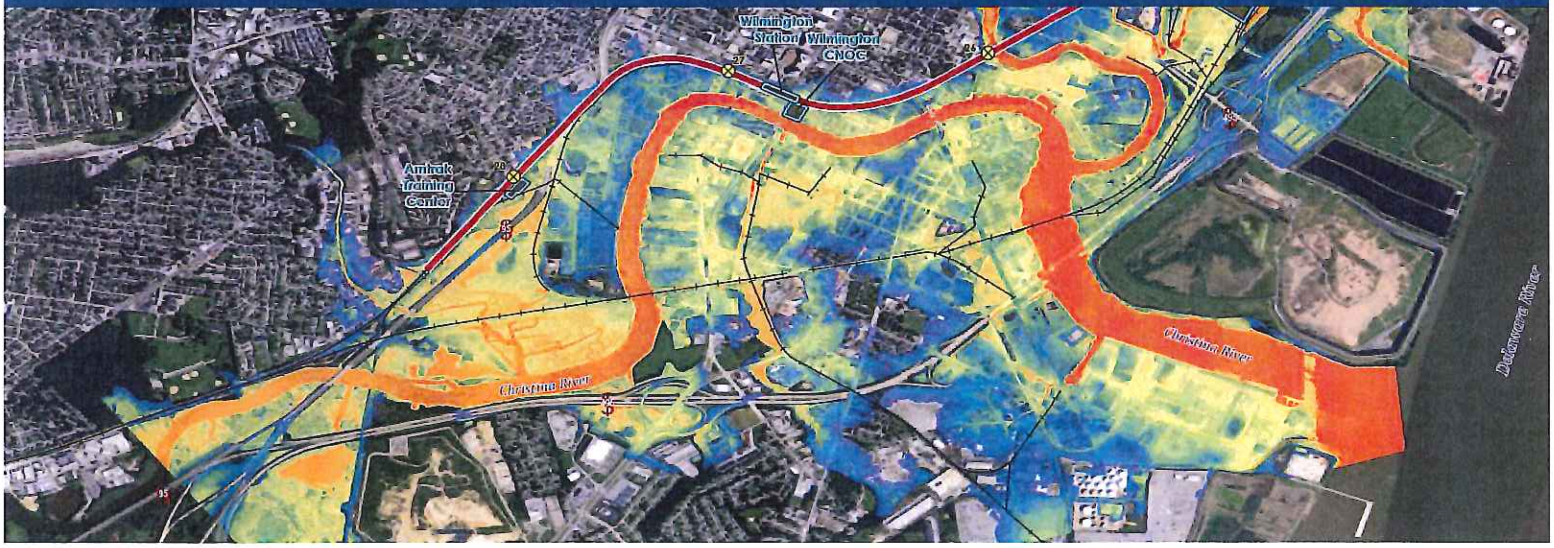
Amtrak NEC Climate Change Vulnerability Assessment: Phase II Pilot Study



AMTRAK®

Amtrak's Northeast Corridor

Infrastructure and Investment Development

Department

September 30, 2015

Stantec

About the Cover:

The graphic image on the cover is a storm surge inundation map using the results of Hazus-MH modelling developed for the study area in Wilmington, DE.

Acknowledgements

The Amtrak Phase II Pilot Study is the result of a coordinated team effort between Amtrak and Stantec Consulting Services Inc. The Amtrak Phase II Pilot Study was led under the direction of Karen Gelman, Infrastructure Planning Manager and Celia Ann Pfleckl, Senior Sustainability Manager at Amtrak.

Valuable information was provided by the members of Amtrak's Climate Change Strategy Subcommittee, which is comprised of subject matter experts from within Amtrak's Environment & Sustainability, Engineering, Emergency Management & Corporate Security (EMCS), and Northeast Corridor Infrastructure and Investment Development Department NECIID departments. A special thank you for the contributions made by each team member: Glen Sullivan, Beth Termini, Anna Barlowe, Michael Hajdak, Mark Benedict, Tobi Palmer, Kelsey Gibbons, Joanne Maxwell, and Brian Schwab. Lastly, a team of scientists and engineers specializing in climate change vulnerability assessments from Stantec supported Amtrak to develop the framework, methodologies, and vulnerability assessment, which cumulated in the development of this report.

How to Cite Reference

References were completed in accordance with the *Chicago Manual of Style* formats for reference.

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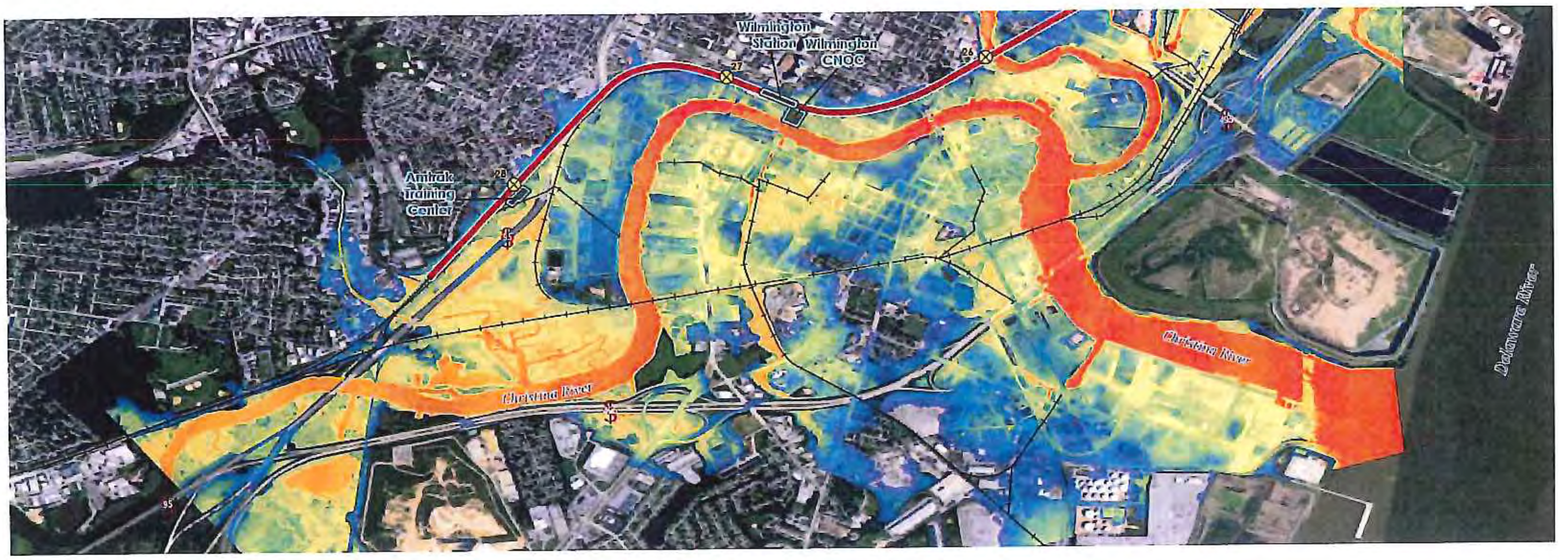
Executive Summary



Executive Summary

Amtrak's Northeast Corridor (NEC) is Amtrak's most essential section of track connecting numerous large and important metropolitan areas. The NEC connects eight states and the District of Columbia and supports a $2.6 trillion dollar economy. Along the NEC, Amtrak provides access and/or operational support to eight commuter lines and six freight operations. In order to address Amtrak's goals of "delivering intercity transportation with superior safety, customer service and financial excellence" (Amtrak, 2014a) it is integral that Amtrak integrate climate change into current and future planning efforts. The NEC proximity to the eastern Atlantic seaboard makes this corridor susceptible to climate change-induced impacts such as sea level change and increased storm surge. Other climate variables such as precipitation, temperature and wind also can have detrimental effects on the overall operation of the Amtrak system.

In response to Climate Change, Amtrak has taken several steps to begin the process of understanding their specific vulnerabilities along the NEC. Amtrak is a participating member of the NEC Commission which was established in September 2010. It is comprised of representatives from all the NEC states and the District of Columbia and the U.S. Department of Transportation (U.S. DOT) as well as other representatives. The NEC Commission is responsible for developing a 5 year Capital Plan and it is anticipated that potential climate change impacts will be included in the near-term capital investment plans. Amtrak implemented a corporate-wide Sustainability Policy in 2013 and in 2014, the Northeast Corridor Infrastructure and Investment Development (NECIID) department completed a Phase I climate change study focused on compiling climate change research and methodologies related to transportation assets and vulnerability assessments (Amtrak, 2014b). Lastly, Amtrak's Environmental and Sustainability Management System Steering Committee created a subcommittee (Climate Change Strategy Subcommittee) in 2014 to assist in the development of climate change strategies and initiative.

This Phase II study, the Amtrak NEC Climate Change Vulnerability Assessment: Phase II Pilot Study (referred to as Pilot Study though out this report) serves as the next step in Amtrak's effort to understand specific vulnerabilities related to NEC assets, as induced by shifts in relevant climate change variables. This Pilot Study focused on a 10-mile section of track within the Wilmington, Delaware area. As part of this Pilot Study, a climate change framework was developed and considered various resources including the FHWA *Climate Change and Extreme Weather Vulnerability Assessment Framework* (Federal Highway Administration, 2012). The main objective of this Pilot Study was not only to assess Amtrak's asset vulnerabilities within the Pilot Study area, but more importantly, to set up a framework and methodology that can be repeated along other stretches or for the entire NEC. This Pilot Study provides the foundational knowledge base necessary for similar efforts along the NEC in the future.

The overall objective of Amtrak's Climate Change Program is to adapt its infrastructure and operations to be more resilient by;

- establishing a vulnerability and adaptation methodology
- addressing future operational challenges
- guiding capital investment priorities

- shaping future design and adaptation standards
- establishing emergency management and security measures

After Amtrak identified their climate change program objectives, data was collected for those assets potentially exposed and susceptible to climate change. This step is essential to provide the information needed for the analysis conducted in the later steps. The data was provided by Amtrak through GIS data exchanges, online surveys, meetings, and one-on-one interviews. Concurrently with the data collection efforts, the Study Team from Stantec prepared information and mapping to show the potential effects of climate change on sea level rise, storm surge, precipitation, temperature, and wind. Using reputable tools, methods, and sources as described in this report, this step identified the climate stressors (i.e. sea level change, storm surge, precipitation, wind, and temperature) specific to the area and asset type under assessment.

Once asset data collection and climate variable development was completed, the assets were screened for exposure and sensitivity to the known climate stressors in the Pilot Study area. For this Pilot Study, the majority of the assets were evaluated due to the relatively small geographic scope of the study area. It should be noted that the methodology developed such as the screening was developed considering that Amtrak in the future would be assessing the vulnerability of other sections of its system.

For the vulnerability assessment, the analysis used three main analysis tools: Federal Emergency Management Agency's (FEMA) Hazus-MH 2.2 (Hazus-MH) software, Hazard Vulnerability Index (HVI) and the U.S. DOT Vulnerability Assessment Scoring Tool (VAST). The Hazus-MH tool was used to model the predicted sea level rise and storm surge inundation levels over the Pilot Study area as well as determine the projected damage and potential losses to Amtrak assets caused by hurricane force winds, changes in sea level, and storm surge. The HVI and VAST tools were used to assess the vulnerability of the selected assets for the selected climate variables. The analyses provide vulnerability scores in which the assets most at risk can be identified. The results ranked the vulnerability of the specific assets as high, moderate and low. This ranking then allowed the Study Team to identify vulnerable areas at risk. It is clear from the sea level rise and storm surge maps that there are several areas that are more vulnerable than others, see Figure 45 through Figure 48 in Chapter 5. This can be seen in the year 2050 projections and are more predominant in the projections for year 2100. The section between mile post 24 and mile post 27 have varying levels of vulnerability based on the projection year but it is clear that this area is the most vulnerable and includes all four facilities that were selected for review. There is also another section between MP 22 and MP 21 in which the track, signals, catenaries and roads are all vulnerable but there are no facilities located within this stretch.

Lastly, the results of this Pilot Study culminated in recommended next steps to help Amtrak move forward in making its infrastructure and operations more resilient to the effects of climate change. The Study Team recommends that Amtrak develop an organizational-wide adaptation strategy, prepare a climate change impact zone (zone of potential influence), develop and implement an internal outreach plan, and lastly continue to implement the next steps for the Pilot Study area by developing an adaptation plan for those assets determined to have high risk of vulnerability to climate-induced impacts.

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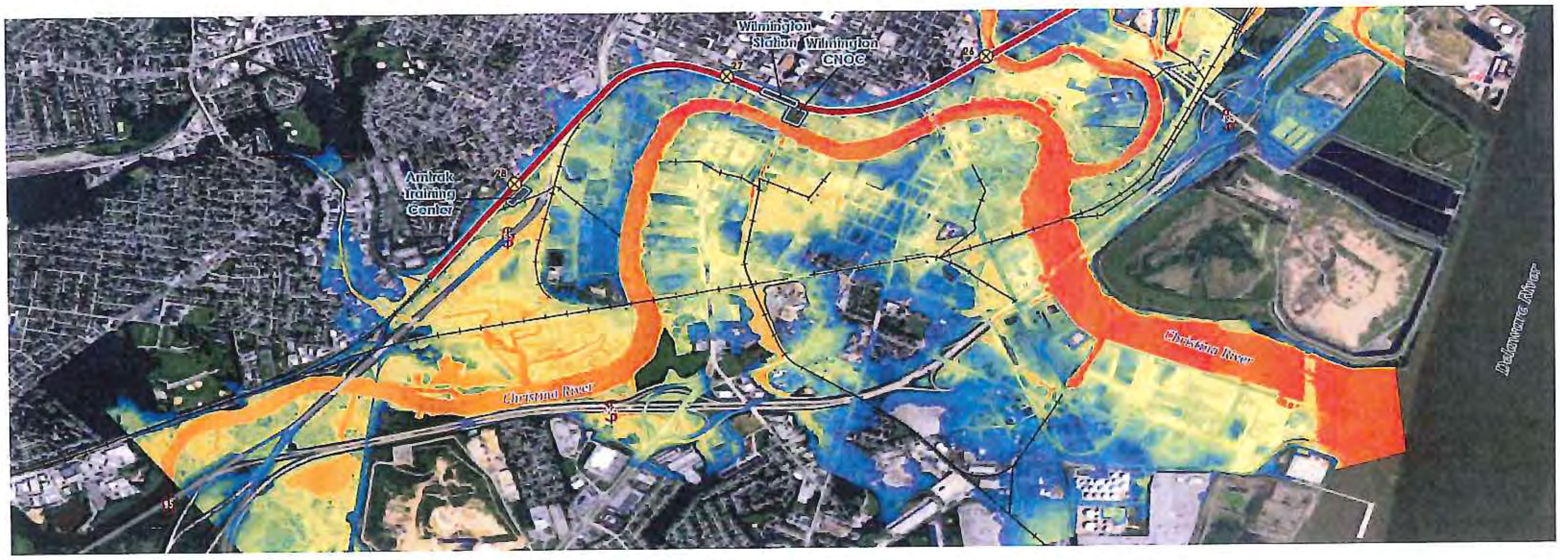
1.0 Introduction



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1.0 Introduction

1.1 Why a Pilot Study?

The Amtrak Northeast Corridor (NEC) Climate Change Vulnerability Assessment: Phase II Pilot Study (Pilot Study) will serve as one of the foundations for Amtrak's future planning to address the effects of climate change. This Pilot Study builds upon the previous work completed by Amtrak which concluded with a final report, Amtrak NEC Climate Change Vulnerability Report Phase I, completed September 30, 2014. The Phase I study recommended a Pilot Study be completed of a selected vulnerable geographic area along the NEC. This Pilot Study fulfills this next recommended step. Furthermore, this report establishes a climate change program framework, which gives Amtrak a structured approach to identify asset vulnerabilities, prioritize risks, develop an adaptation strategy, and plan for the future. This Pilot Study presents a systematic methodology to assess Amtrak's asset vulnerabilities to relevant and applicable climate variables that can then be applied to the entire NEC. For the development of this methodology, Amtrak chose a ten mile segment of rail in Wilmington, Delaware (see Section 1.3 Study Area/Assets). The section was chosen because it has a relatively low elevational topography and is located near the coastline as well as containing mission critical assets. The approach developed for this Pilot Study is adaptable and repeatable; therefore, it can be modified when there is a change in assets or if new climate science data becomes available. The framework, methodology, and lessons learned from this Pilot Study will be used to duplicate this effort in different sections of the NEC or the entire corridor.

This Pilot Study provides the knowledge base that can be built upon for next assessments. Additional assessments will require the collection of specific regional and asset data but can then be plugged into the established methodology. This Pilot Study and future studies should be used to further refine the process making it more efficient and a more robust analysis as models and data precision improve. This process results in a continuous refinement of Amtrak's asset vulnerability framework and methodology. It also allows Amtrak to consider future adaptive capacity measures that can include engineering solutions, best management practices, and maintenance initiatives to reduce the risk of the vulnerabilities identified in this Pilot Study.

1.2 Amtrak Goals and Objectives

The overall objective for Amtrak Climate Change Program is to assist Amtrak to adapt its infrastructure and operations to be more resilient in the future by:

- establishing a vulnerability and adaptation methodology
- addressing future operational challenges
- guiding capital investment priorities
- shaping future design and adaptation standards
- establishing emergency management and security measures

This Pilot Study helps to specifically satisfy Amtrak's goals of establishing a methodology and identifying vulnerabilities of its assets in the Pilot Study area. The next step in this process will be prioritization and adaptation planning to help further fulfil the program objectives. These steps are outlined in Chapter 2, Section 1, of the General Framework. Together, this information will be used to help Amtrak anticipate and prepare for future operational challenges and appropriate funds for adaptation along the corridor.

1.3 Ongoing and Previous Amtrak Climate Change Work

There are several ongoing planning initiatives to address the need to improve the existing NEC while planning for the next generation high speed rail. The Federal Railroad Administration (FRA) NEC FUTURE initiative is leading by example. This Tier 1 Environmental Impact Statement will include an analysis for potential climate change impacts for each of the alternatives (Amtrak, 2015).

In 2013, Amtrak implemented a corporate-wide Sustainability Policy that defined sustainability for Amtrak's operations. Sustainability was defined as evaluating all future efforts to ensure that the needs of the organization where considered equally with the needs of future generations. This sustainability initiative included efforts to understand the risks and potential impacts of climate change on Amtrak's business and the communities in which it operates as an important application of this policy.

In 2014, the first phase of this climate change initiative was led by Amtrak's Northeast Corridor Infrastructure and Investment Development (NECIID) Department. The Phase I report focused on reviewing and summarizing existing climate change research findings and methodologies related to transportation assets and vulnerability assessments. This study identified availability and gaps of Amtrak NEC rail asset data, typical climate change impacts to rail assets, availability of climate data and vulnerability assessment methodologies and recommended a climate change vulnerability assessment approach (Amtrak, 2015).

A subcommittee of Amtrak's Environmental and Sustainability Management System Steering Committee, the Climate Change Strategy Subcommittee was also created in 2014. This subcommittee consists of subject matter experts from Amtrak's Environment & Sustainability, Engineering, Emergency Management & Corporate Security (EMCS) and NECIIS departments. This committee has been an active advisor to the Study Team throughout this assessment and in the preparation of this report.

1.4 Pilot Study Area/Assets

Amtrak's NEC is a 457 mile long corridor of track that extends from Washington DC to Boston, MA. The NEC carries over 2200 passengers daily and is vitally important to the economic vitality of the Northeast. The 10-mile selected Study Area is located in Wilmington, DE. Specifically the study area stretches from the Pennsylvania/Delaware state line and traverses south for 10-miles to Amtrak's yard interlocking (mile post 18.5 to 28.5). This study area was selected based on a need for several desired Study Area-specific characteristics;

- contains relatively low elevation topography within the Amtrak right-of-way
- close proximity to the coastline
- includes mission critical assets
- includes a diversity of railroad assets
- manageable study area size for a Pilot Study

The assets included in the Pilot Study were identified early in the study and selected based on their importance to operation and vulnerability to the climate change variables. The assets being assessed include the main line track (including interlockings and turn outs), the catenary system, signals, bridges, adjacent roadways, and selected facilities and substations. The facilities were selected by Amtrak due to their location within the Study Area and their importance to the overall operation of the NEC. The facilities included; Wilmington Station, Wilmington Shops, Consolidated National Operations Command (CNOC) and the Wilmington Training Center, as well as the Bellevue and West Yard Traction Substations. Figure 1shows the study area and location of each Amtrak facility.

1.5 Amtrak's Study Team

The Study Team consists of technical experts from Amtrak and their consulting partner, Stantec. Amtrak's NECIID Department is leading this effort under the direction of Karen Gelman, Infrastructure Planning Manager and Celia Ann Pfleckl, Senior Sustainability Manager. The Climate Change Strategy Subcommittee is comprised of subject matter experts from within Amtrak's Environment & Sustainability, Engineering, Emergency Management & Corporate Security (EMCS), and NECIID Departments and is responsible for providing cross discipline expertise.

The core Amtrak team, with support from the advisory committee was instrumental in providing the data necessary to successfully complete this analysis. These Amtrak personnel participated in and contributed to monthly team meetings, provided existing asset data, completed surveys, and engaged in one-on-one interviews. These efforts in data exchange form the foundation of knowledge applied in the study. In addition to these data, Amtrak also provided Stantec with a large amount of qualitative and quantitative information for application in the analysis.

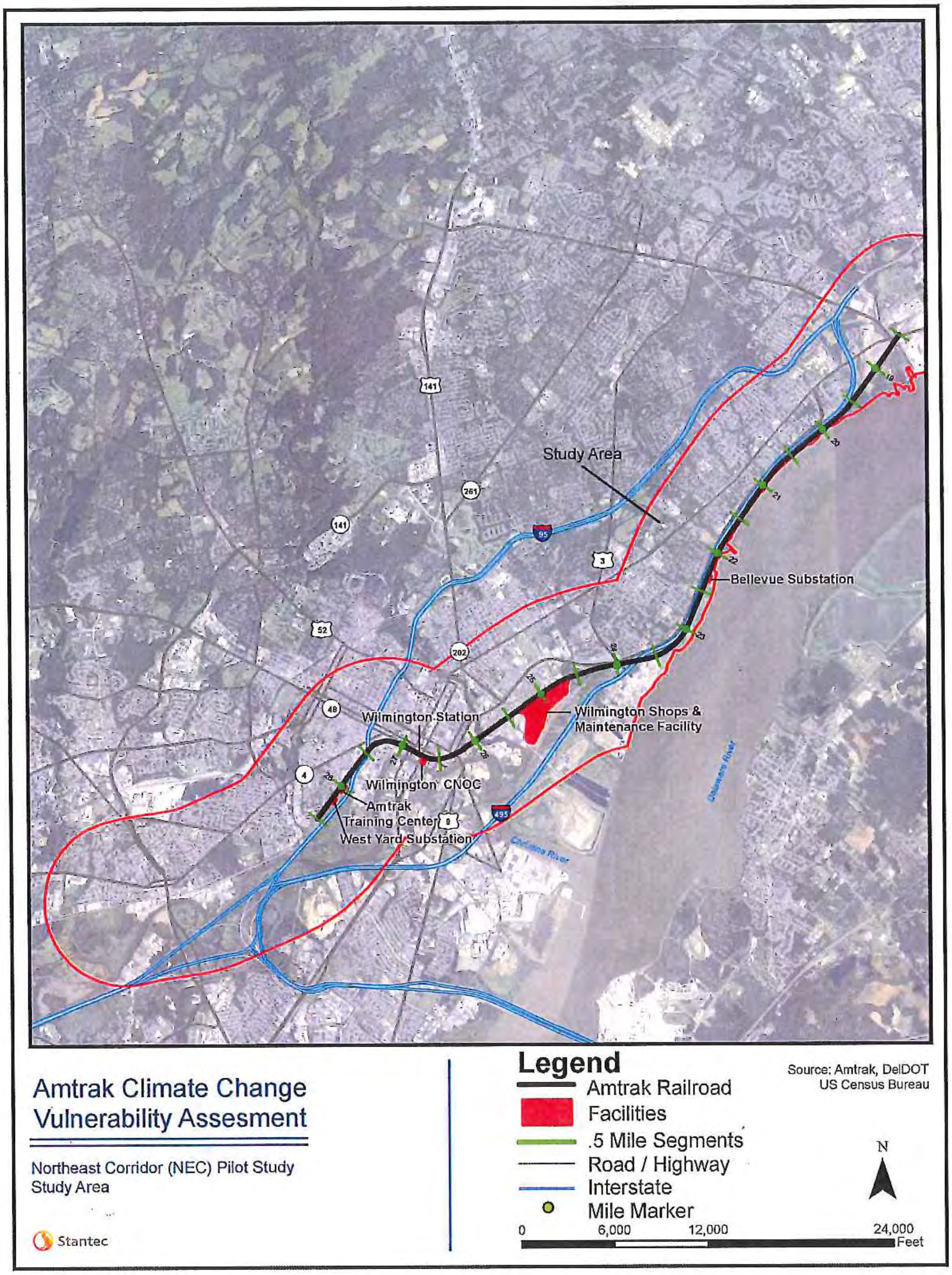
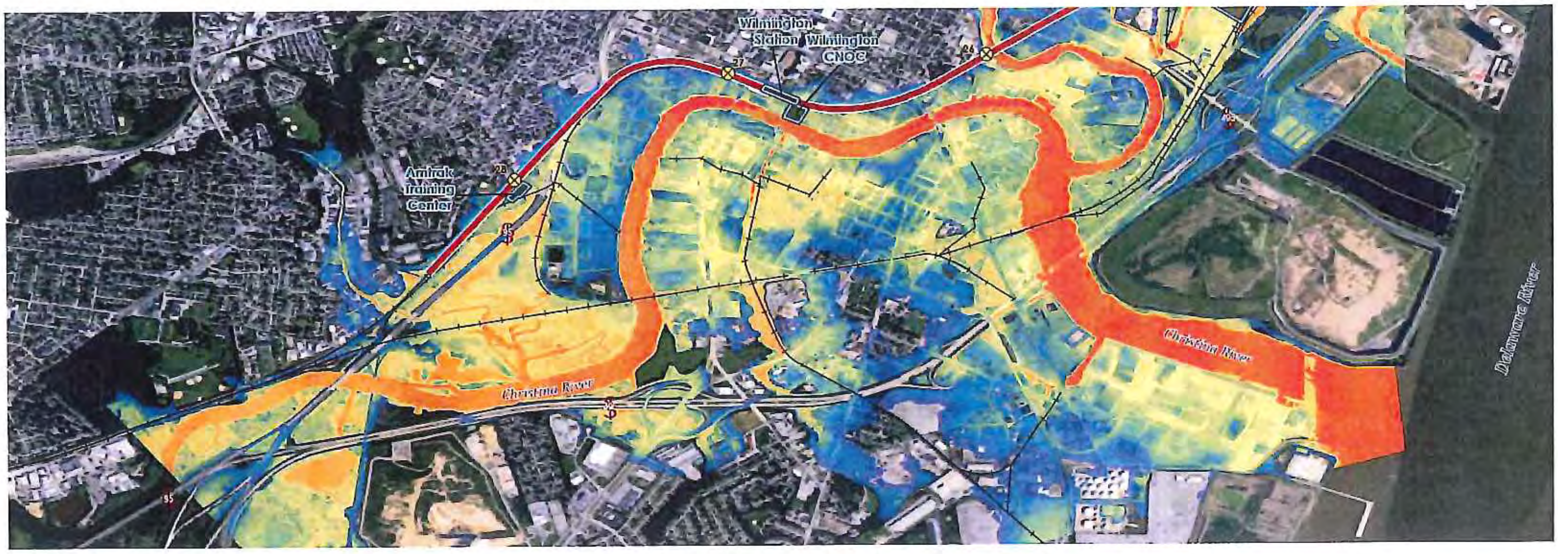


Figure 1. Pilot Study Area including Amtrak Facilities and Substations

2.0 Vulnerability and Adaptation Framework and Methodologies



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2.0 Framework and Methodologies

2.1 General Framework

One important focus of the Pilot Study is to create a repeatable methodology to assess asset vulnerability such that it can be applied system-wide along the NEC. The methods used in the Vulnerability Assessment need to have foresight and consider Amtrak's long-term goal: making Amtrak's system more resilient to future changes in climate. This section describes the general framework to allow Amtrak to move forward in adapting its rail system and operations to provide safe and reliable passenger rail service for its patrons into the future. The development of this framework presented in this chapter considers various resources including the FHWA *Climate Change and Extreme Weather Vulnerability Assessment Framework* (Federal Highway Administration, 2012) and the Transportation Research Board's National Cooperative Highway Research Program (NCRHP) *Report 750 Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report* (NCRHP, 2014). Furthermore, methodologies supporting each of the key steps of the Phase II Vulnerability Assessment are expanded upon in this chapter.

The framework is a systematic approach for assessing climate change impacts to various assets that are potentially at risk from one or more climate stressors. Furthermore, the framework provides Amtrak direction on prioritization, adaptation, implementation, and how to incorporate climate change considerations in its long term planning and decision-making. One objective of this Pilot Study is to create a framework and methodology that is structured, consistent, documented, and repeatable. This objective is intended to allow for revision of vulnerability assessment findings at appropriate future intervals as new data or improved climate datasets become available. It is by definition an iterative process, with the integration of new information and data as they become available.

The framework includes nine general steps as depicted in Figure 2. The framework starts with development of objectives and goals as described in Chapter 1 of this Pilot Study and concludes with monitoring of each adaptation measure. This Pilot Study implements steps 1 through 6. As discussed later, Step 7 adaptation measures often involves a more detailed analysis and can include engineering design and a cost benefit analysis therefore this lends itself to a separate phase of the

Figure 2. Program Framework

project. Each step in this process is discussed in detail in this section.

Step 1 - Program Goals and Objectives

The first step in this process is to identify Amtrak's program goals and objectives as it relates to potential impacts of climate change to its operations and infrastructure. Each organization in various sectors such as transportation, government, water/wastewater etc. have different core missions, different operational thresholds to impacts, and their goals for their climate change program may differ. These goal and objectives are used to help prioritize agency decisions related to climate change and help to shape the program framework. Chapter 1 describes Amtrak's goals and objectives for their climate change program.

Step 2 - Asset Data Collection

Data collection is a critical step. The level of detail and accuracy of the vulnerability assessment hinges on the data available to assess the infrastructure asset's vulnerability to the different climate stressors. Determining asset vulnerability is based on asset information such as condition, age, location, exposure elevation, etc. Most transportation agencies today have asset management systems integrated with Geographic Information System (GIS) technology. Bridge inspection and asset inventories developed in a more tabular format are also useful. Additional data collection in the field may be needed to supplement information or to ground truth data originally provided. Understanding past failures to extreme weather events is also a good indicator of future vulnerabilities and can help validate results of the vulnerability assessment. As a result, data collection can also include surveys or personnel interviews. In this step, the asset information assembled and reviewed from various sources is consolidated into a useable format for the vulnerability assessment in Steps 4 and 5.

Step 3 - Climate Variables Identification

Knowledge of the anticipated ranges of future climate changes is necessary to examine the vulnerability of the passenger rail system and to develop adaptation measures. It is important to use reputable tools, methods, and sources as described later in this chapter. This step identifies climate stressors (i.e., sea level change, storm surge, precipitation, wind, temperature) specific to the area and asset classes under assessment. Step 3 is particularly important to Amtrak's assets given the substantial geographic range and linear nature of the mainline rail infrastructure along the NEC. For instance, the change in climate from Amtrak's facilities in Boston, Massachusetts will be very different than Washington, DC. Practitioners can use state or regional information provided by reputable and unbiased sources to obtain current and projected climatic conditions or use industry acceptable tools. Detailed methodologies and sources used for developing the climate stressors are presented in Section 2.2. These methods were used to provide regional and downscaled climate information specific to the Pilot Study area.

Step 4 - Asset Screening

The screening level analysis (also referred to as a Tier I Analysis – desk top review) is intended to eliminate (i.e., screen out) those assets that are either unlikely to be impacted by climate change impacts or present low risk to Amtrak's system reliability or passenger safety. This step helps to focus resources and funding to assess only those assets and areas that will be most impacted by climate change. Screening reduces the level of data collection, data entry, and effort for conducting the vulnerability impact assessment. There are a number of techniques to screen the assets. For instance, only those assets potentially impacted by specific climate stressors of concern would be retained, and those identified to be unaffected by those climate stressors would be screened out.

The main approach to screen assets is to determine exposure of each asset. If an asset is not exposed to the climate stressor, then it can be eliminated from detailed study. Only those assets exposed to one of more climate stressors will be retained for detailed vulnerability assessment. At this step, information from Step 3 is used to determine which geographic locations are exposed to each climate stressor. One approach is to identify a Climate Change Impact Zone.

A Climate Change Impact Zone is established in GIS using some or all of these layers;

- *the outer limits of the 2100 Mean High High Water (MHHW) Sea Level Change,*
- *Sea, Lake and Overland Surge from Hurricanes (SLOSH) data for a Category 3 hurricane*
- *Federal Emergency Management Agency (FEMA) 100-year floodplain boundaries*
- *Wind and/or temperature data*

This step identifies those assets exposed to water related climate stressors and the data relating to these assets is exported into a compatible format to be carried forward into the detailed vulnerability analysis. In the case of this Pilot Study, the format applied by the team is a Microsoft Excel table specifically formatted for input into the VAST or HVI assessment tools.

For the Pilot Study, a 10-mile of section of Amtrak mainline (including support facilities) was chosen because of this section's criticality to Amtrak's operations and its vulnerable location near the Delaware River and Atlantic Ocean. Most of the Pilot Study area is exposed to sea level rise, storm surge, and flooding from severe weather events such as a hurricane or nor'easter. As a result, the entire section mostly falls within the Climate Change Impact Zone. Therefore, this Pilot Study did not develop a Climate Change Impact Zone to screen assets. Essentially, the selection of the Pilot Study area screened the assets. One goal of this Pilot Study is to create a repeatable methodology for the entire NEC and this step will be very valuable to Amtrak in its assessment of the entire system.

