PWD Water Supply Planning: PWD Salinity Model Production Run Setup

Regulated Flow Advisory Committee December 15, 2021

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PWD Salinity Model Production Run Setup

1. Planning and Model Overview
2. Production Setup
3. Run List

Philadelphia Water Department

Drinking Water

- 1.7 million drinking water customers
- 3 Water Treatment Plants

Wastewater

- 2.2 million wastewater customers
- 3 Water Pollution Control Plants

Stormwater

- 60% Combined, 40% Separate Sewers
- Large-scale green infrastructure pgm.

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PWD Water Supply Planning

- Multi-year water supply planning effort
- Designed to support parallel water and wastewater infrastructure planning efforts
- Critical need to understand the potential risks to infrastructure, regulatory compliance and public health of current and future water quality and quantity
- Water supply planning, specifically, takes into consideration three critical drivers

  -Climate change

  -Ambient water quality changes

  -Policy changes
- Protecting Philadelphia water sources is a priority

Critical Influences on Salinity Intrusion

Streamflow fluctuations cause salinity to rise and fall

Major Storms in the watershed can decrease salinity through advective transport

Sea Level – periodic meteorologically-induced sea-level setups cause significant increases in salt intrusion through upstream advective transport for periods of 2-3 days or more

Estuarine Circulation – increases or decreases salt intrusion absent changes in freshwater inflow or subtidal fluxes. These are three-dimensional hydrodynamic effects that have influence beyond simple axial advective transport

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Main Takeaways from Observed Data that Inform Model Preparation

1. **A three-dimensional model is an absolute necessity**
   - It is evident both from observations and by numerical experimentation that the salt intrusion length to and upstream of Reedy Island is subject to a range of physical influences, and that to a not insignificant degree, the physics of those hydrodynamic influences are 3-dimensional in nature

2. **Episodes of salinity intrusion into the upper tidal river beyond Reedy Island during recent droughts are comparable to observations during the 1960s drought of record**
   - The FFMP flow targets are not intended to manage salinity as far downstream as Reedy Island, they are designed to manage salinity in the area upstream of Chester

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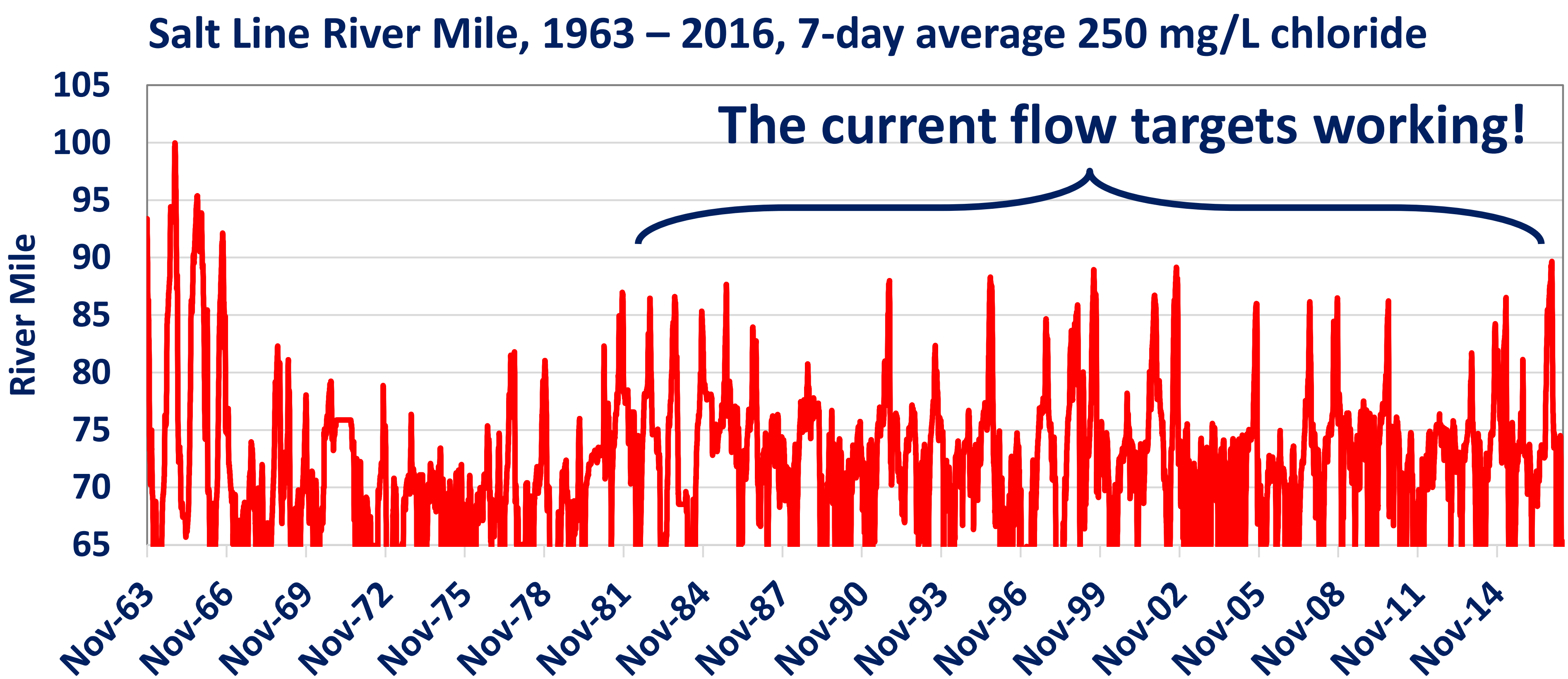
We want to know why the flow targets work

Salinity Modeling

- Informs how changes to flow targets will influence salinity at the PWD drinking water intake
- Salinity is not removed by treatment process



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What Does Water Supply Planning Entail?

3-Dimensional Salinity Modeling

- Informs how changes to flow targets will influence salinity intrusion

Watershed Hydrologic Modeling

- What reservoir policies optimize the use of limited water resources during drought

What Does Water Supply Planning Support?

Infrastructure Planning – PWD Water Master Plan

- Alignment of the life cycle of infrastructure, water quality and regulatory compliance

3- Dimensional Hydrodynamic Modeling Process EPA Environmental Fluid Dynamics Code (EFDC), 3D

Model Development

- Data Collection
  - Sampling
  - Gather inputs
  - QA/QC
  - Data preparation
  - Data formatting
- Model Building
  - Hydrodynamics
  - Salinity transport
  - Bacteria transport
  - Sediment diagenesis
  - Algae

Testing

- Calibration
- Sensitivity analysis
- Validation

EXTERNAL EXPERT REVIEW

Dec. 2021

Analysis

- Production run setup
- Production runs
- Post-processing

Moving from Model Validation to Production Runs

What does model validation tell us?

- When compared to observed data, the PWD salinity model simulates tidal Delaware River hydrodynamics and salinity transport processes during periods of salinity intrusion to a high degree of model skill

What can production runs tell us?

- How salinity intrusion may respond to changes in streamflow, salinity and water level inputs

What changes between model validation setup and production run setup

- It depends on the where/what/when of your objective

Objectives Guide Production Run Setup

Inform the FFMP

- Reservoir operations are currently designed to manage the location of the 7-day average 250 mg/L chloride isochlor (not prevent intrusion, not dilute upstream pollution)
- Changes to NYC drought emergency flow targets are under consideration by the FFMP (detachment)
- The FFMP includes a clause that is critical to Philadelphia regarding possible policy changes in 2023 that would last until 2028

FFMP 2017 Signed

Oct 21, 2017 → Studies and evaluations conducted → May 31, 2023 → NYC detachment implemented → May 31, 2028

Pending results of studies

Parties agree to continue to 2028, modify, temporarily extend and renegotiate, or terminate

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Informing the FFMP Guides Production Run Setup

The production run setup needs to simulate:

1. Severe intrusion upstream of Chester
   - Negotiated flow objectives manage intrusion once it moves upstream of Chester
2. Sustained intrusion
   - Potentially reduced flow targets may lead to more extended events
3. Low streamflow at Trenton and the Schuylkill River and the downstream tributaries
   - Streamflow at and below the existing flow objective tables
4. 2028 conditions
   - Capture the influence of policies decided in 2023 that will last until 2028
   - PWD model validated to 2016 observed intrusion, 12 years prior to end of current FFMP

 The FFMP lasts until 2028 so the runs are setup to simulate 2028

Production Run Setup – What actually is different from the validation setup?

