Delaware River Basin Commission

Potential Impacts of Sea Level Rise on Salinity in the Delaware Estuary

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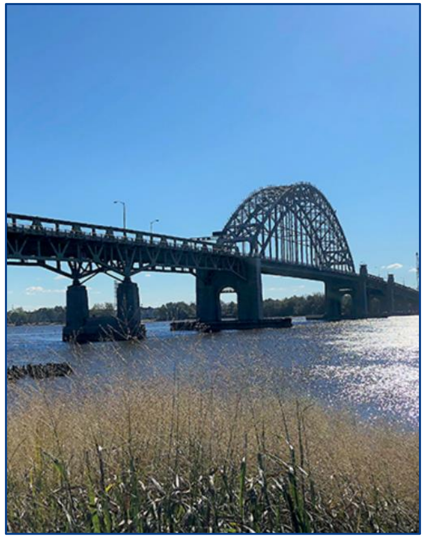
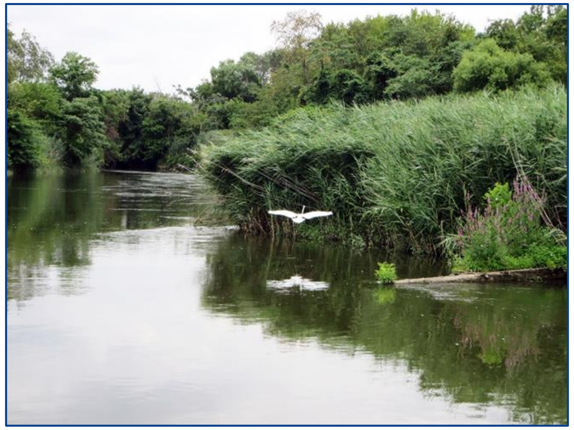


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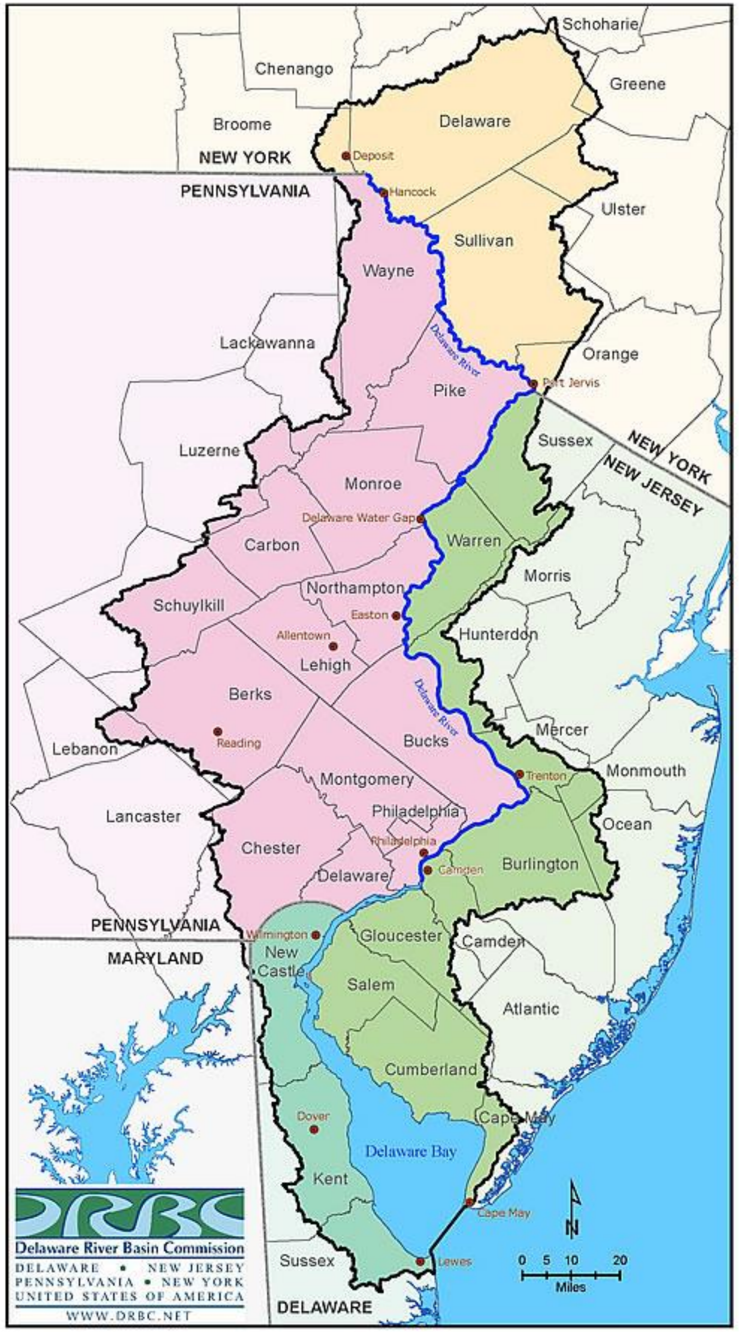
Potential Impacts of Sea Level Rise on Salinity

* Background – we need a tool
* Three-Dimensional Hydrodynamic **Salinity Model**
  * Model Development
  * Input, assumptions, boundary conditions
  * Calibration
* Application of Salinity Model for SLR (assumptions, results, sensitivity)
* Summary
* Next Steps



"A river is more than an amenity, it is a treasure"

-US Supreme Court Justice Oliver Wendell Holmes

- Delaware River Main stem river is **330 miles long**
- Delaware River forms an interstate boundary over its entire length
- **Drains 13,539 square miles** of watershed in 4 states.
- **13.3 million people** (approximately 5% of the U.S. population) rely on the waters of the Delaware River Basin
- Water **withdrawal** in the Basin = **6.4 billion gallons a day**
- **Significant Exports: NYC (up to 800 MGD) and NJ (up to 100 MGD)**
- Longest, un-dammed U.S. river east of the Mississippi (dams are located on tributaries, not the main stem Delaware)
- **Contributes over $21B in economic value** to the Region.

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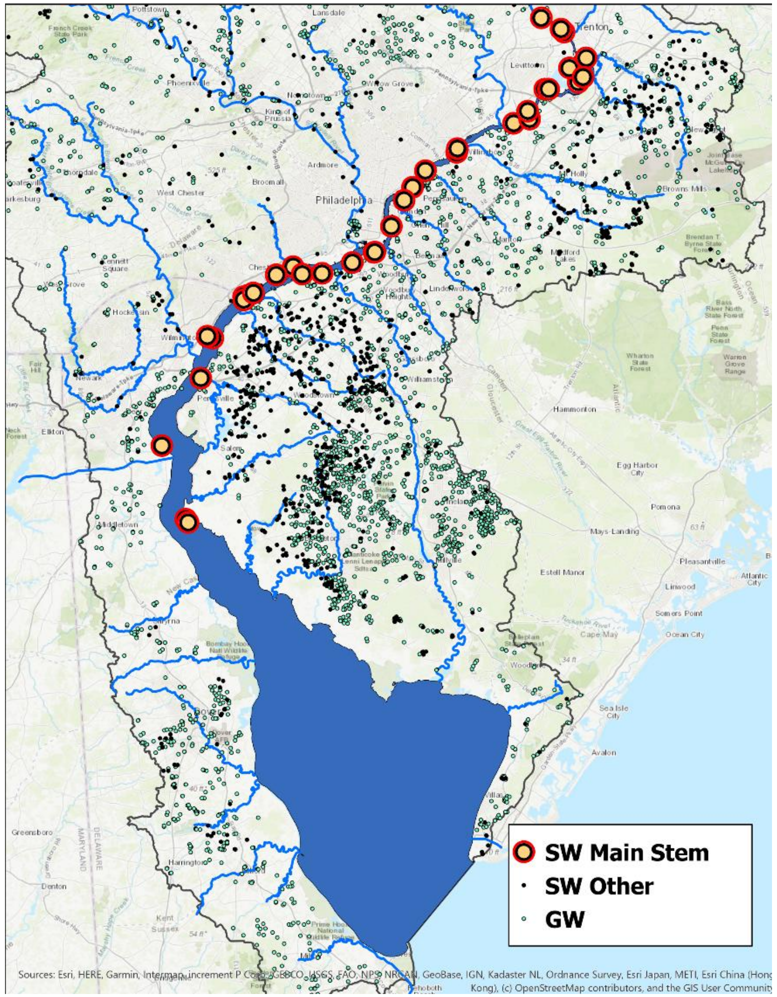
Water Users, Risks and Salinity



Risks to Availability and Usability

Droughts, Spills, Contaminants of Emerging Concern, Salt (deicing, ocean), Sea Level Rise

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Estuary Water Uses

Phila.gov

N. Suk

PDE

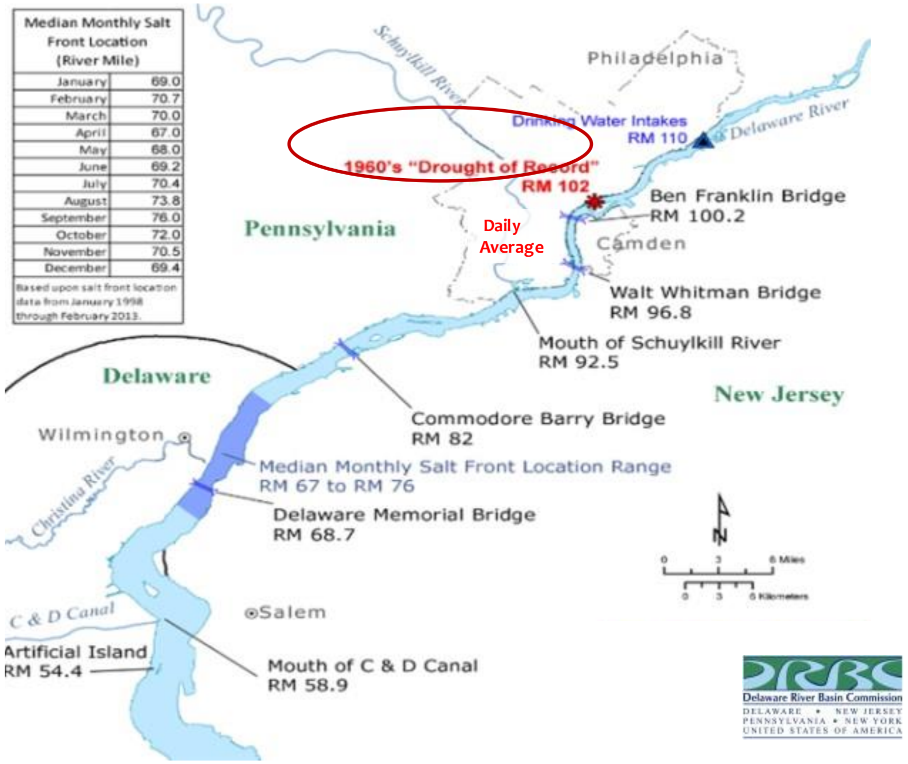
http://wikimapia.org/21274124/Kimberly-Clark-Inc-Chester-Papermill#/photo/1905408

Photo: Peretz Partensky, https://www.flickr.com/photos/ifl/7238282472/in/album-72157629823114004/; unedited

Seneca Park Zoo

The Salt Front and Sea Level Rise

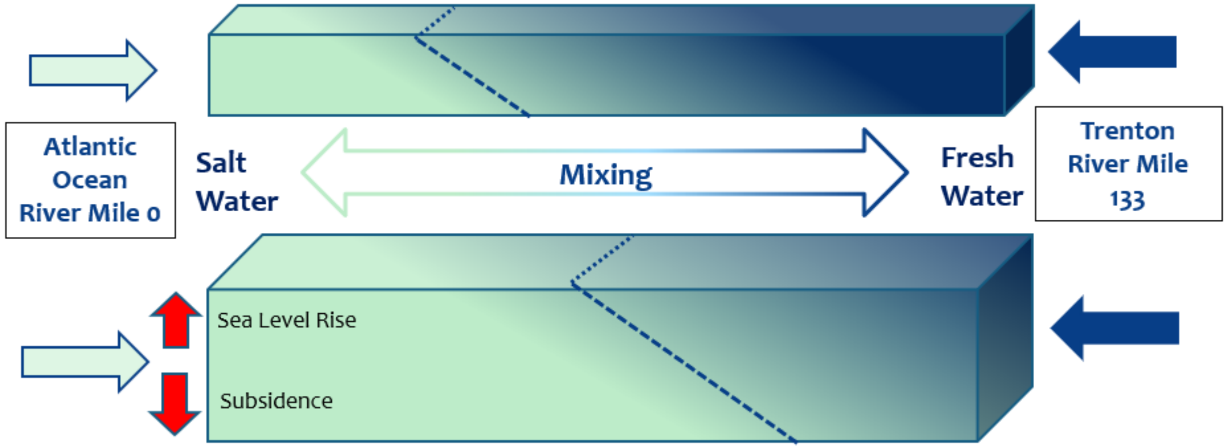
The salt front is a line, in plan view (isochlor), where the 7-day average chloride concentration is 250 mg/l (0.45 ppt salinity). It is not a physical feature. The salt front is used as an indicator to manage water quality and represents a critical salinity related to habitat sensitivity and water suitability for use by industry and for drinking water treatment. More information is available at: https://www.nj.gov/drbc/programs/flow/salt-front.html.



The location of the salt front in the 1960s was as far upstream as the Ben Franklin Bridge, only 8 miles downstream of Philadelphia's water intake.

What are the risks of SLR?

Conceptual diagram of how SLR may affect the location of the salt front.



The location of the salt front in the estuary depends on the tides forcing salt water upstream and the river pushing freshwater downstream. With more force from the ocean, the salt front may be farther upstream more frequently.

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What are the options to reduce the risk?

Past Efforts

- Delaware Estuary Salinity Modeling Studies – *Hull and Tortoriello, multiple staff papers (1980s).*
- Time-Varying Salinity Intrusion Model for the Delaware Estuary (MIT-TSIM), *Thatcher and Harleman (1978).*
- DRBC DynHyd-Toxi5 PCB model plus OASIS, *DRBC (early 2000s).*
- USACE CH3D-Z Hydrodynamic Model (used for consumptive use, SLR), *Johnson and Kim (1998, 2007, 2010).*
- *Multiple Universities and Federal Agency studies*

