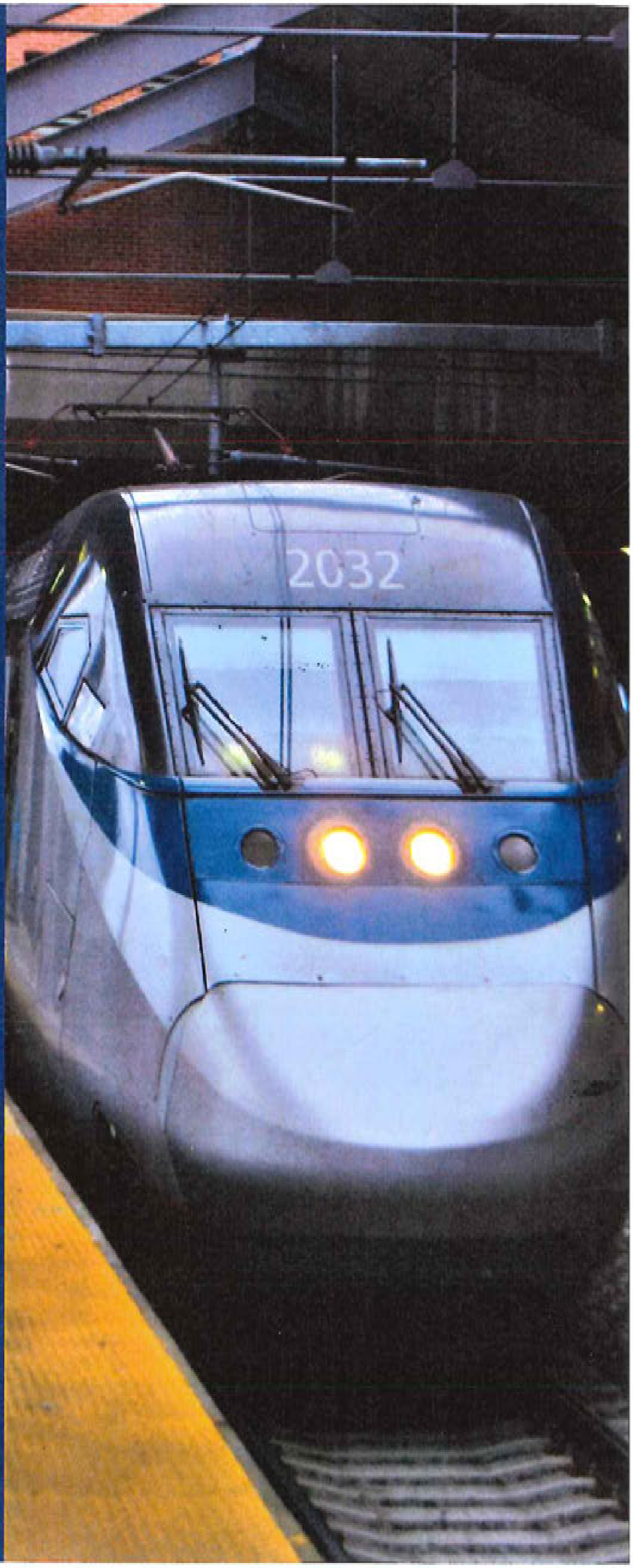
AMTRAK

Phase III Amtrak NEC Climate Change Pilot Study Adaptation Plan

April 2017



About the Cover

The graphic image on the cover was taken Amtrak Acela Express at Back Bay station, Boston, in 2012 (photo licensed uner the Creative Commons Attribution-Share Alike 2.0 Generic license).

Acknowledgements

The Amtrak Phase III Adaptation Study is the result of a coordinated team effort between Amtrak and Stantec Consulting Services Inc. The Amtrak Phase III Pilot Adaptation Study was conducted under the leadership and direction of Karen Gelman, Infrastructure Planning Manager.

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), Finance, and Corporate Planning departments. A special thank you for the contributions made by each team member: Glenn Sullivan, Beth Termini, Anna Barlowe, Michael Hajdak, Mark Benedict, Tobi Palmer, Kelsey Bergan, Joanne Maxwell, Anish Kumar, Phil Balderston, Brian Schwab, and Celia Pfleckl. Lastly, a team of scientists and engineers specializing in climate change vulnerability assessments from Stantec supported Amtrak, whose efforts culminated in the development of this report.

How to Cite Reference

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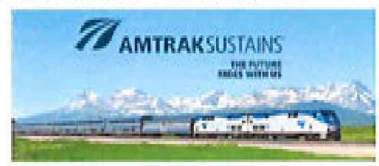
Executive Summary

Introduction

As evident by the 13 million gallons of salt water that flooded the Hudson River tunnels during superstorm Sandy, Amtrak's assets are vulnerable to damage from flooding. (Kaufman et al 2012)

Amtrak's assets and mobility along the Northeast Corridor are at risk to the long-term effects of climate change and require proper planning and adaptation to mitigate the impacts. Amtrak assets are vulnerable to climate induced impacts from sea level rise, storm surge, precipitation, wind, and temperature. In addition to the long-term implications climate change induced impacts can exasperate the current vulnerability increasing the frequency of the flooding and extent of inundation. Today, some Amtrak assets are already vulnerable to localized flooding caused by intense storms. As a result, Amtrak is taking immediate and proactive measures to ensure that they are prepared. Climate change adaptation planning is integral to fulfilling Amtrak's mission, "Delivering intercity transportation with ***superior customer safety, customer services and financial excellence***" (Amtrak, 2017).

Amtrak has undertaken several actions to understand the vulnerability of their assets to climate change and to increase their overall resiliency. Over the past several years, Amtrak has implemented a corporate-wide sustainability policy that includes efforts to understand the risks and potential impacts of climate change on Amtrak's business and the communities in which it operates. Climate change adaptation planning is the understanding and response to the changes caused by climate change. Adaptation planning is critical to increasing Amtrak's resiliency against climate induced impacts. As an organization tasked with the safe transport of people around the country, Amtrak understands the importance of planning and asset management. Amtrak's adaptation plan outlines the steps necessary to make informed decisions on what measures should be selected, when they should be implemented, and where they should be deployed.



Amtrak's Northeast Corridor

Amtrak's Northeast Corridor (NEC) is a 457-mile essential artery that runs through the northeast region connecting eight states and the District of Columbia. The NEC carries approximately 2,200 Amtrak, commuter, and freight trains each day.

The significance of the northeast region to the country's overall economy and success cannot be understated. The northeast region is home to 64 million people and the urban corridor extending from Boston, MA to Washington, DC is one of the most developed environments in the world. The nation's capital, financial centers, and many historic landmarks are located within this part of the country.

The NEC spans a very diverse climate range from north to south and from the coast to the mountains. The NEC's proximity to the eastern Atlantic seaboard increases the susceptibility of this corridor to coastal impact related threats and extreme weather events such as ice storms, floods, droughts, heat waves, hurricanes, and nor'easters.

According to the 2014 National Climate Assessment, this region has been experiencing observable climate change effects. The temperature in the Northeast has "increased by almost two degrees Fahrenheit (0.16° per decade) between the years of 1895 and 2011 and precipitation has increase by approximately five inches (0.4 inches per decade) within those same years. The northeast United States has experienced more than a 70% increase in the amount of precipitation during heavy events, more than any other region in the United States (U.S. Global Change Research Program, 2014)."

Amtrak's NEC Climate Change Planning

Getting Started

Climate change initiatives applied to the NEC began in 2014 and were led by Amtrak's Corporate Planning Department. The initiatives focused on reviewing and summarizing existing climate change research findings and methodologies related to transportation assets and vulnerability assessments. The findings were summarized as the Phase I Report.

Establishing a Framework

Following the Phase I Report, Amtrak's efforts have been modeled after the Federal Highway Administration Climate Change and Extreme Weather Vulnerability Assessment Framework (Federal Highway Administration, 2012). This framework establishes resiliency through the application of nine distinct steps (see below). Amtrak applied the first seven steps through the Phase I Report and two pilot studies for the NEC assets, identified as the Phase II Vulnerability Assessment and Phase III Adaptation Plan.

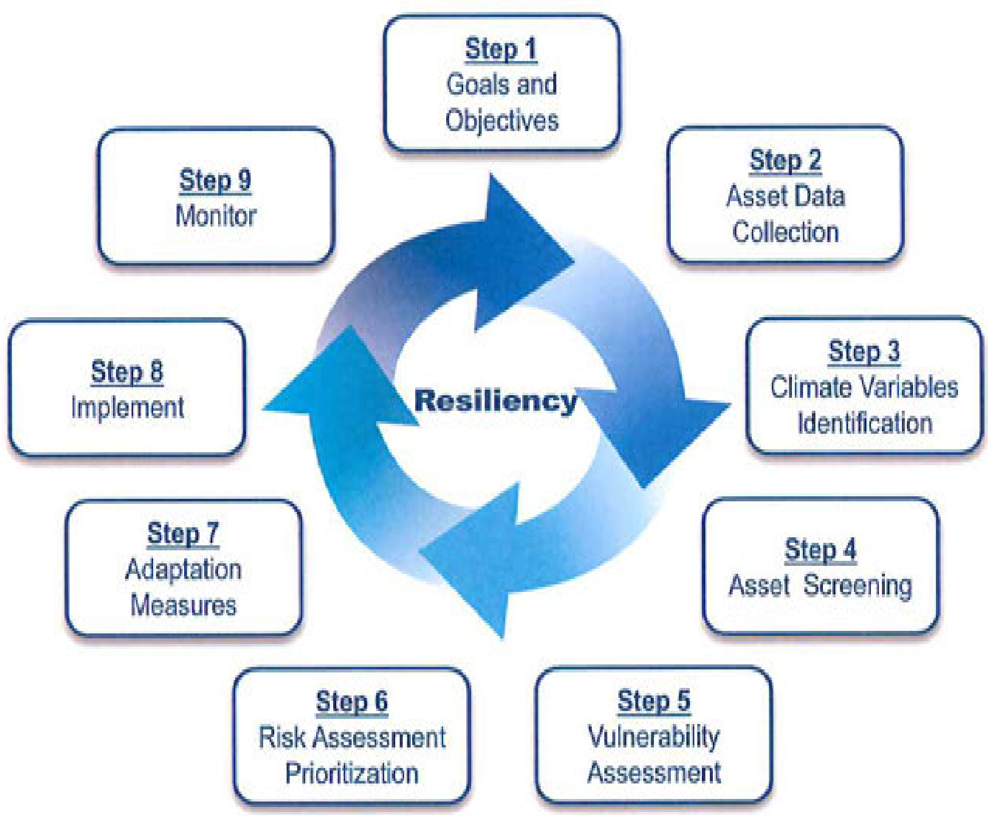
Assessing Vulnerability

Amtrak's Corporate Planning Department led an effort to assess the vulnerability of Amtrak's assets along the NEC. The study, Amtrak NEC Climate Change Vulnerability Assessment: Phase II Pilot Study (Phase II Vulnerability Assessment), was completed in 2015. This study focused on a pilot study area comprised of a 10-mile track segment and accompanying Amtrak infrastructure in Wilmington, Delaware.

The Phase II Vulnerability Assessment helped establish a systematic approach to understanding Amtrak's overall climate change vulnerabilities by:

- building upon the Phase I efforts to collect asset information and identify applicable climate variables; and
- conducting an assessment to categorize and rank the most vulnerable assets.

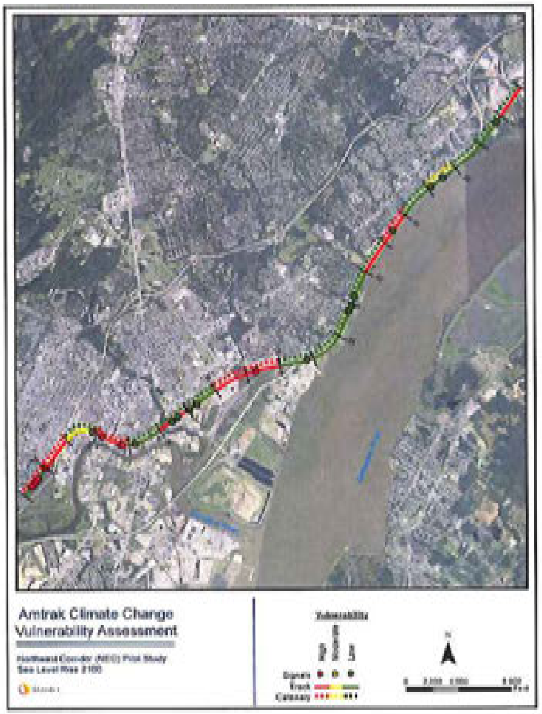
The findings of the Phase II Vulnerability Assessment identified several geographic areas



and assets that are vulnerable to sea level rise, storm surge, increases in precipitation and temperature, and wind. A total of four track segments of 0.5 to 1 mile in length were identified as most vulnerable in the Phase II Vulnerability Assessment (pictured below).

Identifying Adaptation Measures

Adaptation planning includes establishing an acceptable level of risk and identifying the appropriate adaptation measures. Adaptation measures can be evaluated generically for an asset category, such as all NEC buildings, or in detail for a specific asset, such as the Consolidated Nation Operations Center (CNOC).



Implementing Future Steps

The final steps in the framework include implementing adaptation measures and monitoring their successes. This is a logical next step for Amtrak, but is not the subject of this report. The Phase III Adaptation Plan provides the information necessary to make informed preliminary decisions about the applicability of the various adaptation measures for the Pilot Study area. The report can be used to educate Amtrak stakeholders on adaptation needs and opportunities, and serve as a resource for the implementation of adaptation measures through design and best practices. Once implemented, monitoring is essential to understanding the success of the adaptation measure.

Importance of Assessing Asset Vulnerability

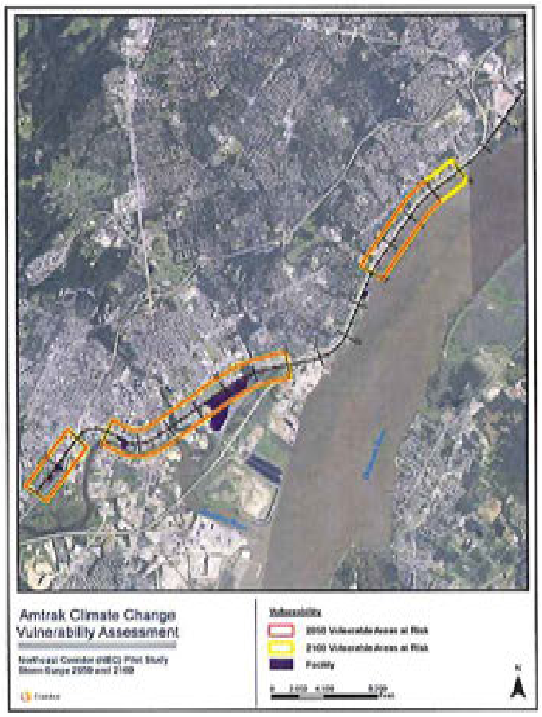
Assessing the vulnerability of an area is a critical step to ensuring that capital investment is spent wisely when planning for and implementing adaptation measures.

It is important to understand the vulnerability of an area or asset for a given projected future year and storm event. The vulnerability of a particular area/asset could differ when looking 30 years into the future versus 50 years. It is common in climate change assessment studies to consider the mid-century year of 2050 and end-century year of 2100. Horizon year 2050 is commonly used because it includes the lifespan of most assets and the data is believed to be more reliable since the projection is closer in time.

Storm events are often categorized by the chance a flood of a certain magnitude will occur within any given year. A 100-year storm event is a rainfall event that statistically has a one percent chance of occurring in any given year. Similarly, a 500-year storm event has a less than one percent chance of occurring each year.

The Phase II Vulnerability Assessment provided a detailed assessment of vulnerability for Amtrak's assets. The study identified assets with the highest level of vulnerability, assessed the asset criticality to the Amtrak system, and then pinpointed highly vulnerable areas based on the location of the most vulnerable assets. The Phase II Vulnerability Assessment assessed the impacts of sea level rise, storm surge, precipitation, wind, and temperature on the assets within the Pilot Study area. Amtrak's assets included rail track, rail at grade bridges, adjacent roadways, and Amtrak buildings, specifically Wilmington Station, Wilmington Training Center, Wilmington Shops and CNOC, as well as the West Yard and Bellevue Substations.

The Phase II Vulnerability Assessment also considered the sensitivity of the assets to flooding, increases in temperature and wind, and the adaptive capacity of the assets. *The sensitivity of an asset examines the degree to which an asset is affected, either adversely or beneficially to a climate variable.* Examples of this include, but are not limited to, age of asset, condition of asset, and frequency of maintenance. *The adaptive capacity of an asset is the ability of an asset to adjust to the impacts of climate change.* Adaptive capacity gives critical consideration to the usage of the assets, and whether there is a detour to avoid the asset if necessary.



The Phase II Vulnerability Assessment study provided information needed to rank the individual assets based on their vulnerability to each climate variable and criticality to the Amtrak NEC system. By grouping assets that received a high risk score, it was possible to identify vulnerable areas at risk. *The track segment between mile post 24 and 27 was determined to be the most vulnerable and includes all four facilities that were selected for inclusion in the Phase III Adaptation Study.* The criticality of the facilities within this area and the large extent of this three-mile track segment of the 10-mile Pilot Study area makes it an important focus area for future actions. Asset specific and regional adaptation measures should be considered for this area.

Why Define Risk?

Defining risk is essential in providing focus and priority.

Determining a level of risk for adaptation measure evaluation is an initial step. *The level of risk is the scenario that adaptation measures should consider for designing mitigation and protection measures.*

The establishment of level of risk acceptable for an area/asset is important because adaptation measures differ in the amount of protection they can provide to assets. For example, permanent perimeter barriers can often be designed to protect an asset from significant flooding, such as that related to a 500-year storm event. In contrast, temporary perimeter barriers often can only protect to a flood height of 10 feet. Depending on the location, this may only correlate to a 100-year storm event in 2050.

The Phase III Adaptation Plan focuses on the 2050 horizon year because of the lifespan of the vulnerable assets. Adaptation measures focus on vulnerability from flooding caused by sea level rise, storm surge, and increased precipitation. In addition, Amtrak has current operational procedures in place for extreme temperatures and high winds. The three risk scenarios include the 2050 100-year storm event, 2050 100 year storm event plus 1 foot, and the 500 year storm event. The decision was based on what other states and municipalities are currently using, the Federal Flood Risk Management Standard (FFRMS), FEMA Flood Maps, Amtrak staff consultation, and engineering recommendations.

Importance of Evaluating Adaptation Measures

Although it is a relatively new concept for project planning and engineering designs, identifying sustainable and cost effective measures for the protection of Amtrak facilities and rail assets is an important aspect of adaptation planning.

Adaptation measures were evaluated in a two-tiered approach for Amtrak assets along the NEC and Pilot Study area. The first tier focused on asset categories and broad measures that could be implemented throughout the entire NEC. Asset categories included buildings, yards, substations, rail bridges, rail tracks, catenary, and signal systems.

The second tier provided a detailed evaluation of adaptation measures to determine which would best protect the most vulnerable assets within the Pilot Study area. Adaptation measures were specifically evaluated for the Wilmington Station, Wilmington Training Center, Wilmington Shops and CNOC as well as the West Yard and Bellevue Substations. A total of four track segments along the associated signals and catenary systems were identified as most vulnerable in the Phase II Vulnerability Assessment and were also evaluated.

Within the Tier II analysis, the adaptation measures were evaluated for three different risk scenarios (in 2050 SLR: 100 year flood event, 100 year flood event plus 1 foot of freeboard, and 500 year flood event). Once the level of risk was defined, evaluations of potential adaptation measures were conducted to identify which measures would best protect Amtrak assets. These evaluations took into consideration the vulnerability, criticality, location, structural integrity, and age of the asset. *Flood barriers were selected as the primary method of flood protection for Amtrak's facilities and assets because this type of system typically offers the most comprehensive and often the least invasive opportunities for flood protection.* Other adaptation measures were considered, but were not selected because they did not protect against the predetermined levels of risk, were cost prohibitive, or required a substantial amount of information regarding the structural integrity of the assets that was beyond the scope of this study.

Three types of flood barriers: **permanent, semi-permanent, and deployable** were suggested and offered a range of cost, storage and deployment time options.

Maps were created to demonstrate the study area locus and the approximate location of the adaptation measure as well as cross-sectional graphics that demonstrate the storm event water levels in relation to the adaptation measure and the asset (see Section 3.4 Asset Vulnerability and Adaptation Plans).

In addition to asset specific adaptation measures, area wide adaptation measures were evaluated for the Wilmington area. A flood gate across the mouth of the Christina River could prevent inundation up river from the most extreme design elevation. Such a flood protection system would need to consider the interests of bordering land owners in addition to Amtrak. Further, it would require a major effort and investment to ensure the entire community would have flood protection.


Permanent Flood Barrier


Semi-permanent Flood Barrier


Deployable Flood Barrier

	Wilmington Station	CNOC	Training Center	Maintenance Facility	Rail Tracks	Rail Bridges	Catenary /Signal	Substations	Average Cost	Level of Protection
Relocate	●	●	●	●				●	$-$$$$$	●●●●●
Elevate	●	●	●	●		●	●	●	$-$$$$	●●●●
Dry Floodproofing	●	●	●	●					$-$$$	●
Wet Floodproofing	●	●	●	●						
Perimeter Barriers	●	●	●	●	●			●	$-$$$$$	●●●
Protection of Critical Components				●	●	●	●		$-$$$	●●●

Potential adaptation measures by asset category (see Appendix 3.2 for a more detailed Table)

Next Steps

The work to-date has established a repeatable methodology on how to efficiently identify vulnerable assets and areas, evaluate the appropriate adaptation measures, and move forward with analysis and implementation of those measures.

Next steps include applying some of the steps comprehensively throughout a region or all the steps holistically in another targeted area. Establishing a regional understanding of which assets are most vulnerable would allow for strategic decisions on where and when adaptation measures should be considered. This information also allows for informed decisions to be made regarding proposed new projects and ongoing maintenance activities. It is important that this step includes an evaluation of the level of risk for a variety of assets. Since a larger area is being evaluated there may be several different risk scenarios necessary, but it is essential that the level of risk is understood since this will affect which adaptation measures are applicable.

Applying the methodology holistically to a targeted area could allow for the quick resolution of an ongoing flooding issue that will only be exacerbated by climate change-induced sea level rise or storm surge.

A benefit cost analysis may be useful when evaluating a targeted area or asset, and it is important to understand what type of information is needed to make this evaluation meaningful. Information should include not only gains and losses directly to Amtrak but also to the surrounding community and stakeholders. For example, loss of Amtrak service for several days will not only impact Amtrak's revenue and reputation, it will also negatively impact the neighboring businesses that are frequented by daily riders.

The Phase III Adaptation Plan includes suggested possible steps for a system-wide Climate Change Adaptation Strategy. The purpose of the strategy is to establish short-term and long-term actions that can be implemented to support Amtrak's overall sustainability and climate change policies. The strategy provides Amtrak's management direction to adapt to changes in sea level rise, storm surge, temperature, and severe weather events. These climate variables affect many aspects of Amtrak's passenger rail operations and supporting assets. Thus, this adaptation strategy stresses the importance of a holistic approach across Amtrak's organization in the areas of capital improvement planning, design, and construction; passenger rail operations, and asset management including maintenance. The adaptation strategy includes a five-element implementation strategy that provides a general road map for scoping near-term and long-term preparation and response. A next step for Amtrak would be to further evaluate and provide a detailed methodology for the implementation of one or all of these strategies. The methodology should include the formation of a committee of those that would be impacted and could contribute to the methodology. The selected strategy elements would be chosen based on Amtrak's preferred direction moving forward over the next several years. The proactive efforts taken to-date have positioned Amtrak to make clear and informed decisions on how to continue to improve the overall resiliency to climate change.

Table of Contents

Contents

1.0 INTRODUCTION 1

1.1 Ongoing and Previous Amtrak Climate Change Work 1
1.2 Importance of an Adaptation Plan 1
1.3 Adaptation Plan Goals and Objectives 2
1.4 Amtrak's Study Team 3

2.0 POTENTIAL ADAPTATION MEASURES FOR THE NEC 5

2.1 Introduction 5
2.2 NEC Adaptation Sheets 4

3.0 PILOT STUDY ADAPTATION PLAN 25

3.1 Introduction 26
3.2 Potential Adaptation Measure Summary Table 29
3.3 Methodology 34
3.4 Asset Vulnerability and Adaptation Plans 44
3.4.1 Wilmington Station 44
3.4.2 Wilmington Shops and Maintenance Yard 50
3.4.3 Training Center 55
3.4.4 Consolidated National Operations Center 63
3.4.5 Bellevue Substation 71
3.4.6 West Yard Substation 75
3.4.7 Track Segments 82
3.4.8 Area-wide Adaptation Measures 91
3.4.9 Precipitation Adaptation Measures 93
3.5 Permitting Requirements and Considerations 100
3.6 Initial Benefit-Cost Analysis 103
3.7 Potential Funding Opportunities 108

4.0 OVERALL AMTRAK ADAPTATION STRATEGY 111

WORKS CITED 110

Figures

Figure 1. Categories Considered for Adaptation Measure Assessment 34
Figure 2. Cross-section Depicting Adaptation and Flooding Heights 35
Figure 3. Typical Wall Anchorage System 36
Figure 4. USACE Final Report 41
Figure 5. Track Section at the Wilmington Shops 41
Figure 6. Crawl Space beneath 1st Floor 41
Figure 7. Water Infiltration between the Rails 41
Figure 8. Deployable Flood Barrier 42
Figure 9. Rendering of possible deployable wall permanent footer 42

Figure 10. Installation of a Deployable Wall 43
Figure 11. Storage option for a deployable system 43
Figure 12. Emergency flood water pump 44
Figure 13. Emergency Window Covering (Flood Panel, n.d.) 44
Figure 14. Wilmington Shops Aerial Map 50
Figure 15. Electric Locomotive above Pit with Standing Water 50
Figure 16. Deployable Flood Barrier 51
Figure 17. Wilmington Shops 50
Figure 18. Semi-permanent wall without beams installed (Source: EKO) 54
Figure 19. Semi-permanent wall with beams installed (Source: EKO) 54
Figure 20. Electric Meter at First Floor at Ground Level 55
Figure 21. Flood Waters below I-95 Overpass at Access Road Preventing Access to Training Center 55
Figure 22. Deployable Flood Barrier 56
Figure 23. Picture of High Speed Way 60
Figure 24. Flood vents located below the first floor. 63
Figure 25. Side Entrance to Facility Adjacent to Christina River 64
Figure 26. Deployable Flood Barrier 64
Figure 27. Typical Storage of Deployable Barrier System 65
Figure 28. Emergency Flood Door Covering (Flood Panel, n.d.) 66
Figure 29. Concrete Knee Wall without Beams Installed 66
Figure 30. Concrete Knee Wall with Beams Installed 66
Figure 31. Semi-permanent flood barrier installation 70
Figure 32. Water Ponding at Bellevue Substation 74
Figure 33. Substation Equipment on Elevated Concrete Footings 71
Figure 34. Deployable Flood Barrier - 4 Feet Tall 72
Figure 35. Depiction of Permanent Concrete Walls 73
Figure 36. West Yard - Substation Equipment 75
Figure 37. Control Pit Flooded During Hurricane Sandy 75
Figure 38. Deployable Flood Barrier 76
Figure 39. Permanent Concrete Flood Wall 81
Figure 40. Low Elevation Tracks Adjacent to Delaware River (MP 21.0 to 21.5) 82
Figure 41. High and Low Elevation Tracks (MP 21.5 to 22.0) 82
Figure 42. Lowlands with Water Adjacent to Tracks (MP 24.0 to 24.5) 82
Figure 43. Northern Approach of Track Segment adjacent to West Yard - Substation 13 (MP 28.0 to 28.5) 82
Figure 44. Rail Ties and Ballast above Culvert Discharging into Delaware River (MP 21.0 to 21.5) 83
Figure 45. Low Elevation Tracks under Bridge (MP 21.5 to 22.0) 84
Figure 46. Storage Equipment and Debris Located near tracks 84
Figure 47. Plan View of the Wall Location Near Stoney Creek MP 21.5 to 22.0) 90
Figure 48. Plan View of the Wall along the Northern Segment of the Track (MP 19.5 to 21.5) 91
Figure 49. Potential Floodgate Location across the Christina River 95

Tables

Table 1. Estimated Dollar Losses Due to Flooding 32
Table 2. Project Adaptation Measures 103
Table 3. Initial Expenditures for Infrastructure Protection 104
Table 4. Benefit-Cost Analysis Summary 105

Appendices

APPENDIX A – BUILDING REPLACEMENT AND CONTENT VALUES

APPENDIX B – GLOSSARY

Introduction

1.0 Introduction

1.1 Ongoing and Previous Amtrak Climate Change Work

Understanding the risks and potential impacts of climate change on Amtrak's business and the communities in which it operates is a critical element of Amtrak's Sustainability Policy. As stated by Beth Termini, Senior Director of Environment and Sustainability at Amtrak, "by assessing our risks, understanding our vulnerabilities and implementing adaptation measures, we will prepare our operations for a sustainable future."

A phased approach to Amtrak's climate change initiatives on the northeast corridor began in 2014 and was spearheaded by Amtrak's Corporate Planning Department and Environment and Sustainability Group.

- **Phase I report**, completed in 2014, focuses on reviewing and summarizing existing climate change research findings and methodologies related to transportation assets and vulnerability assessments.
- **Phase II report**, completed in 2015, is a detailed vulnerability assessment of Amtrak's assets along a 10-mile track segment in Wilmington, Delaware (Pilot Study Area). This study identifies vulnerable areas within the Pilot Study Area, as well as establishes a framework and methodology that can be repeated along other identified vulnerable areas of the entire NEC.
- This report, the **Phase III report,** is titled "Phase III Amtrak NEC Climate Change Pilot Study Adaptation Plan" (Phase III Adaptation Plan). The Phase III Adaptation Plan identifies and evaluates broad adaptation measures that could be implemented along the NEC (Section 2.0: Potential Adaptation Measures for the NEC) and provides a more detailed analysis of adaptation measures that could be implemented for the vulnerable assets identified within the Pilot Study Area (Section 3.0: Pilot Study Adaptation Plan).

Adaptation Framework Methodology

The methodology identified several critical steps that are repeatable for both a small detailed study or a larger overreaching analysis:

- *Identify the level of risk to be assessed including the horizon year and storm events*
- *Refine the area and asset vulnerability based on the determined level of risk*
- *Evaluate the area and assets criticality to Amtrak*
- *Identify asset specific and area wide adaptation measures*
- *Evaluate adaptation measures on a case by case basis including a benefit cost analysis*

The Vulnerability Study and this Phase III Adaptation Plan provide information instrumental to Amtrak's ability to integrate climate change considerations into their planning, design, and construction programs. Section 4.0 of this report also provides information necessary to establish an overarching climate change management strategy and identifies next steps for Amtrak beyond Phase III.

1.2 Importance of an Adaptation Plan

The Adaptation Plan is an important step in identifying how to make Amtrak more resilient in facing the impacts of a changing climate. Amtrak has highly vulnerable assets, including track, rail yards, facilities, tunnels, and bridges, in areas that have been and will continue to be impacted by increasingly heavy precipitation events, rising sea levels, and increased temperature and wind. In order to continue to operate passenger rail operations effectively over the long term in these areas, Amtrak will require concrete measures to adapt to these impacts. This plan provides a high-level assessment of the most applicable adaptation measures for assets along the NEC and can be used by Amtrak to develop more detailed plans going forward.

This Adaptation Plan also includes a more detailed evaluation of climate change adaptation for the most vulnerable assets in the Pilot Study Area in Wilmington, Delaware. The use of a Pilot Study Area allowed Amtrak to identify the best methodology in a smaller, more controlled manner. The established methodology and lessons learned can be applied to assets throughout the entire Northeast Corridor.

In the future, the measures in this Adaptation Plan can be made more robust as manufacturers develop additional adaptation and/or resiliency measures. This process will result in a continuous refinement of Amtrak's asset adaptation measures that can include engineering solutions, best management practices, and maintenance initiatives. Lastly, the adaptation measures identified in this study can be the basis for the development of a best practices manual of adaptation measures that can be used and adopted by Amtrak.

1.3 Adaptation Plan Goals and Objectives

The overall objective for Amtrak's ongoing climate change efforts is to create more resilient infrastructure and operations 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 Adaptation Plan primarily addresses the first goal of establishing a vulnerability and adaptation methodology. The analysis of the adaptation measures begins to address the other objectives and can be integrated into existing Amtrak initiatives. This Adaptation Plan includes an overarching adaptation strategy which provides recommendations for the consideration of climate change in future capital investment decisions as well as design and adaptation standards.

1.4 Amtrak's Study Team

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

The core Amtrak team 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 and assisted with the important decisions surrounding risk and criticality. They consulted with others in the company for a variety of data including but not limited to operational and flooding history.

Potential Adaptation Measures for the NEC

2.0 Potential Adaptation Measures for the NEC

2.1 Introduction

This section offers brief summaries of adaptation measures that could be employed to protect assets against climate change induced sea level rise and storm surge. The "NEC Adaptation Sheets" have been prepared for Amtrak building managers and decision makers to provide these groups with a basic understanding of adaptation measures which can protect Amtrak assets in a variety of situations and locations. Although they may not provide enough information to select a particular adaptation measure for implementation, the sheets are designed to help guide further study.

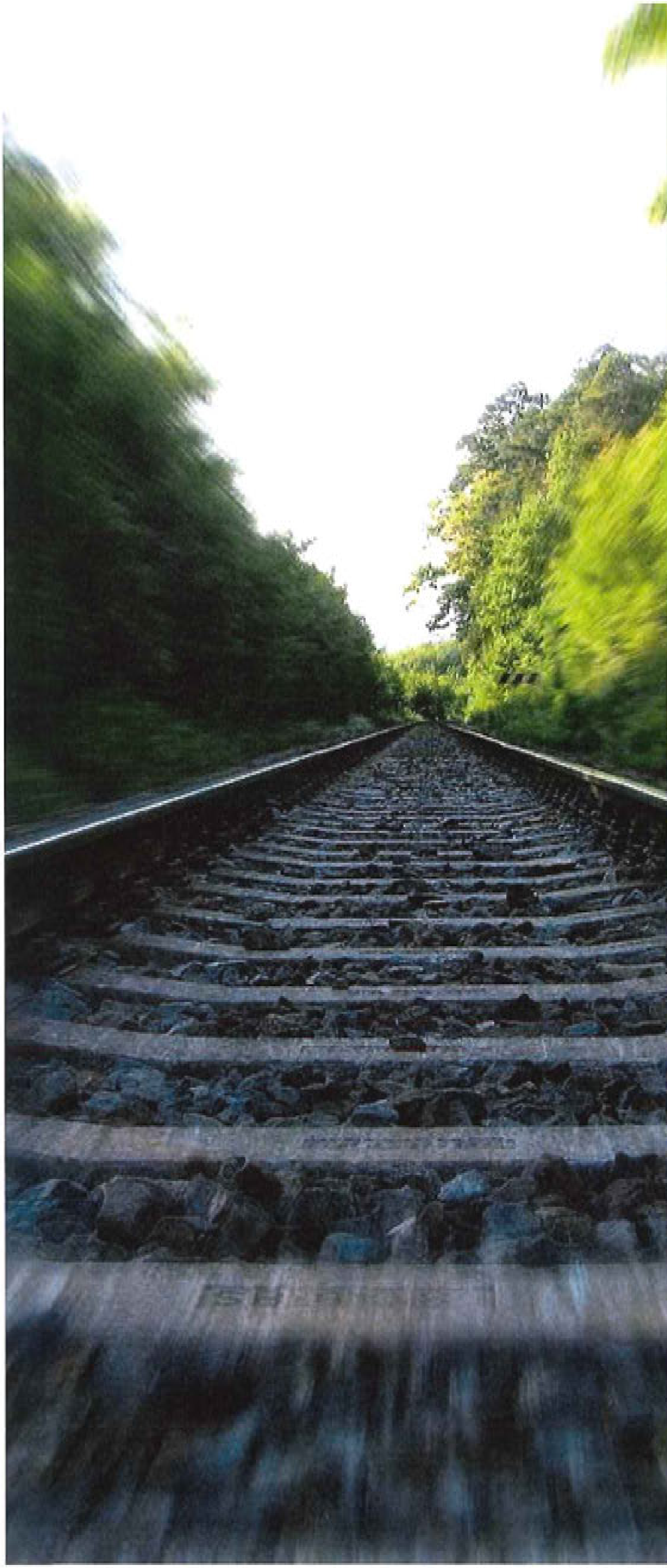
Each adaptation sheet is composed of two pages with a basic description and helpful topics used in evaluating a particular adaptation measure. The topics include:

- Building Strategies
  - Useful recommendations that help assist the proper implementation of the particular adaptation measure.
- Supporting Adaptation Measures
  - Related measures that can assist the adaptation measure being discussed in protecting against floods.
- Operational Considerations
  - Day-to-day activities that should be executed either before or after a flood with the implementation of the adaptation measure.
- Estimated Costs
  - A relative cost range for implementing a particular adaptation measure.

