Statewide Resilience Master Planning: Flood Vulnerability and Adaptation

Adapt, Thrive, and Survive Climate Impacts

Frank Ricciardi, PE, LSP, MVP

Weston & Sampson

Weston & Sampson – Rocky Hill, CT

- Full service, Multi-disciplinary office

- Staff includes Hydraulics/Hydrology, site civil, transportation, structural, environmental, and traffic engineers as well as licensed survey staff

- Designers of resilient infrastructure!

Agenda

- Statewide Resiliency Master Plan (SRMP) – Division of Capital Asset Management and Maintenance (DCAMM), Massachusetts
  - PHASE I: Benchmarking & Criticality Analysis and Climate Scenario Selection
  - PHASE II: Risk and Vulnerability Analysis & Pilot Site Workshops
  - PHASE III: Compilation and Distribution of Guidelines
- Outcomes of SRMP
- Implementing a similar process for CT

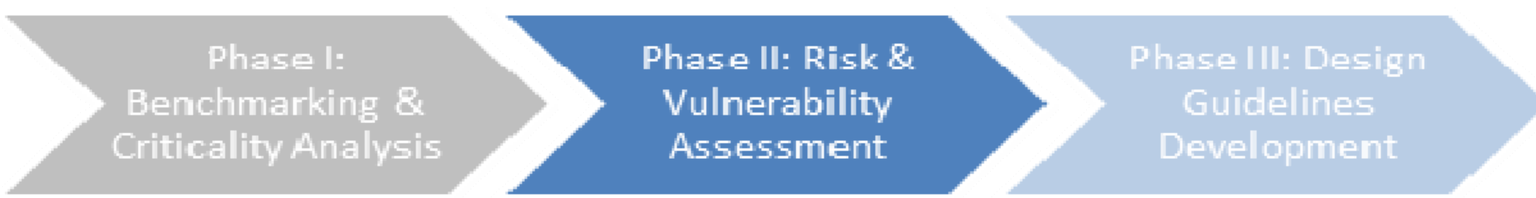
Acknowledgements

- Massachusetts DCAMM
- “Re-Team” – Resiliency team of DCAMM and MEMA staff
- Technical Assistance Group (TAG) – Representatives from MBTA Massport, Partners Healthcare, ULI, MAPC, UMass, MassDOT
- Our project teaming partner: KLEINFELDER Bright People. Right Solutions.

Goal and Scope of Massachusetts SRMP Project

SRMP Project Goal Considerations

- ***Review DCAMM's portfolio vulnerability to climate change impacts and develop design guidelines which encourage climate adaptation and resilience.***
- DCAMM Mission Specific Goals
- Agency Goals for Service Continuity
- Goals for Resilient Design Guidelines



Summer-Fall 2016 | Fall- Winter 2016/17 | Spring-Summer 2017

PHASE 1 - BENCHMARKING & CRITICALITY ANALYSIS

GOAL: Identify representative, critical Commonwealth's assets for Risk and Vulnerability Analysis (RVA) and Guideline Development

- Portfolio Review
- Criticality Definition
- DCAMM Survey
- Criticality Worksheet
- Prioritization

DIVISION OF CAPITAL ASSET MANAGEMENT & MAINTENANCE

DCAMM Portfolio – Over 8300 Assets

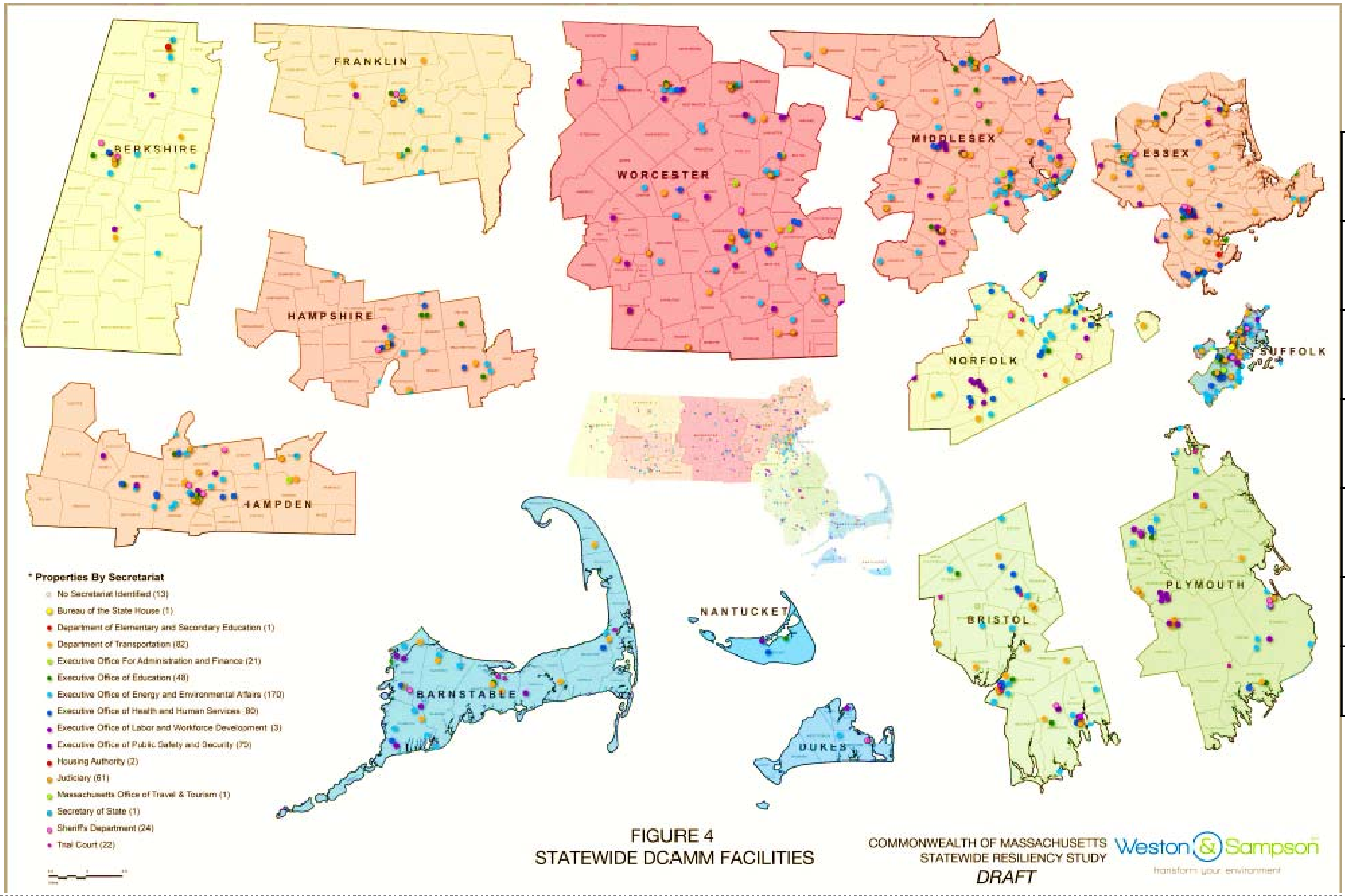
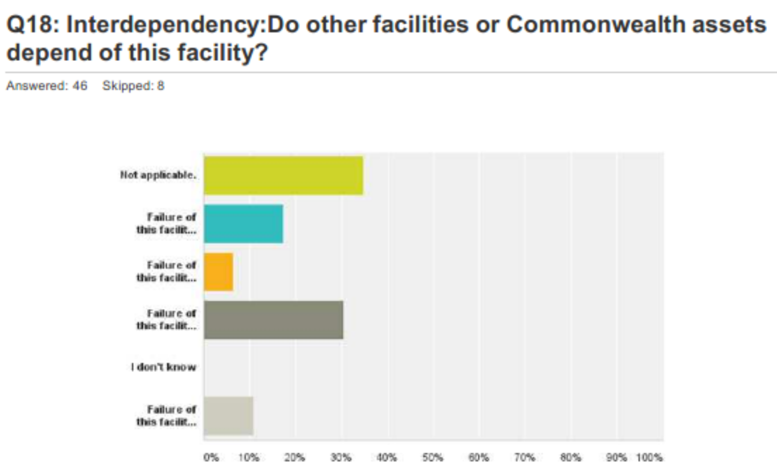


FIGURE 4
STATEWIDE DCAMM FACILITIES

DCAMM Secretariats

	Executive Office For Administration and Finance
	Executive Office of Health and Human Services
	Executive Office of Energy and Environmental Affairs
	Executive Office of Public Safety and Security
	Executive Office of Education
	Judicial Branch
	Office of the State House

