5.4.8 Tsunami

The following section provides the hazard profile (hazard description, location, extent, previous occurrences and losses, probability of future occurrences, and impact of climate change) and vulnerability assessment for the tsunami hazard in Cape May County.

2016 Plan Update Changes

- For the 2016 Plan Update, the hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, probability of future occurrence, and potential change in climate and its impacts on the tsunami hazard is discussed.
- New and updated figures from federal and state agencies are incorporated.
- Previous occurrences were updated with events that occurred between 2009 and 2016.
- A qualitative vulnerability assessment was conducted using the best available data.

5.4.8.1 Profile

Hazard Description

Tsunamis are a series of enormous waves created by an underwater disturbance (for example, earthquake, landslide, volcanic eruptions, or meteorite). They can move hundreds of miles per hour in the open ocean and crash into land with waves as high as 100 feet or more. From the area where the tsunami originates, waves travel outward in all directions (International Tsunami Information Center 2016).

A tsunami consists of a series of high-energy waves that travel outward, like pond ripples, from the area in which the tsunami originated. The sequence of tsunami waves arrives at the shore line over an extended period of time and builds height as it get closer (FEMA, 2007; Humboldt County Hazard Mitigation Plan, 2008). A tsunami approaching the shoreline may take three forms:

- Non-breaking waves that act as a rapidly rising tide
- A large, turbulent wall-like wave (bore)
- A series of partially developed waves (Humboldt County Hazard Mitigation Plan, 2008).

There are two types of tsunamis: local and distant. A locally generated tsunami is caused by an undersea disturbance near the coast. They have minimal warning times and may be accompanied by damage resulting from the triggering earthquake due to ground shaking, surface faulting, liquefaction or landslides. A local tsunami, due to its close proximity to the coast, leaves few options for escaping, except to run to high ground. Distant tsunamis may travel for hours before striking a coastline, leaving enough time for warning (Humboldt County Hazard Mitigation Plan, 2008; Grays Harbor County Hazard Mitigation Plan, 2005).

The first indication of a tsunami may be a rise in water level. An advancing tsunami may initially resemble a strong surge increasing the sea level, similar to a rising tide, but a tsunami surge rises faster and does not stop at the shoreline. Even if the wave height appears to be small, for example three to six feet, the strength of the accompanying surge can be deadly. Waist-high surges can cause strong currents that float cars, small structures, and other debris (Humboldt County Hazard Mitigation Plan, 2008).

All tsunamis are potentially dangerous, even though they may not damage every coastline they strike. A tsunami can strike anywhere along most of the U.S. coastline. The most destructive tsunamis have occurred along the coasts of California, Oregon, Washington, Alaska, and Hawaii (International Tsunami Information Center 2016).

Since the beginning of the 20th century, tsunami events have caused more than 700 deaths and over $200 million in damages to the U.S. coastal states and territories. More than 50-percent of the U.S. population lives in coastal communities and may be at risk for tsunami impacts (Dunbar and Weaver, 2008).

Location

Tsunamis impact areas along the coastline; therefore, all coastal areas of Cape May County are exposed to the threat of a tsunami. However, the tsunami threat level for the east and Gulf coasts of the United States, which includes Cape May County, has a relatively low threat to tsunamis (NOAA National Tsunami Warning Center 2016).

Extent

NOAA issues tsunami warnings in the United States and has two Tsunami Warning Centers: the West Coast and Alaska Tsunami Warning Center (WC/ATWC) located in Palmer, Alaska and the Pacific Tsunami Warning Center (PTWC) located in Ewa Beach, Hawaii. WC/ATWC issues information to all states except Hawaii, U.S. territories in the Caribbean, and Canada. PTWC is responsible for Hawaii, U.S. territories in the Pacific, and international recipients in the Pacific and Indian Oceans, and the Caribbean Sea.

The Warning Centers monitor a worldwide network of seismic and sea level stations, providing a basis for which tsunami warnings, advisories, providing the basis for which tsunami warnings, advisories, watches, and information statements are issued. There are four types of tsunami messages issued by the Warning Centers and are as follows:

- Warnings are initially based solely on seismic data and are issued as quickly as possible indicating that a significant inundation may occur. They can be cancelled or downgraded to an advisory.
- Advisories indicate potential beach and harbor danger due to strong currents; however, significant widespread inundation is not expected.
- Watches indicate that a potentially dangerous distant event has occurred and the area needs to be alert for more information (NOAA 2016).