Step 5 - Vulnerability Assessment

After the assets have been screened to include only assets with exposure and vulnerability to climate stressors, the next step is to conduct a detailed vulnerability assessment. The detailed vulnerability assessment emphasizes the quantitative analysis, referred to as Tier II assessment. For this step, the Study Team used multiple tools to conduct this analysis: VAST, HVI and Hazus. For this Pilot Study, VAST was used to assess the vulnerability of bridges, catenaries, facilities, and other assets for the ten mile segment. VAST is a Microsoft Excel-based analytical tool that requires the input of asset information, climate data, and vulnerability indicators. VAST focuses on asset exposure, sensitivity, and adaptive capacity. The second tool used is the HVI. HVI applies a formula using GIS asset data to delineate segments of rail or roadway (linear assets) which may be considered vulnerable and gives these segments a vulnerability ranking of high, moderate or low. Using the results of the HVI, the Study Team assessed the vulnerability of the 10-mile section of rail line. Lastly, Hazus was an additional tool used to assess the impacts to Amtrak facilities from sea level rise, storm surge, and wind. For the use of each of these tools, a relative ranking or priority is established by asset type. Methodologies for each tool are provided in Section 2.2.

Step 6 - Risk Assessment and Prioritization

After the vulnerability of each asset has been established, risk to the overall operations and safety is determined and re-prioritized. Using VAST, the Study Team assessed risk through the numerical assignment of weighting factors corresponding to different vulnerability indicators. The VAST output consists of a list of different assets at risk, with these risks prioritized numerically through the resulting VAST scoring process. The detailed methodology used for the application of VAST is explained in section 2.2.3. In addition, HVI maps showed rail segments at risk and provided numerical scoring. A workshop involving an interdisciplinary team of Amtrak personnel was also conducted and was successful in assessing risk and prioritizing vulnerability. Once risks are prioritized, the assessment proceeds to characterize areas into high to medium risk categories within the study area. Assets are then mapped according to their risk category. From this exercise, vulnerable areas at risk are identified for further adaptation analysis.

This Pilot Study implements steps 1 through 6 for the study area. Steps 7 through 9 are recommended future actions to fulfill Amtrak's objective to make its assets more resilient.

Step 7 - Adaptation Measures

Adaptation involves two steps: development of (1) an agency wide adaptation strategy and (2) site specific adaptation plans for "Vulnerable Areas at Risk". Each step has its importance in reaching the goals and objectives outlined in Step 1.

Amtrak Adaptation Strategy - A detailed adaptation strategy would be prepared and adopted by Amtrak that would prescribe the steps the agency plans to take to adapt to climate change. The Adaptation Strategy would:

- further establish goals and objectives for adaptation
- recommend Amtrak wide policy related to adaptation
- provide guidance on future planning on capital improvements
- outline steps being taken to adapt areas at risk
- determine the planning horizon for implementation
- prescribe organization wide training and outreach
- set metrics for monitoring success

Site Specific Vulnerability Assessment and Adaptation Plans - In this step, segments of rail or facilities are assessed in detail. System-wide vulnerability assessments are generally completed at a broad planning level. Thus, detailed site-specific vulnerability assessment and adaption plans are needed for vulnerable areas at risk. These plans need to consider the many interdependencies of related assets, adaptation planning being completed by others, or take a more holistic approach to potentially identify a solution that benefits the entire community. For instance, an adaptation strategy could involve working with a local government to implement an upstream watershed improvement project outside of Amtrak's right-of-way (e.g., a levee or upstream stormwater facility). This study, now called a Tier III analysis, and including a higher complexity of assessment, would use more detailed hydraulic modeling and engineering information from as-built plans and survey information. Tier III represents the detailed engineering analysis required to confirm the feasibility and effectiveness of a given adaptation measure or set of adaptation measures in a site-specific context. This analysis would identify and assess adaptation options and lead to detailed planning and design. Cost-Benefits Analyses could also be conducted to further investigate the benefit of a considered adaptation measure related to other needs in the NEC. Also currently being done in some studies is a sustainable return on investment (SROI) analysis. This analysis uses the organizations specific goals to assess the cost and benefit of identified adaptation measures. Recognizing that adaptation measures might be non-traditional or result in added environmental impacts, early coordination with the regulatory agencies and public outreach should occur at this step to educate stakeholders on the purpose and need for the adaptation measure, using the detailed site specific analysis as a basis for the decision.

Step 8 - Implementation

After the adaptation strategy is completed and as detailed vulnerability assessment and adaptation plans are developed, the agency would proceed to implement agency-wide strategies. This agency wide adaptation plan would incorporate adaptation projects into its capital improvement program, and as funding becomes available, proceed with detailed design and construction of the site specific adaptation measures. Implementation of the agency-wide strategy could include such actions as revisions to planning procedures to considering climate change for new projects, changes in maintenance operations in those areas impacted by flooding, changes in operational policies related to high winds and temperature shifts, internal preparation and response training, etc.

Step 9 - Monitor

Performance metrics would be developed in the adaptation strategy, adaptation plans, and incorporated into a larger asset management system and programs. This information would help to measure the success of adaptation and provide feedback for future planning and designs to make the transportation system more resilient while considering cost and the environment.

Periodic Update of Climate Data and Changes to the Environment

Because of the relative uncertainties of climate change science, this framework and methods within need to be easily repeatable and information periodically updated. Updates may be prompted by new data or advances in climate modeling. The frequency of updates will likely be driven by advances in climate science and new climate change policy. On a periodic basis (approximately every five years) steps 4-6 should be repeated. This can happen more often if there is a significant advancement in climate science or if a massive climate event occurs impacting an agency's assets. The essential steps would be updating the exposure, sensitivity, and adaptive capacity indicators in VAST and reassessing the vulnerability of assets at high risk.

2.2 Methodologies

The methodologies employed for this Pilot Study center around data collection and analysis. The larger framework speaks to the overall steps of the process while the methodology focuses on the technical aspects of the climate change vulnerability analysis. As described in earlier sections the analysis uses three main tools; Hazus, HVI and VAST. All three of these tools are needed to identify which areas are vulnerable to the climate change variables and which assets are vulnerable within those areas. Data collection is the first necessary step which then feeds into the Hazus tool. Hazus is utilized for modeling the predicted sea level changes and storm surge effects as well as the project wind field. This information is then used to as input for the assessments tools, VAST and HVI, in order to evaluate the vulnerability of the individual assets. The established analysis methodology allows for assessment of a large number of different assets.

2.2.1 Data Collection

Data collection is an important and time intensive task that is essential to an accurate vulnerability assessment. For this Pilot Study, data was collected using several methods including;

- GIS and asset schematic information provided directly from Amtrak
- online data gathering for publically available information such as Light Detection and Ranging (LiDAR) data and road information (road names and evacuation routes)
- historical and criticality survey
- bi-monthly meetings
- one on one interviews with Amtrak staff

Both qualitative and quantitative data is used in the application of various assessment tools. The availability of critical data will influence which indicators can be applied within the assessment tools and directly affects the accuracy of the modeled outcomes. Table 1 provides a list of the key data sources and their application within this assessment.

Table 1. Asset Data Used for Vulnerability Assessment

Data Source	Asset Information	Data Applicability
Amtrak GIS Data	Amtrak spatial data for track, bridges, facilities/substation, signals, and catenary system	Identifies locations and attributes of assets that could be the focus points of a climate change study
Roads	Reported state road closure records	When correlated with storm events, road closures can help identify problem flooding areas that could be exacerbated by climate change

Data Source	Asset Information	Data Applicability
Emergency Road Designation	Spatial data for Delaware evacuation routes	Identifies primary and secondary evacuation routes for various hazard scenarios.
Sea Level Change (SLC) Depth Grids	Depth grids for projected sea level change in the Study Area for 2050 and 2100. Based on Hazus output.	Used to create SLC inundation areas and depths
Storm Event Depth Grids	Depth grids for probabilistic storm events in the Study Area at projected SLC conditions for 2050 and 2100 time horizons. Based on Hazus output.	Used to create still water (SW) storm surge inundation areas and depths
U.S. Army Corps of Engineers (USACE) Sea Level Change Values	Sea level change values for tidal stations in the Wilmington, DE area. Mean sea level and mean higher high water values for 2050 and 2100 provided in feet above North American Vertical Datum 88 (NAVD 1988).	Used to create SLC and SW depth grids. Provided the basis for SLC and SW predictions for 2050 and 2100
Amtrak Facility Information	Historical flooding information, criticality information and building specific information	Information used in the VAST analysis for the exposure, sensitivity and adaptive capacity indicators
Amtrak Bridge Information	Coordinates from Amtrak's asset group, maintenance reports	Used to provide indicator data for the VAST analysis
Delaware Department of Transportation Road Centerline Data	Inventory of state, county and local roads throughout Delaware. Provides spatial data for roads. Includes evacuation route information.	Used to identify roads included in evacuation routes.
Digital Elevation Model (DEM)	Elevation data for Delaware. LiDAR-based data typically collected individually for each county. Provided in feet.	Used as the basis for current land feature elevations. Input into Hazus for SLC and SW inundation determinations.
FEMA Digital Flood Insurance Rate Maps (DFIRMs)	Delineations of the 100 year riverine and coastal floodplain	FEMA riverine and coastal flood areas with current flood risks can identify areas at risk with climate change

2.2.2 Hazus

Assess Vulnerability of Pilot Study Area

In order to evaluate the vulnerability of Amtrak's NEC assets for the Pilot Study area, the Study Team used ArcGIS 10.2.2 to develop geospatial datasets projecting sea level rise and coastal storm surge combined with sea level change projections. Sea level rise with coastal storm surge was modeled at three intervals: years 2020, 2050, and 2100. Year 2020 will be used to demonstrate a soon to be current condition. The resulting datasets were then used as inputs into Federal FEMA's Hazus-MH 2.2 ("Hazus-MH") software. This tool is used assess vulnerability to sea level change and storm surge within the Pilot Study area. In addition, Hazus-MH was used to assess hurricane wind impacts to Amtrak assets.

Six depth grids and associated inundation boundaries were created to reflect projected sea level rise and projected sea level rise with coastal surge:

- Projected sea level rise (year 2020)
- Projected sea level rise (year 2050)
- Projected sea level rise (year 2100)
- Projected sea level rise with coastal surge (year 2020)
- Projected sea level rise with coastal surge (year 2050)
- Projected sea level rise with coastal surge (year 2100)

The specific inputs to create these geospatial datasets are described below.

Further, the Study Team utilized LiDAR (2007) to develop a DEM that reflected topographic conditions in the Pilot Study area. Next, a Mean Sea Level elevation value of 2.87 feet was combined with the USACE projected sea level rise values. The Mean Sea Level elevation and sea level rise projections were obtained from National Oceanic and Atmospheric Administration (NOAA) based on data at the Reedy Point, Delaware tidal station. The projections used are presented in Table 2.

Table 2. USACE Projected Sea Level Rise

USACE Sea Level Rise Projections (in NAVD88)			
Tidal Station	2020 (highest projection in feet)	2050 (highest projection in feet)	2100 (highest projection in feet)
Reedy Point, DE	0.60'	1.90'	5.53'

Given topographic data, mean sea level elevation, and sea level rise projection, the depth grids and associated boundaries could be developed for each sea level rise scenario. The maps showing sea level rise at each interval are shown in Figure 3 (2020), Figure 4 (2050) and Figure 5 (2100).

In order to determine the impacts of coastal surge combined with sea level rise, the 1-percent annual chance coastal surge still water elevations were obtained from the effective FEMA Flood Insurance Study (FIS) for the Pilot Study area. Stillwater elevations combined with projected sea level rise values were used with ArcGIS (a geographic information system for working with maps and geographic information) to delineate inundation boundaries and produce depth grids for coastal surge for each interval (years 2020, 2050 and 2100). The maps showing coastal storm surge combined with sea level rise at each interval are shown in (Figure 6, Figure 7, and Figure 8).

The sea level rise and coastal storm surge depth grids are the background information that is needed to assess the vulnerability of the assets for flooding due to sea level rise and storm surge. This information and the projected hurricane winds for a 100 year storm event were entered into the Hazus-MH 2.2 program, which is able to model potential losses and damage.

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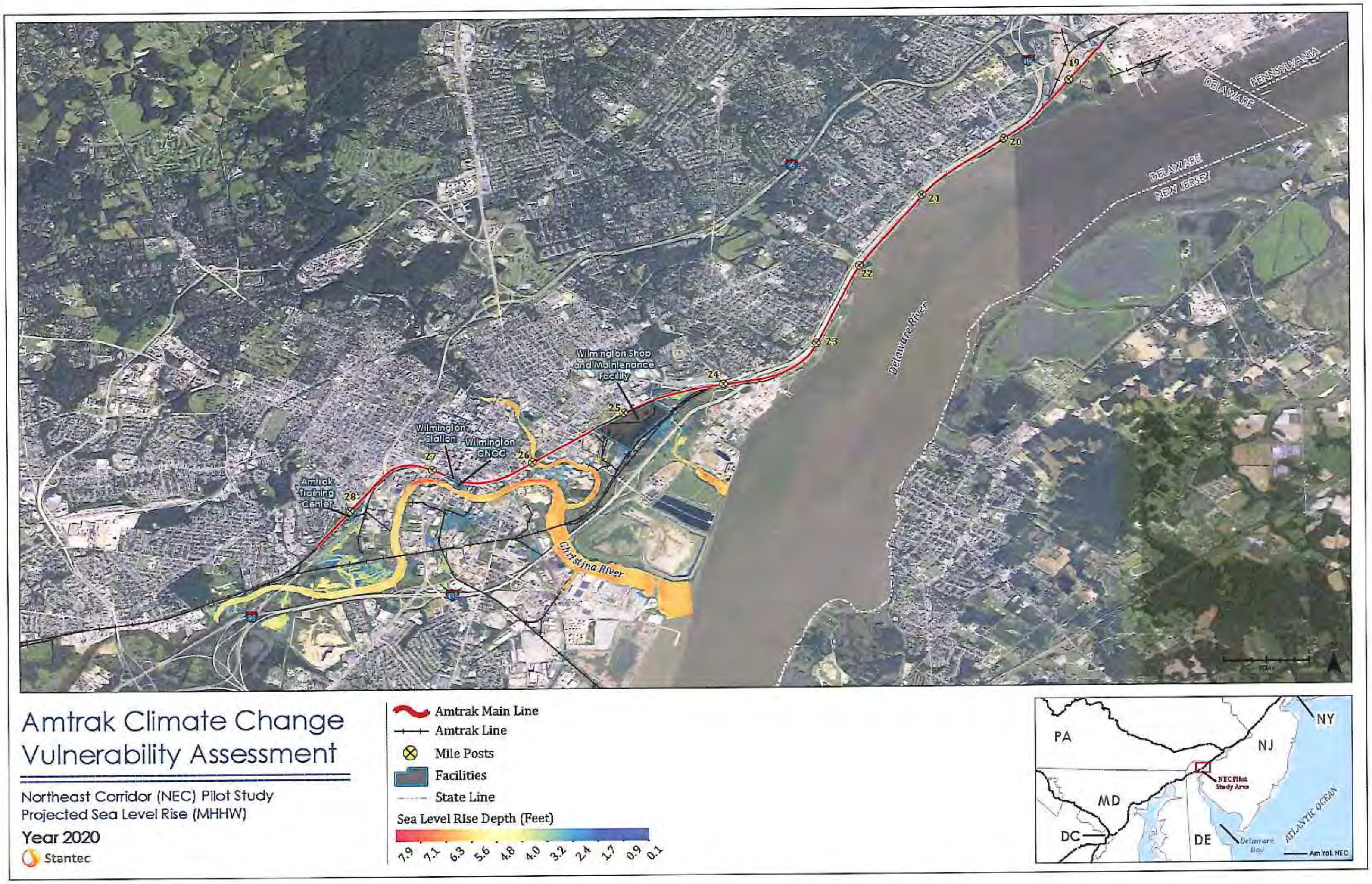


Figure 3. Sea Level Rise (MHHW) 2020

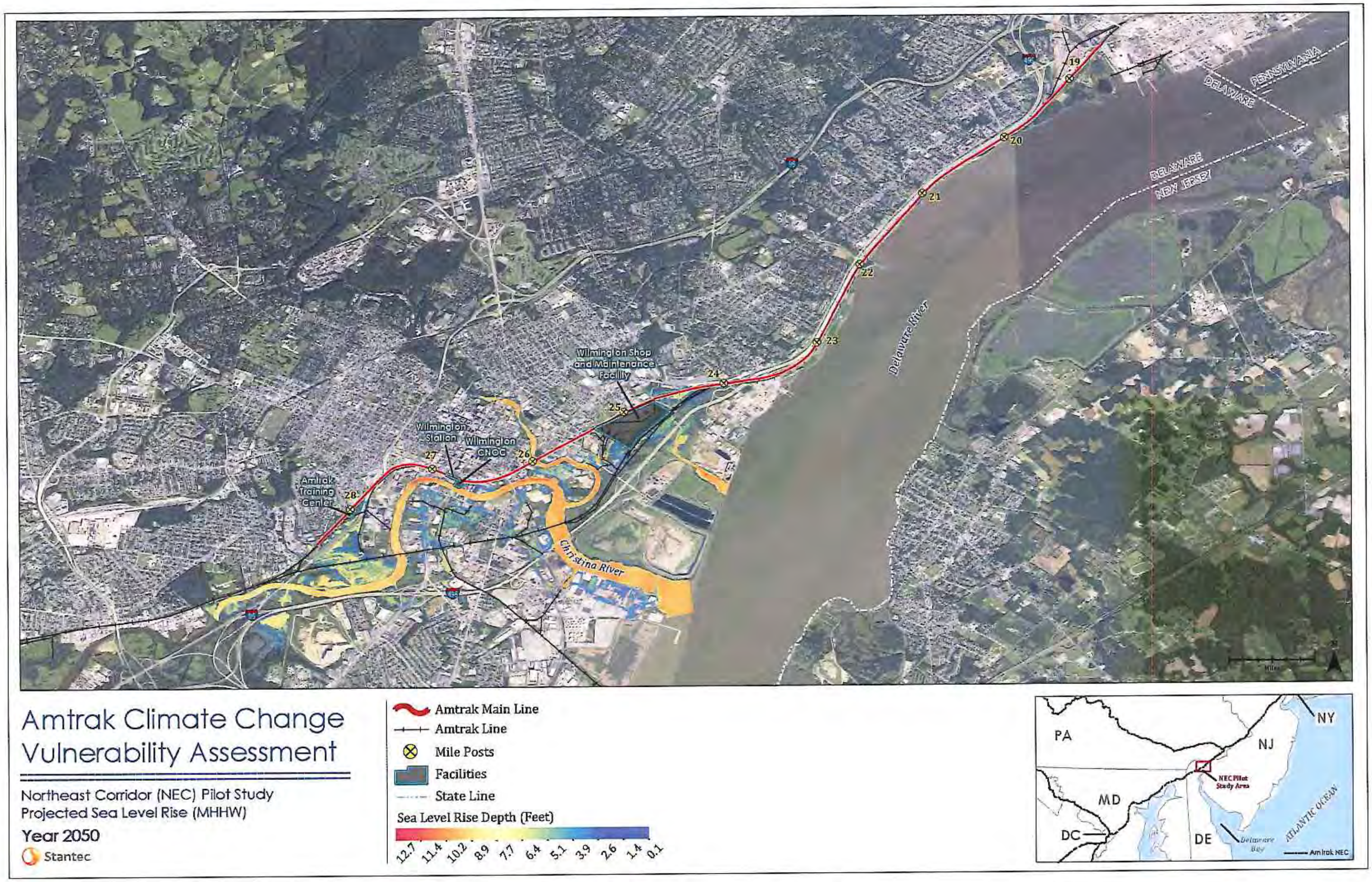


Figure 4. Sea Level Rise (MHHW) 2050

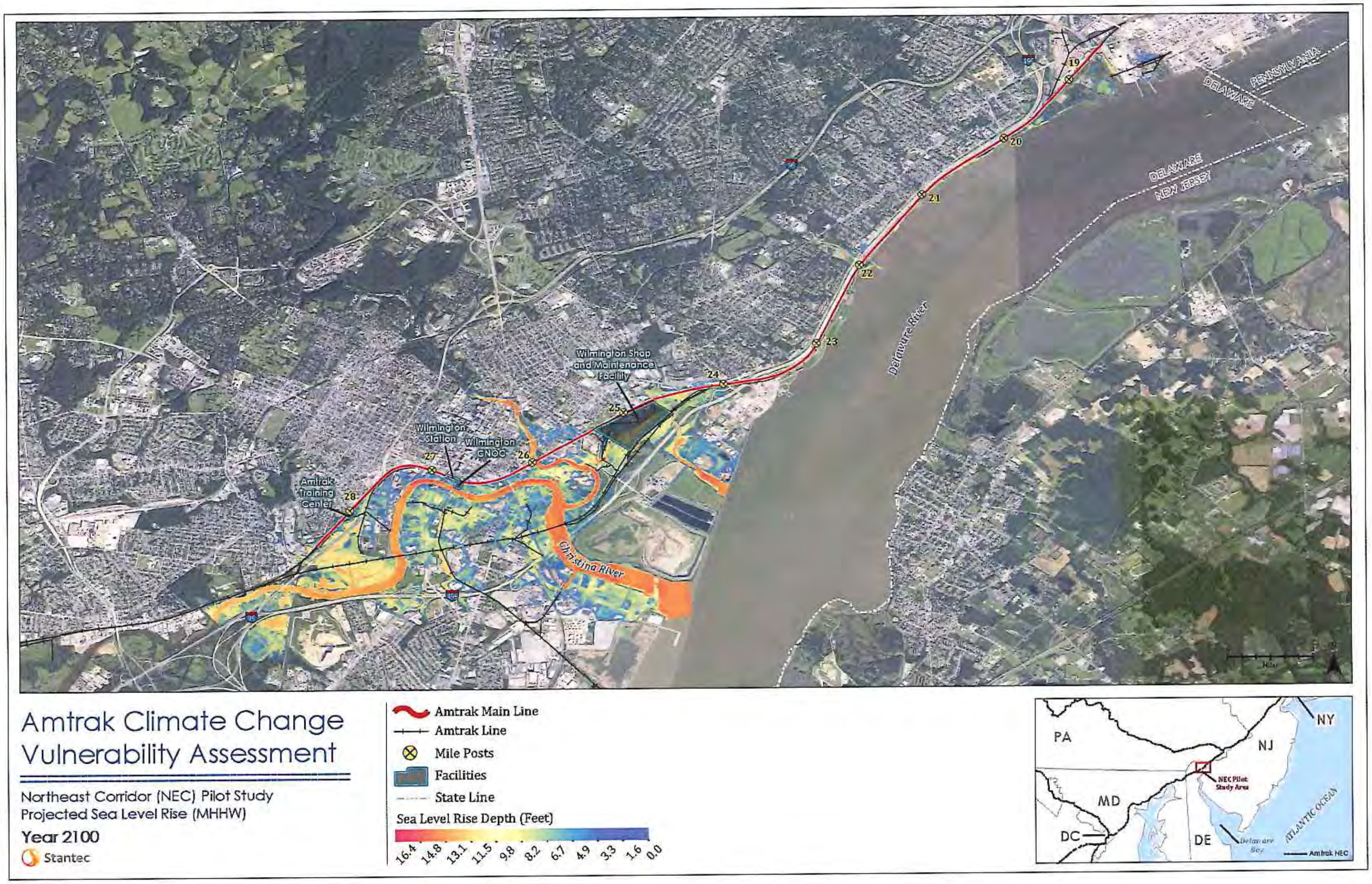


Figure 5. Sea Level Rise (MHHW) 2100

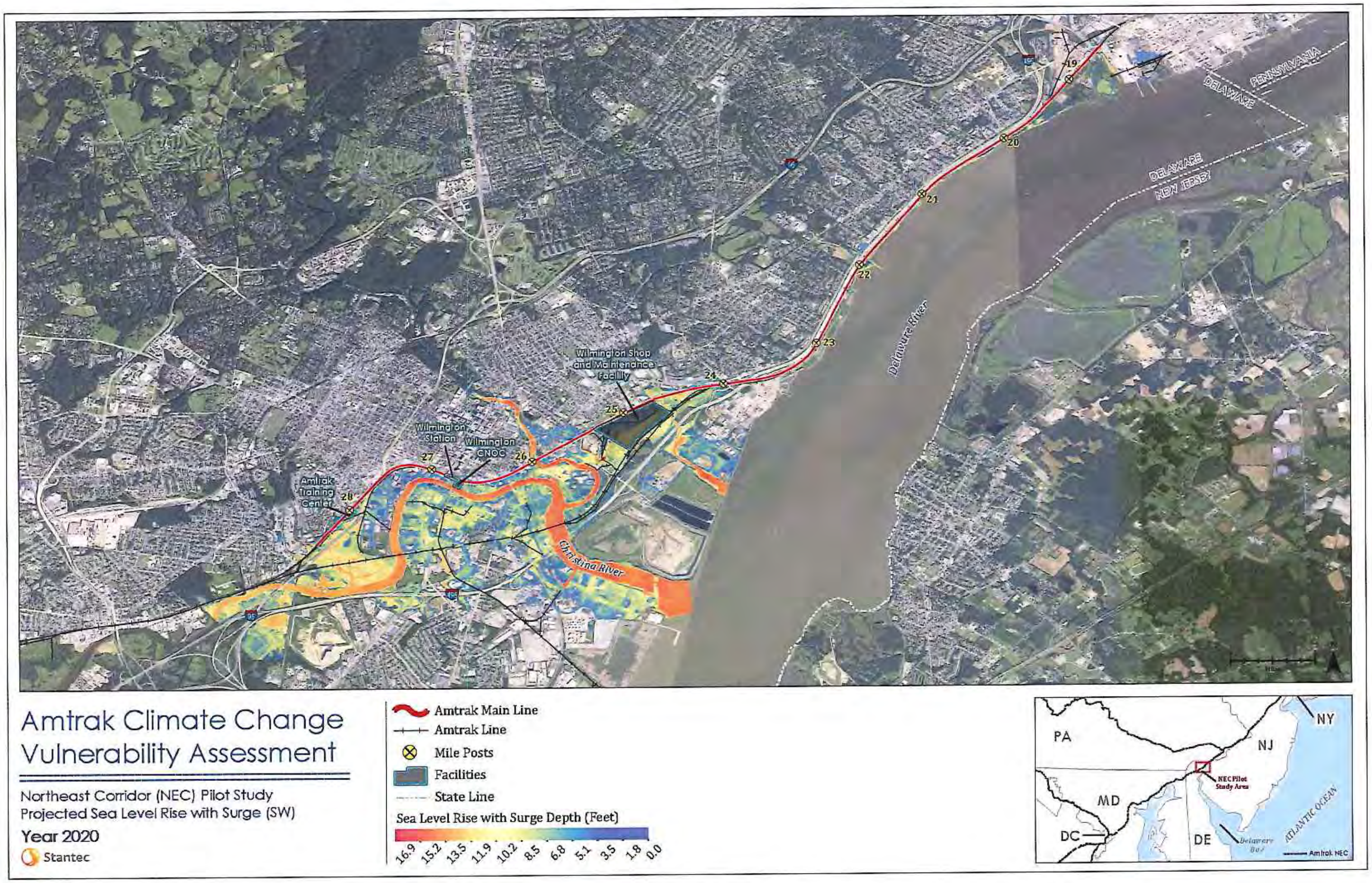


Figure 6. Storm Surge 2020

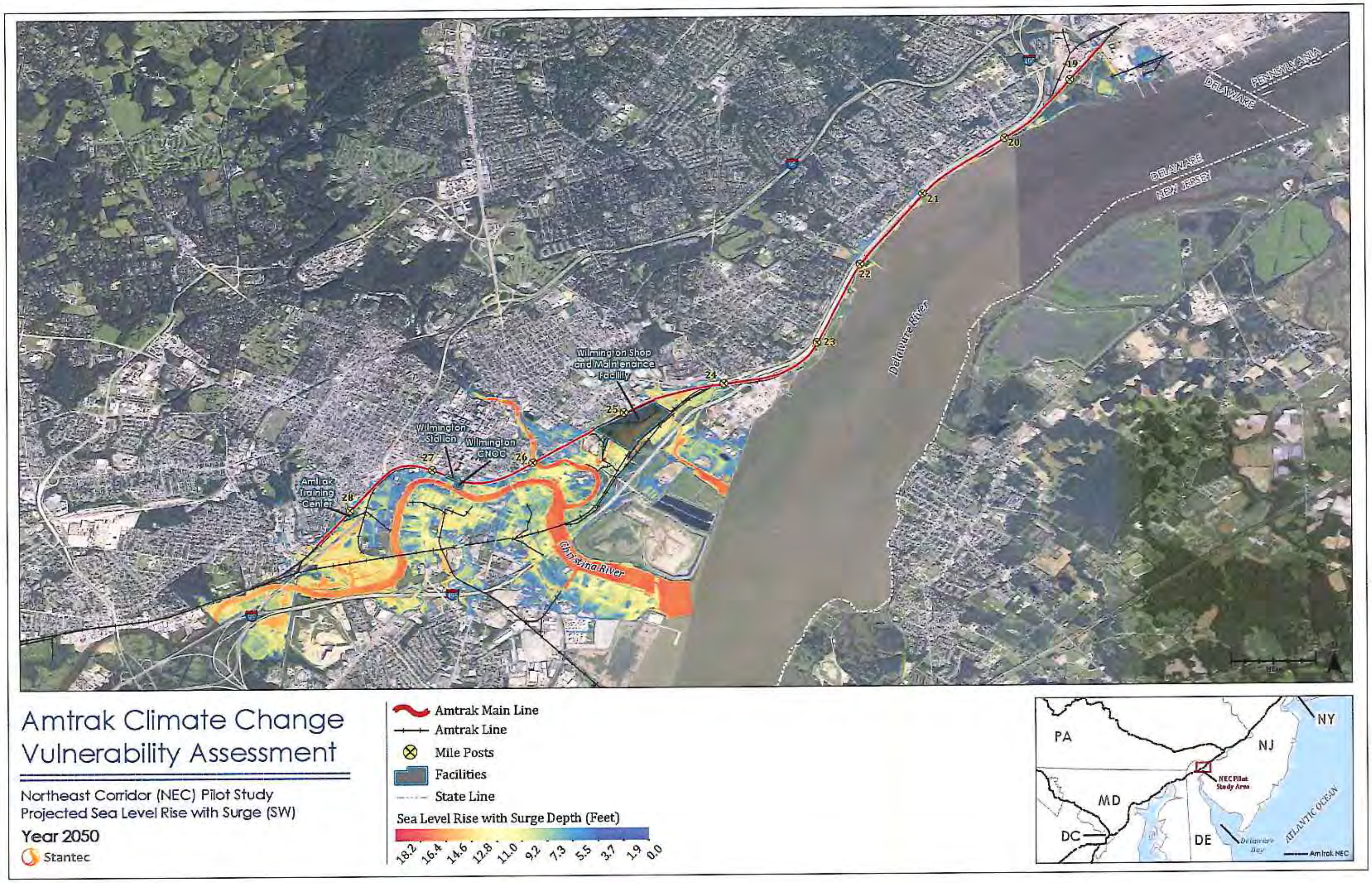


Figure 7. Storm Surge 2050

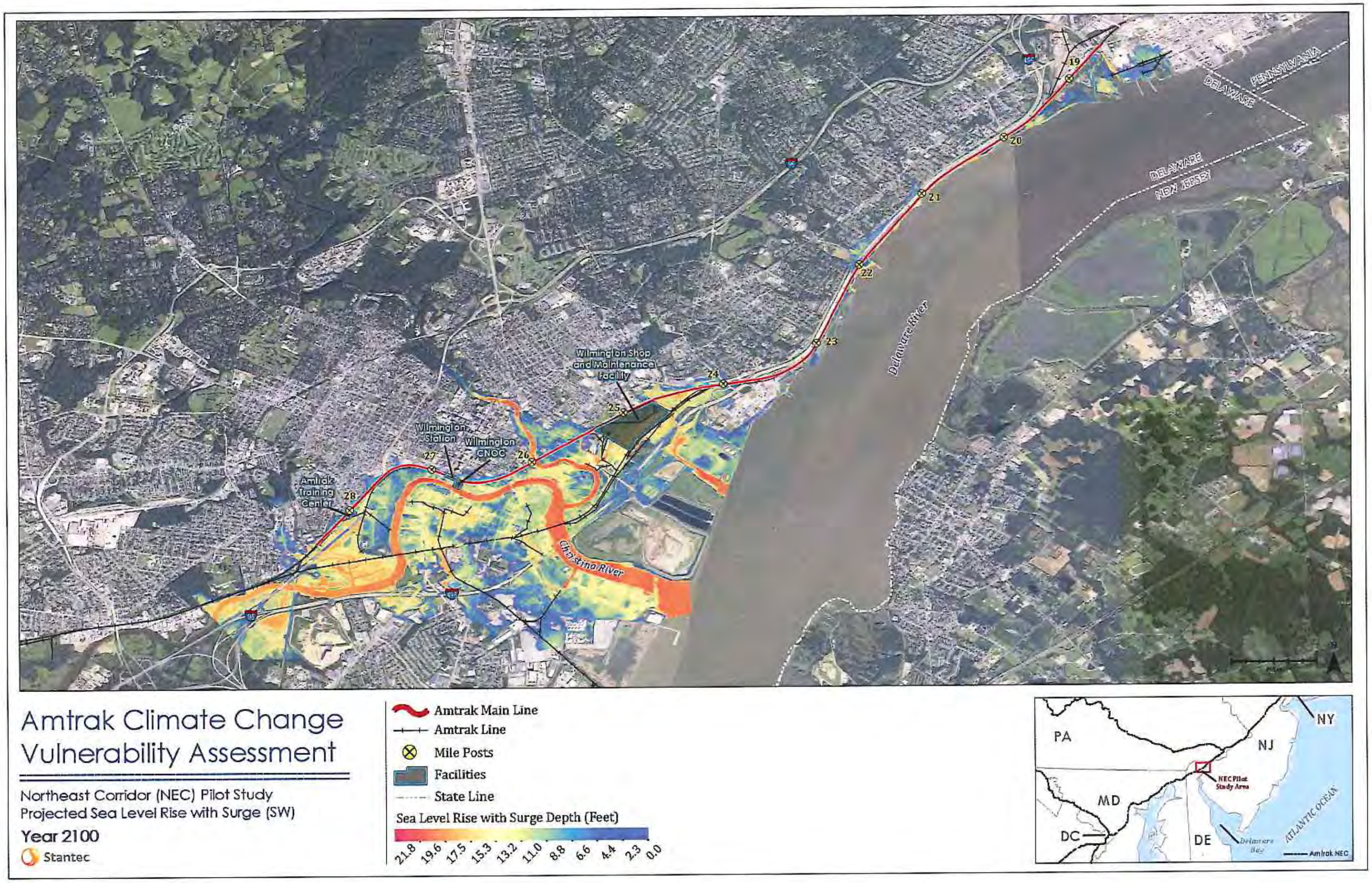


Figure 8. Storm Surge 2100

Hazus-MH Level 2 Modeling for Flood, Surge, and Hurricane Wind

Hazus-MH 2.2 was utilized to determine potential losses to Amtrak assets within the 10-mile Pilot Study area. Amtrak specific asset information was entered into Hazus-MH resulting in more reliable loss estimates. This modeling effort was completed for buildings and bridges within the Pilot Study area.

