June 2026

Salt Front Calculation Method

Technical Report 2026 – 4

Managing, Protecting and Improving
the Water Resources of the
Delaware River Basin since 1961

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

Salt Front Calculation Method

DRBC Report No: 2026-4

Prepared by Sara Sayed, Amy Shallcross, P.E., and Fanghui Chen, Ph.D.

Delaware River Basin Commission

25 COSEY ROAD, WEST TRENTON, NEW JERSEY, 08628

Kristen Bowman Kavanagh, Executive Director

Suggested Citation

Sayed, S., Shallcross, A,. and Chen, F. (2026). *Salt Front Calculation Method* (Technical Report 2026-4). Delaware River Basin Commission. https://www.nj.gov/drbc/library/documents/SaltFrontCalc.pdf

ACKNOWLEDGEMENTS

This report was prepared by the Water Resource Operations Staff of the Delaware River Basin Commission: Amy Shallcross, Manager of Water Resource Operations; Dr. Fanghui Chen, P.E., Senior Water Resource Engineer and Sara Sayed, Water Resource Scientist. Former staff who contributed to calculations of the salt front include Dr. Richard Tortoriello, Richard Fromuth, Gail Blum, and Anthony Preucil.

SCOPE AND ORGANIZATION

This report describes the methodology for calculation of the salt front location, an indication of salinity intrusion into the Delaware River Estuary. During drought emergencies, the salt front location is used to determine the amount of water released from different reservoirs in the basin to meet the Trenton Flow Objective. The Delaware River Basin Commission (DRBC) website has additional information about the salt front and flow management[1]. An additional purpose of the report is to document how the historical record for the salt front location was developed.

The information is presented in the context of creating the historical record. Although the method presented in this report is currently used, it will be adapted as additional data sources at intermediate river locations become available. It should be noted that the seven-day average salt front location is used for flow and drought management purposes because it is a stable indicator of trends in salinity movement. The daily salt front location is presented for informational purposes only[2].

[1] Flow Management - https://www.nj.gov/drbc/programs/flow/flow-mgmt.html

[2] Salt Front - https://www.nj.gov/drbc/programs/flow/salt-front.html

LIST OF ACRONYMS AND ABBREVIATIONS

BR	Below Reedy Island
C	Chlorides
C-BF	Chester – Ben Franklin station pair
C-FM	Chester – Fort Mifflin station pair
CL7D	Salt front (7-day moving average) calculated with chlorides averaged over seven days
DRBC	Delaware River Basin Commission
DV7D	Salt front (7-day moving average) calculated by averaging the daily value over seven days
FM-BF	Fort Mifflin – Ben Franklin station pair
KCC	Kimberly Clark Company
NOSP	Non-Optimal Station Pair for calculating the salt front
OSP	Optimal Station Pair for calculating the salt front
RI-BF	Reedy Island – Ben Franklin station pair
RI-C	Reedy Island – Chester station pair
RM	River Mile (description located on the website at https://www.nj.gov/drbc/basin/river/index.html)
SC	Specific Conductance
SF	Salt Front
USGS	U.S. Geological Survey

TABLE OF CONTENTS

1. INTRODUCTION

The Delaware River Estuary is the tidal portion of the Delaware River from below Trenton to the mouth of Delaware Bay. In the estuary, freshwater from land mixes with saltwater from the ocean and the concentration of salt (salinity) increases from upstream to downstream. The river is freshwater at Trenton, N.J., and salty at the bay.

Saltwater and its movement upstream, called salinity intrusion, have been a concern for the Delaware Estuary since the early twentieth century. The freshwater in the estuary is used for industry, manufacturing, thermoelectric power generation, and drinking water. More than half of Philadelphia's water supply and a large portion of the water supply for several counties in New Jersey come from the Delaware River Estuary. Both intakes are near River Mile 110. Saline water causes corrosion and interferes with drinking water treatment, increasing the costs of equipment and piping (corrosion control) for surface water users, particularly industry, and can raise the treatment costs for public water suppliers.[3] Increased salinity can also affect the taste and odor of finished drinking water and interferes with the chemical treatment processes.

Water resource managers at the Delaware River Basin Commission (DRBC) use the salt front to determine the extent of salinity intrusion into the Delaware River Estuary and release water from reservoirs for its management. The salt front is defined as the 7-day moving average location of the 250 mg/L chloride concentration (also known as the 250 mg/L isochlor). The location is reported using the Delaware River Mile System[4] (RM), which follows the Federal Navigation Channel. The mouth of the bay is RM 0 and the head of tide at Trenton is RM 133. Figure 1-1 presents a map of the Upper Delaware River Estuary. Direct measurement of the salt front location is not possible because an extensive monitoring network along the river or an autonomous underwater vehicle with salinity sensors are cost prohibitive. However, the location of the salt front can be estimated with chloride concentrations calculated from specific conductance data, available from USGS water quality monitoring stations located in the Delaware Estuary, and log-linear interpolation for the 250 mg/l isochlor between adjacent stations. The data sources used to calculate the salt front are summarized in Section 2. The formula and how to use it are presented in Section 3. Section 4 contains a discussion and characteristics about the historical record. Section 5 provides a summary of this project.

[3] https://www.nj.gov/drbc/programs/flow/salt-front.html

[4] https://www.nj.gov/drbc/basin/river/index.html

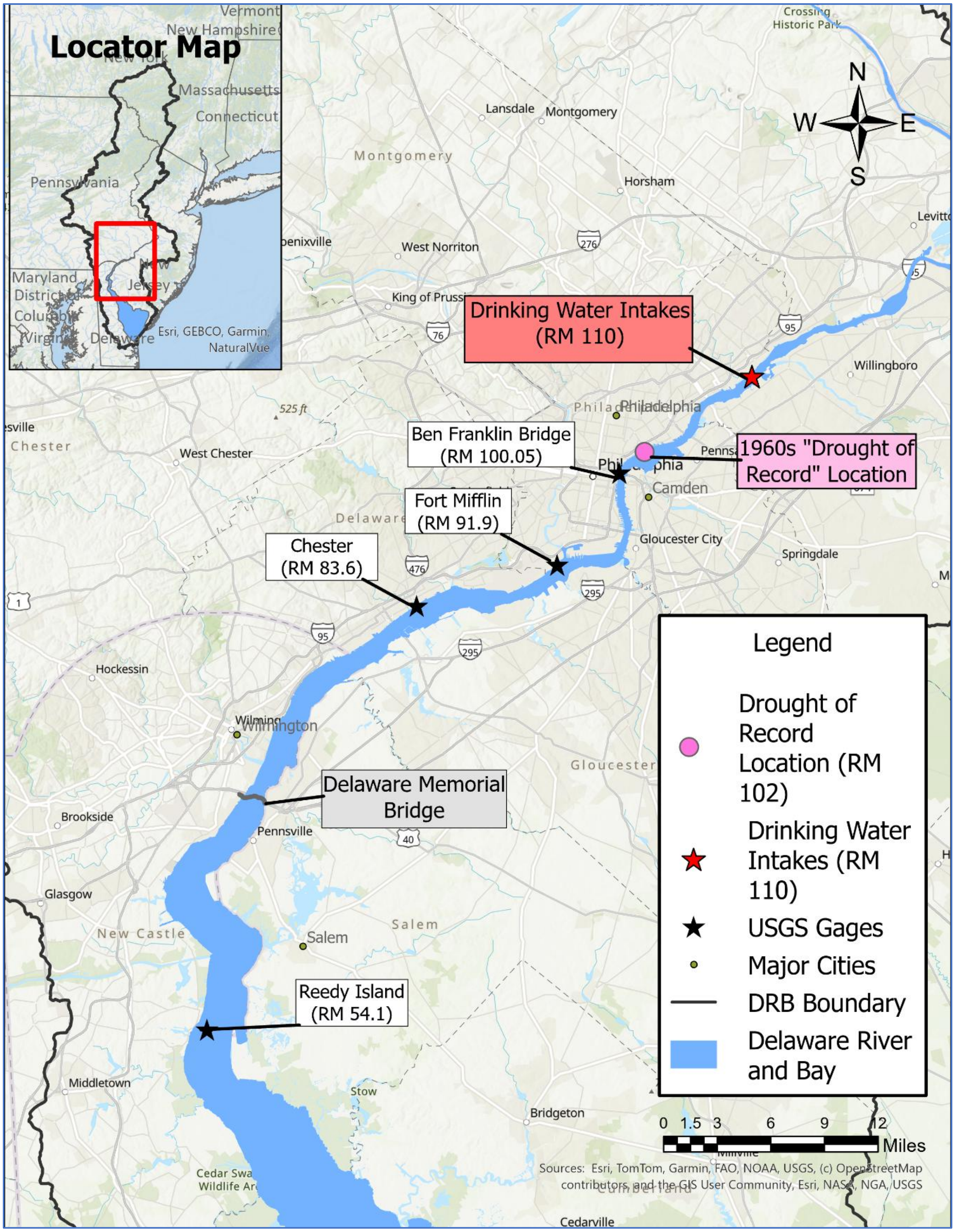

Figure 1-1: Upper Delaware River Estuary

2. DATA AND SOURCES

The average daily Specific Conductance (SC) is used to estimate chloride concentrations for calculation of the salt front. In the Delaware Estuary, SC data are available from four USGS water quality monitoring stations (stations or gages) located along the main stem of the Delaware River at: Reedy Island[5], Chester[6], Fort Mifflin[7], and Ben Franklin Bridge[8]. Table 2-1 contains information about the installation of each gage including its USGS ID, name, river mile (RM), period of record, channel depth, channel width, sensor location, and sensor depth.[9] On occasion and for a variety of reasons, gage installations may be relocated; therefore, it is important to verify the gage location for the period during which the salt front is calculated because the location is used in the calculation.

On days when the daily average SC is not reported, the average of the maximum and minimum SC, if available, is used to approximate the average daily SC. Appendix A contains a discussion of three correlation methods used to evaluate the appropriateness of the use of the average of the maximum and minimum SC when the average daily SC is unavailable. The results indicate that this approximation method is acceptable because the values are highly correlated.

2.1 REEDY ISLAND

The Reedy Island gage, located in New Castle County, Delaware (01482800). was originally installed on a dock on the upstream side of a jetty, approximately 0.4 miles downstream from Reedy Island near Port Penn. SC measurements are available from October 3,1963 through late 2024, when the instrumentation was destroyed. Another site was established 0.75 miles upstream. Data from the new location and the original site are recorded from August 13, 2024, through January 13, 2025. The original site was discontinued after January 13, 2025.

2.2 CHESTER

Chester gage is currently located at Kimberly-Clark Paper Company in Chester, Pennsylvania, approximately 0.5 miles downstream from Ridley Creek. SC observations are available from October 2,1963 to the present. The gage was relocated twice since established. In April 1981, the gage was moved from the end of the Reynolds Aluminum Company pier, 0.5 miles

[5] https://waterdata.usgs.gov/nwis/uv?site_no=01482800
[6] https://waterdata.usgs.gov/nwis/uv?site_no=01477050
[7] https://waterdata.usgs.gov/nwis/uv/?site_no=01474703
[8] https://waterdata.usgs.gov/nwis/uv?site_no=01467200
[9] Personal communication from Matthew Graves (USGS) to Amy Shallcross (DRBC) on February 9, 2018.

downstream from Chester Creek, to the pumphouse on Kimberly Clark property, 400 feet upstream from Chester Creek. In April of 2016, the gage was moved to its current location, approximately 0.5 miles farther upstream. During most of the period of record, USGS discontinues operation of the gage during the winter months. However, if the salt front approaches RM 78, DRBC requests that operation of the gage be continued if the flow regime at the time is expected to remain low. In April 2019, year-round operation of the gage began.

Table 2-1: USGS Gage Installations Used for Salt Front Record

Gage Name and ID	RM*	Dates**	Channel Depth	Channel Width	Sensor Location	Sensor Depth
Reedy Island 01482800	54.1	1963-10-03 to 2025-01-13 2024-08-14 to present	Up to 50 feet in the shipping channel	12,000 feet	4,500 feet from the right bank on the shore-ward side of Jetty.	Approximately 15 feet below the water-surface at low tide.
Chester 01477050	82.34 83.1 83.6	1963-10-02 to 1981-03-31 1981-04-01 to 2016-03-31 2016-04-01 to present	Up to 40–50 feet in the shipping channel.	7,000 feet	Directly along the right bank.	Approximately 10 feet below the water-surface at low tide.
Fort Mifflin 01474703	91.9	1972-06-16 to present	Up to 50 feet in the shipping channel.	5,300 feet	450 feet from the right bank.	Approximately 5 feet below the water-surface at low tide. Affected by Schuylkill River when flows are elevated.
Ben Franklin Bridge 01467200 (now Penn's Landing)	99.95 100.05	1963-10-01 to 1988-06-30 1988-07-01 to 2020-12-03 2020-12-03 to present	Up to 50 feet in the shipping channel.	2,800 feet	500 feet from right bank on downstream side of municipal pier #12.	Approximately 10 feet below the water-surface at low tide.
Bridesburg	105.2	1956-01-01 to 1957-11-01	N/A	N/A	480 feet from the right bank.	Approximately 24 feet below the water-surface at low tide.

*Gage location may have changed over the period of record (Sections 2.1 – 2.4).

**For approved specific conductance data

Data sources: Personal communication from Matthew Graves (USGS) to Amy Shallcross (DRBC) on February 9, 2018 and in April 2026 between Brian Bank and Fanghui Chen.

Note: Data are often not available in winter months. In the 1960s, chloride measurements from locations upstream of the Ben Franklin Bridge. The salt front has not been above RM 91 since 1967, so data above RM 100 was not needed for calculation of the historical record. Recently, additional gages were installed in the Delaware Estuary. In 2011, a gage was established at Pennypack Woods at RM 110 (USGS ID 014670261). Water quality instrumentation was installed at the request of the Philadelphia Water Department, which maintains the gage. In 2018, a gage was installed at the Delaware Memorial Bridge at RM 69 (USGS ID 01482100) for a multi-year study. Data are of insufficient quantity to evaluate how calculation of the salt front with the Delaware Memorial Bridge gage, differs from ones calculated with different gages. For consistency, the Delaware Memorial Bridge gage was not used to calculate the historical record of the salt front location. Data from both gages may be used in the future if needed, if a sufficient record is established, and if a permanent source of funding is identified to support the gage.

