Climate Change

Vulnerability Assessment

September 2022

dcr

Massachusetts

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“This summer we experienced four significant heat waves and more than 25 days over 90 degrees, tropical storms, a record amount of precipitation in the month of July, and significant flooding across the state”

- Gov. Charlie Baker, August 2021


Revere Beach Reservation

Contents

Project Summary

The Massachusetts Department of Conservation and Recreation (DCR) has made a commitment to understanding the climate vulnerability of important natural, cultural, and recreational resources under our stewardship. DCR completed this Climate Change Vulnerability Assessment as the first step in enhancing climate resilience.

DCR is challenged by the large number of its properties and facilities susceptible to anticipated climate change impacts. To begin preparing, DCR must first identify its most vulnerable properties. This climate vulnerability assessment is a tool to help DCR identify those properties. It does not address site-specific needs, nor does it identify approaches to enhance resilience or decrease vulnerability. The assessment is a first pass at prioritizing where to focus site-specific efforts based on best available information and a reasoned approach. DCR is facing a large and complex challenge regarding how to prepare for climate change; this assessment helps us determine where best to start and which questions to ask first.

The goals of the vulnerability assessment are:

- Advance and document DCR's understanding of its climate vulnerabilities.
- Evaluate the anticipated near and long-term vulnerability of DCR properties to different climate hazards.
- Organize content by DCR regions to understand the need to approach climate change differently across the Commonwealth
- Consider the sensitivity and adaptive capacity of properties based on their natural resources and infrastructure assets
- Develop a standardized climate change vulnerability assessment methodology, which will allow DCR to update this assessment as properties change over time and new properties are acquired, as well as when better data become available
- Integrate resilience considerations into asset management, disaster recovery, and capital planning decisions.

This vulnerability assessment model was based on a similar process used by the National Park Service (NPS) Climate Change Vulnerably Assessment and the exposure analysis was based on the Climate Resilient Design Standards Tool, developed by the Executive Office of Energy and Environmental Affairs. This assessment used a spatial data-driven process intended to allow for update, additions, and refinements in the future.

Exposure

Whether an asset is in an area that will experience a given hazard (e.g., an inland property may not be exposed to coastal storm surge)

X

Sensitivity

Whether an asset or its functionality will be damaged or disrupted from exposure to a hazard (e.g., an asset in the floodplain with critical systems located below the expected flood elevation is considered highly sensitive to flooding)

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Adaptive Capacity

The ability of an asset to accommodate or recover from the impacts of climate hazards (e.g. . . . if a DCR site is closed, if another site is located within walking distance (0.5 mi) there is redundancy)

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Vulnerability

The degree to which a system is susceptible to adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of exposure, sensitivity, and adaptive capacity

Figure 1. 528 sites evaluated for this assessment shown in green on the map

DCR properties across the Commonwealth were grouped into 528 sites for this assessment, shown in Figure 1. To conduct the assessment, readily available statewide data was used to understand the vulnerability of DCR properties as a whole, utilizing natural, cultural, and recreational resources present on each property to understand sensitivity and adaptive capacity. These attributes were geospatially referenced and assigned to DCR properties using ArcGIS, which allowed for a scalable and more accurate assessment of vulnerability to the various climate hazards.The vulnerability assessment process is shown in Figure 2.

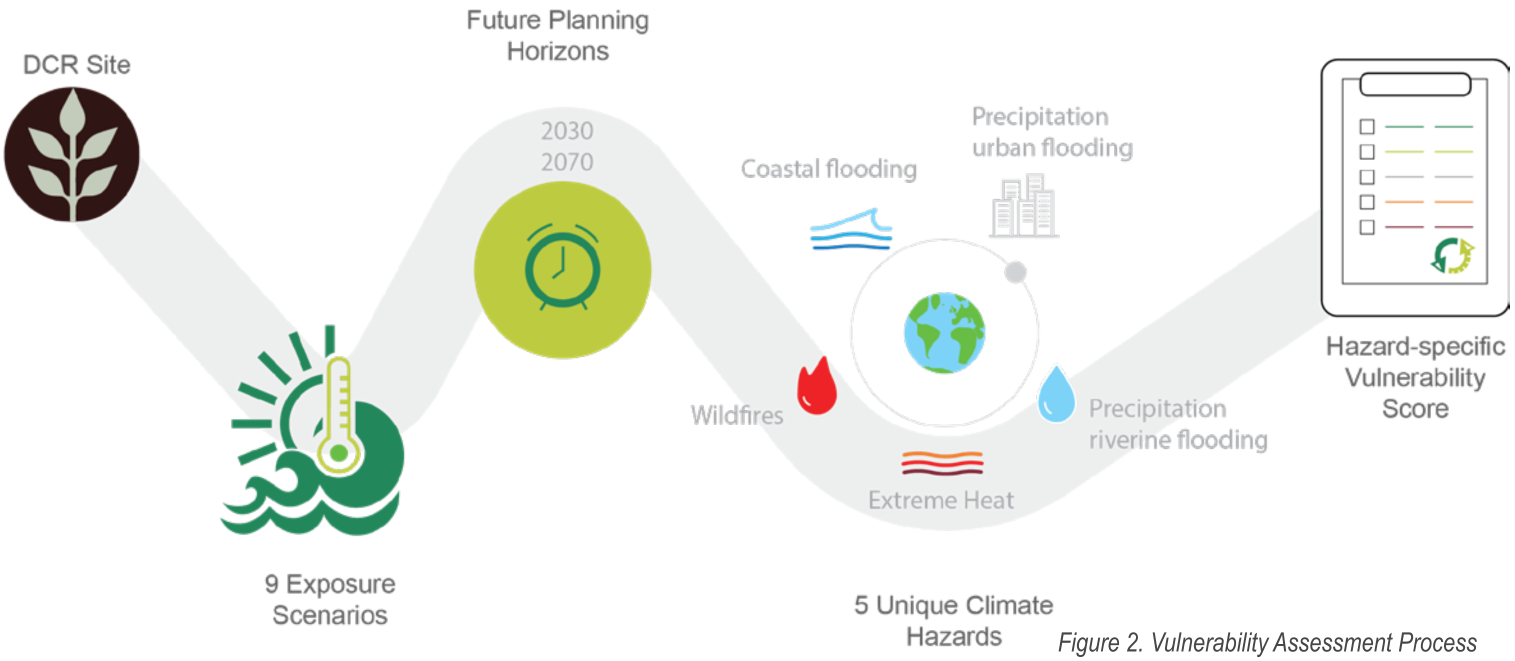

Figure 2. Vulnerability Assessment Process

The results of this assessment (summarized in Figure 3) are intended to help address a baseline understanding by identifying:

- the greatest impacts from climate change;
- the soonest impacts (threshold for effect);
- the highest sensitivity; and
- the lowest adaptive capacity.

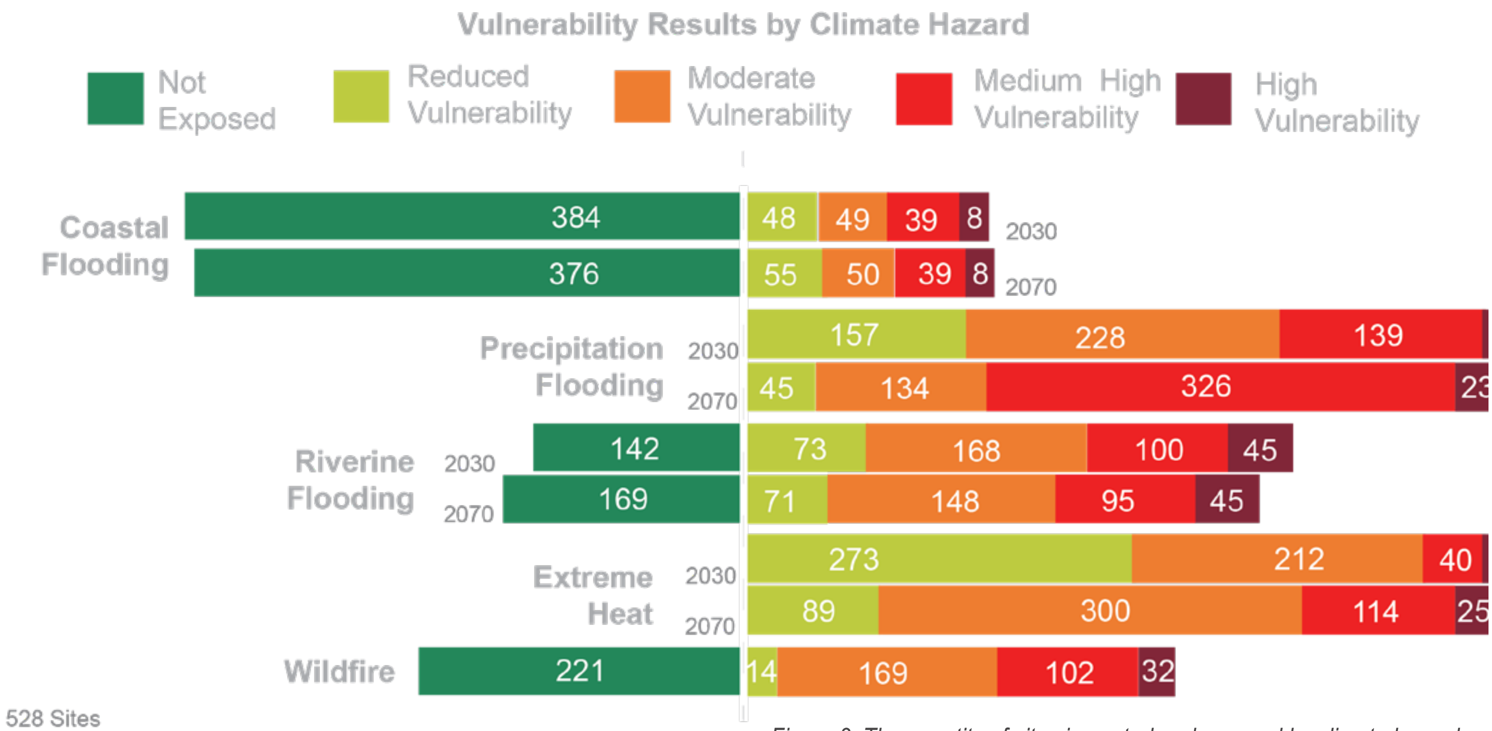

Figure 3. The quantity of sites impacted and grouped by climate hazard.

