



US Army Corps
of Engineers®

Fox Point Storm Surge Barrier System Vulnerability Assessment

Appendix C. Gate Operations Analysis Tool
(GOAT)

April 2026





**US Army Corps
of Engineers®**

Please cite this report as:
Fox Point Storm Surge Barrier System Vulnerability Assessment (2025)
U.S. Army Corps of Engineers: Washington, DC.
Cover photo, Fox Point Storm Surge Barrier, credit Donald Cresitello.

TABLE OF CONTENTS

C.1. IMPACTS OF SEA LEVEL RISE ON PROJECTED ANNUAL CLOSURES.....	1
C.2. CRITICAL ELEVATION THRESHOLDS.....	1
C.3. COASTAL WATER LEVELS.....	1
C.4. SCENARIOS.....	2
C.5. FORECAST FUTURE EXCEEDANCES UNDER SEA LEVEL CHANGE SCENARIOS.....	7
C.5.1. Simulation Method.....	7
C.5.2. Incorporating Sea Level Rise.....	9
C.6. PROJECTION RESULTS.....	11
C.6.1. Top Elevation of Fox Point Feature (24.2 ft NAVD88)	11
C.6.2. Tainter Gate Barrier Closure Elevation Threshold (5.2 ft NAVD88).....	12
C.6.3. Allens Ave Street Gate (11.2 ft NAVD88)	17
C.6.4. Rhode Island Energy (8.2 ft NAVD88)	23
C.6.5. India Street Gate (9.0 ft NAVD88).....	28
C.6.6. South Water Street Gate (13.9 ft NAVD88)	33
C.6.7. South Main Street Gate (14.1 ft NAVD88)	38
C.6.8. Phase 1 Sewer Gate (6.7 ft NAVD88)	43
C.6.9. Phase 2 Sewer Gate (11.7 ft NAVD88)	48

LIST OF FIGURES

Figure C-1. Location of Providence, RI, tide gage.	2
Figure C-2. Mean sea level trend, NOAA Providence 8454000.....	2
Figure C-3. USACE 2019 scenario projections for Providence, using a SLC rate of 4.6 mm/yr (40-year record ARIMA trend).	3
Figure C-4. USACE 2019 scenario projections for Providence, using a SLC rate of 2.62 mm/yr (NOAA-NOS Tides & Currents Trend).....	5
Figure C-5. Fox Point historic closure record.....	8
Figure C-6. Historic daily storm tide data at Providence, RI, from the Gate Operations Analysis Tool.....	8
Figure C-7. Monthly distribution plots visualizing the best-fit distribution, GNG Continuous, for daily peak water levels at the Providence tide gage.....	9
Figure C-8. Monthly boxplots of simulated daily water levels under the Low scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100.	10

Figure C-9. Monthly boxplots of simulated daily water levels under the Intermediate scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100. 10

Figure C-10. Monthly boxplots of simulated daily water levels under the High scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100. 11

Figure C-11. USACE 2019 scenario projections for Providence, using a SLC rate of 4.6 mm/yr (40-year record ARIMA trend) from the 15-foot storm of record. 12

Figure C-12. Probability density function (PDF) illustrating threshold exceedance relative to the 5.2 ft threshold..... 13

Figure C-13. Estimated threshold exceedances by scenario for water levels exceeding 5.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change..... 14

Figure C-14. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change..... 15

Figure C-15. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change. 16

Figure C-16. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change..... 17

Figure C-17. Probability density function (PDF) illustrating threshold exceedance response relative to the 11.2 ft threshold. 18

Figure C-18. Estimated threshold exceedances by scenario for water levels exceeding 11.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change..... 19

Figure C-19. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change..... 20

Figure C-20. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change. 21

Figure C-21. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change..... 22

Figure C-22. Probability density function (PDF) illustrating threshold exceedance response relative to the 8.2 ft threshold. 24

Figure C-23. Estimated threshold exceedances by scenario for water levels exceeding 8.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change..... 24

Figure C-24. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change..... 25

Figure C-25. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change. 26

Figure C-26. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change..... 27

Figure C-27. Probability density function (PDF) illustrating threshold exceedance response relative to the 9.0 ft threshold. 29

Figure C-28. Estimated threshold exceedances by scenario for water levels exceeding 9.0 ft NAVD88 with a 4.6 mm/yr rate of sea level change..... 29

Figure C-29. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.....	30
Figure C-30. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.	31
Figure C-31. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.....	32
Figure C-32. Probability density function (PDF) illustrating threshold exceedance response relative to the 13.9 ft threshold.	34
Figure C-33. Estimated threshold exceedances by scenario for water levels exceeding 13.9 ft NAVD88 with a 4.6 mm/yr rate of sea level change.....	34
Figure C-34. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.....	35
Figure C-35. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.	36
Figure C-36. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.....	37
Figure C-37. Probability density function (PDF) illustrating threshold exceedance response relative to the 14.1 ft threshold.	39
Figure C-38. Estimated threshold exceedances by scenario for water levels exceeding 14.1 ft NAVD88 with a 4.6 mm/yr rate of sea level change.....	39
Figure C-39. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.....	40
Figure C-40. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.	41
Figure C-41. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.....	42
Figure C-42. Probability density function (PDF) illustrating threshold exceedance response relative to the 6.7 ft threshold.	44
Figure C-43. Estimated threshold exceedances by scenario for water levels exceeding 6.7 ft NAVD88 with a 4.6 mm/yr rate of sea level change.....	44
Figure C-44. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.....	45
Figure C-45. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.	46
Figure C-46. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.....	47
Figure C-47. Probability density function (PDF) illustrating threshold exceedance response relative to the 11.7 ft threshold.	49
Figure C-48. Estimated threshold exceedances by scenario for water levels exceeding 11.7 ft NAVD88 with a 4.6 mm/yr rate of sea level change.....	49

Figure C-49. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change..... 50

Figure C-50. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change. 51

Figure C-51. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change..... 52

LIST OF TABLES

Table C-1 USACE SLR scenarios, 1992–2150; projections based on the NOAA Providence tide gage and 40-year record rate of sea-level change (4.6 mm/yr). 4

Table C-2 USACE SLR scenarios, 1992–2150; projections based on the NOAA Providence tide gage and full record rate of sea-level change (2.62 mm/yr). 5

Table C-3 Projected timing of critical threshold exceedance for USACE 2019 scenarios. 6

Table C-4 Projected timing of critical threshold exceedance for USACE 2019 scenarios with an offset of 15 ft: Intersections with top elevation of Fox Point feature (24.2 feet). 11

Table C-5 Upper and lower estimates for elevation thresholds of 5.2 ft NAVD88. 13

Table C-6 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval. 15

Table C-7 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval. 16

Table C-8 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval. 17

Table C-9 Upper and lower estimates for elevation thresholds of 11.2 ft NAVD88. 18

Table C-10 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval. 20

Table C-11 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval. 21

Table C-12 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval. 22

Table C-13 Upper and lower estimates for elevation thresholds of 8.2 ft NAVD88. 23

Table C-14 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval. 25

Table C-15 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval. 26

Table C-16 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval. 27

Table C-17 Upper and lower estimates for elevation thresholds of 9.0 ft NAVD88. 28

Table C-18 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval. 30

Table C-19 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.....	31
Table C-20 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.	32
Table C-21 Upper and lower estimates for elevation thresholds of 13.9 ft NAVD88.....	33
Table C-22 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.	35
Table C-23 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.....	36
Table C-24 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.	37
Table C-25 Upper and lower estimates for elevation thresholds of 14.1 ft NAVD88.....	38
Table C-26 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.	40
Table C-27 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.....	41
Table C-28 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.	42
Table C-29 Upper and lower estimates for elevation thresholds of 6.7 ft NAVD88.....	43
Table C-30 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.	45
Table C-31 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.....	46
Table C-32 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.	47
Table C-33 Upper and lower estimates for elevation thresholds of 11.7 ft NAVD88.....	48
Table C-34 Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.	50
Table C-35 Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.....	51
Table C-36 Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.	52

C.1. Impacts of Sea Level Rise on Projected Annual Closures

This report analyzes historical and projected sea level trends at the Fox Point Hurricane Barrier using daily maximum water level data from 1938–2025 (NOAA Station 8454000, Providence, RI) and the O’Brien (2017) methodology for calculating impacts to critical elevations from sea level change and coastal storms to the gate closure threshold exceedances, overtopping of the barrier feature and impacts to vehicular and sewer gates. The results estimate the frequency of water levels exceeding specified thresholds and incorporate USACE sea level rise scenarios to provide a range of potential annual exceedances, reflecting both historical trends and anticipated future sea level rise.

C.2. Critical Elevation Thresholds

Key elevation thresholds analyzed in this report are listed below.

- 24.2 ft NAVD88 – Top Elevation of Fox Point Feature
- 5.2 ft NAVD88 – Tainter Gate Barrier Closure Elevation Threshold
- 11.2 ft NAVD88 – Allens Ave Street Gate
- 8.2 ft NAVD88 – Rhode Island Energy
- 9.0 ft NAVD88 – India Street Gate
- 13.9 ft NAVD88 – South Water Street Gate
- 14.1 ft NAVD88 – South Main Street Gate
- 6.7 ft NAVD88 – Phase 1 Sewer Gate
- 11.7 ft NAVD88 – Phase 2 Sewer Gate

C.3. Coastal Water Levels

Tide gage data from Providence, RI, available from 1938–2025, was analyzed using the USACE Sea Level Analysis Tool (SLAT), which follows the methods outlined in USACE Engineer Regulation (ER 1100-2-8162) and Engineer Pamphlet (EP 1100-2-1, 2019) to evaluate site-specific rates of sea level rise. These rates, typically expressed in millimeters per year, provide a quantitative measure of ongoing sea level change and are used as input for the downstream modeling tool that projects navigational gate operations through 2100. By incorporating observed sea level trends, the model estimates the frequency and likelihood of water levels exceeding operational thresholds. The analysis uses a daily time step and assumes a single closure per day.

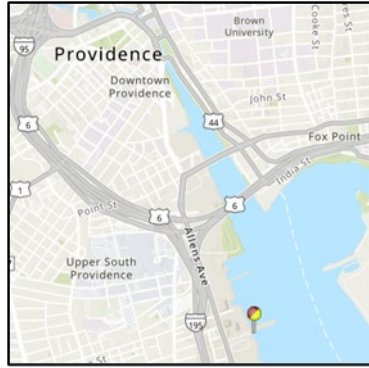


Figure C-1. Location of Providence, RI, tide gage.

C.4. Scenarios

Planning studies and engineering designs over the project life cycle, for both existing and proposed projects, will consider alternatives that are formulated and evaluated for the entire range of possible future rates of SLC, represented here by three scenarios of low, intermediate, and high SLC. (USACE 2019). Table C-1 presents the range of RSLR based on the NOAA tide gage at Providence, RI (8454000). USACE sea level change scenarios are equation based and utilize the mean sea level rate from a tide gage with a published mean sea level trend. The NOAA long term from 1938–2024 mean sea level trend at Providence is 2.62 mm/year (Figure C-2). This trend is a relative sea level rise (RSLR) trend which includes vertical land motion at the tide gage location. The more recent trend from 1985–2025 is 4.6 mm/year.

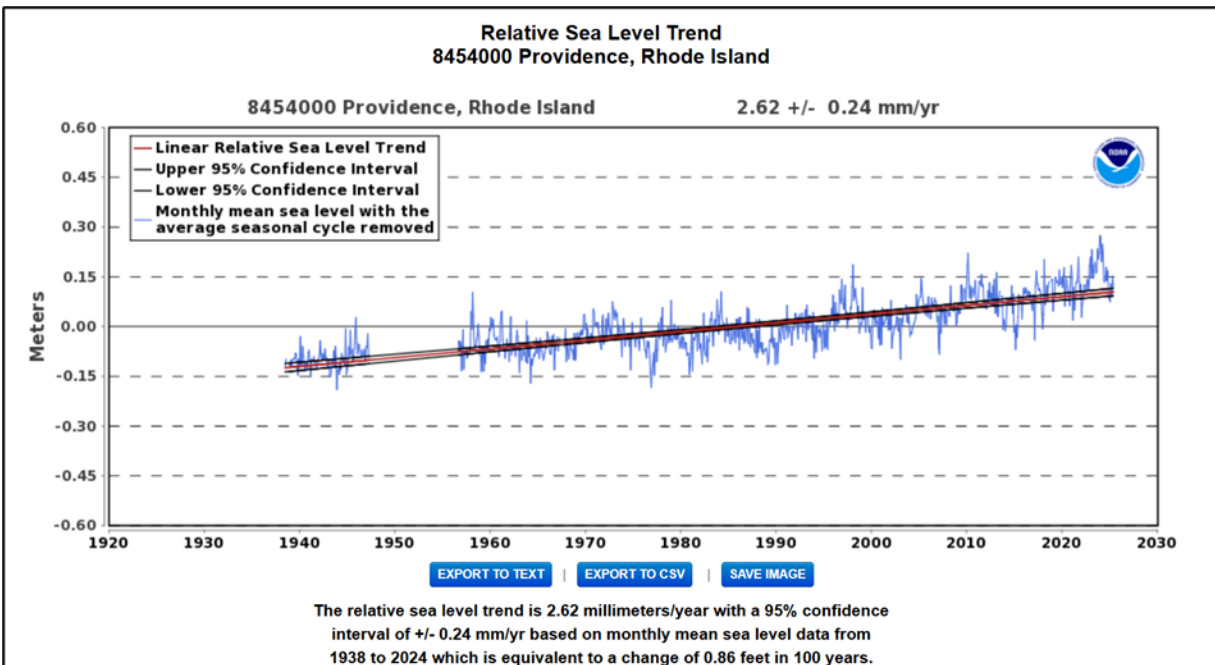


Figure C-2. Mean sea level trend, NOAA Providence 8454000.

Two different rates of sea level rise for Providence were analyzed to explore how different assumptions about long-term change could affect projected water levels. In addition to the full record trend of 2.62

mm/yr, the rate calculated from the most recent 40 years (4.6 mm/yr) was also considered. Using the shorter record provides a consistent basis for comparison with other tide gages over the same period and helps highlight recent trends that may differ from the longer-term average. Using historic tide gage data, both rates were applied to develop projections and estimate when certain thresholds might be exceeded through 2100. Showing results for both rates helps illustrate the range of possible outcomes. For the analysis of predicted threshold exceedances, the higher rate was used to represent a more conservative case, providing insight into conditions that could occur under a faster rate of rise.

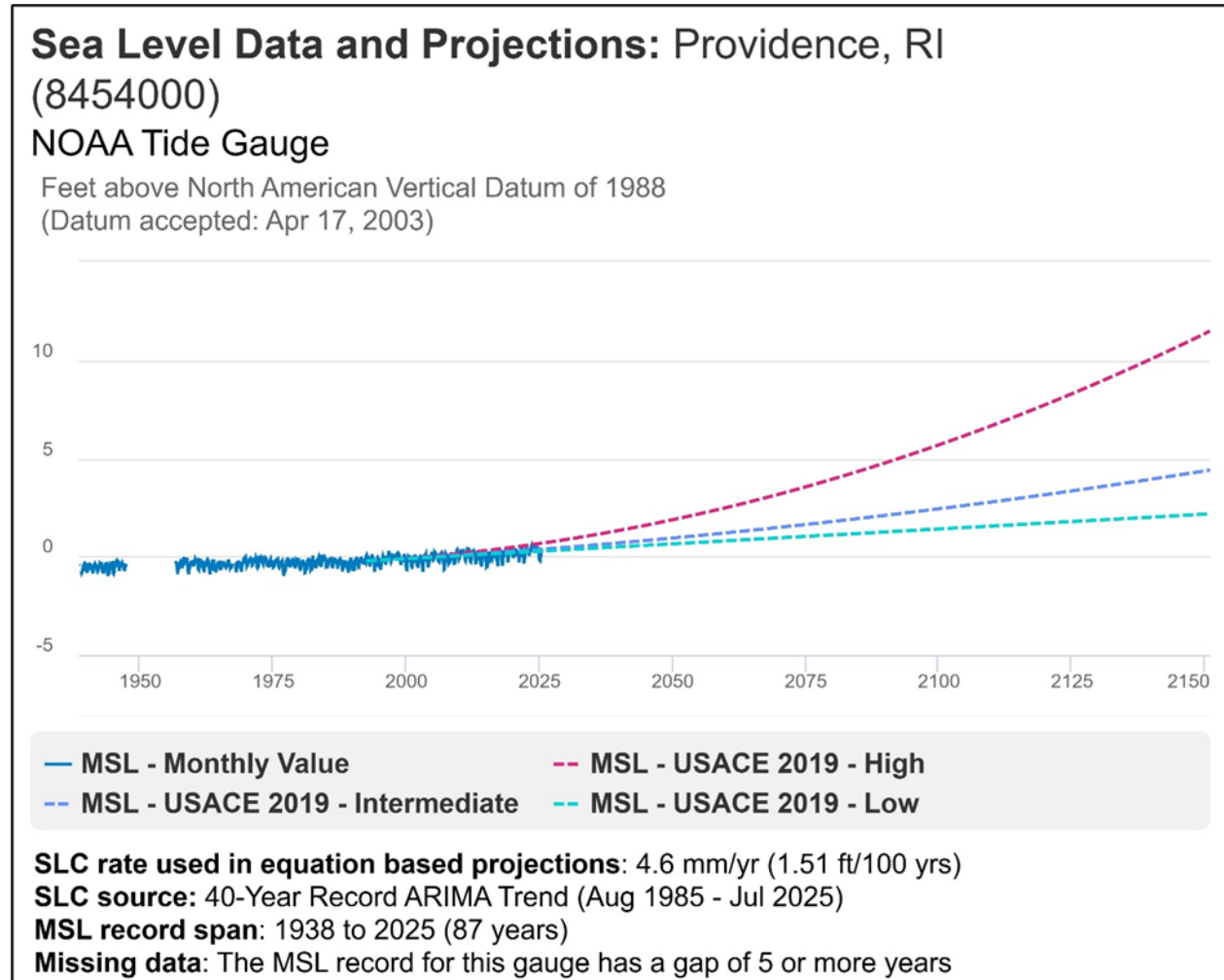


Figure C-3. USACE 2019 scenario projections for Providence, using a SLC rate of 4.6 mm/yr (40-year record ARIMA trend).

Table C-1 and Table C-2 present projected mean water levels in NAVD88 for each decade under the low, intermediate, and high USACE 2019 sea level change scenarios for each rate of sea level rise. Table C-3 shows the estimated timing of critical threshold exceedances, indicating the year each threshold is first likely to be exceeded under the same scenarios.

For both tables, the future water levels only consider projected rates of sea level rise for each scenario plus mean sea level. Equation-based projections for the rates of sea level rise are constructed using a quadratic function based on the estimated linear sea level change rate plus an acceleration constant that differentiates each scenario. Equation-based projections are set to start at 0 feet above the MSL datum at

the midpoint of the datum epoch (currently July 1992 for gages on the National Tidal Datum Epoch). Projected sea level is calculated at a monthly time scale.

Together, these tables highlight how average water levels are projected to change over time and when key thresholds may be crossed, illustrating differences across scenarios and the potential progression of future conditions.

Table C-1
USACE SLR scenarios, 1992–2150; projections based on the NOAA Providence tide gage and 40-year record rate of sea-level change (4.6 mm/yr).