2.3 FORT MIFFLIN

The gage at Fort Mifflin is in Philadelphia, Pennsylvania (01474703), on the right bank of the Delaware River (PA side looking downstream) at the outer end of an L-shaped pier, 0.4 miles downstream from the mouth of the Schuylkill River. The period of record for SC is from July 14, 1970, to December of 1971 and from February of 1981 until present. The gage has remained at the same location during the period of record but until October 2019 was only active intermittently, primarily during dry conditions at the request of the DRBC. The gage is now operated continuously by the USGS.

2.4 BEN FRANKLIN BRIDGE

The fourth gage is located near Ben Franklin Bridge in Philadelphia, Pennsylvania. The period of record for SC observation is November 8,1963, through the present. Previously, the gage was only active during the spring through fall until April of 2018, when full-time data collection was initiated. Prior to July 1988, the gage was located on Pier 11, 300 feet downstream of the Ben Franklin Bridge. Between July 1988 to 2019, the gage was located on Pier 12, 150 ft upstream of Ben Franklin Bridge. Currently, the gage is located at the Philadelphia Seaport Museum, approximately 0.5 miles downstream of Ben Franklin Bridge. The relocated gage has the same gage ID of 01467200 but is named Delaware River at Penn's Landing.

2.5 OTHER DATA SOURCES

Recently, two additional gages were established in the estuary for other purposes: 1) Pennypack Woods, Pennsylvania[10], at RM 110, approximately nine miles upstream of Ben Franklin Bridge, and 2) Delaware Memorial Bridge in Wilmington, Delaware[11], at RM 69. The Pennypack gage was established by the Philadelphia Water Department for decisions related to water supply and the Delaware Memorial Bridge gage was established for the calibration of velocity and other parameters in hydrologic models. Neither has been used to calculate the salt front due to their short periods of record. If conditions develop that cause the salt front to move farther upstream than the Ben Franklin Bridge (RM 100), data from the Pennypack gage (RM 110) would likely be used to calculate the salt front location. Data from the Delaware Memorial Bridge gage may be useful for calculating the salt front because its normal range is in the vicinity of the bridge. However, until a sufficient record is available to assess the quality of the data and comparisons can be made with calculations of the salt front with other gages, it will not be used.

[10] https://waterdata.usgs.gov/nwis/uv?site_no=014670261

[11] https://waterdata.usgs.gov/nwis/uv/?site_no=01482100

2.6 DATA FOR THE HISTORICAL RECORD

The amount of SC data available for the salt front calculation depends on the operational status of the gages and the season. Prior to the late 2010s, the Chester and Fort Mifflin gages were periodically deactivated to protect against damage from ice and spring flood hazards. On occasion during dry periods, DRBC requested that the gages normally discontinue during the winter remain deployed until flow in the Delaware River increased and the salt front was closer to the Reedy Island gage. For instances when the data from the gages were not available, chloride data from the Kimberly Clark Company (KCC) were often used to calculate the salt front. For the historical record generated for this report, only gage-derived salt front locations are reported. However, the KCC chlorides are monitored rather than derived from SC and are used for comparisons with other estimates. The location of the salt front downstream of Reedy Island (RM 54) is typically not reported because the water is not well-mixed, and the log-linear interpolation may not be appropriate. However, for the historical record, the daily salt front location was calculated for short periods when it was below the Reedy Island gage but moved above quickly by assuming the chloride concentration at the mouth of the Delaware Bay was 15,000 mg/L[12], which is representative of the annual median value. In doing so, the number of missing days was reduced, providing more data for estimating the frequency of the salt front at a given location.

When data from a gage were unavailable for a period of fewer than 7 days, the chloride concentrations were estimated from the SC data using a linear interpolation from the last available value to the next available value for the missing days. Estimates for short periods of missing data were used for 650 days in the historical record.

After pre-processing and adding estimates for missing data, SC data for approximately 77.4 percent of the days in the period of record (October 1963 to April 2026) were available for calculation of the historical salt front record. Figure 2-1, known as a raster plot, is a year-by-year, day-by-day comparison of when the SC data were available. Most of the missing data occurred during the winter months when the Ben Franklin and Chester gages were not operational. As shown in gray on the figure, the consistent lack of data in the winter months is evident.

---

[12] DYNHYD-Chloride Modeling Report (2003)
https://www.state.nj.us/drbc/library/documents/TMDL/HydroModelRptDec2003.pdf

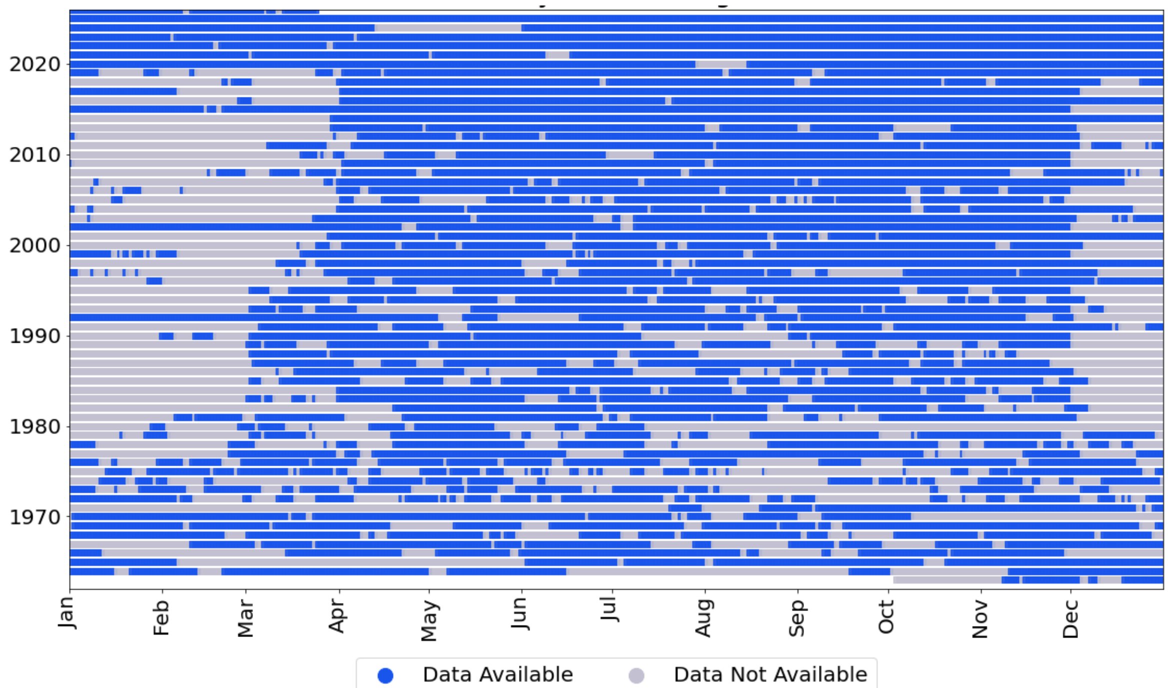

Figure 2-1: Data Availability Raster for Calculation of the Historical Salt Front Record
Blue represents time when data were available. Grey represents time when data are not available. Data are often unavailable in the winter due to the susceptibility of equipment to ice and high flow events.

2.7 STATION PAIRS

The salt front is determined using an interpolation between the two closest stations where the estimated chlorides change from greater than to less than 250 mg/l. Optimal station pairs (OSP) are geographically adjacent stations: Reedy Island–Chester (RI-C); Chester–Fort Mifflin (C-FM); and Fort Mifflin–Ben Franklin (FM-BF). However, data are not always available at adjacent stations (due to routine maintenance, equipment failure, temporary discontinuance in winter, and relocation). During these times, the salt front was calculated using non-optimal station pairs (NOSP): Reedy Island–Ben Franklin (RI-BF), Reedy Island–Fort Mifflin (RI-FM), or Chester–Ben Franklin (C-BF). The number of days each station pair was used to calculate the salt front in the historical record in Table 2-2 and Figure 2-2. The most common station pair used is OSP Reedy Island–Chester (77.4 percent) because the salt front is normally downstream of the Chester gage and upstream of the Reedy Island gage. The other pairs were used as follows: NOSP Reedy Island–Ben Franklin (26.4 percent), OSP Chester–Fort Mifflin (17.7 percent), NOSP Chester–Ben Franklin (10.8 percent), and NOSP Reedy Island–Fort Mifflin (12.6 percent). The OSP Fort Mifflin–Ben Franklin pair was used in 2025 (0.1%) because the salt front was upstream of Fort Mifflin (RM 91.9). This is the first time since the gage became operational in June 1972. The remainder of the time (approximately 7.3 percent), the salt front was below Reedy Island (BR). Approximately ten percent of the values in the historical record were calculated using NOSPs.

Table 2-2: Station Pairs for Calculation of the Salt Front

Station Pair	Type (OSP/NOSP)	Number of Calculations
Below Reedy Island	*N/A Section 2.6*	1,274
Reedy Island – Chester	OSP	13,424
Reedy Island – Fort Mifflin	NOSP	497
Reedy Island – Ben Franklin	NOSP	1,038
Chester – Fort Mifflin	OSP	694
Chester – Ben Franklin	NOSP	425
Fort Mifflin – Ben Franklin	OSP	2
For: October 1963 through April 2026.		

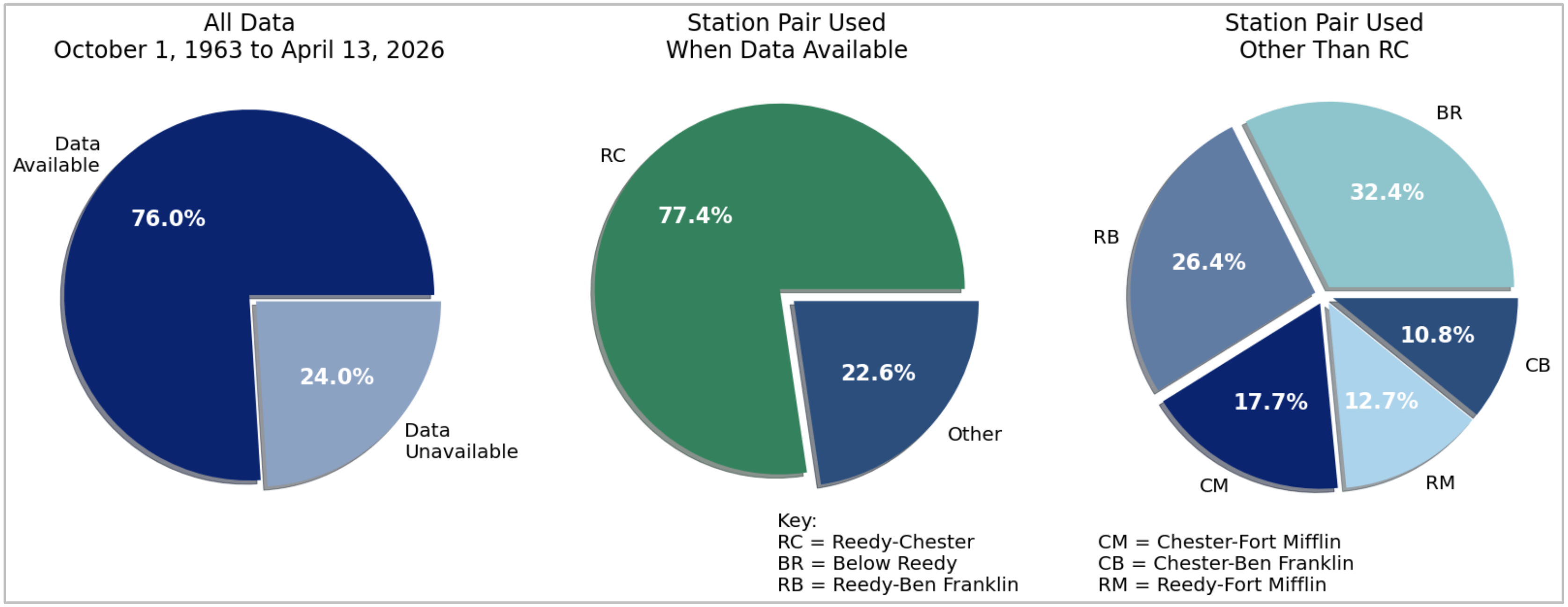

Figure 2-2: Percent of Salt Front Location Values Calculated by Each Station Pair
The pie chart on the left shows the percent of time when data were available for the period of record. The pie chart in the middle shows the percent of time when OSP Reedy Island-Chester (Reedy-Chester) was compared with all other station pairs. The pie chart on the right shows the percent of time an NOSP was used when data were unavailable for an OSP to be used.

2.8 CHLORIDES

Specific conductance is used to calculate the dissolved solids concentrations in water from a measurement of the ability of water to conduct electricity. Figure 2-3 presents an empirical relationship between SC and chlorides, a major component of dissolved solids, that was established for the Delaware River by the USGS in 1971.[13] The relationship is discontinuous over a large range, but linear for smaller ranges of concentration, with increasing slopes for larger values of SC and chlorides. A table for the conversion of specific conductance to chlorides based on this empirical relationship is available on the DRBC website[14].