Critical Period – Time of Year and Drought Considerations

- Permitted Discharges
- Water Temperature
- Tributary Salinity
- Tributary Streamflow
- Open Boundary Salinity

Climate-Related Sea Level Rise and Periodic Set-Ups

- Water Level

Critical Period

For Validation:

- 2014 and 2016 October-into late fall intrusion events

For Production Runs:

- Historical intrusion events during drought conditions that bring salt further upstream than typically occurs in the late fall during October and November
- The PWD production run flow restrictions begin in September and run for four months
- Appropriate drought-related salinity conditions are imposed at the open boundary and sustained through the production run

Permitted Discharges

For Validation:

- 2014 and 2016 monthly DMR data for permitted discharges, flow and salinity, estimates made where needed

For Production Runs:

- DMRs fixed at November 2014 flow and salinity, CSOs are not active due to assumption of no rain during drought
- Intakes and discharges can reflect precipitation and hydrological conditions at the time of data collection, they are each fixed at a representative value so they don't fluctuate during the production runs

Water Temperature

For Validation:

- 2014 and 2016 observed time series

For Production Runs:

- Intrusion typically intensifies after peak annual water temperature and continues into declining water temperatures from October through December
- Need to investigate axial temperature differentials from Trenton to Chester
- Need to investigate if there are any relationships between low streamflow and temperature to consider

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Why is Water Temperature Important

Density

- As water becomes cold, it becomes more dense which may affect transport and mixing

Steric Height

- As water density changes in response to heating-cooling and salt content, it expands or contracts, increasing or decreasing water level

Temperature in the Critical Period

- As air temperature cools in the fall, so does water temperature
- Low streamflow during the critical period affects average seasonal water temperature

Temperature in the Critical Period

There are negligible differences in water temperature from Chester to the Ben Franklin Bridge

- An analysis of axial salinity found a standard deviation <1 deg-C from the mean of all stations (May to Nov.)
- This allows for one critical period water temperature time series

There is a relationship between flow and water temp.

- Water temperature is isolated from low flow conditions and used to develop a weekly time series for production run model input

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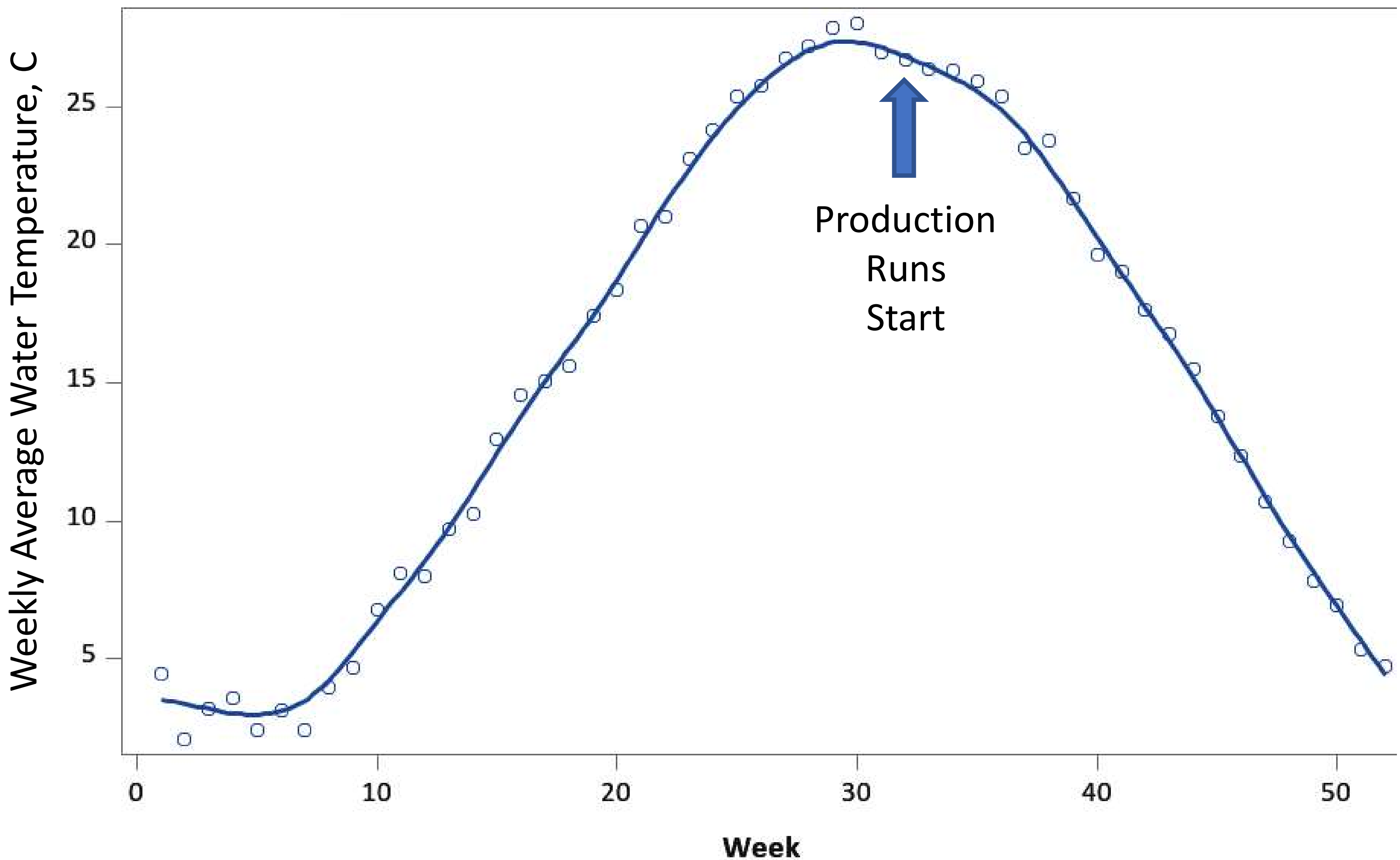
Smoothed Production Run Input



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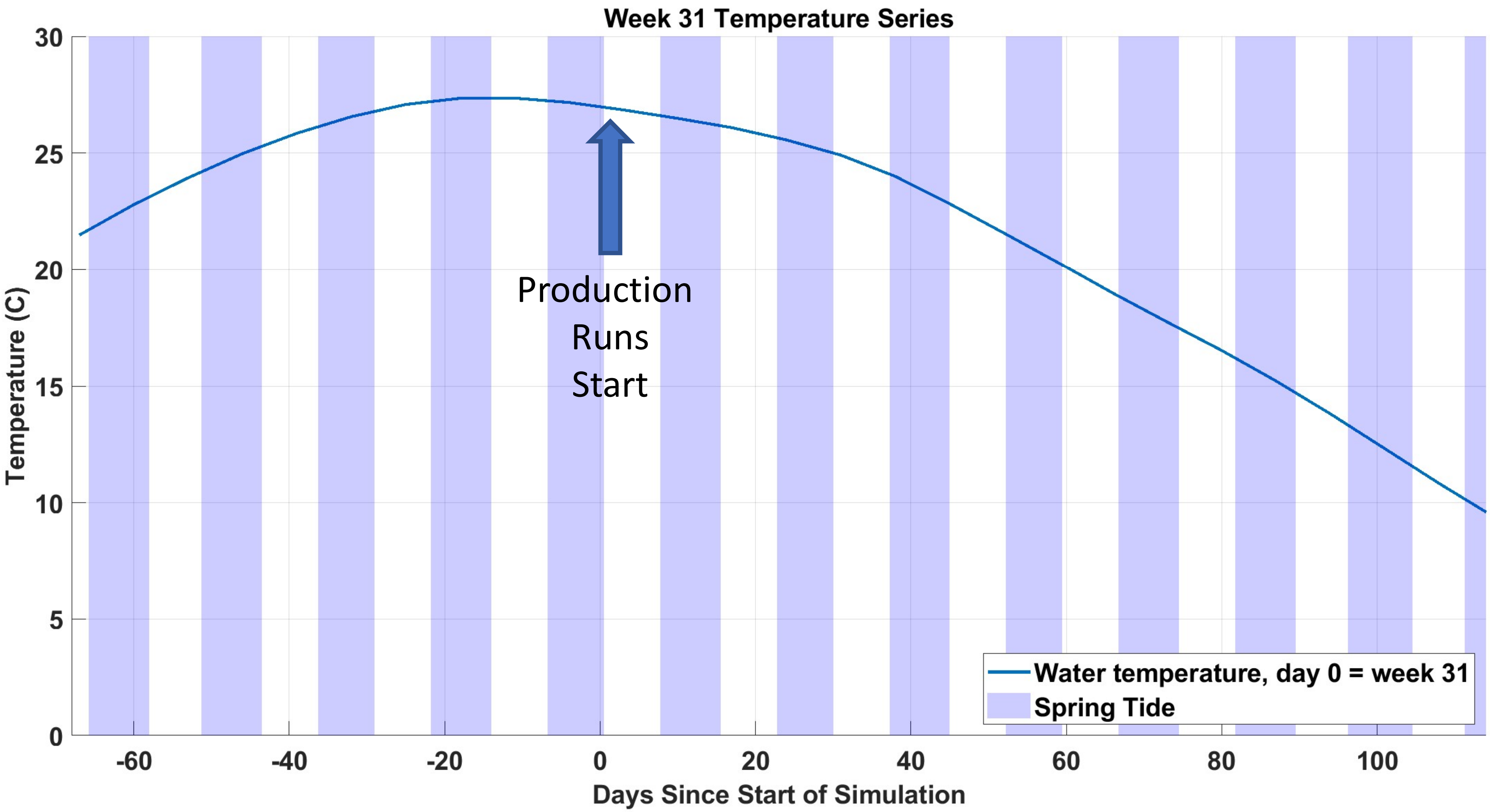
Water Temperature – Final Setup



