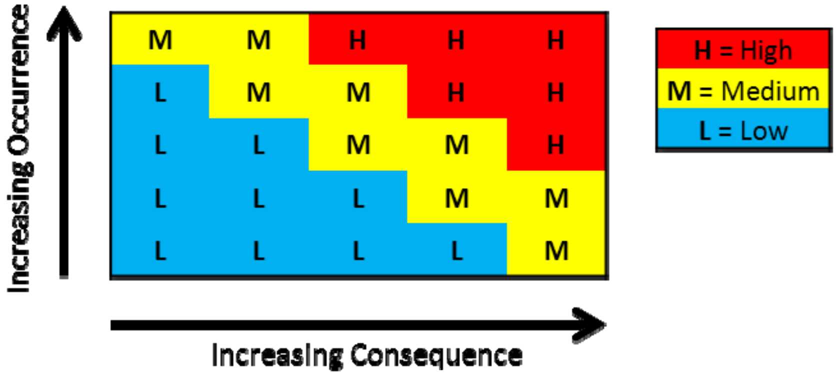
Scenario and Time		**2025**	**2050**	**2075**	**2100**
	Decay %	100%	80%	40%	10%
Historical Trend	100%	100	80	40	10
Low Accel.	75%	75	60	30	7.5
Moderate Accel.	50%	50	40	20	5
		Score by Scenario/Time			

TABLE 5. COASTAL FLOODING OCCURRENCE SCORING TABLE.

Scenario and Time		2025	2050	2075	2100
	Decay %	100%	80%	40%	10%
Historical Trend	100%	40	32	16	4
Low Accel.	75%	30	24	12	3
Moderate Accel.	50%	20	16	8	2
		Score by Scenario/Time			

Consequence scoring was constant; buildings exposed to inundation received a consequence score of 100. For coastal flooding those having minor damage were assigned a score of 25, moderate damage 50, and severe damage 100.

To determine the overall risk class, occurrence and consequence scores were summed across all scenarios. The range of score was established for all buildings in the county, and then used to scale X/Y axis values across a classified risk matrix (Figure 1). Class location for a specific building was determined by locating the specific occurrence (Y-axis) and consequence (X-axis) values relative to the overall range.



M	M	H	H	H
L	M	M	H	H
L	L	M	M	H
L	L	L	M	M
L	L	L	L	M

FIGURE 2. COMPOSITE RISK SCORING MATRIX.

Individual buildings were classified into three composite risk categories according to their exposure and consequence scores. These following definitions were assigned to these classes:

Low Risk Classification indicates that the building has a low risk to inundation and/or increased flood impacts due to sea level rise. The building is not subject to permanent inundation and is expected to experience minor impacts by significant coastal storms on towards the end of the century.

Medium Risk Classification indicates that the building has moderate risk to inundation or increased flood impacts due to sea level rise. Buildings in this category can be subject to permanent inundation, and/or moderate or severe impacts due to significant coastal storms over multiple scenarios from mid- to end-of-century. Owners of buildings in this category should begin planning measures to reduce their long-term exposure to flood impacts.

High Risk Classification indicates that the building is at high risk to inundation and increased flood impacts due to sea level rise. Buildings in this category are subject to permanent inundation and severe impacts due to significant coastal storms over multiple scenarios in the near term. Owners of buildings in this category should act to identify and implement measures to reduce flood exposure.

6. Supporting Data Sources

Floodplain Data: Floodplain elevations were provided by the Federal Emergency Management Agency (FEMA). Storm surge elevations were sourced from the regional storm surge modeling effort completed in 2011.

Elevation Data: Elevation data for floodplain and inundation modeling were sourced from Anne Arundel County. These data were collected by the Maryland Department of Natural Resources. The dataset was derived from countywide high-accuracy/high-resolution LiDAR ground elevations measured in 2004. The reported vertical accuracy of this dataset was a root mean square error of 14.3 centimeters (5.6 inches). These data were processed from a tile format into a continuous elevation model. Additional coverage was added to the overwater area in the Chesapeake Bay to improve cartographic representation of the open water edge.

Building Footprints: Building footprints were sourced from Anne Arundel County. Metadata state that these data were originally developed from 2002 orthophotography and later updated against 2007 orthophotography. Changes in the built environment subsequent to 2007 are not reflected in this dataset.

Property Attributes: The MdProperty View dataset for Anne Arundel County, 2011 edition, was sourced from the Maryland State Department of Planning to support property value and building type data attributes for study purposes.

7. Study Website and Reporting Viewer

7.1. Study Website

The study website, by necessity, needs to be a scalable dissemination solution that provides effective delivery of all study data and information to participants of citizen's discussions in a clear manner and through an easy-to-use portal.

With this in mind, the study team chose Google Sites as the content management system and website platform. Google Sites is a structured wiki- and web page-creation tool offered by Google as part of the Google Apps Productivity suite. The goal of Google Sites is for anyone to be able to create a team-oriented site where multiple people can collaborate and share files. Anticipating the dynamic and ongoing creation and update of study materials and content, we chose a platform that allows the study team to perform updates and maintenance of the website with ease, while leveraging several gadgets made available by Google. Google Sites offers a free hosting solution on the cloud, where websites can be easily replicated and various levels of user permissions can be assigned at an individual web-page level. The Sea Level Rise (SLR) and Coastal Flooding Impact Viewer described in section 7.2 is an interactive map-based application that was created by leveraging Google Fusion tables for storing and displaying geospatial data associated with SLR and Coastal Flooding Impacts. Additionally, integration with Google Docs and the Google Charts Application Programming Interfaces (APIs) were used in the creation of survey forms, and the Survey Results Comparison Gadgets described in section 7.3.

7.2. The Sea Level Rise and Coastal Flooding Impact Viewer

The Data Viewer displays risk assessment results for Anne Arundel County. It provides users with a simple 3-step workflow that allows them to 1) Find a point of interest; 2) select a year in the future and SLR projection scenario for influencing the impact layers shown on the map interface; and 3) to view a summary of potential impacts to specific buildings, impacted coastal neighborhoods and the County as a whole. Initially, the viewer was only accessible by participants of a Citizen's Discussion on April 28, 2012. After this date, the viewer will become publicly available.

The interactive map interface is based on the Google Maps API. The database holding the geospatial data for permanent inundation, the 1% annual chance (100-year) coastal flooding area, and the impacted buildings' footprints are stored and retrieved from Google Fusion Tables.

7.3. Survey Results Comparison Gadget

Shortly following the April 28, 2012 Citizen's Discussion, the Pre- and Post- Survey results from the County-wide effort will be made available for comparison with survey results coming from other subsequent groups that host their own discussion within Anne Arundel County. This survey results comparison gadget will show the results for the specific group in an aggregated form showing distribution of response types. These tabular results will be displayed alongside the results from the initial county-wide effort held April 28, 2012. Along with percent distribution, these reports will show the total number of responses per group and per survey question.

8. Points of Contact

For further information regarding items presented in this report, please contact the following individuals:

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9. Literature Cited

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