PWD Water Supply Planning: PWD Salinity Model and Validation

Regulated Flow Advisory Committee May 14, 2020

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PWD Salinity Model and Validation

1. Utility and Planning Overview
2. Model Development
3. Model Validation

Philadelphia Water Department

Drinking Water

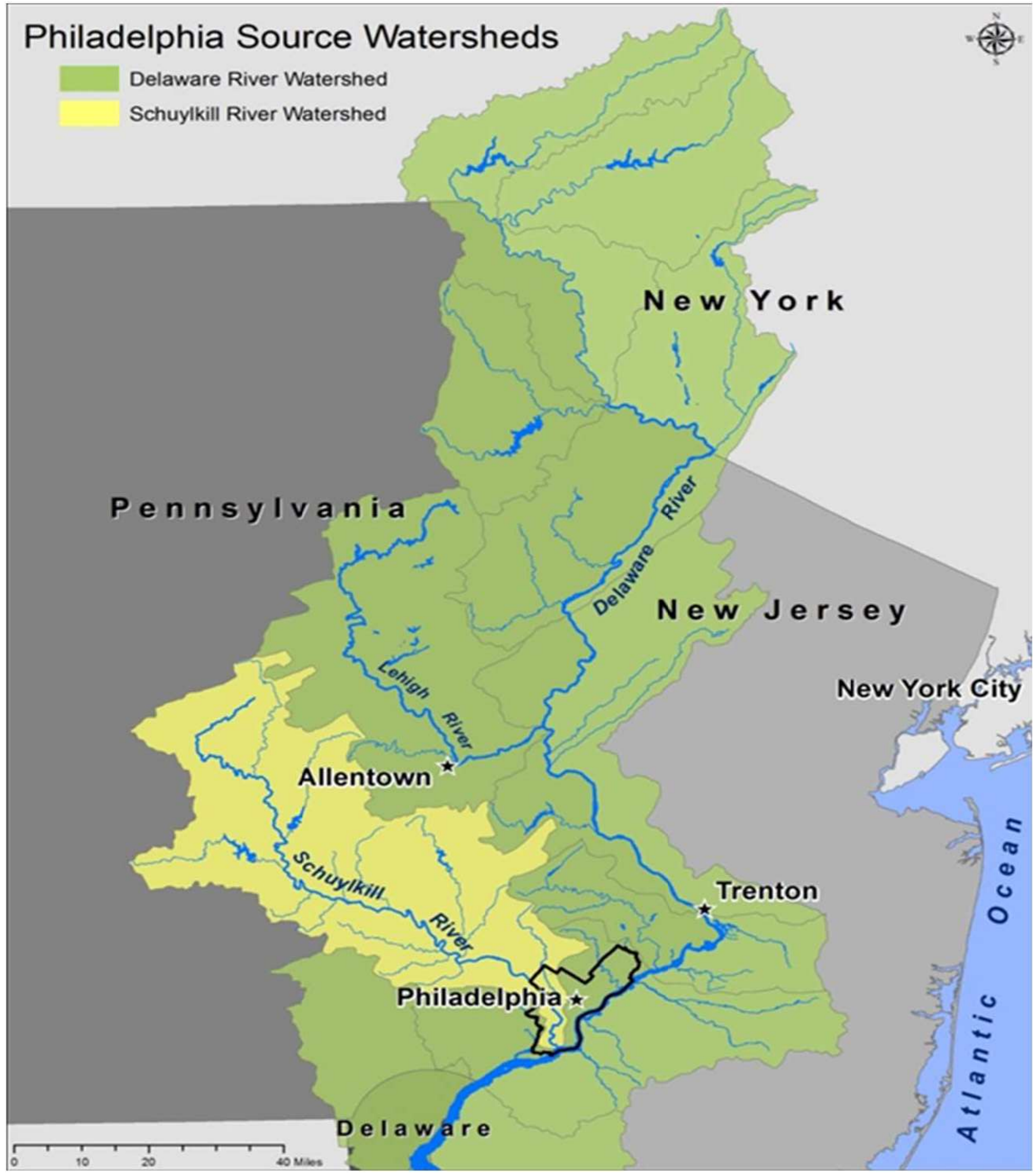
- 1.7 million drinking water customers
- 3 Water Treatment Plants

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

Critical Planning Baseline Observations

1. **Ambient chloride concentrations today are equivalent to the worst salinity intrusion of record in the 1960s**

2. **Current flow targets in the FFMP are critical to manage intrusion of ocean salt**

3. **Any attempt to alter current flow targets needs a carefully crafted assessment of intrusion impacts on public health and infrastructure**

Critical Influences on Salinity Intrusion

Streamflow – can cause salinity to rise and fall

Major Storms – can decrease salinity through advective transport

Sea Level – short-term subtidal fluxes cause significant increases or decreases in salt intrusion through advective transport

Estuarine Circulation – increases or decreases salt intrusion absent changes in freshwater inflow or subtidal fluxes. These are three-dimensional hydrodynamic effects, not simple advective transport

Main Takeaways from Observed Data that Inform Model Preparation

1. **A three-dimensional model is needed**
    - It is evident from observed data 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

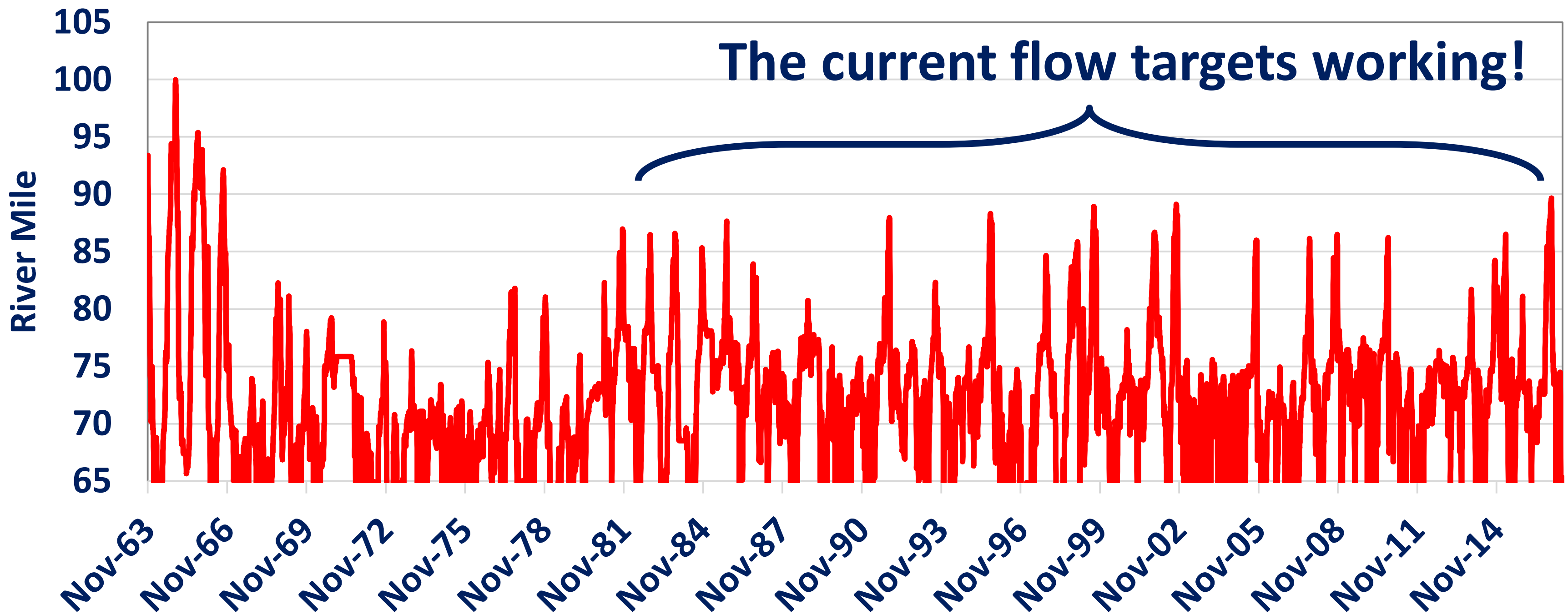
2. **Salinity intrusion events at Reedy Island during recent droughts are comparable to salinity observed in the 1960s drought of record**
    - The FFMP flow targets are not intended to manage salinity as far downstream as Reedy Island, they are designed to manage salinity in the area upstream of Chester

