Orange-Inal:
An Applied Framework to Assess MBTA Rapid Transit Line Vulnerability and Inform Capital Planning

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Weston & Sampson℠

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- Hannah Lyons-Galante, Dept of Energy & Environmental Affairs

- MBTA Engineering and Maintenance Departments (Facilities, Signals, Power, Security, Communications) and Asset Management

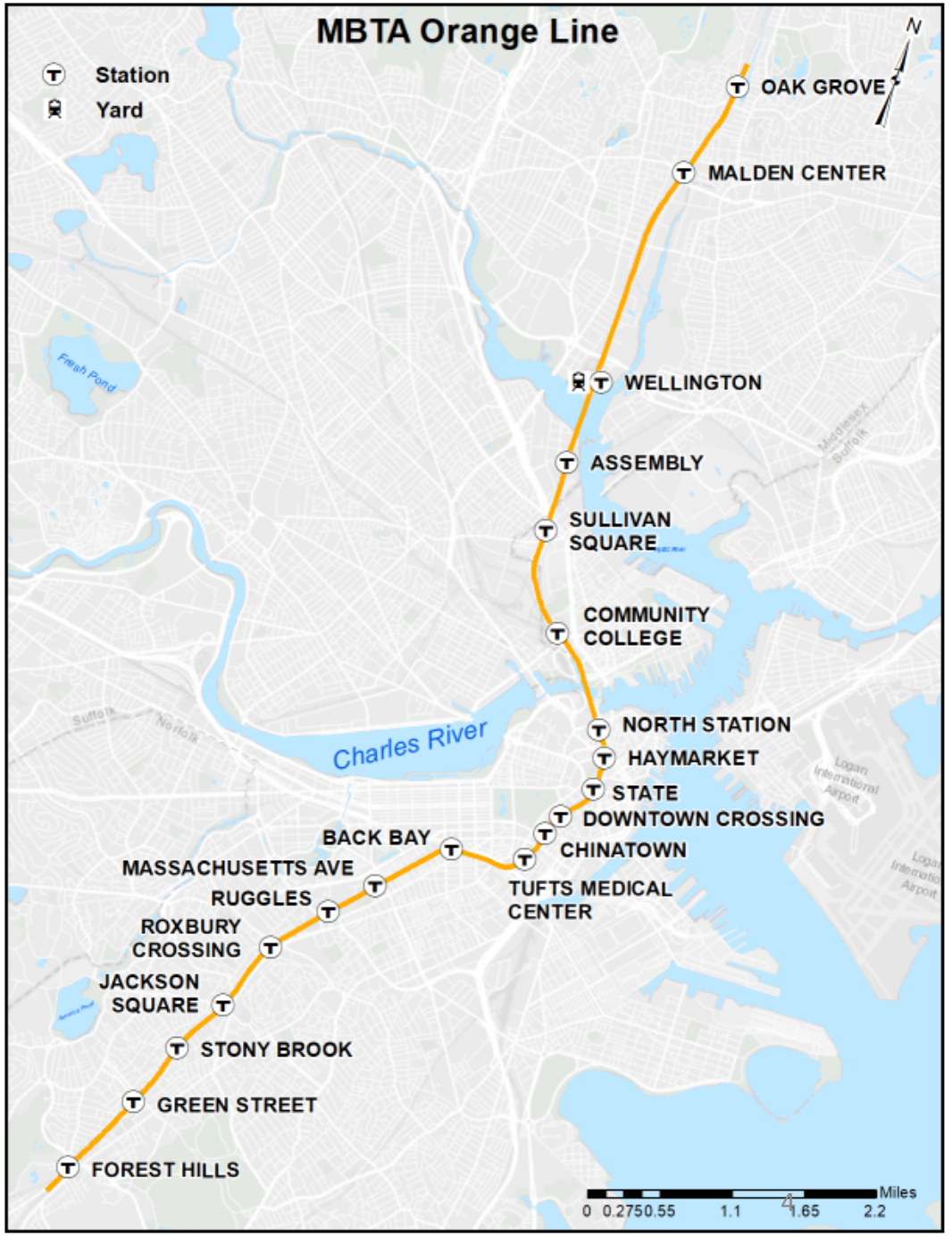
- ARUP, Teaming Partner

Presentation Outline

- Goals & objectives
- Brief overview of methodology
- Data gathering
- Exposure Assessment
- Vulnerability Assessment Results – 2030 and 2070
- Key Findings
- Adaptation Strategies
- Recommendation & Next Steps
- Q&A

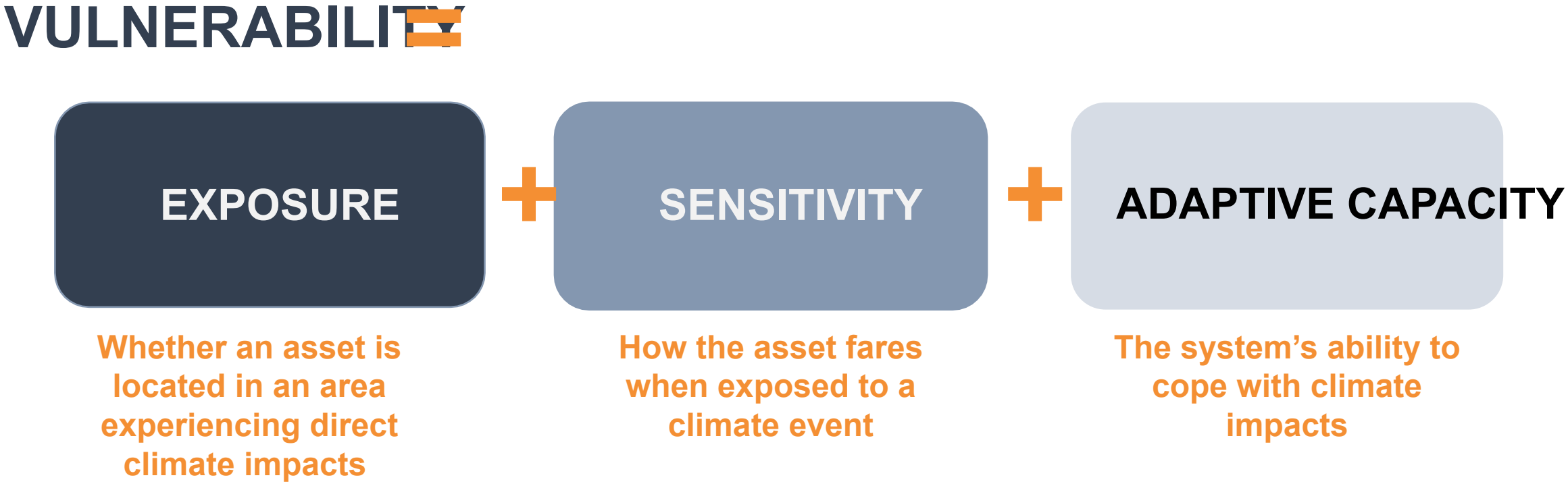
Goals and Objectives

- Advance and document the MBTA's understanding of its **climate vulnerabilities**.
- Evaluate the anticipated **near- and long-term vulnerability of the Orange Line system** to the climate hazards of coastal flooding and sea level rise, extreme precipitation, extreme heat, wind, and winter weather.
- Develop a **standard climate change vulnerability assessment methodology**, which will allow the MBTA to conduct comparable assessments for all of its assets and infrastructure
- **Integrate resilience considerations** into the asset management and capital planning decisions
- Provide representative **climate adaptation strategies** and additional detailed studies for **prioritized most vulnerable** Orange Line system assets.



Process Overview

The Federal Highway Administration's (FHWA) Vulnerability Assessment Scoring Tool (VAST) was used and **adapted** to align with the MBTA's goals and operations.



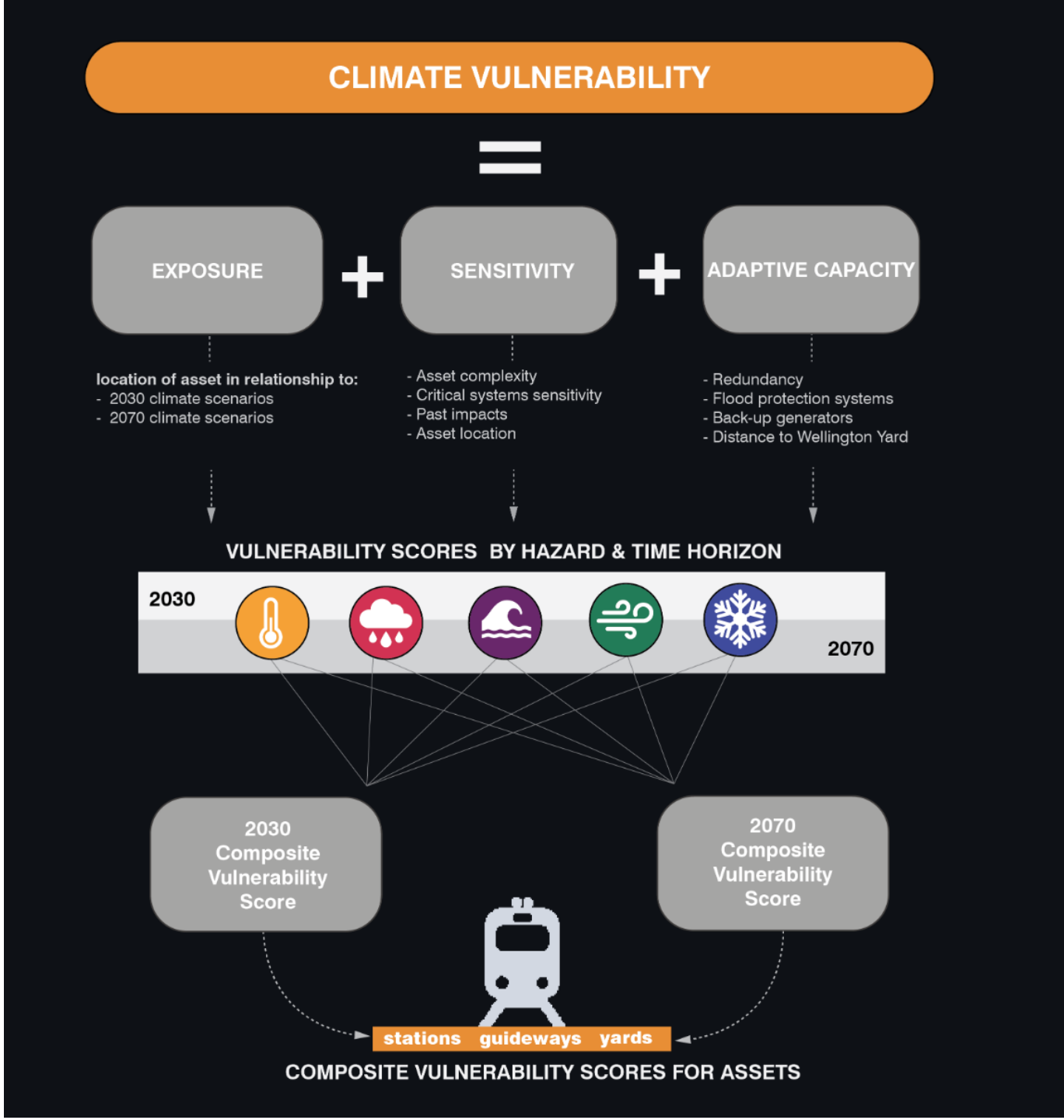
Process Overview

- **Exposure**: Asset location with respect to 2030 and 2070 climate scenarios

- **Sensitivity**
  - ✓ Asset complexity
  - ✓ Critical systems
  - ✓ Past impacts