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Neap-Spring Cycle

Gravitational Effects of Sun and Moon

- During the 29.5-day lunar cycle, the sun and moon are in alignment twice at the new moon and full moon
  - This creates spring tides which have the highest high tides and the lowest low tides
- During the 29.5-day lunar cycle, the moon is at a right angle to the sun twice
  - This creates neap tides which have the lowest high tides and the highest low tides

Why does this matter for salinity intrusion?

- Cyclical swings in water level

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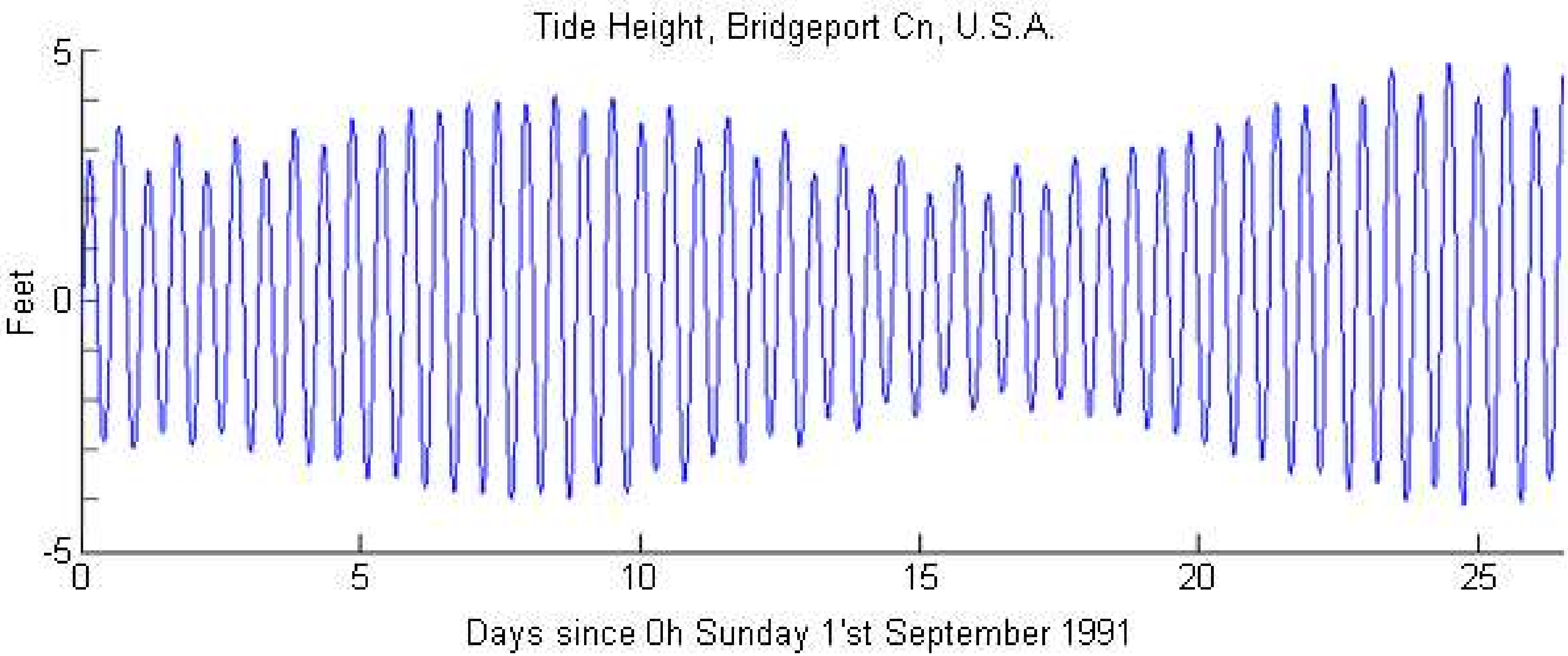
Typical Neap-Spring Tidal Cycle

Interaction of the Principal Lunar Semidiurnal (M_2) and the Principal Solar Semidiurnal (S_2) Harmonic Constituents



Public Domain Image, source: Nicky McLean

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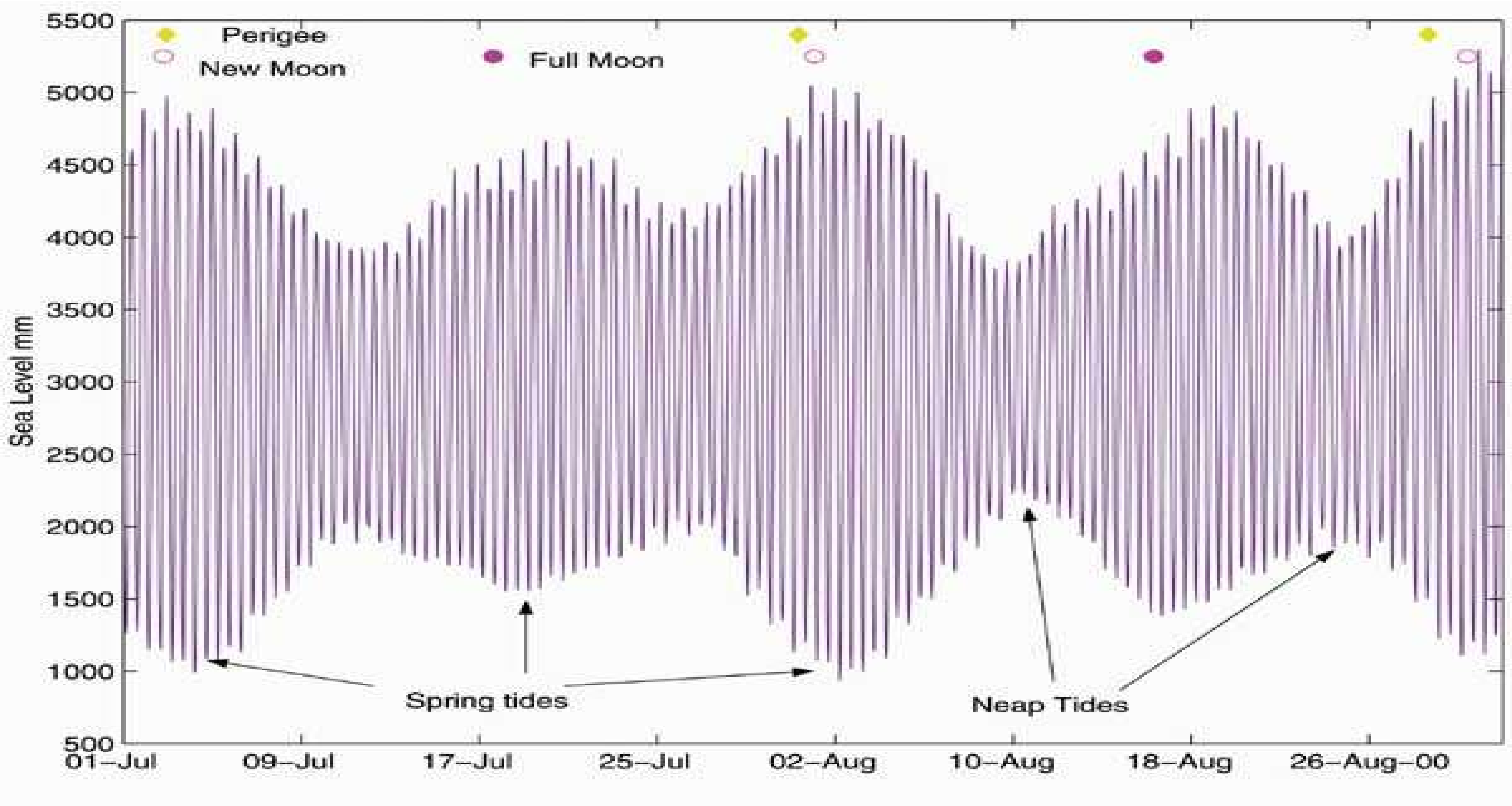
Neap-Spring Cycle