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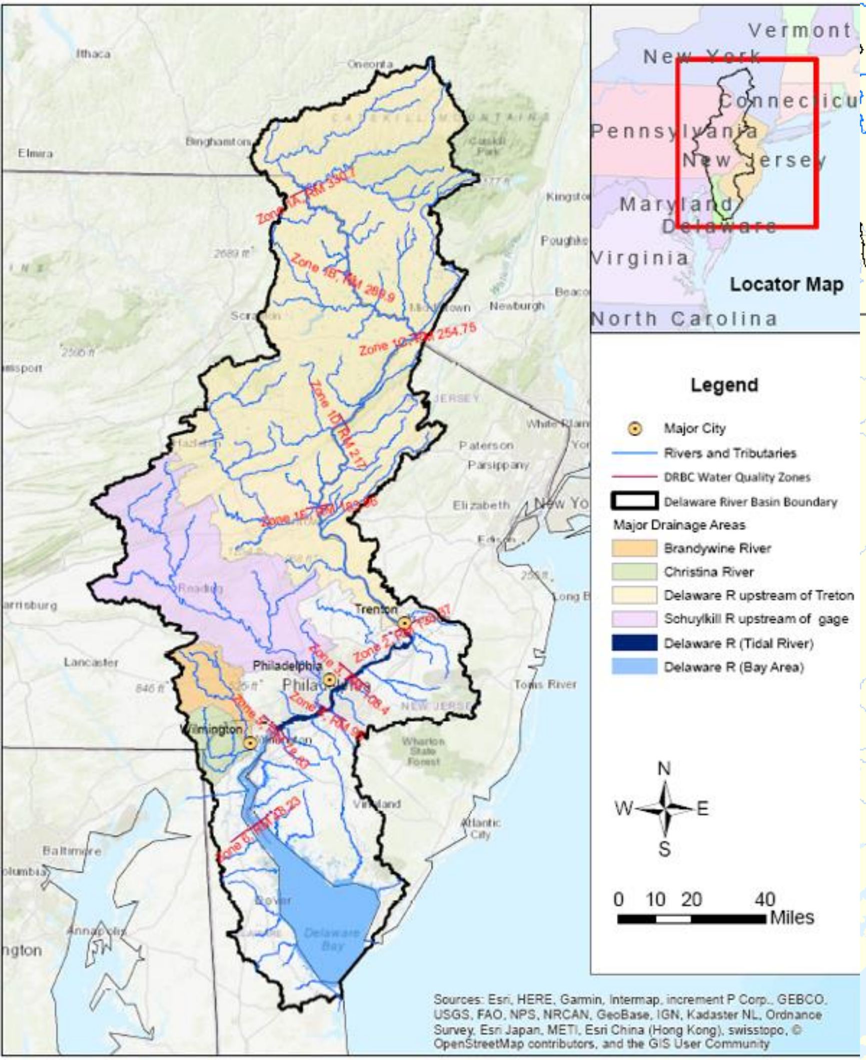
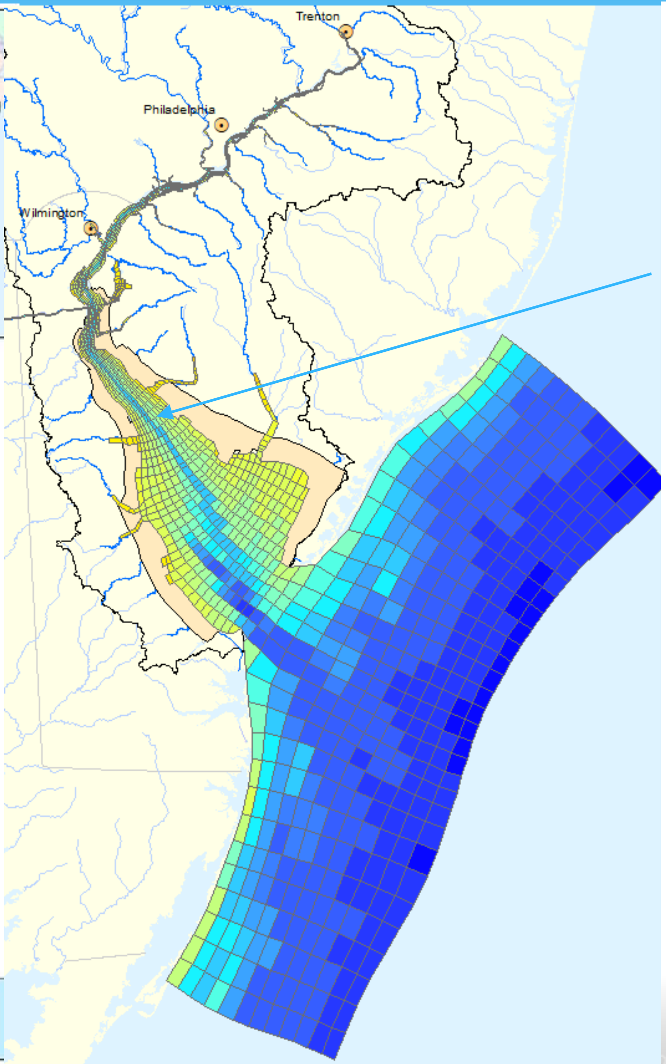
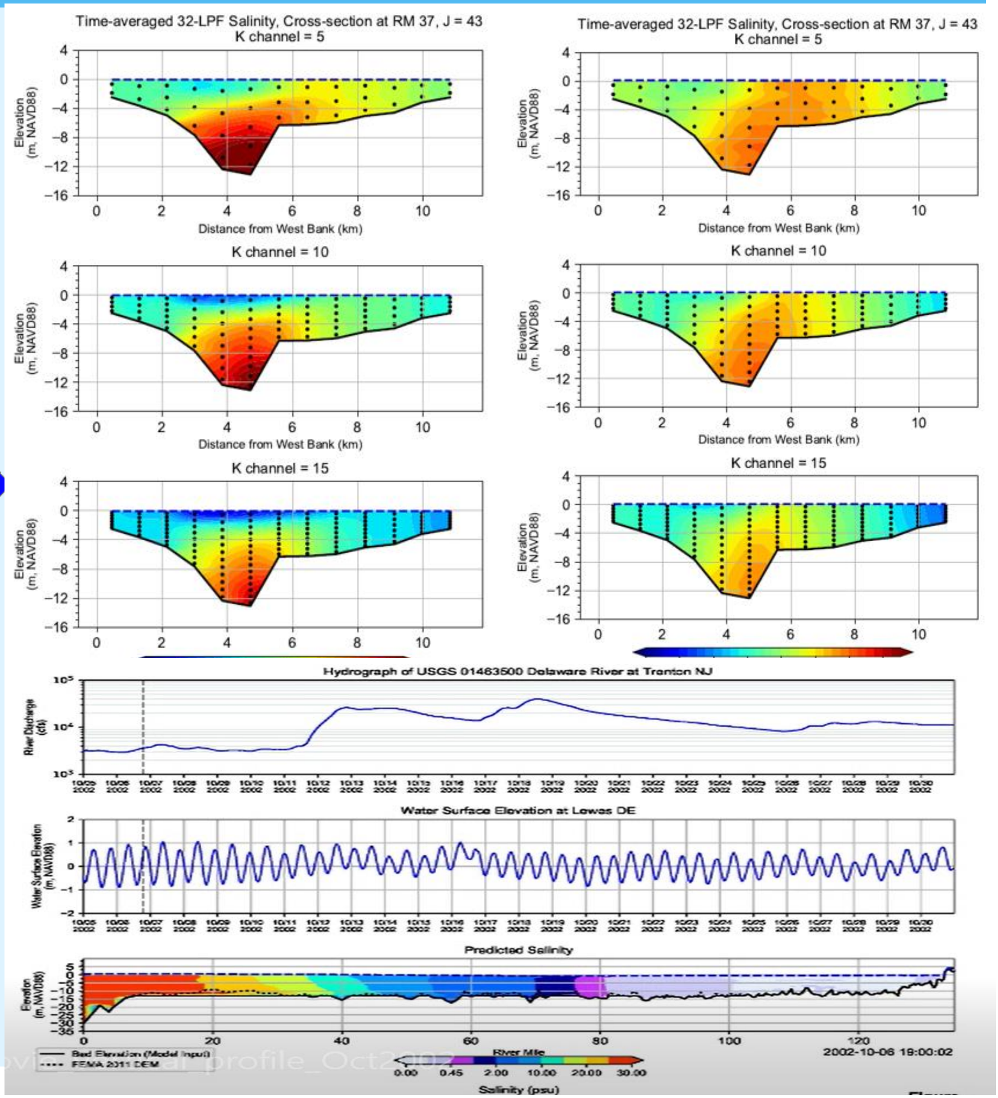
Development of Delaware Estuary Salinity Model



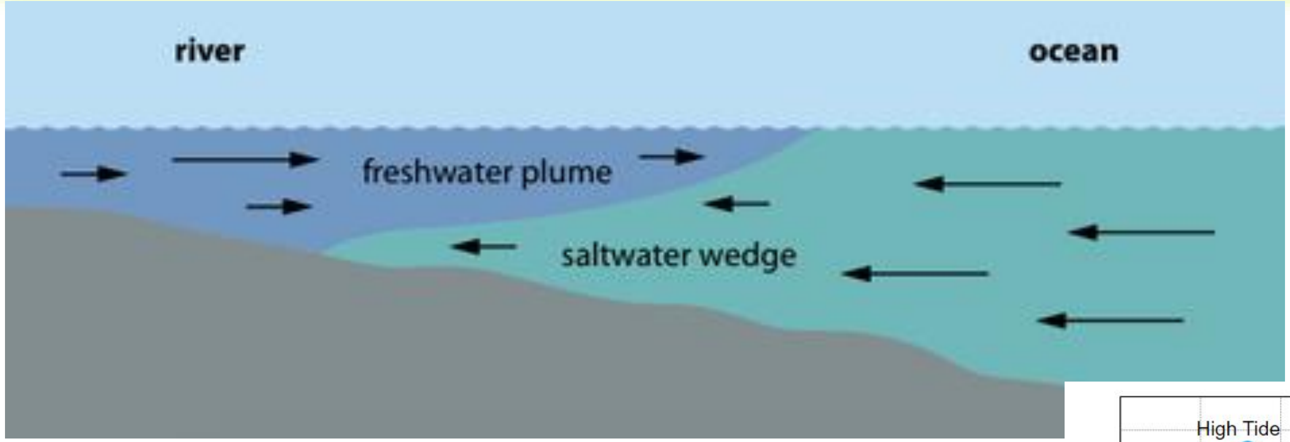




Estuary Hydrodynamics Modeling, General Approach

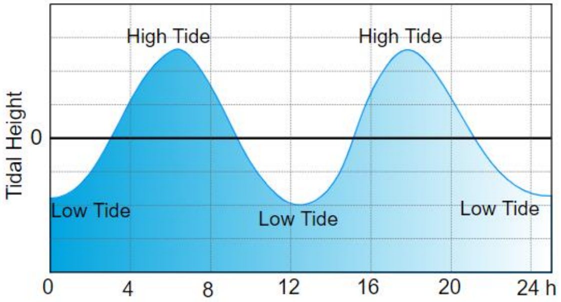
What is 3D hydrodynamic modeling?

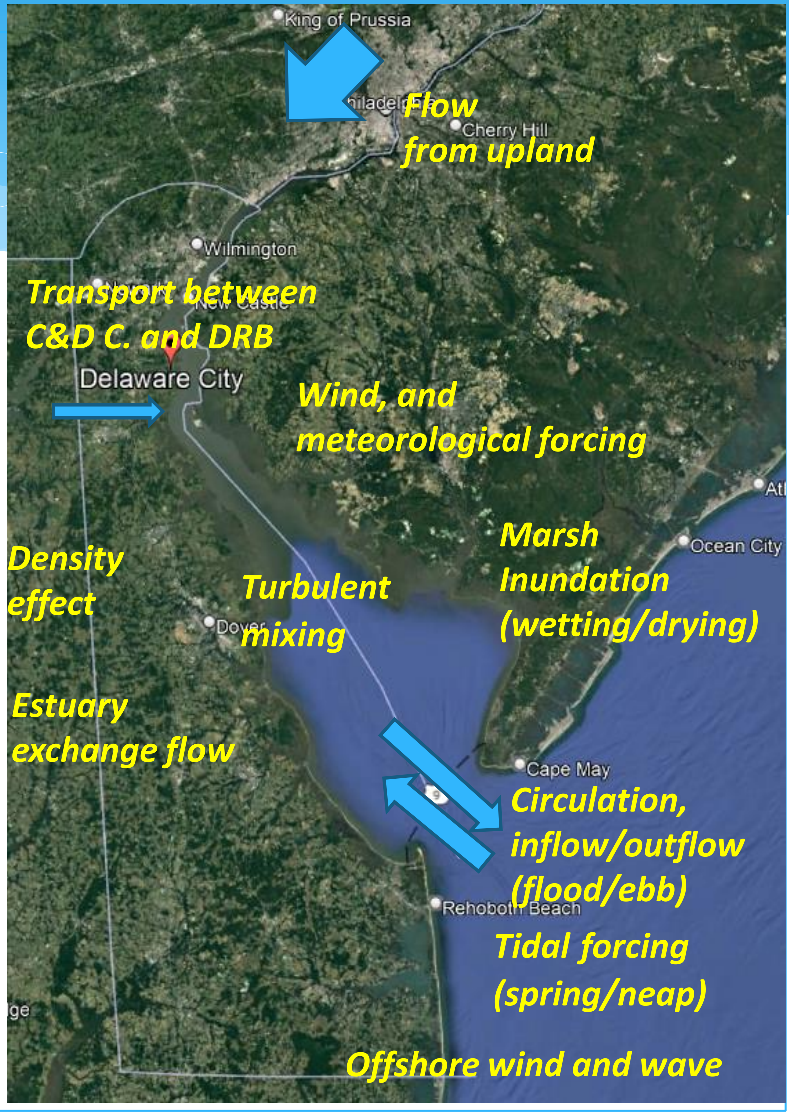
Hydrodynamic models simulate motion of water driven by a variety of forcings using a system of equations that include conservation of mass/momentum/energy. The model provides results for water surface elevation, current velocity, water temperature, and salinity in the Delaware Estuary.



Delaware Estuary is considered as a partially mixed and weakly stratified estuary

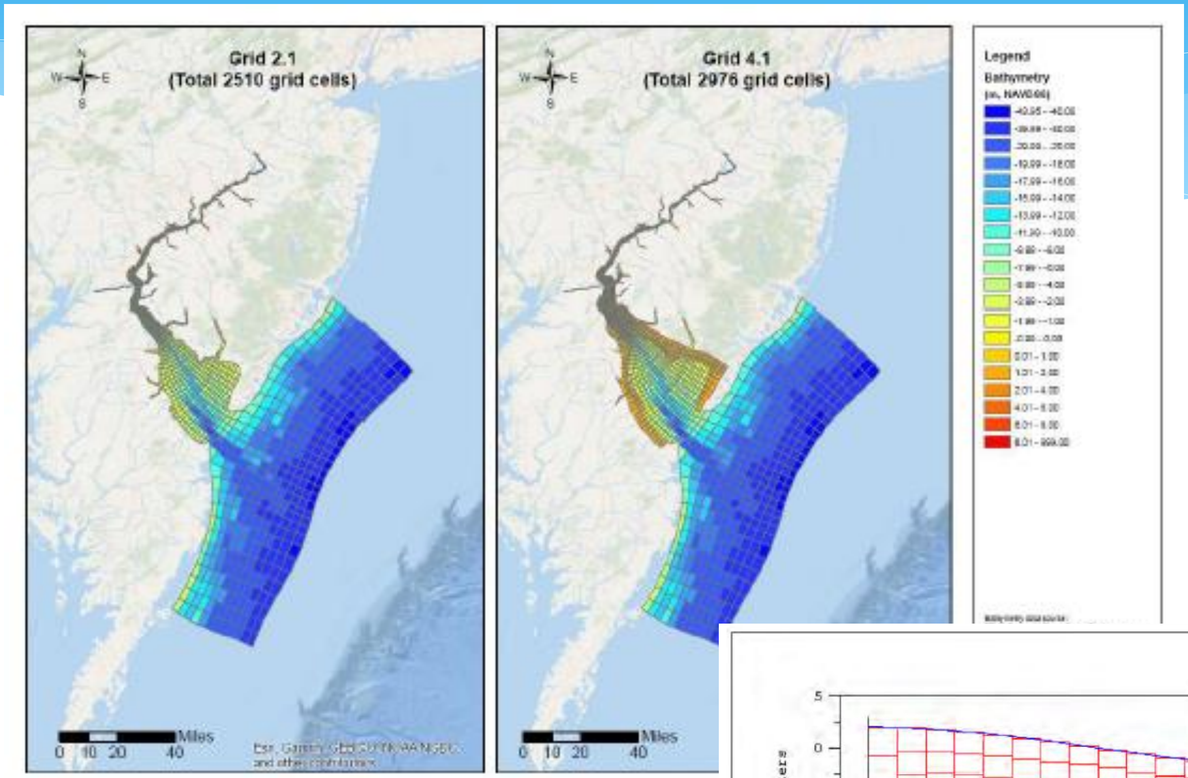
The tide in the Delaware has a semidiurnal tidal cycle



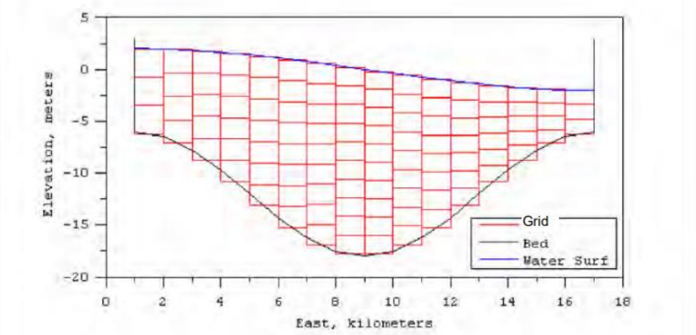


Hydrodynamics Model Development

- Environmental Fluid Dynamics Code (EFDC), supported by US EPA
- Model Development
  - Model Grid and Bathymetry
  - Generalized Vertical Coordinate system (GVC) Grid instead of Sigma Grid
  - Calibration Period (multi-year approach)
  - Boundary Conditions
  - Spatial Variable Bottom Roughness Height Z0 (friction drag)
- Calibration Metrics and Results
  - Water Surface Elevation, including Tidal Harmonic Analysis (T-Tide Program)
  - Current Velocity
  - Water Temperature
  - Salinity



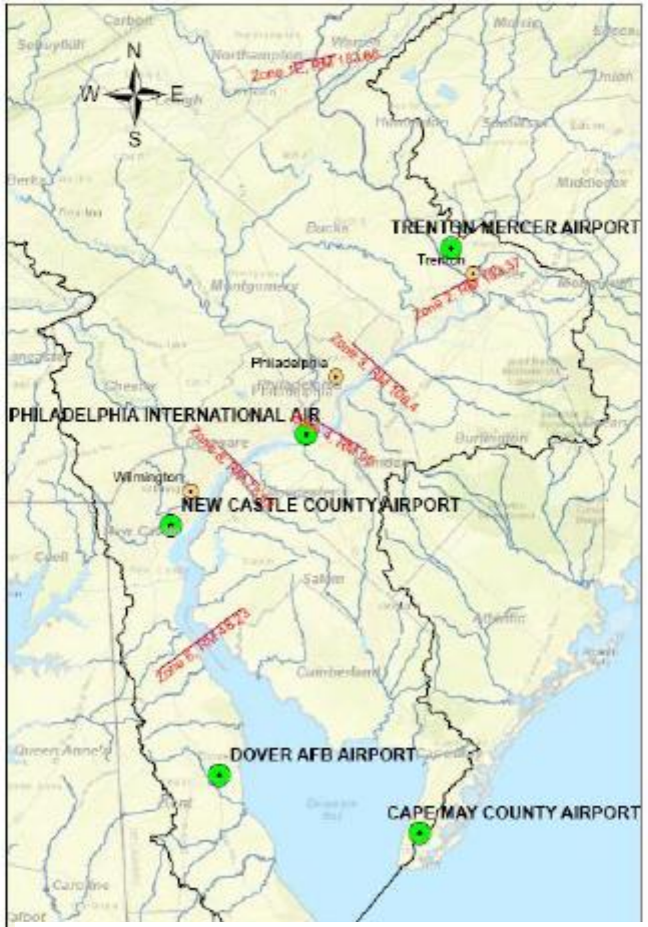
Example of **GVC grid** (right)