- **Adaptive capacity**
  - ✓ Redundancy
  - ✓ Flood protection systems
  - ✓ Back-up generators

- **Composite vulnerability score** for heat, extreme precipitation, sea level rise/storm surge, wind, winter storms



Data Gathering

Data Collection

- MBTA Plans, drawings, and background documents
- Site walks and interviews
- MBTA Asset Management Inventory, Severe Weather Plan, Snow and Ice Operations Plan, Rail Transit Manual, and Ventilation Report

Data Analysis

- Assets linear-referenced in GIS
- Sorted by category and type
- Evaluated based on criticality
- Elevations and critical details documented

42 Assets Selected for

Stations	Maintenance Yards	Guideway Sections
Forest Hills	Storage Track to Forest Hills**	Forest Hills - Green St
Green Street	Wellington Yard	Green St - Stony Brook
Stony Brook	Oak Grove to Northbound Storage Track***	Stony Brook - Jackson Sq
Jackson Square		Jackson Sq - Roxbury Crossing
Roxbury Crossing		Roxbury Crossing - Ruggles
Ruggles		Ruggles - Mass Ave
Massachusetts Avenue		Mass Ave - Back Bay
Back Bay		Back Bay - Tufts Medical Center
Tufts Medical Center		Tufts - Chinatown
Chinatown		Chinatown - DTX
Downtown Crossing		DTX - State
State		State - Haymarket
Haymarket		Haymarket - North Station
North Station		North Station - Community College + Test Track*
Community College		Community College - Sullivan Sq + Test Track*
Sullivan Square		Sullivan Sq - Assembly + Test Track*
Assembly		Assembly - Wellington + Test Track*
Wellington		Wellington - Malden Center + Test Track*
Malden Center		Malden Center - Oak Grove
Oak Grove		

*Scores are based on revenue track. Test track was not included as part of the scoring, but there are guideway segments where test tracks run parallel that were included and, thus, would likely have similar scores.

**Forest Hills storage can accommodate 48 cars and consists of 4 tracks below ground, where each track can hold two 6-car trains for daily pull-out/operations.

*** Wellington Yard can store 72 cars and consists of 10 tracks, where each track can hold 8-car trains, but 6-car trains are preferable.

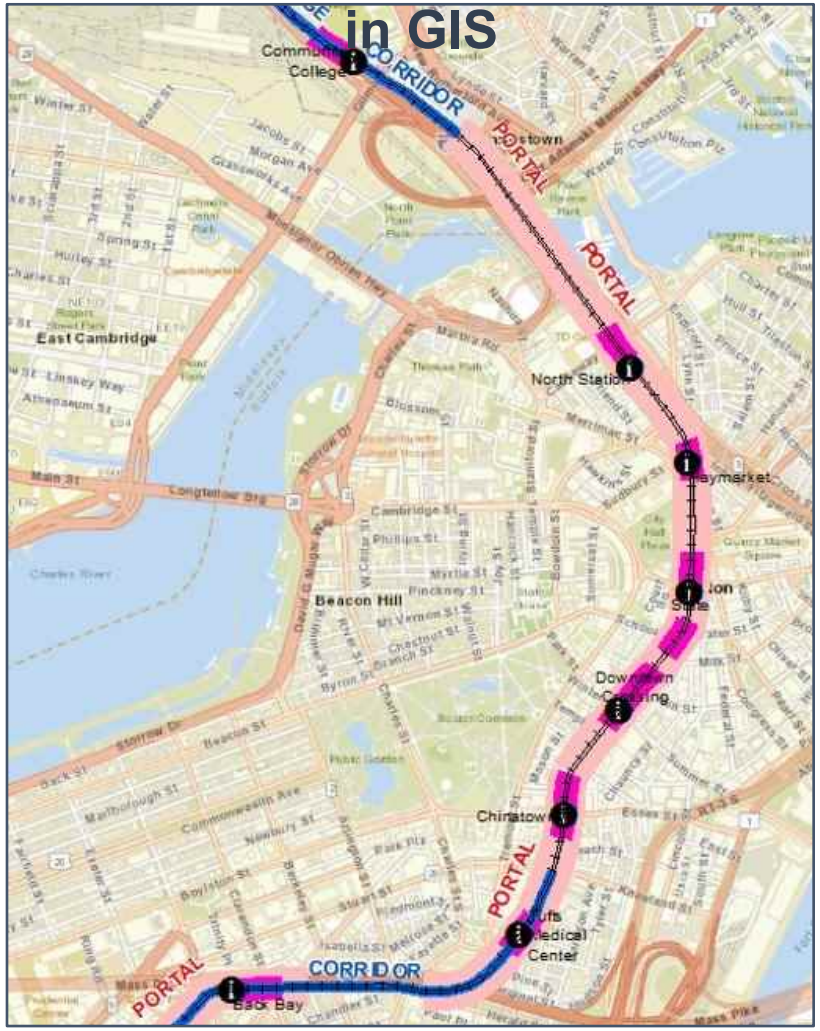
Data Gathering

Station Site Visits

Interviews with MBTA Staff

iDataCollect℠
a Weston&Sampson solution

Assets Linear Referenced in GIS



Data Gathering – Critical Systems Data by Asset Typology

Stations	
System Type	Components Included in Assessment
HVAC	Chillers, cooling towers, AHUs, boilers
Electrical (Site)	Transformer
Conveyance	Escalator/ elevator electrical equipment and controls
Passenger Areas	Platforms & station entrance/lobby
Fire Protection (Building)	Sprinkler system, fire suppression unit

Maintenance Yards	
System Type	Components Included in Assessment
Car House	Building structure & equipment
Signal Tower	Building structure & equipment
Switches & switch heaters	
Tracks & Roadbed	

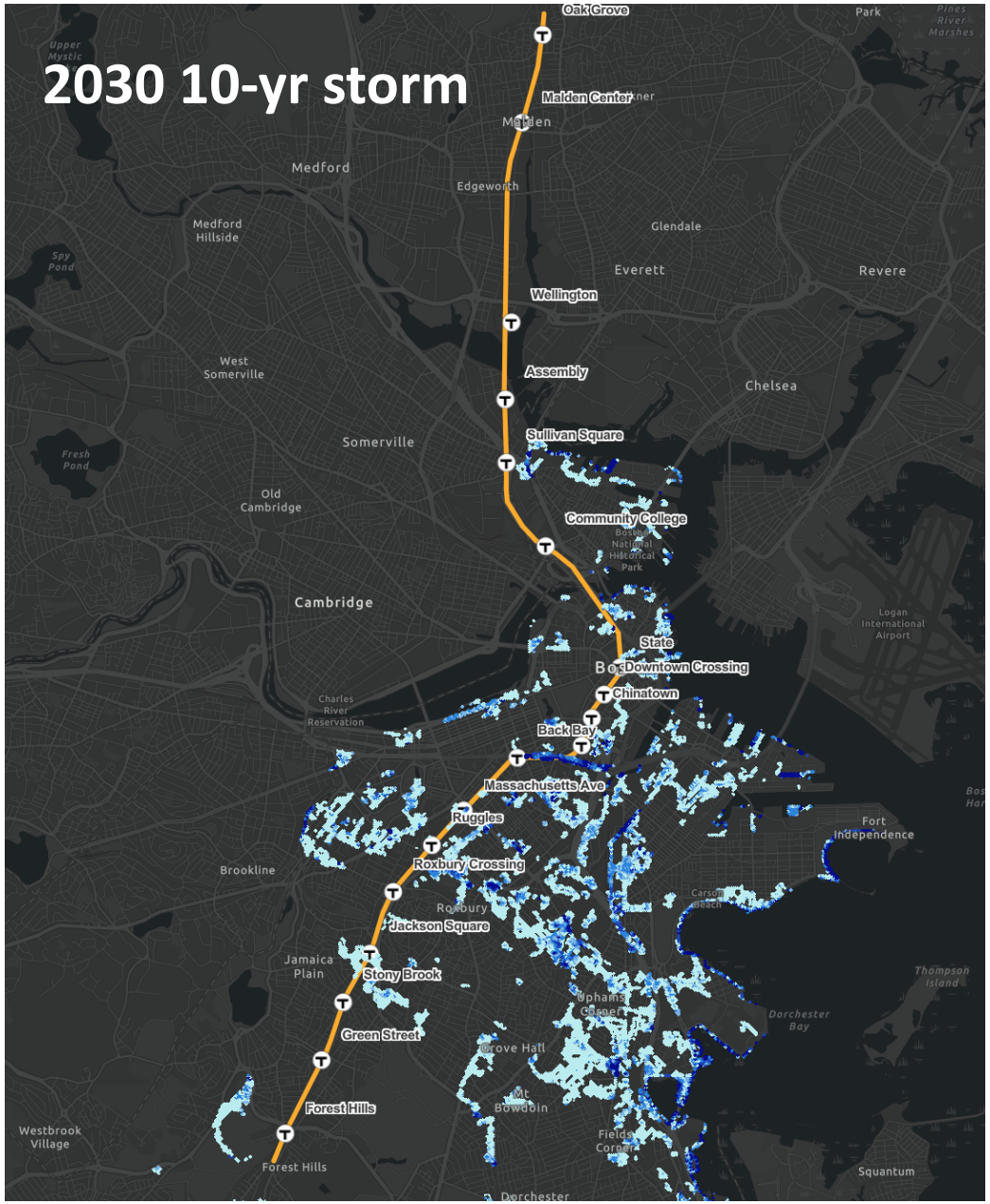
Guideway	
System Type	Components Included in Assessment
Bridge/Viaduct	Substructure, Superstructure
Tunnel Structure	
Tunnel Mechanical - Pump Rooms	Pump rooms
Tunnel Mechanical - Ventilation	Vent shafts, Ventilation fans
Switches & switch heaters	
Catenary	
Track & Roadbed	

