4. Resiliency and Sustainable Design

4.1. Introduction

This chapter presents an overview of climate change and vulnerability, including the USACE's most recent analysis of flood risks along the Connecticut coastline. It presents FTA and CTDEEP guidance documents that respond to climate change and risk, and it addresses the ways that the Walk Bridge Project will incorporate adaptation strategies focused upon resiliency and sustainability.

On January 29, 2013, the Disaster Relief Appropriations Act of 2013 (PL113-2)[1] made funds available for public transportation systems impacted by Hurricane Sandy. On December 26, 2013, FTA announced the availability of funds from the Public Transportation Emergency Relief Program and the Disaster Relief Appropriations Act for projects that will reduce the risk of damage from future disasters in the areas impacted by Hurricane Sandy.[2] The announcement specifically solicited proposals for resiliency projects, defined as "those projects designed and built to address current and future vulnerabilities to a public transportation facility or system due to future occurrence or recurrence of emergencies or major disasters that are likely to occur in the geographic area in which the public transportation system is located; or projected changes in development patterns, demographics, or climate change and extreme weather patterns."[3] CTDOT was one of ten applicants, and the "Replacement of Norwalk River Railroad Bridge on the Northeast Corridor (Walk Bridge Replacement Project)" was one of 61 eligible projects. On November 5, 2014, USDOT and FTA announced that the Walk Bridge Replacement project would be allocated funds through the Act.[4]

In its *Climate Change 2014 Synthesis Report*,[5] the Intergovernmental Panel on Climate Change issued the following findings:

- Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions.
- Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level will continue to rise.

Developing a resilient structure which provides for operational redundancy and which meets current design guidelines for extreme weather events is integral to the Walk Bridge Project purpose and need.

The need for resiliency is further emphasized for critical infrastructure such as Walk Bridge. Presidential Policy Directive 21 (PPD-21): *Critical Infrastructure Security and Resilience* identifies the transportation system as one of 16 critical infrastructure sectors in the United States whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation

[1] Public Law 113-2, H.R. 152, 127 Stat. 4, January 29, 2013
[2] 78 FR 78486
[3] 78 FR 78486 – Notice of Funding Availability for Resilience Projects in Response to Hurricane Sandy. http://www.gpo.gov/fdsys/granule/FR-2013-12-26/2013-30867
[4] 79 FR 65762
[5] Intergovernmental Panel on Climate Change, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. As a key component of the NHL, Walk Bridge is included within this definition of critical infrastructure by the U.S. Department of Homeland Security.[6] In accordance with PPD-21, critical infrastructure is required to be hazard resilient.

4.2. Climate Change and Natural Hazards Vulnerability

Multiple reports have identified the risks of climate change and vulnerability to natural hazards. In its *Hurricane Sandy Rebuilding Strategy*, August 2013, the Hurricane Sandy Rebuilding Task Force identified four sources of future risks to be addressed with hazard mitigation, recovery plans, and infrastructure rebuilding: extreme rainfall, hurricanes, winter storms, and sea level rise.[7] The City of Norwalk participates in multi-jurisdictional hazards planning through the Western Connecticut Council of Governments (WCCOG).[8] The *Natural Hazard Mitigation Plan*, approved by FEMA on 6/9/2011, serves as the City's plan that provides specific information related to natural hazards risk, capabilities, and mitigation strategies. Its latest update, the *Natural Hazard Mitigation Plan, Draft 2016-2021 Update for the South Western Region*, WCCOG identified a number of natural hazards to which the Southwestern Region is vulnerable. Severe storms with hail and/or damaging wind had an overall "high" risk ranking for the City of Norwalk. The following natural hazards had an overall "medium" risk ranking for the City of Norwalk: hurricane and tropical storms, severe wind, severe winter weather, and storm surge.[9]

The following sections describe natural hazards vulnerability along the Connecticut coast and in the vicinity of Walk Bridge.

