CLIMATE RESILIENCE DESIGN STANDARDS

TIERED METHODS TO CALCULATE DESIGN CRITERIA VALUES

Version 1.4
DECEMBER 2024

CLIMATE RESILIENCE DESIGN STANDARDS

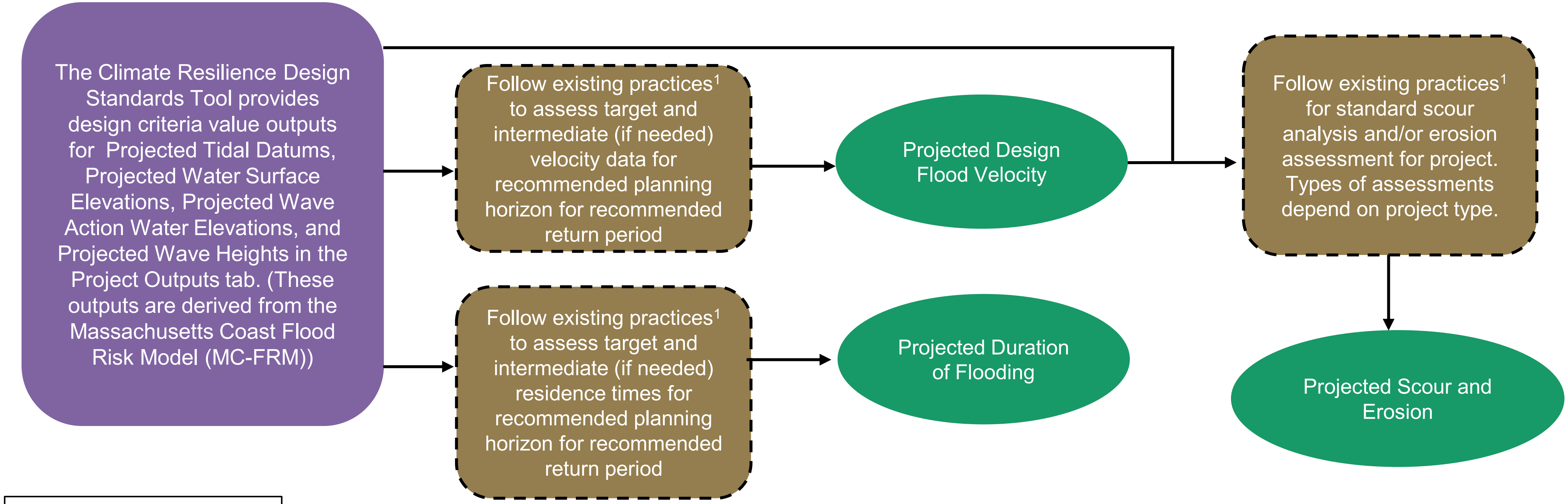
PROJECTED SEA LEVEL RISE / STORM SURGE DESIGN CRITERIA METHODS

ALL TIERS

Version 1.4
DECEMBER 2024

Method to Assess
Projected Sea Level Rise / Storm Surge Design Criteria

Given Standards Output from Tool: Planning Horizon (2030, 2050, 2070); Return Period [Annual Exceedance Probability] (20-yr [5%], 50-yr [2%], 100-yr [1%], 200-yr [0.5%], 500-yr [0.2%], 1000-yr [0.1%])



Legends
Tool Output
Calculation steps
Design Criteria
Existing practice

1. Consult a professional coastal engineer or scientist/modeler to estimate projected Duration of Flooding, Design Flood Velocity, and Scour & Erosion based on the recommended Standards and outputs provided through this Tool.

CLIMATE RESILIENCE DESIGN STANDARDS

PROJECTED TOTAL PRECIPITATION DEPTH DESIGN CRITERIA

TIERED METHODOLOGY

Tier 3 Dams and Flood Control Structure Projects – Pages 2-15

Tier 1 Projects – Pages 16-17

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Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm
Tier 3 - Dams and Flood Control Structures*

Given Standards Output from Tool: Planning Horizon (2030, 2050, 2070); Return Period (5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 200-yr, 500-yr)

Download daily precipitation projections for RCP 8.5 scenario from LOCA[1] dataset (Draft-SOP-Datadownload-LOCA.pptx) using 14 Group1[2] Global Climate Models (GCMs) for the grid(s) corresponding to the project location

↓

Repeat the same steps for two more grids around the project location (a total of 3 grids from each location). Avoid grids that contains more than 1/3rd of water body

↓

Choose 30-yr averaging period around given planning horizon

↓

Calculate annual maximum rainfall for each year for each grid in the 30-yr averaging period per GCM

→

Fit Generalized Extreme Value (GEV) distribution to the annual maxima to calculate modeled baseline and modeled future projections for given planning horizon and given return period for each GCM per grid

↓

Convert the 1-day design storm depths to 24-hour design storm depths using factor 1.11[3] per GCM per grid

↓

Calculate the ratios between modeled baseline and modeled future per GCM per grid

↓

Calculate mean, 5%CL and 95% CL of the ratios between modeled baseline and modeled future for all GCMs and apply that to NOAA Atlas 14 median values[4] to estimate the projected 24-hour precipitation depths for given return period for each grid

→

Calculate mean of the projected 24-hour precipitation depths for all grids

↓

Projected Total Precipitation Depth for 24-hr Design Storm for given planning horizons and given return period*

* Tier 3 Dams and Flood Control Structures will also receive output from the Tool and an Attention note to compare the calculated depth using the methodology shown in this figure with the Tool output.

1. Pierce, D.W., D.R. Cayan, and B.L. Thrasher, Statistical Downscaling Using Localized Constructed Analogs (LOCA). Journal of Hydrometeorology, 2014. 15(6): p. 2558-2585
2. Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61- Final Report) by Kilgore et al., 2019
3. NOAA Atlas 14 Precipitation Frequency Estimates: Northeastern States; NOAA Atlas 14, Volume 10, Version 3

Legends
- Data Gathering
- Calculation steps
- Design Criteria
- Existing practice

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Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures (Step 0: Download LOCA Dataset)

- **Go to https://gdo-dcp.ucllnl.org/ to download data from LOCA**
- **Go to page "Projection: Subset Request"**

STEP 1
Go to sub-tab "Page 1. Temporal & Spatial Extent"

Step 0.1.1: "Time Step and Period", select daily period from Jan-1950 through Dec-2099

Step 0.1.2: "Domain", select "NLDAS"

Step 0.1.3: Select "Location" method and either enter the latitude, longitude pair OR specify interactively within the map based on Project Location. If the selected grid includes more than 1/3rd water body, also download data from the adjacent grid.

STEP 2
Go to sub-tab "Page 2. Products, Variables, Projections"

Step 0.2.4: "Select Projection Sets", check "LOCA-CMIP5-Climate-daily"

Step 0.2.5: Under "Products" select both "1/16 degree" boxes. For "Variables", check "Precipitation Rate (mm/dd)"

Step 0.2.6: Under "Emissions Scenarios, Climate Models and Runs", check boxes associated with Group 1 GCMs per NHCRP15-61 report[1], as shown in the Step 2.6 example slide. For each model, select emission scenario RCP8.5 for precipitation.

STEP 3
Go to sub-tab "Page 3. Analysis, Format, and Notification"

Step 0.3.7: "Analysis", keep dial set to "No Analysis"

Step 0.3.8: "Output Format", choose "ASCII text, comma-delimited (csv)"

Step 0.3.9: "Notification when Processing is Complete", enter your email address twice.

Finally, check your user type, application type, and applicable resource area(s) as appropriate.

STEP 4
Data request and data download

Step 0.4.1: Press button "Submit Request" on top left

Step 0.4.2: A popup box will appear with details of the submission. Press "Submit". Press "Ok".

Step 0.4.3: Click on the link that arrives in the email a few hours later to get to an ftp directory of files produced for your job request

Step 0.4.5: Click folder "Loca5" and download the .csv file for the climate projection data and .txt files for data related information

REFERENCES

1. Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61- Final Report) by Kilgore et al., 2019