Example of GVC Grid reproduced from Figure 3 (p.26) of Theoretical and Computational Aspects of the Generalized Vertical Coordinate Option in the EFDC Model, EFDC Technical Memorandum prepared for USEPA Region 4 (Tetra Tech, March 2006)

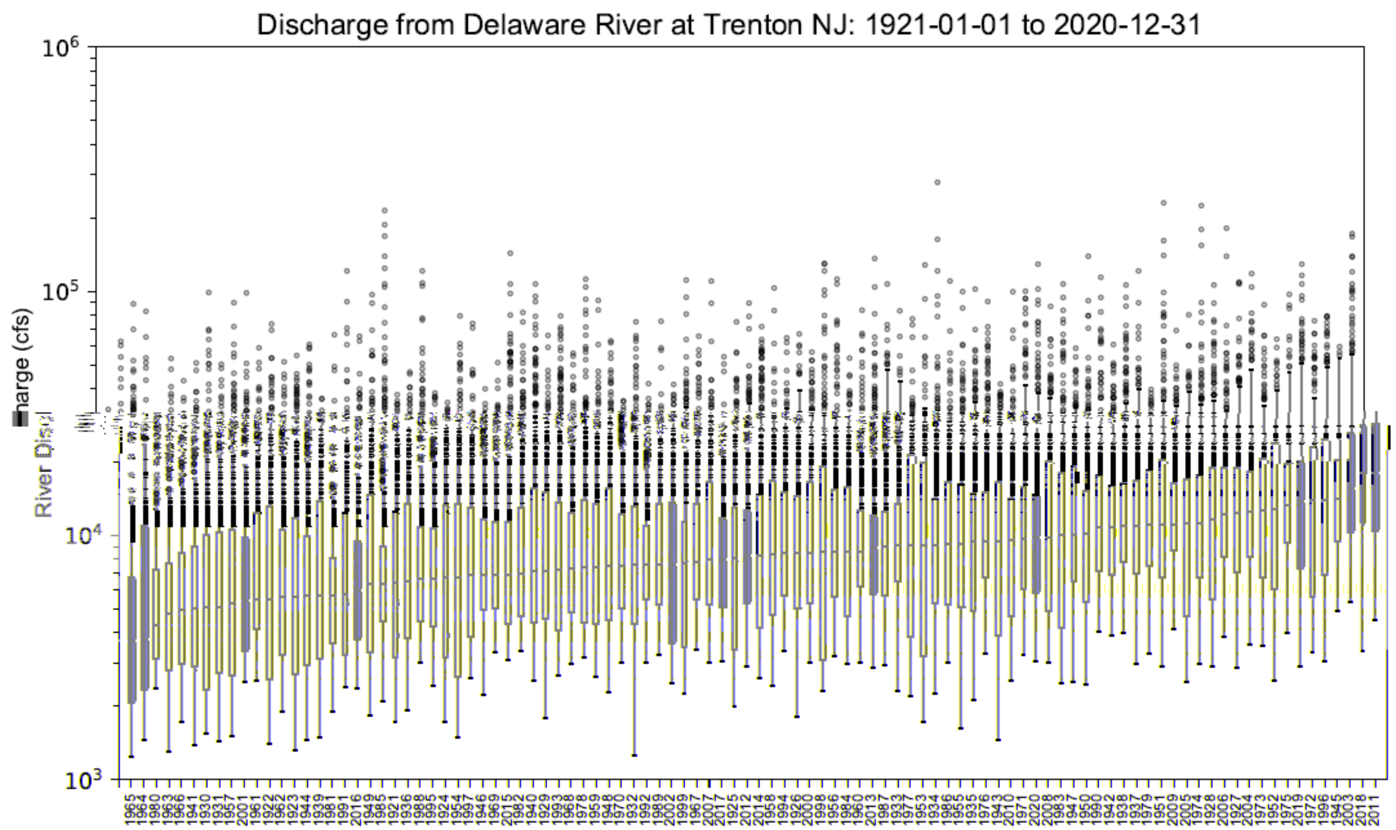
Boundary Conditions

- Freshwater Inflows
  - Freshwater Inflows (mainstem above Trenton and 31 major tributaries)
  - Point Source Discharges (71)
  - Major Withdraws (8)
- Tidal Forcing:
- *Water Surface Elevation (Astronomical/harmonic tide, Subtidal fluctuation)*
  - Open boundary extended into Atlantic Ocean
  - West End of the C&D Canal
- Initial Ambient Conditions *(water temperature, salinity)*
- Meteorological Forcing *(air temp, air pressure, wind, evap, precip, solar radiation)*

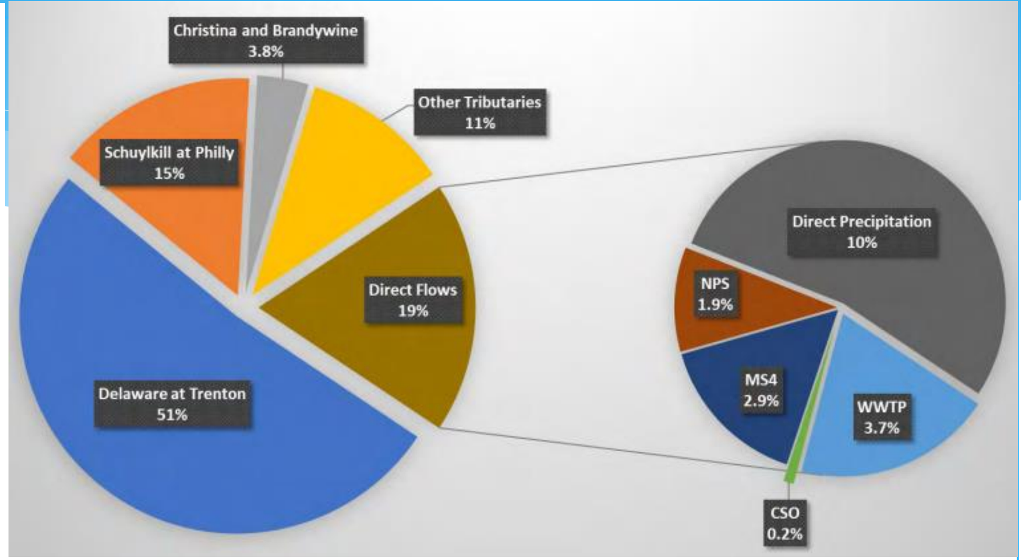


NOAA NCDC Weather Stations

Freshwater Inflow Boundary Conditions

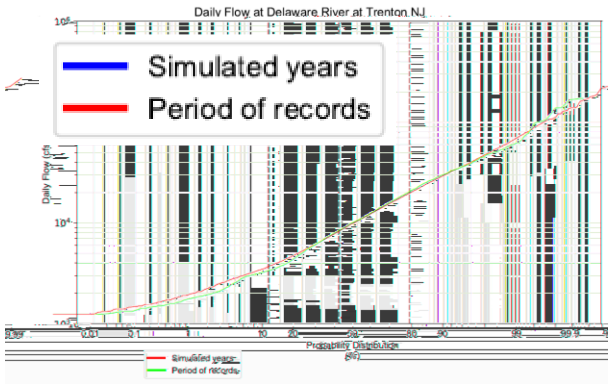


100-yr flow ranking (1921-2020) by annual median flow (left)
Blue coded ones are the years that simulated by the 3D model.



2018-2019 flow budget

Right-→ Cumulative Frequency Distribution (CFD) of Daily Flow at Trenton , POR vs simulated years

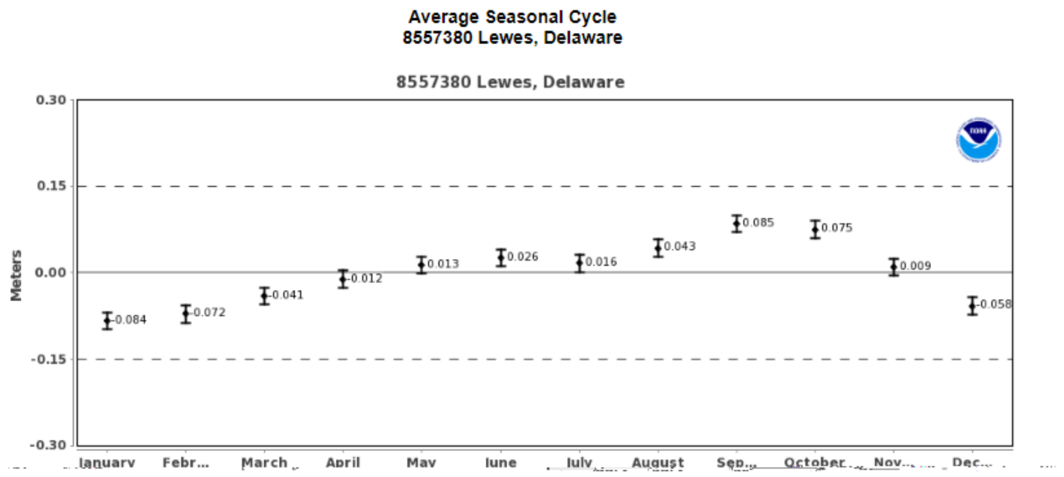


Water Surface Boundary

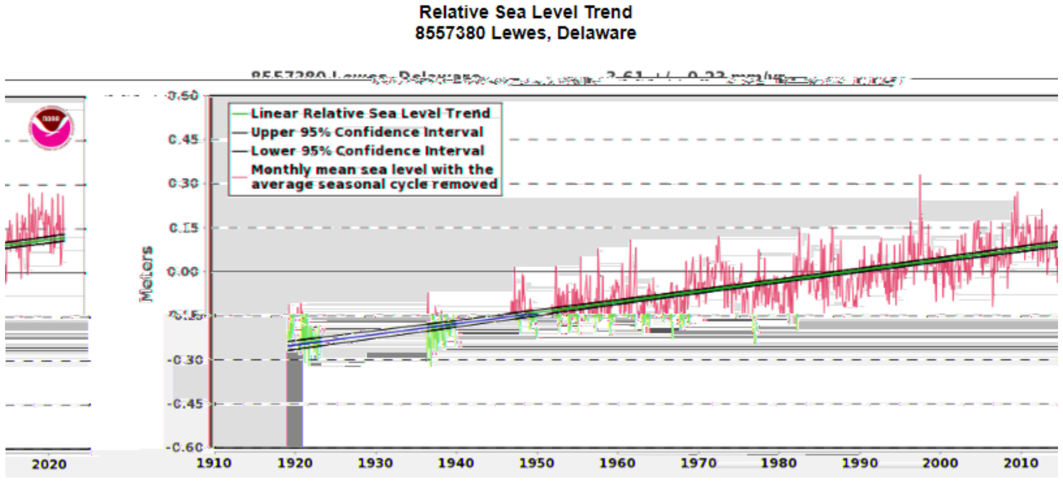
Water surface elevation boundary:
summation of ***tidal*** and ***non-tidal*** parts

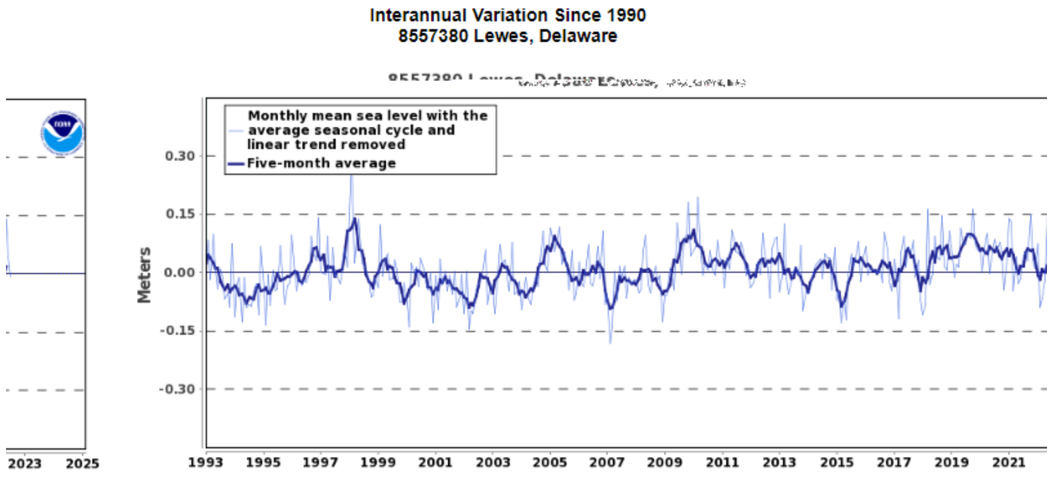
$$\eta_{total} = \eta_T + \eta_{NT} = \eta_T + \eta_C + \eta_S$$

$$WSE_{ob}(t) = \sum_{n=1}^{k} \left(A_n(t) F_n(t_0) \cos \frac{2\pi}{T_n}(t - t_0) + V_n(t) - \emptyset_n \right)$$



