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Typical Year Rainfall Analysis for Cambridge-Somerville-MWRA Combined Sewer Overflow (CSO) Control Plans

Technical Information in Support of the December 15th Public Meeting:

Development of Future Typical Year of Rainfall

12.2.2022

PURPOSE OF THIS PRESENTATION

This presentation provides an **overview of the technical methodology** used to estimate rainfall values for the updated "typical year" that drives the CSO Control Plan Updates being developed by Cambridge, Somerville, and MWRA. This also serves as a technical document to support information provided at the public meeting.

Who is this presentation for?

This presentation is intended for any resident, stakeholder, or practitioner who wants to dive deeper into how the "typical year" is being established. The typical year is used to assess how combined sewer system improvements would perform under a series of rainfall events.

Disclaimer

This presentation does not include a comprehensive review of the values and calculations included in the analysis. Further detailed information will be available in a technical report, available at a later date.

TECHNICAL EXPERTS

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Cornell University

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PRESENTATION OUTLINE

KEY DEFINITIONS & GOALS

OBSERVED RAINFALL ANALYSIS

FUTURE TYPICAL YEAR

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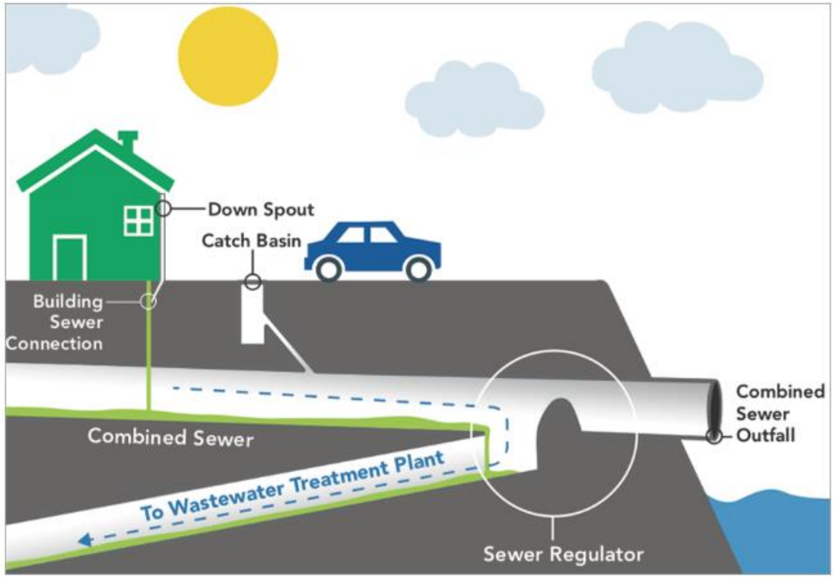
WHAT IS A CSO?

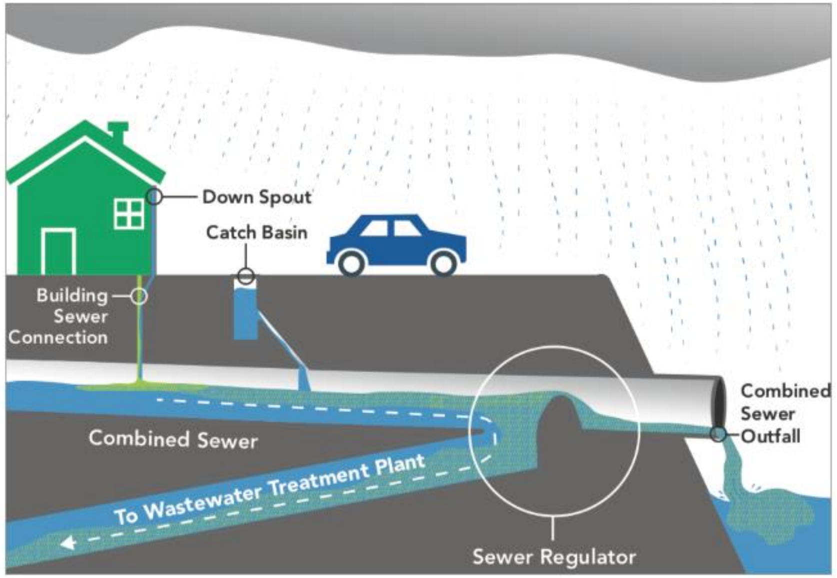
Combined sewer systems are systems that **carry both sanitary flows and stormwater runoff**. During large storm events, these systems sometimes cannot handle the additional volumes, resulting in **discharge into nearest water bodies** to avoid backup into streets, homes, and yards. This discharge or overflow is termed a combined sewer overflow (CSO).

Combined Sewer System:



Dry Weather Conditions in the Combined Sewer System*

Combined Sewer Overflow Event:



Wet Weather Conditions in the Combined Sewer System

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WHAT IS A CSO CONTROL PLAN?

1

MassDEP
Commonwealth of Massachusetts
Department of Environmental Protection

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

EPA & MassDEP Requirements

Establishes water quality and CSO discharge requirements.

2

CSO Control Plan Updates

- ☑ Meets compliance
- ☑ Data Driven
- ☑ Actions to achieve water quality goals

A plan to meet water quality and CSO discharge requirements.

Evaluates how well proposed improvements perform under an agreed upon year of storm events (typical year)

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WHAT IS A TYPICAL YEAR?

A Typical Year is a full year of rainfall data that best represents rainfall conditions over a period of time.

As part of the CSO Control Plan Update, a “typical year” needs to be established to assess how planned improvements would perform under a series of rainfall conditions **(the “typical year”)**

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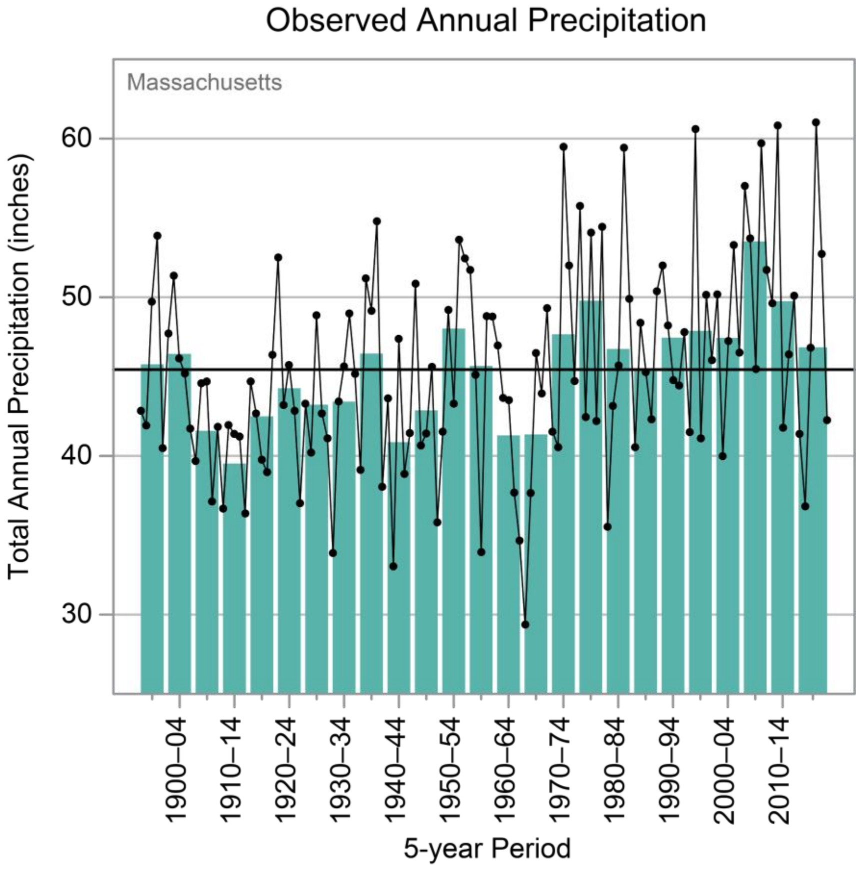
HISTORICAL RAINFALL PATTERNS

Looking at typical rainfall conditions is important because long-term rainfall variability shows substantial **seasonal/decadal fluctuations** with an overall increasing trend for annual total rainfall. If past is the key to the future, then in order to understand future rainfall patterns, it is important to study long term trend in future rainfall variability.



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Runkle, J., K.E. Kunkel, R. Frankson, D.R. Easterling, A.T. DeGaetano, B.C. Stewart, W. Sweet, and J. Spaccio, 2022: Massachusetts State Climate Summary 2022. NOAA Technical Report NESDIS 150-MA. NOAA/NESDIS, Silver Spring, MD, 5 pp.

WHY DEVELOP A TYPICAL YEAR?

A typical year is required by EPA's CSO Control Policy.

The requirements include:

- Analyze rainfall records using statistics and the **best available data**.
- Test the performance of CSO controls during rain events on an **annual average** basis.

HOW IS A TYPICAL YEAR USED IN THE UPDATED CSO CONTROL PLAN?

The typical year is used throughout the CSO control planning process.

- During Development: To **identify** and test alternatives.
- During Implementation: Sets a **benchmark** to measure and assess progress.

This is an example of measuring CSO reduction over time using the **typical year** as a benchmark.

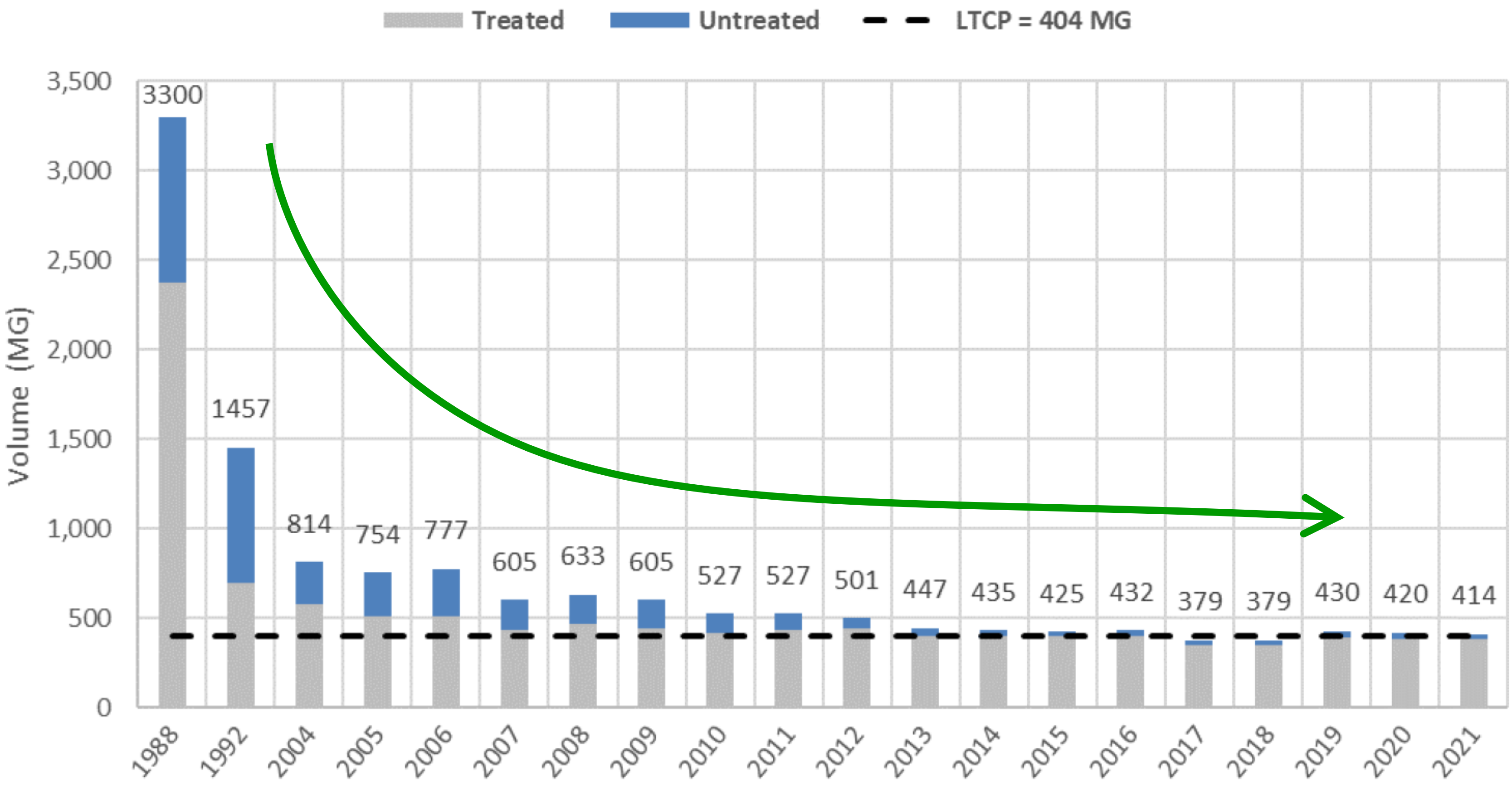

Figure 1-1. Estimated Treated, Untreated and Total CSO Volume in the Typical Year, 1988-2021.

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WHAT IS A TYPICAL YEAR UNDER CLIMATE CHANGE?

According to information available at this time, **there is no EPA/DEP guidance to incorporate future rainfall projections into developing a typical year** for CSO Control Plans.

This CSO Control Plan Update Process is unique because it establishes a **typical year considering future climate change projections, including higher intensity rainstorms**

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WHAT IS A TYPICAL YEAR UNDER CLIMATE CHANGE?