SURVEY AND CRITICALITY WORKSHEET



Criticality

Scope

Geographic area and population affected by loss of facility

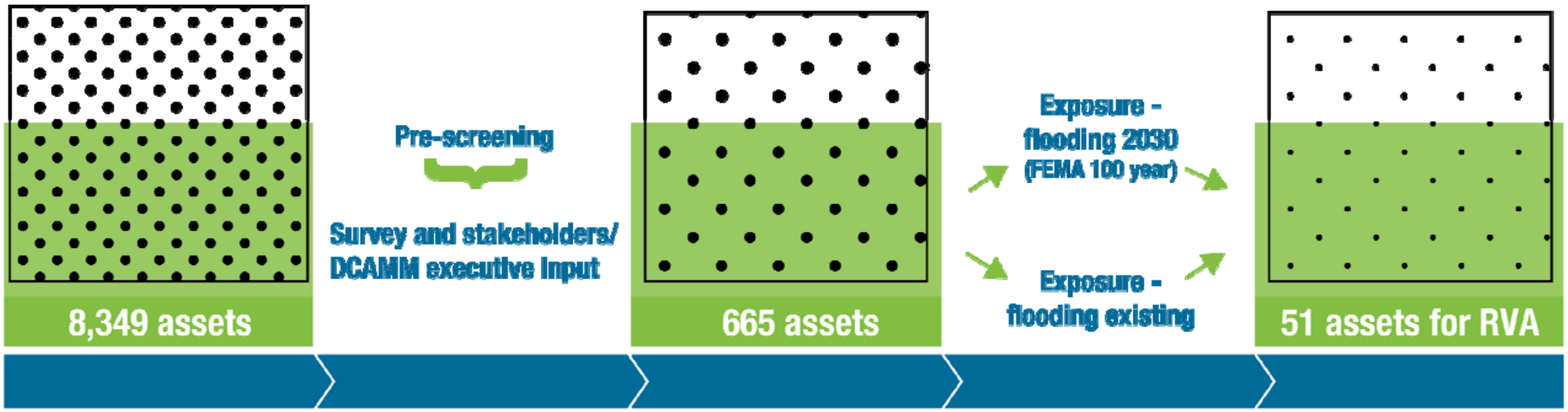
Time

Length of time a facility can be inoperable without consequences

Severity

- Public Health and Safety
- Economic Effect
- Environmental Effect
- Interdependency
- Political Effect
- Psychological Effect

Portfolio Screening



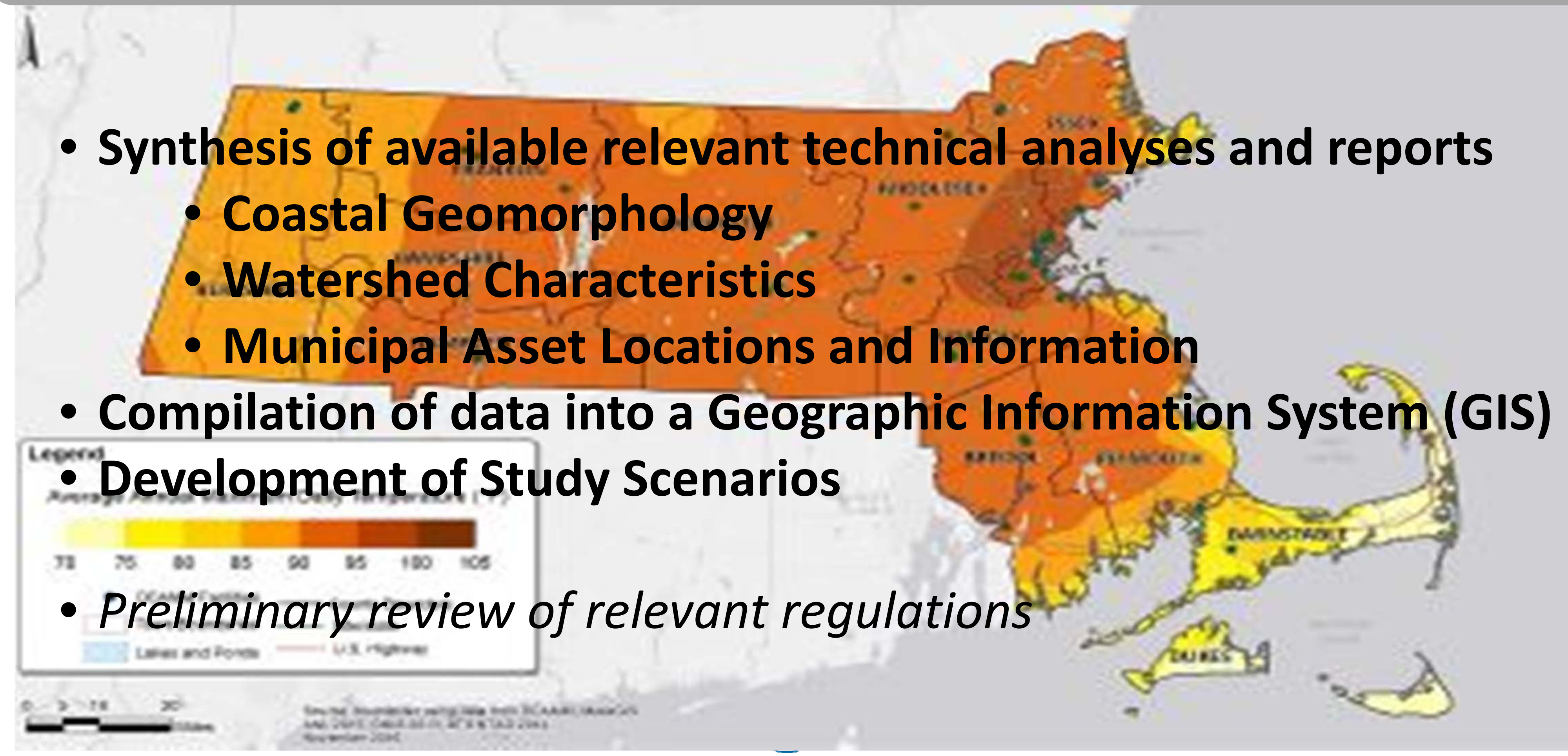
- Pre-screen assets to remove duplicate entries, fences, sheds and other minor items
- Survey DCAMM directors/executives to further understand portfolio nature
- Interview property managers to understand where climate impacts exist currently
- Use existing mapping to identify facilities with short term risk

PHASE 1 – CLIMATE SCENARIO SELECTION

CLIMATE IMPACTS

TIER 1	Sea Level Rise/Storm Surge	Extreme Precipitation			Extreme Temperatures		
TIER 2	Coastal Flooding	Inland flooding	Landslides	Ice Storms	Drought	Fire	Wind

PHASE 1 – CLIMATE SCENARIO SELECTION



- **Synthesis of available relevant technical analyses and reports**
    - **Coastal Geomorphology**
    - **Watershed Characteristics**
    - **Municipal Asset Locations and Information**
- **Compilation of data into a Geographic Information System (GIS)**
- **Development of Study Scenarios**
- *Preliminary review of relevant regulations*