Alternating spring pattern due to the influence of the N_2 constituent in the Delaware Estuary



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Open Boundary Salinity – Pea Patch Island

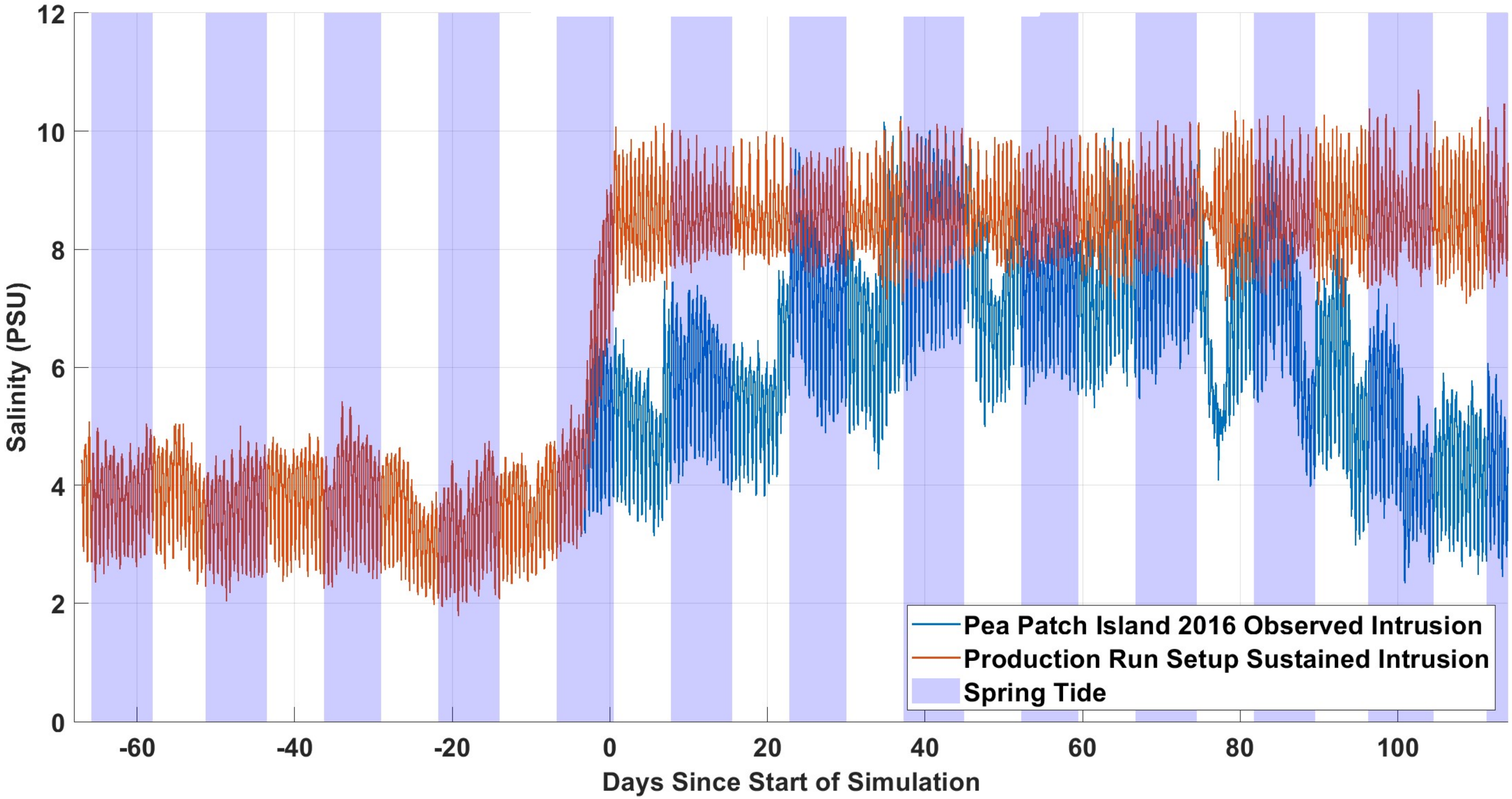
For Validation:

- Pea Patch Island (model lower boundary) salinity synthesized from a regression-based transfer function from the USGS Reedy Island data
    - The details of the transfer function are detailed in the validation report

For Production Runs:

- Want to simulate sustained intrusion behavior and investigate streamflow influences on intrusion severity once ocean salt has reached and moves upstream of Chester
    - Not the conditions that bring intrusion to Chester because these are outside the scope of the FFMP
- A review of historical intrusion conditions revealed that when salinity at Reedy Island reaches 12 PSU, intrusion of ocean salt is observed at Chester
- The statistical model was applied to 2016 observed data to create a Pea Patch Island time series based on Reedy Island salinity of 12 PSU
- The production runs impose these sustained conditions

Open Boundary Salinity Input



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Tributary Streamflow – not Delaware or Schuylkill

For Validation:

- 2016 observed time series and tributary specific flow/area factors developed to estimate ungauged areas

For Production Runs:

- Calculated 7Q10s and 7Q10-based tributary specific flow/area factors developed to estimate ungauged areas

Tributary Salinity

For Validation:

- 2016 observed time series where available and reference streams used for locations with no data

For Production Runs:

- Isolate and average 2016 periods of observed low streamflow and high chloride at Trenton and Schuylkill
- Quantify long-term rate of increasing chloride during mid-low streamflow conditions and apply rate of change to estimate 2028 tributary salinities
- Rate of tributary chloride increase from 2016 to 2028 estimated to be 12.8%

Tributary Salinity – 2016 vs. 2028

Comparison of Chloride Values

- Representative of low streamflow conditions
- Increased 12.4% based on long-term rate of increase

Tributary	2016 mg/L	2028 mg/L
Schuylkill	142	159.6
Delaware at Trenton	36.8	41.4

- What effect does this have on production runs?