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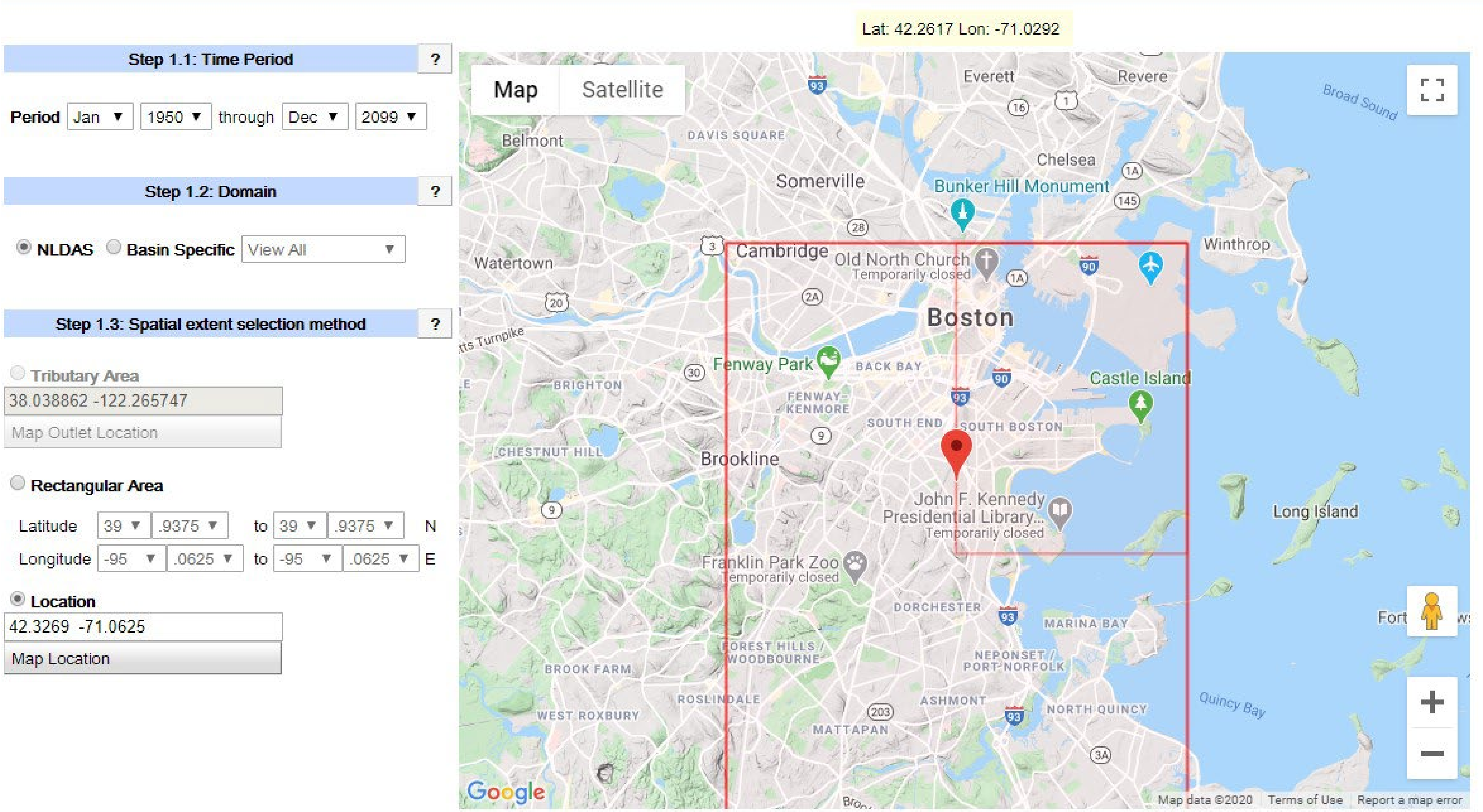
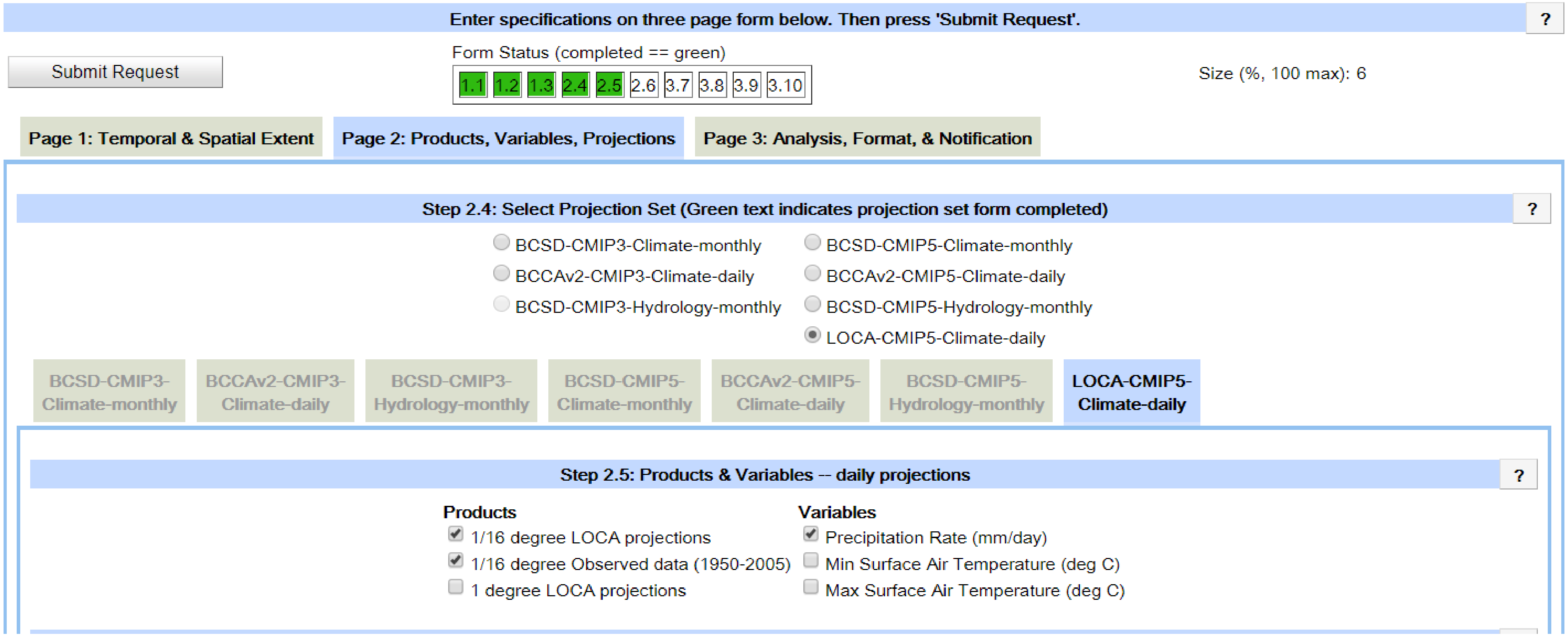
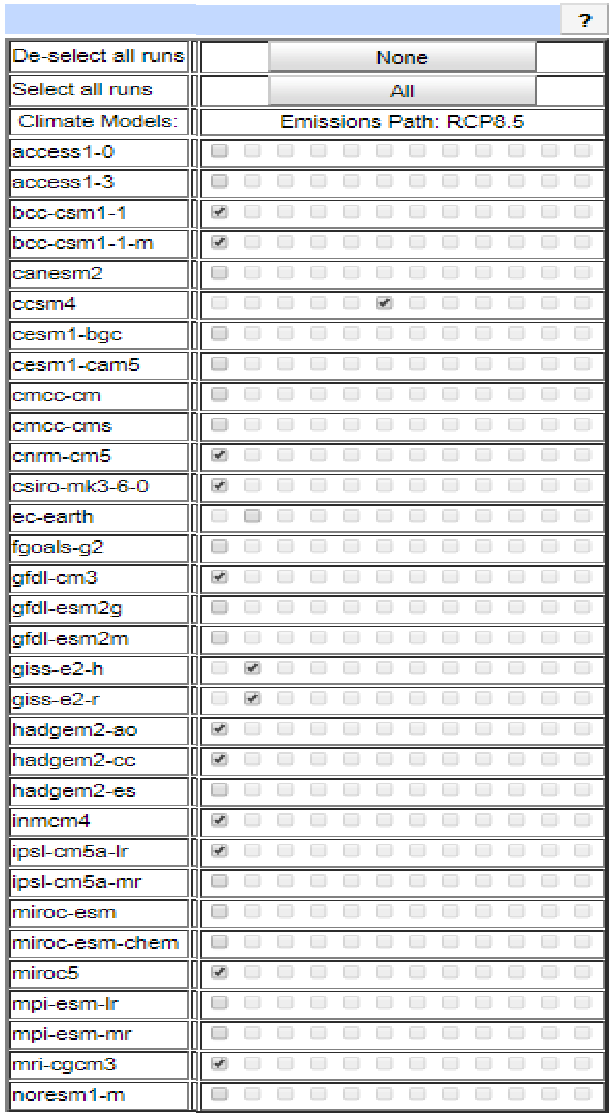
Download LOCA Dataset (Example: Project Area and Time Selection)
Moakley Park, South Boston, MA



Download LOCA Dataset (Example: Projection Set and Variables Selection)
Moakley Park, South Boston, MA



Download LOCA Dataset (Example: Group1* GCM Selections for Emission Scenario RCP8.5)
Moakley Park, South Boston, MA



<u>Check the Following Boxes under RCP8.5:</u>

- ✓ bcc-csm-1
- ✓ bcc-csm-1-m
- ✓ ccsm4
- ✓ cnrm-cm5
- ✓ csiro-mk3-6-0
- ✓ gfdl-cm3
- ✓ giss-e2-h
- ✓ giss-e2-r
- ✓ hadgem2-ao
- ✓ hadgem2-cc
- ✓ inmcm4
- ✓ ipsl-cm5a-lr
- ✓ miroc5
- ✓ mri-cgcm3