Precipitation and Inland Flooding

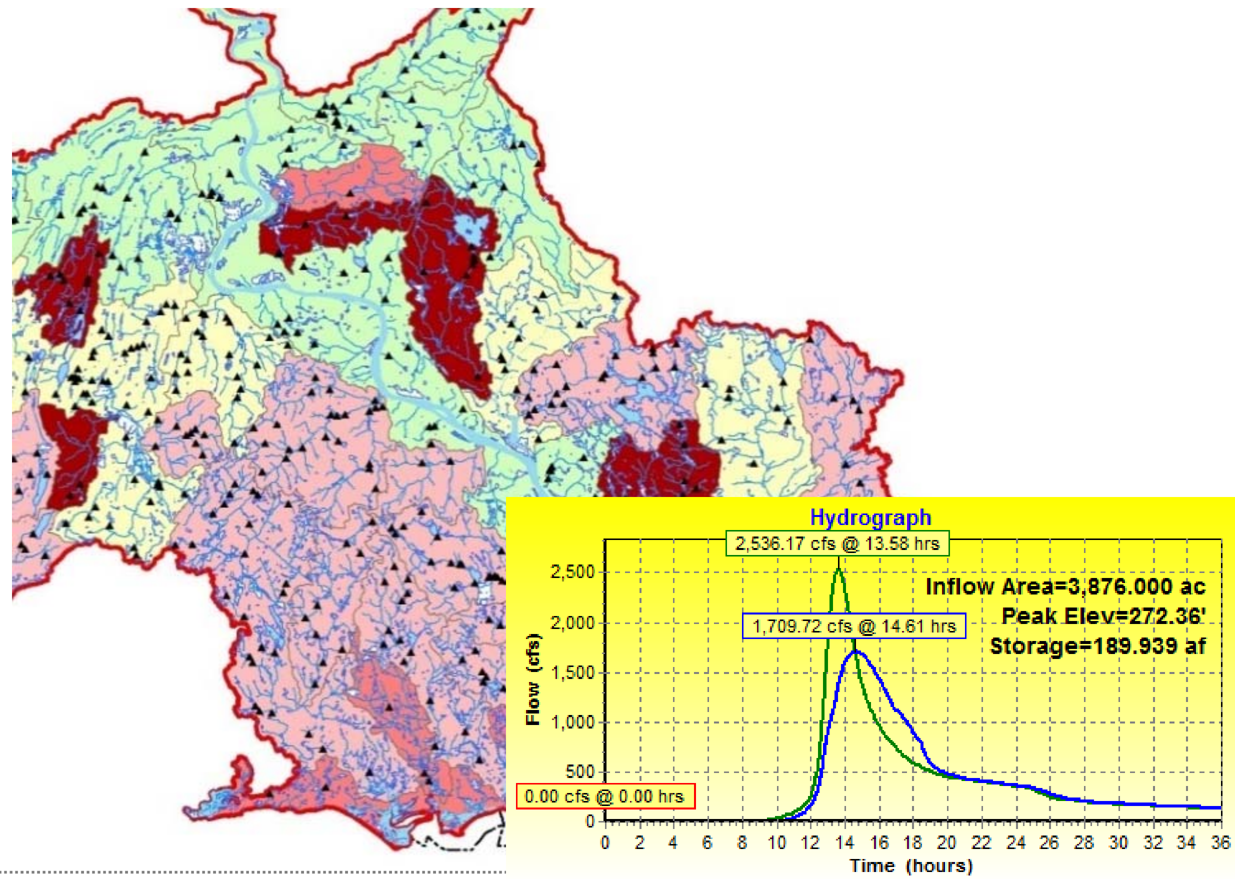
Runoff Model Vulnerability

Develop Runoff Model

- Army Corps HEC-HMS software
- NRCS unit hydrograph method
  - Drainage Area
  - Curve Number
  - Time of Concentration
- Include significant dams/impoundments

Model high-intensity rainfall events

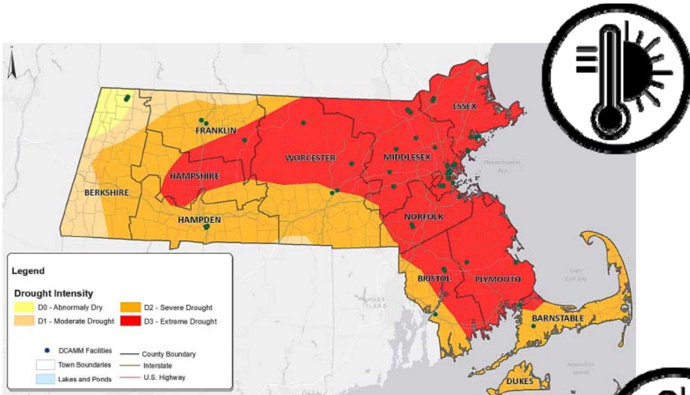
- NRCC/Cornell rainfall data, includes climate change up to ~2010

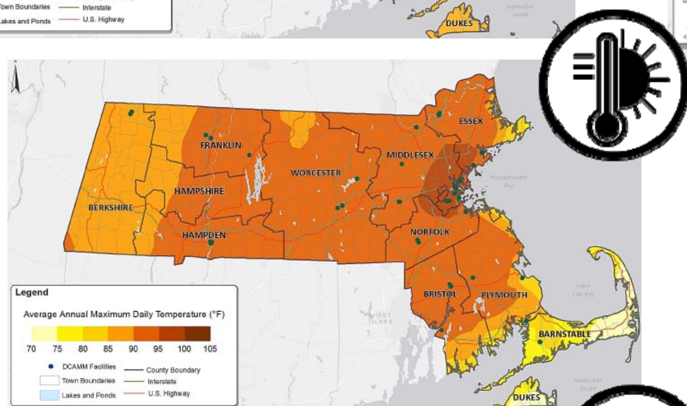


HEC-HMS Impoundment Runoff

Climate Scenarios: 2030 and 2070

CLIMATE PARAMETERS		EXISTING		2030		2070	
		DATA	MAP	DATA	MAP	DATA	MAP
TIER 1 PARAMETERS	SEA LEVEL RISE/ STORM SURGE	NA	NA	SLOSH CAT1 & BH-FRM data in avail. locations	✓	SLOSH CAT2 & BH-FRM data in avail. locations	✓
	PRECIPITATION	Extreme Precipitation Amount greater than 99 percentile from Argonne Lab (1995-2004)	✓	FEMA 100 Year / Extreme Precipitation Amount greater than 99 percentile from Argonne Lab (2045-2054)	✓	FEMA 500 Year / Extreme Precipitation Amount greater than 99 percentile from Argonne Lab (2085-2094)	✓
	TEMPERATURE	Number of heat waves per decade and average annual max temperature from Argonne Lab (1995-2004)	✓ (2 maps)	Number of heat waves per decade and average annual max temperature from Argonne Lab (2045-2054)	✓ (2 maps)	Number of heat waves per decade and average annual max temperature from Argonne Lab (2085-2094)	✓ (2 maps)
TIER 2 PARAMETERS	WINTER STORMS	MEMA	✓	NA	NA	NA	NA
	FIRE	MEMA	✓	NA	NA	NA	NA
	DROUGHT	US Drought Monitor Map for MA	✓	NA	NA	NA	NA
	LANDSLIDE	MEMA	✓	NA	NA	NA	NA
	EARTHQUAKE*	MEMA	✓	NA	NA	NA	NA
	WIND	MEMA	✓	NA	NA	NA	NA


FRANKLIN
ESSEX
WORCESTER
MIDDLESEX
HAMPSHIRE
BERKSHIRE
HAMPDEN
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
Legend
Drought Intensity
D0 - Abnormaly Dry
D1 - Moderate Drought
D2 - Severe Drought
D3 - Extreme Drought
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway


ESSEX
FRANKLIN
WORCESTER
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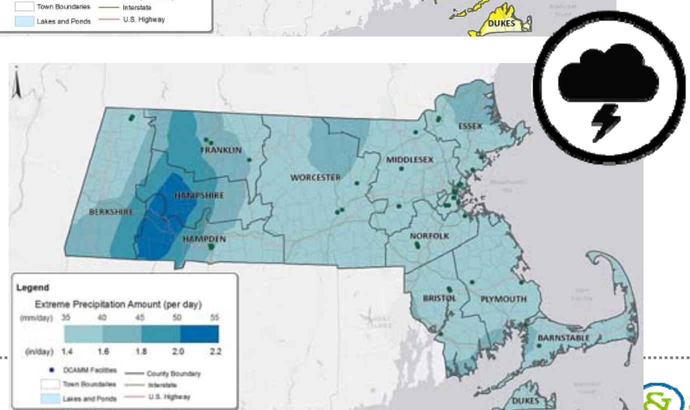
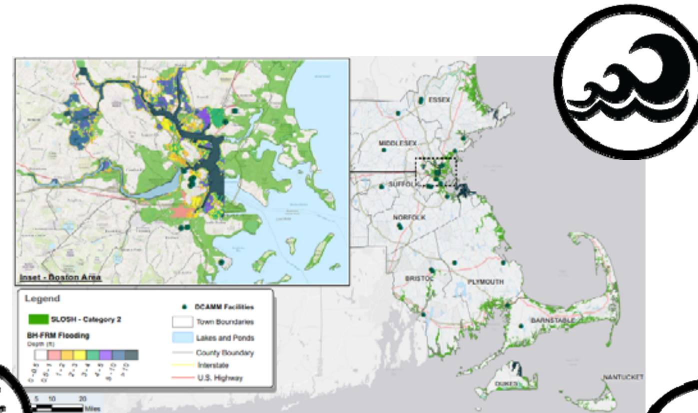
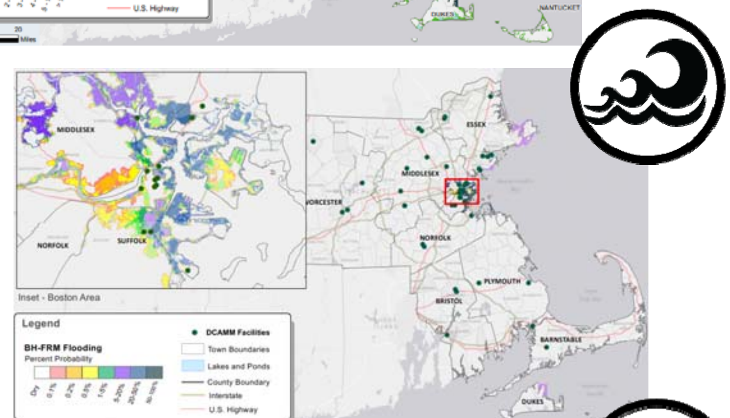
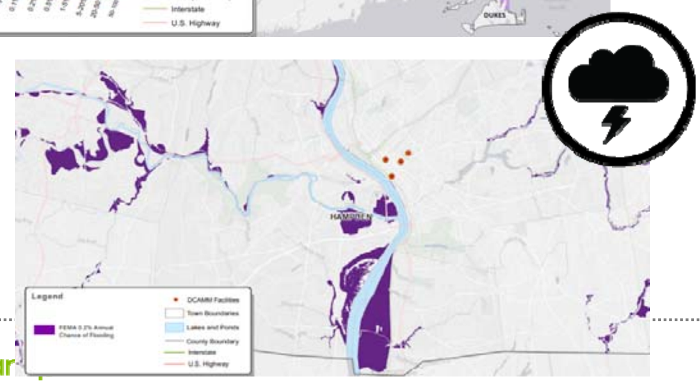
HAMPSHIRE
BERKSHIRE
HAMPDEN
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
Legend
Average Annual Maximum Daily Temperature (°F)
70 75 80 85 90 95 100 105
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway

