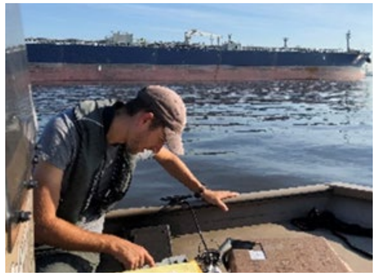


The Impact of Sea Level Rise on Salinity Intrusion in the Delaware River Estuary

Fanghui Chen, Ph.D., P.E.
Senior Water Resource Engineer, DRBC
Amy Shallcross, P.E.
Manager of Water Resource Operations, DRBC

February 17, 2026
Advisory Committee on Climate Change

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Background Information

SLR Impact on Salinity

Potential Future Work

Salt Front Location and DRBC Criteria

Zone 2

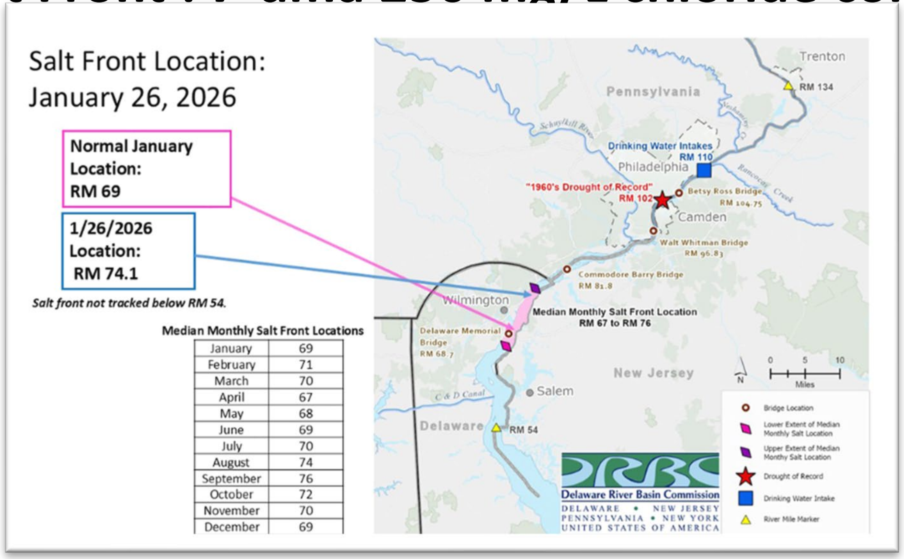
- Chlorides - Maximum 15-day average 50 mg/L

Zone 3

- Chlorides - Maximum 30-day average 180 mg/L at RM 98
- Sodium - Maximum 30-day average 100 mg/L at RM 98

DRBC Water Quality Regulations (2022):
https://www.nj.gov/drbc/library/documents/WQregs.pdf

Salt Front : 7-dma 250 mg/L chloride concentration



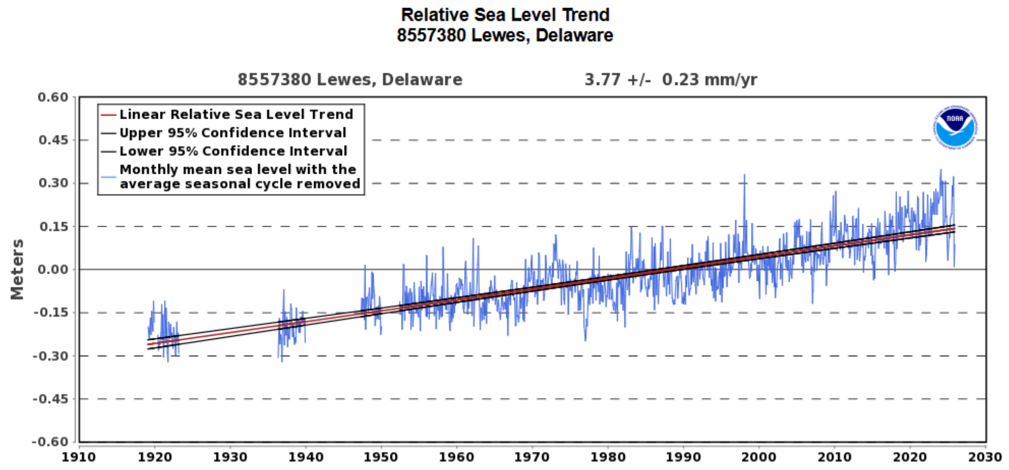
Median Monthly Salt Front Locations

January	69
February	71
March	70
April	67
May	68
June	69
July	70
August	74
September	76
October	72
November	70
December	69

The updated daily SF location are available on hydrosnap.drbc.net

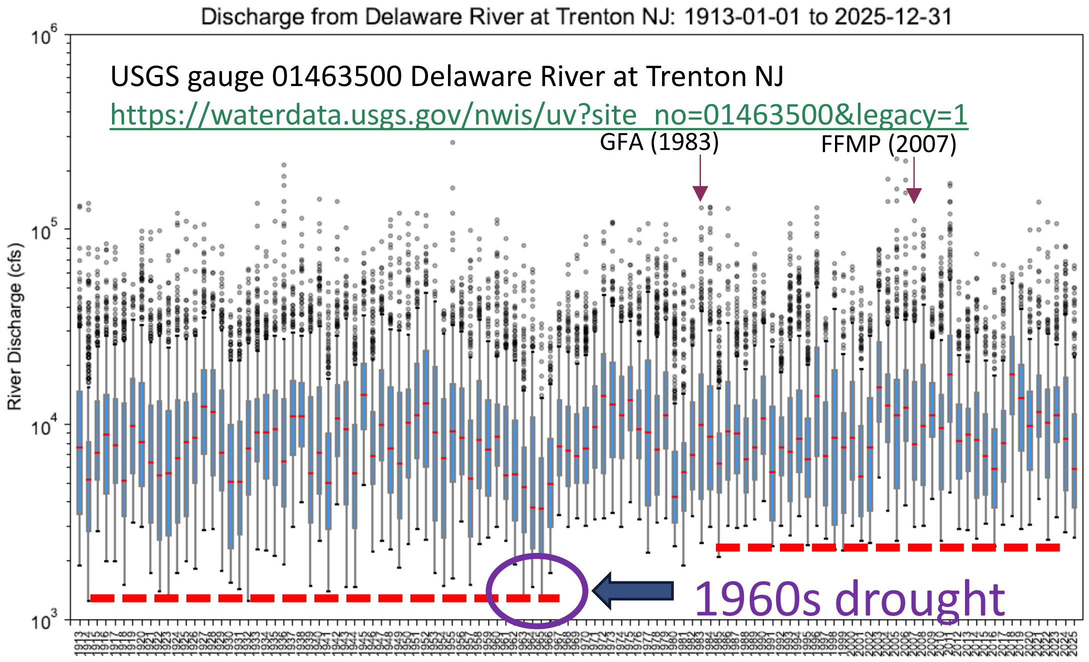
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Status of SLR for the Delaware Estuary

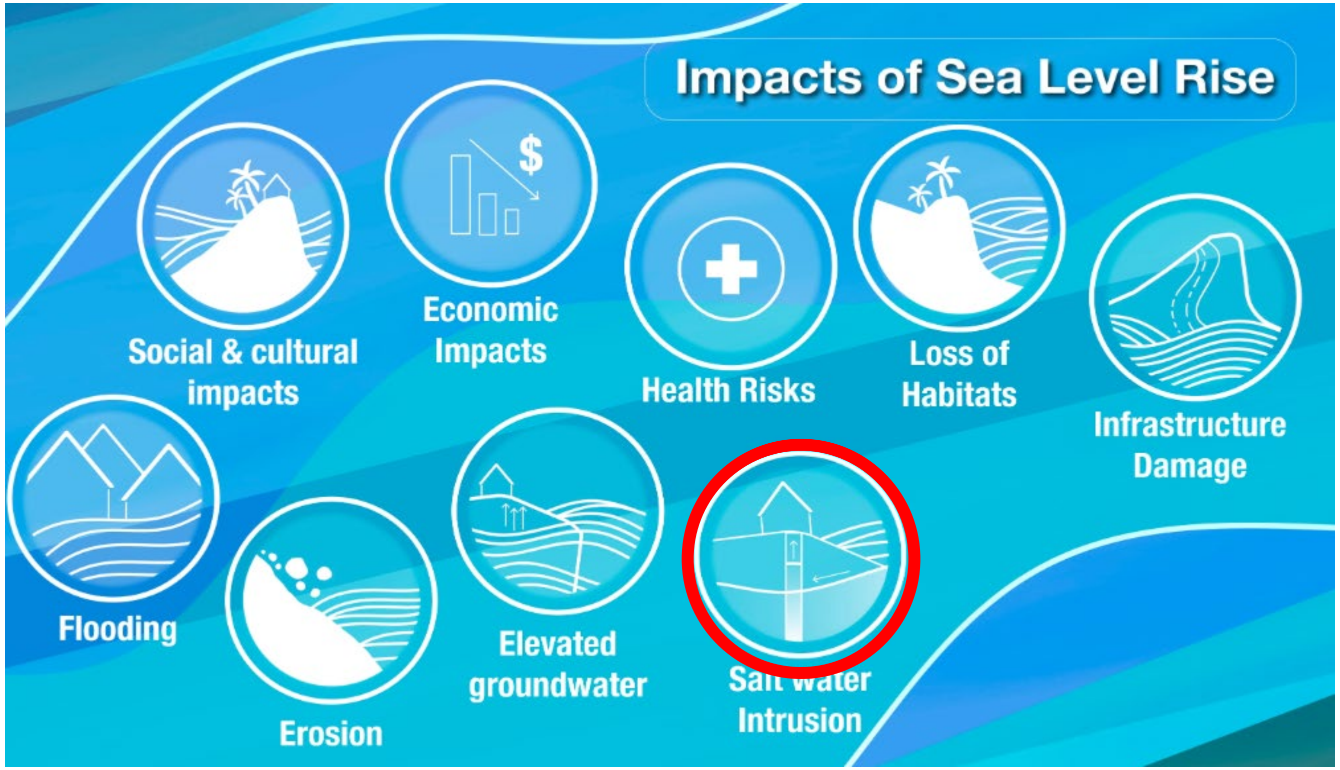


Sea level trend near Delaware Coast

NOAA tide gage at Lewes, DE.
https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8557380