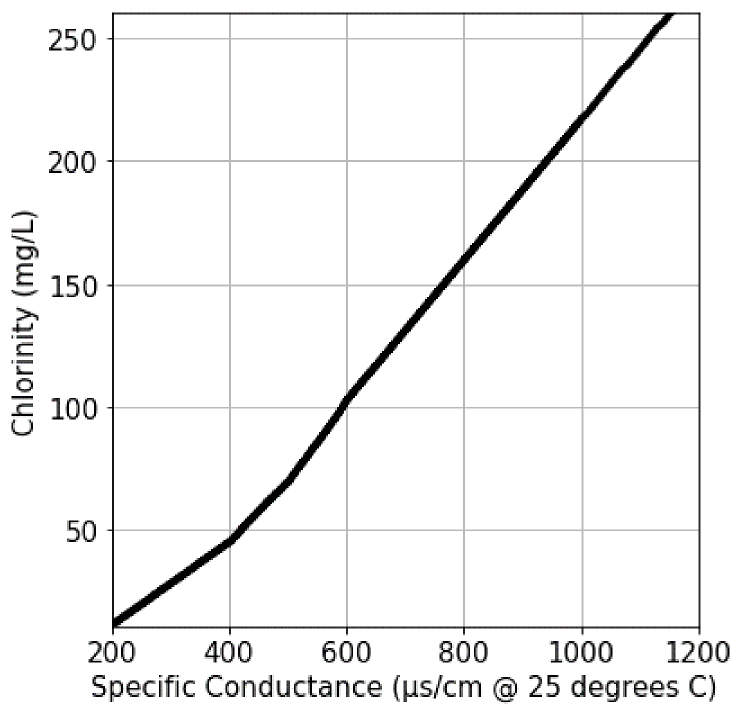

Figure 2-3: Relationship of Specific Conductance (SC) to chlorides

[13] Paulson, R.W., 1970. A graphical summary of specific conductance data for the Delaware River estuary as correlated with Delaware River flow at Trenton, New Jersey. USGS OFR Report 70-260. USGS Publications Warehouse. https://doi.org/10.3133/ofr70260

[14] https://drbc.net/Sky/hydro/USGS_SC_Chloride_Relation.txt

3. CALCULATION METHOD AND EQUATION

The salt front is determined by log-linear interpolation for the location of the 250 mg/l isochlor[15] (chloride concentration) along the river for each day (daily salt front) and those values are averaged over the past seven days for the salt front. Unless otherwise noted, the salt front is the 7-day moving average of 250 mg/l isochlor. The daily value used to calculate the average will be referenced as the daily salt front. The justification for use of log-linear interpolation is explained below in 3.1.

3.1 USE OF LINEAR-LOGARITHMIC INTERPOLATION

The decision to use the logarithm of the chlorides rather than an arithmetic value was determined by comparing measured chloride concentrations along the river. The data were obtained from a DRBC sampling program called the Boat Run.[16] Each year, DRBC contracts with the Delaware Department of Natural Resources and Environmental Control (DNREC) to collect surface water samples in the Delaware Estuary, from the head of tide at Trenton, N.J., to the mouth of Delaware Bay. The samples are collected approximately once per month at 22 locations and analyzed for chlorides and specific conductance along with many other water quality parameters. The Boat Run sampling locations are shown in Figure 3-1. These discrete samples were collected during a 4-to-5-hour period on the same day. Although the sample collection times differ and occur during different portions of the tidal cycle (some are collected during low water slack, while others are collected during high-water slack), they are still representative of how the chloride concentrations decrease from downstream to upstream.

Figure 3-2 presents the chloride concentrations at the sample locations from the arithmetic Boat Run. The gray squares connected by the gray lines represent the samples from one day. The samples are from days in ten of the years with the lowest chloride concentrations, when the salt front was likely to be farther upstream. The ten Boat Run days and years are listed in Table 3-1.The change in chloride concentration from downstream to upstream is not constant, so use of a linear interpolation would be less accurate. Figure 3-3 presents the logarithms of the chloride concentrations. The logarithms of the chloride concentrations demonstrate a more linear relationship with river mile for the portion of the tidal river where the water is well-mixed, typically above Reedy Island (RM 54). Given that the Boat Run data are grab samples and not all samples are collected at the same time, the logarithms of the chloride concentrations were

[15] An isochlor is similar to a plan-view topographical contour but based on the concentration of chloride rather than elevation.

[16] https://www.nj.gov/drbc/programs/quality/boat-run.html

relatively linear use of the log-linear interpolation was determined to be appropriate for calculating the salt front.

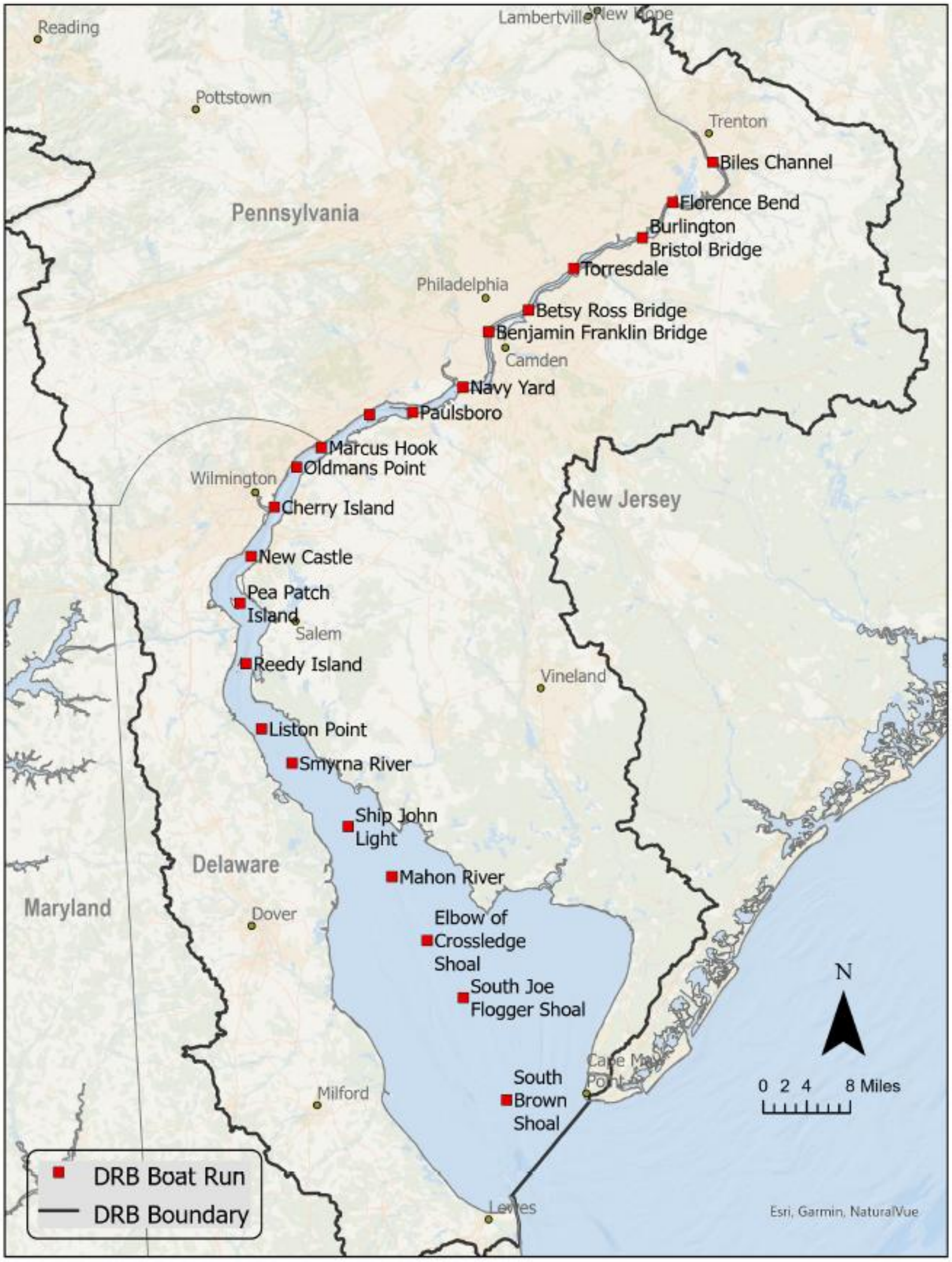

Figure 3-1: Boat Run Monitoring Locations

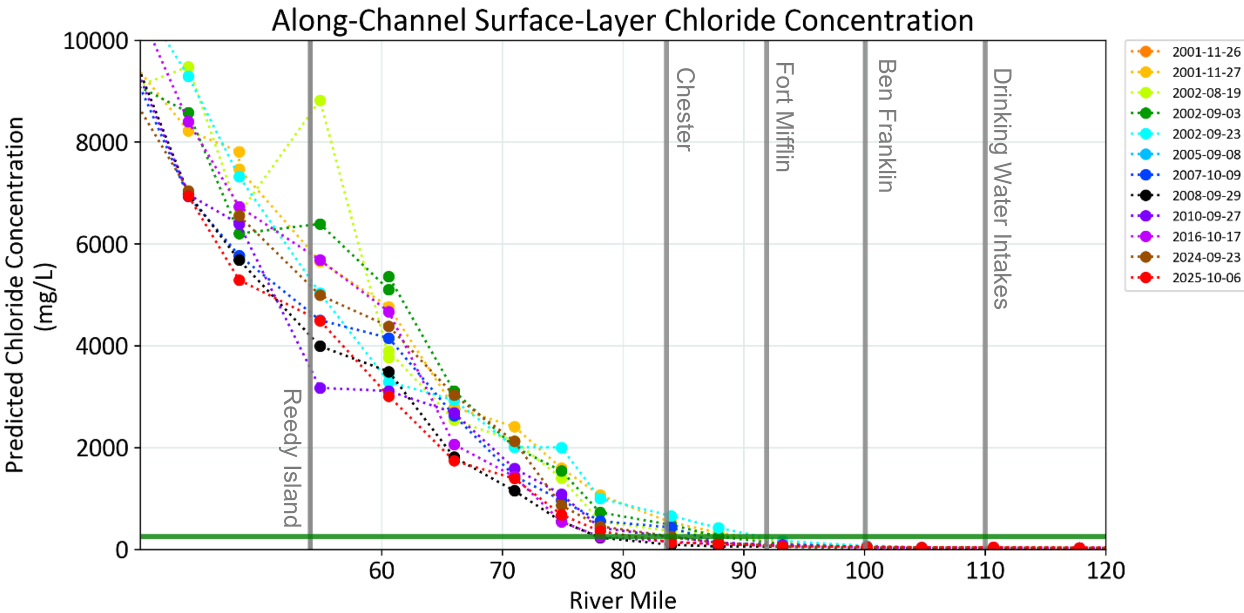

Figure 3-2: Chloride Concentrations at Boat Run Locations (Arithmetic Graph)
The chloride concentrations change by an order of magnitude between Reedy Island and Chester. The salt front is most often between River Miles 64 and 72, where the change in concentration appears non-linear.

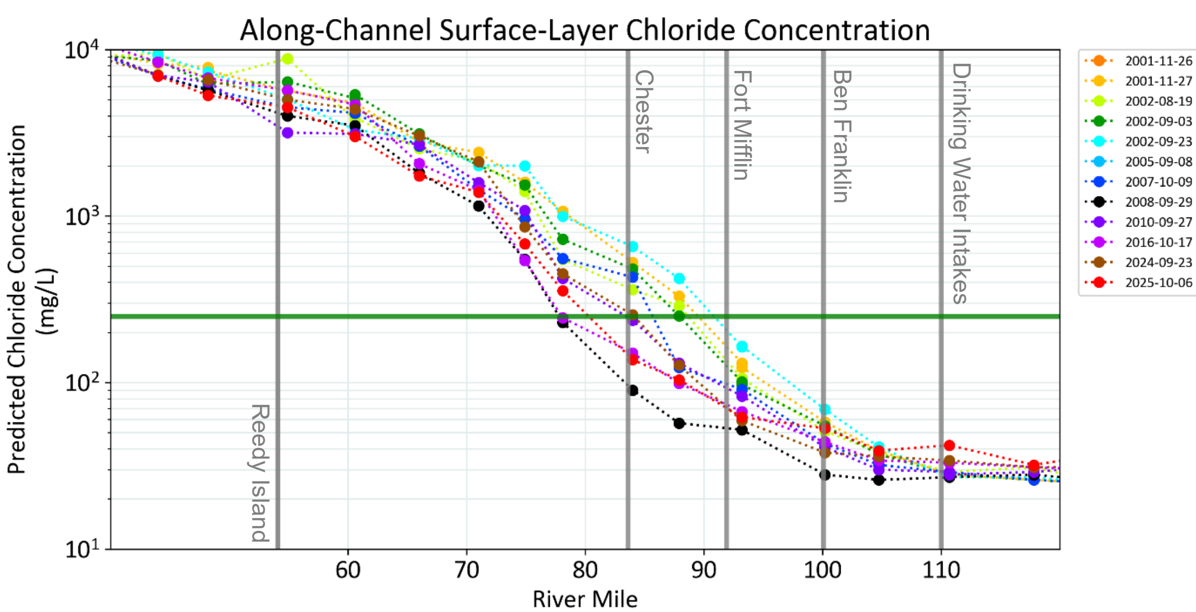

Figure 3-3: Chloride Concentration at Boat Run Locations (Logarithmic Graph)
The order of magnitude difference in the logarithm of the chloride conditions between Reedy Island and Chester appears more linear than the arithmetic values shown in Figure 3-2.

Table 3-1: Boat Run Sample Days used for Figure 3-2 and Figure 3-3

Date	Daily Salt Front Location	Salt Front Location
2024-09-23	80.2	83.5
2008-09-29	83.2	83.5
2002-08-19	84.5	83.5
2016-10-17	85.8	84.4
2007-10-09	86.0	85.1
2005-09-28	85.5	85.2
2002-09-03	84.7	85.3
2010-09-27	86.5	85.4
2001-11-26	86.4	86.3
2001-11-27	86.3	86.4
2025-10-06	86.7	83.5
2002-09-23	88.7	88.2
The daily 250 mg/l isochlor and the salt front are not directly comparable to the Boat Run Data. The Boat Run data represent a snapshot in time whereas these values are based on aggregated SC data. Days are ranked by maximum salt front location from the historical record for the day of the sample (ordered downstream to upstream).		

3.2 PROCEDURE

The method for computing the salt front location in the Delaware Estuary is as follows, with detailed discussions provided in the indicated sections of this report.