4.2.1. Coastal Flooding

PL 113-2 directed the USACE to conduct a comprehensive study to address the flood risks of vulnerable coastal populations in areas that were affected by Hurricane Sandy within the boundaries of the USACE's North Atlantic Division.[10] In January 2015, USACE produced *The North Atlantic Coast Comprehensive Study (NACCS): Resilient Adaptation to Increasing Risk.*[11] The *NACCS* identified nine high-risk areas of the North Atlantic Coast that warrant additional analyses by USACE to address coastal flood risk; the Connecticut coastline was one of the nine high-risk areas.

The *NACCS* reported that coastal Connecticut is vulnerable to storm damage from wave attack, storm surge and erosion. Due to the east-west orientation of the southern shore in relation to the Atlantic Ocean, Connecticut is particularly vulnerable to storm surge flooding when winds from the northeast to east-southeast direction are greater than 30 mph and last for more than 12 hours, continuing through an astronomical high tide. Historically, most hurricanes striking the New England region have re-curved northward on tracks which paralleled the eastern seaboard maintaining a slight north-northeast track direction.[12] Since 1954, Connecticut has had 31storm-related FEMA-declared emergency and major disaster declarations, many of which involved coastal flooding and damages.[13]

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[6] http://www.dhs.gov/critical-infrastructure-sectors

[7] Hurricane Sandy Rebuilding Task Force. Hurricane Sandy Rebuilding Strategy; Stronger Communities, A Resilient Region, August 2013. http://portal.hud.gov/hudportal/documents/huddoc?id=HSRebuildingStrategy.pdf.

[8] Formerly the South Western Regional Planning Association.

[9] WCCOG, Natural Hazard Mitigation Plan, Draft 2016-2021 Update for the South Western Region.

[10] The USACE's North Atlantic Division includes ten states in the northeastern United States, extending from Maine to Virginia, and the District of Columbia.

[11] USACE. *The North Atlantic Coast Comprehensive Study (NACCS): Resilient Adaptation to Increasing Risk.* Main Report. Final Report. January 2015. http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NACCS_main_report.pdf.

[12] USACE. North Atlantic Coast Comprehensive Study, Appendix D.

[13] https://www.fema.gov/disasters/grid/state-tribal-government/31. Accessed 12/03/2015. Note that FEMA started naming storms in 1953.

The *NACCS* identified 15 vulnerable, high exposure areas along the Connecticut coastline, which included the area along the coast from Westport to the west side of Norwalk Harbor and up the Norwalk River to Cross Street. Key facilities identified by the *NACCS* in this high exposure area include Norwalk Harbor (a major port in the area), wastewater treatment facilities, and the major rail line connecting New York City to the northeast region.[14]

4.2.2. Sea Level Rise

The *NACCS* presented relative sea level change scenarios for four planning horizons for the NOAA water level gauge locations across the NACCS study area with measurement records equal to or greater than 40 years. The study concluded that relative sea levels are rising throughout the entire study area. Further, sea level rise will increase the areas exposed to storm surge and will increase the frequency of flooding. The study concurs with a similar analysis conducted in 2013 for the U.S. National Climate Assessment by NOAA, the U.S. Geological Survey, and the Department of Defense Strategic Environmental Research and Development Program. Both the USACE and NOAA estimates incorporate the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report global mean sea level change projections and are consistent with predictions from the IPCC Fifth Assessment Report.

Table 4-1 and Figure 4-1 present the relative USACE and NOAA sea level change scenarios anticipated at the Bridgeport, Connecticut NOAA gauge, which is located approximately 15 miles northeast of Norwalk and the study location nearest to Walk Bridge. USACE's "low scenario" estimate is a linear extrapolation of the historical sea level change records. USACE's "intermediate scenario" is based primarily on ocean warming. USACE's "high scenario" estimate is a combination of more limited ice loss and ocean warming. NOAA's "low scenario" and "intermediate low scenario" estimates are identical to USACE's "low scenario" and "intermediate scenario," respectively. NOAA's "high scenario" estimate is higher than USACE's "high scenario" estimate.

