5.4.10 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.

2021 Plan Update Changes

- New and updated figures from federal and state agencies are incorporated.
- Previous occurrences were updated with events that occurred between 2016 and 2020.

5.4.10.1 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 2020).

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 shoreline over an extended period of time and builds height as it get closer (FEMA 2007). 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 three types of tsunamis: local, regional, and distant. A locally generated tsunami is a tsunami where its destructive effects are experienced on coasts within 100 km from the source of the tsunami. In such cases, the travel time for the tsunami is generally less than one (1) hour. A local tsunami is usually generated by an earthquake, but can also be caused by a landslide or a pyroclastic flow from a volcanic eruption. Locally generated tsunamis are especially dangerous. This type of tsunami may reach a nearby shore in less than ten minutes. In such cases, there is not sufficient time for a Tsunami Warning Center or for local authorities to issue an official tsunami warning. Coastal residents and users should therefore take life-saving action as indicated on the sign based on the shaking of the ground, which is a warning that a tsunami may be imminent (CDEMA 2010).

A regional tsunami is a tsunami capable of destruction in a particular area which lies between 100 km - 1,000 km form the source of the tsunami. Regional tsunamis can take between 1-3 hours to reach the affected shoreline. The most destructive tsunamis can be classified as local or regional (CDEMA 2010).

Also referred to as a tele-tsunami or ocean-wide tsunami, distant tsunamis originate from a faraway source (more than 1000 km away) and generally take more than 3 hours to arrive at affected coasts. When a tsunami is formed, the waves generally radiate and move in opposite directions. In this case, a local tsunami can impact on coastlines which are close to the tsunami source. The waves which are moving in other directions away from the source of the tsunami, can continue to travel across entire ocean basins as distant tsunamis with sufficient energy to cause additional casualties and destruction on far away shores (CDEMA 2010).

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 United States coastline. The most destructive tsunamis have occurred along the coasts of California, Oregon, Washington, Alaska, and Hawaii (International Tsunami Information Center 2020).

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).

While traditional tsunamis are caused by geological triggers, a more common tsunami on the east coast of the United States is the meteotsunami, a tsunami triggered by atmospheric forcing. Meteotsunamis are still being studied to better understand their causes and potential impacts. Meteotsunamis are typically caused by moving atmospheric disturbances such as sharp pressure gradients and/or changes in wind speed associated with a range of underlying atmospheric conditions, such as frontal passages, convective systems, squall lines, tropical cyclones, or nor'easters. The initial ocean wave caused by the atmospheric disturbance is typically quite small on the order of centimeters. However, through resonance achieved within the basin it moves through, the wave can reach a larger open sea height on the order of tens of centimeters prior to reaching the coast. Further amplification of the wave can occur due to harbor resonance, in which the shape of the harbor or estuary is such that oscillations reach an even greater and potentially destructive height (Dusek et. al. 2019). While meteotsunamis may be more common, they are much smaller and less likely to cause damage than geologically triggered tsunamis. The largest east coast meteotsunami found by a 2019 study of the past 22 years of events was 1.19 meters. Globally, however, meteotsunamis have been recorded up to 6 meters. Additional research is necessary to determine the true risks associated with meteotsunamis in Cape May County.

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

Due to the fact there are no major subduction zones in the Atlantic Ocean, with the exception of where it borders the Caribbean Sea, there has been a relatively low frequency of tsunamis along the East Coast, including Cape May County. The tsunamis that have been recorded along the East Coast have been associated with earthquakes in the Caribbean and Puerto Rico.

According to NOAA and USGS, the State of New Jersey has had eight 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; three events had run-ups of between 0.03 and 1.6 feet; and two events had a run-up of between 1.67 and 3.2 feet (NOAA 2020).

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; one of the six tsunamis was caused by an underwater landslide, and one event was caused by meteorological conditions and was classified as a meteotsunami (Dunbar and Weaver 2008, NOAA 2020).

FEMA Disaster Declarations

Between 1954 and 2020, New Jersey and Cape May County were not included in any Federal Emergency Management Agency (FEMA) declared tsunami specific disasters (DR) or emergency declarations (EM).

U.S. Department of Agriculture Disaster Declarations

Between 2016 and 2020, the period for which data was available, Cape May County was not included in any tsunami-related USDA declarations.