Previous Occurrences and Losses

The earliest historical tsunami accounts in the Atlantic include Caribbean tsunamis reported as early as 1498 in Venezuela and the first confirmed observation in the U.S. territories was in 1690 in the Virgin Islands. On the east coast, there were unconfirmed tsunami reports as early as 1688 with the first confirmed report on the Canadian east coast in 1755. The first confirmed tsunami report on the east coast of the U.S. was in 1886 in Charleston, South Carolina. It was observed in South Carolina and Florida. In 1918, a reported earthquake in Puerto Rico generated a tsunami that was recorded on a Galveston, Texas tide gauge (Dunbar and Weaver, 2008).

According to NOAA and USGS, the State of New Jersey has had seven tsunami events with run-up (a measurement of the height of the water onshore observed above a reference sea level). Three of these tsunami events had undetermined run-up heights; two events had run-ups of between 0.03 and 1.6 feet; and two event with a run-up of between 1.67 and 3.2 feet (NOAA 2016).

One of the six tsunamis in New Jersey was caused by an earthquake-triggered landslide; three of the six tsunamis were caused by a Caribbean earthquake; one of the six tsunamis was caused by a non-Atlantic earthquake; and one of the six tsunamis was caused by an underwater landslide (Dunbar and Weaver, 2008). The State of New Jersey was not part of any FEMA disaster or emergency declaration for tsunamis or tsunami-like waves. For this 2016 Plan update, tsunami events were summarized from 2009 to 2016. Tsunami events,

including FEMA disaster declarations, which have impacted Cape May County between 2009 and 2016 are identified in Appendix G. For information regarding tsunami events prior to 2009, refer to the 2010 Cape May County HMP. For detailed information on damages and impacts to each municipality, refer to Section 9 (jurisdictional annexes).

Probability of Future Events

The probability of tsunamis is related to the probability of the events that cause them, so it is similar to that of seismic activities or landslides. Using the NOAA National Geophysical Data Center / World Data Service (NGDC/WDS) tsunami database, it was found that there have been tsunami-related events (waves, runups, etc.) that have occurred along the coastline of Cape May County. Based on this data, Cape May County has a 3.03% chance of a tsunami or tsunami-related event impacting the county. The table below shows these statistics, as well as the annual average number of events and the estimated percent chance of the event occurring in a given year (NGDC/WDS 2016).

Table 5.4.8-1. Probability of Future Occurrences of Tsunamis

Event Type	Number of Incidents (1950 to 2015)	Rate of Occurrence	Recurrence Interval (in years)	Probability of Event Occurring in Any Given Year	% Chance of Occurrence in Any Given Year
Tsunami	2	0.03	33.00	0.03	3.03

Source: NOAA National Centers for Environmental Information (NCEI) 2016

Earlier in this HMP, in Section 5.3, the identified hazards of concern for Cape May County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for ranking hazards. Based on historical records and input from the Planning Committee, the probability of occurrence for tsunami events in Cape May County is considered 'occasional' (likely to occur within 100 years, as presented in Tables 5.3-1 and 5.3-3).

Climate Change Impacts

Providing projections of future climate change for a specific region is challenging. Shorter term projections are more closely tied to existing trends making longer term projections even more challenging. The further out a prediction reaches the more subject to changing dynamics it becomes. As stated earlier in this profile, tsunamis can be caused by: the down drop or upthrust of the earth's crust which results in an earthquake; an undersea landslide; a submarine volcanic eruption; or a large meteor impact at sea. Therefore, climate change impacts on these natural hazards should be referenced to determine how climate change may impact tsunami.