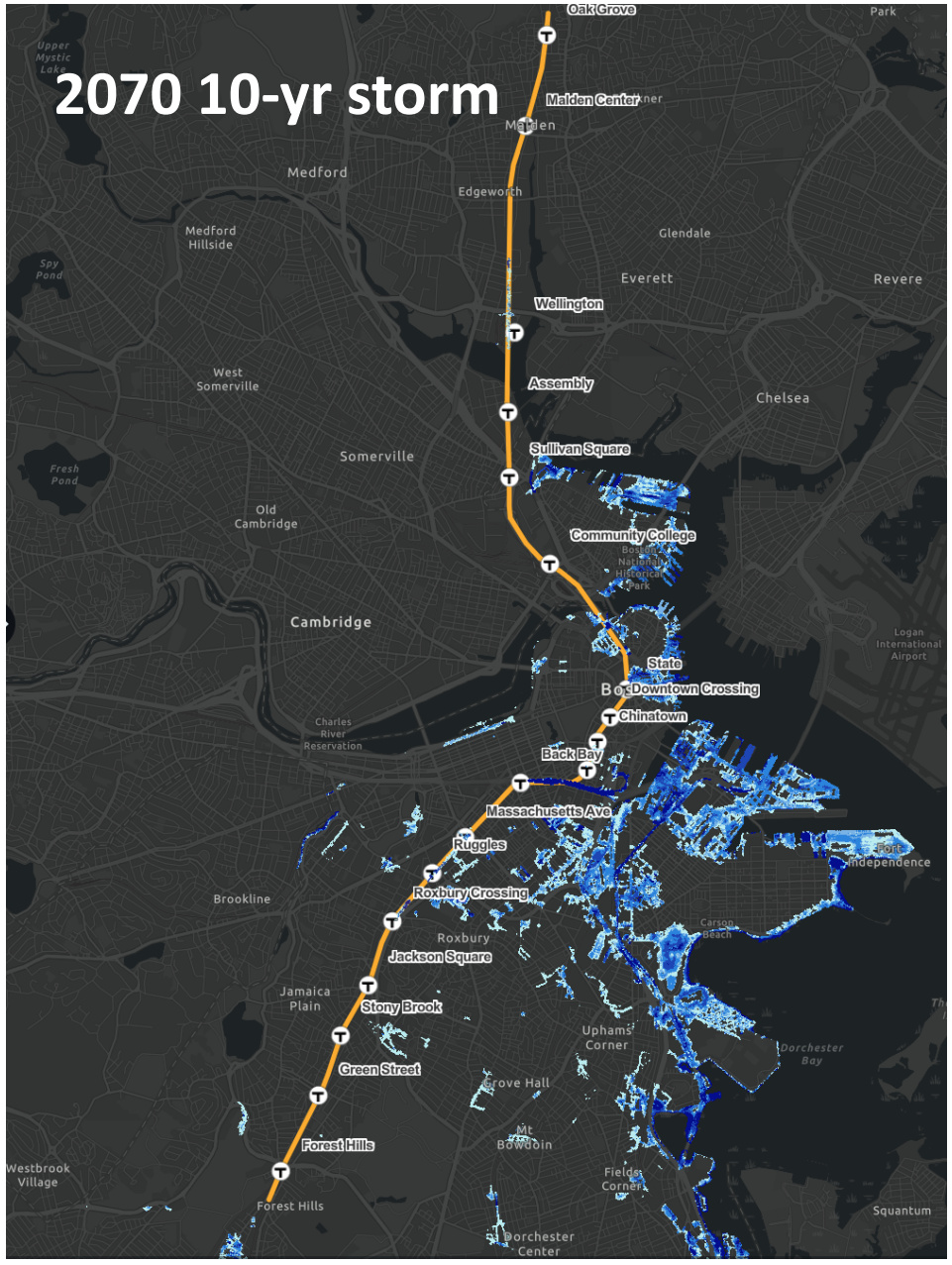
Historic Vulnerabilities

Table 4. Historic Climate Vulnerabilities and Impacts Reported by MBTA Staff

Asset Location					
Open-Air Stations					
Forest Hills Station					
Ruggles Station					
Ruggles Underpass					
Back Bay Station					
Tufts Medical Center Station					
Chinatown Station					
Downtown Crossing Station					
North Station					
Community College Station					
Sullivan Square Station					
Assembly Station					
Wellington Yard Signal Tower					
Wellington Yard Carhouse Basement					
Oak Grove Station					

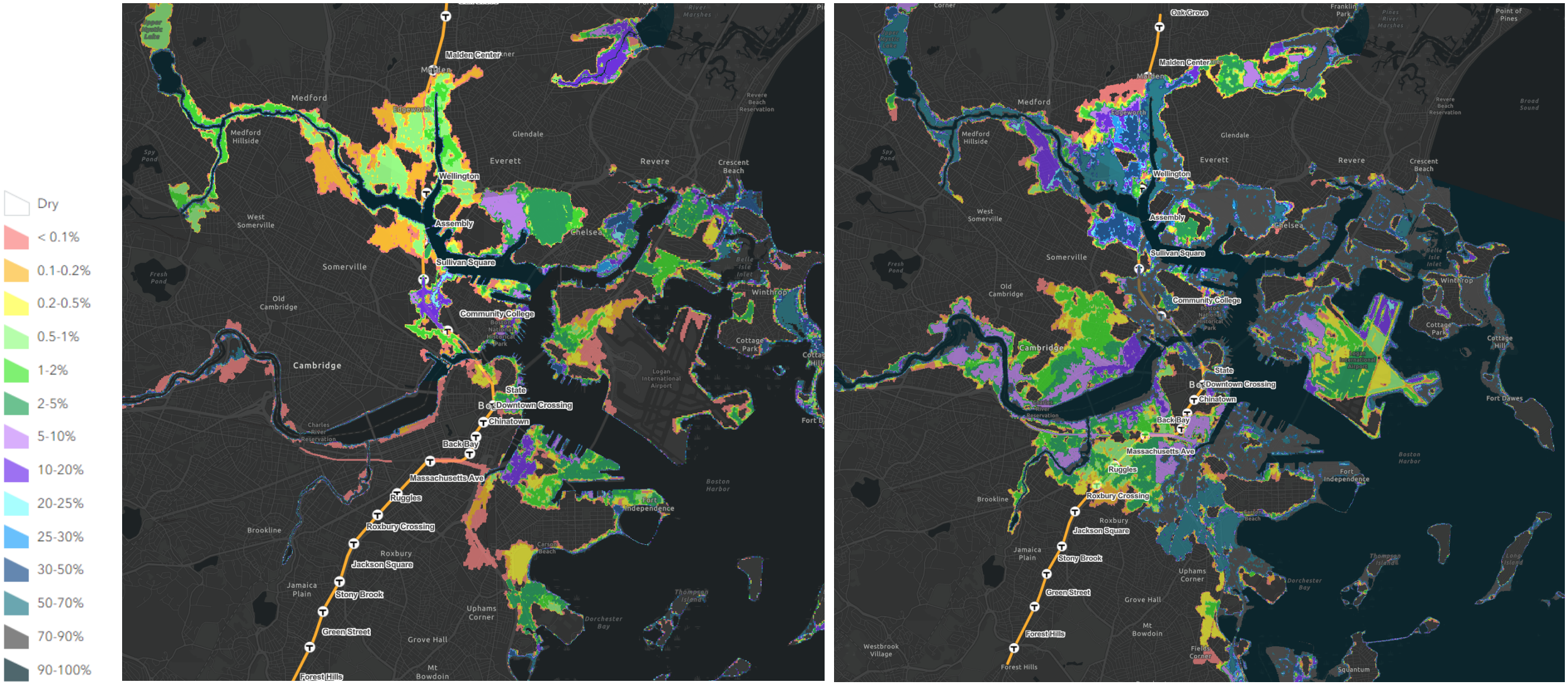
Exposure – Precipitation Flooding





Source: Site-specific 2D flood modeling by Arup, BWSC Inundation Model

Exposure – Sea Level Rise/Storm Surge Flooding



Source: Massachusetts Coast Flood Risk Model (MC-FRM) developed by Woods Hole Group

Assessment Results – 2030

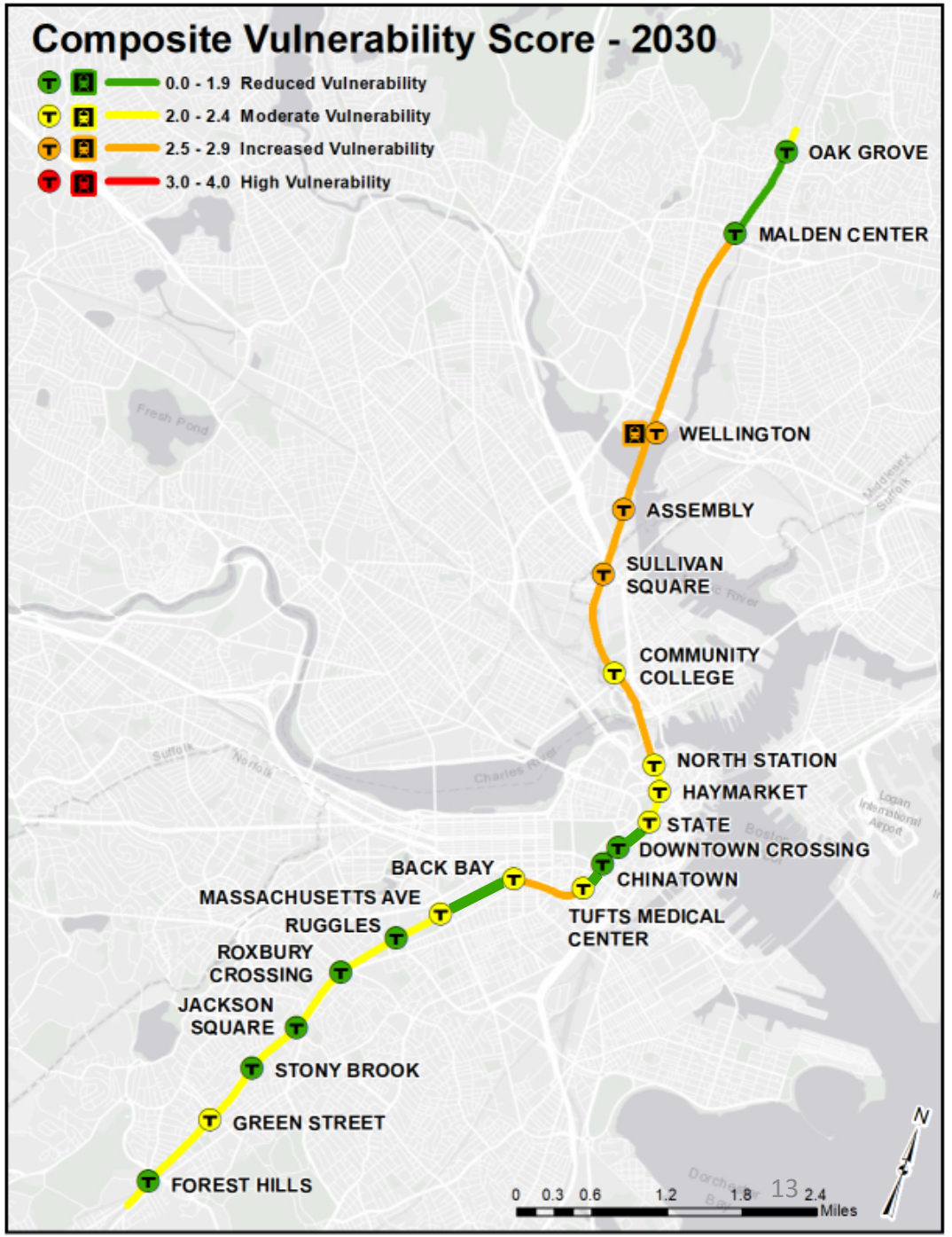
Summary 2030 results map and table of Highly Vulnerable Assets