Flow on the Delaware River at Trenton, NJ

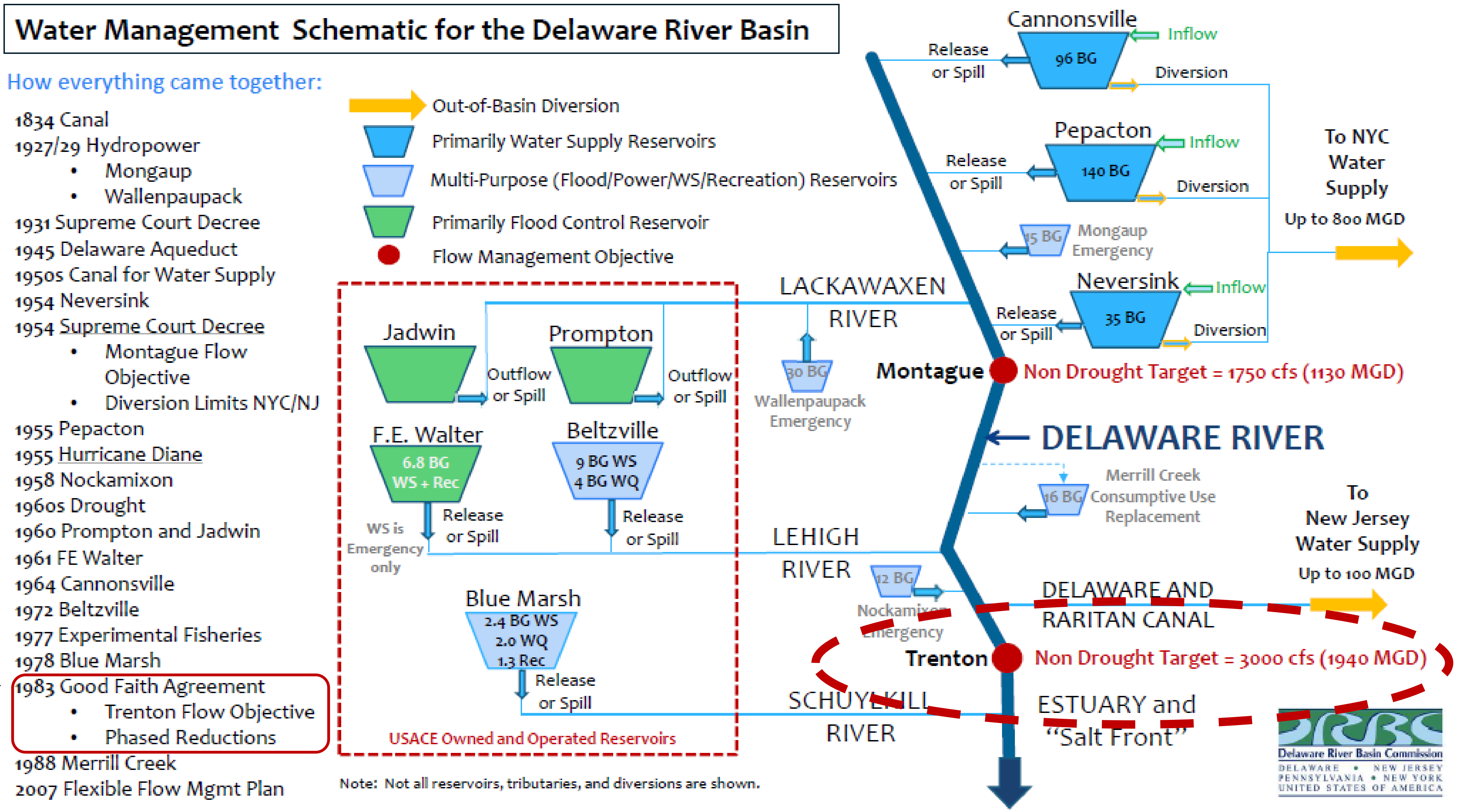


Source: https://earth.gov/sealevel/about-sea-level-change/impacts/the-basics/

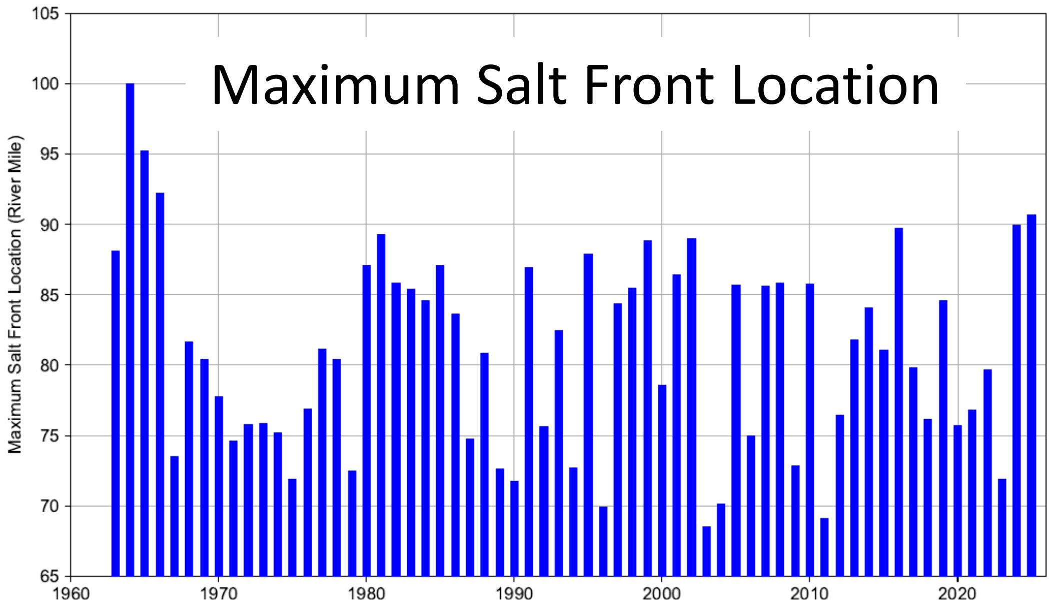
Salinity intrusion is driven primarily by two competing forcings: Flow from upland and Tidal water level (Pressure)

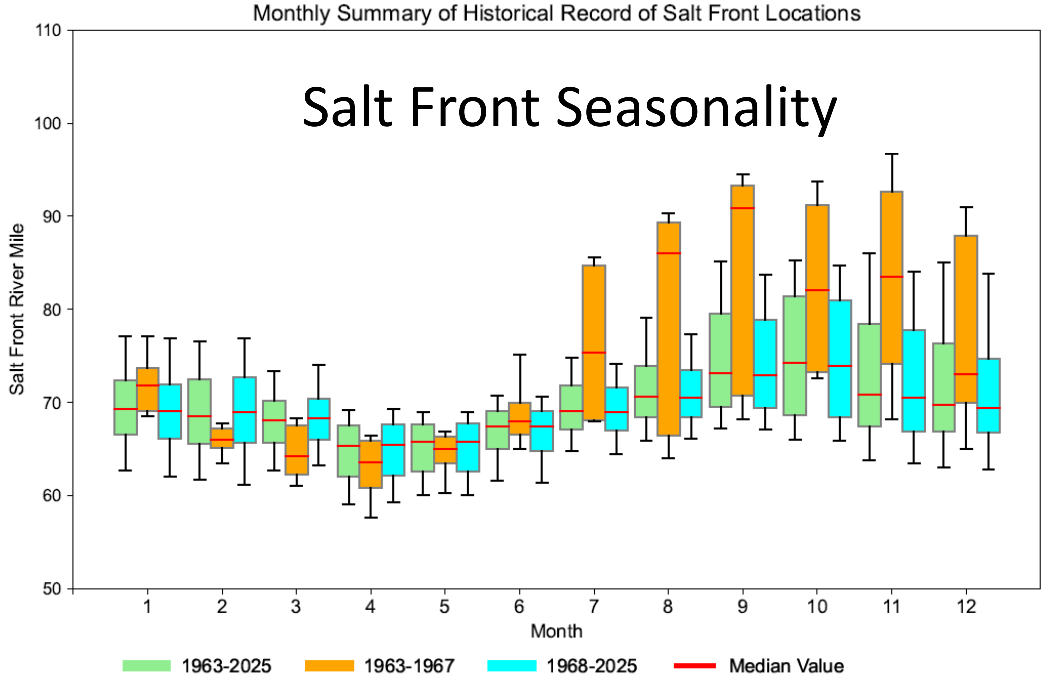
Water Management Schematic for the Delaware River Basin