Temperatures in the Northeast United States have increased 1.5 degrees Fahrenheit (°F) on average since 1900. Most of this warming has occurred since 1970. The State of New Jersey, for example, has observed an increase in average annual temperatures of 1.2°F between the period of 1971-2000 and the most recent decade of 2001-2010 (ONJSC, 2011). Winter temperatures across the Northeast have seen an increase in average temperature of 4°F since 1970 (Northeast Climate Impacts Assessment [NECIA] 2007). By the 2020s, the average annual temperature in New Jersey is projected to increase by 1.5°F to 3°F above the statewide baseline (1971 to 2000), which was 52.7°F. By 2050, the temperature is projected to increase 3°F to 5°F (Sustainable Jersey Climate Change Adaptation Task Force 2013). Both northern and southern New Jersey have become wetter over the past century. Northern New Jersey's 1971-2000 precipitation average was over 5" (12%) greater than the average from 1895-1970. Southern New Jersey became 2" (5%) wetter late in the 20th century (Office of New Jersey State Climatologist).

Future climate change may impact storm patterns, increasing the probability of more frequent, intense storms with varying duration. Increase in global temperature could affect the snowpack and its ability to hold and store water. Warming temperatures also could increase the occurrence and duration of droughts, which could increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All of these factors could increase the probability for landslide occurrences.

The potential impacts of global climate change on earthquake probability are unknown. Some scientists feel that melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the Earth's crust. As newly freed crust returns to its original, pre-glacier shape, it could cause seismic plates to slip and stimulate volcanic activity according to research into prehistoric earthquakes and volcanic activity. National Aeronautics and Space Administration (NASA) and USGS scientists found that retreating glaciers in southern Alaska might be opening the way for future earthquakes (New Jersey State HMP 2014).

5.4.8.2 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed or vulnerable to the identified hazard. For the tsunami hazard, all of Cape May County has been identified as the hazard area. Therefore, all assets in the County (population, structures, critical facilities and lifelines), as described in the County Profile (Section 4), are exposed and potentially vulnerable to a tsunami. The following text evaluates and estimates the potential impact of the tsunami hazard on the County including:

- Overview of vulnerability
- Data and methodology used for the evaluation
- Impact on: (1) life, health and safety of residents, (2) general building stock, critical facilities, economy, and (3) future growth and development
- Effect of climate change on vulnerability
- Change of vulnerability as compared to that presented in the 2010 Cape May County Hazard Mitigation Plan
- Further data collections that will assist understanding this hazard over time

Overview of Vulnerability

Based on the research conducted for this planning process, identified tsunami inundation or hazard areas do not exist for the New Jersey coast. However, tsunami inundation maps have been prepared by the National Tsunami Hazard Mitigation Program, University of Delaware and the University of Rhode Island for portions of the East Coast. However, these maps are to be used for emergency planning purposes only and were prepared to help coastal communities identify their tsunami hazard areas. They display the worst case scenario and do not provide information regarding return periods of the events studied. Three maps have been prepared for Cape May County and include the southern portion of the county, Avalon Borough and Ocean City. Based on these figures (described below) and the county's coastal location and densely population and built shoreline, for the purposes of this planning effort, all of Cape May County is at risk to the impacts of tsunamis.

Data and Methodology

The NOAA's National Geophysical Data Center (NGDC) has built high-resolution digital elevation models (DEMs) for select coastal regions, including along the east cost of the U.S. According to their website: '*These integrated bathymetric-topographic DEMs are used to support tsunami forecasting and modeling efforts at the NOAA Center for Tsunami Research, Pacific Marine Environmental Laboratory (PMEL). The DEMs are part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) currently being*

developed by PMEL for the NOAA Tsunami Warning Centers, and are used in the MOST (Method of Splitting Tsunami) model developed by PMEL to simulate tsunami generation, propagation, and inundation.

Bathymetric, topographic, and shoreline data used in DEM compilation are obtained from various sources, including NGDC, the U.S. National Ocean Service (NOS), the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA), and other federal, state, and local government agencies, academic institutions, and private companies. DEMs are referenced to the vertical tidal datum of Mean High Water (MHW) and horizontal datum of World Geodetic System 1984 (WGS84). Grid spacings for the DEMs range from 1/3 arc-second (~10 meters) to 3 arc-seconds (~90 meters)' (NGDC, 2008).

A DEM was developed for Atlantic City, New Jersey in October 2007. This DEM is the closest in location to Cape May County. Several inquiries have been made to the National Tsunami Hazard Mitigation Program regarding inundation or hazard areas for the New Jersey coast; however this data is not available at this time.