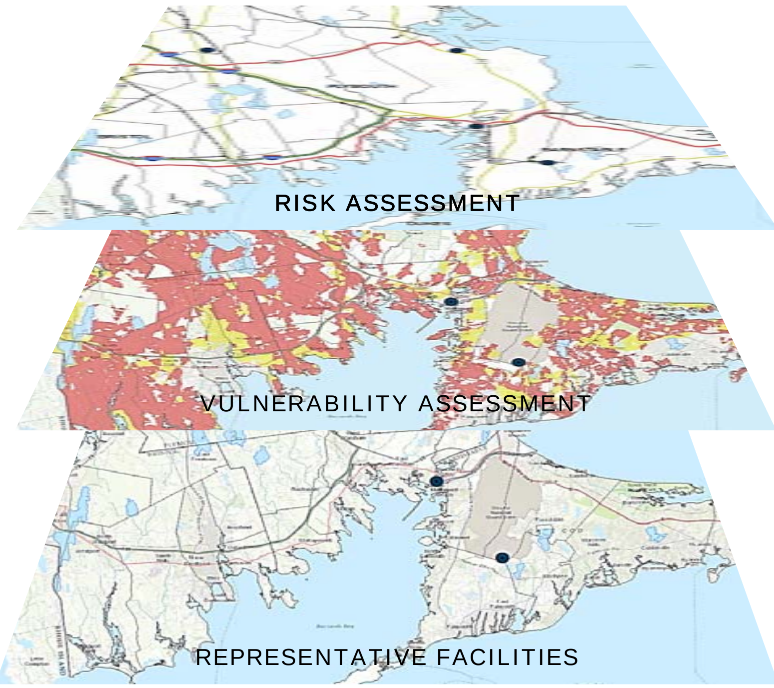

ESSEX
FRANKLIN
WORCESTER
MIDDLESEX
HAMPSHIRE
BERKSHIRE
HAMPDEN
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
Legend
Extreme Precipitation Amount (per day)
(mm/day) 35 40 45 50 55
(in/day) 1.4 1.6 1.8 2.0 2.2
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway

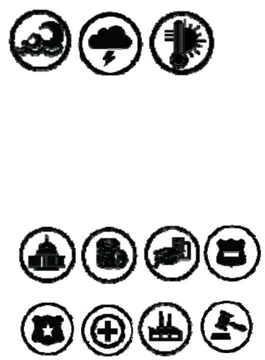

Inset - Boston Area
ESSEX
MIDDLESEX
SUFFOLK
NORFOLK
BRISTOL
PLYMOUTH
BARNSTABLE
DUKES
NANTUCKET
Legend
SLOSH - Category 2
BH-FRM Flooding
Depth (ft)
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway
Miles


MIDDLESEX
NORFOLK
SUFFOLK
Inset - Boston Area
ESSEX
WORCESTER
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
Legend
BH-FRM Flooding
Percent Probability
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway


HAMPDEN
Legend
DCAMM Facilities
Town Boundaries
Lakes and Ponds
County Boundary
Interstate
U.S. Highway

PHASE 2 – RISK AND VULNERABILITY ASSESSMENT (RVA)



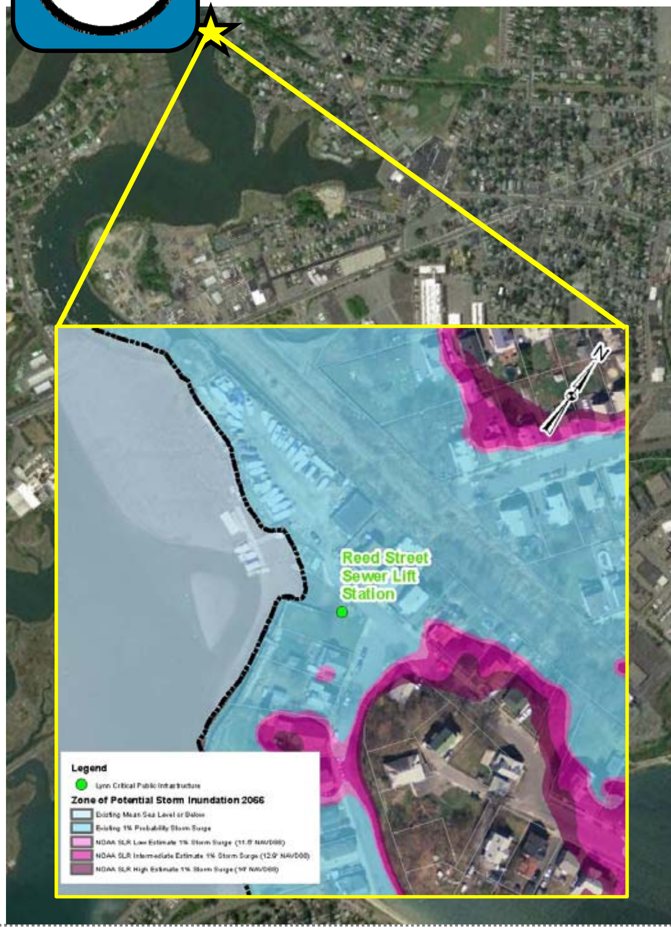


Prioritization

Vulnerability		Risk: Low	Risk: High
	High	*May be priority planning areas*	*Should be priority planning areas*
	Low	*Are unlikely to be priority planning areas*	*May be priority planning areas*

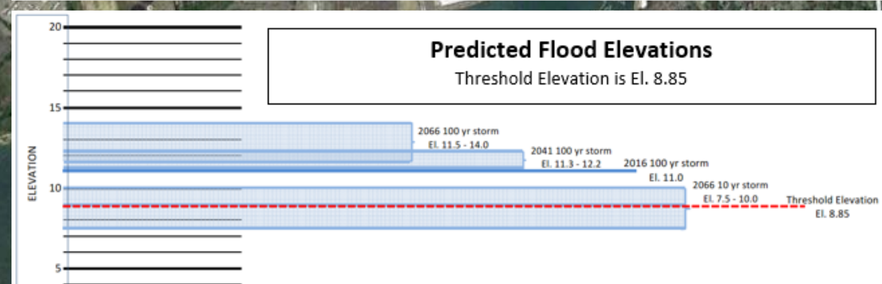
SELECT 3 PILOT SITES

Local Sea Level Rise Example



		Criteria Describing Consequence				
Severity	**Score**	**Public Safety, Emergency Services**	**Public Health, Environment**	**Repair Cost**	**Reduced Economic Activity**	**Public Services; Duration**
	5	Regional Emergency	Regional Emergency	>$20 MM	Regional Emergency	>1 Month
	4	City Emergency	City Emergency	$2 MM - $20 MM	City Emergency	15-30 Days
	3	High	High	$200 K - $2 MM	High	7-14 days
	2	Moderate	Moderate	$20K - $200K	Moderate	1-6 days
	1	Low	Low	<$20K	Low	< 1 day