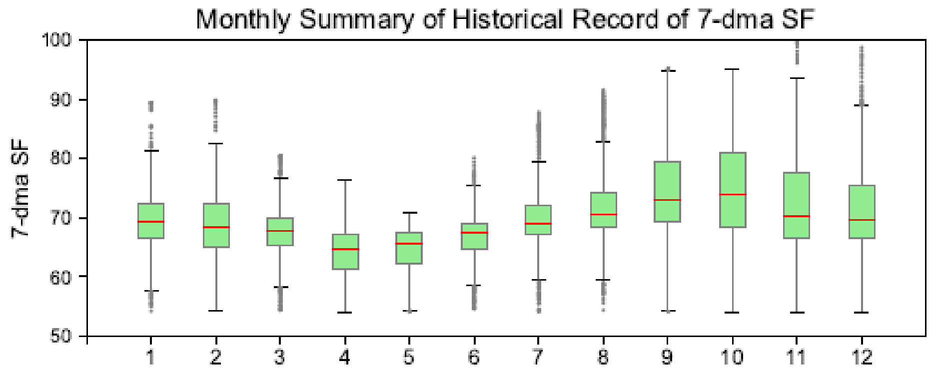
GFA (1983) →



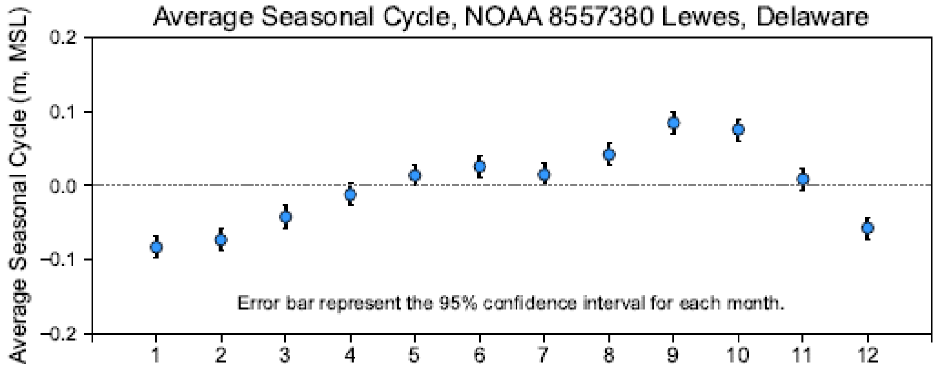
Historical Data of the Salt Front: 1963 - 2025





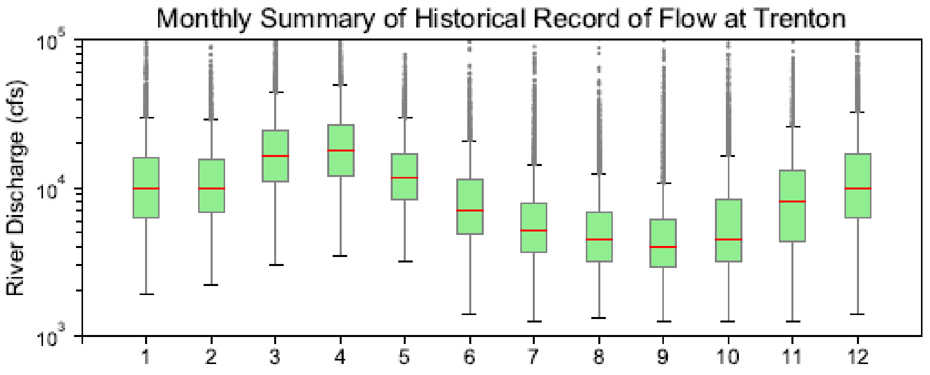


Salt Front



Tide

Average Seasonal Cycle



Trenton Flow

Historical data: https://drbc.net/Sky/hydro/saltfront.html

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Background Information

SLR Impact on Salinity

Potential Future Work

Modeling Approach

Approach

- SM3D hydrodynamic Model
- Literature review of SLR projections
- Multiple values of SLR to account for different planning scenarios, time horizon, and probability of occurrence
- Diagnostic analysis:
  - SLR
  - Bathymetry (dredging) and shape (marsh inundation)
  - Ocean surface temperature
- Multiple years simulation approach
- Conceptual analysis – managing actions

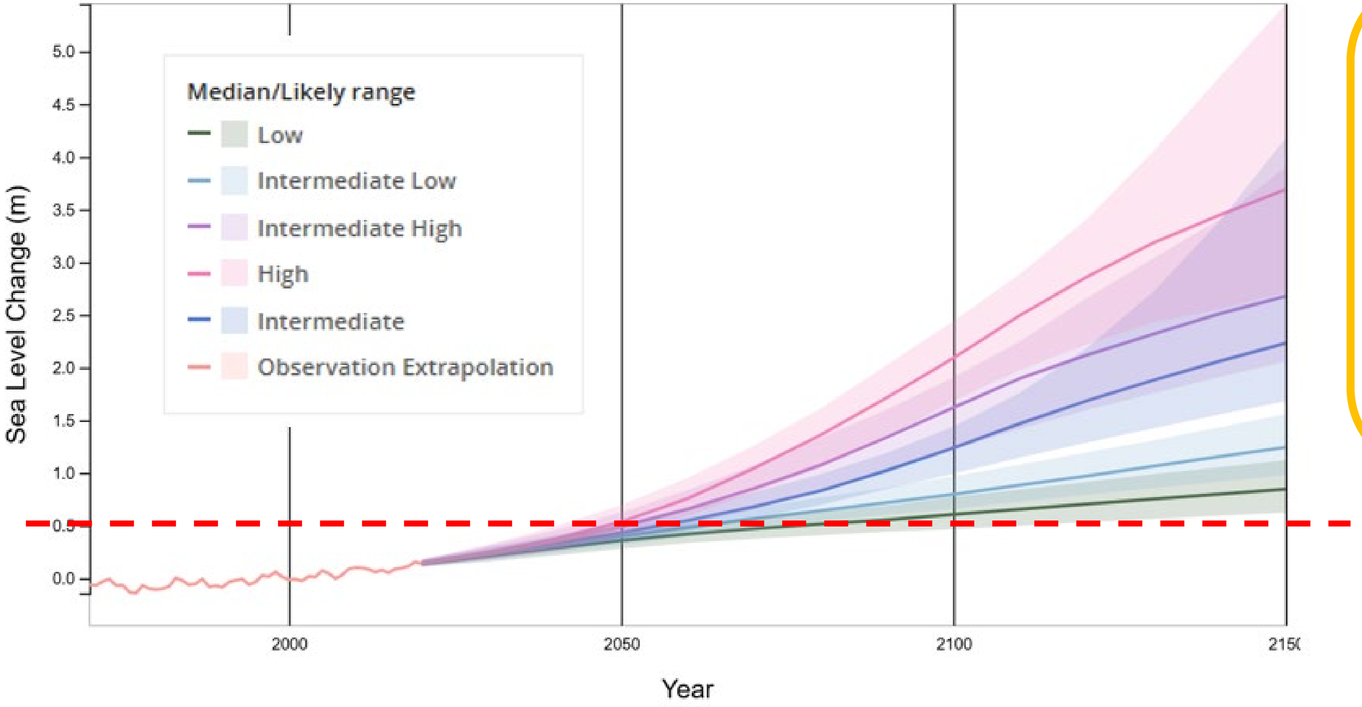
Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Modeling Assumptions

- SLR amount at west C&D boundary is equivalent to the SLR at the mouth of the Bay
- Bed elevation does not change with SLR (dredging/sedimentation impact not included)
- The amplitude and phase of tidal harmonics at the model ocean boundary do not change with SLR.
- The impact of wave and wind wave-current interaction on longterm salinity transport is considered insignificant.
- Changes in water withdrawal and point source discharge for the future is not considered.
- The compounding effect of SLR with the change in hydrologic conditions are not considered
- Groundwater-surface water interactions are insignificant relative to other forcings; among others

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

SLR Projections for the Delaware Estuary (NOAA 2022 Study)



SLR Projections for Lewes, DE (8557380), based on NOAA 2022 Study

Imprecise Exceedance Probability

If SSPs lead to 2 to 4 C global warming

	>98%	50-97%	2- 23%	1 – 2%	<1%
scenario	**Low**	**Int. Low**	**Int**	**Int. High**	**High**
2020	0.135	0.144	0.146	0.147	0.146
2030	0.211	0.227	0.235	0.244	0.246
2040	0.286	0.313	0.330	0.356	0.374
2050	0.358	0.399	0.432	0.489	0.535
2060	0.420	0.482	0.548	0.657	0.757
2070	0.470	0.565	0.680	0.853	1.044
2080	0.514	0.643	0.830	1.073	1.360
2090	0.555	0.718	1.024	1.339	1.715
2100	0.606	0.796	1.238	1.621	2.091
2110	0.655	0.884	1.468	1.898	2.495
2120	0.704	0.970	1.684	2.117	2.858
2130	0.751	1.062	1.878	2.316	3.182
2140	0.799	1.155	2.060	2.510	3.447
2150	0.845	1.242	2.232	2.678	3.691

Source: NOAA (2022 projections, decadal median values are shown)
https://sealevel.nasa.gov/task-force-scenario-tool?psmsl_id=224

DRBC Modeling Study Selected Scenarios:
0 (baseline), 0.3, 0.5, 0.8, 1.0, 1.6 m,
all referenced to baseline 2000

Details on the scenario projections and uncertainty ranges are provided in the 2022 Sea Level Rise Technical Report, https://earth.gov/sealevel/us/resources/2022-sea-level-rise-technical-report.