The Future Typical Year is determined by considering **both historic observed and modeled future** rainfall parameters to understand how the **system improvements will perform under the impacts of climate change.** This methodology has been **peer reviewed and vetted by climate science experts**.

This presentation shows the methodology for evaluating the typical year considering both recent observed data **and** future climate change projections.

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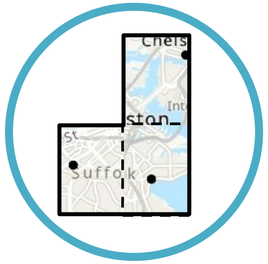
WHAT IS THE GOAL OF THIS TYPICAL YEAR ANALYSIS?

DATA DRIVEN ANALYSIS



Goal

Determine the "typical" or most average year of rainfall patterns over the past 26 years + under future conditions*

Purpose

The "typical" or most average year of rainfall patterns based on modeled future data will be used to evaluate alternatives for the CSO Control Plan Updates considering future climate change

* Identify representative future typical year considering climate change and use observed rainfall pattern from the representative year to assess future CSO control plans.

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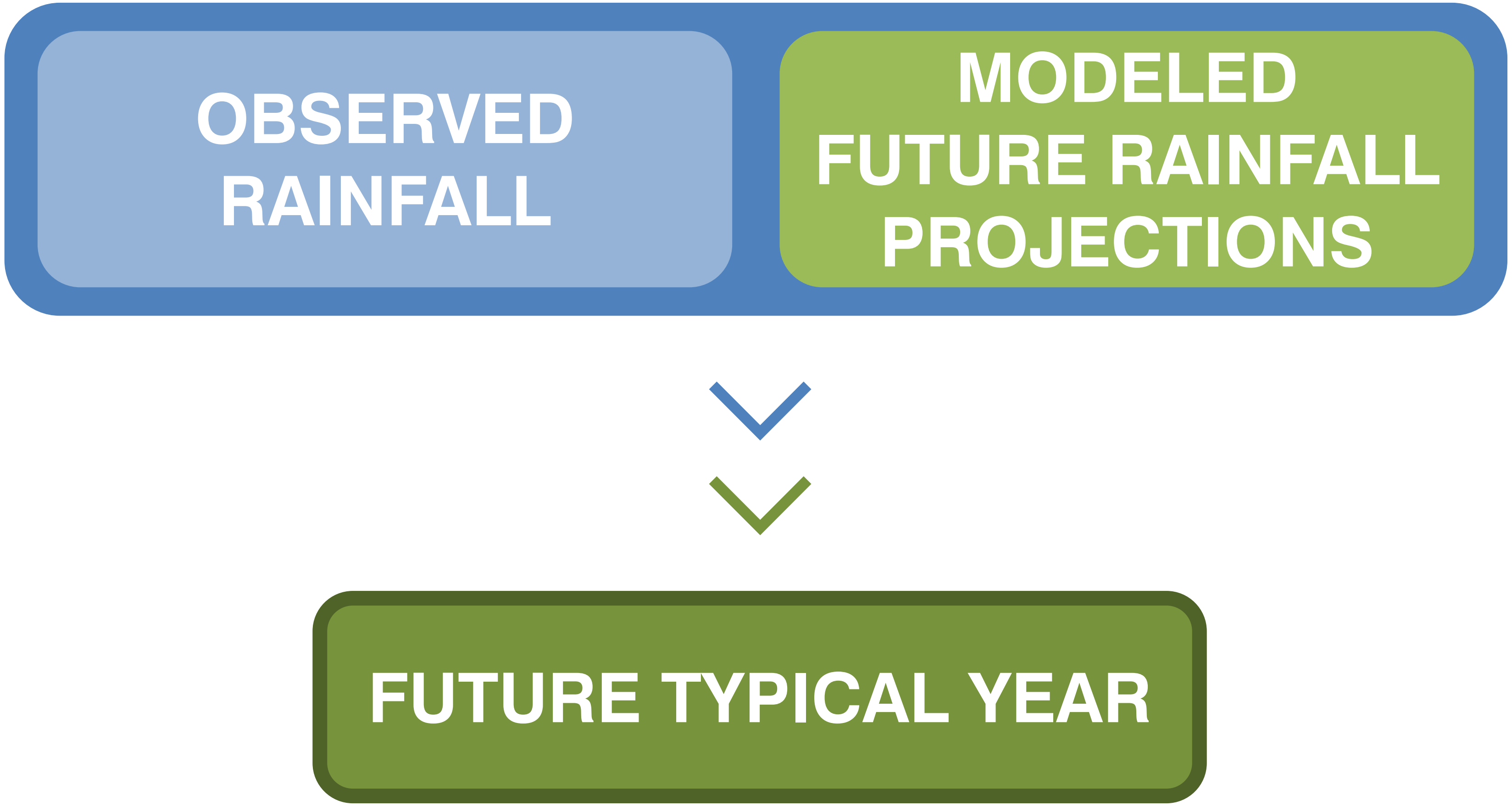
HOW IS THE TYPICAL YEAR ANALYZED?



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WHY DO WE NEED TO CONSIDER BOTH OBSERVED DATA AND FUTURE PROJECTIONS TO EVALUATE A FUTURE TYPICAL YEAR?

Observed data from rainfall gauges is **detailed** at 15-min intervals, which is necessary to run Combined Sewer models for assessing system improvements.

Future rainfall projections from climate change models are needed to evaluate a typical year of rainfall in the future. However, **future rainfall projections are only available at daily rainfall intervals** and not at the 15-min intervals necessary to run Combined Sewer models.

Therefore, the **historical rainfall dataset is used** to identify a year **most representative of future rainfall projections** to run Combined Sewer models for assessing system improvements.

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HOW DO WE CONSIDER BOTH OBSERVED DATA AND FUTURE PROJECTIONS TO EVALUATE A FUTURE TYPICAL YEAR?

- This is a **first of its kind** approach,
- Involves **collaboration with leading climate scientists,** and
- Is **consistent with the Massachusetts Climate Resilience Design Standards and Guidance**.

Identified the Future Period (2040-2069)

↓

Assessed two Greenhouse Gas (GHG) Emissions Scenarios

↓

Analyzed multiple Global Climate Models (GCMs)

↓

Compared Results to Observed Rainfall Data

↓

Identified 2050 Future Typical Year for use in Updated CSO Control Plans (in-progress)

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OBSERVED RAINFALL ANALYSIS

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OBSERVED RAINFALL ANALYSIS: Overall Steps

The process for assessing observed data is as follows:

1. **Rainfall Gauge Data is Processed in 15 Minute Intervals**
2. **Various Rainfall Parameters are Assessed**
3. **Deviation Analysis is Conducted for Two Scenarios**

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OBSERVED RAINFALL ANALYSIS: Rainfall Data

Step 1: The best available rainfall data from the past 26 years was collected and processed from physical rainfall gauges.

Rainfall Gauges

A rain gauge is a meteorological instrument to measure the precipitating rain in a given amount of time over a given area.

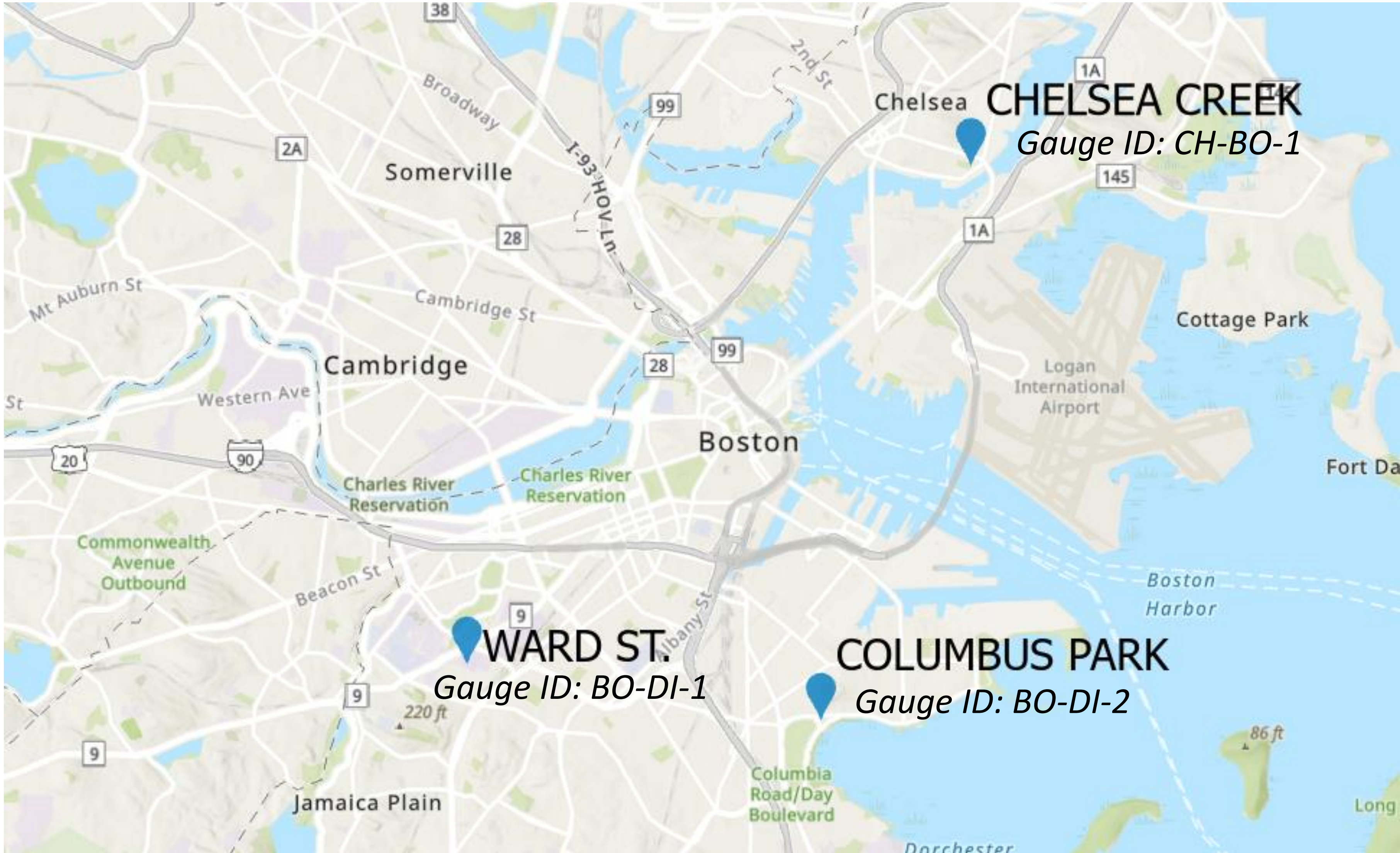
1 OBSERVED RAINFALL ANALYSIS: Rainfall Data

Rainfall data was processed from rain gauges maintained by MWRA at the following locations:

WARD ST
23 years
(1999-2021)

COLUMBUS PARK
26 years
(1996-2021)

CHELSEA CREEK
26 years
(1996-2021)



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2 OBSERVED RAINFALL ANALYSIS: Definitions of Parameters

Step 2: Rainfall parameters assessed from each gauge include:
(see next slides for definitions)

26 YEARS ANALYZED

Consecutive Dry Days	Number of Back-to-Back Events	Number of Storms	Total Annual Rainfall Depth	# X5 Count of Storms Binned by Duration & Depths
Data for each year	Data for each year	Data for each year	Data for each year	Data for each year
Data for each year	Data for each year	Data for each year	Data for each year	Data for each year
Data for each year	Data for each year	Data for each year	Data for each year	Data for each year

These parameters help us understand typical rainfall patterns over the last 26 years.

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2 OBSERVED RAINFALL ANALYSIS: Definition of Parameters

Step 2: Rainfall parameters assessed from each gauge include:

Consecutive Dry Days

The annual average number of two or more consecutive days with less than 0.1 inches of rainfall.

Number of Storms

The total number of independent storm events that occurred in a year, where independent storms are defined by a 12-hour interevent time.

Number of Back-to-Back Events

The total number of independent storm events that occurred back-to-back (where 2 consecutive storm events are separated by more than 12 hours but less than 24 hours).

Total Annual Rainfall Depth

The total amount of rainfall depth (in inches) that fell each year.

These parameters help us understand typical rainfall patterns over the last 26 years.

Rainfall parameters deeper dive:

What does "Count of Storms Binned by Duration & Depths" mean?

#

Count of Storms Binned by Duration & Depths

Data on **storm depth** is "**binned**", meaning organized, by ***storm duration*** and ***frequency of occurrence*** for that duration.

Count of Storms (for different durations of 15-min, 1-hr, 6-hr, 24-hr, or 1-day) are binned by design storm* depths for respective durations for the following return periods, based on Atlas -14**				
Less than 3 months **(<3M)**	3 to 6 months **(3M to 6m)**	6 months to 1 year **(6M to 1Y)**	1 year to 2 years **(1Y to 2Y)**	Greater than 2 years **(>2Y)**

Example

Count of Storms (e.g., for 6-hr duration) are binned using the following 6-hr design storm* depths for the following return periods, based on Atlas -14**				
Less than 3 months **(<3M)**	3 to 6 months **(3M to 6m)**	6 months to 1 year **(6M to 1Y)**	1 year to 2 years **(1Y to 2Y)**	Greater than 2 years **(>2Y)**
<0.72 in.	***0.72-1.19 in.***	***1.19-1.67 in.***	***1.67-2.08 in.***	***>2.08 in.***

See following page for full data table of one of the rainfall gauges.

