COASTAL RISK CONSULTING

Analysis of AREVA Flood Hazard Re-Evaluation Report
Pilgrim Nuclear Power Station
Plymouth, MA

Contents

Acronyms

CLB	Current Licensing Basis
CRC	Coastal Risk Consulting
FEMA	Federal Emergency Management Agency
HMR	Hydrometeorological Report
IPEEE	Individual Plant Examination of External Events
JRWA	Jones River Watershed Association
LIP	Local Intense Precipitation
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NTTF	Near Term Task Force
NWS	National Weather Service
PCA	Plymouth-Carver Aquifer
PMH	Probable Maximum Hurricane
PMP	Probable Maximum Precipitation
PMSS	Probable Maximum Storm Surge
PMWS	Probable Maximum Wind Storm
PNPS	Pilgrim Nuclear Power Station
SLAMM	Sea Level Affecting Marshes Model
USACE	United States Army Core of Engineers
USGS	United States Geological Survey
WIS	Wave Information Studies

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Executive Summary

The Pilgrim Nuclear Power Station (PNPS), owned and operated by Entergy Nuclear Generation Company, is located in Plymouth, Massachusetts directly on the Cape Cod Bay shoreline. PNPS began operating in 1972, and in 2012 it was granted a new, 20-year operating license by the Nuclear Regularly Commission (NRC, 2015a).

In 2012, the Nuclear Regulatory Commission (NRC) requested information from all U.S. nuclear reactors, including PNPS, to support its review of the Fukushima Daiichi nuclear accident (NRC, 2012). Part of this request addressed flood and seismic hazards at reactor sites. In March 2015, Entergy provided the NRC with a Flood Hazard Re-Evaluation Report prepared by AREVA, Inc. (AREVA, 2015). In September 2015, Jones River Watershed Association (JRWA) commissioned Coastal Risk Consulting, LLC (CRC) to provide an expert analysis of the methodologies and conclusions presented in the AREVA Flood Hazard Re-Evaluation Report.

Since JRWA first requested CRC to analyze the AREVA Report, Entergy announced that PNPS will close no later than June 2019, and possibly as much as two years sooner. Even post shutdown, having a detailed and robust flood assessment for PNPS is important. It will provide the basis for good planning and management for the site leading up to and throughout decommissioning, which will help curb flooding risks and ultimately protect public safety, environmental health, and the economic well-being of the area.

The following key points are presented and explained in this report:

- Local Intense Precipitation is shown in the AREVA Report to be a primary hazard of concern that could inundate the site by as much as 2.5 feet of rainwater (AREVA p. 29). However, the AREVA analysis underestimates this risk by using **outdated precipitation data and not considering future climatic conditions,** which are projected to increase precipitation amounts during heavy rainfall events.

- While the storm surge analysis was robust, **sea level rise over the next 50 years was understated** by relying primarily on historic rates of sea level rise. This approach produces only 0.46 feet of sea level rise by 2065. However, the National Oceanographic and Atmospheric Association (NOAA) estimates sea level rise of 3.05 feet by 2065.

- **Groundwater, subsidence, and erosion are not considered** in the analysis, further underestimating the risks to PNPS, particularly when analyzing the combined effects of extreme storm events.

- In addition to storm surge, other factors and mechanisms such as high tide and wave setup dramatically compound flooding. The main flaw in the Combined Flooding section of the AREVA Report relates to the limitations of the term "combined." **Of the five combined event scenarios provided in the NRC guidance document, NUREG/CR-7046, Appendix H, only one is deemed appropriate for PNPS.** This conclusion disregards a wide range of possibilities for analysis with the available tools.

In general, Entergy's AREVA Report focuses solely on past risk conditions and does not include scenarios that address updated projections for future risk, specifically with regard to climate change.

This report is organized as follows:

Introduction

Background information, history, situation analysis, and brief literature review for Pilgrim Nuclear Power Station.

Tasks 1 & 2

A review of the AREVA Flood Hazard Re-Evaluation Report methodology and results, and an analysis of the methodology for the following sections: local intense precipitation, storm surge, combined flooding, erosion, groundwater and subsidence.

Conclusion

A summary of the most important findings of the AREVA Flood Hazard Re-Evaluation Report and a closing argument concerning the evaluation.

Appendices

- A: Task 3, Modeling assessment of future flooding potential includes Coastal Risk Consulting's FIRST Score™, nuisance flood maps, and storm surge analysis from a category 4 hurricane at high tide for PNPS over 70 years of sea level rise. The full Coastal Risk Rapid Assessment™ (CRRA) is preceded by descriptions of each component.
- B: WIS Wave Gage Locations from AREVA, 2015; Figure 3-36, p. 111.

**For simplicity we have converted all values in Mean Seal Level to NAVD88 using the conversion factor of 0.3 obtained from the Boston Tide Gauge from NOAA Tides and Currents. All elevations referenced in Mean Seal Level in the AREVA Report have been converted similarly. A major challenge of the AREVA report is a lack of standardized elevations. This leads to significant confusion and conflict in the flooding evaluations they conducted.*

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Acknowledgements

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Introduction

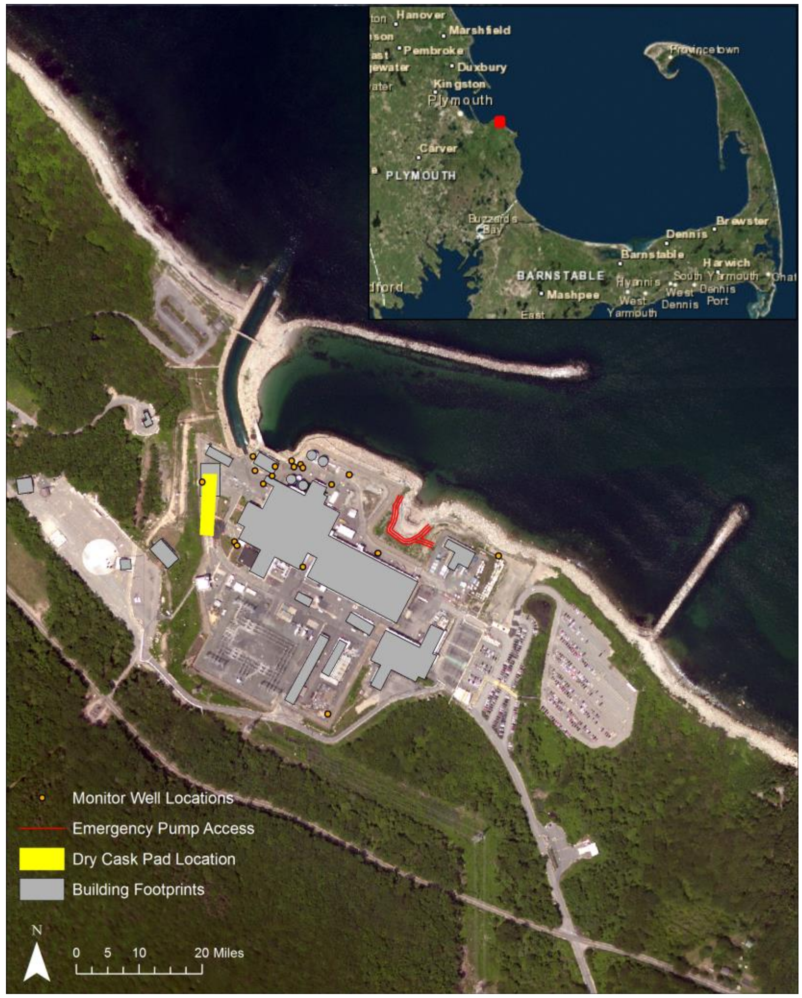

Figure 1. Overview of PNPS

The coastal zone of Massachusetts has a distinctive geological and geographic setting within the framework of the northeastern region of the United States (Ramsey, 2005). Due to the unique characteristics of the area, such as gradual sloping, low-lying coastlines, and a high concentration of people and property on the coast, many municipalities face an array of coastal hazards, specifically those associated with sea level rise, storm surge and nor'easters (Ramsey, 2005). The northeastern seaboard experiences the combined impacts of sea level rise, nor'easters and hurricanes compounded with storm surge, ultimately leading to flood events occurring more frequently (Climate Central, 2014).

Plymouth, Massachusetts is a coastal town, home to Pilgrim Nuclear Power Station (PNPS; Figure 1), and is situated at an average elevation of 23 feet relative to NAVD88 (USGS, 2014). In addition to the pressures of protecting their coastal community, Plymouth has the added responsibility of hosting a nuclear facility and a growing stockpile of nuclear waste at the Pilgrim site.

On March 12, 2012 the Nuclear Regulatory Commission (NRC) requested information from all U.S. nuclear reactors, including PNPS, to support the its Near-Term Task Force (NTTF) review of the 2011 accident at the Fukushima Daiichi nuclear facility in Japan (NRC, 2012). The NTTF was established by the NRC after the Fukushima disaster, to evaluate the current design basis for licensed nuclear facilities in the U.S. and require preparedness to avoid accidents that could challenge the U.S. nuclear fleet. The NTTF developed a report and a set of recommendations.

Part of the NRC's March 12, 2012 request for information addressed NTTF's Recommendation 2.1, which directed licensees to reevaluate flood and seismic hazards at reactor sites.

In March 2015, Entergy provided information for PNPS to the NRC in the form of a Flood Hazard Re-Evaluation Report ("AREVA Report") prepared by AREVA, Inc. (AREVA, 2015). In September 2015, Jones River Watershed Association (JWRA) commissioned Coastal Risk Consulting, LLC (CRC) to provide an expert analysis of the methodologies and conclusions presented in the AREVA Report.

Local residents and organizations, including JRWA, have raised concerns that the AREVA Report excludes or inaccurately assesses certain flood-causing mechanisms that could result in devastating outcomes – including radioactive leaks and releases – for Massachusetts' South Shore communities, especially in the context of a changing climate.

On October 13, 2015 Entergy announced PNPS will shut down no later than June 2019. It is important to understand how coastal hazards will impact PNPS's site now and in the years after shutdown. If Entergy is allowed to opt for long-term "SAFSTOR," full decommissioning and decontamination of the site could be delayed for up to 60 years. If remediation is delayed, flooding and other coastal hazards could lead to increasing and ongoing pollution of Cape Cod Bay. Flooding, sea level rise, and rising groundwater tables could increasingly flush contaminates present in the groundwater and soil into the sea. As for storage of nuclear waste, current NRC rules allow for hundreds of years of storage on-site. PNPS is now storing nuclear waste within reach of rising tides, coastal storms, and salt water degradation – creating another potential source of radioactive leaks and contamination of the environment.

Having a detailed and robust flood assessment is an important foundation for good planning and management. This will help curb flooding risks and ultimately protect public safety, environmental health, and the economic well-being of the surrounding area. This is especially true for areas such as PNPS containing hazardous materials.

Plymouth's historical data provides an indication of the potential threats climate change may pose in the future. Since 1938, at least three storms resulted in 11+ foot storm surges, which resulted in 25+ foot floods above mean sea level. For instance, during the Blizzard of 1978, Plymouth experienced flood elevations that ranged from 12.7 to 21.9 feet, causing severe damage along the coast (Figure 2). A surge of 4 feet, with waves of 12 feet on top of that, meant tides along the southern New England coast were more than 16 feet above normal levels, bringing devastating high tides for four successive tide cycles (two days) with continual onshore flow. Years later in 1991, the "Perfect Storm" caused waves over 30 feet high to develop along the Massachusetts coastline (NOAA, 2015a). More recently in 2012, the


The Boston Globe

Worst storm of century

17 die . . . record high tides . . . up to 4 feet of snow . . . winds gust up to 125 mph . . . highway traffic banned

Figure 2. Morning of Second Day, Blizzard of 1978

Northeast was hit by Hurricane Sandy. The storm caused seas to rise 20 to 25 feet off the East Coast, resulting in surges of 12.65 feet at the south end of Manhattan and 6.25 feet in Providence, Rhode Island (Blake et al., 2013).

As the climate continues to change and sea levels rise, exposure to these types of events are likely to increase, therefore increasing the severity of coastal hazard risks to communities and infrastructure along the Northeast coast.

A recent analysis was conducted for Massachusetts coastal communities that are at severe risk of increased flooding associated with sea level rise. For areas less than one to ten feet above the local high tide line, it is estimated that 121,000 members of the state's population are at risk, in addition to 67,000 homes and 48,000 acres of land area (Climate Central, 2014). Plymouth County is considered one of the largest total exposed populations, following the counties of Suffolk and Middlesex.

There are currently 61 commercially operating nuclear power facilities with 99 nuclear reactors in the U.S. (EIA, 2015). PNPS's performance rating was downgraded by the NRC on September 2, 2015 to Column IV, making it one of the bottom three worst performing reactors in the nation (NRC, 2015b).

Among 99 reactors in the United States, Pilgrim is rated as one of the three worst performers.

As new climate change projections and data emerge, it is essential that thorough and up-to-date flood risk evaluations for PNPS are prepared. This is especially important given that public attention is turning to safe closure and decommissioning, and that coastal hazards and flooding could influence the time frame and success of decommissioning and cleanup. Not understanding all possible causes of flooding will ultimately put coastal populations, ecosystems, and economics of the South Shore – and beyond – at risk.

Tasks 1 & 2: Review and Analyze AREVA Flood Hazard Re-Evaluation Report

This commentary focuses on four specific sections of the AREVA Flood Hazard Re-Evaluation Report: Local Intense Precipitation (Section 3.1), Storm Surge (Section 3.4), Channel Migration or Diversion (Section 3.8), and Combined Effect Flood (Section 3.9).