Year	Low	Intermediate	High
1992	-0.22	-0.22	-0.22
2000	-0.1	-0.09	-0.08
2010	0.05	0.08	0.17
2020	0.2	0.27	0.49
2030	0.35	0.48	0.89
2040	0.5	0.71	1.36
2050	0.66	0.95	1.9
2060	0.81	1.22	2.52
2070	0.96	1.5	3.21
2080	1.11	1.8	3.98
2090	1.26	2.11	4.82
2100	1.41	2.45	5.73
2110	1.56	2.8	6.72
2120	1.71	3.17	7.79
2130	1.86	3.56	8.92
2140	2.01	3.96	10.13
2150	2.16	4.38	11.42

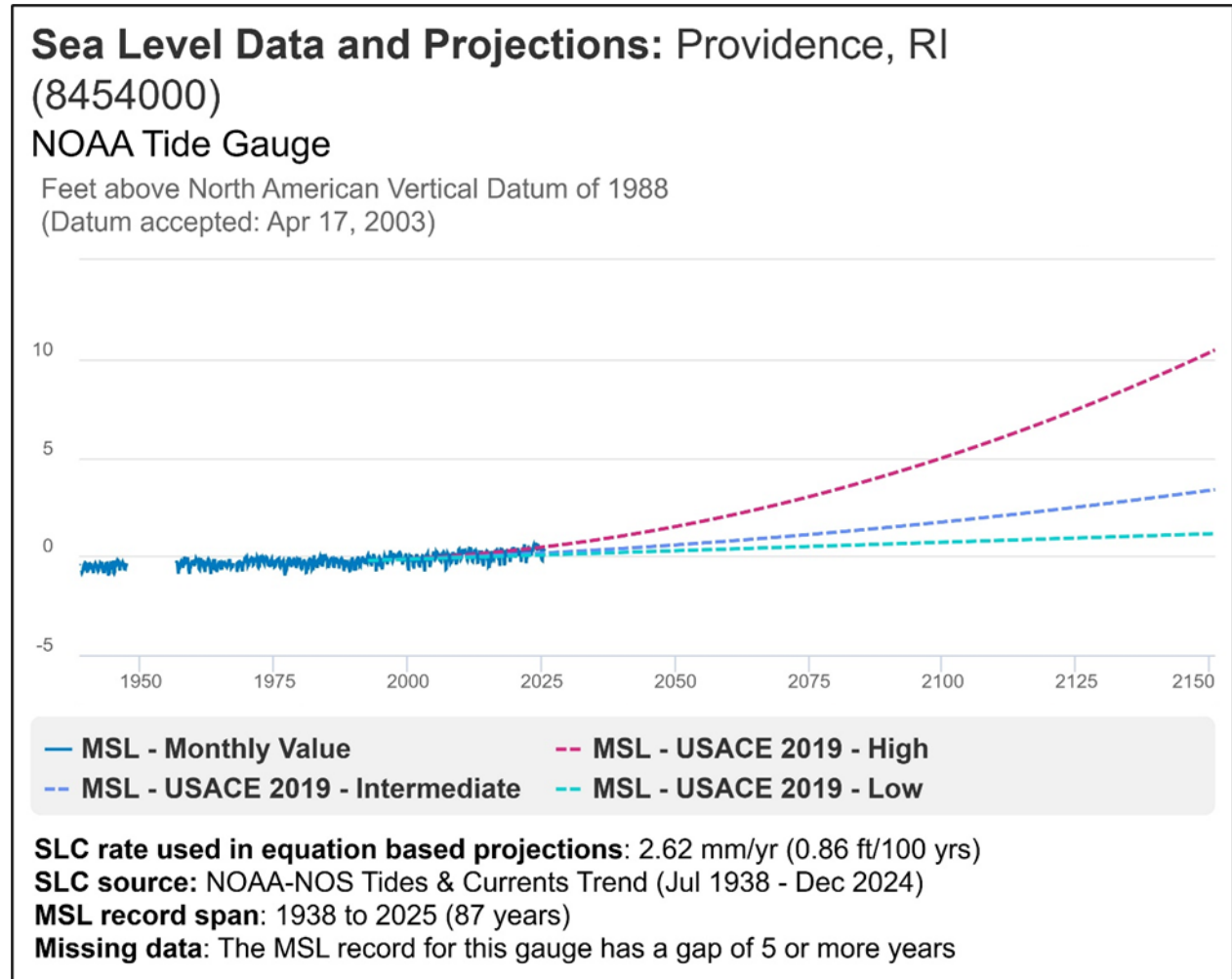


Figure C-4. USACE 2019 scenario projections for Providence, using a SLC rate of 2.62 mm/yr (NOAA-NOS Tides & Currents Trend).

Table C-2

USACE SLR scenarios, 1992–2150; projections based on the NOAA Providence tide gauge and full record rate of sea-level change (2.62 mm/yr).

Year	Low	Intermediate	High
1992	-0.22	-0.22	-0.22
2000	-0.15	-0.15	-0.13
2010	-0.07	-0.04	0.05
2020	0.02	0.09	0.31
2030	0.11	0.23	0.64
2040	0.19	0.4	1.05
2050	0.28	0.58	1.53
2060	0.36	0.78	2.08
2070	0.45	0.99	2.71
2080	0.54	1.22	3.41

Fox Point Storm Surge Barrier System Vulnerability Assessment
Gate Operations Analysis Tool (GOAT)

Year	Low	Intermediate	High
2090	0.62	1.48	4.18
2100	0.71	1.75	5.03
2110	0.79	2.03	5.96
2120	0.88	2.34	6.95
2130	0.97	2.66	8.03
2140	1.05	3	9.17
2150	1.14	3.36	10.39

Table C-3
Projected timing of critical threshold exceedance for USACE 2019 scenarios.

Critical Threshold Description	Critical Elevation (ft NAVD88)	RSLR Used for Projections	Timing of Critical Threshold Exceedance: USACE Low	Timing of Critical Threshold Exceedance: USACE Int	Timing of Critical Threshold Exceedance: USACE High
Top of the Barrier	24.2	4.6 mm/yr (40-year trend)	None	None	None
		2.62 mm/yr (full record trend)	None	None	None
Tainter Gate Barrier Closure Elevation Threshold	5.2	4.6 mm/yr (40-year trend)	None	None	2094
		2.62 mm/yr (full record trend)	None	None	2102
Allens Ave Street Gate	11.2	4.6 mm/yr (40-year trend)	None	None	2148
		2.62 mm/yr (full record trend)	None	None	None
Rhode Island Energy	8.2	4.6 mm/yr (40-year trend)	None	None	2124
		2.62 mm/yr (full record trend)	None	None	2132
India Street Gate	9.0	4.6 mm/yr (40-year trend)	None	None	2131
		2.62 mm/yr (full record trend)	None	None	2139
South Water Street Gate	13.9	4.6 mm/yr (40-year trend)	None	None	None
		2.62 mm/yr (full record trend)	None	None	None
South Main Street Gate	14.1	4.6 mm/yr (40-year trend)	None	None	None

Critical Threshold Description	Critical Elevation (ft NAVD88)	RSLR Used for Projections	Timing of Critical Threshold Exceedance: USACE Low	Timing of Critical Threshold Exceedance: USACE Int	Timing of Critical Threshold Exceedance: USACE High
		2.62 mm/yr (full record trend)	None	None	None
Phase 1 Sewer Gate	6.7	4.6 mm/yr (40-year trend)	None	None	2110
		2.62 mm/yr (full record trend)	None	None	2118
Phase 2 Sewer Gate	11.7	4.6 mm/yr (40-year trend)	None	None	None
		2.62 mm/yr (full record trend)	None	None	None

C.5. Forecast Future Exceedances Under Sea Level Change Scenarios

C.5.1. Simulation Method

The U.S. Army Corps of Engineers (USACE) Gate Operations Analysis Tool forecasts future water levels and potential threshold exceedances using a statistical simulation model in R. Historical daily maximum water levels and gate closure records form the basis of the analysis. The model determines the best-fitting statistical distribution for each month of the year, then generates large sets of synthetic water level data adjusted annually for projected relative sea level rise under low, intermediate, and high scenarios.

These simulated water levels are combined with an empirical relationship between water level and closure probability to estimate future closure frequencies. In the absence of historical closure data, a 100% exceedance probability is assumed for values at or above the operational threshold. The simulation runs on a daily time step from 1992 through 2100, producing thousands of independent trials for each year. Results include mean annual exceedances as well as uncertainty bounds based on the 1% and 99% quantiles.

Figure C-5 shows the historic closures of the Fox Point barrier from 1964–2024. There is a noticeable spike in closures in 2010, but this does not indicate a sudden change in system performance. Instead, it reflects the point at which the U.S. Army Corps of Engineers (USACE) assumed responsibility for operating and maintaining the dam. When USACE assumed control of the barrier in 2010, the functionality of the large river pumps in the pumpstation were questionable and not all pumps were working due to a lot of deferred maintenance. In coordination with the City of Providence, it was agreed to lower the Tainter closure criteria for operation of the barrier until USACE could get the barrier fully functional. The 2010 spike in operations is due to this lowered criterion. The USACE is now back to the original Tainter gate closure criteria and is experiencing fewer closure per year. This is due to operational improvements, which have allowed operators to raise the threshold for when a gate closure is needed, resulting in fewer closures. A reasonable baseline for closures per year based on the historic data is less than five.

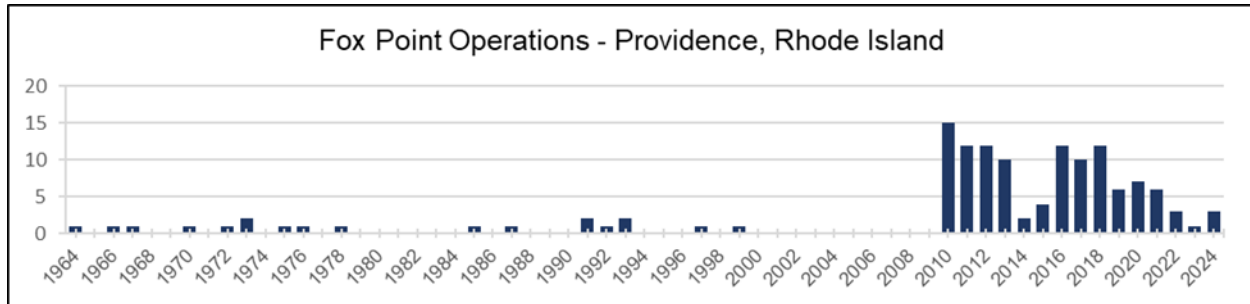


Figure C-5. Fox Point historic closure record.

Before generating simulated water levels, the historic tide gage record was detrended to a 1992 baseline using a first-degree polynomial regression (Figure C-6). The year 1992 was selected because it represents the midpoint of the NOAA National Tidal Datum Epoch (1983–2001), providing a standardized reference for mean sea level. Detrending to this baseline removes the long-term rise signal from the observations, isolating the variability around mean conditions for 1992. This allows projected sea level rise scenarios to be added consistently, ensuring that simulated values reflect observed variability without double-counting the historic trend.

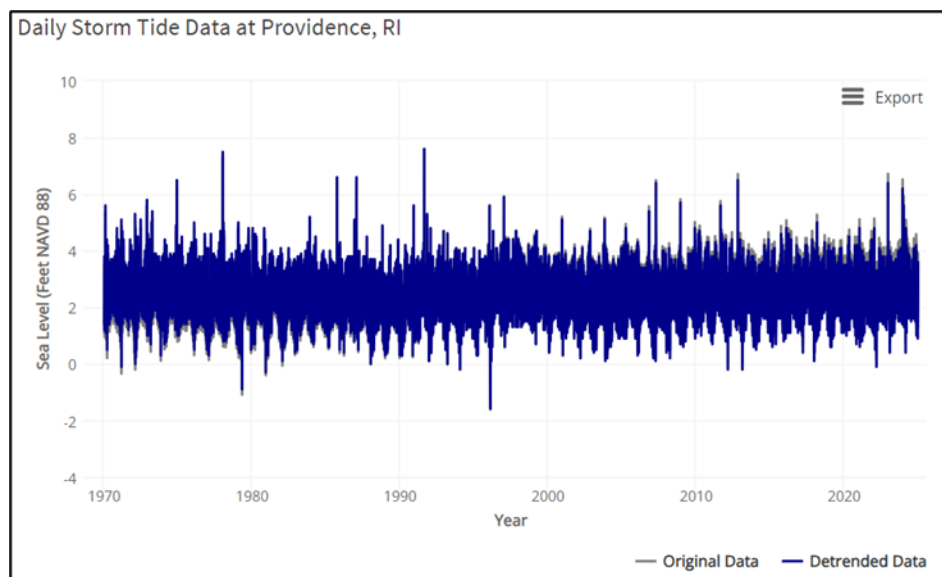


Figure C-6. Historic daily storm tide data at Providence, RI, from the Gate Operations Analysis Tool.

The plots in Figure C-7 show how well the best-fit distribution fits the data for each month in the time series. Consistent with the simulation procedure outlined previously, the distribution is fit to each month in the time series separately, resulting in 12 sets of distribution parameters.

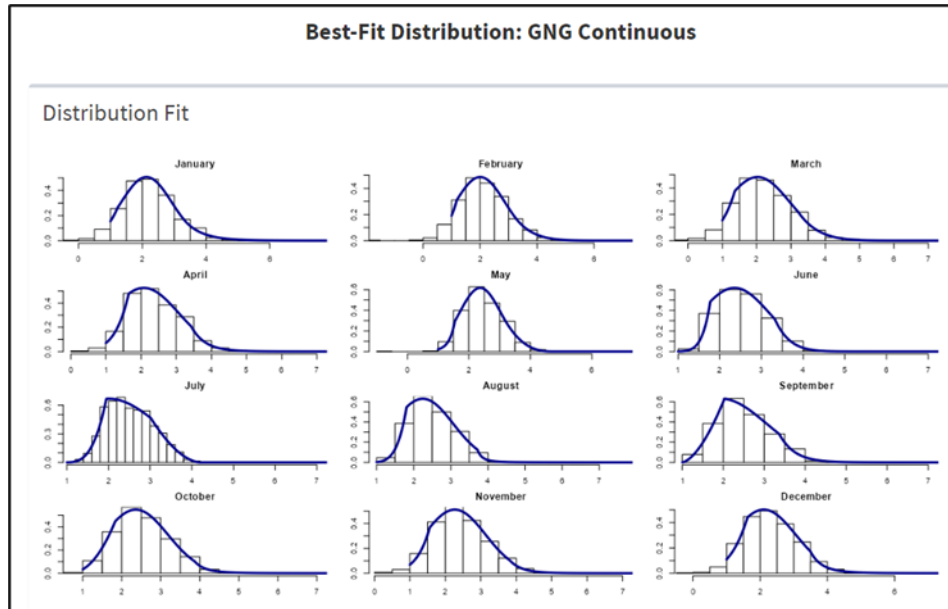


Figure C-7. Monthly distribution plots visualizing the best-fit distribution, GNG Continuous, for daily peak water levels at the Providence tide gage.

C.5.2. Incorporating Sea Level Rise

The threshold exceedance model computes sea level rise for three scenarios: low, intermediate, and high. Projected relative sea level change (RSLC) for each year was calculated in R based on methods used in the USACE Sea Level Analysis Tool. For every year in the simulation period (1992 – 2100), the projected annual RSLC was added to the mean of the monthly distribution, effectively shifting the monthly distributions to the right each year while maintaining the same shape. These future values incorporate both the projected sea level increases with the natural variability of monthly water levels to represent how mean water levels could realistically fluctuate under each scenario.

Figure C-8 through Figure C-10 show the distribution of simulated monthly water levels across all years in the projection period. Each box represents the variability within a month, while the overlaid lines indicate the monthly averages for 1992 and the projected years 2050, 2075, and 2100. There is a box plot for each scenario: low, intermediate, and high. These visualizations highlight both the seasonal variability and the gradual increase in mean water levels over time, showing how typical monthly conditions are represented in the simulations for 1992 and the projected years 2050, 2075, and 2100.

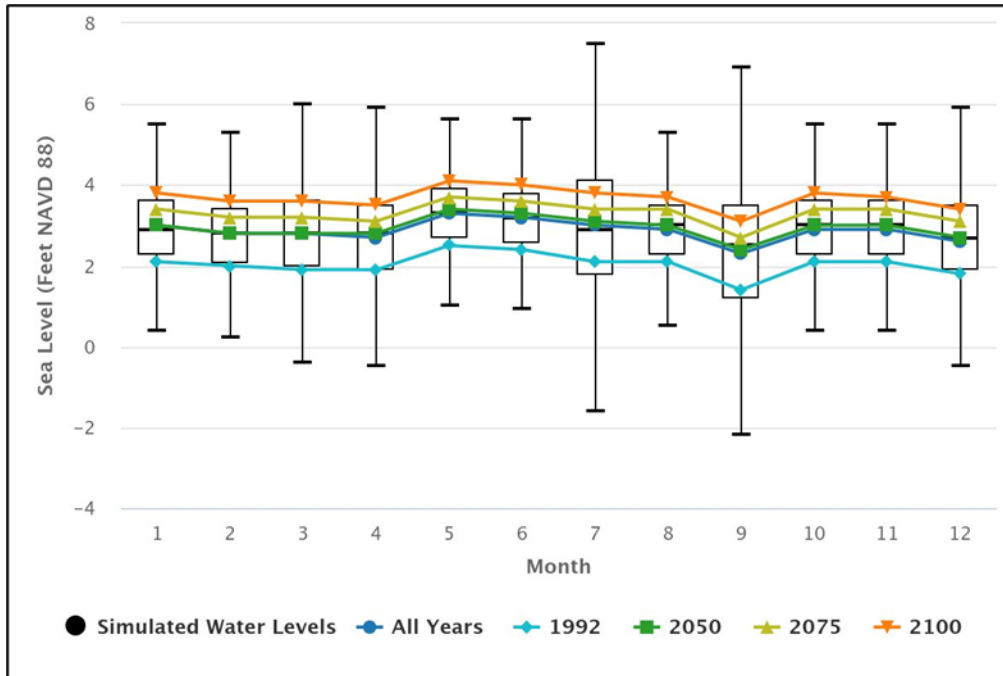


Figure C-8. Monthly boxplots of simulated daily water levels under the Low scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100.

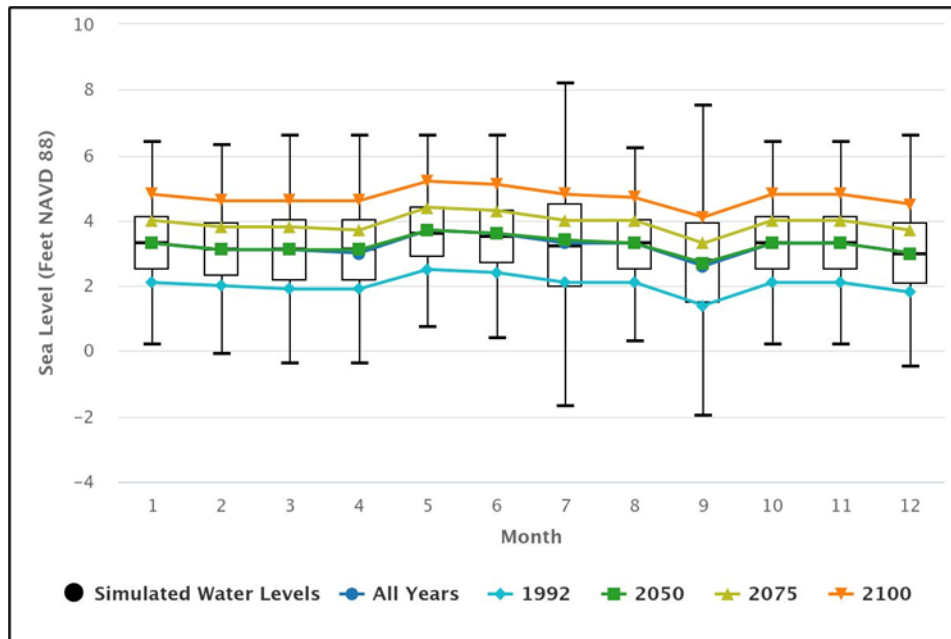


Figure C-9. Monthly boxplots of simulated daily water levels under the Intermediate scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100.

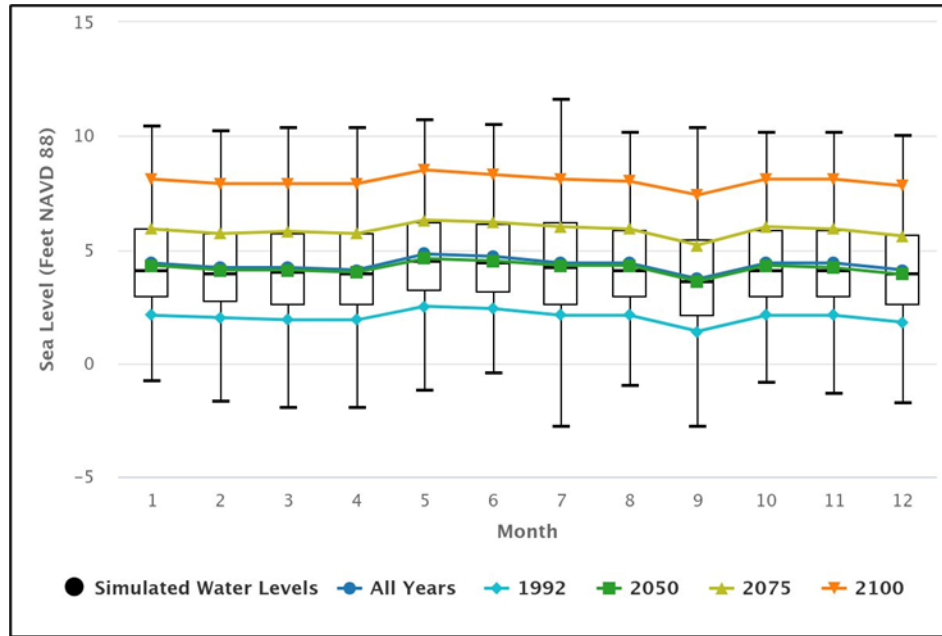


Figure C-10. Monthly boxplots of simulated daily water levels under the High scenario (4.6 mm/yr SLR), with mean values highlighted for 1992, 2050, 2075, and 2100.