Highly Vulnerable Assets: 2030 Vulnerability Scores ≥ 3.0

- Vulnerability = Exposure + Sensitivity + Adaptive Capacity

Asset Description			2030 Vulnerability Scores					
No.	Name	Type	Composite					
1	Wellington Yard	Yard	2.9	2.5	3.0	2.3	3.2	3.2
2	Assembly - Wellington	Guideway	2.8	2.5	2.1	3.1	3.0	3.1
3	Assembly Station	Station	2.7	2.3	2.1	2.8	3.1	3.1
4	Wellington – Malden	Guideway	2.6	2.2	3.0	2.7	2.2	3.0
5	Community College – Sullivan Sq.	Guideway	2.6	2.2	2.9	2.9	2.2	2.9
6	Sullivan Sq. – Assembly	Guideway	2.6	2.6	2.2	2.6	2.5	3.2
7	North Station – Community College	Guideway	2.5	2.2	3.1	3.1	1.9	2.3
8	Back Bay – Tufts Medical Center	Guideway	2.5	2.4	3.2	2.2	2.4	2.4
9	Wellington Station	Station	2.5	2.1	2.6	2.0	2.8	2.9
10	Sullivan Square Station	Station	2.5	2.3	2.1	3.1	2.3	2.4

Vulnerability Score	Description
0 – 1.9	Reduced Vulnerability
2.0 - 2.4	Moderate Vulnerability
2.5 - 2.9	Increased Vulnerability
3.0 – 4.0	High Vulnerability



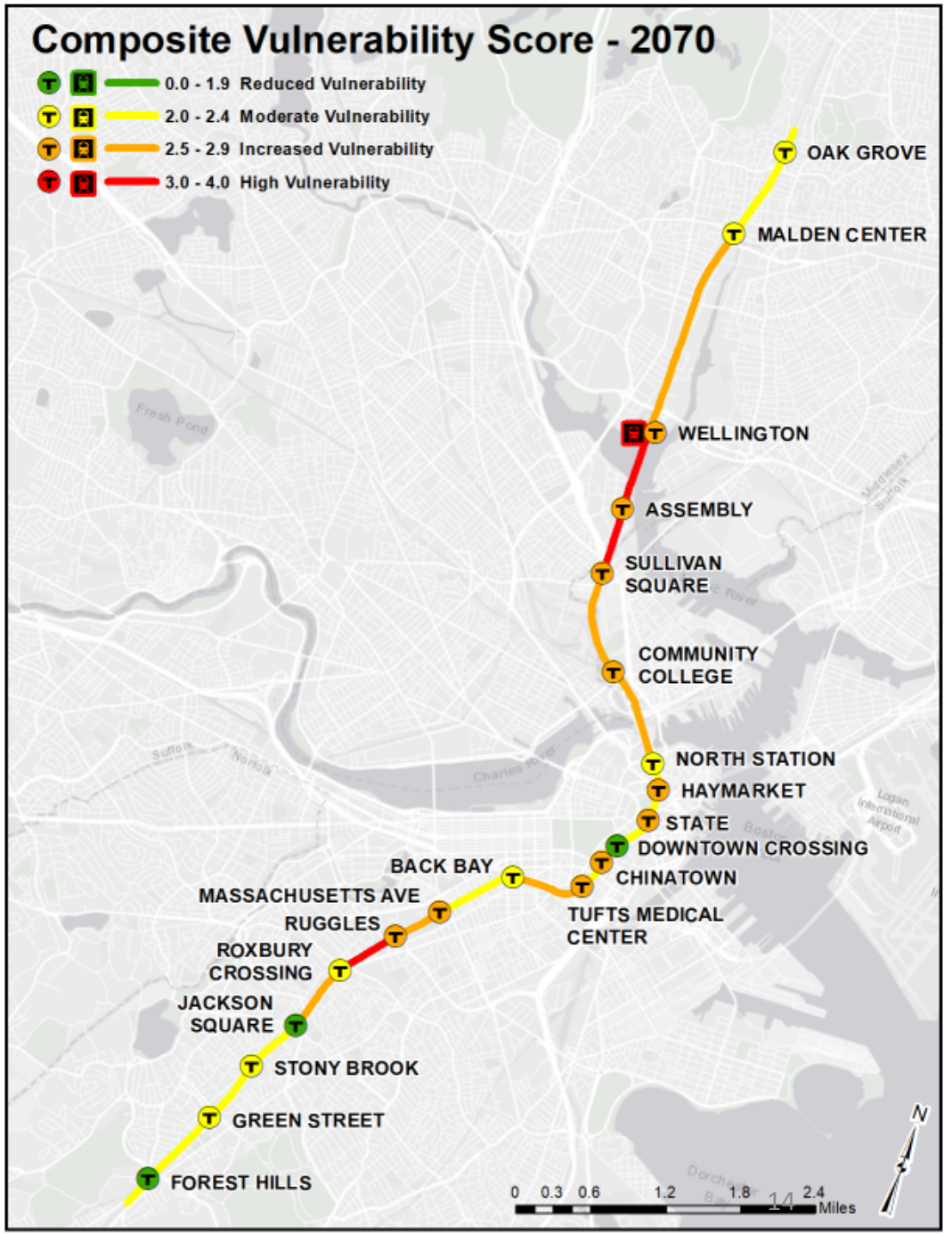
Assessment Results – 2070

Summary 2070 results map and table of Highly Vulnerable Assets

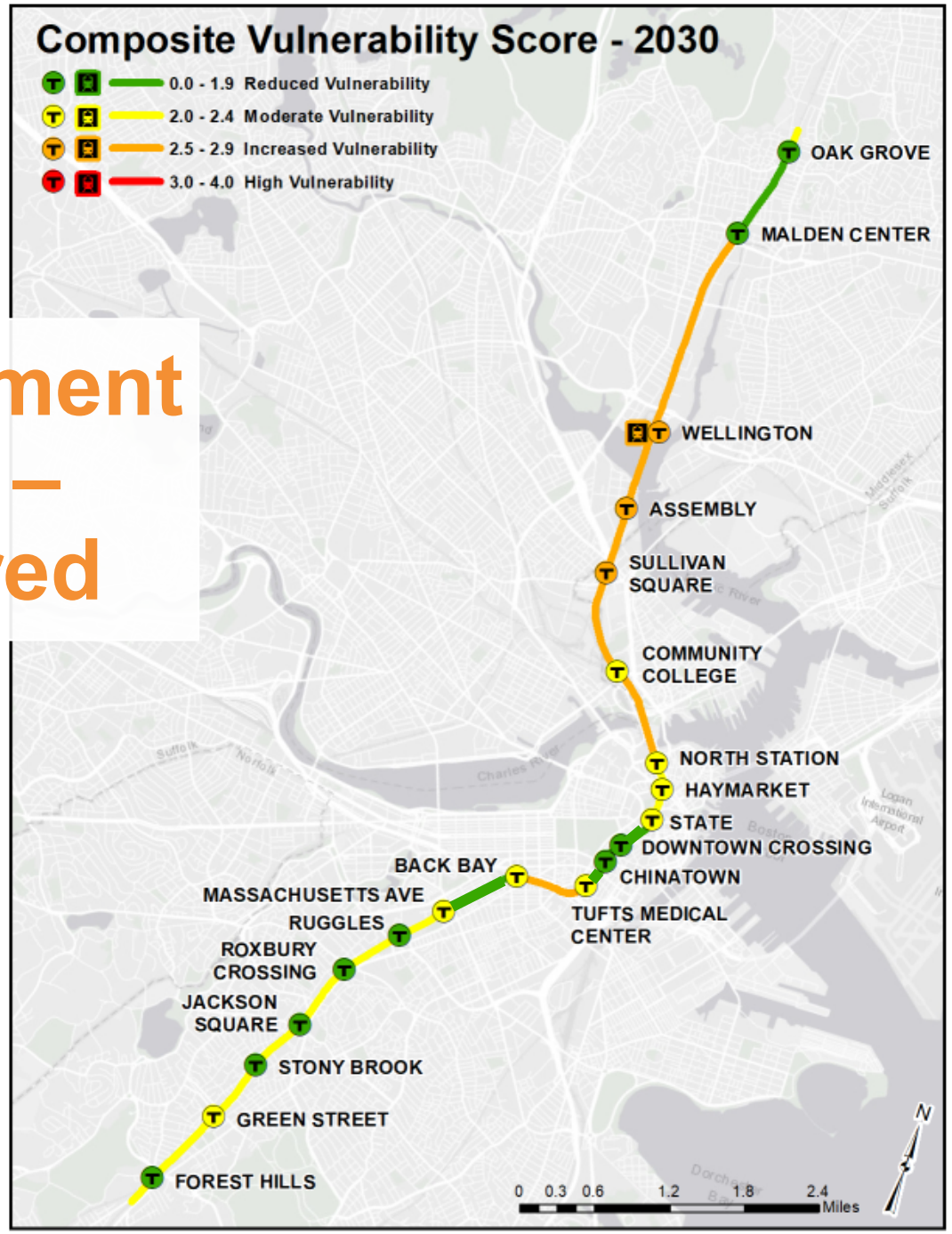
Highly Vulnerable Assets: 2070 Vulnerability Scores ≥ 3.0

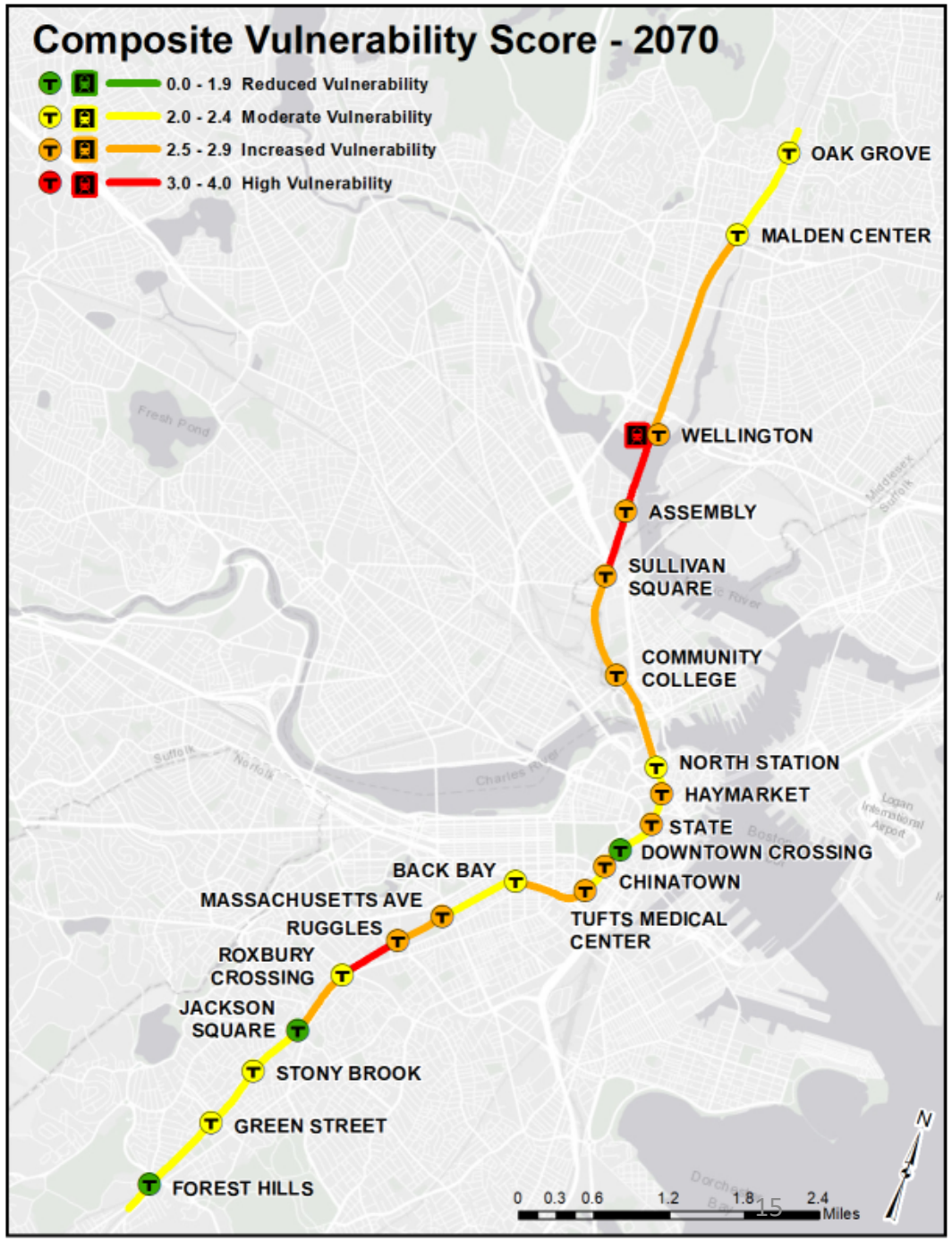
- Vulnerability = Exposure + Sensitivity + Adaptive Capacity