Local Intense Precipitation (AREVA Report, Section 3.1)

Local Intense Precipitation (LIP) refers to a short and heavy rainfall event centered upon the PNPS site itself. LIP is determined by modeling the Probable Maximum Precipitation (PMP) for a specific basin, or the maximum precipitation possible based on meteorological conditions. This is done by taking the largest historical storm for a basin and forcing specific atmospheric conditions in order to "maximize" the storm. PMP is estimated using historical records of extreme precipitation and maximized by the ratio of actual precipitable water in the atmosphere and maximum precipitable water derived from daily maximum dew point records (Rackecha and Singh, 2009). This catalog of extreme rain events from about 1900-1990 was compiled by the National Oceanographic and Atmospheric Association (NOAA) and used to create the Hydrometeorological Reports (HMR; Rackecha and Singh, 2009).

Previous Probable Maximum Precipitation (PMP) evaluation

PMP was evaluated as part of the Individual Plant Examination of External Events (IPEEE), although it is not part of the Current Licensing Basis (CLB). However, it was determined that a PMP event exceeds the CLB extreme storm tide level and is predicted to cause flooding at important safety locations on the plant site. This PMP evaluation was based on 1-hour precipitation rates with a probability of occurrence of $1x10^6$ per year from the National Weather Service (NWS) HYDRO-35 report (NWS, 1977).

The current flood protection measures in place for a PMP event include exterior doors on power block buildings, roof drains, and internal seals for conduits originating in manholes. Furthermore, the plant's procedure for operation during severe weather includes ensuring exterior doors are closed, installing sandbags at door bottoms and drain scuppers. During a hypothetical PMP event they concluded door sills on the south side of the plant would be submerged 1.5 feet below the maximum PMP flood depth, however an evaluation determined that these doors could withstand the force. It was also determined some roof ponding would occur, but that the PMP event would not exceed roof design if the roof drains were fully functioning.

Re-evaluation of Probable Maximum Precipitation (PMP)

LIP flood risk was modeled using FLO-2D, a physical flood routing model that simulates unconfined flow over topography and in channels. This model considers topography, building structures, coastal protection structures, and apparent land cover as static inputs. Parameters for LIP were defined using HMR-51 (NWS, 1978) and HMR-52 (NWS, 1982). They considered two storm scenarios:

1. Total rainfall depth for a 1-hour, 1-mi^2 PMP at 17.1 inches
2. Total rainfall depth for a 6-hour PMP at 25.5 inches

Only the LIP section of the AREVA Report forecasted flooding effects at important safety locations on the plant site. LIP flood elevations near the important locations ranged from 22.5 feet NAVD88 and 24.4 feet NAVD88. Maximum flood depths ranged from 0.6 feet to 2.6 feet. Hydrographs showed that peak flood levels occurred after the peak rainfall intensity due to a lag caused by off-site drainage. Therefore the maximum flood depths occur within the first two hours of the simulation and, in some areas, could take up to 10 hours to recede.

In the AREVA Report, LIP was determined to be one of the only flood hazards that exceeds the minimum entrance level for areas housing systems, structures, and components important to safety (22.7 feet NAVD88). However, as pointed out in the AREVA Report and by the Union of Concerned Scientists (Lochbaum, 2015), the LIP flood hazard is not part of the CLB for PNPS, therefore PNPS has no legal obligation to maintain or create new flood protections regarding the LIP hazard. This fact is a major safety concern for PNPS because, as proven in the AREVA Report, LIP is a primary flood hazard of concern. Furthermore, it shows that they previously underestimated LIP flooding in the IPEEE.

CRC Analysis of Local Intense Precipitation (LIP) Impact

While the issue of LIP flooding has already been brought to the attention of the NRC, CRC suggests that the AREVA Report is still underestimating the risk of LIP for the following reasons:

1. The PMP values do not consider future climatic conditions,
2. this analysis only considered one extreme storm and ignored the potential for multiple storms hitting the area,
3. it assumes static land cover for the area, and
4. it assumes that the roof drains will always be fully functioning.

Probable Maximum Precipitation (PMP) values do not consider future climatic conditions

PMP values were obtained from the NWS HYDRO-35 Report and were based on hourly rainfall measurements from 1948 - 1972 (NWS, 1977). LIP parameters for FLO-2D were derived from HMR-51 and HMR-52 that were published by NOAA's NWS in 1978 and 1982, respectively (NWS, 1978; NWS, 1982). The most discernible issue is that the data are outdated; however, it is the best available verified estimate for PMP because no updates have been made presumably due to the lack of funding for the PMP program (NWS, 2015). Despite this fact, these PMP values are strictly based on historical data and therefore do not take into account global climate change over the 30-plus years since their development or project into the future. The NRC even recognized that it is unclear how climate change will affect probable maximum events and stated that a site-specific analysis may be needed (NRC, 2011).

There have been several studies citing that PMP values are expected to increase in the future due to climate change and have been projected to increase by 20-30 percent by 2070 to 2100 (Stratz and Hossain, 2014; Kunkel et al., 2013). Furthermore, it has been demonstrated that heavy rainfall events are increasing in the northeastern United States and are projected to increase further in the coming years due to climate change (Melillo et al., 2014). The Northeast has seen the most significant increase in heavy rainfall events as compared to the rest of the country (Figure 3; Melillo et al., 2014).

RECOMMENDATION:

CRC recommends that actions be taken to update the PMP values to include more up-to-date rainfall data and future climatic scenarios be included in the LIP flood hazard analysis to achieve a true estimate of the current and future LIP flood risk. This inclusion is especially important because it has already been shown that LIP flooding based on historic conditions can already impact important safety features of PNPS. This could also have implications for decommissioning and site cleanup activities and schedules.

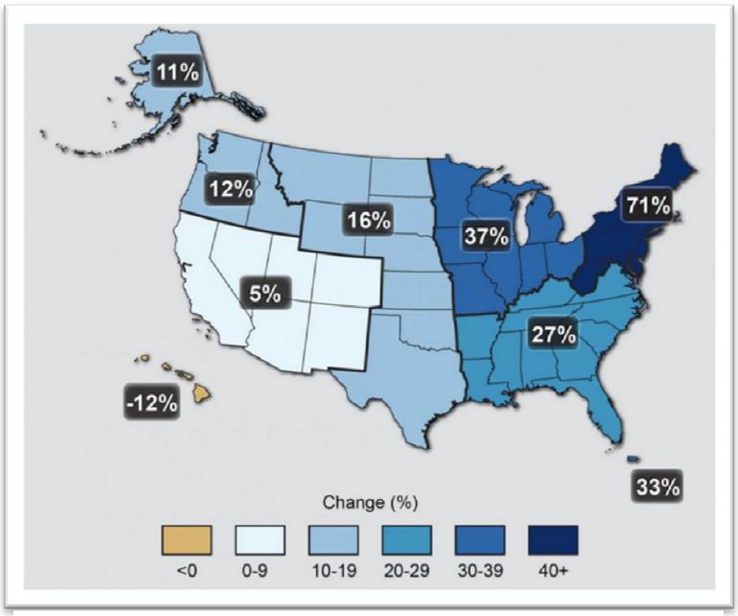

Figure 3. Percent increase in the amount of precipitation in very heavy events (the heaviest 1% of daily events) from 1958-2012. (Source: Melillo et al., 2014)

Re-Evaluation only considered one extreme storm and ignored the potential for multiple storms hitting the area

In the AREVA Flood Hazard Re-Evaluation Report, LIP was modeled using a 1-hour PMP of 17.1 inches and a 6-hour PMP of 25.5 inches. It is unclear why only these two time steps were chosen to model, especially when it is known that nor'easters may produce rain events that can last several days (Zingarelli et al., 2013). Additionally, there is no mention of modeling the combined effects of repeated storms passing over the area.

Long-lasting or repeated storms can saturate the soil and passive drainage systems with water causing significantly greater flooding. While the FLO-2D model did assume "wet conditions" for the land cover and calculations of infiltration, 18 percent of the total precipitation was still infiltrated before the flood routing started. This statement suggests that some passive drainage systems were still assumed functional during the PMP but with multiple storms or a persistent nor'easter with high sea levels backwatering the drains, this might not be the case.

RECOMMENDATION: CRC recommends that scenarios involving long-lasting and repeated storms be included in the LIP flood hazard analysis. Furthermore, in order to evaluate the "worst-case-scenario" model outputs should assume all passive drainage mechanisms are saturated and therefore not functioning. Even today, extreme events are challenging our estimations of PMP. For example, the October 2015 storm events associated with Hurricane Joaquin in Charleston, South Carolina resulted in an astounding 24.23 inches of rain near Mount Pleasant. This quickly surpassed NOAA's estimate for 17.1 inches for a 3-day 1,000-year rainfall event (Halverson, 2015). In the wake of this massive storm, it is important to realize that historical data do not predict the magnitude of storms in the future and even today.

Assuming static land cover for the area

Model infiltration was determined using land cover and soil types based on the United States Department of Agriculture's Natural Resources Conservation Service National Engineering Handbook (Part 630, Hydrology; USDA, 2004). In the model, this layer is assumed static and reflects only current conditions at the plant site. Again, depending on how long PNPS continues to operate, as well as pending decommissioning and site cleanup time frames, land cover is subject to change. For example, sea level rise is projected to cause marsh migration which would have an impact on soil type and therefore infiltration of precipitation during extreme events.

RECOMMENDATION: CRC recommends that land cover change scenarios be investigated to assess the future vulnerability of PNPS to LIP flooding. One such model that can be used to assess changing land cover is the Sea Level Affecting Marshes Model (SLAMM) developed by NOAA. However, a decommissioning program within the next decade could eliminate the need for further consideration of this issue.

Storm Surge (AREVA Report, Section 3.4)

AREVA conducted analyses of the Probable Maximum Hurricane (PMH), Probable Maximum Wind Storm (PMWS; extratropical cyclone/nor'easter), and Probable Maximum Storm Surge (PMSS) at PNPS. The PMH for PNPS was created by using NOAA Technical Report NWS 23 parameters (NOAA, 1979), analysis of past hurricane data for the area with the National Hurricane Center's (NHC) HURDAT2 program alongside synthetic hurricanes for the area created by the renowned meteorologist, Kerry Emanuel. With the analysis of historical hurricanes and synthetic hurricanes, AREVA was able to conduct a statistical study on forward speed, intensity, storm bearing and return periods affecting PNPS. The statistical study was also conducted for nor'easters using historic nor'easter data to create the PMWS.

Storm surge was analyzed for both hurricanes and nor'easters. The PMSS (hurricane related) value included the following data and analysis to be able to obtain the maximum storm surge value on PNPS: the addition of sea level rise onto monthly maximum tide gauge data (antecedent water level), a SLOSH model analysis that evaluated storm parameters that would lead to the worst case surge value, and further and finer model analysis of the conclusions made in SLOSH in ADCIRC. Maximum storm surge for nor'easters was conducted using ADCIRC alone with the data collected from the statistical study and the antecedent water level.

The PMSS for PNPS from the evaluation in this report was 14.9 feet NAVD88 without wave setup and 15.0 feet NAVD88 with wave setup (AREVA Report, Section 3.4) from a storm making landfall on the eastern shore of Cape Cod and heading in a north-northeast direction. Storm surge (still water elevations) from hurricanes for PNPS was found to have directionally dependent sensitivities to forward speed, landfall location and increased surge with an increase in the radius of maximum wind speeds. The maximum storm surge produced by a nor'easter from the evaluation in this report was 14.0 feet NAVD88 without wave setup and 14.5 feet NAVD88 with wave setup (AREVA, Section 3.4, p. 56) from a storm just to the south of Cape Cod heading in an east-northeast direction.

CRC Analysis of Storm Surge Impact

Extratropical storms are storms that have their origin from areas not in the tropics like that of a hurricane (Prociv, 2013). Therefore, a nor’easter is a type of extratropical storm. According to NOAA, “A nor’easter is a cyclonic storm that moves along the east coast of North America. It’s called “nor’easter” because the winds over coastal areas blow from a northeasterly direction” (NOAA, 2013). Nor'easters affect New England more frequently than hurricanes do.

New England should expect to see 1 to 2 severe nor'easters during late fall and winter every year (Storm Solutions, 2010). According to the NHC, the return period for a hurricane (winds greater than 74 mph) is 13 to 16 years and the return period for a major hurricane (category 3 or higher) is even longer at 58 to 62 years (NHC, 2015a). In the last 80 years, New England has seen five major hurricanes along the coast.

Although surge from nor'easters is somewhat less than that for hurricanes, the surge lasts longer and can damage shoreline structures and cause major erosion. The average storm surge from a nor'easter is about 2 feet and occurs over 12 hours to 3 days, whereas a hurricane storm surge only lasts about 6 to 12 hours (Zingarelli et al., 2013). The longer duration of the nor'easter surge allows the storm to be present during multiple tidal cycles (Storm Solutions, 2010). The highest recorded flood elevations from a nor'easter in New England was from the Blizzard of 1978 where water levels reached 20.76 feet NAVD88 at the Boston Harbor with waves offshore at about 30 feet (Zingarelli et al., 2013). Near the PNPS site, there were water levels of 20.3 feet NAVD88 at Pilgrim Sands on Long Beach and 13.4 feet NAVD88 at White Horse Beach in Manomet due to wave action (Figure 4; FEMA, 2012 Flood Insurance Study).