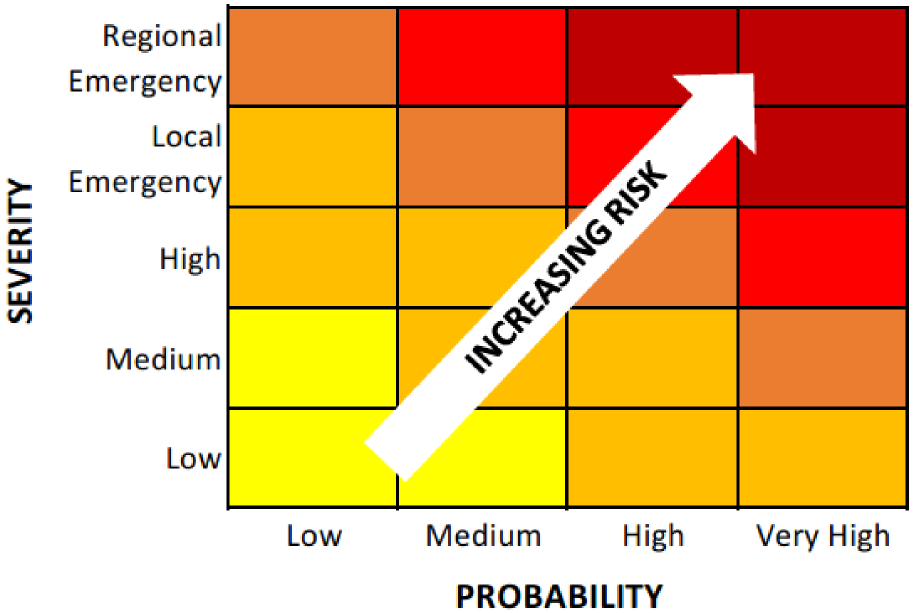
Facility	Consequence Score	Probability 2016	Probability 2041	Probability 2066	Weighted Risk Score
Reed Street Sewer Lift Station	64	0.01	0.01	0.1	2.37

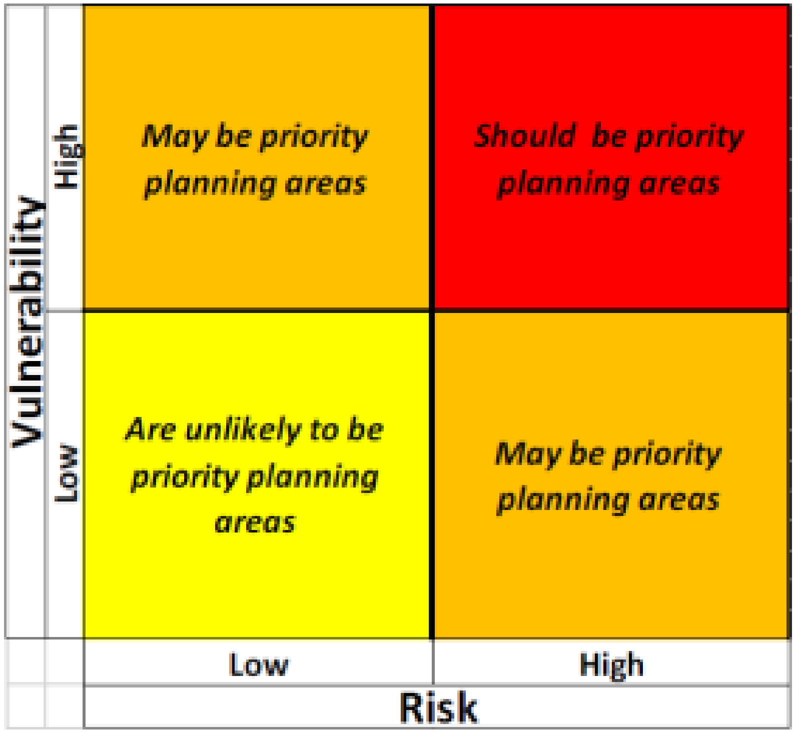


Risk Analysis

– Probability of climate impact versus severity of consequence

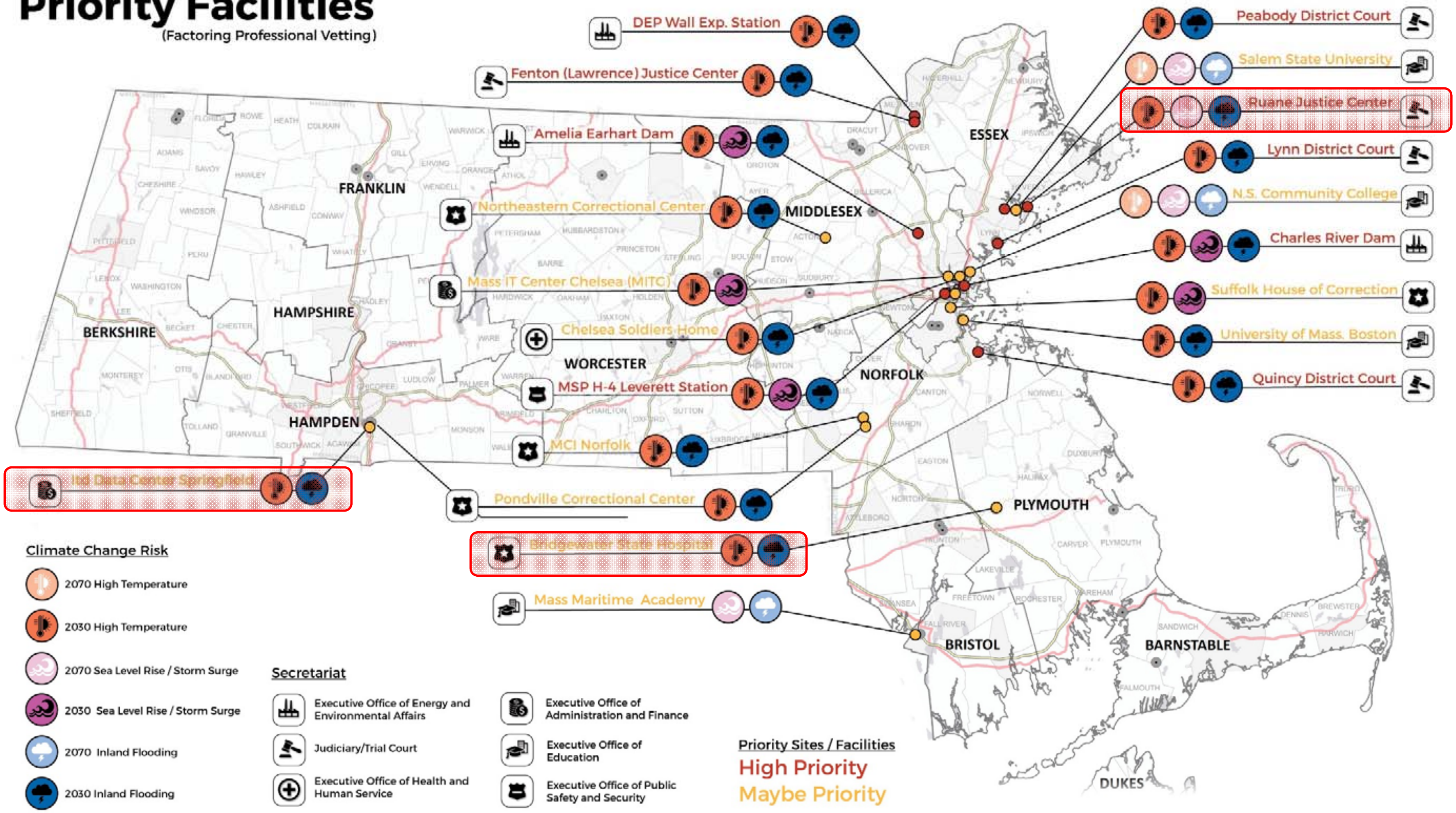
– High Vulnerability, High Risk Sites = High Priority