Based on the results of this assessment, it can be observed that there are some sites, such as the Halibut Point State Park, Spectacle Island, and State Fish Pier appear as some of the most vulnerable sites for multiple climate hazards, such as sea level rise/storm surge, extreme precipitation drainage flooding and extreme heat. The assessment also highlights sites that are likely to experience the greatest increases in vulnerability from different climate parameters between 2030 and 2070. For example, the Roxbury Heritage State Park in Boston shows one of the largest changes in vulnerability from sea level rise/storm surge between 2030 and 2070. The Walden Point State Reservation in Concord/Lincoln is likely to experience one of the highest vulnerability increases from precipitation-driven drainage flooding between 2030 and 2070. The Moore State Park in Paxton is likely to experience one of the highest vulnerability increases from extreme heat between 2030 and 2070. The Blue Hills Reservation and Lovell's Island are among the most sensitive sites likely to be impacted from climate change, whereas Dennis Fire Tower, Frank Perry Restoration Lot and Leadmine Pond Public Access are among the sites that have some of the lowest adaptive capacity scores.

The results of this assessment will help decision makers in DCR be better informed to start preparing for the future and take a closer look at where, how, when and what types of prioritized actions can be taken to mitigate the vulnerabilities from climate change. This assessment also provides a pathway for DCR to revisit its capital planning process by considering climate change, as well as provides the means to revisit these findings as and when more and better data become available.

Introduction

The Massachusetts Department of Conservation and Recreation (DCR) has committed to understanding the climate vulnerabilities of important natural, cultural, and recreational resources across the Commonwealth. In 2022, DCR conducted Phase 2 of a climate change vulnerability assessment across the Commonwealth on DCR properties. The vulnerability assessment follows a methodology similar to what is used by the National Park Service[1], and the exposure analysis is based on the EOEEA Climate Resilient Design Standards Tool[2].

This Climate Change Vulnerability Assessment (CCVA) report documents the methodology and the development process of DCR's statewide climate change vulnerability. In addition to this report, the CCVA Project Team developed an ArcGIS-based web application which visualizes the results of the assessment and provides pertinent climate change projections and related data used for developing different scores in the assessment. This process was guided by DCR's Climate Action Team's Vulnerability Assessment Working Group and through a series of stakeholder workshops DCR Staff were invited to provide feedback and recommendations for developing an assessment reflective of DCR's unique properties and objectives in the Commonwealth.

The initial intent of this project was to refine and streamline the pilot Climate Change Vulnerability Assessment (CCVA) Methodology and Self-Assessment Checklist Tool developed in Phase I that was drafted in Summer 2021. Phase I of the project provided a methodology applied to three pilot properties: Borderland State Park in Sharon and Easton, Mohawk Trail State Forest in Charlemont, and Revere Beach Reservation in Revere. The CCVA Phase II project built upon and further refined the methodology developed during Phase I through a scalable approach. This methodology can be applied to DCR properties across the Commonwealth, through an objective data driven process, which also has the flexibility of being updated as new data become available.

The overarching goal of this assessment is a starting point to understand the vulnerability of over 450,00 acres of Commonwealth land that DCR manages. The results are intended to be a baseline of understanding and to help prioritize where for future planning by DCR.

This assessment included over 450,00 acres of Commonwealth land that DCR owns or manages, which were grouped into 528 sites for evaluation, and used the latest climate science data available for the Commonwealth of Massachusetts. The assessment considered the exposure, sensitivity, and adaptive capacity of each DCR property based on the Department's critical mission, with the final product being vulnerability scores for each climate parameter and a composite vulnerability score

[1] National Park Service, A Strategic Analysis of Climate Vulnerability of National Park Resources and Values, pg. 114, https://irma.nps.gov/DataStore/DownloadFile/664238 (accessed May 2022)
[2] ResilientMA Climate Resilience Design Standards & Guidelines, https://resilientma.mass.gov/rmat_home/designstandards/ (accessed May 2022)

across climate parameters for the 2030 and 2070 planning horizons. This approach allowed properties to be compared and ranked. The results were organized by region, which emphasized the need to approach climate change differently across the Commonwealth as shown in Figure 4.

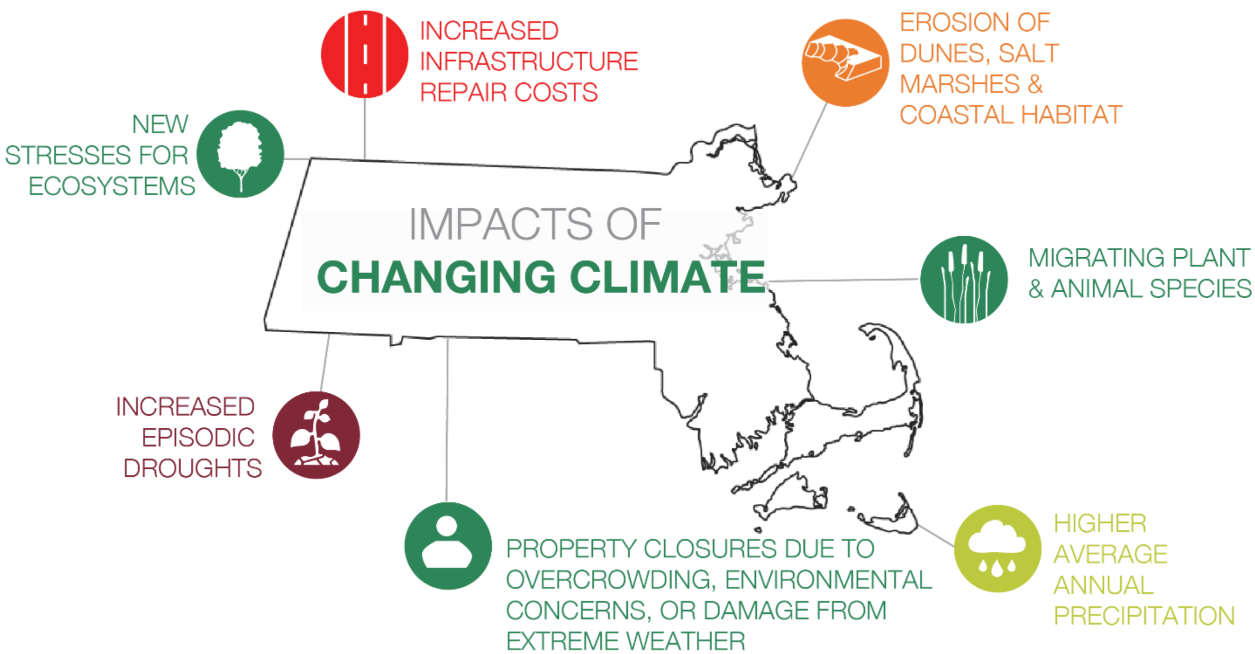

Figure 4. Impacts of climate change across Massachusetts

Vulnerability Assessment Methodology

As part of the vulnerability assessment methodology, the CCVA Project Team collected data and input from stakeholders to reach consensus on a methodology. A review, in collaboration with DCR stakeholders was undertaken to identify data layers to be used in the assessment. Assigning a score to each individual asset was initially explored but discarded because this would result in scores for over 200,000 built and natural resource assets. Instead, the assessment assigned scores at the site scale, which encompasses attributes representing infrastructure, natural resources, and users at these sites. The DCR GIS team developed a geospatial database of DCR sites containing its properties (i.e., land that DCR owns in fee or manages) for this assessment. This database of 528 DCR sites was used to conduct the vulnerability assessment. It is important to note that this is a "living layer" that can be updated to represent land acquisitions and other changes. Selected attributes, such as different types of DCR infrastructure (e.g., mission critical assets, supporting facilities, etc.), presence of multiple core habitat components were geospatially associated with DCR sites and the presence or absence of particular asset types within a site were used as sensitivity indicators for that site.

DCR recognizes that some natural resource "assets" such as flora and fauna cannot be assessed by a parcel-based analysis but were accounted for to the maximum extent practicable.

Vulnerability can be defined as the degree to which a system is susceptible to adverse effects of climate change, including climate variability and extremes. The results are not intended to provide a detailed overview of any one asset's vulnerability to climate change hazards; they are intended to provide an overview for the entire site or property to guide decision-making processes and identify assets that should be studied in more detail. Vulnerability is a function of exposure, sensitivity, and adaptive capacity. [3] For the purpose of this assessment, those terms are defined as follows:

> Exposure (flooding): Whether an area that will experience flooding (e.g., an inland asset may not be exposed to coastal storm surge)
>
> Exposure (extreme heat): Whether an area will experience extreme heat or wildfire (e.g., a forested coastal location may experience less extreme heat than an inland urban area)
>
> Sensitivity: Whether assets or its functionality will be damaged or disrupted from exposure to a hazard (e.g., an asset in the floodplain with critical systems located below the future projected flood elevation is considered highly sensitive to flooding)
>
> Adaptive Capacity: The ability of assets to accommodate or recover from the impacts of climate change (e.g., if a pool is closed and another pool is in walking distance (0.5 mi) there is redundancy.

For the purpose of this assessment, vulnerability is calculated using the following equation:

$$\boldsymbol{Vulnerability = \frac{Exposure \ \times Sensitvity}{Adaptive\ Capacity}}$$

The following tasks were critical to the exposure, sensitivity, and adaptive capacity analysis:

1 Evaluate future climate change projections and identify data to assess exposure across the state of Massachusetts
2 Gather readily available data on existing assets and natural resources

The list of indicators included in this assessment were carefully chosen after considering a long list of possible data sources. The primary criteria were to select datasets with indicators directly impacting DCR properties, rather than using datasets that could be extrapolated to represent impacts. In the future indicators can be added, deleted, or updated following the methodology in Attachment A.