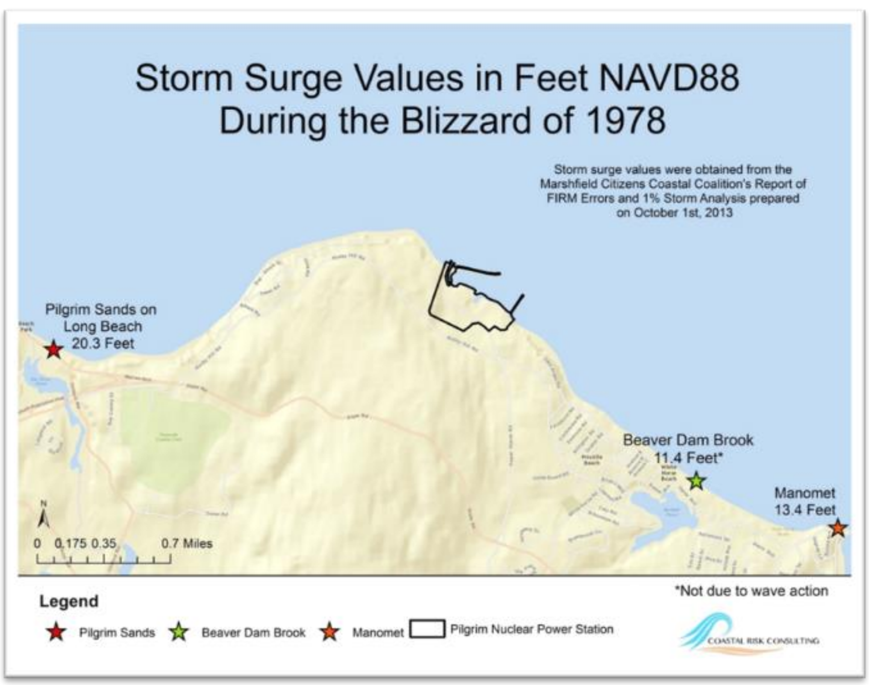

Figure 4. Areas near PNPS and their respective storm surge values from the Blizzard of 1978.

Although most nor'easters have sustained wind speeds below hurricane strength, it has been found that some nor'easters possess hurricane force wind speeds. These speeds typically do not last very long (less than 24 hours) during the lifetime of the storm. The hurricane force winds are found in a small area of the relatively large storm and are common during the rapid strengthening phase found in some nor'easters (OWS, 2015). For this reason, nor'easters provide significant threat to coastal installations such as PNPS and can compound ocean effects including producing significant surge and pounding surf from wave action.

Nor'easters have affected the PNPS area much more frequently than hurricanes, and as in the past, it is likely that at least one nor'easter will affect PNPS this winter (2015-2016).

Use of the NOAA Technical Report NWS 23 Parameters to create the Probable Maximum Hurricane (PMH) and Probable Maximum Wind Storm (PMWS) datasets

The creation and modeling of the hurricane and extratropical storm datasets seem to have sound methodology (AREVA Report, Section 3.4.2). Of concern is the use of the NOAA Technical Report NWS 23 due to its publication date (NOAA, 1979). Using meteorological parameters that follow this report raises red flags, as our climate has changed since 1979. In its report, AREVA does state limitations of the NWS 23 parameters indicating that the values would cause "overly conservative intensity recommendations for west-of-north tracking storms." Due to these limitations, AREVA conducted an in-depth, site-specific meteorology study to determine the hurricane parameters for analysis of storm surge.

It is not clear whether AREVA continues to only use parameters from the NOAA Technical Report NWS 23 report in their analysis of the PMH and the PMWS. This report would have benefited by including more of the PMWS details on data creation and model analysis of the surge produced by a PMWS instead of a PMH.

RECOMMENDATION: The analysis should include more recent methodologies on both nor'easters and tropical cyclones. The site-specific meteorology study for the creation of the PMH should use information and methodology produced in Villarini et al. 2012. In this paper, the HURDAT database is also used, but the authors corrected for storms prior to 1944 as well as modeled the frequencies of storms alongside different climate indexes. It is unclear if AREVA used the data in the HURDAT database prior to 1944. If it was used, it is also unclear if AREVA included any type of correction to the data from before 1944, or if it was just used alongside the synthetic hurricane dataset. A more recent scientific study on nor'easter climatology was conducted by the Northeast Regional Climate Center at Cornell University, which defines a nor'easter by specific meteorological requirements and parameters (Hirsch et al., 2000). This

paper and its parameters for nor'easters would provide a much more robust analysis for the site-specific meteorological study of the PMWS that was then used by AREVA in the modeling of surge.

Sea level rise was not accounted for properly in the storm surge analysis

To create the PMSS for PNPS, AREVA followed a three-step methodology. An antecedent water level was calculated to consider sea level rise, the SLOSH sensitivity analysis was performed, and lastly the results from the sensitivity analysis was put through finer testing in ADCIRC and ADCIRC+SWAN for both the PMH and PMWS storm surge.

The antecedent water level was created using monthly maximum tide gauge data over a 21-year period from the Boston, Massachusetts NOAA tidal gauge station, to obtain a 10 percent exceedance high tide. The sea level rise value for a 50-year period was then added to the antecedent water level. The value was determined by the observed rates at the Boston tidal gauge station. Table 1 summarizes the results of the storm surge from a PMWS and PMH with the sea level rise value added to the tide in feet NAVD88.

Table 1. Summary of storm surge results for both PMH and PMWS in feet NAVD88. (Source: AREVA Report, Section 3.4.3)

Tide Value	Sea Level Rise	Antecedent Water Level	Max Still Water Elevation (PMH)	Max Still Water Elevation (PMWS)
7.34 Ft	0.46 Ft	7.80 Ft	14.9 Ft	14.0 Ft

The methodology AREVA used to determine sea level rise at PNPS raises red flags in terms of current sea level rise projections. According to Table 1 the level used is 0.46 feet NAVD88 over 50 years. This is a significant underestimation of current projections for sea level rise at the PNPS area over the next 50 years. Table 2 depicts the sea level rise projections from the United States Army Corps of Engineers (USACE) and from NOAA out to 2100. It is evident that 0.46 feet is extremely low considering USACE has a value of 2.31 feet and NOAA has a value of 3.05 feet in 2065. This discrepancy in the sea level rise value must be addressed for modeling surge impacts at PNPS.

Table 2. Sea level rise projections from USACE and NOAA in feet NAVD88. High indicates worst case projections and the red outline points out the projections for 50 years. (Source: USACE, 2014)		
Year	**USACE High**	**NOAA High**
2015	0.10	0.17
2025	0.39	0.54
2035	0.76	1.02
2045	1.20	1.59
2055	1.72	2.27
2065	2.31	3.05
2075	2.97	3.94
2085	3.71	4.92
2095	4.52	6.01
2100	4.96	6.59

RECOMMENDATION: Sea level rise values should be based on nationally accepted and established estimates (i.e., NOAA, USACE).

Storm surge analysis for the Probable Maximum Hurricane (PMH)

Storm surge is a very complex phenomenon caused by the buildup of water on the coast due to winds from low pressure systems. There are many factors that affect storm surge in coastal areas. Those factors are storm intensity, forward speed of the storm, radius of maximum winds, angle to which the storm hits land, coastal characteristics and the bathymetry--depth of ocean--of the coast (NHC, 2015b). The slope of the continental shelf--how rapid the transition between the deep and shallow waters--off of the coast of Massachusetts is very shallow (Figure 5). This allows for a higher surge than if the shelf dropped off quickly (NOAA, 2015b).

The AREVA Report analyzes storm intensity, forward speed, radius of maximum winds and the angle to which the storm hits land in a SLOSH PMH parameter sensitivity assessment. It was found that the surge increased in height as the radius of maximum wind in the hurricane increased (see AREVA Report, Figure 3-24, p. 76). The NHC tested this by using the SLOSH model and Hurricane Charley. Hurricane Charley was a very small (small radius of maximum

winds), but strong storm. When the NHC modeled Charley with an increase in the radius of maximum winds, the surge increased (Masters, 2015a).

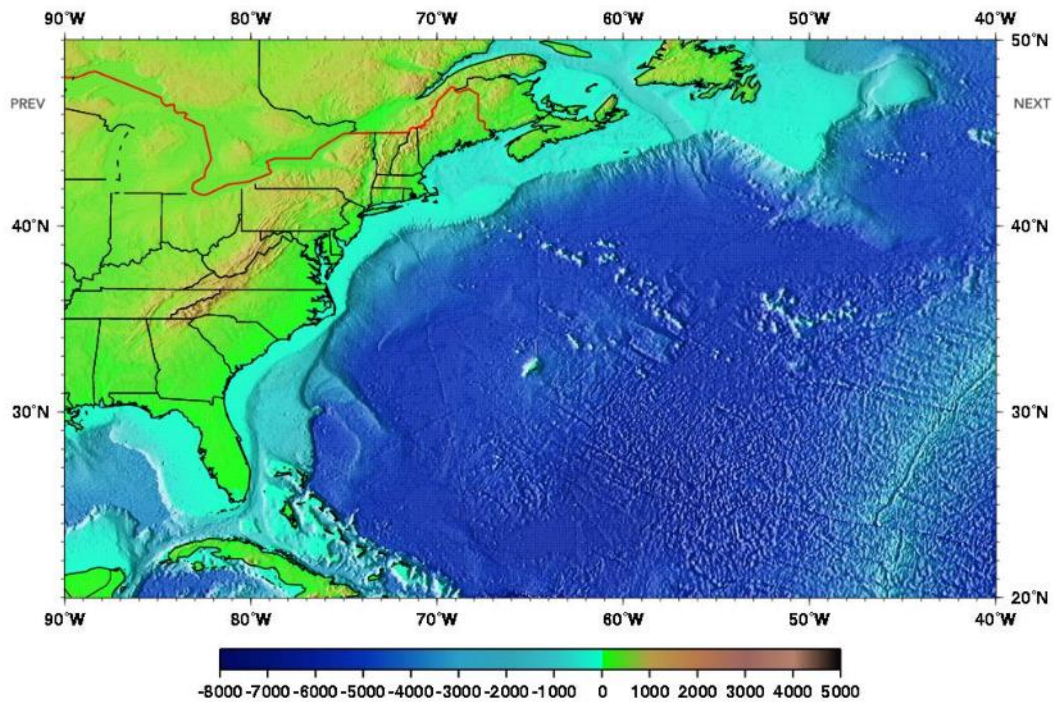

Figure 5. Bathymetry of the Gulf Stream. Lighter blue colors indicate deeper waters. (Source: Mariano and Ryan, 2015)

Another finding from the SLOSH analysis was that the faster a hurricane traveled (forward speed) the lower the surge at PNPS for most storm bearings (see AREVA Report, Figure 3-26, p. 78). In general a fast moving storm will create a greater surge for an open coast and little surge in bays, whereas a slow moving storm will cause greater surge in bays (Masters, 2015b).

An important finding from the SLOSH sensitivity analysis is that surge is affected by the angle to which the storm hits land. A storm may hit the coast from a certain direction and cause flooding in one area, but a small change in direction can cause little to no flooding in the same area and flooding in another (Masters, 2015b). A storm that makes landfall perpendicular to the coast will have a higher storm surge than a storm that makes landfall at an angle or travels parallel to the coast (NHC, 2015b). This makes it possible that, due to atmospheric flow influencing the storm bearing, coastal characteristics and all of the information presented above affecting storm surge, a storm will produce surge that will not breach the PNPS site but produce significant surge heights in other areas of Cape Cod and/or Plymouth. However, it is also possible that a storm could produce significant surge heights at PNPS and little to no flooding in other areas.

RECOMMENDATION: CRC recommends that a more site specific modeling is necessary to evaluate local storm surge heights at PNPS.

Erosion; Channel Migration or Diversion (AREVA Report, Section 3.8)

The AREVA Report addressed erosion briefly in Section 3.8, Channel Migration or Diversion. Based on a Federal Emergency Management Agency (FEMA) study, as well as a comparison of U.S. Geological Survey (USGS) topographic maps from 1977 and 2012, erosion rates were determined to be minimal in the vicinity of the PNPS site (O'Connell, 1999; USGS, 1977 and 2012). Still, an additional site assessment was conducted because Cape Cod Bay is prone to erosion.

This site assessment concluded that the shoreline protection system at the plant consisting of breakwaters, jetties and revetments provide limited potential for erosion of Cape Cod Bay shoreline at the PNPS site. Recognizing the importance of the functioning of the breakwaters to back up this claim, PNPS has committed to the NRC to monitor the breakwaters on an annual basis and after major storms to ensure their integrity (BEC, 1993; PNPS, 2013).

CRC Analysis of Erosion Impact

Erosion of the shoreline at PNPS was largely left out of the flood hazard modeling in the AREVA Report due to the conclusion that historical erosion at the site is minimal and the current shoreline protection system limits the potential for increased erosion. However, this conclusion is based on an outdated study and does not consider future conditions. Updated shoreline change rates and analyses were published after the release of the 1999 report cited by AREVA in Section 3.8. These updated data should have been used in place of the 1999 data (Thieler et al., 2013).

While the exact effect of sea level rise on local erosion rates is still unknown, it is expected that erosion rates will increase. When sea level rise is combined with a major storm, erosion rates for that event have the potential to increase significantly. In particular, it has been shown that severe nor'easters have tremendous erosion potential that is more dependent on storm tide than wave energy and duration (Zhang, 2001; USGS, 2015). Erosion at the rocky shorelines surrounding PNPS may not be the same as nearby open-coast sandy beaches. However, this is no reason to ignore erosional risk, especially considering extreme storm conditions are exacerbated by sea level rise.

Erosional forces are weakened by the coastal protection structures present at PNPS, such as the riprap and jetties. However, gaps in the protected shoreline are vulnerable to erosion such as the shoreline south of the barge ramp/boat landing. This unprotected section of shoreline is known to contain important features that are vital to the safety of PNPS, such as access for an emergency cooling pump and an adjacent storage site for low-level radioactive waste. Additionally, gaps in the protected shoreline can undermine the integrity of the entire coastal protection system in the case of an extreme storm event (JRWA, 2015).

In a standard vulnerability assessment, it is practice to first assess the natural vulnerability of an area without accounting for any man-made coastal protection structures. The reasoning behind such an analysis is that it is somewhat unreasonable to make the assumption that those structures will continue to exist and function to their full capacity through their entire lifetime. Furthermore, it is unrealistic to assume that these protection structures will not fail during an extreme storm event, as they have previously (1978, 1979); therefore, knowledge of the erosion potential if these protection structures are not functioning to their full capacity is essential.

RECOMMENDATION: CRC suggests that erosion hazards be evaluated without the presence of the coastal protection structures and that erosion potential is included in the coastal flood hazard impacts, such as storm surge and wave impacts.