C.6. Projection Results

C.6.1. Top Elevation of Fox Point Feature (24.2 ft NAVD88)

The top elevation of the Fox Point hurricane barrier was analyzed using SLAT to assess potential overtopping when adding projected sea level rise to the water level from the barrier’s storm of record/design, the 1938 hurricane with an estimated elevation of 15 ft NAVD88. Outputs from SLAT include the intersections of the storm of record combined with USACE 2019 Low, Intermediate, and High sea level rise scenarios, assuming the 40-year record rate of 4.6 mm/yr as of July 2025 as used in all other analyses performed for this report. Table C-4 shows the projected intersections with the top of the barrier for each scenario. Figure C-11 shows the projections from 15 ft storm of record water level.

Intersections with only projected mean sea level are available for all thresholds in Table C-3 but are included for the top of the barrier in the table below for easy reference.

Table C-4

Projected timing of critical threshold exceedance for USACE 2019 scenarios with an offset of 15 ft: Intersections with top elevation of Fox Point feature (24.2 feet).

Water Level	Source	Scenario	Intersections
1938 Hurricane: 15' NAVD88	USACE 2019	High	2131
		Intermediate	None
		Low	None
Mean Sea Level (MSL)	USACE 2019	High	None
		Intermediate	None

Water Level	Source	Scenario	Intersections
		Low	None

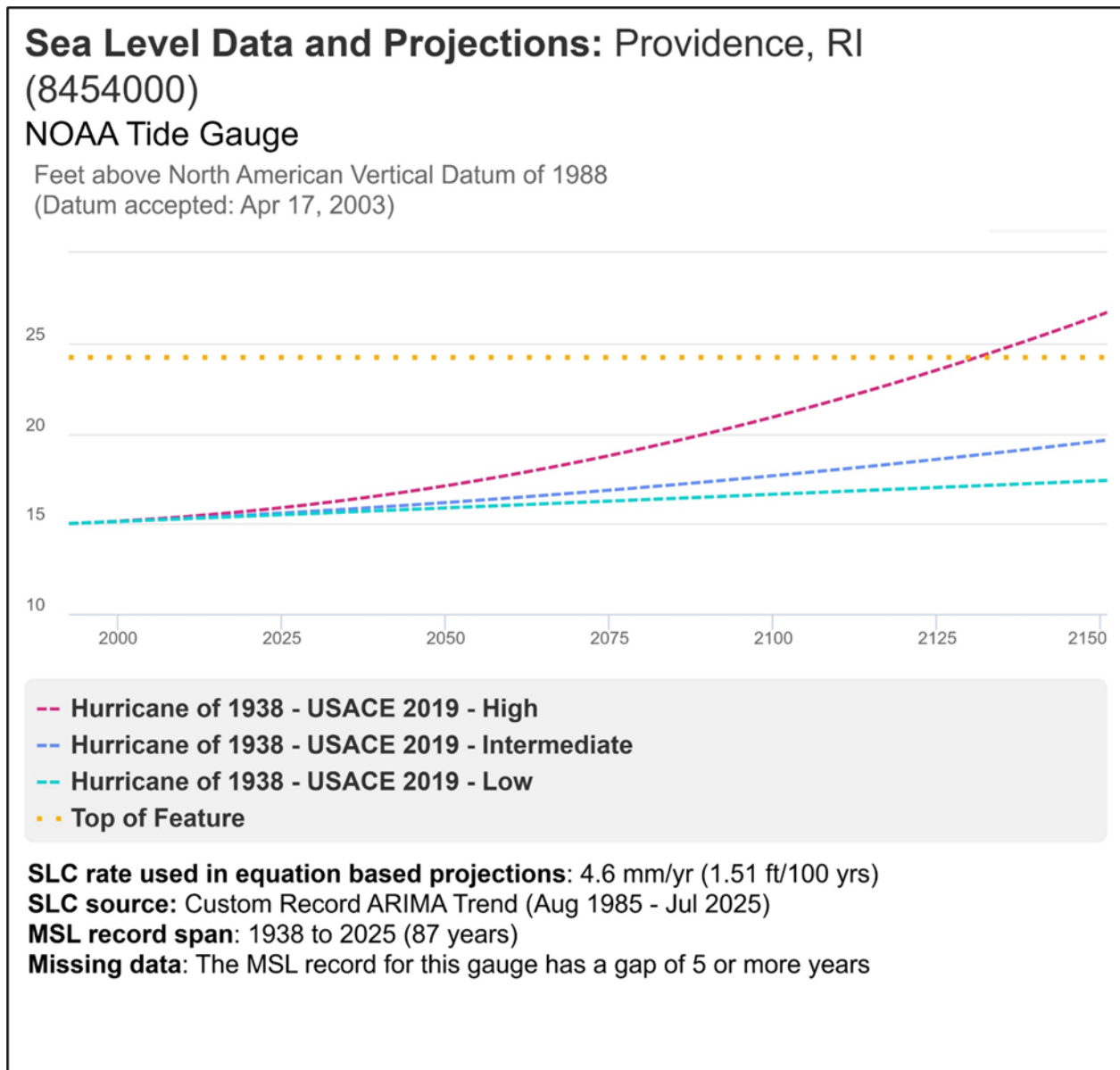


Figure C-11. USACE 2019 scenario projections for Providence, using a SLC rate of 4.6 mm/yr (40-year record ARIMA trend) from the 15-foot storm of record.

C.6.2. Tainter Gate Barrier Closure Elevation Threshold (5.2 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedances for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent

closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-5
Upper and lower estimates for elevation thresholds of 5.2 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Lower (95%)	Upper (99%)
2025	Low	0	1	1	4	7	8	11
	Intermediate	1	1	2	5	8	9	11
	High	2	3	4	7	11	13	14
2050	Low	2	3	4	8	11	12	13
	Intermediate	5	6	6	12	17	18	20
	High	44	46	49	58	70	73	74
2075	Low	5	6	7	13	18	20	23
	Intermediate	21	25	27	35	45	47	50
	High	273	277	278	288	300	302	306
2100	Low	15	17	17	23	30	32	34
	Intermediate	105	111	113	128	144	145	148
	High	350	351	353	357	361	362	362

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of exceedance. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

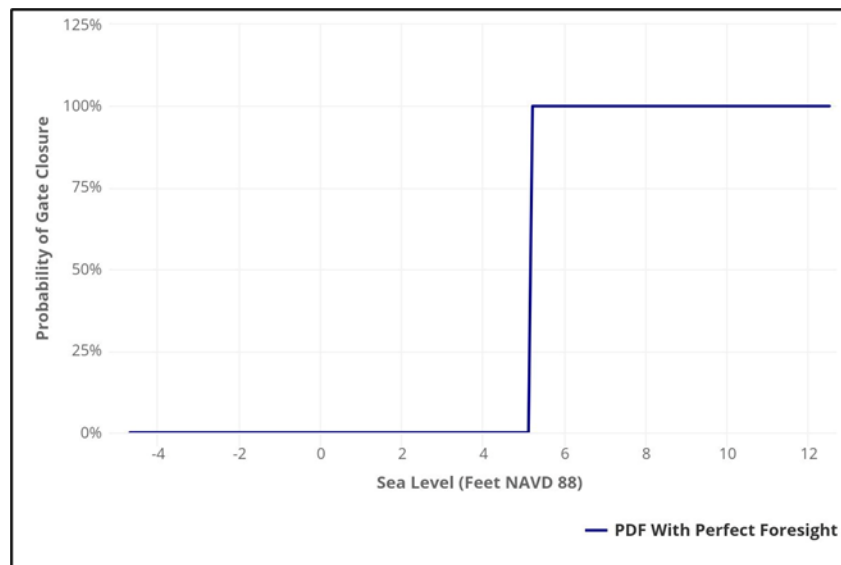


Figure C-12. Probability density function (PDF) illustrating threshold exceedance relative to the 5.2 ft threshold.

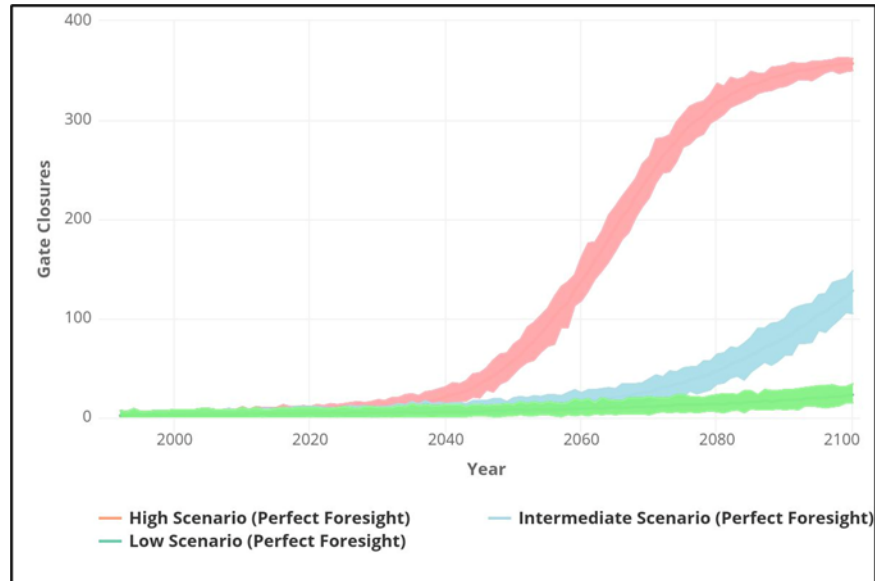


Figure C-13. Estimated threshold exceedances by scenario for water levels exceeding 5.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

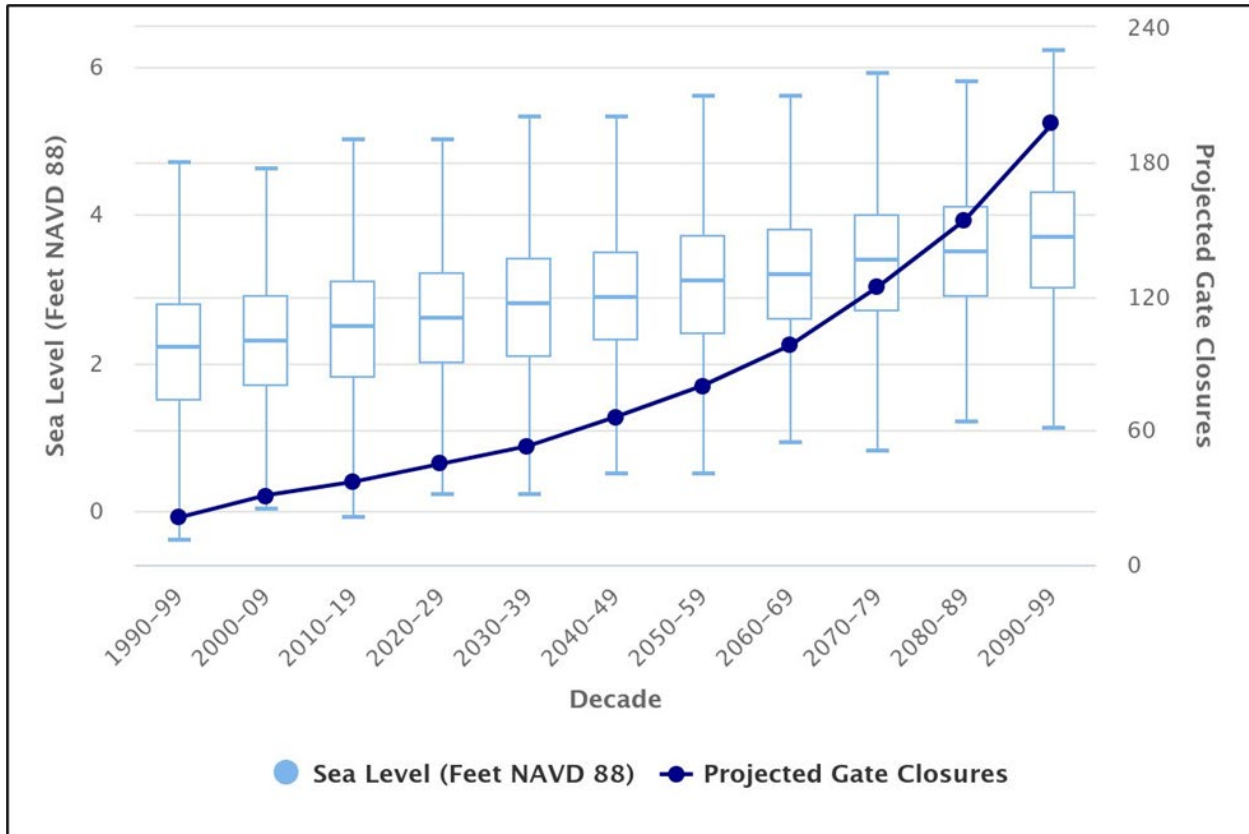


Figure C-14. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-6

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	21	2	11-38
2000-09	31	3	19-45
2010-19	37	3	24-52
2020-29	45	4	31-60
2030-39	53	5	35-70
2040-49	66	6	45-84
2050-59	80	8	60-99
2060-69	98	9	71-122
2070-79	124	12	100-149
2080-89	154	15	131-178
2090-99	197	19	164-228

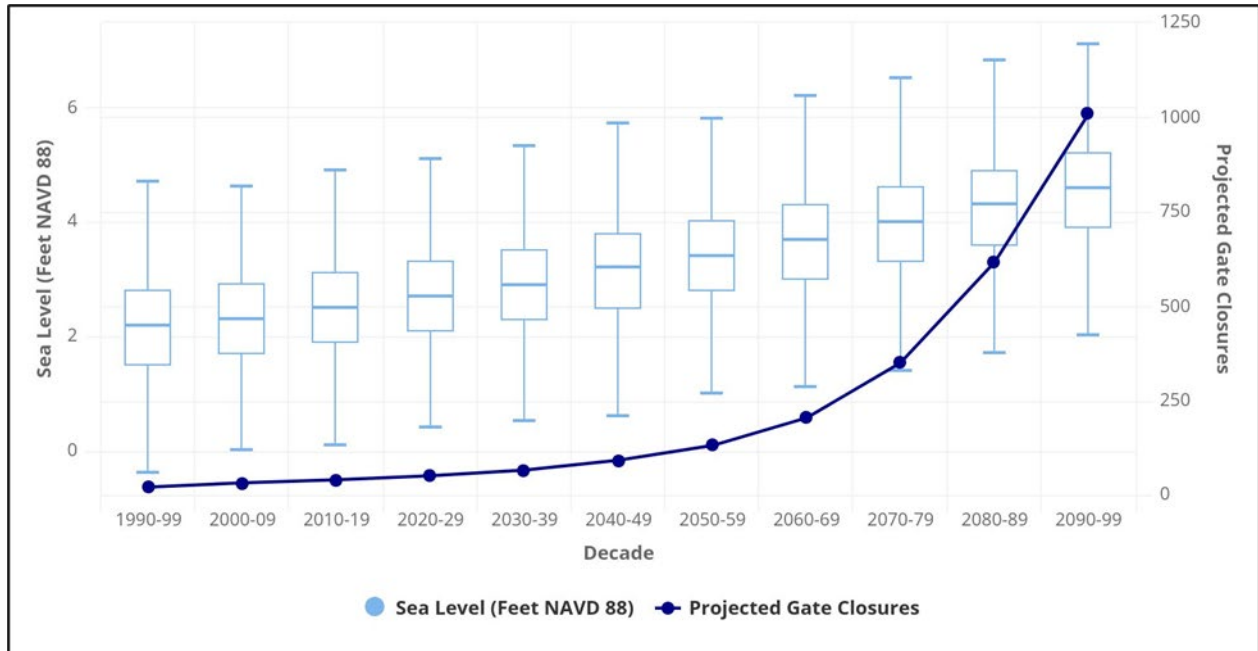


Figure C-15. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-7

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	21	2	11-38
2000-09	32	3	20-47
2010-19	40	4	27-54
2020-29	51	5	37-68
2030-39	66	6	46-86
2040-49	92	9	70-113
2050-59	131	13	105-156
2060-69	204	20	163-237
2070-79	350	35	310-385
2080-89	616	61	568-661
2090-99	1,009	100	946-1,065

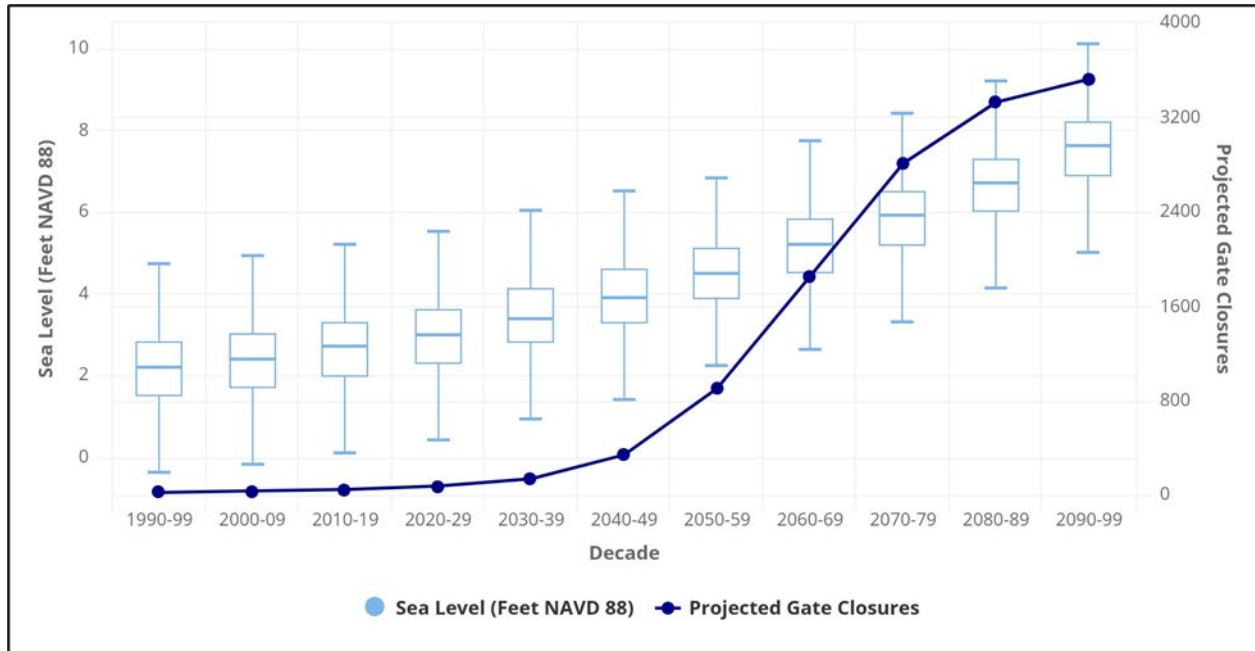


Figure C-16. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-8

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	21	2	11-39
2000-09	34	3	22-49
2010-19	47	4	33-64
2020-29	75	7	58-93
2030-39	137	13	111-164
2040-49	340	34	303-374
2050-59	904	90	837-963
2060-69	1,853	185	1,776-1,921
2070-79	2,808	280	2,749-2,862
2080-89	3,327	332	3,286-3,368
2090-99	3,522	352	3,501-3,550

C.6.3. Allens Ave Street Gate (11.2 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more

frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-9
Upper and lower estimates for elevation thresholds of 11.2 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	0	0	1
2050	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0
2075	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	1	1	2
2100	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	1
	High	0	1	1	3	5	6	8

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

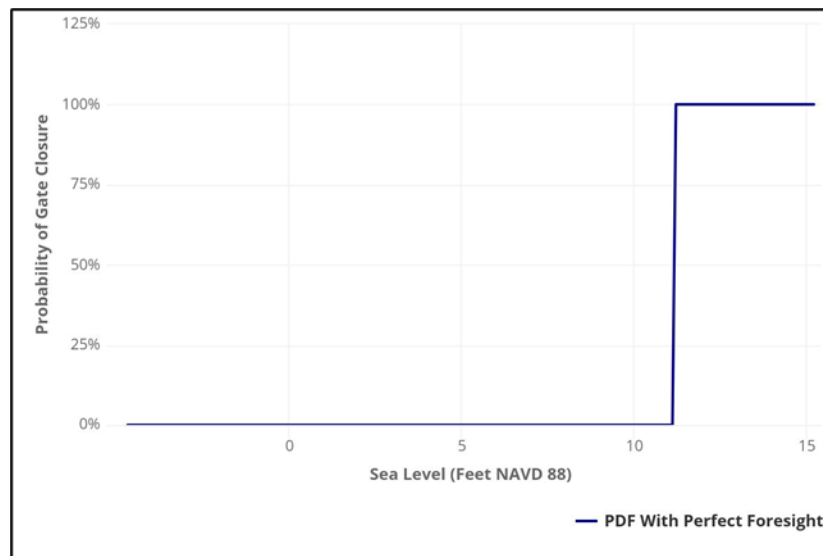


Figure C-17. Probability density function (PDF) illustrating threshold exceedance response relative to the 11.2 ft NAVD88 threshold.

Confidence intervals are not shown in the plot below because the mean values remain consistently near zero. Including the intervals would produce visual fluctuations that do not reflect meaningful variation. Omitting them emphasizes that the observed signal is effectively zero and avoids drawing attention to spurious spikes caused by statistical noise.