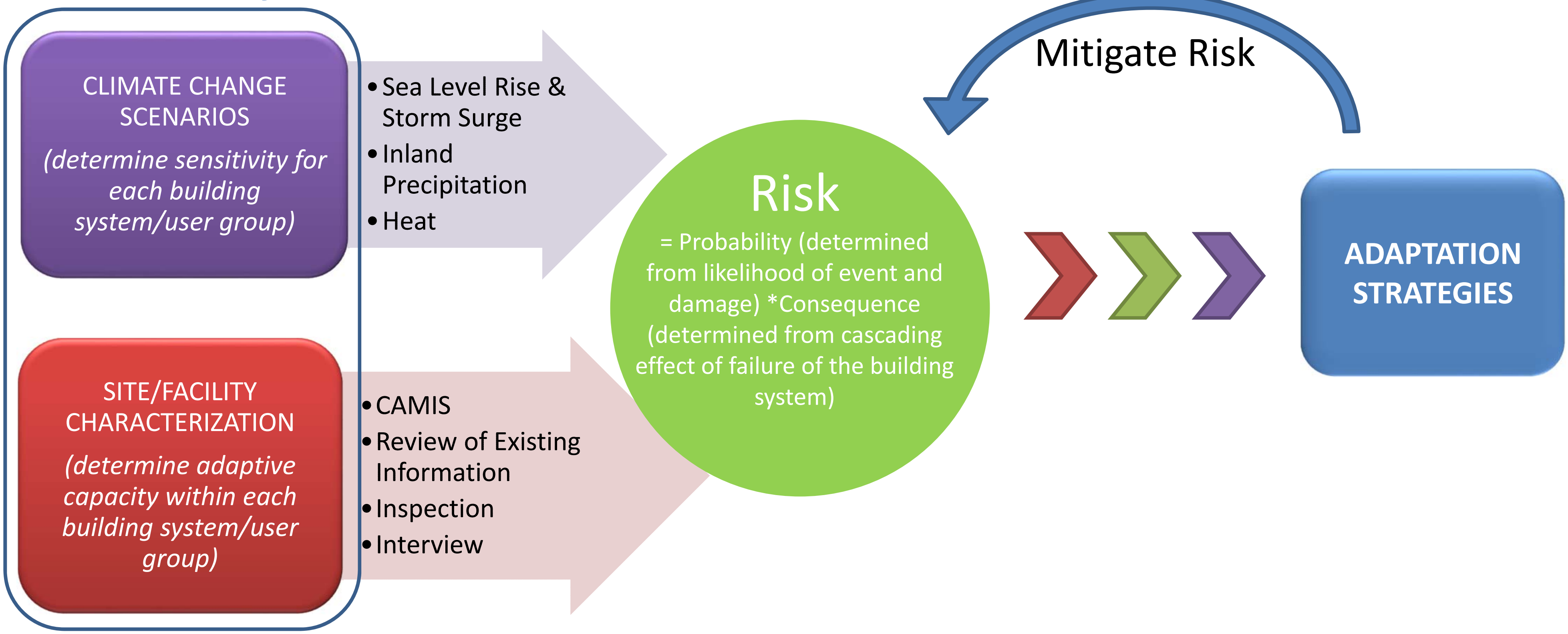
Priority Facilities

(Factoring Professional Vetting)

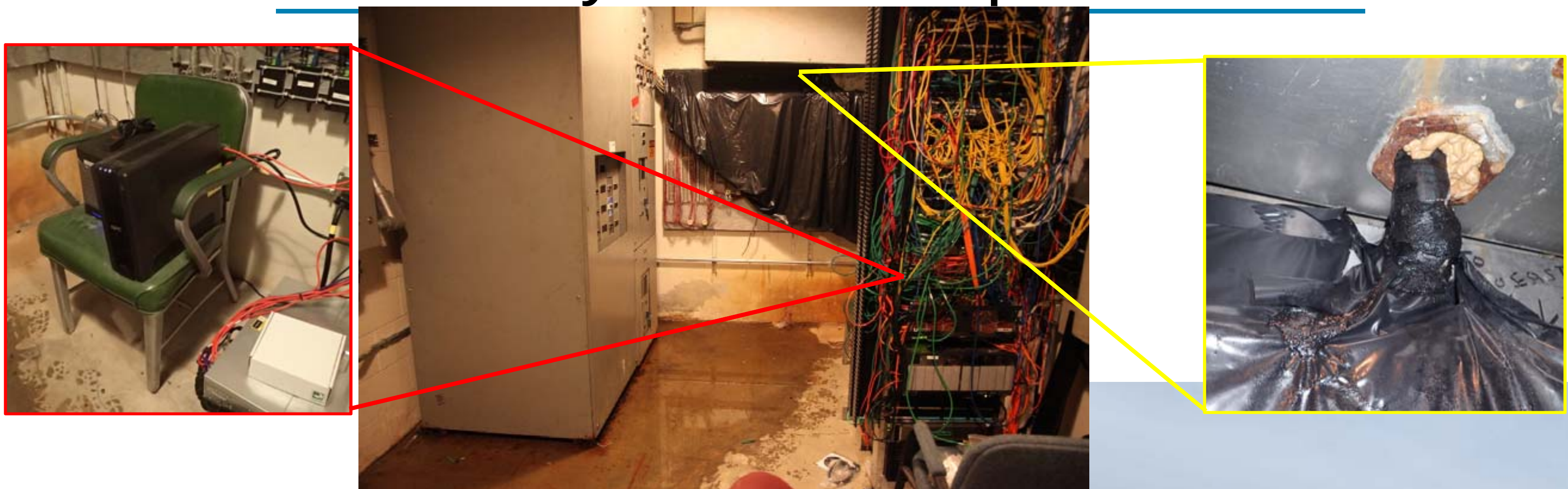


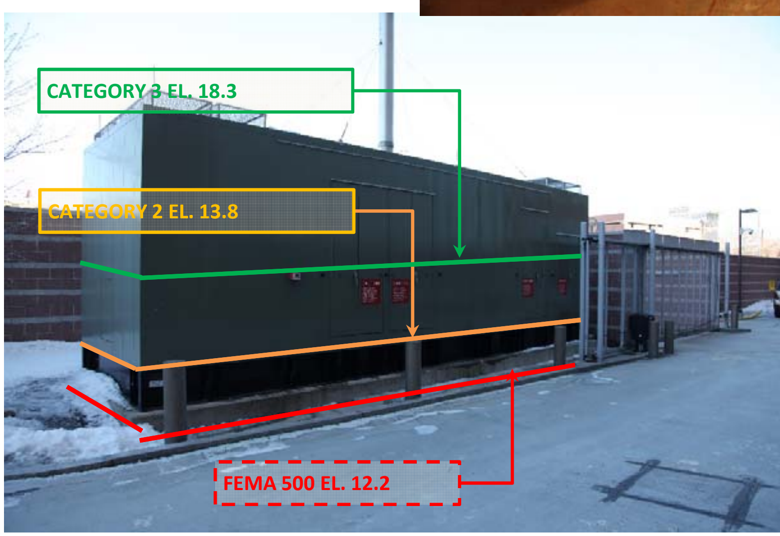
Risk Analysis – Site Specific

Vulnerability



Risk Analysis – Site Specific





Risk Analysis – Site Specific

BUILDING SYSTEMS

SITE FEATURE	OBSERVATIONS	YES	NO	COMMENTS	CLIMATE PARAMETERS	PDAMAGES*	VULNERABILITY RATING	CONSEQUENCE RATING**	RISK RATING
PRE-EXISTING	Existing problems and/or concerns?		x						
ELECTRICAL	Substation below PFE?		x		FLOOD				
	Transformer below PFE?	x		Transformer at ~El. 12 located along bridge street (1)	FLOOD	4	High	4	High
	Temperature control around transformer?		x		HEAT	3	High	4	High
	Switchgear below PFE?	x	x	~1 ft. below	FLOOD	4	High	4	High
	Distribution panel below PFE?	x	x	~1 ft. below	FLOOD	4	High	4	High
	Temperature control around distribution panel?	x		HVAC temperature controlled	HEAT	2	Low	4	High
	Emergency generator below PFE?	x		See generator	FLOOD				
	Communications below PFE? List	x		Server room for trial courts	FLOOD	4	High	4	High
	Temperature control around communications?	x		All conduits insulated, temperature controlled (1)	HEAT	2	Low	4	High
	On-site renewable energy? List		x	No	WIND/WINTER STORM	1	Low	3	Low
MECHANICAL See HVAC systems	Fuel tank below PFE?	x			FLOOD				
	Water heating equipment below PFE?	x			FLOOD	4	High	4	High
	Air handling equipment below PFE?	x	x	Chillers, See HVAC section	FLOOD/WIND				
	Sanitary system below PFE? (Sewer or Septic)	x		Sewer	FLOOD	4	High	4	High
	Temperature control for sprinkler system?		x	Not insulated	HEAT/WINTER STORM	2	Low	3	Low
	Water supply on-site? (well/storage tank)	x		Non-potable water, no potable water stored on site	FLOOD/DROUGHT/FIRE	2	Low	1	Low
	Redundancy between fire suppressant system?		x	Localized fire suppressant areas, no redundancy	FIRE				

NOTE: PFE - PREDICTED FLOOD ELEVATION

ADDITIONAL COMMENTS: (1) Pad height unknown- obscured by snow.