Combined Effect Flood (AREVA Report, Section 3.9)

Section 3.9 evaluates flooding caused by combined events at PNPS. The AREVA Report addresses the impacts of PMSS and wave effects associated with the PMH and PMWS. THE NRC NUREG/CR-7046 document (NRC, 2011) provides five combined event scenarios. From these five scenarios, the AREVA Report only considers the H.3 scenario and determines that the other four scenarios are not applicable to PNPS. The H.3 scenario addresses floods along shores of open and semi-enclosed bodies of water and considers the combination of: probable maximum surge and seiche with wind and wave activity and an antecedent 10 percent exceedance high tide.

The methodologies used to evaluate the H.3 scenario include the following:

1. The review of USACE Wave Information Studies (WIS) stations 63057, 63060, 63061 (see Appendix B, Figure B1) for comparison to simulated offshore, deep water wave heights and periods,

2. use of ADvanced CIRCulation (ADCIRC) model coupled with Delft University's Simulation Waves Nearshore (SWAN) model 41.01 to develop the deep water waves during Probable Maximum Storm Surge,
3. use of the SWAN model and development of a local SWAN grid to develop nearshore and shallow-water waves near PNPS, and
4. use of SWAN model output reflecting wave effects for PMH and PMSS and the use of FEMA and ASCE-7 methodology to address wind-wave effects that include run-up.

The outcome for potential shore-side location on semi-enclosed water-body combined event resulted in historical storms producing wave heights that range from 23.7 to 29.1 feet for peak periods of 12.6 to 17.1 seconds, based on the top 10 wave events reported at the three stations of USACE's WIS project. The report determines that these stations are good indicators of deep-water wave conditions because they are in deeper water compared to the SWAN output points.

Offshore wave results from the coupling of the ADCIRC and SWAN model produced a deep water wave height from 18.4 to 29.7 feet with a height range from 9.9 to 15.7 seconds for peak PMH. For peak PMWS, the significant deepwater wave height varies from 16.8 to 34.5 feet with a wave height range from 11.5 to 16.4 seconds across seventeen boundary output locations. When compared to historical wave height, it produced an output that was 21.9 feet higher than the maximum WIS historical data.

Near-shore wave results simulated by the SWAN model produced a PMH and PMWS for 9 locations that are representative of important locations and structures at PNPS. For PMH, wave heights ranged from 0.9 to 7.3 feet with periods ranging from 1.8 to 9.6 seconds. For PMWS, wave height ranged from 0.6 to 7.1 feet and up to 12.7 seconds.

These results are based on the following wave effects: peak significant wave height, peak wave period and wave crest elevations of peak significant waves for the nine important locations along the PNPS coastal area.

When analyzing standing wave height at vertical structures, wave effects were calculated using the Sainflou formula for fully head-on non-breaking waves at the PNPS Intake Structure headwall. The maximum wave height calculated at the intake headwall compared to the maximum wave crest elevation may result in "infrequent run-up wedge" overtopping the intake head wall. They also considered wave run-up onto a plateau above a low bluff—that is, the site proper, or "yard area."

The AREVA Report found that the combined events water elevation for PNPS is determined to be 21.8 feet NAVD88. This water level would result in flooding the shoreline area of the site by

almost two feet due to the overtopping flow from wave action. The maximum combined flood events at the Intake structure is 19.5 feet NAVD88. AREVA concluded that PNPS will be subject to hydrostatic, hydrodynamic and wave loads.

CRC Analysis of Combined Effect Flood

The main drawback for the Combined Effect Flood section relates to the limitations of the term "combined." Of the five combined event scenarios provided in NUREG/CR-7046, Appendix H (NRC, 2011), only one is deemed appropriate for PNPS. This cuts off a wide range of possibilities for analysis with the available tools.

In addition to storm surge, high tide, and wave setup, there are many other factors and mechanisms which dramatically compound flooding. In particular, intense frequency, duration, and intensity of rain events will significantly exacerbate the combined flooding scenarios. The various combinations of simultaneously occurring events will likely lead to severe impacts including compromised drainage, erosion, and structural damage from wave energy. In these cases, it is essential to consider the range of threats that can synergize to a disastrous worst case scenario. This is not the case with the AREVA Report, in which the impacts are either downplayed or not mentioned at all. The Combined Effect Flood section lacks explanations on why less extreme estimates were used in most cases, for example with the maximum waves, breaking waves, and structure loading. In the Structure Loading and Associated Effects section (3.9.2.1.8), there are slight references to erosion and groundwater, but these are not considered in any way. There is a mention of limited tidal influence on the groundwater table, but current data show otherwise, as discussed in the groundwater section.

Section 3.9.2.1.3 of the AREVA Report states, "Large deep-water waves break along the breakwaters before reaching the site. Shoreward structures are well beyond the breakwater structure and are therefore protected from the larger offshore waves." The text does not provide evidence to support this claim, and in contrast, the LiDAR elevations of the breakwater structure elevations show that they are at a maximum height of 10.9 feet NAVD88 and the partial revetment is 19.9 feet NAVD88. While this height will likely dampen wave energy, it is not rational to assume that this will offer full protection from the force of significant wave action with waves that overtop these structures.

Section 3.9.2.1.4 states, "Because simulated wave conditions generated by the PMWS are equal or less than those generated by the PMH, and because the maximum water surface elevation of [15 feet NAVD88 resulting from the PMWS is approximately 0.6 feet lower than the maximum water surface elevation of 15.6 feet NAVD88][1] resulting from the PMH, the PMH was

[1] Note: CRC has provided conversion from MSL to NAVD88.

determined to be the controlling storm event for combined effects flooding. Therefore, wave effects were calculated based on the PMSS resulting from the PMH and wind-wave effect generated by the PMH. It is noted that while the wave effects generated by the PMWS are not greater than those generated by the PMH, the duration of high intensity wave action ranges from 50 to 60 hours for the PMWS compared to the 10 to 15 hours from the PMH."

These incident wave characteristics do not consider the dynamics by which the steady buildup of surge over several days can combine with intense rain, ice, and or snow, to compromise the safety of the structures, particularly those that are located at lower elevations.

In Section 3.9.2.1.6, the AREVA Report explains, "Wave runup in the yard area at PNPS was determined using empirical equations for runup on a rock armored slope (USACE, 2006)….Wave heights ranging from approximately 0.9 feet to 7.3 feet will occur for a duration of approximately ten to fifteen hours during the PMH controlling event." This statement has misconceptions related to focusing the impacts to wave runup onto a plateau above a low bluff. There is an implicit assumption that the entire slope is armored by solid rock, when in fact there is a large section of the shoreline south of the boat ramp that is not armored and has limited forms of protection. In addition, there are concerns that the revetment is not sturdy and may not withstand the hydrostatic loading levels that are realistic given the projected intensity of past, present, and future events. These kinds of assumptions are particularly dangerous when considering areas in which nuclear waste is being stored. The current coastal armoring is not adequate protection that provides certainty that accidents involving spent fuel or other hazardous substances will be fully avoided. Given the wave heights and the land elevation, it is conceivable that operational systems and structures will be compromised during extreme events.

Chen and Liu (2014) used an integrated storm surge and flood inundation modeling system to simulate compound flooding of storm surge events and high freshwater discharges from upriver. Results showed that storm surge events had dramatically increased damage when combined with freshwater discharges. Wahl et al. (2015) took this methodology in compound flooding analysis a step further by assessing the combination of storm surge events with intense precipitation. The joint occurrence leads to a complex interplay in which flood impacts are exacerbated for both inland and coastal areas. Figure 6 illustrates the results for Boston in which non-stationarity is correlated in the dependence between storm surge and precipitation for 50-year running windows (Wahl et al., 2015). The filled circles denote significant correlation (90% confidence) and grey shaded areas represent the range of natural variability (10% and 90% levels). Correlations have increased since 1970, indicating that historic observations are not sufficient for projecting future events. These results also emphasize the importance of assessing compound flooding in a manner that considers linkages to weather and climate.

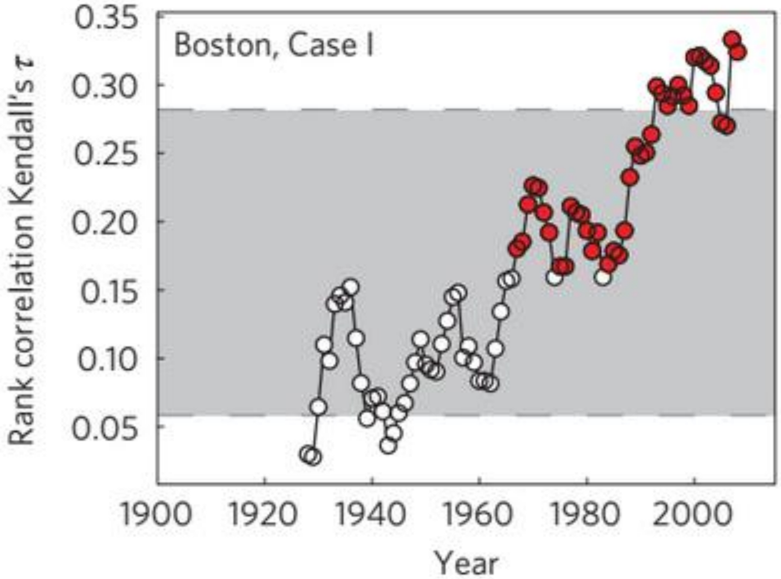

Figure 6. Results for Boston in which non-stationarity is correlated in the dependence between storm surge and precipitation for 50-year running windows. (Source: Wahl et al., 2015)

Section 3.9.2.1.7, Combined Events Water Elevations at PNPS, states, "The maximum combined events water surface elevation at PNPS was determined to be [21.8 feet NAVD88][2] due to runup from a fully head-on wave on the revetment slightly east of the reactor building portion of the plant. This results in shallow flooding of the shoreline area of the site due to overtopping flow from wave action at the revetment."

This is yet another example of how the report downplays the dire potential impacts that result from the breaching of revetment. In addition, if the revetment is damaged in one storm, there is a likelihood of a time-lag that prevents repair of the revetment before the next significant event. The AREVA Report does not look at these kinds of considerations because it is following the guidelines of the NRC. However, these guidelines are generalized and do not allow for realistic timeframes for updates and reaction times to address damage and to repair coastal armoring.

RECOMMENDATION: CRC strongly recommends that a subsequent analysis use methods similar to those used in the references cited above.

[2] Note: CRC has provided conversion from MSL to NAVD88.

Groundwater

The AREVA Report did not include an analysis of groundwater elevations as part of the flood risk assessment at PNPS. Section 3.9.2.1.8 comes to the conclusion that "the effects of storm surge on groundwater elevations are expected to be limited to those areas currently observing tidal influence on groundwater elevations."

CRC Analysis of Groundwater Impact

Omission of an analysis of local groundwater levels at PNPS precludes the ability to accurately assess flood risk at PNPS. Groundwater plays an important role in the magnitude and frequency of flood events because changing groundwater levels (along with land cover and soil type) control how much water the ground can hold during both storm events and chronic flooding due to sea-level rise. As PNPS moves to decommissioning and site cleanup, understanding the impacts from rising groundwater will become more critical.

Pilgrim is sited above the Plymouth-Carver Aquifer (PCA; EPA, 2014). The PCA is the second largest aquifer in Massachusetts and comprised of course-grained soil, sand and gravel glacial outwash deposits (EEEA, 2007). The PCA is bordered by marine waters from the northeast to the southeast (EPA, 1990). The groundwater table in an unconfined aquifer located in a coastal zone, like the PCA, oscillates with the ocean surface because of tidal fluctuations. As sea levels rise, groundwater levels will also rise, which will reduce storage capacity in some areas (Figure 7; Rotzoll and Fletcher, 2013). This positive feedback between the groundwater table elevation and mean sea level occurs because rising sea levels increase the pressure head near the coastline. This mechanism results in the groundwater table lifting by a similar magnitude as the increase in sea level (Romah, 2012). This one-to-one ratio of the groundwater table rising analogously with sea-level rise will lead to a dramatically shallower depth to groundwater below the land in some areas. The reduced soil storage capacity will lead to increased saturated land not only during storm events, but also during high tide (i.e., nuisance flooding).

Availability for accessing groundwater conditions at or near PNPS includes multiple publicly available datasets. USGS manages a network of groundwater wells and provides historical and current records of groundwater levels. However, the closest USGS wells are 6.5 miles away (Myles Standish State Forest) and 8 miles away (Plymouth Airport; USGS 2015). The U.S. Department of Agriculture's Soil Survey Geographic Database (SSURGO) also provides data on minimum water table depth based on soil storage capacity; however data are only available for locations surrounding Pilgrim (USDA, 2015). There are no data from this source for PNPS itself because SSURGO cannot gather data for impervious surfaces.

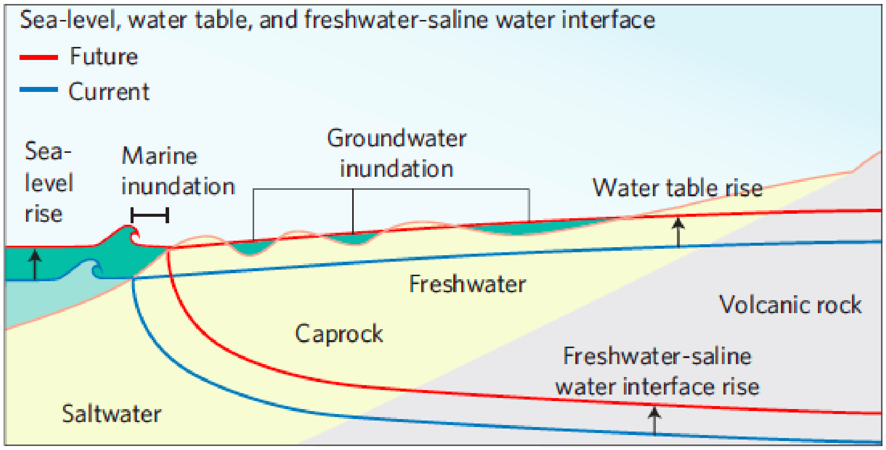

Figure 7. Conceptual diagram of groundwater inundation under sea level rise in a coastal aquifer. (Source: Rotzoll and Fletcher, 2013)

Another source of groundwater elevation data is from Environmental Resources Management's (ERM) Interim Tritium Investigation 2014 Report ("Logic Report"), which investigates tritium detections in groundwater at PNPS (ERM, 2014). The 2014 Logic Report documents results from 22 groundwater monitoring wells at PNPS (today there are 23 wells) as part of a groundwater monitoring program that started in 2007. The Logic Report includes a groundwater elevation analysis for a portion of PNPS's monitoring wells. Monitoring changes in groundwater elevations at PNPS is ongoing and will be documented in future updates to the Logic Report.