Impact on Life, Health and Safety

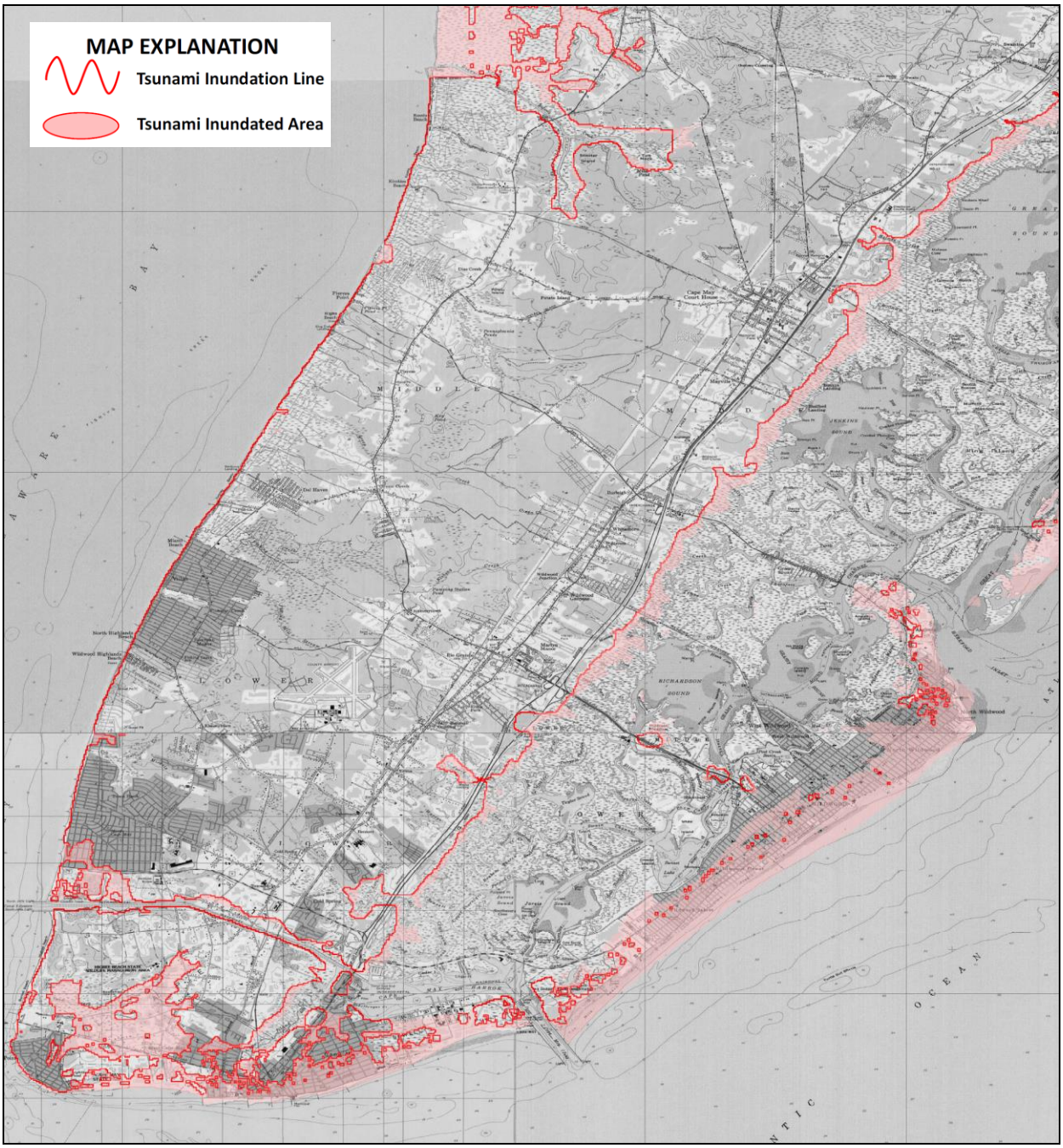
The impact of a tsunami on life, health and safety is dependent upon several factors including the severity of the event and whether or not adequate warning time was provided to residents. The populations in Cape May County that would be most exposed to this type of hazard are those along beaches and low lying coastal areas. In the event of a local tsunami in or near the planning area, there would be little warning time.