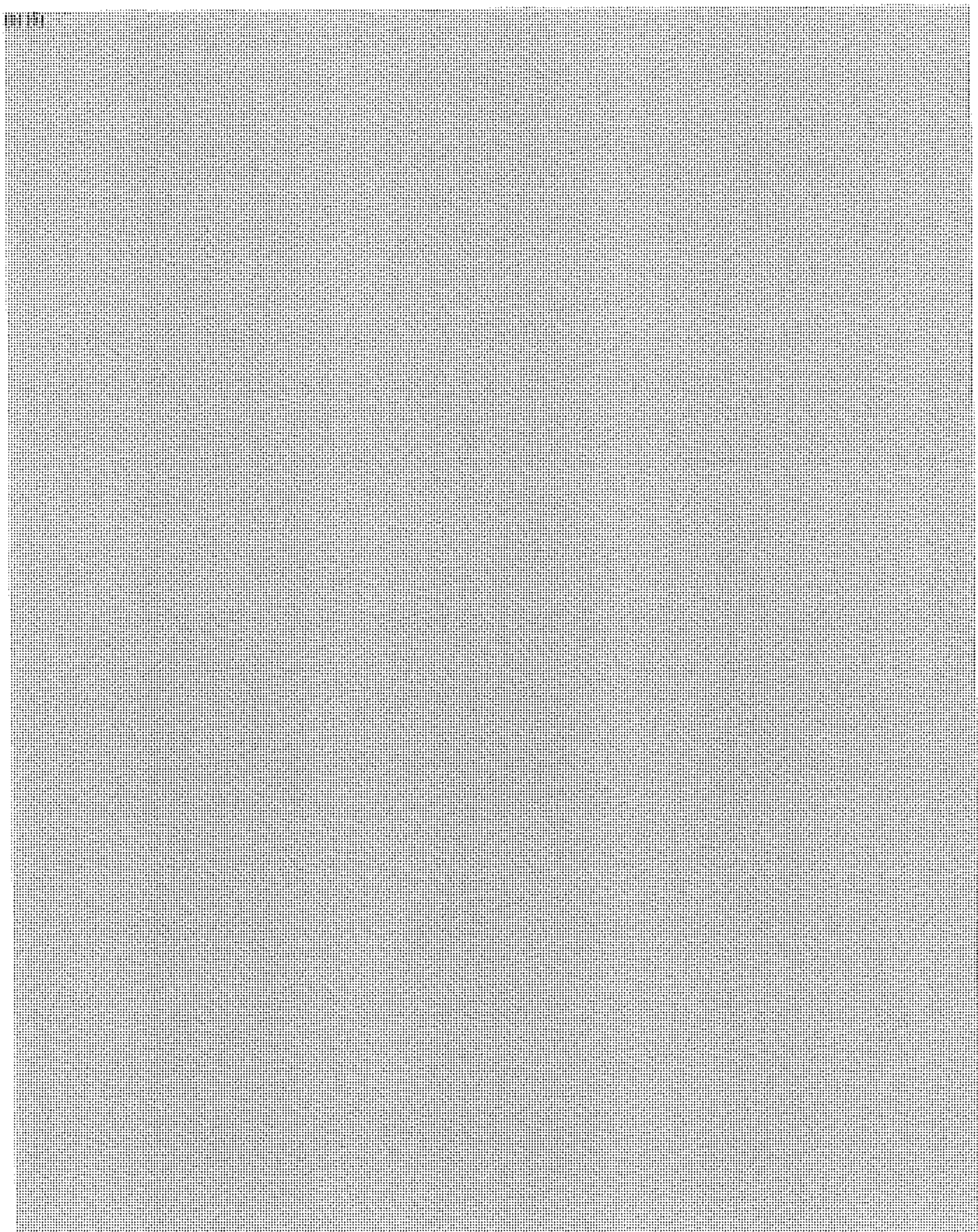
The Study Team made several inventory data enhancements to the Hazus-MH model as presented in Table 3.

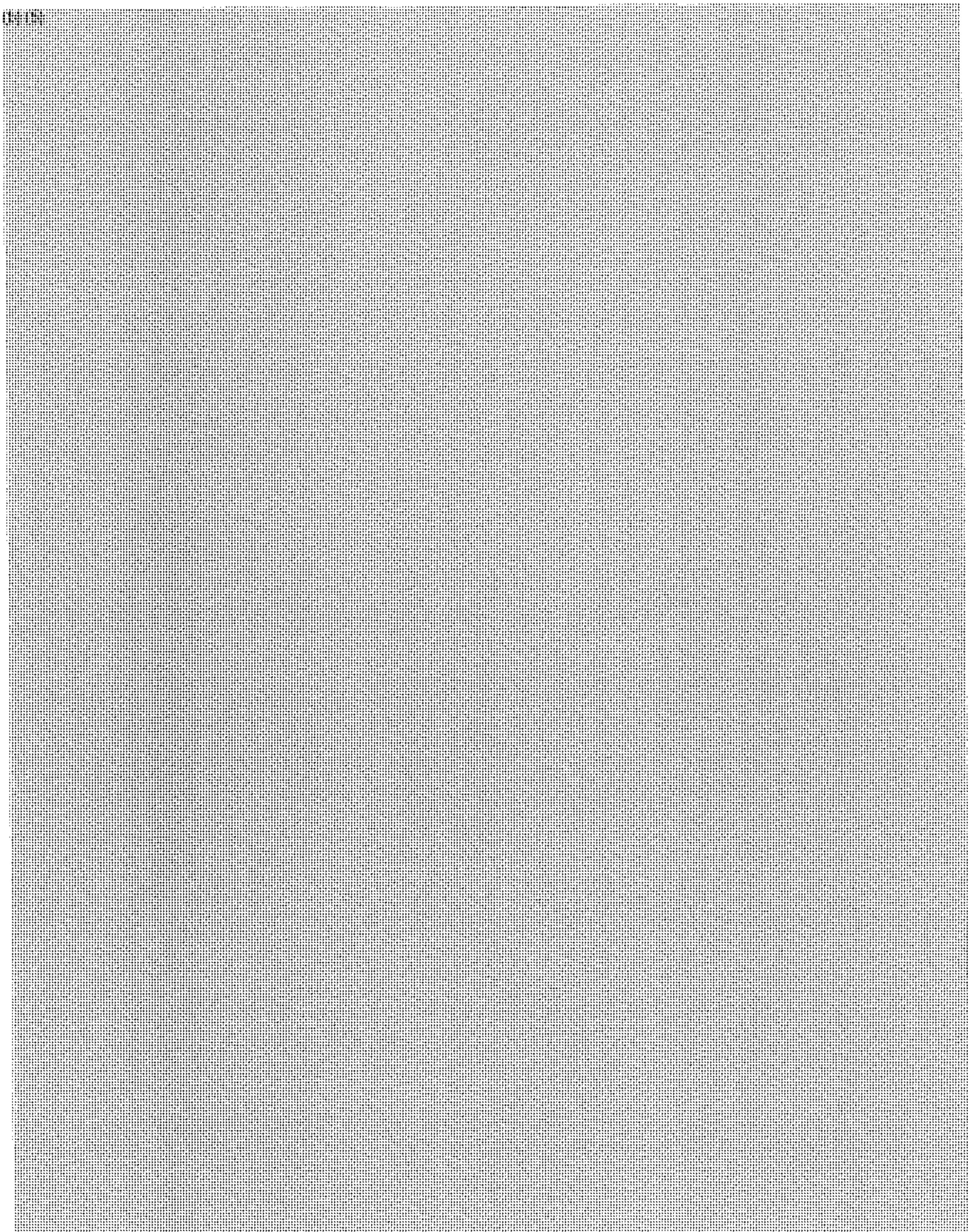
- Four identified stations and facilities were added to the model.
- Building characteristics including the associated replacement value, contents replacement value, first floor elevation (feet above the ground), and building type were incorporated, as provided by Amtrak.
- The building inputs are represented in Table 3.

Table 3. Building Inputs Applied in the Hazus-MH Model

Facility Name	Building Replacement Value	Building Content Value	Building Type	First Floor Height (ft)	Foundation Type
Wilmington Shops	(b) (5) [redacted]	(b) (5) [redacted]	Engineered Commercial Buildings, Low Rise	5	Slab on Grade
Consolidated National Operations Center	(b) (5) [redacted]	(b) (5) [redacted]	Engineered Commercial Buildings, Low Rise	4	Slab on Grade
Wilmington Station	(b) (5) [redacted]	(b) (5) [redacted]	Engineered Commercial Buildings, Low Rise	3	Slab on Grade
Training Center	(b) (5) [redacted]	(b) (5) [redacted]	Engineered Commercial Buildings, Low Rise	5	Slab on Grade

In addition, bridges were added to the Hazus-MH inventory as GIS point feature class. The bridge inputs provided by Amtrak are summarized in Table 4.





(b)(5)

[redacted]

In addition to building and bridge data, the Hazus-MH model was enhanced by using the three sea level change depth grids and three coastal storm surge depth grids created to reflect vulnerability in years 2020, 2050, and 2100 as input for the flood hazard. The coastal storm surge analysis did not include the velocity impacts of storm surge. Each of the six depth grids was modeled separately to determine potential flood losses to buildings and bridges for each interval. Lastly, the Hazus-MH hurricane wind model was run to reflect a 100-year return period (known as a probabilistic scenario). In this approach, the Hazus-MH model draws upon a storm database of probable hurricane events (over 100,000 fictitious events) to represent a 100-year event for the study area. The Hazus-MH model estimates the damage state probability (minor, moderate, severe, complete destruction) for each Amtrak facility within the Pilot Study area. The map showing the 100-year event is depicted as Figure 9.

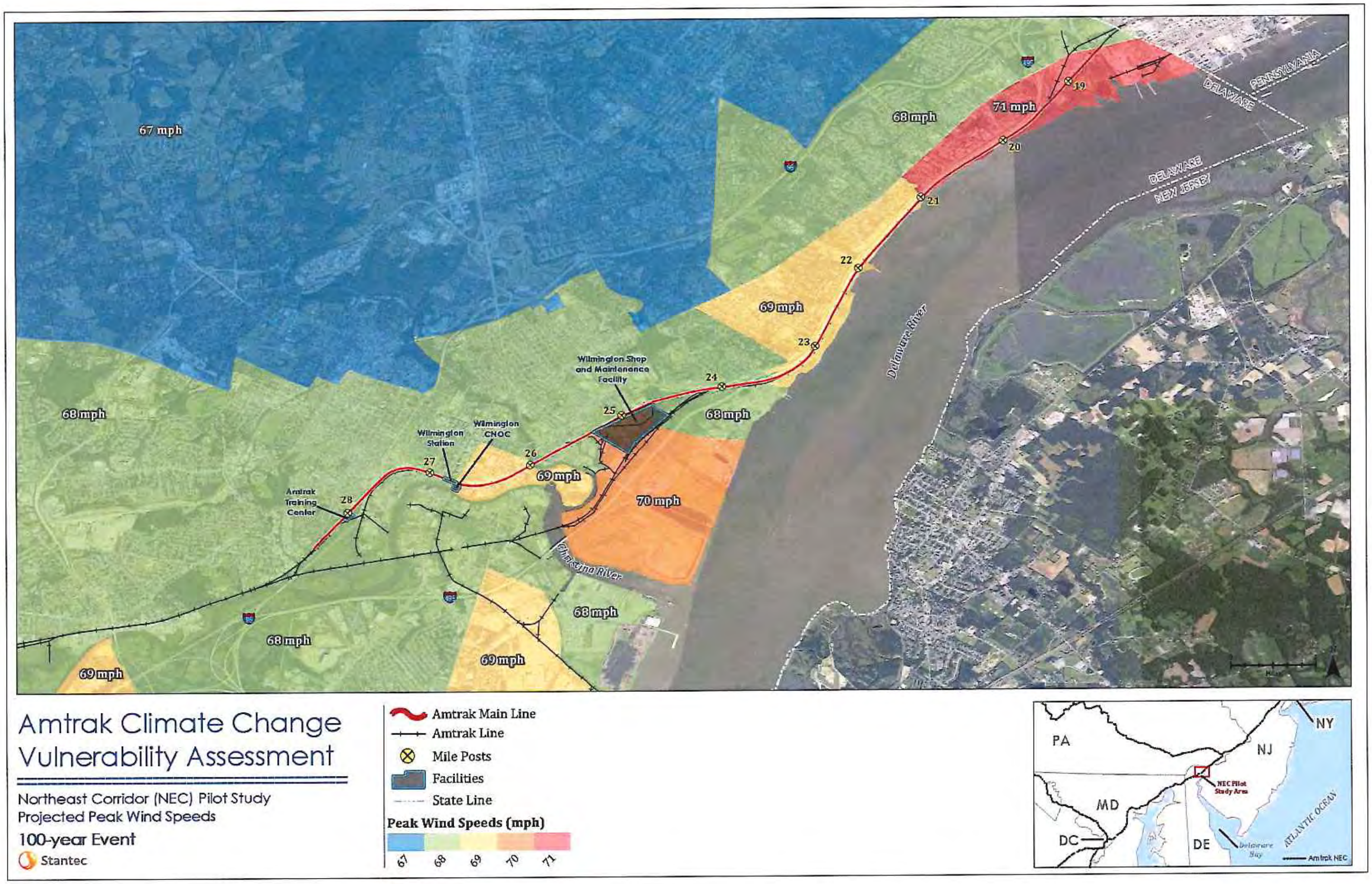


Figure 9. 100 Year event Project Peak Wind Speed

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2.2.3 Vulnerability Assessment Methodology (VAST and HVI)

The vulnerability of the selected assets were evaluated using two assessment tools VAST and HVI. These two tools provide a similar analysis, but have different strengths. The VAST tool is very useful when there are multiple indicators that can be utilized to evaluate the assets exposure, sensitivity and adaptive capacity to the selected climate variables. HVI is useful when there are linear assets that need to be segmented into comparable sections. Due to the Study Team's familiarity with both of these tools the assets were divided in order to assure the most representative analysis was completed. Table 5 illustrates the tools used to evaluate the various assets for each of the selected climate variables. Both tools generate an overall score and allow for the vulnerability to be ranked in the low, moderate or high category. Several of the assets did not lend themselves to a detailed quantitative analysis and therefore a general statement (GS) was presented outlining the potential vulnerabilities to the selected climate variable.

Table 5.Assets evaluated using VAST or HVI

Asset	Sea Level Rise/Storm Surge	Wind	Temperature	Precipitation
Track	HVI	GS	VAST	HVI
Facilities	VAST	VAST	GS	VAST
Bridges	VAST	GS	GS	VAST
Catanary	HVI	VAST	GS	VAST
Signals	HVI	VAST	GS	VAST
Roads	HVI	GS	GS	HVI

Steps of the Vulnerability Assessment:

The assessment process adopted for this Pilot Study consisted of six sequential steps, which were implemented for all asset types. The six steps are summarized as follows:

1. Identify assets and enter asset data
2. Identify climate stressors applicable for each asset type
3. Identify indicators that describe the vulnerability of assets
4. Collect indicator data
5. Insert data into tools and adjust scoring and ranking
6. Review results

A brief description of each step is presented below.

1. Identify assets and enter asset data

The study team used multiple resources to collect a preliminary list of assets within the Pilot Study area. These resources included asset information from Phase I of Amtrak Northeast Corridor Climate Change Vulnerability Assessment report, GIS data provided by Amtrak, and asset records provided by the asset group (Amtrak, 2014b). Over the course of several weeks, the study team met with several Amtrak experts to finalize the list of assets within the Pilot Study area. The analysis identified six major asset types located within the Pilot Study area:

- Amtrak facilities including substations
- Bridges
- Track
- Catenary
- Signal equipment
- Roadways

The Pilot Study focused exclusively on fixed physical assets that are owned or operated by Amtrak, and did not include consideration of any operations or rolling assets like rail cars. Data pertaining to each asset, such as general description and location coordinates were established after the complete list of assets was finalized with stakeholders.

2. Identify applicable climate stressors for each asset type

A multidisciplinary group of Climate Change specialists, rail experts, hydrology and hydraulics engineers reviewed the different asset categories located within Pilot Study area, and identified a preliminary list of climate stressors that could impact each asset type. In the context of this vulnerability assessment, a climate stressor was defined as projected changes in one of the following weather related variables, precipitation, storm surge, sea level rise, temperature, and wind.

During a group workshop, several Amtrak experts provided their feedback on potential impacts of climate change on each asset type, and the preliminary list was updated based on historical occurrences and expert judgment.

3. Identify indicators that describe the vulnerability of assets

To be able to accurately illustrate the vulnerability of the assets within the Pilot Study area, information that described the vulnerability of the assets was gathered. During a workshop that engaged a multidisciplinary group from Amtrak facilitated by the Study Team, an indicator exercise was performed to identify a preliminary list of applicable indicators, and determine the importance, and availability of data for those indicators. A final list of indicators that describe the vulnerability components was created after several phone interviews with Amtrak experts familiar with Amtrak's asset portfolio in the Pilot Study area, and internal meetings with the study group

4. Collect indicator data

A comprehensive and thorough data collection effort was initiated by the stakeholders involved in the assessment to obtain any available data that could describe the vulnerability of an asset. The indicator data used for this vulnerability assessment included both desktop review, as well as data based on expert input and judgment. Desktop analysis included quantitative data based on modeling results in conjunction with GIS and other technical modeling. Stakeholder judgment was based on information extracted from the wealth of knowledge obtained from Amtrak's staff regarding the Pilot Study area's assets and history.

Two surveys were created and distributed to Amtrak staff to obtain information on historical information on vulnerability of assets to certain climate stressors as well as facility criticality.

Asset Historical Vulnerability Survey:

- The intent of this survey was to gather historical information about the vulnerability of the assets located within the 10 mile Pilot Study area. Information about historical impacts from the identified climate stressors provided valuable information about future vulnerabilities of a specific area or asset to the same historical impacts. An interactive map showing all assets within the Pilot Study area was attached to the survey, and responders were able to provide their input of impacted assets, as well as any other information to describe how assets were impacted.

Facility Criticality Survey:

- The intent of this survey was to gather information on the criticality of the facilities included in the vulnerability assessment within the Pilot Study area. Criticality in this survey attempted to extract information on which facilities are critical to Amtrak in regards to operations, revenue, safety/emergency response, and security. This information was used when evaluating the adaptive capacity component of vulnerability.

5. Insert data into the tools and adjust scoring and ranking

Qualitative and quantitative asset data collected and modeled in Step 4 were tabulated and assigned to match each of the identified assets before inserting them into the VAST and HVI tools. Both tools allow for weighing of the different indicators based on their significance to the total vulnerability score.

6. Review results

Final vulnerability scores for each asset in relation to each climate stressor are automatically calculated in VAST and HVI. The assets can then be ranked based on their overall score as well as grouped into the three vulnerability categories; low, moderate, and high. These results will help guide decision makers and planners into identifying the most effective adaptive measures for reducing the vulnerability of that specific asset to a certain climate stressor, and therefore reducing its risk.

2.2.4 Vulnerability Assessment Scoring Tool (VAST)

VAST was developed by the U.S. Department of Transportation (U.S.DOT) to help transportation planners and engineers conduct a quantitative and qualitative indicator based screening to determine the degree and extent in which transportation infrastructure, and their components, are able to cope with the impacts of climate change (U.S. DOT, 2014).

VAST is a user friendly tool that allows for the design of a framework based on the required level of detail or available asset data. It uses both qualitative data, such as expert judgment and stakeholder input, in tandem with quantitative technical data to describe the characteristics of an asset that will determine an asset's vulnerability; these asset characteristics are called indicators.

VAST examines the impacts of extreme weather and climate change on a certain asset by collecting data on three components of vulnerability. These vulnerability components are:

- Exposure
- Sensitivity
- Adaptive capacity

Exposure is defined as the "nature and degree to which an asset is exposed to significant climate variations" (U.S. DOT 2014). Exposure indicators are related to climate conditions and whether the asset is located in an area that will be subject to impacts of climate change or extreme weather.

Sensitivity is defined as "the degree to which an asset is affected, either adversely or beneficially, by climate related stimuli" (U.S. DOT 2014). Sensitivity is associated with the characteristics of the structure's design and material, as well as the threshold in which climate impacts are felt. The higher the threshold due to improved design and material, the more resilient the structure becomes. Sensitivity explains why some assets fail while other assets function well under exposure to the same changes in climate stressors.

Adaptive Capacity is defined as "the ability of a system, or asset to adjust to the impacts of climate change to moderate potential damages, to take advantage of opportunities, or to cope with consequences" (U.S. DOT 2014). Adaptive Capacity is associated with the capacity of the asset's surrounding environment to adjust to the asset's failure or damage. If the rate of projected climate change is faster than the adaptive capacity of a system, then the system is considered vulnerable.

In any VAST assessment, the three vulnerability components are weighted then combined for each climate stressor to come up with the overall vulnerability of each asset. The following equation demonstrates how vulnerability is calculated in VAST.

Vulnerability = Exposure (i) + Sensitivity (i) + Adaptive Capacity (i)

Where the term "(i)" represents a percentage of vulnerability component weight, established through consultation with experts and stakeholder input.

VAST Methodology

VAST was selected as one of the main assessment tools for this study and was applied to directly evaluate certain assets and climate stressors. The selection of VAST for this purpose was based on two main elements:

- Suitability of VAST to assess this specific type of asset; VAST is more successful in assessing independent assets versus linear assets
- Availability of indicator data that describes the three vulnerability components

As described in Section 2.2.3. once the assets and climate stressors have been identified the next step within VAST is to identify the indicators that describe the three vulnerability components; exposure, sensitivity, and adaptive capacity.

The indicator library from the VAST tool was a core source of indicators for assets such as tracks, roadways and bridges. Indicators on other assets such as facilities, catenary, and signal equipment, which were not included in the VAST indicator library, were determined based on discussion with experts familiar with the Pilot Study area. The indicators selected for this vulnerability assessment is listed in Table 6.

Table 6.Final List of Indicators Selected for the Pilot Study Vulnerability Assessment

Exposure Indicator	Sea Level Rise	Storm Surge	Wind	Temp	Precipitation
Modeled Inundation Depth	✓	✓			
Proximity to coastline	✓	✓			✓
Asset Elevation	✓	✓			✓
Location in FEMA Flood Zone					✓
Change in number of consecutive days with precipitation					✓
Change in Annual maximum or Minimum Temperature				✓	
Change in number of consecutive days /year above or below a Threshold				✓	
Modeled Wind Speed			✓		

Sensitivity Indicators	Sea Level Rise	Storm Surge	Wind	Temp	Precipitation
Past Experience with Extreme Weather	✓	✓	✓	✓	✓
Asset Elevation	✓	✓			✓
Impaired Access to asset	✓	✓			✓
Location of key equipment within facility	✓	✓			✓
Building Material Type					

Sensitivity Indicators	Sea Level Rise	Storm Surge	Wind	Temp	Precipitation
Percent inundated	✓	✓			
Height of Building		✓	✓		
Reliance on electric power	✓	✓			✓
Proximity to coast	✓	✓	✓		✓
Age of asset	✓	✓	✓		✓
Operations impacted by wind			✓		
Condition of bridge substructure/super structure and deck	✓	✓			✓
Maintenance Frequency				✓	✓
Roof Material			✓		
Percent of asset within flood zone					
Percent of asset abutting trees			✓		
Number of signals				✓	
Number of turnouts				✓	
Number of interlockings				✓	
Rail curvature				✓	
Ballast material type				✓	✓

Adaptive Capacity Indicators
Facility criticality to operations of Amtrak
Critical from a revenue standpoint to Amtrak
Criticality from a safety/emergency response standpoint to Amtrak

Adaptive Capacity Indicators
Criticality to security of Amtrak
Historical repair/replacement cost
Road function class
Access to critical Amtrak facilities of operations
Evacuation route
Presence of bridges/signals/interchange utilities

During the data collection phase, the study team was able to obtain various types and forms of data. Data were processed for conversion into a format compatible with VAST. The data sources relied upon for the three different vulnerability components are as follows:

- Exposure data: GIS data provided by Amtrak, LiDAR data, output of technical modeling such as Hazus, Coupled Model Intercomparison Project (C-MIP) analysis, FEMA DFIRMs, and other quantitative data sources were used in identifying exposure indicator data.
- Sensitivity data: Maintenance records, surveys of historical extreme weather incidents that were distributed to Amtrak staff and phone interviews with knowledgeable Amtrak sources were used to identify sensitivity indicators data.
- Adaptive capacity data: a criticality survey was distributed to various Amtrak staff, as well as GIS analysis and phone interviews with Amtrak knowledgeable sources.

Qualitative and quantitative asset data were tabulated and assigned to match each of the identified assets before inserting them into VAST. Vast encompasses two options of scoring and weighing of data, which enable the calculation and comparison of vulnerability scores for all assets.

1. Data conversion into scores
2. Indicator weight adjustment

All indicator data were converted into scores from 1 to 4, based on the impact on vulnerability. This process enabled the normalization of both qualitative and quantitative data which allowed for proper scoring of assets. VAST allows for weighing different indicators within each vulnerability component based on their significance for the total vulnerability component score. The VAST tool ranks the most vulnerable assets based on the vulnerability score. VAST presents the assessment results in the following format:

- Result tables that display the overall score for each asset type in relation to each climate stressor
- The top vulnerable assets for each climate stressors
- Asset score sheet, which includes all indicator data for each of the assessed assets, and a breakdown of the vulnerability score.

Results of VAST analysis for all assets types can be found in Chapter 5. These results were useful in identifying the assets at risk to being impacted by a certain climate stressor.

2.2.5 Hazard Vulnerability Index (HVI)

The HVI provides a method of comparing and evaluating asset vulnerabilities. For the Pilot Study, pertinent transportation assets are incorporated into the HVI calculations including tracks, catenaries, signals, and roadways. Climate stressors considered for HVI focus on the flood hazard and include the following sources for year 2050 and 2100 projections:

- Sea Level Rise
- Storm Surge
- Precipitation

HVI calculates vulnerability scores for each 0.5 mile stretch of track based upon critical parameters such as percent of infrastructure inundated by flood water, maximum depth of flood inundation, distance to coast, and historical data. As each track segment is evaluated and scored, the HVI scores correlate to the following vulnerability categories: low, moderate, or high. The range of HVI scores is always a value from 0 to 1.0 because each parameter's value is divided by the maximum value for the entire Pilot Study area. This process of normalizing assists in creating HVI scores where the higher HVI scores are associated with greater vulnerability. The vulnerability categories associated with the HVI scores are presented here:

Sea Level Rise and Storm Surge for Tracks

- Low - HVI scores less than 0.10
- Moderate – HVI scores between 0.10 and 0.20 (including 0.10)
- High – HVI scores greater than and equal to 0.20 (including 0.20)

Sea Level Rise and Storm Surge for Catenaries, Signals, and Roads

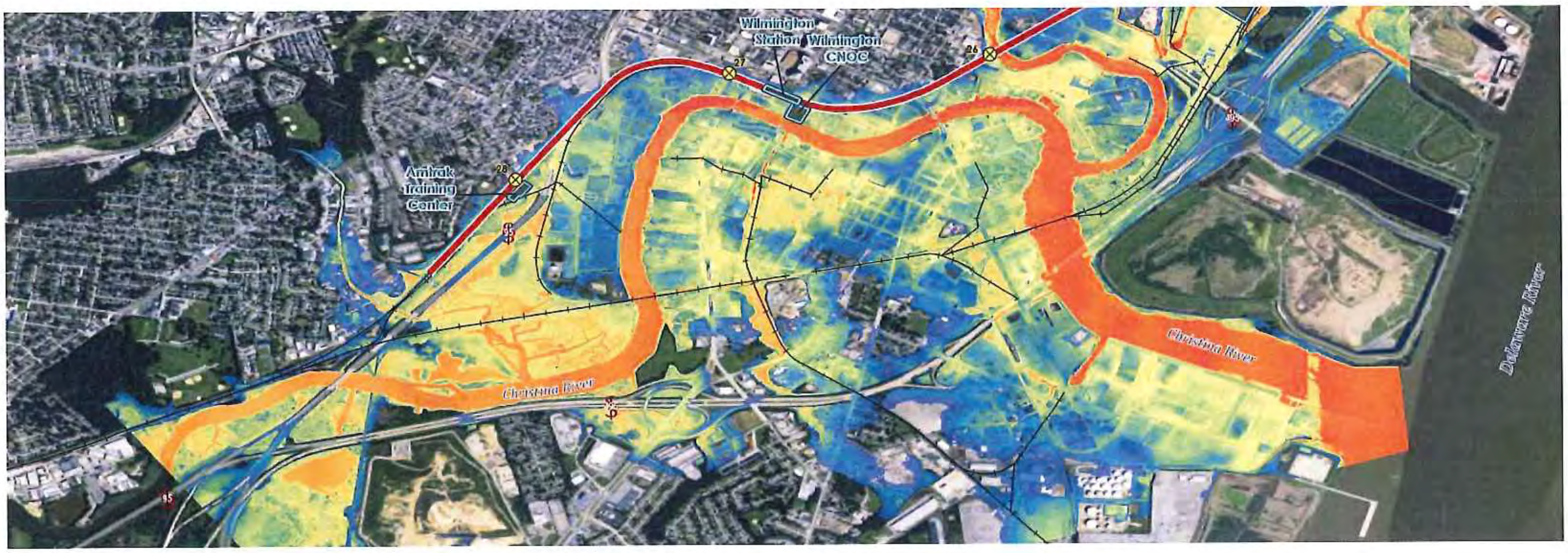
- Low - HVI scores less than 0.10
- Moderate – HVI scores between 0.10 and 0.30 (including 0.10)
- High – HVI scores greater than and equal to 0.30 (including 0.30)

Precipitation for Tracks and Roads

- Low - HVI scores less than 0.10
- Moderate – HVI scores between 0.10 and 0.30 (including 0.10)
- High – HVI scores greater than and equal to 0.30 (including 0.30)

The HVI scores utilize a weighting factor based on the importance of the indicator to the overall vulnerability. An example HVI formula has been included in Appendix A.

3.0 Pilot Study Area Relevant Assets



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3.0 Pilot Study Area Relevant Assets

3.1 Importance of Identifying Relevant Assets

Identifying the relevant assets within the project area is an essential step to achieving an analysis that is targeted and accurate. The assets identified to be included in the overall assessment came from three main sources, the *Northeast Corridor (NEC) Climate Change Vulnerability Assessment Phase I: Final Report* completed by Amtrak in 2014, GIS data provided from Amtrak, and in person interviews with Amtrak staff knowledgeable of Amtrak's assets (Amtrak, 2014b). Similar to the Phase I study, only fixed and physical assets were considered for this Pilot Study and did not include rolling stock. The identified assets were located immediately along the right-of-way of the NEC and within the 10-mile Pilot Study area.

Determining asset vulnerability requires asset information such as condition, age, location, and elevation. Different Amtrak departments provided information identifying which asset types were essential to the operation of the passenger rail trains along the NEC. Asset groups identified in this process included track, bridges, catenaries, signals, identified emergency access roads, four essential facilities, and two electrical substations. The four facilities; Wilmington Station, Wilmington Shops, Wilmington Training Center and the CNOC facility were identified due to their location along the 10-mile Pilot Study area, their critical operations value and their vulnerability to the selected climate change variables. In this section, general vulnerabilities to a given asset type is provided, and more specific discussion on Amtrak specific vulnerabilities is provided in Chapters 5.0 and 6.0.

Each of the assets was assigned a project asset ID code, consisting of an alphabetic character to identify the asset type followed by a sequential number. This unique identifier will remain with the asset throughout the analysis and data reporting, in order to allow for easy translation between study documents and to avoid mislabeling and confusion. A detailed memorandum with asset information in tabular format with supporting GIS maps was prepared for Amtrak as part of this study (available upon request) and is the basis for the development of Chapter 3.0.