Depth to the water table at PNPS varies depending on the specific onsite location as well as throughout time due to the local tidal regime and precipitation or drought events that can recharge or deplete the aquifer, respectively (ERM, 2014). The groundwater elevations obtained in September 2012 are presented in Figure 8 and range in depth from approximately 2 to 14 feet below ground surface. Higher groundwater elevations are found west and south of the Power Block, whereas lower groundwater elevations exist along the station boundary with the Cape Cod Bay (ERM, 2014). Figure 9 depicts ERM's conceptual site model for groundwater elevations and contours on the PNPS site.

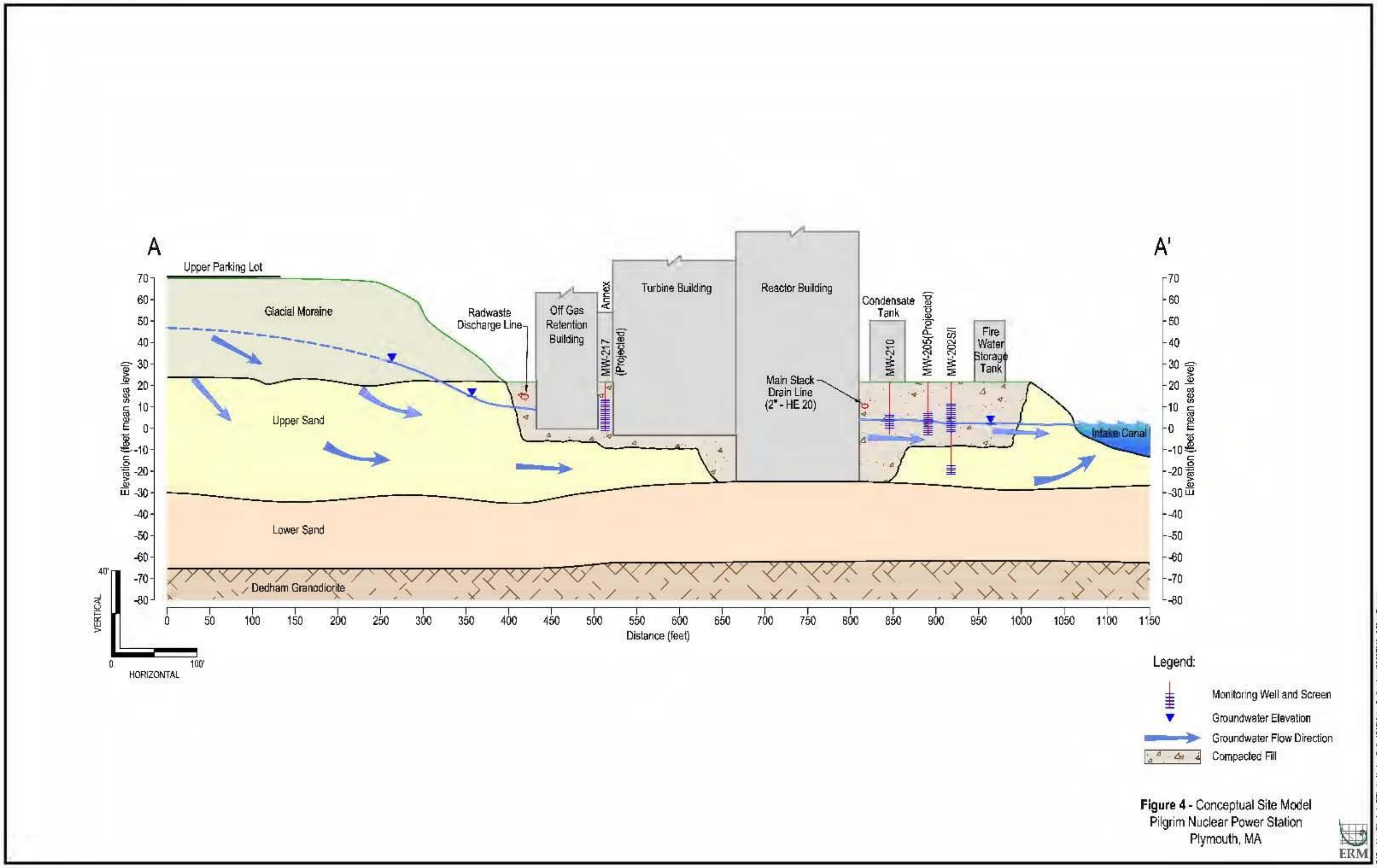

Figure 8. Conceptual PNPS site model of groundwater elevations and flow. (Source: ERM Logic Report, 2014)

Figure 9. Conceptual PNPS site model showing groundwater elevations and contours. (Source: ERM Logic Report, 2014)

Since groundwater elevations impact the capacity of the ground to absorb rain or flood water, changing levels may impact site-wide flooding. Understanding that flood proofing was a part of site construction more than 40 years ago is not proof that time, salt, and elements have not compromised that protection. While existing flood proofing may be able to withstand freshwater, assuming that protection is still in good condition, buried and underground piping and tanks might be vulnerable to saltwater corrosion as saltwater intrusion increases the salinity of the groundwater.

RECOMMENDATION: The AREVA Report should include an analysis of the potential for future groundwater changes in the evaluation of flood risk at PNPS. This type of analysis is important because, depending on the characteristics of the coastal aquifer and local topography, low-lying elevations might be expected to flood as a result of elevated groundwater levels in addition to sea level rise. Groundwater levels at the PNPS site will likely increase with an increase in tide level, with storm surge, and with the increase in precipitation expected with climate change in the northeastern Unites States.

In order to determine if the effects of storms and sea level rise would be limited only to those areas currently observing tidal influence on groundwater elevations, as indicated in the AREVA Report, it is necessary to analyze groundwater conditions at PNPS using the best available data. Current groundwater depths below PNPS are relatively shallow (ERM, 2014; Masterson and Walter, 2009; USDA, 2015) and could become increasingly shallower under future climate scenarios. CRC recommends that a thorough analysis of groundwater, as related to flood risk due to storms and sea level rise be included in the LIP flood hazard analysis, to achieve a better estimate of current and future flood risk.

Subsidence

Subsidence is not mentioned in the AREVA Report but is implicitly included in the 50-year sea level rise of 0.46 feet since that value is derived from historic Boston tide gauge trends.

CRC Analysis of Subsidence Impact

A major limitation in the study conducted by AREVA was the assumption that elevation will remain constant throughout the lifetime of PNPS. Subsidence is an example of an already observed phenomenon that would affect elevation at the PNPS and could increase flood risk in the future and is exacerbated by human activities such as groundwater pumping. Subsidence has been observed in coastal Massachusetts. For example, local vertical land motion at the Boston tide gauge is -0.85 mm/year, -0.97 mm/year at Woods Hole, and -1.16 at Nantucket

Island (Zervas et al., 2013). Coarse estimates for subsidence are included in many sea level rise projections, including those produced by USACE. However, it is clear that no analysis on localized subsidence at PNPS has been included in the AREVA Report.

RECOMMENDATION: CRC suggests that regional land motion be taken into account when examining flood risks at PNPS. There are several techniques that can be used to evaluate land movement at the site, such as extracting vertical land motion from a local tide gauge (i.e., Plymouth). However, lack of long-term, publicly-available tidal data at this site is an issue. Another more intensive option is the use of satellite measurements or GPS to obtain a higher resolution view of land movement on the site, such as using Synthetic Aperture Radar measurements of land displacement like those used to measure natural and anthropogenic subsidence in Venice, Italy (Tosi et al., 2013).

Conclusion

The goal of this report was to thoroughly critique the flood risk assessment done in the AREVA Flood Hazard Re-Evaluation Report for PNPS. Although the combined effects of high tide, storm surge and wave action can flood the landscape of PNPS under AREVA's modeling, as discussed in the above sections, many aspects of flood risk were understated or not considered in the AREVA Report. As a result, the current and future flood risk at PNPS is severely underestimated.

This analysis of the AREVA Report was prepared using the best available data, but performing a site survey or obtaining Entergy's 2014 survey would reveal further details.

It should be noted that while this report was prepared specifically for PNPS, many of these considerations apply more broadly to the NRC Flood Estimation Guidance Document (NUREG/CR-7046). When evaluating the flood risk of coastal power plants, it is essential that the all impacts of changing climate are taken into account. Modeling based solely on historical data no longer accurately represents reality.

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APPENDIX A

Task 3: Modeling assessment of future flooding potential for Pilgrim Nuclear Power Station

COASTAL RISK RAPID ASSESSMENT™

Future Potential Flooding and Storm Surge Analysis

Pilgrim Nuclear Power Station

Plymouth, MA

What is the Coastal Risk Rapid Assessment™?

Coastal Risk Consulting's Coastal Risk Rapid Assessment™ (CRRA) is a flood risk vulnerability assessment performed at the parcel level. This CRRA also includes the Initial Risk Categories, Flood Inundation Risk Score and Table™ (FIRST Score™), Parcel-Specific SLOSH model, and Airborne LiDAR High Resolution Elevation Map. This model has been adjusted for the purposes of evaluating future flood risk at Pilgrim Nuclear Power Station (PNPS) through the year 2085. The sections below outline the methods and purpose of each component of this section.

Initial Risk Categories

The Initial Risk Categories are a compilation of the climate-related, government-designated risk zones that the site currently lies within. The risk zones include: FEMA flood zones, wind zones, evacuation zones, Community Rating Score, Special Flood Hazard Areas, and the Coastal Construction Control Line where applicable.

FIRST Score™

The FIRST Score™ provides the total number of non-storm flood days the site is projected to experience over the next 30 years. A flood day is defined as days when the measured water level, enhanced by sea level rise, is greater than a threshold elevation of the site. For the assessment of PNPS the FIRST Score™ has been modeled out to 70 years (from 2015 to 2085) and is displayed using a table divided into 10-year increments to show the progression of risk over time. For PNPS, we have chosen a threshold elevation of 10 feet (NAVD88) to represent the average top elevation of the breakwaters, which ranges from approximately 9 to 11 feet (NAVD88), according to the LiDAR elevation data used in this analysis (USGS, 2013-2014).

Coastal Risk Rapid Assessment™

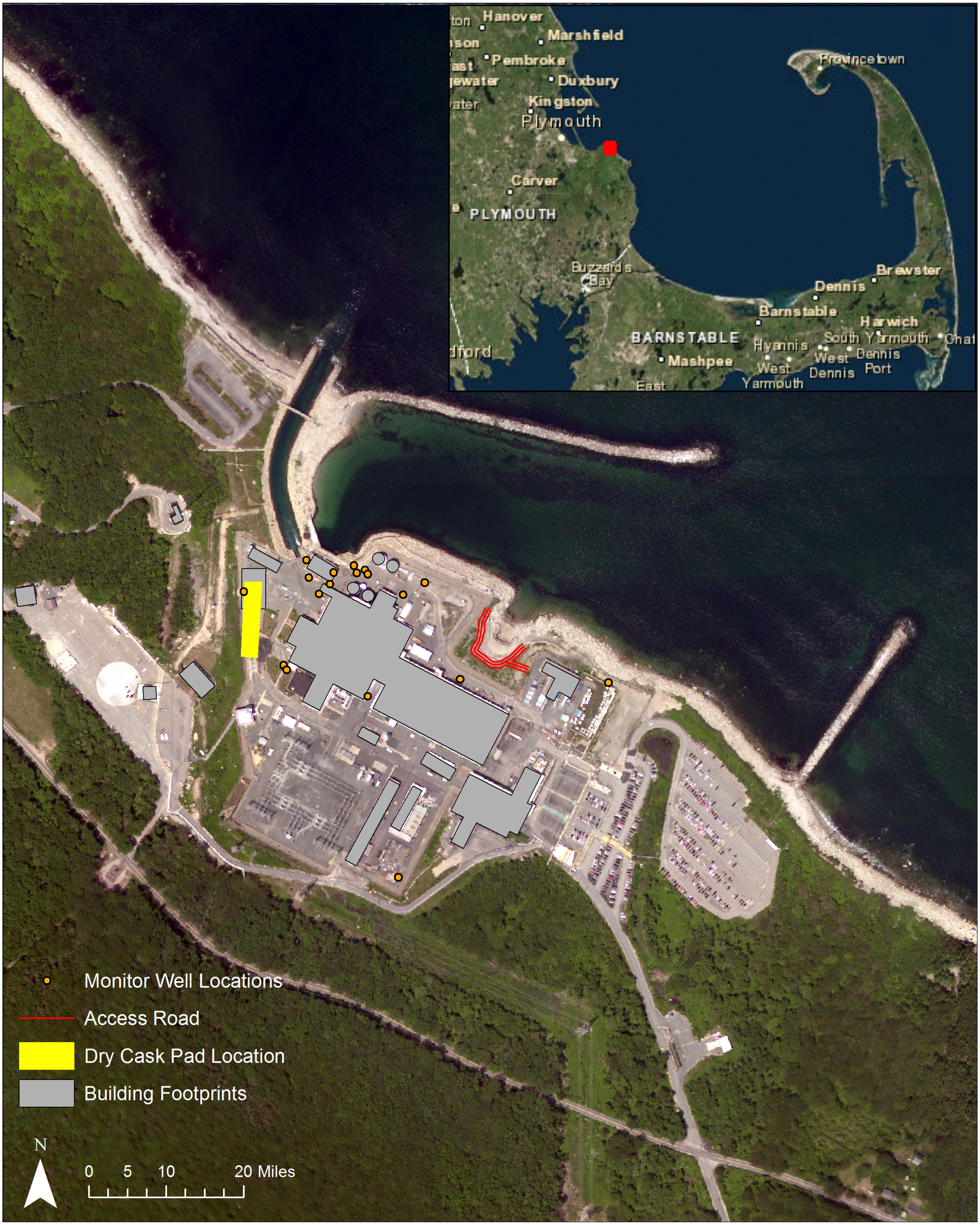
The CRRA focuses on the spatial extent of non-storm or nuisance flooding which is related to factors such as sea level rise, tidal forcing, groundwater depth, and local subsidence. The assessment consists of multiple maps which identify where flooding is projected to occur on the site. This CRRA prepared for PNPS includes 8 maps showing nuisance flooding out to 2085.