[3] ResilientMA Plan Development, https://resilientma.mass.gov/actions/planning (accessed May 2022)

Climate Change Exposure

Exposure Methodology

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Climate Hazards

To aid in the completion[4] of this assessment, the best available climate data has been used for the Commonwealth of Massachusetts at the time of this study. The climate projection data sources and planning horizons were selected based on the EOEEA Climate Resilience Design Standards and Guidelines Tool developed by the Resilient Massachusetts Action Team (RMAT). The intent of using the same data for consistency across State efforts to address climate change. This process does deviate from the Massachusetts Climate Resilience Design Standards and Guidelines Tool, and some other widely accepted sources were added to the analysis to enhance the specificity of DCRs conservation and recreation mission. A general overview of the future climate projections for each of the climate hazards considered in this assessment is provided in the following section:

- coastal flooding (sea level rise and storm surge)
- precipitation urban flooding
- precipitation riverine flooding
- extreme heat
- wildfire

Exposure was assessed for two planning horizons, 2030 and 2070. The planning horizon of 2030 (2021-2039) represents the near-term and is used as a baseline in this assessment. The 2070 (2060-2099) planning horizon represents a long-term planning horizon and is the longest planning horizon available at this time. The exposure indicator that was not evaluated for two planning horizons was wildfire because there were no future wildfire projection sources available to the project team at the time of writing this report. At the time of the assessment, future wind projections were not available.

For each climate hazard, multiple criteria were selected for exposure scoring of sites primarily based on the criteria used in the Massachusetts Climate Resilient Design Standards Tool. Some additional criteria were used for sea level rise/storm surge, extreme precipitation (urban) and extreme heat in this assessment to replace the user input questions used in the Climate Resilient Design Standards Tool. For example, FEMA AE zone was used as an exposure criterion for sea level rise/storm surge in this assessment but was not used in the Climate Resilient Design Standards Tool's exposure. The exposure scoring methodology is provided in Table 1.

[4] The completion date of this analysis on June 30, 2022.

Table 1: Exposure Scoring Methodology			
Climate Hazard	GIS Dataset (if applicable)	Question/Filter	Response/Score
Sea Level Rise/Storm Surge	MC-FRM (Filter: 2030 mean high water shoreline shapefile, probability maps, planning horizon)	The site is located within projected 2030 Mean High Water (MHW) Shoreline	Yes = 4
		The site is NOT located within projected 2030 Mean High Water (MHW) Shoreline	No = 0
	MC-FRM (Filter: probability maps, planning horizon)	The site is located within the projected 1% annual coastal flood exceedance probability (ACFEP)	Yes = 2
		The site is NOT located within the projected 1% annual coastal flood exceedance probability (ACFEP)	No = 0
	FEMA Maps	The site is located within FEMA V Zone	V zone = 2
		The site is outside FEMA V Zone	No = 0
	LiMWA Boundary	The site is located inside LiMWA	Yes = 1
		The site is outside LiMWA	No = 0
	MC-FRM (Filter: probability maps, planning horizon)	The site is located within the projected 0.1% annual coastal flood exceedance probability (ACFEP)	Yes = 1
		The site is NOT located within the projected 0.1% annual coastal flood exceedance probability (ACFEP)	No = 0
Extreme Precipitation *Urban Flooding*	MassGIS (NLCD, 2016)	The site has less than 10% of existing impervious area	< 10% = 0
		The site has between 10-50% of existing impervious area	10 - 50% =1
		The site has more than 50% of existing impervious area	> 50% = 2
	Max Annual Rainfall (Filter: RCP 8.5, 50th pctl, Basin Scale, Planning Horizon)	Maximum annual daily change in rainfall is less than 6 in	< 6 in = 1
		Maximum annual daily change in rainfall is between 6 to 10 in	6 - 10 in = 2
		Maximum annual daily change in rainfall is more than 10 in	> 10 in = 3
	100-yr 24-hr precipitation depth	Projected total precipitation depth of a 100-yr 24-hr design storm (2030 using 2°C warming 2070 using 4.5°C warming)	< 8 in = 1
			8-10 in = 2
			> 10 in = 3

Table 1: Exposure Scoring Methodology			
Climate Hazard	**GIS Dataset (if applicable)**	**Question/Filter**	**Response/Score**
	10-yr 24-hr precipitation depth	Projected total precipitation depth of a 10-yr 24-hr design storm (2030 using 2°C warming 2070 using 4.5°C warming)	< 5 in = 1
			5-6 in = 2
			> 6 in = 3
Extreme Precipitation *Riverine Flooding*	FEMA flood zones	The site is located within the “future riverine environment”. This includes areas outside the 0.1% annual coastal flood exceedance probability, and within the current 0.2% annual chance (500-year floodplain)	Yes = 3
		The site is NOT located within the “future riverine environment”	No = 0
	LiDAR rasters; MassGIS data layer MassDEP Hydrography and polycodes 1, 6 and arccodes 4, 5; waterbodies 500 ft buffers; waterbodies 100 ft buffers	The lowest elevation point on the site is located outside the 0.1% annual coastal flooding exceedance probability, AND: within 100 ft of a waterbody (2A) OR Between 101 – 200 ft away from a waterbody AND less than 30 ft above the waterbody (2B) OR Between 201 – 500 ft away from a waterbody AND less than 20 ft above the waterbody (2C)	Yes = 2
		The lowest elevation point on the site is located outside of the 0.1% annual coastal flooding exceedance probability, and more than 500 ft away or more than 30 ft above a waterbody	No = 0
	waterbodies 100 ft buffer; LiDAR rasters	The site is located outside the 0.1% annual coastal flood exceedance probability, not within a body of water, but within 100 ft of a waterbody with 15% or greater slope between the site and the waterbody	Yes = 1
		The site is located outside the 0.1% annual coastal flood exceedance probability, not within a body of water, but within 100 ft of a waterbody with less than 15% slope between the site and the waterbody	No = 0
Extreme Heat	Days over 90 degrees (Filter: RCP 8.5, Basin Scale, Planning Horizon)	The site is projected to expose to less than 10 days of days over 90°F	< 10 days = 1
		The site is projected to expose 10 to 30 days of increase in days over 90°F	10 to 30 days = 2
		The site is projected to expose to more than 30 days of increase in days over 90°F	30+ days = 3

Table 1: Exposure Scoring Methodology			
Climate Hazard	GIS Dataset (if applicable)	Question/Filter	Response/Score
	GIS Map	The site is located within 100 ft. of an existing water body?	Yes = 0
		The site is NOT located within 100 ft. of an existing water body?	No = 1
	MassGIS (NLCD, 2016)	The site has less than 10% of existing impervious area	< 10% = 0
		The site has between 10-50% of existing impervious area	10 - 50% =1
		The site has more than 50% of existing impervious area	> 50% = 2
	MassGIS (NLCD, 2016)	The site has less than 10% of existing canopy area	< 10% = 2
		The site has between 10-40% of existing canopy area	10 - 40% =1
		The site has more than 40% of existing canopy area	> 40% = 0
Wildfire	WUI (2016)	The site is NOT exposed to wildfire	Not exposed = 0
		The site is exposed to Interface type wildfire	Interface = 3
		The site is exposed to Intermix type wildfire	Intermix = 4

** Blue highlight indicates that these parameters were not includes in the EOEEA Climate Resilience Design Standards Tool.*

Exposure Results

Exposure results are based on the exposure score for each climate hazard, a result of the sum of scores for the criteria contributing to that hazard. The sites with zero score for SLR/SS flooding, extreme precipitation riverine flooding, and wildfire are marked as not exposed. Sites exposed to extreme precipitation drainage (urban) flooding and extreme heat following the same logic used in the Climate Resilience Design Standards Tool. Possible scores for each climate hazard are shown in Table 2.

Table 2: Scores Possible for Each Climate Hazard		
Climate Hazard	Max Possible Score	Min Possible Score*
SLR/SS	10	1
Extreme precipitation riverine	6	1
Extreme precipitation drainage (urban)	11	3
Extreme heat	8	1
Wildfire	4	3

* Does not reflect score of zero for not exposed sites

The non-zero scores were normalized on a scale of 1 to 4 for each climate hazard using the equation:

Normalized score = 1 + ((Actual Site score – Min Possible Score) *(Max normalized score – Min normalized score)) / (Max possible score – Min Possible Score)

Where, Max normalized score = 4 and Min normalized score = 1

Based on the normalized score, the sites are marked as low exposure to high exposure, as shown in Table 3.

Table 3: Normalized Scoring Schema	
0	Not Exposed
< 1.5	Low Exposure
1.5-<2.0	Medium Exposure
2.0-<3.0	Medium-High Exposure
>=3.0	High Exposure

Climate Projections and Hazard Data Limitations

The projections and climate analysis provided by this report are based on relevant and up-to-date climate science and published data available for the region at this time. However, the data does not come without assumptions and uncertainties. The climate data presented in this report have not been independently reviewed by the project team, and the underlying climate projections and data are provided by others. Actual climate conditions will vary and may be more or less extreme than the projections listed in this report. The Commonwealth of Massachusetts plans to update their climate projections at least every five years through the State Hazard Mitigation and Climate Adaptation Plan process.

Sensitivity & Adaptive Capacity

The likelihood of assets to be exposed to the hazard, be sensitive to the hazard, or have adaptive capacity to reduce impacts from the hazard were estimated using the indicators summarized herein.

Sensitivity Indicators

Sensitivity was assessed across fifteen different indicators comprised of a variety of readily available sources or source files developed for this project. Select source files were merged or queried for the purpose of this assessment, however the data itself and its attributes were not altered. Sensitivity indicators can be separated into the following categories: indicators for infrastructure, natural resources, and cultural / social resources.