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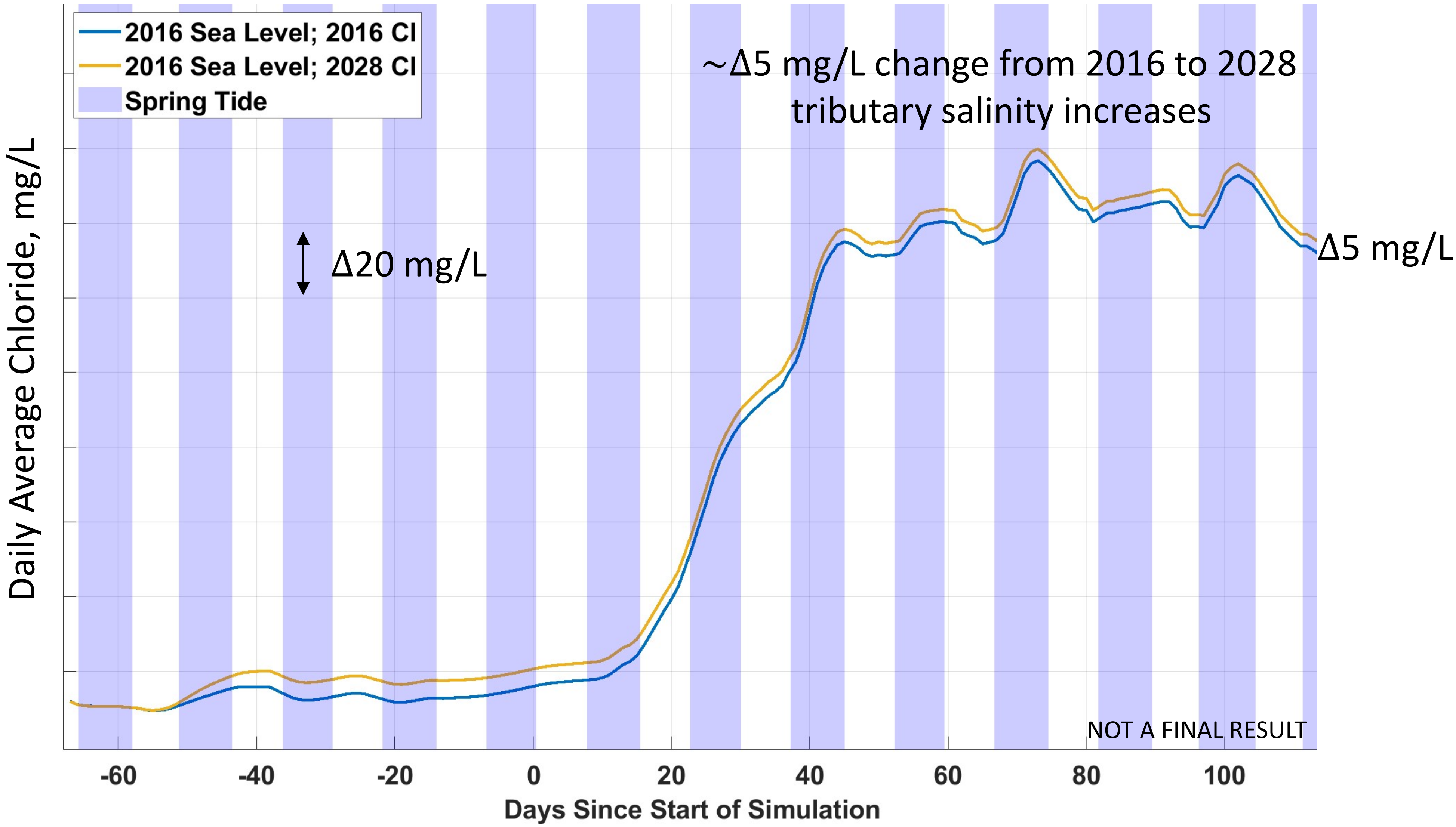
Location: River Mile 100, Ben Franklin Bridge

Trenton Streamflow: 2,900 CFS

Schuylkill Streamflow: 500 CFS

Run Compares: 2016 vs. 2028 tributary salinity, sea level at 2016



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Water Level and Sea Level Rise

For Validation:

- 2016 observed time series from NOAA Delaware City station

For Production Runs:

- NOAA 2016 predicted tides for Delaware City. These have a mean value of zero, and therefore the mean needs to be restored for any given year.
- This is where sea level is applied
- What does observed data tell us?
- How does observed data compare to NOAA projections?
- What sea level to apply?

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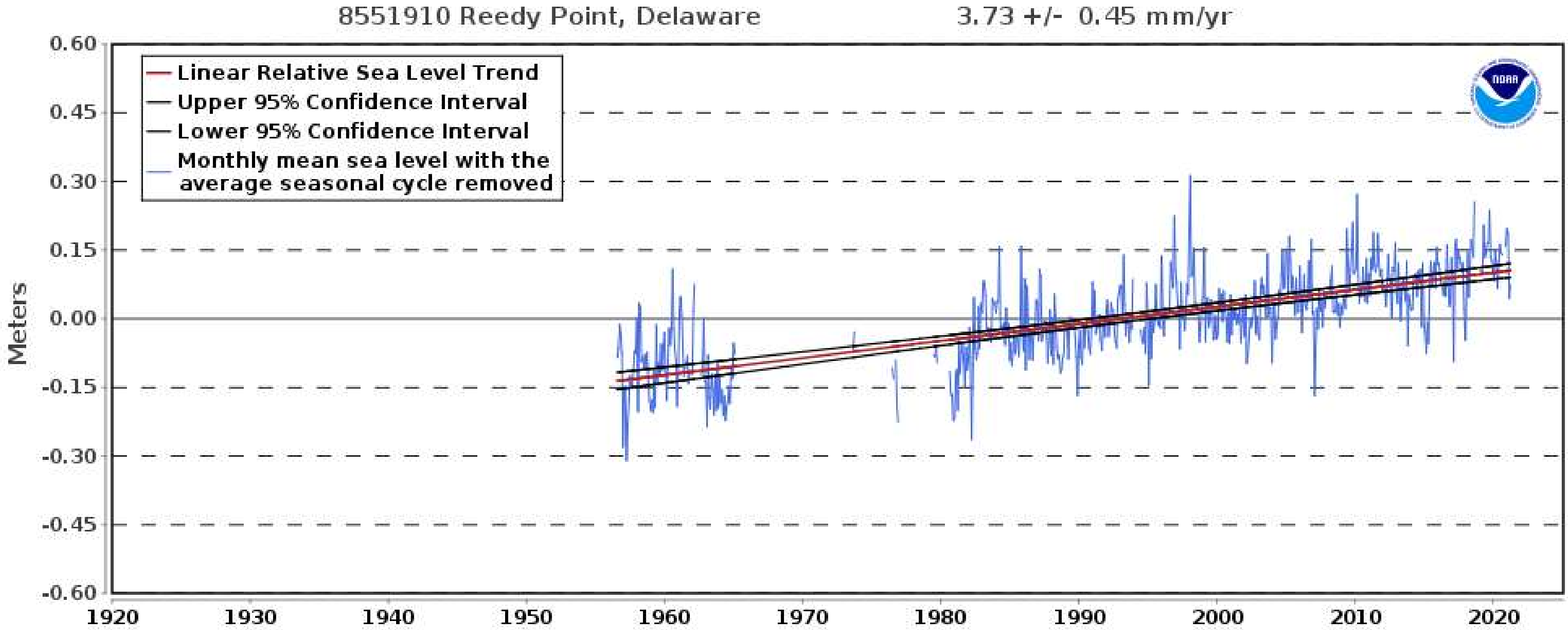
Observed Sea Level Rise at Reedy Point



The plot shows the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

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What does observed data tell us?