*A design storm refers to a hypothetical storm event of a given depth of rainfall over a given duration and distribution that has an annual frequency of occurring

**Atlas 14: NOAA Atlas 14 Point Precipitation Frequency Estimates, https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

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2 OBSERVED RAINFALL ANALYSIS: Analysis Results Example, Columbus Park

YEAR	CONS DRY DAYS	# STORMS	TOTAL DEPTH (IN)	# BACK-BACK	Count of storms - 15-minute depths, Atlas-14					Count of storms – 1-hour depths, Atlas-14					Count of storms – 6-hour depths, Atlas-14					Count of storms – 24-hour depths, Atlas-14					Count of wet days – 1-day depths, Atlas 14				
					<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y
					< 0.23	*0.23 - 0.36*	*0.36 - 0.5*	*0.5 - 0.62*	*> 0.62*	*< 0.38*	*0.38 - 0.61*	*0.61 - 0.85*	*0.85 - 1.06*	*> 1.06*	*<0.72*	*0.72- 1.19*	*1.19- 1.67*	*1.67- 2.08*	*>2.08*	*< 1.14*	*1.14 - 1.85*	*1.85 - 2.60*	*2.60 - 3.23*	*> 3.23*	*<1.01*	*1.01- 1.64*	*1.64- 2.30*	*2.30- 2.86*	*>2.86*
1996	6	104	51.2	20	99	5	0	0	0	94	9	0	0	1	91	5	5	1	2	94	5	2	1	2	116	9	2	0	3
1997	7	95	33.3	16	91	3	1	0	0	92	3	0	0	0	89	5	1	0	0	88	7	0	0	0	123	2	1	0	0
1998	7	90	58.2	17	85	3	1	1	0	79	6	3	0	2	73	10	2	3	2	76	6	5	2	1	115	8	6	2	1
1999	7	87	41.6	15	79	7	1	0	0	78	5	2	1	1	77	6	2	1	1	79	5	1	0	2	109	2	2	0	2
2000	6	98	50.1	18	90	6	2	0	0	84	9	5	0	0	79	*15*	1	1	2	90	5	0	2	1	118	8	1	1	1
2001	6	95	38.1	25	85	5	4	0	1	82	7	3	1	2	85	6	1	2	1	89	1	3	1	1	108	0	1	1	2
2002	5	104	47.7	18	100	4	0	0	0	97	6	1	0	0	93	10	1	0	0	93	8	3	0	0	129	8	2	1	0
2003	6	113	44.6	29	105	5	1	1	1	105	4	2	2	0	95	13	4	1	0	100	10	3	0	0	132	7	3	0	0
2004	7	97	45.4	26	86	9	2	0	0	83	9	5	0	0	81	10	4	2	0	81	12	1	2	1	113	9	2	0	2
2005	6	104	49.4	27	100	2	0	2	0	96	6	1	0	1	91	10	1	1	1	94	4	4	1	1	138	7	2	0	2
2006	6	90	54.1	11	86	1	1	0	2	81	4	4	0	1	80	5	3	1	1	80	4	3	0	3	123	3	3	0	4
2007	7	99	39.8	20	95	1	1	2	0	91	5	1	1	1	86	7	4	2	0	88	7	4	0	0	119	8	4	0	0
2008	5	107	54.3	27	96	8	1	0	2	92	8	5	1	1	91	11	3	1	1	93	7	4	2	1	124	6	4	3	0
2009	5	96	51.5	15	90	5	1	0	0	87	7	1	1	0	81	9	4	0	2	82	10	2	1	1	127	8	2	1	1
2010	6	92	58.3	21	84	5	2	1	0	80	7	4	0	1	76	8	6	0	2	77	11	1	0	3	106	11	1	3	3
2011	5	98	51.7	25	92	3	0	2	1	85	10	1	1	1	81	13	3	1	0	84	11	2	1	0	124	14	4	0	0
2012	7	95	39.2	14	87	6	2	0	0	84	7	3	1	0	83	9	2	0	1	85	8	1	0	1	122	6	3	0	0
2013	7	97	43.4	24	91	4	1	0	1	83	11	2	1	0	86	7	2	0	2	84	9	3	0	1	108	10	1	1	1
2014	6	85	49.1	13	77	7	0	0	1	74	6	3	2	0	73	8	1	1	2	76	5	0	2	2	113	4	2	3	1
2015	6	88	34.8	15	84	3	1	0	0	81	7	0	0	0	79	6	2	1	0	82	4	2	0	0	119	3	1	1	0
2016	6	102	35.7	21	95	6	1	0	0	95	5	1	0	1	91	8	3	0	0	91	10	1	0	0	115	7	1	0	0
2017	6	94	45.3	12	88	4	1	1	0	83	8	2	0	1	79	10	4	0	1	80	12	1	1	0	122	8	3	1	0
2018	5	102	57.0	20	91	7	4	0	0	87	7	7	1	0	83	12	6	0	1	84	14	3	1	0	126	12	2	2	0
2019	4	112	52.2	19	102	5	3	1	1	98	9	2	1	2	96	9	4	3	0	95	13	4	0	0	141	11	2	1	0
2020	6	86	38.5	13	78	4	2	1	1	77	5	4	0	0	74	9	2	1	0	78	5	3	0	0	103	4	3	0	0
2021	5	96	61.3	15	87	6	2	1	0	82	7	4	2	1	78	11	3	1	3	82	6	6	1	1	121	9	6	2	1
AVG*	**6**	**97**	**47.1**	**19**	**90.1**	**4.8**	**1.3**	**0.5**	**0.4**	**86.5**	**6.8**	**2.5**	**0.6**	**0.7**	**83.5**	**8.9**	**2.8**	**0.9**	**1.0**	**85.6**	**7.7**	**2.4**	**0.7**	**0.8**	**119.8**	**7.1**	**2.5**	**0.9**	**0.9**

*Average values for each rainfall parameter, at each gauge, are used in Step 3: Deviation Analysis

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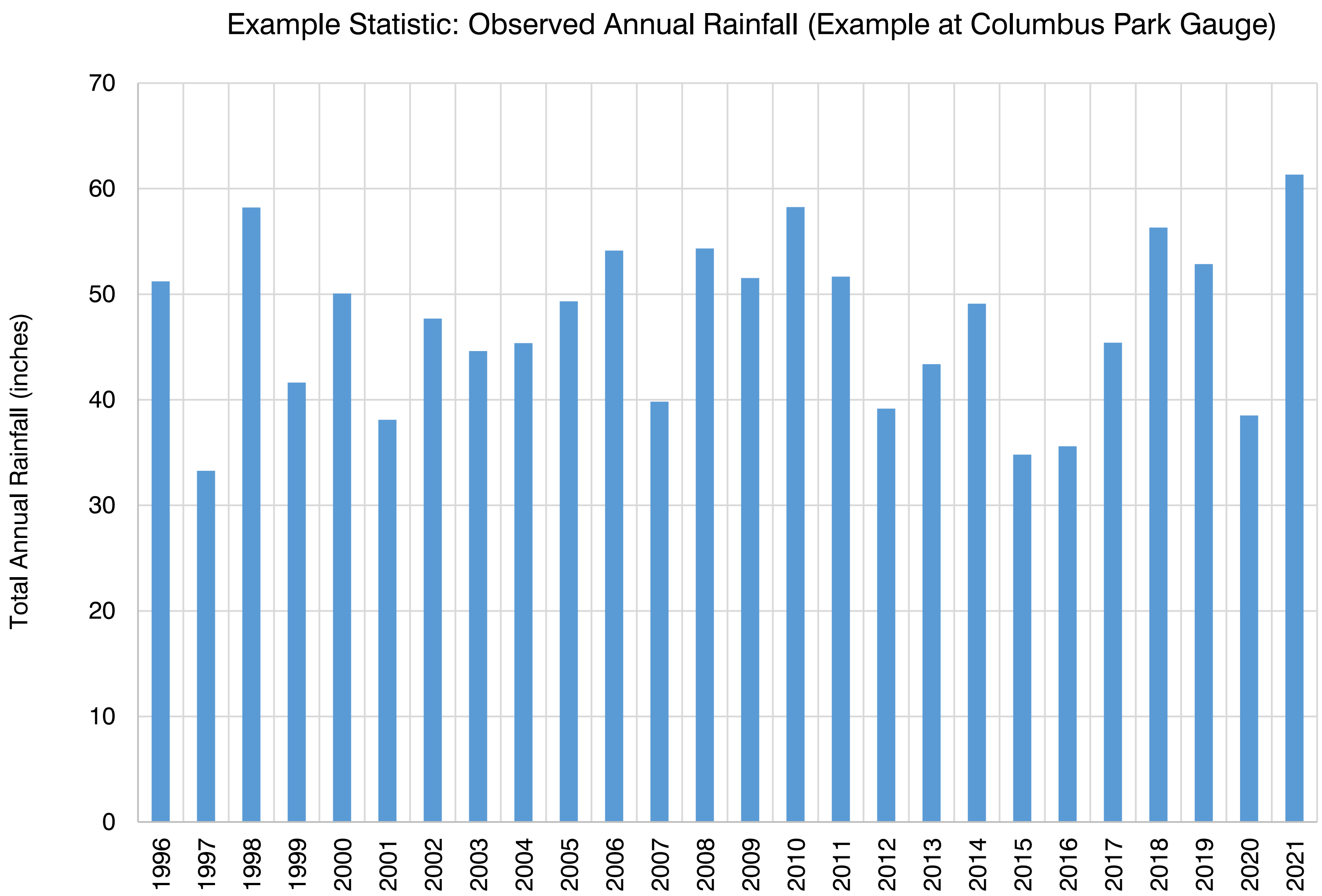
2 OBSERVED RAINFALL ANALYSIS: Annual Rainfall Depth

The figure below shows how Annual Rainfall Depth varies by year.



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OBSERVED RAINFALL ANALYSIS: Results for All Gauges

As shown by the table below, rainfall analysis results vary not only by year but also **spatially by rainfall gauge location**.

GAUGE	YEAR	CONS DRY DAYS	# STORMS	TOTAL DEPTH (IN)	# BACK-BACK	Count of storms – 15-minute depths, Atlas-14					Count of storms - 1 hour depths, Atlas-14					Count of storms – 6-hour depths, Atlas-14					Count of storms – 24-hour depths, Atlas-14					Count of wet days – 1-day depths, Atlas 14+				
						<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6Mto 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y
						< 0.23	0.23 - 0.36	0.36 - 0.5	0.5 - 0.62	> 0.62	< 0.38	0.38 - 0.61	0.61 - 0.85	0.85 - 1.06	> 1.06	<0.72	0.72- 1.19	1.19- 1.67	1.67- 2.08	>2.08	< 1.14	1.14 - 1.85	1.85 - 2.60	2.60 - 3.23	> 3.23	<1.01	1.01- 1.64	1.64- 2.30	2.30- 2.86	>2.86
Ward St	**AVG**	6	95	**46.3**	17	87.7	4.4	1.1	0.6	0.9	84.2	7.1	1.9	0.6	0.9	81.1	9.0	2.8	0.9	0.8	82.6	8.3	2.3	0.7	0.8	115.9	7.4	2.4	0.7	0.8
Columbus Park	**AVG**	6	97	**47.1**	19	90.1	4.8	1.3	0.5	0.4	86.5	6.8	2.5	0.6	0.7	83.5	8.9	2.8	0.9	1.0	85.6	7.7	2.4	0.7	0.8	119.8	7.1	2.5	0.9	0.9
Chelsea Creek	**AVG**	6	100	**44.4**	20	92.6	4.4	1.2	0.4	0.9	89.5	6.6	2.1	0.7	0.7	86.8	8.2	3.0	1.0	0.6	88.0	7.8	2.5	0.5	0.7	121.0	7.3	2.4	0.7	0.7

+ 24-hour depth from NOAA Atlas 14 is divided by a derived factor of 1.13 to convert 24-hour amounts to 1-day depth accumulations