On the second page of each adaptation sheet, descriptions (represented as a book symbol) and graphics are provided that show the different types of strategies within the adaptation measure, along with each strategy's relative benefits and drawbacks (represented as a plus and minus sign). This page can assist in comparing adaptation strategies and determining whether they have enough merit to be included in a subsequent, detailed study.

It is important to note that the evaluation of these measures have focused on asset categories not specific assets, therefore; have not considered asset specific ownership issues. When looking at specific assets it is important to consider real estate issues such as the ownership status and the long-term plan for the asset. For example, when proposing to relocate a building it is crucial to understand if the building is owned or leased. Similarly, if proposing to relocate work locations and/or equipment it is important to have a plan in place for the abandoned building. Amtrak is part of a larger community; therefore, when evaluating these measures, it is also important to consider the surrounding area. For example, if Amtrak assets are made more resilient in a flood-prone area and area-wide flood control measures are not implemented the assets may no longer be necessary because of a lack of nearby customers to support them and a lack of reliable access for people to get to work in them.

2.2 NEC Adaptation Sheets



NEC Adaptation Sheets

Relocate

Relocation offers the most effective method of preventing flood damage. It offers protection by moving assets out of the area subject to flooding. Relocation can be accomplished by physically moving the entire building/ equipment to another location or by moving the business operations to a new location outside of the floodplain.

BUILDING STRATEGIES

» Move preferably to a location outside of the floodplain.

» Construct new foundations and site improvements when asset is physically moved.

» Obtain the appropriate moving permits.

» Ensure acceptable height and width clearances along moving route.

SUPPORTING ADAPTATION STRATEGIES

Not necessary.

OPERATIONAL CONSIDERATIONS

Not necessary if moving outside floodplain.

ESTIMATED COST

$$$$$ - $$$$$

Adaptation through Relocation

Photo Credit: 42N Observations (http://42n.blogspot.com/2011_06_01_archive.html)

1. Relocate Building

Physically moving a building to a location outside of the floodplain.

Benefits: Offers the most robust flood protection by avoiding the threat of flooding by moving away from it. No maintenance or operational concerns.

Drawbacks: Expensive; locating a new site with an acceptable transportation route.

Photo Credit: Paxton Companies (http://www.paxton.com/services/office-and-industrial-moving/)

2. Relocate Work Location

Moving business operations to a new address.

Benefits: Offers a robust flood protection by avoiding the threat of flooding by moving away from it. No maintenance or operational concerns; less expensive than moving physical building.

Drawbacks: New location may not be as convenient for employees; logistically challenging.

Photo Credit: TJ Potter Trucking (http://tjpottertrucking.com/heavy-equipment-trucking)

3. Relocate Equipment

Physically moving equipment to a location outside of the floodplain.

Benefits: Offers a robust flood protection by avoiding the threat of flooding by moving away from it. No maintenance or operational concerns.

Drawbacks: Site preparation; transportation challenges; cost of maintaining operation.

Elevate

Buildings, utilities and equipment can be elevated above flood waters to protect these assets from damage. Elevating an asset typically offers increased protection compared to other adaptation strategies as long as the foundation has been adequately designed and the asset is positioned at an appropriate height. When elevating an asset wind and earthquake loads may increase the foundation requirements.

BUILDING STRATEGIES

» Evaluate building for new structural loads by using a registered design professional.

» Prevent areas below raised building from being used as habitable space.

» Foundation should be evaluated for potential scour.

» Elevate the asset well above potential flood waters because every additional foot of elevation provides dramatic increases in protection compared to the extra cost.

SUPPORTING ADAPTATION MEASURES

» Selecting higher elevation building sites.

» Emergency exits at higher elevations.

» Wet floodproofing the building's lowest level.

OPERATIONAL CONSIDERATIONS

» After flooding: clean and inspect foundation elements.

ESTIMATED COST

$$$$$-$$$$$

Adaptation through Elevation

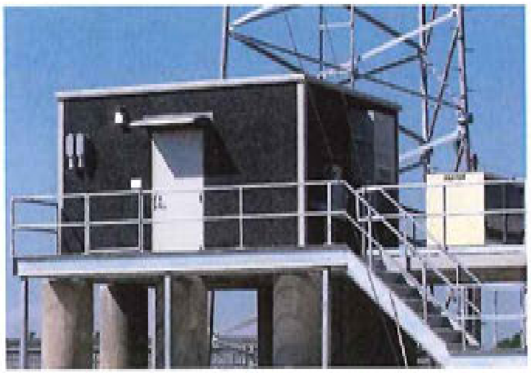


Photo Credit: Modular Connections; modularconnections.com/communication-shelters/

1. Elevate Building

Raising vulnerable structures to avoid flood waters.

Benefits: Components are elevated above design flood levels; limited on-going maintenance requirements.

Drawbacks: May affect building access, structural reinforcement requirements to meet higher wind/ earthquake loads, and additional costs to meet building codes.

Photo Credit: DIS-TRAN Packaged Substations; distransubstations.com/core-products/elevated-substations

2. Elevate Utilities

Raising vulnerable utilities above design flood elevations.

Benefits: Lowers the risk of utility failure.

Drawbacks: May require structural reinforcement of floors to support heavy utilities.

Photo Credit: FEMA Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home From Flooding. 6/2014

3. Elevate Equipment

Raising vulnerable equipment to avoid flood waters.

Benefits: Helps protect against flood damage; keeps primary and secondary systems, with resilience fuel and power sources, functioning during storms.

Drawbacks: May create undesirable views of equipment; may require structural reinforcement.

Dry Floodproofing

Dry floodproofing creates a substantially impermeable barrier on the outside of a building and reduces the potential for flood damage at the interior of a building. If the system relies upon the exterior building walls to act as the flood barrier, the walls must be strong enough to resist flood loads. Water may penetrate the building even with the use of sealants and flood shields so it is recommended to use pumps as a backup measure.

BUILDING STRATEGIES

- Install backflow valves on sanitary water systems, sewer lines, and other building penetrations.
- Provide backup power source for sump pumps.
- Protect entrances and windows with flood shields.
- Routinely inspect dry floodproofing measures such as gaskets, and sump pumps.
- Apply exterior sealants.
- Employ a registered design professional to evaluate the walls which are to be used as flood barriers.

SUPPORTING ADAPTATION MEASURES

- Install flood damage resistant material.
- Seal all building cracks and openings.
- Elevate equipment.
- Secondary protection for critical interior equipment.

OPERATIONAL CONSIDERATIONS

Before flooding:

- Know where to access stored flood shields, how to install them, and the time required for the effort.
- Have an emergency plan with designated managers and operators.
- Periodically practice flood shield installation.
- Be familiar with the operation of pumps.

After flooding:

- Clean and inspect all exterior flood protection measures.
- Clean any interior areas which were in contact with flood waters.
- Place flood shields and movable barriers into storage area.
- Inspect and maintain gaskets and pumps.

ESTIMATED COST

$$$$$-$$$$$

Dry Floodproofing Adaptation Types

Photo Credit: FEMA P-312 Homeowner's Guide to Retrofitting

1. Waterproof Walls and Floors

Sealants or impermeable layers applied to a wall and floor to prevent water from leaking into the building interior.

Benefits: Limits water permeating through the wall and floor and damaging interior finishes/damaging wiring; doesn't require human intervention before a flood.

Drawbacks: Must join with other techniques to prevent water from entering the building; existing equipment and pipes may complicate the process.

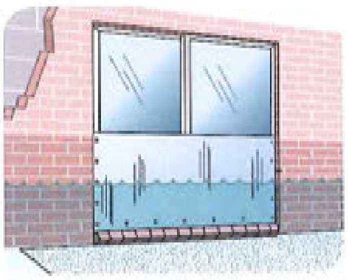


Photo Credit: FEMA P-312 Homeowner's Guide to Retrofitting

2. Flood Shields

Temporary barriers positioned at doors and windows to form a watertight seal with the building.

Benefits: Simple to install on existing buildings, inexpensive.

Drawbacks: Must be properly installed and maintained, most do not protect against floods over 3 feet, may change loading on existing walls requiring wall reinforcement.

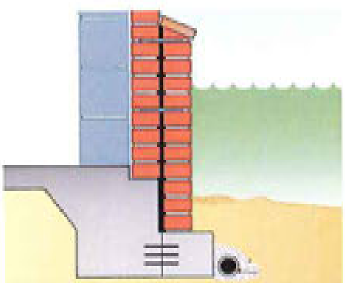


Photo Credit: FEMA P-312 Homeowner's Guide to Retrofitting

3. Reinforce Existing Walls and Floors

Strengthens existing walls and floors against flood loads.

Benefits: Protects against higher floods (over 2 or 3 feet).

Drawbacks: Must be designed by a registered professional, often modifies existing foundations, may disturb interior finishes.

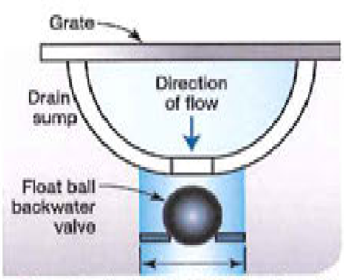


Photo Credit: FEMA P-936 Floodproofing Non-Residential Buildings

4. Backflow Valves

Prevents contaminated water from flowing back into a building through sewer/drain pipes or other pipes.

Benefits: Protects drinkable water system, blocks flood waters from using existing pipes as a route into the building.

Drawbacks: Regular maintenance is necessary, sometimes challenging to install.

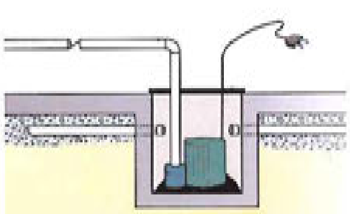


Photo Credit: FEMA P-936 Floodproofing Non-Residential Buildings

5. Pumps

Pumps provide secondary protection against floods by removing water which may infiltrate past the other dry floodproofing measures.

Benefits: Inexpensive drainage option.

Drawbacks: Require power from electricity, fuel, or batteries to operate; can be overwhelmed by severe flooding.

Perimeter Barriers

Perimeter barriers block floods from reaching facility assets and make significant flood upgrades to the structures unnecessary. Proper maintenance, training, and deployment should be executed when using semi-permanent or temporary perimeter barriers. These systems need more attention than permanent barriers and berms/levees.

BUILDING STRATEGIES

- Employ a registered design professional to design a wall system for flood loads.
- Assume some water will get behind the perimeter barrier because of precipitation, wave splash, or water seepage.
- Make sure a particular group of personnel is assigned to erect the temporary or semi-permanent barrier.
- Issue proper training to all personnel assisting with barrier erection.

SUPPORTING ADAPTATION MEASURES

- Site characteristics
- Pressure relief systems
- Flood damage resistant materials
- Alternative/backup power

OPERATIONAL CONSIDERATIONS

Before flooding:

- Know where to access temporary barrier components, how to install them, and the time required for the effort.
- Have an emergency plan with designated managers and operators.
- Periodically practice the installation of temporary barrier components.
- Be familiar with operation of pumps.

After flooding:

- Clean and inspect all exterior flood protection.
- Place temporary barriers into storage area.
- Inspect and maintain pumps.

» ESTIMATED COST

$$$$-$$$$$

Perimeter Barriers

Photo Credit: The Environment Agency (evidence.environment-agency.gov.uk)

1. Temporary Barriers

These structures are stored locally and installed prior to a flood event.

Benefits: Offer a range of height protection and costs.

Drawbacks: Require storage space, adequate warning time, and personnel action. Only offer protection to a particular height, so overtopping is possible.

Photo Credit: EKO Flood USA

2. Semi-Permanent Barriers

Knee walls are installed to protect assets to a certain elevation, though additional design allows temporary barriers for the wall to adapt to higher flood elevations.

Benefits: Offer a range of adaptable height protection and costs.

Drawbacks: Require storage space, adequate warning time, and personnel action. Offer protection only to a particular height, so overtopping is possible.

Photo Credit: U.S. Army Corps of Engineers (mvs.usace.army.mil/Missions/Flood-Risk-Management)

3. Permanent Barriers

Vertical structures designed to prevent flood waters from entering certain areas.

Benefits: Offer a range of height protection and costs. Can prevent flood waters from reaching assets.

Drawbacks: Offer protection only to a particular height, so overtopping is possible. Some permanent walls can block views and may be considered unsightly.

Photo Credit: Marcus de la Houssaye (louisianaswamp.blogspot.com/2011/05)

4. Berms / Levees

Earthen mounds, often with a structural base, designed to block flood waters from entering certain areas.

Benefits: Can protect large areas from flood waters. Often are designed as a park or other community feature. Can be cost effective in certain situations.

Drawbacks: Require a large amount of dedicated land which can be impractical for existing sites.

Wet Floodproofing

Wet floodproofing buildings can greatly reduce flood damage and recovery time. Typically used with older buildings, this type of adaptation can allow water to flow through a building in a controlled way. The space can then be cleaned and dried after flood water has receded.

BUILDING STRATEGIES

- Relocate or protect equipment that cannot be exposed to water.
- Relocate electrical panels, mechanical equipment, gas/electric meters & shut-offs from flood-prone areas to locations above the design flood elevation. Otherwise, protect in place.
- Provide floodwater entry and exit points.
- Provide multiple vent openings to avoid structural damage from flood loads on the walls.
- Use water-resistant building materials below the design flood elevation.

SUPPORTING ADAPTATION MEASURES

- Sump pumps
- Elevate equipment
- Elevate living space
- Surface stormwater management
- Flood damage resistant materials

OPERATIONAL CONSIDERATIONS

Before flooding:

- Items such as vehicles, mechanical equipment, furniture, area rugs, cleaning supplies and toxic chemicals should be moved out of the building or to higher floors.
- An emergency plan should be in place outlining how these items will be removed, and to where.

After flooding:

- Engage professional cleaning teams who have been trained and have equipment to mitigate exposure risk.
- Use commercial fans and dehumidifiers to dry out affected areas to prevent mold growth.
- Prevent mold growth by making the space well ventilated and cleaning non-porous materials (e.g. plastic, glass)
- Take care when pumping out flooded basements. Pumping too quickly or too early can cause damage or collapse.
- Consideration should be given to pumped water discharge location due to contaminants.

ESTIMATED COST

$$$$$-$$$$$

Wet Floodproofing Adaptation Types

Photo Credit: http://www.diabelcissokho.com/

1. Flood Damage Resistant Materials

Minimizes flood damage to areas below the flood protection level of a structure.

Benefits: Maintains function of components; reduces replacements costs.

Drawbacks: May require significant renovation to install.

Photo Credit: FEMA P-312 Homeowner's Guide to Retrofitting

2. Elevate Utilities

Raising vulnerable utilities above the design flood height

Benefits: Keeps utilities above the damaging effects of flood waters, reduces replacement costs, lowers the risk of utility failure

Drawbacks: May require special structural support.

Photo Credit: Smart Vent Products, Inc. smartvent.com

3. Flood Vents

Using flood vents or similar wall openings to allow passage of flood waters into the interior of a building to eventually match the level of flooding at the exterior of a building

Benefits: Helps prevent building walls from collapsing during a flood.

Drawbacks: Requires the assistance of a registered design professional, interior areas of a building will be exposed to contaminated flood waters.

Photo Credit: i901.photobucket.com/albums/ac216/Rockyriver1234/ (Yamaha 3000Seb)

4. Quick Disconnects for Equipment

Simple connections which can prevent flood waters from causing appliances to short out or be filled with contaminated water.

Benefits: Protects appliances, and may allow appliances to be quickly moved to an area more protected from flooding; can allow alternative fueling/power options if the main source is compromised.

Drawbacks: Requires human intervention, training.

Photo Credit: RCR Flooring Products Ltd, www.permaban.com

5. Anchorage for Exterior Equipment

Prevents equipment from being lifted off the ground by flood waters.

Benefits: Reduces the possibility of equipment or fuel tanks moving, or spilling during floods; anchorage mitigates the flood debris potential.

Drawbacks: May require new foundations for equipment.

Photo Credit: Innovative Foundation Solutions, LLC. completefoundationrepairsolutions.com

6. Use Appropriate Pump Timing

Pump out interior flooded areas of building slowly, matching the exterior flood levels as water levels go down.

Benefits: Prevents walls from collapsing from high water levels or water saturated soils.

Drawbacks: Delays the cleanup after a flood occurs.

Maintenance Yard

The maintenance yard includes a large area with many different assets such as rail tracks, locomotives, vehicles, and buildings. Protecting individual assets from floods through relocation or perimeter barriers may help reduce costs. In some cases, particular areas of the yard may have similar characteristics which can utilize the same adaptation measure. The most robust approach would protect all the assets and is typically accomplished by using perimeter barriers. Whether the protective measures are on a small or large scale, they can each benefit from improved communications which monitor asset preparedness and warn of potential floods.

BUILDING STRATEGIES

- Employ a registered design professional to design a wall system for flood loads.
- Assume some water will get behind the perimeter barrier and require pumps because of precipitation, wave splash, or water seepage.
- Make sure a particular group of personnel is assigned to erect the temporary or semi-permanent barrier.
- Issue proper training to all personnel assisting with barrier erection.
- Designate personnel assigned to move assets into flood protected area.

OPERATIONAL CONSIDERATIONS

Before flooding:

- Install temporary perimeter barrier components.
- Move critical components to flood protected area.

After flooding:

- Clean components.
- Assess any flood damages with considerations for implementing adaptation strategies.
- Clean, disassemble, and store temporary barrier components.

SUPPORTING ADAPTATION MEASURES

- Pressure relief systems
- Flood damage resistant materials.
- Backup power/fuel

ESTIMATED COST

$$$$$ - $$$$$

Maintenance Yard Adaptation Types

Photo Credit: Wolfe House & Building Movers, LLC wolfehousebuildingmovers.com

1. Relocate

Moving buildings or assets into protected areas.

Benefits: focuses flood protection efforts.

Drawbacks: requires adequate clearances for moving to new locations, and may need to follow predetermined time constraints.

Photo Credit: Flood Control America, LLC floodcontrolam.com/projects/flood-wall-east-grand-forks

2. Perimeter Barriers

A temporary or permanent structure, designed to a specified flood height, to protect an area from flooding.

Benefits: block flood waters without the additional expense of waterproofing or modifying other systems.

Drawbacks: only offer protection to a particular height - if the built height is lower than a particular flood event, the efforts will be unsuccessful. Temporary barriers require more warning time to install.

Photo Credit: Flood wall gate at Harlan, Kentucky, wikiwand.com/en/Floodgate

3. Isolate Critical Components

Identifying specific critical assets for protection, using the most applicable adaptation measure.

Benefits: Less expensive to protect the most critical assets rather than protecting a large area with a varied number of assets.

Drawbacks: During flood events, damages may occur to assets not protected.

Photo Credit: Valley Construction Company, valleyconstruction.com

4. Protect Individual Buildings

Focusing flood protection resources on centralized buildings where more personnel and/or assets are housed.

Benefits: protection of one building housing many assets; potential for old building areas to be repurposed.

Drawbacks: Will require constructing a new building.

Photo Credit: U.S. Army Corps of Engineers nws.usace.army.mil

5. Levees / Berms

Earthen mounds, often with a structural base, designed to block flood waters from entering certain areas.

Benefits: Can prevent flood waters from reaching railroad infrastructure. Provides potential for community space including parks. Could be cost effective due to potential of large areas of protection

Drawbacks: Require a large amount of dedicated land which can be impractical for existing sites.

Rail Bridges

Rail bridges are critical pieces of infrastructure which can become threatened by floods. Elevating a bridge removes the bridge deck and higher components from the threat of floating debris and fast moving currents of water. Old or weakened bridges may warrant replacement or strengthening of bridge connections. Alternative methods of protection include adding measures to protect against scour, and installing protection which deflects the impact of floating debris on critical bridge members.

BUILDING STRATEGIES

- Assess bridges for scour and debris concerns.
- Determine which bridges would benefit from scour and debris protection.
- Determine which bridges are vulnerable due to their overall elevation.

SUPPORTING ADAPTATION MEASURES

- Anchorage
- Flood damage resistant materials

OPERATIONAL CONSIDERATIONS

Before flooding:

- Monitor bridges for debris and scour problems.
- Increase scour and debris protection for susceptible bridges.
- Consider evaluation of bridge components/connections/lifecycle to replace and elevate.

After flooding:

- Remove any debris which has accumulated around bridge.
- Strengthen any connections which may have been damaged during flooding.
- Increase scour protection for areas damaged by flood waters.

ESTIMATED COST

$$$$$ - $$$$$

Rail Bridge Adaptation Types

Photo Credit:
bostontoat.blogspot.com/2011/04/history-of-el.html

1. Replace and Elevate

Design and construction of a new flood resilient bridge (raised above projected flood elevation).

Benefits: Mitigates flood waters and debris from damaging the bridge deck; upgrades deteriorating bridge components; responds to current flood design standards and/or considerations for climate change.

Drawbacks: Expensive; may cause interruptions in rail service; requires significant planning.

Photo Credit: GeoDesign, Inc.; geodesign.net/projects-2/

2. Scour and Debris Protection

Use of additional riprap or other permanent installations to help protect foundations against swiftly moving flood waters, and defend against debris impacts.

Benefits: Strengthens the bridge foundation and/or the area around the foundation against flooding.

Drawbacks: May change flow patterns of waterway and/or navigation along river.

Photo Credit: localtvktvi.files.wordpress.com/2012/11/2012-11-07-worker-on-bridge.jpg?quality=85&strip=all&w=2000

3. Strengthen Structural Connections

Structural upgrades which increase the strength of bridge parts that may experience higher loading during floods.

Benefits: Can increase resistance to flood waters and debris, prevent bridge failure, increase service life of bridge.

Drawbacks: May disrupt service during construction periods.

Substations

Because flooding can disrupt a substation's ability to feed power into the catenary system, it is vital to protect these assets. Relocation out of the floodplain offers the greatest protection, but other less expensive measures can also be implemented, such as elevating substation equipment, improving flood threat communication, and erecting perimeter barriers around the substations.

BUILDING STRATEGIES

- Relocate equipment to an area which is naturally more elevated than current substation location.
- Hire a company which specializes in elevating substation equipment above flood levels.

SUPPORTING ADAPTATION MEASURES

- Site characteristics
- Pressure relief systems
- Flood Damage Resistant Materials

OPERATIONAL CONSIDERATIONS

Before flooding:

- Install temporary perimeter barrier components
- Assess substations for vulnerability to floods
- Assess substation criticality

After flooding:

- Clean components.
- Test and document any equipment failure with considerations for implementing adaptation strategies.
- Clean, disassemble, and store temporary barrier components.

ESTIMATED COST

$$$$$-$$$$$

Substations

Photo Credit: Transmission & Distribution World, "Power on the Move" 3/12/2014. (tdworld.com)

1. Relocate

Repositioning substation to remove it from flood prone areas.

Benefits: Increased resistance to floods when the substation is positioned outside of the floodplain.

Drawbacks: Expensive; relocation distances from powered equipment and fuel sources must be considered.

Photo Credit: DIS-TRAN Packaged Substations (distransubstations.com)

2. Elevate

Raising flood prone equipment above the projected flood elevation.

Benefits: Can alleviate the maintenance requirements needed for some flood protection measures; reduces vulnerability to flood damage.

Drawbacks: May require additional design/expense to reinforce structural components.

Photo Credit: Penta Corp (http://www.penta-corp.com)

3. Improve Communication

Raising awareness of flood risk to substations and issuing warnings when appropriate.

Benefits: Improves safety; reduces damages; quickens process for repairs; may prevent failure of components.

Drawbacks: May require additional training, coordination, and equipment to implement on a daily basis.

Photo Credit: Flood Control International (floodcontrolinternational.com)

4. Perimeter Barriers

Permanent or temporary vertical structures designed to block flood waters from entering certain areas.

Benefits: Can prevent flood waters from reaching substation equipment.

Drawbacks: Offers protection only to a particular height, so overtopping is possible; may require storage space; personnel training for installation, and adequate warning time.

Catenary / Signal

Flooding can produce fast moving water which weakens foundations. Increasing the anchorage of catenary and signal systems builds resistance to floods and helps keep these assets operational. Elevating signal cabinets and catenary poles can prevent critical electrical equipment from being flooded. If elevating the equipment is not feasible, catenary and signal housing may benefit from improved waterproofing techniques or upgrades.

BUILDING STRATEGIES

- Identify components and locations which have historically been problematic.
- Monitor the areas susceptible to flooding.
- Identify if elevating the catenaries or signals is applicable in an area.
- Evaluate site characteristics and slope stability in areas identified as vulnerable to flooding.

SUPPORTING ADAPTATION MEASURES

- Scour protection
- Ballast integrity sensors
- Perimeter barriers
- Alternative power sources

OPERATIONAL CONSIDERATIONS

After flooding:

- Inspect foundation.
- Inspect waterproofing and electrical components.
- Replace any worn or failed components.

ESTIMATED COST

$$$$$-$$$$$

Catenary / Signal Adaptation Types

Photo Credit: Amtrak (nec.amtrak.com)

1. Anchorage

Extends catenary or signal foundation deeper into the ground for improved stability.

Benefits: Catenary and signal systems are less prone to scour and being pushed over during floods.

Drawbacks: Requires a significant investment; may be more cost-effective as a replacement action after flood damage than as a proactive measure.

Photo Credit: Interrail, Inc. (interrail-signal.com)

2. Elevate

Positions the bottom of catenary or signal posts/equipment above the expected flood level.

Benefits: Elevating signal cabinets is relatively inexpensive and can minimize flood damage to the electrical components.

Drawbacks: Elevating the catenary system should only occur in conjugation with track elevation to ensure the connection is maintained.

Photo Credit: Pento Corporation (pento-corp.com)

3. Improve Communication

Creating faster and more efficient methods to warn personnel of dangerous or potentially dangerous situations.

Benefits: Improves safety, reduces damages, quickens the process for repairs, and may prevent failure of components.

Drawbacks: May require additional training, coordination, and equipment to implement on a daily basis.

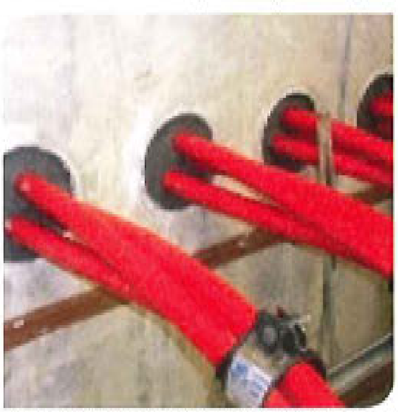


Photo Credit: Thorne & Derrick (cablejoints.co.uk)

4. Waterproof

Prevents water from entering the electrical housing or equipment where it can cause damage.

Benefits: Prolongs the life of electrical equipment, improves resiliency duiring extreme weather.

Drawbacks: Required maintenance to ensure continued resistance to water.

Pilot Study Adaptation Plan

3.0 Pilot Study Adaptation Plan

3.1 Introduction

The Pilot Study Adaptation Plan serves as an initial step toward overall climate change adaptation planning and resiliency for the Pilot Study Area. This plan provides a detailed evaluation of select adaptation measures and establishes a repeatable methodology that can be used for other vulnerable areas along the NEC. Assets identified as most vulnerable in the Phase II Vulnerability Study included four Amtrak buildings and facilities (Wilmington Station, Wilmington Training Center, Wilmington Maintenance Shops, and the Consolidated National Operations Center), several track segments and associated signal and catenary systems, and the West Yard and the Bellevue substations. These assets were analyzed to identify a range of adaptation measures for climate change induced hazards. Sea level rise and storm surge are the primary hazards reviewed, and increased precipitation was a secondary hazard consideration for the plan. This methodology can be followed and additional adaptation measures could be identified and evaluated if additional assets or climate variables such as wind or temperature extremes are selected.

The level of risk used to evaluate the adaptation measures was based on several factors, including: adherence to all required regulations, ordinances and established funding requirements; asset-specific considerations including criticality and expected lifespan of infrastructure; and guidance from established transportation-focused adaptation plans in the northeast. It was determined that the following three risk scenarios would be most appropriate to use for the development of adaptation measures:

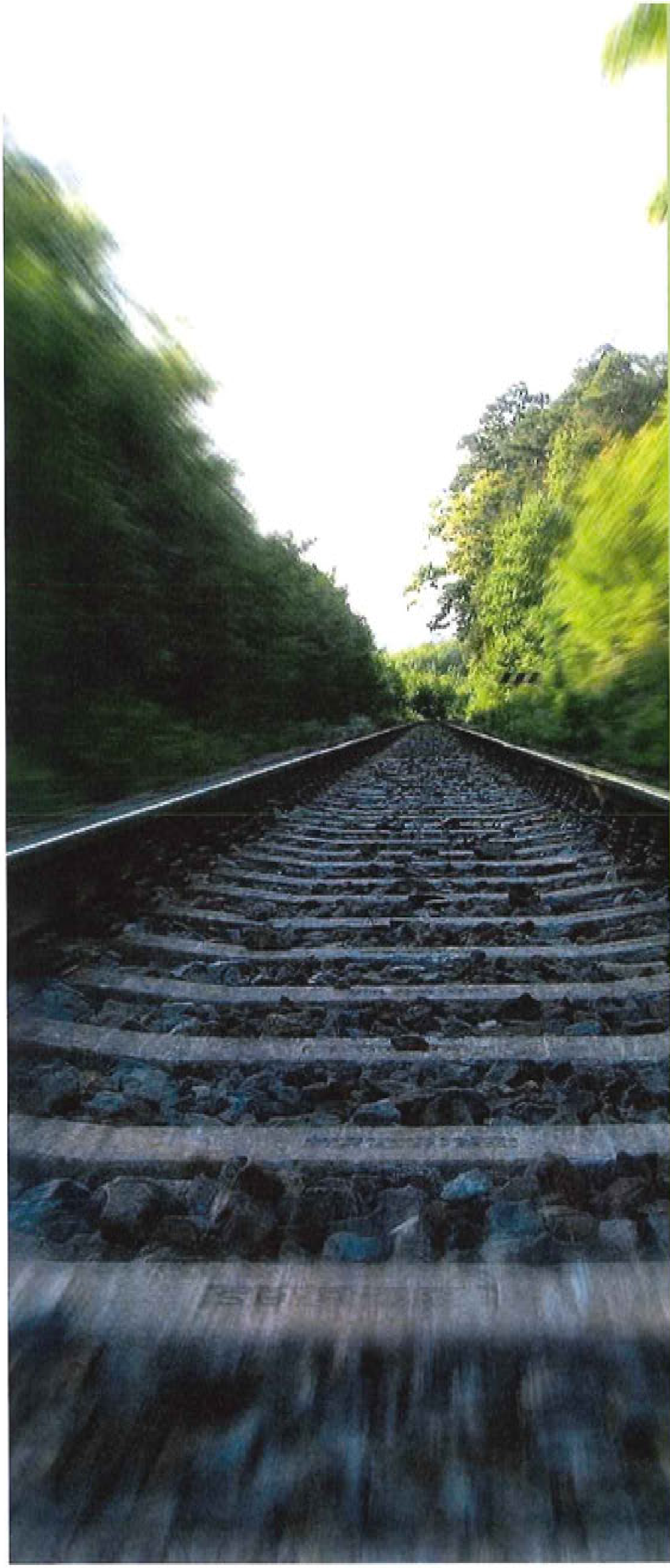
- **100-year storm event with sea level rise in the year 2050 (2050 SLR, 100-year)**
- **100-year event plus one foot of freeboard with sea level rise in the year 2050 (2050 SLR, 100-year +1')**
- **500-year event with sea level rise in the year 2050 (2050 SLR, 500-year)**

The development of the Pilot Study Adaptation Plan for the most vulnerable assets identified in the Phase II Vulnerability Study considered asset vulnerability to the three risk scenarios, asset criticality, depth of flooding, potential adaptation measure siting, structural integrity of asset walls and foundation for hydrostatic and hydrodynamic flood loadings, asset egress and ingress requirements, adaptation measure storage and deployment options, as well as asset age and service life.

Flood wall barriers (flood walls) were selected as the primary adaptation measure for flood protection of the selected assets because they provide the most comprehensive level of protection for all three risk scenarios. Flood barriers can be temporary, semi-permanent or permanent structures, which allows for flexibility in addressing hazard and asset conditions such as egress and ingress requirements and limited workforce availability. Other adaptation measures were evaluated but were not selected due to a variety of factors including limitations for protection to flood significant depths and high flood velocities, were costly to adequately ensure reliability of flood protection during the risk scenarios, or required an additional investigation regarding the structural integrity of asset walls and foundations which was beyond the scope of this study. Section 3.2 Potential Adaptation Measure Summary Table provides a summation of other adaptation measures and their applicability to the Pilot Study Area vulnerable assets.

Pilot Study Adaptation Sheets, found in Section 3.4 of this report, describe flood barrier adaptation measure considerations for each of the selected assets. The sheets provide actionable criteria for the flood barriers including adaptation height, foundation width, anchorage, deployment time, storage requirements, sustainability, durability of material, ease of operation, maintenance, length of flood barrier, and cost of implementation.

Additional information used in the development of the Pilot Study Adaptation Plan is included in Sections 3.5 to 3.7. Area-wide adaptation measures that could protect multiple assets, both Amtrak and non-Amtrak, are presented in Section 3.4.8. Precipitation-specific adaptation measures such as bioswales are described in Section 3.4.9. Regulatory considerations including easements and ownership, environmental permits, floodplain review, stormwater and erosion and sediment control review and construction permits are included in Section 3.5. Section 3.6: Initial Benefit-Cost Analysis describes the method and results of the lifecycle cost for the adaptation measures, as well as the overall resilience benefits. Lifecycle costs for each adaptation measure considered initial capital costs, a useful understanding to quantify investment for measures. Additional analysis for annual expenses required to maintain the measure over the design life should be completed once the adaptation measure selections are finalized. The resiliency benefits for the adaptation measures focused primarily on avoidance of damages and impacts associated with flooding. Avoiding damages or inducing cost savings for recovery should be a key item in risk mitigation and resilience planning. Section 3.7 highlights potential funding opportunities to be further examined once adaptation measure parameters are finalized.