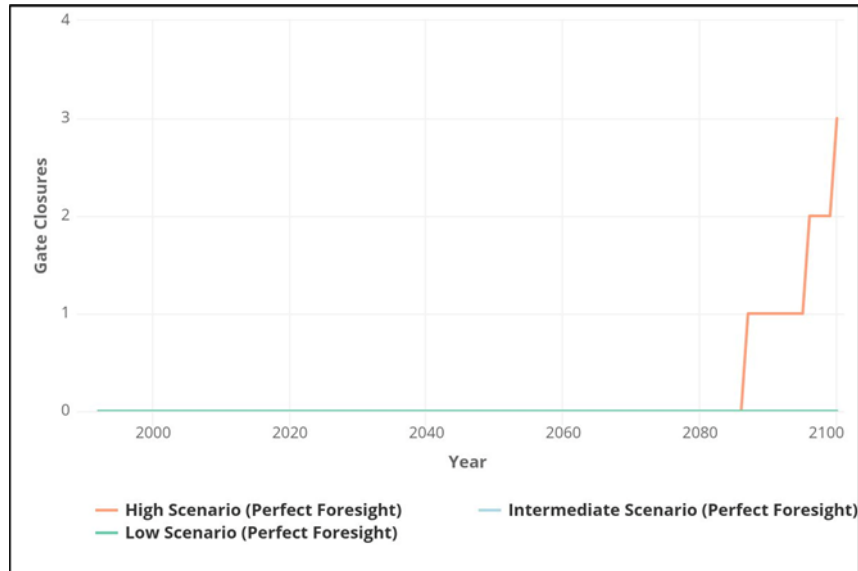


Figure C-18. Estimated threshold exceedances by scenario for water levels exceeding 11.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

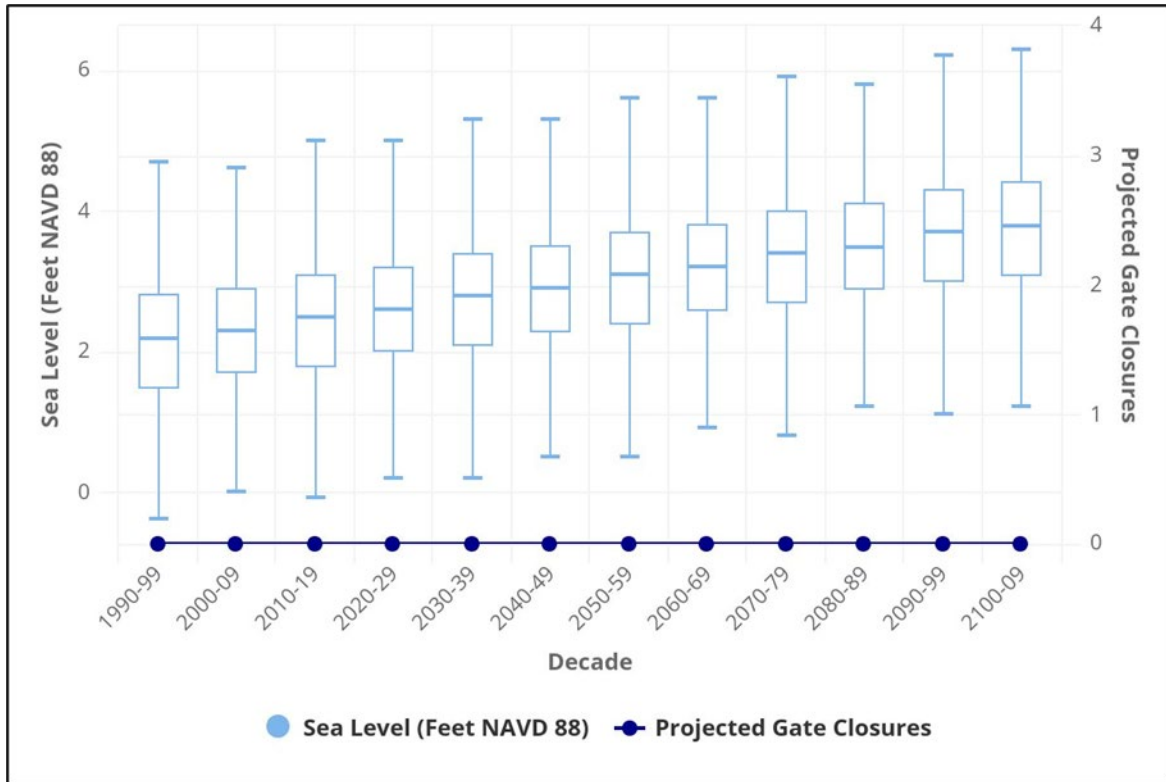


Figure C-19. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-10

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0
2070-79	0	0	0-1
2080-89	0	0	0-1
2090-99	0	0	0-1

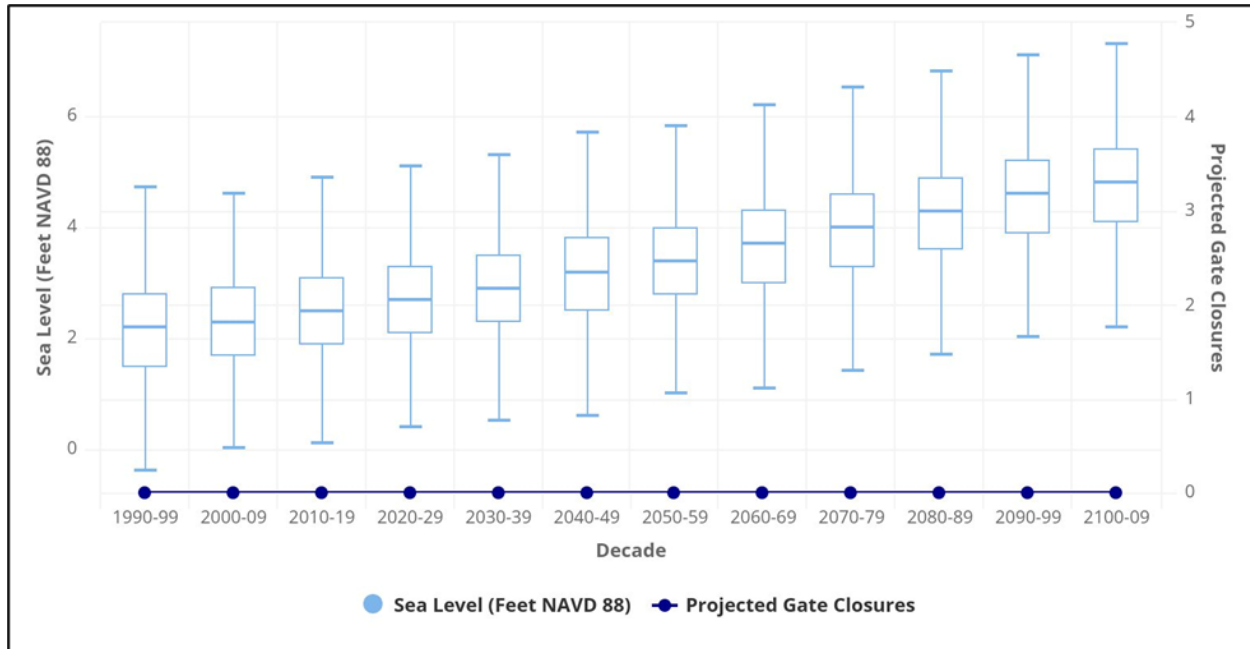


Figure C-20. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-11

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-1
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-1
2070-79	0	0	0-1
2080-89	0	0	0-1
2090-99	0	0	0-1

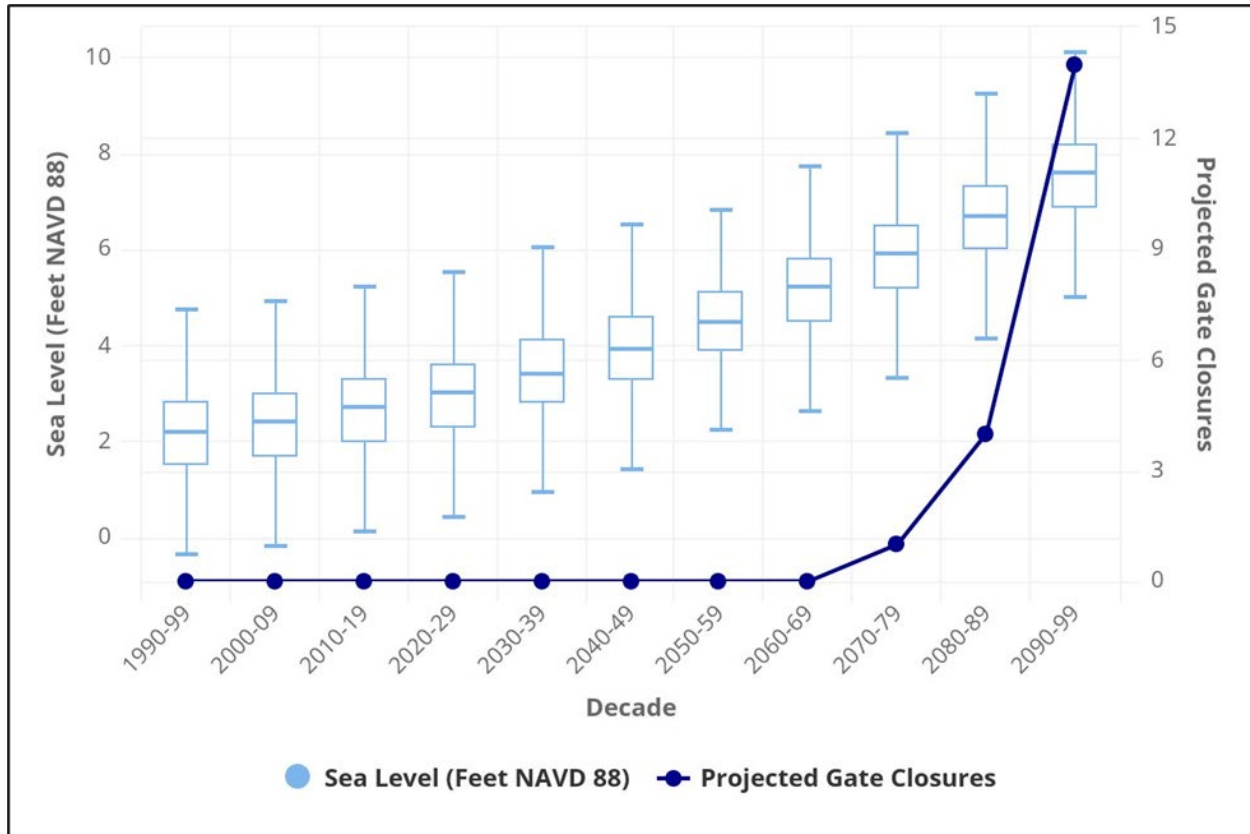


Figure C-21. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-12

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-1
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-2
2070-79	1	0	0-3
2080-89	4	0	0-10
2090-99	14	1	7-25

C.6.4. Rhode Island Energy (8.2 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-13
Upper and lower estimates for elevation thresholds of 8.2 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	1	1	1
	Intermediate	0	0	0	0	1	1	1
	High	0	0	0	0	1	1	2
2050	Low	0	0	0	0	1	1	2
	Intermediate	0	0	0	0	1	1	2
	High	0	0	0	1	2	3	3
2075	Low	0	0	0	0	1	1	2
	Intermediate	0	0	0	1	2	2	3
	High	1	2	3	7	10	11	12
2100	Low	0	0	0	0	2	2	3
	Intermediate	0	0	0	2	3	5	6
	High	148	150	155	171	186	189	193

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

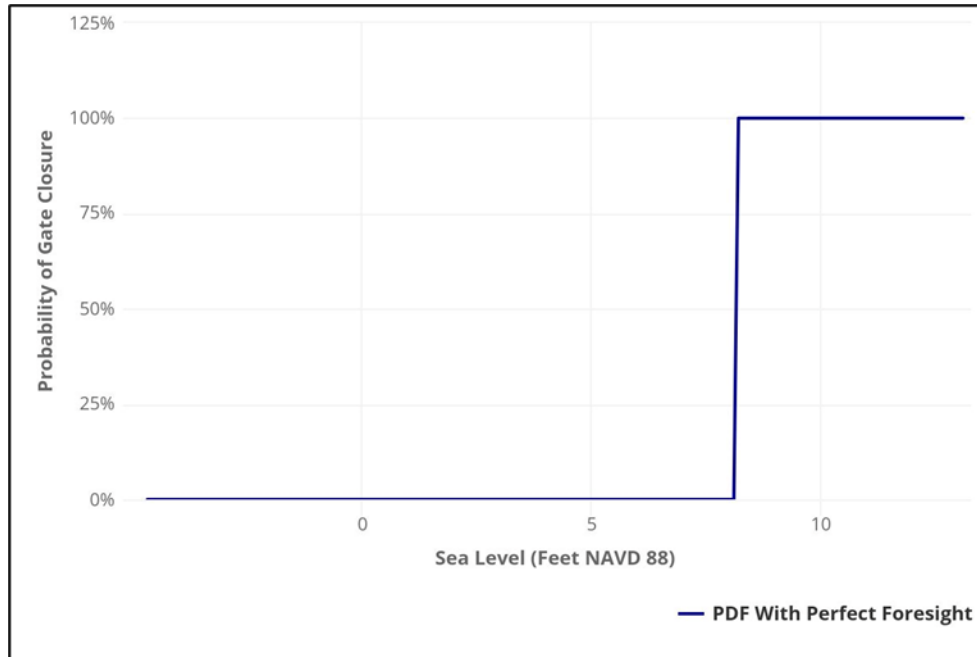


Figure C-22. Probability density function (PDF) illustrating threshold exceedance response relative to the 8.2 ft NAVD88 threshold.

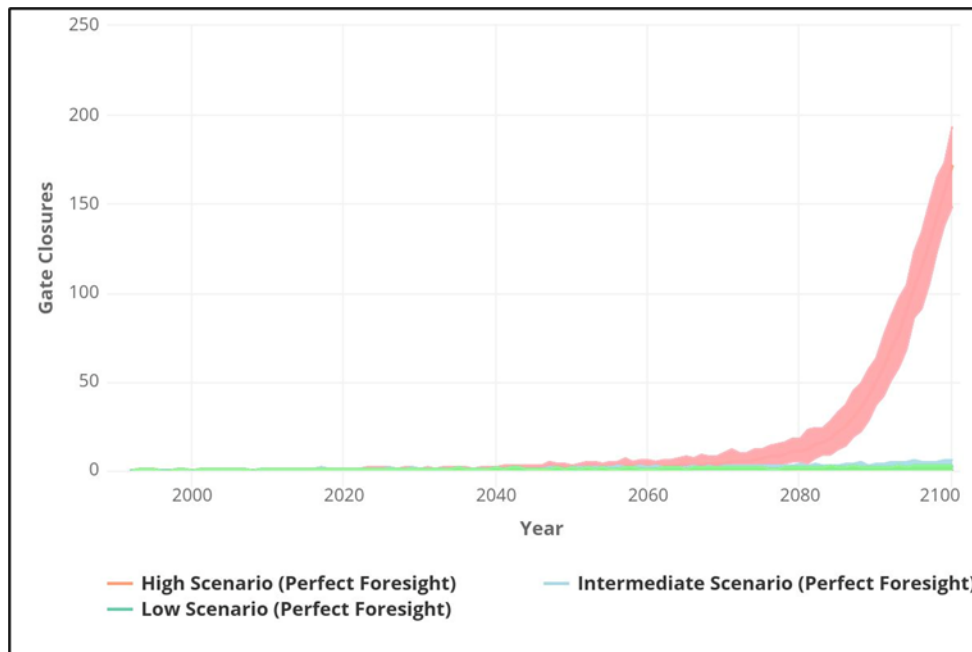


Figure C-23. Estimated threshold exceedances by scenario for water levels exceeding 8.2 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that

period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

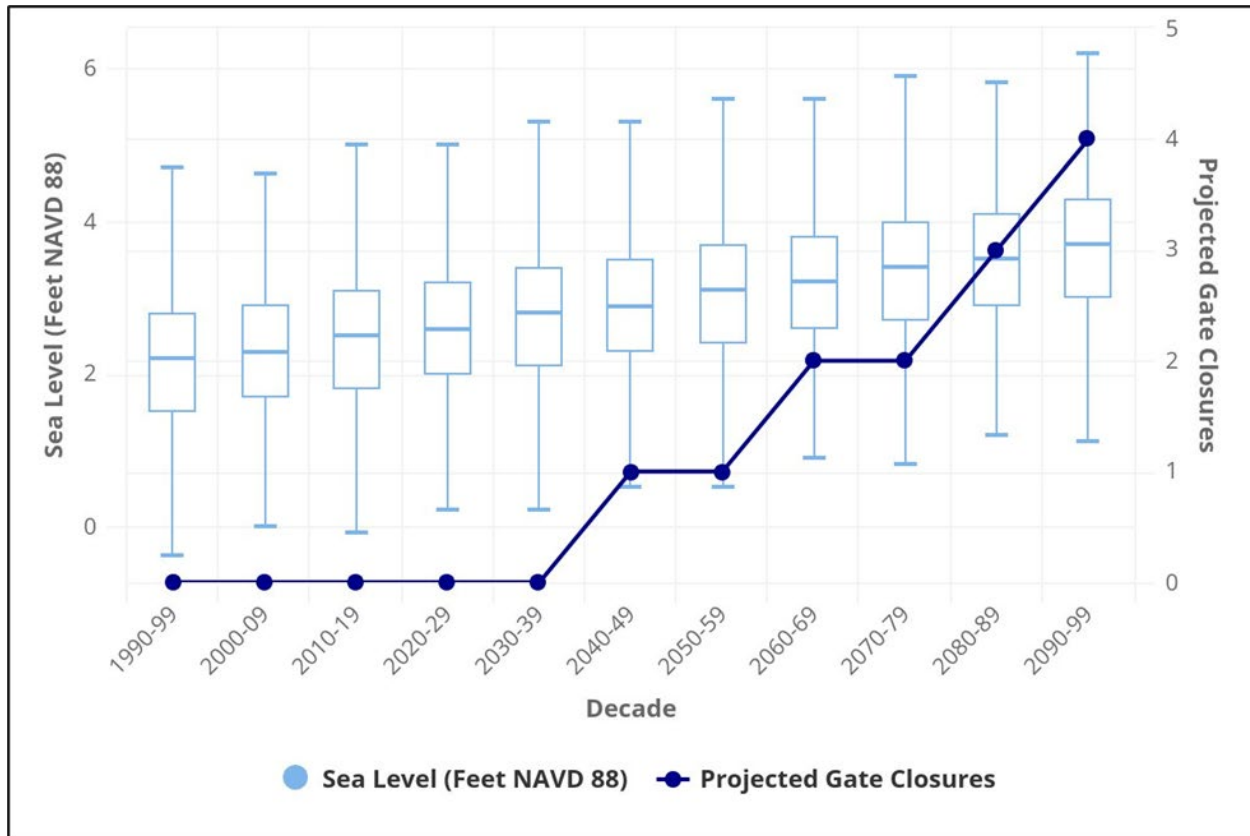


Figure C-24. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-14

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-2
2000-09	0	0	0-2
2010-19	0	0	0-2
2020-29	0	0	0-3
2030-39	0	0	0-3
2040-49	1	0	0-4
2050-59	1	0	0-6
2060-69	2	0	0-6
2070-79	2	0	0-7
2080-89	3	0	0-7