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

Salt Line River Mile, 1963 – 2016, 7-day average 250 mg/L chloride



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What Does Water Supply Planning Entail?

Salinity Modeling

- Informs how changes to flow targets will influence salinity at the PWD drinking water intake

Watershed 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

PWD Modeling Team

PWD Programs

- Water Quality Compliance Modeling Group
- Watershed Protection Program
- Bureau of Laboratory Services
- Hydraulic & Hydrology Modeling Group

Consulting Support

- Woods Hole Group
- CDMSmith Inc.
- SciTek Consultants Inc.
- Tetra Tech
- Sage Services LLC
- Academy of Natural Sciences
- Rutgers University

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

Analysis

- Production runs
- Post-processing

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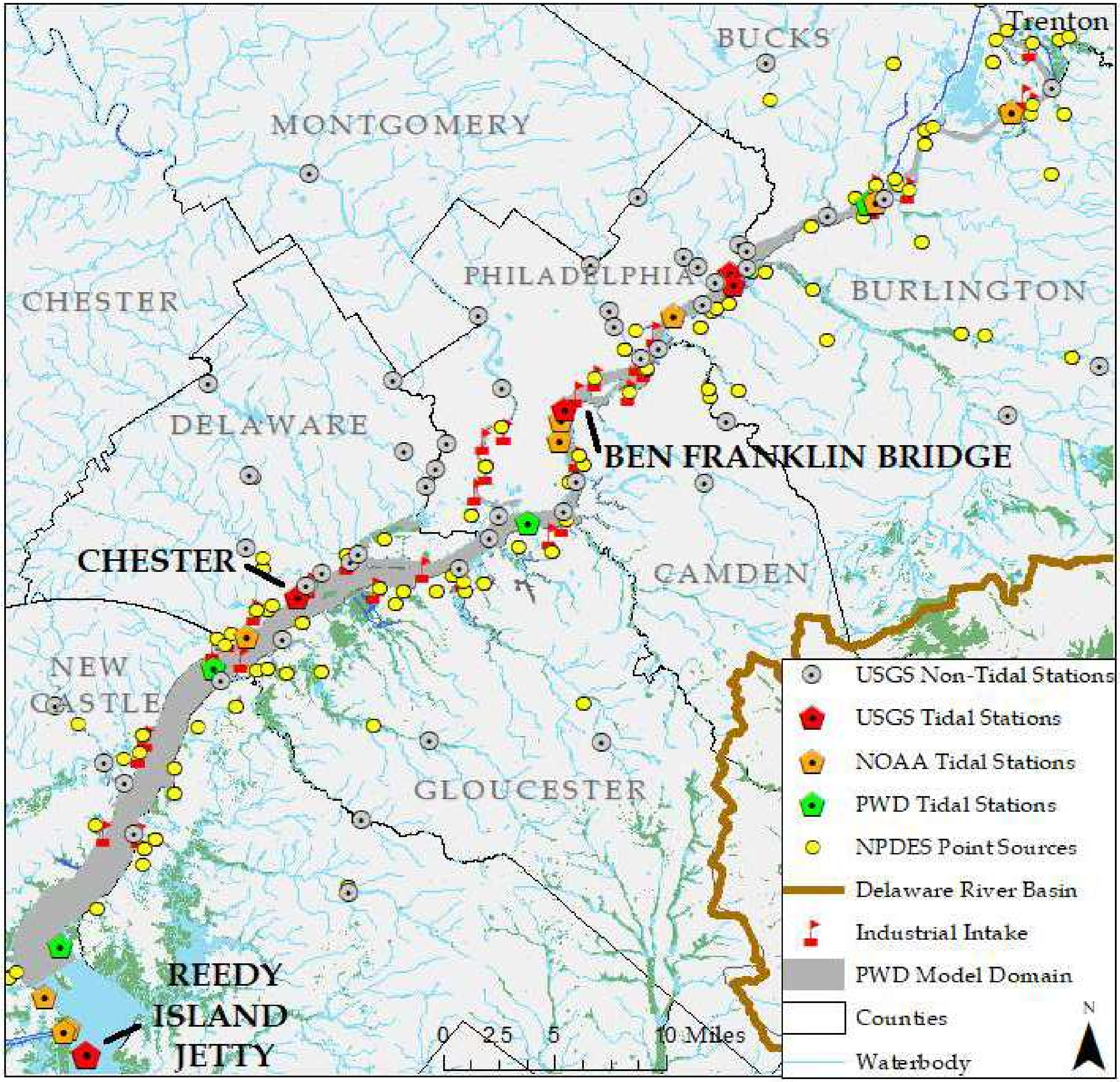
Model Development

- Data Collection
- Boundary Conditions
  - Open Boundary Condition - Salinity
  - Tributaries
  - CSOs
  - Withdrawals and Discharges
- Initial Conditions
- Grid and Bathymetry

Data Collection

- PWD/Woods Hole buoy deployment: velocity, quality
- NOAA: water level, quality, velocity
- USGS: streamflow, water level, quality
- Withdrawals and discharges
- OOW/BLS boat run
- DRBC boat run
- Bathymetry