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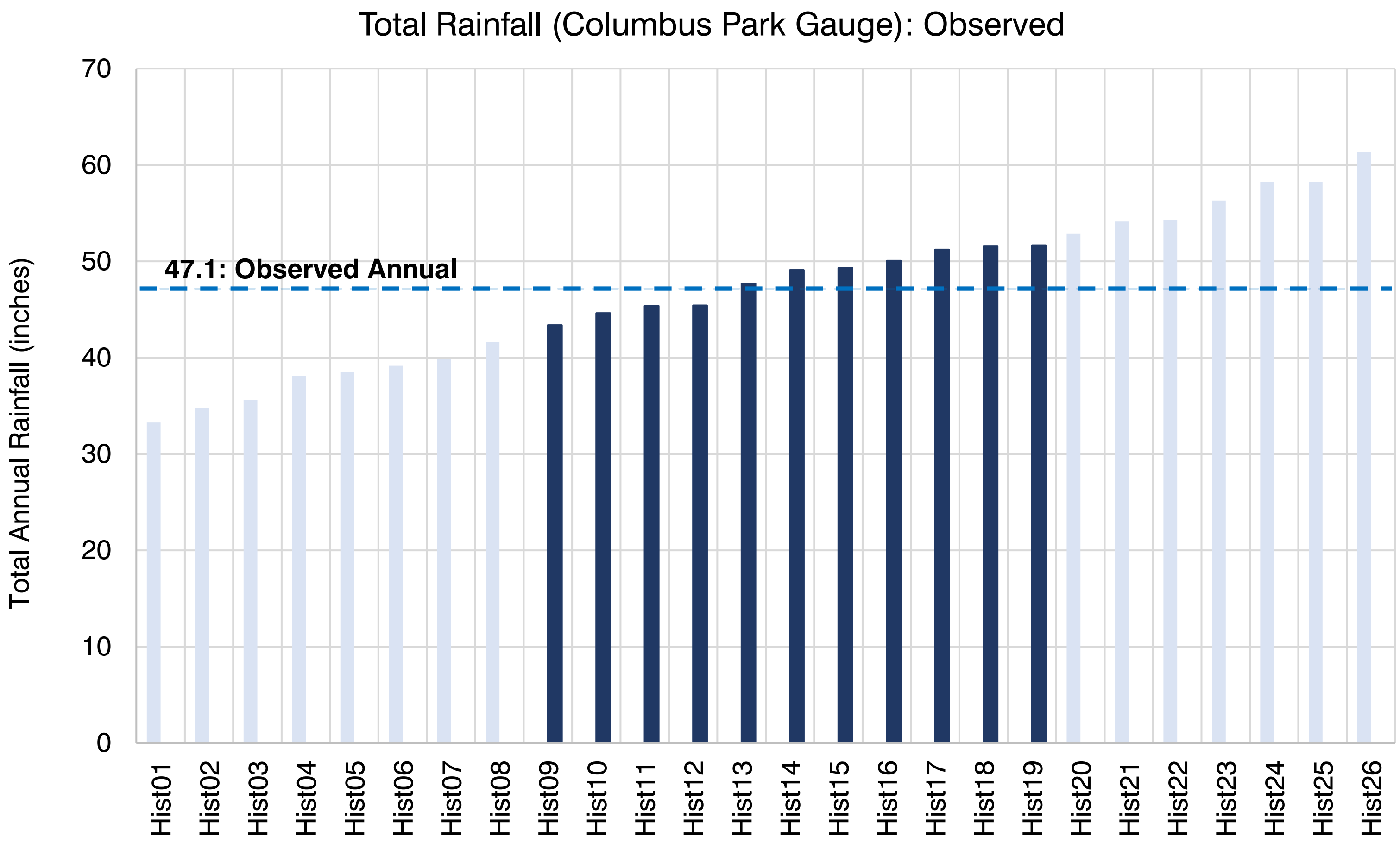
2 OBSERVED RAINFALL ANALYSIS: Annual Rainfall Depth

The figure below shows the Annual Rainfall Depths for the observed years arranged in ascending order for one example gauge. **Years at each gauge within ±10% of the observed annual rainfall depth are pre-selected for deviation analysis at that gauge**.



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OBSERVED RAINFALL ANALYSIS: Deviation Analysis

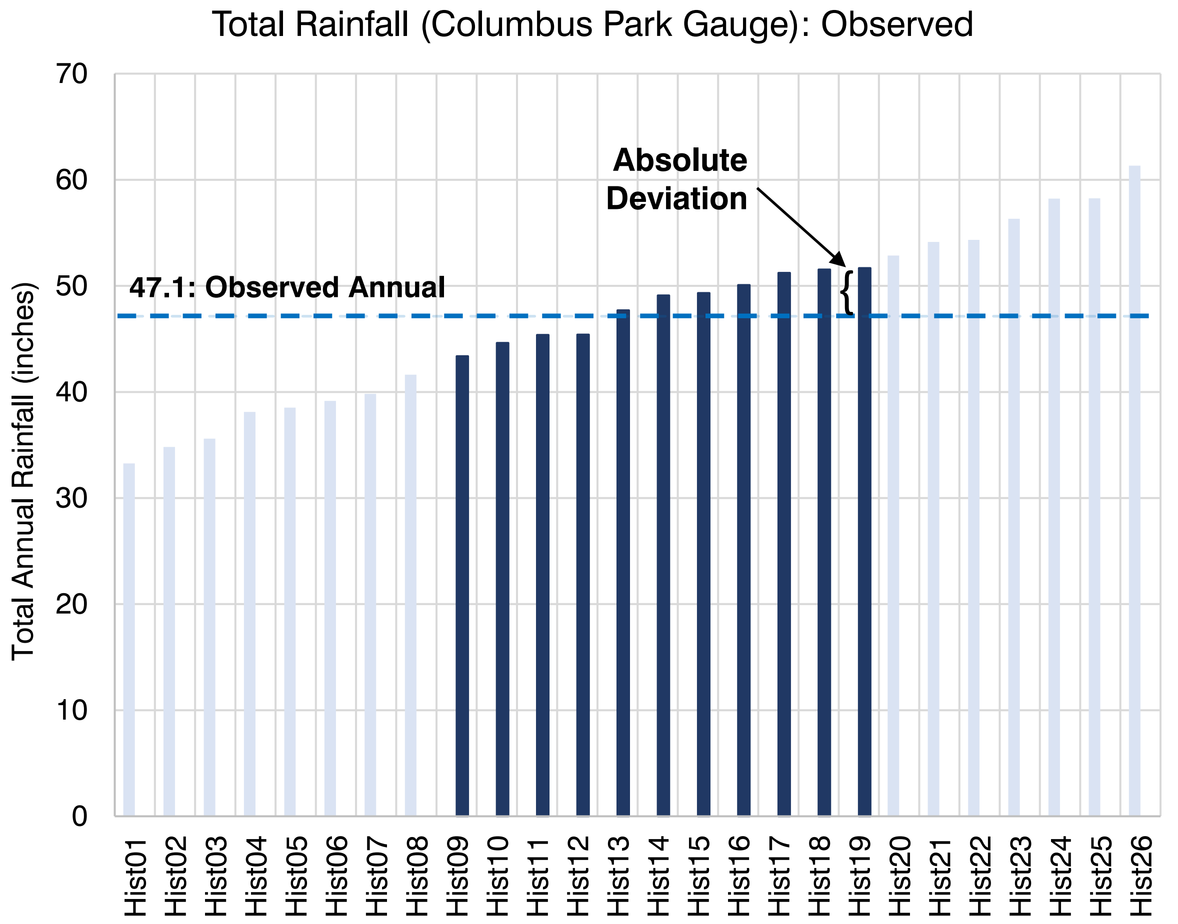
Step 3: Deviation analysis determines the **amount that a single measurement (year) differs from the average.** Deviation analysis is used to understand rainfall variation across the 26 years and determine the year with the **least** deviation from the average.

DEVIATION ANALYSIS STEPS

A. **Absolute deviation:** difference between an individual year and the average over the period of record. *Difference between dashed averaged line and bar height.*

B. **Relative deviation:** absolute deviation divided by the average over the period of record.

C. **Weighted deviation:** relative deviation times a weighting factor (two scenarios of different weights to rainfall parameters).



Example of Absolute Deviation

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3 OBSERVED RAINFALL ANALYSIS: Deviation Analysis

Two Scenarios were evaluated for Weighted Deviation Analysis in order to capture the most detailed available data for all steps in the analysis:

Sub-Hourly Data (more detailed) Scenario, considers

- The most holistic set of climate parameters that contribute to CSOs.
- Available observed 15-min rainfall data, and ideal set of weights to rainfall parameters that seem appropriate for CSOs.

Daily Data (less detailed) Scenario, used to address the availability of only daily rainfall projections in the future (from global climate models).

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OBSERVED RAINFALL ANALYSIS: Deviation Analysis

Two Scenarios were evaluated for Weighted Deviation Analysis:

SCENARIO	CONS DRY DAYS	# STORMS	TOTAL DEPTH (IN)*	# BACK-BACK	Count of storms – 15-minute depths, Atlas-14					Count of storms - 1 hour depths, Atlas-14					Count of storms – 6-hour depths, Atlas-14					Count of storms – 24-hour depths, Atlas-14					Count of wet days – 1-day depths, Atlas 14+				
					<3M**	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M**	3M to 6M	6Mto 1Y	1Y to 2Y	>2Y	<3M**	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M**	3M to 6M	6M to 1Y	1Y to 2Y	>2Y	<3M**	3M to 6M	6M to 1Y	1Y to 2Y	>2Y
					< 0.23	*0.23 - 0.36*	*0.36 - 0.5*	*0.5 - 0.62*	*> 0.62*	*< 0.38*	*0.38 - 0.61*	*0.61 - 0.85*	*0.85 - 1.06*	*> 1.06*	*<0.72*	*0.72- 1.19*	*1.19- 1.67*	*1.67- 2.08*	*>2.08*	*< 1.14*	*1.14 - 1.85*	*1.85 - 2.60*	*2.60 - 3.23*	*> 3.23*	*<1.01*	*1.01- 1.64*	*1.64- 2.30*	*2.30- 2.86*	*>2.86*
Sub-Hourly Data (more detailed) Scenario	12.0%	4.0%	-	12.0%	-	4.5%	4.5%	4.5%	4.5%	-	4.5%	4.5%	4.5%	4.5%	-	4.5%	4.5%	4.5%	4.5%	-	4.5%	4.5%	4.5%	4.5%	-	-	-	-	-
Daily Data (less detailed) Scenario	20.0%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20%	20%	20%	20%

* **no weights** to annual rainfall depth since these weights will be applied to years that have been **pre-selected to be within ±10% of the average annual rainfall depth at each gauge.**

** **no weights** to <3-month storms/<3-month wet days since these storms are less likely to contribute to CSOs in a system that has completed a CSO Control Plan like MWRA.

+ 24-hour depth from NOAA Atlas 14 is divided by a derived factor of 1.13 to convert 24-hour amounts to 1-day depth accumulations

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3 OBSERVED RAINFALL ANALYSIS: Deviation Analysis

The following example illustrates the **stepwise methodology** to **calculate the weighted deviation analysis**, using observed data at Columbus Park Gauge, example year 2017, for the annual number of storms parameter.

A. Absolute deviation:

$$\boldsymbol{Absolute\ Deviation} = abs(Individual\ Year - Record\ Average)$$

$$\boldsymbol{Absolute\ Deviation} = abs(94 - 97) = 3$$

B. Relative Deviation:

$$\boldsymbol{Relative\ Deviation} = \frac{Absolute\ Deviation}{Record\ Average}$$

$$\boldsymbol{Relative\ Deviation} = \frac{3}{97} = 0.03$$

C. Weighted Deviation Using the Sub-Daily Scenario:

$$\boldsymbol{Weighted\ Deviation} = Relative\ Deviation * Scenario\ Weighting\ Factor$$

$$\boldsymbol{Weighted\ Deviation} = 0.03 * 0.04 = 0.0012$$

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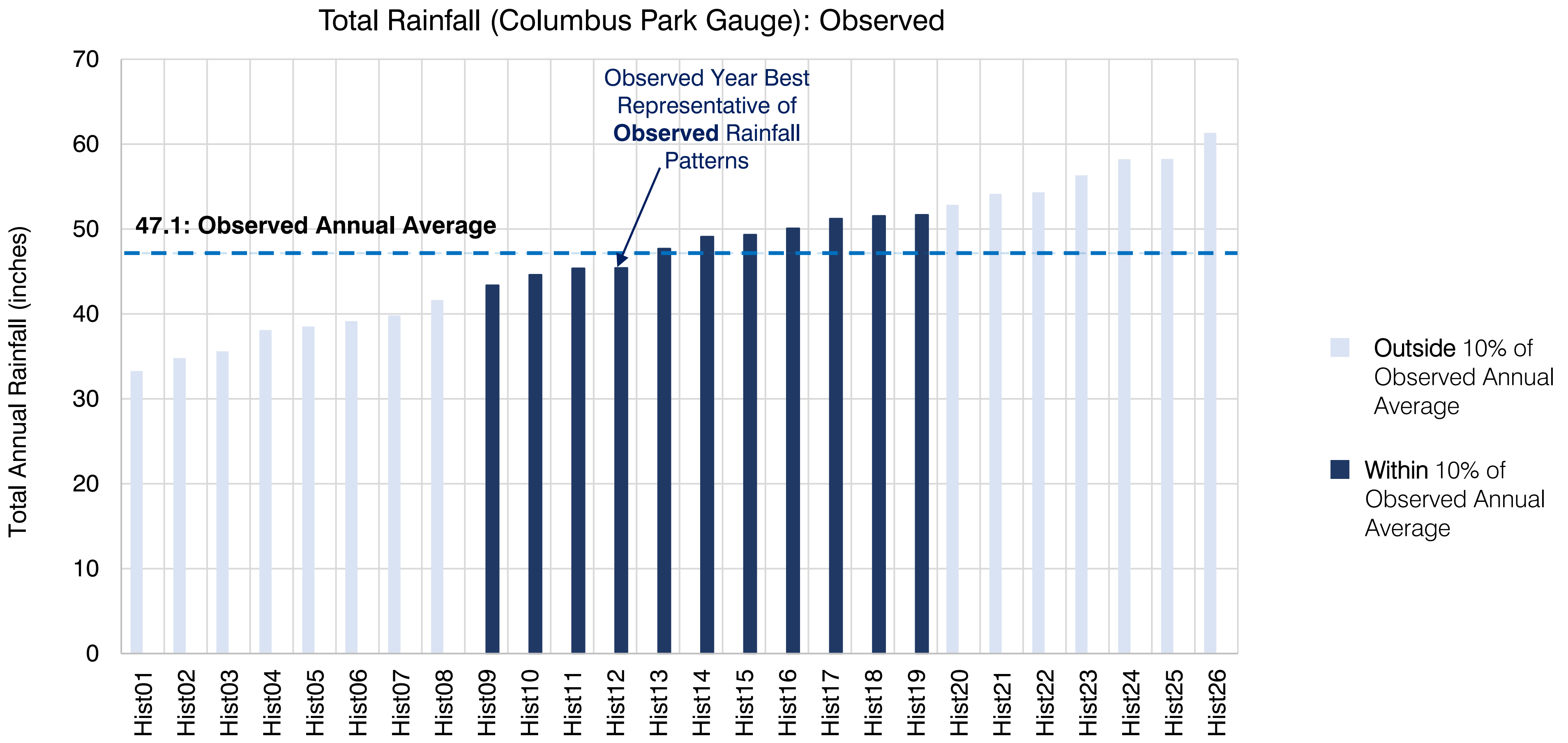
3 OBSERVED RAINFALL ANALYSIS: Deviation Analysis

The most representative observed year of rainfall is **not simply the one closest** to the observed annual average rainfall depth, but also the one that **most closely matches other rainfall parameters analyzed**



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3 OBSERVED RAINFALL ANALYSIS: Results

The years with the **lowest weighted deviations** (least variability from the average) for rainfall parameters considered for the two scenarios are as follows:

Sub-hourly Data Scenario
(more detailed)

- 2000
- 2017
- 2002
- 2009
- 2003

Daily Data Scenario
(less detailed)

- 2000
- 2004
- 2002
- 2009
- 2003

Top candidate years that are representative of average rainfall patterns are similar, if we consider both sub-hourly (more detailed) and daily (less detailed) scenarios.