Parcel-Specific SLOSH Model

The CRRA maps showing nuisance flooding also have the option of including storm surge risk for the site as done by CRC's Parcel-Specific SLOSH Model. This model is an application of the Seas Lakes and Overland Surges from Hurricanes (SLOSH) model developed by NOAA. For the purposes of JRWA, this report models the maximum storm surge from a category 4 hurricane enhanced by sea level rise. A category 4 hurricane at high tide is modeled starting at 14.7 feet and with the addition of the NOAA high sea level rise projections, reach as high as 19.45 feet (NAVD88). A category 4 hurricane is used because no category 5 hurricanes have ever occurred in the New England region. Furthermore, this storm surge value is considered the maximum because no single storm will be able to cause this level of flooding since it is the Maximum of the Maximum Envelope of Waters (MOM) storm surge category (Masters, Storm Surge Inundation Maps for the U.S. Coast).

Airborne LiDAR High Resolution Elevation Map

The Airborne LiDAR High Resolution Elevation Map provides detailed elevation information for the extent of the site. This map provides the client with a visualization of the location of low-lying areas and helps give context to the results of the CRRA, FIRST and SLOSH models, assisting with evaluation, prioritization, and decision-making. The LiDAR data used in this report was flown in 2013-2014 by USGS to evaluate coastlines in Massachusetts, New Hampshire, and Rhode Island following Tropical Storm Sandy in 2012 (USGS, 2013-2014). This digital elevation model was acquired from NOAA digital coast and has a horizontal resolution of 2 feet and a vertical RMSE of 2 inches. All elevations are relative to NAVD88.



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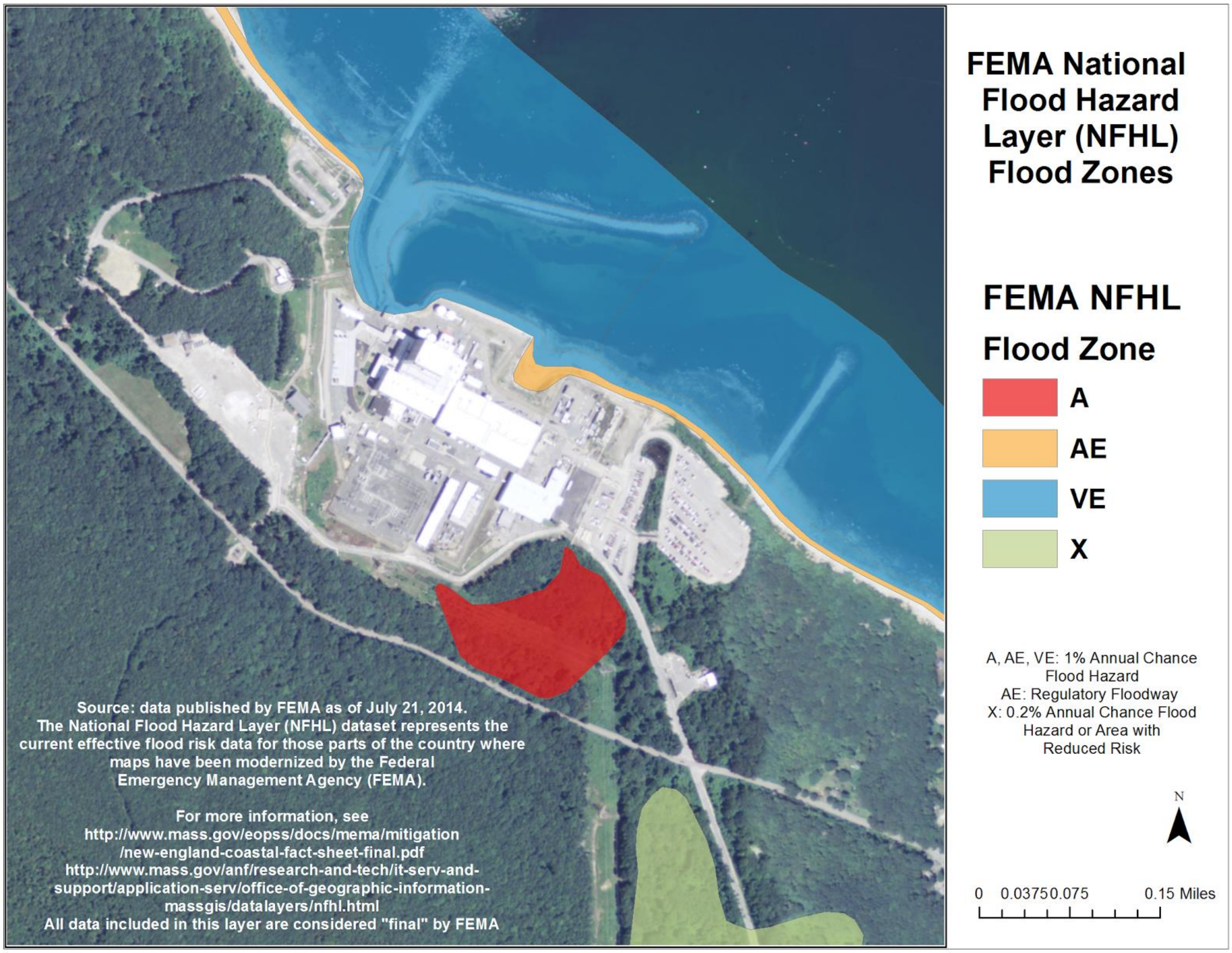
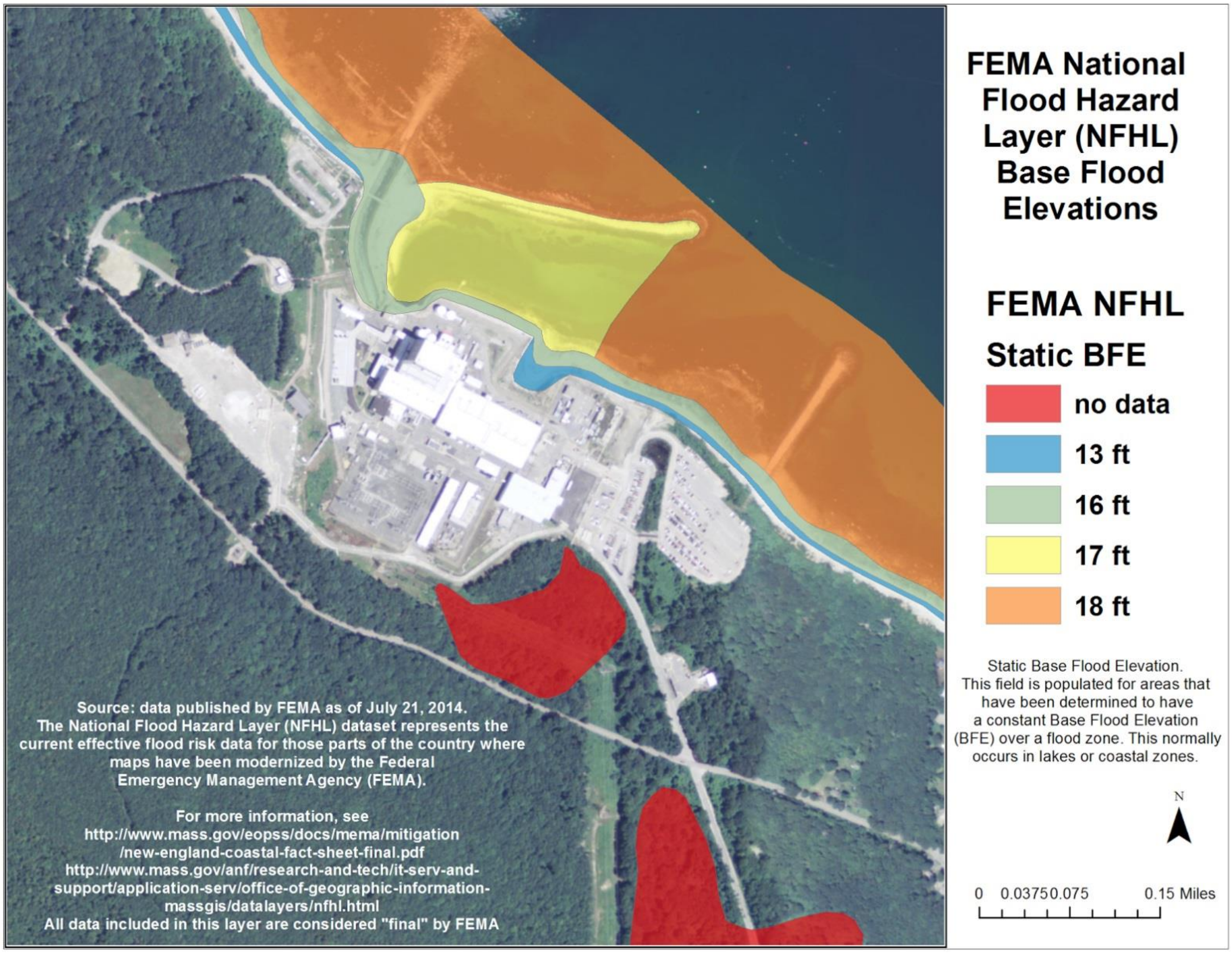
Initial Risk Categories

- **Flood Zones:** PNPS overlaps with flood zones A, AE, and VE. Zones AE and VE contain known base flood elevations calculated by FEMA and are shown in the maps below.

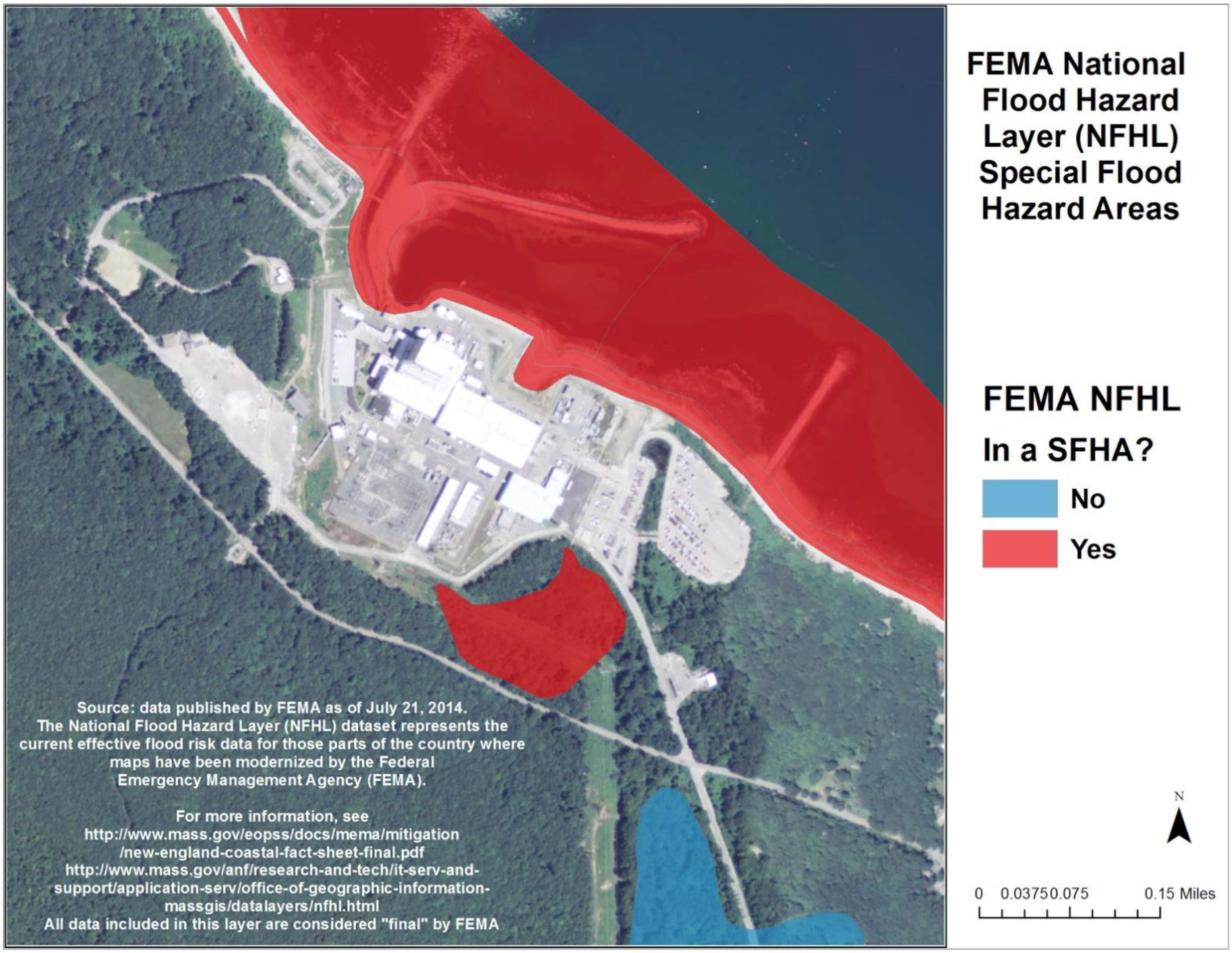




FEMA National Flood Hazard Layer (NFHL) Base Flood Elevations
FEMA NFHL
Static BFE
no data
13 ft
16 ft
17 ft
18 ft
Static Base Flood Elevation. This field is populated for areas that have been determined to have a constant Base Flood Elevation (BFE) over a flood zone. This normally occurs in lakes or coastal zones.
N
0 0.0375 0.075 0.15 Miles
Source: data published by FEMA as of July 21, 2014. The National Flood Hazard Layer (NFHL) dataset represents the current effective flood risk data for those parts of the country where maps have been modernized by the Federal Emergency Management Agency (FEMA).
For more information, see http://www.mass.gov/eopss/docs/mema/mitigation/new-england-coastal-fact-sheet-final.pdf http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/nfhl.html
All data included in this layer are considered "final" by FEMA

- **Wind Zone:** Zone II & Hurricane-Susceptible Region
    - Zone II buildings have to be able to withstand up to 160 mph winds.