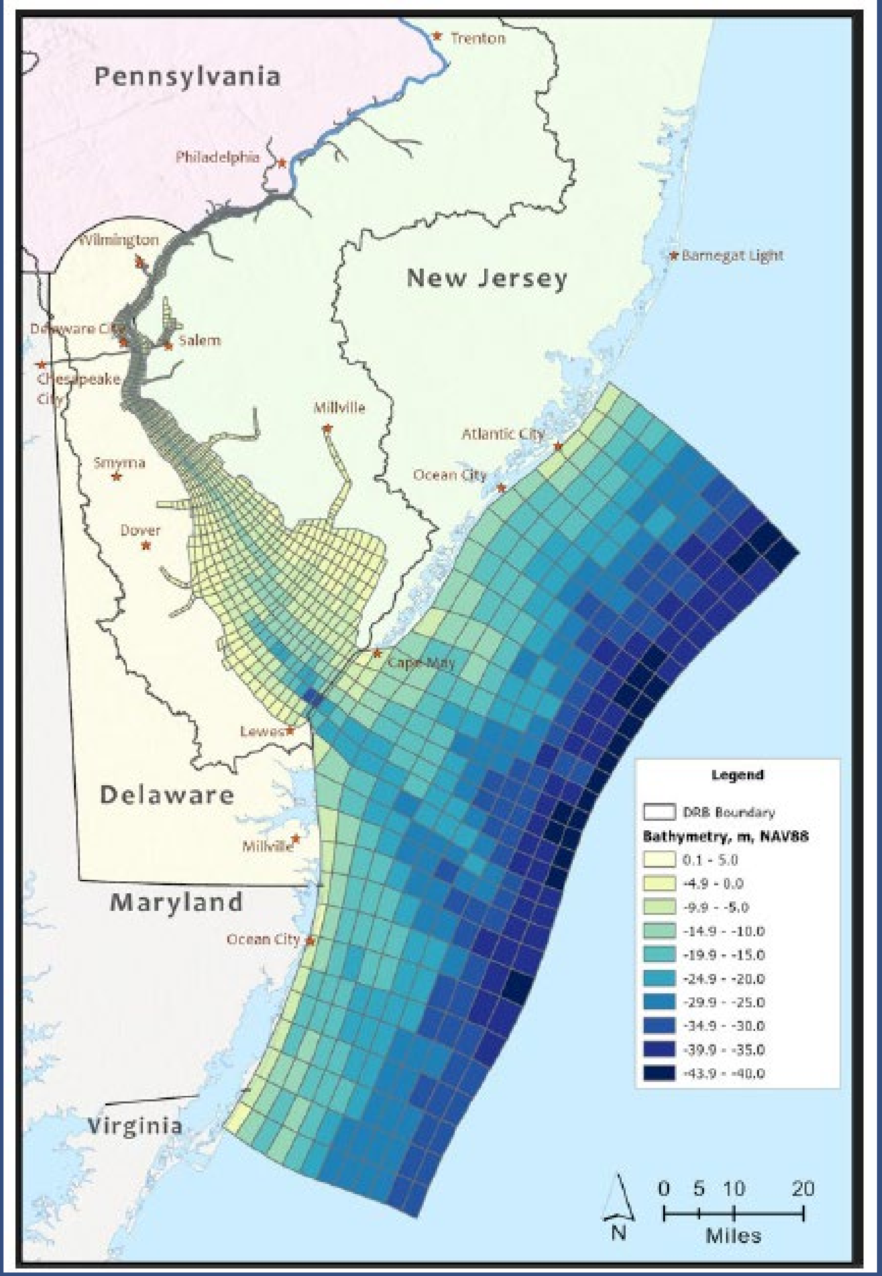
All SLR amounts are relative to the baseline of the year 2000 (1991-2009 epoch)

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

10-year Ensembled Model Results for 6 SLR Scenarios

Delaware River Basin Commission

DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA



Simulated Salt Front Location: 10-year Ensemble Results

(1965, 2001 to 2002, 2011 to 2013, and 2016 to 2019)

With SLR of 0.3 to 1.6m, SF moved farther upstream by 1.6 to 10.5 miles

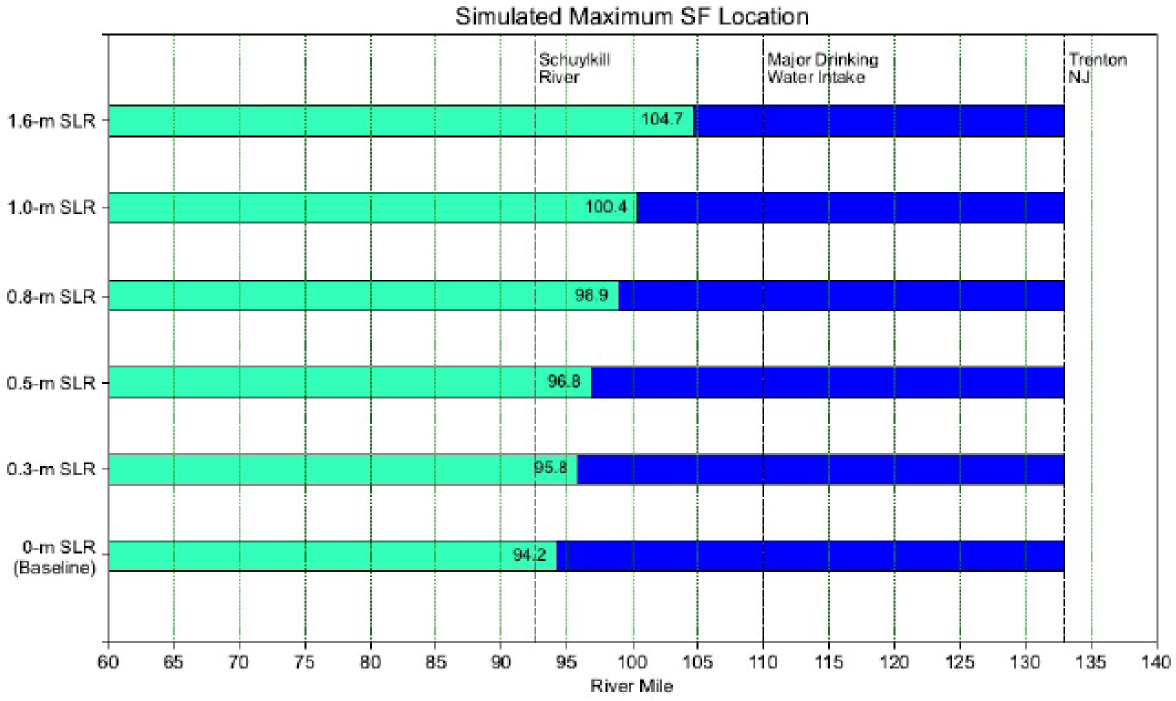


Figure 4.2-2. Simulated maximum location of the salt front with SLR during a hypothetical repeat of 1965 flows with a 2,500 cfs flow objective at Trenton, NJ.

Table G. 6. The percentage of time during the 10 simulated years that the salt front location is above RM 92.5.

0 m SLR	0.3 m SLR	0.5 m SLR	0.8 m SLR	1 m SLR	1.6 m SLR
1.6	2.8	4.0	5.8	7.1	11.3

Table 4.2-1. Simulated maximum location of the salt front with sea level rise and the normal range of the salt front location from the 10-year ensemble simulations.

Sea Level Rise (m)	Normal Range of Salt Front Location from the 10-year Ensemble (RM)	Maximum Salt Front Location (RM)	Increase in Simulated Maximum Salt Front from Baseline (RM)
0	61.6–76.5	94.2	–
0.3	62.7–77.8	95.8	1.6
0.5	63.4–78.7	96.8	2.6
0.8	64.3–80.1	98.9	4.7
1.0	64.9–81.2	100.4	6.2
1.6	66.8–84.1	104.7	10.5

The maximum location of the salt front occurred during the simulated 1965 conditions with implementation of a constant Trenton flow objective of 2,500 cfs.