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Sensitivity Indicators

Sensitivity indicators are scored on a scale of zero to four, with four being the site contains indicators that show lives are at risk and zero being no sensitivity indicators are present within the site boundary. The ranking for each indicator followed these groupings to the greatest extent possible:

4	3	2	1	0
Site provides residency for people or animals, lives are at risk	**Site provides emergency functions; Operations must remain continuous for DCR and greater**	Site contains DCR mission critical assets	Site contains facilities and structures that support mission critical assets	Site does not have any sensitivity indicators present

Infrastructure

Assets from the DCAMM's Capital Asset Management Information System (CAMIS) database which are specifically on DCR sites were used as built infrastructure indicators.[5] Building type data and road type data inform four indicators that contribute to a site's sensitivity. The first indicator looks at the CAMIS built infrastructure building type code data and assesses what building types / functions are present on each site. Sites that provide residency or sleeping quarters are given the highest score, sites providing emergency functions to both DCR, and the Commonwealth are given a score of three, sites containing DCR mission critical assts are given a score of two, sites containing

[5] DCAMM, Capital Asset Management Information System, https://camis.dcp.state.ma.us (accessed May 2022)

supporting infrastructure are given a score of one, and any site not containing any CAMIS built infrastructure assets is given a score of zero.

The presence of roadways is an additional built infrastructure indicator used. A site with plowable parkways[6] was given a score of three because they represent high priority DCR roads that require winter maintenance. A site with public or administrative roads[7] that are not plowed is assigned a score of one. A site with trails, forest roads, or no roads are given a score of zero because they are not considered a critical means of ingress or egress.

Natural Resources

Several different data layers are used to inform six different indicators for natural resources. BioMap 2 Core Habitat component layers are used as an indicator to identify the number of different types of core habitats within a site boundary. Core Habitat layers identify specific areas necessary to promote the long-term persistence of species of conservation concern, exemplary natural communities, and intact ecosystems across the Commonwealth.[8]

The presence of Wellhead Protection Area (Zone I)[9] within a site boundary is an indicator for surface water protection and is assigned a score of three. The presence of Drinking Water Designated Zone A[10] within a site boundary is an indicator for drinking water protection and is assigned a score of three.

Shoreline change data[11] is used as an indicator for how sea level rise along the coast of Massachusetts affects DCR sites, so sites that intersect the short-term change coastline layer are given a score of three.

Snow Water Equivalent data[12] is a dataset that covers the Commonwealth and represents the millimeters of snow melt from a 100-year 1 day storm. Based on the range of values within Massachusetts, DCR properties that are within 200 mm is given a score of four because the lower range of depths indicates that a site may be prone to less groundwater recharge which is essential for ecosystem resilience. If the snow water equivalent of a site is between 201 to 300 mm, it is given a score of three, between 301 to 500 mm is given a score of two, and greater than 500 mm is given a score of one because it represents the highest depths of the range thus there is greater potential for groundwater recharge.

The Fuel for Wildfire is another sensitivity indicator related to natural resource and is based on the US Landfire Behavioral Fuel Model 13[13], which is a raster dataset that covers the State of Massachusetts. This raster dataset is comprised of text values FBF 1 through FBF 13, representing

[6] MA DCR (internally managed dataset), DCR Plowable Parkways, May 2022
[7] MassGIS, DCR Roads and Trails, https://www.arcgis.com/home/item.html?id=38fe6ecae7834fb5a14e57f670048194 (accessed May 2022)
[8] MassGIS, BioMap2, https://www.mass.gov/info-details/massgis-biomap2 (accessed May 2022)
[9] MassGIS, MassDEP Wellhead Protection Areas, https://www.mass.gov/info-details/massgis-data-massdep-wellhead-protection-areas-zone-ii-zone-i-iwpa (accessed May 2022)
[10] MassGIS, Public Water Supplies, https://www.mass.gov/info-details/massgis-data-public-water-supplies (accessed May 2022)
[11] USGS, Massachusetts Shoreline Change Project - 2021 Update, https://www.sciencebase.gov/catalog/item/60ff22dad34e3ccd830d62aa (accessed May 2022)
[12] Eunsang Cho, 25- and 100-year Return Level Extreme Snow Water Equivalent and Snowmelt Maps over the CONUS, https://www.hydroshare.org/resource/c50069a2e1fa43418d1ee75c0e92313e/ (accessed May 2022)
[13] Landfire, U.S. Landfire Fire Behavioral Fuel Model 13 - 2020 remap, https://landfire.gov/viewer/ (accessed May 2022)

fuel sources for different types of wildfires. The values of FBF 3, 11, 12, and 13 represent fuel for rapidly spreading, high intensity fires and when any are present, the site is given a score of four. The values of FBF 4, 7, and 10 represent fuel for moderate to quickly spreading intense fires and when any are present, the site is given a score of three. The values of FBF 2, 6, and 9 represent fuel for low flame, moderately paced spreading fires and when any are present, the site is given a score of two. The values of FBF 1, 5, and 8 represent fuel for very low intensity fires that are not easily spread and when any are present, the site is given a score of one.

Cultural / Social Resources

The Massachusetts Environmental Justice (EJ) mapping layers[14] are used to indicate vulnerable populations across the Commonwealth that are likely to be more sensitive to climate change impacts. The EJ map shows three different criteria at the census block group scale: minorities comprise 40 per cent or more of the population (M), annual median household income is not more than 65 per cent of the statewide annual median household income (I), and 25 per cent or more of households lack English language proficiency (E). The block group polygons are assigned MEI if all three criteria are represented, ME or MI if two minorities are represented, and M, E, or I if one minority is represented. A buffer of a half mile was applied to the polygons to represent walkability to a nearby DCR site. Sites with an MEI block within a half mile buffer receives a score of four because they represent highly sensitive populations. Sites with an ME, MI, or EI block within a half mile buffer receive a score of three. Sites with an M, E, or I block within a half mile buffer received a score of two. Sites with no EJ blocks within a half mile receive a score of zero.

The average population density for the town / towns[15] that each site intersects is used as an indicator of site usage and accessibility. Sites with surrounding population density of more than 5000 people per square mile receive a score of four, between 5000 to 2500 people per square mile receive a score of three, between 2500 to 550 people per square mile receive a score of two, and less than 550 people per square mile receive a score of one.

The MHC Historic Inventory Dataset[16] informs two indicators. Sites with a historic, culturally significant assets (point layer) present receive a score of three and sites where historic, culturally significant landscape areas (polygon layer) are present receive a score of two. If both are present, the site receives a score of three. In the future, it may be prudent to enhance the weight or understanding of cultural resources by assigning different sensitivity scores to these indicators as the historic asset (point layer) is likely to be more sensitive to the impacts of climate change because it could be easily destroyed by one, singular extreme event historic landscapes (polygon layer) is generally impacted over a longer time frame and is more often altered than destroyed.

[14] MassGIS, Environmental Justice Populations in Massachusetts, https://www.mass.gov/info-details/massgis-data-2020-environmental-justice-populations (accessed May 2022)
[15] US Census, City and Town Population Totals: 2020-2021, https://www.census.gov/data/datasets/time-series/demo/popest/2020s-total-cities-and-towns.html (accessed June 2022)
[16] MassGIS, MHC Historic Inventory, https://www.mass.gov/info-details/massgis-data-mhc-historic-inventory (accessed May 2022)

Additional indicators which were developed using the CAMIS database were: Sites containing swimming areas (beaches[17], splashpads, pools[18]) were given sensitivity score of two because swimming areas provide essential relief from heat for many residents of the Commonwealth. Sites containing campgrounds[19] are given a sensitivity score of four because they indicate people sleeping at that location overnight, which indicates potential human lives are at risk from climate impacts.

The indicators used and scoring assigned are shown in Table 4.

Table 4: Sensitivity Scoring Methodology

Indicator	4	3	2	1	0
Is the site located in an EJ census block group? (Buffer of 0.5 mile - walkable)	MIE	ME or MI	M		N/A
Population Density surrounding site	>5000	5000-2500	2500-550	<550	
What is the DCR Infrastructure Type?	locations where people and lives are at risk - highest concern	locations with an emergency Functions continuation of operations are important beyond just DCR parks and sites	DCRs mission critical assets and items that are Critical to DCRs Mission	all other supporting structures and facilities that support "critical infrastructure"	
Presence of roads on DCR Site		Plowable Parkway		Public Road, Administrative Road	Trails, Forest Road / Trail
Has a Campground?	Yes				No
Does the site contain multiple Biomap core components?	5-6 core habitats	3-4 core habitats	2-1 core habitats		none
Is there swimming on the site?			*Yes*		No
Wellhead Protection Area located on site (Zone I)		*ZONE I*			Not present
Drinking Water Designated Zone A surface waters located on site		*Zone A*			No

[17] DCAMM, Capital Asset Management Information System, https://camis.dcp.state.ma.us (accessed May 2022)
[18] MassGIS, DCR Pools, https://www.mass.gov/info-details/massgis-data-department-of-conservation-and-recreation-pools (accessed May 2022)
[19] DCAMM, Capital Asset Management Information System, https://camis.dcp.state.ma.us (accessed May 2022)

Fuel for Wildfires	*FBF 11, 12, 13, 3*	*FBF 10, 7, 4*	*FBF 9, 6, 2*	FBF8, 5, 1	none
Historic, culturally significant assets (Inventory Points)		*Points*	*Polygons*		Not present
Snow melt data -100-year 1-day WSE	*< 200*	*201 - 300*	*301 - 500*	> 500	
Shoreline Change		*Short Term Change*			N/A

Sensitivity of a site shown in Figure 5 was developed by adding the scores from each individual indicator and normalizing them on a scale of one to four (score of zero remains the same). It is important to note that for the indicators that have multiple possible scores, the highest scoring asset for each indicator will contribute to the cumulative score.