1. Obtain data from available gages for which specific conductance measurement is available (Section 2).
2. Convert the daily average specific conductance (SC) to chloride (Cl) concentration at each gage using the table in Appendix B (Section 3.1).
3. Determine the two gage stations (station pair) nearest to the salt front based on the chloride concentration (less than 250 mg/L upstream and greater than 250 mg/L downstream).
4. Classify the station pair. If the stations are geographically adjacent, the station pair is an OSP (e.g., Reedy Island-Chester). If data are missing from the closest station, the station pair is a NOSP (e.g., data are missing at Chester, but available at Reedy Island and Fort Mifflin or Ben Franklin). (Section 2.7)
5. Calculate the daily salt front using the station pair and the salt front equation (Section 3.3) based on the chlorides at each gage (Section 3.2).
6. If the station pair is an OSP, this is the value for the salt front location (Section 3.3).
7. If the station pair is an NOSP, calculate the adjusted daily location (Section 3.5).

a. Use the calculated NOSP location to determine the adjustment (Appendix B).

b. Apply the adjustment to the NOSP river mile location.

c. The adjusted value is used as the salt front location.

8. Use the daily salt front location from Step 6 or Step 7 to calculate the seven-day average salt front location (Section 3.5).

3.3 STATION SELECTION

For each day, the pair of stations nearest each other with observed data and with chloride concentrations less than and greater than 250 mg/L ($RM_{upstream}$ and $RM_{downstream}$, respectively) are used for the interpolation. When these stations are adjacent stations, the calculation for the salt front is straightforward (e.g., OSPs). However, when these data are not adjacent stations (e.g., NOSPs), additional steps are needed to adjust the resulting value to be like the salt front as if it were calculated with an OSP (Section 2.7). The adjustment to an NOSP salt front location is based on the median of the differences (residuals) between the OSP and NOSP values for a given RM interval. The NOSP adjustment was explained in Section 2.7. Calculation of the NOSP adjustment values is described in Section 3.5.

3.4 EQUATION

For calculation of the salt front, the interpolation uses the logarithm of the chlorides and the arithmetic value of the river mile location of the gages in the station pair. The location is calculated every day, then the average of the past seven days is calculated. Three equations are used together for the interpolation.

$$SF = \frac{1}{b} * log(\frac{a}{250})$$

where:

$$a = EXP\left[log(C_{downstream}) + (RM_{downstream} * b)\right]$$

and

$$b = \frac{1}{(RM_{upstream} - RM_{downstream})} log(\frac{C_{downstream}}{C_{upstream}})$$

Where ***SF*** is the salt front, ***RM*** is river mile of the gage, ***C*** is the chloride concentration (in mg/L), and ***a*** and ***b*** are coefficients calculated from RM and chloride concentration (mg/L).

3.5 NOSP ADJUSTMENT

Calculated locations for the salt front differ depending on the type of station pair (OSP or NOSP) used (Section 2.7). The salt front calculated with the OSP is the best estimation of the salt front location, and more accurate than the salt front calculated with an NOSP because the interpolation is performed over a shorter distance Figure 3-4 presents the salt front location calculated with both an OSP and NOSP for December 9, 2019, a day on which data were available for both station pairs (OSP: RI-C, NOSP: C-BF). The salt front (indicated by where the linear interpolation intersects the 250 mg/L concentration) calculated with the NOSP is farther upstream than the salt front calculated with the OSP.

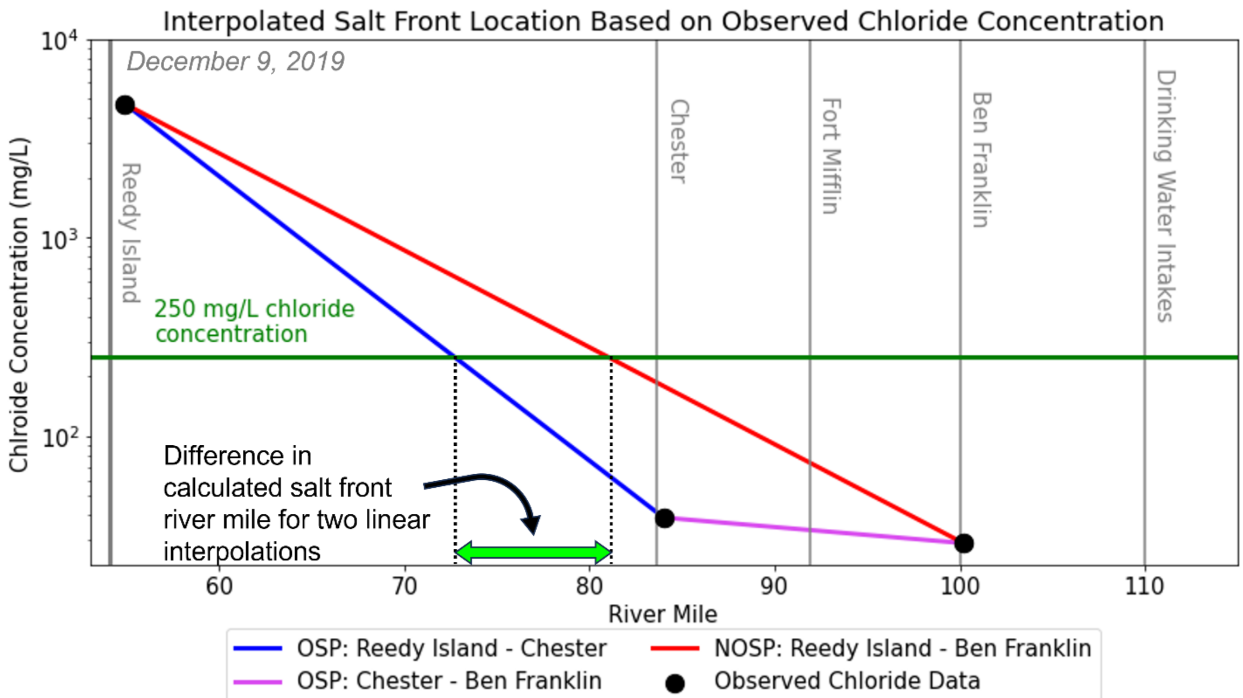

Figure 3-4: Comparison of the Salt Front Location Calculated with an OSP and NOSP
The salt front is at RM 73 if calculated with the RI-C OSP (blue line) and at RM 81 for the RI-BF NOSP (red line).

An adjustment for the NOSP salt front was developed using the difference between an OSP and an NOSP when data were available to calculate both. For example, when data are available at Reedy Island, Chester, and Ben Franklin, OSPs (Reedy Island-Chester or Chester – Ben Franklin) and an NOSP (Reedy Island-Ben Franklin) can be calculated and then compared. Figure 3-5 (top) is a 1:1 comparison of the OSP and NOSP daily salt front values. The daily salt front calculated with RI-BF (NOSP) is larger than the salt front calculated with the OSP (RI-C) when the daily salt front is below RM 83, the location of the Chester gage. The location with the largest differences (residuals), is approximately halfway between Reedy Island (RM 54) and Chester (RM83) at RM 76. Figure 3-5 (bottom) presents the residuals, used to calculate the adjustment, by NOSP location (x-axis). Figure 3-6 presents the daily salt front calculated with an OSP (e.g., RI-C) and the adjusted NOSP (e.g., RI-BF).

An NOSP adjustment for Reedy Island-Fort Mifflin was also developed. No data were available for the OSP Fort Mifflin-Ben Franklin to develop an adjustment for the NOSP Chester-Ben Franklin. The derivation of the adjustment for NOSP Reedy Island-Ben Franklin is described below. Possible station pairs were listed previously in Table 2-2. The NOSP adjustments by river mile are provided in Appendix B**.**

PROCEDURE FOR CALCULATION OF THE NOSP ADJUSTMENT

For days when data are available at Reedy Island, Chester, and Ben Franklin:

- Calculate the salt front using OSPs
  - Reedy Island – Chester (RI-C)
  - Chester -Ben Franklin (C-BF)
  - Chester – Fort Mifflin (C-FM)
  - Fort Mifflin – Ben Franklin (FM-BF) *(data either not available or not needed for historical record)*
- Calculate the salt front using NOSPs
  - Reedy Island – Ben Franklin (RI-BF)
  - Reedy Island – Fort Mifflin (RI-FM) *(data either not available or not needed for historical record)*
- Calculate the difference (residuals) between the salt front locations for the NOSP and OSP values at 0.1 river mile intervals.
- Calculate the median of the residuals, which is the adjustment value.

The adjustment value is added to the calculated daily salt front before the 7-day moving average is calculated. Table B-1 contains the table of NOSP adjustment values.

Figure 3-7 presents a time-series of the daily salt front locations calculated using the OSP, NOSP, and adjusted NOSP for a period in 1981 when data were available at Reedy Island, Chester, and Ben Franklin. If data from Reedy Island and Ben Franklin (NOSP) are used, the reported daily salt front values are calculated to be up to five miles farther upstream than the OSP daily salt front value (Reedy Island-Chester). However, with the NOSP adjustment, the daily salt front location better matches the daily salt front calculated with the OSP (Reedy Island-Chester). When the station pair is used to calculate the daily salt front changes (e.g., data becomes available or unavailable for one of the OSP stations), a discontinuity or unrealistic change in the salt front location is likely to occur.

For example, Figure 3-8 is a time-series plot of the salt front location in the summer of 1978 which includes a one-month period when an NOSP value was required because an OSP value was not available. The transition between using the OSP (Reedy Island-Chester) and NOSP (Reedy Island-Ben Franklin) creates an unrealistic daily change in the salt front location. For example, on July 23, 1978, data from the Chester gage is no longer available, so the salt front location must be calculated with the NOSP (Reedy Island-Ben Franklin). The transition from using the OSP to NOSP gives an unrealistic appearance that the salt front moved upstream by approximately 9 miles in one day. On August 22, 1978, when data at Chester become available again, reverting to the OSP (Reedy Island-Chester) gives the unrealistic appearance that the salt front moved downstream by approximately 6.5 miles in one day. By adjusting the NOSP to more closely match the OSP value, the NOSP daily salt front is within 0.3 miles of the OSP daily salt front, and unrealistic transitions in the record are avoided. Figure 3-9 presents another example from several months in 1980 with an awkward shift in the daily salt front resulting from alternating between using an OSP and NOSP salt front. Between May 27, 1980, and September 1, 1980, the station-pair used changes three times: from OSP to NOSP on May 27, 1980; from NOSP to OSP on June 10, 1980; and from OSP to NOSP on July 11, 1980. Top - Salt Front Location calculated with OSP vs NOSP. The red line represents the one-to-one line. Bottom – The difference between NOSP salt front values and OSP salt front values.

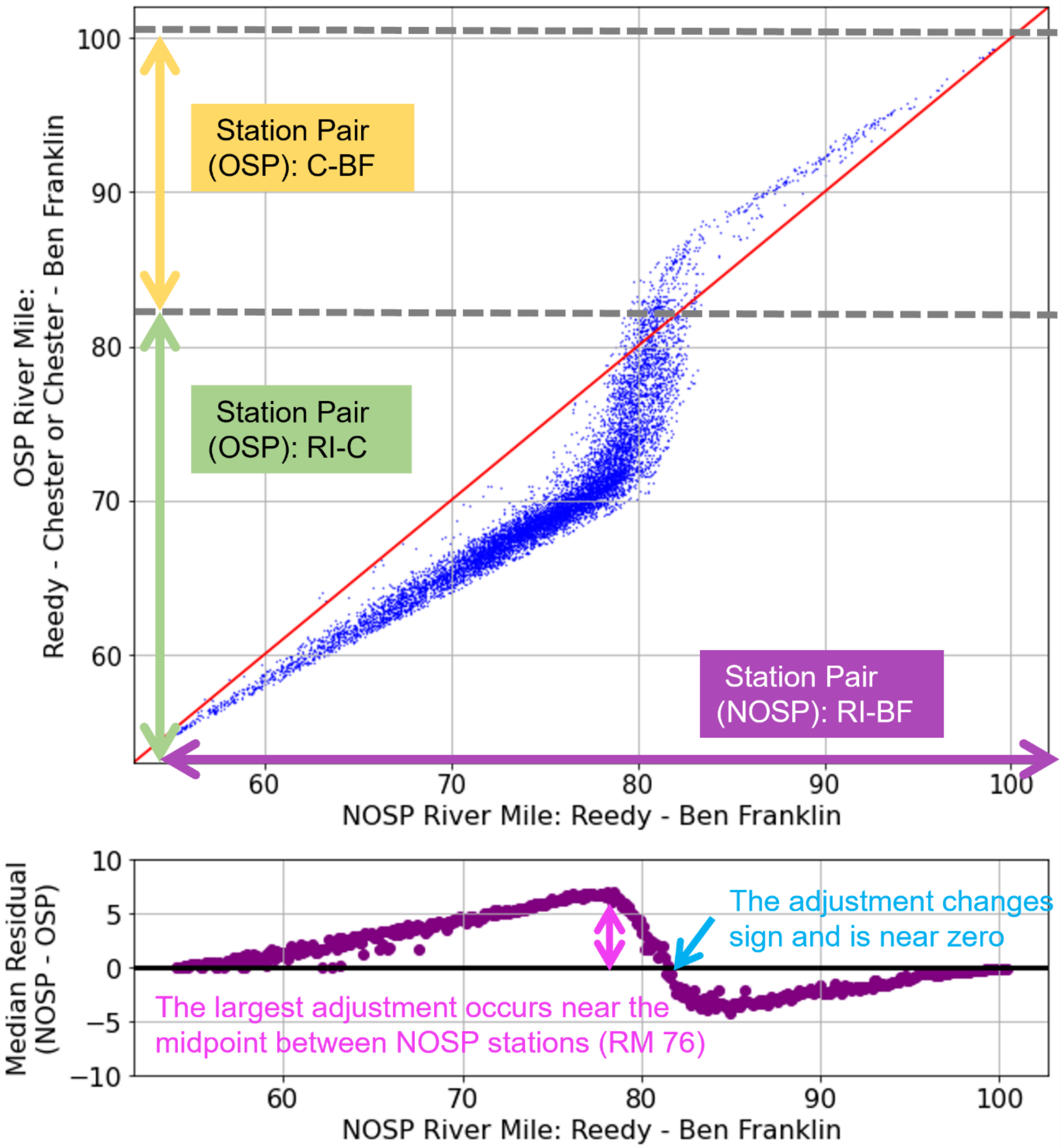

Figure 3-5: Comparison of OSP and NOSP salt front locations

In the top figure, the location calculated with the NOSP (Reedy Island-Ben Franklin) on the x-axis is plotted with the corresponding location calculated with the OSP (either Reedy Island-Chester or Chester-Ben Franklin) on the y-axis. The median difference (residual) between the NOSP and OSP (the adjustment value) is plotted in the bottom figure. The residual is calculated by subtracting the NOSP value from the OSP value so that the sign of the residual reflects how the NOSP is adjusted. For example, the salt front calculated with RI-BF, an NOSP, is near RM 76. Whereas the salt front calculated with RI-C (OSP) is near RM 70.