Average Seasonal Cycle

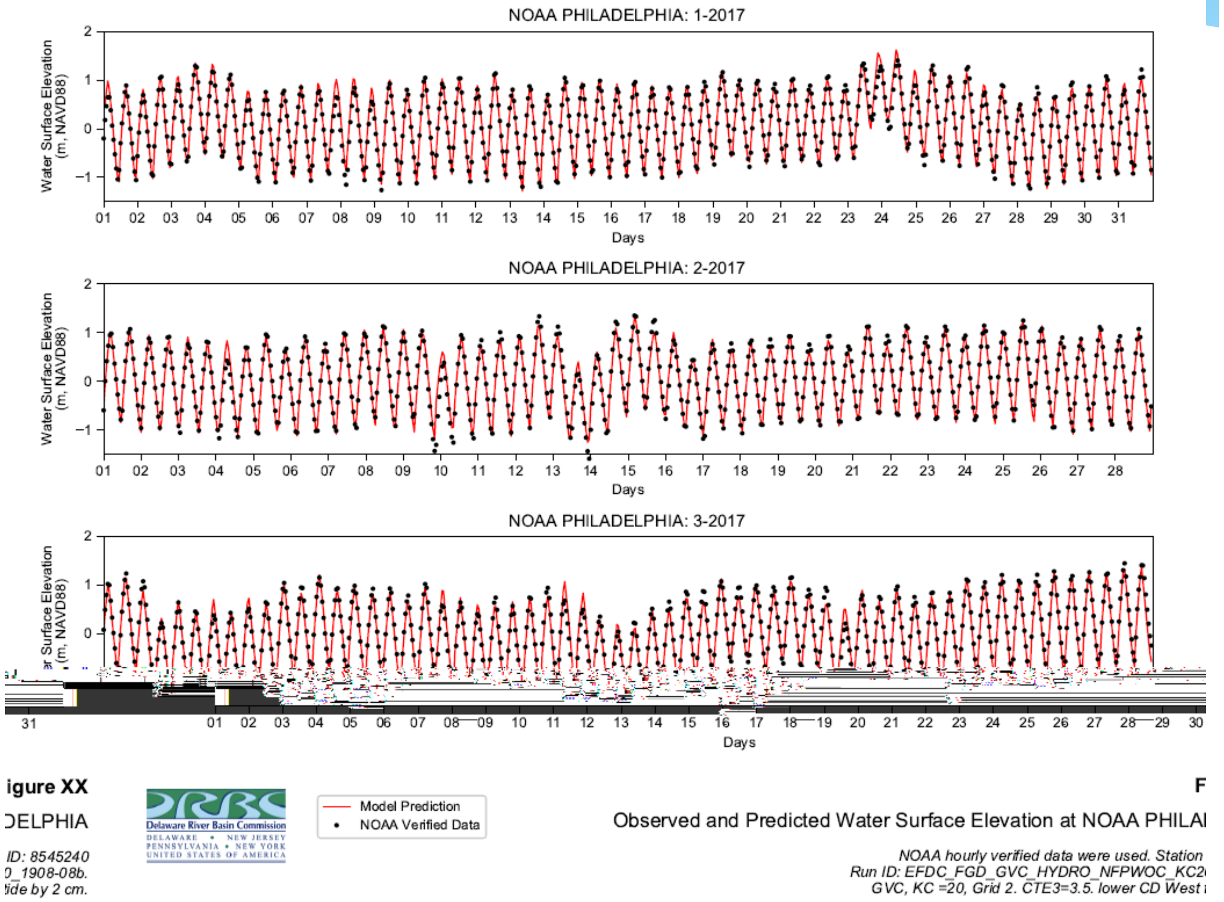


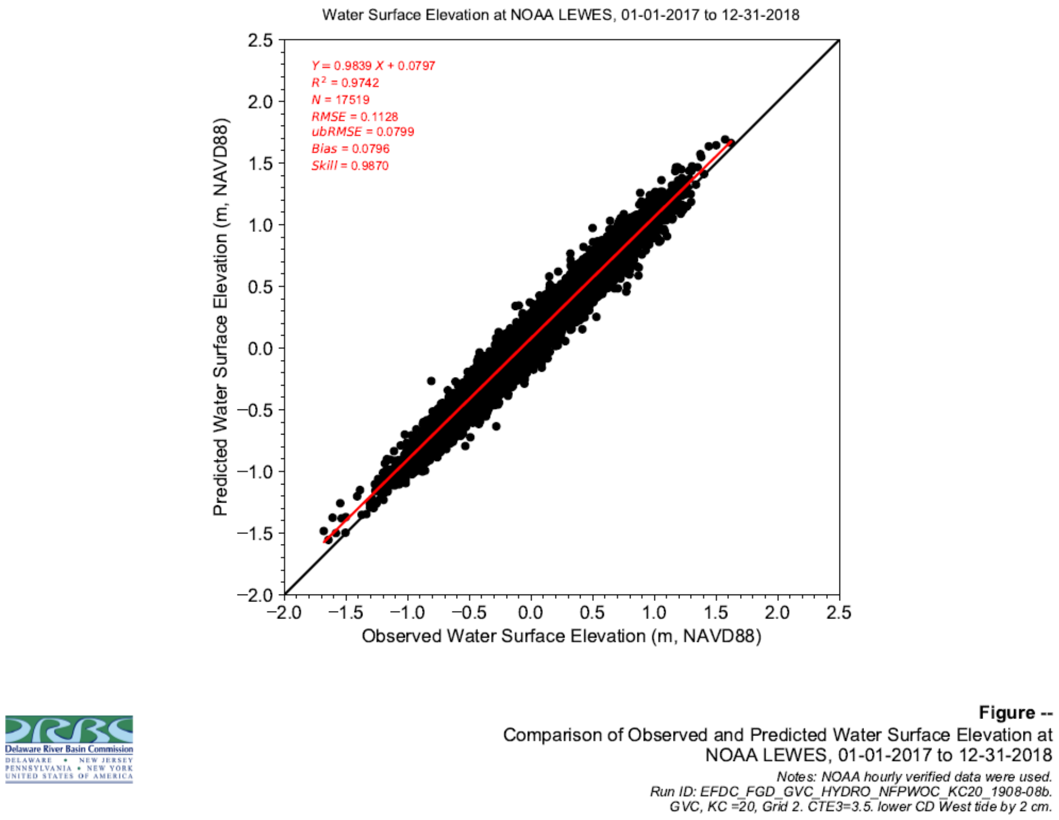


monthly mean sea levels (top) and Interannual variation since 1990 (bottom), source: NOAA

Calibration Results: Water Surface Elevation

Philadelphia





Calibration Results: Depth-Averaged Current Velocity

Station C5, near Ship John Shoal

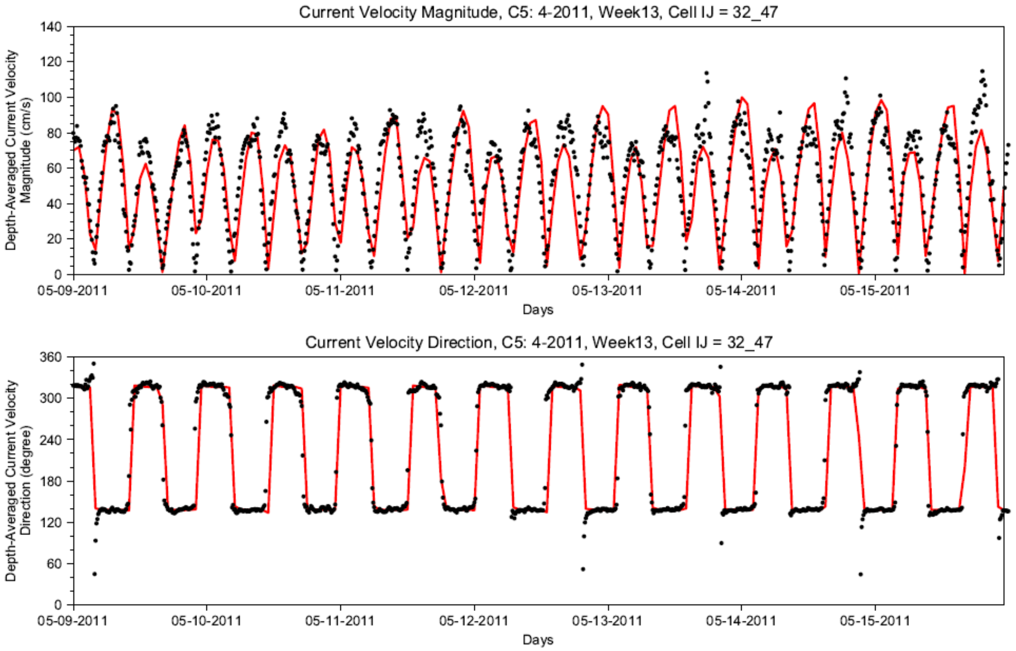


Figure XX

Observed and Predicted Depth-Averaged Current Velocity at C5

Notes: Station ID: C5, C5
Run ID: EFDC_FGD_GVC_HYDRO_NFPWOC_KC20_1909-02, GVC, KC =20, Grid 2. CTE3=3.5. WOA monthly mean ocean salinity. lower CD West tide by 2 cm.

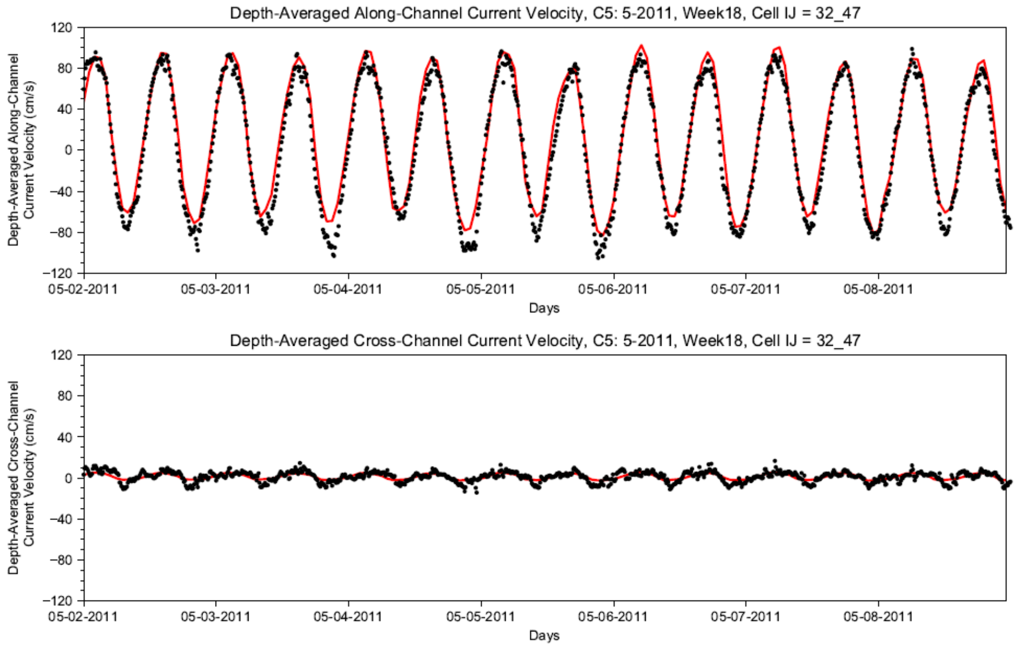


Figure XX

Observed and Predicted Depth-Averaged Along and Cross-Channel Current Velocity at C5

Notes: Station ID: C5, C5
Run ID: EFDC_FGD_GVC_HYDRO_NFPWOC_KC20_1909-02, GVC, KC =20, Grid 2. CTE3=3.5. WOA monthly mean ocean salinity. lower CD West tide by 2 cm.

(ADCP data, April -June 2011)

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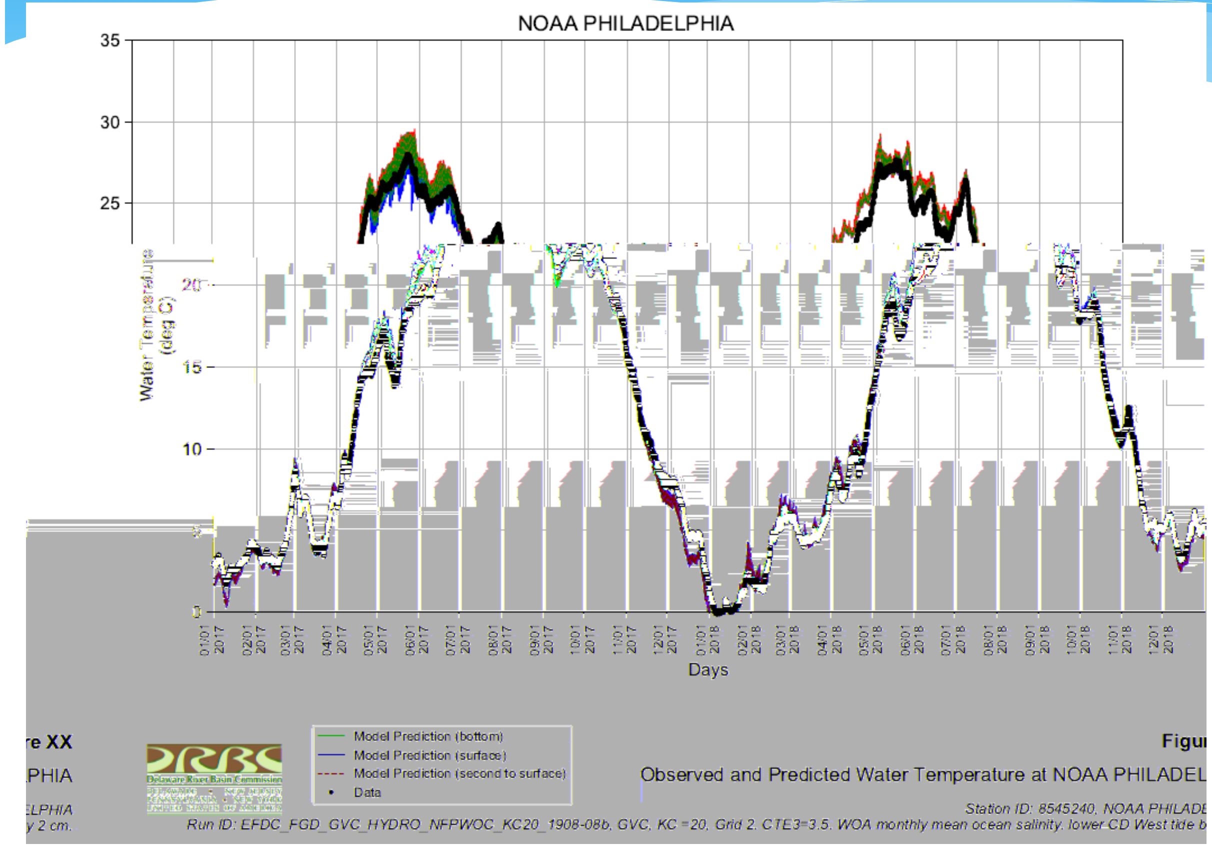
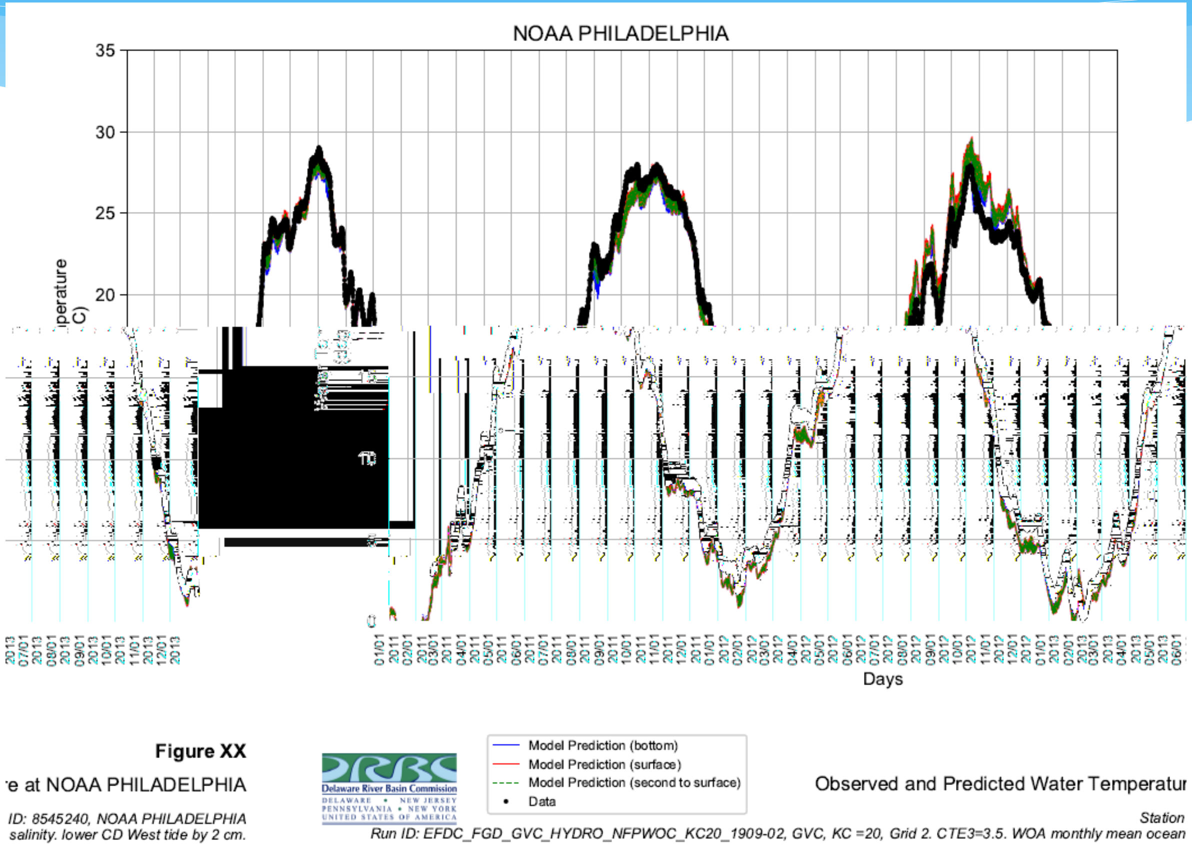
Calibration Results: Water Temperature