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FUTURE TYPICAL YEAR

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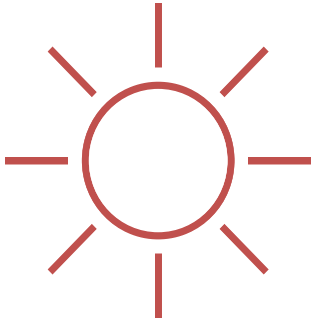
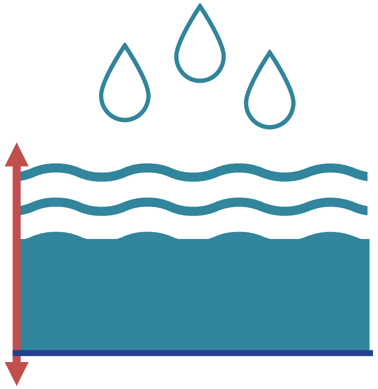
1 FUTURE TYPICAL YEAR: Rainfall Parameters

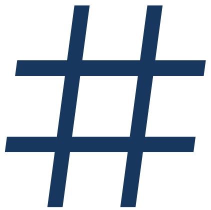
Rainfall data from climate change projections are only available with daily rainfall totals. Parameters assessed from each gauge, grid, and Global Climate Model (GCM), include:



Consecutive Dry Days



Total Annual Rainfall Depth



Count of Wet Days Binned by Depths

These parameters help us understand future conditions with climate change.

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FUTURE TYPICAL YEAR: Overall Process

The process for assessing future data is as follows:

1. **Model Future Rainfall Data is Processed for each Gauge in Daily Intervals**
2. **Model Future Data is Bias Corrected**
3. **Deviation Analysis Conducted to Identify Observed Historical Year that is most Representative of Model Future Average**
4. **Typicalization of the Representative Year**

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FUTURE TYPICAL YEAR: Key Terminology

Key Components of the Future Typical Year Rainfall Analysis:

MACA*
Future daily global climate model (GCM) projections were obtained from the Multivariate Adaptive Constructed Analogs (MACA) statistically downscaled product

GAUGE
MWRA rain gauge locations were used to download modeled future daily rainfall projections

DOWNSCALED
Statistical downscaling is the process of converting large scale global climate models into fine spatial scale so that the data is in close agreement with local data and can be used for station level analysis

GRID
MACA projections used in the analysis are based on approx. 4-km resolution grids, with modeled future daily rainfall projections available for each grid for each GCM

GCM
A global climate model (GCM) is a complex mathematical representation of the major climate system components (atmosphere, land surface, ocean, and sea ice), and their interactions

PLANNING HORIZON
A length of time in the future for which the plannings are made. For climate analysis, typically a 30 years average is taken. For example, 2050 planning horizon represents an averaging period of 2040-2069

*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
**https://www.gfdl.noaa.gov/climate-modeling/

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1 FUTURE TYPICAL YEAR: Model Data

The future planning horizons, Global Climate Models, and Greenhouse Gas Emissions Scenarios used for the future typical year analysis are **based on those that have been adopted by Massachusetts Executive Office of Energy and Environmental Affairs**, as part of the Statewide Climate Resilience Design Standards and Guidance.

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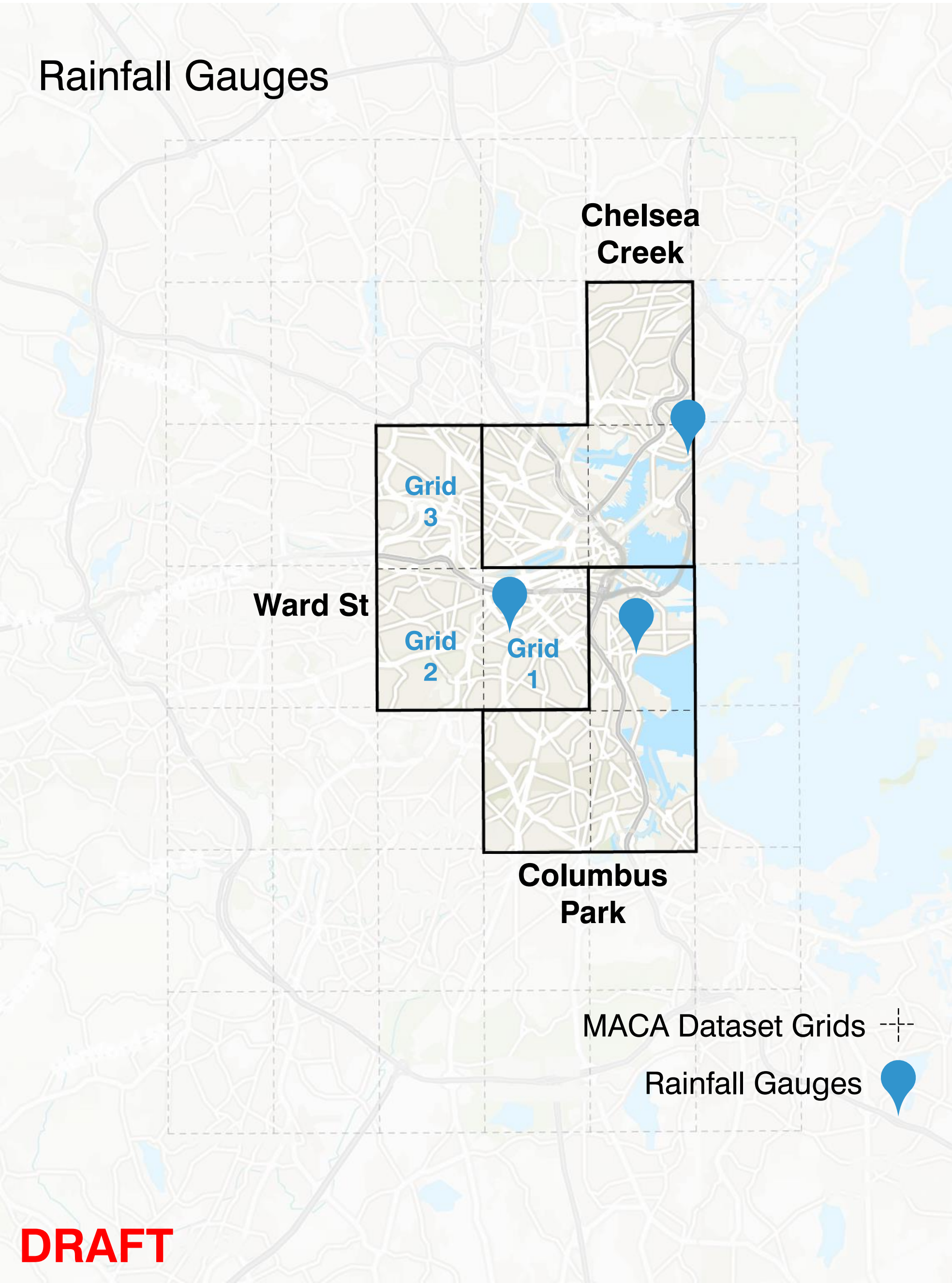
FUTURE TYPICAL YEAR: Model Data



Step 1: To determine the future typical year, modeled daily rainfall data were downloaded for the areas around the rainfall gauges.

MACA grids were identified and 3 grids around each of the 3 existing rainfall gauges were selected:

- Ward St
- Columbus Park
- Chelsea Creek

Multivariate Adaptive Constructed Analogs (MACA) is a statistical method for downloading future climate projection using downscaled *Global Climate Models* (GCMs)

*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
**https://www.gfdl.noaa.gov/climate-modeling/

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FUTURE TYPICAL YEAR: Model Data

1

Model rainfall data is processed for each gauge in daily time intervals.

Model Future Rainfall Data:

11 Global Climate Models (GCMs)*

Greenhouse Gas (GHG) Emission Scenarios:

Low (RCP4.5) and High (RCP8.5)

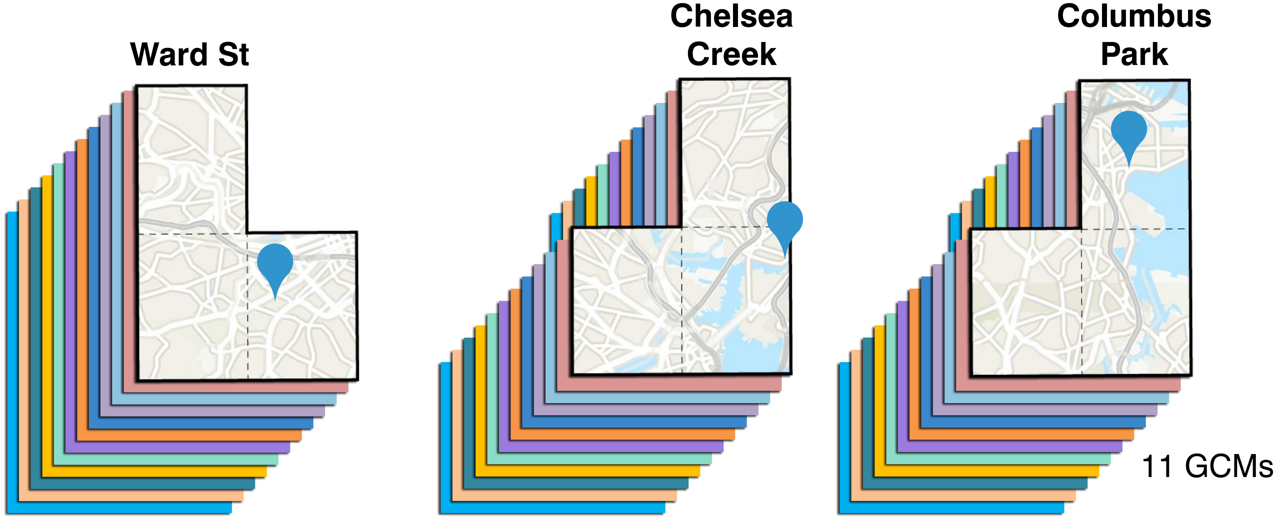
Planning Horizons:

Historical (26 years): 1996 – 2021

(model historical to calculate uncertainties from observed dataset)

Future (30 years): 2050 (2040 – 2069)

(forecasted/projected model data to study future change in rainfall patterns)



11 Global Climate Models

BCC-CSM1-1	CSIRO-Mk3-6-0	IPSL-CM5A-MR
BNU-ESM	GFDL-ESM2M	MIROC-ESM
CAN-ESM2	HADGEM2-ES365	MRI-CGCM3
CNRM-CM5	INMCM4	

Future dataset: 11 GCMs for each of the 3 grids for each of the 3 gauges for 30 years for both emission scenarios.