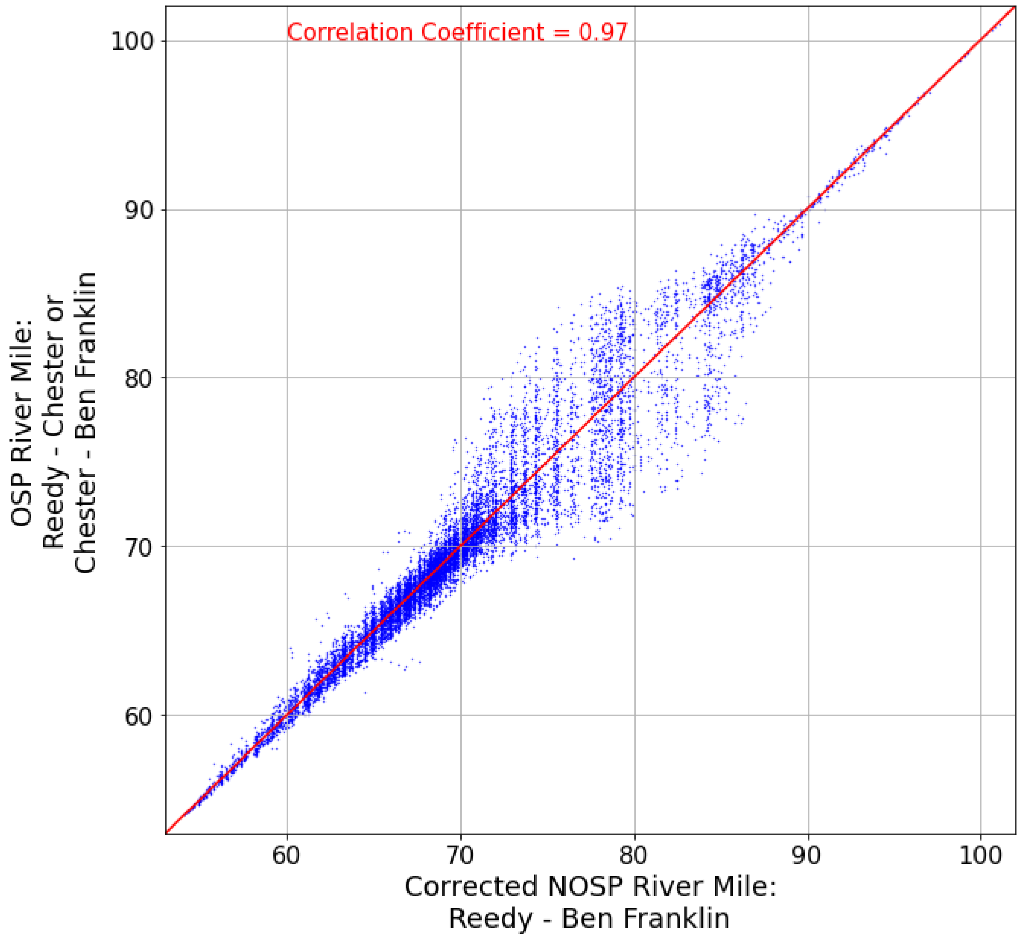

Figure 3-6: Comparison of the Daily Salt Front Calculated with an OSP and Adjusted NOSP
The difference between the OSP and NOSP salt front is largest near the midpoint between Reedy Island and Ben Franklin Bridge (RM 77), gradually decreasing toward the outer gages.

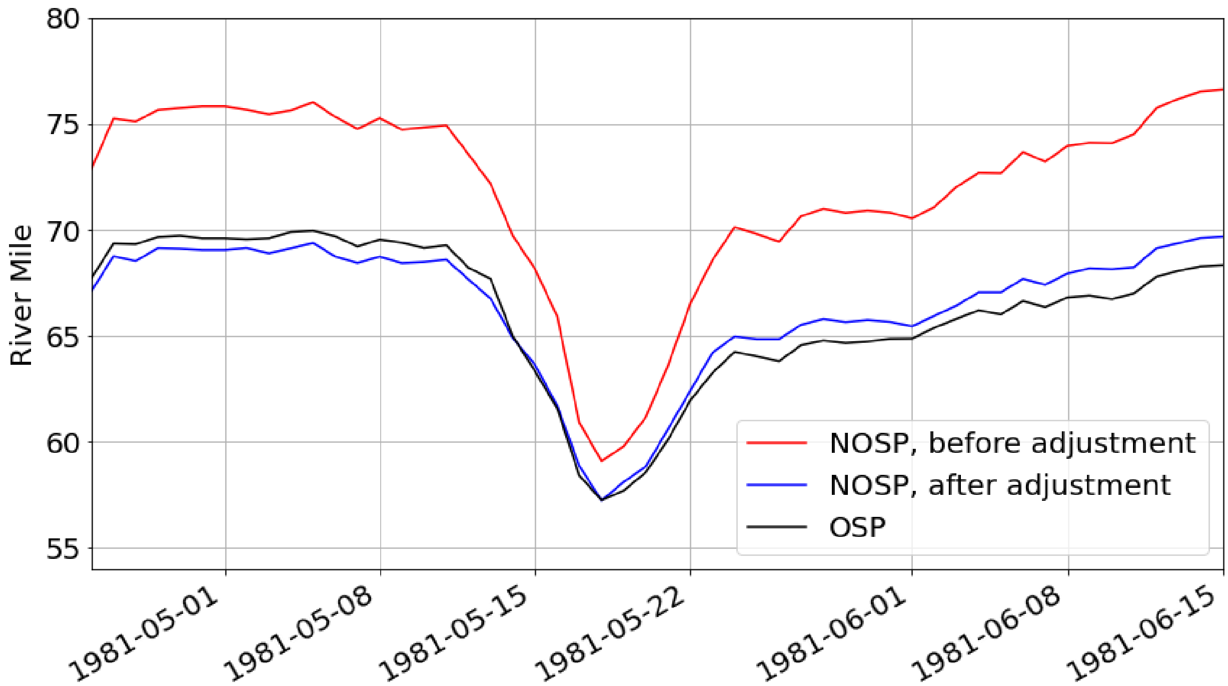

Figure 3-7: Comparison of the Daily Salt Front Locations Calculated with OSP, NOSP and Adjusted NOSP

The salt front location calculated using the OSP (Reedy Island-Chester) in black, NOSP (Reedy Island-Ben Franklin) in red, and the Adjusted NOSP (Reedy Island-Ben Franklin) in blue, are shown for April 23, 1981, through June 15, 1981. Data were available at all three locations, so the values were compared to determine if an adjustment made to the NOSP value would better align the salt front**.**

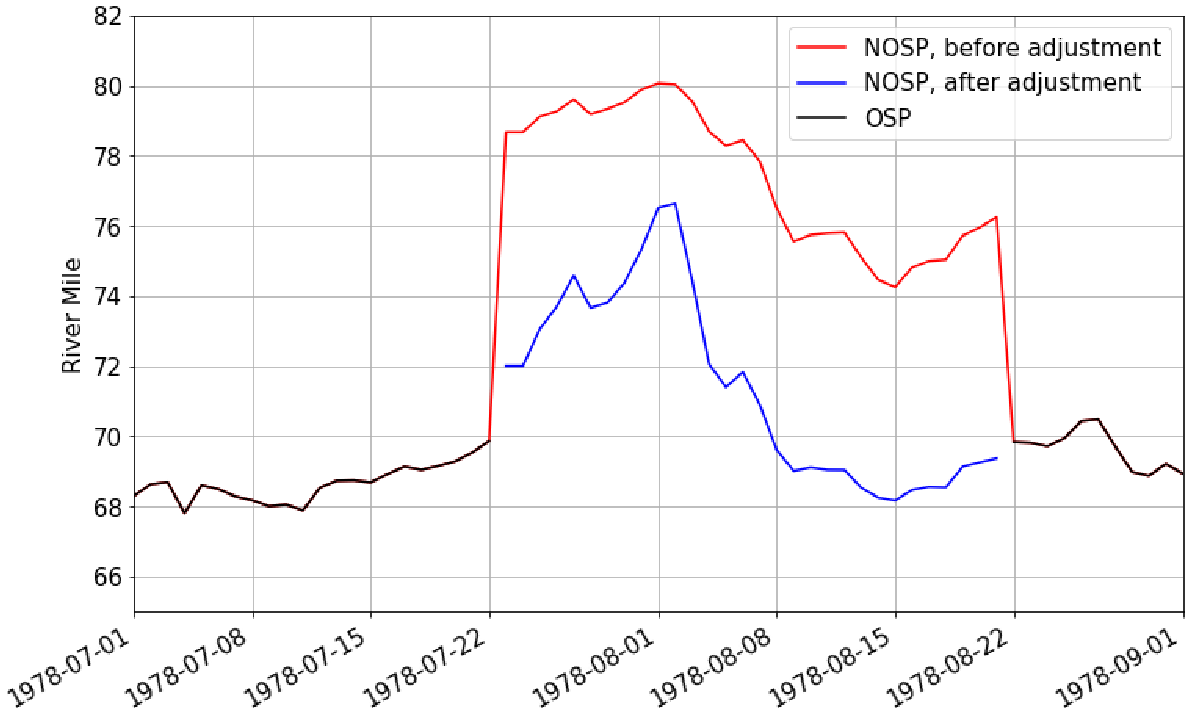

Figure 3-8: Comparison of the Transition between the Daily Salt Front Location Calculated with an OSP and either the NOSP or Adjusted NOSP

Between July 22 and August 22 in 1978, data from the Chester gage were unavailable. The NOSP (Reedy Island-Ben Franklin), was used to calculate the salt front. By adjusting the NOSP, a more realistic daily movement of the salt front is represented in the record.

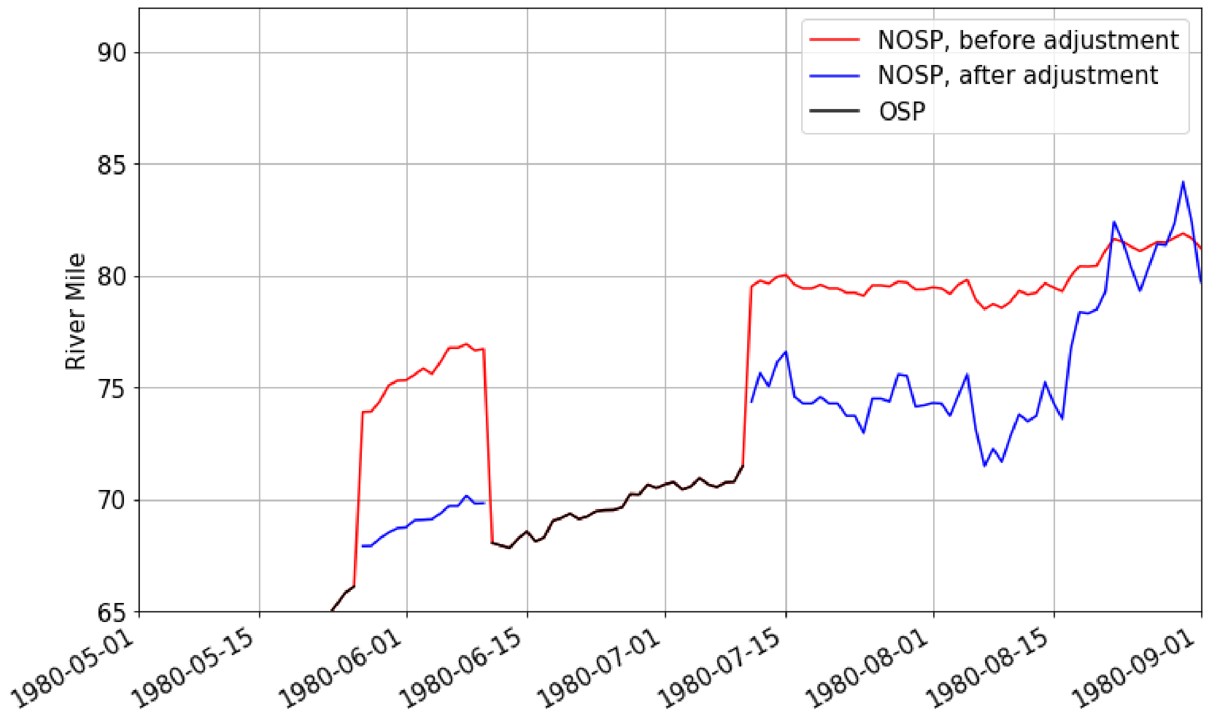

Figure 3-9: Comparison of the Transitions between the Daily Salt Front Location Calculated with an OSP and either the NOSP or Adjusted NOSP
Between May and August 1980, data at the Chester gage were only available between June 13 and July 10. Therefore, the NOSP (Reedy-Ben Franklin) was used for May 21-June 12 and after July 10. The shift in daily salt front location is less drastic on the days when the OSP-NOSP and NOSP-OSP transitions occur.

3.6 SEVEN-DAY MOVING AVERAGE

The salt front location is used to determine flow objectives for Trenton and Montague during a drought emergency to ensure freshwater inflow to the estuary[17]. The drought management program for the Delaware River Basin utilizes the salt front, the seven-day moving average of the daily value (DV7D), to smooth short-term fluctuations and better indicate the trend in salinity intrusion. An alternative is to average the chlorides at the gages for seven days and then interpolate the salt front location (CL7D).