Asset Description			2070 Vulnerability Scores					
No.	Name	Type	Composite					
1	Wellington Yard	Yard	3.2	2.9	3.4	3.3	3.2	3.2
2	Assembly - Wellington	Guideway	3.0	2.8	3.1	3.1	3.0	3.1
3	Sullivan Sq. – Assembly	Guideway	3.0	2.9	3.2	3.2	2.5	3.2
4	Roxbury Crossing – Ruggles	Guideway	3.0	3.2	3.0	3.0	2.9	3.0
5	Ruggles – Mass Ave	Guideway	2.9	2.9	3.3	2.9	2.5	3.2
6	Wellington Station	Station	2.8	2.5	3.0	3.0	2.8	2.9
7	Assembly Station	Station	2.8	2.6	2.1	3.1	3.1	3.1
8	Wellington – Malden Center	Station	2.8	2.6	3.0	3.0	2.2	3.0
9	Sullivan Square Station	Station	2.7	2.6	3.1	3.1	2.3	2.4
10	Back Bay – Tufts Medical Center	Guideway	2.7	2.7	3.2	2.9	2.4	2.4
11	Community College – Sullivan Sq.	Guideway	2.7	2.6	2.9	2.9	2.2	2.9
12	Massachusetts Ave Station	Station	2.7	2.6	3.1	2.8	2.4	2.4
13	Haymarket Station	Station	2.6	2.6	3.3	3.3	2.0	2.0
14	State Street Station	Station	2.6	2.6	3.3	3.3	2.0	2.0
15	North Station – Community College	Guideway	2.6	2.6	3.1	3.1	1.9	2.3
16	Ruggles Station	Station	2.6	2.7	2.6	2.8	2.4	2.4
17	Chinatown Station	Station	2.6	2.6	3.0	3.3	1.9	2.0
18	Jackson Sq. – Roxbury Crossing	Guideway	2.5	3.1	3.3	0.0	2.8	3.5
19	Community College Station	Station	2.5	2.6	2.0	3.0	2.3	2.4
20	Tufts Medical Center Station	Station	2.5	2.6	2.6	3.3	1.9	2.0



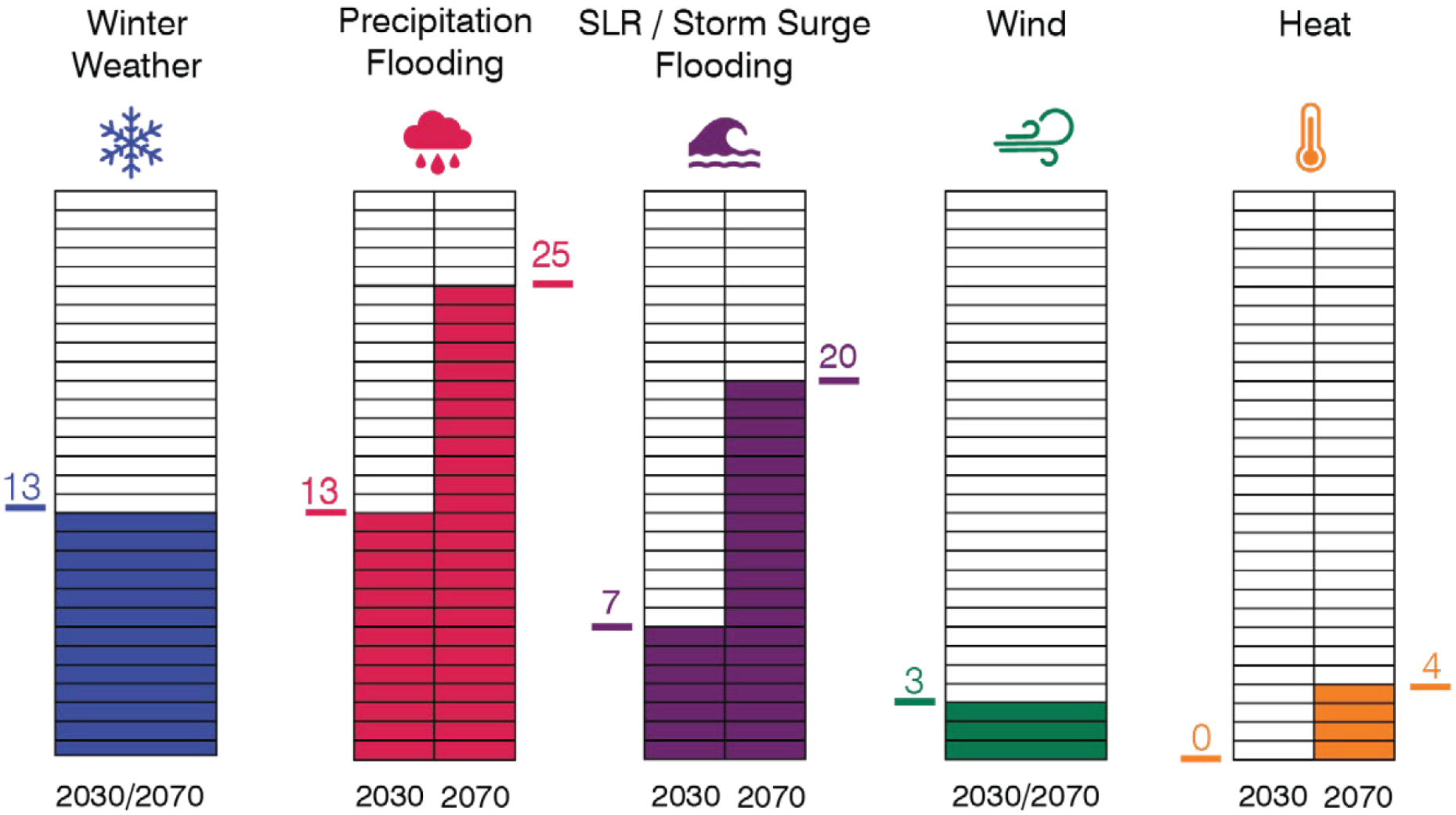
Assessment Results – Compared





Key Findings – Summary

MBTA Orange Line assets with “High Vulnerability” scores noting quantity of assets impacted by planning horizon and climate hazard



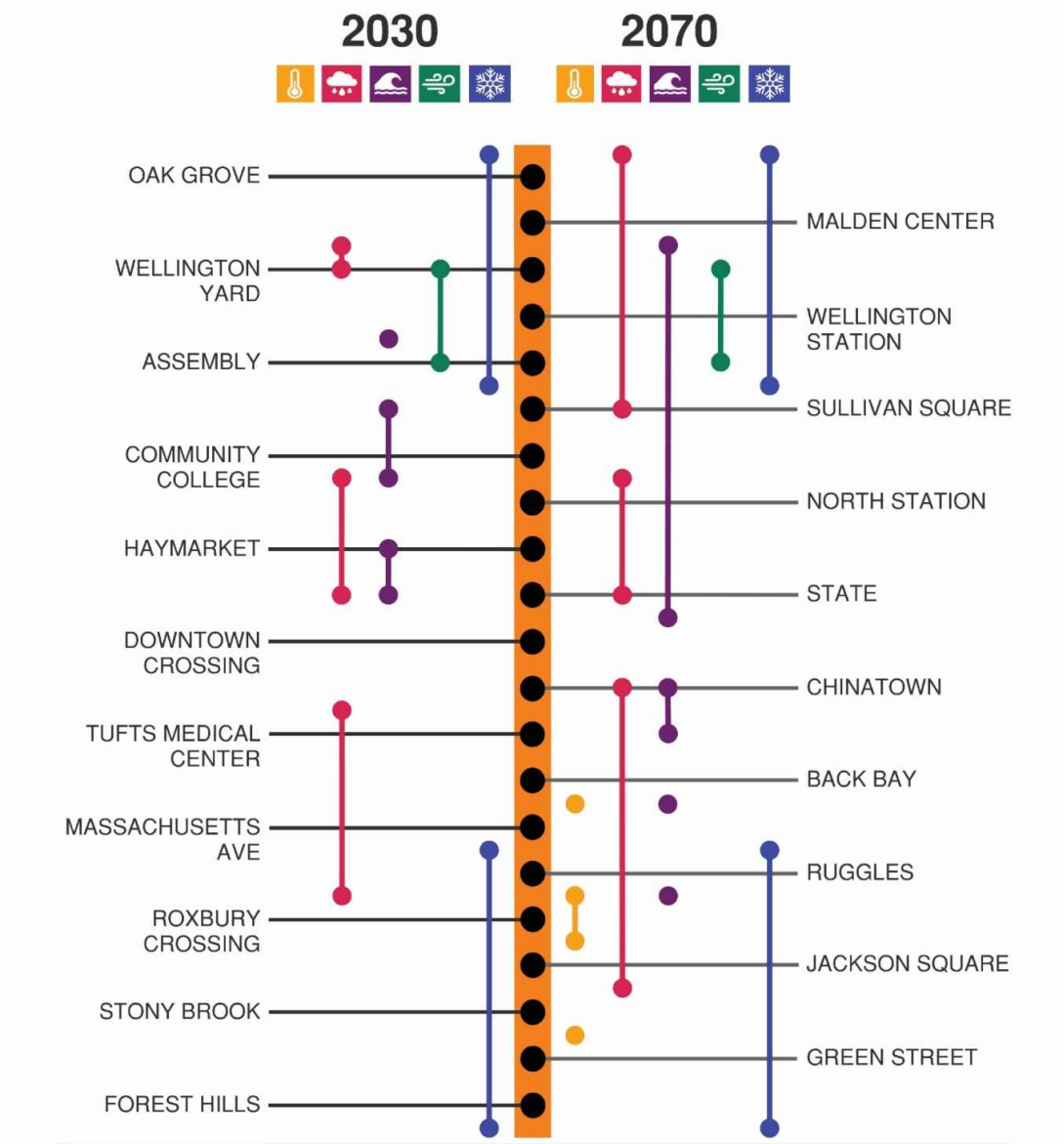
Key Findings – Trends

- **Sea Level Rise / Storm Surge and Precipitation** flooding are responsible for the greatest **increases in vulnerability scores from 2030 to 2070**

- Assets with greatest change in Vulnerability from 2030 to 2070 are:
  - Roxbury Crossing – Ruggles guideway to Mass Ave – Back Bay guideway,
  - from Tufts – Chinatown guideway to Chinatown Station,
  - the DTX – State Street guideway,
  - and Wellington Yard to Malden Center guideway.
  - Changes due to new areas and/or the expansion of existing areas being exposed to Sea Level Rise / Storm Surge Flooding

- Vulnerability assessment scoring for heat is based on a **uniform increase in heat exposure from 2030 to 2070** for each asset to reflect overall more significant impacts associated with rising temperatures and more extreme heat days by 2070.