Potential Adaptation Measure Summary Table

POTENTIAL ADAPTATION MEASURES

● Applicable
◉ Potentially Applicable
○ Marginally Applicable
Not Applicable

Wilmington Area Assets

	Wilmington Station	CNOC	Training Center	Maintenance Facility	Rail Tracks	Catenary and Signal	Substations	Rail Bridges	Estimated Cost	Level of Protection
BUILDING										
Relocate	○	◉	◉	○					$-$$$$$	🛡🛡🛡🛡🛡
(B1) Relocate Building	○	○	○	○					$$$$$	
(B2) Relocaate Work Location	○	○	◉	○					$$-$$$$	
(B3) Relocate Equipment	○	○	●	○					$-$$$$	
Elevate	●	◉	○	◉					$-$$$$	🛡🛡🛡🛡
(B4) Elevate Building	◉	◉	◉	◉					$-$$	
(B5) Elevator Retrofits	◉	◉	◉	◉					$-$$$	
(B6) Elevate Utilities	●	●	●	●					$$-$$$$	
Dry Floodproofing	●	●	●	●					$-$$$	🛡
(B7) Pumps	●	●	◉	●					$-$$	
(B8) Backflow Valves	●	●	●	●					$-$$	
(B10) Flood Shields for Windows & Doors	●	●	●	●					$-$$	
(B11) Waterproof Walls & Floor	●	●	●	●					$ -$$$	
(B12) Flood Shields for Vents and Louvers	●	●	●	●					$	
(B13) Reinforce Existing Walls & Floor	●	●	●	●					$-$$$	
(B14) Backup Power	●	●	●	●					$-$$$	
Perimeter Barriers									$-$$$$$	🛡🛡🛡
(B15) Temporary	●	●	●	●					$-$$$	
(B16) Semi-Permanent	◉	●	●	●					$$-$$$	
(B17) Permanent		●	●	●					$$-$$$	
(B18) Berms / Levees				◉					$$$-$$$$$	

$ = <$100,000 $$ = $100,000 - $500,000 $$$ = $500,000 - $3,000,000 $$$$ = $3,000,000 - $10,000,000 $$$$$ = >$10,000,000

POTENTIAL ADAPTATION MEASURES

● Applicable
◉ Potentially Applicable
○ Marginally Applicable
Not Applicable

WILMINGTON AREA ASSETS

	Wilmington Station	CNOC	Training Center	Maintenance Facility	Rail Tracks	Catenary and Signal	Substations	Rail Bridges	Estimated Cost	Level of Protection
BUILDING (CONTINUED)										
Wet Floodproofing	●	●		◉					$-$$$	▼▼
B19 Flood Damage Resistant Materials	●	●	●	●					$-$$$	
B20 Elevate Utilities	●	●	●	●					$-$$$	
B21 Flood Vents	●	●		◉					$-$$	
B22 Quick Disconnects for Equipment	●	●	●	●					$	
B23 Anchorage for Exterior Equipment	◉	◉	◉	●					$	
B24 Use Appropriate Pump Timing	●	◉	◉	◉					$	
B25 Pumps	●	●	◉	●					$-$$	
B26 Reinforce Existing Walls & Floor	●	●	●	●					$$-$$$	
B27 Elevator Retrofits	◉	◉	◉	◉					$-$$	
B28 Backup Power	●	●	●	●					$-$$$	
MAINTENANCE YARD (GROUNDS)										
M1 **Relocate**				○					$-$$$$$	▼▼▼
M2 **Isolate Critical Components**				●					$-$$$	▼▼▼
M3 **Protect Individual Buildings**				●					$-$$$$	▼▼▼
Perimeter Barriers									$$$-$$$$	▼▼▼
M4 Temporary				●					$-$$$$	
M5 Semi-Permanent				●					$$-$$$$$	
M6 Permanent				●					$$-$$$$$	
M3 Berms / Levees				◉					$$$-$$$$$	

$ = <$100,000 $$ = $100,000 - $500,000 $$$ = $500,000 - $3,000,000 $$$$ = $3,000,000 - $10,000,000 $$$$$ = >$10,000,000

POTENTIAL ADAPTATION MEASURES

● Applicable
◉ Potentially Applicable
○ Marginally Applicable
Not Applicable

WILMINGTON AREA ASSETS

	Wilmington Station	CNOC	Training Center	Maintenance Facility	Rail Tracks	Catenary and Signal	Substations	Rail Bridges	Estimated Cost	Level of Protection
RAIL TRACKS										
(T1) Elastocoast Ballast Protection					●				$-$$$	▼
(T2) Ballast Integrity Sensors					●				$-$$	▼
(T3) Concrete Ties					●			◉	$-$$$	▼
(T4) Ballast Drainage & Slope					●			◉	$-$$$$	▼▼
(T5) Green Track/Aggregate Replacement					●				$$-$$$$	▼
Perimeter Barriers									$$-$$$$$	▼▼▼
(T6) Temporary	●			●	◉				$$-$$$$	
(T7) Semi-Permanent	◉			●	●				$$-$$$$$	
(T8) Permanent				●	●				$$-$$$$$	
(T9) Berms / Levees				◉	◉				$$$-$$$$$	
RAIL BRIDGES										
(R1) Replace & Elevate								●	$$$$-$$$$$	▼▼▼
(R2) Scour Protection					●			●	$$-$$$	▼▼
(R3) Strengthen Structural Connections					●			●	$ $-$$$	▼▼

$ = <$100,000 $$ = $100,000 - $500,000 $$$ = $500,000 - $3,000,000 $$$$ = $3,000,000 - $10,000,000 $$$$$ = >$10,000,000

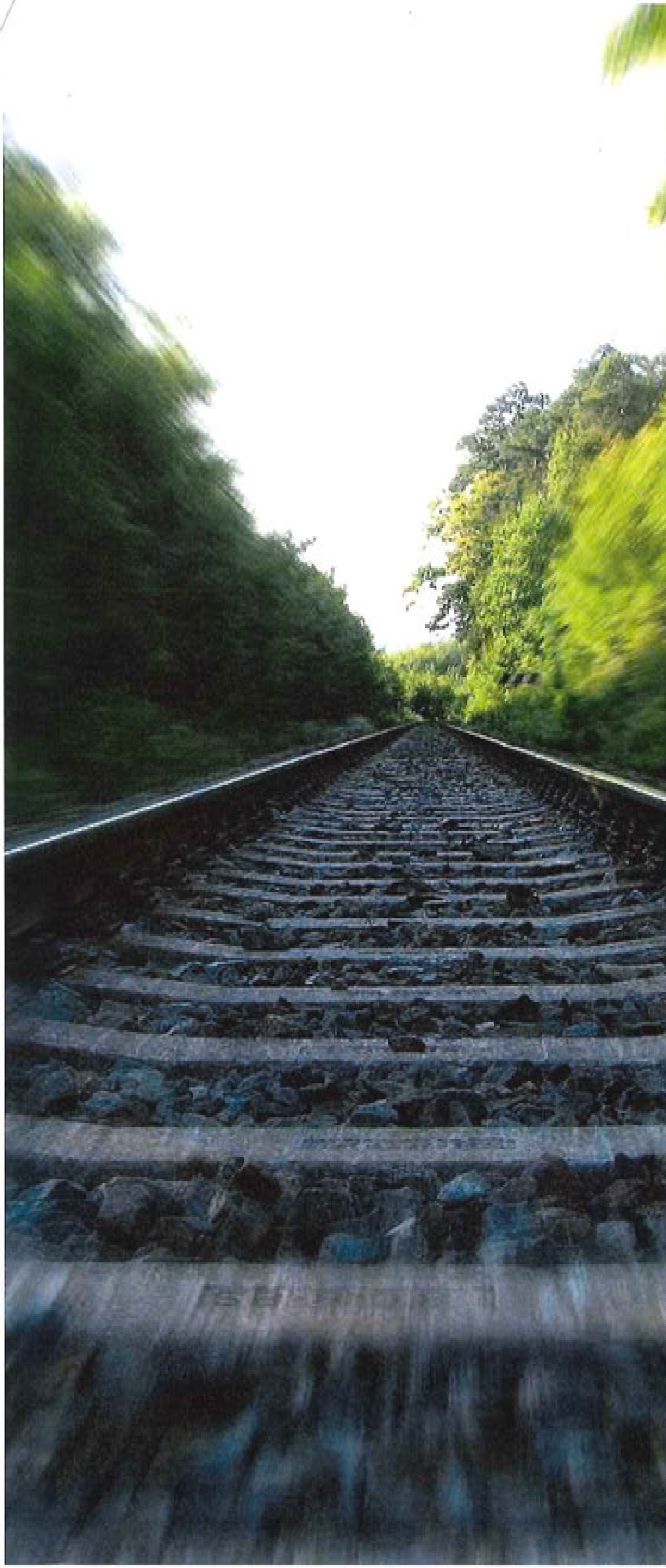
POTENTIAL ADAPTATION MEASURES

● Applicable
◉ Potentially Applicable
○ Marginally Applicable
Not Applicable

WILMINGTON AREA ASSETS

	Wilmington Station	CNOC	Training Center	Maintenance Facility	Rail Tracks	Catenary and Signal	Substations	Rail Bridges	Estimated Cost	Level of Protection
SUBSTATION										
(S1) Relocate					◉		◉	○	$$$-$$$$$	▼▼▼
(S2) Elevate					●	●	●	○	$$-$$$$	▼▼
Perimeter Barriers									$-$$$$	▼▼▼
(S3) Temporary					◉		●		$-$$$	
(S4) Semi-Permanent					●		●		$$-$$$	
(S5) Permanent					●		●		$$-$$$	
(S6) Berms / Levees					◉		◉		$$$-$$$$	
CATENARY / SIGNAL										
(C1) Anchorage					●	●			$-$$$	▼
(C2) Elevate	●			◉	●	●		○	$-$$$$	▼
(C3) Improve Communication	●			●	●	●		●	$-$$$	▼
(C4) Waterproof						●			$-$$$	▼

$ = <$100,000 $$ = $100,000 - $500,000 $$$ = $500,000 - $3,000,000 $$$$ = $3,000,000 - $10,000,000 $$$$$ = >$10,000,000



Methodology

3.3 Methodology

The methodology for the Pilot Study Adaptation Plan began with clarifying which assets would be included and which climate variables would be considered. It was decided that the assets identified as the most vulnerable in the Phase II Vulnerability Assessment would be addressed in Phase III. These include the four facilities (Wilmington Station, Wilmington Shops, Wilmington Training Center and CNOC), several segments of track and the associated signal and catenary systems, and both the West Yard and the Bellevue substations. The climate variables most likely to impact these assets were those that would cause flooding; therefore, the plan focused on sea level rise, storm surge and increased precipitation.

Once the assets and climate variables were established it was important to determine the level of risk that would be considered. This decision was made considering the vulnerability and criticality of the individual assets, what other states, cities, transportation managers were already putting in place as well as regulatory and grant considerations. It is necessary to define the level of risk so that the adaptation measures can be evaluated to determine if they can provide the appropriate protection. This study considered three climate scenarios when determining the most appropriate adaptation measures:

- 100-year storm event with sea level rise in the year 2050 (2050 SLR, 100-year)
- 100-year event plus one foot of freeboard with sea level rise in the year 2050 (2050 SLR, 100-year +1')
- 500-year event with sea level rise in the year 2050 (2050 SLR, 500-year)

The initial modeling during the Phase II Vulnerability Assessment only included the 100-year storm event; therefore, it was necessary to conduct additional modeling to include the 2050 SLR, 100-year +1' of freeboard and the 500-year. Federal Emergency Management Agency (FEMA) EMA's Hazus-MH 3.0 software was used to project the sea level rise and storm surge scenarios and the results were presented on Geographic Information Systems (GIS) maps.

The Hazus software also estimates dollar losses due to flooding for each building and its contents (as available). Inputs include building replacement value, content replacement value, number of stories, foundation type, building type, and elevation. For this phase, which conducted a high-level benefit-cost analysis, the following information was used, as shown in the table below (Table 1).

Table 1. Estimated Dollar Losses Due to Flooding

	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)	(b) (5)	(b) (5)	2	4	Masonry	Crawl Space
Station	(b) (5)	(b) (5)	(b) (5)	3	3	Masonry	Basement/Yard

	Building Replacement Value	Content Replacement Value	Total Replacement Value	Number of Stories	Elevation (ft.)	FL Building Type	Hazus Flood Foundation Type
Training Center	(b) (5)	(b) (5)	(b) (5)	2	5	Concrete	Slab on Grade

3.3.1 Adaptation Measures

A range of adaptation measures were evaluated for their ability to protect the individual assets within the three risk scenarios chosen. The development of an adaptation plan took into consideration asset vulnerability to the three risk scenarios, asset criticality, depth of flooding, potential adaptation measure siting, structural integrity of asset walls and foundation for hydrostatic and hydrodynamic flood loadings, asset egress and ingress requirements, adaptation measure storage and deployment options, as well as asset age and service life.

Flood wall barriers (flood walls) were selected as the primary method of flood protection for Amtrak facilities and assets because they provide the most comprehensive level of protection for all three risk scenarios. Other adaptation measures were considered but were not recommended because they did not protect against the predetermined levels of risk, were cost prohibitive, or required a substantial amount of information regarding the structural integrity of the assets, which was beyond the scope of this study. For example, dry floodproofing often requires reinforcing all walls, windows, and doors. Dry floodproofing also requires detailed preventative measures which eliminate water from seeping into the building at exterior pipes or outlets. Unfortunately, this method offers inadequate protection if the initial waterproofing fails. It is preferable to extend the protection away from the building perimeter to protect all the critical assets and allow for pumps to serve as a backup measure for resisting flooding. Using flood walls and pumps as a combined approach seems to be less prone to failure. Although flood walls often have a large upfront expense the long-term maintenance and damage resulting from failure is minimal.

Green infrastructure best management practices were recommended to mitigate the potential ponding impacts resulting from increased precipitation during single storm events. An area adjacent to a segment of track and the maintenance shop yard were identified as being vulnerable to ponding; therefore, bioswales and rain gardens were proposed in these areas.

The primary distinction between any flood walls is the type of system being utilized. Flood walls are classified as permanent, semi-permanent, and deployable. A **permanent system** uses components which are erected well before any flooding threat has occurred and since they remain in place they require no further human intervention. This system may include some limited deployment at egress locations, but otherwise the system does not change in height, or location. A **semi-permanent system** requires some assembly to fully protect assets against the 2050 SLR, 500-year. In addition to typical deployment at egress locations, the semi-permanent system has infill components or extension members which must be assembled/added to increase the height of the flood wall. The **deployable system** has no components which offer uninterrupted flood protection. All protective measures of a deployable system must be fully erected each time flood protection is needed.

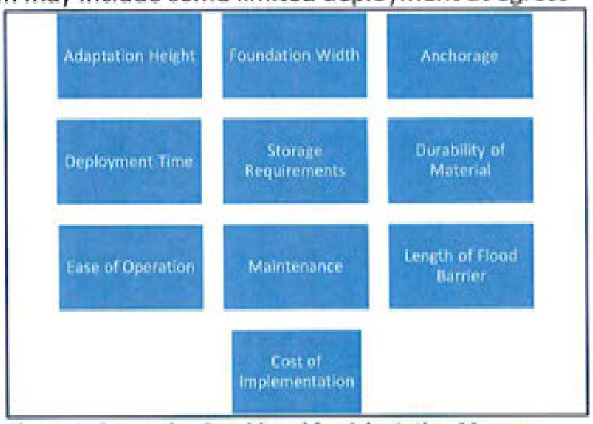


Figure 1. Categories Considered for Adaptation Measure Assessment

Each flood wall adaptation measure was compared against ten criteria. These categories include adaptation height, foundation width, anchorage, deployment time, storage requirements, sustainability, durability of material, ease of operation, maintenance, length of flood wall, and cost of implementation. Each category offers helpful insight into the particular characteristics of the adaptation measure.

3.3.2 Adaptation Height

The adaptation height is the assumed deepest flood level at the assumed flood wall locations with an extra half-foot of height. These values do not necessarily match the inundation values associated with exterior walls of buildings because the ground often slopes down away from a building, see Figure 2. Some flood walls will have additional portions of the wall below the ground surface. This extra wall depth is not included in the adaptation height.

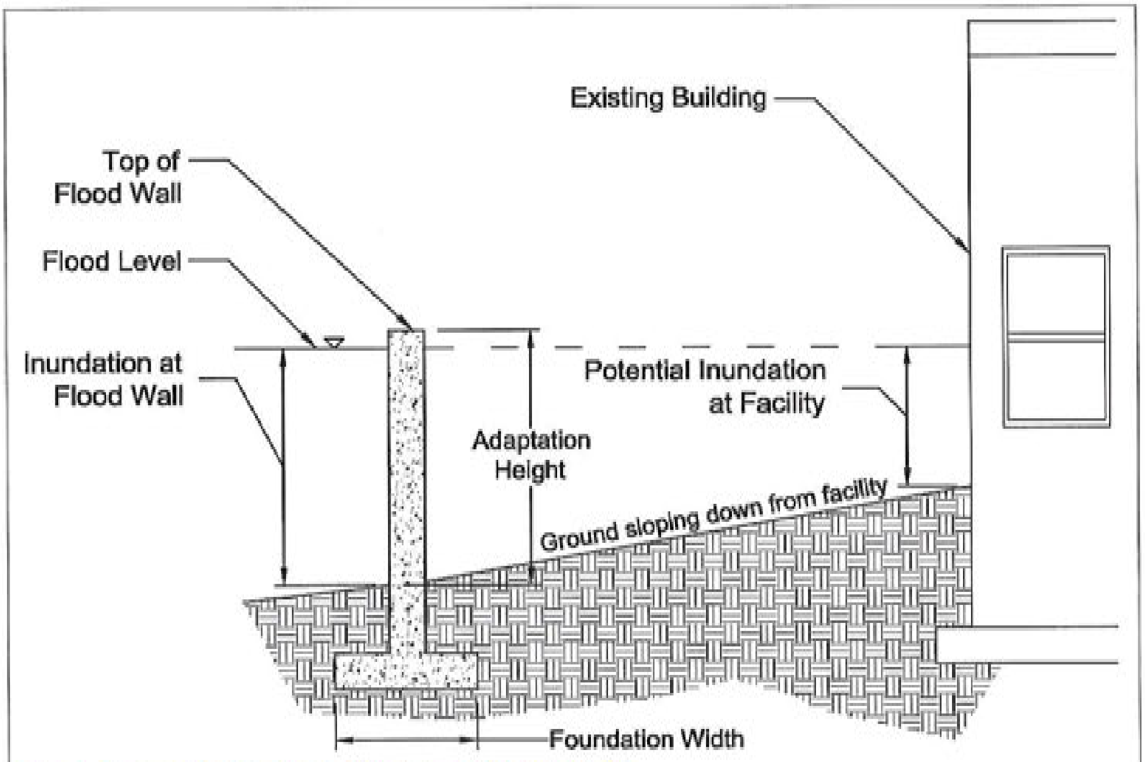


Figure 2. Cross-section Depicting Adaptation and Flooding Heights

3.3.3 Foundation Width

All walls have a footprint which exceeds the actual wall width, and this is categorized as foundation width. Some wall types have a foundation located at the ground surface, and other walls have a foundation buried under the ground surface. In both cases, the foundation width takes more space than the vertical wall element itself. This is an important consideration because some wall widths prevent a wall from being erected or constructed immediately adjacent to an existing facility. There is normally some setback distance between an existing facility wall and the new flood wall to accommodate the additional foundation width. When permanent foundations are constructed, the foundation width is also a helpful guide to understand what portion of existing ground will be impacted by construction.

3.3.4 Deployment Time

Deployment time offers a helpful statistic for comparing flood wall systems. When severe storms are approaching, there may not always be extended warning periods to allow for deployment of the flood wall. Therefore, deployment times for flood wall systems should be kept as short as possible. All deployment times provided assume a crew of four to six people will be working together to assemble wall components. Increasing the number of crews will reduce the deployment times. It is recommended that an action plan be developed in association with each deployable system to minimize the risk to assets by having trained personnel assigned to efficiently erect deployable flood walls when called upon.

3.3.5 Cost of Implementation

The actual cost of each wall system will vary based upon terrain, soil/ground stability, as well as the length and height of the wall. In the Pilot Study Adaptation Sheets in Section 3.0, an estimated cost was provided for relative cost comparison purposes. Actual costs will vary, and may be higher or lower depending on the suitability of the ground receiving flood walls. For instance, some deployable flood walls require the ground to be graded to being near flat or for concrete to be poured on the ground to level the surface receiving the deployable flood wall. In addition, permanent wall foundations may require the removal and replacement of underground pipes, utilities, or cable. These unknowns were not considered in the cost values provided. The possible additional cost due to some of the measures' close proximity of the construction to rail or catenary was also not considered.

3.3.6 Length of Flood Wall

Length of wall describes the estimated length of the flood wall required to surround the critical assets being protected at a facility. The actual wall length will vary because choosing the positioning of the wall is dependent on many factors. Some flood walls are better placed farther away from buildings to avoid underground utilities. In other cases, the ground slope may push the flood wall further or closer to the facility because repositioning the wall proves more economical than re-grading the ground. Based upon construction costs, Amtrak may also choose to forgo protection of certain parts of facilities because it may provide savings in flood wall construction.

3.3.7 Anchorage

Figure 3. Typical Wall Anchorage System

Anchorage was categorized as simple, fair, or complex. **Simple anchorage** can be done quickly and with very limited instruction. **Fair anchorage** utilizes connections requiring some training, but can be performed after proper instruction and usually requires some practice before a person becomes proficient in the technique. **Complex anchorage** may only be accomplished by well trained and experienced professionals. Complex anchorages were avoided because the failure of properly anchoring a deployed system could result in wall failure. In addition, it is recommended that anchorages be kept simple because storm events may approach quickly without enough warning to send experts to the site. The proper deployment of adaptation measures should not be dependent on experts; optimally all skill levels can assist with their deployment.

3.3.8 Sustainability

Sustainability requires building materials to be in part or in whole readily recyclable. **High sustainability** classifies flood wall components as almost entirely readily recyclable. **Average sustainability** allows most components to be recycled after use. When the majority of the components cannot be recycled and do not biodegrade, this is considered **low sustainability**.

3.3.9 Material Durability

Material durability is used for relative comparison between flood prevention systems to demonstrate acceptable resistance to floodwaters based upon FEMA Flood Damage-Resistant Materials Requirements (FEMA, 2008). The cumulative description of material durability (as high, average, or low) included considerations of debris impact; long term degradation; component damage; and long-term functionality. **High durability** is associated with the longest lasting systems which would be expected to degrade very little over a 50-year lifespan when constructed properly. **Average durability** is categorized as some limited replacement of system components over a 50-year lifespan. **Low durability** is considered widespread replacement of components over a 50-year lifespan.

3.3.10 Ease of Operation

Each flood wall system requires some operation to establish its full protection of assets. The ease of operation describes how easily the system may be deployed to attain full protection. **High ease of operation** is classified as a system which requires specific limited deployment. **Average ease of operation** entails a system which has components along most the flood wall length which must be erected. However, the components themselves are not considered complex to construct. Any flood wall system which poses difficult and extensive challenges in erection is classified as **low ease of operation.**

3.3.11 Maintenance

Flood walls, as with all constructed protection methods, require some on-going maintenance. **Low maintenance** could include visually evaluating the adaptation measure on an annual basis and performing simple cleaning efforts after a flood event. The cleaning associated with adaptation measures can even be optional for most components with spot or localized cleaning providing sufficient remediation. **Average maintenance** requires every element of the deployable flood adaptation measure to be cleaned after a flood event. This involves a significant commitment of workers and time. Average maintenance systems also require every component be visually inspected for degradation or flaws. Any component significantly damaged should be repaired or replaced. **High maintenance** requires on going inspection and repairs in addition to all the duties associated with the average maintenance.

3.3.12 Storage Requirements

Requirements for storage of flood wall systems were estimated in terms of a typical 9 feet by 20 feet parking space. All values associated with storage containers assume they will be stacked up to 17 feet high in each parking space. For some flood wall systems, this equates to four containers stacked one on another, and for other manufacturers this may be equivalent to stacking two containers.

3.3.13 Precipitation

According to *Climate Change Projections and Indicators for Delaware*, the projected increase in the rainfall over a 24-hour period at the 10-percent-annual-chance probability level (10 Year) in the year 2050 is 0.46 inches. As the existing rainfall over a 24-hour period at this probability level is 6.67 inches, this represents a 6.9% increase owing to climate change (Hayhoe, Stoner, & Gelca, 2013). It was assumed that all rainfall will runoff and accumulate in low points. The low points where ponding may occur adjacent to vulnerable assets were identified based on LIDAR elevations. LIDAR stands for light detection and ranging and is a remote sensing method used to examine the surface of the earth. The resulting data is used to understand the elevations within a specified area. An increase in rainfall can lead to ponding issues adjacent to Amtrak assets which can lead to temporary flooding issues. It should be noted that this relatively small increase in rainfall intensity is unlikely to create additional hazards that are not already present following intense rains.

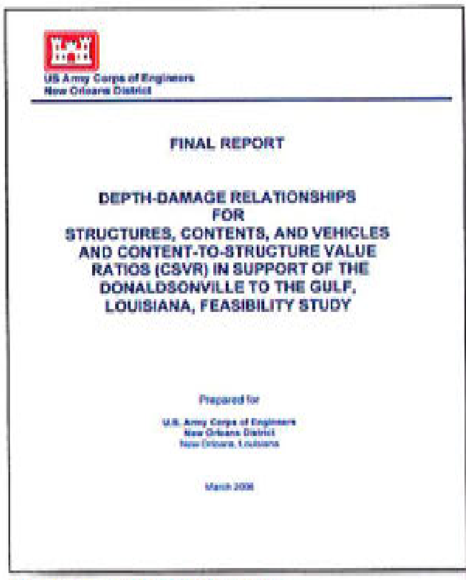
3.3.14 Initial Benefit-Cost Analysis

Initial benefit-cost analyses (BCA) were conducted to determine the value the adaptation measures would provide to Amtrak and the region. Benefit-cost ratios (BCRs) as well as net-benefit values were produced for each project to serve as an indicating metric of the value added. BCRs are calculated by taking each project's total dollar amount for expected benefits (net present value) and dividing by the total lifecycle costs to implement and maintain the same project. When a project has a BCR greater than 1.0, the expected net-benefit value will be positive and the benefit dollars will be more than the costs. On the other hand, a BCR less than 1.0 means that the costs are greater than the benefits. A BCR equal to 1.0 means that the total expected benefits are equal to the total lifecycle costs of the project. A full evaluation of benefits was outside the scope of this study. As such, most of the recommended adaptation strategies currently show negative BCRs.

Coastal Flood Damages Avoided

The installation of flood walls will prevent flooding and damages to the specified Amtrak assets. The BCA analysis assumed that the proposed adaptation measures will protect against damages up to the 2050, 500-year event, and that there will be no residual damages following the installation of these adaptation measures. Using the pre- and post- project scenarios, damages to structures and building contents were calculated using the FEMA Benefit-Cost Analysis (BCA) Software. This accounts for the two components of risk: magnitude of potential loss and probability of loss. The greater the frequency and depth of flooding for a given structure, the higher the annualized damages and losses. Benefits are calculated as the difference between annualized damages with and without undertaking the mitigation project. The net present values are then determined utilizing the useful life of the project and the time value of money.

Damage Avoidance - Buildings and Contents


US Army Corps of Engineers
New Orleans District

FINAL REPORT

DEPTH-DAMAGE RELATIONSHIPS
FOR
STRUCTURES, CONTENTS, AND VEHICLES
AND CONTENT-TO-STRUCTURE VALUE
RATIOS (CSVR) IN SUPPORT OF THE
DONALDSONVILLE TO THE GULF,
LOUISIANA, FEASIBILITY STUDY

Prepared for

U.S. Army Corps of Engineers
New Orleans District
New Orleans, Louisiana

March 2006

Figure 4. USACE Final Report

Damage avoidance benefits were calculated by estimating the inundation depth of individual structures at event magnitudes including the 2050 SLR, 100- and 500-year event. First floor elevations for structures were estimated using the average DEM elevation (digital model or 3D representation of a terrain's surface) within the building footprint. It was assumed for this analysis that all the buildings are built on slab (no basements or crawlspaces). The water surface elevations and estimated sea level rise of 2.0 feet in 2050 was obtained from the Phase II Vulnerability Assessment and was applied to all elevations to account for rising sea level projections. Depth-damage relationships for commercial building structures and contents were obtained from a report prepared by the USACE New Orleans District (USACE, 2006), Figure 4.

The USACE depth-damage curves for commercial buildings were applied using the assumption that the flooding was short duration and consisted of salt-water. Building structures were analyzed individually and assigned a structure type of Metal Frame, Masonry Frame, or Wood/Steel Frames. Non-residential content damages were applied based on the assignment of building facility type (Repair, Professional Business, or Public & Semi-Public). The damages were then calculated based on the flooding depths, depth-damage curves, and infrastructure/content value estimates. Inundation depths and assessed building replacement and content values are documented in the attached calculation Excel sheet, Appendix A.

Damage Avoidance - Railway Infrastructure

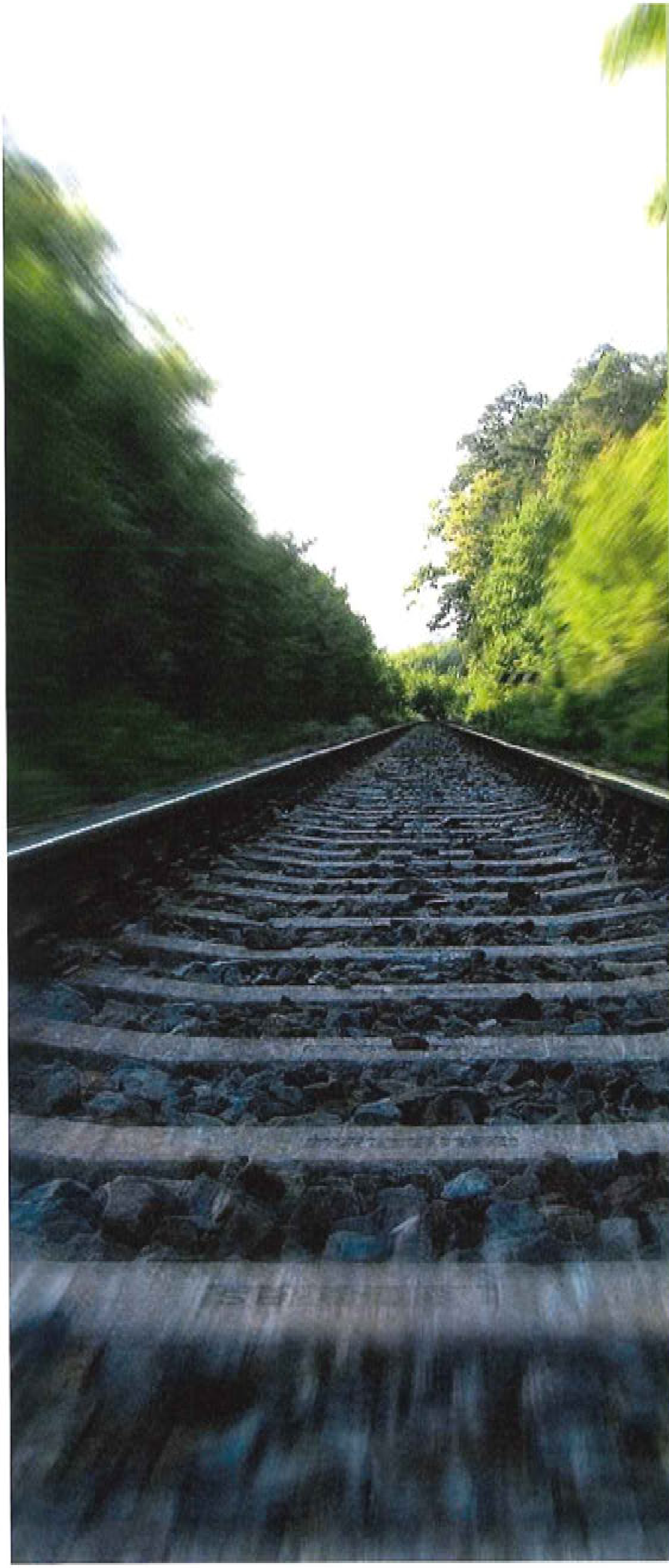
Damage avoidance benefits for the railway infrastructure were calculated in a similar way by estimating the inundation depth of individual track segments (half-mile lengths) at event magnitudes including the 2050 SLR, 100- and 500-year event. Railway elevations were estimated using the average DEM elevation at the midpoint of the half-mile segment. The assumption is that the elevations would be similar to the remaining track segments. Stillwater water surface elevations were obtained from the effective FEMA Flood Insurance Survey (FIS) for the City of Wilmington, Delaware. The FEMA FIS is a compilation of flood risk data for a specific area. The estimated sea level rise of 2.0 feet in 2050 was applied to all elevations to account for rising sea level projections. Typical infrastructure total replacement costs were applied assuming a 1-mile segment of ballasted track with wooden ties

Figure 5. Track Section at the Wilmington Shops

($3,200,000). The total replacement cost includes factors for at grade crossings, sidings, signals, structures (steel &concrete) and the track structure and was adjusted based on a depth-damage curve from an Austrian Northern Railway study, *Estimating Flood Damage to Railway Infrastructure - The Case Study of the March River Flood in 2006 at the Austrian Northern Railway* (Kellerman, Schobel, Kundela, & Thieken, 2015). The depth-damage curve within this study was applied using inundation depths and the total replacement cost for a typical segment of track. The damages were multiplied based on the number of tracks observed at each segment.

Avoidance of Loss of Service

Revenue loss estimates were based on direct revenue lost from ticket sales from the Hurricane Sandy event. Direct revenue losses were estimated as $2.8 million per day of disruptions. It was assumed that loss of service would occur if the CNOC, Wilmington Station, substations, or track segments are damaged. Review of published articles from past railway damages indicate repair time to range from days to weeks. When bridges are undermined, repair times can take months. This study assumed loss of time estimates based on the USACE depth-damage curves and engineering judgment based on hypothetical damages. A loss of time curve of 0 to 6 days was applied for the building infrastructure and 0 to 14 days for the railway infrastructure including bridges. The damages were then calculated based on the flooding depths, depth-damage-loss of service curves, and daily loss of revenue estimates.



Asset Vulnerability and Adaptation Plans

3.4 Asset Vulnerability and Adaptation Plans

3.4.1 Wilmington Station

Vulnerability Summary

Site Features

The tracks at Wilmington Station are elevated and positioned on the roof of the building. With proper drainage, flooding does not threaten the tracks. However, the facility has a crawl space beneath the first floor with electrical, mechanical, and plumbing equipment as displayed in Figure 6, which is susceptible to inundation. The facility is located within 400 feet of the Christina River, and the associated storm surge which could arise from this waterway threatens the building.

Figure 6. Crawl Space beneath 1st Floor

Criticality

Wilmington Station serves the Northeast corridor as one of the top 15 busiest Amtrak stations (b) (5) (b) (5) [redacted] The station currently has 16 Amtrak employees at the station.

Historical Flooding Summary

There have been repetitive problems with track drain clog and back-up, causing ceiling leaks and support bean rusting, Figure 7. Personnel interviewed during a recent site visit were not aware of any flooding issues related to Hurricane Sandy at this location.