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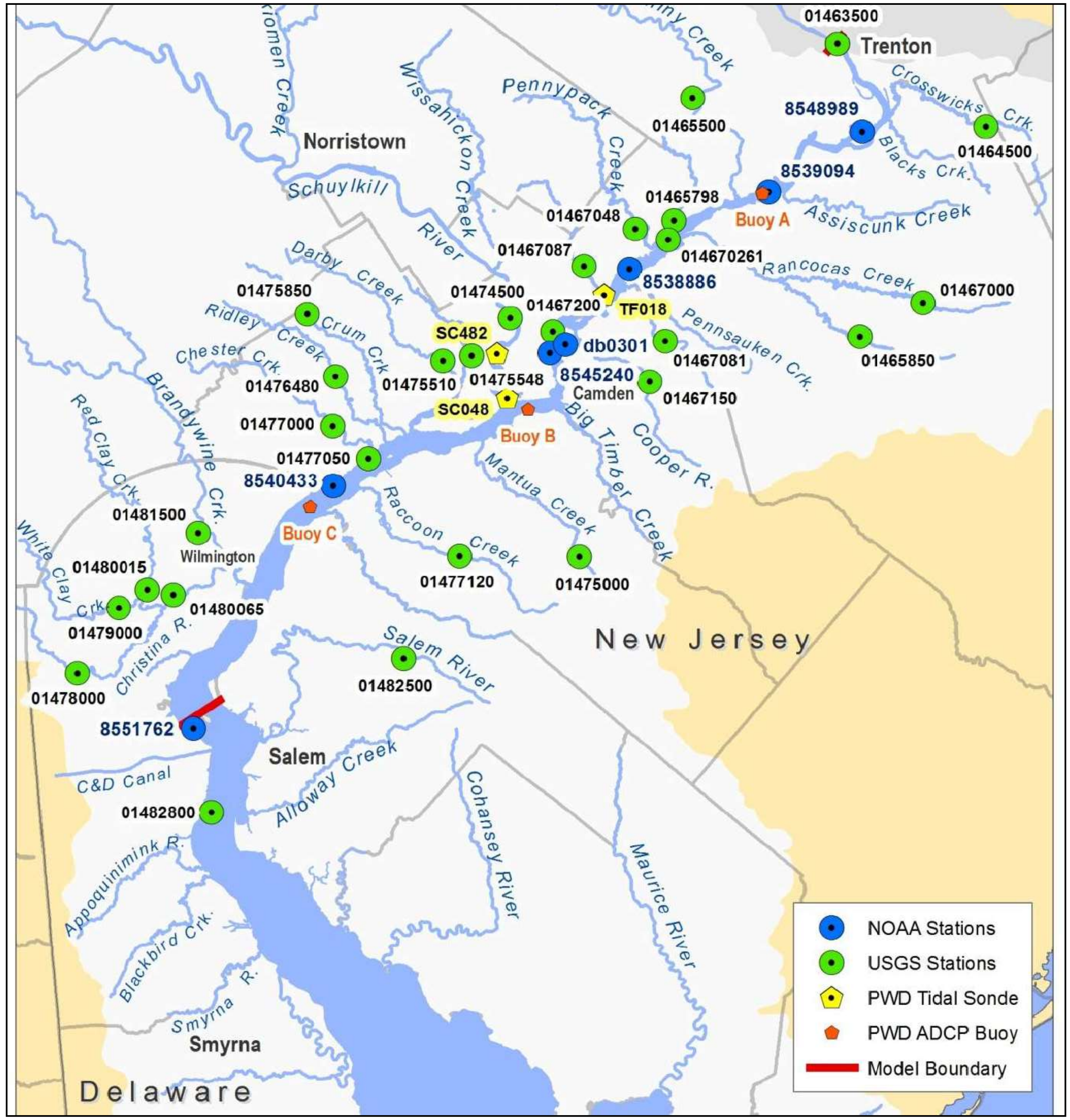
Data Collection

Open Boundary

- Pea Patch Island, continuous salinity
- Delaware City, continuous water level

Tributaries

- Streamflow
  - USGS data
  - Ungauged areas estimated
- Salinity
  - USGS grab samples
  - Reference location approach

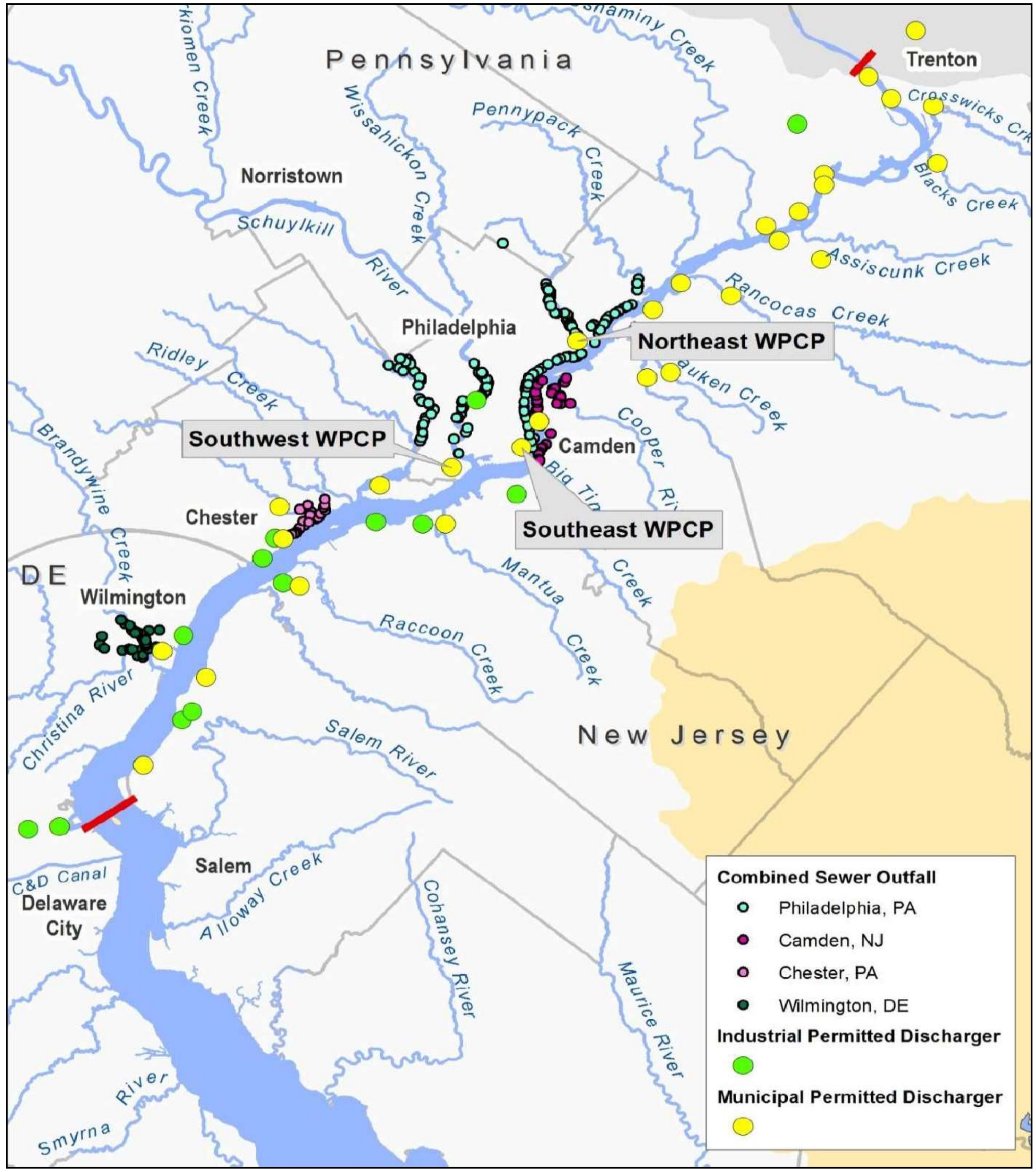


CSOs

- Philadelphia, Camden, Gloucester City, Chester, Wilmington
- Flows estimated and assigned a salinity (0.11 PSU)