2017-2018



2011-2013

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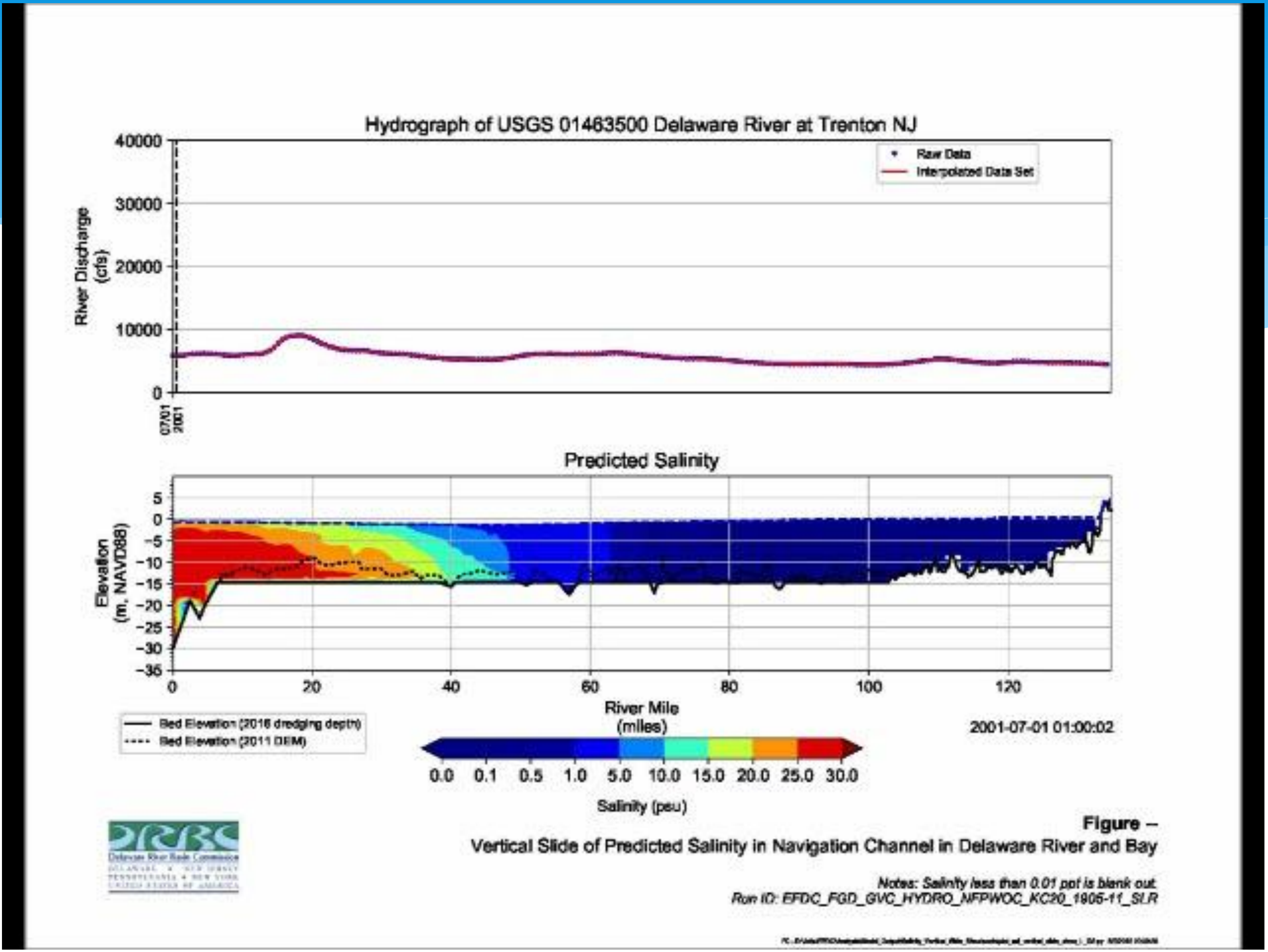
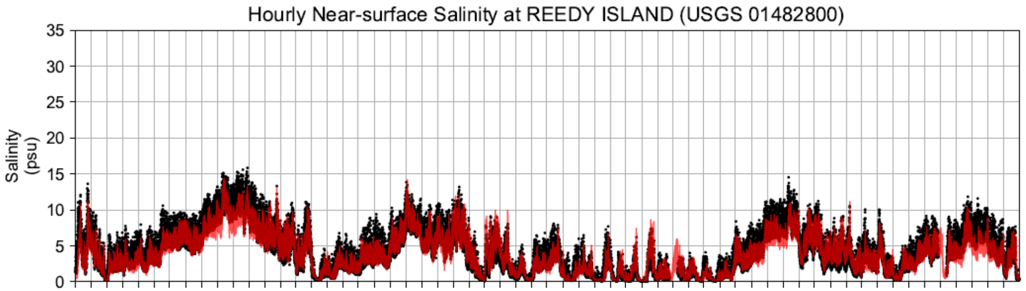
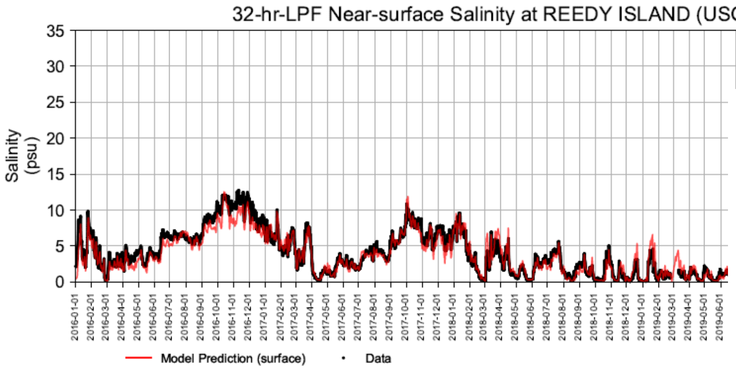
Simulated Salinity Transport and Vertical Stratification

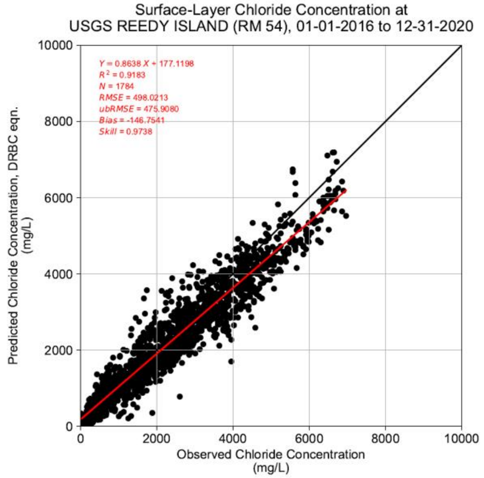


Calibration Results: Salinity (2016-2020)

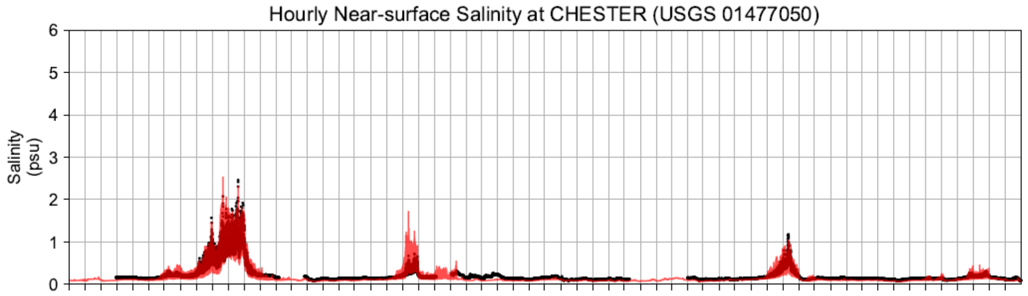
Reedy Island

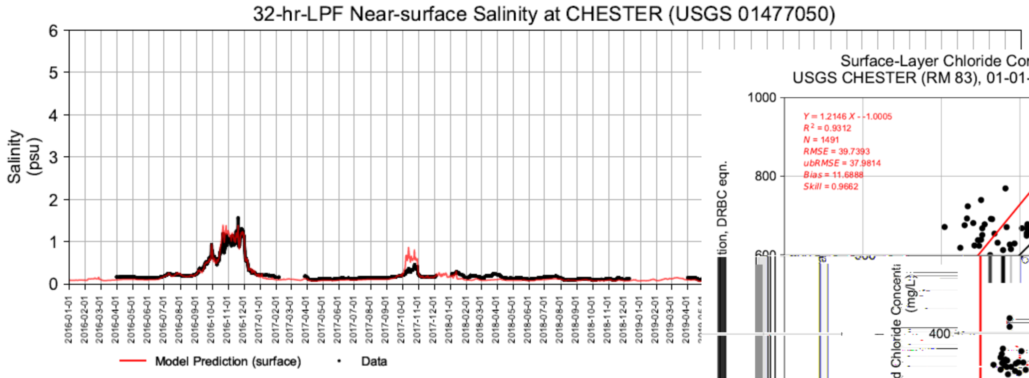


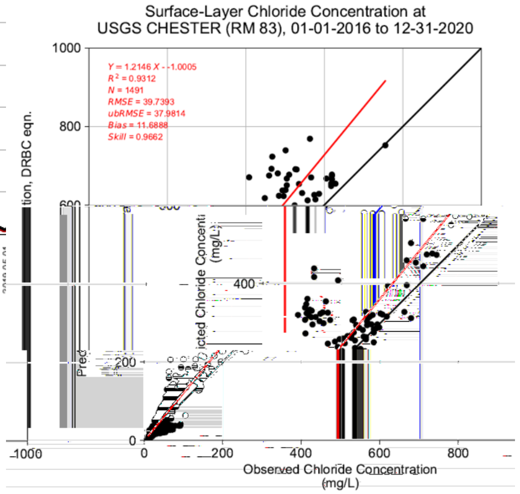




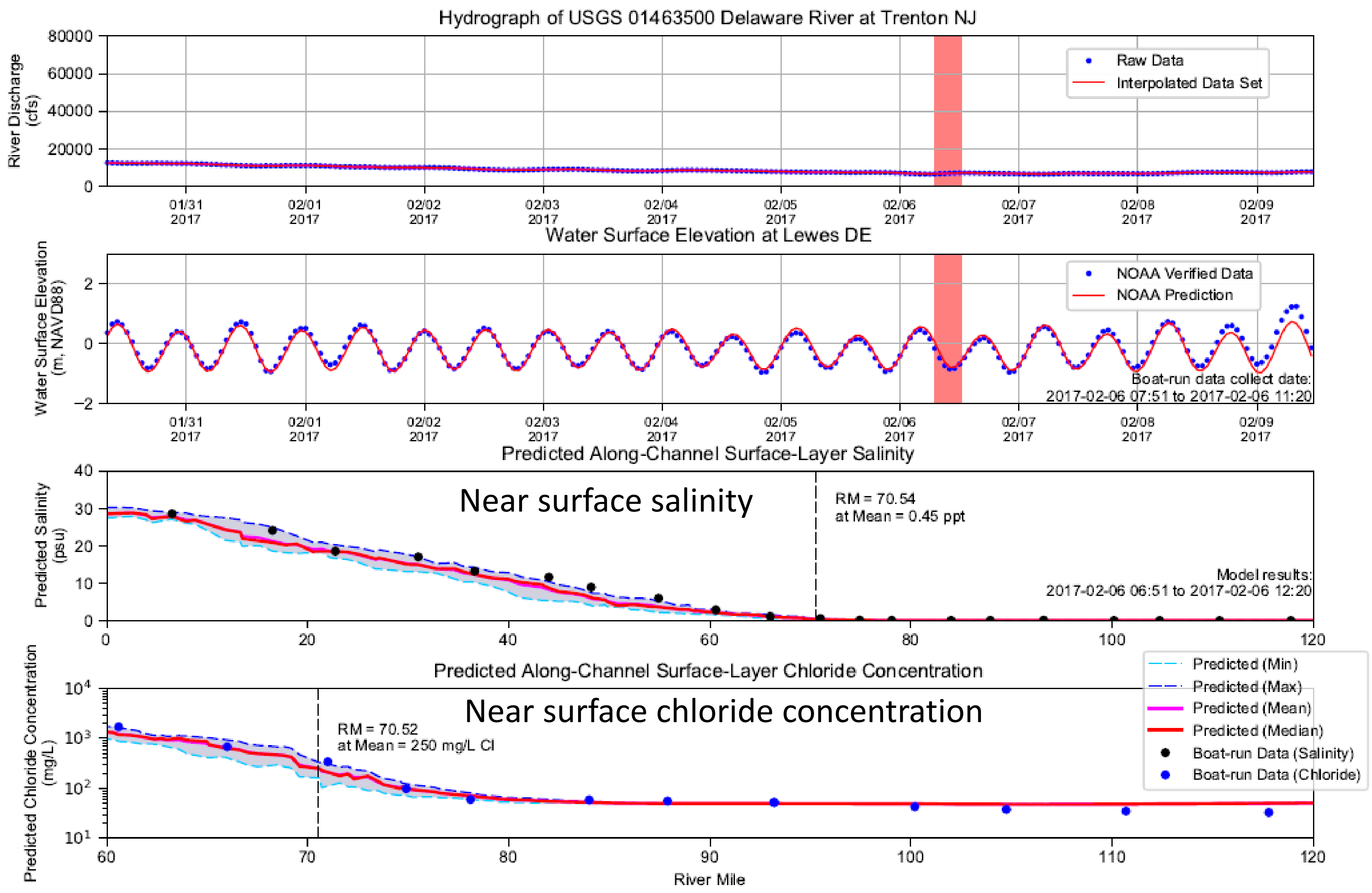
Chester







Calibration Results: Spatial Distribution of Near Surface Salinity



DRBC Boat Run Survey

Data are collected on a monthly basis at 22 locations along the channel over a period spanning 4 to 5 hours.

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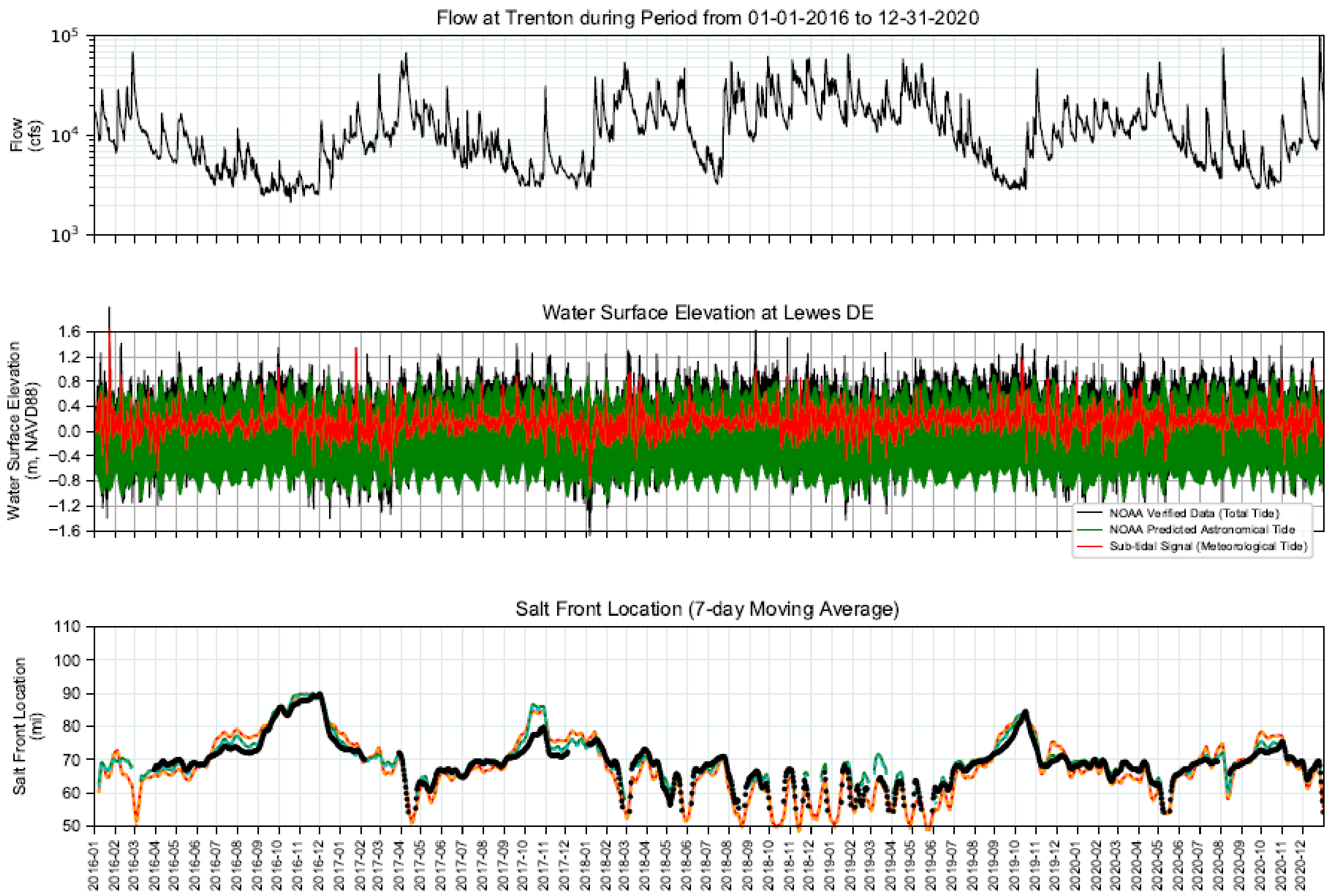
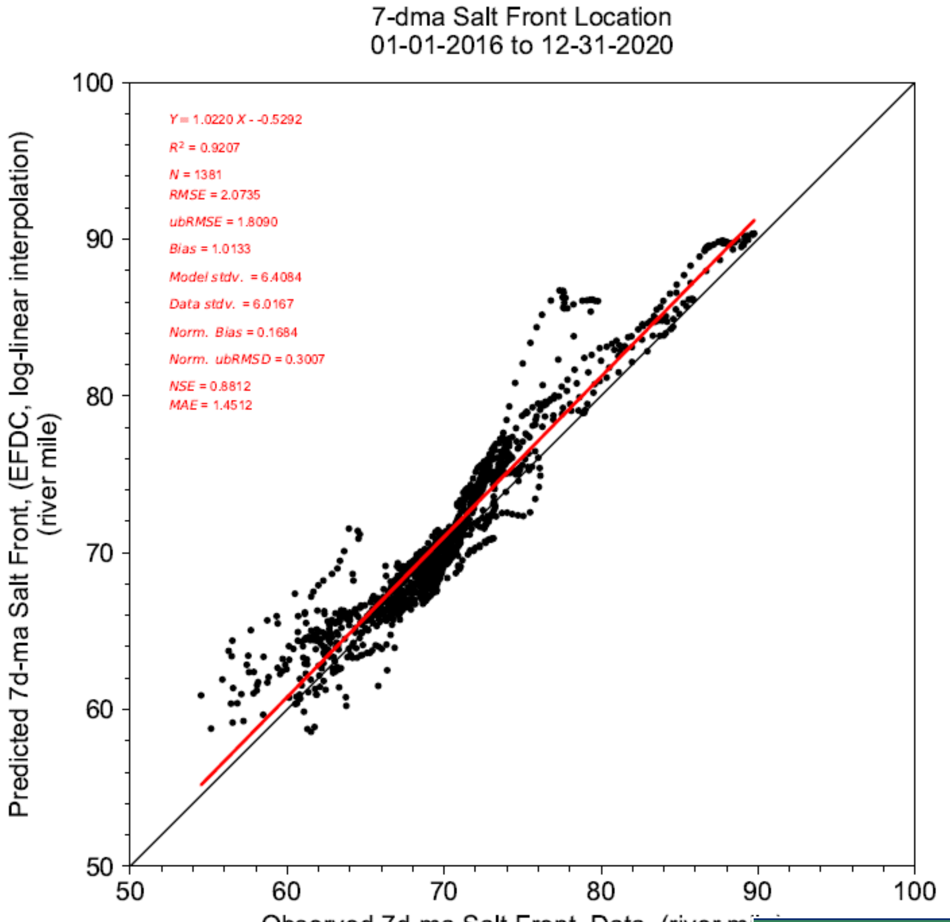
Calibration Results: Predicted Salt Front (2016-2020)