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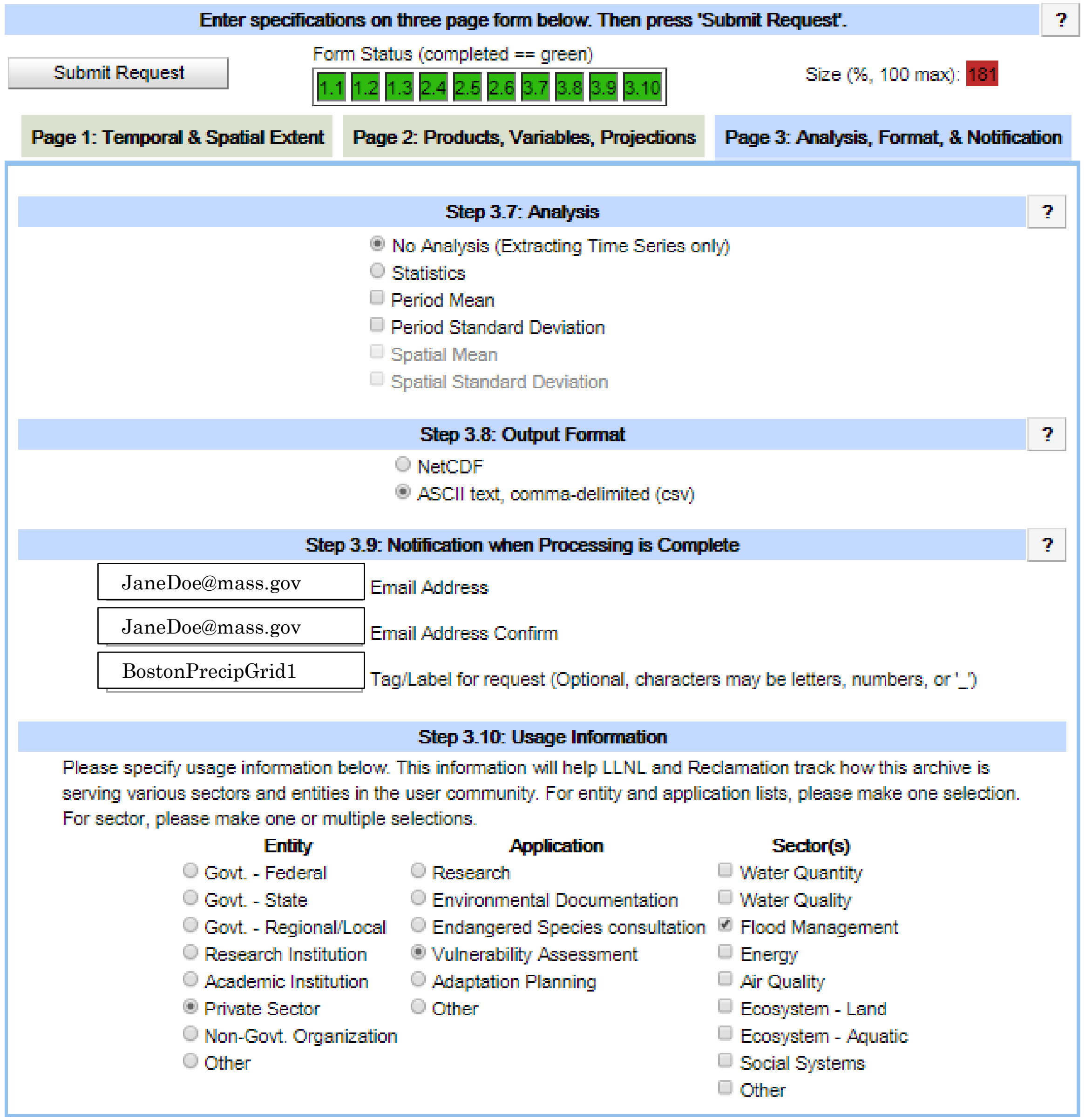
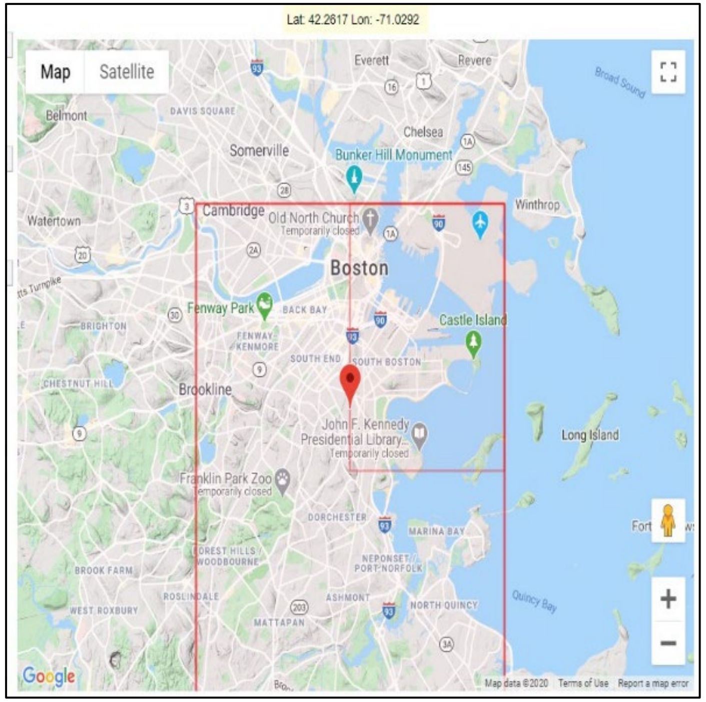
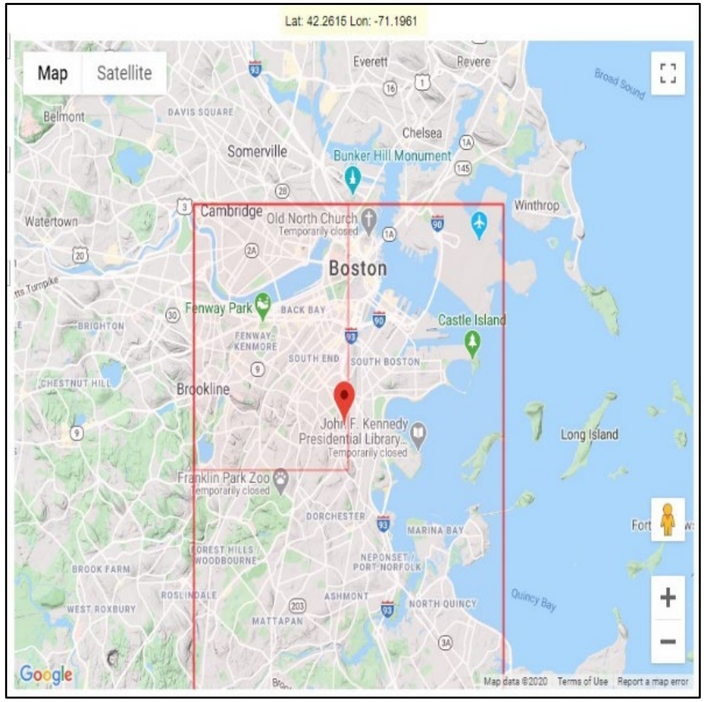
* Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61- Final Report) by Kilgore et al., 2019

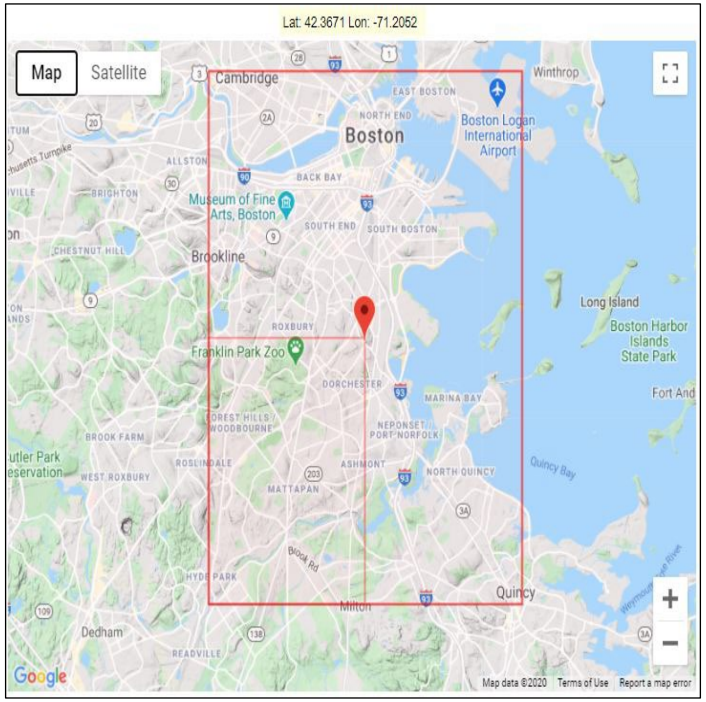
Download LOCA Dataset (Example: Type of Analysis, Output Format, and Others)
Moakley Park, South Boston, MA



Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm Tier 3 - Dams and Flood Control Structures (Step 1 Example: Select 2 More Grids Around Project Location to Download LOCA Datasets) Moakley Park, South Boston, MA







Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm
Tier 3 - Dams and Flood Control Structures

(Step 2 – 3 Example: Calculating Annual Maximum for each GCM for each Grid for RCP 8.5 in the 30 Year Span Surrounding Each Planning Horizon*) Moakley Park, South Boston, MA

YEAR	Max of bcc-csm1-1.1	Max of bcc-csm1-1-m.1	Max of ccsm4.6	Max of cnrm-cm5.1	Max of csiro-mk3-6-0.1	Max of gfdl-cm3.1	Max of giss-e2-h.6	Max of giss-e2-r.6	Max of hadgem2-ao.1	Max of hadgem2-cc.1	Max of inmcm4.1	Max of ipsl-cm5a-lr.1	Max of miroc5.1	Max of mri-cgcm3.1
2060	208.7	170.6	221.6	189.3	317.2	139.8	194.6	171.1	173.6	183.2	154.5	175.5	146.2	128.9
2061	173.0	163.2	157.1	182.5	152.1	125.6	146.5	156.9	160.6	171.5	125.3	169.7	144.3	119.9
2062	111.9	152.9	145.4	151.6	125.8	124.8	127.3	133.6	150.4	122.3	116.4	143.6	140.2	117.3
2063	109.7	135.1	129.2	130.0	119.0	116.1	124.7	114.6	142.2	117.6	112.9	124.2	135.5	107.4
2064	104.9	134.4	120.3	92.5	92.7	109.5	123.4	111.6	118.1	116.2	112.2	97.9	125.4	104.3
2065	92.4	132.1	109.3	92.2	91.3	107.8	110.4	105.9	117.4	109.8	101.8	90.3	117.1	103.8
2066	92.0	124.4	108.8	87.5	90.3	104.0	100.6	99.2	107.9	93.9	100.7	90.1	113.3	91.3
2067	85.6	118.6	99.6	87.1	90.2	96.6	88.5	98.7	102.0	89.9	91.2	89.9	107.9	91.0
2068	85.0	112.8	90.8	86.8	87.3	95.9	88.2	98.3	100.3	87.5	85.8	85.5	103.3	89.9
2069	82.1	111.1	76.8	85.1	83.9	93.1	82.5	87.6	99.3	86.5	75.9	80.9	100.0	88.5
2070	81.8	105.2	74.7	78.6	82.0	91.9	81.7	86.1	98.8	84.6	73.8	80.4	93.7	87.0
2071	73.3	98.7	72.1	78.0	81.9	87.6	80.8	76.5	98.2	79.3	72.4	78.4	88.9	84.5
2072	72.5	91.1	69.9	77.9	79.5	85.9	78.6	69.1	90.0	77.9	71.0	76.3	88.9	78.0
2073	72.2	90.5	68.1	77.6	76.3	80.3	75.6	68.3	87.9	77.1	71.0	72.7	86.8	74.9
2074	69.1	86.3	68.0	71.0	76.2	78.0	74.9	65.4	84.1	75.1	70.6	71.2	81.9	73.2
2075	67.6	82.4	66.3	68.6	75.9	75.1	72.6	64.5	81.8	74.7	70.2	70.8	74.6	73.0
2076	66.9	79.1	66.2	68.1	75.2	74.2	70.5	64.1	76.3	73.6	68.1	69.9	73.7	72.1
2077	66.8	75.4	65.4	67.3	70.7	74.0	66.5	63.8	74.9	73.4	63.1	69.7	70.7	71.3
2078	65.6	74.0	62.6	65.0	70.3	73.2	64.7	62.2	74.4	72.4	61.1	68.8	68.5	66.4
2079	65.1	68.0	61.2	64.3	69.1	73.2	64.6	61.2	74.4	72.3	59.8	68.2	68.2	66.4
2080	64.7	67.7	61.1	60.6	66.9	70.9	61.6	59.5	73.8	67.9	59.3	64.9	66.9	65.3
2081	62.6	67.0	59.0	59.1	66.0	68.9	61.4	59.2	71.8	63.8	58.0	62.9	65.7	65.0
2082	61.3	65.8	57.1	56.6	65.0	68.0	56.0	58.7	62.5	59.0	51.3	62.6	61.4	59.1
2083	60.5	65.1	53.8	54.5	62.1	60.8	55.7	56.5	62.4	58.9	49.0	60.0	60.1	52.3
2084	54.7	64.4	53.6	49.9	61.7	60.2	52.2	56.4	60.3	58.9	47.0	59.1	59.7	51.3
2085	54.7	61.1	51.2	49.4	58.0	56.5	51.2	52.2	56.0	58.5	45.9	54.1	57.8	50.2
2086	50.1	51.4	45.6	47.0	57.4	55.0	50.1	48.3	55.3	56.3	45.5	53.9	54.5	48.9
2087	43.8	49.8	43.4	46.8	53.5	52.5	48.0	47.7	55.1	54.6	45.3	50.4	54.4	46.5
2088	40.9	45.6	40.8	43.8	50.8	50.5	46.4	45.8	51.5	53.6	43.7	44.9	54.1	40.6
2089	28.1	40.4	36.5	41.2	47.8	42.4	44.9	37.5	50.5	46.6	43.0	44.0	50.2	40.1