3.2 Facilities

As specified by Amtrak, analysis of the Pilot Study area included focusing on four facilities, Wilmington Station, Wilmington Shops, Wilmington Training Center, and the CNOC. These facilities were chosen because their relative importance to Amtrak's operations and location within the 10-mile study area. The Wilmington Station is an active rail station for Amtrak and SEPTA. The Wilmington Shops is a large rail yard use to perform maintenance and stage/store maintenance equipment. The Wilmington Training Center is a facility used to train Amtrak staff. The CNOC facility (b) (5) [redacted] (b) (5) [redacted] (b) (5) [redacted] Figure 10 depicts the location of these facilities.

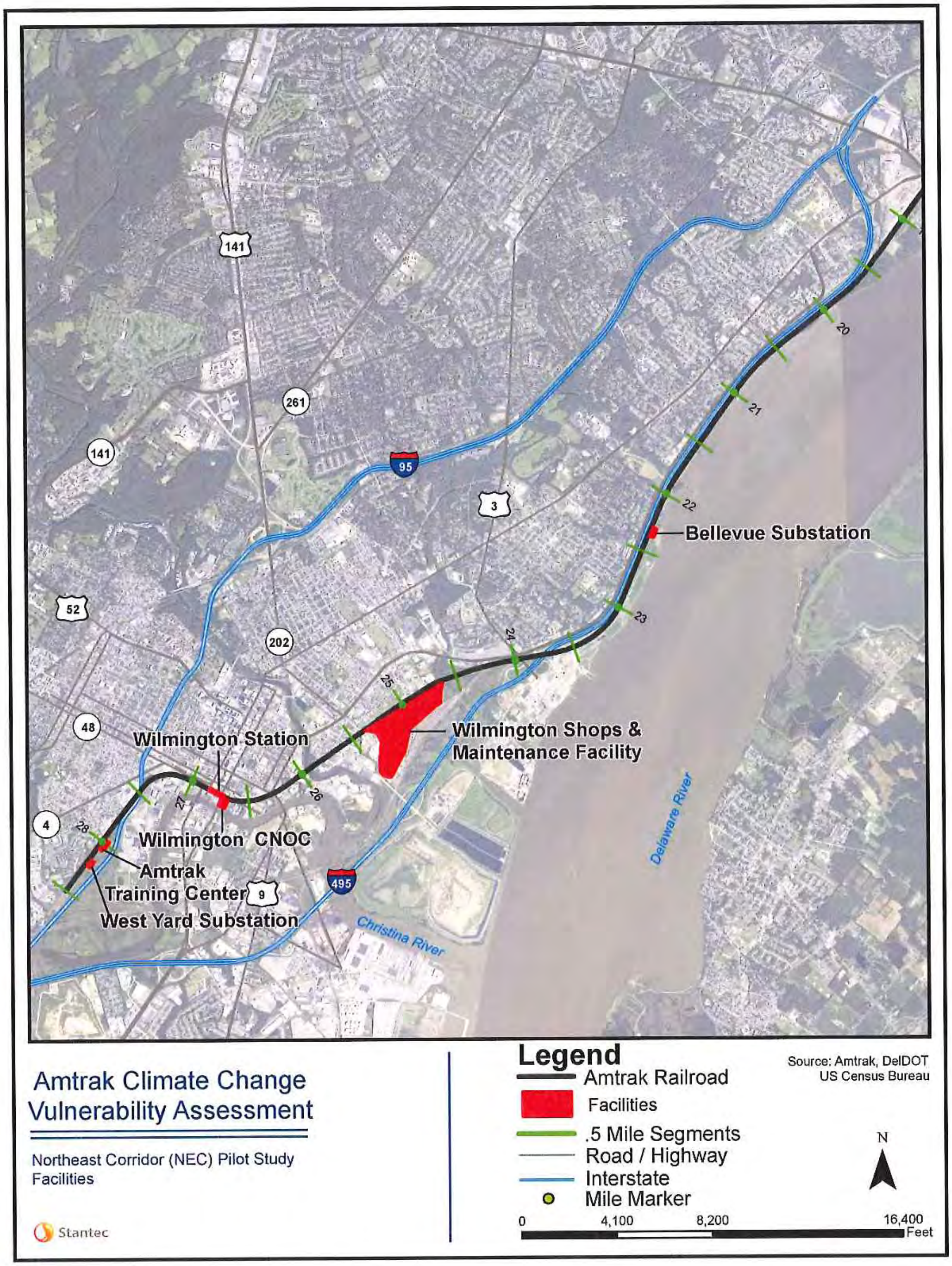


Figure 10. Facilities Included in the Vulnerability Assessment

Why are these facilities vulnerable? Facilities have the potential to be impacted by precipitation, sea level rise and storm surge. These facilities are close to several riverine systems as well as the Delaware River, Delaware Bay, and Atlantic Ocean. Buildings are at risk to inundation due to heavy precipitation, sea level rise, or subject to temporary flooding from storm surge (see Figure 11). Secondary vulnerabilities may include loss of access road usability, flooding of the parking lots, or impacts to power sources. These buildings can also be damaged by wind associated with storms.

Figure 11. Flooding near Amtrak Training Facility (2009), Wilmington, DE (photo source: Amtrak)

3.3 Bridges

Bridges identified in the Amtrak database include both undergrade grade and overhead bridges. Below grade bridges are those where the track crosses over a feature such as road, water or land. Overhead bridges are those that carry a feature such as a road over the tracks. Since overhead bridges do not directly affect the functionality of the line and are often not owned by Amtrak they were not included in this analysis. Below grade bridges include all bridges that support the track and can cross both land and water features. Working under the assumption that the bridges crossing over water will be more vulnerable to inundation from sea level rise, increase storm surge and precipitation than those traversing other land features only undergrade bridges crossing over a watercourse were included in the analysis. Figure 13 depicts the location of these bridges.

Why are bridges vulnerable? Bridges are vulnerability to sea level change, storm surge, increased precipitation and extreme temperature change. Heavy precipitation can increase flow velocities and change flow depths causing scour of bridge approaches, piers, and abutments and damage to other supporting infrastructure. Temporary or permanent inundation can lead to long term deterioration of the bridge materials. Increased temperature (heat) can cause thermal expansion in the bridge joints.

Figure 12. Perkin Creek Bridge located within the Pilot Study Area (b) (5) [redacted] ***Example of bridge crossing water*** **(photo source: Amtrak)**

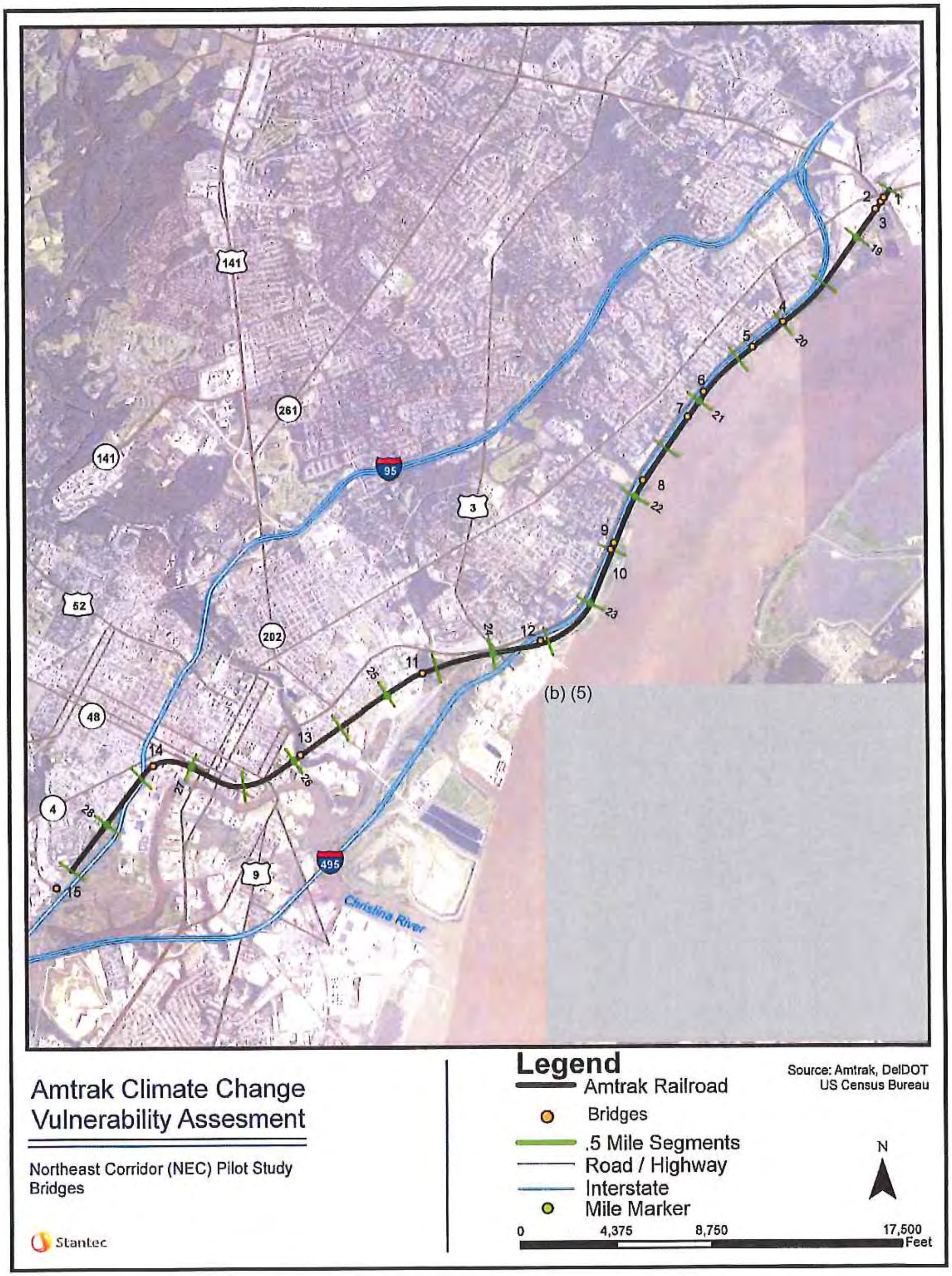


Figure 13. Bridges Included in the Vulnerability Assessment

3.4 Track including Turnout and Interlocking Infrastructure

The main line track from mile post 18.5 to 28.5 was included in this analysis including turnouts and interlockings along this section. Interlockings (Figure 14) and Turnouts (Figure 14) were included because they serve as junction points and therefore understanding their vulnerability is important to the overall line functionality. The analysis looked at the segments in 0.5 mile increments to facilitate the assessment. Within the study area there are a total of seven interlocking infrastructure sites and 94 turnouts. (b) (5) [redacted]

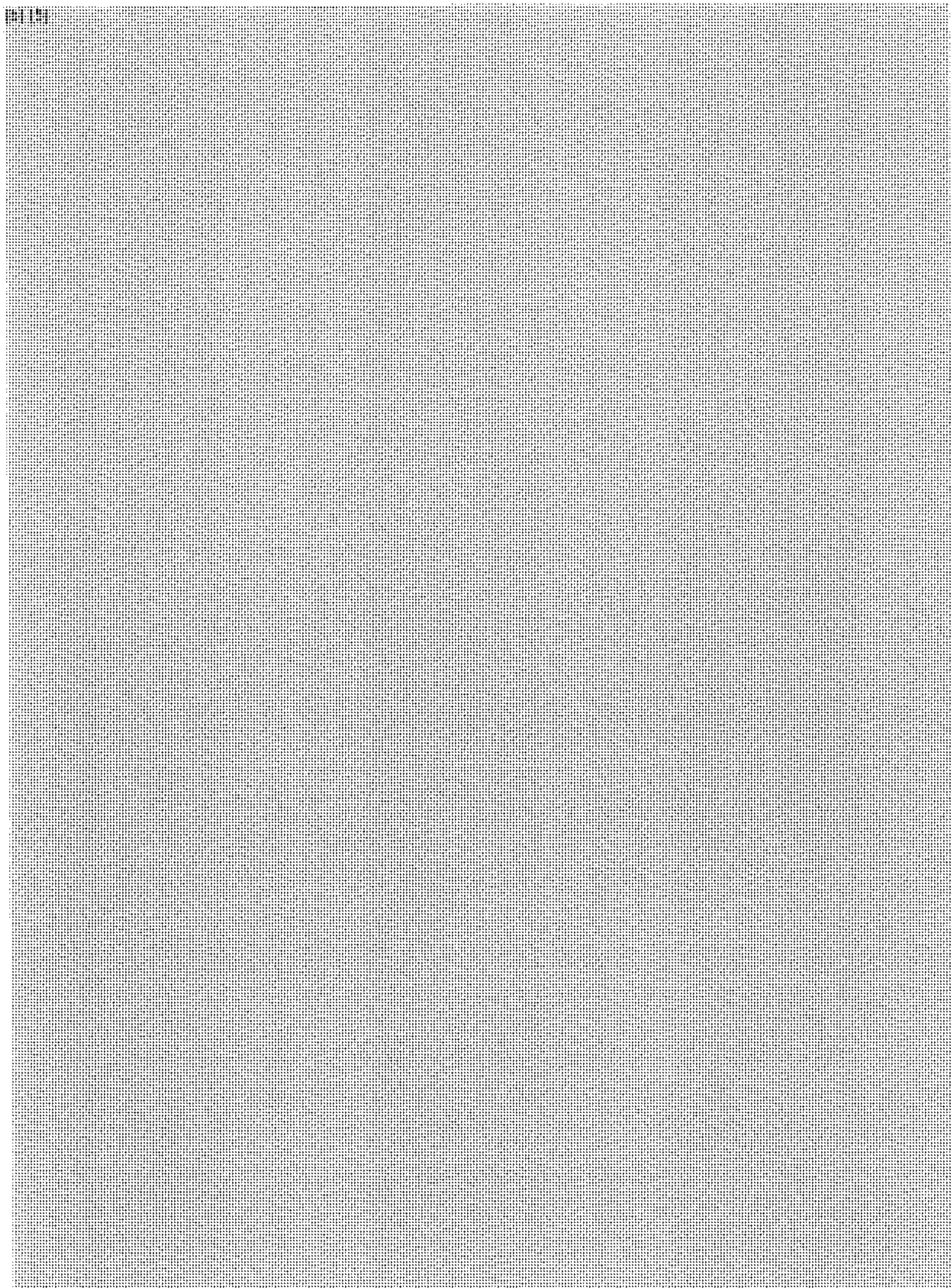
Figure 14. Interlocking Track Example

(Metro Transit-St.Louis)

Figure 15. Turnout Track Example

(Teve, 2006)

Why is track vulnerable? Track is vulnerable to inundation from precipitation, sea level rise, storm surge flooding, as well as to extreme temperatures. Permanent or temporary inundation of rail restricts service and impacts the ballast and rail roadbed. An increase in extreme high temperature days can potentially increase the material stress induced on the tracks, cause switch failures, and lead to an increase in track expansion and buckling. Railroads including Amtrak have policies in place to reduce train operating speeds when temperatures exceed a maximum threshold.



3.5 Catenaries

A total of (b) (5) [redacted] catenary poles exist within the 10-mile Pilot Study area. These poles are critical to operations because they support the catenary lines that provide power to the trains. The catenary systems were assessed as a group within a 0.5 mile segment. The locations of the catenary systems including poles are identified in (b) (5) [redacted]

Why are Catenaries vulnerable? Catenaries could be vulnerable to inundation from precipitation, sea level rise and storm surge flooding as well as wind and extreme temperatures. Inundation and flooding can weaken foundations that support each pole. In combination with the weakening of poles from inundation, wind can blow projectile material or vegetation at catenary systems thereby interrupting rail service. An increase in extreme high temperature can cause catenary lines to expand and sag reducing clearance and in some cases interrupting rail service.

3.6 Signal Equipment

The signal equipment includes signals equipped with mounts on signal bridges, cantilevers, on the ground, along with the signal housings. A total of (b) (5) [redacted] signals were identified within the Pilot Study area. (b) (5) [redacted] depicts the location of the signals and signal housings.

Why is signal equipment vulnerable? The vulnerability of these assets is a function of their location along the corridor tracks and where they are mounted at each location. Signals mounted on bridges and cantilevers are most vulnerable to wind, and those located on the ground are vulnerable to inundation from precipitation, sea level rise and storm surge flooding. Electrical equipment can also be vulnerable to extreme heat that can lead to conditions that cause critical components within these systems to melt or malfunction.

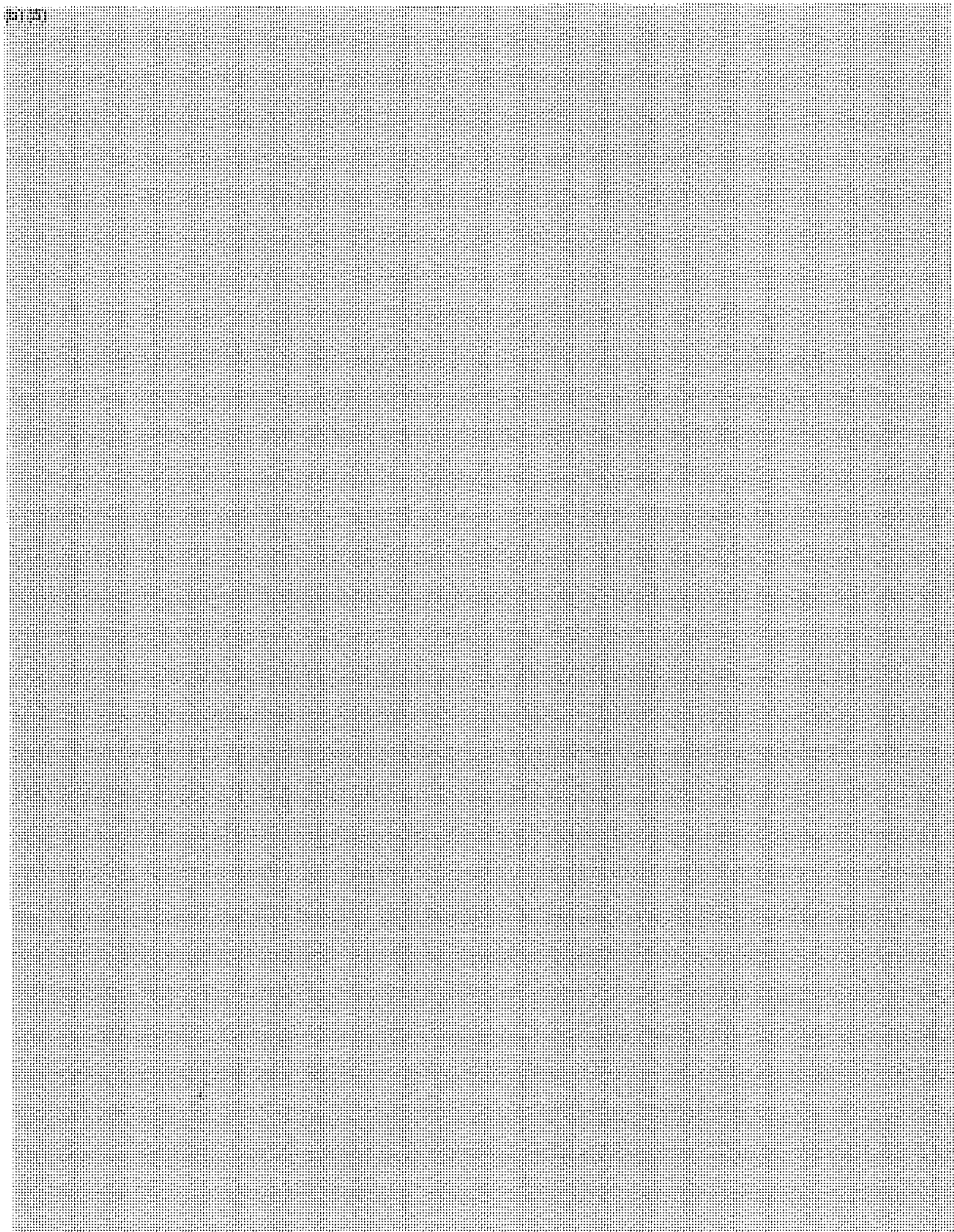
3.7 Traction Substation (including Electrical Systems)

There are two traction substation identified in the Pilot Study area. The substations identified are known as the Bellevue Substation (Substation #12), which is located close to mile post 22 along the shoreline of the Delaware River. Substation #13, the West Yard Substation, is located south of Wilmington, Delaware in close proximity to the Amtrak Wilmington Training Center. The locations of the substations are shown in Figure 19.

Why are substations vulnerable? Traction substations, including electrical systems are vulnerable to inundation due to precipitation, sea level rise and storm surge as well as potential damage caused by wind during extreme weather events. Increases in the number of days at higher temperatures can also have impacts on the system.

(b)(5)

[redacted]



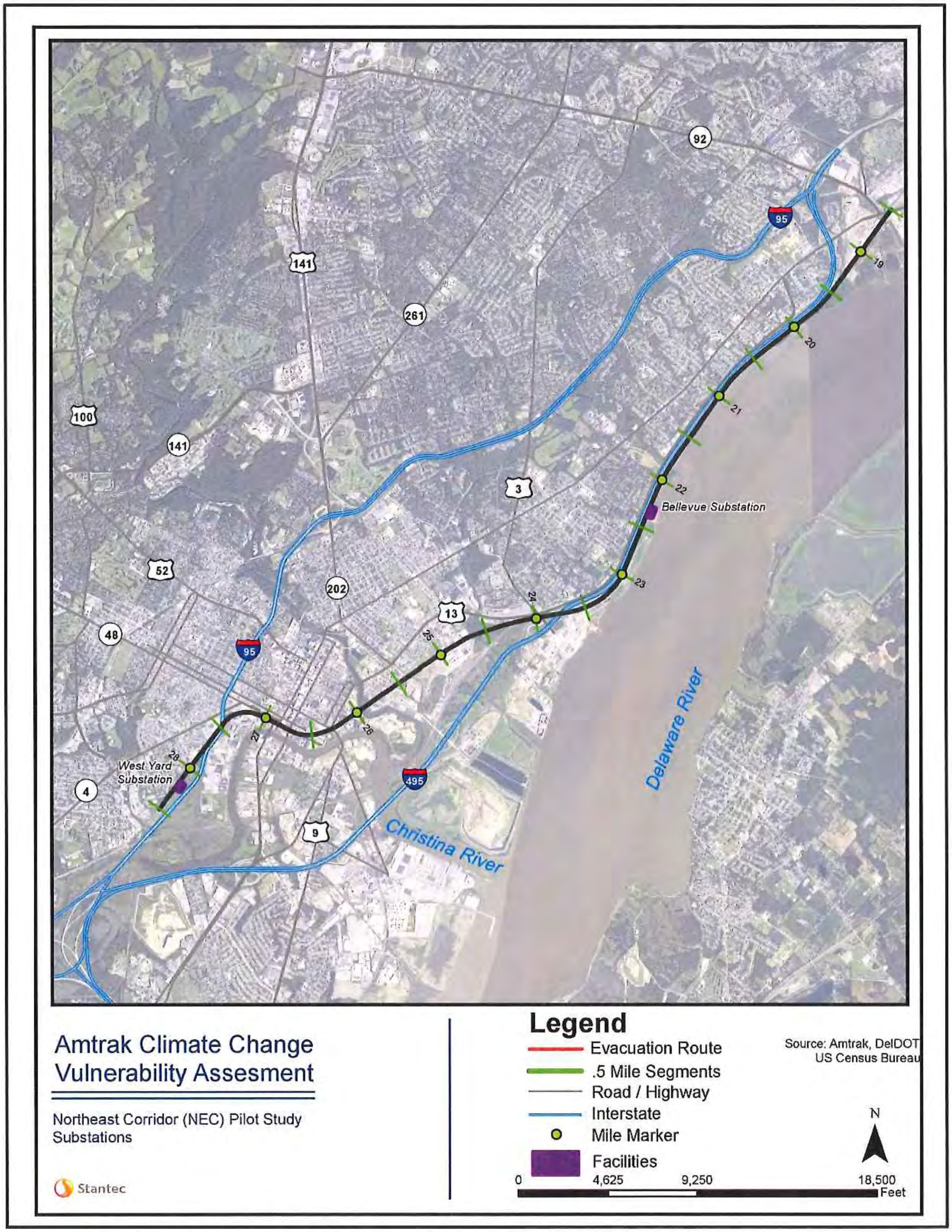


Figure 19. Amtrak Substations included in the Vulnerability Assessment

3.8 Roads

Roads within a one mile buffer of the Amtrak 10-mile track section were extracted from the publically available DelDOT Centerline digital file. This centerline road data was updated in May 2014 and includes the roads within the State of Delaware's transportation network. The emergency routes were identified and were the focus of this study due to their importance during storm events. Figure 20 depicts the roads included in the assessment.

Why are these assets vulnerable? Roads are generally susceptible to sea level rise and storm surge inundation as well as localized flooding from precipitation. Emergency roads were the focus of this study due to their critical nature.

3.9 Summary of Asset Information

Identifying the vulnerable assets within the Pilot Study area is one of the first steps because it directs the magnitude and the depth of the analysis. It is important to first evaluate which assets are exposed or sensitive to the selected climate change variables and essential to Amtrak's operations to assure that the assessment is focused only on the necessary assets. The challenge to gathering asset information is the extent of information needed in order for the assessment to be meaningful. The first essential information is GIS information that identifies the accurate location of the assets. Once the assets have been identified to be vulnerable, critical additional information regarding the history of the asset and the current state of the asset is needed. Amtrak was able to provide very useful GIS locational information as well as schematics describing most of the assets. Qualitative information regarding the asset's past history with flooding, maintenance schedule, and current condition were provided and applied for use within the assessment tools.

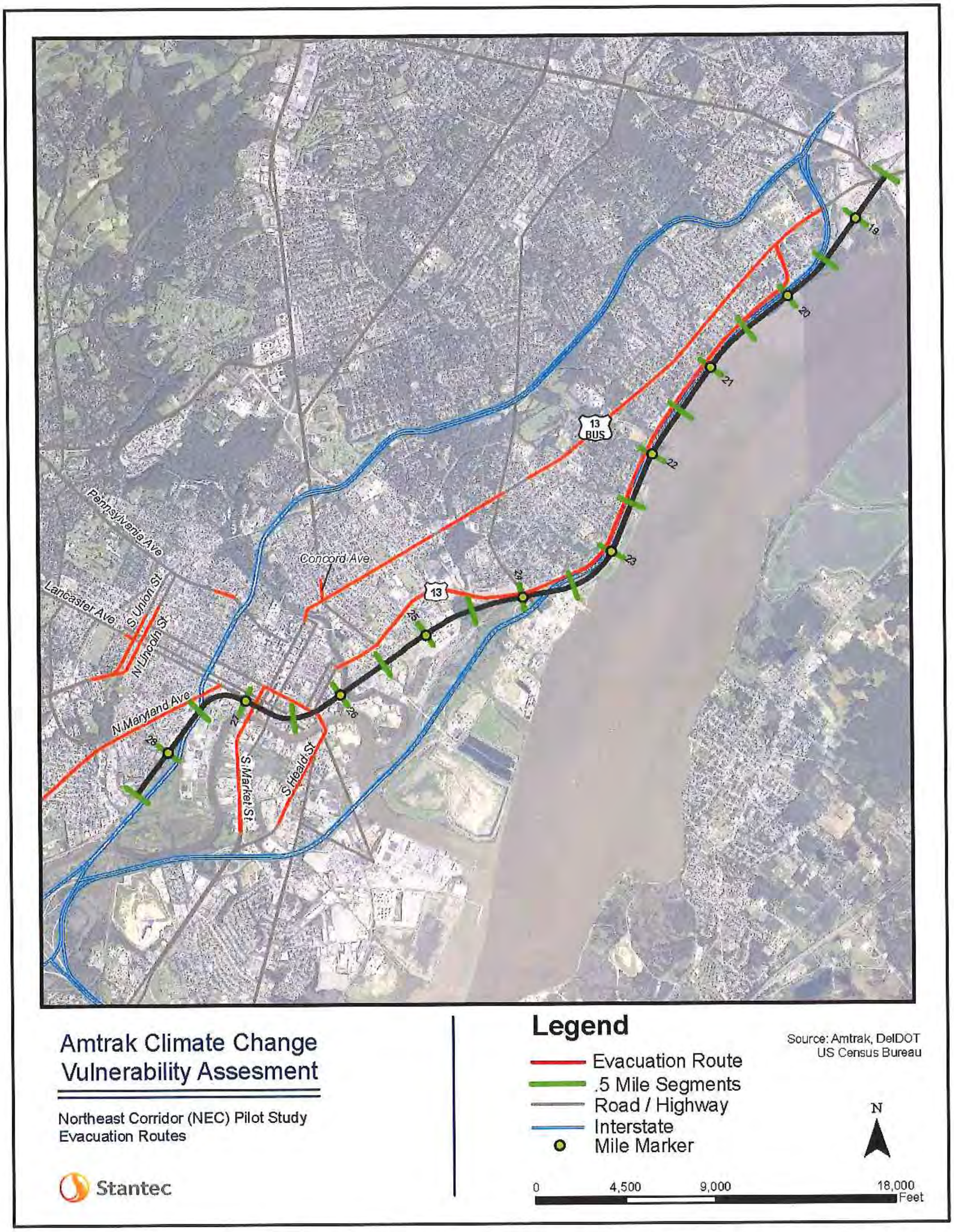
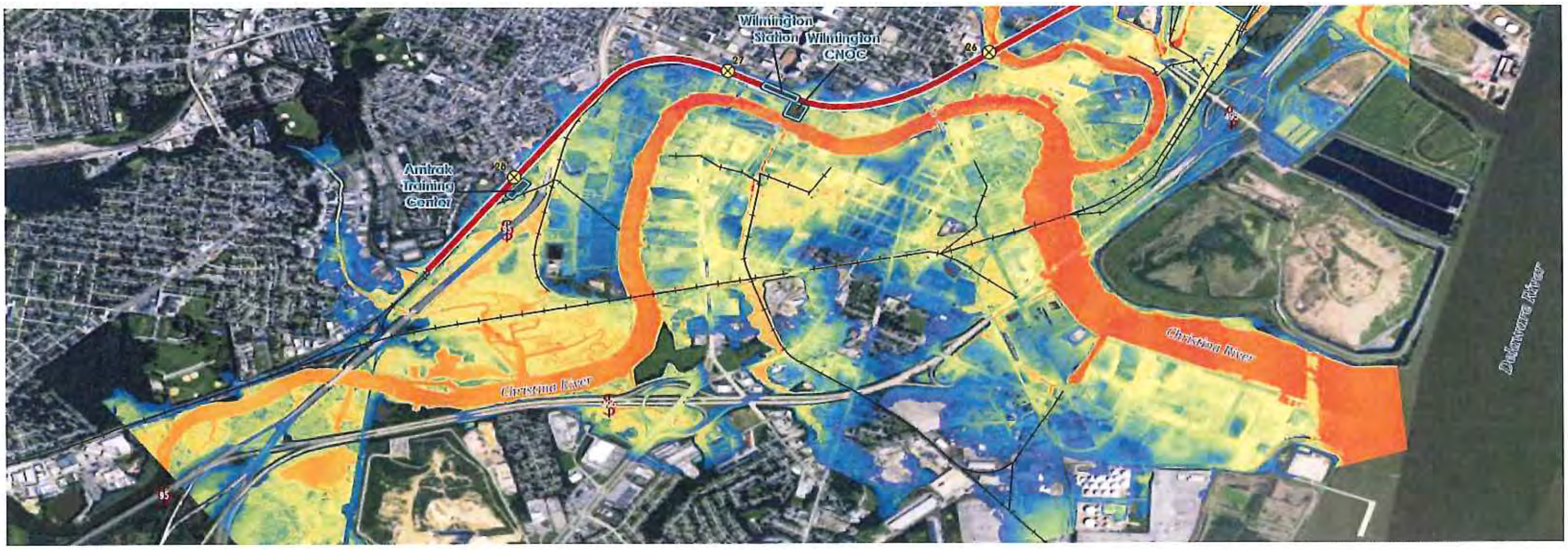


Figure 20. Roadway Network with Evacuations Routes included in the Vulnerability Assessment

4.0 Climate Variables for the Pilot Study Area and Delaware



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4.0 Climate Variables for the Pilot Study Area and Overview of Delaware's Climate

In order to identify appropriate climate variables for the Amtrak climate change vulnerability assessment, a comprehensive literature review was completed. The objective of the literature review was to identify climate variables with relevance to Amtrak assets and to compile available quantitative projections for the Delaware region.

The literature review included the following sources:

- Climate Change Projections and Indicators for Delaware (Hayhoe, Stoner, & Gelca, 2013)
- Delaware Climate Change Impact Assessment (Division of Energy and Climate, 2014)
- Federal Emergency Management Agency (FEMA) sponsored study on the potential impacts of climate change on the National Flood Insurance Program (NFIP) (AECOM, 2013).
- Intergovernmental Panel on Climate Change guidance for policy makers (IPCC, 2007).
- Climate Change 2014: Synthesis Report (IPCC, 2014)
- U.S. DOT Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool.
- The Government Accountability Office's Climate Change: Future Federal Adaptation Efforts Could Better Support Local Infrastructure Makers.
- U.S. Army Corps of Engineers Technical Letter 1100-2-1: Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation (USACE, 2014)
- Academic and scholarly authored scientific articles

4.1 Key Climate Variables

In order to merit consideration, a key climate variable must: (1) be relevant to the geography and climate of Delaware; (2) be relevant to Amtrak's transportation infrastructure; and (3) have supporting scientific data. After detailed review, the project team determined that five climate variables meet these criteria: sea level change, storm surge, precipitation, temperature, and wind. Each climate variable is described in detail in the following sections.