The difference between using CL7D rather than DV7D is insignificant for values calculated with OSPs as shown in Figure 3-10. Larger differences between the two alternatives (DV7D and CL7D) primarily occur during the days immediately following a transition from OSP to NOSP station pairs and vice versa. Figure 3-11 compares the difference between the CL7D salt front

[17] https://www.nj.gov/drbc/library/documents/watercode.pdf (Section 2.5.3)

and the DV7D salt front for both OSPs and NOSPs. For CL7D, the chlorides cannot be averaged between stations, so the transition results in a discontinuity seven days after the transition. For the DV7D, the shift is less apparent because the difference is effectively spread over seven days by the averaging.

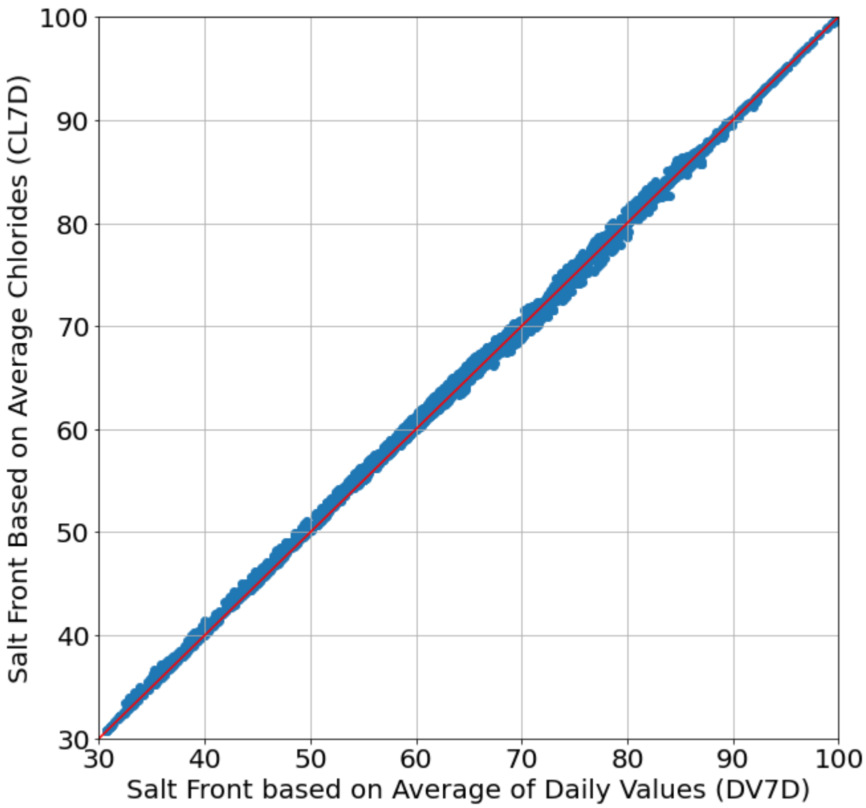

Figure 3-10: Comparison of the CL7D and DV7D Salt Front Location for OSPs Only

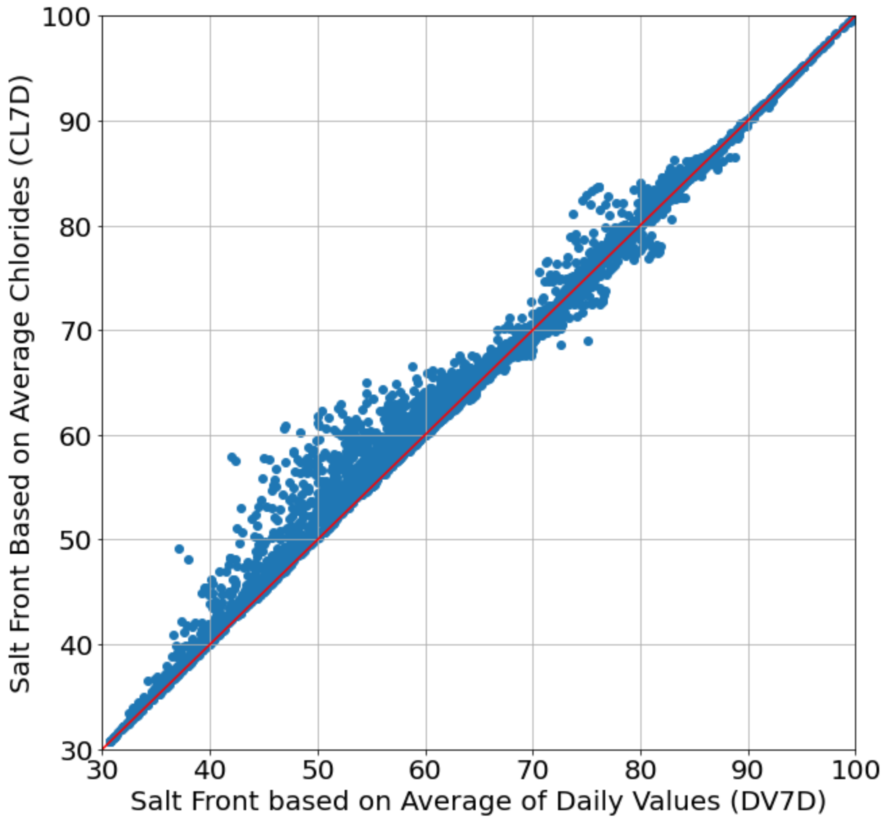

Figure 3-11: Comparison of the CL7D and DV7D Salt Front Location (OSPs and NOSPs)

Figure 3-12 presents a time-series of the seven-day average salt front from July – August 1978, which shows how the transition between OSP and NOSPs is reflected in the historical record. Until July 22, the CL7D and DV7D are similar because the OSP is used. On July 23, the data from the gage at Chester were not available. For the CL7D, the change in station pair from an OSP to an NOSP does not affect the calculated salt front location until seven days later because the average chloride concentration at each gage station is calculated based on available data (e.g., average of three days of data rather than seven when only three days of values are available) On the eighth day, the change in salt front location is abrupt. For the

DV7D, the transition is gradual because the large shift in the salt front location is averaged over seven days.

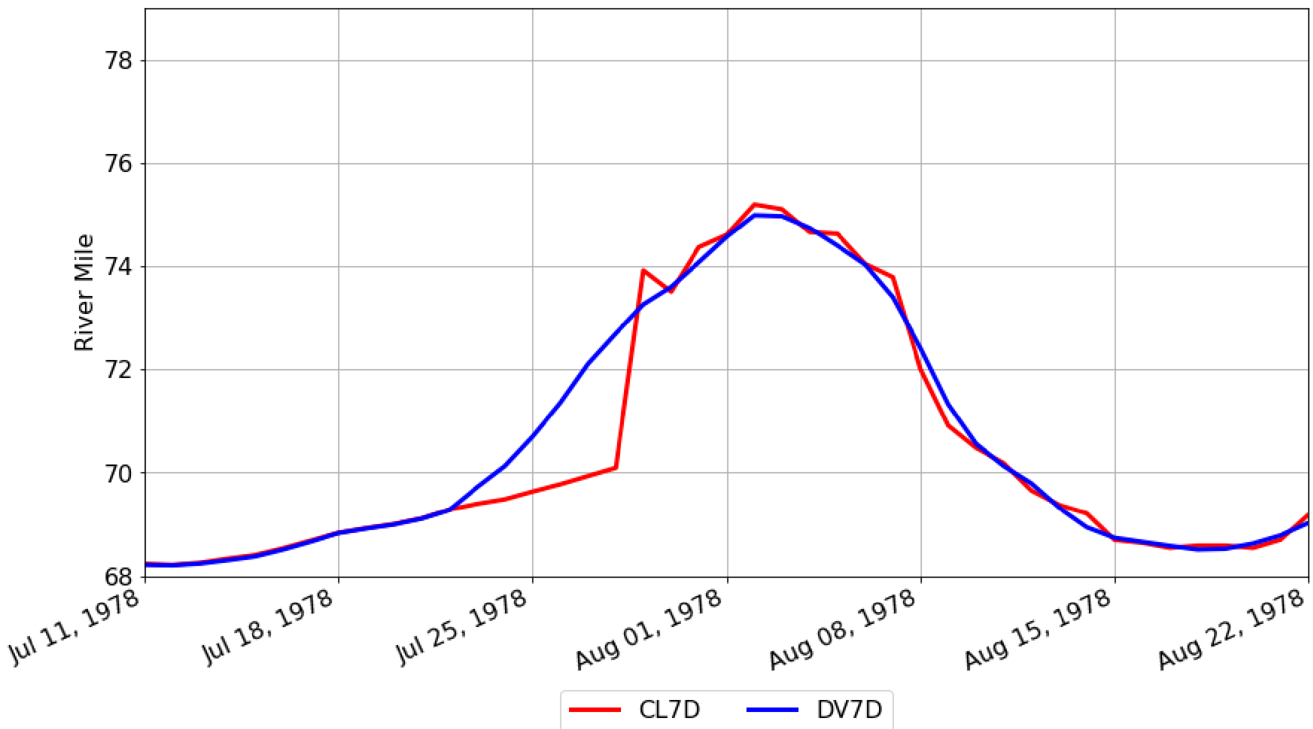

Figure 3-12: Comparison of Alternatives for Calculating the Salt Front

Alternatives for calculating the seven-day moving average location of the 250 mg/l isochlor (chloride concentration) are to average the chlorides for seven days then calculate the location (CL7D) or to calculate the daily salt front value and then average for seven days (DV7D). The salt front is similar for either method except for days surrounding the transition between the station pairs for the calculation. Using the seven-day average of chlorides (CL7D) to calculate the salt front (CL7D) results in abrupt changes in the location. Whereas, calculating the daily salt front then the seven-day average (DV7D) results in a smoother transition.

Using the method outlined in this report, the historical record of the salt front location was developed for October 1963 through December 2021. The historical record is updated annually, typically in the second quarter of the calendar year, when the USGS specific conductance data are approved and no longer considered provisional. The salt front is calculated every day and reported on the DRBC's hydrologic conditions dashboard "Snapshot for Flow and Drought Management in the Delaware River Basin", located at hydrosnap.drbc.net. For October 1963 through April 2026, data were available to calculate the salt front for approximately 77.4 percent of the days in the record. The salt front is the value used for flow and drought management purposes because it is a stable indicator of trends in salinity movement. The daily value of the salt front location is only calculated to average over seven days and should not be used for other purposes. It is included for informational and demonstration purposes only.

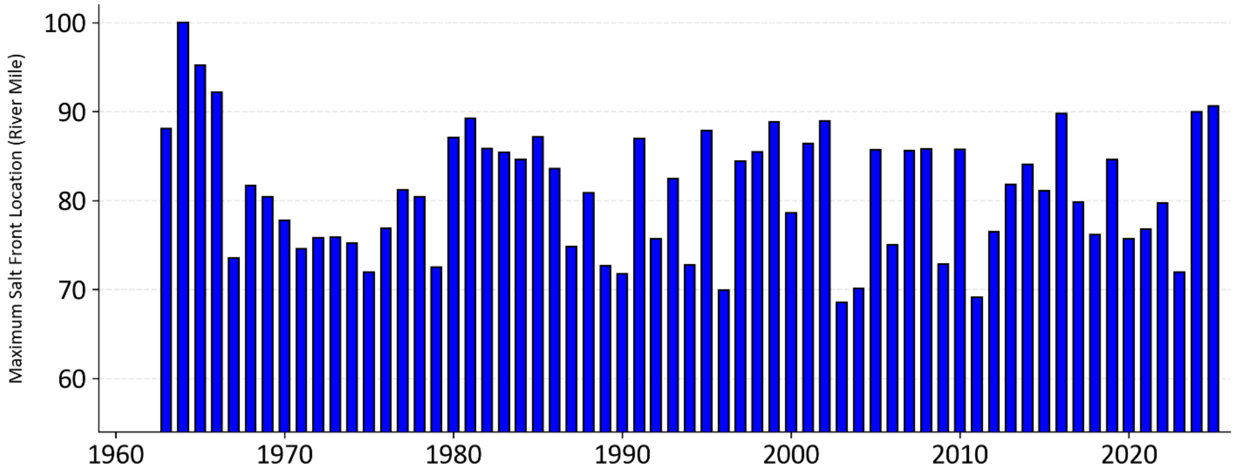

Figure 3-13: Maximum Annual Salt Front Location 1963 through 2025[18]

Figure 3-13 presents the time-series of the maximum salt front location through December 2025. Except for discontinuous periods between October 1963 and October 1966, the maximum annual salt front has remained below RM 91. The most upstream location of the salt front occurred on November 26, 1964, during the 1960s drought. Figure 3-14 presents the salt front location from October 1963 through October 1967, during the drought of record for the Delaware Basin. During the drought, real-time measurements of salinity, specific conductance, and/or chlorides were not contiguous as indicated by the gaps in the historical record.

[18] The salt front has not been upstream of RM 91 since the 1960s drought. The 1970s were a wet decade and the salt front was not above RM81.16. In 1983, a flow objective at Trenton, N.J. was established to maintain freshwater inflows to the Estuary and impede salinity intrusion.