* EXISTING CONDITION - ABILITY TO WITHSTAND CLIMATE EVENT
1. EXCELLENT – Very unlikely to result in damage given the related climate parameter
2. GOOD – Unlikely to result in damage given the related climate parameter
3. SATISFACTORY – May result in damage given the related climate parameter
4. FAIR – Likely to result in damage given the related climate parameter
5. POOR – Very likely to result in damage given the related climate parameter

** CONSEQUENCE TO PUBLIC HEALTH AND SAFETY, INTERDEPENDCIES, AND/OR COST OF DAMAGE
1. Damage would result in low consequences (minor injuries and/or <$5,000)
2. Damage would result in moderate consequences (moderate injuries and/or <$250,000)
3. Damage would result in high consequences (severe injuries and/or <$1,000,000)
4. Damage would result in very high consequences (possible loss of life and/or <$10,000,000)
5. Damage would result in a local or regional emergency to interdependent systems

Risk Analysis – Site Specific

SUMMARY OF FINDINGS

VULNERABLE FACILITY ELEMENT	LOCATION	CLIMATE	VULNERABILITY RANK	RISK RANK
PATIENTS/TEMPERATURE CONTROL	OCCUPANCY	HEAT	High	High
ROOFS	ALL (except replaced modular roof)	EXT. PRECIPITATION/WIND	High	High
AIR HANDLING	HEALTH SERVICES	HEAT	High	High
TRANSFORMERS	SUBGRADE VAULTS	EXT. PRECIPITATION	High	High
ELECTRICAL & MECHANICAL ROOMS	DORMS/MAX.	EXT. PRECIPITATION	High	High
ELECTRICAL & MECHANICAL ROOMS	ADMIN. BLDG.	EXT. PRECIPITATION	High	High
SPRINKLER SYSTEM	ADMIN. BLDG.	FIRE	Low	High
FENCES (non-reinforced)	EXTERIOR	WIND/WINTER STORM	High	Low
LOUVERS FOR ELEC/MECHANICAL ROOMS	DORMS/MAX.	EXT. PRECIP	High	Low
WINDOWS	ALL	HEAT	High	Low
GENERATORS	OFF-STE	EXT. PRECIP/WINTER STORM/WIND	Low	High
POTABLE WATER SUPPLY	OCCUPANCY	DROUGHT	Low	High
TRANSFORMERS	ABOVE GROUND	HEAT/FLOOD	Low	Low
POWER SUPPLY	ON-SITE POWER PLANT	HEAT	Low	Low

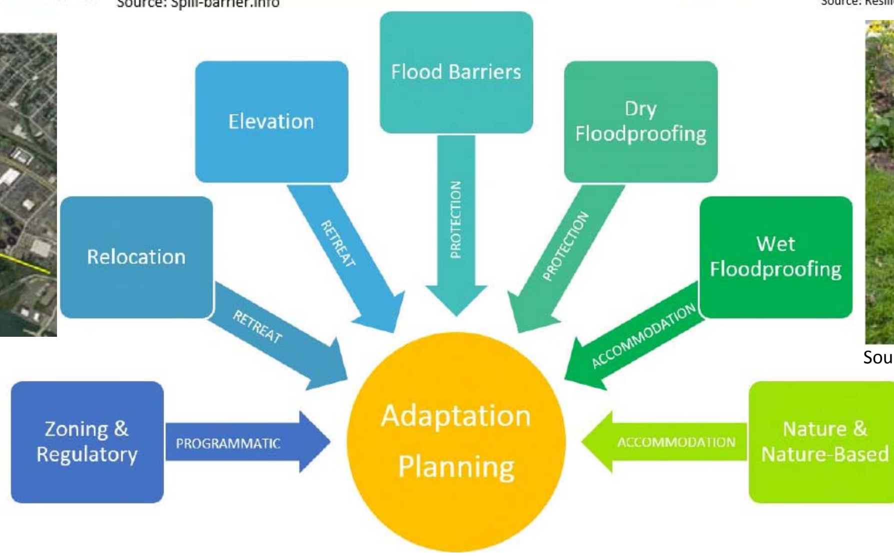
NOTES:
HIGH PRIORITY
MEDIUM PRIORITY
LOW PRIORITY

PHASE 3 – DESIGN GUIDELINE DEVELOPMENT


Source: FEMA.

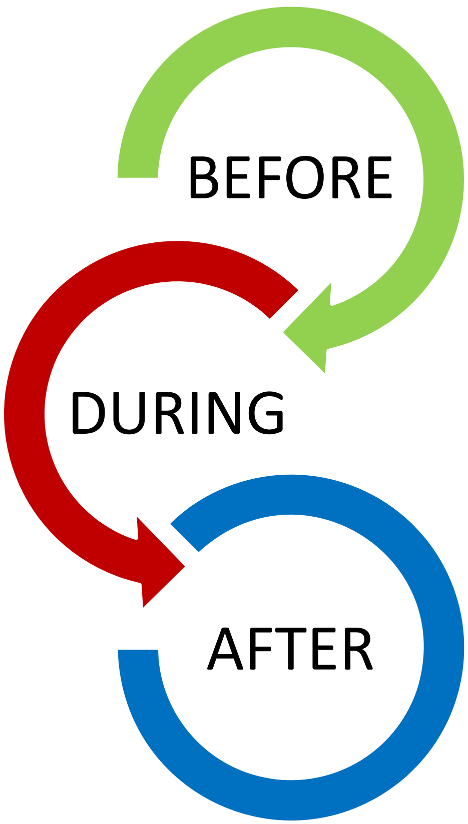

Source: Spill-barrier.info


Source: Resilientdesign.org




Source: Massachusetts Stormwater Handbook

Adaptation Planning



- **PREPARE** FOR CHRONIC AND ACUTE CLIMATE IMPACTS
- **RESIST** CLIMATE EVENT (HEATWAVE, STORM)
- **RECOVER** FROM CLIMATE EVENT (FLOODING, DAMAGES)

Adaptation/Resiliency Strategies: Grouped by Type of Action

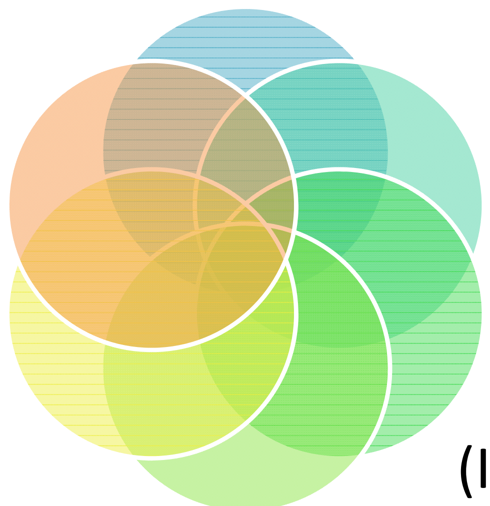
Policy (DCAMM Standards)	Retreat	Protect	Accommodate
Programmatic	Remove CC sensitivity	Prevent CC impact	Allow CC impact, reduce damage
Deferred Maintenance Request	Relocate on site	Flood Barriers	Increase drainage capacity
O&M	Relocate off-site	Backflow preventers/flood gates	Green infrastructure
Master Plan	Elevate above PFE	Reinforce Windows/Wall	Wet floodproofing

Adaptation Criteria – C.E.F.T.A.C

Cost
$$$

Co-benefits
(Mitigation)

Effectiveness
(Risk Reduction)



Adaptability
(Flexibility)

Feasibility
(Implementation)

Timing
(Short Term vs. Long Term)

Adaptation Strategies – Example

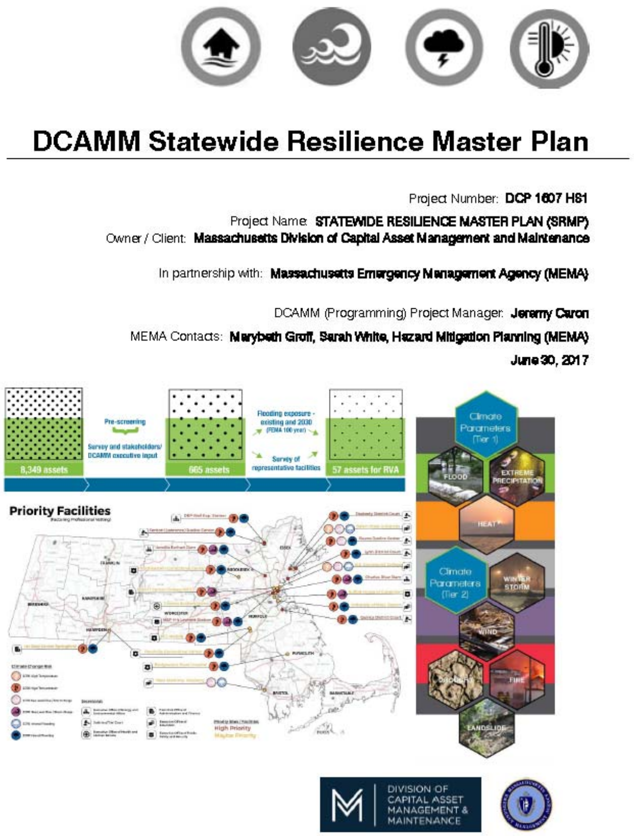
VULNERABLE FACILITY ELEMENT	LOCATION	CLIMATE STRESS	PRIORITY
Basement doorways to Outdoor Equipment Room, Mechanical Room, etc.	North side of site	Extreme Precipitation & Flooding	High

- **Planning Horizon:** Before & During
- **Strategy:** Protect
- **Cost** – $ - $$. Customized to openings
- **Effectiveness** – Max: depends on structural strength of building walls and connections
- **Feasibility** – Yes: easy to install, use, store and transport
- **Adaptability** – Flexible: Adjust to water height
- **Timing** - Short term: <1 hour installation
- **Co-benefits** - No.

