Appendix K
Benefit Cost Analysis Costs for Asset Adaptation Strategies

Benefit Cost Analysis Costs for Asset Adaptation Strategies: **Bridge Assets** **Updated: January 2019**
North Jersey Transportation Planning Authority

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate		Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)	Reactively Repair/Rebuild (Do Nothing Scenario)	Heat	Flooding		
Reduce Thermal Expansion (TE)							
TE5	Increase seat lengths of expansion joints and/or the range of finger joints in bridges	10% of BRC	18% of BRC	X		Design	
TE6	Monitor for temperatures of assets and heat-related impacts by installing sensor systems	$ 2,000 per bridge	10% of BRC	X		Design, O&M	The proactive cost is for the sensor only. Note that operational costs are highly dependent on the type of transmission of the data (cellular, internet, radio, etc.). Assume data is transmitted and monitored as part of operational duties of individuals at the owning agency. The reactive costs assumes that damages will result from lack of monitoring and early signs of damage will go unnoticed, leading to more expensive repairs. For example, lack of proper functionality in the bridge's movement system can result in heavy damages to the sub-structure during extreme heat periods. This can be detected through monitoring the bridge movement and identifying abnormal performance.
FD1	Protect bridge piers and abutments with riprap	10% of BRC	75% of BRC		X	Design	
FD2	Alter, upgrade, or retrofit bridge movement system (e.g. bearings) to prevent excessive lateral or vertical displacement due to buoyancy forces or water pressure	8% of BRC	38% of BRC		X	Design	
FD4	Monitor bridge for scour and other conditions that could undermine a bridge's structural integrity during a flooding event	$ 100,000 per bridge	88% of BRC		X	O&M	Costs are for O&M only.

Cost Notes: Federal Highway Administration (FHWA): $450 per square foot replacement cost
Bridge Replacement Cost (BRC) = Bridge Deck Area x $450 per square foot
When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html.

Acronyms: % = precent O&M = operation and maintenance

Benefit Cost Analysis Costs for Asset Adaptation Strategies: **Culverts Assets** **Updated: January 2019**
North Jersey Transportation Planning Authority

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate		Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)	Reactively Repair/Rebuild (Do Nothing Scenario)	Heat	Flooding		
Increase or Improve Stormwater Drainage (SW)							
SW10	Enlarge culverts to increase the capacity	$ 1,000,000 per culvert	$ 1,000,000 per culvert		X	Design, O&M	
SW12	Replace culverts with bridges	$ 450 per sq ft	$ 450 per sq ft		X	Design	

Cost Notes: These costs are applied to all culverts as follows: 55% of culverts use SW10, 15% culverts use SW12, and 25% of culverts are no action for the BCA.
Federal Highway Administration (FHWA): $450 per square foot replacement cost
When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-

Acronyms: % = percent O&M = operation and maintenance sq ft = square foot

Benefit Cost Analysis Costs for Asset Adaptation Strategies: **Facilities Assets** **Updated: January 2019**
North Jersey Transportation Planning Authority

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate				Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)		Reactively Repair/Rebuild (Do Nothing Scenario)		Heat	Flooding		
Reduce Thermal Expansion (TE)									
TE6	Monitor for temperatures of assets and heat-related impacts by installing sensor sytems	$ 2,000	per facility	$ 2,000	per facility	X		Design, O&M	The proactive and reactive costs are for the sensor only. Note that operational costs are highly dependent on the type of transmission of the data (cellular, internet, radio, etc). Assume data is transmitted and monitored as part of operational duties of individuals at the owning agency.
Increase Flood Protection (FP)									
FP5	Incorporate wet floodproofing: Install flood openings and water-resistant materials to allow building to withstand some exposure to floodwaters and the associated loads/pressures	$ 3,600	per facility	$ 3,600	per facility		X	Design	Assume each facility would need six flood vents at $400 each; wet floodproof applied about 3 feet high (120 linear feet of wall x 3 feet high = $3,600)
FP8	Elevate critical mechanical and electrical equipment	$ 20,000	per facility	$ 20,000	per facility		X	Design	Estimate $20,000 for each facility for electrical and plumbing
FP15	Install sensor systems along or within assets to monitor for water level and changing conditions	$ 15,000	per facility	$ 15,000	per facility		X	Design, O&M	The proactive and reactive costs are for the sensor only. Note that operational costs are highly dependent on the type of transmission of the data (cellular, internet, radio, etc). Assume data is transmitted and monitored as part of operational duties of individuals at the owning agency.