- **Special Flood Hazard Area (SFHA):** Yes certain areas within PNPS are located within a SFHA as shown in the map below.



Flood Inundation Risk Score and Table (FIRST SCORE™)

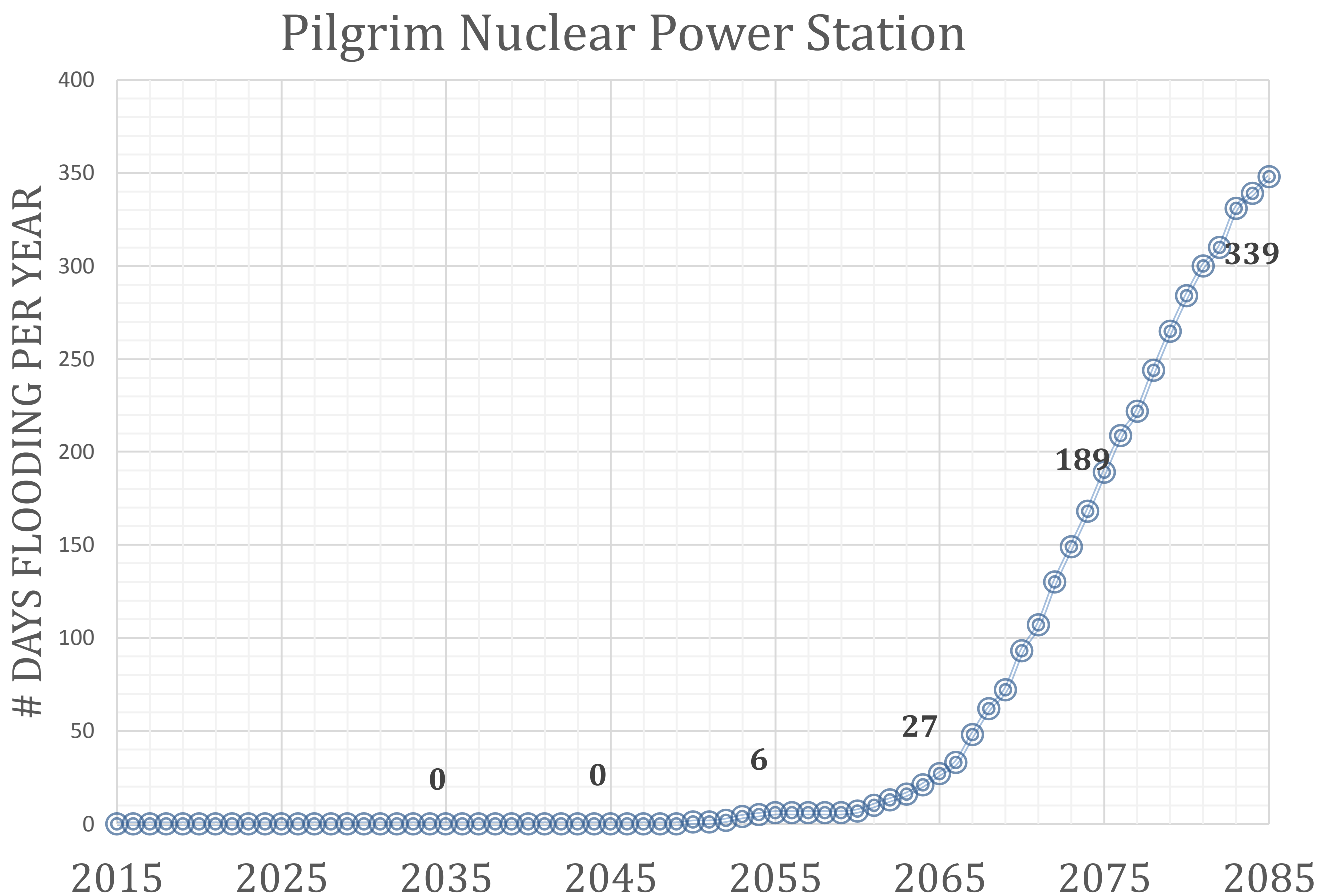
The FIRST Score™ is the total number of non-storm flood days the property will experience over the next 70-years. A flood day is defined as a day when the measured water level -- enhanced by sea level rise, is greater than a threshold ground elevation of the site. The following table shows the Cumulative FIRST Score™ divided into 10-year increments to show progression of risk over time.

Pilgrim Nuclear Power Station

Date Range	2015-2025	2026-2035	2036-2045	2046-2055	2056-2065	2066-2075	2076-2085
# Total Flood Days	0	0	0	19	118	1051	2852
Risk Meter							

Cumulative FIRST Score™ = 4040

Each year, the number of days with nuisance flooding increases, as shown in the graph below.

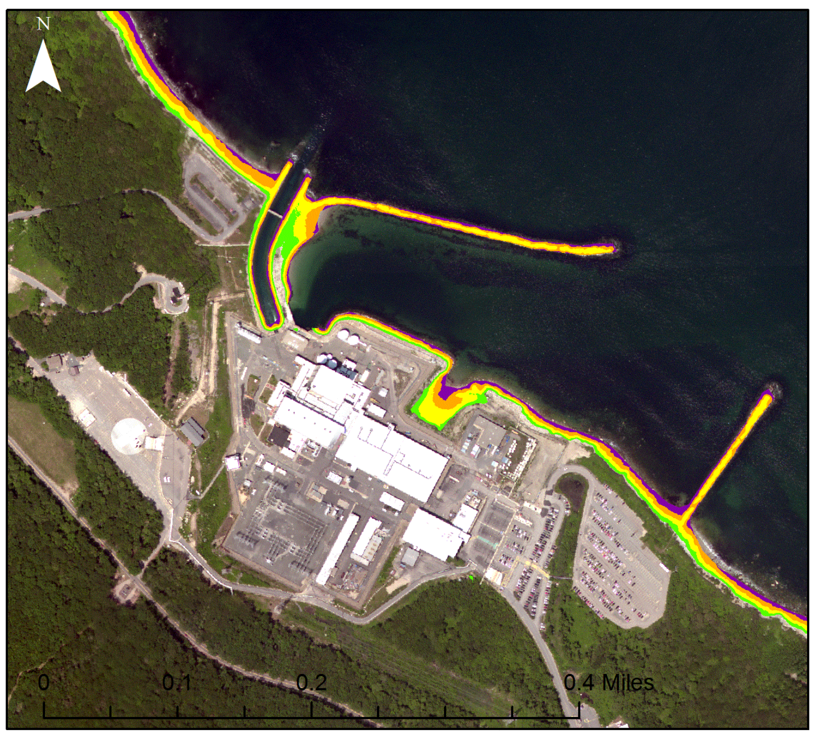


The FIRST Score™ is also correlated with the Coastal Risk Rapid Assessment™ (CRRA), which is shown as a series of maps on the next seven pages. These maps display non-storm flooding extent and maximum water depth every 10 years from 2015 to 2085. These maps also display the storm flooding extent and water depth of a category 4 hurricane. Each year the surge heights are enhanced with sea level rise, as projected by NOAA.

Coastal Risk Rapid Assessment™
Pilgrim Nuclear Power Station

Nuisance Flooding 2015

The property is at risk of limited to no days of non-storm flooding in 2015. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.



Category 4 hurricane storm surge: 2015

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

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Nuisance Flooding 2025

The property is at risk of limited to no days of non-storm flooding in 2025. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.

Category 4 hurricane storm surge: 2025

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

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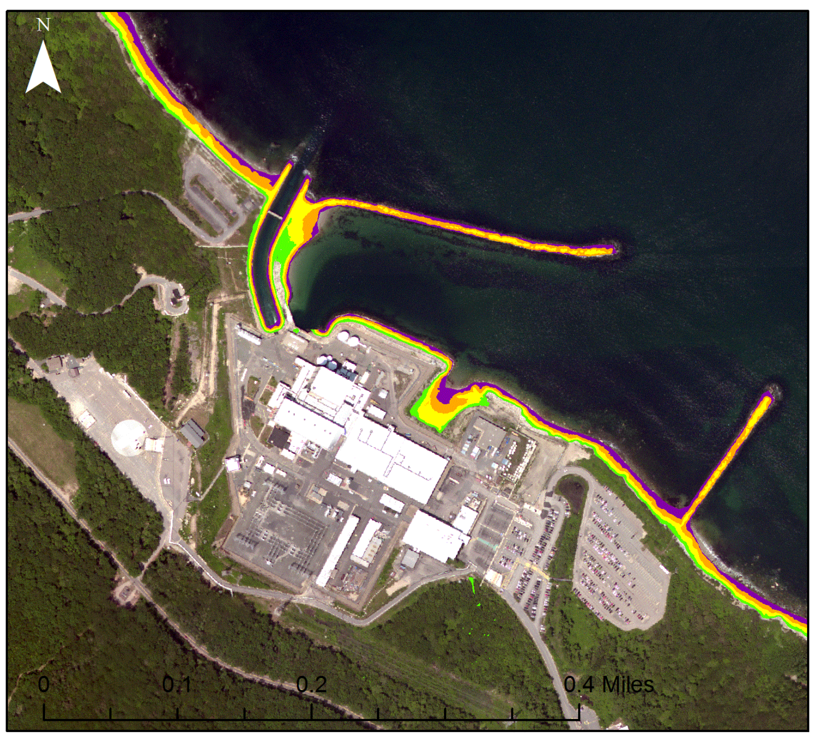
Nuisance Flooding 2035

The property is at risk of limited to no days of non-storm flooding in 2035. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.



Category 4 hurricane storm surge: 2035

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

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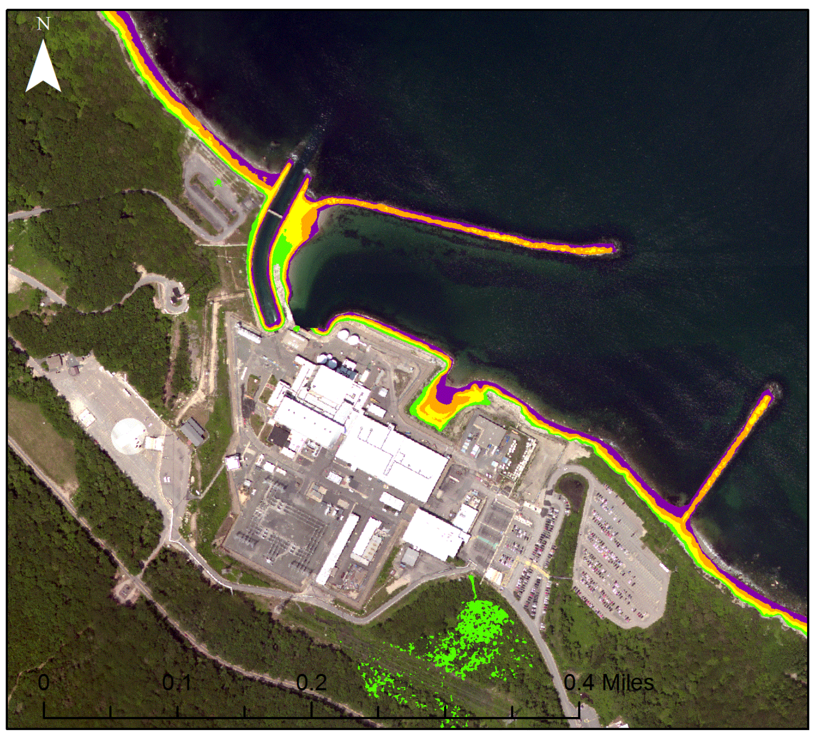
Nuisance Flooding 2045

The property is at risk of limited to no days of non-storm flooding in 2045. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.

Category 4 hurricane storm surge: 2045

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft



The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

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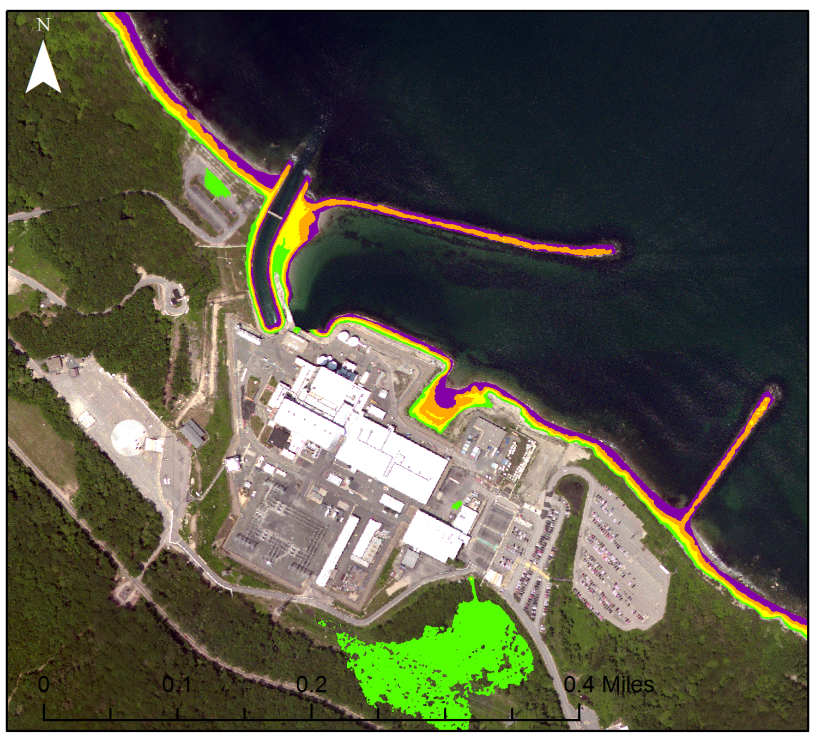
Nuisance Flooding 2055

The property is at risk of up to 6 days of non-storm flooding in 2055. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.