Table 4-1—Relative Sea Level Change Scenarios, Connecticut Coast

Horizon Year	Estimated Feet of Water Level Rise NOAA Gauge 8467150, Bridgeport, CT			
	USACE Low Scenario[a]	USACE Intermediate Scenario[b]	USACE High Scenario	NOAA High Scenario
2018	0.0	0.1	0.2	0.3
2068	0.4	0.9	2.5	3.3
2100	0.7	1.7	5.0	6.6
2118	0.8	2.2	6.7	8.9

Notes:
a. Identical to NOAA's "low scenario" estimate
b. Identical to NOAA's "intermediate low scenario" estimate.
Source: USACE North Atlantic Division, NACC

The State of Connecticut has not officially adopted a sea level change scenario. The Connecticut Institute for Resilience and Climate Change Adaptation, a joint partnership between the University of Connecticut and CTDEEP, currently is researching the impacts of climate change along the coast, including mapping shoreline change.[15]

[14] USACE. North Atlantic Coast Comprehensive Study, Appendix D.
[15] http://circa.uconn.edu/research/index.htm.

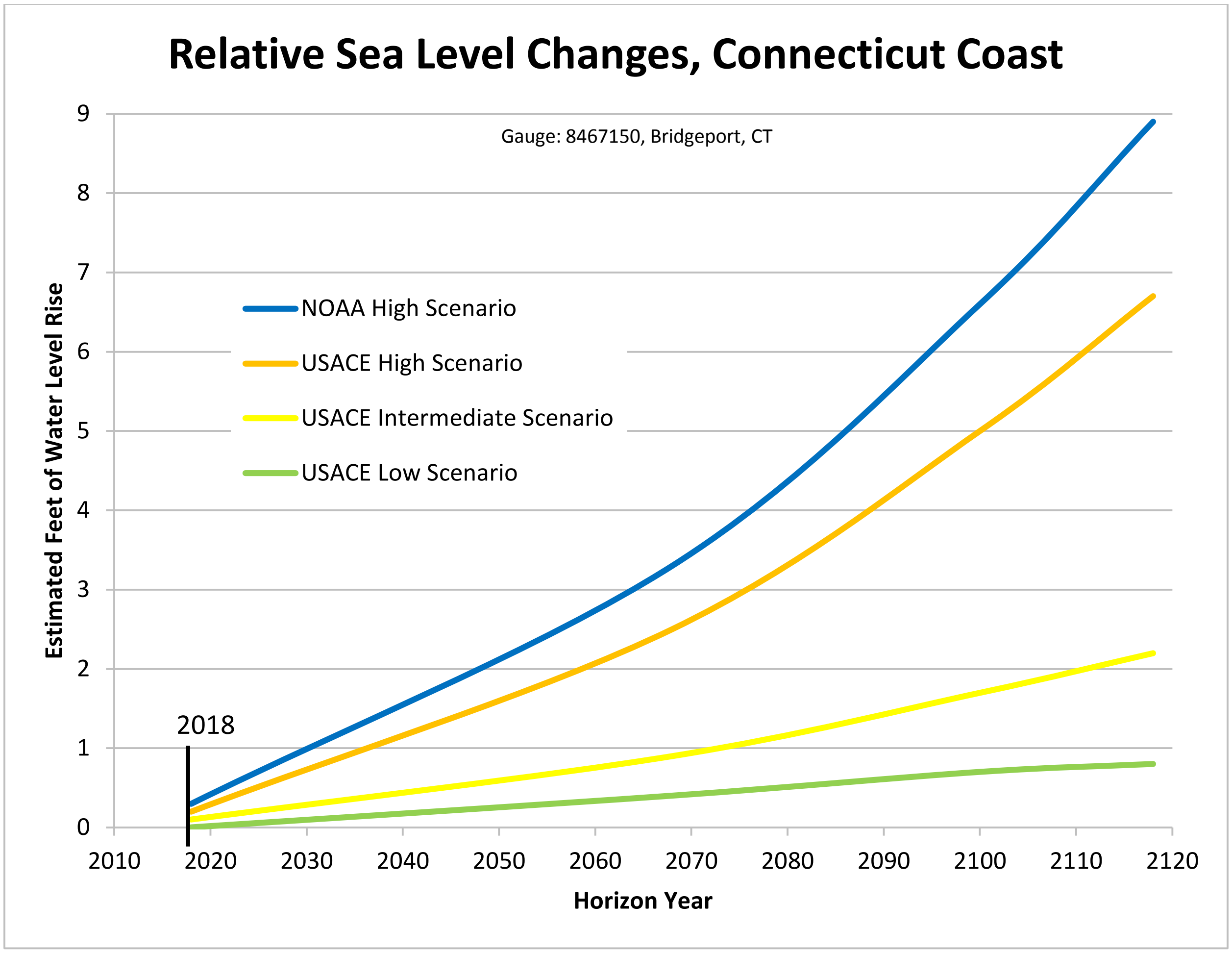


Figure 4-1—Relative Sea Level Change Scenarios, Connecticut Coast

As required by Public Act No. 08-98, "An Act Concerning Connecticut Global Warming Solutions," the Adaptation Subcommittee to the Governor's Steering Committee on Climate Change produced a report in 2010: *The Impacts of Climate Change on Connecticut Agriculture, Infrastructure, Natural Resources and Public Health*. With respect to the impacts of climate change upon infrastructure, including transportation, the report notes that changes in storm intensity and flooding, precipitation, and sea level rise present the most concern. The sensitivity of railroads to the impacts of climate change, particularly sea level rise and precipitation, is high, as many of railroads were constructed in floodplains and along coastal areas. The report indicates that the potential for adaptation is low, however, unless systems can be redesigned for future storms, flooding, and sea level rise.[16]

4.2.3. Hurricane Surge