*This chart shows annual maximums for the 2070s planning horizon only.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 4 Example: Fitting GEV Distribution on annual maxima of each grid for each GCM*)

Moakley Park, South Boston, MA

	Year	Rank	Max of bcc-csm1-1.1	b1	b2	Max of bcc-csm1-1-m.1	b1	b2	Max of ccsm4.6	b1	b2	Max of cnrm-cm5.1	b1	b2	Max of csiro-mk3-6-0.1	b1	b2
	2060	1	208.71	6.96	6.96	170.61	5.69	5.69	221.58	7.39	7.39	189.26	6.31	6.31	317.22	10.57	10.57
	2061	2	173.04	5.57	5.37	163.16	5.25	5.06	157.13	5.06	4.88	182.48	5.87	5.66	152.11	4.90	4.72
	2062	3	111.94	3.47	3.23	152.89	4.74	4.41	145.41	4.51	4.19	151.57	4.70	4.37	125.79	3.90	3.62
	2063	4	109.66	3.28	2.93	135.07	4.04	3.60	129.24	3.86	3.45	129.98	3.88	3.47	119.04	3.56	3.18
	2064	5	104.93	3.02	2.58	134.39	3.86	3.31	120.34	3.46	2.96	92.48	2.66	2.28	92.67	2.66	2.28
	2065	6	92.40	2.55	2.09	132.09	3.64	2.99	109.28	3.01	2.48	92.16	2.54	2.09	91.25	2.52	2.07
	2066	7	91.96	2.43	1.91	124.36	3.29	2.58	108.83	2.88	2.26	87.52	2.31	1.82	90.31	2.39	1.88
	2067	8	85.59	2.16	1.62	118.61	3.00	2.25	99.63	2.52	1.89	87.07	2.20	1.65	90.21	2.28	1.71
	2068	9	84.98	2.05	1.47	112.78	2.72	1.94	90.79	2.19	1.57	86.78	2.09	1.50	87.27	2.11	1.50
	2069	10	82.12	1.89	1.28	111.11	2.55	1.73	76.80	1.77	1.20	85.12	1.96	1.33	83.86	1.93	1.31
	2070	11	81.81	1.79	1.15	105.16	2.30	1.48	74.71	1.63	1.05	78.59	1.72	1.10	82.04	1.79	1.15
	2071	12	73.29	1.52	0.92	98.71	2.04	1.24	72.07	1.49	0.91	78.01	1.61	0.98	81.90	1.69	1.03
	2072	13	72.54	1.42	0.81	91.09	1.78	1.02	69.88	1.37	0.78	77.91	1.52	0.87	79.51	1.55	0.89
	2073	14	72.18	1.33	0.71	90.53	1.66	0.89	68.11	1.25	0.67	77.59	1.43	0.76	76.28	1.40	0.75
	2074	15	69.13	1.19	0.60	86.34	1.49	0.74	67.96	1.17	0.59	71.05	1.22	0.61	76.24	1.31	0.66
	2075	16	67.65	1.09	0.51	82.42	1.33	0.62	66.32	1.07	0.50	68.58	1.10	0.51	75.89	1.22	0.57
	2076	17	66.87	1.00	0.43	79.15	1.18	0.51	66.19	0.99	0.42	68.07	1.02	0.44	75.20	1.12	0.48
	2077	18	66.78	0.92	0.36	75.39	1.04	0.41	65.41	0.90	0.35	67.33	0.93	0.36	70.74	0.98	0.38
	2078	19	65.60	0.83	0.30	73.99	0.94	0.33	62.64	0.79	0.28	65.00	0.82	0.29	70.27	0.89	0.32
	2079	20	65.08	0.75	0.24	67.99	0.78	0.25	61.16	0.70	0.23	64.27	0.74	0.24	69.15	0.79	0.26
	2080	21	64.67	0.67	0.19	67.69	0.70	0.20	61.11	0.63	0.18	60.55	0.63	0.18	66.86	0.69	0.20
	2081	22	62.56	0.58	0.14	66.98	0.62	0.15	59.04	0.54	0.14	59.12	0.54	0.14	66.01	0.61	0.15
	2082	23	61.25	0.49	0.11	65.79	0.53	0.11	57.07	0.46	0.10	56.61	0.46	0.10	65.03	0.52	0.11
	2083	24	60.52	0.42	0.07	65.08	0.45	0.08	53.76	0.37	0.07	54.54	0.38	0.07	62.13	0.43	0.08
	2084	25	54.71	0.31	0.04	64.38	0.37	0.05	53.64	0.31	0.04	49.87	0.29	0.04	61.66	0.35	0.05
	2085	26	54.67	0.25	0.03	61.13	0.28	0.03	51.20	0.24	0.03	49.41	0.23	0.02	57.98	0.27	0.03
	2086	27	50.08	0.17	0.01	51.35	0.18	0.01	45.65	0.16	0.01	47.01	0.16	0.01	57.42	0.20	0.01
	2087	28	43.76	0.10	0.00	49.85	0.11	0.00	43.45	0.10	0.00	46.79	0.11	0.00	53.47	0.12	0.00
	2088	29	40.95	0.05	0.00	45.56	0.05	0.00	40.79	0.05	0.00	43.82	0.05	0.00	50.76	0.06	0.00
	2089	30	28.13	0.00	0.00	40.44	0.00	0.00	36.53	0.00	0.00	41.18	0.00	0.00	47.77	0.00	0.00
# of years	**30**																
	L-Moments			48	36		57	42		51	39		49	37		53	40
GEV w/ Lmom	lambda1		78.92			92.80			81.19			80.32			86.53		
	lambda2		17.57			20.43			20.54			18.65			19.12		
	lambda3		5.81			3.35			7.58			6.62			9.36		
	skew		0.33			0.16			0.37			0.35			0.49		

*This chart shows fitting a GEV Distribution on annual maxima of the 2070s planning horizon only.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 5 - 6 Example: Calculate ratios between baseline and future for each GCM for each grid*)

Moakley Park, South Boston, MA

2070s (2060-2089) RCP8.5 Grid1														
T-yr Event	Max of bcc-csm1-1.1	Max of bcc-csm1-1-m.1	Max of ccsm4.6	Max of cnrm-cm5.1	Max of csiro-mk3-6-0.1	Max of gfdl-cm3.1	Max of giss-e2-h.6	Max of giss-e2-r.6	Max of hadgem2-ao.1	Max of hadgem2-cc.1	Max of inmcm4.1	Max of ipsl-cm5a-lr.1	Max of miroc5.1	Max of mri-cgcm3.1
	Ratios to modeled baseline													
2-yr, 24-hr	1.14	1.47	1.15	1.10	1.16	1.10	1.13	1.09	1.31	1.30	1.12	1.18	1.19	1.24
5-yr, 24-hr	1.15	1.51	1.30	1.16	1.20	1.05	1.24	1.10	1.32	1.27	1.18	1.29	1.22	1.25
10-yr, 24-hr	1.16	1.50	1.41	1.21	1.29	1.02	1.31	1.11	1.32	1.28	1.19	1.40	1.25	1.21
25-yr, 24-hr	1.17	1.45	1.55	1.30	1.49	0.99	1.39	1.13	1.32	1.32	1.18	1.61	1.30	1.15
50-yr, 24-hr	1.19	1.40	1.66	1.39	1.71	0.96	1.45	1.15	1.31	1.37	1.16	1.80	1.33	1.09
100-yr, 24-hr	1.20	1.34	1.78	1.48	1.99	0.94	1.51	1.17	1.30	1.43	1.13	2.03	1.36	1.03
200-yr, 24-hr	1.22	1.28	1.90	1.58	2.36	0.92	1.56	1.19	1.29	1.50	1.09	2.31	1.40	0.97
500-yr, 24-hr	1.25	1.19	2.08	1.74	3.01	0.89	1.63	1.22	1.27	1.61	1.04	2.75	1.45	0.89

Future design depth / baseline design depth = ratio
2070s example for 10-yr, 24-hr:
5.267 in. / 4.557 in. = 1.16

*This chart shows ratios for the 2070 planning horizon only.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 7 Example: Calculating mean of the ratios for all GCMs and adding ratios to NOAA Atlas 14 Values*)

Moakley Park, South Boston, MA

2070s (2060-2089) RCP8.5 Grid1											
Return Period	NOAA 14 Precip. (in.)	NOAA 14 Precip. 5% CI (in.)	NOAA 14 Precip. 95% CI (in.)	No. of Models	Mean of ratios	Std Dev. of ratios	5% CL of ratios	95% CL of ratios	Projected Precip. (in.)	Projected Precip. 5% CI (in.)	Projected Precip. 95% CI (in.)
2-yr	3.3	2.8	3.8	14	1.19	0.11	1.15	1.24	3.9	3.7	4.0
5-yr	4.3	3.6	5.1	14	1.23	0.11	1.18	1.28	5.3	5.1	5.5
10-yr	5.1	4.3	6.1	14	1.26	0.13	1.21	1.32	6.5	6.2	6.7
25-yr	6.3	5.1	8.0	14	1.31	0.18	1.23	1.39	8.2	7.8	8.7
50-yr	7.2	5.6	9.3	14	1.35	0.24	1.25	1.46	9.7	8.9	10.4
100-yr	8.1	6.1	11.0	14	1.41	0.33	1.26	1.55	11.4	10.2	12.6
200-yr	9.3	6.4	12.8	14	1.47	0.45	1.27	1.67	13.6	11.8	15.4
500-yr	11.1	7.3	15.9	14	1.57	0.65	1.29	1.86	17.5	14.3	20.6

*This chart shows NOAA Atlas 14 values and projected total precipitation depths for 24-hr design storms for the 2070 planning horizon using an ensemble of 14 GCMs from LOCA dataset following NCHRP 15-61 methodology.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 8 Example: Calculating mean of the projected 24-hour precipitation depths for all grids*)