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2090–99	4	0	0–10

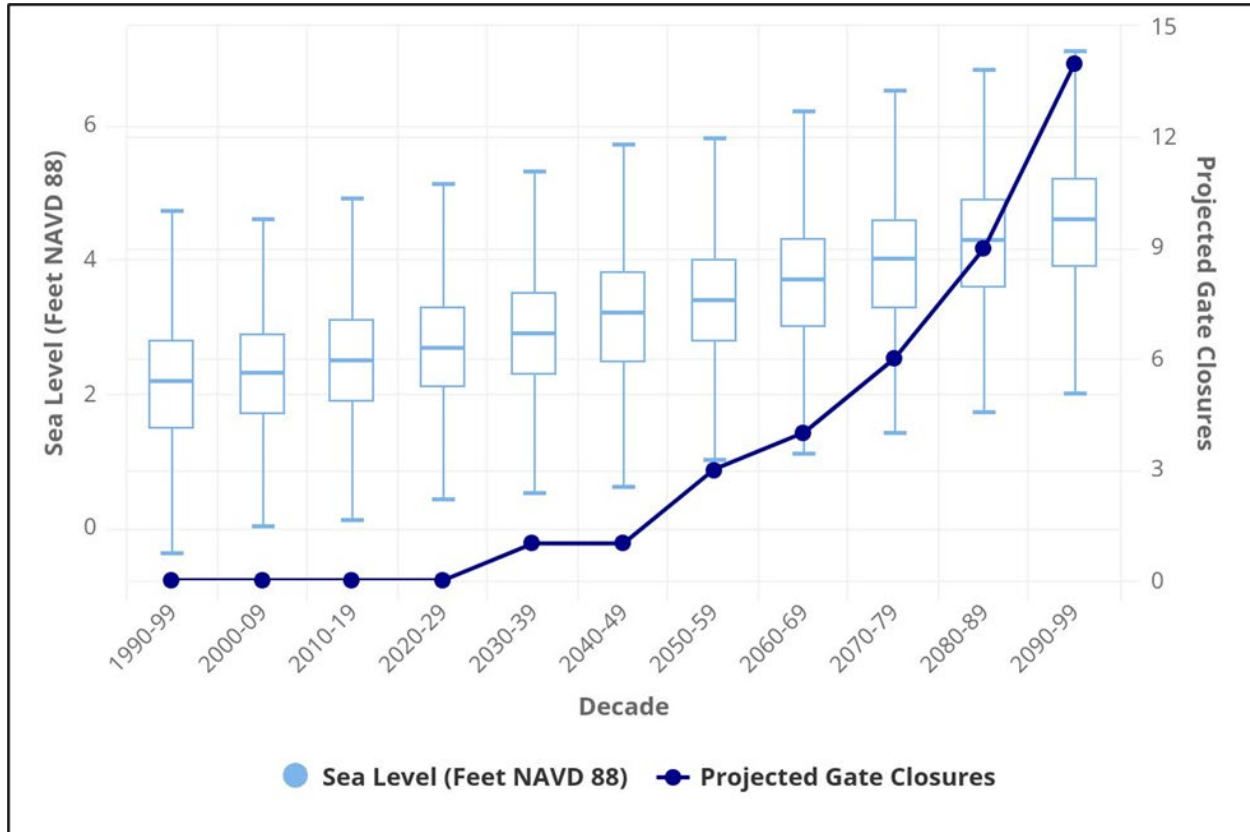


Figure C-25. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-15

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–2
2000–09	0	0	0–2
2010–19	0	0	0–3
2020–29	0	0	0–4
2030–39	1	0	0–4
2040–49	1	0	0–5
2050–59	3	0	0–7
2060–69	4	0	0–11
2070–79	6	0	1–13

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2080–89	9	0	2–17
2090–99	14	1	8–27

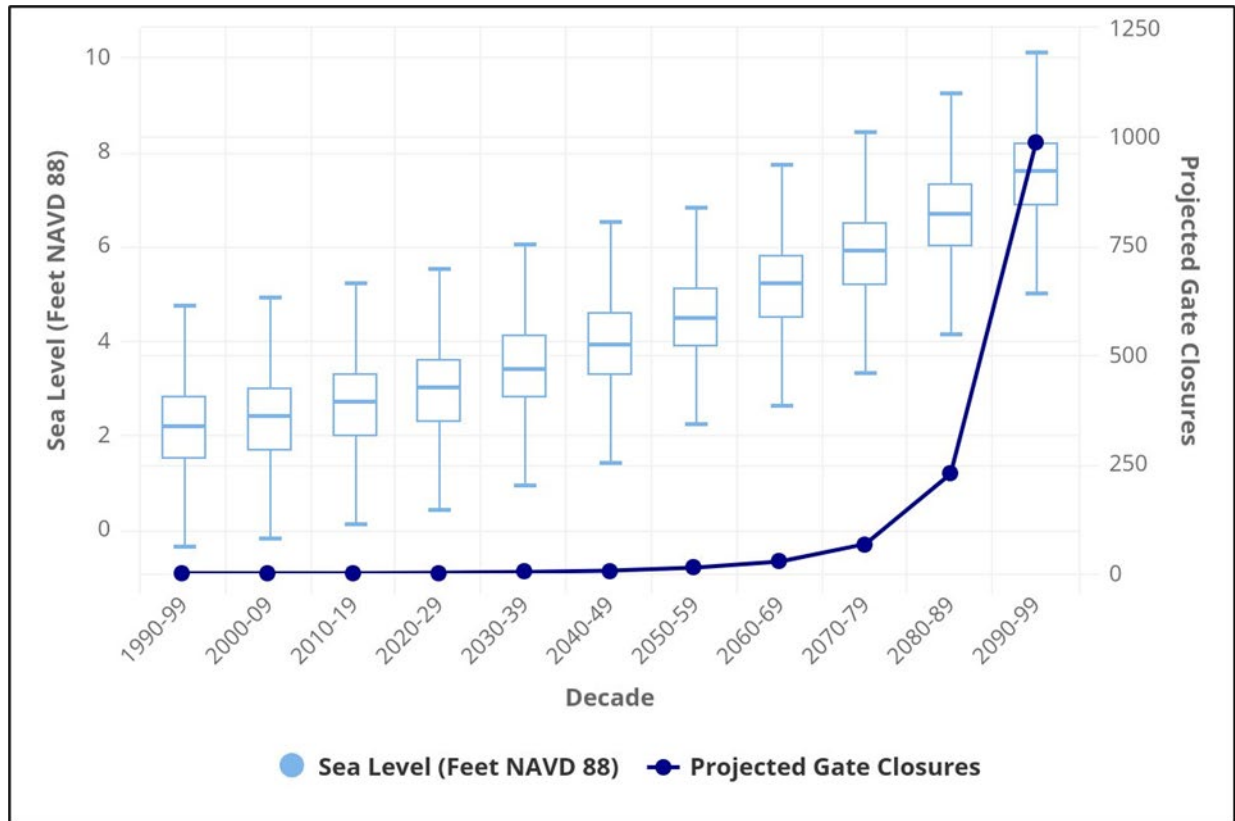


Figure C-26. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-16

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–2
2000–09	0	0	0–2
2010–19	0	0	0–3
2020–29	1	0	0–5
2030–39	3	0	0–6
2040–49	6	0	0–13
2050–59	13	1	8–24
2060–69	27	2	15–39
2070–79	67	6	49–88

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2080–89	228	22	202–258
2090–99	986	98	922–1,039

C.6.5. India Street Gate (9.0 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-17
Upper and lower estimates for elevation thresholds of 9.0 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	0	1	1
	Intermediate	0	0	0	0	0	1	1
	High	0	0	0	0	1	1	1
2050	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	1	2	2
2075	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	1	1	2
	High	0	0	0	2	5	5	7
2100	Low	0	0	0	0	1	1	2
	Intermediate	0	0	0	1	2	3	3
	High	47	50	52	62	71	75	75

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

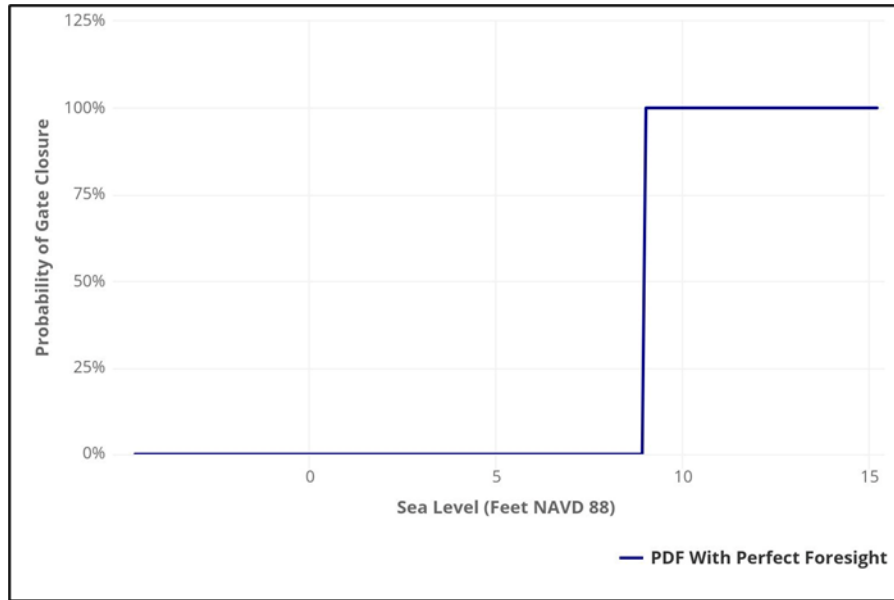


Figure C-27. Probability density function (PDF) illustrating threshold exceedance response relative to the 9.0 ft NAVD88 threshold.

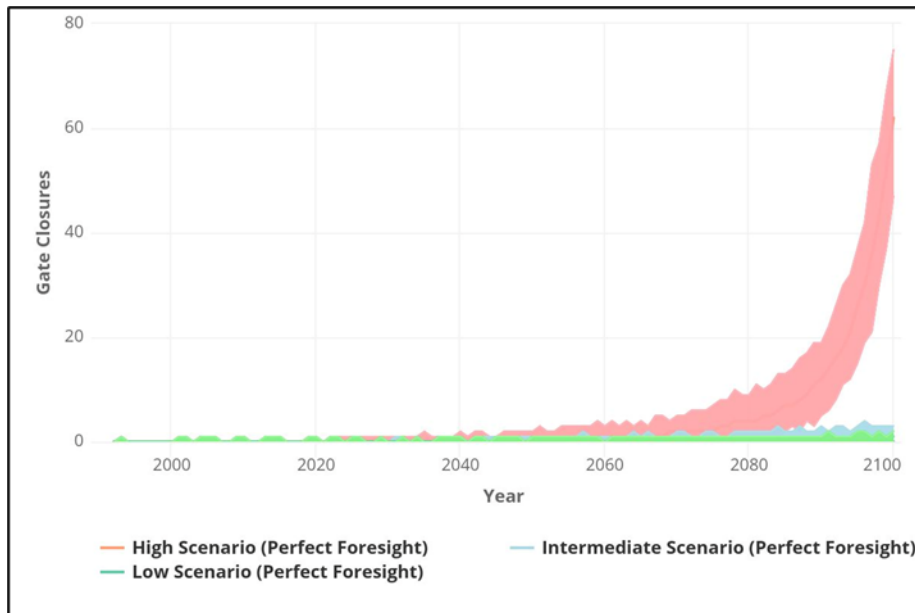


Figure C-28. Estimated threshold exceedances by scenario for water levels exceeding 9.0 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

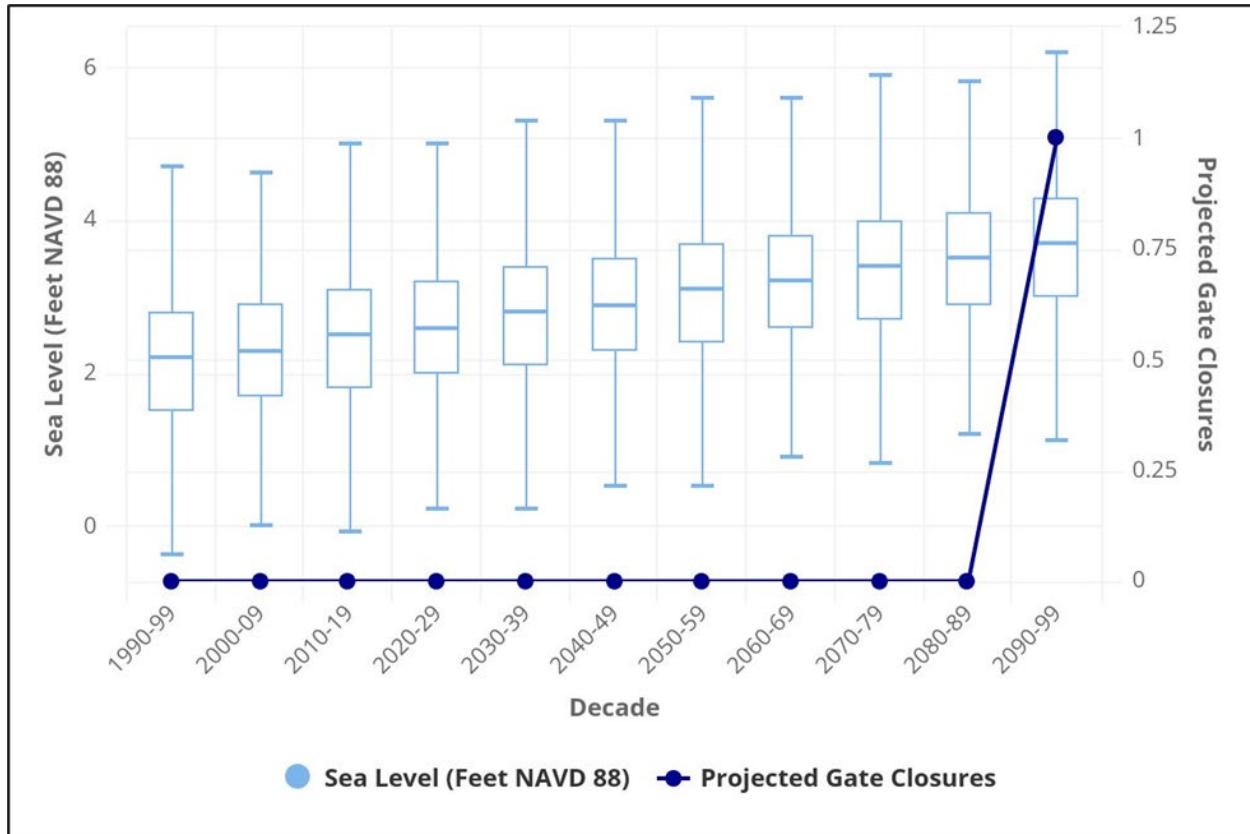


Figure C-29. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-18

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-1
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-1
2040-49	0	0	0-2
2050-59	0	0	0-2
2060-69	0	0	0-2
2070-79	0	0	0-3
2080-89	0	0	0-3
2090-99	1	0	0-5

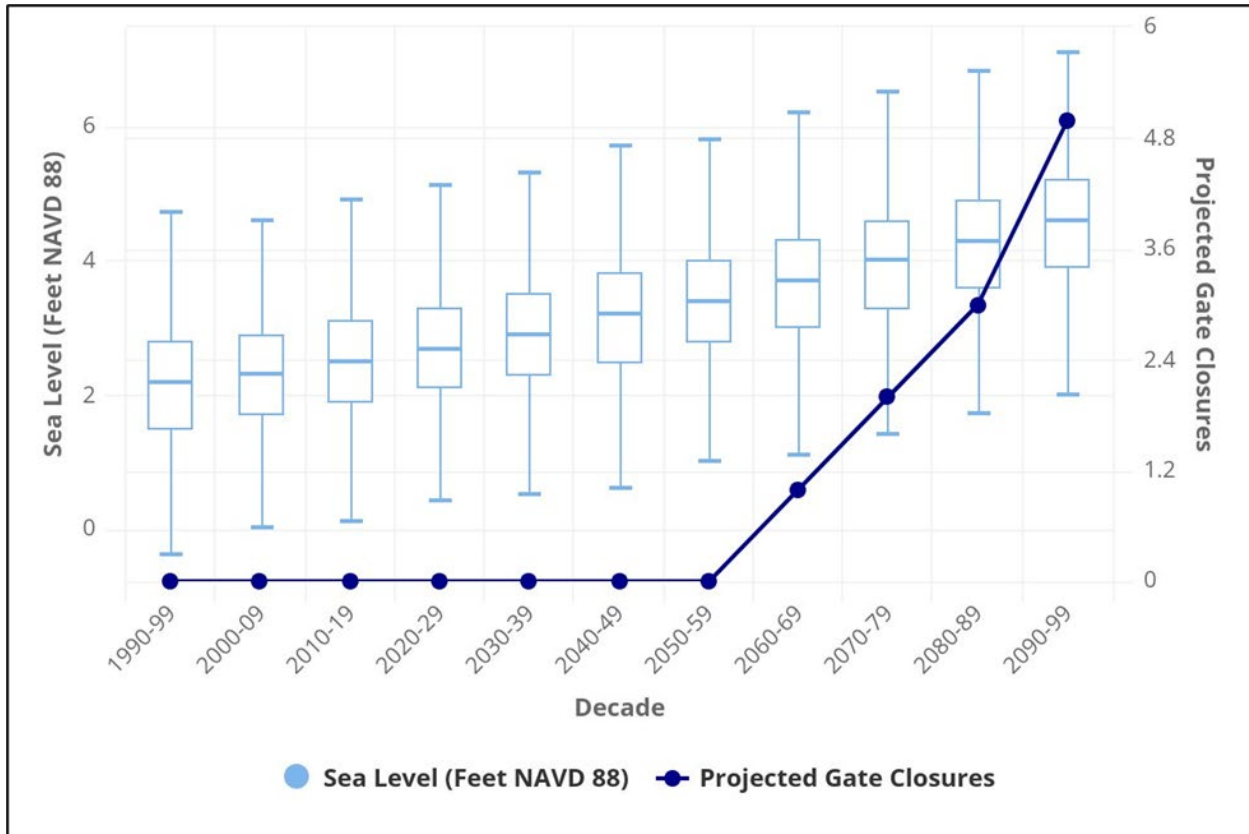


Figure C-30. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-19

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-1
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-1
2040-49	0	0	0-2
2050-59	0	0	0-3
2060-69	1	0	0-3
2070-79	2	0	0-5
2080-89	3	0	0-7
2090-99	5	0	0-12

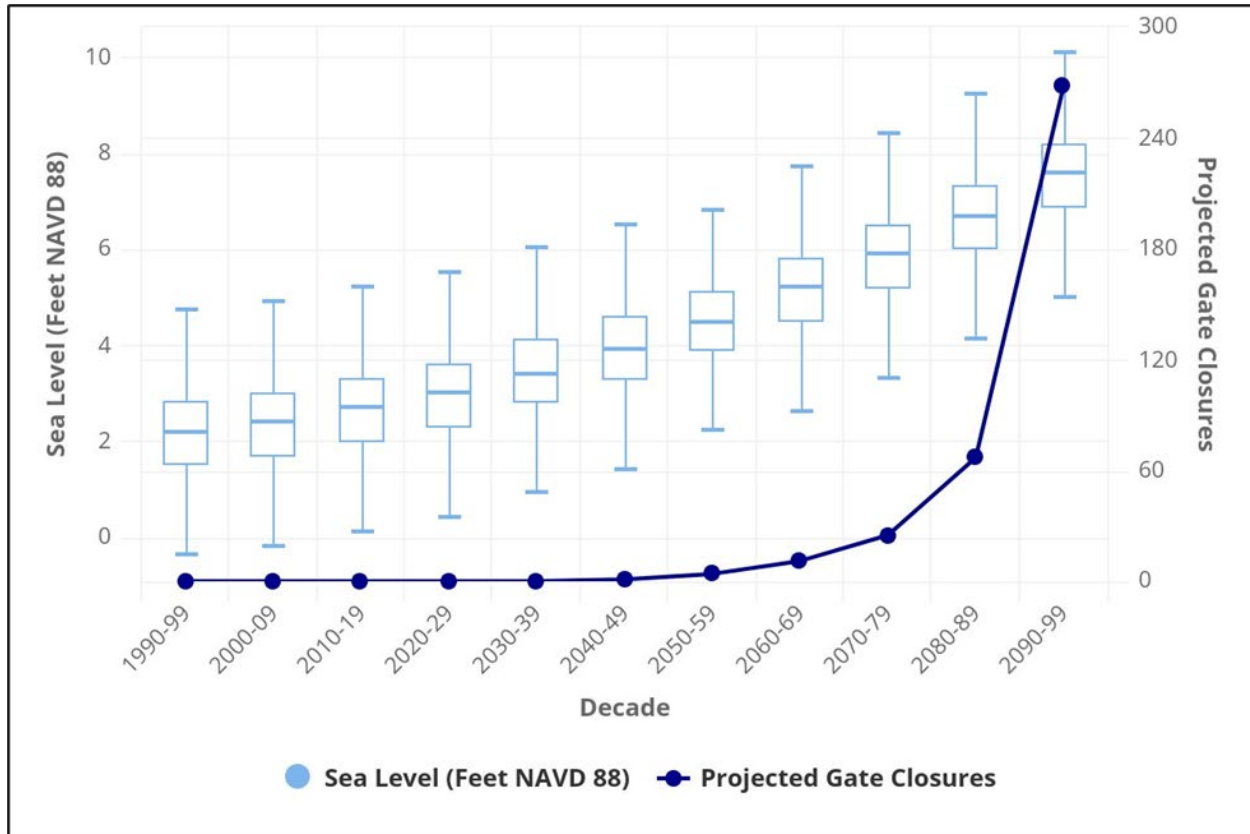


Figure C-31. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-20

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-1
2000-09	0	0	0-1
2010-19	0	0	0-1
2020-29	0	0	0-2
2030-39	0	0	0-3
2040-49	1	0	0-5
2050-59	4	0	0-10
2060-69	11	1	2-19
2070-79	25	2	16-41
2080-89	67	6	45-90
2090-99	268	26	232-311

C.6.6. South Water Street Gate (13.9 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-21
Upper and lower estimates for elevation thresholds of 13.9 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	0	0	1
2050	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0
2075	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	1
2100	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	1

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system's response once the threshold is crossed, without accounting for uncertainty or operational discretion.