4.1.1 Sea Level Change

Given the Pilot Study area's exposure to the tidal and coastal influence of the Delaware Bay and Delaware River, sea level change is already a prime concern for Amtrak infrastructure. Ocean thermal expansion and glacier mass loss are the dominant contributors to global sea level rise (Boesch, et al., 2013). Relative sea level change is the combined effect of vertical land movement (subsidence) and global sea level rise. Climate change over the next century is expected to increase the rate of sea level rise, and there are several recent, well documented projections of what magnitude Delaware communities can expect. In September of 2013, the Delaware Coastal Programs (DNREC) published sea level rise projections of 1.6 to 4.9 feet above current conditions (Delaware Coastal Programs, 2013).

Between 36 to 73% of the Port of Wilmington's property, an area near the Pilot Study area, could be inundated by sea level rise by 2100. Additionally, 2 to 6% of Delaware's rail lines are projected to be inundated by sea level rise by 2100 according to the report (Delaware Coastal Programs, 2013).

Table 7 outlines sea level rise projections for two NOAA tidal stations nearest to the Amtrak Pilot Study location. These projections are based on the guidance of the USACE Technical Letter 1100-2-1: Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation (USACE, 2014). This document outlines a methodology for sea level change projections that is based on historical trends of NOAA tidal stations, with at least 40 years of historical data. For the Pilot Study locations, the Reedy Point, Delaware NOAA tidal station is the nearest data source and is included in the table. However, the station has only 38 years of available data for the SLC projections. Due to this limitation, the Lewes, Delaware NOAA tidal station, the nearest available data source with at least 40 years of available data is also included in Table 7. Sea level rise projections are shown for 2020 (current) and the two future years (2050 and 2100). These projections are based on the greenhouse gas emission projections (low, intermediate and high) from IPCC. It is commonly accepted that the low emission projection is based on a linear increase in greenhouse gas emission (best case scenario) and the high emission projection is equal to a an exponential increase in greenhouse gas emission, which is more in line with what we have seen the past few years.

Table 7. Sea Level Change Values

USACE SLC Projections (NAVD88) in feet									
	2020			2050			2100		
Tidal Station	Low	Inter-mediate	High	Low	Inter-mediate	High	Low	Inter-mediate	High
Reedy Point, DE	0.31'	0.38'	0.60'	0.65'	0.95'	1.90'	1.21'	2.25'	5.53'
Lewes, DE	-0.09'	-0.02'	0.20'	0.24'	0.54'	1.49'	0.79'	1.83'	5.12'

4.1.2 Storm Surge

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. It is typically caused by tropical storms such as hurricanes and is occasionally attributed to winter storms including Nor'easters. The Pilot Study area and many of Amtrak's assets are vulnerable to storm surge as they are located in close proximity to the Atlantic Ocean and Delaware Bay. According to the National Hurricane Center, only two hurricanes have made landfall in Delaware since 1851 (NOAA, 2005). This statistic can be misleading as direct impacts, including damaging storm surge, from several hurricanes, tropical storms, and tropical depressions have effected Delaware, even though these storms did not make landfall in Delaware. For Hurricane Sandy in 2012, the Delaware Bay and River achieved a maximum storm surge/residual storm-induced runoff of 5.3 to 6.4 feet (NOAA, 2013). This is more than what was seen within the Chesapeake Bay (2.5 to 4.9 ft) and less then what was experienced from New Jersey to Connecticut (5.2-12.7 ft). Hurricane Irene in 2011 resulted in storm surge/residual storm-induced runoff values of 2.9 to 8.8 feet (NOAA, 2011), and the maximum value was in Newbold, PA approximately 25 miles northeast of the Pilot Study area. These recent measurements are two of the highest storm surges on record in Delaware, and these values are consistent with a trend of hurricanes achieving maximum strength at higher latitudes (Kossin, Emanuel, & Vecchi, 2014). Kossin et al. attributes this phenomenon to tropical conditions comprising a larger area, possibly due to sea surface temperature (SST) increases along the Atlantic Coast related to climate change.

Thomas Knutson and team in 2010 provide a comprehensive review of literature related to projected climate change impacts on the frequency and severity of tropical storm systems (i.e. hurricanes and tropical storms) (Knutson, et al., 2010). The model data shows significant variation and the general consensus is that in the northern Atlantic, tropical storm systems will see a mean increase in storm intensity of about 8% and a mean decrease in storm frequency of about 8%.

Another contributing factor to increased storm surge potential in Delaware is the rise of sea level. Tidal influenced areas experiencing sea level rise would see greater effects from storm surge and inland areas typically immune from storm surge effects could become more vulnerable. Coastal bathymetry (underwater topographic land survey), a significant factor in storm surge magnitudes, could also be altered due to sea level rise and contribute to storm surge impacts. Vegetation and infrastructure closer to the land-sea interface could be affected, resulting in increased debris potential from storm surge.

4.1.3 Precipitation

An analysis of statewide precipitation data obtained from 14 weather stations (shown in Figure 21) across the state demonstrates that there is large inter- and intra-annual variability in precipitation.

There are no significant trends in annual precipitation patterns, nor in seasonal patterns, except for in autumn. During the fall months, there is a statistically significant increasing trend of 0.27 inches per decade (Division of Energy and Climate, 2014).

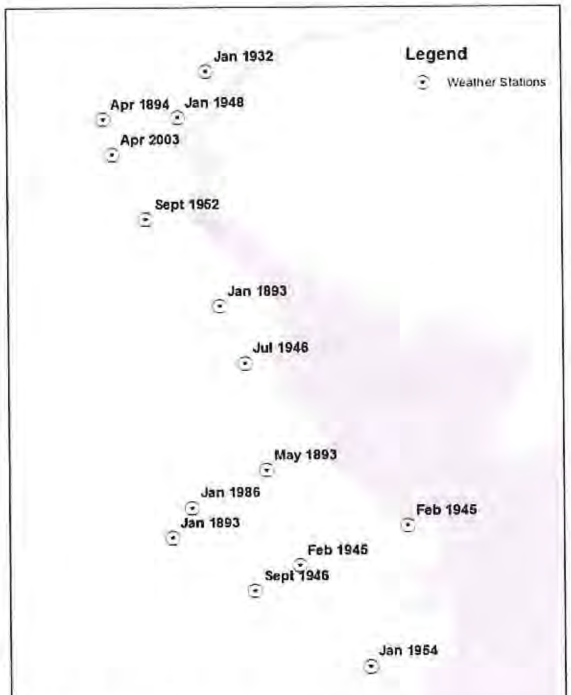


Figure 21. Weather Stations in Delaware Used for Climate Hindcasting and Model Downscaling. (Dates indicate when each station was established.)

To assess future changes in temperature- and precipitation-related climate indicators for the state, Hayhoe, et al. downscaled simulations from the CMIP global climate models (CMIP3 and CMIP5) to the 14 weather stations located throughout Delaware (Figure 21). In general, climate models project increases in average annual precipitation over the upcoming century. The model predictions are inconsistent for the near- (2020-2039) and mid- (2040-2059) century. Some individual climate models project a decrease while the multi-model average shows an increase, which is consistent with projections for mid-latitude regions. For the late-century (2080-2099) projections, the models more consistently predict an increase in average annual precipitation with only one individual model simulation showing a decrease. During this period, the average annual precipitation is predicted to increase by approximately 6.5% and 10.3% on average for the low and high greenhouse emissions scenarios, respectively.

The range of precipitation change by percentage annually is presented in Table 8. It is important to note that the low emission scenario is based on declining global population after mid-century, transitioning to lower emission technologies and economies while the high emissions scenario is based on high population growth, regional economic development and slower technology change.

Table 8. Precipitation Projections for Delaware for the near- (2020-2039), mid (2040-2059) and end-of-century (2080-2099) time horizons relative to 1981-2010 Baseline Data.

Percent Precipitation Change		Near-Century (2020-2039)	Mid-Century (2040-2059)	End-of-Century (2080-2099)
Annual	Low Emissions	5 – 12%	3 – 9%	1 – 12%
	High Emissions	3 – 12%	7 – 14%	3 – 23%

4.1.4 Temperature

Unlike precipitation, rising temperature indicators are found within the measured, available record. Since 1895, there has been an approximate 0.2°F per decade rise in temperature across Delaware (Division of Energy and Climate, 2014). Temperature is projected to continue to rise at rates dependent on rates of greenhouse gas emissions loading in the future. The temperature increases due to low and high emission scenarios are more comparable in the near-century; this is because of the lag in climate's response to changes in emissions and lags in installations of cleaner technologies. By the end-of-century period, the two emissions scenarios yield distinct temperature differences. Similar to precipitation, temperature extremes are predicted to greatly increase in the future.

Table 9 summarizes the change in average temperature relative to recent decades for the annual daytime highs and per season. These results are presented in ranges because of the uncertainty associated with model predictions.

Table 9. Temperature Projections for the Delaware over the near-(2020-2039), mid-(2040-2059) and end-of-century (2080-2099) relative to 1981-2010. (Division of Energy and Climate, 2014)

Temperature Change (°F)		Near-Century (2020-2039)	Mid-Century (2040-2059)	End-of-Century (2080-2099)
Annual	Low Emissions	1.1 - 3.2°	2.2 - 5.3°	3.5 - 7.0°
	High Emissions	1.4 - 3.5°	3.1 - 6.1°	7.2 - 12.0°
Winter	Low Emissions	0.8 – 2.5°	1.5 – 4.9°	2.1 - 6.1°
	High Emissions	1.4 - 3.0°	1.9 – 5.3°	5.7 - 10.7°
Spring	Low Emissions	0.9 - 2.8°	2.2 - 4.9°	3.7 - 6.3°
	High Emissions	0.9 - 3.0°	3.3 - 5.7°	7.1 - 11.1°
Summer	Low Emissions	1.5 - 4.1°	2.5 - 6.2°	3.8 - 8.7°
	High Emissions	1.8 – 4.6°	3.3 - 7.7°	7.4 - 15.0°
Fall	Low Emissions	0.5-3.7°	1.8 - 5.3°	2.8 - 7.6°
	High Emissions	1.1 - 3.8°	2.7 - 6.4°	6.7 - 12.5°

In addition to the numbers of extremely hot days increasing and numbers of freezing lows decreasing, the analysis yields projections for increases in the average annual and seasonal day time highs and night time lows. By the end of the century, the increases in day time highs range from 3.5°F to 5.5°F and 8.5°F to 9.5°F for the low emissions and high emissions scenarios, respectively. Nighttime lows demonstrate similar increases. This demonstrates not only the high certainty that warming will occur, but also indicates that warming is highly dependent on emissions.

4.1.5 Wind

Projections on the effect of climate change on wind are inconclusive at this time; primarily due to the localized nature of wind conditions. Changes to nearby land use (e.g. deforestation resulting in surface roughness change) and the significant variability of extreme wind events cause difficulty in developing projections. A recent study comparing projections of five Regional Climate Model (RCM) and atmosphere-ocean general circulation models (AOGCMs) to historical wind data concluded that future wind projections are minimally different from historic wind climates (Pryor & Barthelmie, 2014). Based on this knowledge, the use of observed wind speed records and modeled wind speed results from storm events scenarios have been identified as the most appropriate tools for determining the effect of climate change wind exposure of Amtrak assets.

A review of design guidelines including ASCE 7-10: Minimum Design Loads for Buildings and Other Structures concludes that the Pilot Study area's design wind speed is 120 mph for the structures in Risk Category III-IV (ASCE, 2014). Most Amtrak facilities in the Pilot Study are included in Risk Category III-IV due to their importance in continuity of Amtrak operations and criticality for resilience.

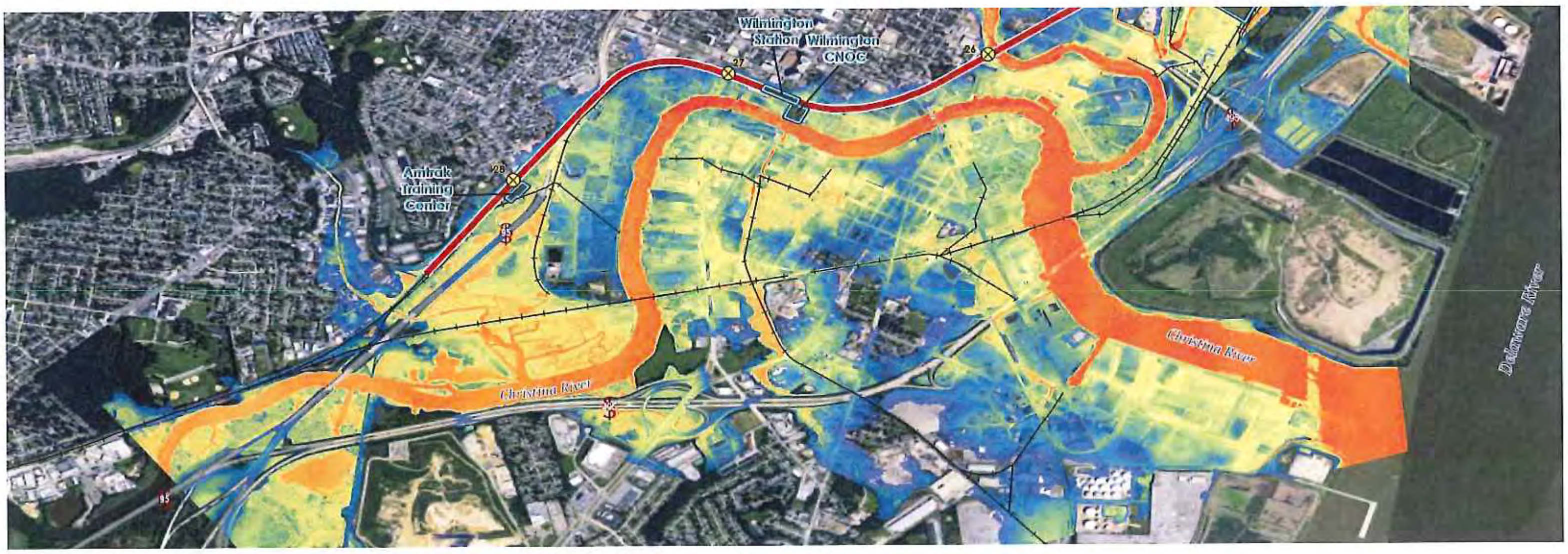
4.2 Rationale for Dismissing Certain Climate Variables

Several climate variables were determined by the Study Team to be of minor significance to Amtrak assets in the Pilot Study area and therefore, these climate variables were evaluated but then dismissed from detailed assessment. These climate variables were dismissed because they were not applicable to the geographic region or the scope of this study. For example, permafrost thaw (permafrost is ground that remains frozen for two or more years) would have little applicability in Delaware. Earthquakes are another variable not included in this study because the science of forecasting increases in earthquake frequency and magnitude due to climate change is not sufficiently advanced to warrant actionable guidance. Studies have shown correlations between natural climate change and geological activity (McGuire, 2012); however, the findings are not widely implemented into design.

Tornados were not evaluated as part of this analysis because currently there is no actionable climate change science indicating an increase in tornadic activity, nor are tornado wind speeds a typical design criterion. Best management practices are available for application regarding tornadoes. The American Society of Civil Engineers Tornado guidance shows the Amtrak Pilot Study area to be in Zone II (160 mph) sheltering design wind zone (ASCE 7-10). This wind zone is outside of the typical area in which tornado wind speeds significantly influence design. The 2015 version of the International Building Code (IBC) now mandates ICC-500 storm sheltering for schools, hospitals, emergency operations and first responder facilities in Zone IV or wind speeds of 250 mph; however, Wilmington currently cites IBC 2012 as the adopted code and is not in Zone IV. The Best Available Refuge Area Selection per FEMA P-431 Tornado Protection: Selecting Refuge Area in Buildings as well as safe sheltering guidance per FEMA P-361 and FEMA P-320 should be considered.

Additional variables exist that may have relevance, such as seawater salinity, relative humidity, and solar radiation (FHWA, 2011); however, these are not key climate interaction variables for the asset holdings specific to Amtrak's NEC or reliable projections for these variables do not exist presently. The key quantifiable impacts to Amtrak infrastructure will generally be limited to those variables that increase the potential for episodic flooding, permanent inundation, and high water velocity or wave action in the vicinity of floodplain crossings and coastal highways. Temperature (heat) is a variable in Delaware that could impact rail assets (specifically tracks). Closures of Amtrak facilities, alterations in operating procedures and damage to assets from windstorms are considered as well.

5.0 Pilot Study Vulnerability Assessment Results



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5.0 Pilot Study Vulnerability Assessment Results-

5.1 Overview of Results

This chapter presents the results of a comprehensive assessment using a number of different tools to assess the vulnerability of Amtrak's assets in the Pilot Study Area. In this chapter, the results are organized and described by asset type (i.e., track, signals, catenaries, bridges, facilities, and roads). The vulnerability assessment concluded with each asset getting a qualitative ranking of low, moderate, or high vulnerability. After the vulnerability ranking was completed, all assets were plotted on a map using GIS, and each asset was color coded based on its vulnerability. Assets with the highest vulnerability ranking were given the color code red, those with moderate vulnerability were yellow, and the ones with low vulnerability were green. From this step, the Vulnerable Areas at Risk for the 2050 and 2100 planning scenarios became evident based on areas of high vulnerability. Amtrak can use this information to focus its future site-specific adaptation planning as listed in Step 7 of the Climate Change Program Framework.

The Study Team examined the potential impacts of future sea level rise, storm surge, precipitation, temperature (heat) and wind on Amtrak assets. In general, vulnerability by assets varied. In summary, 4 of the 6 facilities, 4 of the 15 bridges, and 7.5 linear miles of track of the 10 miles study area had a "high' vulnerability ranking in the year 2100 for at least one climate stressor.

Amtrak assets with high vulnerability rankings are provided in Table 10. Roads are not included in the table for brevity and because they are best illustrated graphically on a map. In addition, roads in most cases are not Amtrak owned assets; but they were included because their vulnerability would have an effect on Amtrak's operations. Areas with a cluster of highly vulnerable assets were called Vulnerable Areas at Risk. Figure 22 illustrates the Vulnerable Areas at Risk for the 2050 and 2100 planning scenario. The remainder of this chapter describes in more detail the vulnerability rankings by asset, the potential loss at Amtrak facilities, and more detail on the Vulnerable Areas at Risk.

Table 10. Summary of Assets with High Vulnerability Ranking

Asset Type	Asset ID	Climate Stressor(s)[1]	Vulnerability
Facility	F1 Maintenance Shop	Precipitation, Sea Level Rise (2050), Storm Surge (2050), Wind	Flood and Wind Damage
	F2 CNOC	Precipitation, Sea Level Rise (2050), Storm Surge (2050)	Flood Damage
	F4 Training Center	Precipitation	Flood Damage
	F6 West Yard	Precipitation	Flood Damage

Asset Type	Asset ID	Climate Stressor(s)[1]	Vulnerability
Bridge	21.98 Quarryville Creek	Precipitation, Sea Level Rise (2050), Storm Surge (2100)	Overtopping/Inundation
	21.24 Perkins Creek	Precipitation, Storm Surge (2100)	Overtopping/Inundation
	24.69 Shellpot Creek	Precipitation	Overtopping/Inundation
	28.72 Mill Creek	Precipitation	Overtopping/Inundation
Track	Mile Post 18.5 to 19.0	Sea Level Rise (2050)	Inundation
	Mile Post 21.5 to 22.0	Sea Level Rise (2050)	Inundation
	Mile Post 24.5 to 25.0	Sea Level Rise (2050)	Inundation
	Mile Post 27.5 to 28.0	Sea Level Rise (2050)	Inundation
	Mile Post 21.0 to 21.5	Precipitation, Storm Surge (2050) Sea Level Rise (2100)	Overtopping/Inundation
	Mile Post 24.0 to 25.0	Precipitation, Storm Surge (2050)	Overtopping
	Mile Post 28.0 to 28.5	Storm Surge (2050)	Overtopping/Inundation
	Mile Post 26.5 to 27.0	Sea Level Rise (2100) Temperature (2050)	Inundation, Buckling. Expansion
	Mile Post 25.5 to 26.0	Sea Level Rise (2100) Temperature (2100)	Inundation, Buckling. Expansion
	Mile Post 26.0 to 26.5	Sea Level Rise (2100) Temperature (2100)	Inundation, Buckling. Expansion
	Mile Post 20.0 to 21.5	Storm Surge (2100)	Overtopping/Inundation
	Mile Post 25.0 to 25.5	Storm Surge (2100)	Overtopping/Inundation
Catenary	Mile Post 18.5 to 19.5	Wind	Structural Failure
	Mile Post 20.0 to 20.5	Wind, Storm Surge (2050)	Structural Failure
	Mile Post 25.0 to 25.5	Wind	Structural Failure
	Mile Post 21.0 to 21.5	Precipitation, Sea Level Rise (2100)	Structural Failure
	Mile Post 24.0 to 24.5	Precipitation, Storm Surge (2050)	Structural Failure

Asset Type	Asset ID	Climate Stressor(s)[1]	Vulnerability
		Sea Level Rise (2100)	
	Mile Post 25.0 to 25.5	Precipitation, Storm Surge (2100)	Structural Failure
	Mile Post 20.5 to 20.0	Storm Surge (2050)	Structural Failure
	Mile Post 24.5 to 25.0	Storm Surge (2050), Sea Level Rise (100)	Structural Failure
	Mile Post 26.5 to 27.0	Storm Surge (2050)	Structural Failure
	Mile Post 27.5 to 28.5	Storm Surge (2050) Sea Level Rise (2100)	Structural Failure
	Mile Post 27.0 to 27.5	Storm Surge (2100)	Structural Failure
	Mile Post 22.0 to 23.0	Storm Surge (2100)	Structural Failure
	Mile Post 19.5 to 20.0	Storm Surge (2100)	Structural Failure
Signal	Mile Post 19.0 to 19.5	Wind	
	Mile Post 20.0-20.5	Wind, Temperature, Precipitation , Storm Surge (2100)	Structural, Electrical Failure
	Mile Post 21.0-.21.5	Temperature, Precipitation, Storm Surge (2050)	Structural, Electrical Failure
	Mile Post 22.5-23.0	Storm Surge (2100)	Structural, Electrical Failure
	Mile Post 24.0- 24.5	Sea Level Rise (2100), Storm Surge (2100)	Structural, Electrical Failure
	Mile Post 26.5-27.0	Temperature, Precipitation, Sea Level Rise (2100), Storm Surge (2050)	Structural, Electrical Failure
	Mile Post 27.0-28.0	Storm Surge (2100)	Structural, Electrical Failure
	Mile Post 28.0-28.5	Sea Level Rise (2100), Storm Surge (2050)	Structural, Electrical Failure

[1] The planning horizon (2050 or 2100) listed is when that asset becomes highly vulnerable. If the asset is vulnerable in 2050, then that asset showed continued high vulnerability in 2100. For precipitation and wind, the timeframe is the present day prediction for a 100 year storm event. From these results, one can determine which assets will become vulnerable sooner than others. For instance, the Quarryville Bridge is vulnerable to sea level rise in 2050 whereas the Perkin Creek Bridge is vulnerable to sea level rise in 2100.

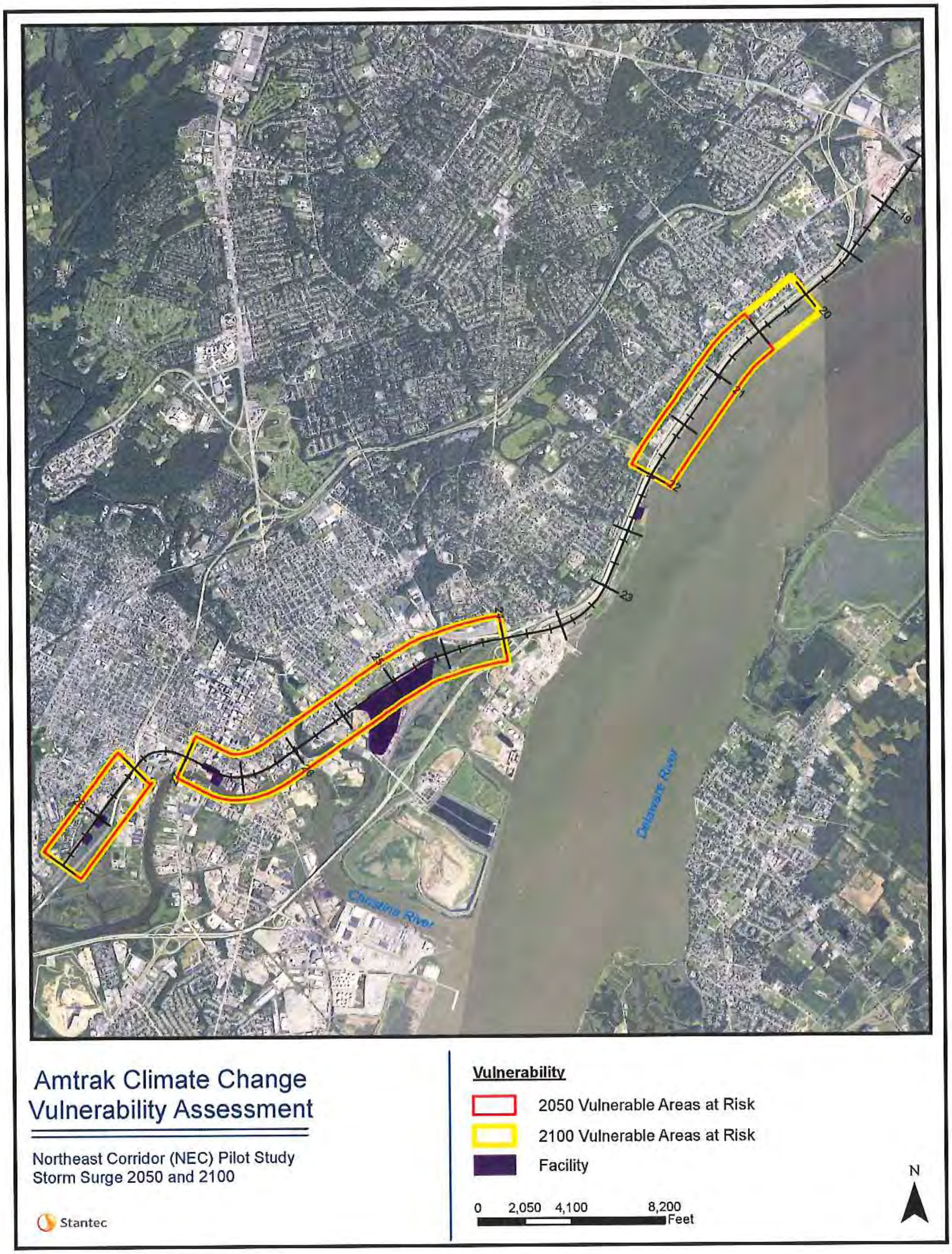

Figure 22. Vulnerable Areas at Risk in the Pilot Study Area

5.2 Linear Asset Vulnerability Assessment Results

The linear assets (track, catenary, and signals) within the Pilot Study area were assessed using a combination of HVI and VAST, while HVI was used exclusively for roadways. The tracks vulnerability to sea level rise (2050 and 2100) and storm surge (2050 and 2100) as well as flooding caused by precipitation was assessed. VAST was used to identify the tracks vulnerability to temperature because this data was more readily digested by the VAST tool. Both tools generate an overall score and allow for the vulnerability to be ranked in the low, moderate, or high category.

5.2.1 Tracks

Sea Level Rise and Storm Surge in 2050

In the year 2050, tracks having vulnerability as a result of sea level rise are measured to be within one of two extremes, either low vulnerability or high vulnerability. The majority of the track segments have low vulnerability to sea level rise in 2050, as shown in Figure 23. Four of the track segments have high vulnerabilities and all of the highly vulnerable track segments have continual inundation with depths greater than 4 feet and 3 inches.

Four 0.5 mile segments in the 10 mile study area displayed high vulnerability in 2050 to Sea Level Rise. The most severe threat (inundation) is the track segment from mile post 25.0 to 24.5.

Half of the track segments demonstrate high vulnerability for a storm surge in the year 2050 (see, Figure 24). These segments have percent linear feet of inundation values higher than 13%, with some values as high as 83%. Their maximum depths of inundation also display values larger than 1 feet and 6 inches and extend as deep as 12 feet and 6 inches. Four track segments are within the moderate vulnerability category. These segments have at least 3% linear feet of inundation, which is approximately 79 feet of track inundated with water. The maximum depth of inundation ranges from 1 foot and 3 inches to 9 feet and 9 inches. The remaining track segments have low vulnerability with no inundation.

Sea Level Rise and Storm Surge in 2100

All track segments with inundation due to sea level rise will have a daily problem with water because inundation from sea level rise creates an ongoing operational issue rather than a temporary problem. Table 11 provides an example of track vulnerability associated with sea level rise for the year 2100. The vulnerability levels fall within 3 categories; low, moderate, and high, with the majority of 0.5 mile segments either classified with low or high vulnerabilities. The segments with low vulnerability have less than 2.5% linear feet of inundation with less than 7 inches of depth from inundation. Only one 0.5 mile track segment is classified as moderate vulnerability (approximately 1 foot and 3 inches of inundation). Significantly higher values of percent linear feet of inundation or maximum depth of inundation produce eight segments of high vulnerability. The most severe values of percent linear feet of inundation and maximum depth of inundation are associated with mile posts 24.5 to 24.0 and 26.0 to 25.5 respectively. Figure 25 depicts the linear assets vulnerability to sea level rise in the year 2100.

In 2100, Sea Level Rise becomes a more prevalent problem causing permanent inundation to a larger portion of the study area (4 miles or 40% of the study area).

The ten mile stretch of track in the Pilot Study has a significant number of segments with high vulnerability due to storm surge for the year 2100 as shown in Figure 26. The storm surge creates temporary inundation problems and fourteen of the twenty track segments have high vulnerability. These segments display noteworthy values of percent linear feet of inundation or large maximum depths of inundation with values ranging from 3.96% to 100.00% and 3 feet 10 inches to 16 feet and 6 inches respectively. Two of the track segments have moderate vulnerability. The maximum amount of percent linear feet of inundation is approximately 15% with maximum depths of inundation being 5 feet. The other four segments of track are classified as low vulnerability segments with less than 3% linear feet of inundation and less than 4" of water depth.

Table 11. Vulnerability of Tracks from Sea Level Rise 2100

HVI Category	Mile Posts		HVI	Percent Linear Feet Inundated for Year 2100	Maximum Depth of Inundation for Year 2100 (ft)	Distance to Coast (ft)	Number of Interlockings	Number of Turnouts	Vulnerability for Year 2100
	Beginning	Ending							
	28.0	27.5	0.32	19.61%	4.5	1,339	0	0	High
	27.0	26.5	0.31	19.84%	2.9	375	3	4	High
	26.0	25.5	0.43	10.04%	11.1	0	1	5	High
	25.0	24.5	0.45	19.28%	9.5	3,473	0	15	High
	24.5	24.0	0.66	66.77%	1.8	2,662	0	0	High
	22.0	21.5	0.35	2.87%	10.9	54	0	0	High
	21.5	21.0	0.29	27.53%	0.5	0	0	0	High
	19.0	18.5	0.28	3.19%	8.0	0	0	0	High

(b)(5)

[redacted]

(b)(5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

Precipitation for Tracks

Five 0.5 mile segments of track displayed high vulnerability associated with flooding from a 100 year storm event.

Track vulnerability associated with precipitation falls within 3 categories; low, moderate, and high, with the majority of 0.5 mile segments classified as low vulnerability (see Figure 27). The most significant parameter built into this HVI equation comes from the percent of linear feet within flood zone. The low vulnerable segments have less than 2% of the tracks within flood zones. Moderate vulnerability is associated with flood zone percent values ranging from 3% to 11%. In the high vulnerability category, the percent of linear feet within flood zone increases to a range between 28% and 95%. The most vulnerable segment of track occurs at mile posts 24.5 to 24.0.

Temperature for Tracks

The track segments most vulnerable to temperatures increases were located in an area that is projected to experience the most increases in temperatures in 2050 and 2100 based on the output of CMIP analysis. Other indicators that contributed to the high vulnerability score of these segments were the presence of certain features that are considered vulnerability triggers for temperatures. These include increased rail curvature, and higher numbers of interlocking, turnouts, signaling and bridges per segment of track.

Almost all track segments had low vulnerability to future changes in temperature (heat) in 2050 and 2010. One 0.5 mile segment in 2100 was ranked high vulnerability mainly attributed to the high number of track features such as signal equipment, interlockings, and turnouts.

For example, curved sections of rail can experience more track buckling due to higher temperatures. Also, the presence of certain elements within a segment of the track, such as signal equipment, bridges, interlocking and turnouts will make the segment more vulnerable as it will require more time and resources to address any compression or buckling in that specific segment.

VAST analyses showed that almost all track segments had low vulnerability for temperature in 2050 and 2100. Only one 0.5 mile segment scored high for temperature vulnerability in 2050, and one segment scored moderate. Also, two of the 20 segments scored high for temperature vulnerability in 2100, and four segments scored moderate. All other segments of track were considered low in vulnerability for 2050 and 2100. These results are presented in Figure 28 and Figure 29.