Normal range:
(25 – 75 percentile range)

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Chloride Concentration: 10-year Ensemble Results

(1965, 2001 to 2002, 2011 to 2013, and 2016 to 2019)

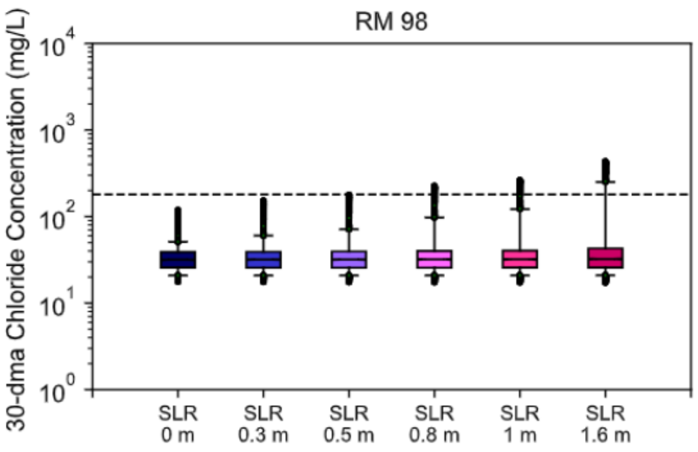


Figure 4.2-4. Simulated maximum 30-day moving average chloride concentration at RM 98 based on 10-year ensemble results.

Note: dashed line indicates the water quality standard of 180 mg/L chloride concentration at RM 98. In these ensemble simulations, a 2,500 cfs minimum flow was set on the Delaware River at Trenton to reflect the flow objective under drought conditions of 1965. Simulated years are 1965, 2001-2002, 2011-2013, and 2016-2019.

Table 4.2-2. Simulated maximum 30-dma chloride concentration at River Mile 98.

Sea Level Rise (m)	30-dma chloride concentration at Camden, RM 98 (mg/L)	Total number of days 30-dma chloride concentration exceeds 180 mg/L	Percent of time 30-dma chloride concentration exceeds 180 mg/L
0	119	0	0%
0.3	152	0	0%
0.5	178	0	0%
0.8	225	80 *	2.2% *
1.0	263	118 *	3.2% *
1.6	431	273	7.5%

Total number of days simulated = 3652.
* Simulated exceedances only occurred in 1965 with the constant 2,500 cfs flow objective at Trenton. For 1.6 m SLR, exceedances occurred in 4 years (2001, 2002, 2016, and 1965).

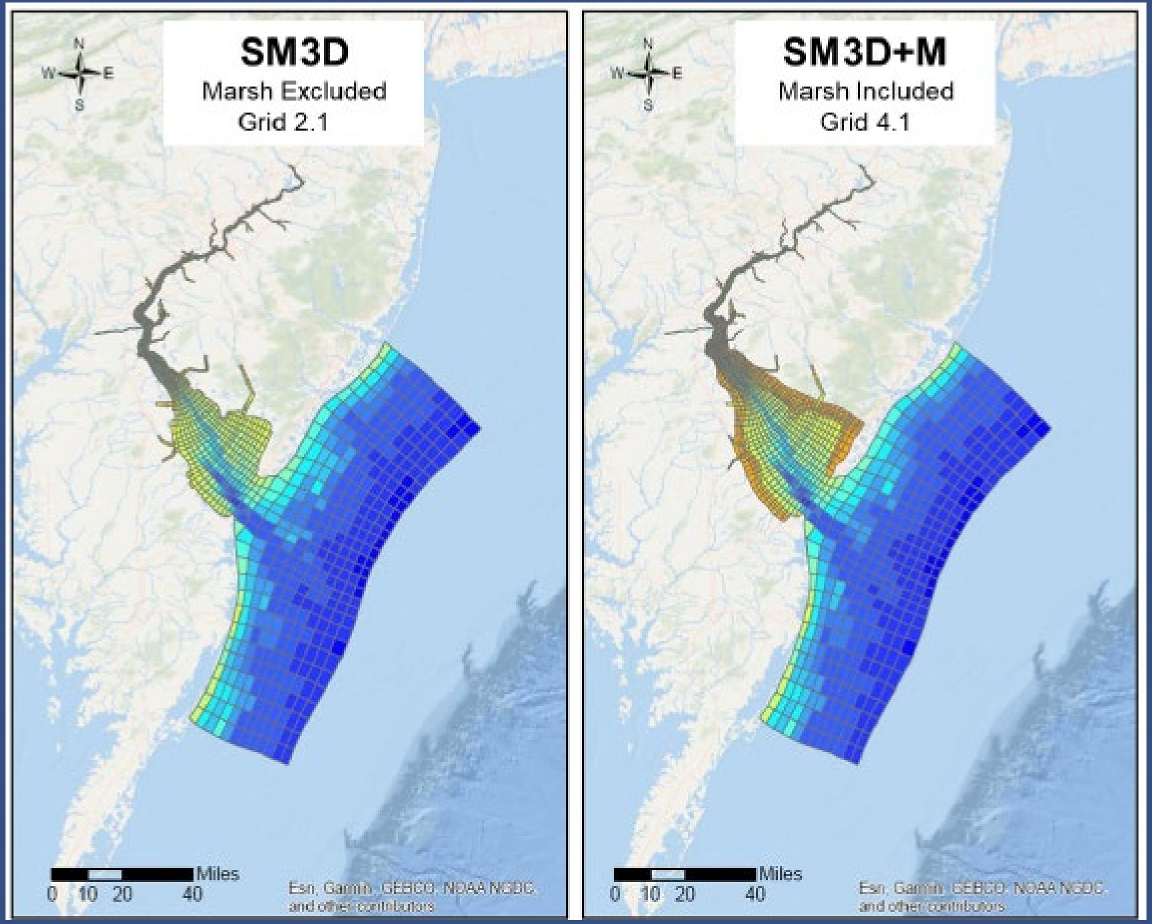
Sea level rise exceeding 0.5 m may result in water quality standard exceedances, and current flow objectives at Trenton may not provide sufficient salinity control.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Effects of Other Factors

- **Bathymetry**
- **Marsh inundation**
- **Ocean Surface Temperature (OST)**
- **Increased drought severity**

Among others



Federal Navigation Channel was deepened from 40 to 45 ft below MLLW from 2010 to 2020

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Effects of Marsh Inundation

2002 low-flow hydrological condition, 45-ft channel bathymetry

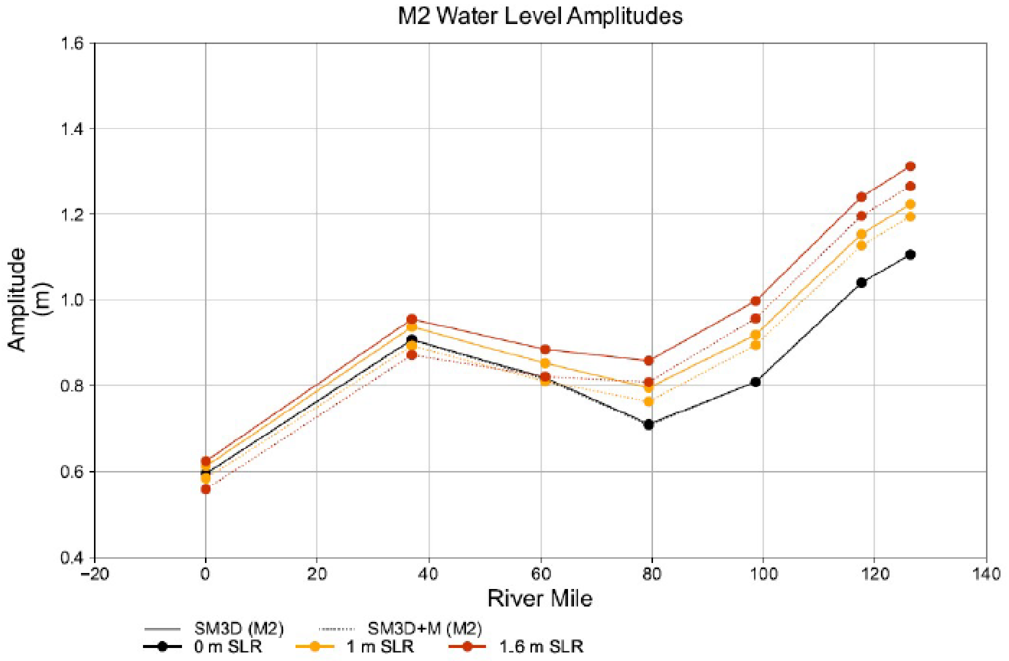


Figure J. 1-4. Simulated spatial distribution of M2 tidal water level amplitude with sea level rise; without extended marsh area (SM3D) and with extended marsh area (SM3D+Marsh).

Comparison of the predicted maximum salt front location with (SM3D+M) and without (SM3D) additional marsh area

SLR (m)	SM3D (RM)	SM3D+M (RM)	Difference (Miles)
0	90.7	90.5	-0.2
0.3	92.4	92.2	-0.2
0.5	93.4	93.0	-0.4
0.8	95.0	94.0	-1.0
1	96.3	94.8	-1.5
1.6	101.4	98.8	-2.6

Note: Simulated flows of July-October 2002.