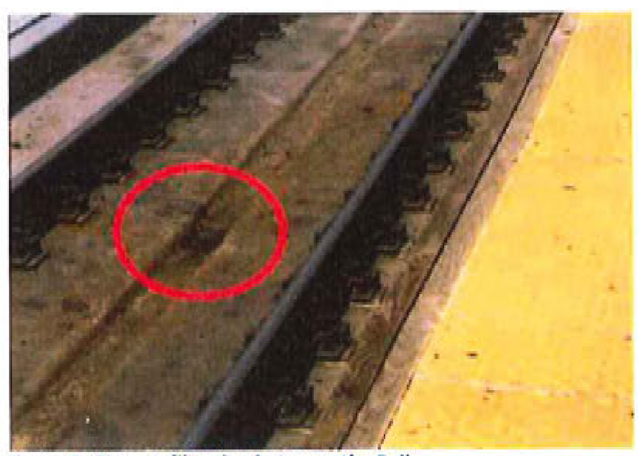


Figure 7. Water Infiltration between the Rails

Hazard Characteristics

As the Christina River rises and expands during flood events, the Wilmington Station crawl space will be most at risk. The 2050 SLR, 100-year may cause 4 feet of inundation at the southwest corner of the building. This storm has the potential to flood the entire crawl space and damage the mechanical, electrical, and plumbing systems located beneath the first floor. A more severe storm with the additional 1 foot of freeboard could reach the first-floor elevation of the Station and threaten assets inside. The 2050 SLR, 500-year may expose the building to 7 feet of water. This level of inundation would cause extensive damage of the entire first floor of the station.

Adaptation Strategy

Description of Measure

A deployable flood wall system would greatly assist the station facility. It is estimated that a 1,100 linear foot wall would be necessary and could be erected in some cases by a six-person crew in 27-36 hours. One recommended wall uses a post and beam system to create a flood wall which can be adapted to the particular requirements of a site. Aluminum beams are positioned between vertical steel posts at set intervals, and the post has a base plate which is bolted into the ground as shown in Figure 8. For taller walls the flood wall uses kickers on the outside of the wall which form a triangular brace behind the posts. Depending on the manufacturer and the height of the wall permanent anchorage may need to be in place prior to installation. This anchorage would remain in place permanently and often includes metals plates or runs that are level with the ground. Figure 9 depicts a rendering of the anchorage system at the west yard substation. This system would surround the entire at-grade portion of the Wilmington Station building, and the posts would be located at the sidewalk curbs adjacent to the roadways.

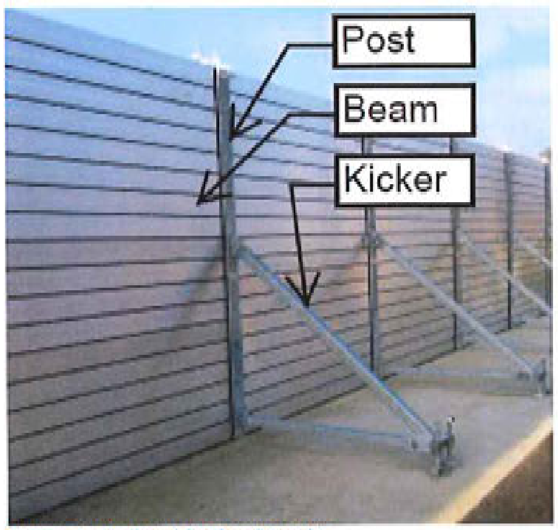


Figure 8. Deployable Flood Barrier


Figure 9. Rendering of possible deployable wall permanent footer

Selection Rationale

Given the urban setting of the Wilmington Station, it would be difficult to construct a permanent or semi-permanent flood wall capable of resisting a 2050 SLR, 100-year or 500-year event, while also providing visibility and accessibility necessary for an active train station. A permanent or semi-permanent wall would reduce the sidewalk width, require extensive excavation for the wall footings while requiring significant replacement of existing sidewalks and roadways, and limit the overall passenger drop off area around the station. Grouped together these factors would reduce the functionality of the facility.

The deployable barrier system has the capability of protecting a facility against deep flood waters while not permanently limiting visibility or restricting access. A 2050 SLR, 500-year could produce 9 feet of inundation at the flood wall. Flood waters of this height would require kickers and force the flood wall to be positioned approximately 4 to 6 feet back from the exterior walls of the facility. The total wall height is recommended as a maximum of 9.5 feet above grade to reduce wave splash and overtopping. This wall design would also protect against the 2050 SLR, 100-year. In areas were the ground elevation is higher the total height of the wall can be reduced, resulting in cost saving while maintaining protection against the 2050 SLR, 500-year.

Pros and Cons Summary

Like all systems, deployable flood walls have varying degrees of strengths and weaknesses. On the positive side, the post and beam system allows continuous access to the site up to an hour or two prior to the arrival of the storm. Moreover, the beams can be removed from the wall system to provide access to the site at any segment along the wall. The foundation width is typically smaller than permanent measures such as concrete flood walls. The steel and aluminum materials comprising the system are flood and weather resistant which should help sustain the product for a long time. The operation and erection of the wall is not difficult or complex and can be performed with only minor instruction. One of the greatest strengths of the post and beam system is the ability of the flood wall to eliminate the need for any waterproofing or modification of the existing structure. The barrier system can prevent the expensive costs of strengthening the exterior walls of a building, since many of the existing exterior walls were not likely designed for flood water pressures.

Figure 10. Installation of a Deployable Wall

Some other important considerations include the durability, deployment, and storage of wall components. The durability of the post and beam system is better than other deployable systems, but is less durable than most permanent flood walls. Deployment of the post and beam system takes a moderate amount of time, but it can be accelerated with more crews and equipment. One downside of the post and beam system is that deployment requires the use of a forklift. All the wall components must be carried by forklift from the storage container to the erection point. This makes the entire system dependent on sufficient nearby storage. The storage needs of each system are noted in the summary tables, and can include the equivalent of 3 to 4 parking spaces. Storing the flood wall components off-site would delay the process of erecting the flood wall. The size of storage material required per foot of wall is one of the highest storage demands of any deployable system. Some tall barrier systems are also more expensive than permanent walls, and it is important to weigh the cost and benefits of each option.

Figure 11. Storage option for a deployable system

Other Temporary Measures

Flood walls serves as the primary protection for facilities and assets, but secondary measures are also important. A minimum of two pumps and possibly a generator is recommended to remove water which may seep under the wall, or splash over the wall after wave action. In general, they offer redundant protection to the facility.

Figure 12. Emergency flood water pump

Water-tight shields over windows and waterproof wall coverings were considered but were determine to be insufficient. Some temporary measures which were considered insufficient flood protection methods include. Window coverings (Figure 13) may be susceptible to debris penetrating the windows and allowing water to enter the building. In addition, a window protection system must be capable of being water tight which often requires on- going maintenance. Even when properly installed, window coverings require the existing window frames to have enough strength to resist the flood loads. In some cases, the existing window frames may need to be strengthened to resist the flood loads.

Figure 13. Emergency Window Covering (Flood Panel, n.d.)

Waterproofing exterior walls with impermeable membranes and sealants can seal walls to reduce or prevent the penetration of floodwater through the walls of a building. This can give the impression of being water-tight; however, the Wilmington Station has numerous penetrations which make this option difficult to implement. The lowest level of the building has vents for access and ventilation of the mechanical equipment, and these areas should not be permanently covered unless a mechanical contractor is able to provide a secondary method of ventilation. Even if waterproofing is performed, the walls should be inspected and analyzed to determine if it can support the horizontal flood loads. Many existing walls do not have adequate strength to resist flood loads, and reinforcing the wall system may be necessary. The combination of strengthening and waterproofing walls is often a very expensive solution.

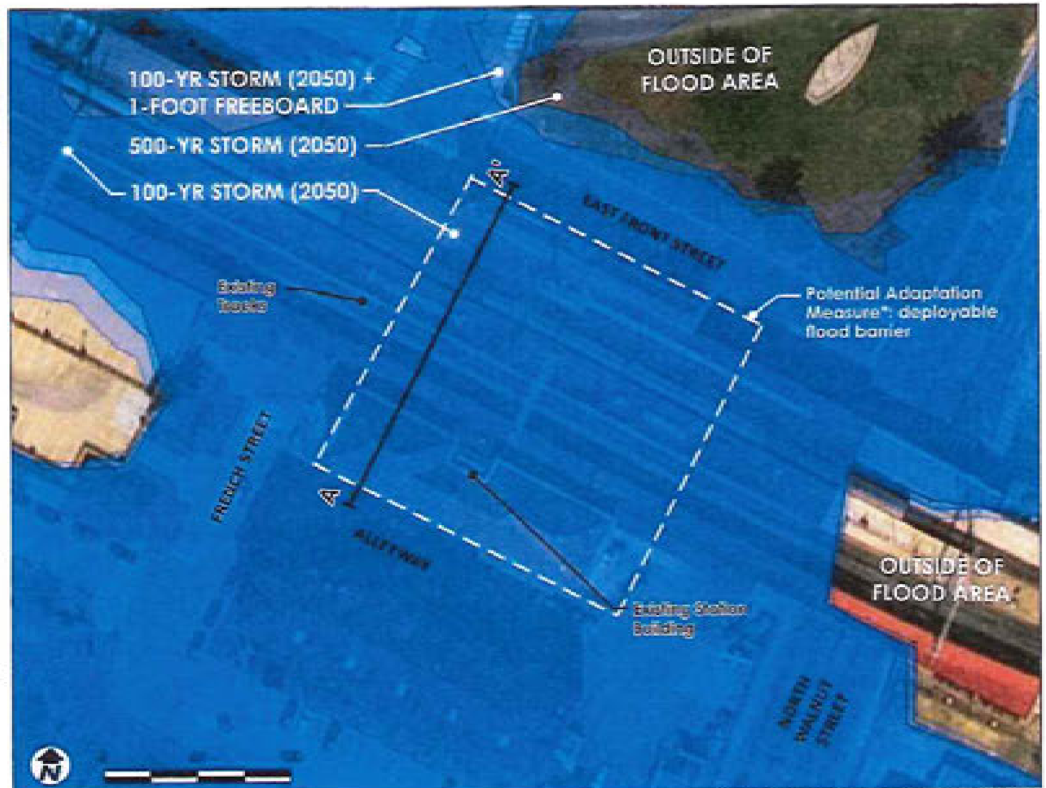
Wilmington Station

Vulnerability Summary

Site Features	• electrical, mechanical, plumbing equipment
Importance	(b) (5) • 16 employees
Flood History	• roof drains between the rails leak into building • no flooding reported from Hurricane Sandy
Potential 2050 Flood Hazard	• 100-year storm: 4 feet at southwest corner of building, flooding equipment under 1st floor • + 1-foot freeboard: • 500-year storm: 7 feet would threaten entire first floor

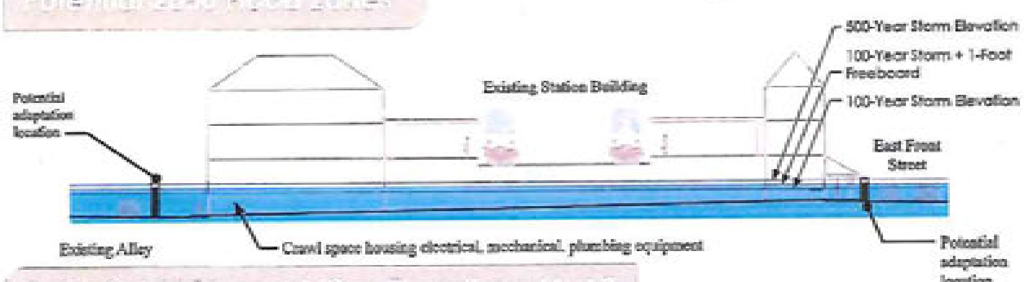
AMTRAK Stantec

Study Area Locus



*See Wilmington Shops and Maintenance Yard Adaptation Measures sheet for more information.

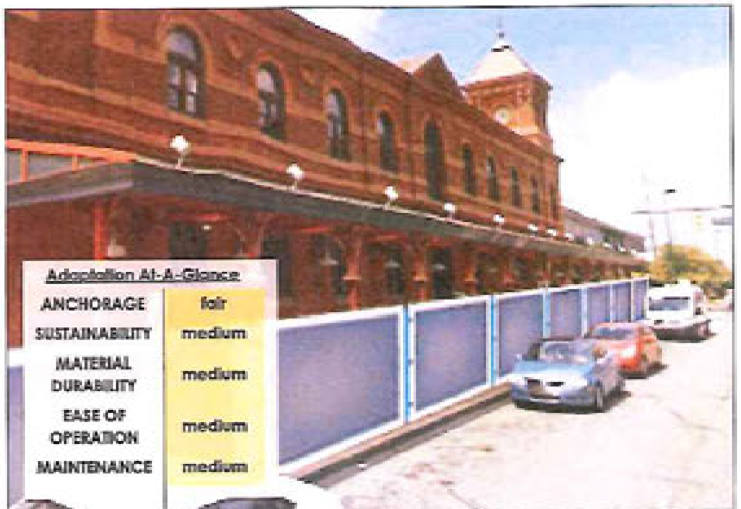
Potential 2050 Flood Zones



Potential 2050 Inundation Elevations (A-A)

Wilmington Station

Potential Adaptation Measures



Adaptation At-A-Glance	
ANCHORAGE	fair
SUSTAINABILITY	medium
MATERIAL DURABILITY	medium
EASE OF OPERATION	medium
MAINTENANCE	medium

Type	DEPLOYABLE FLOOD BARRIER		
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (6.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (9 feet)
Adaptation Height	7 feet	8 feet	9.5 feet
Foundation Width	4.5 feet	5 feet	6 feet
Adaptation Length		1,000 linear feet	
Deployment Time	27 hours	30 hours	36 hours
Storage Requirements*	2.9 parking spaces	3.1 parking spaces	3.5 parking spaces
Cost	$1,800/linear foot	$2,000/linear foot	$2,400/linear foot
(b) (5)		(b) (5)	

* cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high

3.4.2 Wilmington Shops and Maintenance Yard

Vulnerability Summary

Site Features

Situated along a tributary of Brandywine Creek on the eastern side and abutting Shellpot Creek in the north, the Wilmington Shops and Maintenance Yard is susceptible to flooding from sea level rise and severe storm events. The site is approximately 96 acres, and numerous Amtrak assets at this facility are at risk from flooding including: buildings, railcars, tracks, access roads, and ancillary equipment.

Figure 14. Wilmington Shops Aerial Map

Criticality

As one of the few shops in America capable of major repairs for electric locomotives, the Wilmington Shops and Maintenance Yard serves as a critical Amtrak asset along the Northeast Corridor. This facility and its roughly 550 employees offer year-round basic maintenance to locomotives. On any particular day there may be 17 locomotives located within the Wilmington shop property. Each year approximately 300 locomotives are serviced and released. However, the facility's ability to continue operation is threatened by flooding.

Figure 15. Electric Locomotive above Pit with Standing Water

Historical Flooding Summary

In the past, flood waters have inundated portions of the site. Rail tracks at the southern end of the facility have been flooded as water from the tributary on the eastern side of the site extended over 200 feet westward from the normal waterway boundaries. Severe storms have been known to also flood parts of locomotive shop #3. Nearby outdoor pits under the locomotives, similar to what is shown in Figure 15, have collected water. After a storm, water must be pumped out of these pits and sent offsite to a treatment plant. It is understood that there are municipal non-functioning floodgates on the Brandywine River in this area.

Hazard Characteristics

Flooding concerns for this facility are present starting with the 2050 SLR, 100-year. This storm event has the potential of covering nearly the entire site with 1 foot of water requiring extensive flood protection measures to effectively protect assets on the site. Some portions of the site may experience as much as 6 feet of inundation. These high water levels are expected to block site access, compromise buildings, and prevent normal operations. A more extreme event with an additional 1 foot of freeboard would cover much of the site in 2 feet of water and increase the time and costs of restoring the facility to normal operations. Moreover, the associated 2050 SLR, 500-year may produce 3 feet of consistent flooding at the facility, potentially threatening most of the facility buildings with 5 feet of inundation.

Adaptation Strategy – Deployable

Description of Measure

Protecting the numerous buildings and assets on the 96-acre maintenance facility site can be accomplished through the deployment of a flood wall system. Due to the size of the facility, it is estimated to be 7,500 feet in length, such a system could take a six-person crew 240 to 300 hours to erect. One recommended barrier uses a post and beam system to create a flood protection wall which can be adapted to the particular requirements of a site. Aluminum beams are positioned between vertical steel posts at set intervals, and the post has a base plate which is bolted into the ground as shown in Figure 16. For taller walls the flood wall uses kickers located on the outside of the wall which form a triangular brace behind the posts. This system would surround all the critical buildings at site. At locations where the wall will need to span over tracks, concrete, and/or other materials will need to infill the gap between the lowest beam and the ground. Posts could be located up to 10 feet apart.

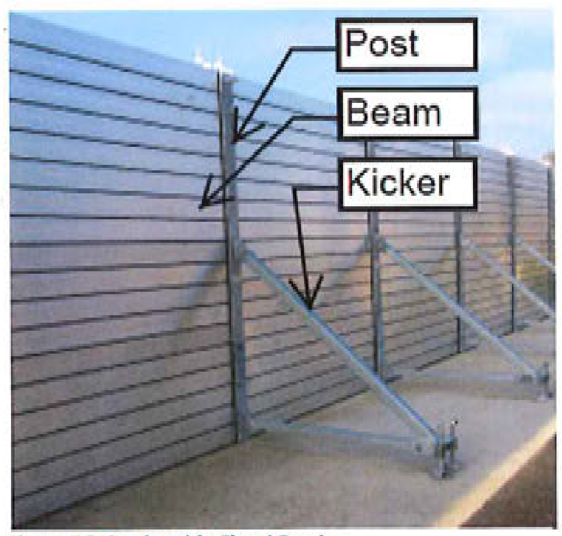
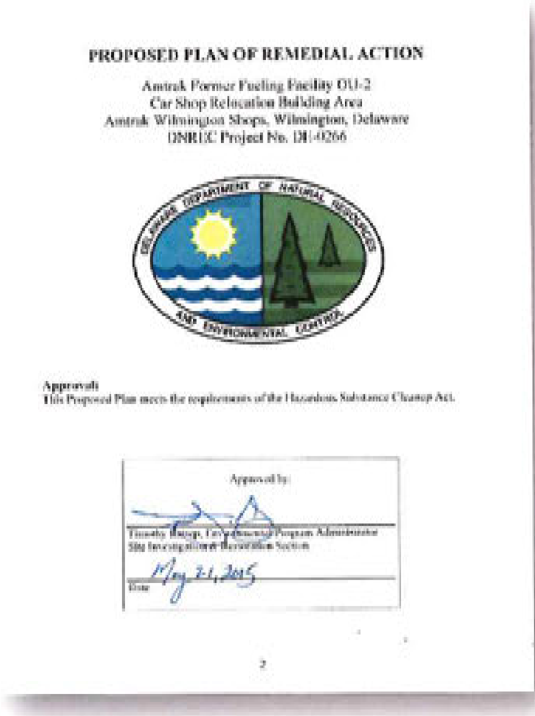


Figure 16. Deployable Flood Barrier


PROPOSED PLAN OF REMEDIAL ACTION

Amtrak Former Fueling Facility OU-2
Car Shop Relocation Building Area
Amtrak Wilmington Shops, Wilmington, Delaware
DNREC Project No. DE-0266

Approval:
This Proposed Plan meets the requirements of the Hazardous Substance Cleanup Act.

Approved by:

Timothy Ratsep, Environmental Program Administrator
Site Investigation & Restoration Section

May 21, 2015
Date

2

The deployable wall can surround the entire facility or be placed strategically to protect the most critical assets. Restricting the protected area to the critical areas will limit the overall cost and reduce the deployment time. Currently, the wall is being shown at its full extent surrounding all assets but excluding the remediation site located at the southwest corner of the property. Currently a remediation feasibility and investigation is occurring at the Wilmington Shops (DE- 0266/DE- 0170). All proposed adaptation measures will need to be coordinated with the final remedy. It is important that any proposed adaptation measures do not impede the implementation of the final remediation plans.

Selection Rationale

The deployable barrier system has the capability of protecting the facility against deep flood waters. Considering a flood depth of 10 feet for the 2050 SLR, 500-year, a barrier system capable of resisting these flood loads needs to be strong and robust. Kickers help support the wall and aluminum and steel materials help limit the size and weight of wall components, but also give the structure the strength necessary to resist high flood loads. The total wall height is recommended as a maximum 10.5 above grade to reduce wave splash and overtopping of the 500-year flood. This wall design would also protect against the 2050 SLR, 100-year. It is important to understand that the total height of the wall needed will vary based on the site topography. In areas were the ground is elevated the wall height will be reduced.

A flood barrier wall is helpful for stopping most water from penetrating the facility, but it does require some other temporary measures. A minimum of six water pumps and possibly a generator would be required to alleviate the entire site of water that may seep under the wall, splash over the wall after wave action, or be deposited within the walls as precipitation. Given the proximity to some local waterways, backflow preventers should be installed in any drainage pipes which serve the area protected by the flood walls.

This flood wall is recommended for this site if less excavation of the foundations is desired. The deployable barrier system often uses smaller footing compared to permanent walls and offers the option of increased visibility, since a permanent wall would not always block viewing angles.

A combination of permanent walls and deployable walls may be chosen as an integrated strategy.

Pros and Cons Summary

Like all systems, the deployable flood barrier has both strengths and weaknesses. On the positive side, the system allows for tall barrier walls which provide continuous access to the site until an hour or two before a storm. Moreover, the beams can be removed from the wall system to provide access to the site before or after the storm or in the case of an emergency at any segment along the wall. The foundation width is considered small when compared to some permanent measures such as concrete flood walls. The durability of the post and beam system is better than many deployable systems, but would still fall short of most permanent measures. However, the materials used are flood and weather resistant which should help sustain the product for a long time. The operation and erection of the wall is relatively simple and can be performed with only minor training. Although some precautionary measures are needed such as backflow preventers and water pumps, one of the greatest strengths of the system is the ability of the barrier wall to eliminate any waterproofing or modification of the existing structures. Since many existing structural walls could collapse from high flood waters, the barrier system prevents the expensive costs of strengthening the exterior walls of buildings which could become a very expensive and complex endeavor given the numerous buildings at the site.

Deployment of the system takes a moderate amount of time, in some cases, but it can be accelerated with more crews and equipment. Unfortunately, each crew requires the use of a forklift. All the wall components must be carried with a forklift from the storage container to the erection point. This makes the entire system dependent on sufficient storage capability relatively close to the barrier wall location. The farther wall components are from the actual flood wall location the more time will be lost in transporting materials. The size of storage material required per foot of wall is one of the highest storage demands of any deployable system. Some tall barrier systems are also more expensive than permanent walls, and it is important to weigh the cost and benefits of each option. As mentioned above, it may not be necessary to surround the entire facility, but rather to isolate critical areas.

Other Temporary Measures

Some temporary measures which were considered insufficient flood protection methods include window coverings and wall coverings. The window coverings on their own will not protect a building from water infiltration, and they may still be susceptible to water breaching the windows if the additional protection is not strong enough to resist the flood loads. Existing windows may be supported at the window framing by structural materials designed to resist wind loads, but which are not strong enough to resist flood loads. When a new flood shield is installed to protect the window, the adjacent wall need to be strong enough to resist the flood loads

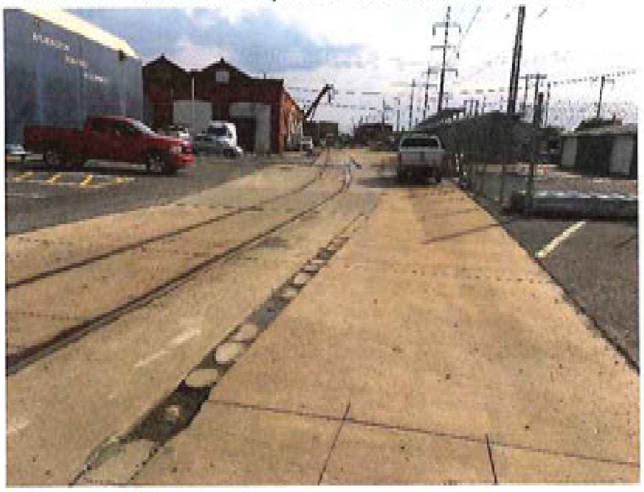


Figure 17. Wilmington Shops

without causing the wall to fail. Even when this is accomplished, water may leak into the building through air vents or porous materials. Wall coverings offer the expectation of being water-tight, but this would be difficult to integrate into the Maintenance Shops. There are over 30 buildings at the site and different types of construction techniques. Therefore, making each building water tight would be a very expensive and lengthy process. Each building wall needs to be inspected and analyzed to determine if it can support the horizontal flood loads. Many existing walls do not have adequate strength to resist flood loads, and reinforcing the wall system would be required. Strengthening and waterproofing walls is often very expensive. This expenditure would direct capital funds away from other assets on site and would not provide a comprehensive strategy to the threat of flooding.

Adaptation Strategy – Semi-Permanent

Description of Measure

The maintenance facility may be best served by using a semi-permanent concrete knee wall (7,500 feet in length) with supporting deployable barrier walls above. A semi-permanent measure has some portions of the system which always remain intact and other components which must be erected at the time of a flood. Figure 18 depicts the system without the deployable aluminum beams inserted between the concrete posts, while Figure 19 offers a view with the beams inserted. This system would not use kickers and it may offer an aesthetically pleasing wall depending on the concrete finish, veneer, and/or coloring. This measure would be expected to surround the facility and protect all the buildings and assets inside. The deployable portion of the wall would be comprised of infill aluminum beams which only need to be installed for severe storm events. Essentially the concrete columns support the aluminum beams and simplify the deployable system.

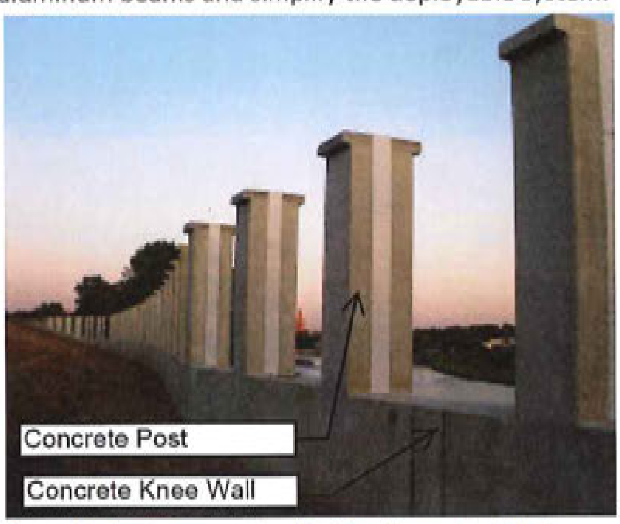


Figure 18. Semi-permanent wall without beams installed (Source: EKO)

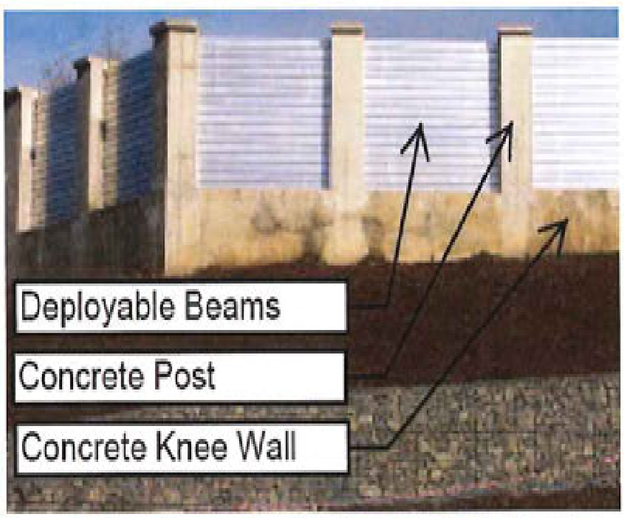


Figure 19. Semi-permanent wall with beams installed (Source: EKO)

Selection Rationale

This system offers resistance up to the 2050 SLR, 500-year and can protect against the associated 10 feet of inundation that could be expected with a severe storm. The semi-permanent system offers the potential of having half of the wall provide a permanent protection measure, with the other half of the wall height being deployed in far less time than a fully deployable wall. The permanent knee wall can be constructed to varying heights and can be built to withstand the 2050 SLR, 100-year +1' which would protect against the most likely storm events; therefore, reducing the likelihood that the deployable beams will need to be installed. A minimum of six water pumps and possibly a generator would be required to alleviate the entire site of water that may splash over the wall after wave action, or be deposited within the walls as precipitation. The semi-permanent wall retains some of the original views instead of a permanent wall which blocks sight views.

Pros and Cons Summary

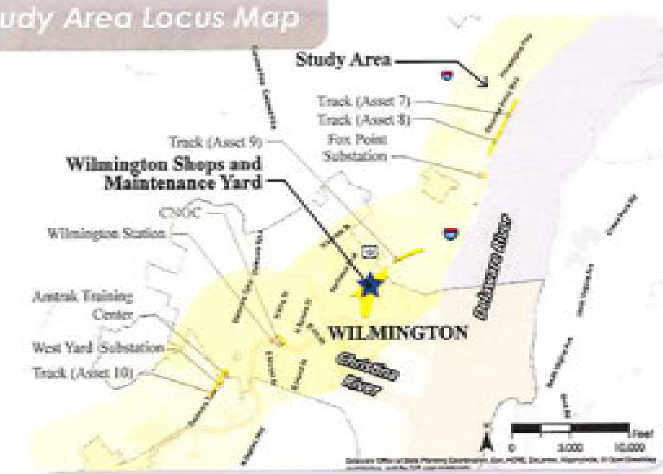
The benefits of a semi-permanent flood barrier include access, deployment time, durability, sustainability, ease of operation, and maintenance. There is no restriction on access to the site if the knee wall locations are well thought out. Any access to the site can be accommodated by stopping the knee wall and providing a full height barrier wall at access points. The deployment time of this system will take far less time than a fully deployable system. Given that approximately half of the wall height is permanent and made of durable concrete there should be little degradation of these materials. The simplified system also makes operation less complex. The system should sustain flood events well and can be easily cleaned with spray washing. After flood waters recede, all deployable components should be washed clean, and all wall components should be inspected for damage. Damaged members should be removed and replaced.

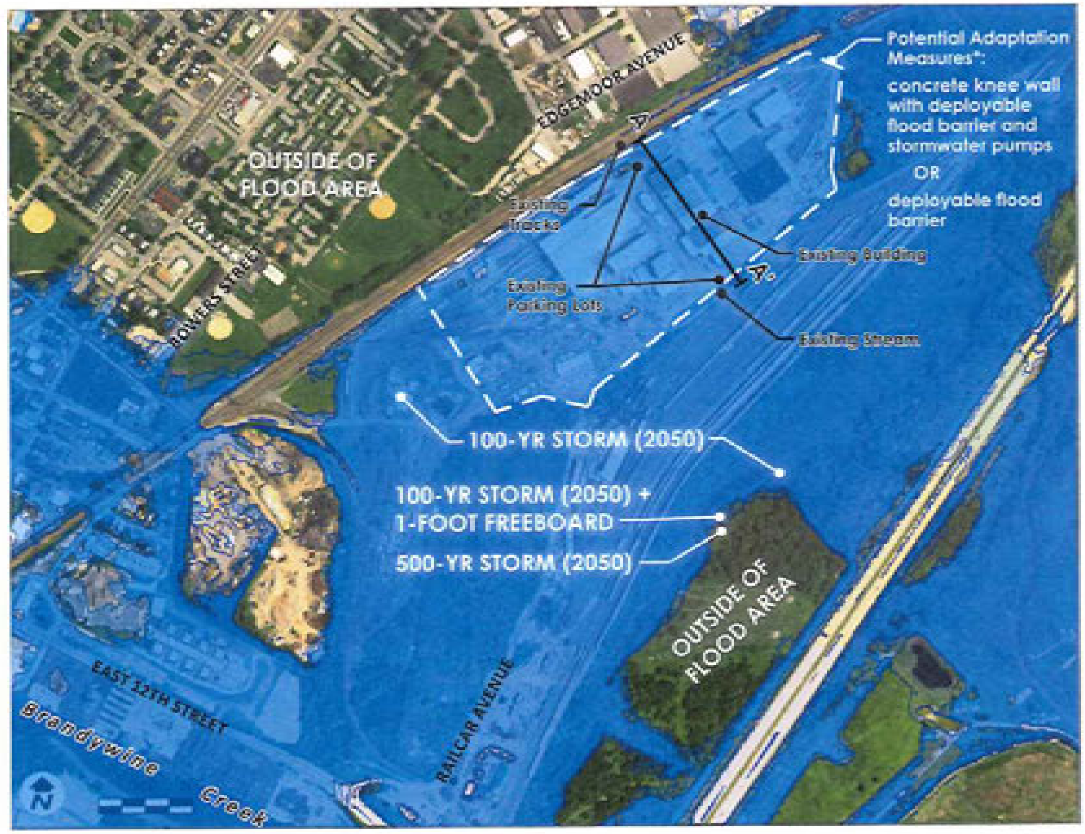
Wilmington Shops and Maintenance Yard

Vulnerability Summary

Site Features	• buildings • railcars • tracks • access roads • ancillary equipment
Importance	• 300 locomotives serviced/repaired each year • 550 year-round employees
Flood History	• rail tracks, locomotive shop #3 • outdoor pits under locomotives
Potential 2050 Flood Hazard	• 100-year storm: 1-foot of flood depth across entire site, with some locations up to 6 feet deep • + 1-foot freeboard: 2 feet of water • 500-year storm: 3-5 feet deep across site

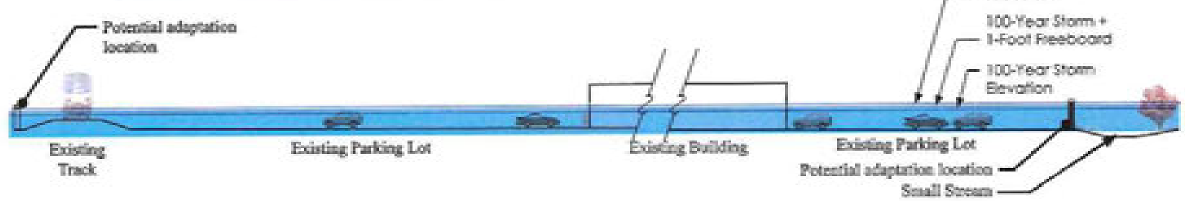
Study Area Locus Map





Potential 2050 Flood Zones

*See Wilmington Shops and Maintenance Yard Adaptation Measures sheet for more information.



Potential 2050 Inundation Elevations (A-A')

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Wilmington Shops and Maintenance Yard

Adaptation Measures

Type	4-FOOT CONCRETE KNEE WALL WITH DEPLOYABLE FLOOD BARRIER			DEPLOYABLE FLOOD BARRIER		
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (8 feet)	100-year Storm + 1-foot Freeboard	500-year Storm (10 feet)	100-year Storm (8 feet)	100-year Storm + 1-foot Freeboard	500-year Storm (10 feet)
Adaptation Height	8.5 feet	9.5 feet	10.5 feet	8.5 feet	9.5 feet	10.5 feet
Foundation Width	8.5 feet	9.5 feet	10.5 feet	5.5 feet	6 feet	6.5 feet
Adaptation Length		7,500 linear feet			7,500 linear feet	
Deployment Time*	40 hours	60 hours	75 hours	240 hours	268 hours	296 hours
Storage Requirements**	-	-	-	24 parking spaces	26 parking spaces	29 parking spaces
Cost	$3,500/linear foot	$4,000/linear foot	$4,300/linear foot	$2,200/linear foot	$2,400/linear foot	$2,600/linear foot
(b) (5)		(b) (5)			0.55	

* based on two crews of 4-6 workers.
** cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high.

3.4.3 Training Center

Vulnerability Summary

Site Features

The first floor of the Training Center building is located at ground level with some exterior equipment positioned close to the ground, such as the electric meter seen in Figure 20. The building is slightly elevated in relation to the surrounding area. However, approaching the building requires driving along High Speed Way which traverses through a low elevation area predisposed to flooding.