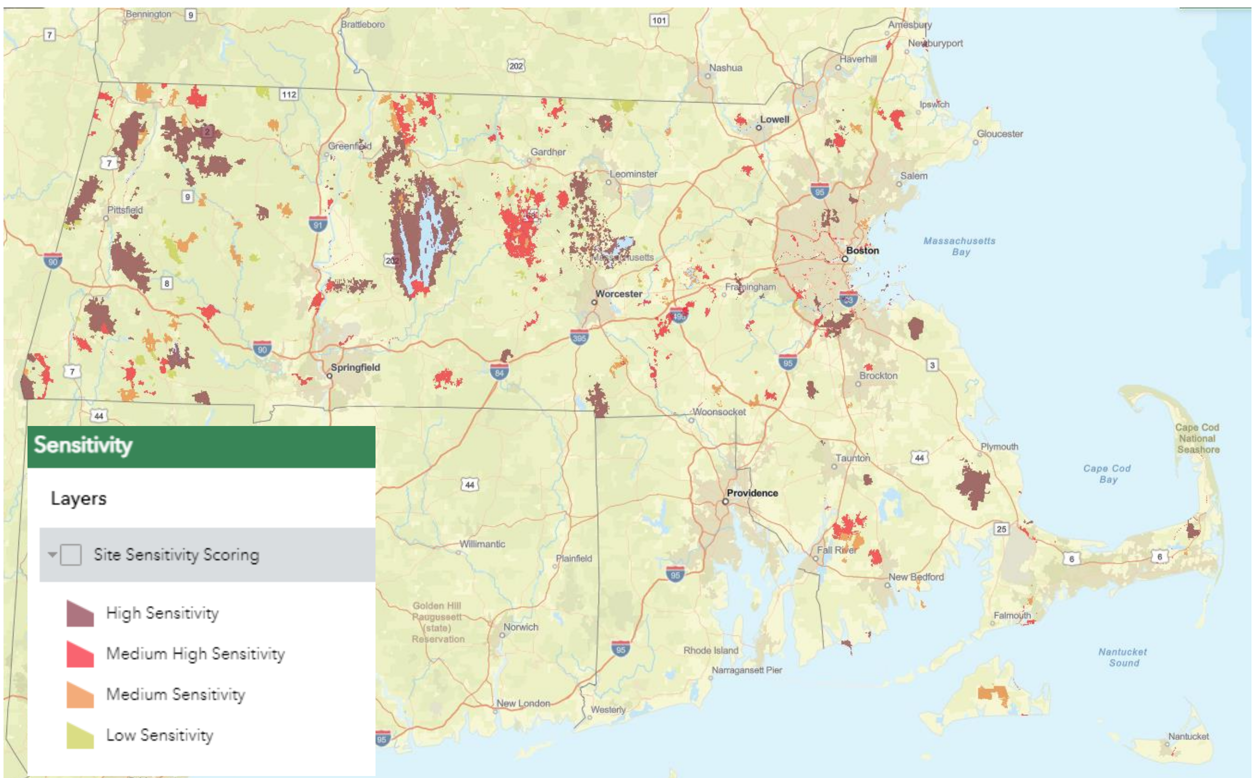

Figure 5. Sites scored for sensitivity

Sensitivity Results Findings

Sensitivity indicator scores were summed for each site by adding the scores of each individual indicator present on that site. While no sensitivity indicator is more heavily "weighted" in the summation, based on the highest possible score for each indicator some indicators can impact the sensitivity score of a site more than others. Raw sensitivity scores were used in the composite vulnerability calculation for each climate parameter, however a normalized sensitivity score on a scale of 1-4 was calculated to rank sites between low sensitivity, medium sensitivity, medium-high sensitivity, and high sensitivity.

TABLE 5: TOP SITES WITH HIGHEST SENSITIVITY			
SITE NAME	REGION	TOWN	Sensitivity, actual
Blue Hills Reservation	South Region, Boston Region	MILTON, BRAINTREE, RANDOLPH, QUINCY, CANTON	34.0
Nickerson State Park	South Region	BREWSTER, ORLEANS	32.0
Lovells Island	South Region	BOSTON	30.0
Harold Parker State Forest	North Region	TEWKSBURY, NORTH ANDOVER, NORTH READING, ANDOVER	29.0
Watson Pond State Park	South Region	TAUNTON	29.0
Middlesex Fells Reservation	North Region	MELROSE, STONEHAM, MALDEN, WINCHESTER, MEDFORD	28.0
Mount Greylock State Reservation	West Region	WILLIAMSTOWN, NEW ASHFORD, LANESBOROUGH, NORTH ADAMS, CHESHIRE, ADAMS	28.0
Myles Standish State Forest	South Region	WAREHAM, PLYMOUTH, CARVER	28.0
Peddocks Island	South Region	HULL	28.0
Revere Beach Reservation	North Region	REVERE	28.0
Wompatuck State Park	South Region	COHASSET, HINGHAM, SCITUATE, NORWELL	28.0

The sites with the highest sensitivity are provided in Table 5. Indicators that appear to increase the sensitivity scores more than others include population density, environmental justice populations, presence of core habitat components (from BioMap2), presence of fuel sources for different types of wildfires, historic / culturally significant assets, and lower snow water equivalent numbers since these indicators each have a maximum possible sensitivity score of three or four. Urban sites generally have a higher population density and more EJ populations resulting in higher sensitivity scores for the sites located in those areas. Less developed sites generally have higher presence of core habitat components. The eastern half of the State generally has lower snow water equivalent values than the western half of the State. The indicators of campgrounds, swimming areas, wellhead protection areas, surface water protection zones, and shoreline changes contribute to the sensitivity scores for a few of the DCR properties.

Adaptive Capacity Indicators

4

Adaptive Capacity Indicators

The adaptive capacity analysis of sites for the CCVA Phase 2 project was significantly updated compared to Phase 1. In this project, the adaptive capacity methodology was based on readily available data sources compared to stakeholder led qualitative process followed in Phase I. The indicators used were largely influenced by the National Parks Service adaptive capacity methodology, and in some cases using similar data sources.

Four indicators for adaptive capacity were identified in the data review process. Adaptive capacity indicators are scored on a scale of zero to four, with four being the site contains indicators representing the highest adaptive capacity possible and zero being when the respective adaptive capacity indicator is not applicable. This framework is applied to four different indicators for this assessment. Adaptive capacity of a site was developed by adding the scores from each individual indicator and normalizing them on a scale of one to four (score of zero remains the same). The ranking for each indicator followed these groupings to the greatest extent possible:

4	3	2	1	0
Site has assets and landscapes that support adaptation of many resources	Site has assets and landscapes that support adaptation of some resources	**Site has assets and landscapes that support adaptation of few resources**	**Site does not have assets and landscapes that support adaptation of resources**	Not Applicable

Recreation access redundancy represents the ability to travel from one DCR site to another if any given site closed, due to capacity issues, water quality, or myriad other reasons. This analysis does not account for redundancy specific to the type of site, but it represents the calculated distance to the closest DCR site. If a site has another site within less than 0.5 miles, it receives a score of four because this is deemed as "comfortable walkable distance". If the next closest site is 0.5 to 1 mile away, it receives a score of three because it is uncomfortably walkable, particularly by children, the elderly, and the disabled. If the next closest site is 1 to 3 miles away, it receives a score of two because it is uncomfortably walkable, and thus most accessible by bike, car, or public transportation where applicable. If the next closest site is greater than 3 miles away the site receives a score of one because it is deemed unwalkable in most circumstances.

A similar indicator of increased accessibility is proximity to a public transportation stop. MBTA Rapid Transit[20] and Bus Stop[21] and RTA Bus Stop[22] data inform this indicator. If a transit stop is within 0.5-mile buffer of the site, it gets assigned a score of two. If a transit stop is within 0.51 mile to 1 mile buffer of the site, it gets assigned a score of one.

BioMap 2 Critical Natural Landscape component layers[23] are used as an indicator to identify the number of different types of critical natural landscapes within a site boundary. Critical natural

[20] MassGIS, MBTA Rapid Transit, https://www.mass.gov/info-details/massgis-data-mbta-rapid-transit (accessed June 2022)
[21] MassGIS, MBTA Bus Routes and Stops, https://www.mass.gov/info-details/massgis-data-mbta-bus-routes-and-stops (accessed June 2022)
[22] MassDOT, RTA Bus Stops, https://geo-massdot.opendata.arcgis.com/datasets/rta-bus-stops/explore (accessed June 2022)
[23] MassGIS, BioMap2, https://www.mass.gov/info-details/massgis-biomap2 (accessed May 2022)

landscape identifies larger landscape areas that are better able to support ecological processes and disturbances, which is why it is used to represent adaptive capacity in this assessment.

Backward climatic velocity[24] is an indicator that was sourced from the NPS vulnerability assessment methodology. According to the NPS assessment, backward velocity is the distance an organism would need to travel to colonize a given location with future climatic conditions analogous to the conditions at the organism's present-day site. Some researchers consider backward velocity to be a potential indicator of climatic refugia because in areas with low climatic velocity, species adapted to those conditions would not have had to move far to reach those areas.[25]

The indicators used and scoring assigned are shown in Table 6.

Table 6: Adaptive Capacity Scoring Methodology

Indicator	4	3	2	1	0
Recreation Access Redundancy	< 0.5 miles	*.5 - 1 miles*	*1 - 3 miles*	*> 3 miles*	
Proximity to a Public Transportation Stop			*<= 0.5 miles*	*0.51 - 1 mile*	
Does the site contain multiple Biomap CNL components?	>=3 CNL criterion	2 CNL Criterion	1 CNL Criterion		*none*
Backward Climatic Velocity - 30 km buffer	0-0.5	0.51-1.5	1.51-2.5	*> 2.5*	

Adaptive Capacity Score Findings

Adaptive capacity (AC) indicator scores were summed for each site by adding the scores of each individual indicator present on that site. Recreation redundancy contributes heavily to the higher AC scores, as many DCR properties are in close proximity to each other. This is true across the Commonwealth, not just in either urban or rural parts of the state. Backward climatic velocity contributes heavily to the higher scores, as many sites received a two or three for that indicator. Proximity to transit is more impactful for urban and suburban sites throughout the Commonwealth. The sites with the lowest adaptive capacity are provided in Table 7.