(b) (5)

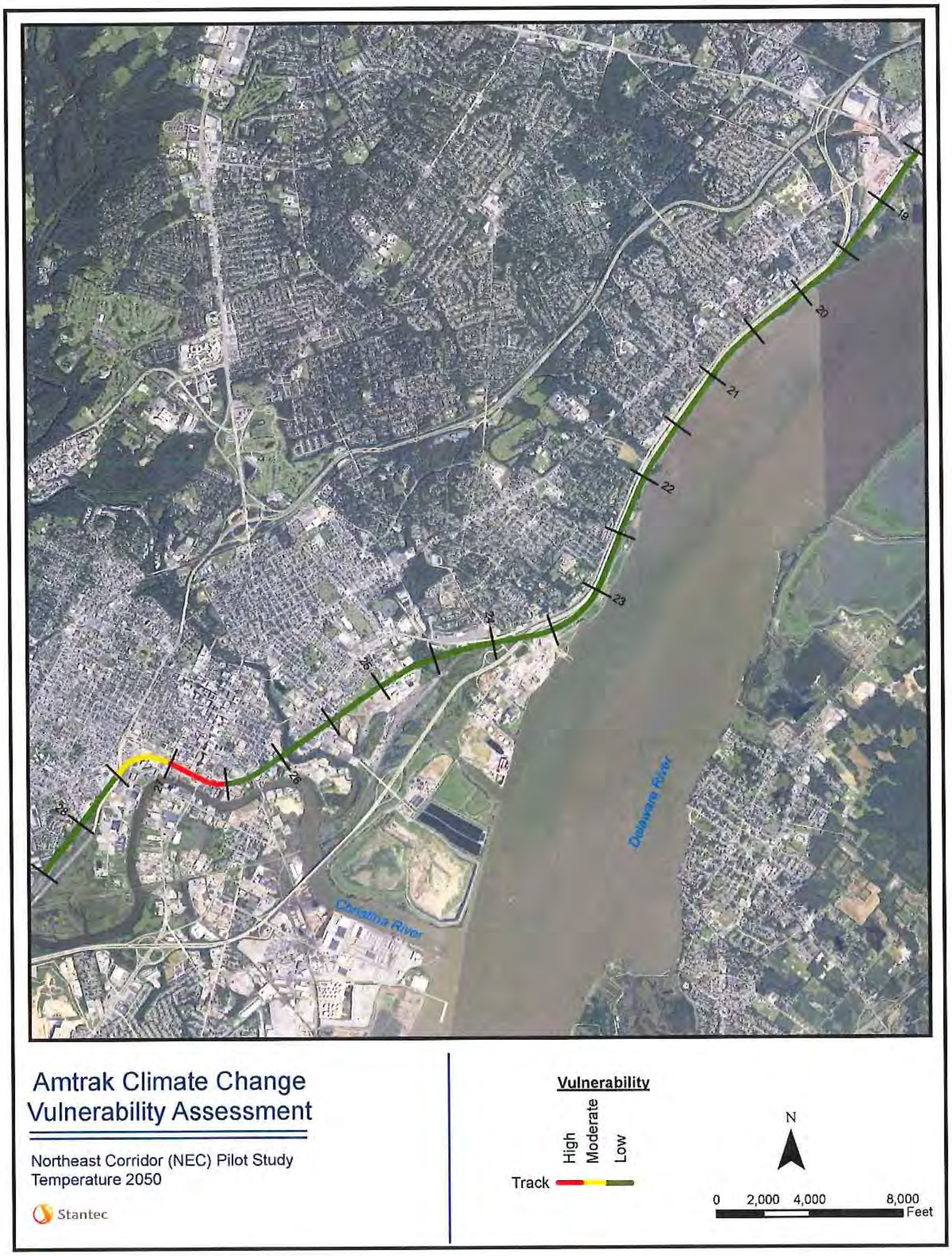

Figure 28. Linear Asset Vulnerability to Temperature 2050

Figure 29. Linear Asset Vulnerability to Temperature 2100

5.2.2 Signals

Sea Level Rise and Storm Surge for Signals in 2050

In the year 2050, signals having vulnerability because of sea level rise are all categorized as low vulnerability. Their HVI scores show no amount of inundation. The only parameter effectively translating into an HVI score is related to the coastal distance. The results are presented in Figure 23.

In 2050, all signals were classified as low vulnerability to sea level rise. This vulnerability increases dramatically when storm surge is added to sea level rise in 2050.

The majority of the 0.5 mile segments of signals also demonstrate low vulnerability for a storm surge in the year 2050. Fifteen of the segments have low HVI scores, and no inundation is expected for these signals. One segment has a moderate vulnerability classification because approximately 12% of the signals may be inundated with water at a maximum depth of 10 inches. The other four segments do display high levels of vulnerability. These areas have inundation covering 50% to 100% of the signals. The maximum inundation depths around the signals range from 1 foot to approximately 3 feet. The results are presented in Figure 24.

Sea Level Rise and Storm Surge for Signals in 2100

Signal vulnerability associated with sea level rise for the year 2100 displays either low or high vulnerability scores. All signals with inundation due to sea level rise will have a daily problem with water. The segments with low vulnerability have no inundation. Considerably high values of percent of signal inundation or maximum depth of inundation are associated with three segments of high vulnerability. The most severe values of signal poles with inundation are associated with mile post 24.5 to 24.0. The results are presented in Figure 25.

In 2100, the ten mile stretch of track in the Pilot Study has a significant number of signals with high vulnerability to storm surge.

Storm surge creates temporary inundation problems in 2011, and seven of the twenty track segments achieved a high vulnerability score. The signals within these segments display high values of percent signal inundation ranging from 50% to 100%. One segment of signals has moderate vulnerability; this 0.5 mile stretch has approximately 16% of the signals inundated with water at a maximum depth of approximately 3 feet and 2 inches. The remaining twelve segments of signals are classified as low vulnerability with no inundation. The results are presented in Figure 26.

Precipitation for Signals

Signals that were located in the FEMA 100 year flood zone (the area impacted by the 1 percent annual chance flood) were considered more vulnerable to precipitation than the ones located outside the flood zone, and among these within the flood zone, 0.5 mile segments with higher number of signals or ones that were closer to coast were considered more vulnerable. Out of the 20 0.5 mile segments, three segments achieved high vulnerability scores, nine achieved moderate vulnerability, and eight were considered low in vulnerability. The vulnerable signals were scattered across the 20 mile segments, and followed areas of riverine or coastal flood vulnerability (see Figure 27).

Over 50% of signals assessed were impacted by precipitation and achieved either moderate or high vulnerability.

Wind for Signals

Results from Hazus wind speed modeling across the Pilot Study area were used to indicate signal exposure to wind, where areas that experienced higher wind speed during a storm were the most vulnerable. Also, the higher number of signaling equipment within any specific segment contributed to the vulnerability, as well as the percent of signals abutting trees, vegetation or projectile material, as debris is often the major cause of wind related damage.

As demonstrated in Figure 30, the majority of signals within the 0.5 mile segments of the Pilot Study area demonstrated low vulnerability to wind. Only two segments achieved high vulnerability. Three segments achieved a moderate vulnerability, and all remaining 15 segments within the pilot study area achieved low vulnerability and were considered the most resilient to the impacts of wind.

Two signals located in close proximity to the Delaware River between mile post 20.5 and 19.0 had a high vulnerability to wind. In general, signal vulnerability to wind was low.

(b)(2)

[redacted]

5.2.3 Catenary System

Sea Level Rise and Storm Surge for Catenaries in 2050

In the year 2050, the majority of the catenaries achieved low vulnerability score to sea level rise, see Figure 23. Their HVI scores display no amount of inundation. Only one track segment of catenaries has high vulnerabilities with a high HVI score between mile posts 24.5 and 24.0. These catenaries have continual inundation with inundation covering approximately 10% of the catenary poles at a maximum depth of 11 inches.

Half of the catenary pole segments within the Pilot Study demonstrated high vulnerability for a storm surge in the year 2050. These segments have percent pole inundation values higher than 13%, with some values as high as 100%. Their maximum depths of inundation also display values larger than 1 feet and 6 inches and extend as deep as 6 feet. Three track segments have HVI scores between 0.1 and 0.3 positioning them within the moderate vulnerability category. These segments have at least 8% of catenary pole inundation and a maximum depth of pole as deep as 1 foot and 4 inches. The remaining track segments have low vulnerability with no inundation. The results are presented in Figure 24.

In 2050, one 0.5 mile segment of catenaries had a high vulnerability to sea level rise. This vulnerability increases to over half of the segments (five miles) when storm surge is added to sea level rise in 2050.

Sea Level Rise and Storm Surge for Catenaries in 2100

Vulnerability associated with sea level rise for the year 2100 related to catenaries may be categorized as low, moderate, or high. The majority of 0.5 mile segments are either classified with low or high vulnerabilities (see Figure 25). All catenaries with inundation due to sea level rise will have a daily problem with water. The segments with low vulnerability have no inundation, and only one 0.5 mile track segment of catenaries is classified as moderate vulnerability as 10% of catenary poles are inundated with approximately 1 foot and 3 inches of water. Significantly higher values of percent of pole inundation or maximum depth of inundation are displayed in six segments of high vulnerability for catenaries. The most severe values of percent catenary pole inundation and maximum depth of inundation are associated with mile post 24.5 to 24.0.

In 2100, 50% of catenary system received a high vulnerability ranking to Sea Level Rise and this number increases to 80% when storm surge is added to sea level rise.

The ten mile stretch of track in the Pilot Study has a significant number of catenary poles with high vulnerability due to storm surge for the year 2100. The temporary inundation of storm surge creates higher threats to sixteen of the twenty track segments. The catenaries within these segments display significant values of percent pole inundation or large maximum depths of inundation with values ranging from 27.78% to 100.00% and 1 feet 9 inches to 9 feet and 3 inches respectively. One segment of catenaries has moderate vulnerability with approximately 4% of the poles inundated with water at a maximum depth of approximately 6 inches. The other three segments of catenaries are classified as low vulnerability no inundation. The results are presented in Figure 26 above.

Precipitation for Catenaries

Similar to the vulnerability assessment process for signals, Catenary systems located in the FEMA 100 year flood zone were considered more vulnerable to precipitation than the ones located outside the FEMA 100 year flood zone. Also, among those within the FEMA flood zone, 0.5 mile segments with higher number of catenary or ones that were closer to coast were considered more vulnerable.

Out of the 20 0.5 mile segments of catenaries, only two segments scored high vulnerability to the 100 year storm event.

Results of VAST showed that only 6 of the assessed 0.5 mile segments were impacted by precipitation and achieved either moderate or high vulnerability, see Figure 27. Out of the 20 0.5 mile segments, only two segments scored high vulnerability, and 4 scored moderate vulnerability, while the remaining were considered low in vulnerability. The vulnerable Catenary systems were scattered across the Pilot Study area, and followed areas of riverine or coastal flood vulnerability.

Wind for Catenaries

Similar to the vulnerability assessment process for signals, results from Hazus wind speed modeling across the Pilot Study area identified catenary system exposure to wind, where areas that experienced higher wind speed during a storm were the most vulnerable. Also, the higher number of Catenary poles within any exposed segment contributed to the vulnerability, as well as the percent of catenary systems abutting trees, vegetation or projectile material, as debris is often the major cause of wind related damage.

Five 0.5 mile segments of Catenaries scored a high vulnerability ranking. The main factor for the high vulnerability was area exposed to higher wind speeds during a storm event.

Almost half of the catenary systems within the Pilot Study area demonstrated some vulnerability to wind, and five segments achieved high vulnerability. As shown in Figure 30, three segments achieved moderate vulnerability, and all remaining 12 segments within the pilot study area achieved low vulnerability and were considered the most resilient to the impacts of wind.

5.3 Railroad Bridge Vulnerability Assessment Results

As explained in section 5.3, VAST was used to assess the vulnerability of bridges to the future impacts of climate change. Amtrak provided GIS data for multiple bridges along the Pilot Study area. However, a total of (b)(5) Amtrak bridges were identified as being under grade bridges that pass over water bodies, or are located within close proximity to the coast. These (b)(5) bridges were incorporated into VAST while other bridges that were identified as over grade bridges were excluded from the analyses. A list of the (b)(5) bridges included in the VAST assessment is shown in Table 12 below.

(b) (5)

Bridges within the Pilot Study area were vulnerable to three different climate stressors: precipitation and heavy storms; sea level rise; and storm surge. Table 13 through Table 17 show the final VAST vulnerability score for bridges, as well as the result in terms of vulnerability. These results are also depicted in Figure 31 through Figure 35. Similar to facilities, only bridges that were identified as highly vulnerable and moderately vulnerable were included in the tables. The remaining assets that were identified as low in vulnerability are shown on the results maps.

Bridge Results. *Mainly, bridges near the Wilmington Shops and the Training Center ranked high on the vulnerability scale, while other bridges close to the shore were also considered vulnerable. Shellpot Creek Bridge, Mill Creek Bridge, Perkins Creek Bridge (at MM 20.94), and Quarryville Creek Bridge were the most vulnerable bridges in all categories.*

The overall vulnerability threshold was set to 3.0; all bridges that obtained a total vulnerability score of 3 or higher for any climate stressor was considered vulnerable to that specific climate stressor. Bridges that achieved vulnerability score between 2.4 and 2.9 were considered moderately vulnerable, and all bridges that obtained a score of 2.4 and lower were considered the most resilient, and were low in vulnerability. The analyses results identified many vulnerable bridges within the Pilot Study area.

(b)(5)

[redacted]

(b) (5)

5.4 Facility Vulnerability Assessment Results

A total of six Amtrak facilities were identified within the Pilot Study area. Substations were grouped with facilities for the purposes of this discussion and this assessment. Some facilities included multiple buildings such as the CNOC and Wilmington Shops. A list of the six facility assets is shown in Table 18.

Table 18. Facilities and Substations included in VAST

Asset ID	Asset Name
F1	Wilmington Shops
F2	CNOC
F3	Wilmington Station
F4	Training Center
F5	Bellevue Substation
F6	West Yard Substation

Facilities within the Pilot Study area were vulnerable to four different climate stressors: Precipitation and heavy storms; sea level rise; storm surge; and wind. Table 19 through Table 23 shows the final VAST vulnerability score, as well as the result in terms of vulnerability. The results are also depicted in Figure 31 through Figure 35. Only those assets that were identified as highly vulnerable and moderately vulnerable were included in the tables. The remaining assets that were identified as low in vulnerability are shown on the results GIS based maps. In VAST, precipitation indicators did not incorporate modeling of changes in exposure to heavy storm in 2050 and 2100, therefore future exposure indicators were very similar and results were identical for the year 2050 and 2100.

The overall vulnerability threshold was set to 3.0; all facilities that obtained a total vulnerability score of 3 or higher for any climate stressor was considered vulnerable to that specific climate stressor. Facilities that obtained vulnerability score between 2.5 and 2.9 were considered moderately vulnerable, and all facilities that obtained a score of 2.4 and lower were considered the most resilient, and low in vulnerability.

Facilities Results. *The CNOC facility and the Wilmington Shops were the two most vulnerable assets to all flooding related climate stressors. The Amtrak training center was highly vulnerable to future impacts of heavy storms and precipitation, which corresponds with the historical flooding incidents around that area. The West Yard substation was also considered highly vulnerable to precipitation and moderately vulnerable to storm surge and wind.*

The CNOC facility and the Wilmington Shops achieved a high level vulnerability for all climate stressor, and in both future climate scenarios 2050 and 2100. Vulnerability scores for CNOC ranged between 3.1 and 3.9 for all flood related climate stressors, while the Wilmington Shops vulnerability scores ranged between 3.0 and 3.7.

The Amtrak Training Center was highly vulnerable to future impacts of heavy storms and precipitation, which corresponds with the historical flooding incidents around that area. Also, the training center was identified as moderately vulnerable for future impacts of storm surge. The West Yard substation was also considered highly vulnerable to projected impacts of precipitation, and was also considered moderately vulnerable for storm surge and wind.

The Wilmington Station was considered relatively resilient, as it didn't score any high vulnerability for any climate stressor and was only considered moderately vulnerable for sea level rise and storm surge. Also, the Bellevue substation scored low vulnerability for all climate stressors and was considered the most resilient facility in the Pilot Study area.

Table 19. Facility Vulnerability to Precipitation VAST Results

Facilities Vulnerability to Precipitation		
Facility ID	**VAST Score**	**Result**
F1 Wilmington Shops	3.7	High
F2 CNOC	3.4	High
F6 West Yard Substation	3.4	High
F4 Training Center	3.1	High

Table 20. Facility Vulnerability to Sea Level Rise 2050 VAST Results

Facilities Vulnerability to Sea Level Rise 2050		
Facility ID	**VAST Score**	**Result**
F2 CNOC	3.1	High
F1 Wilmington Shops	3.0	High

Table 21. Facility Vulnerability to Sea Level Rise 2100 VAST Results

Facilities Vulnerability to Sea Level Rise 2100		
Facility ID	**VAST Score**	**Result**
F2 CNOC	3.4	High
F1 Wilmington Shops	3.0	High
F3 Wilmington Station	2.7	Moderate

Table 22. Facility Vulnerability to Storm Surge 2050 VAST Results

Facilities Vulnerability to Storm Surge 2050		
Facility ID	**VAST Score**	**Result**
F2 CNOC	3.9	High
F1 Wilmington Shops	3.6	High
F4 Training Center	2.7	Moderate
F3 Wilmington Station	2.7	Moderate

Table 23. Facility Vulnerability to Storm Surge 2100 VAST Results

Facilities Vulnerability to Storm Surge 2100		
Facility ID	**VAST Score**	**Result**
F2 CNOC	3.9	High
F1 Wilmington Shops	3.6	High
F4 Training Center	2.9	Moderate
F3 Wilmington Station	2.7	Moderate
F6 West Yard Substation	2.6	Moderate

Wind did not impact many facilities within the Pilot Study area, however, the Wilmington Shops, with its various types of buildings and sheds was identified as a facility with potential vulnerabilities to wind (see Figure 36). This was mainly based on Hazus results of wind fields, which showed the area near the Wilmington Shops being exposed to highest level of wind during future hurricane events.

Table 24. Facility Vulnerability to Wind Vast Results

Facilities Vulnerability to Wind		
Facility ID	**VAST Score**	**Result**
F1 Wilmington Shops	3.6	High
F2 CNOC	2.9	Moderate
F6 West Yard Substation	2.5	Moderate

(b)(3)

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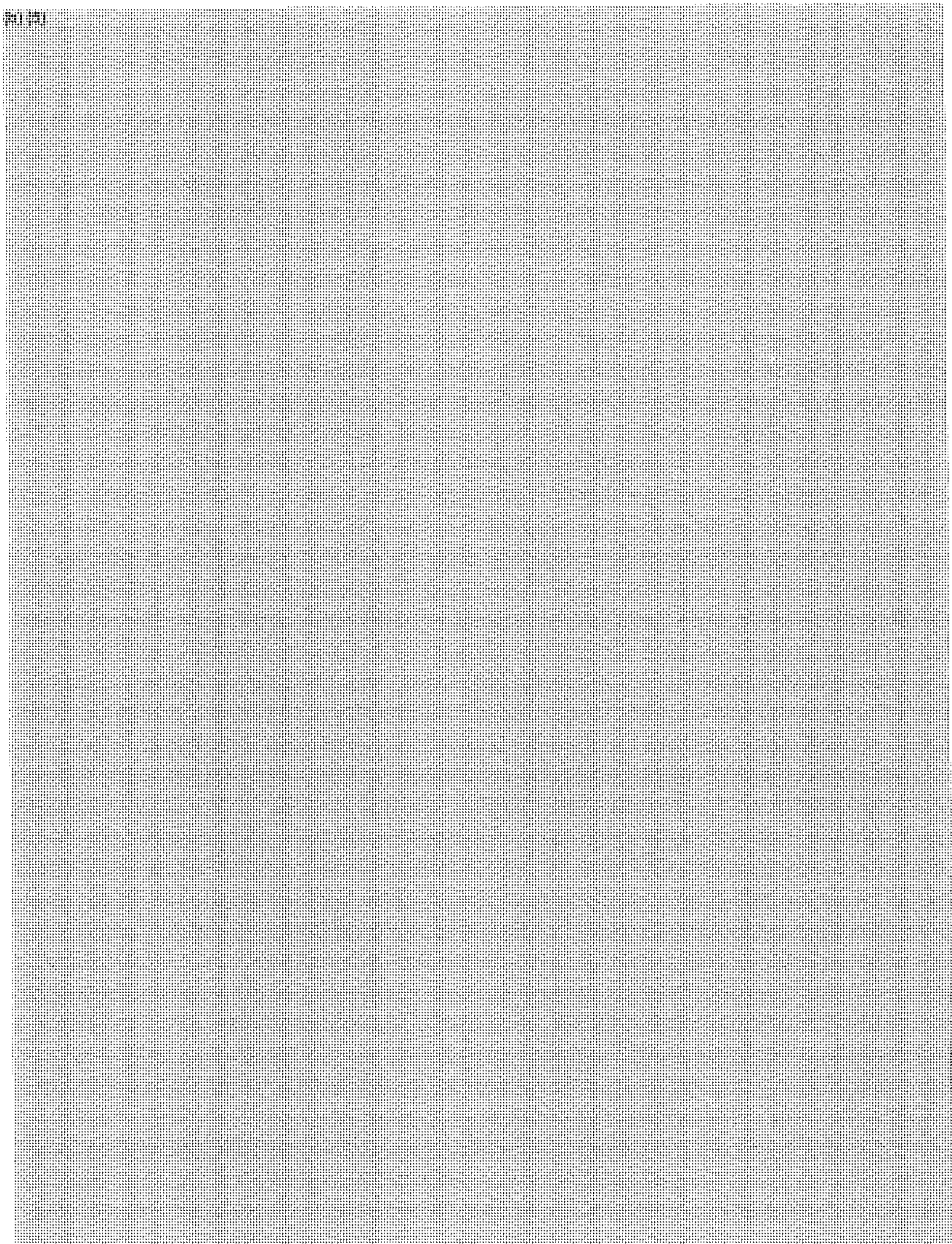

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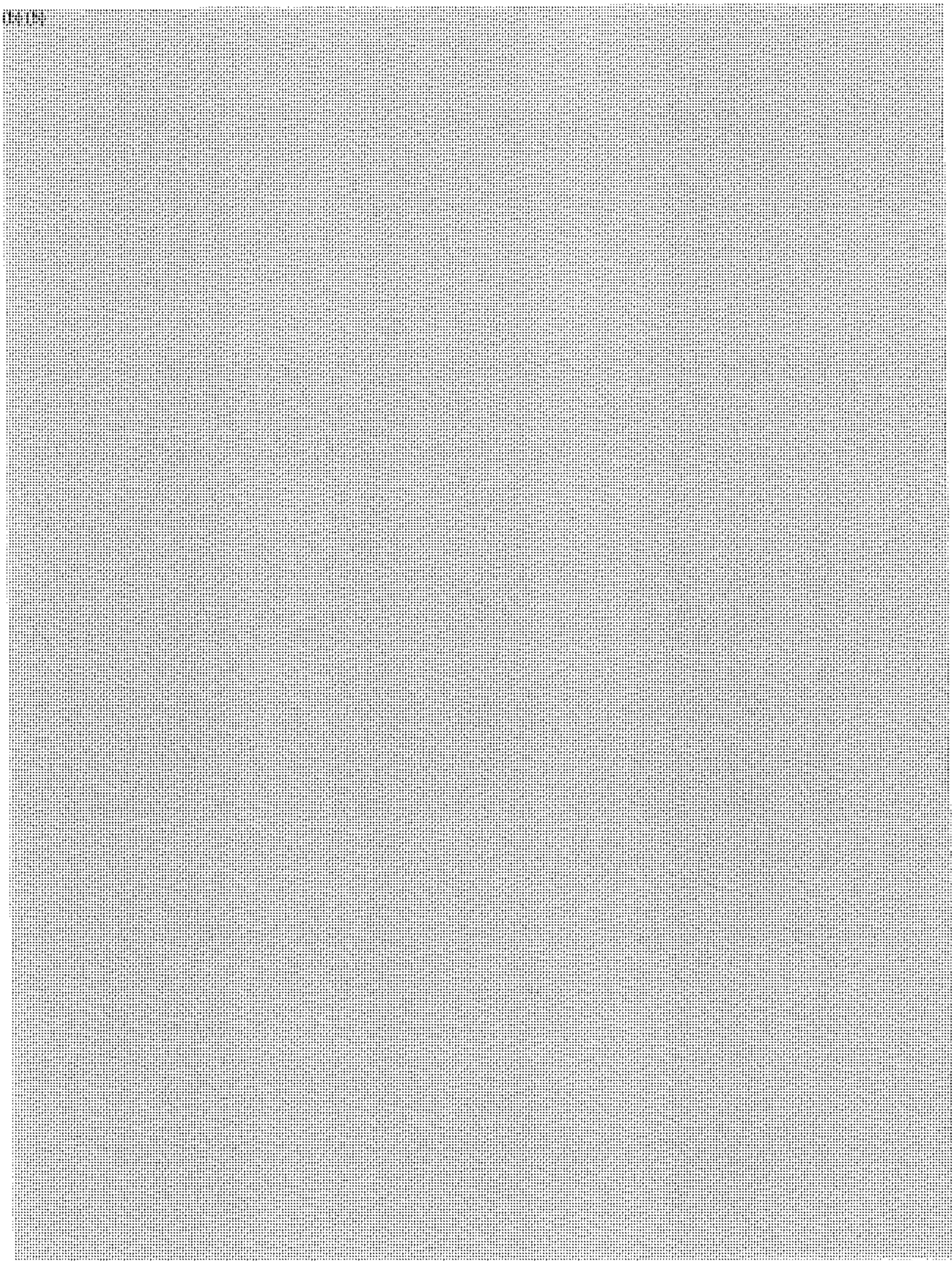

(b)(5)

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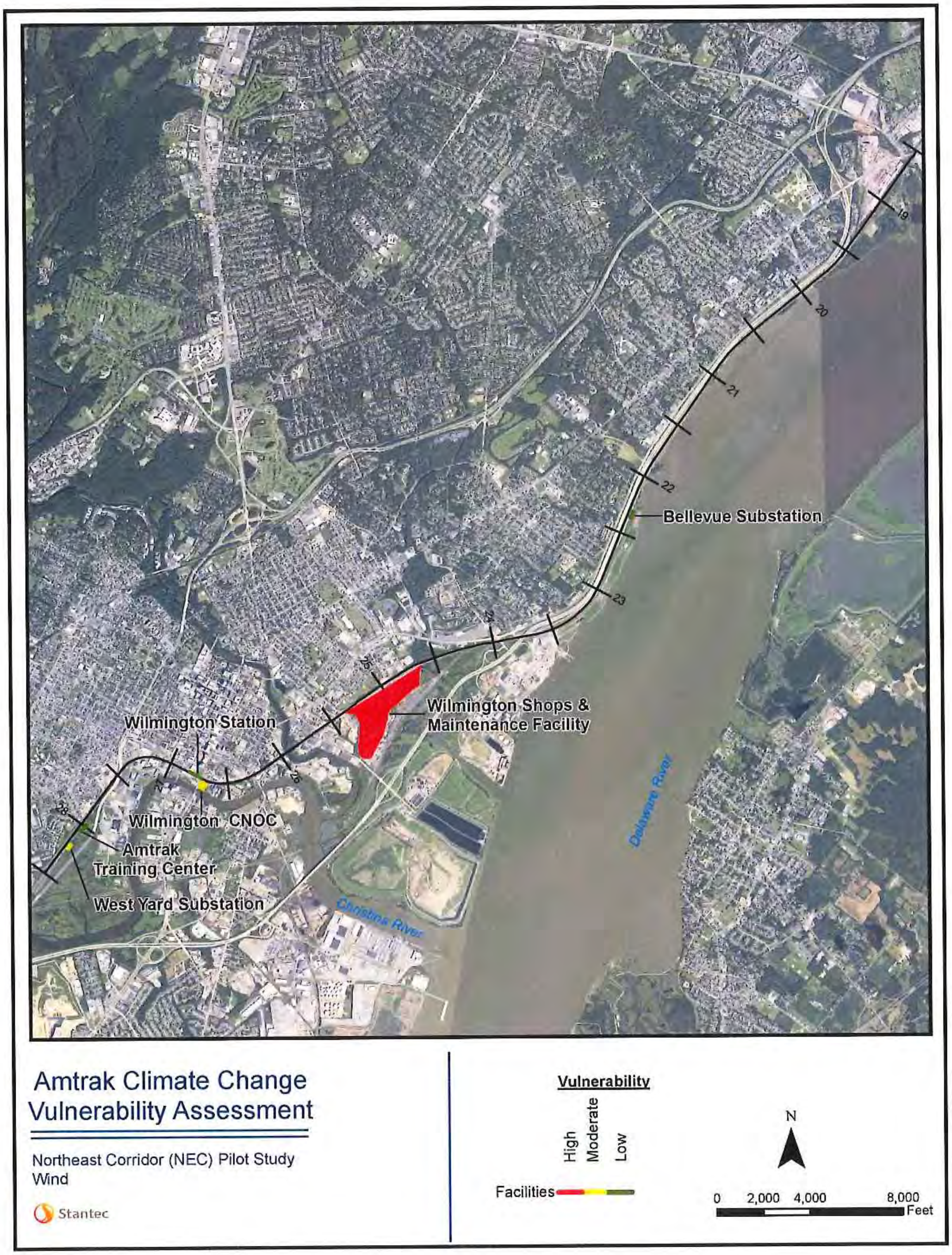


Figure 36. Facility Vulnerability to Wind VAST Results

5.5 Results of Modeling - Calculate Losses

The Study Team assessed the potential losses to facilities and bridges within the Pilot Study area using the Hazus-MH flood and wind models. The required inputs differ for the flood and wind models as do the results; therefore, each model's results are described separately below.

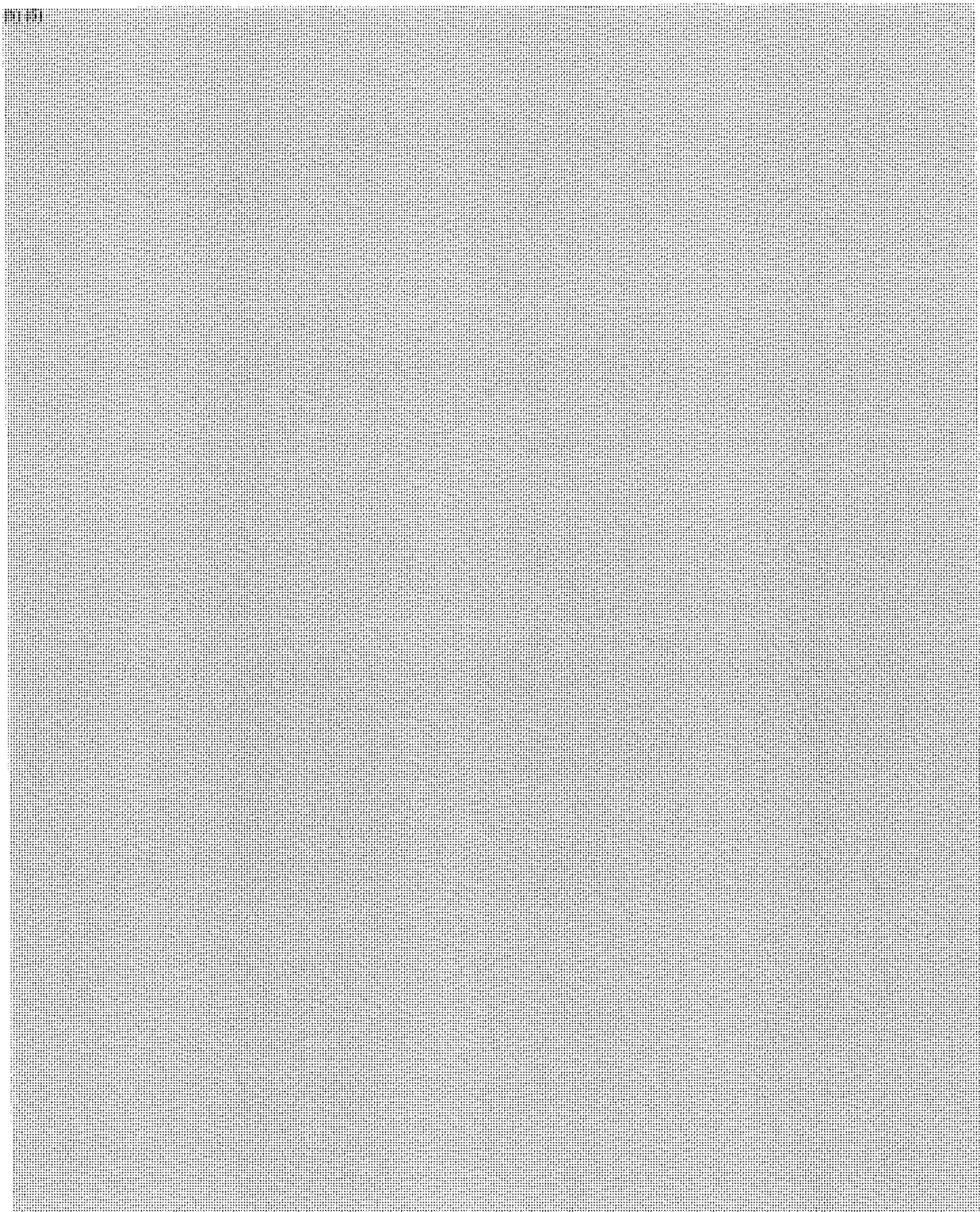
5.5.1 Flood Model Results

The Hazus-MH flood model was used by the Study Team to determine potential dollar losses to buildings, building contents, and bridges within the Pilot Study area. The flood model also provided estimates for potential functionality loss of bridges (in number of days). Inputs required estimating potential damages to assets include elevation, foundation type, location, and depth of flooding. Amtrak buildings and bridges and their associated attributes (foundation type, replacement value, content value, and elevation) were added as GIS point features to the Hazus-MH model, and the depth grids provided flood depth (please refer to Section 2.2.4). The inputs used for the flood model are presented in Table 25. Potential losses to facilities due to projected sea level rise are presented in Table 26, while Table 27 indicates potential losses for coastal surge combined with projected sea level rise. Both tables display results at two intervals: years 2050 and 2100. There were no losses associated with bridges in any of these scenarios.