Moakley Park, South Boston, MA

2070s (2060-2089) RCP8.5 Average of the Grids			
Return Period	**Projected Precip. (in.)**	**Projected Precip. 5% CI (in.)**	**Projected Precip. 95% CI (in.)**
2-yr	3.8	3.6	4.0
5-yr	5.2	4.9	5.4
10-yr	6.4	6.1	6.7
25-yr	8.1	7.6	8.6
50-yr	9.5	8.8	10.3
100-yr	11.2	10.1	12.4
200-yr	13.5	11.6	15.3
500-yr	17.4	14.1	20.6

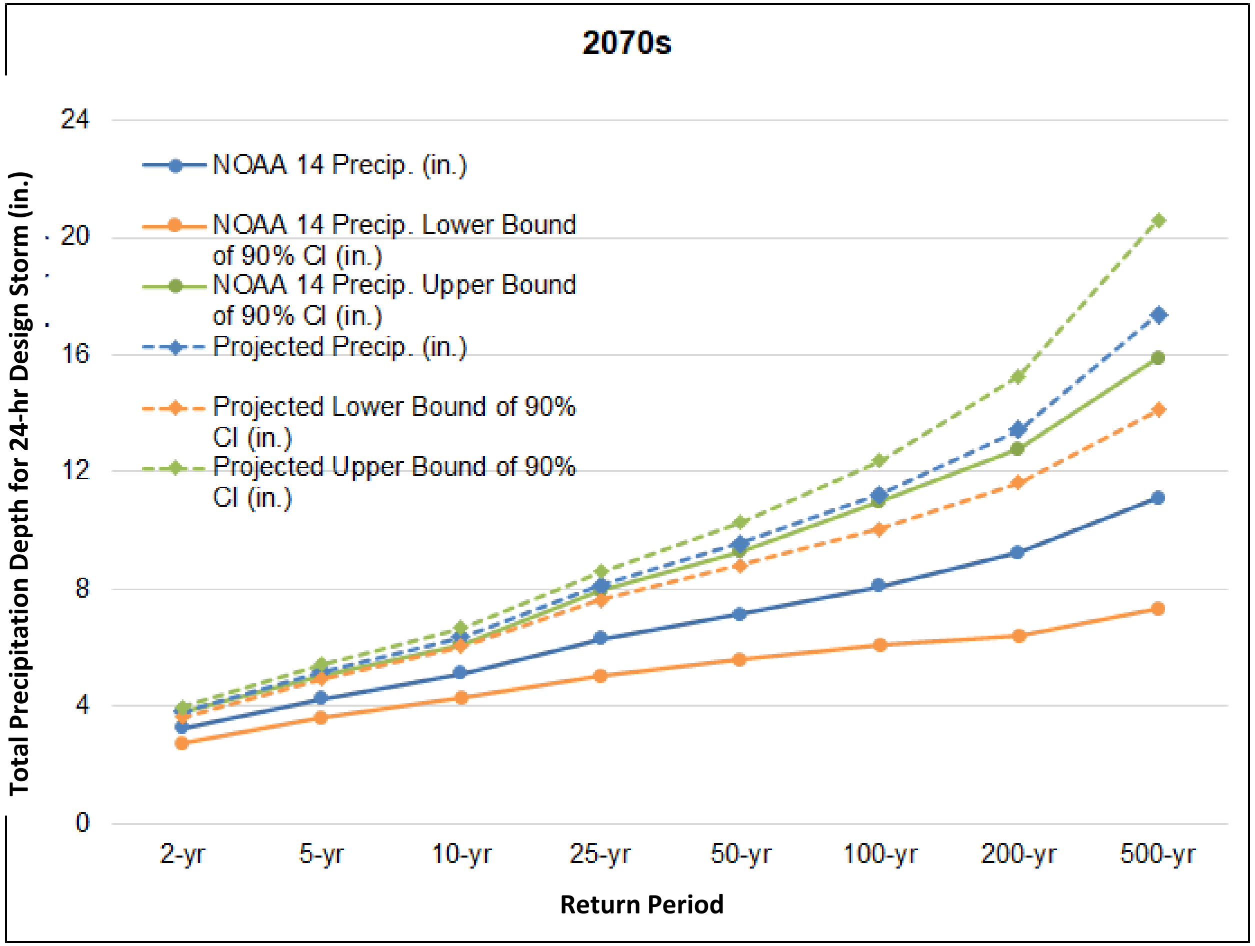
*This chart shows mean of the projected total precipitation depth for 24-hr design storms for the 2070 planning horizon using an ensemble of 14 GCMs from LOCA dataset following NCHRP 15-61 methodology.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 9 Example: Comparing the projected precipitation quantiles with NOAA Atlas 14 historical estimates*)

Moakley Park, South Boston, MA



*This figure shows comparison between projected precipitation quantiles with NOAA Atlas 14 historical estimates for the 2070s planning horizon only.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 3 - Dams and Flood Control Structures

(Step 11 Example: 24-hr design storm hyetographs for peak intensity for given planning horizon and design storm*)

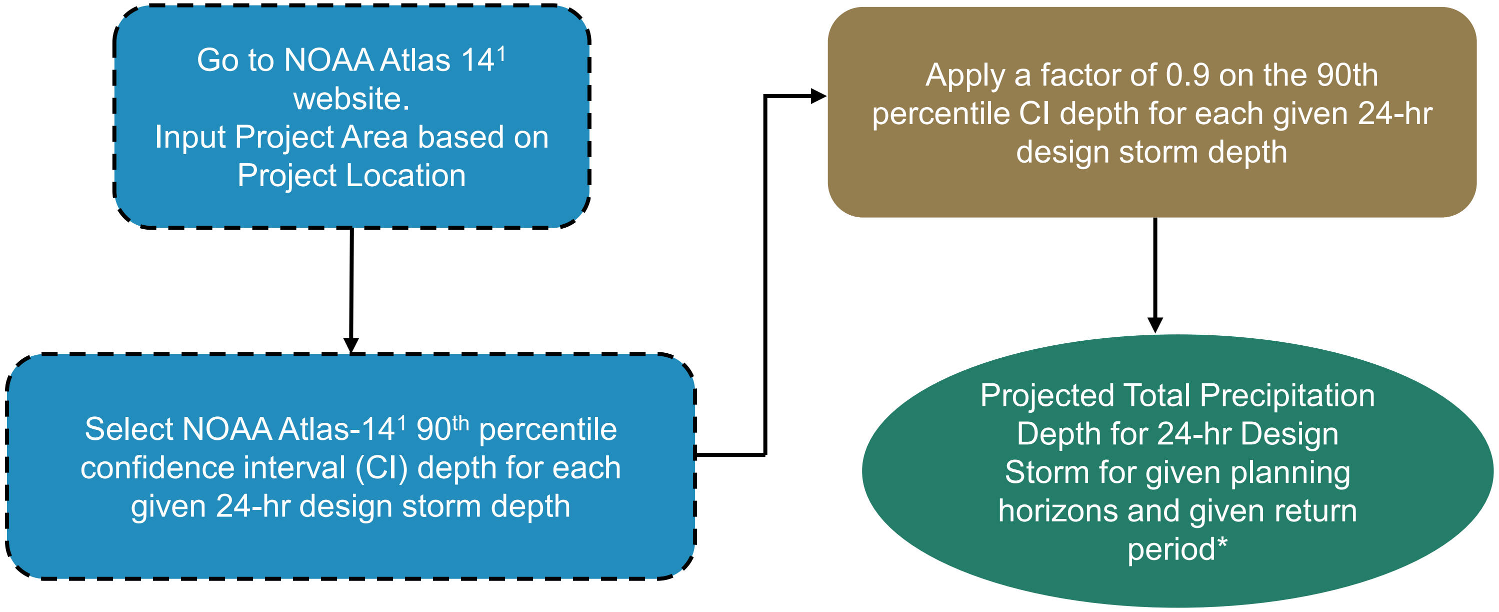
Moakley Park, South Boston, MA

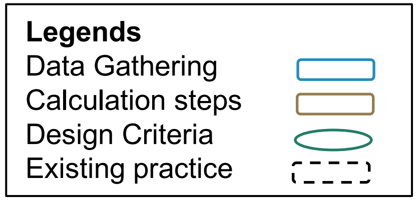
Return Period	NOAA Atlas 14 Present Baseline - 24hr (in)	Tier 3 Projected Total Precip Depth 2070 Values - 24hr (in)
2-yr	3.3	3.8
5-yr	4.3	5.2
10-yr	5.1	6.4
25-yr	6.3	8.1
50-yr	7.2	9.5
100-yr	8.1	11.2
200-yr	9.3	13.5
500-yr	11.1	17.4

*This chart shows mean of the projected total precipitation depth for 24-hr design storms for the 2070 planning horizon using an ensemble of 14 GCMs from LOCA dataset following NCHRP 15-61 methodology.

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm Tier 1 Projects*

Given Standards Output from Tool: Planning Horizon (2030, 2050, 2070); Return Period (5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 200-yr, 500-yr)





* Tier 1 Projects will also receive output from the Tool and an Attention note to compare the calculated depth using the methodology shown in this figure with the Tool output.