Tsunami Events

For this 2021 Plan update, tsunami events were summarized from 2016 to 2020. According to record keeping by NOAA, no tsunami events have impacted Cape May County between 2016 and 2020. However, one event was recorded that impacted the northeast on July 15, 2018. Classified as a meteotsunami, a 0.15 meter wave runup was recorded at the Atlantic City tide gauge. The event was not recorded at the Cape May gauge but it is possible that the event did impact Cape May County as other locations throughout the mid-Atlantic and northeast recorded the event and meteotsunamis are known to be very location dependent (NOAA 2020, Dusek et al. 2019). For information regarding tsunami events prior to 2016, refer to Appendix E.

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 New Jersey. Based on this data and assuming that a tsunami impacting New Jersey would also impact Cape May, Cape May County has a 4.96% 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 (NOAA 2020).

A total of 548 meteotsunami events were detected on the U.S. East Coast from 1996 to 2017, for an average of about 25 events per year (Dusek et. al. 2019). Additional research of these events is necessary to determine the frequency of meteotsunami events in Cape May County.

Using the history of tsunami events recorded in Cape May County, Table 5.4.10-1 provides the probability of tsunamis occurring each year in Cape May County. Based on the information researched, the County has a 4.96 percent chance of a tsunami, of any magnitude, occurring each year.

Table 5.4.10-1. Probability of Future Occurrences of Tsunamis

Event Type	Number of Incidents (1900 to 2020)	% Chance of Occurrence in Any Given Year
Tsunami	6	4.96

Source: NOAA National Centers for Environmental Information (NCEI) 2020, NOAA 2020

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 'rare' (between 1 and 10% annual chance of occurring).

Climate Change Impacts

Due to the increase in greenhouse gas concentrations since the end of the 1890s, New Jersey has experienced a 3.5° F (1.9° C) increase in the State's average temperature (Office of the New Jersey State Climatologist 2020), which is faster than the rest of the Northeast region (2° F [1.1° C]) (Melillo et al. 2014) and the world (1.5° F [0.8° C]) (IPCC 2014). This warming trend is expected to continue. By 2050, temperatures in New Jersey are expected to increase by 4.1 to 5.7° F (2.3° C to 3.2° C) (Horton et al. 2015).

Since the end of the twentieth century, New Jersey has experienced slight increases in the amount of precipitation it receives each year, and over the last 10 years there has been a 7.9% increase. By 2050, annual precipitation in New Jersey could increase by 4% to 11% (Horton et al. 2015). By the end of this century, heavy precipitation events are projected to occur two to five times more often (Walsh et al. 2014) and with more intensity (Huang et al. 2017) than in the last century. New Jersey will experience more intense rain events, less snow, and more rainfalls (Fan et al. 2014, Demaria et al. 2016, Runkle et al. 2017).

A warmer atmosphere means storms have the potential to be more intense (Guilbert et al. 2015) and occur more often (Coumou and Rahmstorf 2012, Marquardt Collow et al. 2016, Broccoli et al. 2020). In New Jersey, extreme storms typically include coastal nor'easters, snowstorms, spring and summer thunderstorms, tropical storms, and on rare occasions hurricanes. Most of these events occur in the warmer months between April and October, with nor'easters occurring between September and April. Over the last 50 years, in New Jersey, storms that resulted in extreme rain increased by 71% (Walsh et al. 2014) which is a faster rate than anywhere else in the United States (Huang et al. 2017). As temperatures increase so will the energy in a storm system, increasing the potential for more intense tropical storms (Huang et al. 2017), especially those of Category 4 and 5 (Melillo et al. 2014). Stronger and more frequent storms could result in an increase in the frequency of meteotsunamis.

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.

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 2019).

In Atlantic City, Cape May, and Sandy Hook, sea-level has risen at a rate of approximately 0.2 to 0.5 inches per year since the beginning of the 20th century, and this rate will continue to increase (Kopp et al. 2019). The amount of greenhouse gases that are emitted is tied to rates of sea-level rise. By 2050, New Jersey will likely experience at least a 0.9 to 2.1-foot increase (above the levels in 2000; all emissions scenarios), 1.4 to 3.1-foot increase by 2070 (moderate emissions scenario), and potentially a 2.0 to 5.1-foot increase by 2100 (moderate emissions scenario). Higher sea levels could increase the severity of tsunami events.

For details regarding climate change and sea level rise, refer to Section 5.4.1 (Climate Change and Sea Level Rise).

5.4.10.2 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.