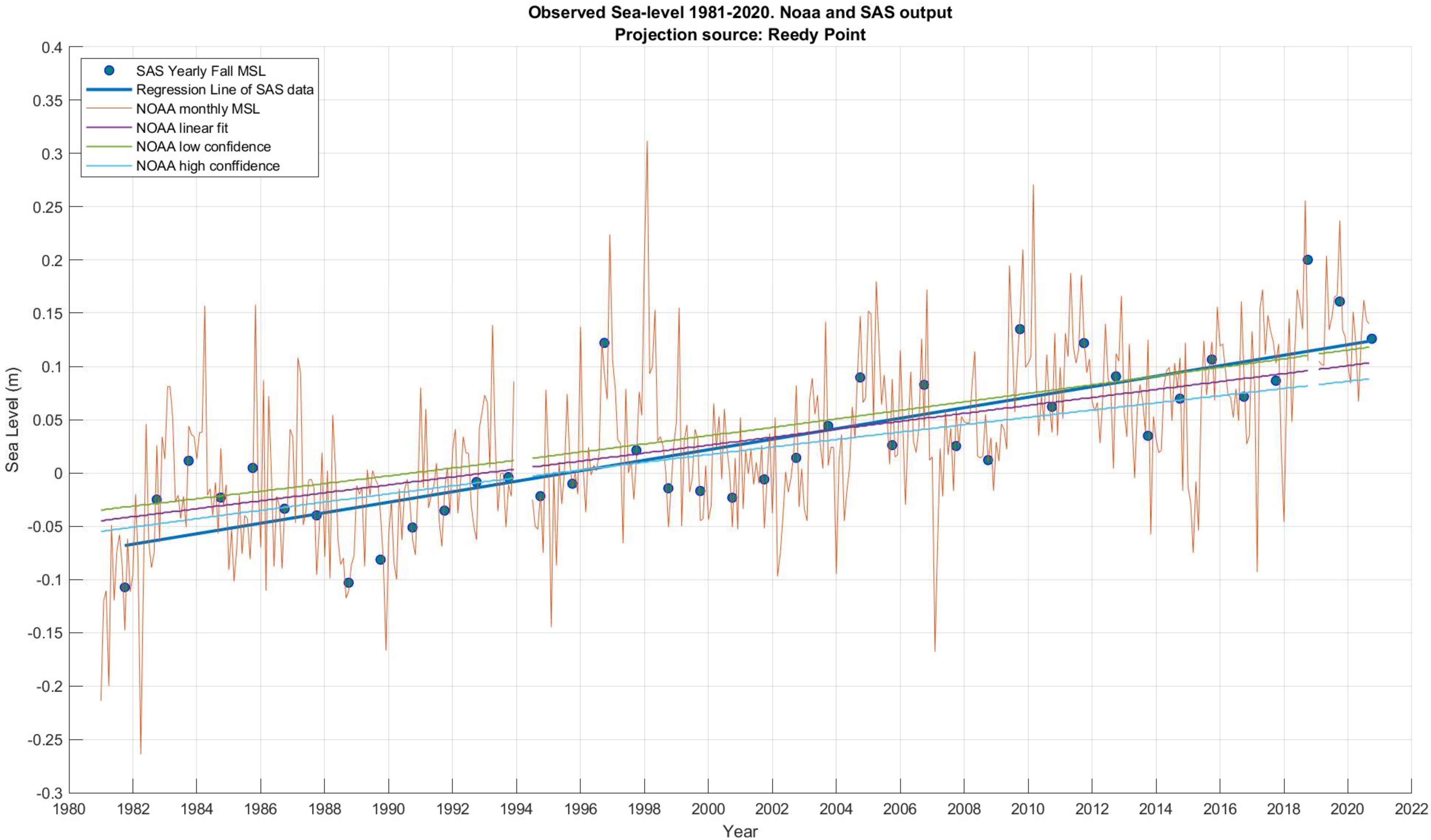
NOAA Trend at Reedy Point

- NOAA graph indicated 0.00373 m/yr from 1960-2020

Annual vs. Critical Period Linear Regression

- PWD analysis of annual mean sea level calculates 0.00428 m/yr from 1981-2020
- PWD analysis of Sept.-Dec. mean sea level calculates 0.00494 m/yr from 1981-2020
- Linear regression inferred-results for NAVD88-based results:

Year	Annual Mean sea level, m	Sept. – Dec. Mean sea level, m
2016	0.0823	0.104
2028	0.134	0.162
2038	0.177	0.213



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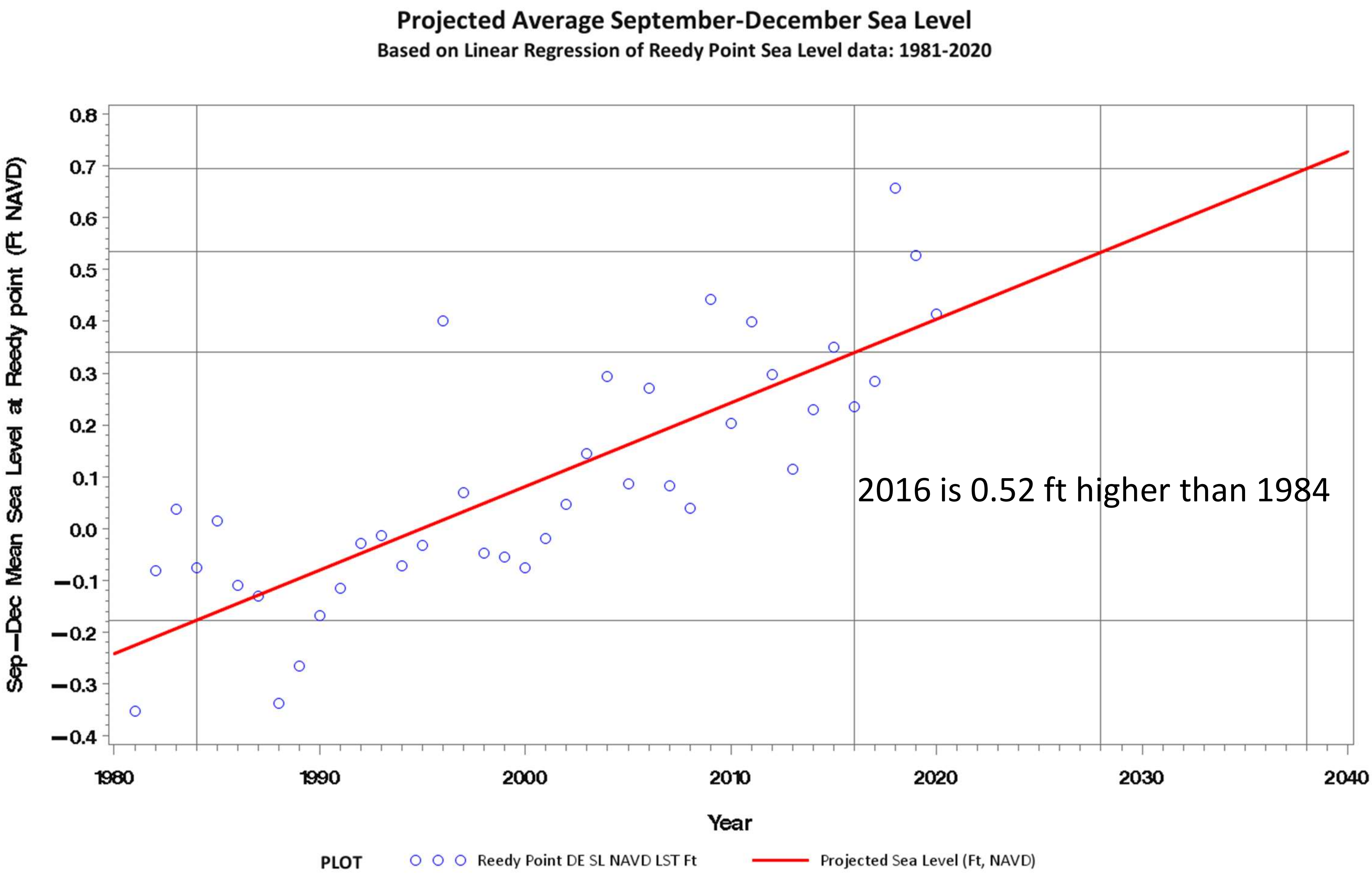

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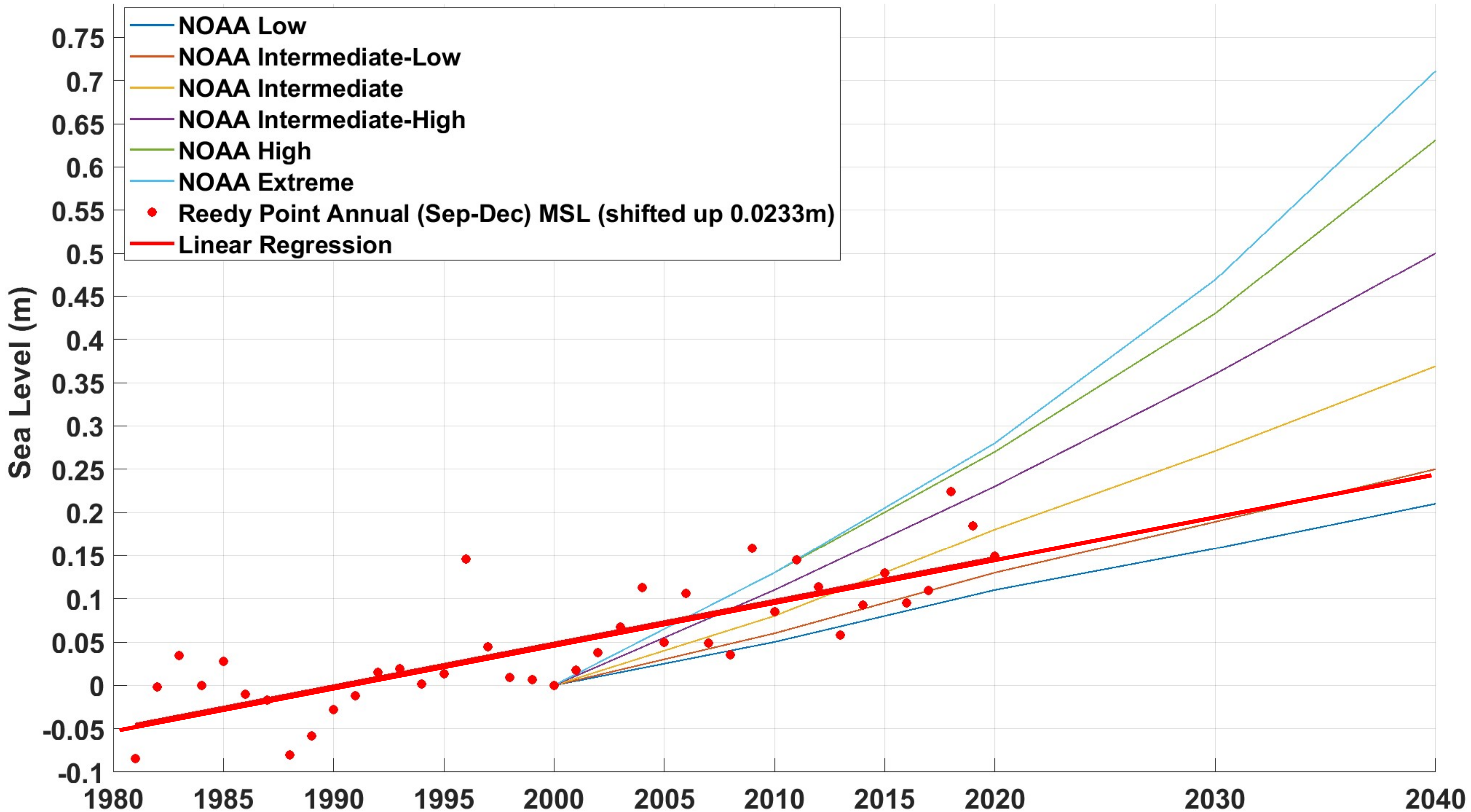
What do Government Projections Say?