1. NOAA Atlas 14 Precipitation Frequency Estimates: Northeastern States; NOAA Atlas 14, Volume 10, Version 3

VERSION 1.4 METHODS
December 2024

Tiered Methodology to Assess Projected Total Precipitation Depth for 24-hr Design Storm

Tier 1 Projects (24-hr design storm depths for recommended return periods)

Moakley Park, South Boston, MA

Return Period	NOAA Atlas 14 Present Baseline - 24hr (in)	NOAA Atlas 14 Present Baseline - 24hr (90th percentile) (in)	Tier 1 90% of 90th percentile of NOAA baseline (in)
2-yr	3.3	3.8	3.4
5-yr	4.3	5.1	4.6
10-yr	5.1	6.1	5.5
25-yr	6.3	8.0	7.2
50-yr	7.2	9.3	8.4
100-yr	8.1	11.0	9.9
200-yr	9.3	12.8	11.5
500-yr	11.1	15.9	14.3

CLIMATE RESILIENCE DESIGN STANDARDS

PROJECTED PEAK INTENSITY DESIGN CRITERIA METHODS

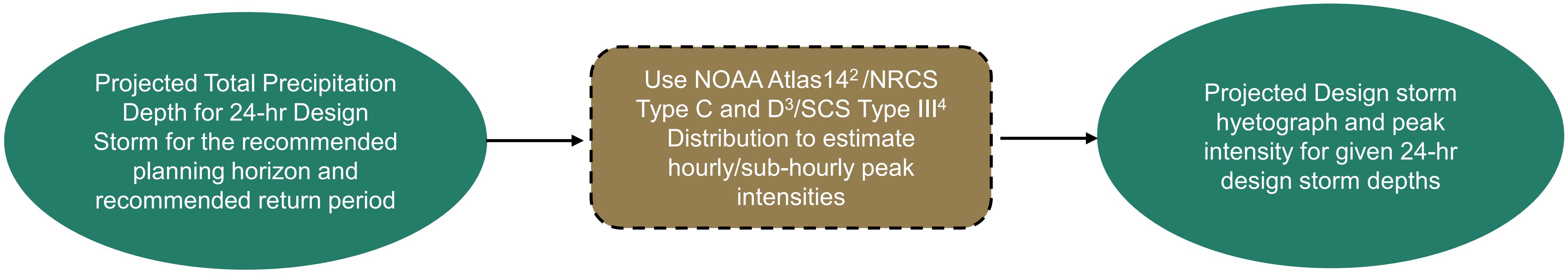
All Tiers

Version 1.4

DECEMBER 2024

Tiered Method to Assess Projected Peak Intensity for All Tiers

Given Standards Output from Tool: Projected Total Precipitation Depth for 24-Hr Design Storm for recommended Planning Horizon (2030, 2050, 2070); Return Period (5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 200-yr, 500-yr)



Legends

Calculation steps
Design Criteria
Existing practice

VERSION 1.4 METHODS
December 2024

1. NOAA Atlas 14 Precipitation Frequency Estimates: Northeastern States; NOAA Atlas 14, Volume 10, Version 3
2. Engineering Field Handbook Chapter 2: Estimating Runoff and Peak Discharges: Massachusetts EFH-2 Supplement Number: MA-EFH2. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1097125.pdf
3. HEC-HMS Technical Reference Manual – SCS Storm; https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/precipitation/scs-storm

Tiered Methodology to Assess Projected Peak Intensity

Example: 24-hr design storm hyetographs for projected peak intensity for given planning horizon and design storm*, Moakley Park, South Boston, MA using SCS Type III Distribution

Return Period	NOAA Atlas 14 Present Baseline - 24hr (in)	Projected Total Precip Depth 2070 Values - 24hr (in)
2-yr	3.3	3.8
5-yr	4.3	5.2
10-yr	5.1	6.4
25-yr	6.3	8.1
50-yr	7.2	9.5
100-yr	8.1	11.2
200-yr	9.3	13.5
500-yr	11.1	17.4

*These charts show 24-hr design storm hyetographs for peak intensity for the 2070s planning horizon only

10yr - 24 hr 2070s		6.4 in	
Duration (hr)	Ratio	Cumulative depth (in.)	Hourly peak intensity (in./hr)
0	0	0	0
1	0.01	0.06	0.06
2	0.02	0.13	0.06
3	0.03	0.19	0.07
4	0.04	0.27	0.08
5	0.06	0.36	0.09
6	0.07	0.45	0.10
7	0.09	0.57	0.12
8	0.11	0.72	0.15
9	0.15	0.92	0.20
10	0.19	1.19	0.27
11	0.25	1.58	0.38
12	0.50	3.15	1.58
13	0.75	4.73	1.58
14	0.81	5.11	0.38
15	0.85	5.38	0.27
16	0.89	5.58	0.20
17	0.91	5.73	0.15
18	0.93	5.85	0.12
19	0.94	5.94	0.10
20	0.96	6.03	0.09
21	0.97	6.11	0.08
22	0.98	6.18	0.07
23	0.99	6.24	0.06
24	1	6.30	0.06

CLIMATE RESILIENCE DESIGN STANDARDS

PROJECTED RIVERINE DESIGN CRITERIA
TIERED METHODS

Tier 3 & 2 Projects – Page 2

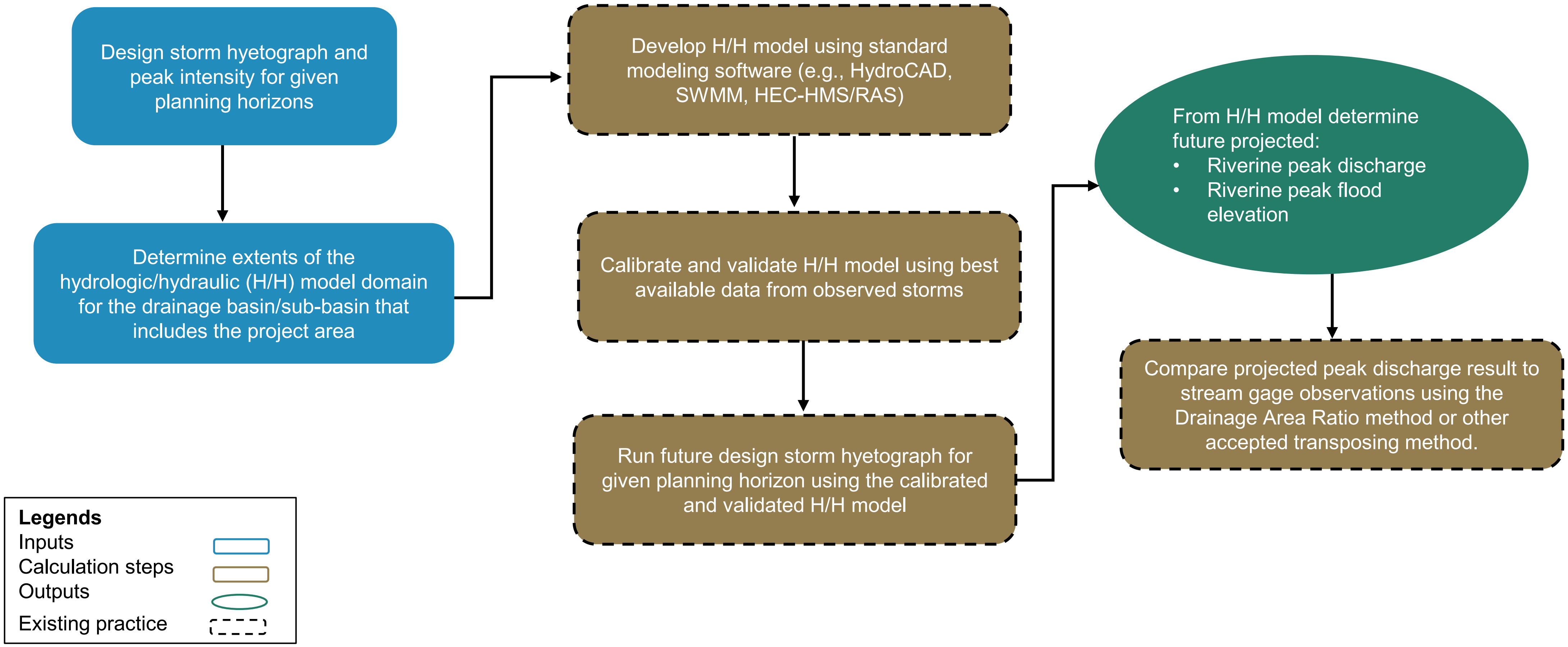
Tier 1 Projects – Page 3

Version 1.4

DECEMBER 2024

Tiered Method to Assess Projected Riverine Peak Discharge Criteria For Tier 3/Tier 2 Projects

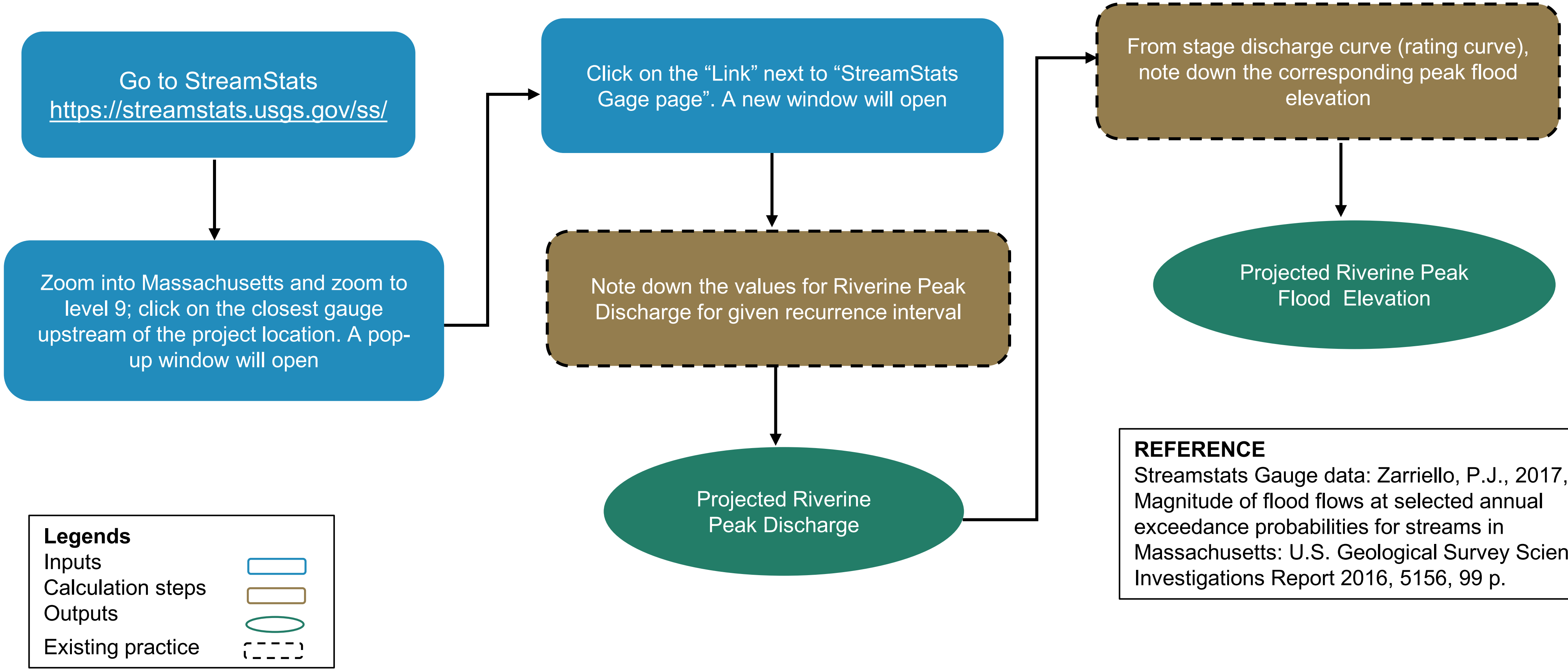
Given Standards Output from Tool: Projected 24-hour Design Storm for Recommended Planning Horizon (2030, 2050, 2070); Recurrence Interval (5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 200-yr, 500-yr)



VERSION 1.4 METHODS
December 2024

Tiered Method to Assess Projected Riverine Peak Discharge Criteria For Tier 1 Projects

Given Standards Output from Tool: Projected 24-hour Design Storm for Recommended Planning Horizon (2030, 2050, 2070); Recurrence Interval (5-yr, 10-yr, 25-yr, 50-yr, 100-yr, 200-yr, 500-yr)



REFERENCE
Streamstats Gauge data: Zarriello, P.J., 2017, Magnitude of flood flows at selected annual exceedance probabilities for streams in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2016, 5156, 99 p.