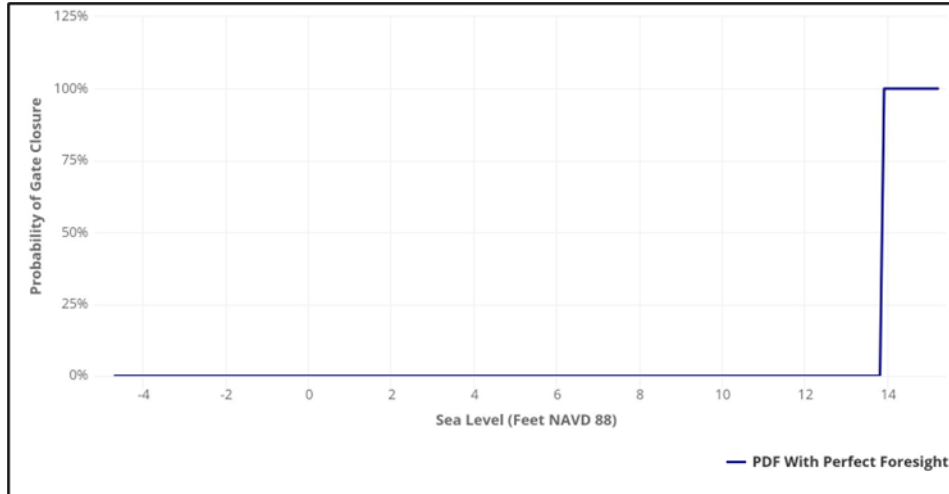


Figure C-32. Probability density function (PDF) illustrating threshold exceedance response relative to the 13.9 ft NAVD88 threshold.

Confidence intervals are not shown in the plot below because the mean values remain consistently near zero. Including the intervals would produce visual fluctuations that do not reflect meaningful variation. Omitting them emphasizes that the observed signal is effectively zero and avoids drawing attention to spurious spikes caused by statistical noise.

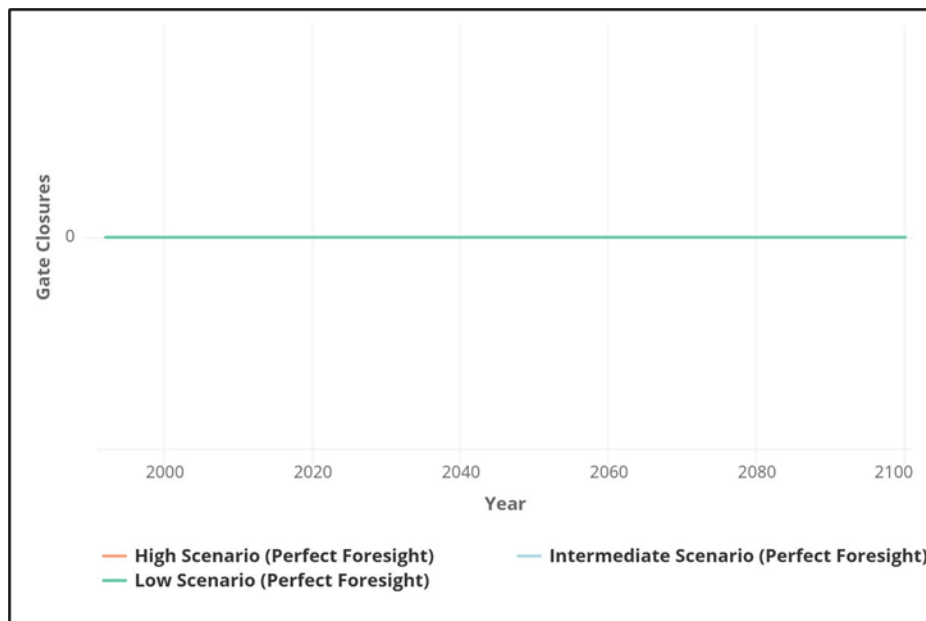


Figure C-33. Estimated threshold exceedances by scenario for water levels exceeding 13.9 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of

threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

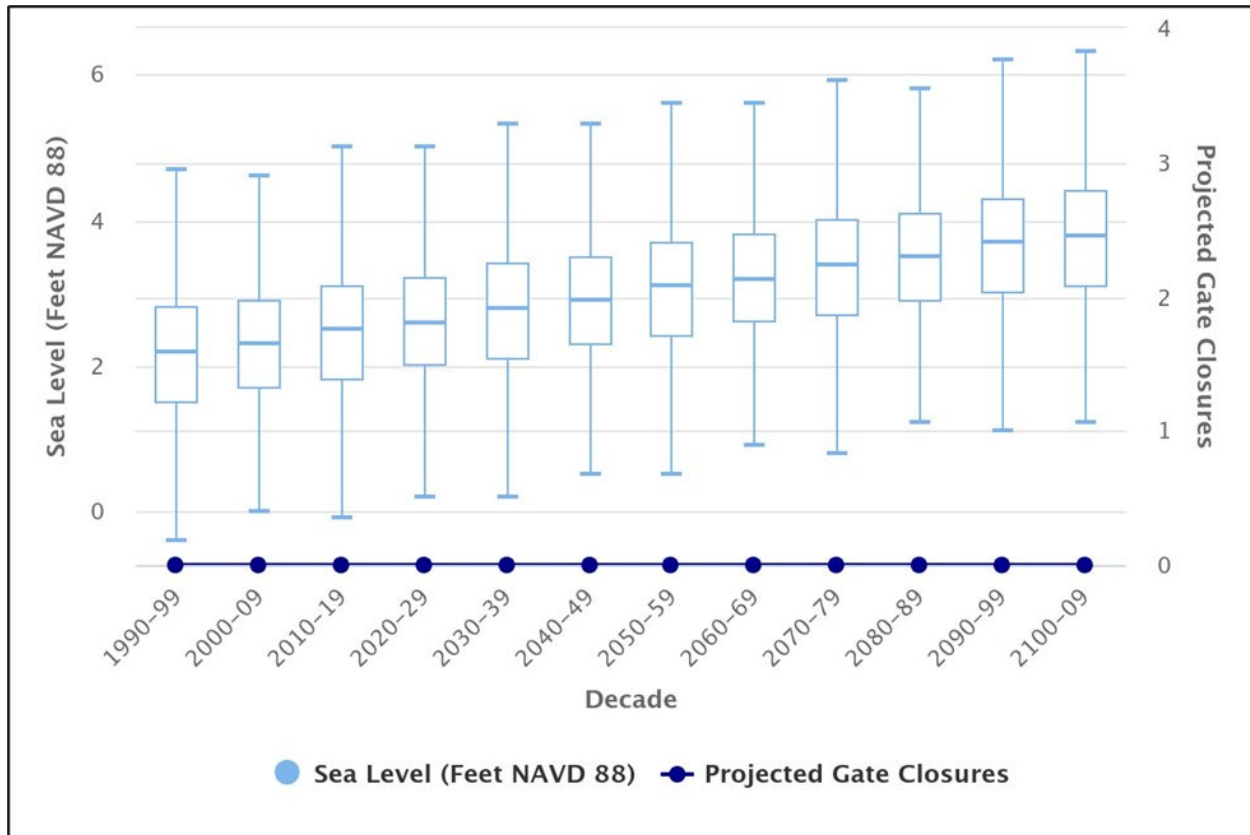


Figure C-34. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-22

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-0
2010-19	0	0	0-0
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0
2070-79	0	0	0-0
2080-89	0	0	0-0
2090-99	0	0	0-0

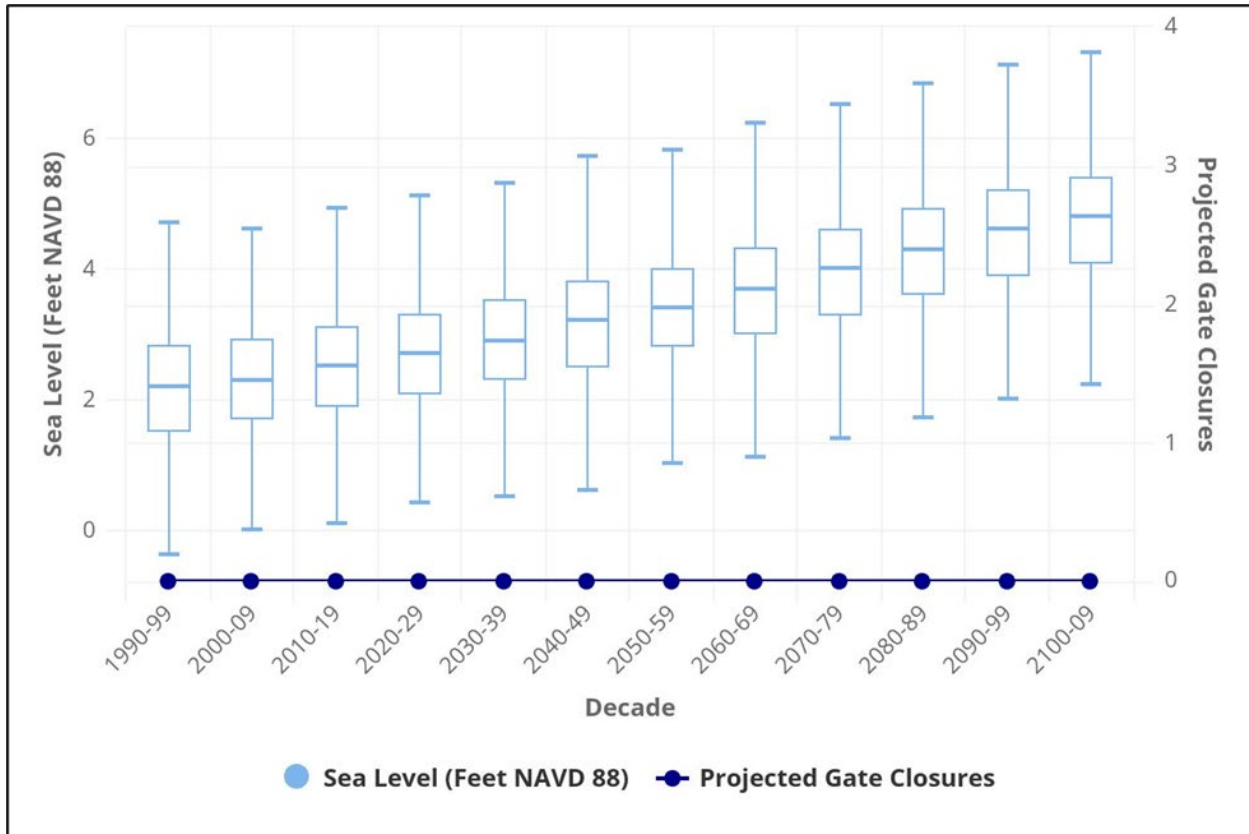


Figure C-35. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-23

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-0
2010-19	0	0	0-0
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0
2070-79	0	0	0-0
2080-89	0	0	0-0
2090-99	0	0	0-1

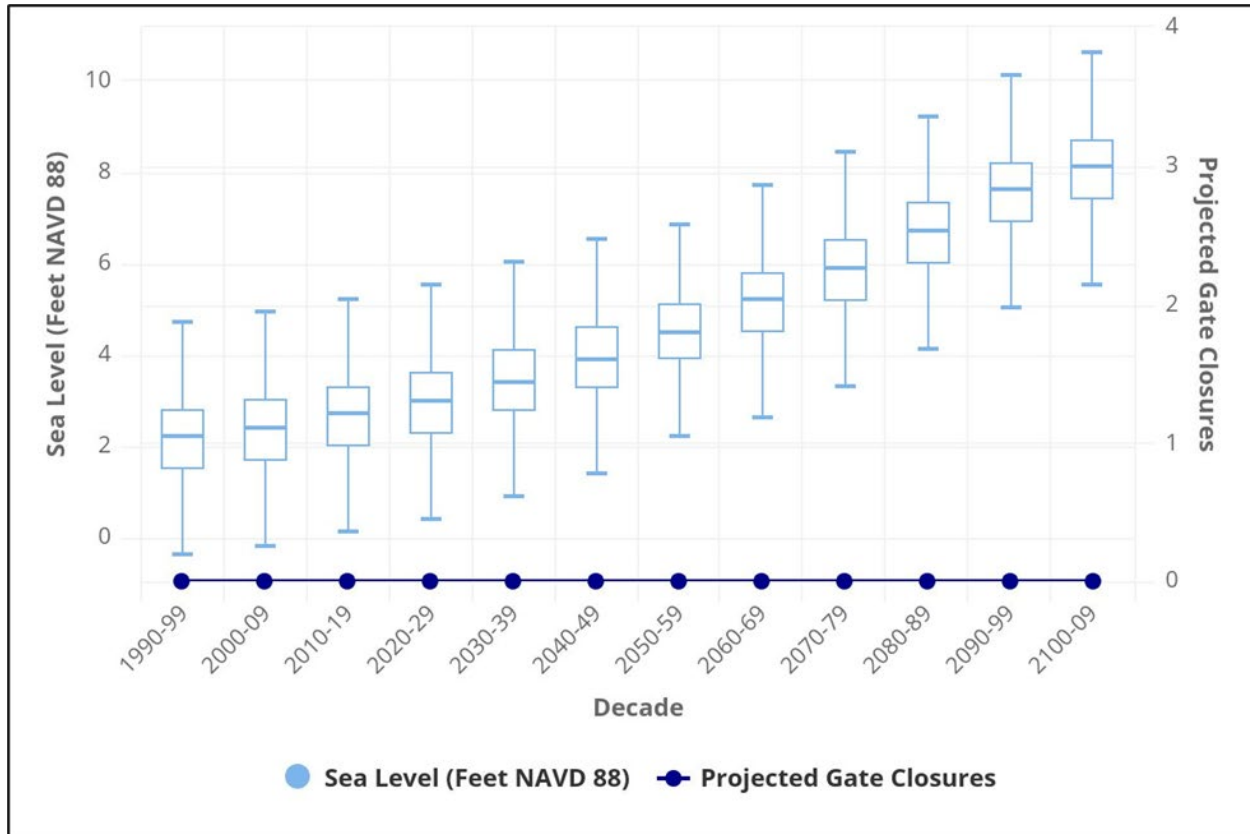


Figure C-36. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-24

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-0
2010-19	0	0	0-0
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0
2070-79	0	0	0-1
2080-89	0	0	0-1
2090-99	0	0	0-1

C.6.7. South Main Street Gate (14.1 ft NAVD88)

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-25
Upper and lower estimates for elevation thresholds of 14.1 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	0	0	1
2050	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0
2075	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	1
2100	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	1

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system's response once the threshold is crossed, without accounting for uncertainty or operational discretion.

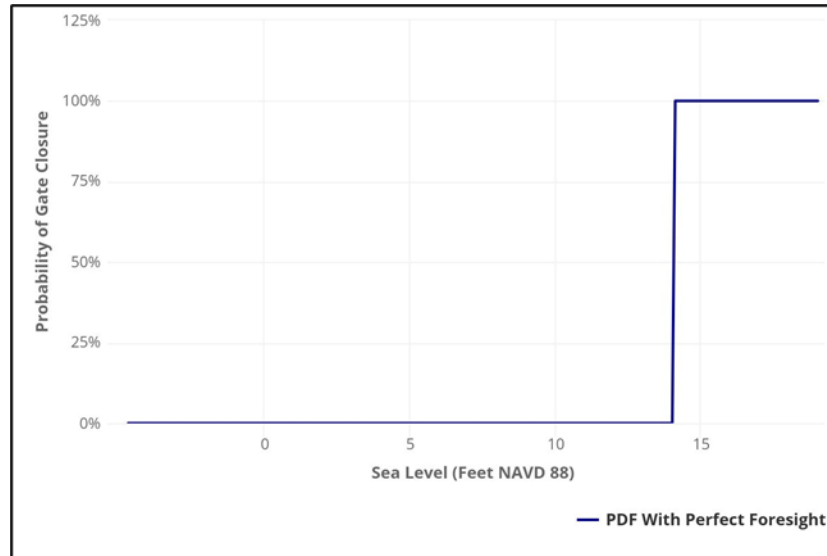


Figure C-37. Probability density function (PDF) illustrating threshold exceedance response relative to the 14.1 ft NAVD88 threshold.

Confidence intervals are not shown in the plot below because the mean values remain consistently near zero. Including the intervals would produce visual fluctuations that do not reflect meaningful variation. Omitting them emphasizes that the observed signal is effectively zero and avoids drawing attention to spurious spikes caused by statistical noise.

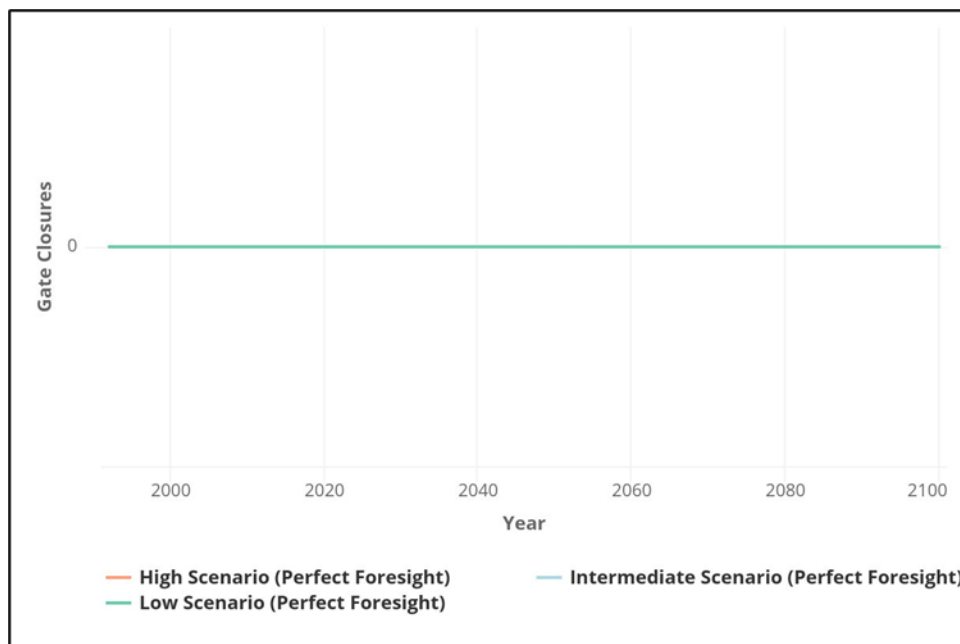


Figure C-38. Estimated threshold exceedances by scenario for water levels exceeding 14.1 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade,

capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

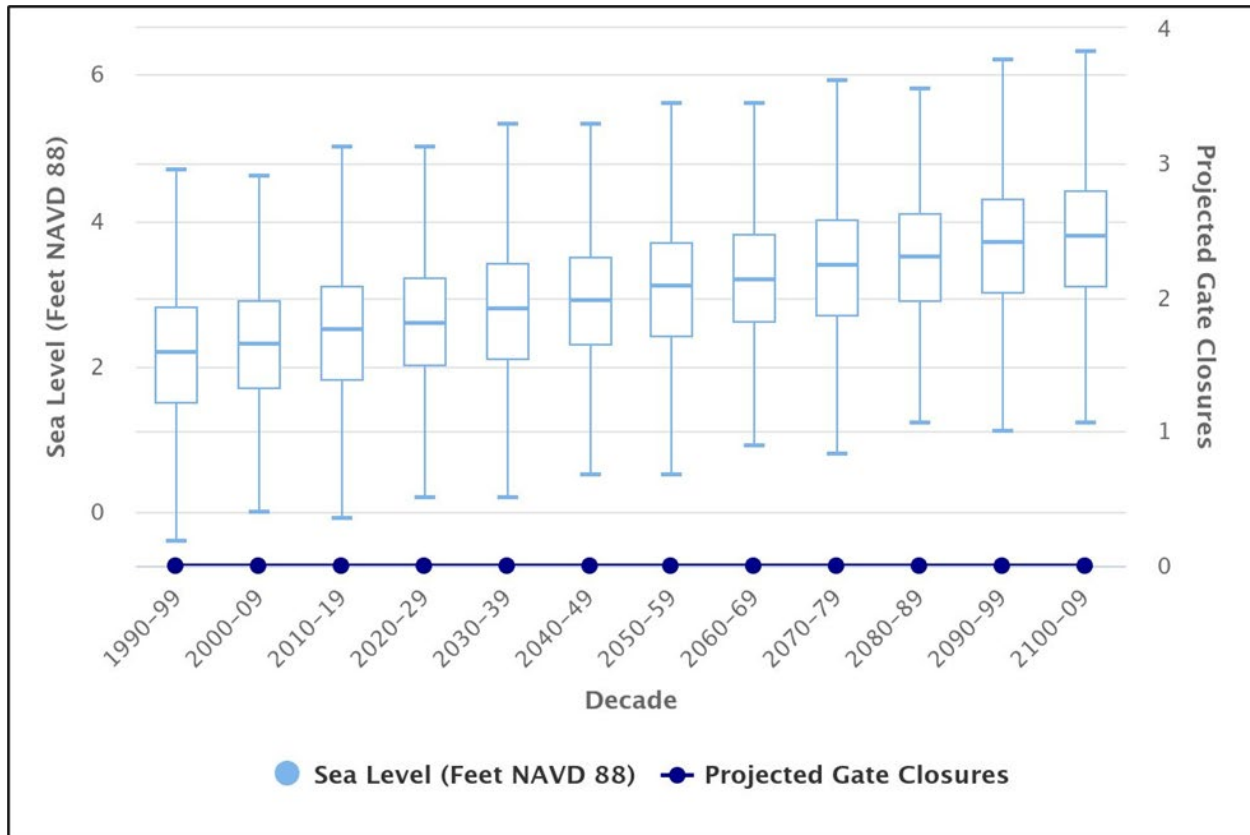


Figure C-39. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-26

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-0
2010-19	0	0	0-0
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2070–79	0	0	0–0
2080–89	0	0	0–0
2090–99	0	0	0–0