Withdrawals and Discharges

- All 2014 permitted facilities, flow and salinity
- State DMRs, DRBC dockets
- Estimates as needed



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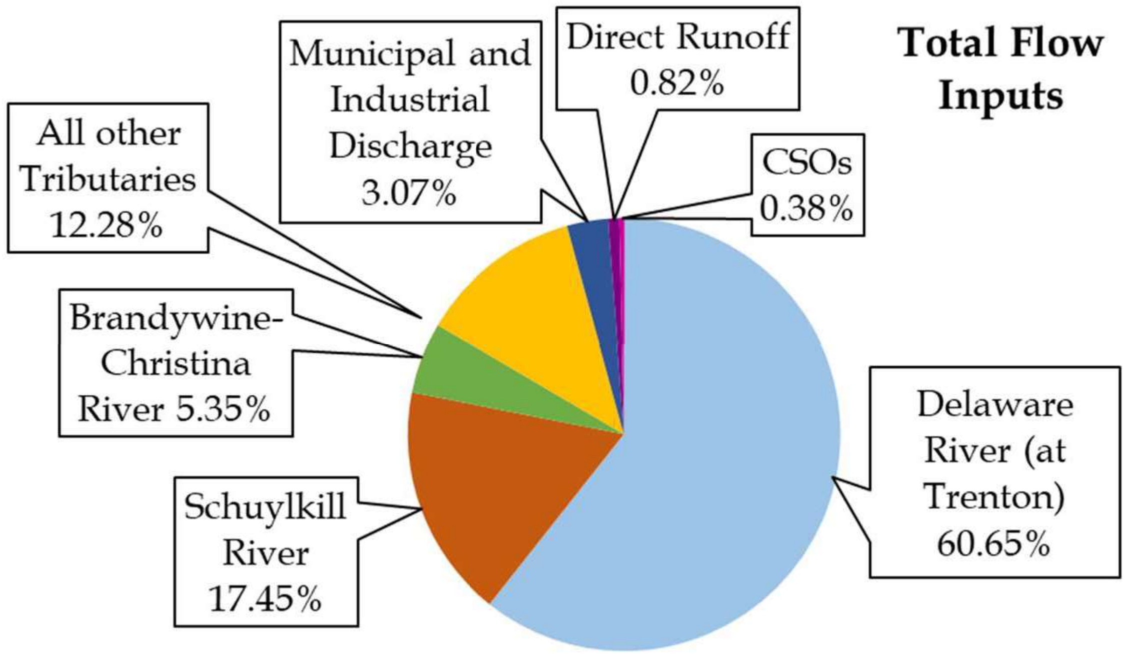
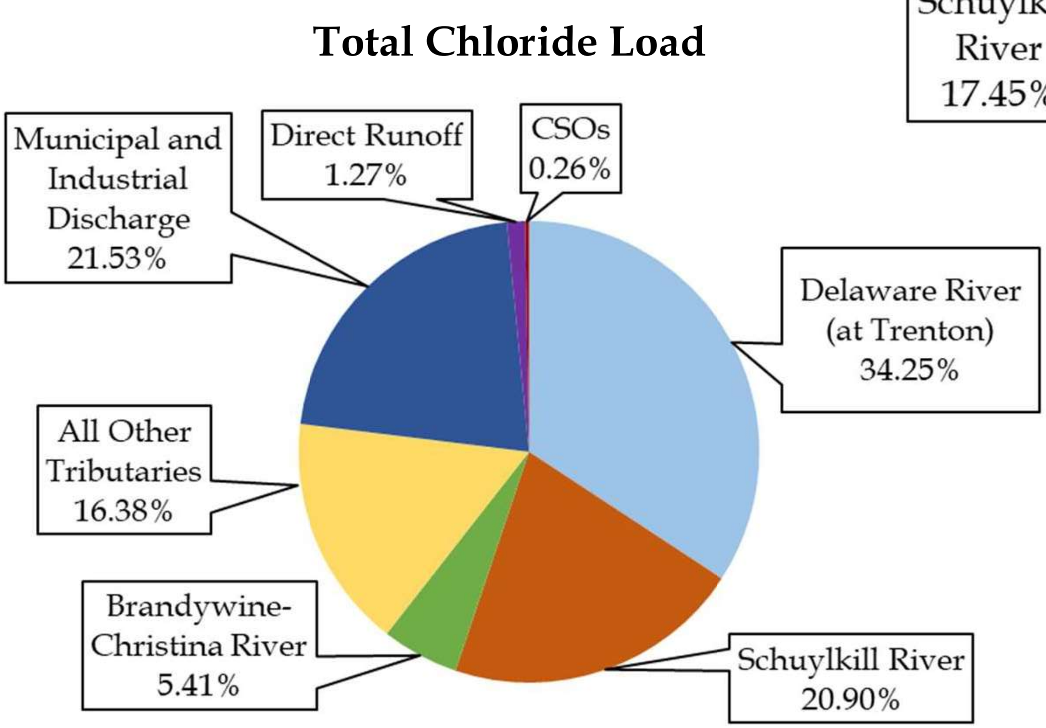
Overview of Boundary Conditions