General Locations of Increased and High Vulnerabilities



MBTA Staff & Passenger Impacts

MBTA Staff and Passenger Impacts					
Slippery surfaces					
Reduced visibility					
Hypothermia or cold temperature exposure					
Heat exhaustion or extreme heat temperature exposure					
Reduced ridership					
Difficulty with access/walking					
Dangerous and potentially harmful conditions, particularly for elderly or vulnerable populations					

Near Term Recommended Adaptation Strategies

Stations

Assess **utility room flood vulnerability**, backup power supply, and extreme weather event access restrictions

Develop **flood warning** & communications system

Implement **Flood Event Parking Plan** for MBTA staff

Guideways

Increase **drainage system capacity**

Coordinate with Medford to **divert runoff** to Malden river

Assess **structural design** of poles, foundations, & structures

Yards

Identify flood adaptation strategies for **protecting critical utility room equipment**

Elevate tracks & trailers to address flood hazards that cannot be diverted away from the MBTA corridor, or develop contingency plan for extreme flood events

Collect and monitor **winter storm response data**; update Snow and Ice Plan as needed

Longer Term Recommended Adaptation Strategies

Stations

Assess **feasibility of SLR/SS flood barrier system**

Develop **flood warning** & communications system

Elevate station tracks & platform to address flood hazards that cannot be diverted away from the MBTA corridor

Guideways

Evaluate **track stability** and assess need for **rail buckling detection**, improved preventative maintenance, & support structures

Assess bungalow HVAC & **backup power supply**

Elevate tracks & bungalows and provide flood barriers at underpasses and tunnels to address flood hazards

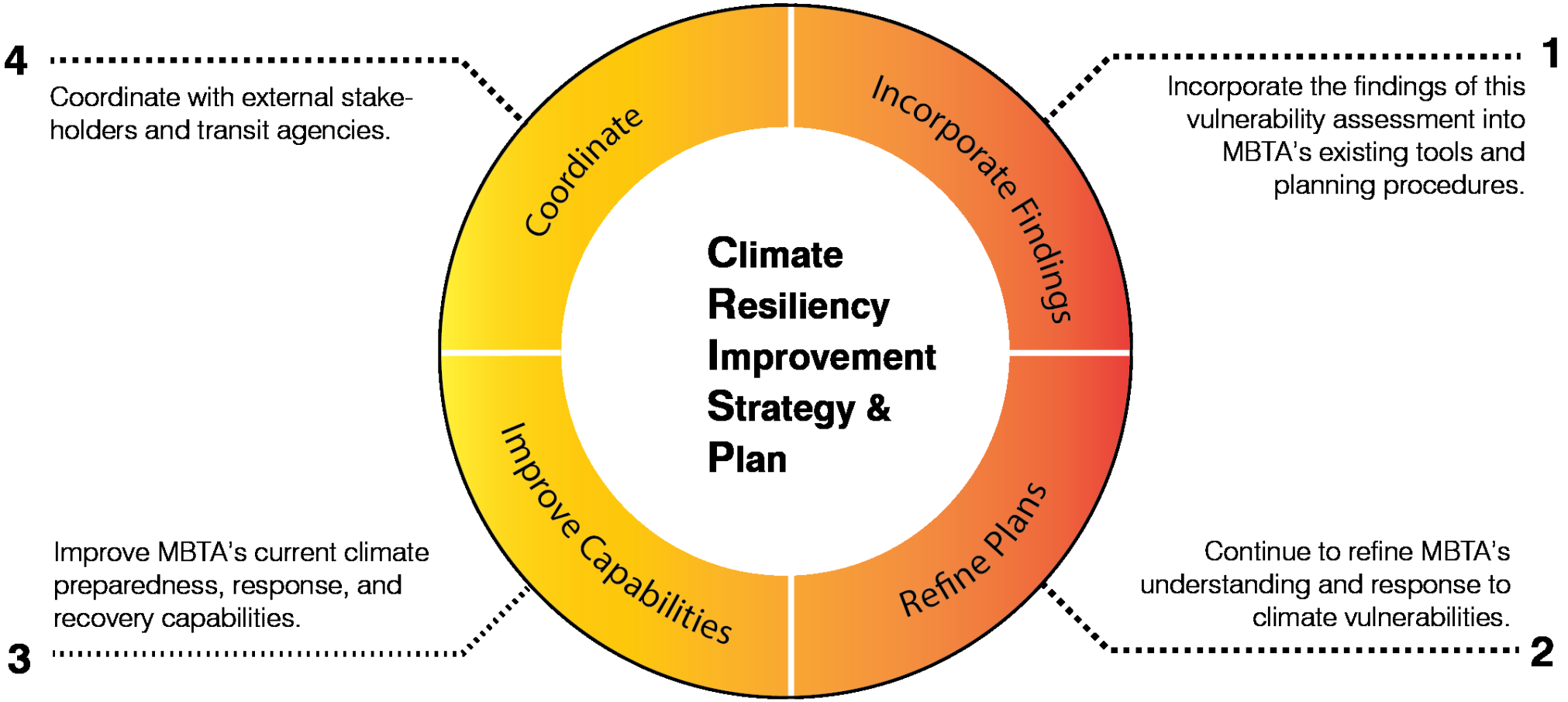
Yards

Assess **feasibility of SLR/SS flood barrier system**

Elevate tracks & trailers to address flood hazards that cannot be diverted away from the MBTA corridor

Develop **flood warning** & communications system

Use the Assessment Findings for Longer Term Planning



THANK YOU

Questions?

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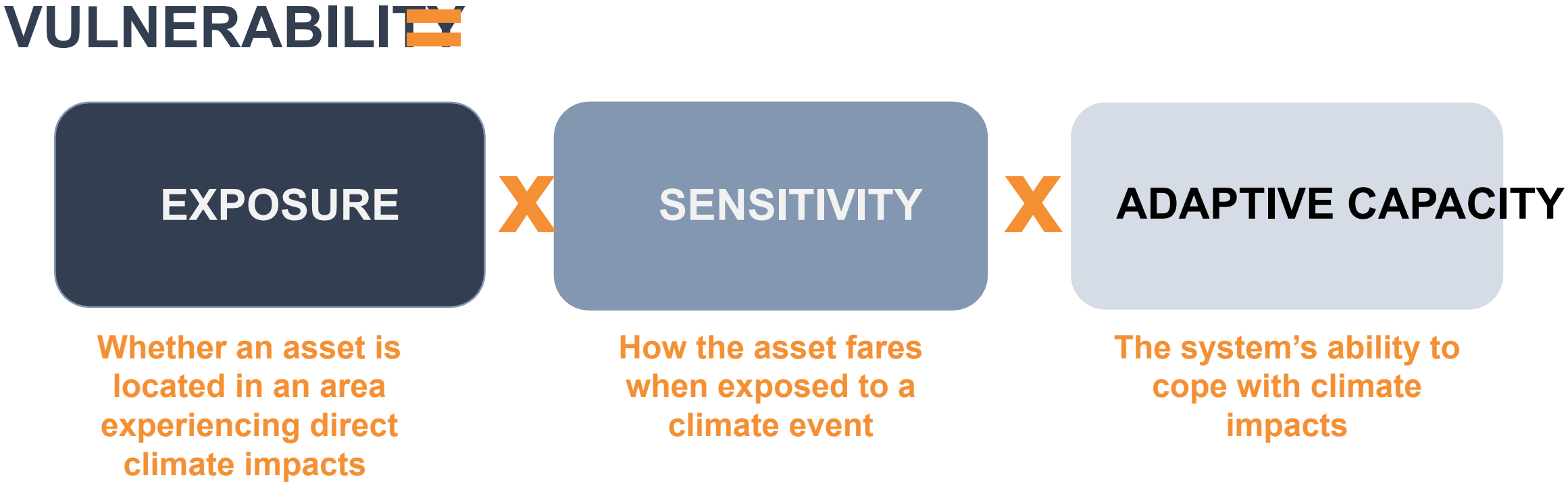
Supplemental Slides for Discussion and Q&A

Process Overview

The Federal Highway Administration's (FHWA) Vulnerability Assessment Scoring Tool (VAST) was used and **adapted** to align with the MBTA's goals and operations.