*The 11 Global Climate Models (GCMs) have been selected from a wider set of GCMs as adopted by the Massachusetts Executive Office of Energy and Environmental Affairs for the Statewide Climate Resilience Design Standards and Guidance

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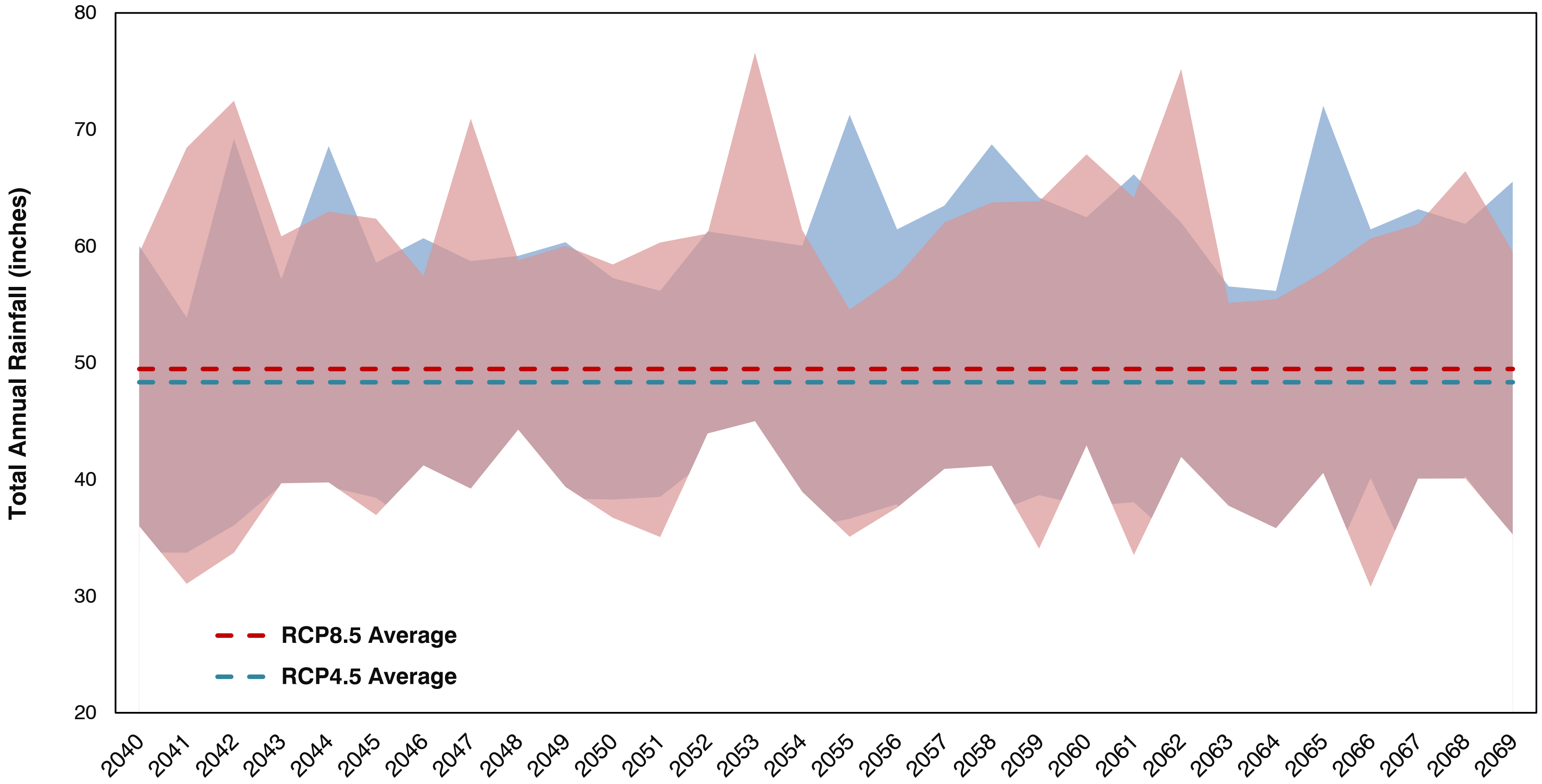
2 FUTURE TYPICAL YEAR: Annual Rainfall Depth

Annual Rainfall Depth variability across the 11 Global Climate Models, for both GHG Emission Scenarios. This figure shows how rainfall projections are likely to vary in the future.

Shaded area represents the spread across 11 models

Dashed lines represent the 330-model year average (11 models over 30 years)



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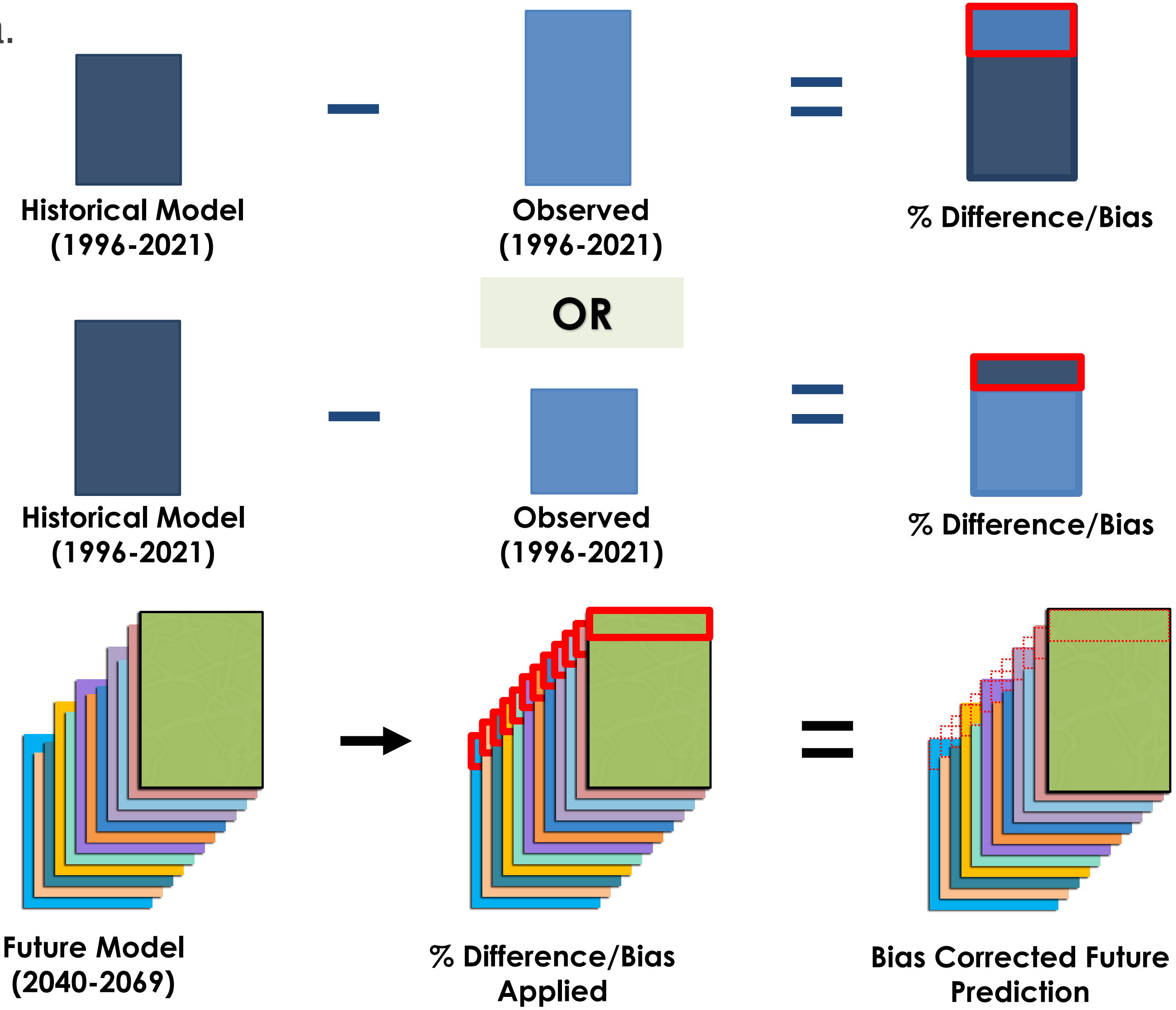
FUTURE TYPICAL YEAR: Bias Correction

Bias Correction is the process of **adjusting** the future model data so that it aligns with observed data. Bias correction factor is the difference between the **model historical data** and the **observed historical data** and can be **either positive or negative**. The purpose of the bias correction process is to correct uncertainties in model future dataset based on observed data.

First, find the Bias Correction Factor by comparing observed data with historical model data for each GCM.

Then, apply that Bias Correction Factor to the respective model future data. This will "correct" the future data to best represent future conditions.



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2 FUTURE TYPICAL YEAR: Bias Correction

Step 2: To evaluate future rainfall parameters, the *bias correction factor* for each GCM, grid, and gauge must be calculated. This is derived from comparison of observed data to modeled historical data.

The table shows an example of calculating the bias correction factor

MODEL FUTURE, COLUMBUS PARK, RCP8.5							
CNRM-CM5, GRID 1							
			Count of Wet Days - 1-Day Depths				
	Consecutive Dry Days	Total Depth (inches)	<3M	3M to 6M	6M to 1Y	1Y to 2Y	>2Y
Model Hist Avg (1996-2021)	5.9	46.1	152.3	6.6	2.2	0.6	0.5
Obs. Hist Avg, Columbus Park Gauge (1996-2021)	5.9	47.1	119.8	7.1	2.5	0.9	0.9
Bias correction (% change)	0%	2%					
Bias correction (additive)			-32.5	0.5	0.2	0.3	0.5

For some parameters, % change was compared, while for others the difference in the two values was compared.

This was based on recommendation from climate scientists

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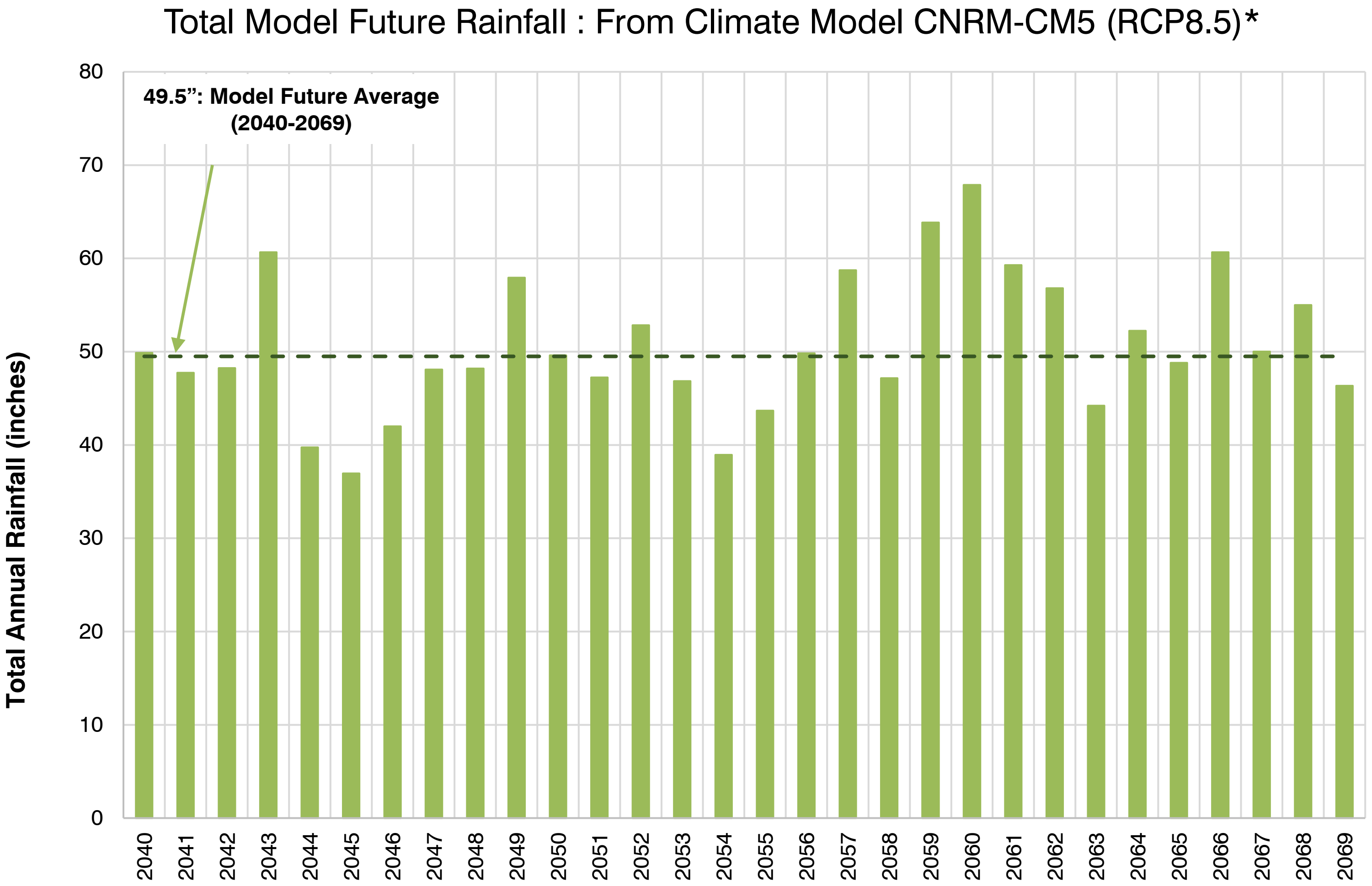
2 FUTURE TYPICAL YEAR: Model Future Rainfall Depth

The figure below shows how bias corrected Annual Rainfall Depth is projected to vary by year for a sample GCM for a sample gauge



*RCP 8.5 scenario has been selected by the Massachusetts Executive Office of Energy and Environmental Affairs for the Statewide Climate Resilience Design Standards and Guidance