Marsh inundation reduces salinity intrusion up to 2.6 miles. The effect is insignificant with SLR less than 0.5 m and more pronounced with SLR greater than 0.8 m. SM3D produces more conservative results for evaluating salinity intrusion.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Effects of Federal Navigation Channel Deepening

2002 low-flow hydrological condition, 45-ft channel bathymetry

Table 5.4-1. Sensitivity of salt front location to channel bathymetry and SLR.

SLR (m)	Channel Depth (ft)	Simulated Maximum Salt Front Location (RM)	Change in Salt Front Location Due to Increased Channel Depth (mi) [1] SF45 – SF40	Change in Salt Front Location Due to SLR for 40-ft Channel (mi) [2] SF(SLR) – SF(0m)	Change in Salt Front Location Due to SLR for 45-ft Channel (mi) [3] SF(SLR) – SF(0m)	Total Change in Salt Front Location Due to SLR and Channel Depth (mi) [4]* SF(45ft,SLR) – SF(40ft,0m)
0	40	88.3		–	–	
	45	90.7	2.4	–		2.4
0.5	40	91.3		3.0		
	45	93.4	2.1		2.7	5.1
1.0	40	94.1		5.8	–	
	45	96.3	2.2		5.6	8.0
1.6	40	99.0		10.7	–	
	45	101.4	2.4		10.7	13.1

Note: the analysis was based on the 2002 hydrologic conditions. 2002 is one of the dry years.
* The total change in the salt front location with the channel deepening (45-ft channel) AND SLR compared to the SF for a 40-ft channel and 0 m SLR.

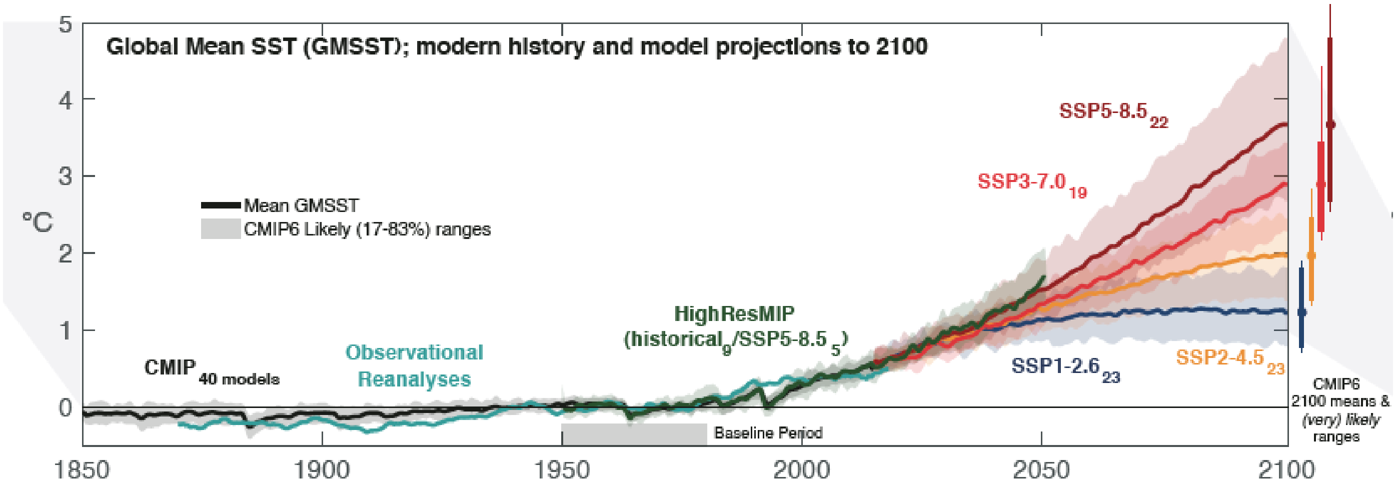
A deeper channel makes salinity intrusion farther upstream, while the SLR has a greater impact on salinity intrusion than the 5-ft channel deepening project

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Sensitivity to Ocean Surface Water Temperature

2002 low-flow hydrological condition, 45-ft channel bathymetry

When compared to the 1850-1900 averages, the land average in 2025 has increased 2.03 ± 0.17 °C (3.66 ± 0.32 °F) and the ocean surface temperature, excluding sea ice regions, has increased 1.03 ± 0.05°C (1.86 ± 0.09 °F). Most of this warming has occurred since 1970.



Observation-based estimated and CMIP6 multi-model means, biases and projected changes in sea surface temperature.

Source: IPCC AR6 (2022)

Table 6.3-1. Predicted salt front location sensitivity to ocean temperature.

SLR (m)	Maximum Salt Front Location (RM)		
	Base	+1°C	Difference
0	90.7	90.4	-0.3
0.5	93.4	93.1	-0.3
1	96.3	95.9	-0.4
1.6	101.4	101.0	-0.4

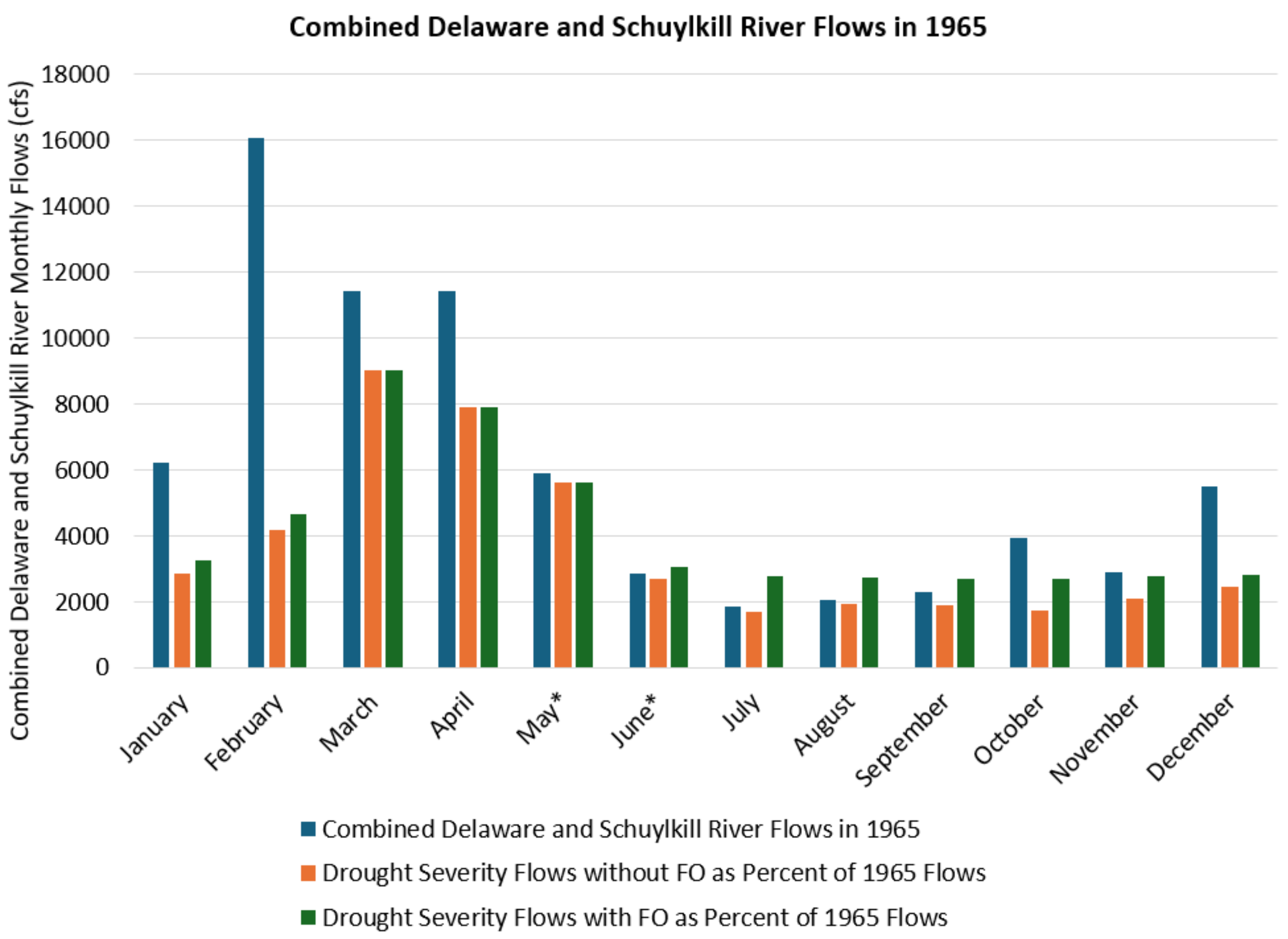
Note: these simulations used a representative low flow condition from 2002.

Potential future warmer ocean temperatures may slightly reduce the upstream extent of the salt front. 1 C increase may result in SF locations roughly 0.3 - 0.4 mile farther downstream.