The FEMA floodplain (shown on Figure 3-15) is based on a storm of a particular strength that currently has a 1-percent annual chance of occurrence. It is also useful to look at scenario-based storms, which can result in water levels that far exceed those anticipated during the 1-percent- annual-chance flood event. FEMA and the USACE have produced hurricane surge maps using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. The SLOSH model was developed using current NOAA storm surge

[16] Adaptation Subcommittee to the Governor's Steering Committee on Climate Change, *The Impacts of Climate Change on Connecticut Agriculture, Infrastructure, Natural Resources and Public Health*, April 2010.

modeling for Long Island Sound and does not include a parameter for sea level rise. SLOSH is based on tidal elevations, wind speed, and wind direction of a given event.

The SLOSH model hurricane surge maps show inundated areas based upon different categories of hurricanes, ranging in strength from Category 1 (with winds ranging from 74 to 95 miles per hour [mph] and coastal flooding with some damage) to Category 4 (with winds of 130 to 156 mph and catastrophic damage requiring extensive evacuations).[17]

Figure 4-2 shows the area around Walk Bridge that becomes inundated in the four categories of hurricanes. Note that although the figure shows hurricane Category 1 inundation at the western bridge abutment and tracks, the inundated area is not actually the bridge or tracks, but the ground under the bridge's west approach spans. Similarly, the small area of inundation at the eastern bridge abutment is actually inundated ground under the bridge's east approach spans.

Table 4-2 presents the elevations of key bridge elements on existing Walk Bridge and their ability to withstand inundation levels of different categories of hurricanes, based upon the peak water surface elevations of different events. The bridge's mechanical equipment for the center (pivot) pier is housed within the engine (machine) room. Additional mechanical equipment for the swing span is located below the engine (machine) room, very close to the top of pivot pier.