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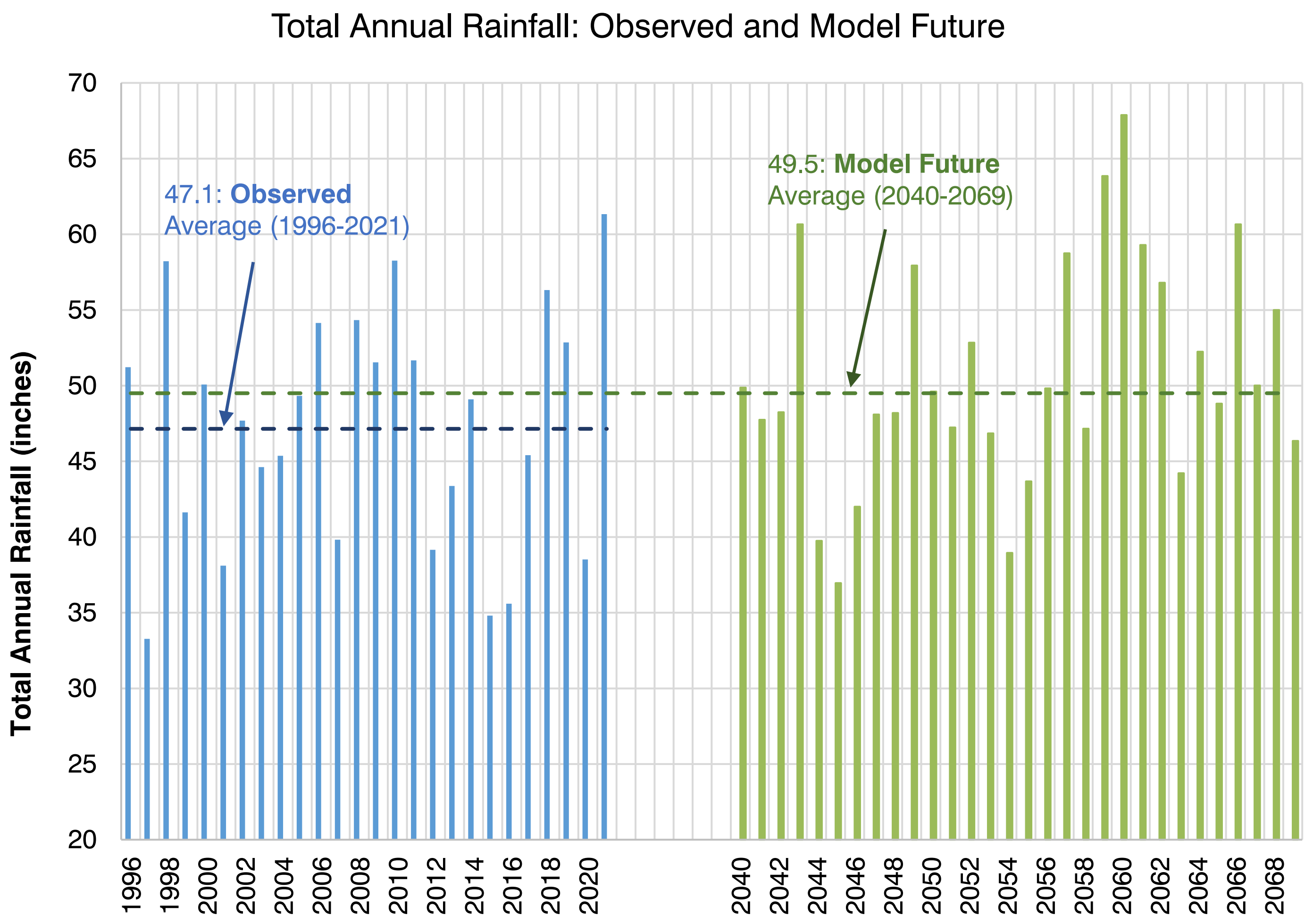
Typical statistics from future years are used to identify observed year that **best represents** climate change conditions.



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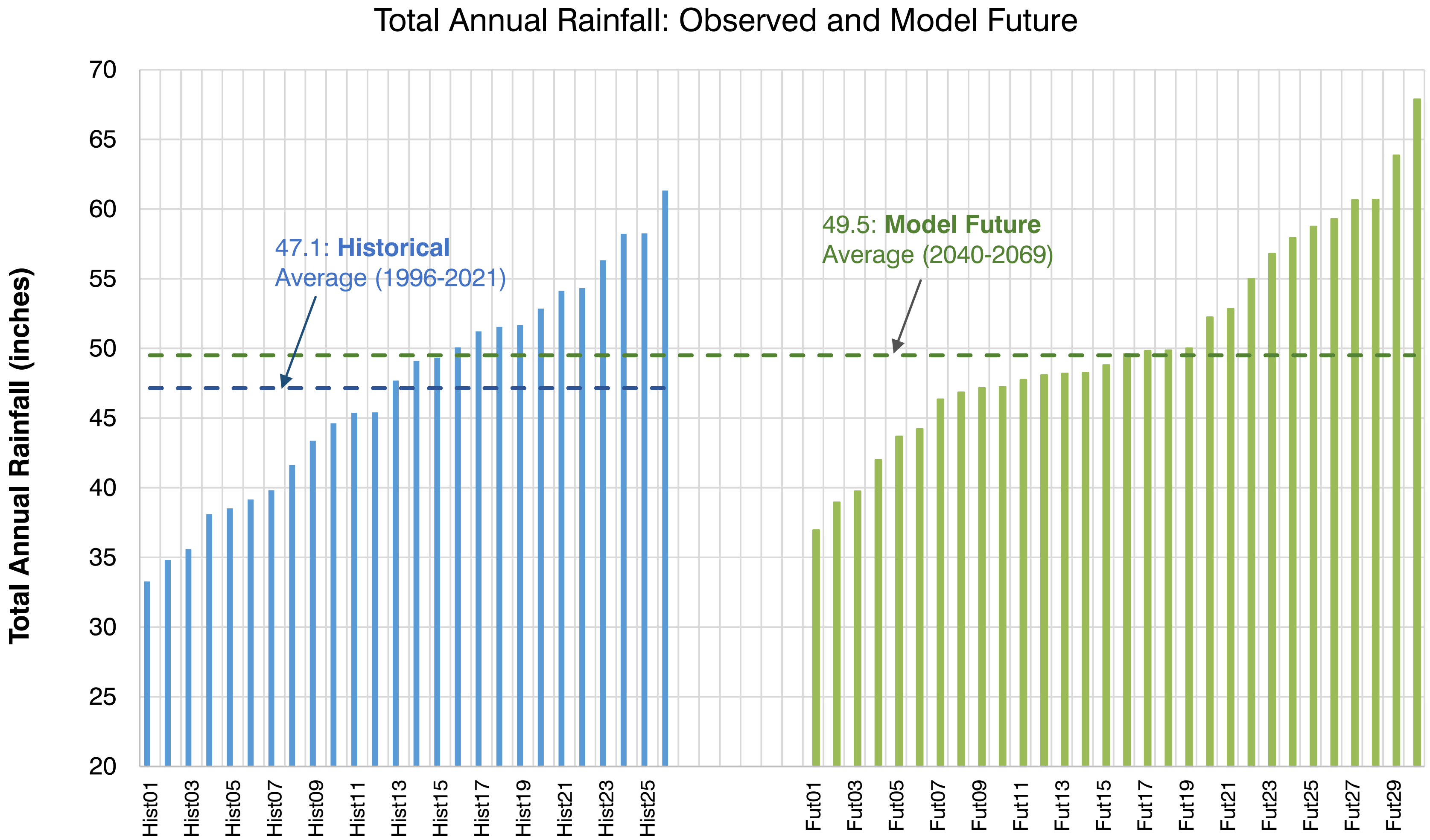
FUTURE TYPICAL YEAR: Model Future Rainfall Depth

Climate change projections show **higher variability** of future annual rainfall compared to observed years.



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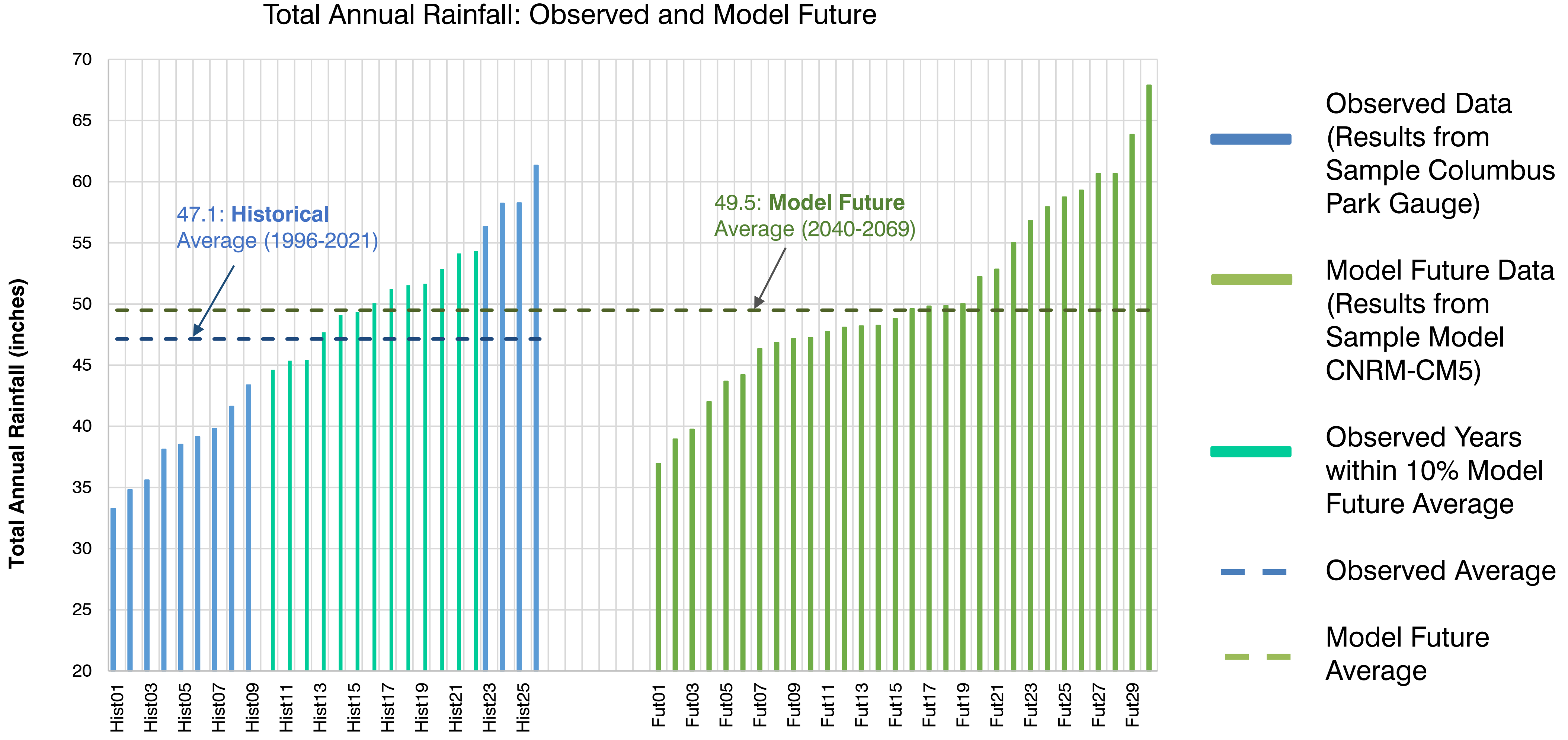
3 FUTURE TYPICAL YEAR: Model Future Rainfall Depth

Years at each gauge within ±10% of the observed annual rainfall depth are pre-selected for deviation analysis at that gauge.



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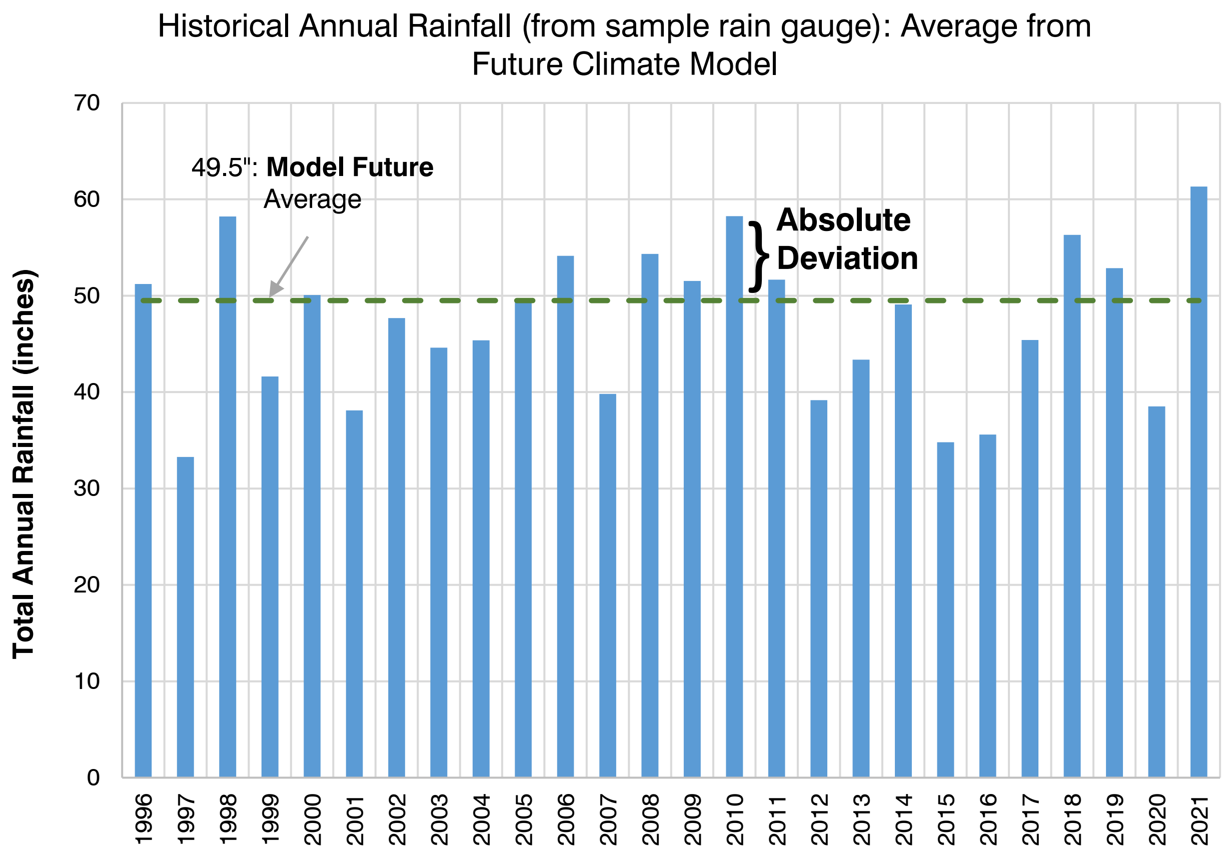
FUTURE TYPICAL YEAR: Deviation Analysis

Step 3: Deviation analysis evaluates the amount that a single measurement (year) differs from the average. Deviation analysis is used to understand rainfall variation across the 26 years under climate change.