Facilities Flood Model Loss Results. *The results indicate losses occur to projected sea level rise beginning in year 2100. When coastal storm surge is added to project sea level rise, losses begin in year 2050. The CNOC building is the first asset to be impacted by these projected future conditions and has the second highest potential damage (as a percentage of total replacement value) of all assets combined.*

Table 25. Flood Model Inputs

	Building Replacement Value	Content Replacement Value	Total Replacement Value	Number of Stories	Elevation (ft)	FL Building Type	Hazus Flood Foundation Type
Wilmington Shops	(b) (5)	(b) (5)	(b) (5)	3	5	Masonry	Slab on Grade
CNOC Operations Center	(b) (5)	*Not available*	(b) (5)	2	4	Masonry	Crawl Space
Wilmington Station	(b) (5)	(b) (5)	(b) (5)	3	3	Masonry	Basement/ Yard
Training Center	(b) (5)	*Not available*	(b) (5)	2	5	Concrete	Slab on Grade



(b) (5)

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As with all models, some uncertainty is inherent, and potential loss estimates should be used only as a planning tool. In addition to the required model inputs, there are several factors that may impact the results for potential building losses.

- **Point Location** - Amtrak facilities were added to the Hazus-MH model as GIS point features, representing a specific point (latitude and longitude) where the building resides. This could affect the results because the depth of flooding was taken at the specific point representing the asset, as opposed to other methods of determining flood depth (e.g. calculating the average depth of flooding or maximum depth of flooding for the entire surface area of the facility).
- **Classification of Building Data** – Building data collected must be correlated and classified to meet the required inputs of the model. For example, a building might have two foundation types – part crawl space and part slab on grade; however, the model requires only one foundation type be chosen. In such cases professional judgement and best available data were used to classify to building data.
- **Availability of Building Data** – Model results may be affected if assumptions are made about any unknown actual building characteristics (e.g. elevation or foundation type. Given the just four facilities within the Pilot Study area, actual characteristics were collected for all buildings. (b) (5) [redacted]
  (b) (5) [redacted]
- **Wilmington Shops** – These buildings were modeled as a single asset.
- **Velocity** – The coastal storm surge modeling does not account for velocity impacts from storm surge.

Factors that may impact the results for rail bridges include elevation, replacement cost, and point location.

- **Elevation** – The elevation provided represents the maximum height of the bridge. Therefore, results are reflective of whether or not a bridge was overtopped but do not consider clearance (the surface height of the water compared to the low point on the bridge).
- **Replacement value** – This is a necessary input to estimate losses, and it was only provided for six bridges in the Pilot Study area.

- **Point Location** - Bridges are added to the model as GIS point features, presenting the same challenges as buildings (i.e. assessing the depth of the water at a single point versus the entire span of the bridge).
- **Velocity** – The coastal storm surge modeling does not account for velocity impacts from storm surge.

5.5.2 Hazus-MH Wind Model Results

The Hazus-MH wind model was used to determine the damage state probability of each facility during a 100-year wind event. The Hazus-MH wind model does not provide dollar loss estimates or analyze bridges. The potential damages are based on the building construction type, location, and severity of the hazard (peak wind speed). The Hazus-MH wind model requires facilities to be classified into model-specific building types. The building classifications used in the analysis are presented in Table 28. The model results are shown in Table 29.

Facilities Wind Hazus Loss Results. *The Hazus-MH model predicted limited impacts from a 100-year wind event. Each facility has a potential 1-percent chance (or lower) probability of incurring minor damage.*

Table 28. Building Classification into Hazus-MH Wind Model Specific Building Type

	Hazus-MH Wind Model Specific Building Type
Wilmington Shops	Engineered Commercial Buildings, Low-Rise (1-2 Stories), Steel
CNOC	Engineered Commercial Buildings, Low-Rise (1-2 Stories), Masonry
Wilmington Station	Engineered Commercial Buildings, Medium-Rise (3-5 Stories), Masonry
Training Center	Engineered Commercial Buildings, Low-Rise (1-2 Stories), Steel

Table 29. Potential Damage State Probability Based on a 100-year Wind Event

	Peak Wind Speed (MPH)	Potential Damage State Probability			
		Minor	Moderate	Severe	Complete Destruction
Wilmington Shops	70	1%	0	0	0
CNOC	69	1%	0	0	0
Wilmington Station	68	1%	0	0	0
Training Center	68	1%	0	0	0

Model results could be impacted by the required classification of each facility into a Hazus-MH wind model specific building type. The model has several specific building construction classifications, and each facility must be assigned based on available building data. Where building data was limited or multiple construction types were present, assumptions regarding specific building type were necessary for facility classification.

5.6 Roadway Vulnerability Assessment Results

Sea Level Rise and Storm Surge for Roads in 2050

The majority of the road segments have low vulnerability to sea level rise in 2050. The roadway network near the confluence of the Christiana River had a high vulnerability in 2050. Storm surge added slightly to the overall vulnerability.

In the year 2050, roads having vulnerability because of sea level rise are measured to be within one of two extremes, either low vulnerability or high vulnerability (see Figure 37), where the majority of the road segments have low vulnerability to sea level rise in 2050 with no amount of inundation. Four of the road segments have high vulnerabilities with high HVI scores, and all of these 0.5 mile segments have continual emergency road inundation with depths as large as 7 feet.

Thirteen out of the twenty segments demonstrate either high or moderate vulnerability for storm surge in the year 2050 (see Figure 38). The six highly vulnerable sections demonstrate percent of emergency roads with inundation values greater than 20%. These sections have a minimum of 5,000 feet of linear roads with inundation. The five moderate 0.5 mile segments have as much as 8% of the roads inundated with water or 17% of the emergency roads inundated with water. The remaining nine segments have no inundation within the emergency roads.

Sea Level Rise and Storm Surge for Roads in 2100

The road vulnerability associated with sea level rise for the year 2100 falls within 3 categories; low, moderate, and high, with the majority of 0.5 mile segments classified as low vulnerability (see Figure 39). All road segments with inundation due to sea level rise will have a regular problem with water because inundation from sea level rise generates an ongoing critical situation rather than a short-term problem. The most critical parameters in the HVI scores are related to the emergency roads. The segments with low vulnerability have less than 76 linear feet of total emergency road inundation. Four of the 0.5 mile segments of roadways are classified as moderate vulnerability with at least 3% of linear feet of roadway inundation and maximum inundation depths of 10 feet and 6 inches. Significantly high values of percent of roads inundated with water are found within the high vulnerability category. More than 1,390 feet of total emergency road are expected to be inundated. The most severe values of inundation are associated with mile posts 27.0 to 26.5.

In 2100, greater than 20% of the total amount of roads will be covered with water in four of the 0.5 mile segments.

The ten mile stretch of track in the pilot study has a significant number of roads with high vulnerability due to storm surge for the year 2100 (Figure 40). The storm surge produces temporary inundation problems and eight of the twenty segments have high vulnerability. These segments display values of percent of emergency road inundation ranging from 24% to 74%. Four of the track segments have moderate vulnerability with approximately 15percent of emergency road inundation and a maximum depths of inundation of approximately 5 feet 10 inches. The other eight segments of track are classified as low vulnerability segments with less than 5% inundation for emergency roads.

Precipitation for Roads

Nineteen out of the twenty segments demonstrate either high or low vulnerability for precipitation associated with roads. One 0.5 mile segment is classified as moderate as shown in Figure 41. The HVI scores for highly vulnerable sections are mostly influenced by the percent of road and emergency road within the flood zone. Of the eight 0.5 mile segments with high vulnerability, mile posts 27.0 to 25.5 demonstrate the greatest vulnerability. These roads also have a minimum of 34% of the roads within flood zones. The single 0.5 mile stretch with a moderate vulnerability has an HVI score of 0.34 and as much as 15% of the emergency roads positioned within a flood zone. The remaining eleven segments have less than 3.5% of the roads within flood zones and no emergency roads within flood zones.

Of the eight 0.5 mile segments with high vulnerability, mile posts 27.0 to 25.5 demonstrate the greatest vulnerability to precipitation.

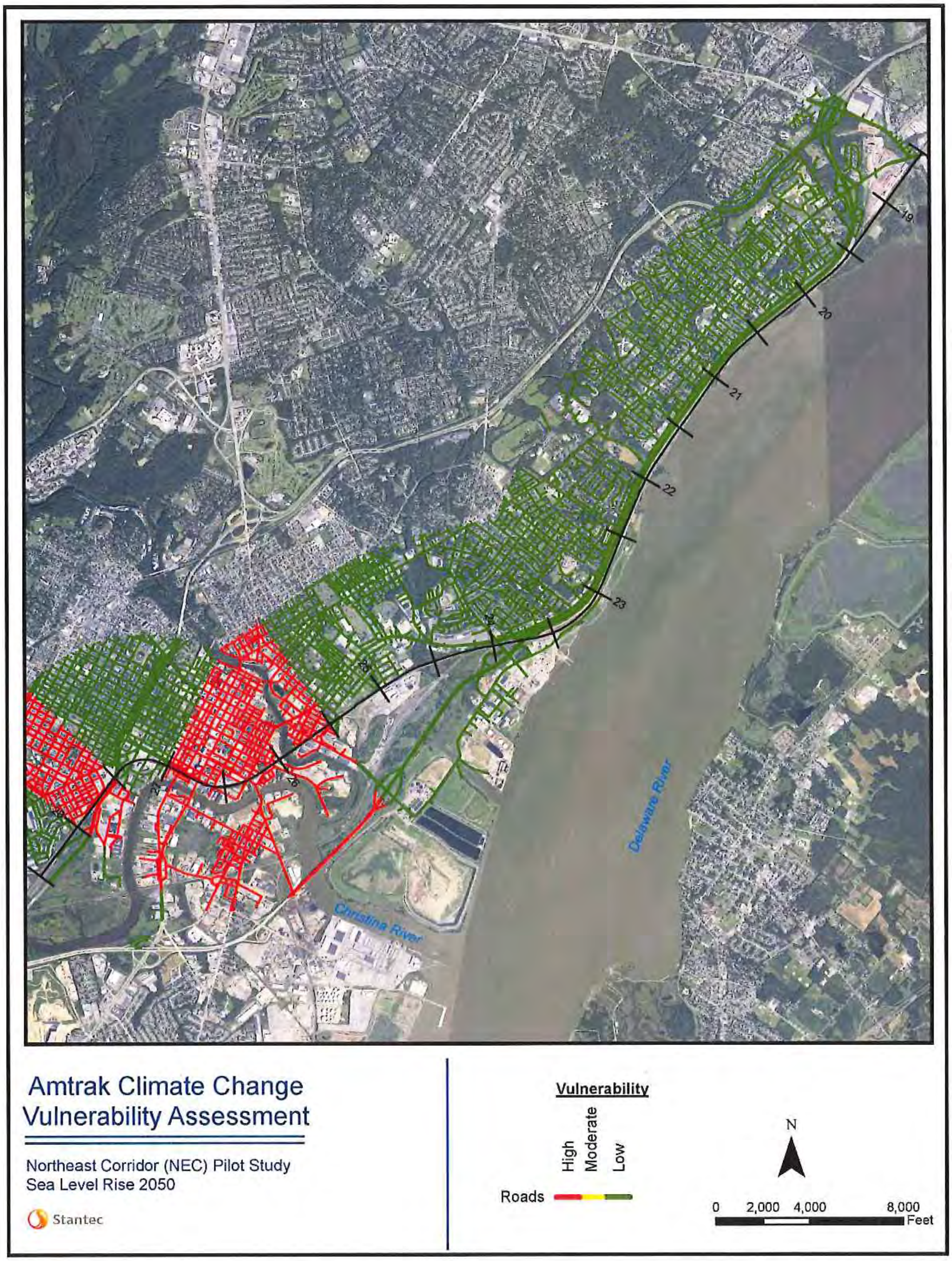


Figure 37. Roadway Network Vulnerability to Sea Level Rise (2050)

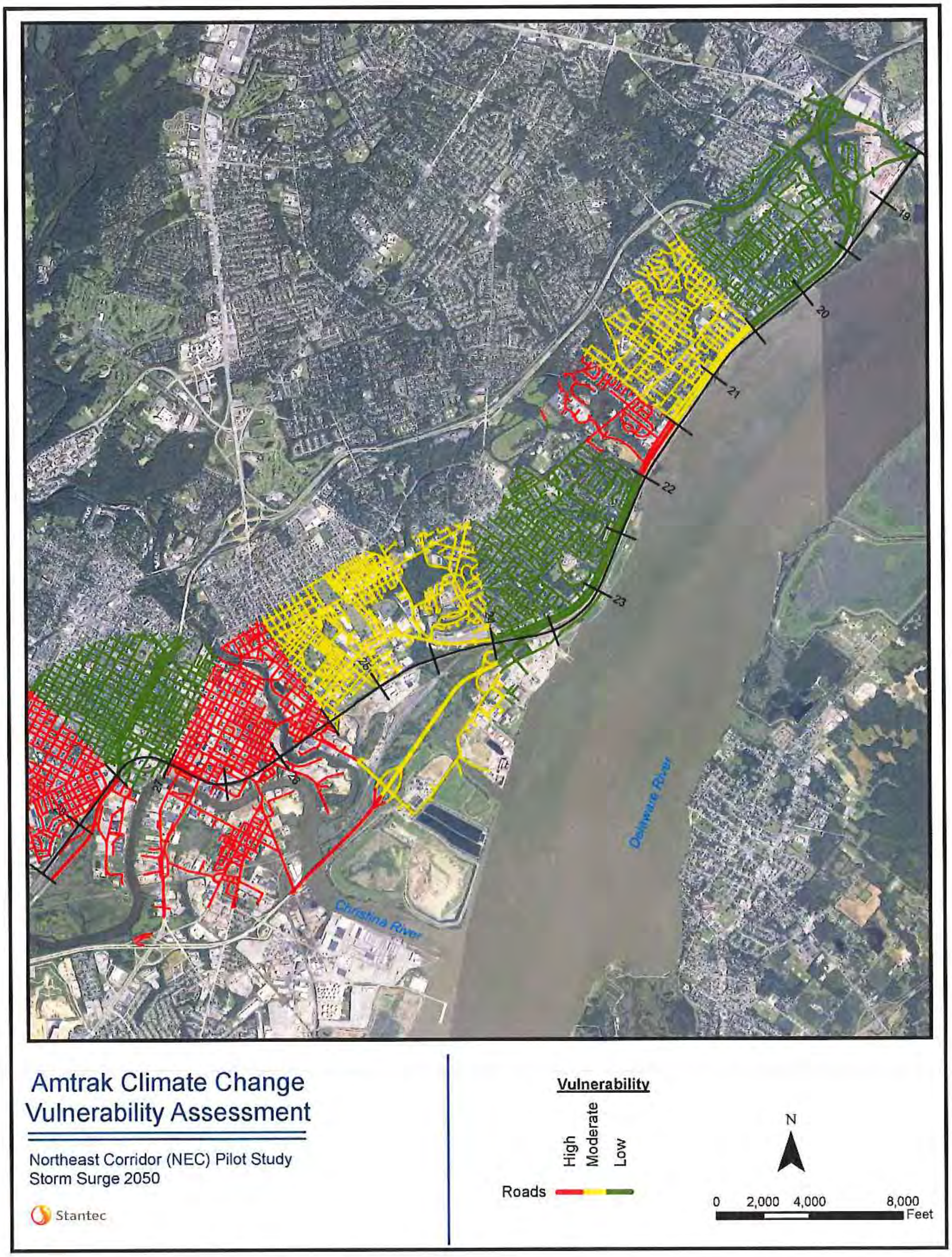


Figure 38. Roadway Network Vulnerability to Storm Surge (2050)

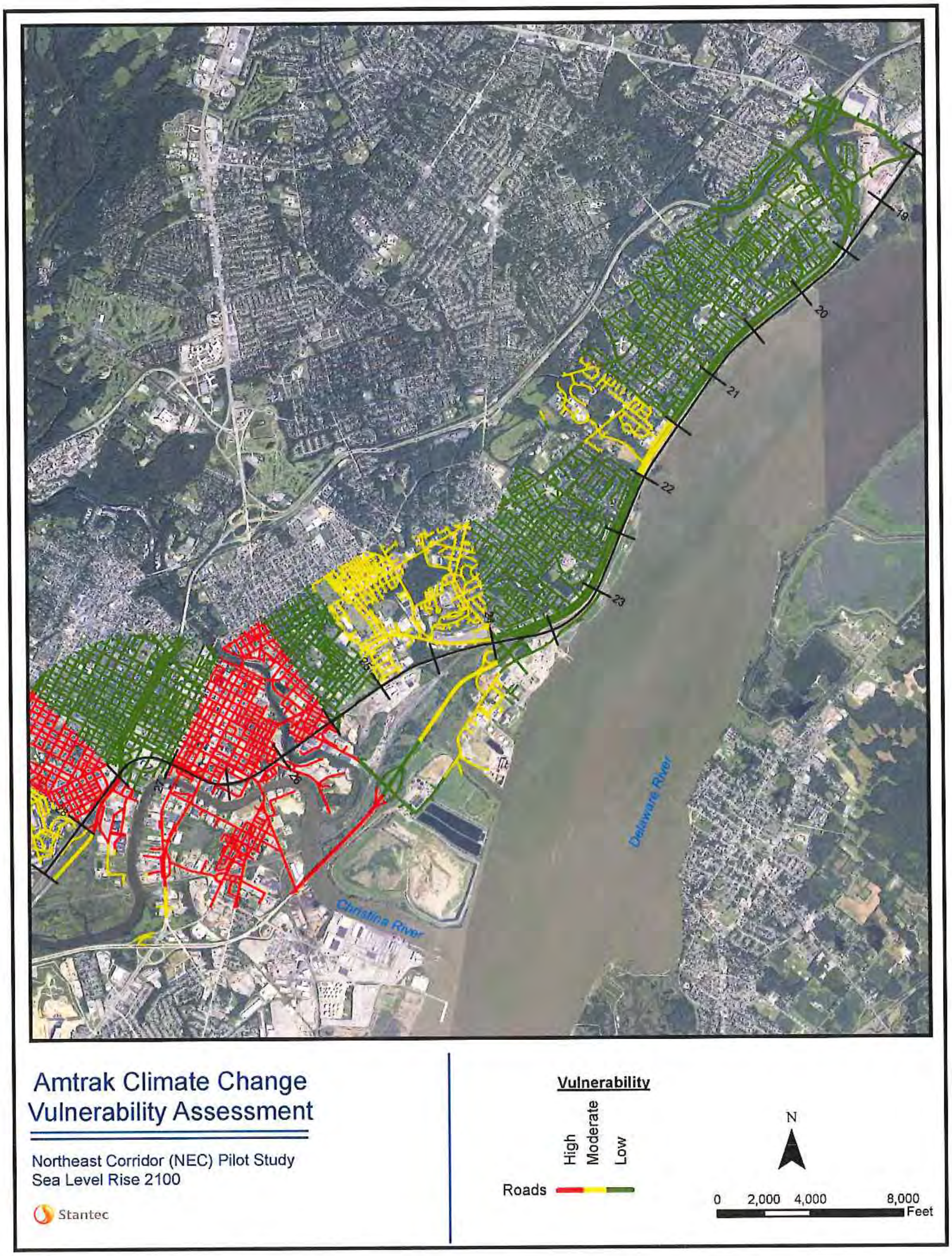


Figure 39. Roadway Network Vulnerability to Sea Level Rise (2100)

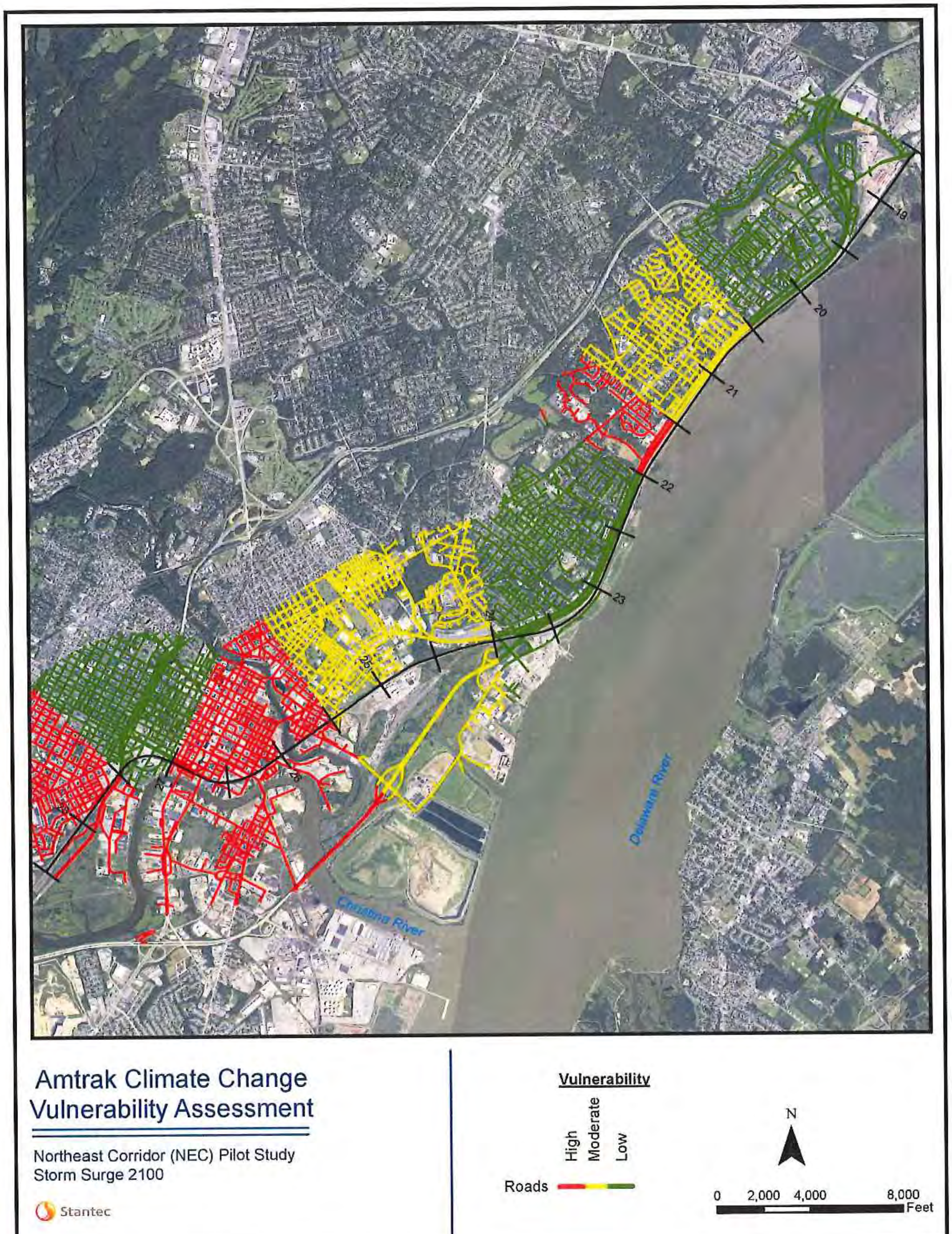


Figure 40. Roadway Network Vulnerability to Storm Surge (2100)

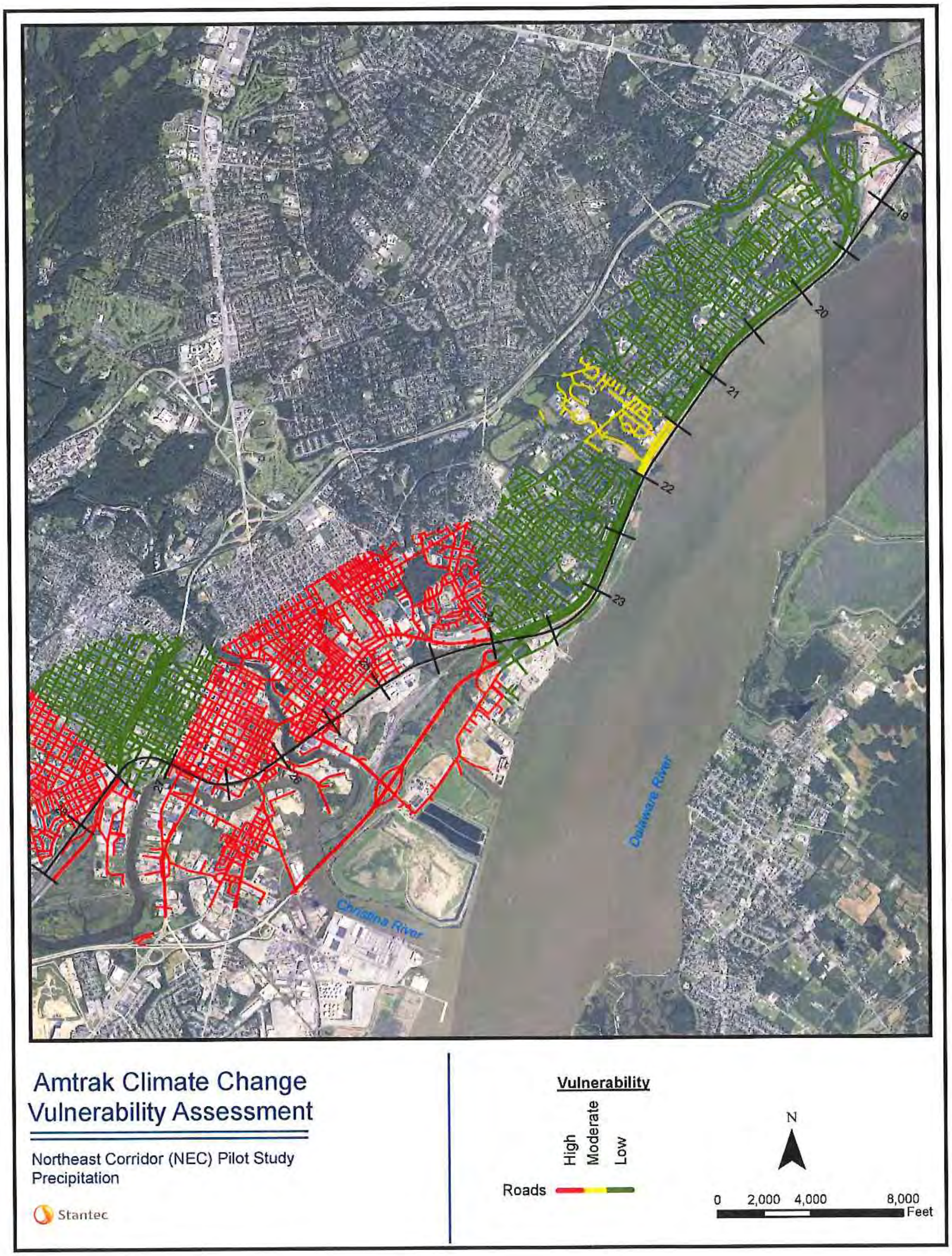


Figure 41. Roadway Network Vulnerability to Precipitation

5.7 Additional Vulnerabilities not assessed using VAST or HVI

Some Amtrak assets are vulnerable to climate stressors, but the expected effect is general and difficult to provide comparative analysis. For these asset vulnerabilities a general discussion has been provided to explain the possible impacts. In future studies when more information is available about the assets specific vulnerability or more information is available about the asset themselves a more detailed analysis can be provided.

5.7.1 Facility Vulnerabilities to Temperature

In general, the identified facilities are vulnerable to high temperatures due its effects on the building and supporting infrastructure materials. Facilities are also vulnerable from a maintenance and operations stand point. High temperatures can cause damage to the building roofs and asphalt parking lots. Similar to roads, the asphalt surfaces around and on the buildings are vulnerable to thermal expansion. Electrical components used for lightning or heating/cooling are also vulnerable to extreme temperatures. It is also likely that maintenance costs associated with repairs to the buildings and parking areas will increase as temperatures increase (FHWA, Climate Change & Extreme Weather Vulnerability Assessment Framework, 2010). An ancillary consequence of increased temperature is the reduction in operational activities that can occur outside due to worker safety.

Substations

Substations are spaced strategically along the line and are necessary to convert electricity to the frequency used by trains. Vulnerability to temperature for the substations centers around the potential damage high temperatures can have on electric components. Substations are integral to the catenary system and powering the trains therefore damage to the electric system can result in the trains being shut down completely.

5.7.2 Bridge Vulnerabilities to Wind and Temperature

Movable bridges are most vulnerable to storm generated winds. There are no movable bridges within the Pilot Study area, but there are five movable bridges along the NEC all between New Haven, Connecticut and Boston, Massachusetts (Amtrak, 2015).

There is expected to be an increase in stress on bridge integrity due to temperature caused expansion on concrete joints, steel, asphalt, protective cladding, coats and sealants (FHWA, Climate Change & Extreme Weather Vulnerability Assessment Framework, 2010). Similar to road surfaces paved bridges can be vulnerable to thermal expansion. Asphalt concrete pavement can soften

Figure 42. Niantic River Bridge (Amtrak, 2015)

when exposed to consecutive days of high temperature resulting in rutting and shoving (Heitzman, 2010). Bridges are typically designed to withstand temperatures ranging from 100°F to -20°F. This vulnerability would only be applicable to paved bridges not crossings that consist of large concrete culverts or bridges made of timber. Extreme temperatures can also effect any electrical equipment that is mounted on the bridge. This is further discussed in the signal section (5.5.4). It is likely that maintenance costs associated with bridge repair are likely to increase as temperatures increase.

5.7.3 Catenary System/Signals Vulnerabilities to Temperature

Figure 43. "Constant-tension" Catenary System (NEC Commission, 2015)

The majority of the NEC trains are powered by electricity carried through the catenary system. Portions of the catenary system date back to the 1930s and are therefore more susceptible to failure. Extreme high heat causes the lines to sag. Fast moving trains have in the past gotten tangled in the catenary wires resulting in them being torn down and stopping all trains on the track (NEC Commission, 2015). These extreme events and the slowing of the train preemptively during days if extreme heat delay riders and can increase maintenance cost repairs. An adaptation measure has been identified and has been installed on a 22 mile stretch of track in New Jersey. "Constant-tension" catenary lines keep the wires taut regardless of the temperature. This installation allows for the Acela Express to operate at speeds of 160 MPH as opposed to the previous speed of 135 MPH.

The electric components within the signals are vulnerable to extreme temperatures. Extreme temperatures can cause the signals to become un-operable which could cause the line to be temporarily shut down.

5.7.4 Road Vulnerabilities to Wind and Temperature and Track Vulnerability to Wind

Road vulnerabilities due to extreme temperatures are very similar as to what was discussed for bridges. High temperatures can cause asphalt to rut or shove although the threshold depends on the pavement design. Pavement binders may begin to exhibit sensitivities beginning at 108 °F (Heitzman, 2010).

Wind does not directly affect roadways but there is a risk to drivers when debris plows on the roadways. Also high winds can make it difficult to drive at high speeds. Similar to roadways wind does not directly affect the tracks themselves but can affect operation of the train as well as cause damage to platforms and stations. Currently Amtrak's operational standards state that when winds reach as sustained speed of 50 mph, the engineer must reduce speed to 60 mph. Sustained wind speeds of 60 mph or above requires the trains to stop (Hajdak, 2015).

5.8 Vulnerable Areas at Risk

There are several vulnerable areas resulting from heavy precipitation, sea level rise and storm surge that become evident when the results of the vulnerability assessment for all assets are plotted on one map. Figure 45 to Figure 48 show the results of the analyses for sea level rise vulnerability in 2050 and 2100. In 2050, the area around the Wilmington Shops and a section at mile post 22 show multiple assets as being vulnerable. The vulnerability of the Wilmington Shops areas is well known by Amtrak staff that typically experience flooding of the entranceway and parking area after a typical heavy rainfall.

By 2100, these areas expand and include;

- the mile stretch between 28.5-27.5 (includes the west yard substation and training center),
- the section of track between mile post 27 and 24 (includes CNOC and the Wilmington Shops), and
- a section between mile post 22 and 21

Figure 44. Example of Flooding to the Parking Area at the Wilmington Training Center Flooding

The vulnerable areas at risk in 2100 include all four of the assessed facilities. These areas include multiple assets at risk including the track, bridges and associated catenary and signals. The section of track between MP 27 and 24 is located on either side of the Christina River. The facilities within this stretch, both the Wilmington Shops and especially CNOC are considered critical to the operation and safety of the Amtrak NEC.

The results are similar but more expansive when determining the vulnerable areas at risk from storm surge in 2050 and 2100. In 2050, the areas near the CNOC and Wilmington Shops are vulnerable as well as the area between mile post 28.5 and 27.5 (Figure 47). In these areas, high to moderate levels of vulnerability are indicated for some of all the asset types including facilities, bridges, track, signals, catenaries and surrounding roads. In 2100 the areas considered vulnerable expand to include the majority of the southern end of the project from mile marker 28.5 to mile marker 24. This section includes all of the facilities. As is evident in Figure 48, there are some assets within this stretch that have a low vulnerability score but overall the assets have been ranked to have a moderate to high vulnerability score.