Figure 20. Electric Meter at First Floor at Ground Level

Criticality

The Amtrak Training Center is the only Amtrak facility dedicated exclusively to training locomotive engineers in the U.S. and is an essential asset to educate engineers and crews about their jobs. The two-story building contains 25,000 square feet of usable space with some of the following critical components: a full motion multi-million dollar locomotive training simulator, five non-motion network simulators, a mainframe computer lab, and a dispatch system simulator. A group of approximately 40 people comprise the full-time staff at the facility, who support 10 to 100 trainees a month.

Historical Flooding Summary

The building opened in 1999 and, although the facility has no known flooding problems, the road approaching the facility has flooded at times. As displayed in Figure 21, the access road can become inundated and impassable. Flood waters filling the area beneath the Interstate 95 overpass have extended to the facility's parking lot and prevented access to the building. This has placed significant stress on employees who become concerned about being able to leave the facility after arriving for work. As a result of these flooding issues, classes have been postponed and graduation dates delayed.

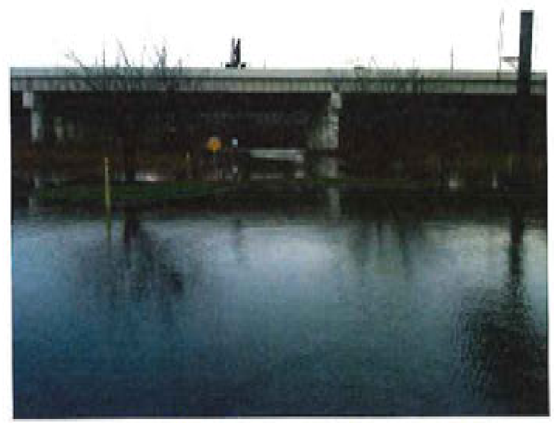

Figure 21. Flood Waters below I-95 Overpass at Access Road Preventing Access to Training Center

Hazard Characteristics

As described in the historical summary, severe storm events may produce flooding along the access road approaching the facility and future storms may extend flooding up to the building. The 2050 SLR, 100-year may cause the facility to experience 1.5 feet of inundation at the northwest corner. An additional one foot of freeboard will completely surround the facility with floodwaters with depths of up to 2.5 feet. The 2050 SLR, 500-year would consistently raise flood waters to 2 feet around the building with a maximum of 4 feet. At this height flood waters would infiltrate the structure and damage most, if not all, of the expensive equipment housed on the first floor.

Adaptation Strategy – Deployable

Description of Measure

The Training Center can be protected with a deployable flood wall surrounding the perimeter of the building. It is estimated that the wall would need to be 750 feet in length. Some deployable flood walls are predesigned for specific wall heights with the caveat that the flood depths are less than 8 feet. Examples of this type of system are pictured in Figure 22. These systems have integrated door access points and can typically be constructed with a three- or four-person crew. This flood barrier can protect against the 7.5 feet of inundation at the Training Center which is created by the 2050 SLR, 500-year. One manufacturer offers these L-shaped barrier walls made of marine laminated plywood, PVC, and canvas. Other bracing and anchorage components are formed of aluminum and steel. The entire system can be installed with no special equipment.

Figure 22. Deployable Flood Barrier

Selection Rationale

The Training Center has a relatively flat area surrounding the building and slightly lower maximum flood inundation values compared to many of the other Amtrak facilities. To protect this building and associated assets from the 2050 SLR, 500-year, a deployable flood barrier system can quickly be installed at lower costs compared to a permanent measure. This system would protect all the assets inside the flood wall using one mitigation technique. Waterproofing the mechanical, electrical, and plumbing systems would not be required, and there would be less threat of water reaching the critical and expensive equipment housed in the Training Center.

Pros and Cons Summary

A deployable flood barrier has the benefit of protecting the Amtrak Training Center and outdoor mechanical and electrical equipment using one simple method. Complex waterproofing and modification of existing building components is not required. Given the lower flood depths at this site, the system also offers cost savings compared with permanent or semi-permanent walls. The simplistic erection of this type of flood wall also saves time by providing a protectant shield against rising flood waters within a half day or less.

All flood wall components should be stored on or very near to the facility. After flood waters recede, all components should be washed clean, and all wall components should be inspected for damage. Damaged members should be removed and replaced. This system would probably have a shorter life-span than a permanent or semi-permanent wall.

Other Temporary Measures

A flood barrier wall is helpful for stopping most water from penetrating the facility, but it does require some other temporary measures. A minimum of two pumps and possibly a generator would be expected to alleviate the site of water which may seep under the flood wall, splash over the flood wall after wave action, or accumulate from precipitation.

Some temporary measures which were considered insufficient flood protection methods include waterproofing the walls and windows of the Training Center. Past experience with these measures has shown that water often infiltrates the building. Once water enters the building, some damage will occur. As the flood waters outside the building rise walls may fail from the increasing water pressure if they do not have adequate strength. The windows would almost certainly require separate protection as well. Therefore, wet floodproofing or dry floodproofing the exterior of the building becomes overly complex and an unnecessarily challenging method of protecting a building and the assets inside. Moreover, the mechanical and electrical equipment located outside of the building would need separate adaptation measures for their protection. Relocating the critical equipment to the second floor could be considered, but would require a detailed structural evaluation of the building to assure that the second floor can accommodate the weight.

Adaptation Strategy – Elevating High Speed Way

High Speed Way leading to the Amtrak Training Center experiences frequent nuisance flooding. In 2050 SLR, the 500-year will result in 10 feet of flooding above the road, and the more frequent 100-year will result in 8 feet of inundation. Elevating the roadway will reduce the flooding impacts allowing cars to enter and exit the site more readily. Unfortunately, it is not possible to adapt this roadway to protect it against the 2050 SLR, 500-year or 100-year without having to substantially modify the road and the interstate overpass above. Substantial environmental impacts to the adjacent wetlands would occur and modifications to the concrete columns supporting the interstate overpass would be required for the higher level of protection.

Figure 23. Picture of High Speed Way

Therefore, the proposed solution is to elevate the road above the nuisance flooding, approximately 2.0 feet. This effort should be coordinated with the owner of Delmarva Lane, which is the road High Speed

Way intersects because this road also experiences nuisances flooding and if not addressed can create a restriction.

Two options were considered, elevating both lanes of the roadway and elevating one lane while leaving the other at the current elevation. The first option is to reconstruct the entire roadway from Delmarva lane to just past the parking lot entrance to the elevation that prevents the roadway from nuisance flooding. This option will maintain the two-way road even during emergency situations, but will limit the overall clearance under the bridge. The clearance is needed under this bridge to maintain the current usage by trucks. In elevating the entire roadway, the roadway will need to be widened which will result in a larger impact to the adjacent wetland habitat then only elevating one lane.

In the second option, one lane would remain at its current height while the other lane would be raised above the nuisance flooding elevation creating an emergency route so that vehicles can exit from the Amtrak Training Center when the road is flooded. This option maintains the existing clearance for one lane and allows for access in and out when the road is flooded. This option could provide some traffic directional confusion. As this is a minor roadway that is only used for the training center it is thought that the traffic flow pattern can be explained using information signs. This option has a smaller environment footprint considering there is a smaller area that is being reconstructed.

Both options would require the installation of a culvert under the elevated roadway portion to allow water to pass under the roadway. The environmental footprint is a major consideration since both options involve impacting adjacent wetland habitat. During construction, sediment runoff and alterations of the soil properties can also impact natural resources. The extent of construction impacts on the wetland would need to be further quantified as well as the use of wetland enhancement or green infrastructure on site to treat the site runoff.

Training Facility

Vulnerability Summary

Site Features	• first floor and exterior equipment at or near ground level • learning center with specialized technological tools
Importance	• dedicated facility for engineer and crew education • training simulators; mainframe computer lab • 39 year-round staff; 10-100 trainees/mo.
Flood History	• High Speed Way (the only access to the facility) and facility's parking lot flood during severe storm events
Potential 2050 Flood Hazard	• 100-year storm: 1.5 feet at NW corner of building • + 1-foot freeboard: 2.5 feet • 500-year storm: 2-4 feet, infiltrating the structure

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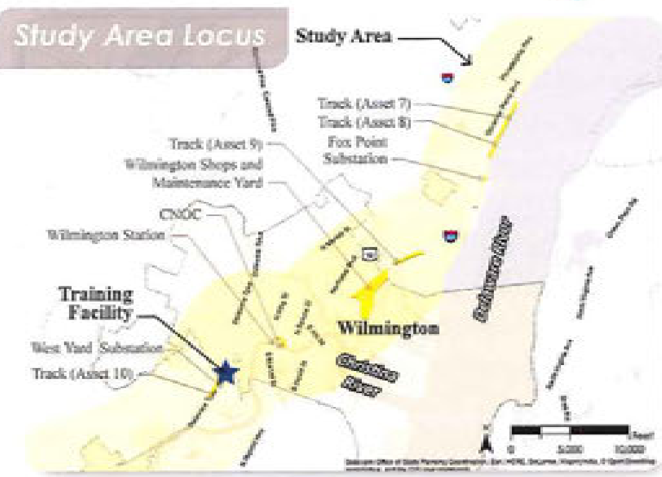
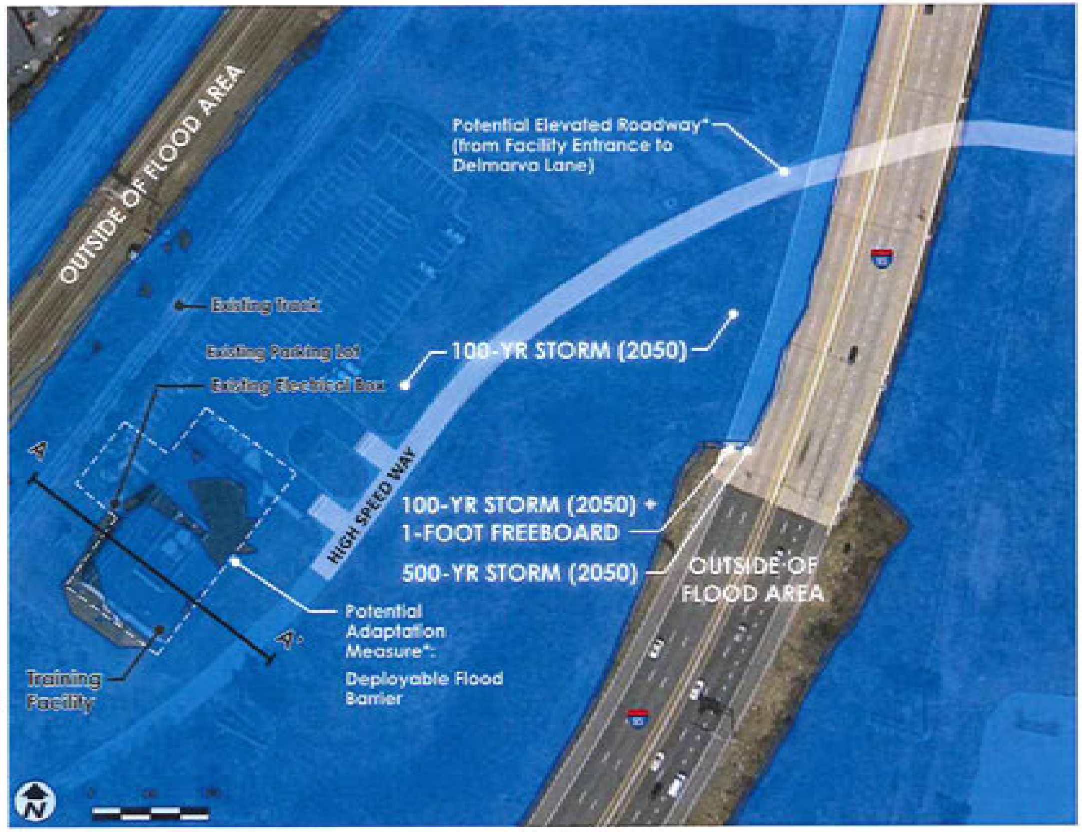
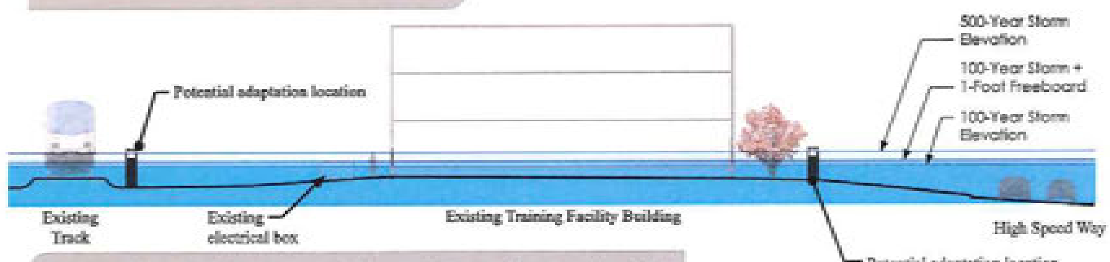
Study Area Locus





Potential 2050 Flood Zones

*See Training Facility Potential Adaptation Measures sheet for more information.



Potential 2050 Inundation Elevations (A-A')

Training Facility

Potential Adaptation Measures

AMTRAK

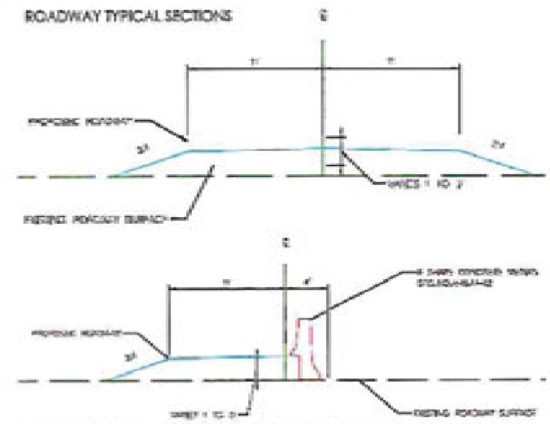
Stantec

Adaptation At-A-Glance

ANCHORAGE	fair
SUSTAINABILITY	medium
MATERIAL DURABILITY	medium
EASE OF OPERATION	medium
MAINTENANCE	medium

Adaptation At-A-Glance

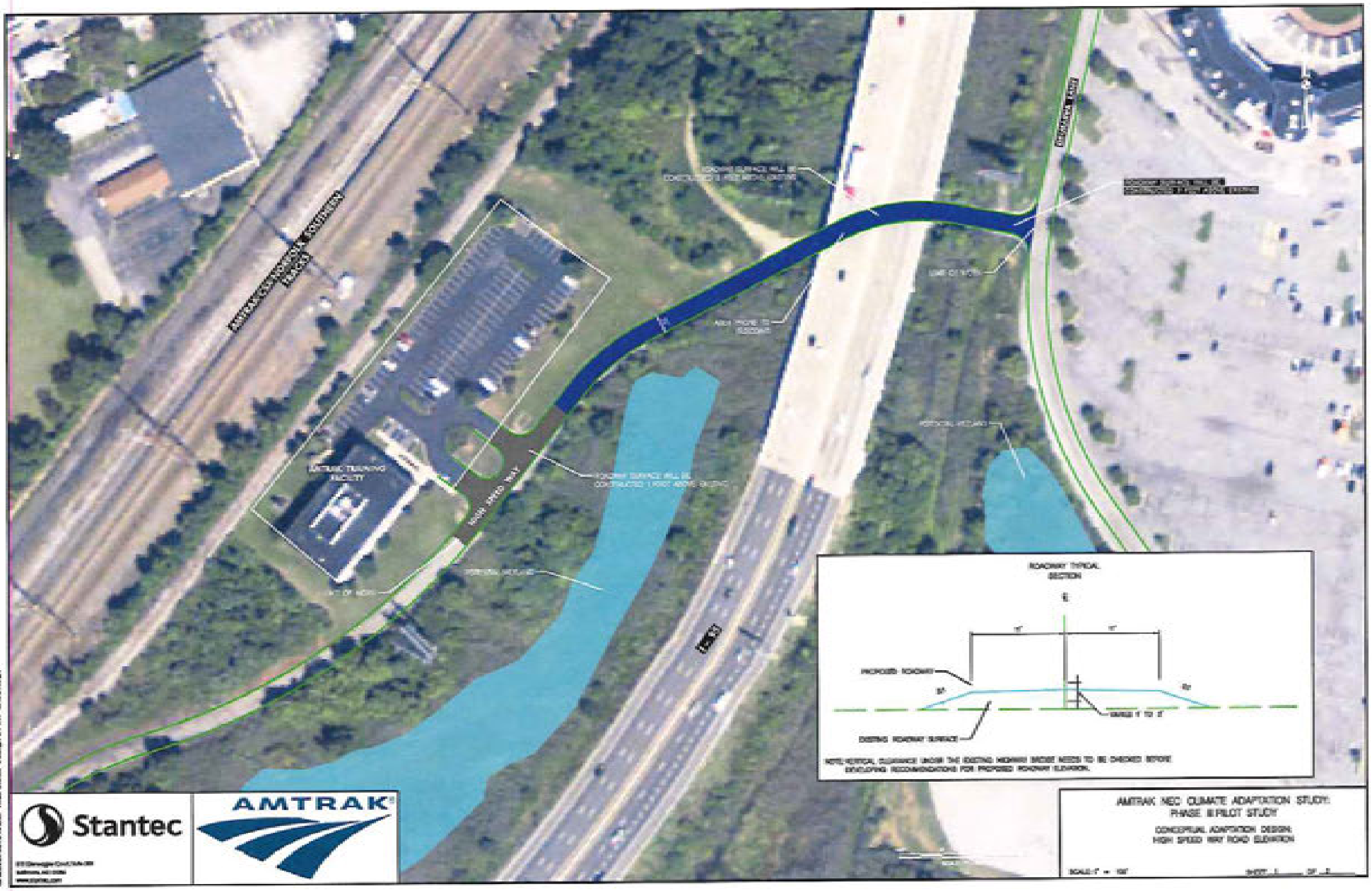
ANCHORAGE	n/a
SUSTAINABILITY	high
MATERIAL DURABILITY	high
EASE OF OPERATION	high
MAINTENANCE	low

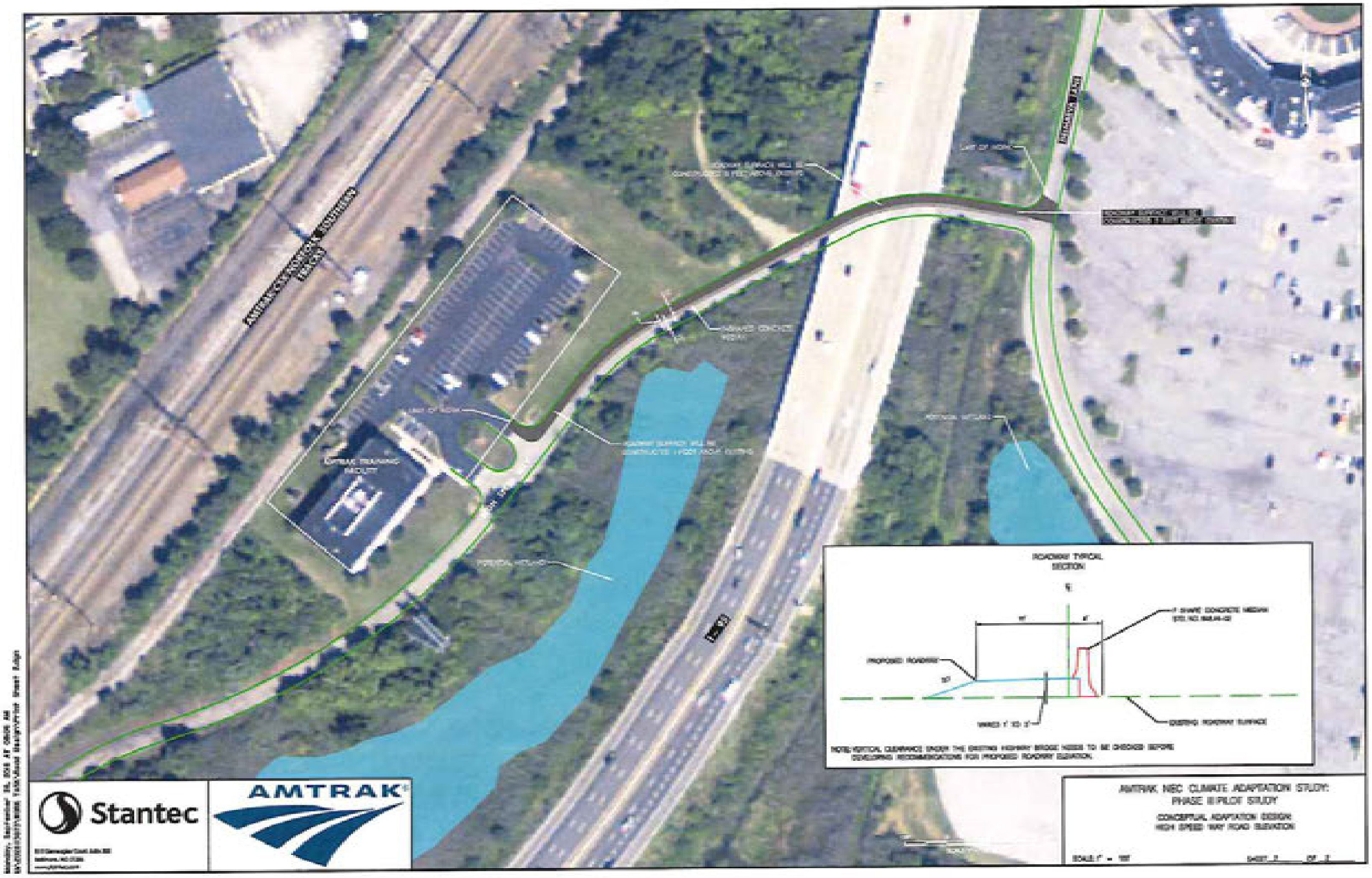


Note: Vertical clearance under the existing highway bridge needs to be checked before developing recommendations for proposed roadway elevation

Type	DEPLOYABLE FLOOD BARRIER			SOLID CONCRETE RETAINING WALL & ELEVATED ROADWAY
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (4.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (7.5 feet)	100-year Storm + 1-Foot Freeboard
Adaptation Height	5 feet	6 feet	8 feet	6.5 feet
Foundation Width	4 feet	6 feet	7 feet	6.5 feet
Adaptation Length		750 linear feet		670 linear feet
Deployment Time	3 hours	4 hours	4 hours	n/a (permanent installation)
Storage Requirements*	0.6 parking space	1 parking space	1.2 parking spaces	n/a (permanent installation)
Cost	$405/linear foot	$575/linear foot	$750/linear foot	
(b) (5)		(b) (5)		

* cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high


AMTRAK TRAINING FACILITY
HIGH SPEED WAY
ROADWAY TYPICAL SECTION
PROPOSED ROADWAY
EXISTING ROADWAY SURFACE
NOTE: VERTICAL CLEARANCE UNDER THE EXISTING HIGHWAY BRIDGE NEEDS TO BE CHECKED BEFORE DEVELOPING RECOMMENDATIONS FOR PROPOSED ROADWAY ELEVATION.
Stantec
AMTRAK
AMTRAK NEC CLIMATE ADAPTATION STUDY: PHASE II PILOT STUDY
CONCEPTUAL ADAPTATION DESIGN: HIGH SPEED WAY ROAD ELEVATION


ROADWAY TYPICAL SECTION
PROPOSED ROADWAY
EXISTING ROADWAY SURFACE
Stantec
AMTRAK
AMTRAK NEC CLIMATE ADAPTATION STUDY:
PHASE II PILOT STUDY
CONCEPTUAL ADAPTATION DESIGN
HIGH SPEED WAY ROAD ELEVATION

3.4.4 Consolidated National Operations Center

Vulnerability Summary

Site Features

The Consolidated National Operations Center (CNOC) is located along the Christina River in a 50,000 square foot facility that controls national rail operations. CNOC serves as one of Amtrak's most important facilities as it monitors rail traffic. The building houses the critical components of the Centralized Electrification and Traffic Control (CETC) system and critical servers on the first floor which assist the Boston CETC. Both CNOC and CETC are crucial to the dispatching and tracking of Amtrak trains along the Northeast Corridor. The building was constructed in 1998 with an elevated first floor which is positioned approximately 4 feet above the surrounding grade to prevent flood waters from damaging components on the first floor. The building has flood vents located below the first floor as shown in Figure 24. Given the proximity of the Christina River, the facility is susceptible to flooding from sea level rise and severe storm events.

Figure 24. Flood vents located below the first floor.

Criticality

Amtrak' s CNOC is a high-tech, 50,000 square foot facility controlling national operations and contains the CETC center. (b) (5) [redacted]
(b) (5)
(b) (5)

Historical Flooding Summary

Historically, storm surge and precipitation have combined to produce flooding at the facility. Flooding in the facility parking lot has occurred several times. Afterwards, the water has been pumped out to restore access to the facility. During Hurricane Sandy, CNOC came within inches of getting flooded out. There is no information regarding the performance of the flood vents during Hurricane Sandy.

Figure 25. Side Entrance to Facility Adjacent to Christina River

Hazard Characteristics

A 2050 SLR, 100-year may produce flooding throughout the site. The parking lot area may get 5 feet of inundation which would prevent any access to the facility during the storm event. The 2050 SLR, 100-year +1' causes flood waters to exceed the current 1st floor elevation. If the building is not properly protected, the flood waters may seep into the building and damage significant amounts of expensive equipment. Lastly, the 2050 SLR, 500-year may elevate water levels up to 6 feet high along the exterior walls of the building.

Adaptation Strategy – Deployable

Description of Measure

An approximately 1,000-foot deployable flood barrier can be constructed along the perimeter of the CNOC facility and stretched across the parking lot area to fully encompass the facility. Such a system could be erected in some cases by a six-person crew. One recommended barrier uses a post and beam system to create a flood protection wall which has successfully been utilized at sites adjacent to rivers. Aluminum beams are positioned between vertical steel posts at set intervals, and the post has a base plate which is bolted into the ground as shown in Figure 26. For taller walls the flood wall uses kickers which form a triangular brace behind the posts. Post could be located up to 10 feet apart.

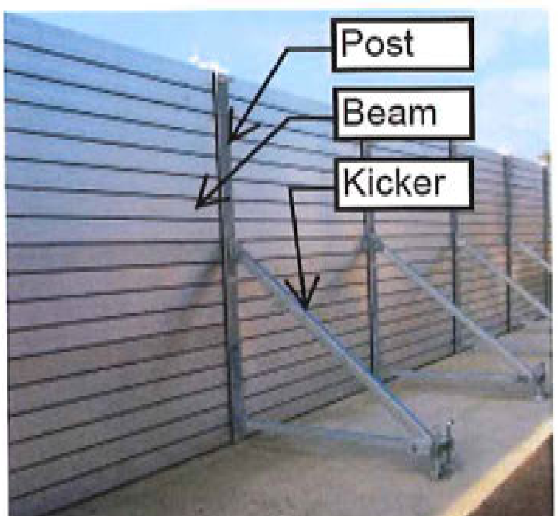


Figure 26. Deployable Flood Barrier

Selection Rationale

The deployable barrier system has the capability of protecting the facility against deep flood waters. Considering a flood depth of 9 feet for the 2050 SLR, 500-year, a barrier system capable of resisting these flood loads needs to be strong and robust. Aluminum and steel materials help limit the size and weight of wall components but also supply the strength necessary to resist high flood loads. The total wall height is recommended as a maximum 9.5 feet above grade to reduce wave splash and overtopping of the 500-year flood. This wall design would also protect against the 2050 SLR, 100-year. As the site topography goes up the overall wall height could be reduced.

This wall may be more compatible with the site than over permanent concrete foundations which require excavation and replacement of demolished sidewalks, curbs, and asphalt. The deployable barrier system often uses smaller footing compared to permanent walls.

Pros and Cons Summary

The benefits of the deployable flood wall should be weighed against the disadvantages. The foundation width is smaller than some permanent measures such as concrete flood walls. The durability of the post and beam system is better than many deployable systems, but would still fall short of most permanent measures. The materials used are flood and weather resistant which should help sustain the product for a long time. The operation and erection of the wall is relatively simple and can be performed with only minor training. One of the greatest strengths of the system is the ability of the barrier wall to eliminate any waterproofing or modification of the existing structure. Since existing structural walls could collapse from high flood waters, the barrier system prevents the expensive costs of strengthening the exterior walls of the building.

Figure 27. Typical Storage of Deployable Barrier System

Deployment of the system takes a moderate amount of time, but it can be accelerated with more crews and equipment. Unfortunately, each crew requires the use of a forklift. All the wall components must be carried from the storage container to the erection point. This makes the entire system dependent on a storage location relatively close to the barrier wall location. The farther wall components are from the actual flood wall location, the more time will be lost in transporting materials. Furthermore, the size of storage material required per foot of wall is one of the highest storage demands of any deployable system. It is anticipated that storage of this wall would require 4 to5 parking spaces. Some tall barrier systems are also more expensive than permanent walls, and it is important to weigh the costs and benefits of each option.

Other Temporary Measures

Flood walls serves as the primary protection for facilities and assets, but secondary measures are also important. A minimum of two pumps and possibly a generator is recommended to alleviate the site of water which may seep under the wall, splash over the wall after wave action, or accumulate from precipitation. In general, they offer redundant protection to the facility. Given the proximity to the Christina River, backflow preventers should be installed in any drainage pipes which serve the area protected by the flood walls. Backflow preventers are recommended for assets within close proximity to a waterbody to mitigate water flowing into the structure from the waterbody when the water level begins to rise.

Water-tight shields over windows and waterproof wall coverings were considered but were determine to be insufficient. Window coverings may be susceptible to debris penetrating the windows and allowing water to enter the building. In addition, a window protection system must be capable of being water tight which often requires ongoing maintenance. Even when properly installed, window coverings require the existing window frames to have enough strength to resist the flood loads. In some cases, the existing window frames may need to be strengthened to resist the flood loads. Waterproofing exterior walls of a building offers the expectation of being water-tight, but this is often difficult to implement. In addition, the walls should be inspected and analyzed to determine if they can support the horizontal flood loads. Many existing walls do not have adequate strength to resist flood loads, and reinforcing the wall system may be necessary. The combination of strengthening and waterproofing walls is often a very expensive solution.

Figure 28. Emergency Flood Door Covering (Flood Panel, n.d.)

Adaptation Strategy – Semi-Permanent

Description of Measure

CNOC may be best served by using a semi-permanent concrete knee wall with supporting deployable barrier walls above, approximately 1,300 feet in length. A semi-permanent measure has some portions of the system which always remain intact, and other components which must be erected. Figure 29 depicts the system without the deployable beams installed, while Figure 30 offers a view with the aluminum beams inserted between the concrete posts. This system would not utilize kickers, and it may offer a permanent and aesthetically pleasing wall depending on the concrete finish, veneer, and/or coloring. This measure would be expected to surround the facility and protect all the buildings and assets inside. The deployable portion of the wall would receive infill aluminum beams which only need

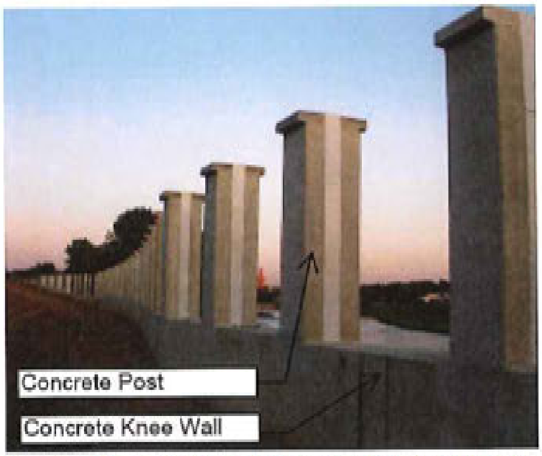


Figure 29. Concrete Knee Wall without Beams Installed

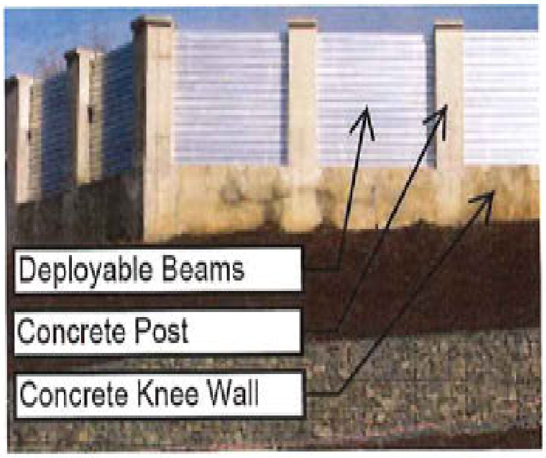


Figure 30. Concrete Knee Wall with Beams Installed

to be installed for severe storm events. The permanent wall portion could be sufficient to protect against less severe storms. Essentially the concrete columns support the aluminum beams and reduce the number of deployable components.

Selection Rationale

This system offers resistance up to the 2050 SLR, 500-year and, can protect against the associated 9 feet of inundation that could be expected with the severe storm. The semi-permanent system offers the potential of having half of the wall provide a permanent protection measure, with the other half of the wall height being deployed in far less time than a fully deployable wall. The permanent concrete wall can be constructed to varying heights and can be built to withstand the 100-foot storm event which would protected against the most likely storm events, thereby reducing the likelihood that the deployable beams will need to be installed for each storm event. A minimum of two pumps and possibly a generator is recommended to alleviate the site of water which may splash over the wall after wave action, or accumulate from precipitation. In general, they offer redundant protection to the facility. The semi-permanent wall retains some of the sight views instead of a full height permanent wall which blocks sight views.

Pros and Cons Summary

The benefits of a semi-permanent flood barrier include access, deployment time, durability, sustainability, ease of operation, and maintenance. There is no restriction on access to the site if the knee wall locations are appropriately placed. Any access to the site can be accommodated by stopping the knee wall and providing a full height deployable barrier wall at access points. The deployment time of this system will take far less time than a fully deployable system. Given approximately half of the wall height is permanent and made of durable concrete there should be little degradation of these permanent materials. With fewer components, less of the deployable system should wear out over time. The simplified system also makes operation even less complex. The system should sustain flood events well, and can be easily cleaned with spray washing. After flood waters recede, all components should be washed clean, and all wall components should be inspected for damage. Damaged members should be removed and replaced. This system would probably have a shorter life-span compared to a permanent wall.

Figure 31. Semi-permanent flood barrier installation

Other Temporary Measures

All other temporary measures can be reviewed under the deployable adaptation strategy within the other temporary measures section.

Adaptation Strategy – Moving CNOC to Another Facility

The CNOC's location adjacent to the Christina River exposes it to a high vulnerability from flood events. It is recommended the facility be moved to another location where there will be less risk from the serious impacts of floods. Amtrak could rank the most important attributes they need in a facility housing CNOC and pursue a property with these characteristics. A complete understanding of the costs associated with relocation would need to be fully understood. Ideally the facility would be above the 2050 SLR, 500-year.