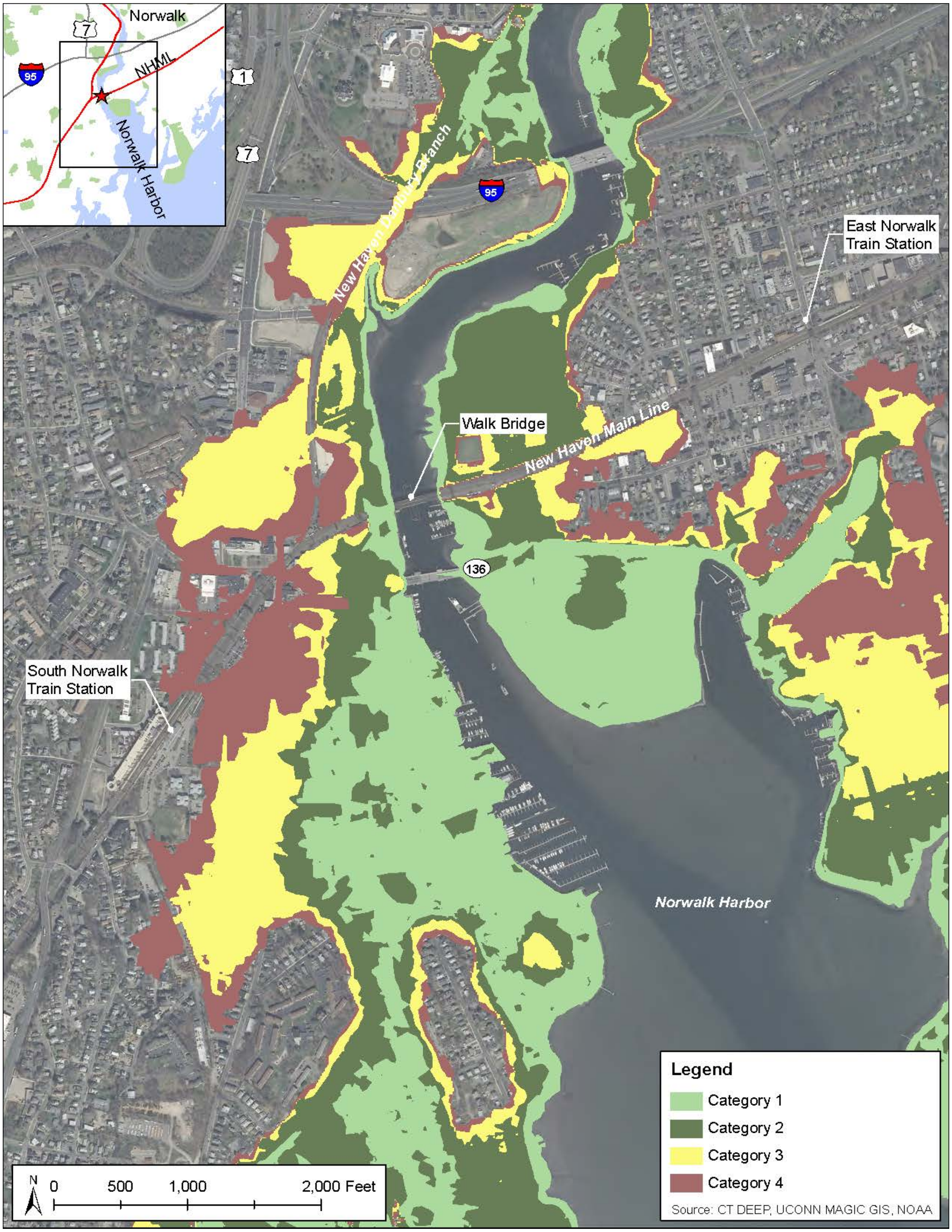
Table 4-2—Existing Walk Bridge Structural Elevations and Hurricane Resistance

Bridge Element	Approx. Elevation[a]	Resistance to Hurricane Inundation Levels[a]			
		Category 1 El. 9.2	Category 2 El. 14.1	Category 3 El. 19.0	Category 4 El. 24.4
Main Span Low Chord	19.8	yes	yes	yes	no
Approach Span Low Chord	18.0	yes	yes	no	no
Control House Lowest Floor	36.0	yes	yes	yes	yes
Engine (Machine) Room Floor	19.7	yes	yes	yes	no
Top of Pivot Pier	9.0	no	no	no	no

Note: a. Elevations shown in (NAVD88).