Composite Vulnerability Scoring

2030 Composite Vulnerability Score

= (0.2 x 2030 Heat Vulnerability Score)
+ (0.2 x 2030 Coastal Flood / SLR Vulnerability Score
+ (0.2 x 2030 Precipitation Vulnerability Score)
+ (0.2 x 2030 Wind Vulnerability Score)
+ (0.2 x 2030 Winter Weather Vulnerability Score)

2070 Composite Vulnerability

= (0.2 x 2070 Heat Vulnerability Score)
+ (0.2 x 2070 Coastal Flood / SLR Vulnerability Score)
+ (0.2 x 2070 Precipitation Vulnerability Score)
+ (0.2 x 2070 Wind Vulnerability Score)
+ (0.2 x 270 Winter Weather Vulnerability Score)

Exposure – Climate Change Projections

Climate Hazard	Vulnerability Score: 1 (least exposed) → 4 (most exposed)		Data Sources
	2030	**2070**	
Extreme Heat	**2**	**3**	General trend from ResilientMA
Precipitation	**1** – not in the 10-year or 100-year or no data available **2** – 100 yr (any flood depth) **3** – 10 yr (≤ 1ft inundation) **4** – 10 yr (> 1 ft inundation)	**1** – not in the 10-year or 100-year or no data available **2** – 100 yr (any flood depth) **3** – 10 yr (≤ 1ft inundation) **4** – 10 yr (> 1 ft inundation)	• Arup 2D flood modeling • BWSC stormwater modeling • City of Somerville stormwater modeling • Upper Mystic flood modeling
Sea Level Rise + Storm Surge	**N/A** – <0.1% ACE or not in floodplain **1** – 0.1%-0.19% ACE **2** – 0.2%-0.9% ACE **3** – 1%-9% ACE **4** – 10%+ ACE	**N/A** – <0.1% ACE or not in floodplain **1** – 0.1%-0.19% ACE **2** – 0.2%-0.9% ACE **3** – 1%-9% ACE **4** – 10%+ ACE	Massachusetts Coast Flood Risk Model (MC-FRM)
Wind	**N/A -** Completely below ground **1** – Below ground with some portions above ground or open to outside/fully enclosed **2** – Dense urban/suburban environment & heavily wooded areas (Exp. B) **3** – Flat areas with buildings no taller than 30' within 1500' of asset (Exp. C) **4** – Within 600' of open waterway that is 1 mile across (Exp. D)		Based on ASCE 7-10 wind exposure categories
Winter Weather	**1** – Not exposed to snow and ice (fully enclosed or underground) **2** – Partially exposed to outdoors **4** – Fully outdoors		No projections, just based on exposure to outside

**N/A for exposure = Vulnerability Score of 0*

Sensitivity – Indicators and Metrics

Indicators

Sensitivity Score: 1 (least sensitive) → 4 (most sensitive)

Sensitivity Indicators	Sensitivity Scores			
	1	2	3	4
Past Impact/Failure	No	Yes, Minor	--	Yes, Major
Asset Location (SLR/SS)	Elevated	At grade (fully enclosed)	At grade (open, partially enclosed)	Below ground
Asset Location (Wind, Heat, Winter Weather)	Below ground	Fully enclosed	Partially enclosed	Not enclosed
Asset Complexity	0-25%	26%-50%	51-75%	76-100%
Critical Systems Sensitivity	0-25%	26%-50%	51-75%	76-100%

Critical Systems

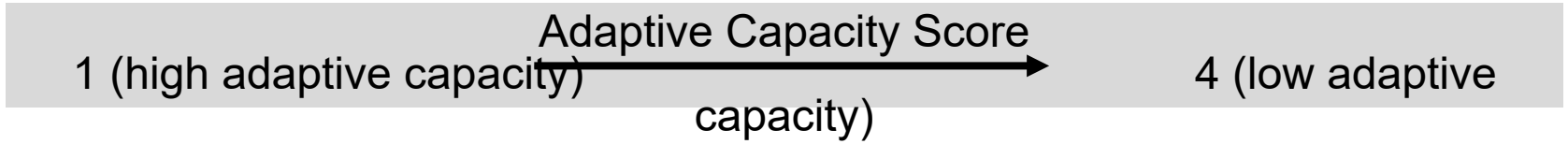
Asset Type	Critical Systems
Stations	• HVAC • Electrical (site) • Conveyance • Passenger Areas • Fire Protection (Building)
Guideway	• Bridge/Viaduct • Tunnel structure • Pump Rooms • Tunnel Ventilation • Switches & Switch Heaters • Catenary • Track & Railbed
Maintenance Yards	• Car House • Signal Tower • Switches & Switch Heaters • Tracks & Roadbed

Critical Systems Sensitivity Indicator – Example of Default Values

Asset	Critical System		Heat	Precip/ Freshwater inundation	SLR/Storm Surge - Salt Water Inundation	Wind	Winter Weather
	Name	Description					
Passenger Stations	HVAC	Chillers, cooling towers, AHUs, boilers	2 (power outage or high temp automatic shut down; shorter equipment lifespan; increased wear/tear)	4 (motors, electrical components, safety controls, and valves may require replacement when submerged)	4 motors, electrical components, safety controls, and valves may require replacement when submerged)	3 (cooling tower excessive fan blade rotation or fan shroud contact with blades resulting in damage to motors & other components; power outage)	2 (assumes equipment is winterized against water tubing bursts)
	Electrical (Site)	Transformer	2 (power outage or high temp automatic shut down)	4 (electrical components & safety controls may require replacement when submerged)	4 (electrical components & safety controls may require replacement when submerged)	2 (debris)	2

Sensitivity Score	Description	Criteria
1	Not affected	Asset maintains full functionality through exposure
2	Minimally affected	Asset ceases to function temporarily or functions at a reduced level during exposure; resumes normal function afterwards (passive recovery)
3	Significantly affected	Asset ceases to function temporarily or functions at a reduced level during exposure; resumes normal function following repair (active recovery)
4	Fail	Asset ceases to function; requires replacement following exposure

Adaptive Capacity – Indicators

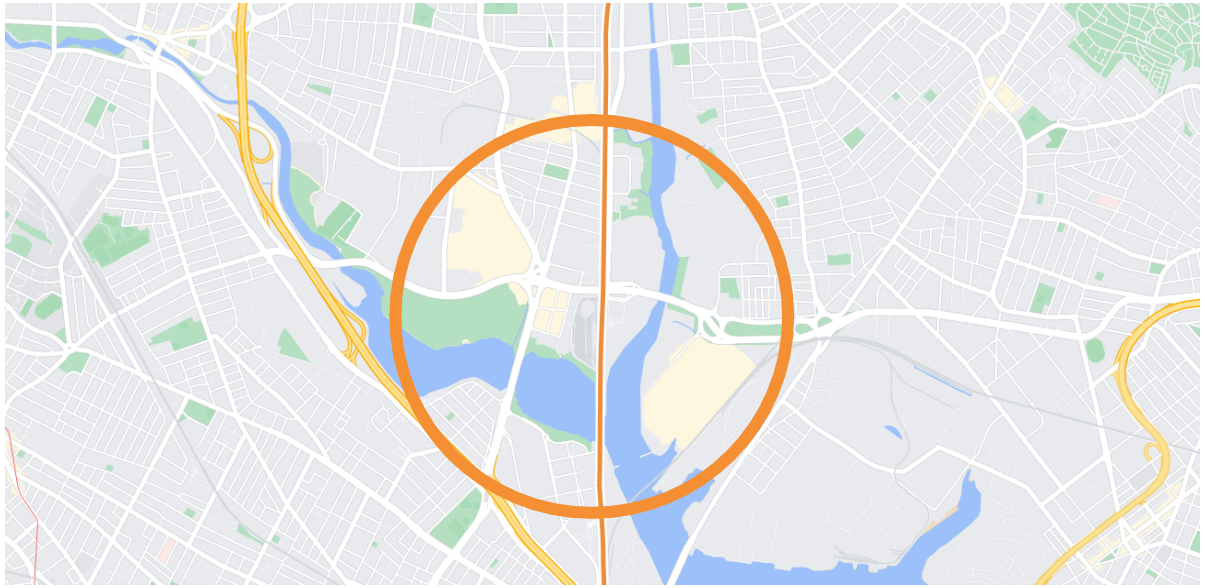


Indicators

Adaptive Capacity Indicators	Adaptive Capacity Scores				
	N/A	**1**	**2**	**3**	**4**
Distance from Central Point of MBTA System	Unknown or Not Applicable	< 1 miles from central point of MBTA system (Downtown Crossing)	1-3 miles from central point of MBTA system (Downtown Crossing)	3-5 miles from central point of MBTA system (Downtown Crossing)	> 5 miles from central point of MBTA system (Downtown Crossing)
Redundancy (Service Option, Interchange Utility*)		Ability to transfer (bus service line, commuter rail, other yard, other lines)			No ability to transfer (bus service line, commuter rail, other yard, other lines)
Presence of Backup Generator(s) for critical infrastructure		Has a backup generator on-site		Has ability to connect to mobile generator	Does not have a backup generator on-site
Flood Protection Systems		Passive system (designed to appropriate design storm)		Deployable system (designed to appropriate design storm)	No flood protection / limited to Standard Operating Procedures (sandbag only)

Case Study – Wellington Station

0 – 2.0	Reduced Vulnerability
2.0 - 2.4	Moderate Vulnerability
2.5 - 2.9	Increased Vulnerability
3.0 – 4.0	High Vulnerability



Climate Hazard	Exposure - 2030	Exposure - 2070	Adaptive Capacity	Sensitivity	2030 Vulnerability - Final Score	2070 Vulnerability - Final Score
Extreme Heat	2.0	3.0	3.0	2.3	2.4	2.7
Precipitation	3.0	4.0		2.8	2.9	3.2
SLR/Storm Surge	1.0	4.0		2.8	2.2	3.2
Wind	4.0	4.0		2.3	3.1	3.1
Winter Weather	4.0	4.0		2.5	3.1	3.1
					2.7	**3.1**

Case Study – Wellington Station Exposure

Climate Hazard	2030		2070	
	Exposure Score	Data	Exposure Score	Data
Extreme Heat	2.0	All 2030 heat exposure scores are 2	3.0	All 2030 heat exposure scores are 3
Precipitation	3.0		4.0	
SLR/Storm Surge	1.0		4.0	
Wind	4.0		4.0	
Winter Weather	4.0		4.0	

0 – 2.0	Reduced Vulnerability
2.0 - 2.4	Moderate Vulnerability
2.5 - 2.9	Increased Vulnerability
3.0 – 4.0	High Vulnerability

Case Study – Wellington Station Sensitivity

Climate Hazard	Sensitivity Score	Past Impact Score	Past Impact Data	Asset Location Score	Asset Location Data	
Extreme Heat	2.3		No past impact		Partially enclosed	**+ Asset Complexity & Critical Systems Sensitivity Scores (shown in next 2 slides)**
Precipitation	2.8		No past impact		At grade (open/partially enclosed)	
SLR/Storm Surge	2.8		No past impact		At grade (open/partially enclosed)	
Wind	2.3		No past impact		Partially enclosed	
Winter Weather	2.5		Minor past impact - 2015		Partially enclosed	

Case Study – Wellington Station Sensitivity

Asset Complexity Score

Critical System	Present at Wellington Station
HVAC	No
Electrical (Site)	Yes
Conveyance	Yes
Passenger Areas	Yes
Fire Protection (Building)	Yes
Multiple rapid transit lines at station	No
CRITICAL SYSTEM COMPLEXITY CALCULATION	
Total critical systems present (sum of “yes” answers)	4
Total possible critical systems at asset (sum of all “yes” and “no” answers)	6
Asset complexity (%)	4/6 = 67%
Asset complexity score	3

→ Multiple lines is only used for calculating the complexity score; not incorporated into the critical system sensitivity score

Case Study – Wellington Station Sensitivity

Critical System Sensitivity Score

Critical System	Present at Wellington Station	Critical System Sensitivity to Hazard				
		Heat	Precip	SLR	Wind	Winter Weather
HVAC	No					
Electrical (Site)	Yes	2	4	4	2	2
Conveyance	Yes	2	4	4	2	2
Passenger Areas	Yes	1	2	2	2	1
Fire Protection (Building)	Yes	2	4	4	2	1
~~Multiple rapid transit lines at station~~	~~No~~	-	-	-	-	-
CRITICAL SYSTEM SENSITIVITY CALCULATION						
Critical systems sensitivity score by hazard (sum of scores)		7	14	14	8	6
Total possible sensitivity scores (highest possible sensitivity score is 4 – multiply # of systems x highest possible score of 4)		4 x 4 = 16				
Critical system sensitivity (%)		7/16 = 44%	14/16 = 88%	14/16 = 88%	8/16 = 50%	6/16 = 38%
Critical system sensitivity score		2	4	4	2	2