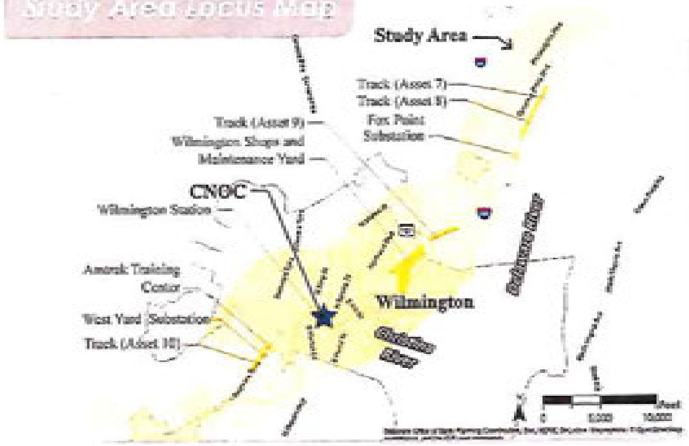
Consolidated National Operations Center (CNOC)

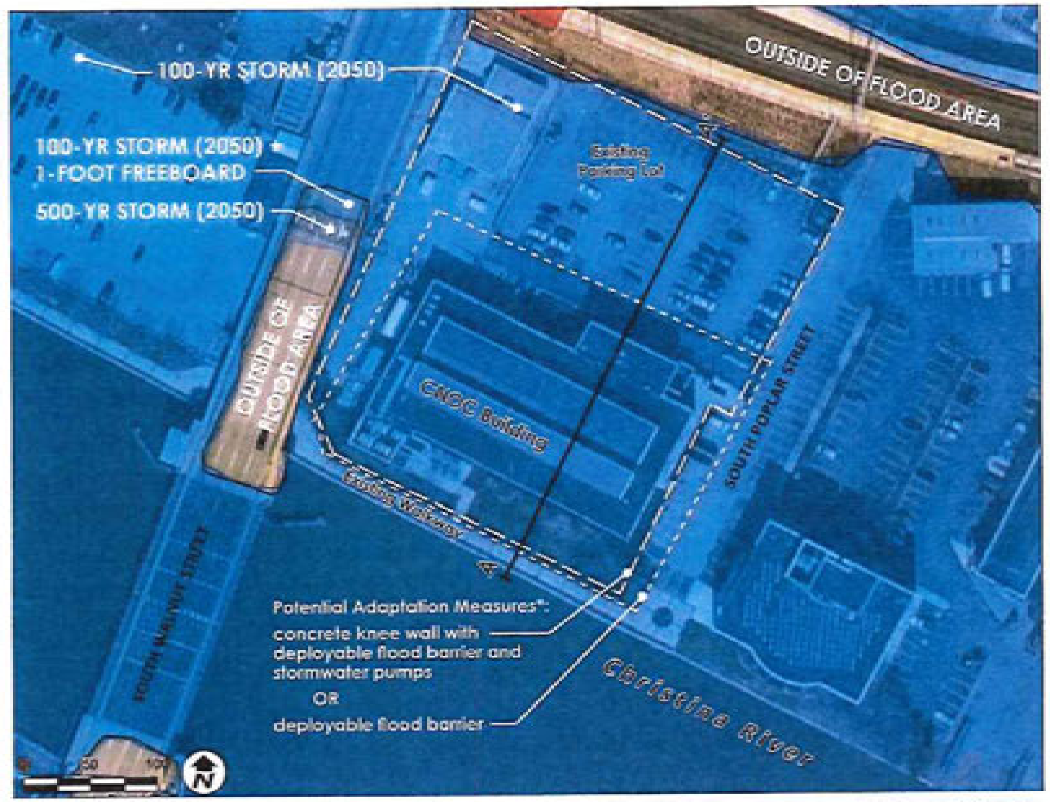
Vulnerability Summary

Site Features	• buildings • parking lot • servers
Importance	• controls national rail operations (b) (5)
Flood History	• parking lot floods during storm surges • building almost flooded during Hurricane Sandy
Potential 2050 Flood Hazard	• 100-year storm: 5 feet in parking lot • + 1 foot freeboard: 6 feet in parking lot • 500-year storm: 6 feet along exterior walls of building

AMTRAK Stantec

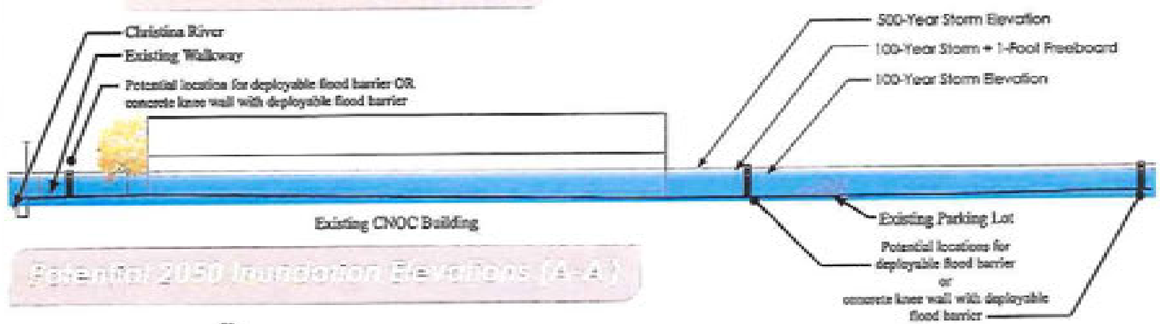
Study Area Locus Map





Potential 2050 Flood Zones

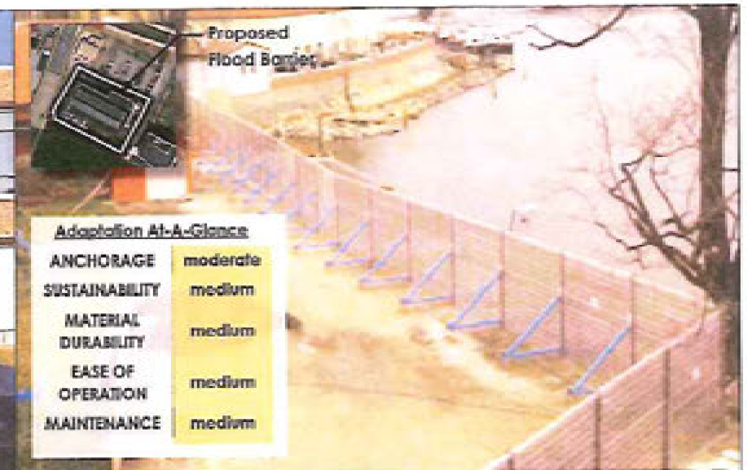
*See CNOC Adaptation Measures sheet for more information.



Potential 2050 Inundation Elevations (A-A)

Consolidated National Operations Center

Adaptation Measures



Type	4-FOOT CONCRETE KNEE WALL WITH DEPLOYABLE FLOOD BARRIER			DEPLOYABLE FLOOD BARRIER		
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (6.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (9 feet)	100-year Storm (6.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (9 feet)
Adaptation Height	7 feet	8 feet	9.5 feet	7 feet	8 feet	9.5 feet
Foundation Width	7 feet	8 feet	9.5 feet	4.5 feet	5 feet	6 feet
Adaptation Length		1,300 linear feet			1,000 linear feet	
Deployment Time	15 hours	20 hours	27 hours	34 hours	39 hours	47 hours
Storage Requirements*	3.75 parking spaces	4 parking spaces	4.5 parking spaces	2.9 parking spaces	3.1 parking spaces	3.5 parking spaces
Cost	$2,800/linear foot	$3,300/linear foot	$3,900/linear foot	$1,800/linear foot	$2,000/linear foot	$2,400/linear foot
(b) (5)		(b) (5)			(b) (5)	

* cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high

3.4.5 Bellevue Substation

Vulnerability Summary

Site Features

The Bellevue substation situated between the Delaware River and Interstate 495 supplies voltage into the catenary system to power trains. Expensive equipment is used to convert utility voltage into the amount required for trains to operate. Most of the equipment is elevated above the ground at least 1 foot on a concrete slab foundation; however, this may not be sufficient to protect against flood waters.

Figure 32. Water Ponding at Bellevue Substation

Criticality

The Bellevue Substation supplies trains with the power through overhead catenary systems by first converting the voltage. The substation power is necessary for the normal operation along the line.

Historical Flooding Summary

No historical flooding is known for this facility, though water ponding was documented during a recent site visit as displayed in Figure 32.

Hazard Characteristics

This facility demonstrates a reduced risk for flooding. The 2050 SLR, 100-year and the additional 1 foot of freeboard does not produce any significant flooding. During the 2050 SLR, 500-year the site begins to experience some flooding. This storm event may create up to 1.5 feet of flooding and water levels may reach equipment located on elevated concrete footings as viewed in Figure 33.

Figure 33. Substation Equipment on Elevated Concrete Footings

Adaptation Strategy – Deployable

Description of Measure

The Bellevue substation is less threatened by flooding than many other critical Amtrak assets, however it still needs an adaptation strategy to protect the critical equipment it contains from the 2050 SLR, 500-year. Since flood inundation values are less at this facility, a smaller flood barrier would offer the necessary protection. A 4-foot tall deployable flood wall approximately 1,000 feet in length encompassing the entire facility would provide protection against this event and provide even greater protection against more severe storms. Door access can be integrated with the system if desired and typically a 3- or 4-person crew can construct the wall within a few hours. A particular manufacturer offers L-shaped deployable flood walls made of marine laminated plywood, PVC canvas, and aluminum and steel structural members. The entire system can be installed with no special equipment. An example is displayed below in Figure 34.

Figure 34. Deployable Flood Barrier - 4 Feet Tall

Selection Rationale

Flood levels at Bellevue Substation are lower than other facilities, and selecting a suitably smaller flood wall system will save money. One benefit of using the deployable flood wall is the ability to protect all the assets within the wall perimeter using one mitigation technique. Since this particular deployable wall comes in specific height increments of 4 feet and up, the shortest height of 4 feet would protect against the 1.5 feet of flooding associated with the 2050 SLR, 500-year. Another benefit of choosing this deployable system over a permanent solution would be the reduced upfront costs.

Pros and Cons Summary

Like all systems, the deployable flood wall has strengths and weaknesses of varying degree. On the positive side, the system allows for cost savings associated with a pre-designed smaller barrier wall which can provide continuous access to the site within an hour or two of the actual storm. The operation and erection of the wall is not complex and can be performed with minimal training. One of the greatest strengths of the system is the ability of the barrier wall to eliminate any waterproofing or modification of the existing assets. There is no need to raise the foundations of equipment, and no requirement to strengthen existing walls because flood waters should never reach these assets.

It is best to keep the flood wall stored at the facility. Given the small area of storage it requires this may not be a prohibitive item. If the wall cannot be placed inside of the fence line where it is flat, the site may need to be modified to receive the deployable wall system. The ground elevation may require some additional grading and/or the underbrush around the facility may need to be removed. The deployable system has a shorter life span then permanent and semi-permanent walls as well it requires trained personnel to install prior to the storm.

Other Temporary Measures

A flood barrier wall is helpful for stopping most water from penetrating the facility, but it does require some other temporary measures. A minimum of one pump and possibly a generator would be expected to alleviate the site of water which may seep under the flood wall, splash over the flood wall after wave action, or accumulate from precipitation.

Some temporary measures which were considered insufficient flood protection methods include elevating the mechanical equipment. Typically elevating mechanical equipment of this size and number starts to match the costs of purchasing entirely new equipment. The substation equipment certainly costs a great deal of money, and elevating all the equipment would also demand a large investment in structural renovation using concrete and steel construction. Some of the ancillary buildings at the site would also need to be elevated and additional accessibility requirements could add cost to the project.

Adaptation Strategy – Permanent

Description of Measure

Permanent flood prevention methods remain at the site in a mostly prepared state of resisting flood waters. The recommended measure for the Bellevue Substation utilizes concrete flood walls constructed a little above the 2050 SLR, 500-year. The approximately 1,000-foot wall would encompass all the substation assets and leave an opening at a few locations for pedestrian and vehicular access. These opening could be closed using deployable flood walls as seen in Figure 35. Depending on the look desired, the concrete wall finish could be modified to be more aesthetically pleasing based upon the selection of concrete finish, veneer, and/or coloring.

Figure 35. Depiction of Permanent Concrete Walls

Selection Rationale

The 2050 SLR, 500-year threatens to expose the site to 1.5 feet of flooding. To protect against this event, a short concrete flood wall would offer a near continuous protection of all the assets of the substation with a reduced effort since personnel is not needed to install prior to the event.

Pros and Cons Summary

A permanent concrete flood wall offers the benefit of ease of operation, low maintenance, while also limiting storage, minimizing deployment, and having a similar cost to a fully deployable wall. The concrete wall only requires operation for installing the deployable wall doors when a severe storm is approaching. Other than wall entrances, no other operations are necessary. Similarly, the maintenance of this wall is little more than for a typical fence. This measure would be expected to have a longer life span than any alternative, which is important since future events may exceed expectations. In addition, the storage for the wall openings should be small and be available on site. If properly planned and executed, the time to fully install the deployable walls in the openings could take less than 1 hour. With all these benefits, the similar costs for a deployable system make this option the optimal choice. The negative aspects of the concrete wall include higher installation costs compared to deployable flood walls.

3.4.6 West Yard Substation

Vulnerability Summary

Site Features

The West Yard substation is located near the Amtrak Training Center and provides trains with power through overhead catenary systems. Before transmitting power into the catenary system, the substation converts utility supplied voltage into an appropriate amount for trains. Substations utilize expensive transformers, circuit breakers, cables, and underground wires to accomplish this work. See Figure 36 for some of these pieces of equipment.

Figure 36. West Yard - Substation Equipment

Criticality

The West Yard Substation supplies trains with the power through overhead catenary systems by first converting the voltage. The substation power is necessary for the normal operation along the line.

Historical Flooding Summary

The facility does have a history of flooding concerns. Entering the substation has been difficult at times when the access road floods. In some cases, the flood waters have reached the substation equipment. The control pit pictured in Figure 37 was flooded during Hurricane Sandy. Afterwards it was necessary to pump the water out of the pit.

Figure 37. Control Pit Flooded During Hurricane Sandy

Hazard Characteristics

This particular substation has a high vulnerability to flooding. The 2050 SLR, 100-year has the capability to inundate the entire facility with 3.5 feet of water. Although some components of the substation are elevated on concrete foundations, most elevated components would still be exposed to flood waters during the 100-year storm. In 2050, 100-year +1' may create flood depths of 5.5 feet. Moreover, the 2050 SLR, 500-year could produce flooding of 7 feet. These elevated water levels could put ancillary buildings at risk. When water levels rise, they impose pressure onto building walls which may not be designed to resist the addition pressure which may cause the walls to collapse and damage equipment stored inside.

Adaptation Strategy – Deployable

Description of Measure

The West Yard substation is a facility housing critical mechanical and electrical equipment which may be protected by an approximate 1,100-foot deployable flood wall system. One recommended flood barrier uses a post and beam system to create a flood wall which can adapt to the particular requirements of a site. Aluminum beams are positioned between vertical steel posts at set intervals, and the post has a base plate which is bolted into the ground as shown in Figure 38. For taller walls the flood wall uses kickers which form a triangular brace behind the posts. This system would surround all the critical equipment at site. Knowing the site already utilizes a fence, the deployable wall could be permanently erected in place of the fence. Alternatively, the deployable wall could be positioned outside of the existing fence.

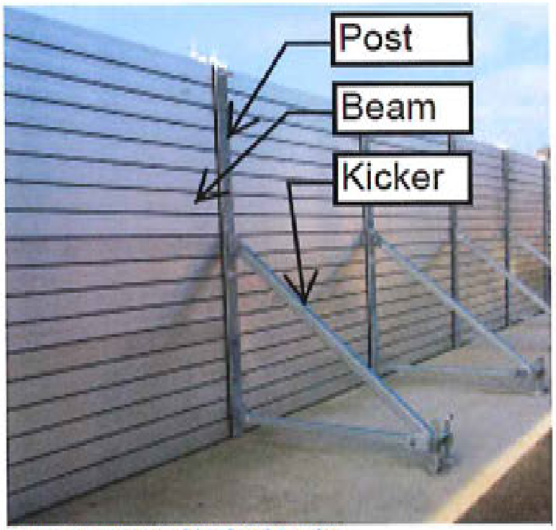


Figure 38. Deployable Flood Barrier

Selection Rationale

This site is susceptible to flood depths of 9 feet by the 2050 SLR, 500-year. A barrier system capable of resisting these flood loads needs to be strong and robust. Kickers help support the wall and aluminum and steel materials help limit the size and weight of wall components, but also give the structure the strength necessary to resist high flood loads. The total wall height is recommended as a maximum 9.5 feet above grade to reduce wave splash and overtopping of the 500-year flood. This wall design would also protect against the 2050 SLR, 100-year.

This wall may be more compatible with the site if less excavation of the foundations is desired. The deployable barrier system often uses smaller footings compared to permanent walls. A minimum of one pump and possibly a generator would be expected to alleviate the site of water which may splash over the flood wall after wave action, or accumulate from precipitation. This system also offers the option of increased visibility, since a permanent wall would block viewing angles. Currently an environmental assessment and remediation work is being completed for the West Yard Substation (DE-0156). All proposed adaptation measures will need to be coordinated with the final remedy so as to not impede the final remediation actions.

Pros and Cons Summary

Like all systems, the deployable flood barrier has strengths and weaknesses of varying degree. On the positive side, the system allows for tall barrier walls which can provide continuous access to the site within an hour or two of the actual storm. Moreover, when needed the beams can be removed from the wall system to provide access to the site at any segment along the wall. The foundation width may be considered small when compared to some permanent measures such as concrete flood walls. The durability of the post and beam system is better than many deployable systems, but would still fall short of most permanent measures. The materials used are flood and weather resistant which should help sustain the product for a long time. The operation and erection of the wall is relatively simple and can be performed with only a small period of instruction. One of the greatest strengths of the system is the ability of the barrier wall to eliminate any waterproofing or modification of existing buildings on the site.

Deployment of the system takes a moderate amount of time, in some cases, but it can be accelerated with more crews and equipment. Unfortunately, each crew requires the use of a forklift. All the wall components must be carried by a forklift from the storage container to the erection point. This makes the entire system dependent on sufficient storage capability relatively close to the barrier wall location. The farther wall components are from the actual flood wall locations, the more time will be lost in transporting materials. The size of storage material required per foot of wall is one of the highest storage demands of any deployable system. Some tall deployable wall systems are also more expensive than permanent walls, and it is important to weigh the cost and benefits of each option. For this site, the landscaping and topography of the area immediately around the fenced in substation may need to be modified to properly deploy the temporary flood wall. The ground elevation may require some additional grading and/or the underbrush around the facility may need to be removed.

Other Temporary Measures

A flood barrier wall is helpful for stopping most water from penetrating the facility, but it does require some other temporary measures. A minimum of two pumps and possibly a generator would be expected to alleviate the site of water which may seep under the wall, or splash over the wall after wave action.

Some temporary measures which were considered insufficient flood protection methods include elevating the mechanical equipment. Typically elevating mechanical equipment of this size and number starts to match the costs of purchasing entirely new equipment. The substation equipment certainly costs a great deal of money, and elevating all the equipment would also demand a large investment in structural renovation using concrete and steel construction. Some of the ancillary buildings at the site would also should be elevated and additional accessibility requirements would add cost to the project.

Adaptation Strategy – Permanent

Description of Measure

Permanent flood prevention methods remain at the site in a mostly prepared state of resisting flood waters. The recommended measure for the West Yard Substation utilizes approximately 1,100 linear

Figure 39. Permanent Concrete Flood Wall

feet of concrete flood walls constructed a little above the 2050 SLR, 500-year. The wall would encompass all the substation assets and leave an opening at a few locations for pedestrian and vehicular access. These opening could be closed using a deployable flood wall as shown in Figure 39. The concrete wall finish could be modified to be more aesthetically pleasing with options on the concrete finish, veneer, and/or coloring.

Selection Rationale

The 2050 SLR, 500-year threatens to expose the site to 9 feet of flooding. To protect against this event, a concrete flood wall would offer a less expensive option than a fully deployable system or a semi-permanent system using a concrete knee wall. Although a tall permanent concrete wall would limit views at the site, there seems little benefit from maintaining the current visibility. A minimum of one pump and possibly a generator would be expected to alleviate the site of water which may splash over the flood wall after wave action, or accumulate from precipitation. The permanent flood wall also protects all the assets of the substation with a reduced effort and a lower cost compared to the other options.

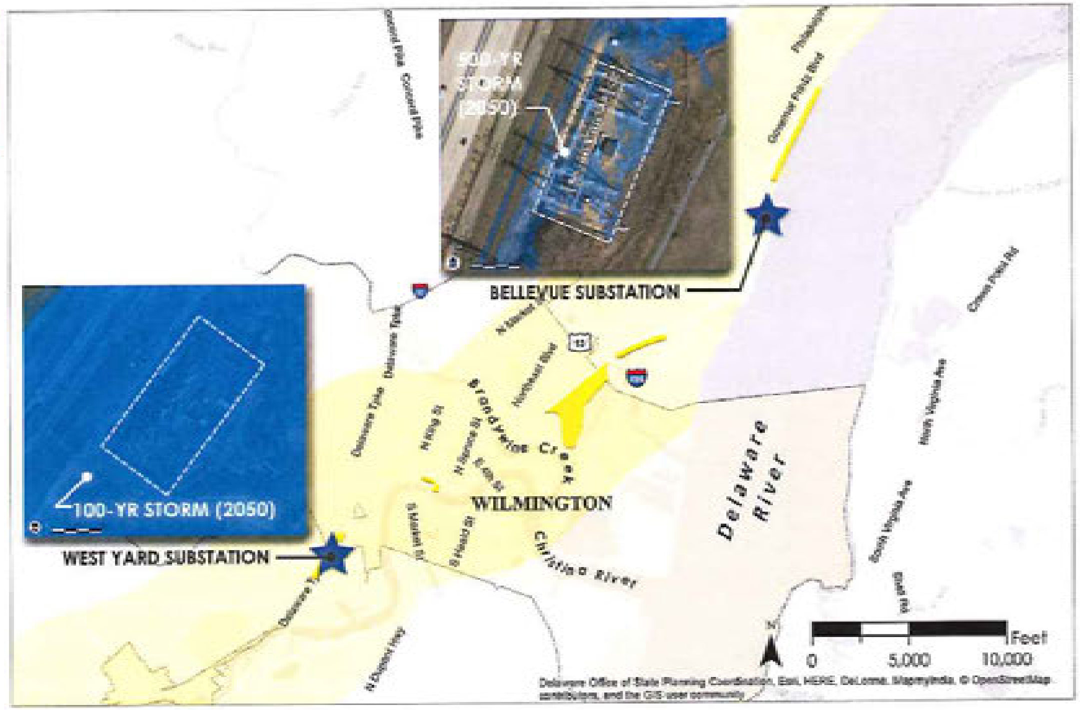
Pros and Cons Summary

A permanent concrete flood wall offers the benefit of ease of operation, low maintenance, while also limiting storage, minimizing deployment, and having a similar cost to a fully deployable wall. The concrete wall only requires installation of the deployable wall doors when a severe storm is approaching. Other than wall entrances, no other actions are necessary. Similarly, the maintenance of this wall is little more than for a typical fence. This measure would be expected to have a longer life span than any alternative, which is important since future events may exceed expectations. In addition, the storage for the wall openings should be small and be available on site. If properly planned and executed, the time to fully install the deployable walls in the openings could take less than 1 hour. With all of these benefits, the similar costs for a deployable system seem to make this option the optimal choice. The negative aspects of the concrete wall include a larger footing width and permanent visibility restrictions.

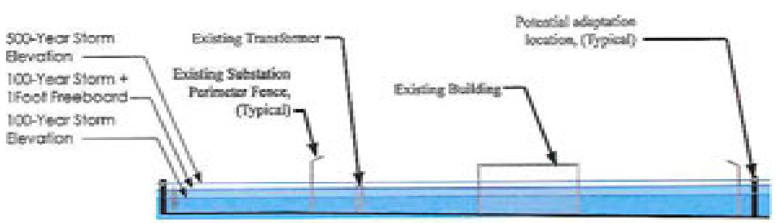
Substations

Vulnerability Summary

Site Features	• transformers • circuit breakers • cables • underground wires
Importance	• supplies voltage into catenary system to power trains
Flood History	**West Yard Substation** - access road floods during severe flood events; control pits were flooded after Hurricane Sandy **Bellevue Substation** - ponding occurs regularly on site
Potential 2050 Flood Hazard	2050 data for substations varies (see sections below)

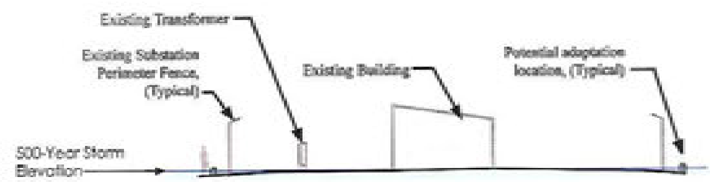


Substation Locus Map



WEST YARD SUBSTATION

100-year storm: 3.5 feet of flooding
+ 1 foot of freeboard: up to 5.5 feet of flooding
500-year storm: 7 feet of water



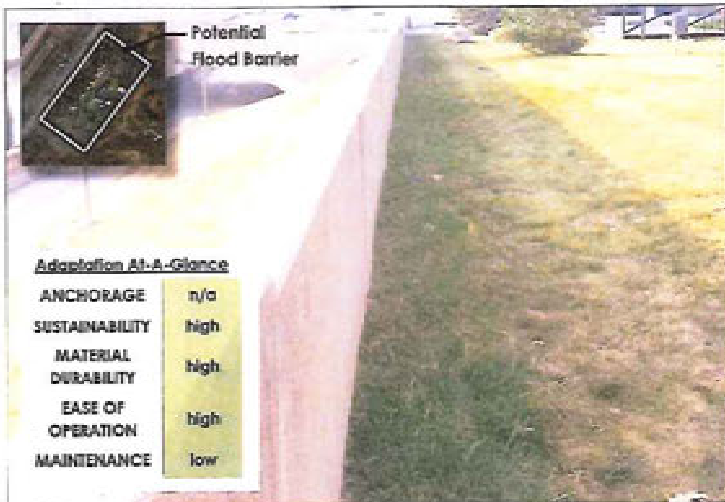
BELLEVUE SUBSTATION

100-year storm: none
+ 1 foot of freeboard: none
500-year storm: 1.5 feet of water

Potential 2050 Inundation Elevations

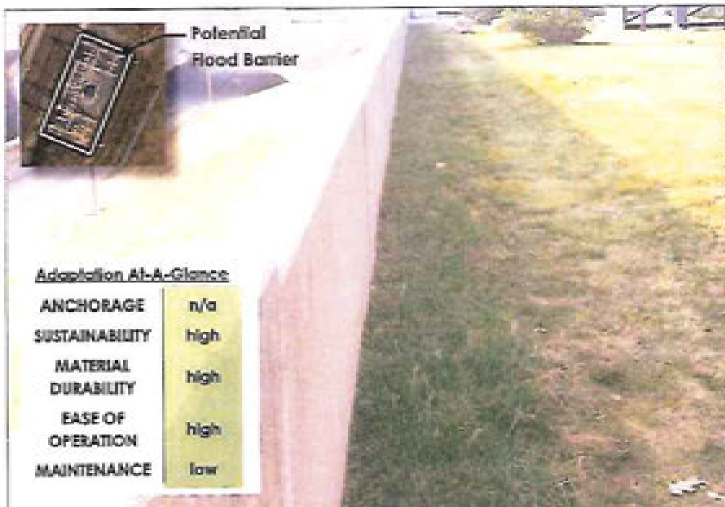
West Yard Substation

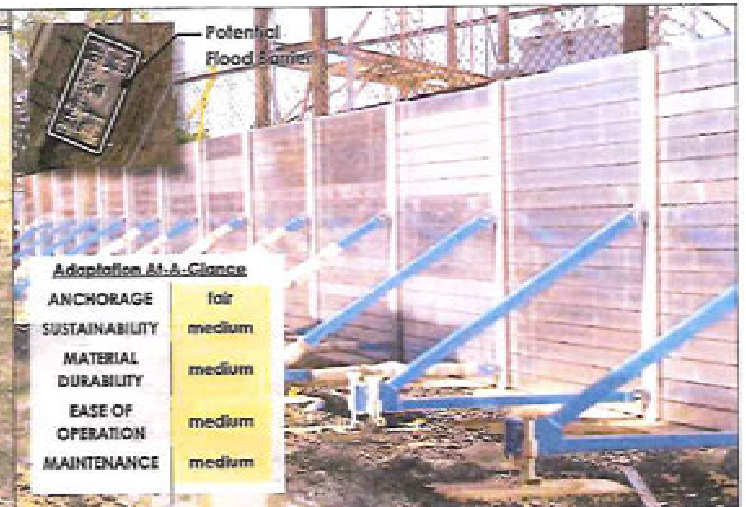
Potential Adaptation Measures



Type	SOLID CONCRETE WALL			DEPLOYABLE FLOOD BARRIER		
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (6.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (9 feet)	100-year Storm (6.5 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (9 feet)
Adaptation Height	7 feet	8 feet	9.5 feet	7 feet	8 feet	9.5 feet
Foundation Width	7 feet	8 feet	9.5 feet	4.5 feet	5 feet	6 feet
Adaptation Length		1,100 linear feet			1,100 linear feet	
Deployment Time		n/a (permanent installation)		29 hours	33 hours	40 hours
Storage Requirements*		n/a (permanent installation)		3.2 parking spaces	3.4 parking spaces	3.8 parking spaces
Cost	$1,800/linear foot	$2,000/linear foot	$2,100/linear foot	$1,800/linear foot	$2,000/linear foot	$2,400/linear foot
(b) (5)		(b) (5)			(b) (5)	

* cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high





Type	SOLID CONCRETE WALL			DEPLOYABLE FLOOD BARRIER		
Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm	100-year Storm + 1-foot Freeboard	500-year Storm (1.5 feet)	100-year Storm	100-year Storm + 1-foot Freeboard	500-year Storm (1.5 feet)
Adaptation Height	n/a	n/a	2 feet	n/a	n/a	4 feet
Foundation Width			2.5 feet			4 feet
Adaptation Length			1,000 linear feet			1,000 linear feet
Deployment Time			3 hours			3 hours
Storage Requirements*			n/a			
Cost			$450/linear foot			$305/linear foot
(b) (5)		(b) (5)			(b) (5)	

* cubic foot dimensions described in terms of number of 9'x20' parking spaces with containers stacked up to 17 feet high

3.4.7 Track Segments

Vulnerability Summary

Site Features

The four identified segments of track are vulnerable largely due to their location. Segments MP 21.0 to 21.5, MP 21.5 to 22.0 and MP 24.0 to 24.5 are located close to the Delaware River while MP 28.0 to 28.5 is close to the Christina River.

Figure 40. Low Elevation Tracks Adjacent to Delaware River (MP 21.0 to 21.5)

The segment located at MP 21.0 to 21.5 has some of the lowest elevated track in relation to the Delaware River as displayed in Figure 40. When storm surge occurs, the rising water levels may expose the nearby track segment to flooding. The next half mile of track (MP 21.5-22.0) has a combination of highly elevated track and low-lying track, see Figure 41. Without the additional height, the low elevation track is threatened by sea level rise and flooding.

Figure 41. High and Low Elevation Tracks (MP 21.5 to 22.0)

The half-mile track segment between MP 24.0 to 24.5 is located northeast of the Wilmington Shops and Maintenance Facility. The track is positioned near Shellpot Creek and some local lowlands seen in Figure 42. A neighboring marsh area serves as a potentially dangerous source of flood waters.

Figure 42. Lowlands with Water Adjacent to Tracks (MP 24.0 to 24.5)

Figure 43. Northern Approach of Track Segment adjacent to West Yard - Substation 13 (MP 28.0 to 28.5)

Between mile post 28.0 and 28.5 lies a half mile segment of track which is more susceptible to flooding than the northern portion of elevated track. After descending from the higher elevation, this segment of track passes the Amtrak Training Center and the West Yard – Substation 13, Figure 43.

Criticality

These tracks are critical because there is not an alternate track that can be used as a detour if a segment of the track is inundated or damaged. The segments of track are vital to travel within the NEC, in particular for travel between the main southern hubs of Washington, DC and Baltimore, MD to the main northern hubs of Philadelphia, PA and New York, NY. If one of the segments of track shuts down it will shut down traffic along this segment of the NEC until the track can be repaired or the water has receded. It has been estimated that a major storm event like Hurricane Sandy could result in revenue loss of $2.8 million per day.

Historical Flooding Summary

Flooding has been anecdotally noted, but a more detailed search is necessary to confirm. There are no known written records of historical flooding for any of the vulnerable track segments.

Hazard Characteristics

Track Segment MP 21.0-21.5

Given the relatively low elevation of the tracks in relation to the Delaware River, the 2050 SLR, 100-year has the capability to inundate most of the tracks along this half-mile segment. The flooding depth may reach 2 feet and completely cover all four tracks. An additional 1 foot of freeboard raises the flood depth to 3 feet. This storm event would make 2 feet of water above the tracks a common occurrence for this track segment. The 2050 SLR, 500-year would increase the flooding to as much as 4.5 feet. Given the proximity to the Delaware River, these flood events will most likely be accompanied by wave action. As waves propagate over the inundated tracks, some

Figure 44. Rail Ties and Ballast above Culvert Discharging into Delaware River (MP 21.0 to 21.5)

scouring may occur at the track bed which could weaken and disturb the rail ties or underlying ballast displayed in Figure 44.

Track Segment MP 21.5-22.0

Severe storm events endanger the stability and operation of this particular track segment. Approximately 1,500 linear feet of the track will have some flooding during the 2050 SLR, 100-year +1'. Some of the rail lines may sustain flood depths of 1.5 feet during this storm event. The low elevation tracks displayed in Figure 45 are most threatened by flooding with flood depths reaching 3 feet during the 2050 SLR, 500-year. As the water levels increase some of the tracks may be exposed to scouring effects from waves propagating over the tracks. The waves may carry away portions of the track bed and necessitate extensive repairs.

Figure 45. Low Elevation Tracks under Bridge (MP 21.5 to 22.0)

Track Segment MP 24.0-24.5

Severe flooding is predicted for this half-mile of track. Starting with the 2050 SLR, 100-year, more than 75% of the track segment is expected to experience flooding. Some flood depths will approach 3.5 feet above the track. At this depth the tracks will be impassable. When an additional 1-foot of freeboard supplements this storm event, water depths will increase to 4.5 feet above the track in several locations. The 2050 SLR, 500-year has the capability of inundating the entire half-mile segment of track. most the track will experience 3 feet or more of flooding and the maximum flood depths above the track will approach 7.5 feet. Quite obviously the assets of this half-mile segment of track are greatly at risk.

Track Segment MP 28.0-28.5

The flooding concerns of this half-mile track segment rank as one of the most threatened areas. The 2050 SLR, 100-year has the potential of inundating the tracks with 1 foot to 2 feet of water. After including an additional 1-foot of freeboard, some of the track along this half-mile segment may experience 3.5 feet of flooding. At the 2050, 500-year more than 75% of the track will have some flood waters accumulating above the track. The most significant will contain depths of approximately 4.5 feet. As these water levels increase, the risk of other debris damaging or blocking the tracks increases. Figure 46 displays some assets being stored near the tracks, as well as a pile of debris which flood waters could carry onto the nearby tracks.

Figure 46. Storage Equipment and Debris Located near tracks

Adaptation Strategy – Semi-permanent

Description of Measure

Two walls are proposed for two separate sections within the MP 19.0 and 22.0 segment. The first is a small segment between MP 21.5 and 22.0 where the source of flooding is the below grade crossing of tracks which occurs roughly 900 feet northeast of Stoney Creek. The ground elevation in this segment is below design flood elevations permitting flooding from the Delaware River. A wall constructed along the rail in this location, as shown in Figure 47 could prevent this segment from flooding. The wall can be tied into a railroad bridge at the south end at 13,900 feet of track distance from MP 19.0 and tied into the bridge abutment at the north end at approximately 14,400 feet from MP 19.0. The required wall height to achieve an elevation above the 2050 SLR, 100-year ranges from less than 0.5 feet and 3.5 feet to approximately 1.5 feet and 4.5 feet without and with 1 foot of freeboard, respectively.