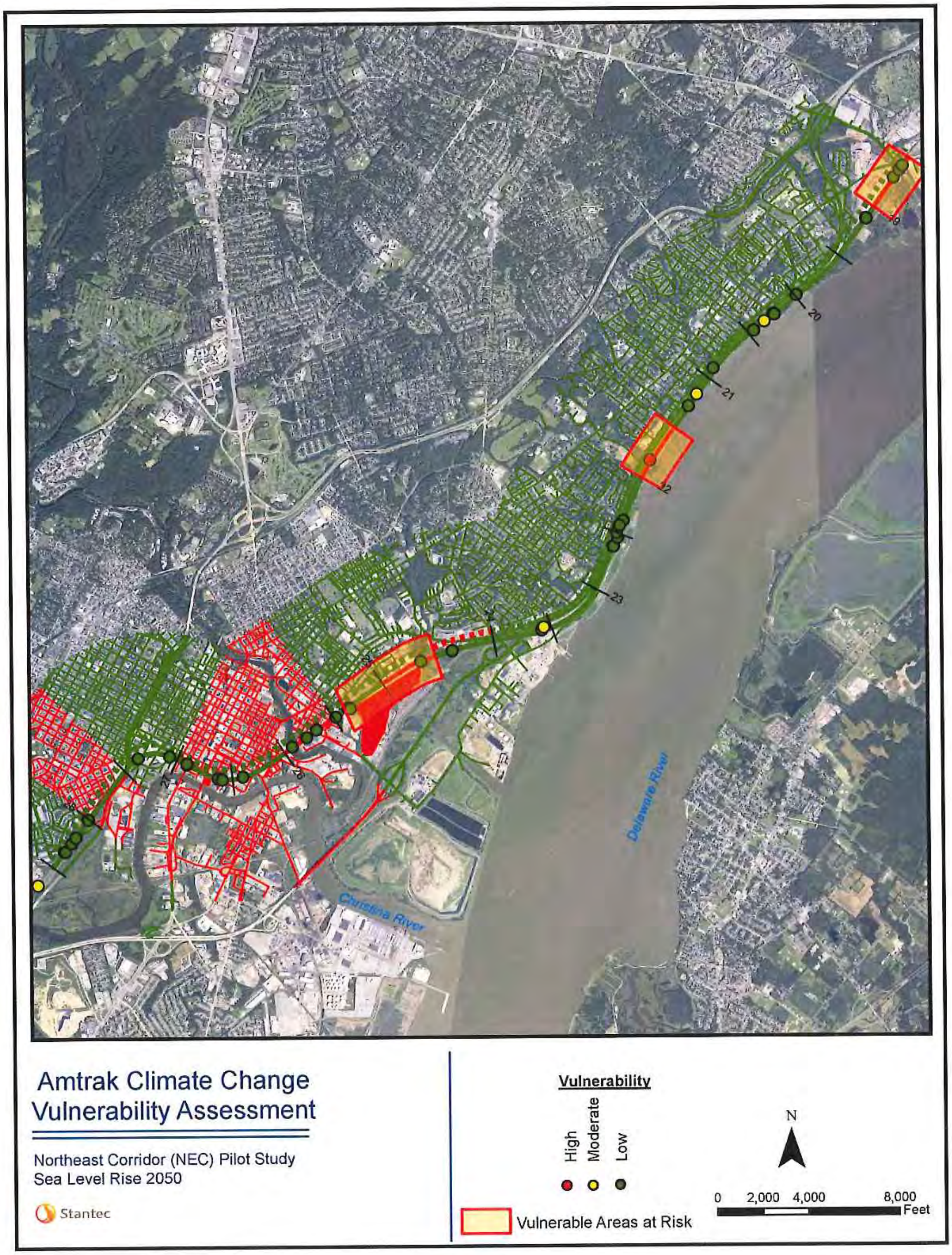


Figure 45. Vulnerable Areas at Risk from Sea Level Rise in 2050

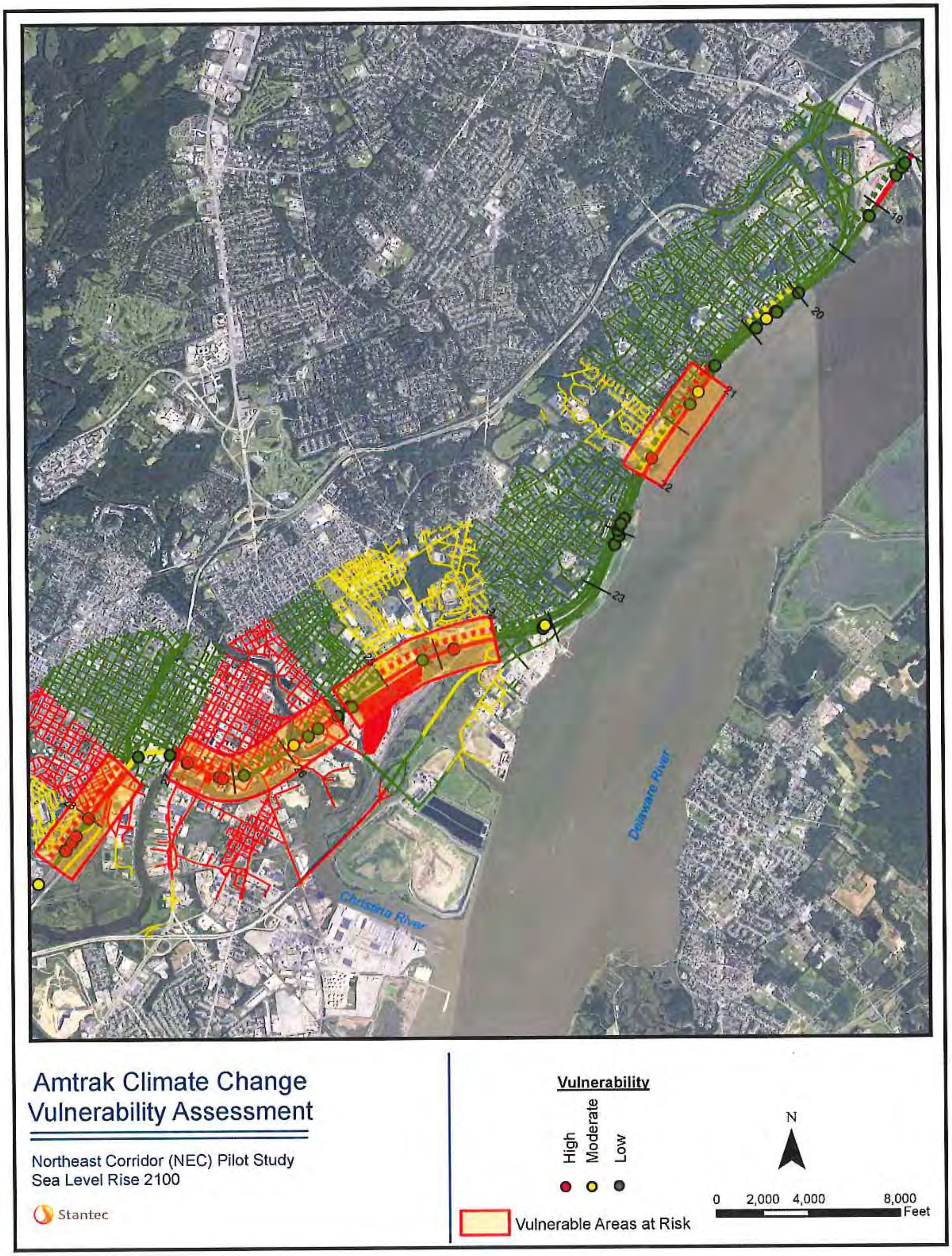


Figure 46. Vulnerable Areas at Risk from Sea Level Rise in 2100

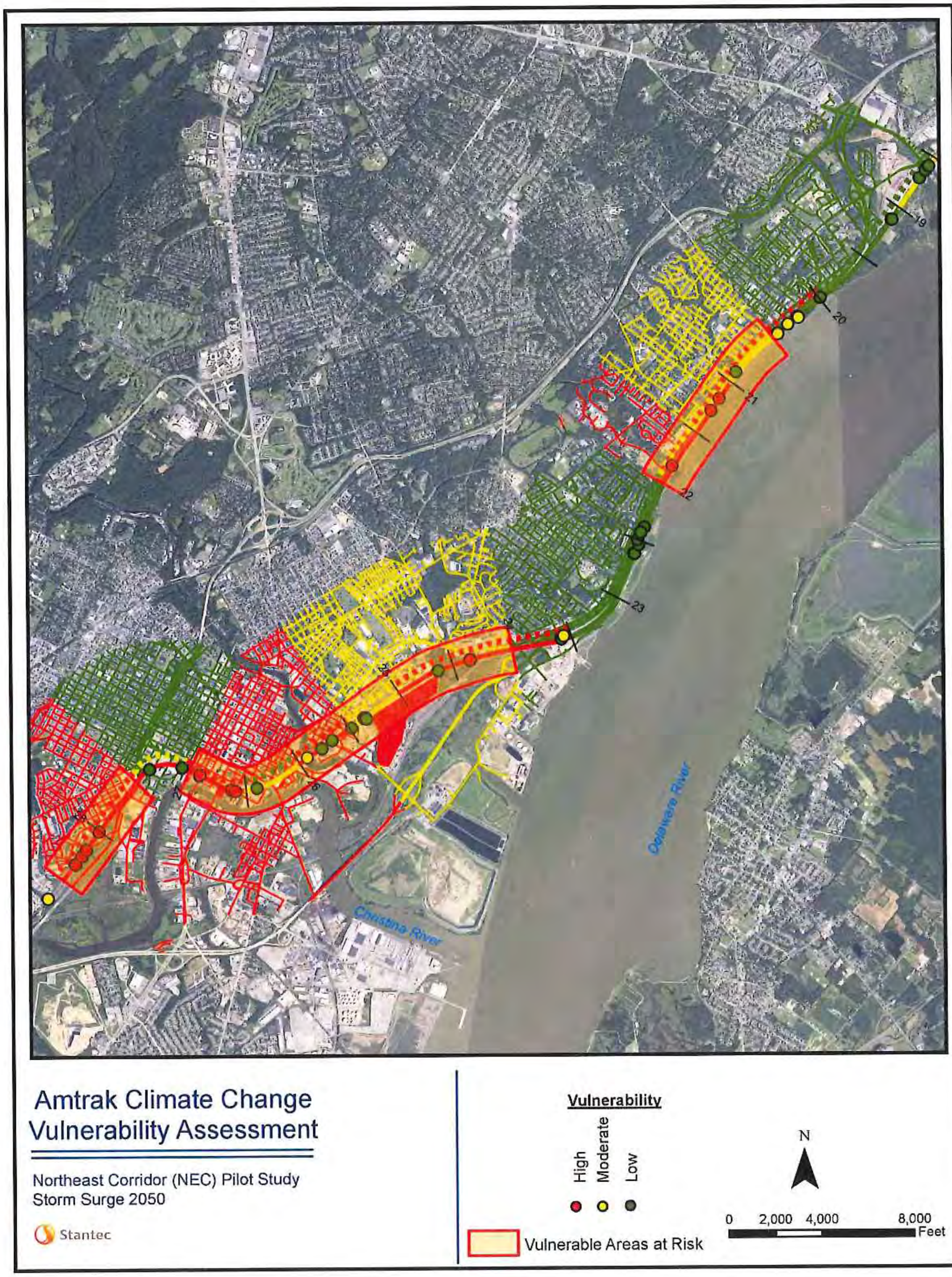


Figure 47. Vulnerable Areas at Risk from Storm Surge in 2050

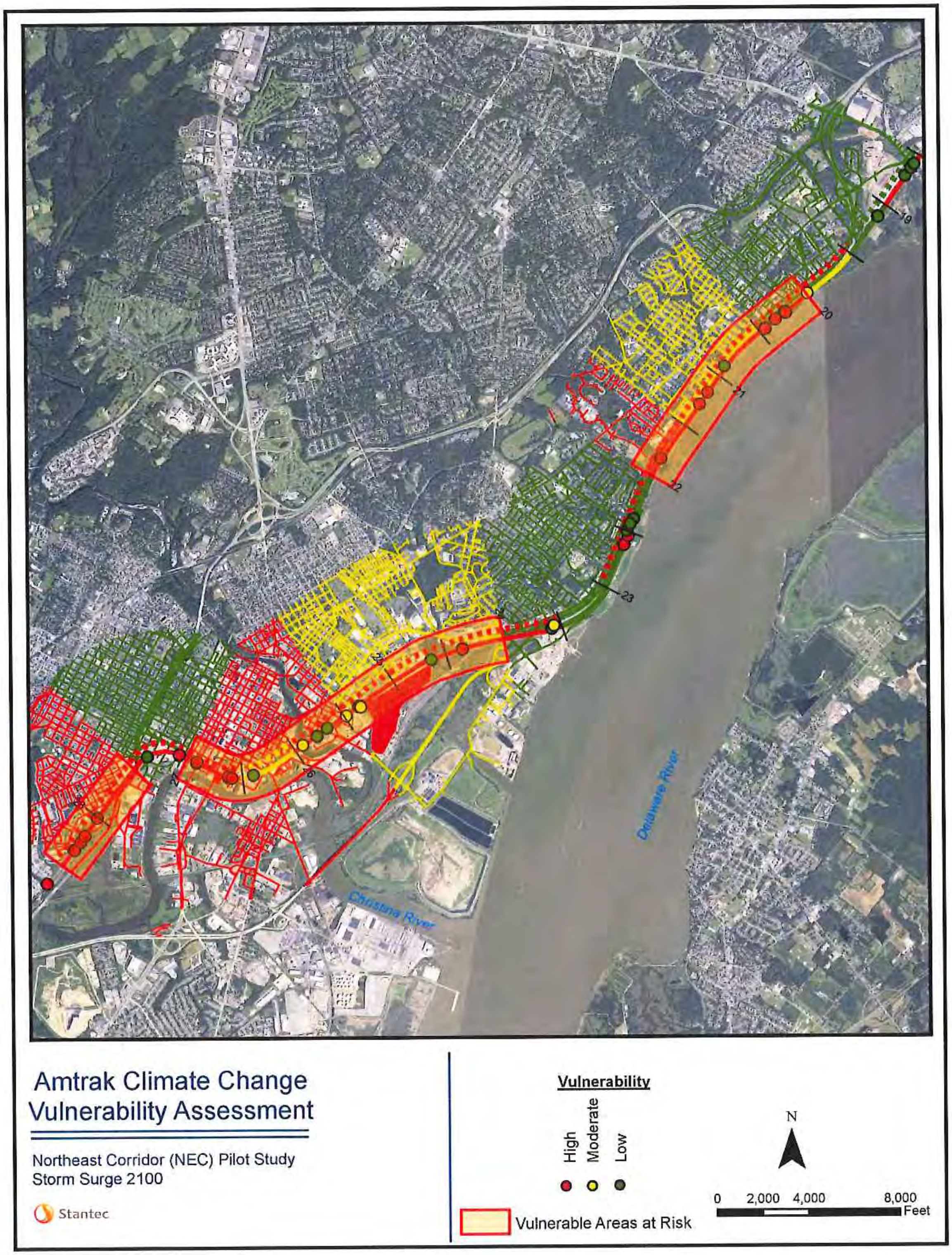
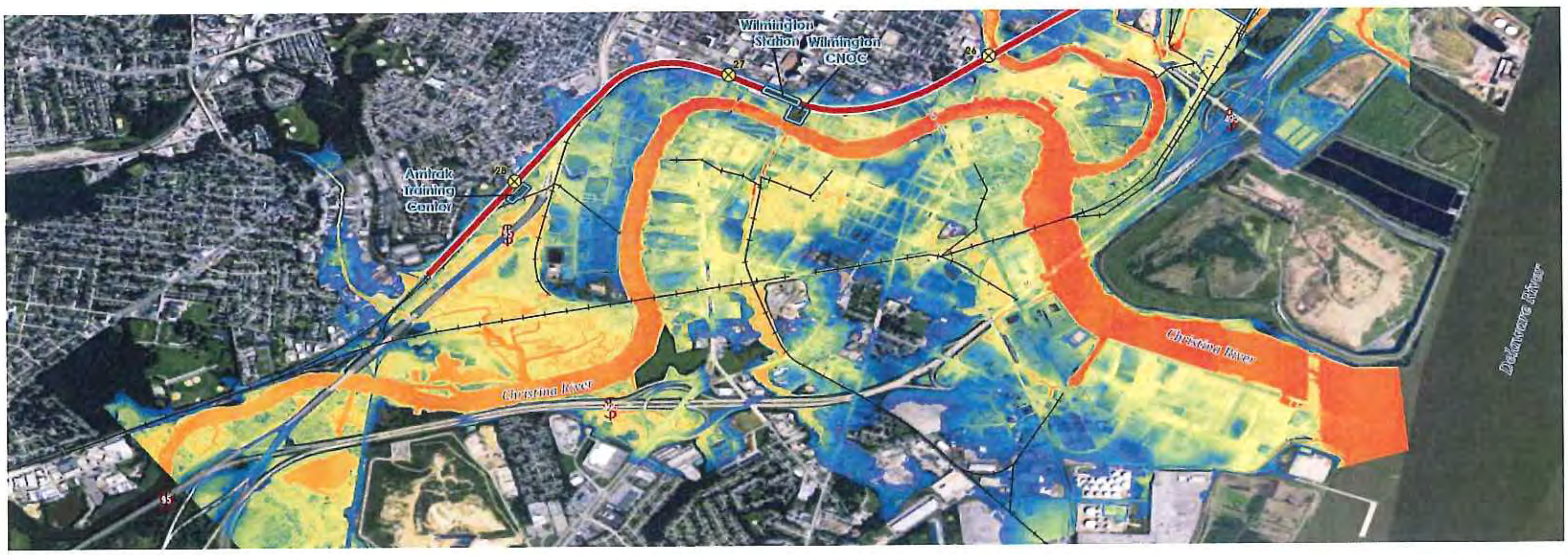


Figure 48. Vulnerable Areas at Risk from Storm Surge in 2100

6.0 Conclusions and Next Steps



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6.0 Conclusions and Next Steps

6.1 Summary of Key Findings

The result of the individual asset analyses provides the Study Team with information needed to rank the individual assets as to their level of risk. More importantly when looking at all the information as a whole it is possible to identify vulnerable areas at risk. It is clear from the sea level rise and storm surge maps that there are several areas that are most vulnerable to future inundation. This can be seen in the year 2050 but more predominantly in the projections for 2100. The section between mile post 24 and mile post 27 have varying levels of vulnerability based on the projection year but it is clear that this area is the most vulnerable and includes all four facilities that were selected for review. The criticality of the facilities within this area and the extent of the track and associated assets (3 miles) within the 10-miles Pilot Study area makes this an important focus area for future actions. As discussed in the recommendations section below, this area could be the focus of a more detailed study including adaptation measures.

6.2 Next Steps and Recommendations

As described in the results section, this Pilot Study identifies vulnerabilities of Amtrak's assets along a 10-mile section of Amtrak's NEC. Following the identification of vulnerabilities, the Study Team has identified a number of next steps for progress towards Amtrak's goal to make Amtrak's system more resilient to the effects of Climate Change. Referring back to the Climate Change Program framework in Chapter 2, this Pilot Study completed steps 1-6 for a relatively small 10- mile section of Amtrak's NEC. As a result of this Pilot Study, Amtrak has developed a repeatable vulnerability assessment methodology that can be applied to other parts of the NEC as resources are available. If needed, this methodology can continue to be refined to best suit the needs of Amtrak. Based on the information gathered, outcomes of this assessment, and understanding of Amtrak's climate change initiatives, the Study Team has developed the following recommendation for Amtrak's consideration to identify the potential next steps for this program.

1. Develop a System-wide Climate Change Impact Zone in GIS for the NEC

Recognizing the level of effort and resources needed to complete the remaining assets in the NEC, Amtrak will need to prioritize future geographic areas for assessment. To help with this prioritization and to give a general overview of the Amtrak system that is exposed to the different climate stressors, the Study Team has the following recommendations.

- Identify those area within the NEC that are most exposed to sea level rise, storm surge, precipitation and heat using a similar methodology as presented in Chapter 2;
- Develop a Climate Change Impact Zone in GIS to assist in identifying and prioritizing future assessments based on available funding and resources.
- Develop and use the Climate Change Impact Zone maps to identify existing and future capital improvement projects that will be affected by climate change, allowing adaptation measures to be developed and/or taken into consideration early in the project life cycle.

2. Prepare an Amtrak Adaptation Strategy

The Study Team recommends that Amtrak define its position on climate change and develop a short-term and long-term strategy for Climate Change risk reduction and adaptation planning. To accomplish this, the Study Team recommends that Amtrak:

- Review their policy, design standard, operations, and maintenance practices to help minimize impacts in the event of a severe weather incident;
- Hold a workshop with Amtrak's senior management team to develop a strategy moving forward for adaptation;
- Prepare a short position paper/strategy from the results of this workshop that outlines Amtrak's short-term and long-term goals and actions;
- Implement process for continual review and improvement of climate change methodology and protocols based upon new research and advances in technology and climate change science.
- Incorporate Climate Change consideration into existing programming, planning and design processes;
- Develop a planning approach for programed projects to incorporate regional resiliency based decisions on climate stressors in a given region;
- Develop and maintain a "best management practice" manual of adaptation measures that can be distributed and adopted by planning and engineering teams; and
- Implement a system wide outreach program for Amtrak (see next recommendation).

3. Promote Awareness and Educate Amtrak Staff on Climate Change

The Study Team recommends that Amtrak develop and implement an outreach plan to promote awareness and educate Amtrak staff on Climate Change. This is a logical part of the Adaptation Strategy that can be implemented in phases starting immediately. The plan would include development of a systematic program targeted to the different groups of Amtrak personnel about the impacts of climate change, potential vulnerabilities, and adaptation measures. Sharing information on climate change could be accomplished through internal publications, website, workshops, webinars, and can be incorporated into existing Amtrak training.

4. Prepare an Adaptation Plan for the Pilot Study area

Building on this Pilot Study, the Study Team recommends that Amtrak continue to move forward to prepare an adaptation plan for those areas identified as "high vulnerability" such as the CNOC Facility, Wilmington Shops, and nearby portions of track mainline. The adaptation plan would be a more detailed assessment that includes: (1) hydraulic modeling to further assess vulnerability of culverts, bridges, etc. in known vulnerable locations at risk (2) engineering evaluation of different adaptation alternatives to assess the resiliency, costs, and environmental impacts, (3) conflict analysis with existing policies and regulations, (4) cost-to-benefits analysis, and (5) detailed costs and risks stemming from inaction (the "do nothing" approach). The results of this study should be summarized, shared, and considered in future decisions on adaptation planning.

5. Develop Amtrak Regional and National Climate Change Adaptation Teams

Develop Amtrak Regional and National Climate Change Adaptation Teams with the goal of sharing information, lessons learned and identifying opportunities to standardize methodologies, approaches and adaptive actions.

6. Develop Amtrak Partnership Programs

Develop Amtrak Partnership Programs with the goal of identifying regional and national partners that can work together to create new or expanded resiliency benefits. It is important that Amtrak work with the local governments on large scale adaptation measures that will include assets outside their ownership. Expanded benefits to be achieved could include capital and operational cost savings. Gains in efficiencies or effectiveness considering other holistic values related to social, environmental and economic considerations.

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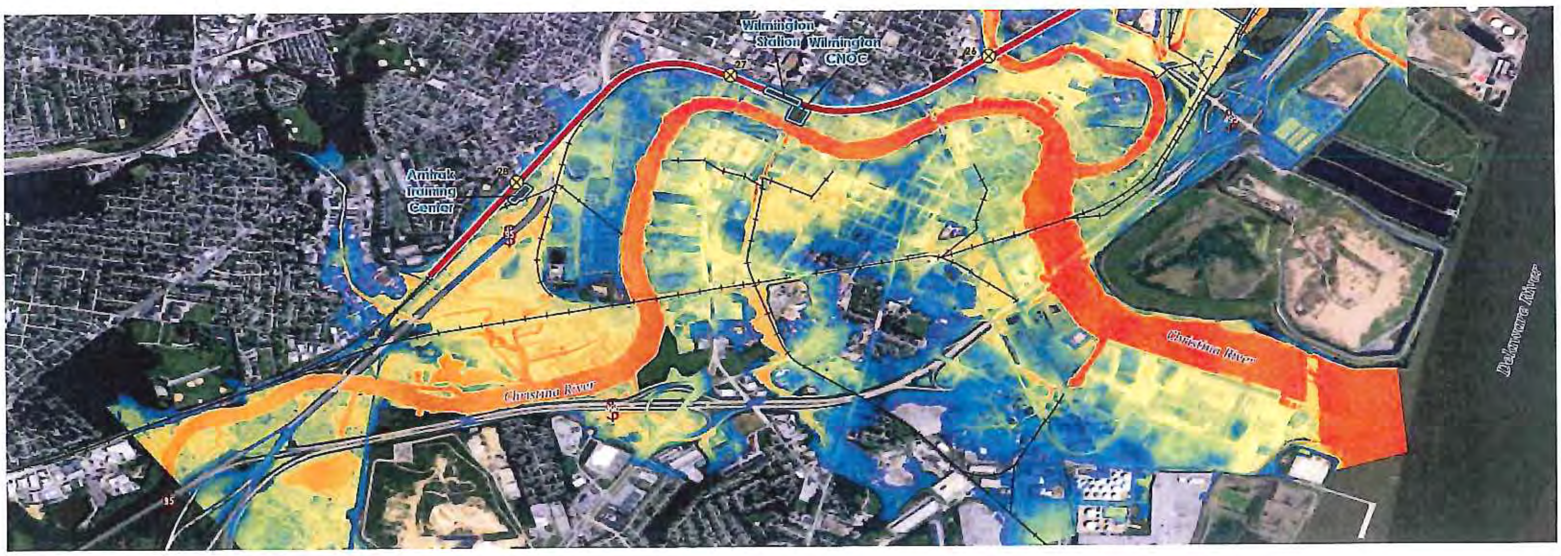
Acronyms, Glossary, and References



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List of Acronyms

AOGCM	Atmosphere-ocean general circulation models
ASCE	American Society of Civil Engineers
CCIZ	Climate Change Impact Zone
CMIP	Coupled Model Intercomparison Project
CNOC	Consolidated National Operations Command
CETC	Centralized Electrification and Traffic Control
DelDOT	Delaware Department of Transportation
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
DNREC	Delaware Coastal Programs
EMCS	Environment & Sustainability, Engineering, Emergency Management & Corporate Security
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIS	Flood Insurance Study
FRA	Federal Railroad Administration
GIS	Geographic Information Systems
HVI	Hazard Vulnerability Index
IBC	International Building Code
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection And Ranging
MHHW	Mean Higher High Water
MPH	Miles Per Hour
NAVD88	North American Vertical Datum 88
NCRHP	National Cooperative Highway Research Program

NEC	Northeast Corridor
NECIID	Northeast Corridor Infrastructure and Investment Development
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
RCM	Regional Climate Model
SLOSH	Sea, Lake and Overland Surge from Hurricanes
SLC	Sea Level Change
SROI	Sustainable Return on Investment
SST	Sea Surface Temperature
SW	Still Water=Storm Surge
USACE	United States Army Corp of Engineers
USDOT	U.S. Department of Transportation
VAST	Vulnerability Assessment Scoring Tool

Glossary

Adaptive Capacity – The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (FHWA, 2012).

Asset – A physical component of the highway system, such as section of asphalt, a drain pipe, or overhead lighting, that contributes to the overall function of the highway.

Climate Change – Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer (EPA, 2014)

Digital Elevation Model (DEM) – A format for elevation data, tiled by map sheet, produced by the National Mapping Division of the United States Geological Survey.

FEMA 100 year Flood – The 100-year flooding event is the flood having a 1 percent chance of being equaled or exceeded in magnitude in any given year.

Flood – 1) period when tide level is rising; often taken to mean the flood current which occurs during this period. 2) a flow beyond the carrying capacity of a channel.

Floodplain – land area adjacent to a river, stream, lake, estuary, or other water body that is likely to be inundated during a flood.

Freeboard – 1) the vertical distance between the design water level and the top of a coastal levee or dike; 2) the distance from the design waterline to the low-chord of the bottom of a suspended deck such as a bridge deck or offshore platform; or 3) the distance from the crest of the design wave to the low-chord of the bottom of a suspended deck such as a bridge deck or offshore platform (FHWA, 2008).

Geographic Information Systems (GIS) – A geographic information system, or GIS, is a computerized data management system used to capture, store, manage, retrieve, analyze, and display spatial information. Data captured and used in a GIS commonly are represented on paper or other hard-copy maps.

Hazard – An event which affects the ability of the highway system, or an element thereof, to functioned as designed.

Hazard Vulnerability Index (HVI) – A vulnerability index is a measure of the exposure of a group of assets to some hazard. Typically, the index is a composite of multiple ratings that via some formula, delivers a single numerical result.

Hazus Modeling – Hazus is a nationally applicable standardized methodology, developed by the Federal Emergency Management Agency (FEMA) that contains models for estimating potential losses from earthquakes, floods and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters.

Mean Higher High Water Sea Level – The average maximum elevation of the daily high tide as observed within the National Tidal Datum Epoch.

Mean Sea Level – The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

National Elevation Dataset (NED) –The National Elevation Dataset is the primary elevation data product of the United States Geological Survey and serves as the elevation layer of The National Map. The NED provides basic elevation information for earth science studies and mapping applications in the United States.

Light Detection and Ranging (LiDAR) – LIDAR, stands for Light Detection and Ranging and is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system— generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

National Tidal Datum Epoch – The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years. Tidal datums in certain regions with anomolous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch.

Resiliency – A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment (FHWA, 2012)

Sea Level Rise or Sea Level Change – The long-term trend in mean sea level (FHWA, 2012)

Sea Level Change Depth Grids – Digital maps which predict the depth of water at certain location under a specific flooding scenario.

Scour – Removal of underwater material by waves and currents, especially at the base or toe of a structure.

SLOSH Data – The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field which drives the storm surge.

Special Flood Hazard Area – The land area covered by the floodwaters of the base flood is the Special Flood Hazard Area (SFHA). The SFHA includes Zones A, AO, AH, A1-30, AE, A99, AR, AR/A1-30, AR/AE, AR/AO, AR/AH, AR/A, VO, V1-30, VE, and V on FEMA Flood Insurance Rate Maps (FIRMs). http://www.fema.gov/floodplain-management/special-flood-hazard-area

Storm Surge – An abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone (EPA, 2014).

Vulnerability Assessment Scoring Tool (VAST) – Acrosoft Excel-based analytical tool that uses key asset information (e.g. bridge age), climate data (e.g. flood elevation), and other vulnerability indicators (e.g. current frequency of flooding) to develop a composite vulnerability score.

Vulnerability – The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (FHWA, 2012).

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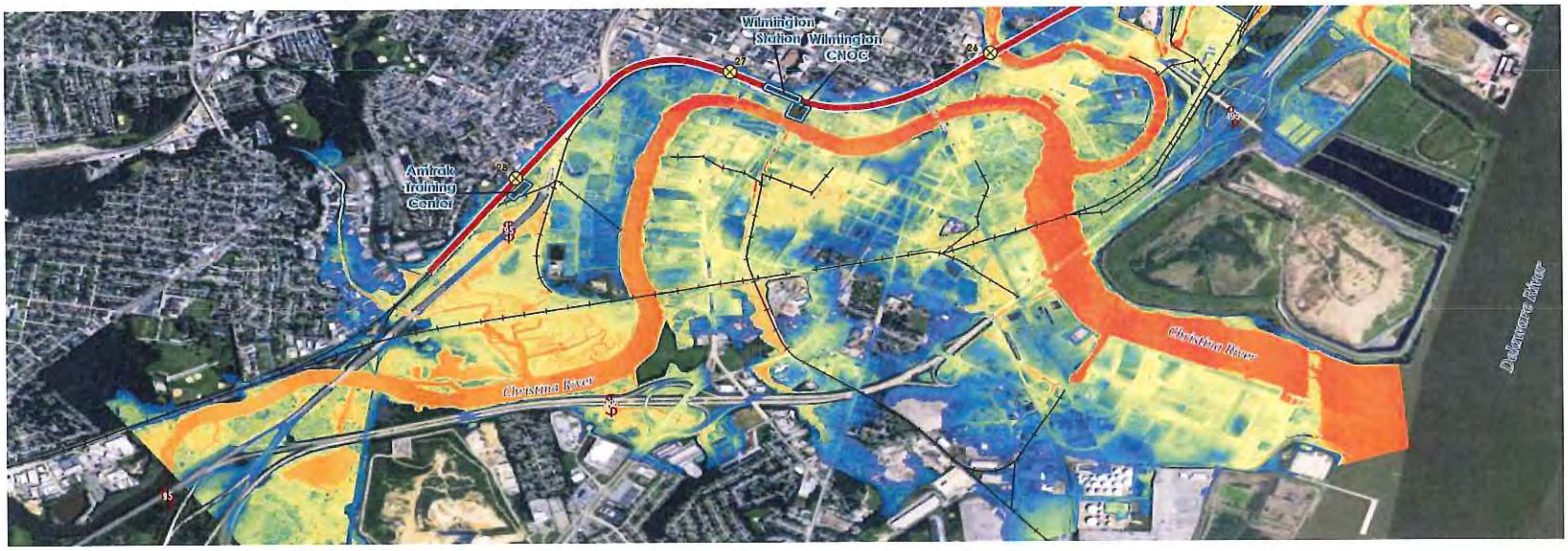

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Appendix A- HVI Sample Formula and Data

Example HVI calculation for year 2010 Sea Level Rise projections for Tracks:

$$HVI =$$

$$0.60 * \frac{\textit{Percent of Linear Feet Inundated}}{\text{Maximum Percent of Linear Feet Inundated}} + 0.30 * \frac{\textit{Maximum Depth of Inundation}}{\text{Greatest Maximum Depth of Inundation}}$$

$$+ 0.03 * \frac{\textit{Maximum Distance to Coast} - \textit{Distance to Coast}}{\text{Maximum Distance to Coast}}$$

$$+0.02 * \frac{\textit{Number of Interlockings}}{\text{Maximum Number of Interlockings}} + 0.05 * \frac{\textit{Number of Turnouts}}{\text{Maximum Number of Turnouts}}$$

Example HVI calculation for year 2010 Sea Level Rise projections for Tracks:

$$HVI =$$

$$0.6 * \frac{19.6\%}{66.77\%} + 0.3 * \frac{4.5}{11.1} + 0.03 * \frac{3{,}473 - 1{,}339}{3{,}473}$$

$$+0.02 * \frac{0}{3} + 0.05 * \frac{0}{48}$$

$$HVI = 0.32$$

$$\textit{Vulnerability Category} = \text{High}$$

The HVI score above demonstrates this particular ½ mile stretch of track has a HVI = 0.32 which equates to a vulnerability rating of High.