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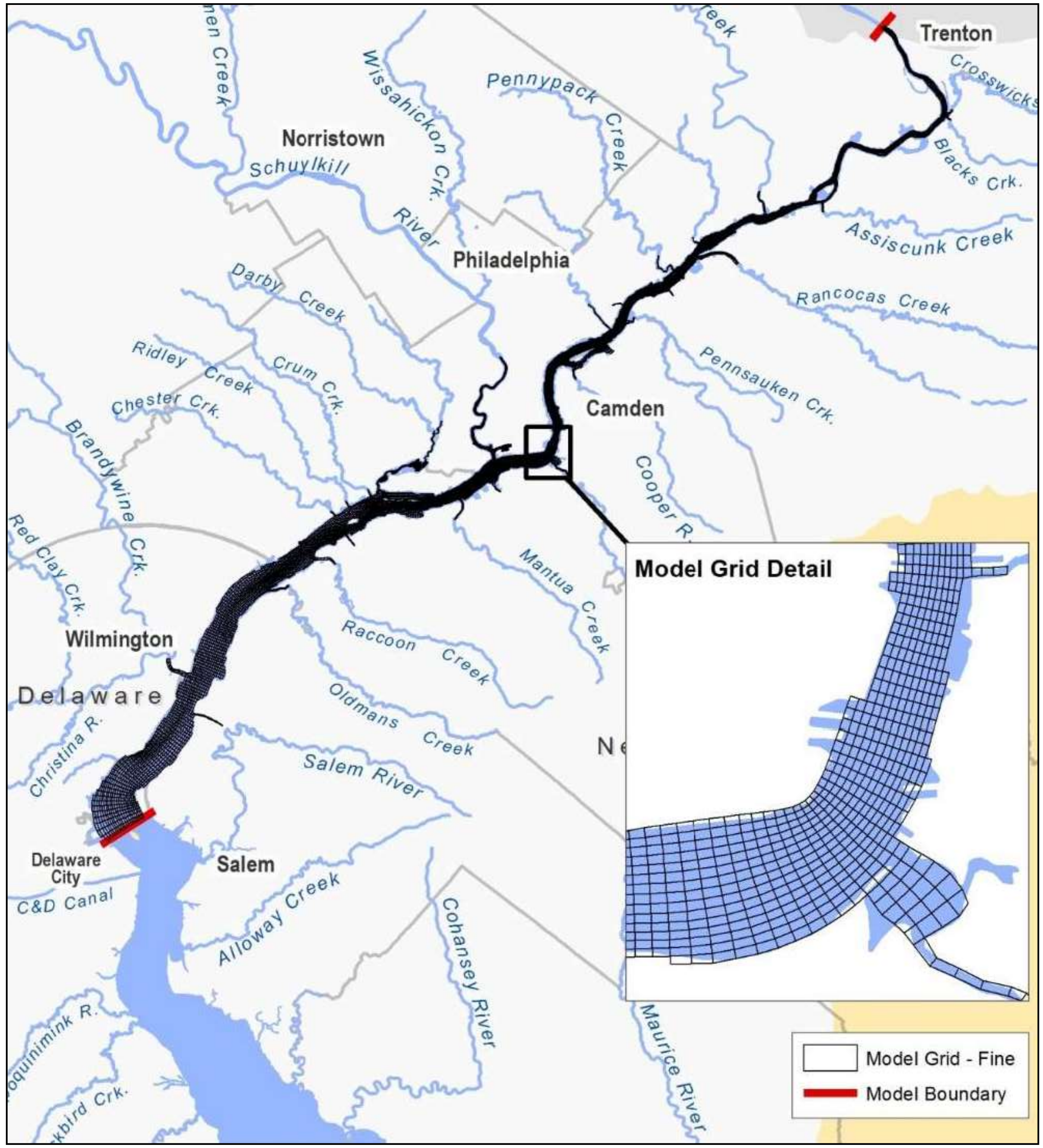
Initial Conditions

- Temperature set constant to NOAA Philadelphia at start
- Observed salinity values interpolated among grid at start

Grid and Bathymetry

- 2014 bathymetry
- Fine grid, 5 vertical layers, 9,746 grid cells



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Model Validation

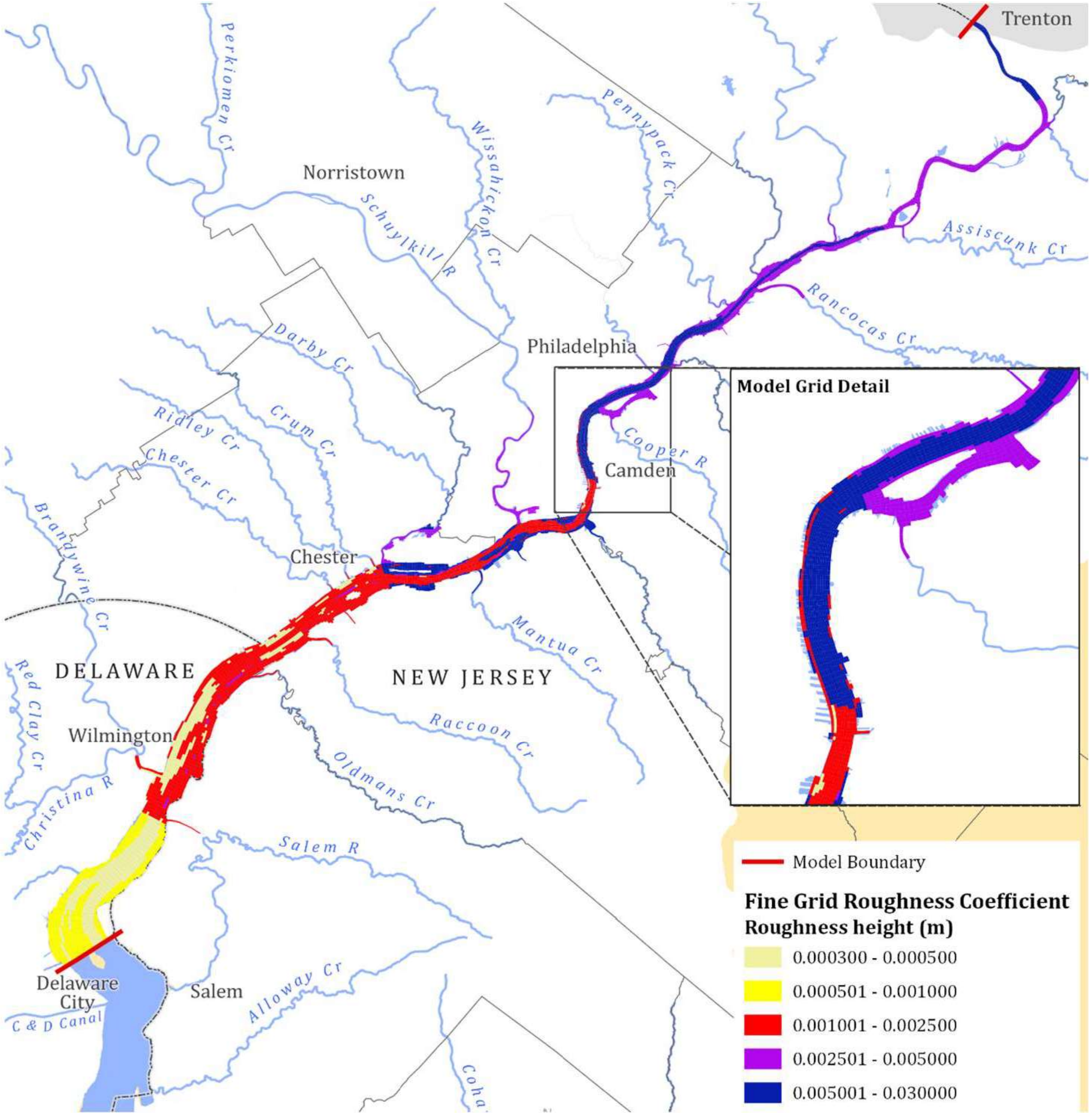
- Sensitivity Studies
  - Bottom Roughness
  - Turbulent diffusion and turbulent closure
  - Open boundary salt loading
  - Tributary salt loading
  - Grid resolution
- Validation results

Bottom Roughness

- Spatially varying roughness
- Lower friction in the channel and higher friction in the shoals