NOAA Trend at Reedy Point

- NOAA graph indicated 0.00373 m/yr from 1960-2020

SLR Projection Source	Scenario	Projected 2030 SLR from 2000	Projected 2040 SLR from 2000
		Meters	Meters
PWD	Observed Critical Period Trend	0.149	0.198
NOAA Reedy Point	Low	0.158	0.210
	Intermediate-Low	0.189	0.250
	Intermediate	0.271	0.369
	Intermediate-High	0.360	0.500
	High	0.430	0.631
	Extreme	0.469	0.711

Reedy Point NOAA Sea Level Rise Projections vs. NOAA Observed Data Summarized with Trend



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Sea Level Rise Final Setup

What is Selected:

- The observed data trend of average Sept. – Dec. water level from 1984 – 2020, projected to 2028, values in NAVD88
- Means to be applied to the open boundary are 0.072m for 2016, 0.162m for 2028, 0.213m for 2038
  - Note, these are different then reports comparing sea level rise against 2000. To do that comparison these numbers would have to be adjusted.

Why it is Selected:

- The trend of observed data projecting to 2028 presents a minimum expected sea level rise case.
- The NOAA Low and Intermediate-Low projections are lower than the observed trend, implying they are projecting a slow down in the observed rate of change. Climate change is projected to continue, so in the short term from 2020 to 2028, and even from 2028 to 2038, it doesn't make sense that the rate of sea level rise would slow down from the current observed rate of change.

Sea Level Rise Final Setup

Why it is Selected, Continued:

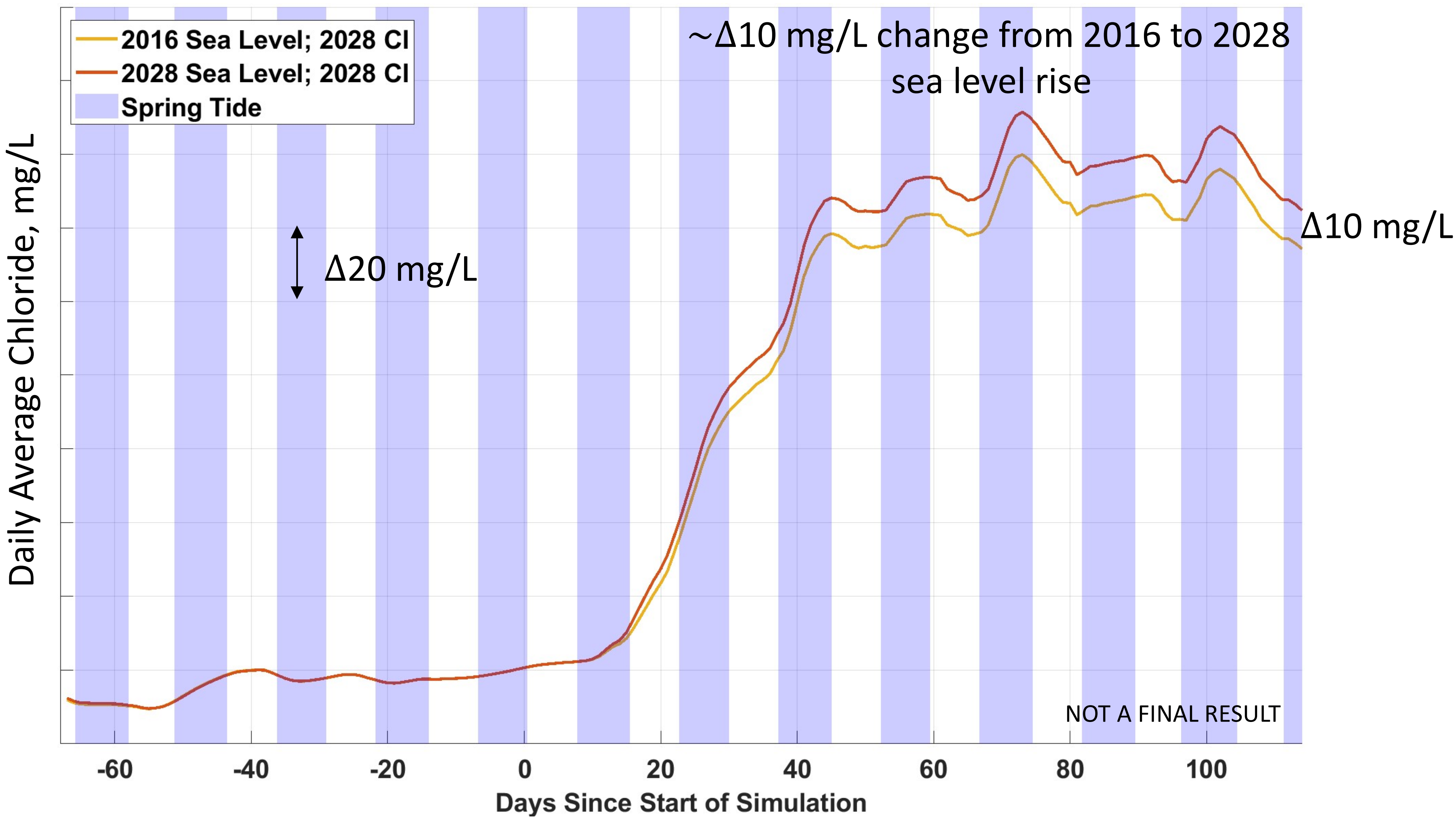
- The other NOAA projections are much higher than the observed trend, and it seems unlikely that from 2020 to 2028 the observed rate of change would accelerate so dramatically.
- Projecting from the most recent full year of observed data (2020) to 2028 is less than ten years.
  - A climate model is not necessary to project in such a short term when there is a clear observed trend.
- Long-term sea level rise projections are typically used to inform the design and placement of extended service life hardened infrastructure. The utility of the projections for short-term water quality planning applications is limited.