The second proposed semi-permanent wall segment is between MP19.5 and 21.5 as shown in Figure 48. In this segment along the coast, the ground elevation undulates above and below the 2050 SLR, 100-year flood elevation. Therefore, a continuous wall is not necessary along this segment. Rather, wall segments can tie into existing high ground along this segment to protect against flooding from the 2050 SLR, 100-year.

Selection Rationale

Due to their proximity to the Delaware River, tracks between MP 20.0 and 22.0 have the greatest risk of experiencing flooding from 2050 SLR, 100-year event. To prevent flooding along this segment of tracks, semi-permanent walls are proposed. These walls consist of a permanent knee wall and logs that can be inserted between pillars. As such, the logs can be inserted ahead of flooding events to prevent hazards and removed thereafter to maintain aesthetics and passenger views. The height of the knee wall is variable and can depend on many factors including;

- Amtrak's desire to maintain viewshed
- Amtrak's ability to deploy the insertable logs
- Overall investment cost

Pros/Cons summary

The benefits of a semi-permanent flood barrier include access, deployment time, durability, sustainability, ease of operation, and maintenance. Access to the rail is possible at any point if the knee wall locations are appropriately placed. Any access to the site can be accommodated by stopping the knee wall and providing a full height deployable barrier wall at access points. Given approximately half of the wall height is permanent and made of durable concrete there should be little degradation of these permanent materials. With fewer components, less of the deployable system should wear out over time. The simplified system also makes operation even less complex. The system should sustain flood events well, and can be easily cleaned with spray washing. This system should have a shorter life-span compared to a permanent or semi-permanent wall. Due to the overall length, deployment time is estimated to be 280 to 710 hours depending on the height of the wall and the storage requirements range from 53-105 parking spaces. Logistically, the storage location should be as close to the site as possible to avoid a long transport time. Advanced planning is necessary to determine the best way to transport the logs to the site.

Other Temporary Measures

Other temporary measures considered included deployable and permanent walls which are both possible solutions. These measures have restrictions including cost and time of implementation. Other more extreme measures could include raising or relocating the vulnerable track segments.

Figure 47. Plan View of the Wall Location Near Stoney Creek MP 21.5 to 22.0)

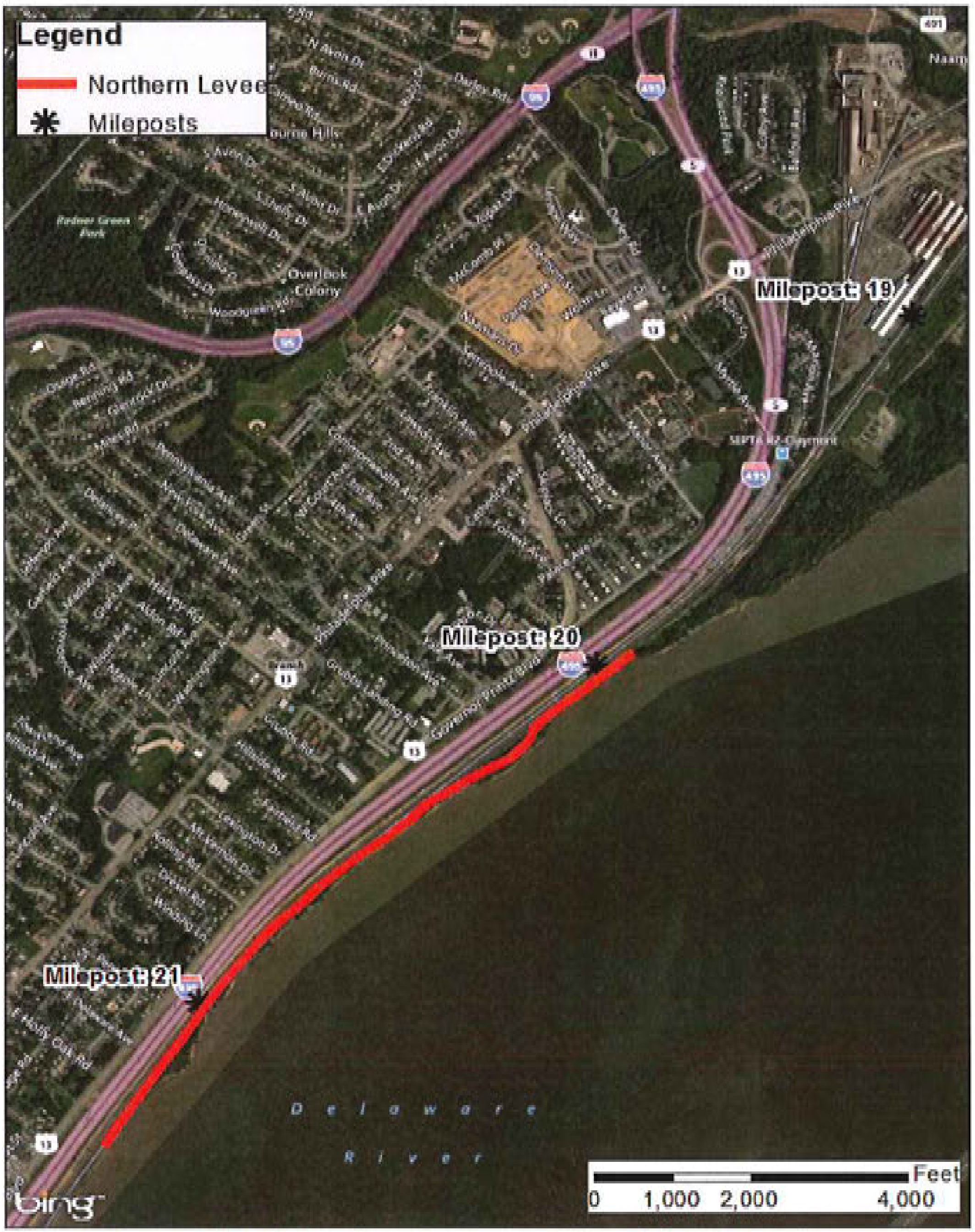


Figure 48. Plan View of the Wall along the Northern Segment of the Track (MP 19.5 to 21.5)

Track Segments

Vulnerability Summary

Site Features	• tracks • turnouts • signals • rail ballast • interlocking • catenaries
Importance	• rider safety • regional operation
Flood History	no flood history recorded for these sections of track
Potential 2050 Flood Hazard	2050 data varies among the four sections of track (see sections below)

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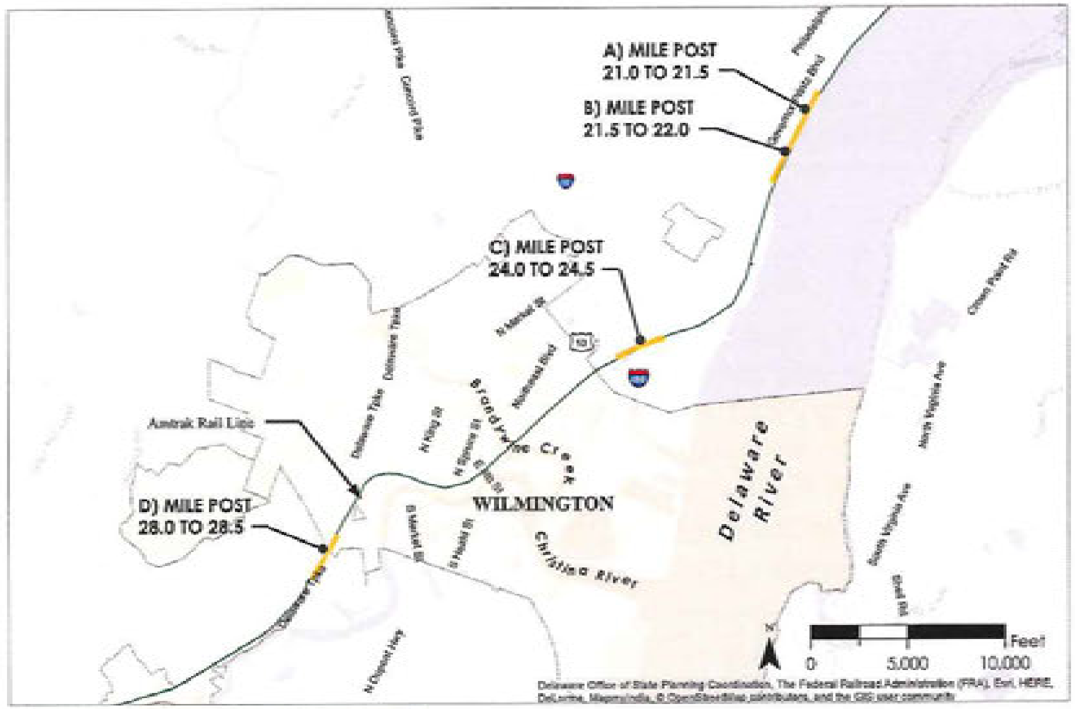
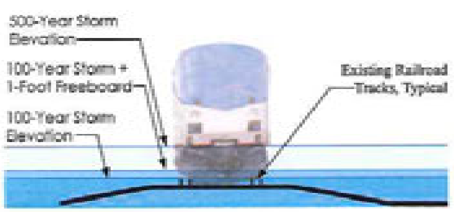
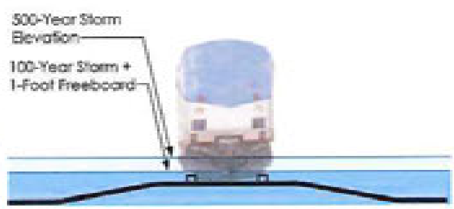


Track Segment Locus Map



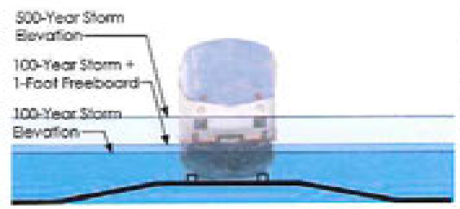
A) MILE POST 21.0 TO 21.5

100-year storm: all 4 tracks under 1 foot of water
+ 1 foot of freeboard: 2 feet of water above tracks
500-year storm: 4.5 foot depth, plus scouring from wave action



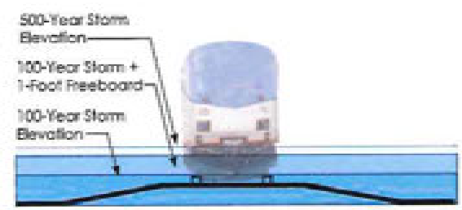
B) MILE POST 21.5 TO 22.0

100-year storm: none
+ 1 foot of freeboard: 1.5 feet of flooding
500-year storm: 3 feet of water, plus scouring from wave action



C) MILE POST 24.0 TO 24.5

100-year storm: portions of track impassible, with 3.5 feet of flooding
+ 1 foot of freeboard: 4.5 feet
500-year storm: entire segment under water, 3 to 7.5 feet



D) MILE POST 28.0 TO 28.5

100-year storm: 1 to 2 feet of water over portions of track
+ 1 foot of freeboard: 3.5 feet
500-year storm: 75% of tracks flooded, up to 4.5 feet of water

Potential 2050 Inundation Elevations

Track Segments

Potential Adaptation Measures

4-FOOT CONCRETE KNEE WALL WITH DEPLOYABLE FLOOD BARRIER

Potential 2050 Flood Event Elevation + Sea Level Rise	100-year Storm (8 feet)	100-year Storm + 1-Foot Freeboard	500-year Storm (11 feet)
Adaptation Height	8.5 feet	9.5 feet	11.5 feet
Foundation Width	8.5 feet	9.5 feet	11.5 feet
Adaptation Length	16,500 linear feet (typical)		
Deployment Time	280 hours	430 hours	710 hours
Storage Requirements*	53 parking spaces	71 parking spaces	105 parking spaces
Cost	$3,500/LF	$4,000/LF	$4,300/LF

(b) (5)

(b) (5)

MILE POST 21.0 TO 21.5

MILE POST 24.0 TO 24.5

MILE POST 21.5 TO 22.0

MILE POST 28.0 TO 28.5

* cubic foot dimensions described in terms of number of 9"x20" parking spaces with containers stacked up to 17 feet high

3.4.8 Area-wide Adaptation Measures

Floodgate on the Christina River

Area-wide Adaptation Measures provide an opportunity to protect a large area that may include several Amtrak assets in contrast to protecting each asset individually. These measures often have a large upfront cost but can provide long-term protection for an entire area. Area-wide Adaptation Measures require coordination with the surrounding stakeholders because it is likely that the area needed for deployment and the area protected are not solely owned by Amtrak. This allows for an opportunity to work with the local communities for the betterment of the region. Coordination for the area-wide adaptation measures should begin early in the process to gain consensus and support. The majority of the vulnerable assets within the Pilot Study Area are threatened by sea level rise and storm surge from the Christina river with the exception of some of the northern track segments which are adjacent to the Delaware river.

A floodgate across the mouth of the Christina River could prevent flooding up river from the most extreme design elevation and protect several of Amtrak's assets, most importantly CNOC. A significant consideration regarding the floodgate is that the mouth of the River is not within the right of way or property of Amtrak. Building a floodgate is an effective way to protect against regional flooding rather than protecting an individual structure(s). Such a flood protection measure would be under the purview of considerations by bordering land owners. Further, it would require a major effort and investment to ensure the entire community would have flood protection. The floodgate alone would not provide sufficient protection on a regional basis, as shown in the Figure 49. Flood waters would inundate the community through low lying areas and require a series of levee systems to be constructed.

Storm surges generated by severe storms can cause flooding along the banks of the Christina and Delaware river. Sea level rise exacerbates this flood hazard. A floodgate across the mouth of the Christina river can block storm surges from entering the Christina river to prevent coastal flooding upstream. Given a design standard to prevent flooding from the 2050 SLR, 500-year, the floodgate would need to block flood waters entering the Christina river that would reach 12.8' NAVD88 in elevation. A floodgate could be effective given that there are high points in the terrain at either side of the mouth where the floodgate can tie into. More specifically, a floodgate could be tied in with the banks at the Cherry Island Landfill and Citrosuco port terminal. In Figure 49, the land masked by the white area are grounds that are above 13' NAVD and, therefore, are above the most extreme design flood elevation.

However, the physical setting poses constructability issues owing to the deep river channel and shallow banks at the mouth of the Christina River. The variation in depth as well as the large depths in the shipping channel is not conducive to floodgate construction without a major investment. Based on a

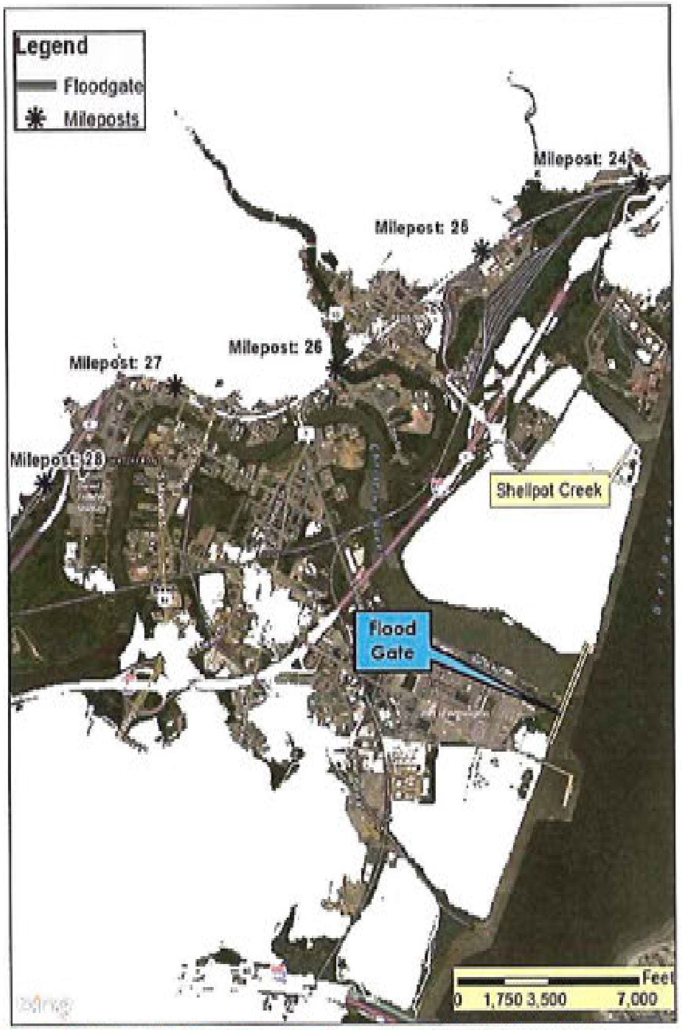


Figure 49. Potential Floodgate Location across the Christina River

preliminary analysis, the cost of constructing a floodgate would range between $385 million and $700 million. This cost is for the floodgate only and does not include maintenance/operations costs (0.05 to 2.0 % per year) and costs to construct adjacent levees to tie in the entire community for flood protection.

Due to these cost, property, and physical constraints, further investigation of floodgates is not recommended. Due to the regional nature of the flooding in this area, it is best for property owners and stakeholders who are in areas of higher vulnerability to develop a network of protection in the form of a system of levees or semi-permanent walls with or without floodgates.

3.4.9 Precipitation Adaptation Measures

For a variety of assets and locations, installation of stormwater green infrastructure (GI) best management practices (BMPs) could be a very effective method of mitigating for future increases in rainfall due to climate change. The increase in rainfall volume will translate into a total increase in stormwater runoff volume which leads to flooding. New GI facilities could potentially reduce that increase in runoff volume in a way that traditional storm drain infrastructure cannot. These measures are proposed to mitigate for increases in precipitation and should be considered in conjunction with the adaptation measures discussed previously that are proposed to address the impacts resulting from sea level rise and storm surge.

Many of these measures are intended to mimic natural or predevelopment hydrologic environments. However, in this case, these facilities could be designed to mimic pre-climate change conditions. This could have the benefit of providing the same level of flooding and ponding protection under future rainfall conditions. Green infrastructure would have the added benefit of providing stormwater treatment and surface water body protection in addition to flood protection.

Description

Two areas were considered a good opportunity for the use of green infrastructure, a section of the track and the maintenance shops. Bioswales along the track could be used to capture and treat the ponded water.

Bioswales are long linear drainage systems that collect and treat stormwater along roadways, rail lines and parking lots. Low vegetation as well as check dams help slow down the surface runoff so that it has adequate time to collect and infiltrate through the bed of landscaping and filter media and into the underdrain collection system. Swales generally rely on sheet flow along their length to collect runoff.

Rain gardens are recommended for use within the maintenance shop yard. Rain gardens are low lying, shallow depressions in the ground that are often filled with native plants and permeable stone material which promote temporary water storage and efficient infiltration of rainwater runoff. Rain gardens generally rely on curb cuts or storm drain to route runoff into the garden area, where runoff is collected and then infiltrated into the landscaping, filter media, and underdrain system.

GI BMPs promote infiltration and ground water recharge. When sized and sited ideally BMPs can reduce or eliminate runoff for smaller more frequent precipitation events, thus relieving the more traditional storm drain infrastructure. Both rain gardens and bioswales promote infiltration via the use a highly permeable filter media, generally a sand, topsoil, compost mix. Well landscaped rain gardens can also mitigate for the "heat island" effect often created by large impervious areas.

Selection Rationale

Selection of proposed GI BMPs should be based on constructability, space constraints, and long term maintenance constraints.

Bioswales have been proposed along railway corridors because they are well suited for draining long linear drainage areas. They can be placed along existing corridors and can be fit into very tight rights-of-way. They can also be installed in place of existing open channel and storm drainage systems. Due to the proposed location the construction of the bioswales would need to be reviewed to ensure compliance with FRA regulations.

Rain gardens have been proposed in the Wilmington Shops and Maintenance Yard site. These locations are well suited for the placement of rain gardens, where site drainage can be routed to small depressions located in landscaping areas adjacent to parking lots and maintenance yards.

Pros and Cons Summary

These measures can be used in place of installing additional storm drain lines and catch basins. They can not only be an effective method of handling runoff, but can also serve to provide water quality treatment for downstream surface water bodies. These measures can also be implemented as part of a landscaping plan to provide aesthetically pleasing stormwater infrastructure.

GI BMPs take up more space and often require more landscaping work as well as more maintenance and monitoring than traditional storm drains. Initial construction and long-term maintenance of these facilities can be more costly than traditional storm drain. Also, these facilities cannot always handle major flooding events and so generally bypass and underdrain storm drain infrastructure does need to be constructed, although this infrastructure is generally smaller and less expensive than a traditional storm drain line would be.

GI BMPs may be the most cost effective method of reducing future increases in runoff volume and providing protection against flooding or ponding issues under current as well as future conditions.

Potential Ponding Areas

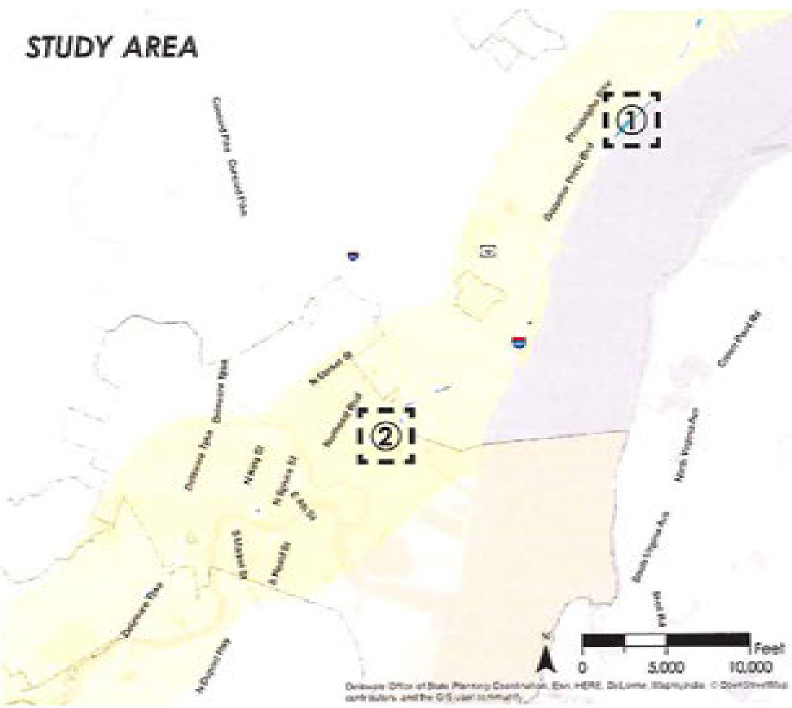
Adaptation Measures for Precipitation

Green infrastructure techniques, such as bioswales and rain gardens, are becoming more commonly installed to help reduce and treat stormwater. Conventional "gray infrastructure" is designed to quickly move stormwater away from a site. However, many urban stormwater systems of catch basins and pipes will flood during certain storm events, leaving the water with nowhere to go. Green infrastructure mimics natural systems to assist communities with flood protection and water treatment.

Installation of these best management practices (BMPs) in certain areas may help offset future projected increases in rainfall.

AMTRAK Stantec

STUDY AREA



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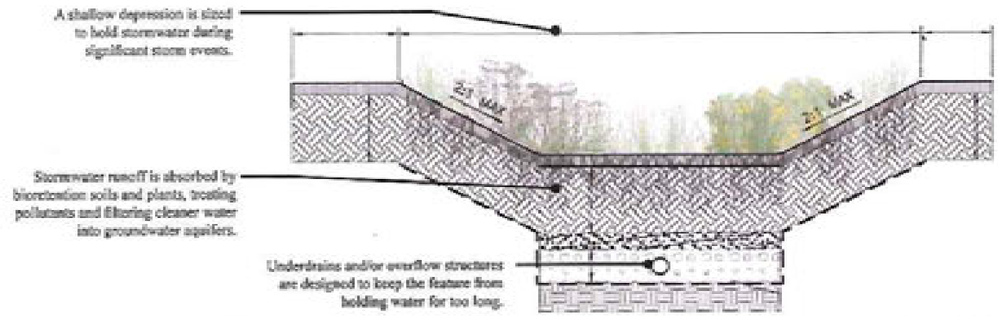
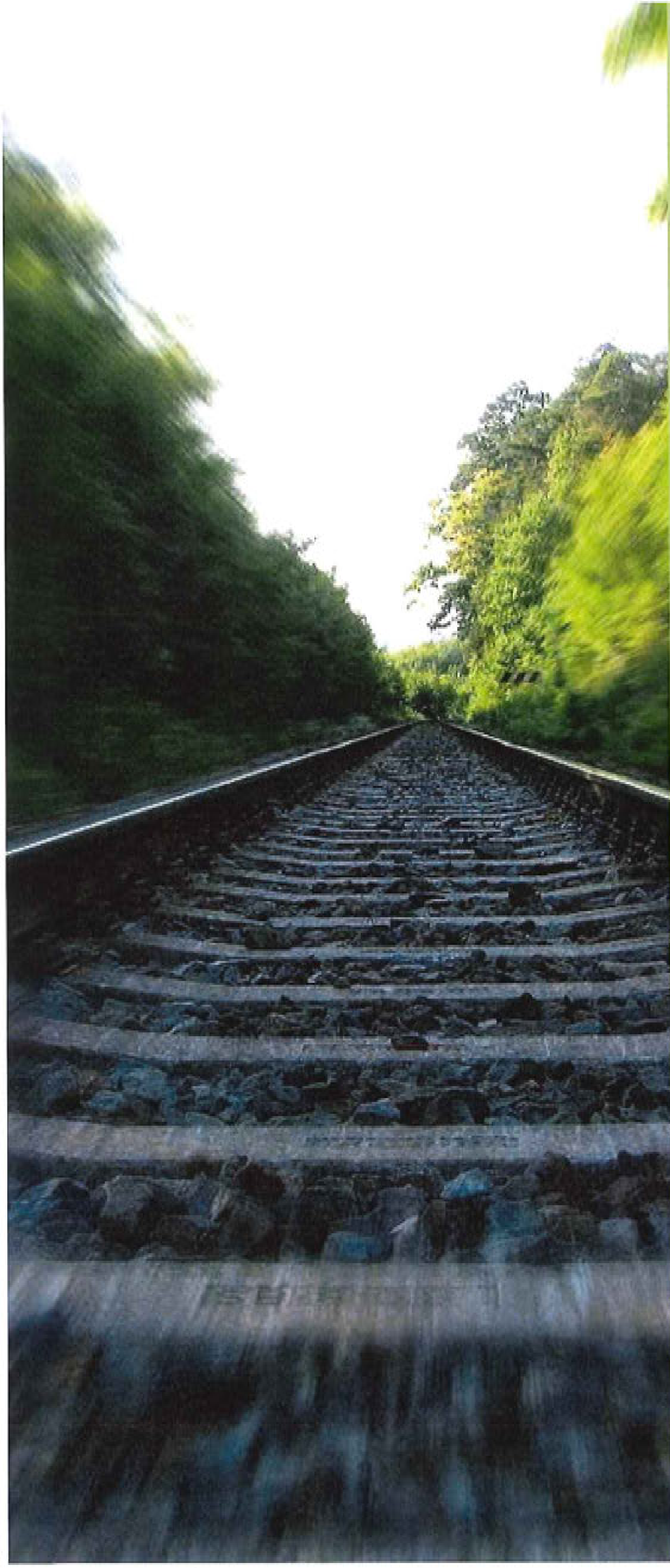




Permitting Requirements and Considerations

3.5 Permitting Requirements and Considerations

Permitting requirements and considerations can be categorized into several categories; ownership, environmental, and construction. The types of permits necessary will vary based on the asset location and chosen adaptation measures. It is possible that temporary emergency measures would qualify for emergency authorization through such agencies as the US Army Corp of Engineers (USACE). When evaluating the adaptation measures before an emergency, it is important to consider the regulatory requirements, anticipated environmental and property impacts, and the permitting timeline. It is important to note that this is not an exhaustive list of possible permits, but a discussion of the most likely permits to be encountered. Amtrak is not typically subject to executive orders but if a funding mechanism triggers it, Amtrak may need to comply with the National Environmental Policy Act (NEPA) and the National Historical Preservation Act (NHPA) for larger area-wide projects.

3.5.1 Easements and Ownership

Coordination with surrounding stakeholders will be necessary when proposed adaptation measures affect property outside of Amtrak's current ownership or easements. This occurrence is likely when proposing adaptation measures along the track outside of Amtrak's right of way or for area-wide adaptation measures. Area-wide adaptation measures will most likely need to be deployed or installed outside of Amtrak property. Coordination for the area-wide adaptation measures should begin early in the process involving all affected stakeholder discussion about ownership and easements will be part of this overall process.

3.5.2 Environmental Permits and Reviews

Adaptation measures that will impact wetlands and/or waters of the US will require authorization from the USACE and the Delaware Department of Natural Resources (DNREC). Authorization from the Wetlands and Subaqueous Lands Section (WSLS) is required for all activities in tidal and non-tidal wetlands within Delaware. The WSLS issues various authorizations depending on the location and what type of activity is being proposed. Section 401 of the Clean Water Act requires states to certify that activities authorized by the federal government will not violate the State Water Quality Standard therefore DNREC also reviews projects that will be issued an individual permit from the USACE for water quality compliance and issues a water quality certification.

The USACE regulates impacts to wetlands and waterways under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. The type of permit required will depend largely on the type of adaptation measure and location. The USACE has a general permit for emergency actions that could be considered for actions deployed during a storm to protect assets. USACE has policies that direct that wetland impacts should be avoided when possible. If wetland impacts cannot be avoided, then compensatory mitigation is often required. Mitigation is typically accomplished in three ways; mitigation banks, in-lieu fee mitigation, and permittee responsible mitigation. USACE will coordinate with the federal wildlife agencies to review the proposed activity and possible impacts on local wildlife and habitat.

Environmental permits will be issued on a case by case basis and will require more detailed plans for the proposed activity. Additional information will need to be provided to the agencies including, but not limited to, a formal wetland jurisdiction, wetland report, wildlife surveys, soil, and hydrologic information.

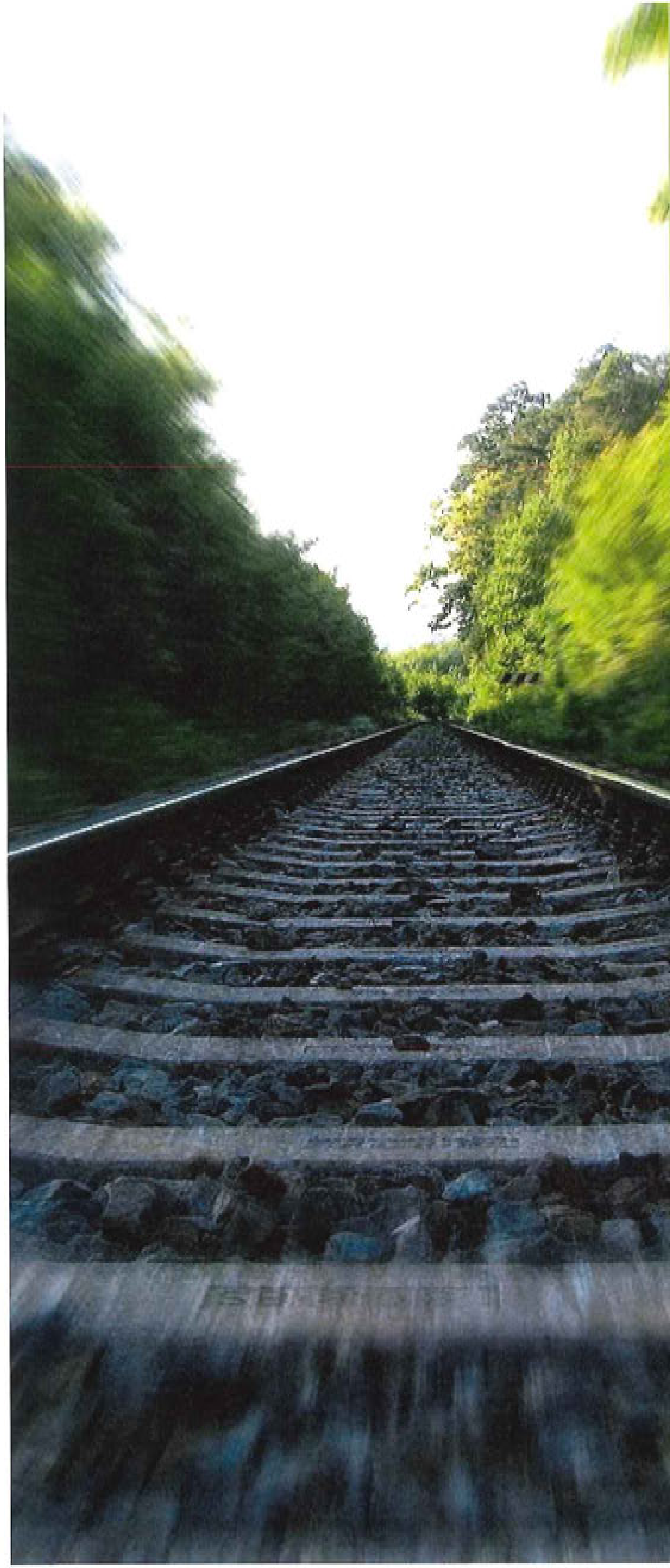
Based on the size of the area disturbed, a stormwater permit may be required, from the designate permitting agency (State or U.S. EPA), along with the development of an erosion and sedimentation control plan. The Amtrak Lead Environmental Specialist for the region should be consulted for review of permit applicability early in the process.

3.5.3 Floodplain Review

Adaptation measures that occur within the floodplain and receive federal grant funds will require compliance with Executive Order 11988/11990. (Note, Amtrak could be required to be compliant; a determination would have to be made regarding whether a particular funding mechanism would trigger their applicability.) This executive order establishes the eight-step planning process for floodplains and wetlands. This process includes:

1. Determining whether the proposed action is location in a wetland and/or 100-year floodplain
2. Notifying the public of the intended action
3. Completing an alternatives analysis
4. Identifying the full range of impacts to the floodplain
5. Minimizing the potential adverse impacts within the floodplain and wetlands
6. Re-evaluating the proposed action
7. Preparing a floodplain memo to explain the findings and decisions
8. Reviewing the implementation and post implementation phases

In addition to this evaluation process, if the proposed activity affects the hydrologic or hydraulic characteristics of a flooding source and thereby result in the modification of the existing regulatory floodway, a Letter of Map Revision (LOMR) from FEMA could be required.



Initial Benefit Cost Analysis

3.6 Initial Benefit-Cost Analysis

The Benefit-Cost Analysis used information provided by Amtrak and other researched sources, and an applied engineering methodology to analyze the costs and potential quantitative benefits for the various assets and adaptation measures.

3.6.1 Costs

Initial expenditures were determined for each project associated with individual Amtrak asset adaptation measures as outlined in the individual adaptation sheets. Adaptation measures consisted of permanent projects (solid concrete walls), semi-permanent projects (4-feet concrete knee wall with deployable flood barrier) and deployable solutions (deployable flood barriers). For this BCA review, the following adaptation measures listed in Table 2 were assumed.

Table 2. Project Adaptation Measures

Amtrak Infrastructure	Adaptation Measure Type	Adaptation Measure
Building/Substation Protection		
Wilmington Shops and Maintenance Yard	Deployable	Flood Full Wall Barrier
Consolidated National Operations Center	Deployable	Flood Full Wall Barrier
Wilmington Station	Deployable	Flood Full Wall Barrier
Training Center	Deployable	Temporary Flood Barrier
Bellevue Substation	Permanent	Solid Concrete Wall
West Yard Training Center Substation	Permanent	Solid Concrete Wall
Rail Protection		
Mile Post 21.0 to 21.5	Semi-Permanent	4-Feet Concrete Knee Wall with Deployable Flood Barrier
Mile Post 21.5 to 22.0	Semi-Permanent	
Mile Post 24.0 to 24.5	Semi-Permanent	
Mile Post 28.0 to 28.5	Semi-Permanent	

The costs associated with the adaptation measures from Table 2 were determined for protection to withstand the 2050 SLR, 100-year and 500-year event.