Impact on Life, Health and Safety

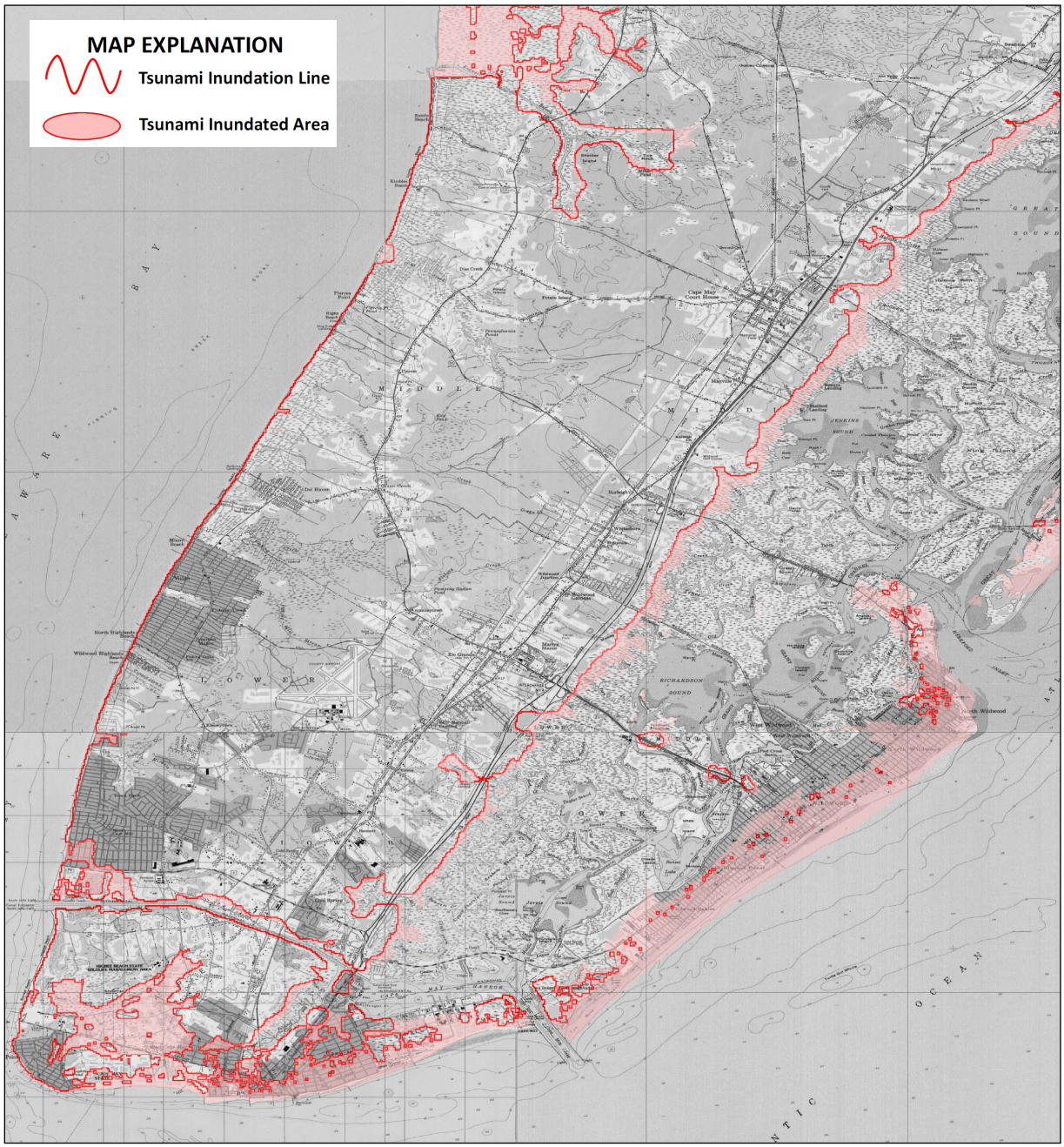
The impact of a tsunami on life, health and safety is dependent upon several factors including the severity of the event and whether or not adequate warning time was provided to residents. The populations in Cape May County that would be most exposed to this type of hazard are those along beaches and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