Basin Commission
NEW JERSEY
IA • NEW YORK
ES OF AMERICA

Stress Test: Increase Drought Severity

More severe drought, 45-ft channel bathymetry



Combined minimum monthly flows from DR and Schuylkill River designed for more severe drought scenario with & w/o FO

Month	Drought Severity Flows without FO as Percent of 1965 Flows	Drought Severity Flows with FO as Percent of 1965 Flows	Combined Delaware and Schuylkill River Flows in 1965 (cfs)	Drought Severity Flows without FO as Percent of 1965 Flows (cfs)	Drought Severity Flows with FO as Percent of 1965 Flows (cfs)
January	46%	52%	6,232	2,864	3,241
February	26%	29%	16,048	4,161	4,668
March	79%	79%	11,439	9,026	9,026
April	69%	69%	11,435	7,883	7,883
May*	95%	95%	5,902	5,608	5,608
June*	95%	108%	2,833	2,693	3,057
July	91%	150%	1,837	1,670	2,761
August	94%	133%	2,062	1,937	2,737
September	82%	116%	2,298	1,882	2,671
October	44%	69%	3,917	1,722	2,692
November	72%	96%	2,889	2,077	2,778
December	45%	51%	5,488	2,468	2,811

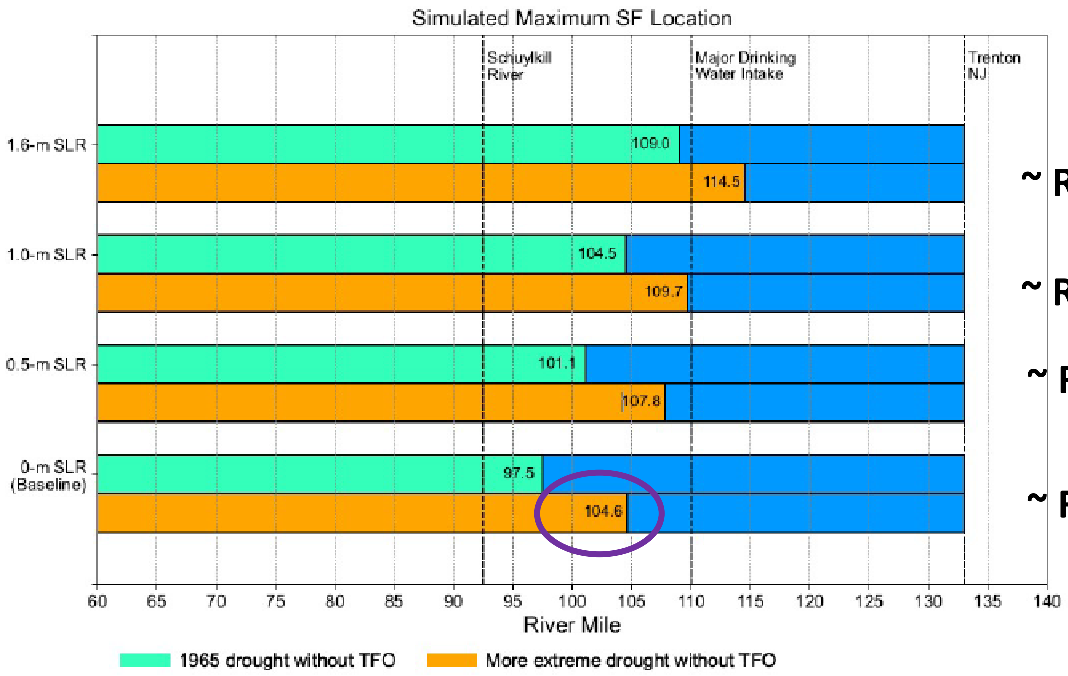
(*) For May and June, the historical minimum monthly flows were greater than 95 percent of the monthly flow from 1965. To increase the drought severity for these months, the combined monthly inflows were adjusted to be 95% of the historical combined minimum monthly flow. FO = flow objective

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Effects of Increase in Drought Severity

More severe drought, 45-ft channel bathymetry

Without TFO



~ RM 115

~ RM 110

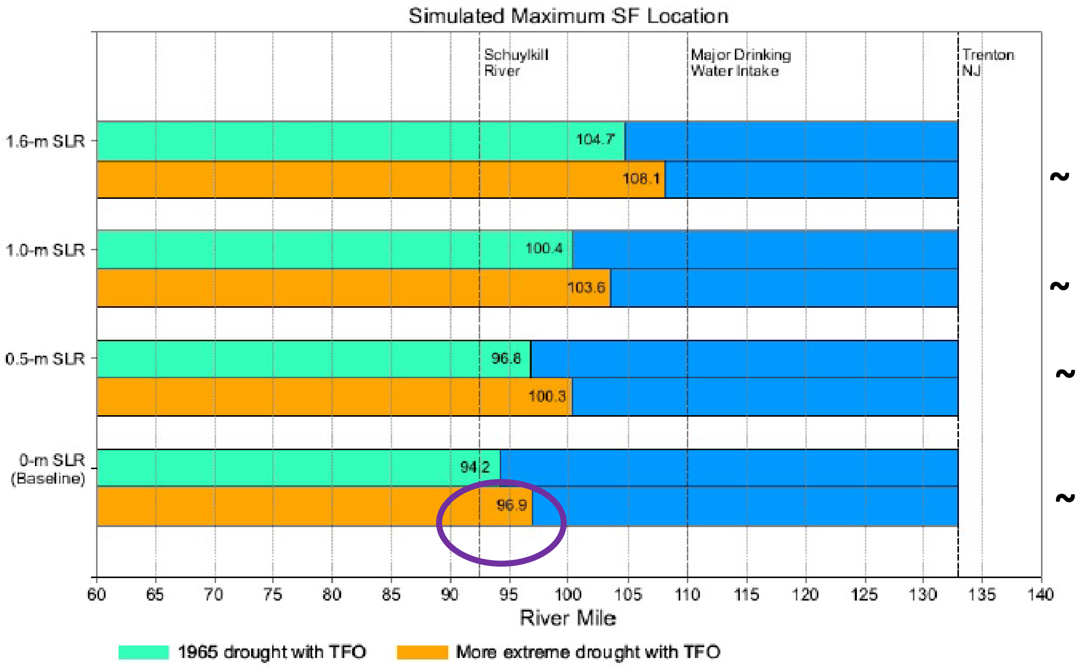
~ RM 108

~ RM 105

Note: The green bars represent simulation results using 1965 drought flow condition without the Trenton Flow Objective. The orange bars represent the results of simulations of a more severe drought; the differences between the lengths of the green and orange bars quantify the impact of the more severe drought flow conditions on salinity intrusion.

Figure K.2-2. Simulated maximum salt front location with more extreme drought flows in comparison with the simulated location with 1965 Flows. The Trenton Flow Objective was not represented in these simulations.

With TFO



~ RM 108

~ RM 104

~ RM 100

~ RM 97

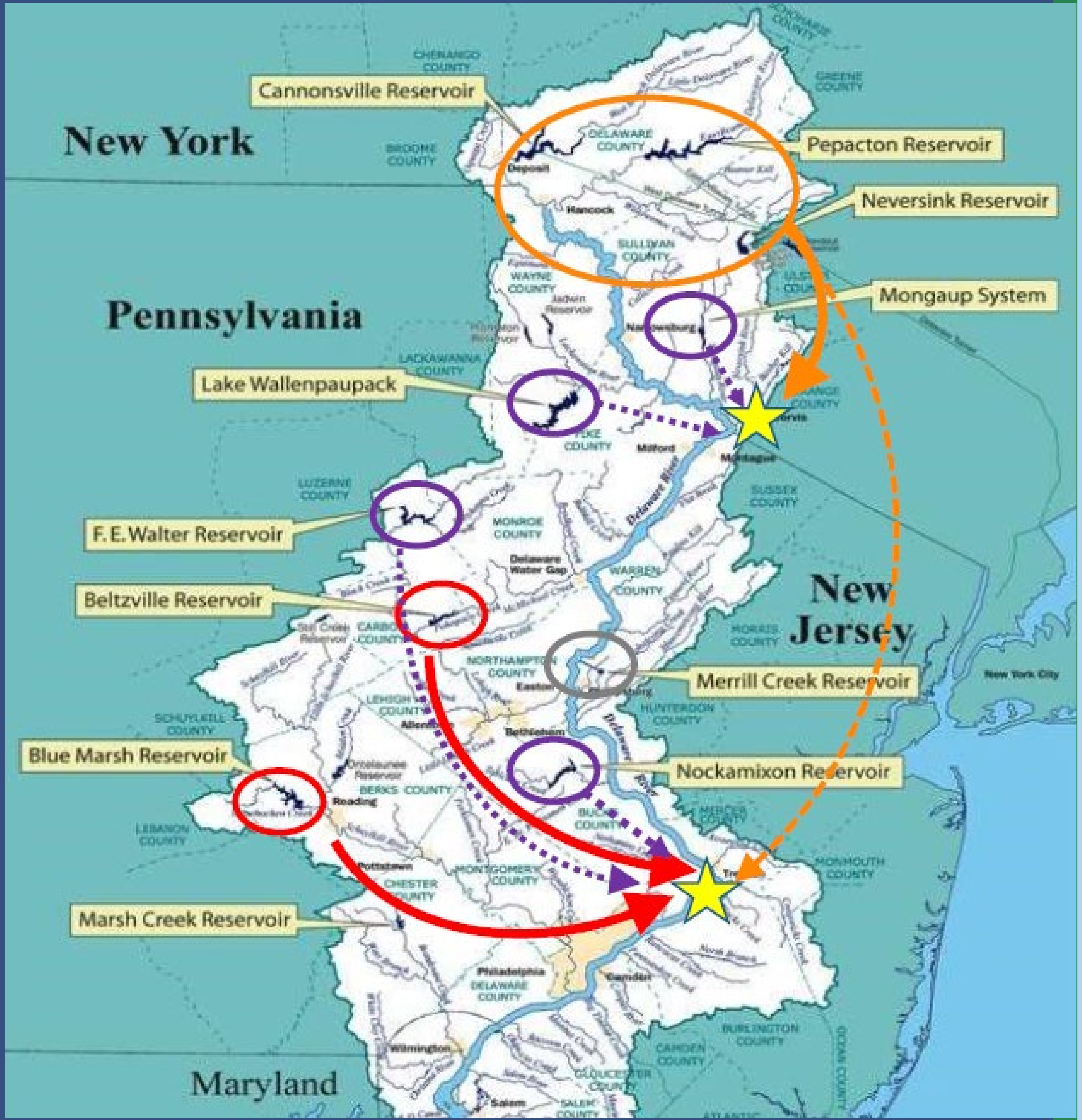
Figure 6.2-2. Simulated maximum location of the salt front with sea level rise during a hypothetical repeat of 1965 flows during the 1960s drought and during a more extreme drought.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