VERSION 1.4 METHODS
December 2024

CLIMATE RESILIENCE DESIGN STANDARDS

PROJECTED HEAT INDEX DESIGN CRITERIA TIERED METHODS

Tier 3 Projects – Pages 2-9

Tier 2 & 1 Projects – Page 10

Version 1.4

DECEMBER 2024

Tiered Method to Assess Projected Heat Index
Tier 3 Projects (Highest Level of Effort)

Given from Standards Output: Average Temperature for recommended Planning Horizon (2030, 2050, 2070); Percentile (50th, 90th)

Step 0: Download data from MACA[1] dataset for the following parameters for RCP8.5 using Group 1[2] GCMs
- rhsmax (Maximum Rel. Humidity)

Step 1: Choose 30-yr averaging period around the given planning horizon

Step 3a: Calculate average relative humidity of each year per GCM, for the given planning horizon

Step 3b: Projected 50^{th}, and 90^{th} average temperature for the recommended planning horizon and recommended return period

Step 4: Estimate heat index for given planning horizon using the equation from NOAA[3], also visualized in the following table from NOAA[4]

NWS Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Step 5: Calculate the 50^{th} and 90^{th} percentiles of heat index per GCM per year for the 30-yr averaging period around given planning horizon

Step 6: Calculate the average of all GCMs for each of the 50^{th} and 90^{th} percentiles for projected heat index for the 30-yr averaging period around the given planning horizon

Step 6: Projected heat index for given planning horizon

Legends
Data Gathering
Calculation steps
Design Criteria

REFERENCES

1. Abatzoglou J.T. and Brown T.J. A comparison of statistical downscaling methods suited for wildfire applications, International Journal of Climatology (2012), 32, 772-780
2. Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61-Final Report) by Kilgore et al., 2019
3. National Oceanic and Atmospheric Administration (NOAA). 2014. The Heat Index Equation. https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml
4. National Oceanic and Atmospheric Administration (NOAA).n.d. Heat Index. https://www.weather.gov/safety/heat-index

Tiered Method to Assess Projected Heat Index - Tier 3 Projects (Step 0: Complete MACA data download)

- **Go to https://climate.northwestknowledge.net/MACA/data_portal.php to download data from Multivariate Adaptive Constructed Analogs (MACA) data portal**

STEP 1
Domain selection

STEP 2
Products, Time frequency, Variables selection

STEP 2 (..cont.)
Model, Emission Scenarios, Time periods selection

STEP 3
Data download

Step 0.1.1: Select “Rectangular Subset” from “Domain” dropdown list

Step 0.1.2: A rectangle will appear on the interactive map. Move the rectangle and place it around the project area. Increase or decrease the size of the rectangle based on the area you want to cover around the location. Make sure that water body does not cover more than 1/3rd of your grid.

Step 0.1.3: Select “files of URLs for downloading data” from “Download Format” dropdown list

Step 0.2.1: “MACA Product” : “MACAv2-METDATA”

Step 0.2.2: “Time Frequency” : “daily”

Step 0.2.3: “Variables” : Check boxes for the climate parameters relevant to the project for examples,

- “rhsmax (Maximum Relative Humidity)”

Step 0.2.4: “CMIP5 Models” : Check boxes for all the Group 1 models from NCHRP report[1]

Step 0.2.5: “CMIP5 Scenarios/Time Periods” : Check boxes for the following parameters for

- “**RCP8.5**” : “future RCP8.5 (2006-2099)”

Step 0.3.1: Press button “Download file“ on top right

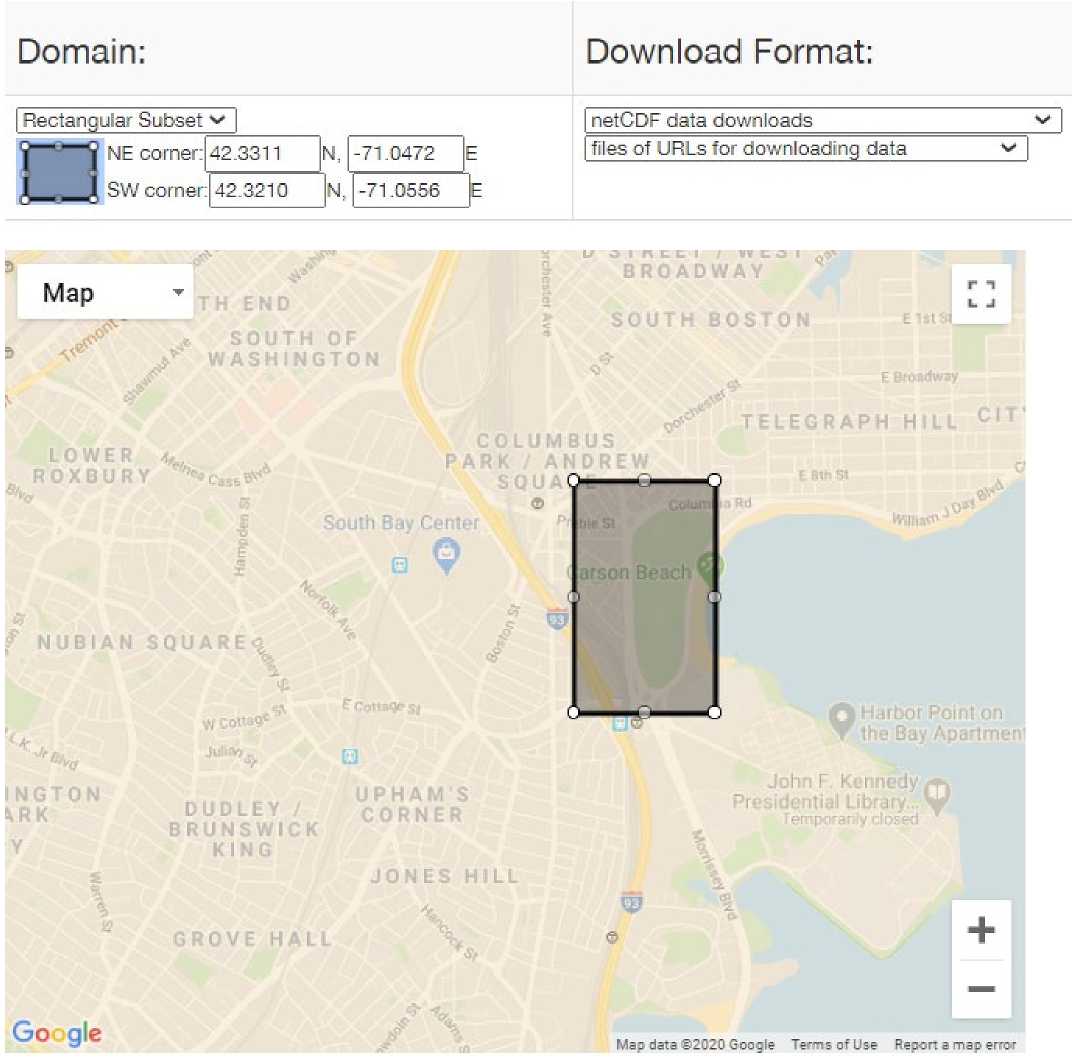
Step 0.3.2: Open the text file to extract the downloaded data

Step 0.3.3: Climate projection files are downloaded as Netcdf files. Convert the files in your preferred file format for climate projection analysis

REFERENCES

1. Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61- Final Report) by Kilgore et al., 2019

Download MACA Dataset
(Example: Project Area, and Download Format Selection)



Download MACA Dataset
(Example: Product, Time Frequency, and Variables Selection)

MACA PRODUCT

- ( ) MACAv2-LIVNEH
- ( ) MACAv1-METDATA
- (•) MACAv2-METDATA

TIME FREQUENCY

- (•) daily
- ( ) monthly
- ( ) Annual
- ( ) DJF(Dec-Feb)
- ( ) MAM (March-May)
- ( ) JJA (June-Aug)
- ( ) SON (Sept-Nov)

VARIABLES

Select All | DeSelect All

- [ ] huss (Specific Humidity)
- [ ] pr (Precipitation)
- [x] rhsmax (Maximum Relative Humidity)
- [ ] rhsmin (Minimum Relative Humidity)
- [ ] rsds (Downwelling Solar Radiation)
- [ ] tasmin(Minimum Air Temperature)
- [ ] tasmax(Maximum Air Temperature)
- [ ] vpd (Vapor Pressure Deficit)
- [ ] uas (Eastward Wind Component)
- [ ] vas (Northward Wind Component)

Download MACA Dataset
(Example: Group1[1] GCM Selections)

CMIP5 MODELS

Select All | DeSelect All

- [x] bcc-csm1-1 (China)
- [x] bcc-csm1-1-m (China)
- [ ] BNU-ESM (China)
- [ ] CanESM2 (Canada)
- [x] CCSM4 (USA)
- [x] CNRM-CM5 (France)
- [x] CSIRO-Mk3-6-0 (Australia)
- [x] GFDL-ESM2G (USA)
- [ ] GFDL-ESM2M (USA)
- [x] HadGEM2-CC365 (United Kingdom)
- [ ] HadGEM2-ES365 (United Kingdom)
- [x] inmcm4 (Russia)
- [x] IPSL-CM5A-LR (France)
- [ ] IPSL-CM5A-MR (France)
- [x] IPSL-CM5B-LR (France)
- [x] MIROC5 (Japan)
- [ ] MIROC-ESM (Japan)
- [ ] MIROC-ESM-CHEM (Japan)
- [x] MRI-CGCM3 (Japan)
- [ ] NorESM1-M (Norway)

REFERENCES
1. Applying Climate Change Information to Hydrologic and Coastal Design of Transportation Infrastructure (NCHRP Project 15-61- Final Report) by Kilgore et al., 2019

Download MACA Dataset
(Example: Emission Scenario (RCP8.5) and Time Selection)