Turbulence Closure Settings

- Adjustment of model manual settings regulating diffusion and turbulent mixing



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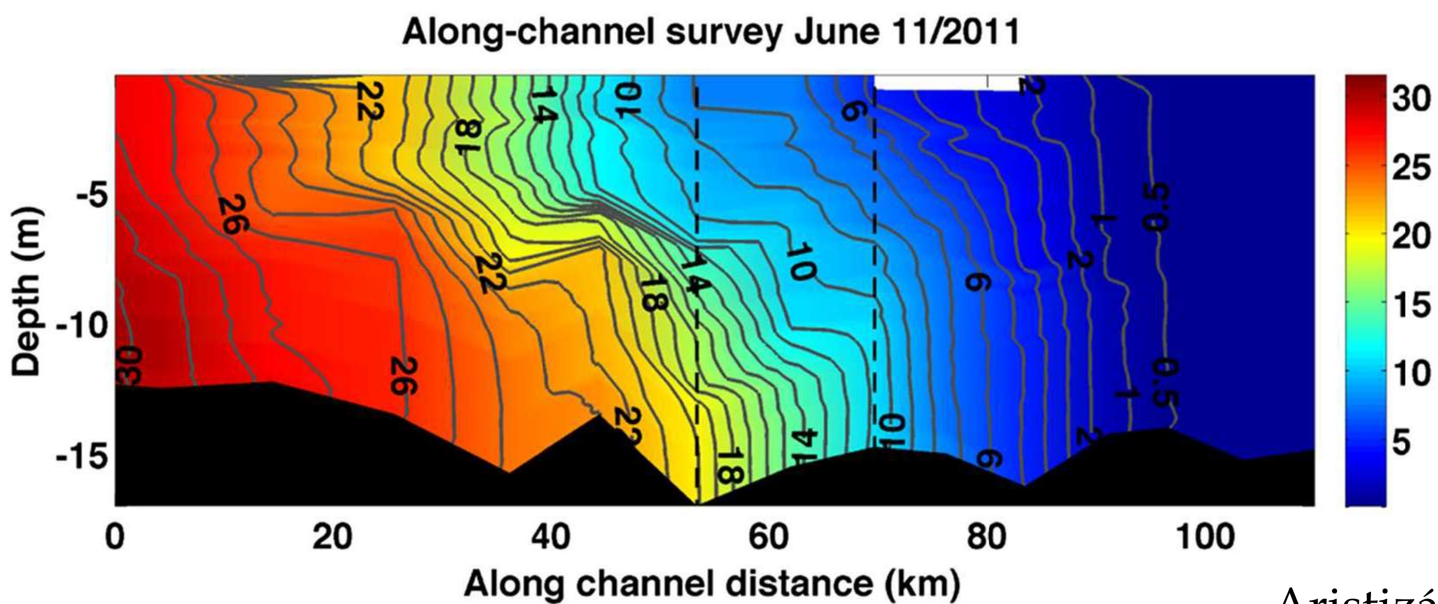
Open Boundary Salt Loading

- Salinity is stratified at the open boundary during intrusion
  - Observed data measured at surface only
  - Multiplier needed to capture total salinity at open boundary, 1.15 selected
  - Model adjusts itself for stratification



Aristizábal & Chant, 2014

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Tributary Salt Loading

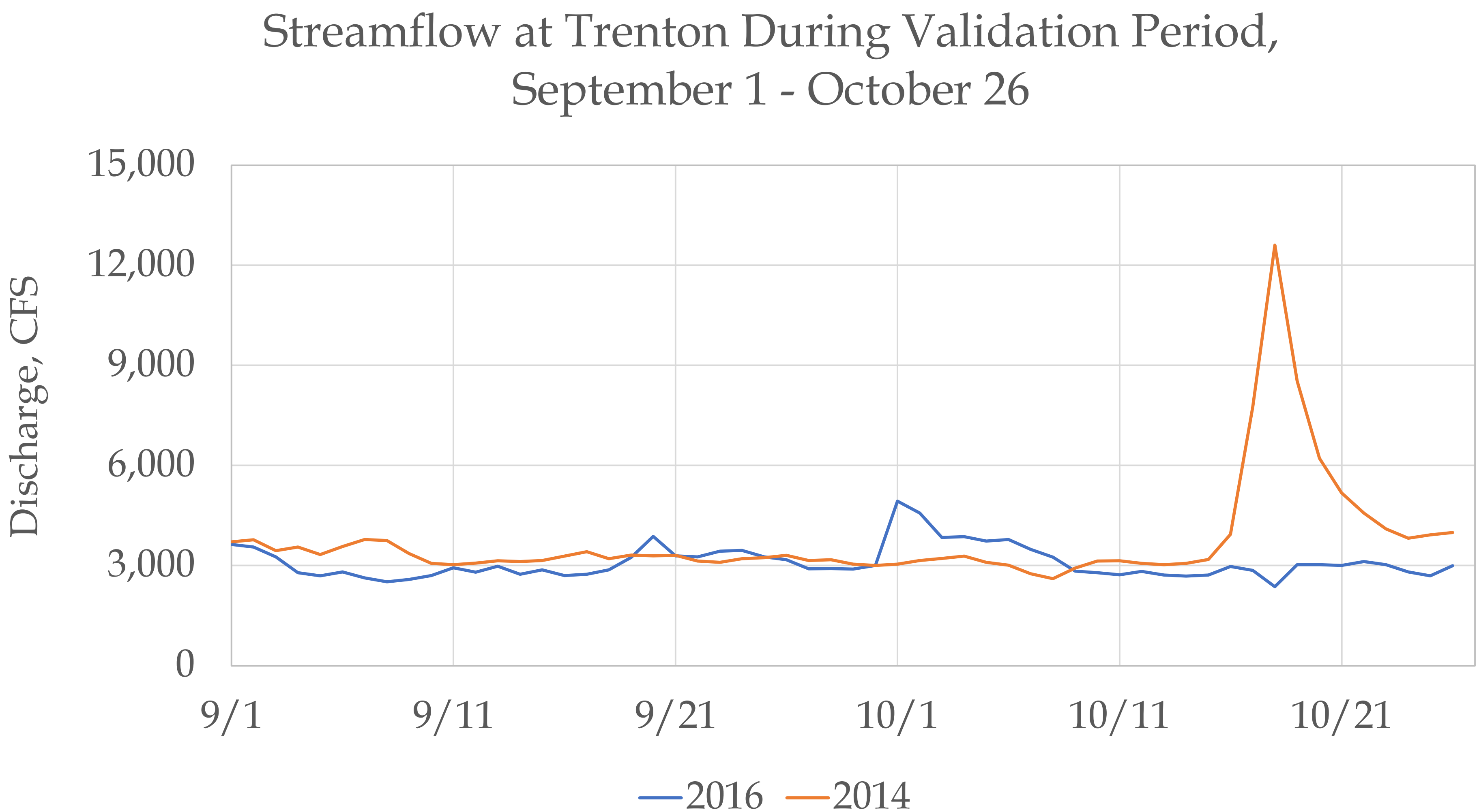
- Drainage to the model domain is 11,085 mi^2
- 10,015 mi^2 gaged (86%), 902 mi^2 ungaged (12%), 168 mi^2 direct runoff (2%)
- Flow and salinity from direct and ungaged areas are estimated, and used as a calibration parameter in sensitivity analyses
- Ultimately model performance was improved by reducing the estimated flow from ungaged areas by 375 CFS
- The ungaged areas in the model domain are all tidal, and their salinity is approximate to the mainstem Delaware River