Cost Notes: When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html .

Acronyms: O&M = operation and maintenance sq ft = square foot

Benefit Cost Analysis Costs for Asset Adaptation Strategies: **Rail Track Assets** **Updated: January 2019**

North Jersey Transportation Planning Authority

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate		Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)	Reactively Repair/Rebuild (Do Nothing Scenario)	Heat	Flooding		
Reduce Thermal Expansion (TE)							
TE1	Design rail for higher maximum temperatures in replacement or new rail infrastructure	$ 250 per linear foot per track	$250 per linear foot per track	X		Design, O&M	
TE2	Lower speeds and use shorter trains to shorten braking distance and to allow for lighter loads to reduce track stress in extreme heat events	$ 5,000 per rail line	$100,000 per track mile	X		O&M	
TE6	Monitor for temperatures of assets and heat-related impacts by installing sensor sytems	$ 2,000 per 10 miles	$100,000 per track mile	X		Design, O&M	The proactive cost is for the sensor only. Note that operational costs are highly dependent on the type of transmission of the data (cellular, internet, radio, etc). Assume data is transmitted and monitored as part of operational duties of individuals at the owning agency. Reactive costs assumes there will be track damages and thus replacement will result from lack of monitoring where early signs will go unnoticed.
Use Heat-Resistant Materials (HR)							
HR6	Tree planting to shade assets, plant locations to be balanced against safety protocols	Not applicable to rail tracks due to right of way issues.		X	X	Design, O&M	
Prevent System Failure (SF)							
SF3	Incorporate redundant power and communication lines and systems	$ 337,500 per mile	$ 337,500 per mile	X	X	Design	
.							
SW8	Increase capacity of stormwater infrastructure and drainage system	$ 250,000 per acre	$ 250,000 per acre		X	Design	
SW11	Upgrade bridge deck and road drainage systems to manage a higher capacity of stormwater	$ 250,000 per acre	$ 250,000 per acre		X	Design	
Increase Flood Protection (FP)							
FP10	Construct and raise protective dikes, bulkheads, berms and levees, including tide gates as necessary	$ 30,000 per 1,000 linear feet	$ 100,000 per 1,000 linear feet		X	Design	
FP15	Install sensor systems along or within assets to monitor for water level and changing conditions	$ 15,000 per 10 miles	$ 15,000 per 10 miles		X	Design, O&M	These costs are for the sensor only. Note that operational costs are highly dependent on the type of transmission of the data (cellular, internet, radio, etc). Assume data is transmitted and monitored as part of operational duties of individuals at the owning agency.

Cost Notes: When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html.

Acronyms: O&M = operation and maintenance

Benefit Cost Analysis Costs for Asset Adaptation Strategies:
North Jersey Transportation Planning Authority

Subarea-wide

Updated: January 2019

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate		Subarea			Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)	Reactively Repair/Rebuild (Do Nothing Scenario)	A	B	C	Heat	Flooding		
Increase or Improve Stormwater Drainage (SW)										
SW1	Construct stormwater retention basins	$ 250,000 per acre	$ 250,000 per acre		X			X	Design	
SW2	Install internal drainage system using basins and sump pumps	$ 1,850 per pump	$ 1,850 per pump		X			X	Design, O&M	
SW3	Install green infrastructure: bioretention ponds, bioswales and rain gardens	$ 172,800 per acre	$ 172,800 per acre		X	X		X	Design	
SW4	Install green infrastructure: pervious pavements	$ 550,000 per acre	$ 550,000 per acre		X			X	Design	
Increase Flood Protection (FP)										
FP9	Protect and restore wetlands to protect infrastructure	$ 60,500 per acre	$ 60,500 per acre			X		X	Policy, Design	
FP10	Construct and raise protective dikes, bulkheads, berms and levees, including tide gates as necessary	$ 30,000 per 1000 linear feet	$ 30,000 per 1000 linear feet			X		X	Design	
Reduce Flood Damage (FD)										
FD5	Use of vegetation or earthwork to stabilize river and stream embankments and provide riverine buffers	$ 425 per linear foot	$ 425 per linear foot	X	X	X		X	Design, O&M	

Cost Notes: When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html.