Category 4 hurricane storm surge: 2055

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

Coastal Risk Rapid Assessment™
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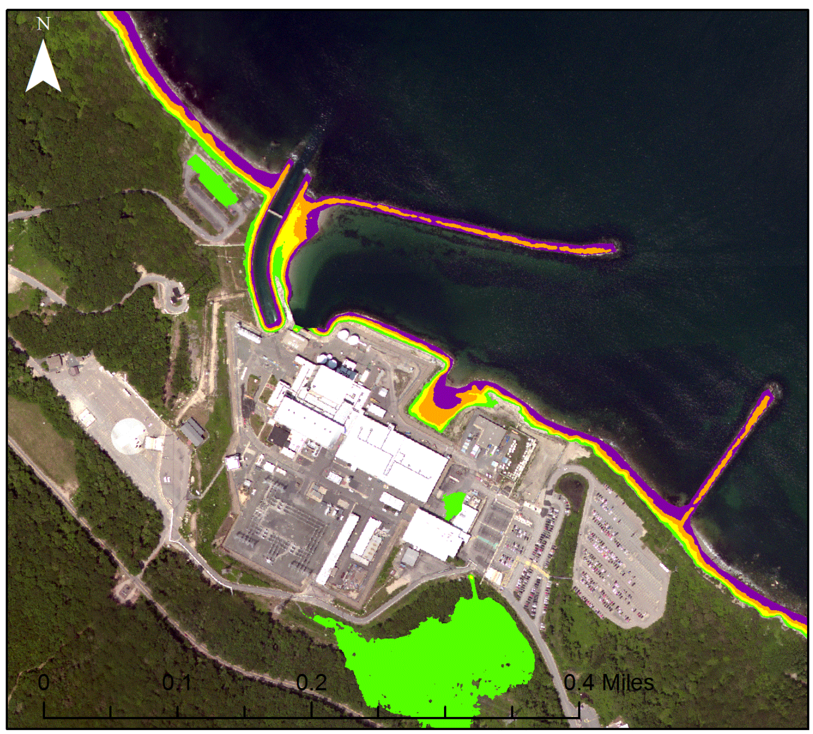
Nuisance Flooding 2065

The property is at risk of up to 27 days of non-storm flooding in 2065. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.



Category 4 hurricane storm surge: 2065

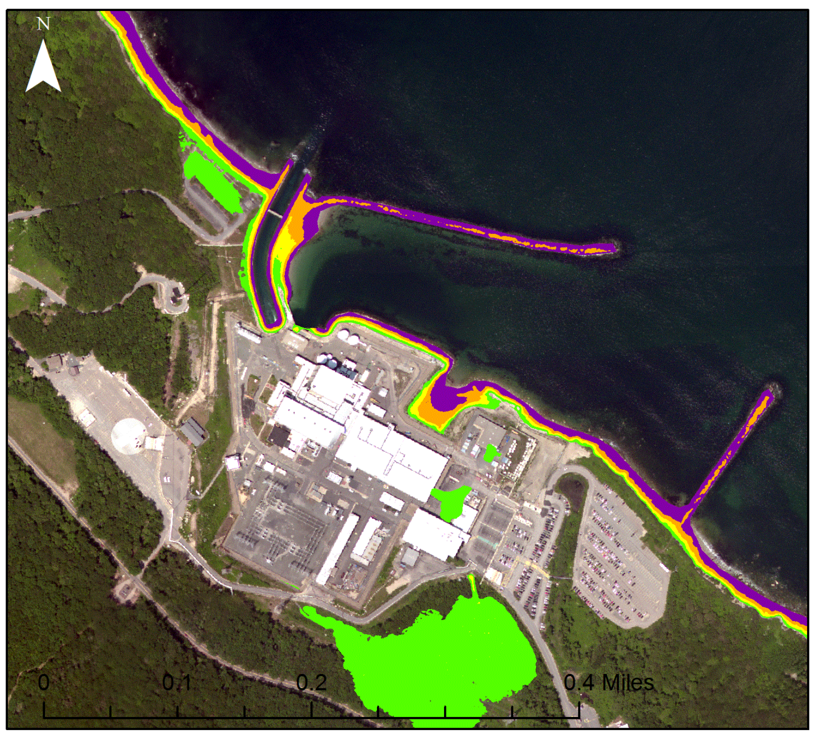
- **0.1 - 3 ft**
- **3 - 6 ft**
- **6 - 9 ft**
- **9 - 15 ft**

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

Coastal Risk Rapid Assessment™
Pilgrim Nuclear Power Station

Nuisance Flooding 2075

The property is at risk of up to 189 days of non-storm flooding in 2075. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.



Category 4 hurricane storm surge: 2075

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

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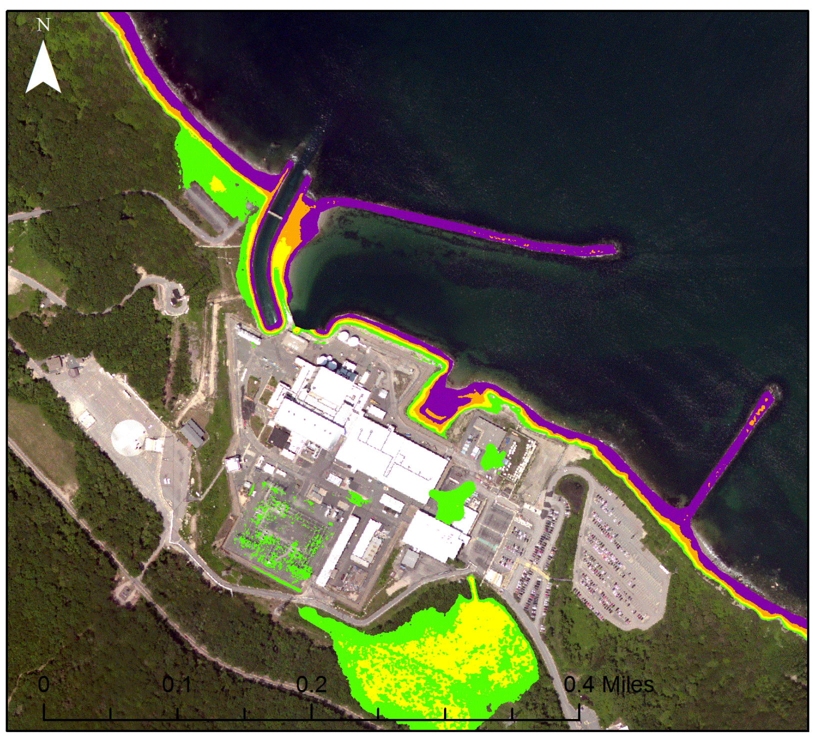
Nuisance Flooding 2085

The property is at risk of up to 348 days of non-storm flooding in 2085. The map on the right is a close-up look at the area surrounding the property. The upper left map is zoomed out to show extent, but not flood risk. The black outline shown on this map depicts the extent of the close-up map as a reference.

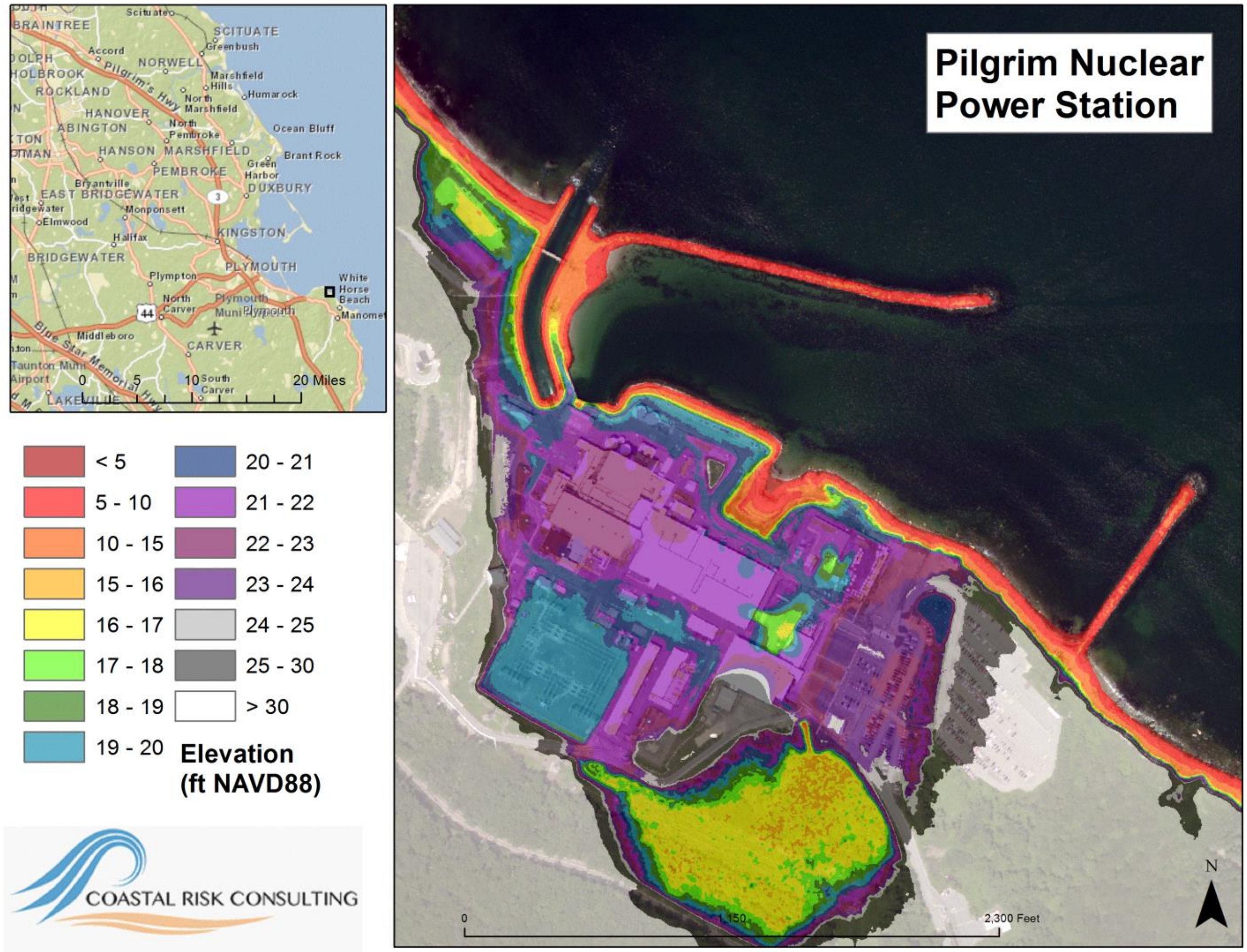


Category 4 hurricane storm surge: 2085

- 0.1 - 3 ft
- 3 - 6 ft
- 6 - 9 ft
- 9 - 15 ft

The map shows land vulnerable to flooding and from a category 4 hurricane surge at high tide. The different colors portray the depth of flooding in terms of water above land, as shown in the legend. Green shows up to 3ft of water, yellow is 3 to 6ft, orange is 6 to 9ft, and purple is up to 15 ft. No color is no impact from storm surge.

Elevation Map



The average ground elevation of the PNPS site is 22.7 feet NAVD88 and the elevation ranges from 0.73 feet to 71.15 feet NAVD88.

CRRA Conclusions

PNPS is located within 3 government-designated coastal, high-risk zones. However, these are not indicative of current resilince measures that may have been taken.

The **FIRST Score™** for PNPS is 4040 flood days for the next 70 years. The green indicates a very low score and therefore limited nuisance flooding initially; the yellow shows an increase in nuisnace flooding events from 2046-2055, the orange shows a further increase to a medium score, and by 2066 a threshold is reached where high risk of nuisance flooding has been reached. By 2085, the CRRA model projections show that PNPS will experience up to 348 flood days a year. By 2066, PNPS will surpass the known nuisance flooding threshold of 30 non-storm flood days a year.

Pilgrim Nuclear Power Station

Date Range	2015-2025	2026-2035	2036-2045	2046-2055	2056-2065	2066-2075	2076-2085
# Total Flood Days	0	0	0	19	118	1051	2852
Risk Meter							

Cumulative FIRST Score™ = 4040

As shown in the maps, nuisance flooding remains along the coastal perimeter of PNPS through 2085. However, by 2055 the breakwaters will be inundated up to 6 days a year, thereby greatly compromising their ability to protect PNPS from wave action, erosion, or the effect of a major storm. Furthermore, by 2055 PNPS also becomes vulnerable to storm surge on the site itself. The major storm surge risk, again, occurs mostly along the perimeter of PNPS in the beginning but by 2055 areas within the site, although not hydrologically connected, become vulnerable to flooding by a major storm. While the results show that nuisance flooding will not reach buildings or infrastructure on the site, the compound effects of extreme tides combined with a major storm

surge, precipitation, and groundwater risk are likely to impact important locations on PNPS, especially if the revetments are overtopped

APPENDIX B

Figure 3-36: WIS Wave Gage Locations

Any illegible text or features in this figure are not pertinent to the technical purposes of this document.

Figure B1. WIS Wave Gage Locations (stations 63057, 63060, 63061). (Source: AREVA, 2015; Figure 3-36, p. 111)