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Future Scenarios: Range of Simulated Sea Level Rise

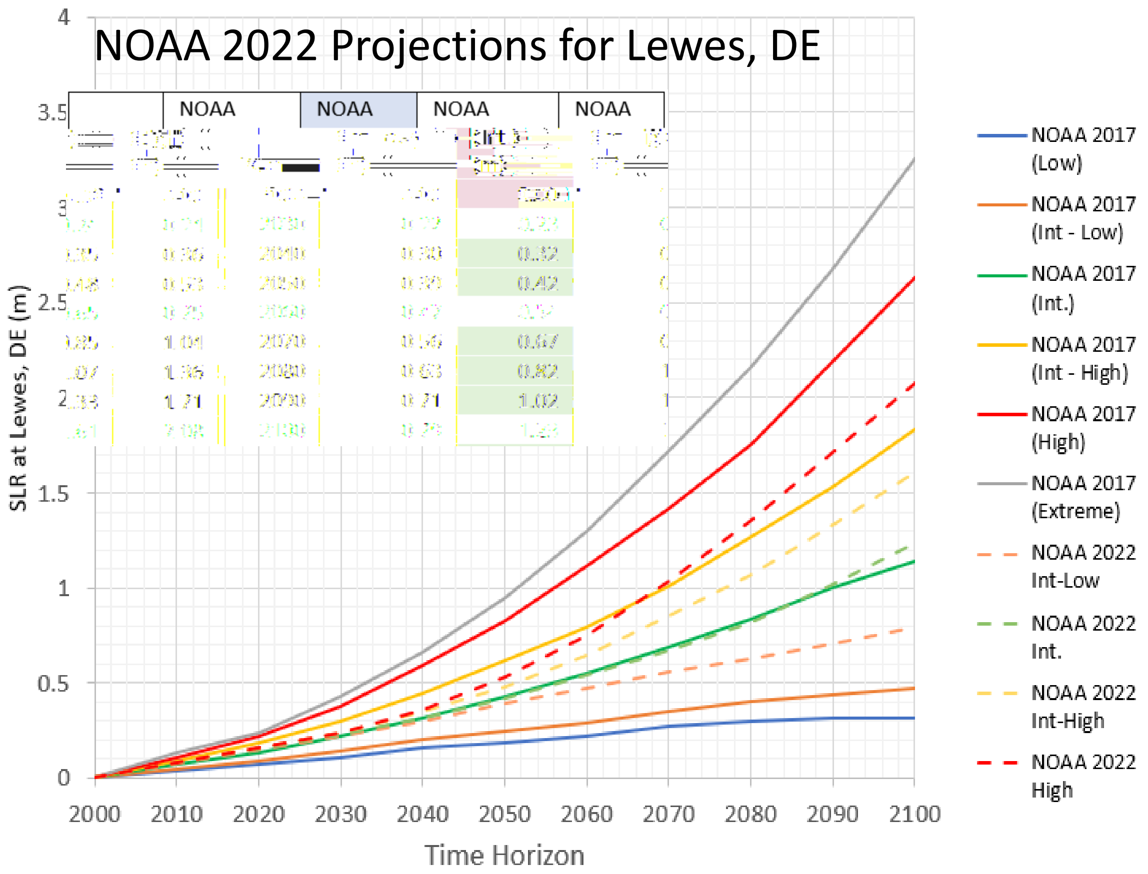
Six SLR values with a wide range of hydrologic conditions (flow) were simulated to represent a range of values for different planning horizons, probabilities, and emission scenarios: 0 m (year 2000 baseline), 0.3, 0.5, 0.8, 1.0, and 1.6 m..

Clarification:
We acknowledge that the climate science is improving, and SLR projection and associated likelihood is changing. Hence, this **Salinity Model aimed to provide information** for planners, such as the extent of saltwater intrusion under certain SLR conditions, **rather than recommend specific SLR projection or selection of a risk level** for specific industry. (Figure (right) Compares NOAA 2017 vs 2022 projections).

Although the likelihood of certain SLR may change, the information from the model won't change. This information could be served as additional metrics in the process of climate change resilience and adaptation planning.

This modeling study **focused on salinity intrusion** to provide information for flow management and planning of other water users.

Relative Sea Level Rise (SLR) Projections at NOAA Station 8557380, Lewes, DE



Future Scenarios: Assumptions and Uncertainties

Assumptions

* Historical flows (e.g., only evaluating SLR), including rivers, tributaries, point sources
* Subtidal signal remains similar
* Navigation channel is maintained
* Bathymetry remains similar
* SLR projections for Lewes applied at ocean boundary and C&D Canal

Sensitivity Simulations

* Marsh area and inundation
* Increased river flows
* Channel bathymetry
* Shoreline migration/retreat
* Ocean surface temperature
* Ocean salinity boundary

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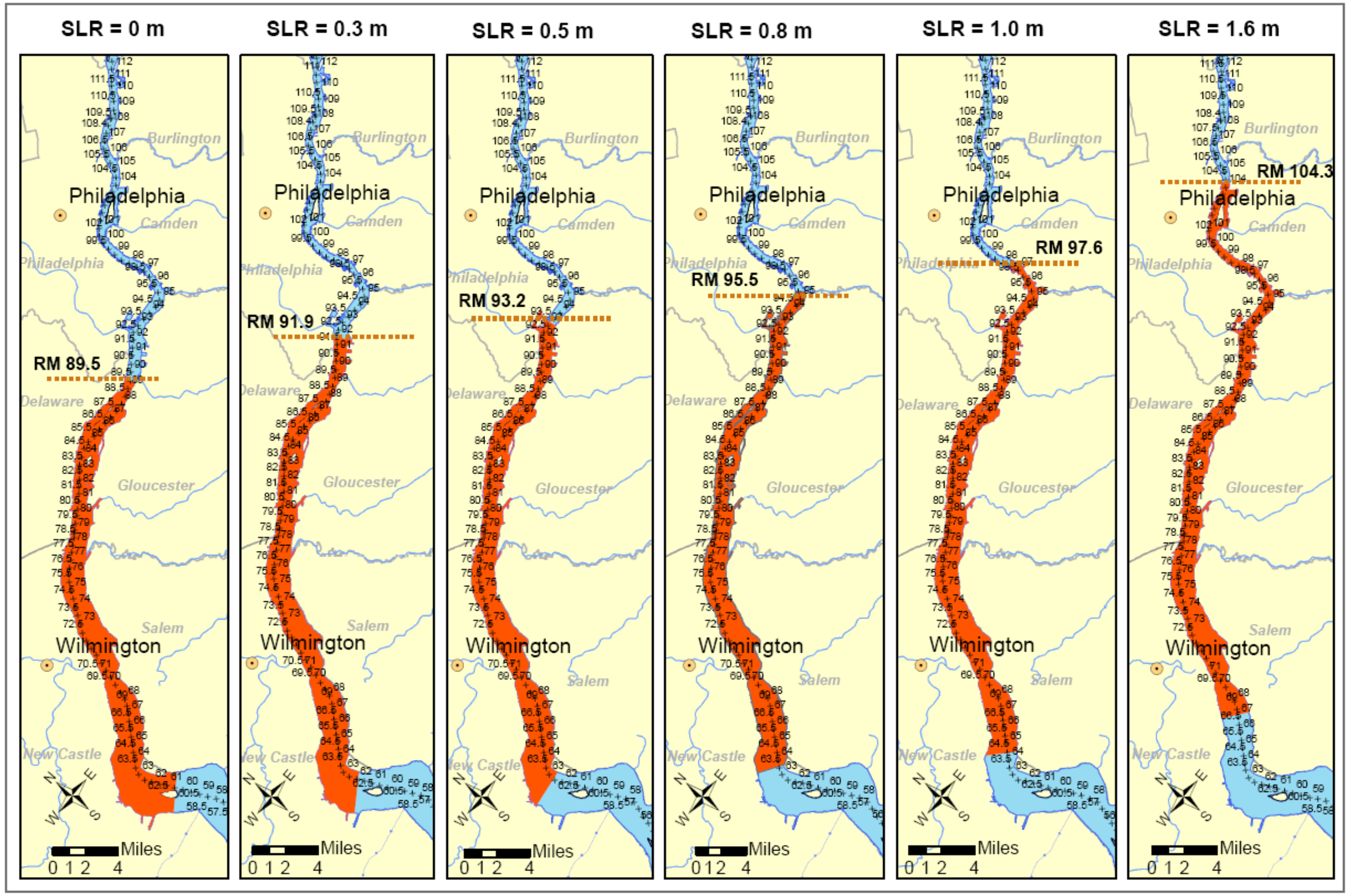
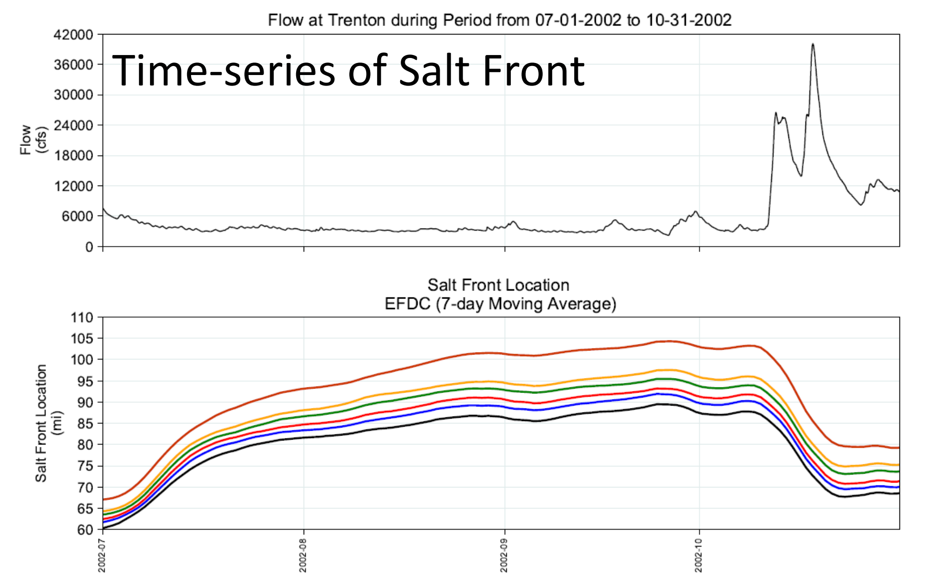
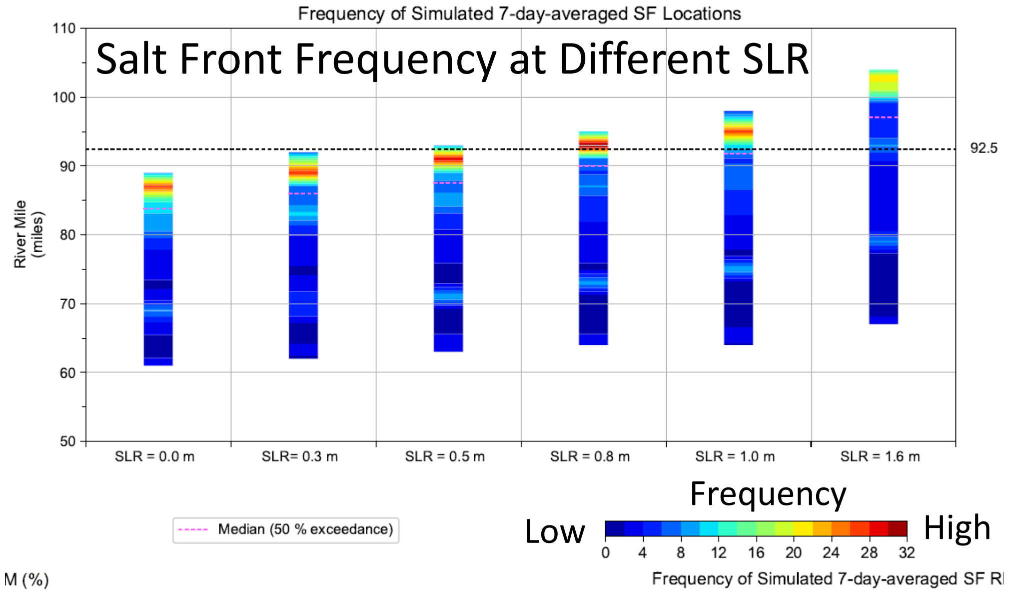
Results: Salt Front Location with SLR and Low Flows

(Simulated using flow from July-October 2002)