Currently, the Center for Applied Coastal Research, University of Delaware, and the Department of Ocean Engineering, University of Rhode Island are collaborating on a project to create flood inundation maps appropriate for both the public and emergency management personnel, pertaining to modeled runs of tsunami waves off the mid-Atlantic coast. Detailed inundation studies are being conducted for highest-risk East Coast communities, and results of these studies will be used to construct a first-generation of tsunami inundation maps for the chosen communities. The tsunami inundation maps are being prepared to help coastal communities identify their tsunami hazard. The maps were created using the best available data and portray the worst case scenario. Funding for this project is from the NOAA National Tsunami Hazard Mitigation Program (NTHMP).

In Cape May County, tsunami inundation maps have been created for portions of the County including the Borough of Avalon and Ocean City. These figures show inundation lines which represent the maximum tsunami runup extent and the tsunami inundation areas which show the areas in which be impacted if a tsunami were to occur. The figures indicate that the coastal areas of these communities have the potential to inundate if a tsunami were to occur. For details of these figures, refer to: http://www.udel.edu/kirby/nthmp/maps/

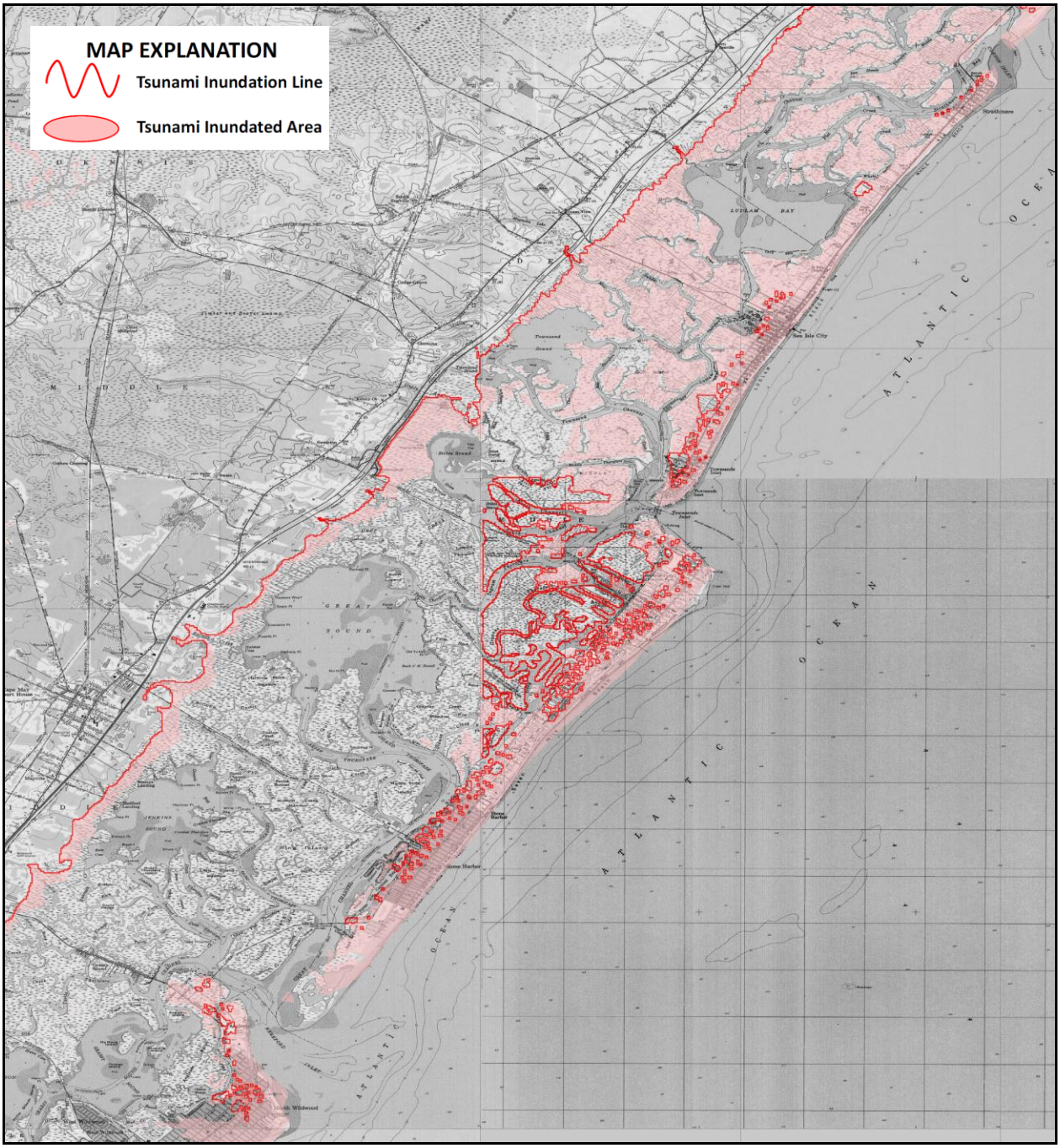
Based on the research conducted for this planning process, there are tsunami inundation areas developed for portions of Cape May County; however, the data portrays worst case scenario for the areas mapped. For the purposes of this plan, as a conservative approach, it is assumed that the entire county population (permanent and seasonal) is exposed to the tsunami hazard. Development of tsunami inundation or hazard areas can be used to conduct a spatial analysis to identify the most vulnerable residents living in the tsunami hazard zone and can be used to focus public education and outreach efforts on these communities.