RCP 8.5

- [ ] rcp85 (2006-2010)
- [ ] rcp85 (2011-2015)
- [ ] rcp85 (2016-2020)
- [ ] rcp85 (2021-2025)
- [ ] rcp85 (2026-2030)
- [ ] rcp85 (2031-2035)
- [ ] rcp85 (2036-2040)
- [ ] rcp85 (2041-2045)
- [ ] rcp85 (2046-2050)
- [ ] rcp85 (2051-2055)
- [ ] rcp85 (2056-2060)
- [ ] rcp85 (2061-2065)
- [ ] rcp85 (2066-2070)
- [ ] rcp85 (2071-2075)
- [ ] rcp85 (2076-2080)
- [ ] rcp85 (2081-2085)
- [ ] rcp85 (2086-2090)
- [ ] rcp85 (2091-2095)
- [ ] rcp85 (2096-2099)
- [x] future RCP8.5 (2006-2099)
- [ ] future RCP8.5 (2006 - 2099)

Tiered Method to Assess Projected Heat Index - Tier 3 Projects

(Step 3 Example: Calculate the median max. temp. and median avg. rel. Humidity*)

Moakley Park, South Boston, MA

2070s Tasmax

Row Labels	Max of bcc-csm1-1	Max of bcc-csm1-1-m	Max of CCSM4	Max of CNRM-CM5	Max of CSIRO-Mk3-6-0	Max of HadGEM2-CC365	Max of inmcm4	Max of IPSL-CM5A-LR	Max of IPSL-CM5B-LR	Max of MIROC5	Max of MRI-CGCM3	Median Max of Max-Temp
2060	104.5	99.3	99.9	97.1	102.1	105.7	97.7	98.2	100.4	101.0	97.6	99.87
2061	96.4	102.4	102.0	99.1	102.0	105.0	99.3	101.0	101.6	101.3	105.2	101.64
2062	92.2	101.5	103.0	104.8	101.0	109.2	96.7	99.3	100.4	97.0	97.0	100.43
2063	101.4	103.2	100.8	105.8	101.8	105.3	97.7	100.7	99.1	99.4	102.0	101.41
2064	101.2	102.5	101.1	102.9	104.0	106.5	97.9	102.3	96.7	102.7	96.7	
2065	98.0	102.3	101.2	96.8	107.9	107.7	92.6	102.0	98.8	101.1	96.9	
2066	100.6	101.4	98.7	94.5	104.9	103.5	99.7	102.6	103.3	99.6	97.6	
2067	99.4	101.6	101.9	96.9	107.8	102.9	96.7	97.6	101.8	100.0	98.2	
2068	100.0	101.8	99.2	101.7	105.1	109.6	97.2	105.0	99.1	100.7	98.3	
2069	103.3	102.0	100.0	104.7	102.1	101.2	102.0	101.9	100.0	101.4	96.7	
2070	101.9	101.8	104.2	103.6	101.1	107.7	94.8	104.2	100.5	98.5	105.2	
2071	102.8	103.3	100.5	105.3	98.7	108.1	95.2	99.2	100.6	104.1	100.9	
2072	94.1	108.0	103.1	97.2	103.7	104.7	93.8	100.6	103.2	103.4	98.1	
2073	105.8	100.8	104.5	103.4	103.1	111.8	92.5	102.6	101.0	102.6	98.1	
2074	102.3	98.9	104.4	99.5	107.7	107.6	99.6	100.1	104.0	100.0	104.6	
2075	102.5	101.0	104.7	102.4	106.1	109.6	93.3	102.9	97.7	101.5	98.2	
2076	102.0	101.2	102.7	103.2	101.9	106.4	93.1	99.1	102.6	100.8	98.5	
2077	102.4	95.1	98.7	97.1	103.0	113.4	103.4	105.9	100.2	102.1	98.1	
2078	105.3	99.8	102.1	107.8	104.6	108.3	95.4	105.8	100.1	101.9	98.7	
2079	101.2	102.5	102.2	98.9	98.3	105.7	98.6	103.2	102.3	105.2	97.7	
2080	104.1	100.9	103.6	102.3	104.8	109.1	97.4	104.5	102.6	103.0	98.6	
2081	104.3	104.5	104.9	103.2	104.8	113.7	98.6	104.2	100.1	98.7	96.3	
2082	103.8	102.9	102.1	103.4	104.4	112.8	95.9	103.1	102.0	101.5	100.9	
2083	100.3	97.9	102.9	98.8	101.2	112.0	95.5	102.6	102.5	100.0	100.0	
2084	101.5	103.4	103.2	97.3	102.1	104.6	99.9	106.0	102.5	98.2	97.8	
2085	102.6	101.6	104.9	98.5	100.9	112.9	93.9	109.2	101.3	102.4	96.9	
2086	105.1	104.8	107.2	97.1	104.8	112.5	98.7	105.8	102.3	99.7	102.2	
2087	96.9	103.9	100.2	96.8	103.3	109.7	102.6	107.3	101.3	105.1	97.4	
2088	102.4	102.8	105.3	101.3	103.6	111.6	99.4	106.4	102.0	100.7	100.6	
2089	108.0	105.0	107.5	101.8	110.3	105.1	91.9	105.6	107.5	105.5	101.7	

YEAR	Average of bcc-csm1-1	Average of bcc-csm1-1-m	Average of CNRM-CM5	Average of CSIRO-Mk3-6-0	Average of HadGEM2-CC365	Average of inmcm4	Average of IPSL-CM5A-LR	Average of IPSL-CM5B-LR	Average of MIROC5	Average of MRI-CGCM3	RHavg MEDIAN OF ALL GCMS
2060	78.5	79.2	79.4	78.7	76.7	78.9	79.4	74.6	79.1	79.2	79.0
2061	79.5	78.6	79.2	81.2	75.9	80.3	76.7	77.7	76.9	77.8	78.2
2062	79.5	79.4	79.2	80.1	76.5	80.6	76.6	77.2	78.9	79.4	79.3
2063	79.6	80.1	76.8	79.6	75.1	78.2	77.2	77.2	77.8	79.6	78.0
2064	76.8	77.7	78.6	79.1	76.0	79.5	76.0	77.8	77.6	79.2	77.7
2065	79.4	78.0	78.7	77.6	74.1	79.4	76.2	77.7	75.9	78.9	77.8
2066	79.6	79.6	80.3	79.9	74.6	79.9	76.6	77.3	78.9	78.5	79.3
2067	79.5	78.3	79.3	78.3	76.5	80.2	75.6	78.6	78.0	78.6	78.4
2068	79.1	80.4	78.3	76.7	75.8	80.9	76.9	75.6	79.3	79.2	78.7
2069	78.3	77.7	80.2	77.6	76.4	79.7	75.7	76.1	77.1	77.8	77.6
2070	79.0	78.4	77.9	78.0	76.5	79.1	74.6	77.6	78.3	80.2	78.1
2071	78.6	79.3	76.9	82.2	74.6	79.1	77.1	75.5	77.1	79.7	77.8
2072	79.1	77.8	78.0	78.2	78.1	79.7	75.0	76.5	77.1	80.0	78.0
2073	77.4	78.2	77.6	78.9	76.6	79.5	74.7	75.9	77.3	76.4	77.3
2074	80.0	80.9	80.3	76.9	74.4	80.1	76.7	76.5	76.9	79.5	78.2
2075	78.8	80.2	79.3	78.8	74.7	78.7	77.1	75.8	77.9	78.3	78.5
2076	79.5	79.4	77.2	79.7	75.0	79.5	76.3	77.1	77.2	78.7	78.0
2077	77.5	79.7	78.0	79.1	75.5	80.3	75.9	75.4	79.8	78.9	78.5
2078	79.2	81.1	77.3	79.1	75.7	80.2	75.5	76.0	77.8	80.0	78.5
2079	78.9	77.8	79.4	81.2	76.4	80.1	77.7	76.1	77.1	78.0	77.9
2080	77.4	80.8	77.6	81.7	73.5	77.6	75.9	77.1	76.5	78.1	77.5
2081	77.9	78.8	78.3	78.6	74.2	79.6	73.9	74.8	76.5	79.4	78.1
2082	79.3	78.6	76.9	80.3	75.5	80.0	78.6	75.3	76.7	80.7	78.6
2083	78.7	79.5	79.0	79.9	74.3	79.2	74.4	76.0	79.1	79.0	79.0
2084	77.4	80.5	78.3	79.6	76.3	79.9	76.3	74.8	79.2	79.1	78.7
2085	79.8	79.1	77.2	81.9	75.8	79.1	73.9	78.0	76.2	80.1	78.5
2086	78.9	77.8	80.2	79.3	74.0	78.6	73.9	78.7	76.5	79.1	78.7
2087	80.7	80.1	78.4	80.5	75.2	81.5	76.2	78.6	78.5	78.5	78.6
2088	80.3	80.3	77.9	78.4	75.8	79.4	74.9	76.0	78.7	78.4	78.4
2089	77.4	79.5	77.7	78.9	75.1	79.2	75.1	78.8	77.1	78.1	77.9

*These charts show calculations for the 2070 planning horizon only

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Tiered Method to Assess Projected Heat Index - Tier 3 Projects (Step 4: Calculate heat index per year based on the NOAA Heat Index Eqn.)* Example: Moakley Park, Boston

HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH

where,

HI = Heat Index

T = Temperature (tasmax)

RI = Relative Humidity (average rhsmax)

2070s Data			
Year	RHavg Median of All GCMs	Median Max of Max-Temp	Heat Index (As Per NOAA Eqn.)
2060	79	100	156
2061	78	102	164
2062	79	100	159
2063	78	101	162
2064	78	102	166
2065	78	101	160
2066	79	101	160
2067	78	100	156
2068	79	101	160
2069	78	102	164
2070	78	102	165
10th percentile	78	100	158
50th percentile	78	102	$\boxed{166}$
90th percentile	79	104	177

*This chart shows calculations for the 2070 planning horizon only

Tiered Method to Assess Projected Heat Index
Tier 2 and Tier 1 Projects

Given from Standards Output: Average Temperature for recommended Planning Horizon (2030, 2050, 2070); Percentile (50th, 90th)

Step 1: Use baseline value of the historical average heat index

↓

Step 2: Apply percent increase[5] to historical average values based on given planning horizon

Planning Horizons	Increase
Mid-Century (2030s, 2050s)	13%
Late-Century (2070s, 2090s)	36%

↓

Step 3: Projected heat index for given planning horizon

Legends
Data Gathering
Calculation steps
Design Criteria

REFERENCES
5. Percent Increase data based on Climate Change Vulnerability Assessment (November 2015) report for City of Cambridge, MA (Table 2, pp. 23)

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