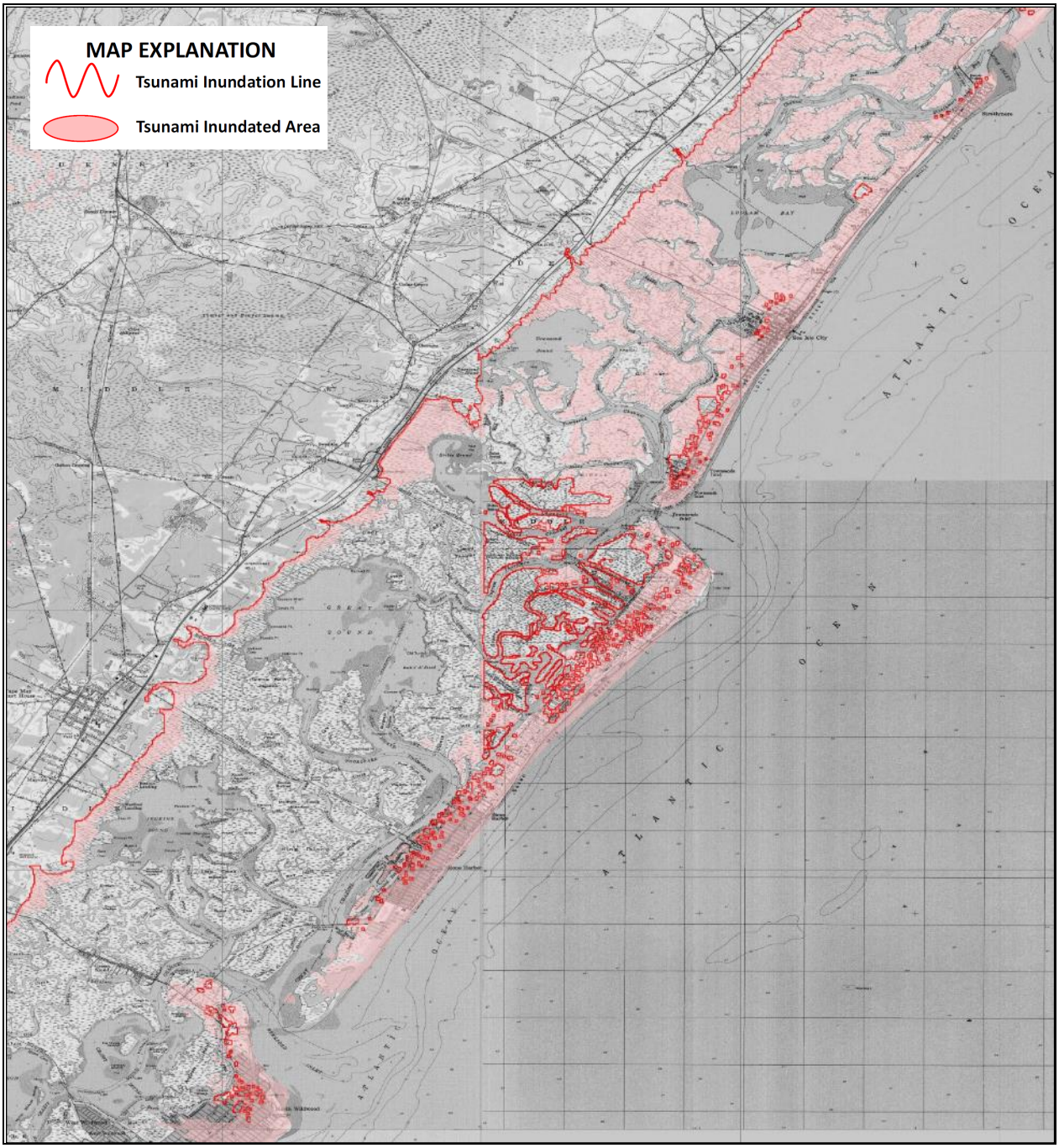
Based on the research conducted for this planning process, there are tsunami inundation areas developed for portions of Cape May County. For the areas that have been mapped, the mapping portrays the maximum tsunami runup extent utilizing a number of extreme, but scientifically realistic tsunami sources. 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. The greatest vulnerability would exist along the eastern shores of the County, due to greater exposure to tsunami events. 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 5.4.10-1. Tsunami Inundation Map for Cape May