Lifecycle costs for each project consider initial capital costs, but do not include annual expenses required to maintain the measure over the design life. These costs can vary depending on the size and location of the adaptation measures and should be investigated if a specific adaptation measure is being considered for implementation and/or design. Capital cost estimates are based on local knowledge and resources. Based on this information, a net present value (NPV) representing the lifecycle cost was computed based on a discount rate of 7% over the useful life of the project per guidance from Office of Budget and Management (OBM) Circular A-94, revised October 29, 1992.

Table 3 below details the costs associated with the 2050 SLR, 500-year level protection and adaptation measures.

Table 3. Initial Expenditures for Infrastructure Protection

Amtrak Infrastructure	Lifecycle Cost Calculation		
Component/Activity	Initial Expenditure	Design Life (YFN)	Lifecycle Cost (NPV)
Building/Substation Protection	**$30,382,500**	**50**	**$30,382,500**
Wilmington Shops and Maintenance Yard	$19,800,000	50	$19,800,000
Consolidated National Operations Center	$2,500,000	50	$2,500,000
Wilmington Station	$2,600,000	50	$2,600,000
Training Center	$662,500	50	$662,500
Bellevue Substation	$2,410,000	50	$2,410,000
West Yard Training Center Substation	$2,410,000	50	$2,410,000
Rail Protection	**$47,520,000**	**50**	**$47,520,000**
Mile Post 21.0 to 21.5	$11,880,000	50	$11,880,000
Mile Post 21.5 to 22.0	$11,880,000	50	$11,880,000
Mile Post 24.0 to 24.5	$11,880,000	50	$11,880,000
Mile Post 28.0 to 28.5	$11,880,000	50	$11,880,000
Total	**$77,902,500**	**50**	**$77,902,500**

3.6.2 Benefits

The Wilmington, DE region is at risk of flooding from coastal storm events including tropical storms, hurricanes, and nor'easters, a risk that is increasing due to the threat of sea level rise. The adaptation measures were selected with the intention of helping Amtrak achieve a safe and resilient baseline for the critical infrastructure needed to support their current customers and seek future growth while keeping in mind any impact from future climate change.

Resilience benefits for the Amtrak projects focus primarily on avoidance of damages and impacts associated with flooding. Avoiding damages or inducing cost savings should be key considerations in risk mitigation and adaptation planning. In this case, the savings are a result of avoiding damages from the flood related impacts. The adaptation measures seek to reduce future expenses and reduce the amount of property damage in the event of a natural disaster. For this analysis, benefits were calculated as damages avoided through protection of infrastructure and through avoidance of direct revenue lost through loss of service. Building the flood barriers would be an expenditure now; however, because they are mitigation projects, benefits are expected to be realized in the future. The benefit-cost analysis results described in the next section summarize the expected costs versus the expected benefits.

> Induced savings are the benefits received once a project is implemented.

3.6.3 Preliminary Results

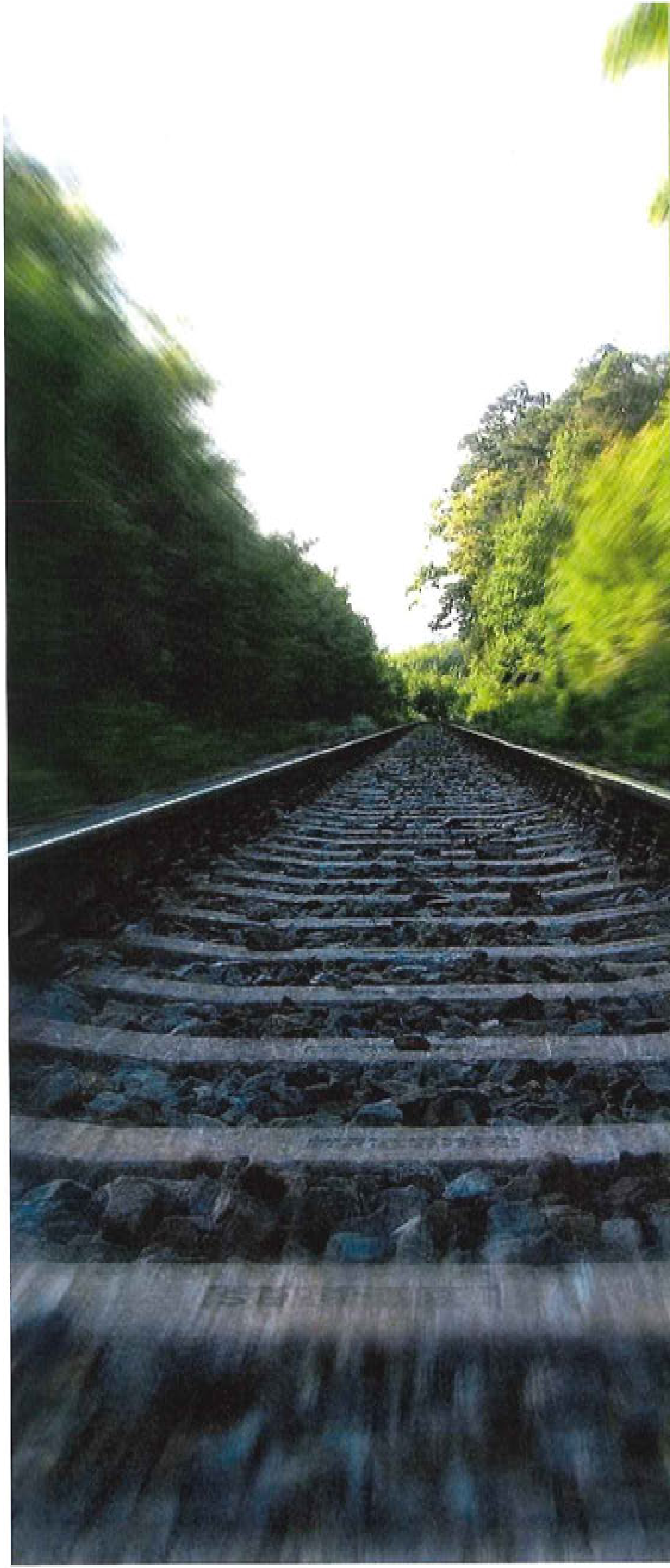
Benefit-cost ratios, as well as net-benefit values, were produced for each project to serve as an indicating metric of the value added. A full analysis was not performed as part of this BCA. (b) (5) [redacted] (b) (5) [redacted] (b) (5) [redacted] It is believed if additional information was provided regarding the total loss of revenue resulting from a shutdown of the various assets not only to Amtrak but to the surrounding community, the NPV numbers could be different. Other items that could be quantified and factored into the analysis include but are not limited to: environmental, social, economic and resiliency factors. It is recommended that the BCA be expanded for specific adaptation measures if they are being considered for future planning efforts or implementation.

> Net-benefit values provide the net present value difference between Project Benefits and Lifecycle Costs.

Table 4. Benefit-Cost Analysis Summary

Amtrak Infrastructure	Costs		Benefits	
Component/Activity	Lifecycle Cost	Benefits	Benefit-Cost-Ratio (BCR)	Net Present Value (NPV)
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]
(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]	(b) (5) [redacted]

Amtrak Infrastructure	Costs		Benefits	
Component/Activity	Lifecycle Cost	Benefits	Benefit-Cost-Ratio (BCR)	Net Present Value (NPV)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
Total	(b) (5)	(b) (5)	(b) (5)	(b) (5)



Potential Funding Opportunities

3.7 Potential Funding Opportunities

To develop and implement a climate change strategy that addresses identified vulnerabilities and adaptation measures, it is critical to understand the potential funding opportunities. The first resource that must be considered for climate change and adaptation measures should be Amtrak's own capital

improvements budget. There are two main reasons for considering these measures within the agency's capital improvements budget. One, it begins to exhibit a commitment to facing the vulnerabilities of climate change proactively and helps drive a culture change. The Northeast Corridor Infrastructure and Investment Development Business Line (NECIID), which focuses on advancing network planning, conceptual design, commercial partnerships, infrastructure access and funding, and financing strategies that support the future needs of Amtrak's infrastructure is a positive step toward promoting proactive adaptation measures in the face of climate change. Second, these internal dollars can typically be leveraged through other funding opportunities. Depending on the funding source these leveraged dollars can be substantial and offer a huge opportunity for an entity like Amtrak to explore multiple options for adaptation measures. The remainder of this section will provide an overview of what existing and potential opportunities are available as funding sources.

Amtrak, has typically received funding for adaptation measures through High-Speed and Intercity Passenger Rail (HSIPR) and Transportation Investment Generating Economic Recovery (TIGER) grant programs managed by the Federal Railroad Administration (FRA), as well as the Department for Homeland Security (DHS), the Department of Transportation (DOT), and others. These projects have ranged from rail, bridge and tunnel resilience retrofits, to transportation infrastructure security activities through FEMA's Interagency Passenger Rail Program (IPR).

Programs and funding are needed to develop the capacity to adequately plan for adaptation, and to implement climate adaptation strategies. Each of the strategies described within this study will require funding, through internal or external sources, or a combination of both. The number and range of funding opportunities for climate change adaptation measures can be overwhelming and can vary daily. A current search for climate change adaptation grants on Grants.gov found 80 grants for adaptation, 503 grants for climate change, and 71 grants for resilience. Each grant should be vetted for available funding options and eligibility criteria, internal budget impacts from leveraged funds, and project maintenance costs. In addition, a legal review should be completed. Amtrak, should also explore various jurisdictional funding opportunities (federal, state, local, private non-profit organizations, and financing options) when considering the funding of adaptation measures.

The federal funding opportunities come in multiple formats. Some are competitive, while others are formula based programs that an entity may already be receiving. As mentioned above, these dollars often require a match so being proactive and being able to procure the matching funds can be advantageous. State funding is also available for adaptation measures, and many of Amtrak's partner states have provided dollars toward adaptation measures in the past. Local funding opportunities can also be used in the forms of user fees, and tend to be more flexible. Private non-profit groups such as the Rockefeller Foundation, Kresge Foundation, and others are now heavily involved in financing climate change adaptation initiatives and can provide expertise. Government financing options such as bonds, loans, and Tax Increment Financing (TIFs) have also been used to finance adaptation measures. Lastly, another option for funding is to review public-private partnerships (PPP). PPP's provide innovative approaches to leverage private capital along with government capital.

The EPA Smart Growth Grants offer grants that support activities that improve the quality of development and protect human health and the environment. The Office of Sustainable Communities manages these grants. The US Department of Housing and Urban Development (HUD), the US DOT, and the EPA work together to help communities nationwide improve access to affordable housing, increase transportation options, and lower transportation costs while protecting the environment through their Partnership for Sustainable Communities program.

FEMA offers several options for funding adaptation measures. Amtrak is not considered a public entity by FEMA and, is therefore, limited on what it qualifies for and how it applies for grants. FEMA has two main categories of grants: non-disaster grants and disaster relief grants. Amtrak qualifies for the FEMA Non-Disaster Grants, such as Emergency Management and Corporate Security (EMCS) grants that fund entities to enhance their capacities to prevent, respond, and recover from a range of hazards. Amtrak has previously received funds for EMCS and Automated Data Processing (ADP) security-focused activities.

The second set of FEMA grants available are the FEMA Hazard Mitigation Assistance (HMA) grants that provide funding to protect life and property from future natural disasters. Since Amtrak is not considered a public entity, it is not qualified to receive these grants. Eligible applicants for these funds include: State, Territory, Federally-recognized tribe, community, or private non-profit entities. It is possible that Amtrak can apply for funds under the umbrella of an eligible applicant. Another avenue to acquire these funds can be achieved under the category of critical infrastructure, for which Amtrak would have a strong argument.

As mentioned it is imperative to develop a strategy that helps identify funding resources. This strategy should have a prioritization process and be flexible in terms of evaluating the right funding combinations both internally and externally.

Overall Amtrak Adaptation Strategy

4.0 Overall Amtrak Adaptation Strategy

4.1 Background

In response to climate change, Amtrak has systematically taken several steps to understand their specific vulnerabilities along the Northeast Corridor (NEC) and prepare for the future. These steps include:

1. implementing a corporate-wide Sustainability Policy,
2. completing a Phase I climate change study focused on compiling climate change research and methodologies related to transportation assets and vulnerability assessments,
3. Establishing a multi-disciplinary Climate Change Subcommittee as part of the Environmental and Sustainability Management System Committee, and
4. conducting a Vulnerability Assessment Pilot Study.

These steps are leading to the overall objective of Amtrak's Climate Change Program, which is to adapt its infrastructure and operations to be more resilient to the effects of climate change. This overreaching long term goal will take a continuous effort and involve many interim steps but is necessary to ensure the safe and continuous transportation of Amtrak patrons. One of the last steps in this process is to develop an organizational adaptation strategy as part of the overarching climate change strategy that establishes Amtrak's management position and provides direction on the necessary steps to make Amtrak's assets and operations more resilient. The implementation of this strategy throughout the organization is necessary to successfully implement climate change resiliency into Amtrak's policies and standards.

4.2 Adaptation Strategy Purpose

The purpose of the overall Climate Change Adaptation Strategy is to establish short term and long-term actions that Amtrak can implement to protect and reinforce its assets and infrastructure and ensure long-term sustainability of its passenger rail operations. This strategy provides Amtrak's management direct actions that can be implemented to adapt to changes in sea level rise, storm surge, temperature, and severe weather events. Flooding resulting from sea level rise and storm surge threatens not just Amtrak's rail lines but also the supporting buildings, substations, and yards. Temporary shutdowns not only affect daily travel but erode patron's long term trust and overall use. Temporary or permanent impacts to stations and training facilities can reduce efficient operations for that area and potentially have company-wide implications depending on the asset. Thus, this adaptation strategy stresses the importance of a holistic approach across Amtrak's organization in the areas of capital improvement planning, design, and construction; passenger rail operations, and assets management including maintenance. This strategy also serves as a supplement to Amtrak's overarching Sustainability Plan. A key aspect of this strategy is outreach and training of Amtrak's personnel responsible for planning, design, operations, and maintenance of the Amtrak system.

4.3 Implementation Strategies

Amtrak's preparedness to address the threats posed by climate change and Amtrak's ability to achieve program goals require (1) identifying specific near-term actions to respond to the weather threats currently facing Amtrak and (2) creating a process to identify and address long-term threats exacerbated by climate change (such as sea level rise). The five-element implementation strategy that follows provides a general road map for scoping near-term and long-term preparation and response.

Strategy Element 1: Review current planning and design practices and standards to consider asset and operational resiliency in future projects

Strategy Element 2: Evaluate current operations including maintenance and emergency management practices

Strategy Element 3: Enhance the organizational understanding of longer-term threats to Amtrak's asset posed by the prospect of a changing climate and the need for adaptation

Strategy Element 4: Develop adaptation approach recommendations for existing assets and new projects to increase their resiliency to a changing climate

Strategy Element 5: Develop metrics to track adaptation measure performance and provide feedback for continual improvement

Strategy Element 1: Review current planning and design practices and standards to consider asset and operational resiliency in future projects.

Amtrak's Climate Change Strategy Subcommittee is preparing an overall climate change strategy statement in which a process is established to integrate climate change considerations into current and future planning, design, and construction of their infrastructure. It is becoming more imperative that Amtrak consider the impacts of climate change in their planning and design standards. Extreme weather events are a current threat and a daily reminder of the damage that can be caused by flooding and inundation. Climate change models demonstrate an increase in sea level rise, storm surge, as well as changes in precipitation and temperature, that should be accounted for in Amtrak's current policies and standards. Thus, Amtrak's strategy includes:

- Establish a working group made up of various discipline leads to:
  - Review the current design standards to evaluate how they currently account for precipitation and flooding events. Typically design standards take into consideration historical rainfall and storm events and do not consider future climate changes.
  - Modify the existing planning approach to incorporate regional resiliency based decisions grounded on climate variables. This approach includes consideration for climate change in environmental planning and compliance activities and processes.

- Utilize information from the Phase I and Phase II Study to begin to formulate an understanding of the general climate change trends and how this will affect future planning and design projects.
- Investigate how other modal agencies are addressing climate change in their planning and design standards. As an example, the Rail Safety and Standards Board (RSSB) completed a Climate Change Adaptation Plan in 2016. The overall objective of this report was to enhance and disseminate knowledge within the Great Britain (GB) railway industry about how climate and weather are projected to change in the future, the potential impact on the GB railway, what is already being done by the GB rail industry to respond and adapt, and what else can be done.
- Prepare a memorandum outlining the information gathered by the working group and identify the necessary next steps. The next steps should summarize the actions required to propose modifications to the planning and design standards. This memorandum should be presented internally to Amtrak leadership to solicit feedback and gain support for the initiative. Based on the recommendations of this memo and senior management input, Amtrak should provide supplemental guidance or revise the applicable policies, processes, and standards.

Strategy Element 2: Evaluate current operational procedures including maintenance and emergency management practices

Amtrak has current operational procedures that account for extreme weather, including decreased train speeds during episodes of high wind or heavy rain. These operational procedures are initiated daily, when necessary. Current operational procedures should be reviewed in light of the predicted increases in temperature, precipitation, and extreme weather events. In addition, increases in sea level rise and storm surge can exasperate the effect of these events. For example, an area that previously did not flood during a typical summer storm may begin to experience more common nuisance flooding. The review of these operational procedures will allow Amtrak to be more prepared for extreme weather events and should include the following steps.

> Amtrak engages in a regular year-round, tree-trimming program to proactively minimize impacts to the catenary system and passengers caused by winter storms**Invalid source specified.**.

- Regularly scheduled maintenance and preventative maintenance activities in advance of predictable weather events should also be reviewed to determine if current practices are robust enough to handle future weather patterns.
- Establish a working group made up of various discipline leads to take a comprehensive look at current asset operation, maintenance activities and schedules, and emergency management practices for implementation of measures to prepare for the short-term extreme weather events and long-term climate change impacts.

- Review maintenance activities and emergency management practices in light of predicted increases in temperature, extreme weather, sea level rise and storm surge. Examples of this include:
  - Implement a more rigorous tree trimming protocol to remove all potential threats to the catenary system during high winds.
  - Implement a visual assessment along the tracks for objects that could become movable during high water or high winds and block the tracks.
  - Increase visual inspections of the tracks after episodes of extreme heat.
  - Review emergency response protocols for extreme weather and flooding in light of the potential climate change impacts.
- Establish or update set protocols for preventative maintenance as part of emergency planning to make the rail system more resilient to severe weather events.
- Review safety protocols for staff and passengers considering increased temperatures, wind, and extreme weather. Safety protocols should set limitations on when it is safe for maintenance crews to be outside and establish procedures for working in extreme temperatures. Passenger safety should focus on the platform and within the train. For example, how passengers are going to be kept cool on the platform during an episode of extreme heat.

Strategy Element 3: Enhance the organizational understanding of long-term threats to Amtrak's asset posed by the prospect of a changing climate and the need for adaptation

Sharing the information obtained during Phase I and Phase II of the Climate Change studies as well as the work being completed internally by the Climate Change Strategy Subcommittee is essential to the eventual implementation of a successful Adaptation Plan. Adaptation Planning and eventual implementation is the point in the framework where activities begin to shift from planning to implementation. This requires understanding and support from the entire organization since funding may be needed and cooperation from those people that will be involved in the design, construction, implementation, or maintenance activities is imperative. A targeted education campaign is needed to assimilate climate change into Amtrak's culture. The following steps are recommended to successfully present this information to the various stakeholders:

- Hold a workshop with Amtrak's senior management during which the information gathered and lessons learned during the Phase I and Phase II studies will be presented. This presentation should use the framework to illustrate the process and the work completed to date. The intent of the workshop is to present the information collected to date to illustrate the need for Adaptation Planning. This workshop also provides an opportunity to discuss preliminary Adaptation Planning information, including the results of Strategy Element #1, and #2 if completed, and to formulate the necessary steps moving forward.
- Launch a climate change roadshow in which the information and lessons from Phase I and Phase II are presented to a selected audience. The audience should include those that could potentially be impacted by the future implementation of adaptation measures.

- Utilize email to inform Amtrak staff about the threats posed by climate change and integrate Amtrak's climate change message into the culture as well as alternative ways of passing on information for those that do not have email access.

Strategy Element 4: Develop adaptation approach recommendations for existing assets and new projects to increase their resiliency to a changing climate

Identifying the most applicable and efficient adaptation measure is dependent on several factors including location, vulnerability, criticality, cost, and benefit. These factors make up the backbone of the overall assessment which will vary from asset to asset. This approach is only as strong as the amount of information included and, therefore, should be made as detailed as possible. Identifying an adaptation approach for a specific region allows for a more generalized implementation strategy. When considering a whole region in contrast to a specific asset the adaptation approach must consider a variety of adaptation measures and can consider area-wide measures. It also allows for a comprehensive evaluation that may result in eliminating some assets from consideration or grouping assets and looking at them as a whole. An adaptation approach would outline the steps necessary to identify the best adaptation measure as well as provide a menu of possible adaptation measures. Separating the approach by region is important because the impact of predicted climate change effects varies depending on the location within the U.S. In order to develop adaptation approach recommendations, it is necessary to:

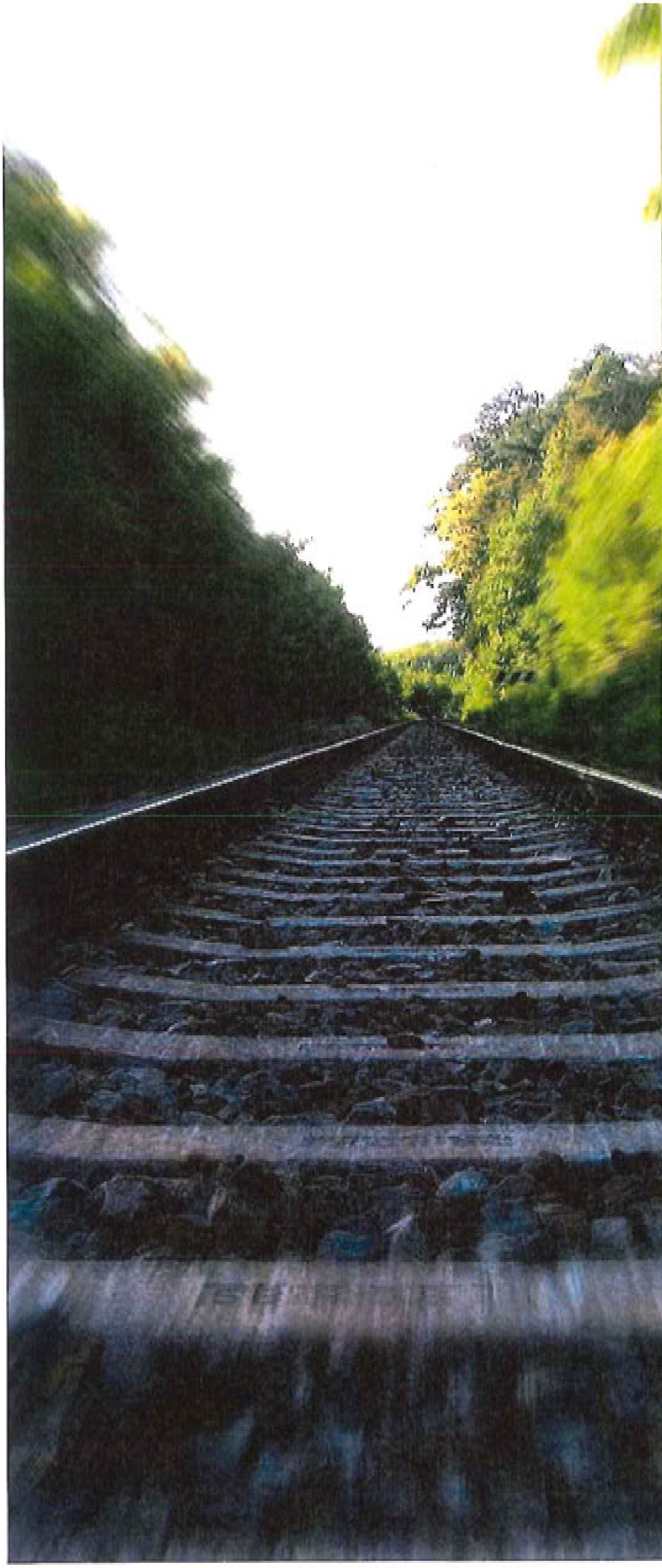
Separating the approach by region is important because the impact of predicted climate change effects varies depending on the location within the U.S.

- Identify the regional breakdowns based on the location and vulnerability of Amtrak's assets and an understanding of regional climate change predictions.
- Compile a database of assets that are vulnerable to the climate variables including sea level rise, storm surge, and changes in precipitation, temperature, and/or wind patterns. This wide spread assessment can be completed using existing climate model predictions thereby reducing the initial effort and allowing Amtrak to refine the analysis once an area or asset has been targeted for adaptation.
- Compile information regarding the criticality of Amtrak's various assets. This can be best achieved by grouping assets of similar function, i.e. train station, maintenance shop, track.
- Establish a database of typical adaptation measures that can be deployed when needed to increase asset resiliencies. This database should include:
    - a description of the adaptation measure,
    - what climate variable it mitigates for cost of adaptation measure,
    - durability,
    - deployment time, and
    - other characteristics that allow Amtrak to make quick and easy decisions regarding their use.

Strategy Element 5: Develop metrics to track adaptation measure performance and provide feedback for continual improvement

Although this step is not expected to be applicable in the near future, in the long term, a successful Adaptation Plan needs to provide feedback on the performance of the adaptation measures as they are deployed. The implementation of adaptation measures to increase resiliency to climate change is relatively new in the United States and information regarding the success of these measures is limited. In order to increase the benefit to cost ratio it is necessary to implement efficiencies in deployment and maintenance thereby reducing the overall cost. A successful monitoring plan will include the following components:

- Establish a qualitative protocol based on visual observation that can be easily understood and implemented by maintenance staff.
- Establish a regular schedule in which inspections should be completed and assign the responsibility to an Amtrak staff member or division.
- Establish a tracking database in which the collected data can be easily stored and accessed overtime.
- Information collected should include details about maintenance, durability, and success rate during storm events.



(b) (5)

Amtrak Infrastructure	Costs			Benefits (NPV)		
Component/Activity	Initial Expenditure	Design Life (YFN)	Lifecycle Cost (NPV)	Benefits (NPV)	Benefit-Cost-Ratio (BCR)	Net Benefit Value (NPV)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5) (b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)
Total	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)	(b) (5)

(b) (5)

(b) (5)

Client: Amtrak
Phase III - NEC Climate Change
Project: Adaptation Study
Activity: Building/Content Damages

Date: 9/15/2016
Performed by: DTH
Reviewed by: JW

(b) (5) [redacted]

(b) (5) [redacted]

(b) (5) [redacted]

(b) (5) [redacted]

(b) (5) [redacted]

Client: Amtrak

Phase III - NEC Climate Change

Project: Adaptation Study

Activity: Building Loss of Service

Date: 9/16/2016

Performed by: DTH

Reviewed by: JW

(b) (5)

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Client: Amtrak
Phase III - NEC Climate Change Adaptation
Project: Study
Activity: Railway Loss of Service

Date: 9/16/2016
Performed by: DTH
Reviewed by: JW

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Client: Amtrak | Date: 9/16/2016

Project: Phase III - NEC Climate Change Adaptation Study | Performed by: DTH

Activity: Building Loss of Service | Reviewed by: JW

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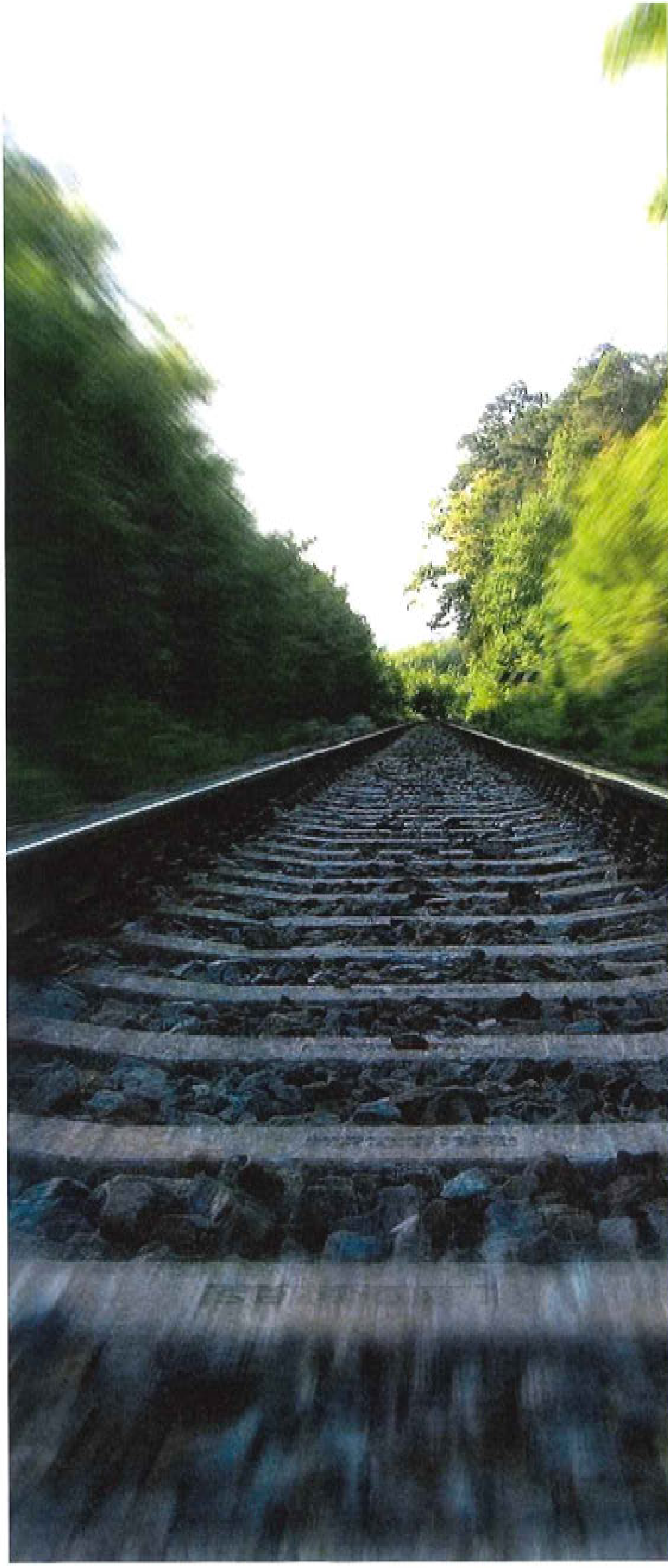

Appendix B - Glossary

Glossary

- **Adaptive Capacity** - the ability of a system to adjust to climate change (including climate variability and extremes) to take advantage of opportunities, or to cope with consequences.
- **Base Flood Elevation (BFE)** - the regulatory requirement for the elevation or floodproofing of structures. If a structure's elevation is lower than the BFE, the structure may require coverage under the National Flood Insurance Program (NFIP).
- **Climate Stressors** – climate variations that can enact stress on humans and the environment, also referred to as climate change variables. Examples include sea level rise, extreme temperatures, and increased precipitation.
- **Dry Floodproofing** – sealing the perimeters of a building (exterior walls, windows, and doors) to make it watertight. This can be done by using a continuous *water-impermeable membrane* on walls, use of *watertight doors* or latching *flood shields* on windows and doors, and sewage *backflow valves.*
  - ***Water impermeable membrane*** – permanent sealant or temporary cover that is applied around the perimeter of a structure to prevent water absorption and leakage through walls and other openings.
  - ***Flood shield*** - watertight structural system that is manually placed in front of a window or door before a flood event.
  - ***Watertight door*** – engineered door that mechanically seals on all four sides, preventing water seepage.
  - ***Backflow valve*** – valve that prevents floodwater flow from backing up into the building through the sanitary sewer system.
- **Egress** – means of entry/exit through windows and doors, including the basement level.
- **Elevate building** – disconnecting an existing flood-prone building from its previous foundation to raise it to a height where the lowest interior floor is not vulnerable to flood hazards. A new foundation is built after the building is raised to its desired height.
- **Exposure** – the degree and nature to which an asset is exposed to significant climate stressors.
- **Flood Mitigation** – action(s) taken to reduce loss of life and property by lessening the impact of floods.
- **Floodplain** – an area of land that experiences flooding during periods of high rainfall, coastal surge, or upstream flooding.

- **Flood Protection** – efforts to prevent property damage from flooding.
- **Freeboard –** elevating a structure above the base flood elevation requirement to compensate for factors like climate change and extreme flood events. Freeboard significantly lowers flood insurance rates due to lower flood risk.
- **Geographic Information System (GIS)** – a computer system designed to store and display geographic data in map form, to understand local or national relationships, patterns, and trends.
- **Horizon year** – the projection year for which adaptation strategies are planned and analyzed. In this study, climate stressors and adaptation strategies were analyzed for the horizon years 2050 and 2100.
- **Intergovernmental Panel on Climate Change (IPCC)** - the leading international body for the assessment of climate change and its potential political and economic impacts.
- **Levee/Berm –** compacted earthen structures that run along a body of water or encircle a structure or group of structures in order to provide flood protection.
- **LIDAR**- Light detection and ranging and is a remote sensing method used to examine the surface of the earth.
- **National Climate Assessment** – a governmental interagency report conducted every four years which summarizes the impacts of climate change on the United States, now and in the future.
- **National Flood Insurance Program (NFIP)** – a Federal program, managed by the Federal Emergency Management Administration (FEMA), that provides flood insurance, develops flood risk maps, and establishes compliance for floodplain management enforcement.
- **Perimeter Barriers** – temporary inflatable barriers, water gates, or water panel systems that can be placed around a defined area to hold back water during flood events.
- **Quick connect/disconnect (for utilities)** – enables rapid disconnection from utilities, including natural gas lines. Reduces potential damage from buoyant equipment, flood debris and other considerations. Can be connected to emergency generators after flood.
- **Relocate building –** moving a flood prone building to an area less likely to flood, either by disassembling and reassembling it at the new site or separating it from the foundation and transporting the building as a whole.
- **Resiliency –** the 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).
- **Scour** – removal of underwater material by waves and currents, especially at the base or toe of a structure.

- **Sensitivity** – the degree to which an asset is affected, either adversely or beneficially, by climate-related variations. An asset's sensitivity to climate change stressors can be affected by age, materials, and location.

- **Storm Surge** – an abnormal rise in sea level accompanying a hurricane or other intense storm. Storm surge elevation is defined as the difference between the observed level of the sea surface and the level that would have occurred in the absence of the storm (EPA, 2014).

- **Sump Pump** – a pump used to remove water accumulation from minor leaking and seepage sustained during flood events, when using dry floodproofing, levee/berm, and temporary barrier mitigation.

- **Tolerance of risk** - the level at which humans and the built environment can endure or accept the effects of natural hazards and their increased frequency and intensity due to climate change.

- **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).

- **Vulnerability Assessment** – an inspection of a structure, building site, and area to determine the level of risk against known hazards.

- **Wet Floodproofing** – allowing flood waters to temporarily enter the enclosed areas of a building, thereby relieving pressure that can cause structural damage to the walls and foundation, and preventing buoyancy. This application should be used in conjunction with flood-resistant building materials and elevation of mechanical electrical components.

  — **Flood vents** – engineered vents that allow water to temporarily enter the building to prevent structural collapse of the walls and foundation.

  — **Flood-damage-resistant materials** - building products that can withstand the damages of flooding without having to be replaced. Building materials at or below the Base Flood Elevation (BFE) must be flood-resistant.