Acronyms: O&M = operation and maintenance

Benefit Cost Analysis Costs for Asset Adaptation Strategies:
North Jersey Transportation Planning Authority

Road, Transit (Bus Line) Assets

Updated: April 2019

Adaptation Strategy Identification	Adaptation Strategy	Cost Estimate		Type of Event		Project Stage	Assumptions
		Proactively Implement Strategy (Build Scenario)	Reactively Repair/Rebuild (Do Nothing Scenario)	Heat	Flooding		
Reduce Thermal Expansion (TE)							
TE6	Monitor for temperatures of assets and heat-related impacts by installing sensor sytems	$ 2,000 per 10 miles	$ 250,000 per lane mile	X		Design, O&M	The reactive costs assumes damages will result from lack of monitoring/inspection, and will require resurfacing the road.
Use Heat-Resistant Materials (HR)							
HR3	Use heat-resistant materials, including heat-resistant asphalt, concrete, or painted roadways	$ 30 per linear foot per track	$ 30 per linear foot per track	X		Policy, Design, O&M	
HR4	Overlay or rebuild roads with new or more rut-resistant asphalt or concrete	$ 185,000 per lane mile	$ 250,000 per lane mile	X		Design, O&M	
HR6	Tree planting to shade assets, plant locations to be balanced against safety protocols	$ 300 per tree	$ 300 per tree	X	X	Design, O&M	Both costs are applied to two sides of the road at 10 foot intervals.
Prevent System Failure (SF)							
SF3	Incorporate redundant power and communication lines and systems	$ 337,500 per mile	$ 337,500 per mile	X	X	Design	
Increase or Improve Stormwater Drainage (SW)							
SW8	Increase capacity of stormwater infrastructure and drainage system	$ 250,000 per acre	$ 250,000 per acre		X	Design	Only one of these two strategies is assigned, where applicable.
SW11	Upgrade bridge deck and road drainage systems to manage a higher capacity of stormwater	$ 250,000 per acre	$ 250,000 per acre		X	Design	
Increase Flood Protection (FP)							
FP10	Construct and raise protective dikes, bulkheads, berms and levees, including tide gates as necessary	$ 30,000 per 1000 linear feet	$ 100,000 per 1000 linear feet		X	Design	
FP15	Install sensor systems along or within assets to monitor for water level and changing conditions	$ 15,000 per 10 miles	$ 15,000 per 10 miles		X	Design, O&M	
Reduce Flood Damage (FD)							
FD8	Use new asphalt/concrete mixtures able to withstand flood conditions	$ 550,000 per acre	$ 550,000 per acre		X	Design	

Cost Notes: Total cost per mile calculated as number lanes x cost per lane mile
New Construction: $2.2 million per mile lane
Resurfacing: $250K per mile lane
Reconstruct Existing: $765K per mile lane
When a range of costs was provided, the average of the range was used for the BCA.

Sources of adaptation strategy cost research include "Post Hurricane Sandy Transportation Resilience Study in NY, NJ, and CT," available at https://www.fhwa.dot.gov/environment/sustainability/resilience/publications/hurricane_sandy/fhwahep17097.pdf; "Fresh Coast Green Solutions," available at https://www.mmsd.com/application/files/8514/8779/6598/SustainBookletweb1209.pdf; "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation," Electric Light and Power Newsletter, available at https://www.elp.com/articles/powergrid_international/print/volume-18/issue-2/features/underground-vs-overhead-power-line-installation-cost-comparison-.html.

Acronyms: O&M = operation and maintenance