DEVIATION ANALYSIS STEPS

1. **Absolute deviation:** difference between an individual year and the period of record average.
2. **Relative deviation:** absolute deviation divided by the period of record average.
3. **Weighted deviation:** relative deviation times a weighting factor (two scenarios of different weights).



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FUTURE TYPICAL YEAR: Deviation Analysis

Daily-Data Scenario was evaluated for Weighted Deviation Analysis:

SCENARIO	Cons Dry Days	Total Rainfall Depth*	Count of wet days – 1-day depths, Atlas 14[+]				
			<3M**	3M to 6M	6M to 1Y	1Y to 2Y	>2Y
			<1.01”	*1.01”-1.64”*	*1.64”-2.30”*	*2.30”-2.86”*	*>2.86”*
Daily-Data Scenario	20%	-	-	20%	20%	20%	20%

* **No weights** to annual rainfall depth since these weights will be applied to years that have been **pre-selected to be within ±10% of the average annual rainfall depth at each gauge.**

** **No weights** to <3-month storms/<3-month wet days since these storms are less likely to contribute to CSOs in a system that has completed a CSO Control Plan like MWRA.

[+] 24-hour depth from NOAA Atlas 14 is divided by a derived factor of 1.13 to convert 24-hour amounts to 1-day depth accumulations

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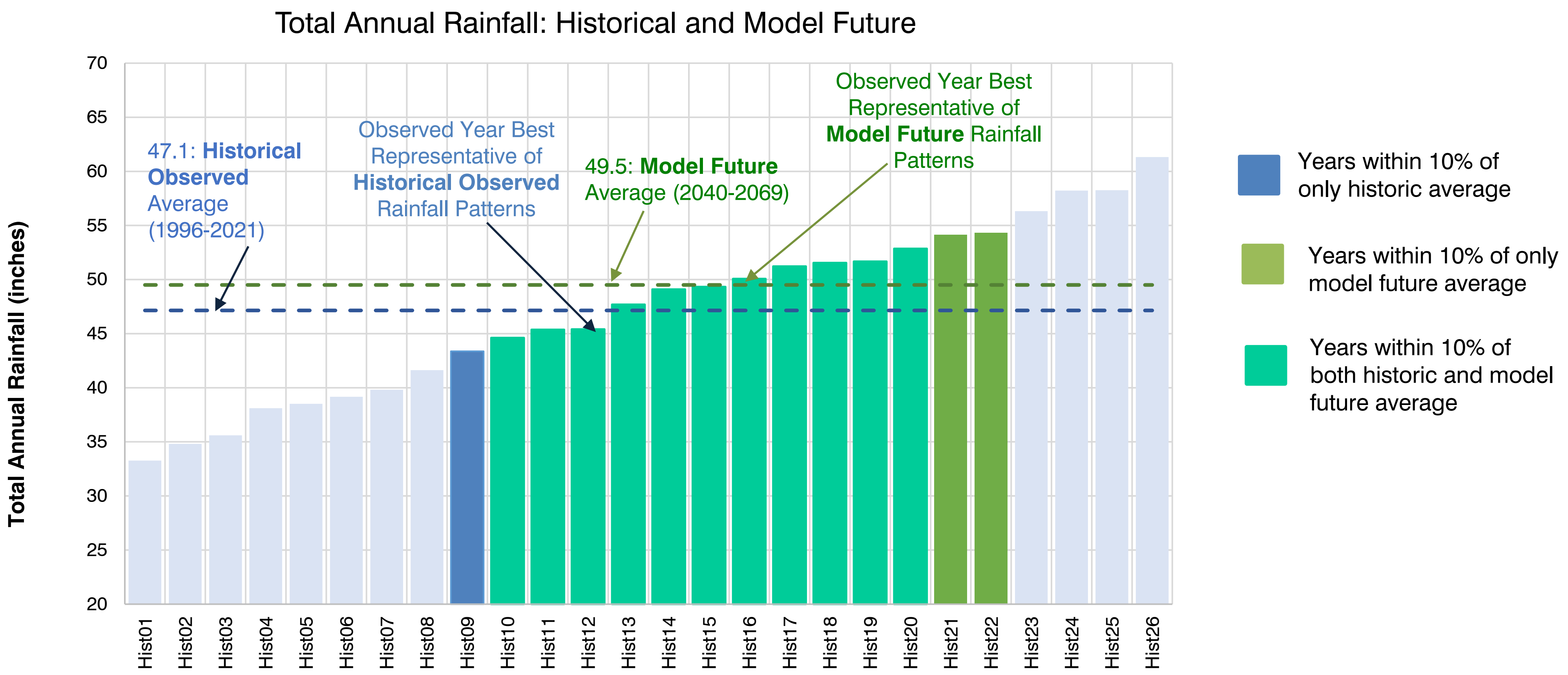
FUTURE TYPICAL YEAR: Observed Year Most Representative of the Future

The observed year that is most representative of future rainfall patterns is **not simply the one closest** to the projected future annual average rainfall depth, but also the one that **most closely matches other rainfall parameters analyzed.**



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4 FUTURE TYPICAL YEAR: Typicalization of the Representative Year

The rainfall events in the observed year that are most representative of future rainfall patterns are compared with the **future Intensity-Duration-Frequency (IDF) curves based on projections that have been adopted by the Massachusetts Executive Office of Energy and Environmental Affairs**, as part of the Statewide Climate Resilience Design Standards and Guidance.

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4 FUTURE TYPICAL YEAR – Future Design Storm Projections

BINS		PRESENT DAY (NOAA ATLAS 14) DEPTHS (IN.)	2050 (2040-2069) RAINFALL DEPTH PROJECTIONS*
Duration	***Return Period***		
15-minute	*3M*	0.23	0.46
	6M	0.36	0.50
	1Y	0.5	0.61
	2Y	0.62	0.76
1-hour	*3M*	0.38	0.78
	6M	0.61	0.87
	1Y	0.85	1.06
	2Y	1.06	1.31
6-hour	*3M*	0.72	1.54
	6M	1.19	1.71
	1Y	1.67	2.08
	2Y	2.08	2.57
24-hour	*3M*	1.14	2.37
	6M	1.85	2.63
	1Y	2.60	3.22
	2Y	3.23	4.0
1-day	*3M*	1.01	2.10
	6M	1.64	2.33
	1Y	2.30	2.85
	2Y	2.86	3.54

The future rainfall projections used are **best available projections from Cornell University**, developed as part of the **Massachusetts Executive Office of Energy and Environmental Affairs (EEA) Climate and Hydrologic Risk Project** and adopted by the **State's Climate Resilience Design Standards Tool***

*Using RCP 8.5 scenario, which has been selected by the Massachusetts Executive Office of Energy and Environmental Affairs for the Statewide Climate Resilience Design Standards and Guidance https://resilientma.mass.gov/rmat_home/designstandards/

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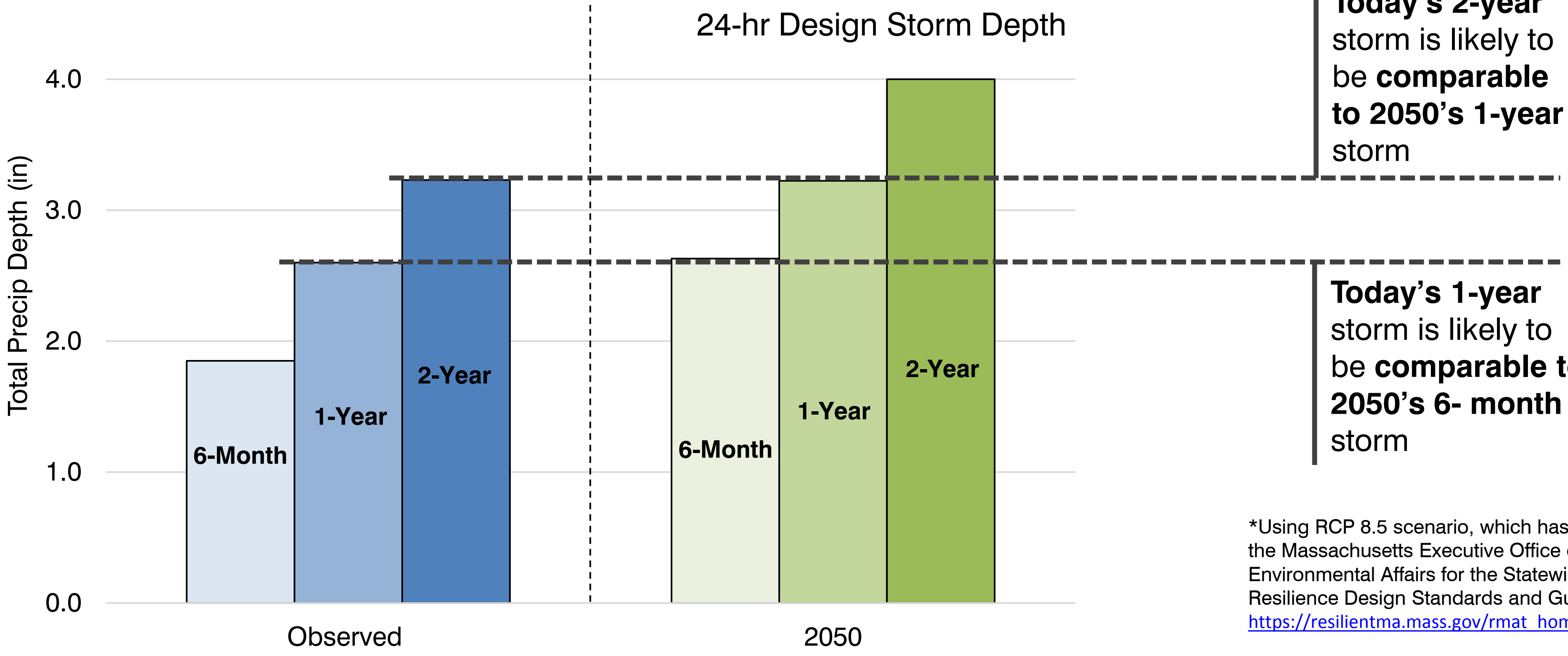
FUTURE TYPICAL YEAR – Future Rainfall Projections

Observed (1996-2021)

Average annual rainfall: 47.1"

Future (2040-2069), RCP8.5*

Average annual rainfall: 49.5" ← From a Sample Gauge



Today's 2-year storm is likely to be **comparable to 2050's 1-year** storm

Today's 1-year storm is likely to be **comparable to 2050's 6- month** storm

*Using RCP 8.5 scenario, which has been selected by the Massachusetts Executive Office of Energy and Environmental Affairs for the Statewide Climate Resilience Design Standards and Guidance https://resilientma.mass.gov/rmat_home/designstandards/

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FUTURE TYPICAL YEAR – Typicalization of the Representative Year

Comparing Representative Year Against Future Sub-Hourly Bins

Substituting alternative events from other historical years of record would be targeted to **add events with higher intensities over short durations** and **reduce the largest event**.

			Count of storms – 15-minute depths, Atlas-14					Count of storms - 1 hour depths, Atlas-14					Count of storms - 6 hour depths, Atlas-14					Count of storms – 24-hour depths, Atlas-14				
YEAR	# STORMS	TOTAL DEPTH (IN)	<3M*	3M to 6M*	6M* to 1Y	1Y to 2Y	>2Y	<3M*	3M to 6M*	6M* to 1Y	1Y to 2Y	>2Y	<3M*	3M to 6M*	6M* to 1Y	1Y to 2Y	>2Y	<3M*	3M to 6M*	6M* to 1Y	1Y to 2Y	>2Y
Future (2040-2069) bins			< 0.46	0.46 - 0.50	0.50 - 0.61	0.61- 0.76	> 0.76	< 0.78	0.78 - 0.87	0.87 – 1.06	1.06- 1.31	> 1.31	<1.54	1.54- 1.71	1.71- 2.08	2.08- 2.57	>2.57	< 2.37	2.37 – 2.63	2.63 – 3.22	3.22- 4.0	> 4.0
1992 TYP	94	46.83	94	0	0	0	0	93	0	0	1	0	92	1	1	0	0	92	0	2	0	0
Representative 2050 (Observed)	98	50.07	97	1	0	0	0	98	0	0	0	0	95	0	1	2	0	95	0	2	0	1
2050 Typical Year (Targets)	**+/- 98**	**+/- 50**	**+/- 97**	**~4 events**			**0**	**+/- 98**	**~4 events**			**0**	**95**	**0**	**1**	**2**	**0**	**95**	**0**	**2**	**1**	**0**

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NEXT STEPS

- Finalize the Future Typical Year
- Finalize technical report related to development of Future Typical Year

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THANK YOU

Written comments to this Technical Information can be submitted by January 5th (include **"CSO Control Typical Year"** in the subject) to:

Cambridge: Catherine Woodbury, cwoodbury@cambridgema.gov

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