TFO = Trenton Flow Objective

Analysis of Management Actions

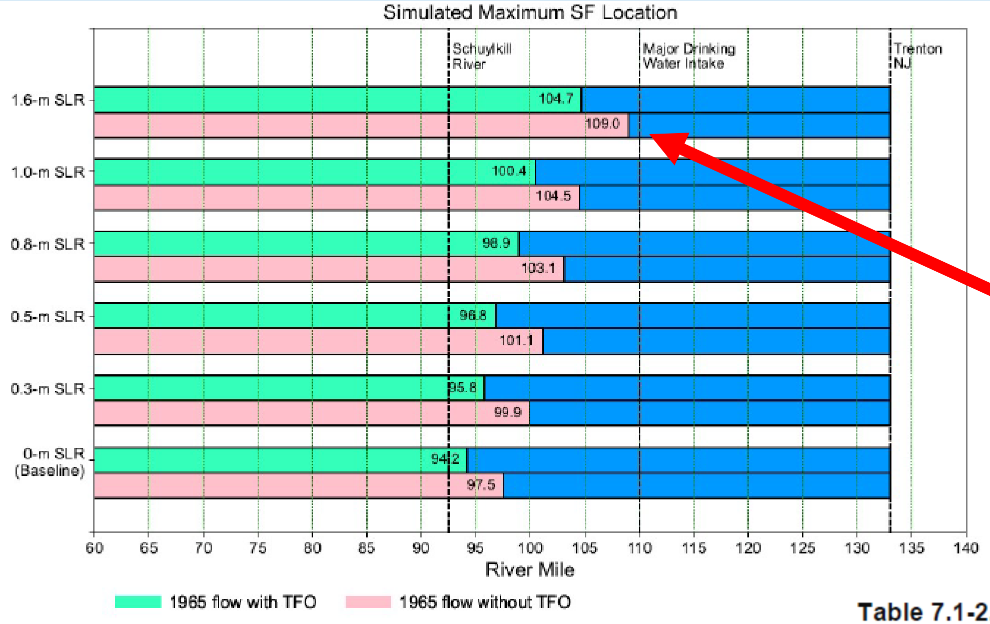
- Flow objective
- Pulse release
- Source of water for salinity repulsion
  - ✓ Release from Delaware R. vs. release from Schuylkill R.



Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Impact of Trenton Flow Objective

1965 hydrological condition, 45-ft channel bathymetry



SF is kept below RM 105 for all SLR scenarios with minimum 2500 cfs flow objective at Trenton with 1965 flow conditions.

Table 7.1-1. Simulated maximum salt front location during a repeat of 1965 flows during the 1960s drought with sea level rise: Evaluation of the Trenton Flow Objective.

Sea Level Rise (m)	Maximum Salt Front Location with Historical Flows (River Mile)	Maximum Salt Front Location with Historical Flows plus 2,500 cfs Flow Objective (River Mile)	Change in Simulated Maximum Salt Front Location (mi)
0	97.5	94.2	-3.3
0.3	99.9	95.8	-4.1
0.5	101.1	96.8	-4.3
0.8	103.1	98.9	-4.2
1.0	104.5	100.4	-4.1
1.6	109.0	104.7	-4.3

Table 7.1-3. Simulated days (percent of year) the maximum 30-dma chloride concentration at RM 98 (Camden) exceeds the water quality standard of 180 mg/L with sea level rise during a repeat of 1965 flows during the 1960s drought: Evaluation of the Trenton Flow Objective.

Sea Level Rise (m)	Historical Flows (days) [percent of year]	Historical Flows plus 2,500 cfs Flow Objective (days) [percent of year]	Difference (days)
0	43 [11.8%]	0 [0%]	-43
0.3	84 [23.0%]	0 [0%]	-84
0.5	115 [31.5%]	4 [1.1%]	-111
0.8	150 [41.1%]	91 [24.9%]	-59
1.0	160 [43.8%]	132 [36.2%]	-28
1.6	180 [49.3%]	170 [46.6%]	-10

Table 7.1-2. Simulated maximum 30-dma chloride concentrations at RM 98 (Camden) with sea level rise during a repeat of 1965 flows during the 1960s drought: Evaluation of the Trenton Flow Objective.

Sea Level Rise (m)	Maximum 30-dma Chloride Concentration with Historical Flows (mg/L)	Maximum 30-dma Chloride Concentration with Historical Flows Plus 2,500 cfs Flow Objective (mg/L)	Difference in 30-dma Chloride Concentration (%)
0	224	123	-45%
0.3	278	175	-37%
0.5	322	218	-32%
0.8	417	298	-29%
1.0	489	358	-27%
1.6	768	607	-21%

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Main Take-away Message

As sea level rise increases, the salt front advances closer to drinking water intakes, and existing freshwater flow management may no longer be sufficient to control salinity.

Water quality standards are met under low sea level rise scenarios but are exceeded more often under higher sea level rise scenarios, particularly during low flow conditions.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Background Information

SLR Impact on Salinity

Potential Future Work

POTENTIAL FUTURE WORK

Additional Analysis associate to SLR, Planning Scenarios

- Additional systematic analysis of the SF response to the tide and flows → Flow Objective with SLR → Water availability → Risk and sustainability study.
- Climate-impacted flow conditions → Climate change may alter the distribution and seasonality of inflows to the Estuary, so additional analysis of other climate-impacted flow conditions may be warranted.
- Planning scenarios → Model assumptions, non-tidal salinity, ocean temperature, future flows, and other boundary conditions, may also be factors to consider when designing detailed scenarios for future planning efforts.

Adaption, Mitigation, and Sustainability

- Protection of public health and safety: water quality, water availability and water supply sustainability.
- Impact of sea level rise on habitat and the health of aquatic life.
- Inform and improve flow and drought management programs for changing climate

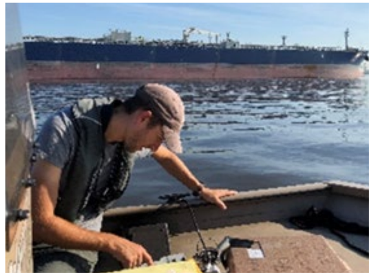
Acknowledgements

The Delaware River Basin Commission (DRBC) staff are grateful to the following national renowned experts for their engagement, valuable guidance on methodology and modeling approach, and insightful technical advice for this project: Dr. Carl Cerco from USACE (retired); Dr. Bob Chant from Rutgers University, Professor in the Department of Marine and Coastal Sciences; Dr. Hugo Rodriguez, who is a former senior water resources & coastal engineer from GHD1; and Dr. Gaurav Savant from USACE-ERDC-CHL2, Rivers and Estuarine Engineering Branch. All four have extensive experience in the fields of oceanography and estuary environmental hydrodynamics modeling and were engaged to provide external technical review of this report. We also acknowledge the guidance from members of DRBC's Advisory Committee on Climate Change about the use of sea level rise projections and their review and input on the draft report.

The project was developed, performed, and documented by Dr. Fanghui Chen, P.E., and Amy L. Shallcross, P.E., of the DRBC Water Resource Operations branch. The draft report was reviewed by former DRBC Executive Director Steven J. Tambini, and edited by Robert S. Nicholson, retired hydrologist formerly of U.S. Geological Survey. Development of this scientific modeling study would not have been possible without the contributions of Dr. Li Zheng, Dr. Joseph Fogarty, and others at the DRBC who provided guidance and support.

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA

Questions ?



Additional information

- Report Website: https://www.nj.gov/drbc/programs/flow/SLR-impacts-report.html
- Salt Front: https://www.nj.gov/drbc/programs/flow/salt-front.html
- Salt Front Data and Data Viewer: https://drbc.net/Sky/hydro/saltfront.html

Delaware River Basin Commission
DELAWARE • NEW JERSEY
PENNSYLVANIA • NEW YORK
UNITED STATES OF AMERICA