Validation Periods

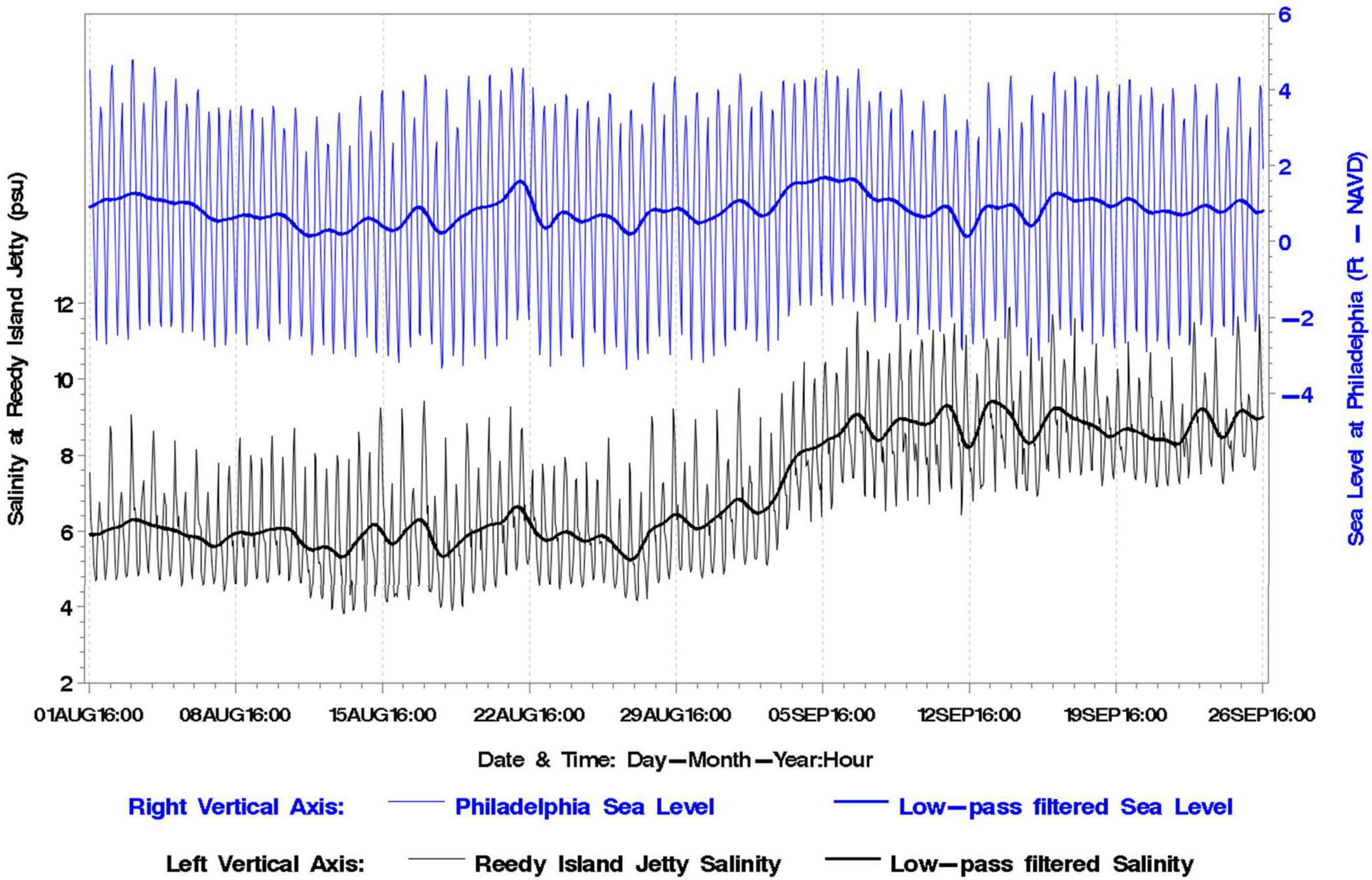
- Significant observed data is required to validate the model
- Water level, velocity and salinity not measured at all stations, some stations are used for some parameters and not others
- Data limitations exist, such as probe issues or missing values. Time periods with unavailable data are excluded from the calculation of validation statistics

	Stations	Validation Period	Year
Velocity	Buoy B PWD, Buoy C PWD	Sept. 1 to Nov. 31	2014
		April 1 to June 30	2016
Water Level	Marcus Hook NOAA, Philadelphia NOAA, Burlington NOAA, Newbold NOAA	Sept. 1 to Nov. 31	2014
		April 1 to June 30	2016
Salinity	Buoy C PWD, Chester USGS, Buoy B PWD, Ben Franklin USGS, Baxter USGS	Sept. 1 to Oct. 26	2014 and 2016

Validation Period- Hydrological Conditions



Quick Overview – Tidal Data Signal Filtering



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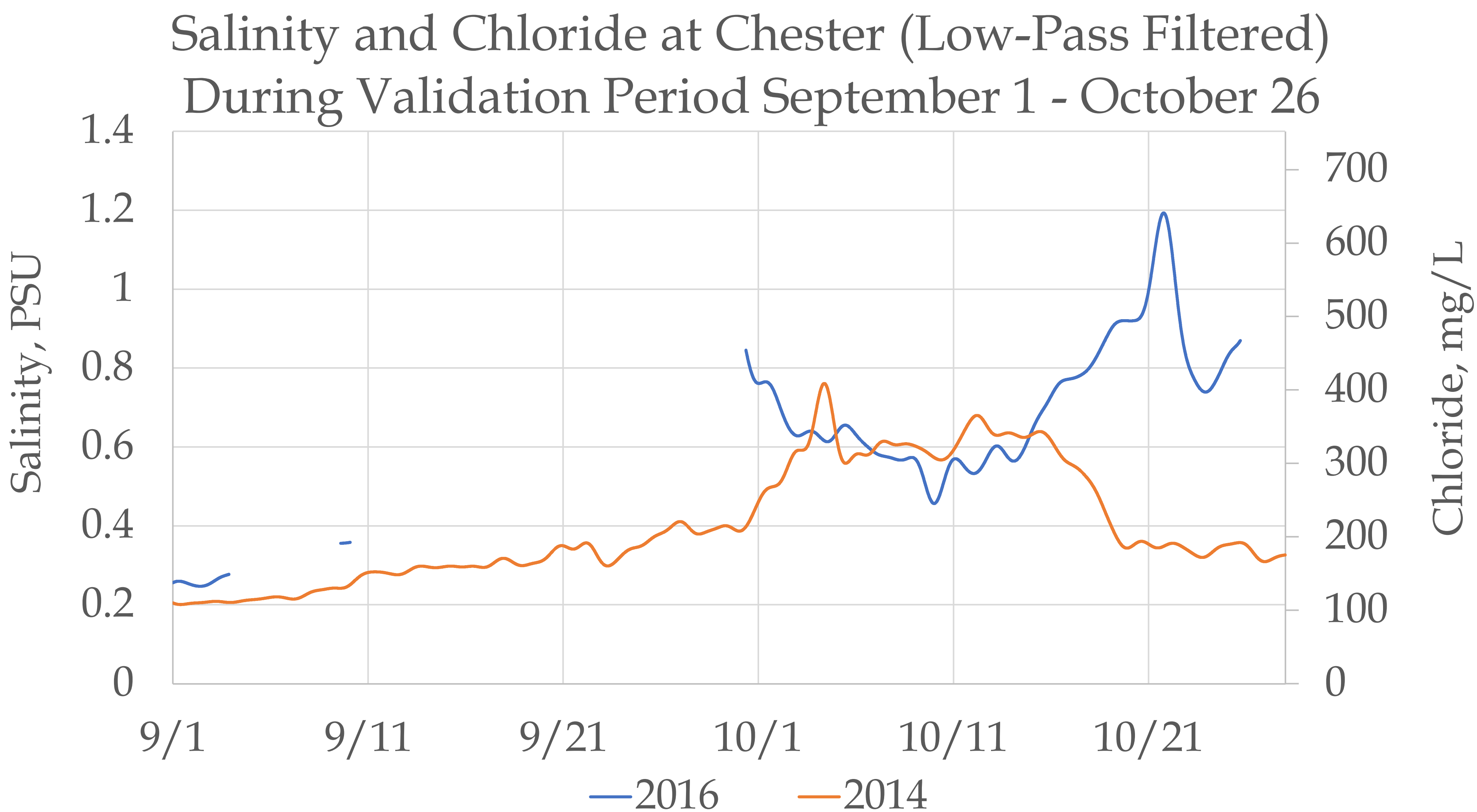
Validation Period- Chester Salinity