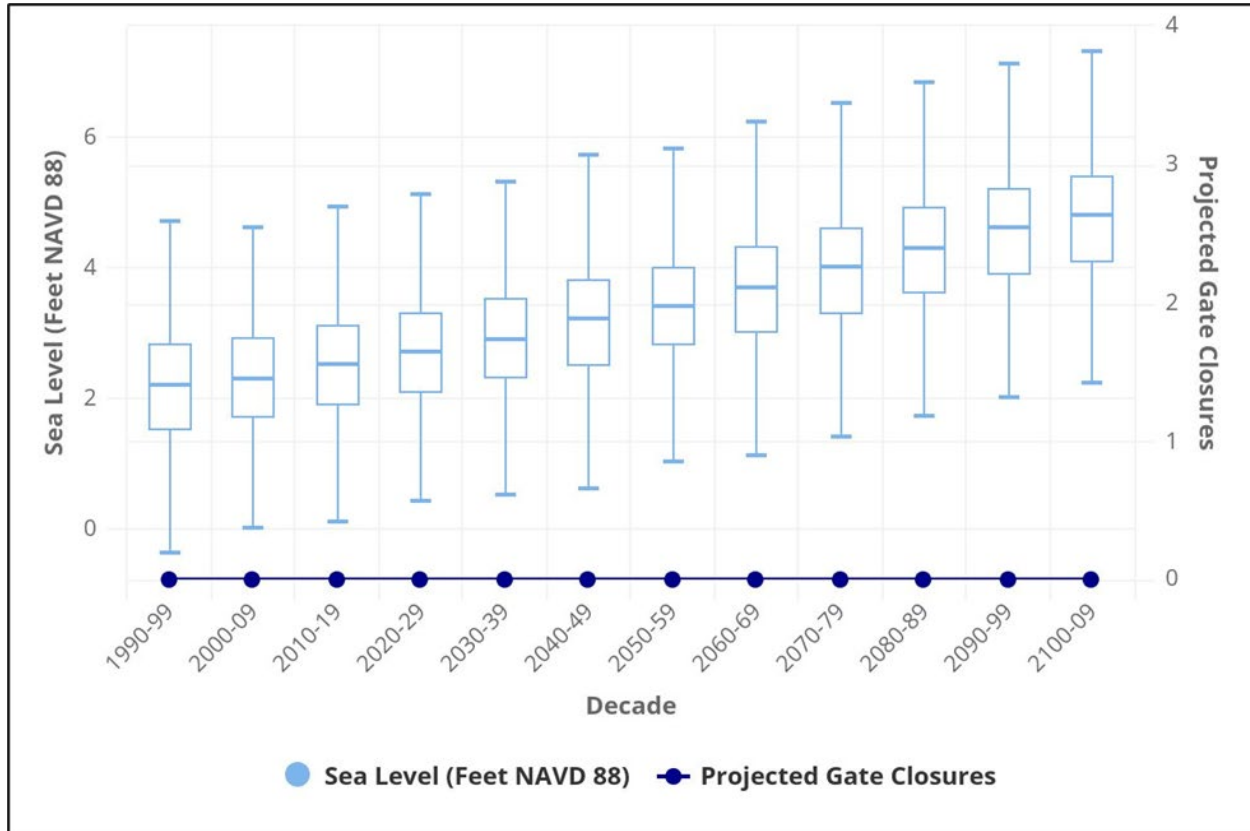


Figure C-40. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-27

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–0
2000–09	0	0	0–0
2010–19	0	0	0–0
2020–29	0	0	0–1
2030–39	0	0	0–0
2040–49	0	0	0–1
2050–59	0	0	0–1

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2060–69	0	0	0–0
2070–79	0	0	0–0
2080–89	0	0	0–0
2090–99	0	0	0–0

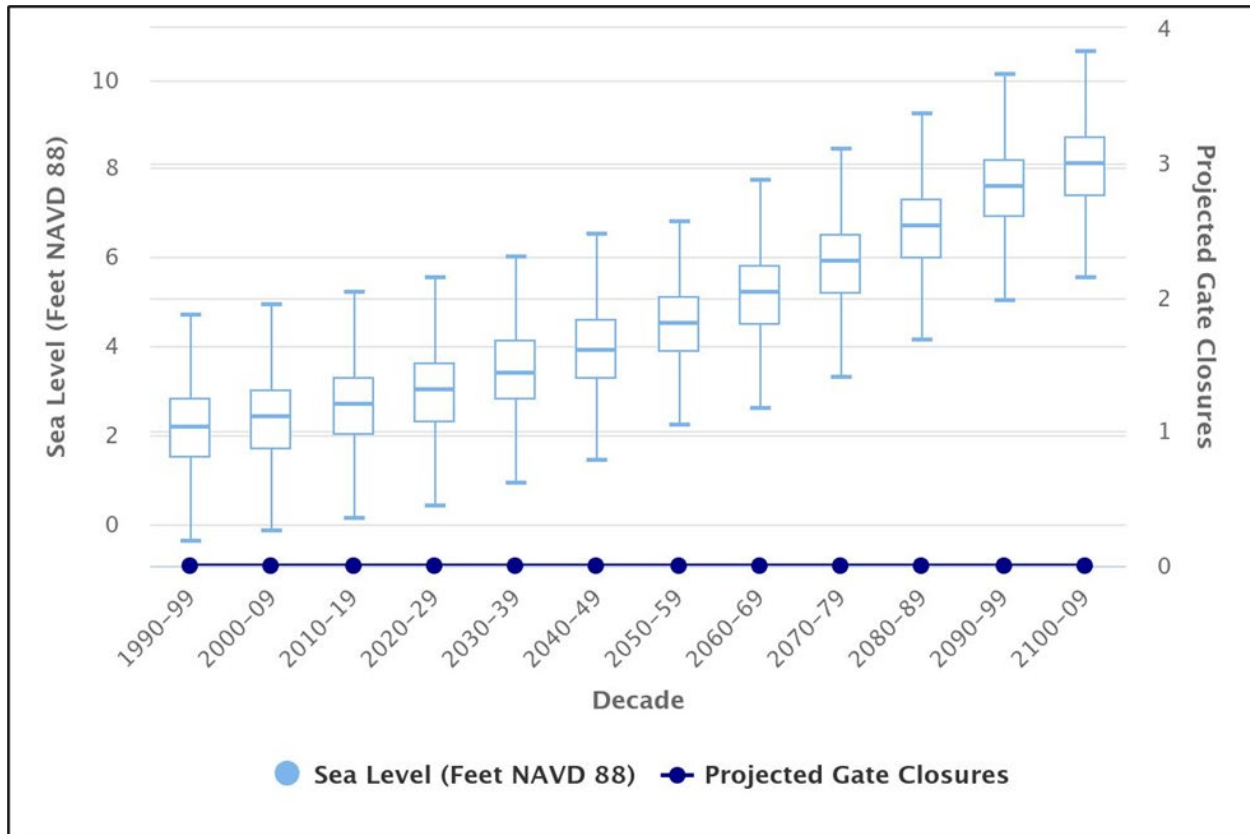


Figure C-41. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-28

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–0
2000–09	0	0	0–0
2010–19	0	0	0–0
2020–29	0	0	0–1
2030–39	0	0	0–0
2040–49	0	0	0–1

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2050–59	0	0	0–1
2060–69	0	0	0–0
2070–79	0	0	0–1
2080–89	0	0	0–1
2090–99	0	0	0–1

C.6.8. Phase 1 Sewer Gate (6.7 ft NAVD88)

For the Phase 1 Sewer Gate, an operational threshold of was calculated by converting the MLLW trigger elevation of 9.25 ft to a NAVD88 trigger elevation of $(9.25 - 2.47 = 6.78)$, rounded down to the nearest tenth).

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-29
Upper and lower estimates for elevation thresholds of 6.7 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	1	3	3	3
	Intermediate	0	0	0	1	3	3	4
	High	0	0	0	1	3	4	4
2050	Low	0	0	0	1	3	3	5
	Intermediate	0	0	0	2	4	5	6
	High	1	2	3	6	9	10	11
2075	Low	0	0	0	2	4	5	6
	Intermediate	0	0	1	4	7	8	8
	High	64	64	65	78	92	95	95
2100	Low	0	1	1	3	5	7	8
	Intermediate	5	6	6	11	17	18	19
	High	314	316	319	329	337	339	342

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

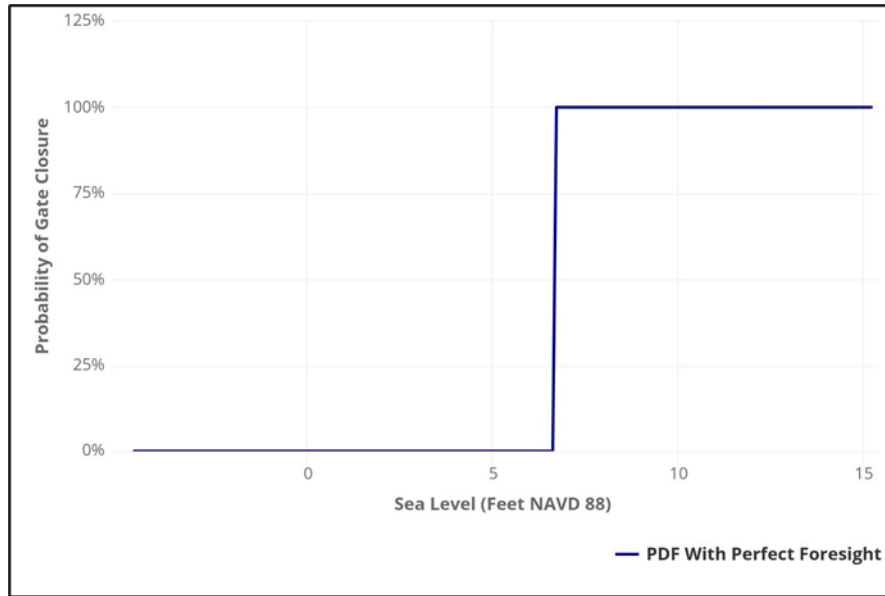


Figure C-42. Probability density function (PDF) illustrating threshold exceedance response relative to the 6.7 ft NAVD88 threshold.

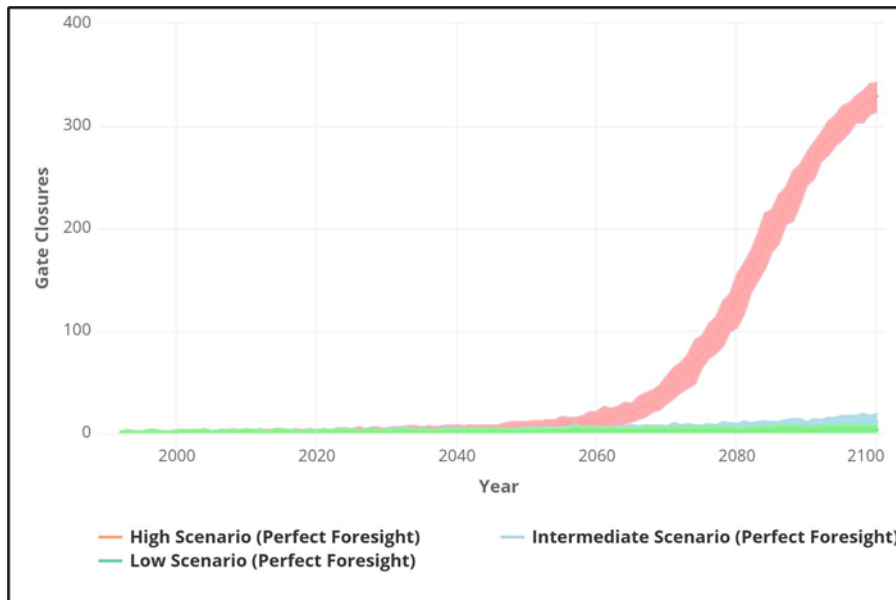


Figure C-43. Estimated threshold exceedances by scenario for water levels exceeding 6.7 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

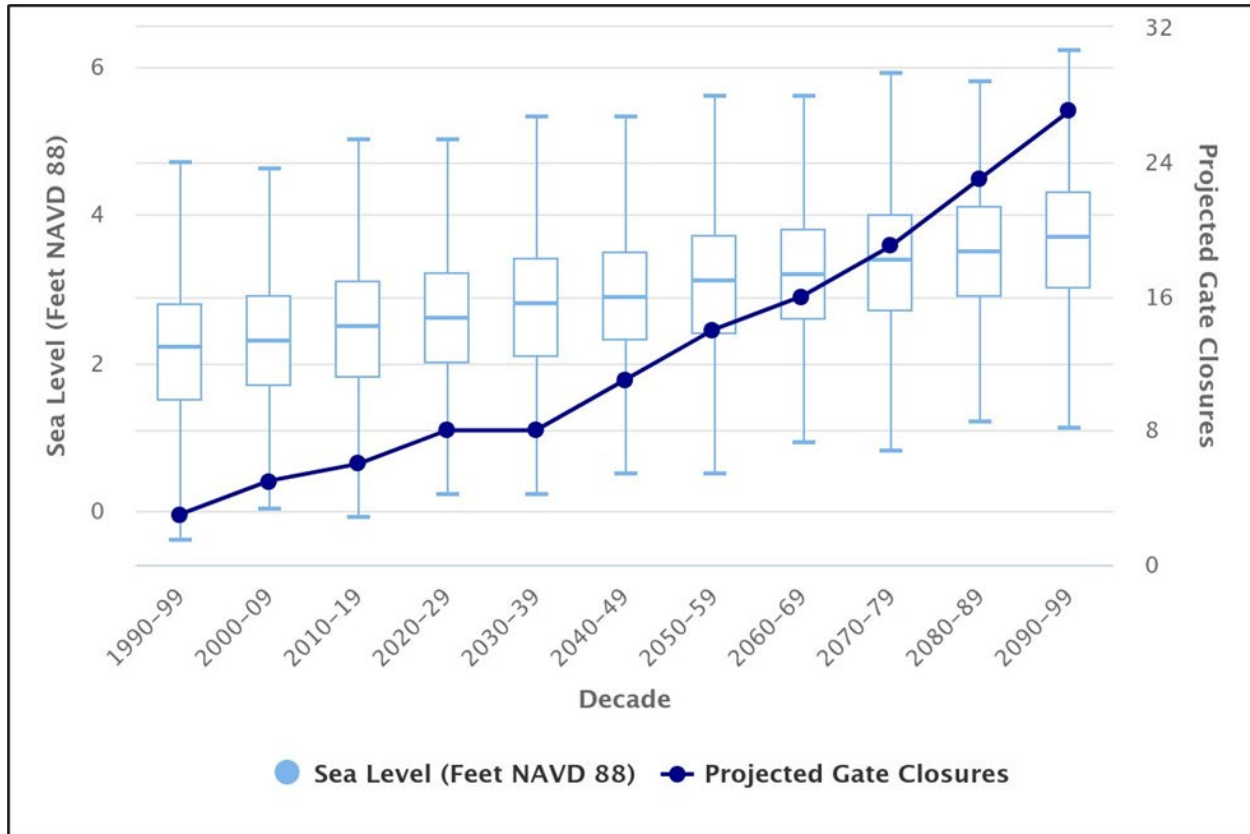


Figure C-44. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-30

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	3	0	0-7
2000-09	5	0	0-11
2010-19	6	0	2-14
2020-29	8	0	2-16
2030-39	8	0	2-16
2040-49	11	1	4-20
2050-59	14	1	8-25
2060-69	16	1	5-26
2070-79	19	1	11-32
2080-89	23	2	12-35
2090-99	27	2	16-40

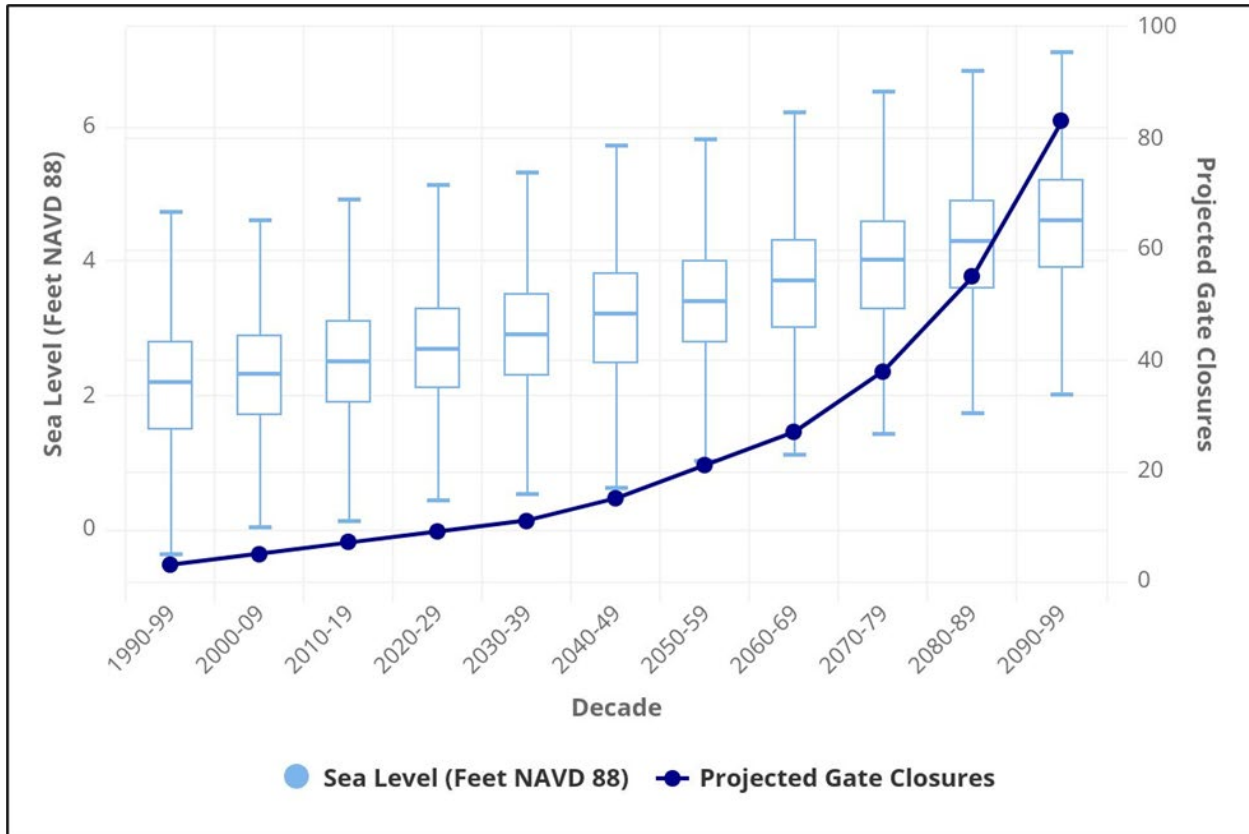


Figure C-45. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-31

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	3	0	0-7
2000-09	5	0	1-11
2010-19	7	0	2-15
2020-29	9	0	2-17
2030-39	11	1	3-19
2040-49	15	1	7-26
2050-59	21	2	13-34
2060-69	27	2	16-40
2070-79	38	3	23-55
2080-89	55	5	34-76
2090-99	83	8	66-104