Case Study – Wellington Station Adaptive Capacity

Adaptive Capacity	Indicators	Indicator weights	Indicator Scores	Indicator Data
3.0	Distance from DTX	0.25	3	4.3 miles from DTX
	Redundancy	0.25	1	Multiple bus lines for redundancy (97/99/100/106/108/110/112/134)
	Backup Generators	0.25	4	No generators
	Flood Protection	0.25	4	No flood protection systems

Calculation:

(0.25 x 3) + (0.25 x 1) + (0.25 x 4) + (0.25 x 4)

0.75 + 0.25 + 1 + 1 = **Adaptive Capacity Score of 3.0**

Case Study – Wellington Station Composite Scores

Climate Hazard	Exposure - 2030	Exposure - 2070	Adaptive Capacity	Sensitivity	2030 Vulnerability - Final Score	2070 Vulnerability - Final Score
Extreme Heat	2.0	3.0	3.0	2.3	2.4	2.7
Precipitation	3.0	4.0		2.8	2.9	3.2
SLR/Storm Surge	1.0	4.0		2.8	2.2	3.2
Wind	4.0	4.0		2.3	3.1	3.1
Winter Weather	4.0	4.0		2.5	3.1	3.1
					2.7	**3.1**

Calculations:

(0.33 x Exposure) + (0.33 x Sensitivity) + (0.33 x Adaptive Capacity) = Hazard-specific Vulnerability Score

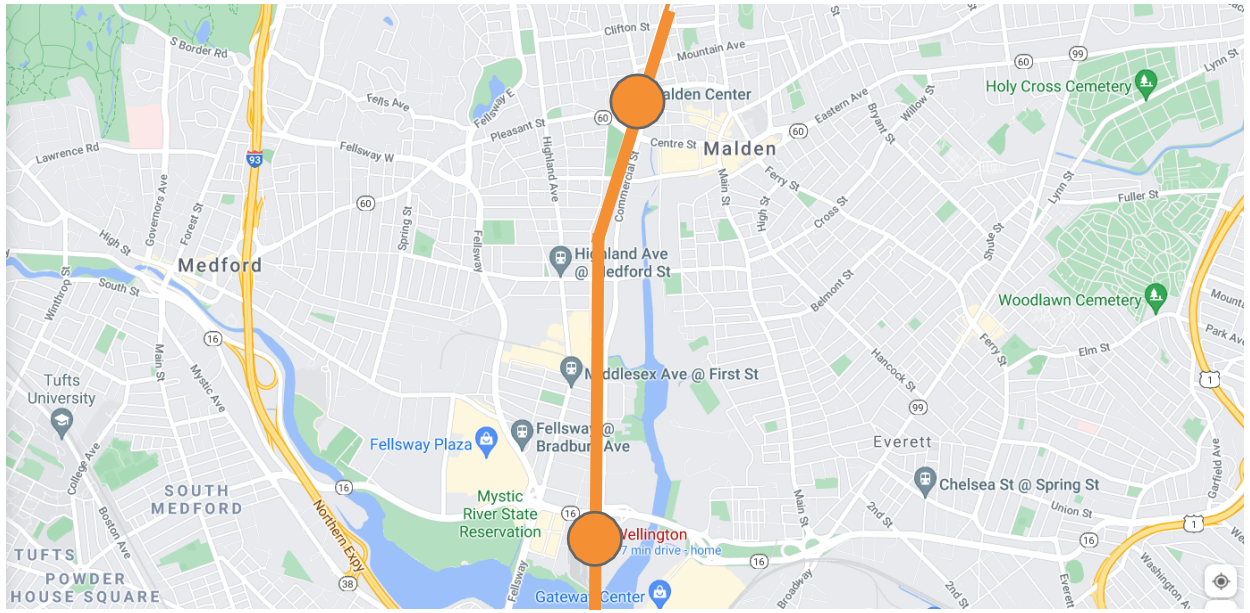
(0.2 x Heat) + (0.2 x Precipitation) + (0.2 x SLR) + (0.2 x Wind) + (0.2 x Winter Weather) = Composite Score

2030 Composite Score: (0.2 x 2.4) + (0.2 x 2.9) + (0.2 x 2.2) + (0.2 x 3.1) + (0.2 x 3.1) = **2.7**

2070 Composite Score: (0.2 x 2.7) + (0.2 x 3.2) + (0.2 x 3.2) + (0.2 x 3.1) + (0.2 x 3.1) = **3.1**

Case Study – Wellington to Malden Cer

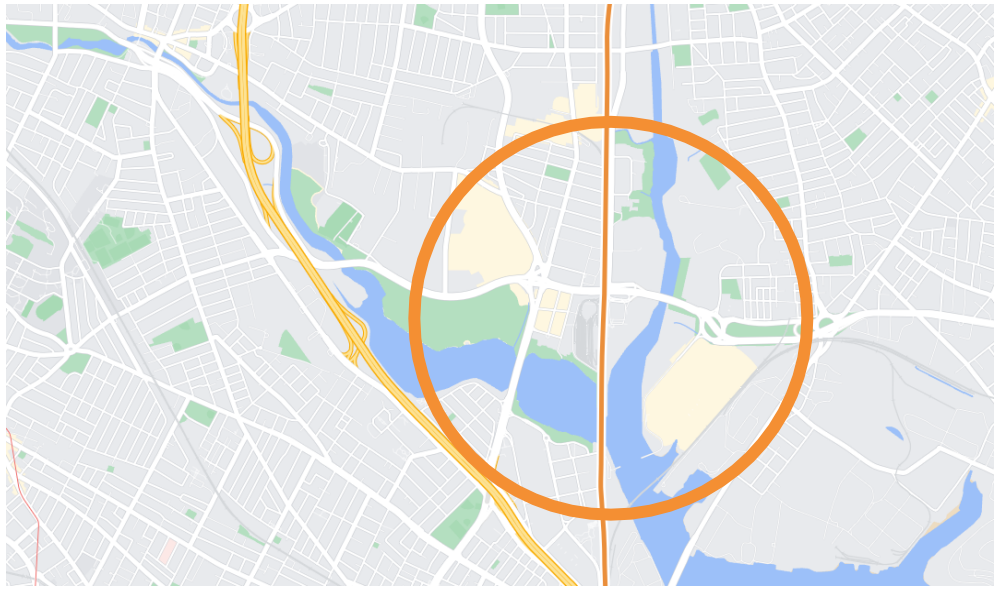
0 – 2.0	Reduced Vulnerability
2.0 - 2.4	Moderate Vulnerability
2.5 - 2.9	Increased Vulnerability
3.0 – 4.0	High Vulnerability



Climate Hazard	Exposure - 2030	Exposure - 2070	Adaptive Capacity	Sensitivity	2030 Vulnerability - Final Score	2070 Vulnerability - Final Score
Extreme Heat	2.0	3.0	3.0	2.5	2.8	3.1
Precipitation	4.0	4.0		2.8	3.5	3.5
SLR/Storm Surge	3.0	4.0		2.8	3.2	3.5
Wind	2.0	2.0		2.5	2.8	2.8
Winter Weather	4.0	4.0		2.8	3.5	3.5
					3.2	**3.3**

Case Study – Wellington Maintenance

0 – 2.0	Reduced Vulnerability
2.0 - 2.4	Moderate Vulnerability
2.5 - 2.9	Increased Vulnerability
3.0 – 4.0	High Vulnerability



Climate Hazard	Exposure - 2030	Exposure - 2070	Adaptive Capacity	Sensitivity	2030 Vulnerability - Final Score	2070 Vulnerability - Final Score
Extreme Heat	2.0	3.0	3.0	2.8	2.5	2.9
Precipitation	3.0	4.0		3.3	3.0	3.4
SLR/Storm Surge	1.0	4.0		3.0	2.3	3.3
Wind	4.0	4.0		2.8	3.2	3.2
Winter Weather	4.0	4.0		2.8	3.2	3.2
					2.9	**3.2**

Recommendations & Next Steps

Evaluate holistic impacts & considerations for extreme weather to MBTA staff & passengers.

Incorporate Findings:

- Integrate Vulnerability Scores to Trapeze
- Develop instructions for MBTA staff to incorporate resiliency into Project Charters.
- Integrate vulnerability data with other MBTA applications.

Refine Plans:

- Expand on the findings by studying potential cascading impacts and conduct a comprehensive risk assessment.
- Develop resilience design standards and guidance for use in the design of new assets and repair of existing assets.
- Develop a system-wide Climate Resilience Preparedness, Response, and Recovery Plan.

Improve Capabilities

Demonstrate leadership support for incorporating climate resiliency into planning, design and maintenance

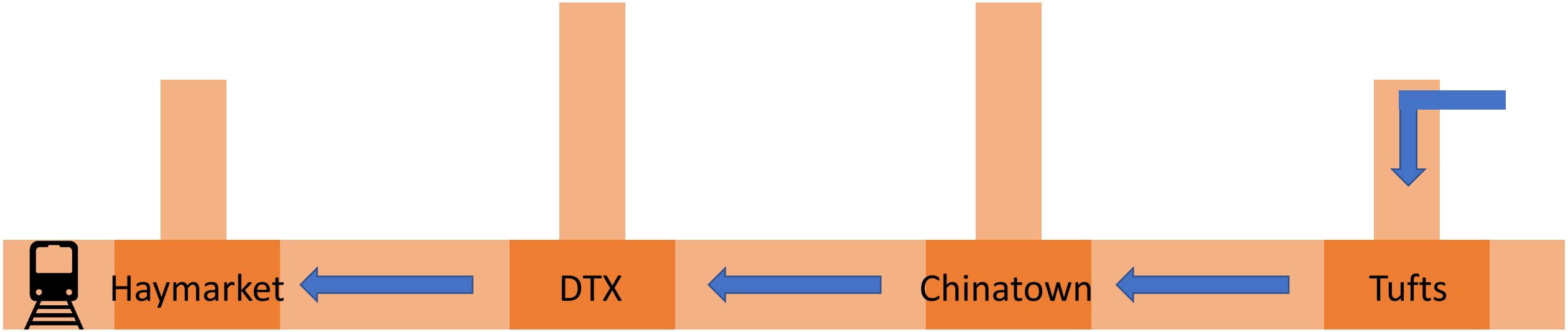
Train MBTA staff

Coordinate:

- Continue ongoing participation in regional efforts to coordinate climate resiliency strategies.
- Coordinate with other transit agencies to identify successful strategies and products, as well as lessons learned.

Refine Plans – Evaluating Cascading Impacts Across the MBTA Lines

- Understanding consequences of impacts within the OL
- Understanding consequences of impacts across the different lines, and other modes of transportation
- Evaluating avoided costs and benefits
- Conducting a system-wide risk assessment across the different lines
- Developing risk-based prioritized projects for implementation



Regional Coordination

- Continue discussions on regional resiliency efforts
- Continue partnerships with municipalities, other State agencies, watershed organizations for pursuing regional approach to interventions