As shown in Table 4-2, the top of pivot pier and the mechanical equipment in its vicinity are impacted by inundation levels of all categories of hurricanes. With the exception of those mechanical elements located at the top of the pivot pier, the critical bridge elements can withstand inundation levels of Category 1 and Category 2 hurricanes. The majority of mechanical elements located in the engine (machine) room are impacted by inundations levels of Category 3 and Category 4 hurricanes.

[17] National Weather Service, National Hurricane Center. Saffir/Simpson Hurricane Wind Scale, http://www.nhc.noaa.gov/aboutsshws.php.



Note: Category 1 inundation shown at the western bridge abutment and tracks and the eastern bridge abutment is actually inundated ground under the bridge's approach spans

Figure 4-2—Hurricane Inundation Existing Conditions

4.3. Guidelines, Directives and Initiatives

Guidance documents have been produced at the federal, regional, and state government levels to assist state agencies and municipalities in addressing climate change and natural hazard vulnerability. Two agencies which have recently provided guidance include FTA and CTDEEP.

In its August 2011 report, "Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation,"[18] FTA identifies four categories of adaptation strategies to address climate change and natural hazard vulnerability:

- Maintain and manage, including adaptive management and accommodation, incorporating "smart" technologies such as sensors that detect changes in pressure and temperatures in materials;
- Strengthen and protect, by designing new infrastructure and assets to withstand future climate conditions, and building protective features such as retaining walls and vegetative buffers;
- Enhance redundancy, consisting of duplicating critical components of a system to increase system reliability; and
- Retreat, by avoiding increasing impacts by abandoning transportation infrastructure located in extremely vulnerable or indefensible areas, relocating, and/or siting new facilities in less vulnerable locations.

FTA's August 2014 report, *Transit and Climate Change Adaptation: Syntheses of FTA-Funded Pilot Projects*,[19] identifies adaptation strategies developed from seven pilot projects funded through its Climate Change Adaptation Initiative. Strategies to address flooding and extreme precipitation include raising minimum top-of-rail height based on 100-year flood elevations; extending design standards for flood-sensitive equipment to the 500-year flood zone; and strengthening protection around piers to reduce bridge scour. Strategies to address extreme heat and rail buckling include setting and maintaining high "rail-neutral temperatures;" installing rail temperature monitoring systems; using expansion joints to provide space for rail expansion; using concrete slab rather than stone ballast to increase stability; placing running rail on a structural concrete base; adding ventilation and cooling for key electronics; and providing backup power generation.

In 2013, CTDEEP released the final *Connecticut Climate Preparedness Plan*,[20] per the requirements of Public Act No. 08-98. The *Plan* has been used to inform the state agencies' work on resiliency and is available as a basis for developing action plans across state and local governments to address the potential impacts related to climate change in Connecticut. The *Plan* sets forth a series of resiliency and adaptation goals and also establishes action items for various planning topics, including infrastructure.

4.4. Project Design Adaptation Strategies

The Walk Bridge Replacement Project is being designed to increase system resiliency and enhance operational redundancy. System resiliency describes the ability to return the bridge to use, either partially or completely, in a relatively short period of time in the aftermath of a compromising event. It also refers to minimizing the vulnerability of critical elements of the bridge to facilitate its return to use. Operational redundancy means the ability to maintain train service on a limited number of tracks following an event that otherwise would have rendered all tracks inoperable.

[18] FTA, Buckled Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation, FTA Report No. 0001, August 2011.
[19] FTA, Office of Budget and Policy, Transit and Climate Change Adaptation: Synthesis of FTA-Funded Pilot Projects, FTA Report No. 0069, August 2014. ://www.fta.dot.gov/documents/FTA_Report_No._0069.pdf
[20] CTDEEP, *Connecticut Climate Change Preparedness Plan: Adaptation Strategies for Agriculture, Infrastructure, Natural Resources and Public Health Climate Change Vulnerabilities*, 2013.