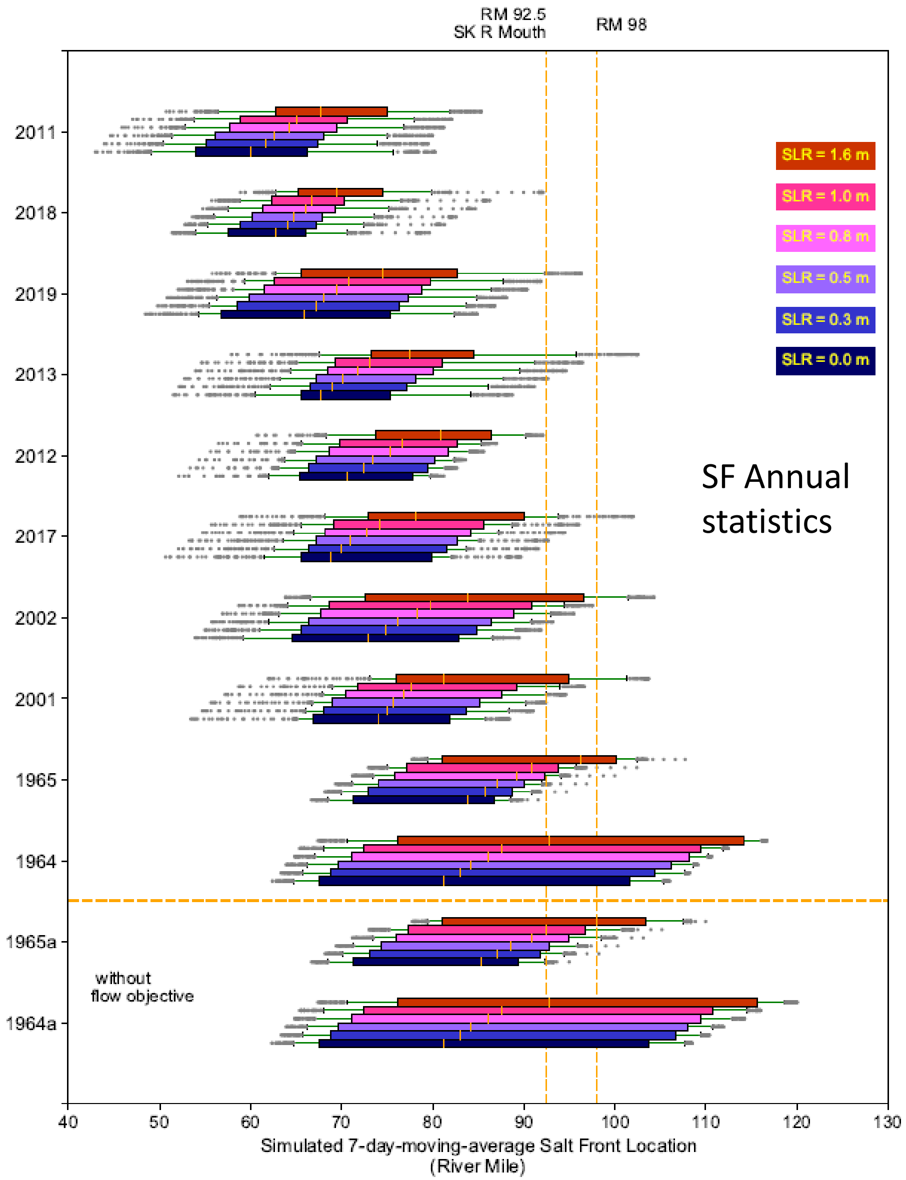
Maximum Extent of Salinity Intrusion

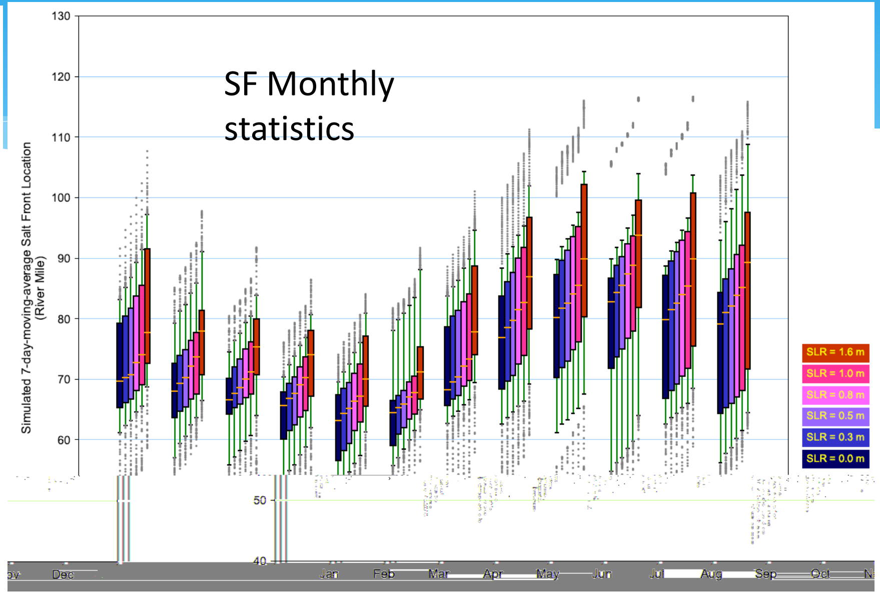




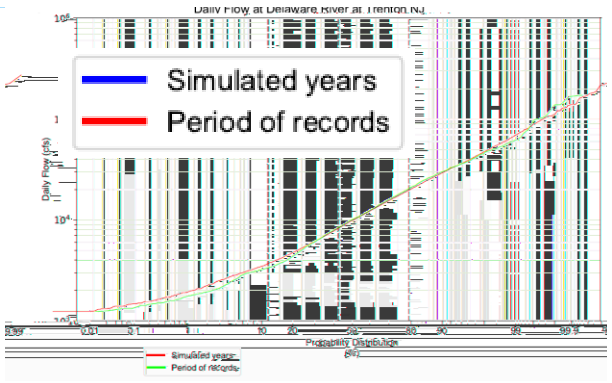


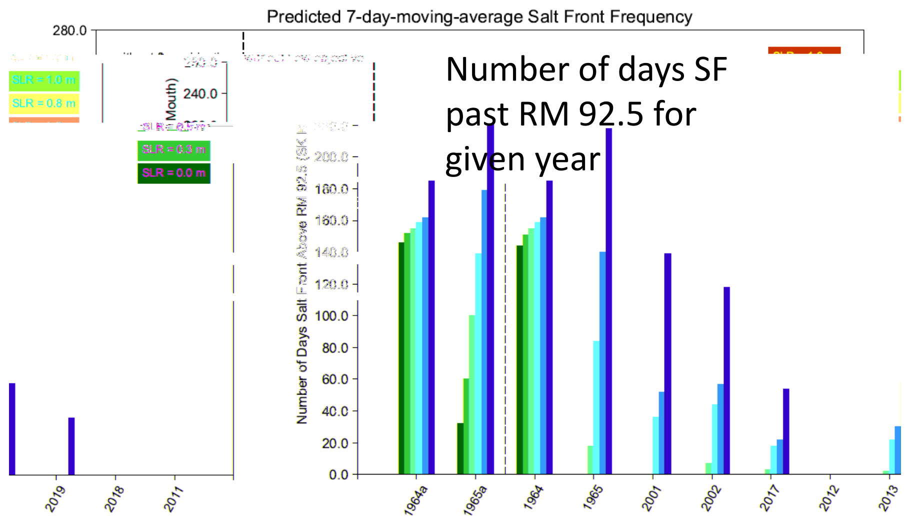
Results: Salt Front Location with SLR and Different Flow Regimes



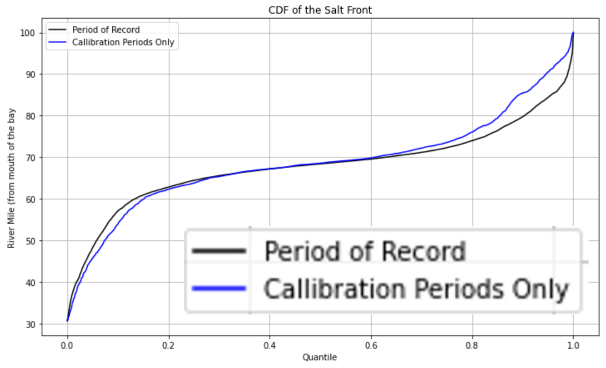


Cumulative Frequency Distribution (CFD) of Daily Flow at Trenton POR vs simulated years



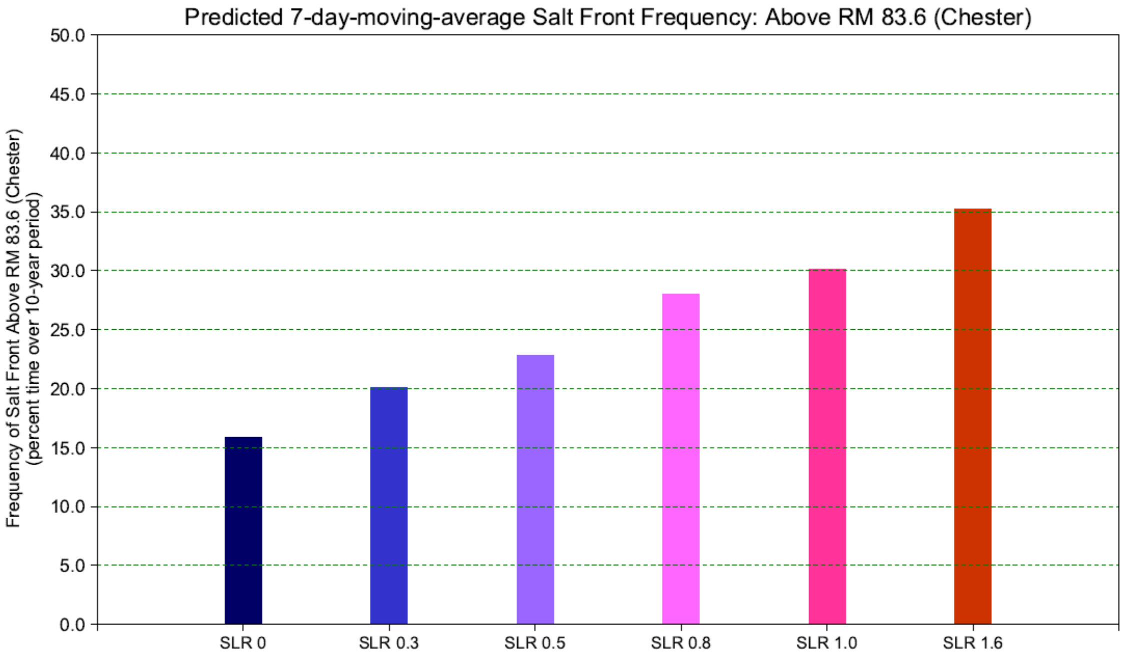


Cumulative Frequency Distribution (CFD) of SF, POR vs simulated years

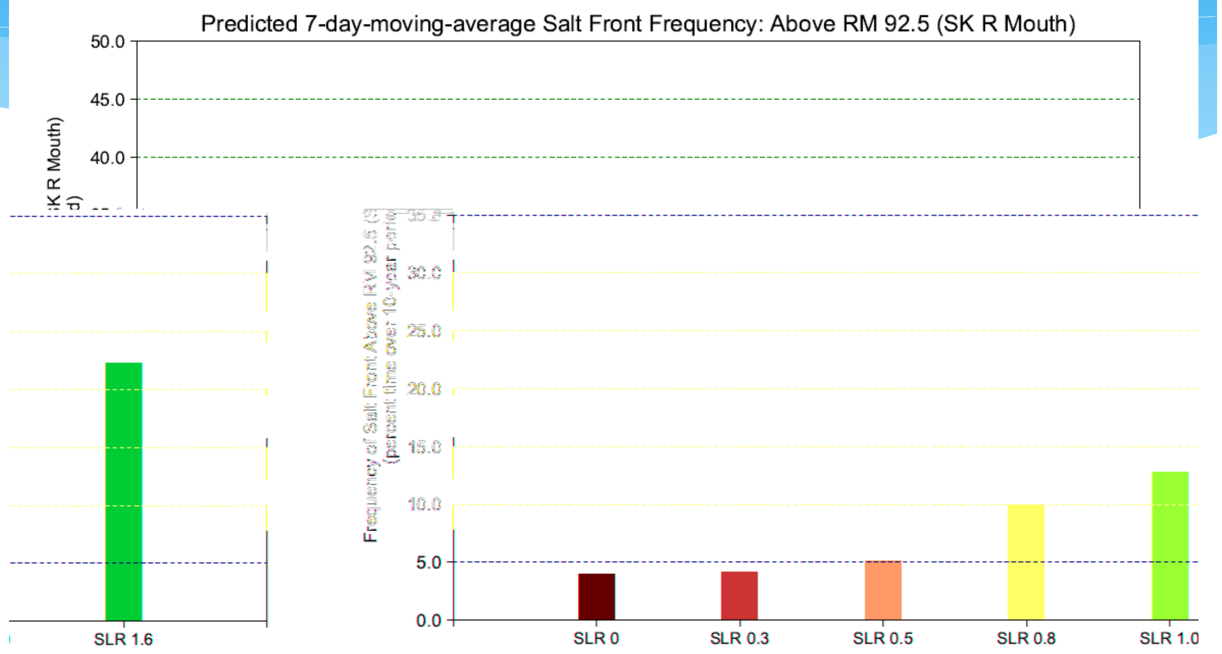


Results: Salt Front Location with SLR and Different Flow Regimes

(continued)



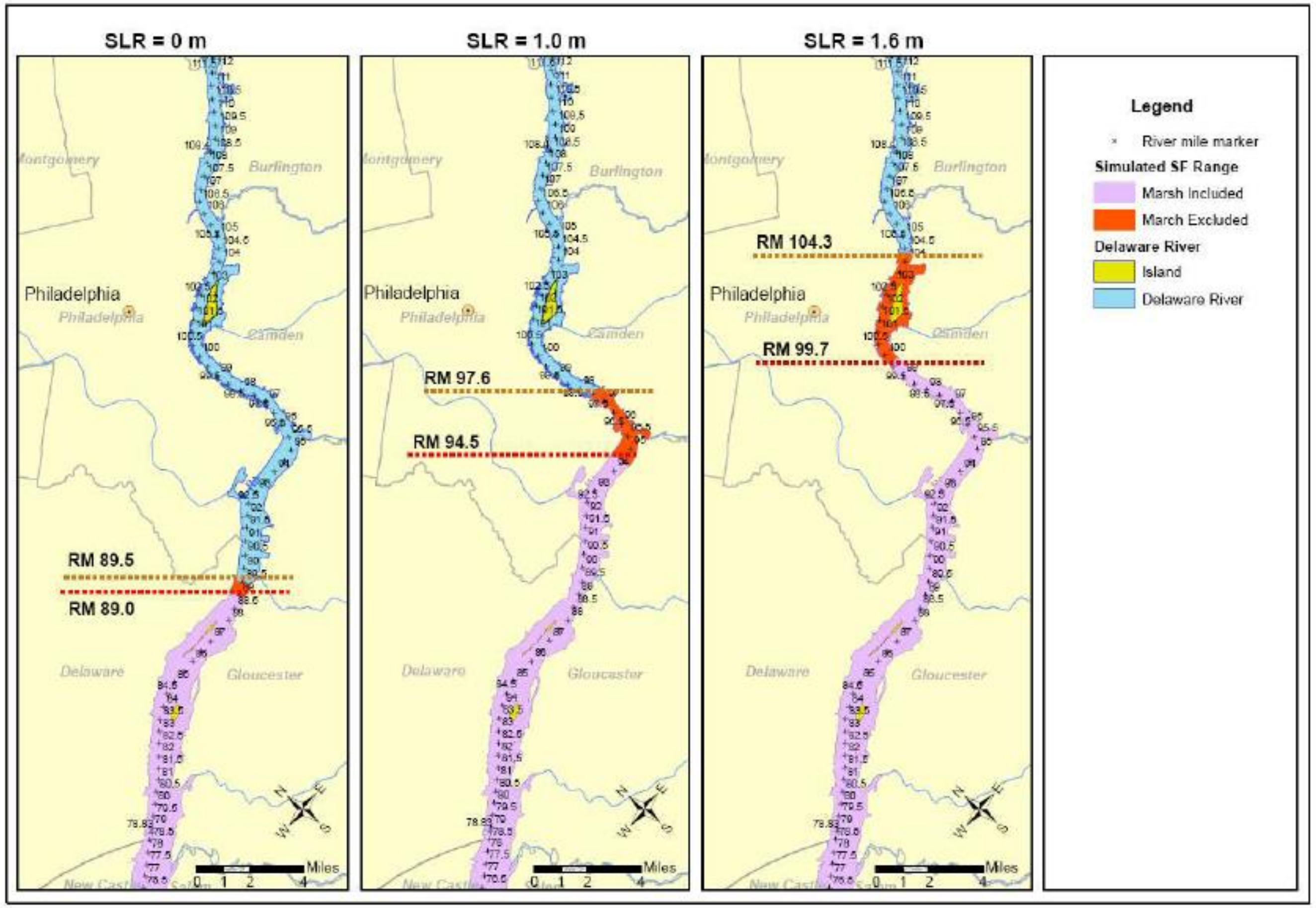
Frequency of Simulated 7-dma Salt Front Location above Chester (RM 83.6) Based on Ensembled 10-year Hydrological Conditions, and Set Trenton flow objective of 2500 cfs was applied for 1964-1965

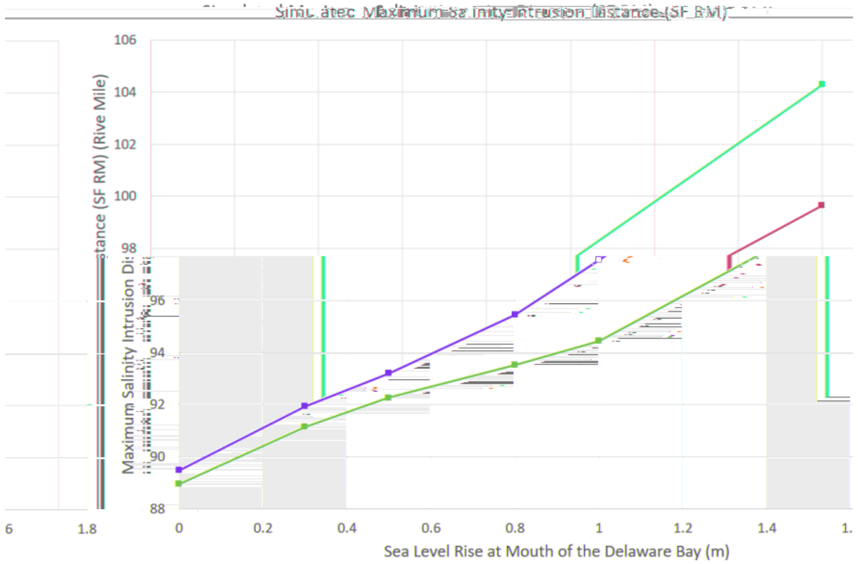


Frequency of Simulated 7-dma Salt Front Location above the Schuylkill River (RM 92.5) Based on Ensembled 10-year Hydrological Conditions, and Set Trenton flow objective of 2500 cfs was applied for 1964-1965

The frequency of the salt front above the Chester, PA (RM 83) or the mouth of the Schuylkill River (RM 92.5) increases with SLR. Major drinking water intakes are located at RM110.

Results: Sensitivity of Salinity Intrusion to Marsh Area Inundation





SLR (m)	Min	Max	Average
0	60.53 / 60.75	89.47 / 88.95	80.69 / 80.44
0.3	61.89 / 62.12	91.92 / 91.13	82.78 / 82.32
0.5	62.60 / 62.74	93.19 / 92.26	84.18 / 83.45
0.8	63.62 / 63.39	95.45 / 93.52	86.32 / 84.81
1	64.39 / 63.84	97.56 / 94.45	87.83 / 85.68
1.6	67.14 / 66.09	104.3 / 99.65	93.4 / 89.20

Range of Salt Front for Different SLR under 2002 Low-Flow Conditions (from July through October 2002), marsh excluded vs. marsh included.