Location: River Mile 100, Ben Franklin Bridge

Trenton Streamflow: 2,900 CFS

Schuylkill Streamflow: 500 CFS

Run Compares: 2016 vs. 2028 sea level, tributary salinity at 2028 condition



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Location: River Mile 100, Ben Franklin Bridge

Trenton Streamflow: 2,900 CFS

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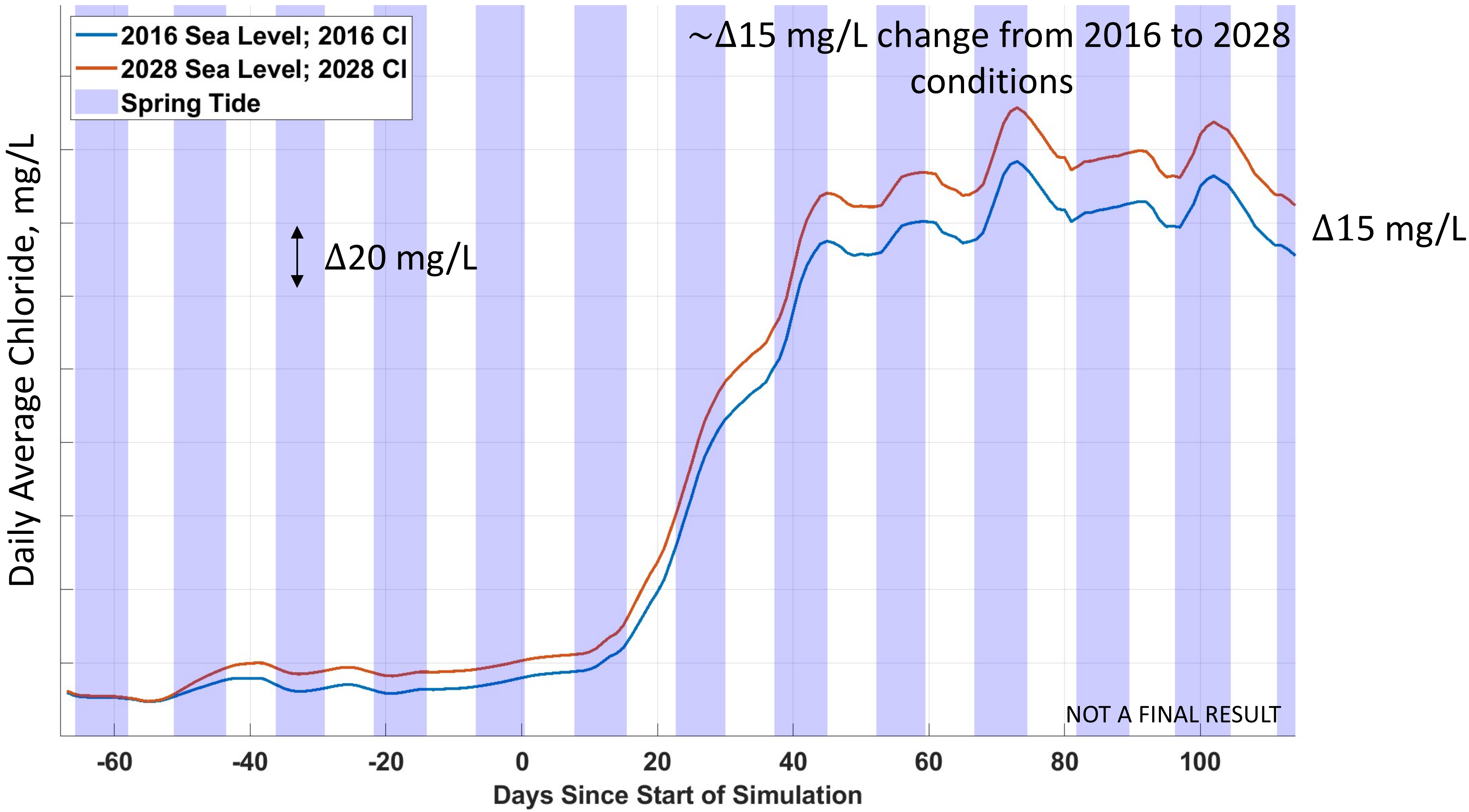
Run Compares: 2016 vs 2028 sea level and tributary salinity



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What are we working on now?

- Metric development
  - Flags for ocean salt at Baxter and Ben Franklin Bridge
- Production run execution – Phase I
- Production run QA and certification of Phase I
  - Needed to release results
- Production run execution – Phase II
- Production run QA and certification of Phase II
  - Needed to release results

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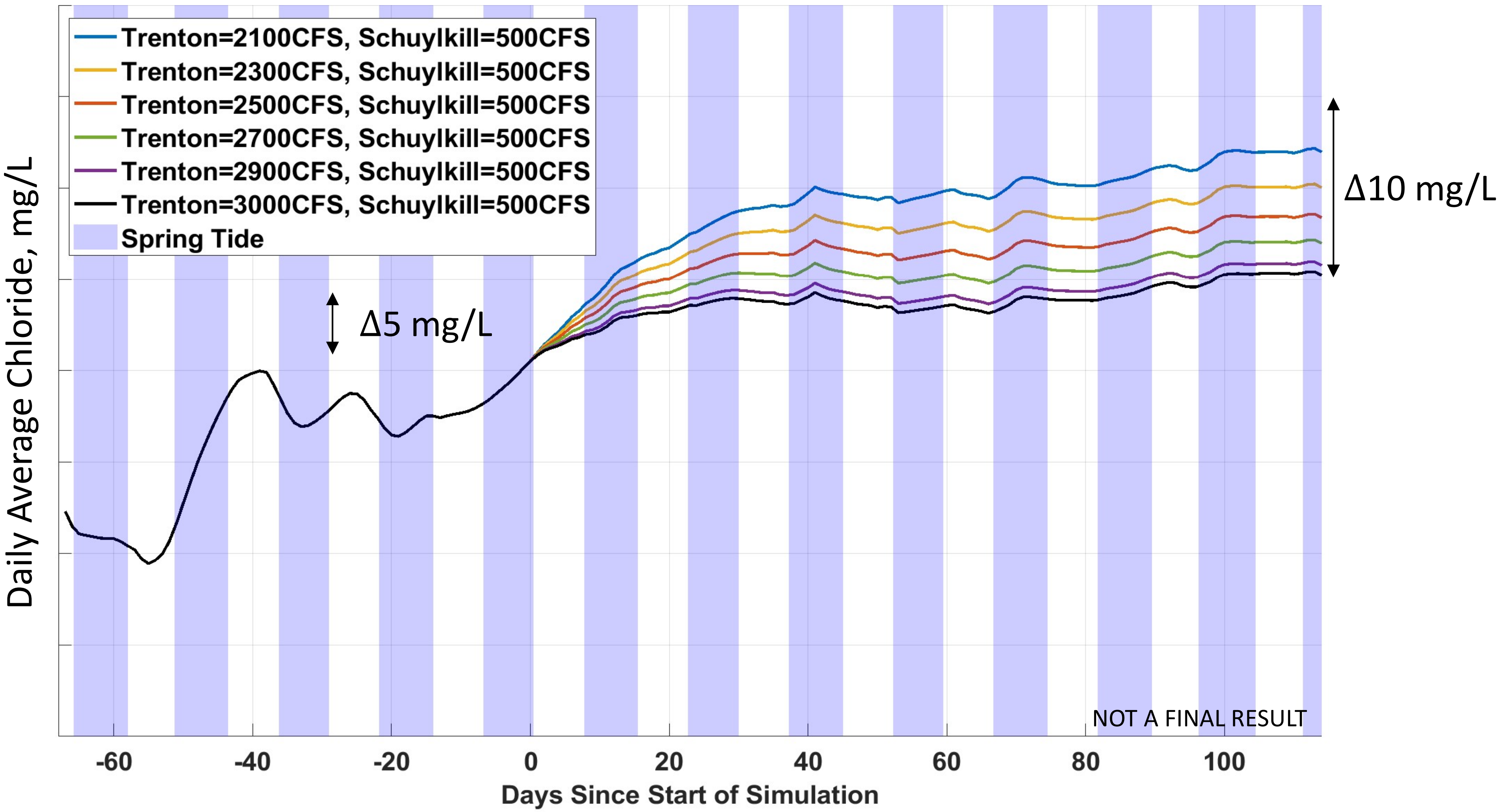
Location: River Mile 100, Ben Franklin Bridge

Trenton Streamflow: Varied CFS

Schuylkill Streamflow: 500 CFS

Run Compares: 0.2 PSU at the open boundary (NO ocean salt run), 2028 conditions



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Production Runs – Phase I

- Process ongoing, anticipated completion June 2022
- 45 initial runs
- Series to develop metrics
- Series to study influence of the Schuylkill
- Series to analyze sea level rise
- Series to analyze tributary chloride inputs
- Series matching a range of flows at Trenton (3,000 CFS – 1,500 CFS) to a range of flows at Schuylkill (700 – 100 CFS)

Production Runs – Phase II

- Anticipated start July 2022
- Synthetic hydrology timeseries
- Select runs with 2038 sea level rise and 2038 tributary salinity conditions
- Compounded Risks – 2028 severe intrusion with:
  - Large extended meteorologically-induced (i.e., offshore shelf wind-induced) setup based on historical observations, such as 1991

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THANK YOU!

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Inquiries may be directed to:

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