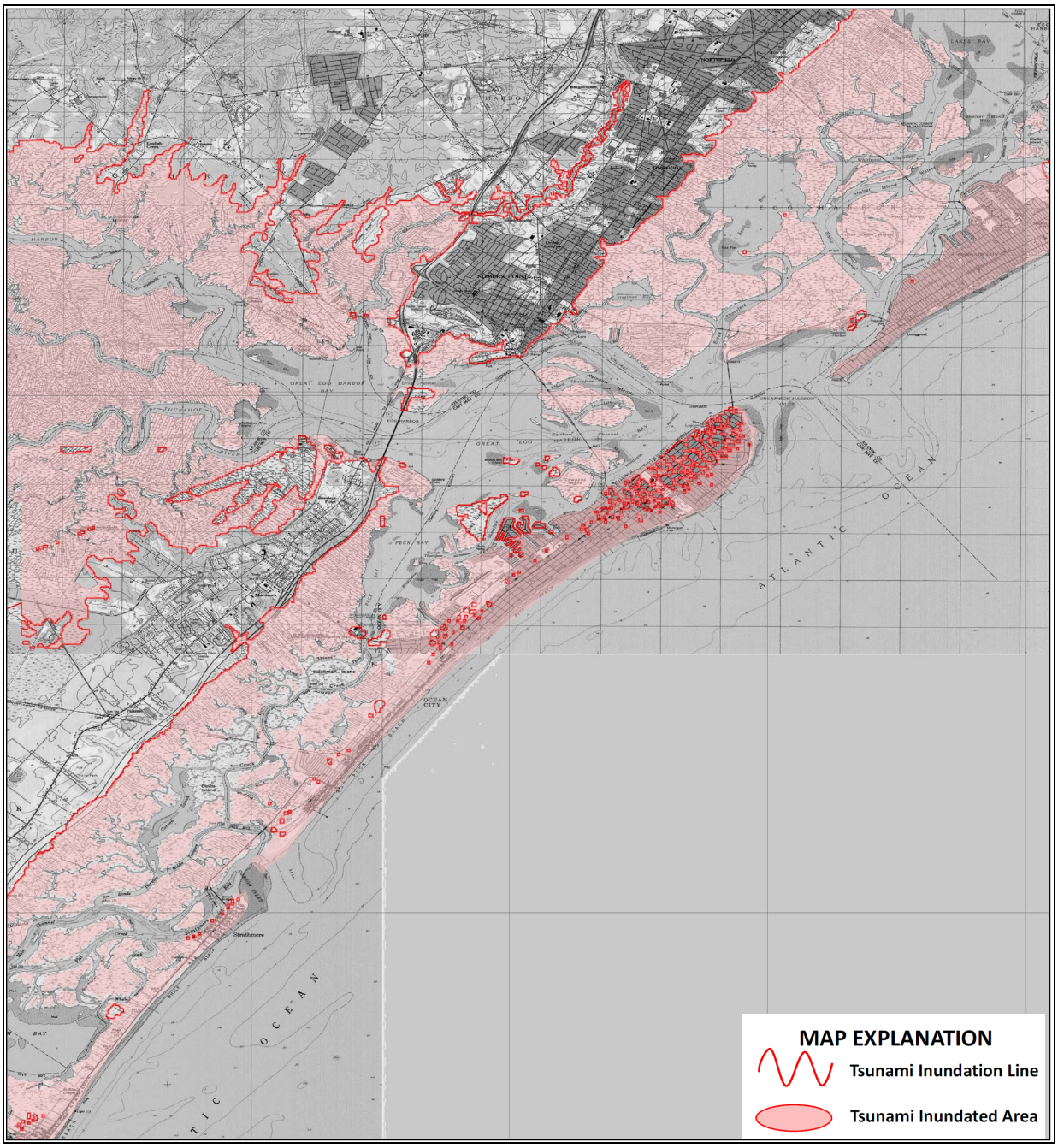
Source: University of Delaware 2015

Figure 5.4.10-2. Tsunami Inundation Map for Avalon Borough



Source: University of Delaware 2015

Figure 5.4.10-3. 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. However, the areas with the highest vulnerability are those areas that are low-lying along the coastline located on the eastern shores of Cape May County. 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.

Future Changes that May Impact Vulnerability

Understanding future changes that effect vulnerability in the County can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. Cape May County considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development.
- Projected changes in population.
- Other identified conditions as relevant and appropriate, including the impacts of climate change.

Projected Development

As discussed in Section 4 (County Profile), areas targeted for future growth and development have been identified across Cape May County. Any areas of growth along the coastline of Cape May County could be potentially impacted by a tsunami because the entire coastline is exposed and vulnerable. Specific areas of recent and new development are indicated in tabular form and/or on the hazard maps included in the jurisdictional annexes in Volume II, Section 9 (Jurisdictional Annexes) of this plan.

Project Changes in Population

Between 2000 and 2010, the County lost nearly five percent of its population. Between 2010 and 2020, the County is expected to have experienced a similar decrease. It is expected that in the next 20 years, population growth will be relatively stagnant (U.S. Census Bureau 2020 SJTPO). Any population growth in the coastal communities of Cape May County could be impacted by a tsunami in the future. Refer to Section 4 (County Profile) for a detailed discussion on population change in Cape May County.

Climate Change

As discussed earlier, studies project that the State of New Jersey will see an increase in average annual temperatures and precipitation. 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. None of these events are likely to be influenced by climate change. However, as noted previously, meteotsunami events are influenced by severe weather events and climate change could increase the frequency and severity of weather events that spawn meteotsunamis.

Change of Vulnerability Since the 2016 HMP

Overall, the County's vulnerability has not changed; the entire County continues to be exposed and vulnerable to tsunami.