Image courtesy of PS Flood Barriers

Image courtesy of Global Industrial

Final SRMP Document



DCAMM Statewide Resilience Master Plan

Project Number: **DCP 1607 HS1**

Project Name: **STATEWIDE RESILIENCE MASTER PLAN (SRMP)**

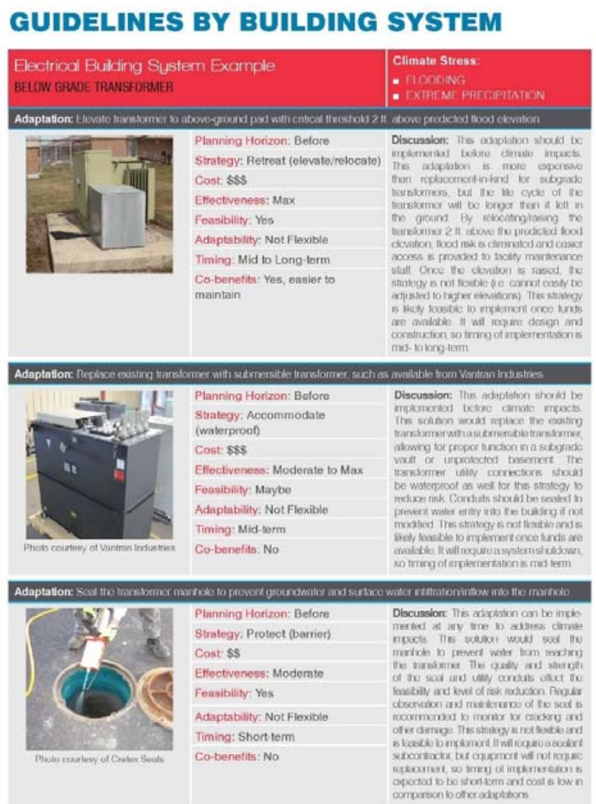
Owner / Client: **Massachusetts Division of Capital Asset Management and Maintenance**

In partnership with: **Massachusetts Emergency Management Agency (MEMA)**

DCAMM (Programming) Project Manager: **Jeremy Caron**

MEMA Contacts: **Marybeth Groff, Sarah White, Hazard Mitigation Planning (MEMA)**

June 30, 2017



GUIDELINES BY BUILDING SYSTEM

Electrical Building System Example
BELOW GRADE TRANSFORMER

Climate Stress:
- FLOODING
- EXTREME PRECIPITATION

Adaptation: Elevate transformer to above-ground pad with critical threshold 2 ft. above predicted flood elevation

Planning Horizon: Before
Strategy: Retreat (elevate/relocate)
Cost: $$$
Effectiveness: Max
Feasibility: Yes
Adaptability: Not Flexible
Timing: Mid to Long-term
Co-benefits: Yes, easier to maintain

Discussion: This adaptation should be implemented before climate impacts. This adaptation is more expensive than replacement-in-kind for subgrade transformers, but the life cycle of the transformer will be longer than if left in the ground. By relocating/raising the transformer 2 ft. above the predicted flood elevation, flood risk is eliminated and easier access is provided to facility maintenance staff. Once the elevation is raised, the strategy is not flexible (i.e. cannot easily be adjusted to higher elevations). This strategy is likely feasible to implement once funds are available. It will require design and construction, so timing of implementation is mid- to long-term.

Adaptation: Replace existing transformer with submersible transformer, such as available from Vantran Industries

Photo courtesy of Vantran Industries

Planning Horizon: Before
Strategy: Accommodate (waterproof)
Cost: $$$
Effectiveness: Moderate to Max
Feasibility: Maybe
Adaptability: Not Flexible
Timing: Mid-term
Co-benefits: No

Discussion: This adaptation should be implemented before climate impacts. This solution would replace the existing transformer with a submersible transformer, allowing for proper function in a subgrade vault or unprotected basement. The transformer utility connections should be waterproof as well for this strategy to reduce risk. Conduits should be sealed to prevent water entry into the building if not modified. This strategy is not flexible and is likely feasible to implement once funds are available. It will require a system shutdown, so timing of implementation is mid-term.

Adaptation: Seal the transformer manhole to prevent groundwater and surface water infiltration/inflow into the manhole

Photo courtesy of Crefex Seals

Planning Horizon: Before
Strategy: Protect (barrier)
Cost: $$
Effectiveness: Moderate
Feasibility: Yes
Adaptability: Not Flexible
Timing: Short-term
Co-benefits: No

Discussion: This adaptation can be implemented at any time to address climate impacts. This solution would seal the manhole to prevent water from reaching the transformer. The quality and strength of the seal and utility conduits affect the feasibility and level of risk reduction. Regular observation and maintenance of the seal is recommended to monitor for cracking and other damage. This strategy is not flexible and is feasible to implement. It will require a sealant subcontractor, but equipment will not require replacement, so timing of implementation is expected to be short-term and cost is low in comparison to other adaptations.

GUIDELINES BY BUILDING SYSTEM

Exterior Site Features and Grounds Example
SITE DRAINAGE

Climate Stress:
- EXTREME PRECIPITATION
- FLOODING

Adaptation: Install permeable pavement in the parking lot and walkways to aid with infiltration on site and reduce stormwater runoff

Photo courtesy of Oregon State University

Planning Horizon: During/After
Strategy: Accommodate
Cost: $$
Effectiveness: Moderate
Feasibility: Maybe
Adaptability: Not Flexible
Timing: Mid-term
Co-benefits: No

Discussion: This adaptation will reduce stormwater runoff during extreme precipitation events and help reduce recovery times after flooding. Porous pavement should be maintained in accordance with the designers' recommendations. Facility Managers should develop a schedule for maintaining the pavement in order to maximize effectiveness. Porous pavement may not be feasible at all sites.

Adaptation: Increase drainage capacity for site drainage systems.

Planning Horizon: Before
Strategy: Accommodate
Cost: $$
Effectiveness: Moderate
Feasibility: Yes
Adaptability: Not Flexible
Timing: Mid-term
Co-benefits: No

Discussion: This adaptation should be considered at low lying areas of the site. The designer should consider the initial rainfall volumes used for drainage sizing and compare to predicted rainfall volumes. Increasing the capacity of the system is effective as long as the surrounding drainage system is not over capacity, which could result in backflow on the site. A drainage study should be performed.

Adaptation: Deploy temporary barriers to alter the flow of stormwater runoff away from the site.

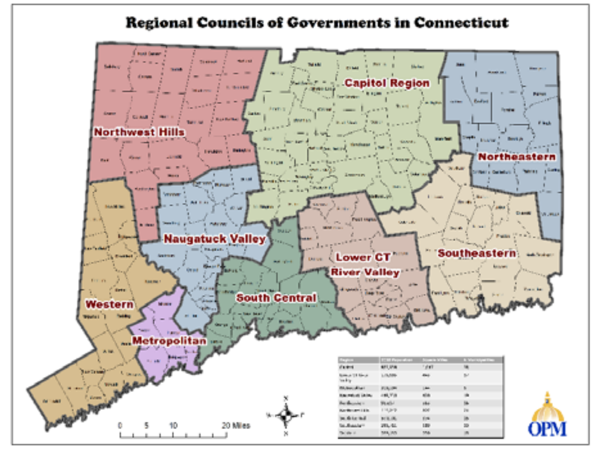
Photo courtesy of NOAQ BOXWALL FLOOD BARRIER

Planning Horizon: During
Strategy: Protect
Cost: $
Effectiveness: Moderate
Feasibility: Yes
Adaptability: Flexible
Timing: Short-term
Co-benefits: No

Discussion: This adaptation should be during climate impacts when stormwater is flowing from another site onto this site. This solution provides temporary relief from water damage. This solution requires personnel on site immediately before, during, and after an event to implement. It will require purchase of the barriers, so timing of implementation is short-term. Barriers can range from sandbags, quick dams, to NOAQ flood defenses (pictured).

Connecticut SRMP

- The process is established!
- Use existing studies and expand on them
- Mapping can be expanded to CT-Statewide, COGs and Municipalities
- Update current data
- Select climate scenarios most applicable to state goals
- Prioritize assets based on criticality and run RVA
- Conduct workshops - identify example adaptation strategies
- Prepare final guidelines for adaptation



COG Communities

Uconn CIRCA Resources

questions?

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thank you

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