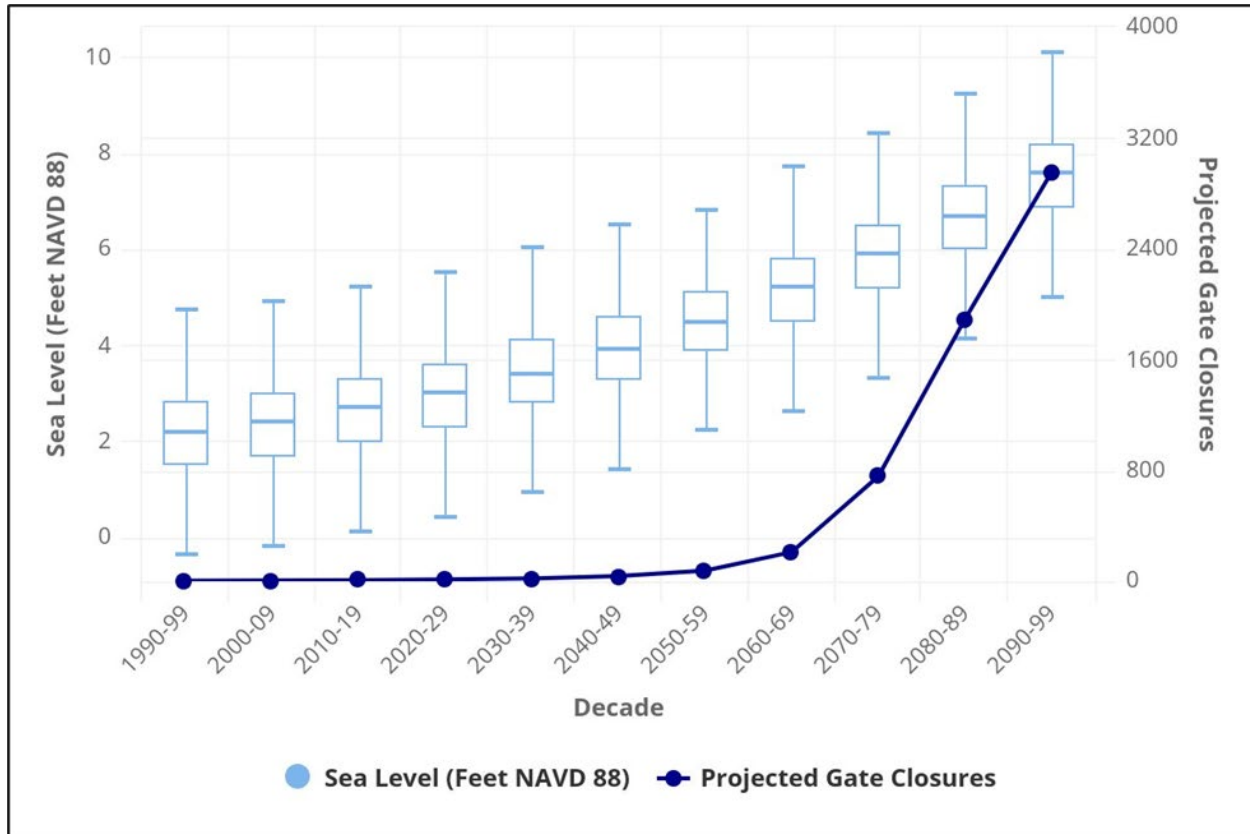


Figure C-46. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-32

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	3	0	0-7
2000-09	5	0	1-12
2010-19	8	0	2-17
2020-29	13	1	4-24
2030-39	20	2	9-31
2040-49	37	3	23-52
2050-59	77	7	56-95
2060-69	211	21	171-243
2070-79	759	75	701-808
2080-89	1,894	189	1,827-1,964
2090-99	2,955	295	2,903-3,001

C.6.9. Phase 2 Sewer Gate (11.7 ft NAVD88)

For the Phase 2 Sewer Gate, an operational threshold of was calculated by converting the MLLW trigger elevation of 9.25 ft to a NAVD88 trigger elevation of $(14.25 - 2.47 = 11.78$, rounded down to the nearest tenth).

The table and figures below present the simulated number of predicted threshold exceedance days for the low, medium, and high sea level rise scenarios through 2100 with a 4.6 mm/yr rate of sea level change. Lower and upper estimates, corresponding to the 1% and 99% quantiles, indicate the range of possible outcomes based on variability in the simulated water levels. The results illustrate how the frequency of threshold exceedances is projected to change over time, with higher scenarios generally showing more frequent closures and an increasing trend in later decades. Differences among scenarios highlight the potential variability in closure frequency under different sea level rise conditions, while the quantiles capture uncertainty from both seasonal and interannual fluctuations in the simulations.

Table C-33
Upper and lower estimates for elevation thresholds of 11.7 ft NAVD88.

		Lower (1%)	Lower (5%)	Lower (10%)	Mean	Upper (90%)	Upper (95%)	Upper (99%)
2025	Low	0	0	0	0	0	0	1
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	0	0	1
2050	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	0	0	0	0
2075	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	1
	High	0	0	0	0	0	0	1
2100	Low	0	0	0	0	0	0	0
	Intermediate	0	0	0	0	0	0	0
	High	0	0	0	1	3	3	6

In this framework, the concept of perfect foresight is applied by treating the threshold as an absolute determinant of closure. The probability density function (PDF) is evaluated such that any value above the threshold corresponds to a 100% probability of closure, while any value below the threshold corresponds to 0%. This binary interpretation assumes complete certainty in the system’s response once the threshold is crossed, without accounting for uncertainty or operational discretion.

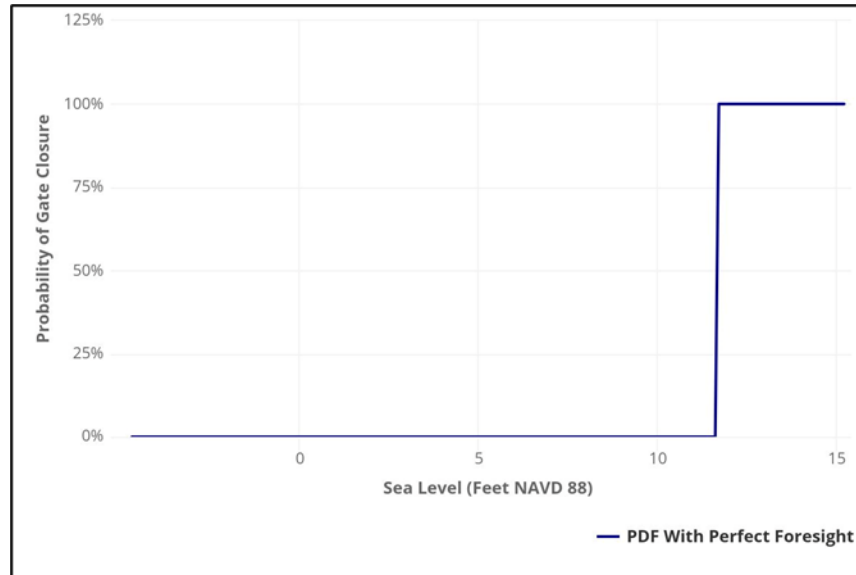


Figure C-47. Probability density function (PDF) illustrating threshold exceedance response relative to the 11.7 ft NAVD88 threshold.

Confidence intervals are not shown in the plot below because the mean values remain consistently near zero. Including the intervals would produce visual fluctuations that do not reflect meaningful variation. Omitting them emphasizes that the observed signal is effectively zero and avoids drawing attention to spurious spikes caused by statistical noise.

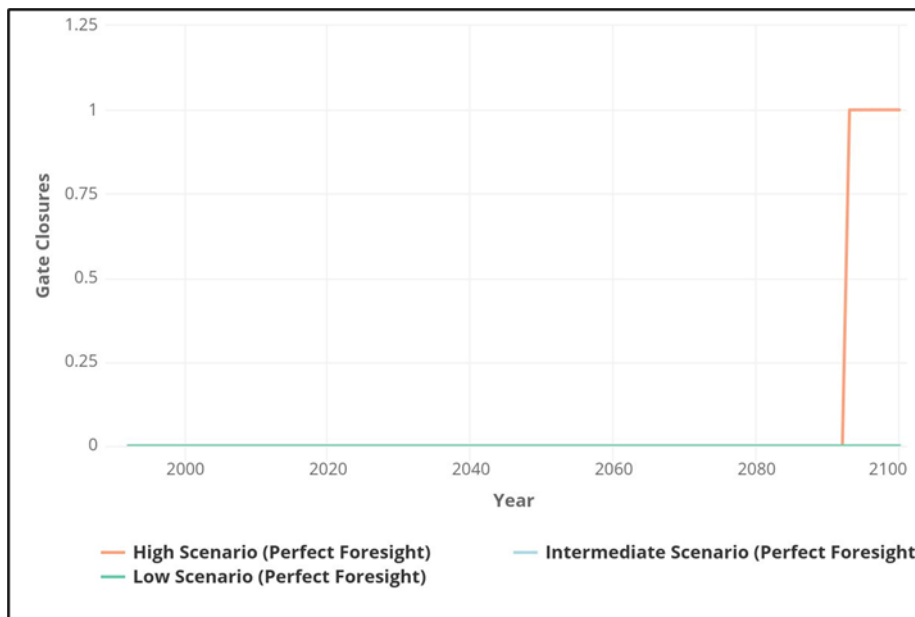


Figure C-48. Estimated threshold exceedances by scenario for water levels exceeding 11.7 ft NAVD88 with a 4.6 mm/yr rate of sea level change.

The charts below show projected sea level on the left axis and predicted threshold exceedances on the right axis. Decadal boxplots represent the distribution of simulated mean water levels within each decade, capturing the variability across months and years. Overlaid on the right axis is a line showing the total

number of predicted threshold exceedance days for each decade, summed across all years within that period. This visualization enables comparison of how changes in sea level relate to the frequency of threshold exceedances, highlighting both the range of possible water levels and the projected trend in closures over time.

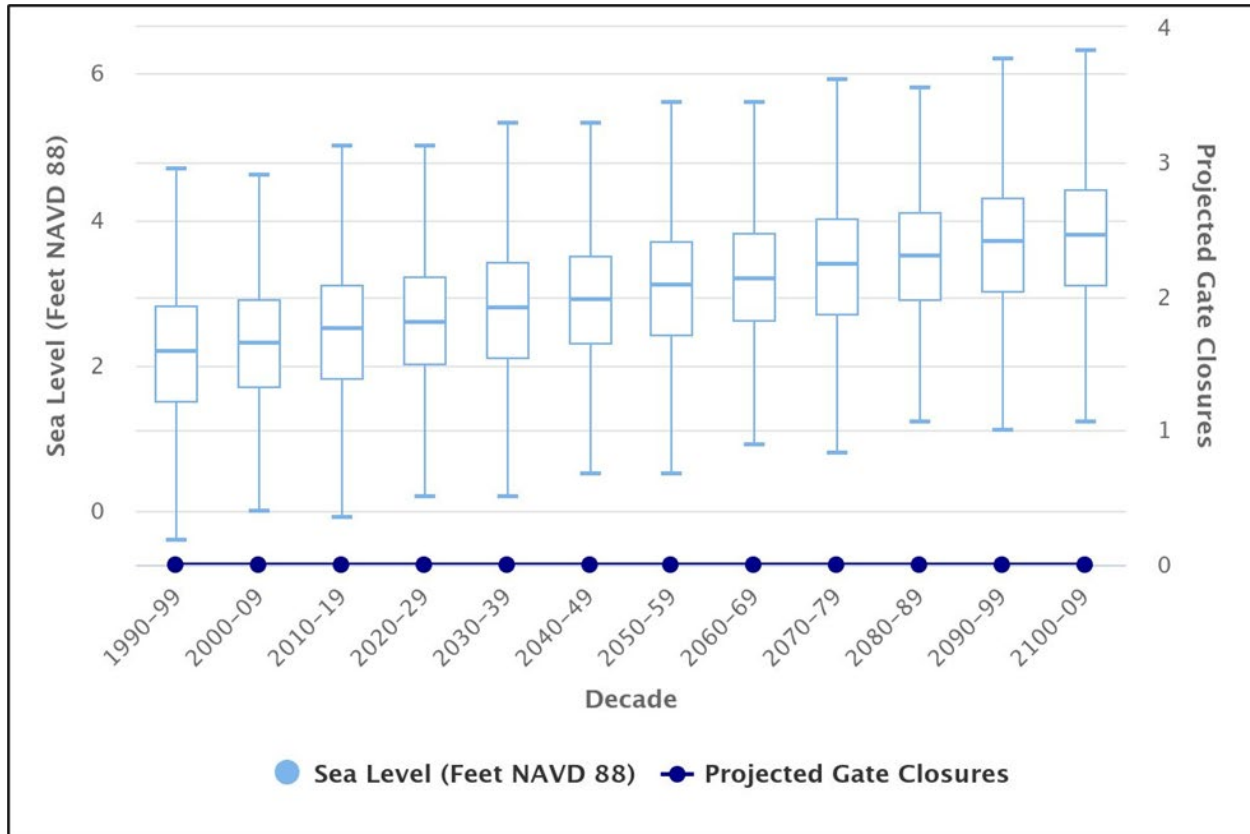


Figure C-49. Projected water levels by decade vs. projected threshold exceedances for the Low scenario with a 4.6 mm/yr rate of sea level change.

Table C-34

Projected threshold exceedances by decade for the Low scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990-99	0	0	0-0
2000-09	0	0	0-0
2010-19	0	0	0-1
2020-29	0	0	0-1
2030-39	0	0	0-0
2040-49	0	0	0-1
2050-59	0	0	0-1
2060-69	0	0	0-0
2070-79	0	0	0-0

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2080–89	0	0	0–1
2090–99	0	0	0–1

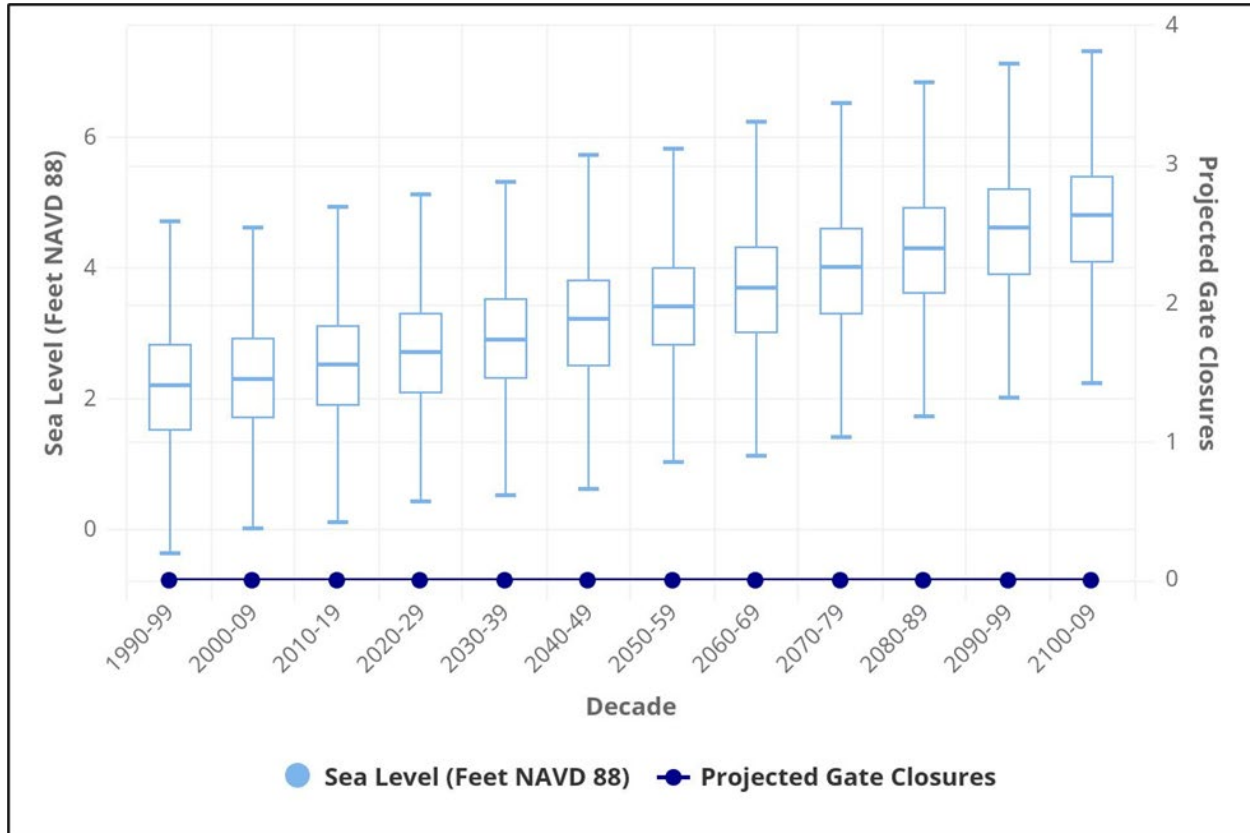


Figure C-50. Projected water levels by decade vs. projected threshold exceedances for the Intermediate scenario with a 4.6 mm/yr rate of sea level change.

Table C-35

Projected threshold exceedances by decade for the Intermediate scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–0
2000–09	0	0	0–0
2010–19	0	0	0–1
2020–29	0	0	0–1
2030–39	0	0	0–0
2040–49	0	0	0–1
2050–59	0	0	0–1
2060–69	0	0	0–0

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2070–79	0	0	0–1
2080–89	0	0	0–1
2090–99	0	0	0–1

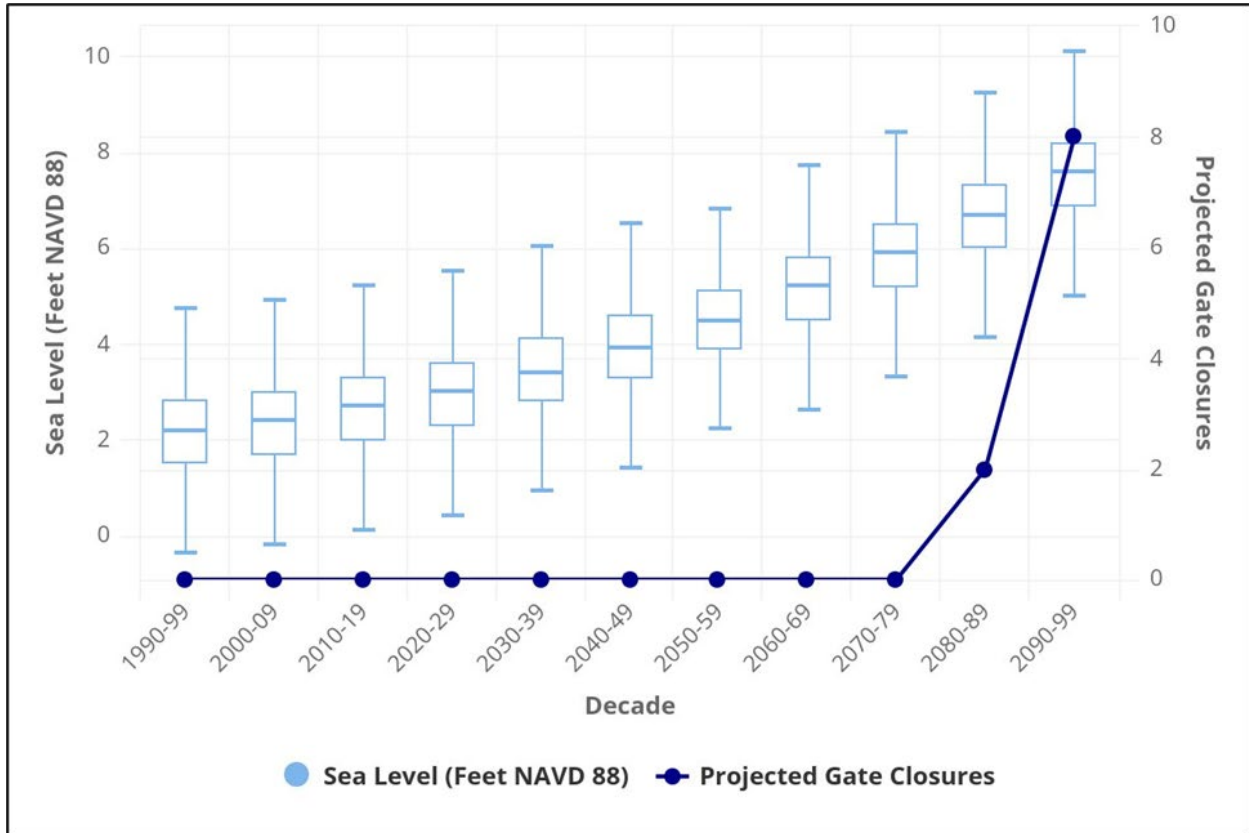


Figure C-51. Projected water levels by decade vs. projected threshold exceedances for the High scenario with a 4.6 mm/yr rate of sea level change.

Table C-36

Projected threshold exceedances by decade for the High scenario, including the per-year average and the 99% confidence interval.

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
1990–99	0	0	0–0
2000–09	0	0	0–0
2010–19	0	0	0–1
2020–29	0	0	0–1
2030–39	0	0	0–1
2040–49	0	0	0–1
2050–59	0	0	0–1

Fox Point Storm Surge Barrier System Vulnerability Assessment
Gate Operations Analysis Tool (GOAT)

Decade	Threshold Exceedances (Projected)	Per Year Average (Projected)	99% Confidence Interval (Projected)
2060–69	0	0	0–1
2070–79	0	0	0–2
2080–89	2	0	0–6
2090–99	8	0	2–17