Figure 5.4.8-1. Tsunami Inundation Map for Cape May



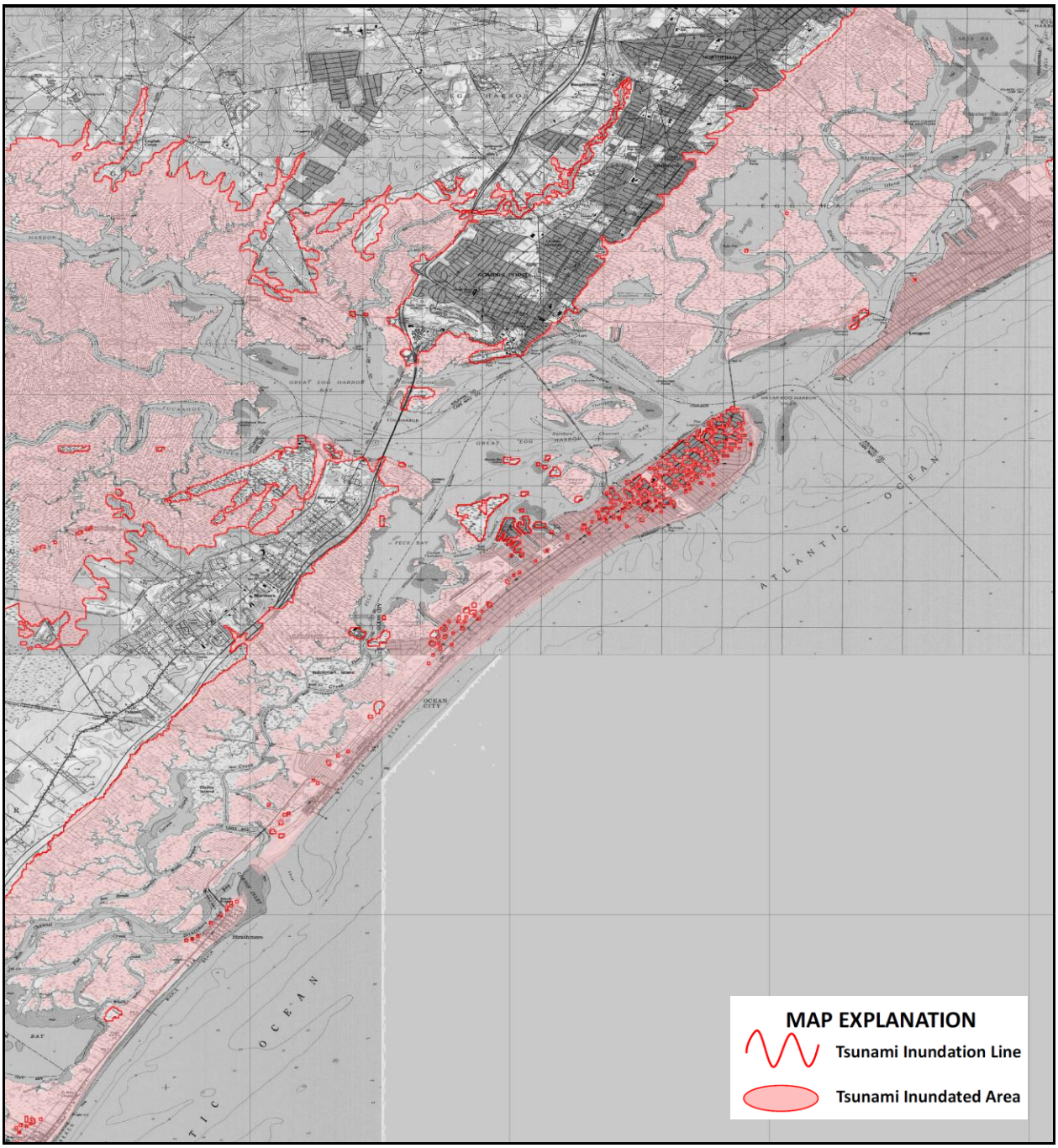
Source: University of Delaware 2015

Figure 5.4.8-2. Tsunami Inundation Map for Avalon Borough



Source: University of Delaware 2015

Figure 5.4.8-3. Tsunami Inundation Map for Ocean City



Source: University of Delaware 2015

Impact on General Building Stock, Critical Facilities, and the Economy

Similar to the population exposed, for the purposes of this planning effort, all general building stock, critical facilities and infrastructure are considered vulnerable to the tsunami hazard. The impact of the waves and the scouring associated with debris that may be carried in the water could be very damaging to structures located in the tsunami's path. Structures that would be most vulnerable are those located in the front line of tsunami impact and those that are structurally unsound (Humboldt County Hazard Mitigation Plan, 2008).

Roads are the primary resource for evacuation to higher ground before and during the course of a tsunami event. Flooding caused by a tsunami will greatly impact this important component in the management of tsunami related emergencies. Bridges exposed to tsunami events can be extremely vulnerable due to the forces transmitted by the wave run up and by the impact of debris carried by the wave action. The forces of tsunami waves can also impact above ground utilities by knocking down power lines and radio/cellular communication towers. Power generation facilities can be severely impacted by both the velocity impact of the wave action and the inundation of floodwaters (Humboldt County Hazard Mitigation Plan, 2008).

Tsunamis may induce secondary hazards such as water quality and supply concerns, and public health concerns. Impacts on the economy are difficult to quantify. As discussed above, losses include but are not limited to general building stock damages, business interruption/closure, impacts to tourism and tax base to Cape May County.

Effect of Climate Change on Vulnerability