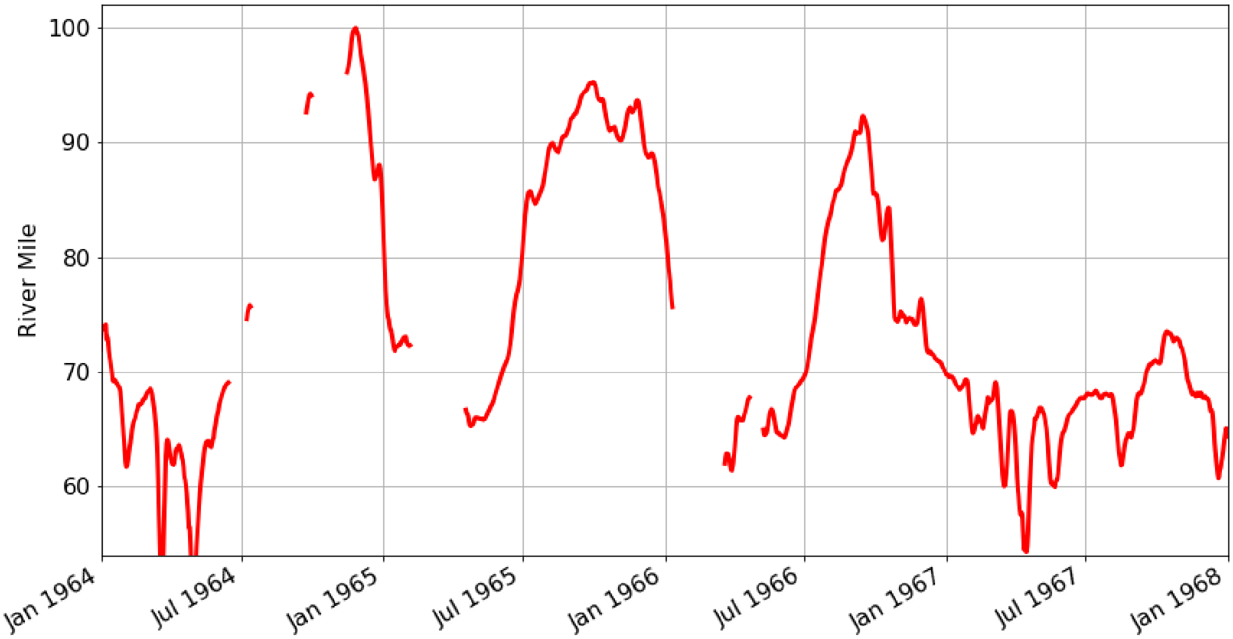

Figure 3-14: Location of the Salt Front During the 1960s Drought.
The 1960s drought was the worst drought on record for the Delaware River Basin. The salt front was as far upstream as RM 100, near the Ben Franklin Bridge, and within 10 miles of Philadelphia's Baxter Drinking Water Treatment Plant. The commonly reported maximum location of the salt front is 102 miles, which was calculated with the maximum daily chloride concentrations at Ben Franklin Bridge (RM 100) and not the seven-day moving average.

The salt front was characterized by the frequency of occurrence along the river, the range of location by month, and the median and average location by month. Figure 3-15 presents the frequency of the salt front for two-mile mile ranges. The normal range of the salt front, represented by the values between the 25th and 75th percentiles, is between RM 64 and RM 72. Table 3-2 presents the percentiles of the salt front location for the historical record.

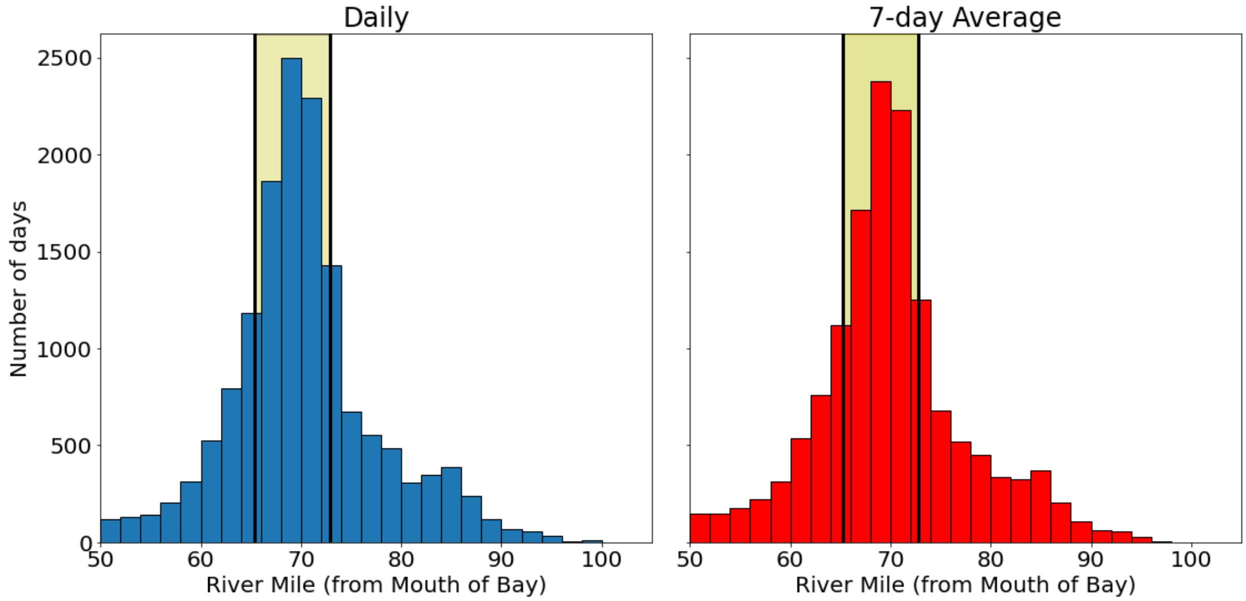

Figure 3-15: Frequency of the Salt Front at Specific River Mile Locations (2-mile segments)

Table 3-2: Percentile of the Salt Front Location

	Salt Front (DV7D)	Salt Front (Daily)
Count	15639	15639
Mean	68.1	67.9
Standard Deviation	9.6	9.9
Minimum	30.7	30.7
10%	57.8	58.0
20%	63.1	63.3
25%	64.7	64.8
30%	65.8	65.9
40%	67.3	67.4
50%	68.4	68.5
60%	69.6	69.6
70%	71.2	71.0
75%	72.3	72.0
80%	74	73.7
90%	79.7	79.3
95%	84.4	84.3
99%	90.4	90.2
Maximum	100	100.7

The normal range of the salt front location varies by month. Figure 3-16 is a graphical representation, known as a box-whisker plot, of the salt front range and extreme values. A more detailed description of the box plot is below the caption. The normal range is defined by the box and is the area in the river where the salt front is likely to be each month. A seasonal cycle is apparent by comparing the range of the salt front location by month. The salt front tends to be farther upstream in the fall when flows tend to be lower, and farther downstream in the spring, when flows tend to be higher. Table 3-3 presents the daily and seven-day moving average salt front by month.

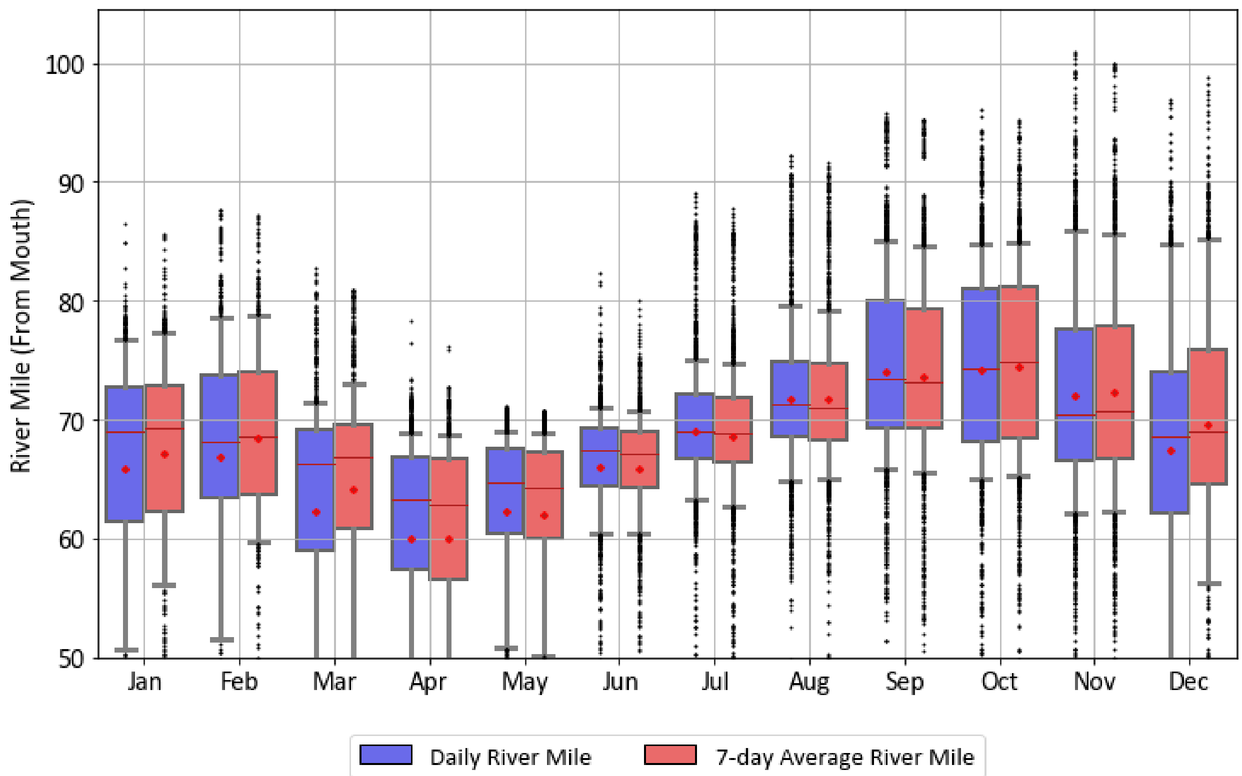

Figure 3-16: Range of the Salt Front Location by Month.

The range of the salt front by month is represented by the box-whisker plot above. The boxes represent the normal range (between the 25th and 75th percentile) for each month. The red horizontal line in the box represents the median. The red dot in the box represents the mean. The grey vertical lines or whiskers above and below each box represent the 10th and 90th percentile range of the salt front. The black points above and below the whiskers represent values of the salt front below and above the 10th and 90th percentiles, respectively. The period of record summarized with the box plot is October 1963 - April 2026. Note: the larger 7-day average in December is related to the nature of the moving average including days in November until December 6.

Table 3-3: Monthly Median and Average Location of the Salt Front

Month	Count	Salt Front Location (DV7D)		Daily Salt Front Location	
		Median	Average	Median	Average
January	716	69.9	67.5	68.8	66.6
February	579	67.2	66.5	67.7	66.1
March	1105	67.4	64	66.9	62.9
April	1554	63.2	60.3	63.6	60.3
May	1693	64.7	62.1	65.2	62.5
June	1630	67.1	65.6	67.5	66.0
July	1684	68.9	68.8	69.2	69.2
August	1629	70.5	71.4	70.8	71.7
September	1621	72.7	73.8	73.2	74.0
October	1645	73.4	73.8	73.1	73.6
November	1645	70.1	71.6	70.1	71.5
December	956	68.4	68.5	68.6	67.2

4. SUMMARY

The salt front is defined as the 7-day moving average of the 250 mg/L isochlor (chloride concentration) and reported based on the Delaware River Mile System. The salt front is determined using a log-linear interpolation of average daily chloride concentrations estimated from specific conductance at USGS water quality monitoring stations located in the Delaware Estuary. The historical record calculated for this report is from October 3, 1963 through April 16, 2026. Throughout the period of record, data were often unavailable during the winter months when gages were typically removed from service to avoid potential damage from flooding and ice.

The location of the salt front is most accurate when calculated with Optimal Station Pairs (OSPs) because the log-linear interpolation is made over a shorter distance. However, Non-Optimal Station Pairs (NOSPs) can also be used when data are unavailable at OSPs. An adjustment to salt front calculated with NOSPs was developed by comparing OSP and NOSP values of the salt front location when both values could be calculated. Based on the historical record, the normal range of the salt front is located between RM 64.7 and RM 72.3 (between the 25th and 75th

percentile)[19]. The range varies monthly and is related to the relative magnitude of seasonal flow. In the months when flows tend to be low, the salt front will be farther upstream. When flows are high, the salt front will be farther downstream. The most upstream location of the salt front was RM 100, which occurred in November 1964. The salt front has not been upstream of RM 91 since the 1960s, during the drought of record. DRBC maintains the historical record of the salt front location, as well as current measurements. Both are available on its website.

REFERENCES

Paulson, R.W., 1970. A graphical summary of specific conductance data for the Delaware River estuary as correlated with Delaware River flow at Trenton, New Jersey. USGS OFR Report 70-260. USGS Publications Warehouse. https://doi.org/10.3133/ofr70260

LINKS TO RELEVANT INFORMATION

https://www.nj.gov/drbc/programs/flow/salt-front.html

https://www.nj.gov/drbc/basin/river/index.html

https://waterdata.usgs.gov/nwis/uv?site_no=01482800

https://waterdata.usgs.gov/nwis/uv?site_no=01477050

https://waterdata.usgs.gov/nwis/uv/?site_no=01474703

https://waterdata.usgs.gov/nwis/uv?site_no=01467200

https://waterdata.usgs.gov/nwis/uv/?site_no=01482100

https://waterdata.usgs.gov/nwis/uv?site_no=014670261

https://www.state.nj.us/drbc/library/documents/TMDL/HydroModelRptDec2003.pdf

[19] The likely range of the salt from is 61.5 to 75.7. The likely range is defined by the 17th and 83rd percentiles, where the salt front is 66 percent (2/3) of the time,

APPENDIX A: USE OF DAILY MAXIMUM AND MINIMUM SPECIFIC CONDUCTANCE FOR DAILY AVERAGE SPECIFIC CONDUCTANCE

Typically, maximum daily SC, minimum daily SC, and average daily SC are reported for each gage. The average daily SC is used to calculate the salt front. For some periods, only the maximum and minimum SC values were reported. For those days, the average of the minimum and maximum SC was used to approximate the average daily SC. The appropriateness of substituting the average of the minimum and maximum SC for the average daily SC was evaluated for days when all three measurements were available using three correlation methods: Pearson, Kendall Tau, and Spearman. A value greater than 0.6 indicates a moderate correlation, a value greater than 0.8 indicates a strong correlation, and a value greater than 0.9 indicates a very strong correlation. The correlation results for Reedy, Chester, Fort Mifflin, and Ben Franklin are shown in Table A- 1. Figure A-1 (a-d) contains comparisons of the reported average SC and the average of the daily minimum and maximum SC.