The team acknowledges the possibility that by splitting BioMap Critical Natural Landscape components and core habitat components into separate sensitivity and adaptive capacity indicators, the scores may end up cancelling each other out. However, 30% (157 sites) received different scores for critical natural landscape (factored in adaptive capacity) and core habitat components (factored in sensitivity). So, for at least one third of the DCR properties, this distinction of biomap scores for natural landscape and core components has an impact on the scores.

[24] Hamann et al. (2015) available via AdaptWest, Backward Climatic Velocity, adaptwest.databasin.org (accessed May 2022)
[25] National Park Service, A Strategic Analysis of Climate Vulnerability of National Park Resources and Values, pg 114, https://irma.nps.gov/DataStore/DownloadFile/664238 (accessed May 2022)

TABLE 7: TOP SITES WITH LOWEST ADAPTIVE CAPACITY			
SITE NAME	REGION	TOWN	Adaptive Capacity, actual
Dennis Fire Tower	South Region	DENNIS	2.0
Frank L. Perry Reforestation Lot	South Region	FALMOUTH	3.0
Leadmine Pond Public Access	Central Region	STURBRIDGE	3.0
Quabbin Aqueduct - Quabbin Reservoir Watershed	Central Region	HARDWICK	3.0
Angle Tree Monument Reservation	South Region	NORTH ATTLEBOROUGH, PLAINVILLE	4.0
Berkley State Forest	South Region	BERKLEY	4.0
C.M. Gardner State Park	West Region	HUNTINGTON	4.0
Dunn State Park	Central Region	GARDNER	4.0
Gustav A.- Swede - Johnson Swimming Pool	Central Region	FITCHBURG	4.0
Halibut Point State Park	North Region	ROCKPORT	4.0
Hanson Fire Tower	South Region	HANSON	4.0
James E McVann and Louis F OKeefe Memorial Skating Rink	North Region	PEABODY	4.0
Moore State Park	Central Region	PAXTON	4.0
Nantucket State Forest	South Region	NANTUCKET	4.0
Rawson Hill Brook Flood Control Site	Central Region	SHREWSBURY	4.0
Raynham State Forest	South Region	RAYNHAM	4.0
Shelburne State Forest	West Region	SHELBURNE	4.0
Whalom Lake Access	Central Region	LEOMINSTER	4.0

Raw AC scores are used to calculate the composite vulnerability scores for each climate parameter, however a normalized AC score on a scale of 1-4 was calculated to easily compare sites between low AC, medium AC, medium-high AC, and high AC. Raw AC scores are used to calculate the composite vulnerability scores for each climate parameter, however a normalized AC score on a scale of 1-4 was calculated to easily rank sites between low AC, medium AC, medium-high AC, and high AC. Figure 6 shows the spatial distribution of the normalized AC scores across the DCR sites in the Commonwealth.

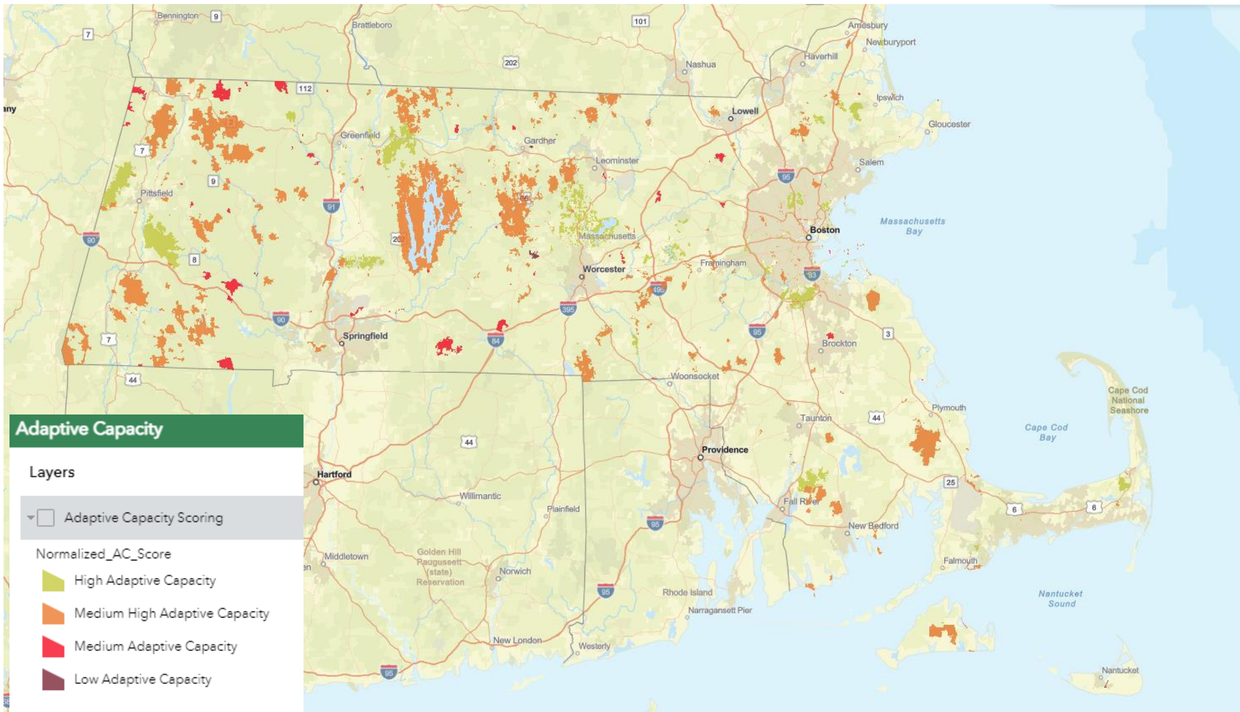

Figure 6. Sites scored for adaptive capacity

Sensitivity and Adaptive Capacity Data Limitations

The sensitivity data used is not a complete or comprehensive list of assets or critical systems present on the sites. The project team did not independently confirm or verify asset data.

Additionally, the analysis and findings in this report are based on the results of the data gathering processes as described herein. The analysis and findings may change if there are changes to the asset data used by DCR, including but not limited to new or updated data sets. The vulnerability assessment should be reevaluated as the asset data changes and/or new information or data become available for any of the exposure, sensitivity or adaptive capacity indicators.

Vulnerability Assessment Results

Scoring

Vulnerability was calculated for each of the climate hazards for each planning horizon (2030 and 2070), except for wildfire which does not vary by planning horizon. In addition, composite vulnerability scores were calculated for each site for 2030 and 2070 by summing up the vulnerabilities of all climate hazards (except wildfire) for 2030 and for 2070. This means there are 11 vulnerability scores available for each site.

1. $Vulnerability_{climate\ parameter,\ 2030}\ (Exp_{climate\ parameter.\ 2030} * Sensitivity\ /\ Adaptive\ Capacity)$
2. $Vulnerability_{climate\ parameter,\ 2070}\ (Exp_{climate\ parameter.\ 2070} * Sensitivity\ /\ Adaptive\ Capacity)$
3. $Vulnerability_{Composite\ 2030}\ (Vul_{SLR\ 2030} + Vul_{PU\ 2030} + Vul_{PR\ 2030} + Vul_{Heat\ 2030})$
4. $Vulnerability_{Composite\ 2070}\ (Vul_{SLR\ 2070} + Vul_{PU\ 2070} + Vul_{PR\ 2070} + Vul_{Heat\ 2070})$

Objectives of the Results

The objective of this GIS-based screening level exposure analysis was to broadly understand vulnerability to the DCR system (both statewide and by region) and provide a list/database and map of areas that are most vulnerable for the primary climate change interactions. The output of this robust scalable approach provides decision makers with a foundation of understanding of which DCR sites:

- Will experience the greatest impacts from climate change (Table 8)
- Be impacted the earliest
- Have the highest sensitivity
- Have the lowest adaptive capacity.

Table 8: Top 10 vulnerable sites greatest impacts from climate change

Vul SLR, actual 2030	*Vul* SLR, actual 2070	*Vul* PU, actual 2030	*Vul* PU, actual 2070	*Vul* PR, actual 2030	*Vul* PR, actual 2070	*Vul* Heat, actual 2030	*Vul* Heat, actual 2070	*Vul* WF, actual	*Vul* comp, actual, noWF 2030	*Vul* comp, actual, no WF 2070
Halibut Point State Park*	Halibut Point State Park*	Halibut Point State Park	Halibut Point State Park	Halibut Point State Park	Halibut Point State Park	State Fish Pier	State Fish Pier	Halibut Point State Park	Halibut Point State Park	Halibut Point State Park
Spectacle Island	Spectacle Island	Granville State Forest	State Fish Pier	Great Brook Farm State Park	Great Brook Farm State Park	Revere Beach Reservation	Halibut Point State Park	Walden Pond State Reservation	Spectacle Island	Spectacle Island
Demarest Lloyd State Park	Demarest Lloyd State Park	State Fish Pier	Walden Pond State Reservation	Moore State Park	Moore State Park	New Charles River Basin	Revere Beach Reservation	Nantucket State Forest	State Fish Pier	State Fish Pier