In January 2015, EO 13690 - Establishing a Federal Flood Risk Management Standard – was issued, which established a flood risk reduction strategy for federally funded projects. EO 13690 requires that agencies site, design, and construct in accordance with the changing nature of flood risks, including the risks of sea level rise, using one of several approaches. In one approach, "critical actions," such as the mechanical system of a bridge, would be designed and constructed at least three feet above the FEMA 100-year flood elevation, the base flood elevation (BFE). The critical action elevation for the replacement of the Walk Bridge is 15 feet NAVD88, which is three feet above 12 feet (NAVD88), the BFE at this location.

As shown in Table 4-3, the proposed elevations of key bridge elements of the Bascule Bridge option would be higher than the mandate of EO 13690 and would substantially improve the bridge's resistance to hurricane inundation levels.

Table 4-3—Bascule Bridge (Option 4S) - Structural Elevations and Resiliency Measures

Bridge Element[a]	Elevation (+/-)	Critical Action Elevation (El. 15)	Resistance to Hurricane Inundation Levels[b]			
			Category 1 El. 9.2	Category 2 El. 14.1	Category 3 El. 19.0	Category 4 El. 24.4
Main Span Low Chord	30.2	yes	yes	yes	yes	yes
Approach Span Low Chord	24.0	yes	yes	yes	yes	no
Control/Electric Room Lowest Floor	24.6	yes	yes	yes	yes	yes
Machine Room (Drive Machinery & Motors) Lowest Floor	62.5	yes	yes	yes	yes	yes

Notes:
a. Elevations of the bridge elements are based on preliminary-level design.
b. Elevation shown for peak water surface elevation (NAVD88)

With the exception of the approach span low chord, which would withstand inundations levels of a Category 3 hurricane, the preliminary design of the Bascule Bridge would provide for key elements of the bridge to withstand inundation levels of a Category 4 hurricane. The Bascule Bridge would allow storms to flow through the bridge without inundating or impacting the bridge's main span, including beams, deck, ballast, and rails. In all category events, storms would not impact critical mechanical and electrical elements in the control house or machine room.

As shown in Table 4-4, the proposed elevations of key bridge elements of the short-span and long-span Vertical Lift Bridge options also would be higher than the mandate of EO 13690 and would substantially improve the bridge's resistance to hurricane inundation levels.

Table 4-4—Vertical Lift Bridge (Options 8A and 11C) - Structural Elevations and Resiliency Measures

Bridge Element[a]	Elevation (+/-)	Critical Action Elevation (El. 15)	Resistance to Hurricane Inundation Levels[b]			
			Category 1 El. 9.2	Category 2 El. 14.1	Category 3 El. 19.0	Category 4 El. 24.4
Main Span Low Chord	29.9	yes	yes	yes	yes	yes
Approach Span Low Chord	23.7	yes	yes	yes	yes	no
Control/Electric Room Lowest Floor	22.0	yes	yes	yes	yes	no
Machine Room (Drive Machinery & Motors) Lowest Floor[c]:	65.6	yes	yes	yes	yes	yes

Notes:
a. Elevations of the bridge elements are based on conceptual-level design. The elevations of the critical bridge elements would be the same regardless of the span length of the vertical lift bridge.
b. Elevation shown for peak water surface elevation (NAVD88).
c. Elevation is shown for a span-driven option, which represents the lowest possible elevation of the machine-room lowest floor.

Option 8A and Option 11C could be designed as either a span-driven bridge or a tower-driven bridge. In a span-driven configuration, the machinery would be mounted on top of the truss. In a tower-driven configuration, the machinery would be mounted on top of the tower. For a tower-driven bridge, CTDOT will determine the tower height during final design. Regardless of the tower height, the elevation of the machinery would be substantially higher than the elevation provided by the span-driven option and the elevations of a critical action and a Category 4 hurricane inundation level. For either a span-driven or a tower-driven vertical lift bridge design, the resiliency of this critical bridge element would not be compromised.