Table A- 1: Correlation Coefficients for Use of the Average Daily SC versus the Average of the Maximum SC for Calculation of the Salt Front

Gage	Pearson	Kendall	Spearman
Reedy Island	0.994	0.939	0.994
Chester	0.997	0.966	0.997
Fort Mifflin	0.988	0.919	0.987
Ben Franklin	0.998	0.982	0.999

For all stations, the three correlations (Pearson, Kendall Tau, and Spearman) are greater than 0.9 and more than half are greater than 0.99. Therefore, using the average of the maximum and minimum SC for the average daily SC is appropriate for periods when the average daily value is missing.

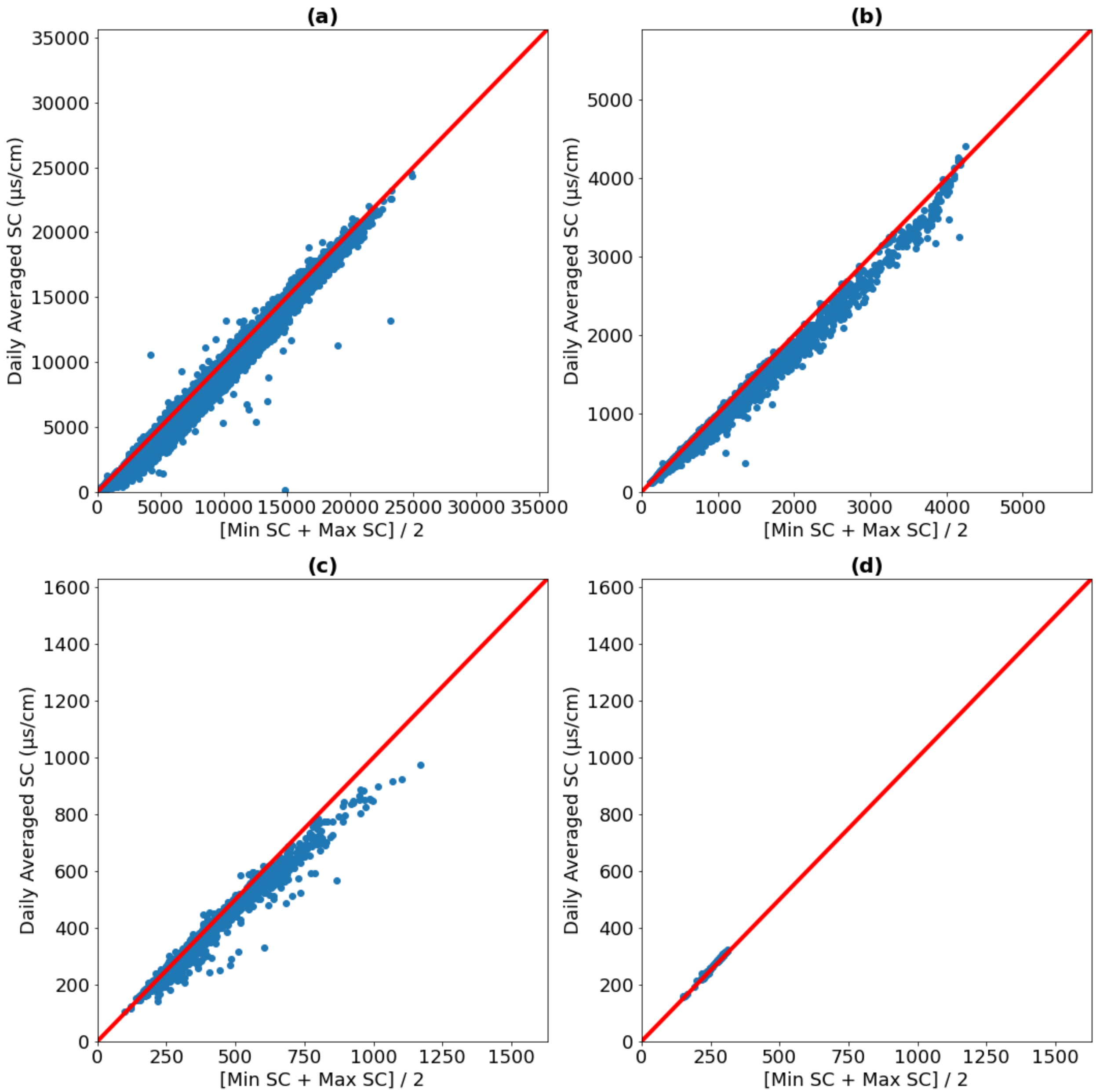

Figure A-1: Correlation Coefficient for the Average Daily SC versus the Average of the Daily Maximum and Minimum SC for Calculation of the Salt Front for (a) Reedy Island; (b) Chester; (c) Fort Mifflin; (d) Ben Franklin Bridge

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

APPENDIX B: ADJUSTMENT AMOUNTS FOR NON-OPTIMUM STATION PAIRS BY RIVER MILE

Table B-1: Table of NOSP Adjustment Values

Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment
54	0.00	63.2	2.81	72.4	5.56	81.6	1.12	90.8	-1.59
54.1	0.02	63.3	3.05	72.5	5.61	81.7	1.52	90.9	-2.56
54.2	0.04	63.4	3.07	72.6	5.55	81.8	-1.26	91	-1.87
54.3	0.06	63.5	3.01	72.7	5.67	81.9	-2.31	91.1	-2.35
54.4	0.11	63.6	2.93	72.8	5.72	82	-2.01	91.2	-2.12
54.5	0.13	63.7	3.56	72.9	5.81	82.1	-2.07	91.3	-1.93
54.6	0.15	63.8	2.63	73	5.67	82.2	-0.99	91.4	-1.73
54.7	0.24	63.9	3.07	73.1	5.85	82.3	-2.47	91.5	-1.77
54.8	0.24	64	2.74	73.2	5.78	82.4	-2.07	91.6	-1.97
54.9	0.24	64.1	2.83	73.3	5.63	82.5	-2.17	91.7	-2.27
55	0.34	64.2	2.89	73.4	5.78	82.6	-2.06	91.8	-1.80
55.1	0.35	64.3	3.23	73.5	5.82	82.7	-3.15	91.9	-1.85
55.2	0.37	64.4	3.11	73.6	6.00	82.8	-2.79	92	-1.94
55.3	0.33	64.5	3.24	73.7	6.01	82.9	-2.67	92.1	-2.02
55.4	0.44	64.6	3.57	73.8	5.95	83	-3.15	92.2	-1.86
55.5	0.52	64.7	3.46	73.9	5.80	83.1	-3.19	92.3	-1.55
55.6	0.47	64.8	3.54	74	6.08	83.2	-3.03	92.4	-1.84
55.7	0.54	64.9	3.64	74.1	5.94	83.3	-3.51	92.5	-1.75
55.8	0.42	65	3.22	74.2	6.07	83.4	-2.76	92.6	-2.07
55.9	0.68	65.1	3.50	74.3	6.08	83.5	-3.19	92.7	-1.82
56	0.70	65.2	3.26	74.4	6.18	83.6	-2.72	92.8	-1.64
56.1	0.43	65.3	3.23	74.5	6.30	83.7	-2.54	92.9	-1.88
56.2	0.82	65.4	4.00	74.6	6.29	83.8	-2.69	93	-1.14
56.3	0.84	65.5	3.58	74.7	6.29	83.9	-3.17	93.1	-1.70
56.4	0.81	65.6	3.55	74.8	6.32	84	-3.85	93.2	-1.66
56.5	0.54	65.7	3.79	74.9	6.34	84.1	-2.36	93.3	-1.60
56.6	0.68	65.8	3.78	75	6.45	84.2	-3.36	93.4	-1.71
56.7	0.81	65.9	4.24	75.1	6.52	84.3	-2.64	93.5	-1.55
56.8	0.99	66	4.14	75.2	6.52	84.4	-2.50	93.6	-1.58

Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment
56.9	0.90	66.1	3.85	75.3	6.66	84.5	-2.40	93.7	-1.60
57	0.90	66.2	3.85	75.4	6.58	84.6	-2.99	93.8	-1.63
57.1	0.84	66.3	3.71	75.5	6.63	84.7	-3.69	93.9	-1.12
57.2	0.97	66.4	4.14	75.6	6.49	84.8	10.26	94	-1.24
57.3	1.21	66.5	3.85	75.7	6.47	84.9	-3.10	94.1	-1.46
57.4	1.15	66.6	3.79	75.8	6.66	85	-2.87	94.2	-1.32
57.5	1.17	66.7	3.94	75.9	6.77	85.1	-2.05	94.3	-1.18
57.6	1.18	66.8	3.62	76	6.70	85.2	-3.73	94.4	-1.04
57.7	0.81	66.9	4.32	76.1	6.67	85.3	-3.24	94.5	-0.90
57.8	1.05	67	4.38	76.2	6.91	85.4	-3.23	94.6	-1.02
57.9	1.47	67.1	4.13	76.3	6.94	85.5	-3.18	94.7	-1.14
58	1.27	67.2	4.09	76.4	6.81	85.6	-2.68	94.8	-1.26
58.1	1.19	67.3	3.84	76.5	6.91	85.7	-3.00	94.9	-1.25
58.2	1.25	67.4	3.99	76.6	6.82	85.8	-1.43	95	-1.11
58.3	1.43	67.5	4.30	76.7	6.63	85.9	-2.84	95.1	-0.98
58.4	1.54	67.6	4.09	76.8	6.93	86	9.36	95.2	-0.84
58.5	1.12	67.7	4.40	76.9	6.96	86.1	9.34	95.3	-0.70
58.6	1.68	67.8	4.46	77	7.05	86.2	-3.07	95.4	-1.11
58.7	1.71	67.9	4.46	77.1	7.12	86.3	-2.98	95.5	-0.94
58.8	1.40	68	4.20	77.2	6.86	86.4	-3.06	95.6	-0.76
58.9	1.23	68.1	4.68	77.3	6.99	86.5	-3.23	95.7	-0.59
59	1.65	68.2	4.23	77.4	7.20	86.6	-1.79	95.8	-1.02
59.1	1.88	68.3	4.56	77.5	6.94	86.7	-3.02	95.9	-0.58
59.2	1.69	68.4	4.11	77.6	6.98	86.8	-2.99	96	-0.59
59.3	1.94	68.5	4.24	77.7	7.06	86.9	-3.10	96.1	-0.60
59.4	1.61	68.6	4.40	77.8	6.92	87	-3.21	96.2	-0.85
59.5	1.99	68.7	4.01	77.9	7.09	87.1	-2.95	96.3	-0.72
59.6	1.71	68.8	4.39	78	6.76	87.2	-2.85	96.4	-0.58
59.7	1.96	68.9	4.41	78.1	7.29	87.3	-2.86	96.5	-0.67
59.8	1.71	69	4.40	78.2	7.10	87.4	-2.58	96.6	-0.76
59.9	1.57	69.1	4.57	78.3	6.98	87.5	-2.81	96.7	-0.72
60	1.76	69.2	4.74	78.4	6.69	87.6	-3.16	96.8	-0.68
60.1	1.80	69.3	4.79	78.5	7.26	87.7	-2.85	96.9	-0.64
60.2	1.82	69.4	4.68	78.6	6.53	87.8	-2.75	97	-0.61
60.3	2.02	69.5	4.57	78.7	6.37	87.9	-2.68	97.1	-0.57
60.4	2.14	69.6	4.62	78.8	6.68	88	-2.62	97.2	-0.53
60.5	2.02	69.7	4.81	78.9	6.29	88.1	-2.62	97.3	-0.49

Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment	Starting RM	Reedy - Ben Franklin Adjustment
60.6	1.97	69.8	4.88	79	6.43	88.2	-2.84	97.4	-0.48
60.7	2.13	69.9	4.82	79.1	5.82	88.3	-3.07	97.5	-0.47
60.8	2.32	70	4.90	79.2	5.41	88.4	-2.92	97.6	-0.46
60.9	2.02	70.1	5.08	79.3	5.57	88.5	-2.21	97.7	-0.45
61	2.48	70.2	5.00	79.4	5.90	88.6	-2.79	97.8	-0.43
61.1	2.22	70.3	4.79	79.5	5.12	88.7	-2.68	97.9	-0.42
61.2	2.34	70.4	5.00	79.6	5.03	88.8	-2.56	98	-0.41
61.3	2.47	70.5	5.05	79.7	5.29	88.9	-2.82	98.1	-0.40
61.4	2.36	70.6	5.09	79.8	4.69	89	-2.49	98.2	-0.39
61.5	2.57	70.7	4.98	79.9	4.25	89.1	-2.33	98.3	-0.45
61.6	2.40	70.8	5.14	80	4.09	89.2	-2.43	98.4	-0.32
61.7	2.45	70.9	5.20	80.1	4.76	89.3	-2.52	98.5	-0.30
61.8	2.63	71	5.18	80.2	2.13	89.4	-1.97	98.6	-0.29
61.9	2.55	71.1	5.08	80.3	3.46	89.5	-2.44	98.7	-0.27
62	2.56	71.2	5.29	80.4	3.24	89.6	-2.26	98.8	-0.25
62.1	2.40	71.3	5.23	80.5	2.06	89.7	-2.39	98.9	-0.25
62.2	2.85	71.4	5.32	80.6	2.26	89.8	-1.92	99	-0.29
62.3	2.95	71.5	5.32	80.7	1.48	89.9	-1.52	99.1	-0.22
62.4	2.29	71.6	5.28	80.8	2.45	90	-1.13	99.2	-0.20
62.5	2.79	71.7	5.25	80.9	1.30	90.1	-1.79	99.3	-0.18
62.6	2.85	71.8	5.57	81	2.05	90.2	-2.44	99.4	-0.16
62.7	3.07	71.9	5.31	81.1	1.98	90.3	-2.23	99.5	-0.15
62.8	2.95	72	5.56	81.2	1.73	90.4	-2.14	99.6	-0.13
62.9	2.57	72.1	5.56	81.3	1.02	90.5	-2.04	99.7	-0.12
63	2.69	72.2	5.28	81.4	1.19	90.6	-2.07	99.8	-0.10
63.1	3.18	72.3	5.51	81.5	1.98	90.7	-1.69	99.9	-0.09