Table 8: Top 10 vulnerable sites greatest impacts from climate change

$Vul_{SLR,\ actual}$ 2030	$Vul_{SLR,\ actual}$ 2070	$Vul_{PU,\ actual}$ 2030	$Vul_{PU,\ actual}$ 2070	$Vul_{PR,\ actual}$ 2030	$Vul_{PR,\ actual}$ 2070	$Vul_{Heat,\ actual}$ 2030	$Vul_{Heat,\ actual}$ 2070	$Vul_{WF,\ actual}$	$Vul_{comp,\ actual,\ noWF}$ 2030	$Vul_{comp,\ actual,\ no\ WF}$ 2070
Ellisville Harbor State Park	Ellisville Harbor State Park	Dennis Fire Tower	Spectacle Island	Brimfield State Forest	Brimfield State Forest	Angle Tree Monument Reservation	Angle Tree Monument Reservation	Great Brook Farm State Park	Furnace Brook Parkway	Furnace Brook Parkway
Fort Phoenix State Reservation	Fort Phoenix State Reservation	Chester-Blandford State Forest	Dennis Fire Tower	Chicopee Memorial State Park	Chicopee Memorial State Park	Lynn Shore Reservation	Dennis Fire Tower	Moore State Park	Ellisville Harbor State Park	Great Brook Farm State Park
Lovells Island	Lovells Island	Walden Pond State Reservation	Great Brook Farm State Park	Dunn State Park	Dunn State Park	Melnea A. Cass Swimming Pool	New Charles River Basin	Watson Pond State Park	Fort Phoenix State Reservation	Ellisville Harbor State Park
Nickerson State Park	Nickerson State Park	Houghton's Pond Recreation Area	Moore State Park	Myles Standish State Forest	Myles Standish State Forest	Halibut Point State Park	Lynn Shore Reservation	Granville State Forest	Nantasket Beach Reservation	Fort Phoenix State Reservation
Bumpkin Island	Bumpkin Island	Spectacle Island	Watson Pond State Park	Watson Pond State Park	Watson Pond State Park	Fresh Pond Parkway	Walden Pond State Reservation	Wells State Park	Revere Beach Reservation	Revere Beach Reservation
Carson Beach	Carson Beach	Great Brook Farm State Park	Granville State Forest	Borderland State Park	Borderland State Park	Nantasket Beach Reservation	Nantucket State Forest	Angle Tree Monument Reservation	Nickerson State Park	Nickerson State Park
Furnace Brook Parkway	Furnace Brook Parkway	Moore State Park	Nantucket State Forest	Granville State Forest	Granville State Forest	Dennis Fire Tower	Spectacle Island	Dennis Fire Tower	Lovells Island	Lovells Island

Note: * Halibut State Point Park was identified as being most vulnerable to SLR/SS in 2030 and 2070. The project team recognizes that the majority of the site and most critical elements of the site are elevated above future flood projects. This result is due to the polygon developed to represent the site boundary and is one of the limitations of the analysis. In the future, DCR may choose to alter the site polygon, which would likely remove this site from coastal flooding exposure.

Complete results of this assessment can be found in Appendix A.

Uses and Limitations

The results of the vulnerability assessment can be used to inform capital planning decisions and designs, identify opportunities for resilience and climate adaptation, identify hazards and constraints at the site level, and inform prioritization within the Department. The vulnerability assessment is not intended to provide project specific recommendations.

Indicators for exposure, sensitivity, and adaptive capacity considered in this report were identified in coordination with DCR staff. The vulnerability assessment excluded the following:

- Scores for specific assets
- Recommendations on how to apply the score outputs from the assessment
- A correlation between the vulnerability assessment scores and sustainability/carbon reduction

This assessment is not intended to identify risks of the DCR based on the probability of extreme weather events, consequences of impact from failure of assets, or impacts to people. The flood vulnerability assessment scores provided in this study do not account for site-specific flooding impacts and should not be considered a substitute for the site-specific flood assessment and modeling.

Glossary of Terminology

The terms use in this report are terms used in the Climate Resilience Design Standards and Guidance and in the Climate Resilience Design Standards Tool and are defined in Table 9.

Table 9: Glossary

Terms	Description	Options or Examples
100-year floodplain	Area with a 1% annual chance of flooding (or 1 in 100 chance)[26]. Also known as a 1% Annual Exceedance Probability (AEP) flood event (see definition for Annual Exceedance Probability below).	Flood Insurance Rate Maps (FIRM) show the extent of the FEMA-defined 100-year floodplain. See definition for Flood Insurance Rate Map below.
500-year floodplain	Area with a 0.2% annual chance of flooding (or 1 in 500 chance).[1] Also known as a 0.2% Annual Exceedance Probability (AEP) flood event (see definition for Annual Exceedance Probability below).	Flood Insurance Rate Maps (FIRM) show the extent of the FEMA-defined 500-year floodplain. See definition for Flood Insurance Rate Map below.
Adaptation	An action that seeks to reduce vulnerability and risk to an anticipated climate impact. For the Tool, this term is focused on the design of physical assets only.	Flood barriers, stormwater infiltration, living shorelines, elevated infrastructure, increased tree canopy.
Adaptive Capacity	The ability of assets to accommodate or recover from the impacts of climate change	If a pool is closed and another pool is in walking distance (0.5 mi) there is redundancy.
Annual Exceedance Probability (AEP)	Probability of a flood event being equaled or exceeded in a given year.	The 0.2% AEP flood event has a 1 in 500 chance of being equaled or exceeded in any year (return period of 500 years, "500-year flood").
Asset	Assets are major physical components of a project and organized into three main Asset Categories (see definition below).	In the Draw 7 Park case study project, the park and living shoreline are assets.

[26] Federal Emergency Management Agency (FEMA), "Flood Zones." https://efotg.sc.egov.usda.gov/references/public/NM/FEMA_FLD_HAZ_guide.pdf

Table 9: Glossary		
Terms	Description	Options or Examples
	Also known as Physical Assets (see definition below).	
Asset Category	Division of Physical Assets into high-level primary groups for a project.	Building/Facility, Infrastructure, and Natural Resources. In the Draw 7 Park case study project, both the park and living shoreline belong to the Natural Resources Asset Category.
Climate Change	According to the Massachusetts State Hazard Mitigation and Climate Adaptation Plan (SHMCAP) climate change refers to "a change in the state of the climate that can be identified by statistical changes of its properties that persist for an extended period, whether due to natural variability or as a result of human activity."[27]	Temperatures are increasing, rainfall events are becoming more frequent and intense, and sea levels are rising.
Climate Resilience Design Guidance (the Guidance)	The Guidance are supplemental resources that provide useful instructions and best practices for implementing the Standards (see definition for Climate Resilience Design Standards below).	The Guidance constitute design principles related to site suitability, flexible adaptation strategies and regional coordination that are illustrated through forms and specific "best practices," which may include case studies and/or existing published resources that exemplify the Guidance.
Climate Resilience Design Standards Tool (the Tool)	The Tool provides Climate Risk Screening (preliminary exposure rating and risk rating) and Climate Resilience Design Standards (see definition below) based on Project Inputs.	

[27] Massachusetts State Hazard Mitigation and Climate Adaptation Plan, 2018. https://www.mass.gov/service-details/massachusetts-integrated-state-hazard-mitigation-and-climate-adaptation-plan

Table 9: Glossary		
Terms	**Description**	**Options or Examples**
Climate Resilience Design Standards (the Standards)	A Climate Resilience Design Standard is a scientifically based process or method that produces a consistent outcome, which uniformly guides users in the selection of planning horizons, return period, and flexible design criteria, by climate parameter. The Standards provide "what you design to" in a project.	For example, the Climate Resilience Design Standards for the Draw 7 Park case study project include recommended target planning horizon of 2070, 1% AEP for return period, and design criteria of peak flood elevation for sea level rise/storm surge corresponding to design criteria value of 13.9 ft-NAVD88 determined from the Massachusetts Coast Flood Risk Model (MC-FRM).
Climate Parameters	The primary climate hazards referenced by the Standards.	Sea level rise and storm surge, extreme precipitation, and extreme heat.
Climate Vulnerable Populations	Climate vulnerable populations are those who have lower adaptive capacity or higher exposure and sensitivity to climate hazards like flooding or heat stress due to factors such as access to transportation, income level, disability, racial inequity, health status, or age.	Climate vulnerable populations could include people with disabilities, people experiencing homelessness, elderly residents, children, and others.
Criticality	Score that expresses the consequences of failure of an asset as a function of scope, time, and severity. Criticality is an internal metric in the Tool and is expressed as low, medium, or high. See definitions for scope, time, and severity below.	A hospital located in the 100-year floodplain would have a higher criticality.
Environmental Justice Populations	Environmental justice populations typically include climate vulnerable populations, who may have lower adaptive capacity or higher exposure and sensitivity to climate hazards like flooding or heat stress due to factors such as access to transportation,	Environmental Justice populations include areas where: • 25% or more of the population identifies as a person of color • 25% or more of households have limited English fluency

Table 9: Glossary		
Terms	Description	Options or Examples
	income level, disability, racial inequity, health status, or age.[28]	• Households with an annual median income equal to or less than 65% of the state median
Exposure (Extreme Heat)	Whether an area will experience extreme heat or wildfire	A forested coastal location may experience less extreme heat than an inland city
Exposure (Flooding)	Whether an area will experience flooding	An inland asset may not be exposed to coastal storm surge
Flood Insurance Rate Map (FIRM)	Official map of a community on which FEMA has delineated the Special Flood Hazard Areas (SFHAs), the Base Flood Elevations (BFEs), and the risk premium zones applicable to the community, based on historic information.[29] See definitions for 100- and 500-year floodplains, and BFE, above.	FIRMs are available on the FEMA Flood Map Service Center online.
Infrastructure	Infrastructure is an Asset Category in the Tool. Refer to definition for Asset Category above.	Examples of infrastructural asset sub-types include transportation, flood control, utilities, solid and hazardous waste.
Massachusetts Coast Flood Risk Model (MC-FRM)	The projected sea level rise / storm surge data values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time, for a hydrodynamic,	

[28] https://mass-eoeea.maps.arcgis.com/apps/webappviewer/index.html?id=1d6f63e7762a48e5930de84ed4849212
[29] FEMA National Flood Insurance Program Terminology Index, 2020. https://www.fema.gov/flood-insurance/terminology-index

Table 9: Glossary		
Terms	Description	Options or Examples
	probabilistic model that considers hundreds of thousands of historic and simulated storms. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.	
Natural Resources	Natural Resources is an Asset Category in the Tool, which is a high-level primary group of physical assets. Refer to definition for Asset Category above.	Examples of natural resources asset sub-types include coastal resource areas, forested ecosystems, aquatic ecosystems, wetland resource areas (inland), agricultural resources, and open space.
NOAA Atlas 14	Precipitation frequency estimates data server, provided by NOAA.[30]	
Number of Heat Waves Per Year & Average Heat Wave Duration	A Heat Wave is defined as three or more consecutive days with maximum temperatures of 90°F or above. Number of Heat Waves represents number of events (with one event representing at least three consecutive days with maximum temperatures of 90°F), and Average Heat Wave Duration represents the number of days for the average duration of each event over the year. Heat Waves are a public health and safety threat that may result in heat-related deaths. According to World Health Organization (WHO), Heat Waves, "can burden health and emergency services and also increase strain on water, energy and transportation resulting in power shortages or even blackouts. Food and livelihood security may also be strained if people lose their crops or livestock due to extreme heat."	