As design of the vertical lift structure is advanced, it may be possible to raise the elevations of the approach span low chord and the control house lowest floor to withstand Category 4 hurricane inundation levels. Additionally, the sight-line study, an evaluation of the ability of the bridge operator to have unobstructed views in all directions, will be completed during final design. This study will determine the control house operator elevation level. Final design attributes could include bridge elements placed to withstand Category 4 hurricane levels.

Table 4-5 presents components that CTDOT will investigate as project design advances to increase system resiliency and enhance operational redundancy. These adaptation strategies, which include strategies for bridge, track and supporting infrastructure, primarily focus upon addressing the impacts of climate change relative to flooding and extreme precipitation. The strategies also include design and construction methods to preclude or minimize impacts due to other natural hazards, including severe winter weather, heat, wind, and earthquakes. As applicable and appropriate, these project design components would be incorporated in either the Bascule Bridge option or the Vertical Lift Bridge options.

Table 4-5—Build Alternative Design Strategies for Resiliency and Redundancy

Resiliency/Redundancy Strategy	Project Design Response
Extend design standards to 500-year flood zone and incorporate safeguards	Locate the mechanical drive machinery and supports above the Design Flood Elevation (DFE), which is equal to the BFE plus 3 ft.[a]
	Locate the electrical system components critical to safety and bridge operations above the DFE.[a]
Extend design standards for seismic design	Design for seismic provisions at Level 3 at the Survivability Limit State.
Incorporate operational redundancy	Construct two independent movable spans, each supporting two tracks, over the navigation channel.
Incorporate drive and mechanical system redundancy	Operate each movable span by two motors and drives, alternating between motor/drive pairs on successive bridge openings. Each drive will be capable of operating each main motor.
	Use dampers if they are determined to contribute to the overall system redundancy.
Incorporate electrical system redundancy	Provide dual-drive systems so that if the selected main drive system is inoperable, the alternative main drive system may be selected.
	Provide Dual Programmable Logic Controller (PLC) central processing units (CPUs) so that the bridge operator can switch to the second unit if the first unit fails.
	Provide motor control centers (MCC) to allow for manual bridge operation if the PLC fails.
	Use redundant dual fiber optic cables and configure in diverse cable paths so that fiber communications can continue in the event of a fiber break.

Resiliency/Redundancy Strategy	Project Design Response
	Provide a standby generator for backup utility power. The generator, which will be equipped with an automatic transfer switch to transfer loads to the generator upon loss of power, will be sized to handle all bridge loads required for bridge operation and the Control House, including navigation lighting.
Provide sustainable materials and methods	Provide track spacing between the movable structures to accommodate the requirements of the moving leaves, and access for inspection and maintenance.
	Install bearings and anchor bolts to allow the entire bearing and bolt to be removed for replacement.
	Construct machinery rooms to accommodate a clearance envelope around static and moving obstructions and to promote ease of access and maintenance.
	Avoid drainage discharge onto other bridge elements, into the waterway, or onto traffic beneath the bridge. Direct drainage system discharges to a storm drain or at the toe of embankment slopes.
	Construct drainage system with corrosion-resistant materials and provide cleanouts for maintenance.
Strengthen and protect critical infrastructure	Locate mechanical drive machinery within a heated weather-tight enclosure constructed of non-combustible materials.
	Protect equipment in the Control House and electrical rooms with transient voltage surge suppression (TVSS) devices.
	Mount all outdoor power outlets within enclosures for protection. Use watertight conduit connectors on externally mounted conduits.
	Fasten the fixed side of rail miter joints to resist movement from continuous welded rail thermal stresses
	Incorporate static and dynamic ice loading into the substructure design.
	Use small diameter electrical cables, rather than bundled, large diameter cables, to maximize flexibility and longevity.
	Select electrical materials to provide protection from accelerated corrosion due to condensation, cold weather conditions, and the marine environment.

a. The DFE, defined as the BFE (at 12 ft NAVD88) plus additional 3 ft (for Critical Actions), is higher than the 500-year floodplain elevation of 11.9 ft NAVD88.