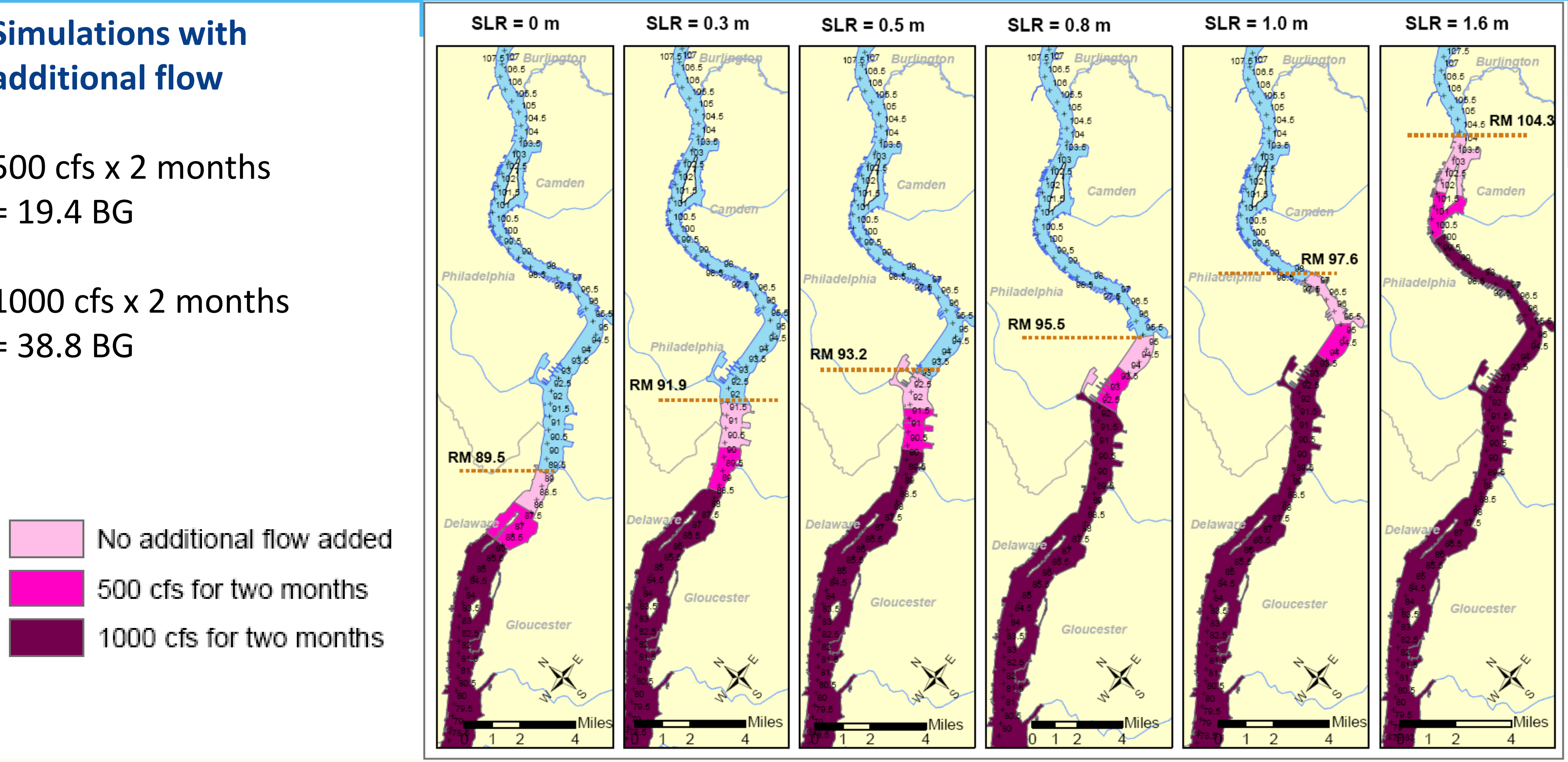
The amount of marsh area/inundation affects the extent of salinity intrusion (esp. for higher SLR)

Results: Sensitivity of Salinity Intrusion to River Flow
(reservoir releases)

Simulations with additional flow

500 cfs x 2 months
= 19.4 BG

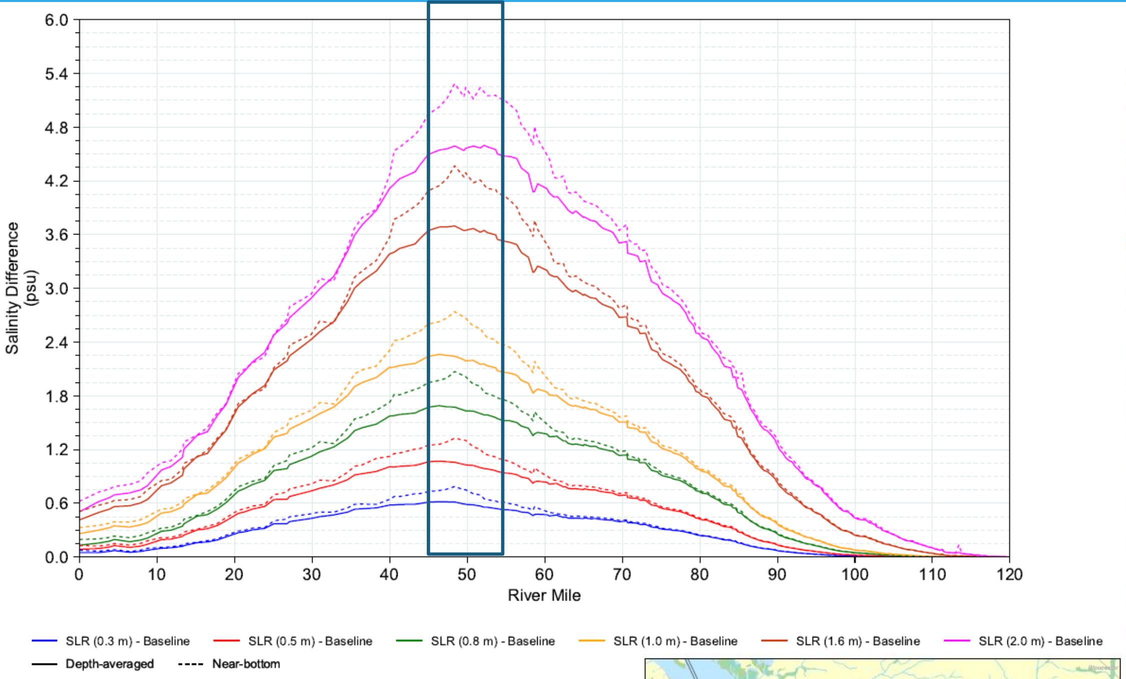
1000 cfs x 2 months
= 38.8 BG



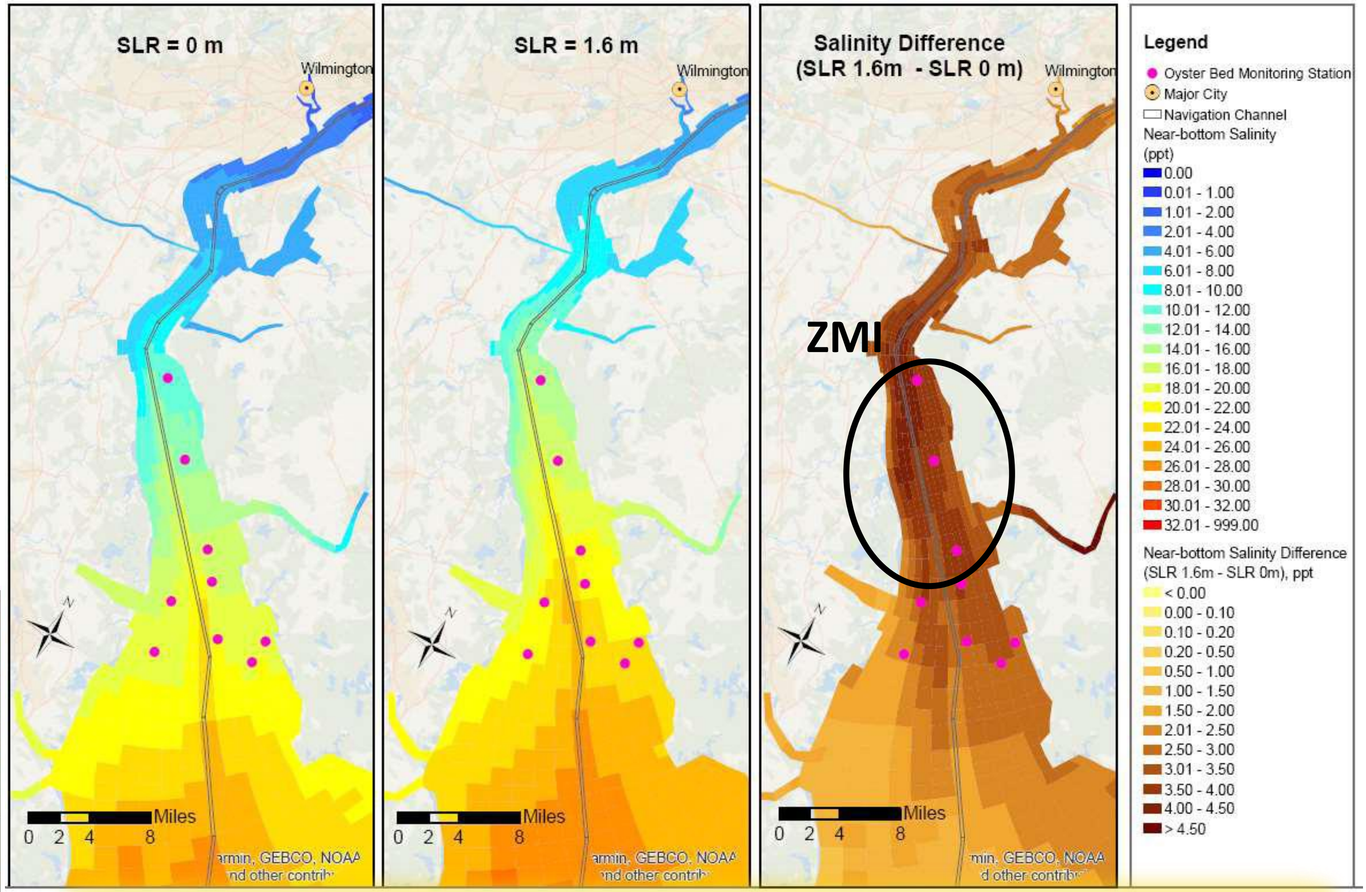
Reservoir Storage
(for reference):
Beltzville – 13 BG
Blue Marsh – 6.5 BG
FE Walter (rec) – 11 BG
Neversink – 34 BG

Additional flow (i.e., from reservoir releases) may not be effective for salinity repulsion: too much water may be required.

Results: Potential Impact on the Ecosystem in the Delaware Bay

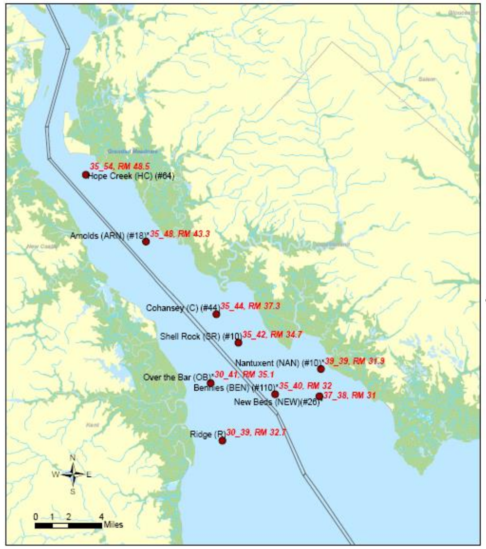


Near-bed salinity (0 m - baseline, 1.6m, and difference)



Zone of
maximum impact (ZMI)
(RM 45 to 55), this is 8 mil
upstream of Ship John Shoal
To Reedy Island

Simulation w/o inundation
of marshes



SLR may adversely impact ecosystems in the Delaware Bay. For example, oyster drills (predators) are more prevalent at higher salinities.

Summary

* A three-dimensional hydrodynamic salinity model was developed to evaluate the impacts of sea level rise on salinity.
* The model was reviewed by experts and is an appropriate tool for its intended purpose.
* Simulations were performed to test the importance of the various assumptions needed to evaluate SLR (including river inflows, inclusion of marsh area, etc.)
* The extent of salinity intrusion is not proportional to SLR and also depends on flows.
* The model is intended to be refined as additional data become available (e.g., new data are being collected through various studies and monitoring programs).

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Next Steps

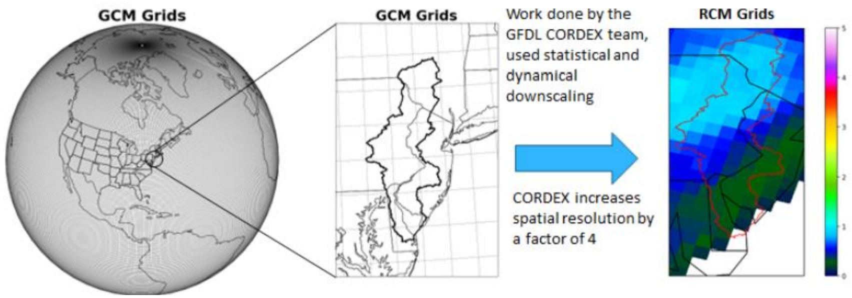
* Salinity Model:
  * Release calibration and initial application report – this Fall 2022
  * Continue model refinement (new gages, C&D Canal flows, boundary conditions, climate change scenarios – flow, land cover/use, water use projections, etc.)
  * Engage AC3 and stakeholders for consensus on planning assumptions
* Build on analyses:
  * Climate impacted flows – report due Spring 2023*
  * Flow management programs (Flexible Flow Management Program, default, proposals, additional storage – e.g., FE Walter)

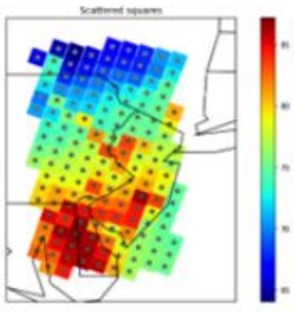
Climate Change – Coming Attractions

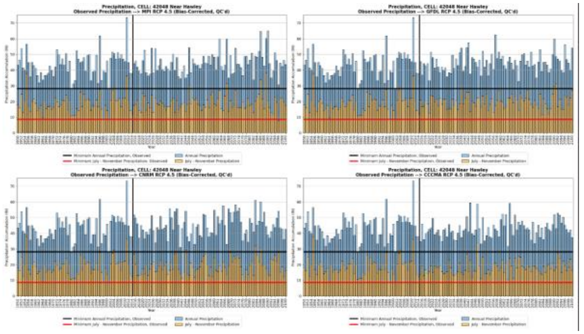
Do we have enough water? + Can we manage what we have for the multiple uses of the water resources of the DRB?

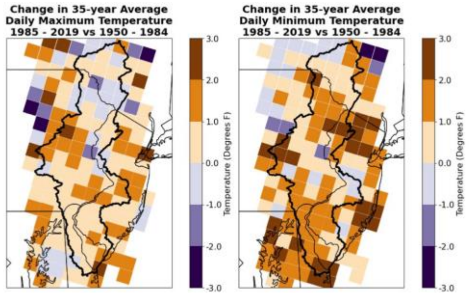
DRBC Climate Change Study and Tools:

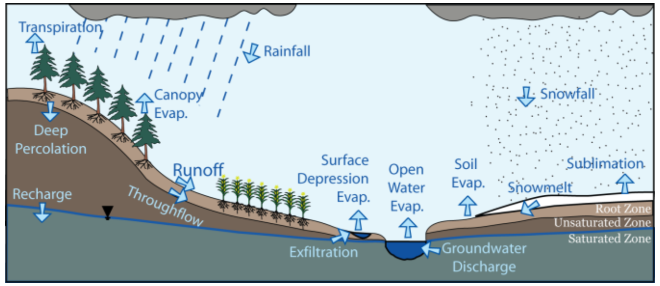
GCMs (4) => RCMs (Cordex) => RCPs (2: 4.5,8.5) => Temperature and Precipitation => Hydrologic Models (2: USGS-WATER; HEC-HMS) => inflows => DRB-PST + Salinity Model

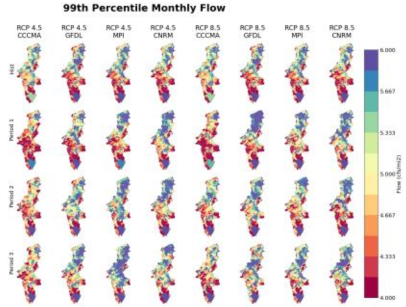


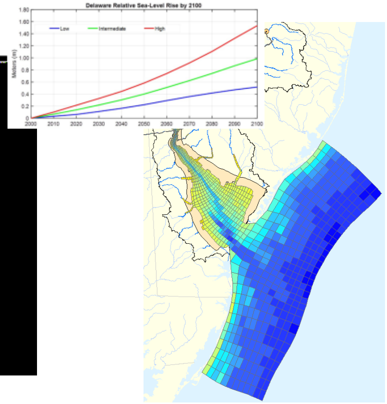


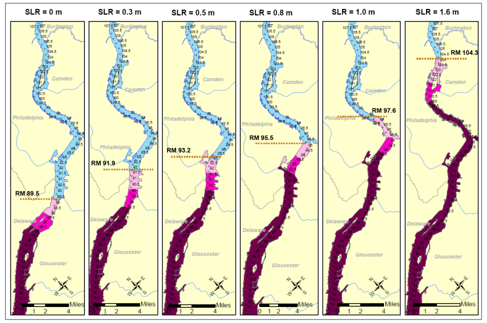












Questions and Discussion

Photo: DRBC

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