Providing projections of future climate change for a specific region is challenging. Shorter term projections are more closely tied to existing trends making longer term projections even more challenging. The further out a prediction reaches the more subject to changing dynamics it becomes. As stated earlier in this profile, tsunamis can be caused by: the down drop or upthrust of the earth's crust which results in an earthquake; an undersea landslide; a submarine volcanic eruption; or a large meteor impact at sea. Therefore, climate change impacts on these natural hazards should be referenced to determine how climate change may impact tsunami.

Change of Vulnerability

There was no quantitative vulnerability assessment conducted for tsunami events in the 2010 or 2016 HMP. Overall, the County's vulnerability has not changed; the entire County continues to be exposed and vulnerable to tsunami.

Future Growth and Development

As discussed and illustrated in Sections 4 and 9, areas targeted for future growth and development have been identified across the County. Any areas of growth could be potentially impacted by the tsunami hazard because the entire Planning Area is exposed and vulnerable. Areas targeted for potential future growth and development in the next five (5) years have been identified at the jurisdiction level. Refer to the jurisdictional annexes in Volume II (Section 9) of this HMP.

Additional Data Needs and Next Steps

When the NGDC completes their analysis for the East Coast of the U.S. and develops tsunami inundation areas and/or heights, this data can be used to conduct a spatial analysis to determine the population, building stock and infrastructure exposed to this hazard of concern. For future plan updates, existing modeling programs, such as FEMA's HAZUS-MH can be customized for the tsunami hazard to quantify the losses associated with the hazard. Updated demographic and general building stock data in HAZUS-MH would produce more accurate estimates.