[30] NOAA Atlas 14 Point Precipitation Frequency Estimates: Northeastern States; NOAA Atlas 14, Volume 10, Version 3

Table 9: Glossary		
Terms	Description	Options or Examples
Planning Horizon	A future date to which a project can be designed, which allows the project to incorporate anticipated climate change conditions.	Present (2030), Mid-Century (2050), Mid-late Century (2070), End of Century (2090/2100)
Population Affected	The number of people who directly use or receive services from this asset.	For example, in a residential building, the number of people directly served or affected by the building are the number of residents.
Representative Concentration Pathways (RCP)	Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its Fifth Assessment Report in 2014. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use.[31]	The RCPs include a stringent greenhouse gas mitigation scenario (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0) and one scenario with very high greenhouse gas emissions (RCP 8.5).
Resilience Massachusetts Action Team (RMAT)	An inter-agency team tasked with implementing the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP).[32] Members of the RMAT provided project management for the development of the Tool.	
Risk	According to SHMCAP, risk is defined as "the potential for an unwanted outcome resulting from a hazard event, as determined by its likelihood and associated consequences; and expressed, when possible, in dollar losses. Risk represents potential	For example, if a state highway is flooded that also serves as an evacuation route, it will have a high probability of flooding and its consequence of flooding (as measured by its severity, with respect to geographic area and

[31] Climate Change 2014: Synthesis Report, 2014. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf
[32] Resilient MA Action Team (RMAT) https://www.mass.gov/info-details/resilient-ma-action-team-rmat

Table 9: Glossary		
Terms	Description	Options or Examples
	future losses, based on assessments of probability, severity, and vulnerability."[33]	people affected, economic impacts and cascading impacts to other infrastructure) will also be high, which would lead to a high risk rating.
Sensitivity	Whether assets or its functionality will be damaged or disrupted from exposure to a hazard	An asset in the floodplain with critical systems located below the future projected flood elevation is considered highly sensitive to flooding
State Hazard Mitigation and Climate Adaptation Plan (SHMCAP)	The SHMCAP for the Commonwealth was adopted on September 17, 2018. This plan, the first of its kind to comprehensively integrate climate change impacts and adaptation strategies with hazard mitigation planning, also complies with current federal requirements for state hazard mitigation plans and maintains the Commonwealth's eligibility for federal disaster recovery and hazard mitigation funding under the Stafford Act.[34]	
Sea level rise (SLR)	The worldwide average rise in mean sea level, which may be due to a number of different causes, such as the thermal expansion of sea water and the addition of water to the oceans from the melting of glaciers, ice caps, and ice sheets; contrast with relative sea-level rise.[35]	
Storm Surge	An abnormal rise in sea level accompanying a hurricane or other intense storm, whose height is the difference between the observed	Storm surge is usually estimated by subtracting the normal or astronomic tide from the observed storm tide.

[33] Massachusetts Integrated State Hazard Mitigation and Climate Adaptation Plan, 2018. https://www.mass.gov/service-details/massachusetts-integrated-state-hazard-mitigation-and-climate-adaptation-plan
[34] https://resilientma.org/shmcap-portal/index.html#/
[35] NH Coastal Flood Risk Science and Technical Advisory Panel, 2020. New Hampshire Coastal Flood Risk Summary, Part II: Guidance for Using Scientific Projections. Report published by the University of New Hampshire, Durham, NH.

Table 9: Glossary		
Terms	Description	Options or Examples
	level of the sea surface and the level that would have occurred in the absence of the cyclone.[36]	

Data Gaps

The project team completed a thorough analysis of available data to include as exposure, sensitivity, and adaptive capacity indicators throughout the project timeline. Several feedback sessions with DCR staff members were held in order to identify possible data gaps and provide suggestions of additional datasets to include. Table 8 summarizes the datasets that were not included with corresponding explanations.

TABLE 8: DATASETS CONSIDERED AND NOT USED IN ASSESSMENT		
Layer name	Source	Comments
DCR park closure data	DCR	Closure data not specific to capacity, could also include staffing or environmental closures, could not be applied to one specific indicator
DCR revenue producing parking lots	DCR	Data limitations, relevant data not available
CFI(continuous forest inventory)	DCR internal access only	Access limitations prevented this data from being used
Land use intensity (pervious vs. Impervious)	LiDAR data	Data overlaps with exposure indicators
Flood control structures (dams)	MassGIS	DCR is completing a specific Dam vulnerability assessment, decided to remove from this assessment
NHESP natural community	MassGIS	Data overlaps with BM2 dataFnorth
Interior forest area	MassGIS	Data overlaps with BM2 Core Habitats

[36] Glossary – Storm Surge, 2009. National Weather Service. https://w1.weather.gov/glossary/index.php?word=Storm+Surge

State designated barrier beaches	MassGIS	Shoreline Change data used as an indicator to emphasize the importance of coastal beaches instead
Vernal pools (potential and certified)	MassGIS	Data overlaps with BM2 Core Habitats
Ability for wetland to accommodate future flooding (palustrine vs estuarine)	MassGIS and MC-FRM	Determined to be an extrapolation of data that could not be defended

How to Update the Assessment

The methodology for this assessment was created with the intention such that it can updated over time. Updates could include:

- Adding or removing site polygons
- Adding or removing indicators for exposure, sensitivity, or adaptive capacity
- Updating existing indicators with latest version of data
- Reflecting changes and or changes in visualizing the data in the Online Climate Viewer

Step-by-step instructions for each update type are detailed below.

Adding or removing site polygons

The DCR Sites polygon layer was created internally by DCR staff to represent land that DCR owns or manages across the Commonwealth. In the event that DCR acquires new properties, there is a land disposition of existing properties, or wants to divide one site polygon into multiple, the DCR Sites layer must be updated to reflect these changes.

Step1. Using the updated DCR Sites layer, run the python scripts for each indicator (See Appendix B) in ArcGIS to re-assign scores for the updated sites.

Step 2. Export the updated scores from GIS attribute table to Excel.

Step 3. Paste the updated scores in the master scoring spreadsheet in the applicable tab (See Appendix A). Calculation results in all the remaining tabs will automatically get updated for the remaining tabs.

Adding or removing indicators for exposure, sensitivity, or adaptive capacity

Step 1. Update the methodology and scoring spreadsheets to remove the indicator and update the relevant GIS layer to reflect the intended changes.

Step 2. Keep the indicator in an archived GIS file for record keeping purposes, but it can be removed from the active GIS scoring layer.

Step 3. If an indicator is added, add it as an attribute in GIS manually. If an indicator is removed, delete it from the existing Excel scoring spreadsheet and the remaining scoring in the other tabs should be automatically updated.

Step 4. If an indicator is added, evaluate appropriate scoring thresholds to score sites with this indicator based on whether it is an exposure, sensitivity, or adaptive capacity indicator.

Step 5. If the scoring indicator has a range of values, evaluate the maximum, minimum, and any intermediate scores based on the dataset using the respective scoring methodology outline.

Step 6. Choose a threshold within the bounds of maximum and minimum values so that the data distribution is uniform within the range.

Step 7. Update the methodology and scoring spreadsheets to reflect these changes.

Step 9. Update the GIS analysis to reflect changes with the new indicator. Adopt one of the existing python codes from a similar indicator or write an original code to update scoring based on new threshold.

Step 10. Export the calculate values of this added indicator across the sites as a new column to the master scoring spreadsheet raw data tab. Calculation results in all the remaining tabs will automatically get updated for the remaining tabs.

Updating existing indicators with latest version of data

Step 1. First confirm that the new dataset is in the same format and has the same attributes as the prior dataset.

Step 2. If the new data has a different format or has new attributes that should be used, proceed with steps as though it is a new indicator.

Step 3. If the new data has a similar format, update the existing python script to reflect values from the new dataset and rerun the script as-is. Each site will receive an updated score.

Step 4. This data can be exported to excel and the master scoring spreadsheet raw data tab column for this indicator can be updated to reflect the new scores. Summary and calculation cells in the spreadsheet should automatically update for the remaining tabs.

Reflecting Changes in the Online Climate Viewer

Step 1. Export the updated layers in the ArcGIS desktop app as web layers.

Step 2. For new layers, export as new layer (“Share as Web Layer”), For updated layers, export and replace the existing layers. Note that the layers need to be (“Overwrite web layer”).

Step 3. Export the updated layers in the ArcGIS desktop app as web layers. For new layers, export the data as new layer (“Share as Web Layer”), and for updated layers, export the layers to replace the existing layers (“Overwrite web layer”).

Step 4. Reorganize the new and/or updated layers similar to how they would be displayed in the Tool.

Step 5. Update the pop-up messages in the webmap using the codes provided in Appendix B. “DCR Climate Change Webmap” hosted on DCR server under the folder “DCR Climate Change Dashboard”, which contains the layers that were used in the current Tool.