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Validation Metrics

- PWD uses NOAA sponsored guidelines for model benchmarking developed for the Delaware Estuary, also known as the Model Evaluation Environment (MEE)
- Mean Error – 0 in a perfect model, measure of average error and indicates by +/- over or under simulation
- RMSE – 0 in a perfect model, no sign, indicates how far off the model can be expected to be on the next prediction
- Skill Factor – 1 in a perfect model, utilized by other Delaware Estuary simulation tools to compare model performance
- Tidal Harmonic Analysis – measure of how results align with known tidal constituents

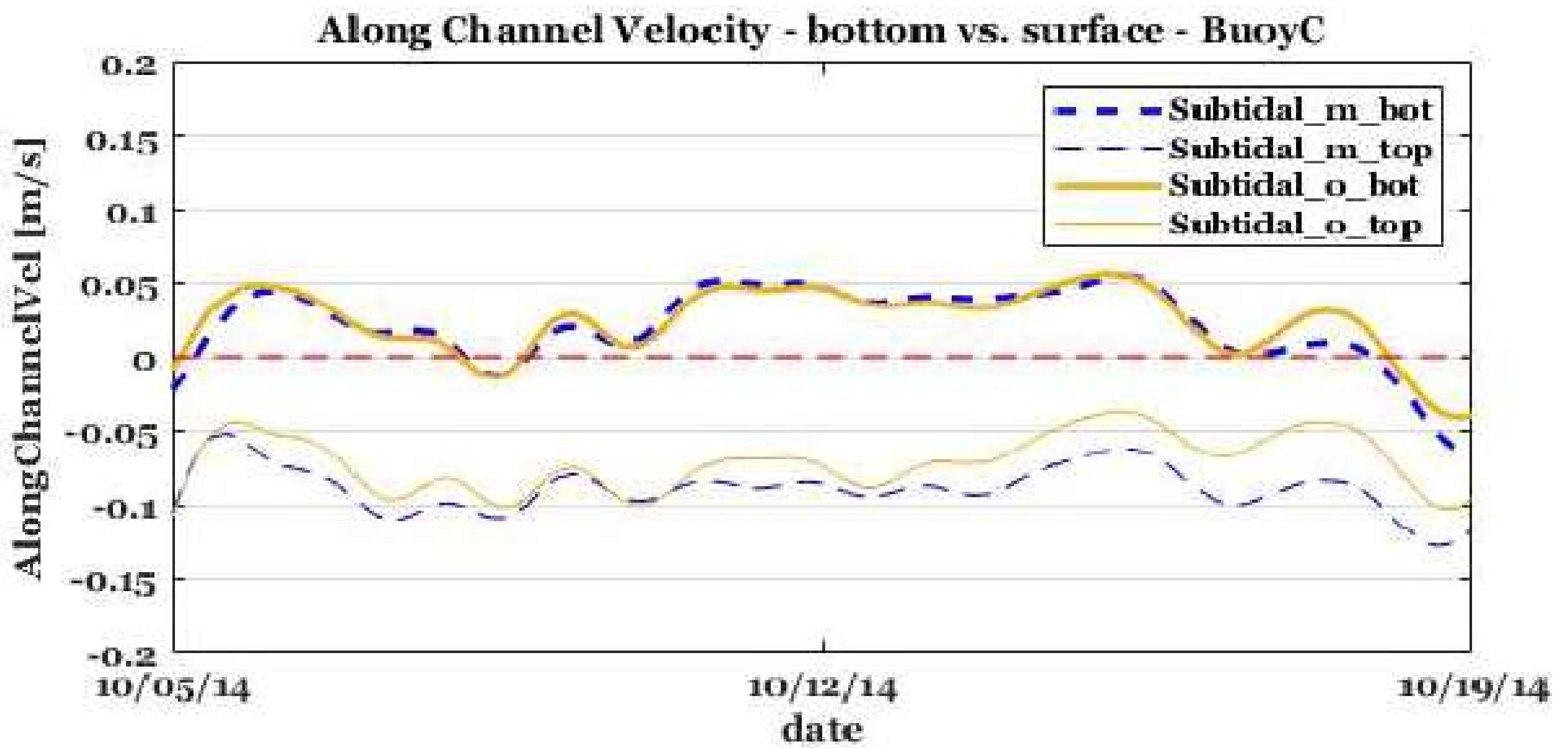
Validation Metrics – Tidal Harmonic Analysis

- 37 harmonic constituents that represent characteristics of semidiurnal, diurnal and long-period tides driven by astronomical conditions
- PWD metrics evaluate 7 constituents, 4 will be presented today
- M2 tide – principal lunar semidiurnal constituent, main contributor to tidal amplitude
- S2 tide – principal solar semidiurnal constituent, responsible for spring neap cycle
- M4, M6 tides – shallow water overtides that draw energy from the M2 tide due to friction and bathymetry, responsible for transport

Validation Result Examples

- Velocity – 2014 at Buoy C (just south of Chester)
- Water Level – 2014 at Philadelphia
- Salinity – 2014 and 2016 at Chester, Ben Franklin, Baxter

Validation – Velocity Metrics



Station	Mean Error [m/s]		RMSE [m/s]		Skill Factor [-]	
	2014	2016	2014	2016	2014	2016
Buoy C	-0.015	-0.016	0.094	0.066	0.988	0.996
Buoy B	-0.001	0.056	0.082	0.132	0.989	0.985

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Validation – Velocity Harmonic Analysis

- 2014 validation results at Buoy C

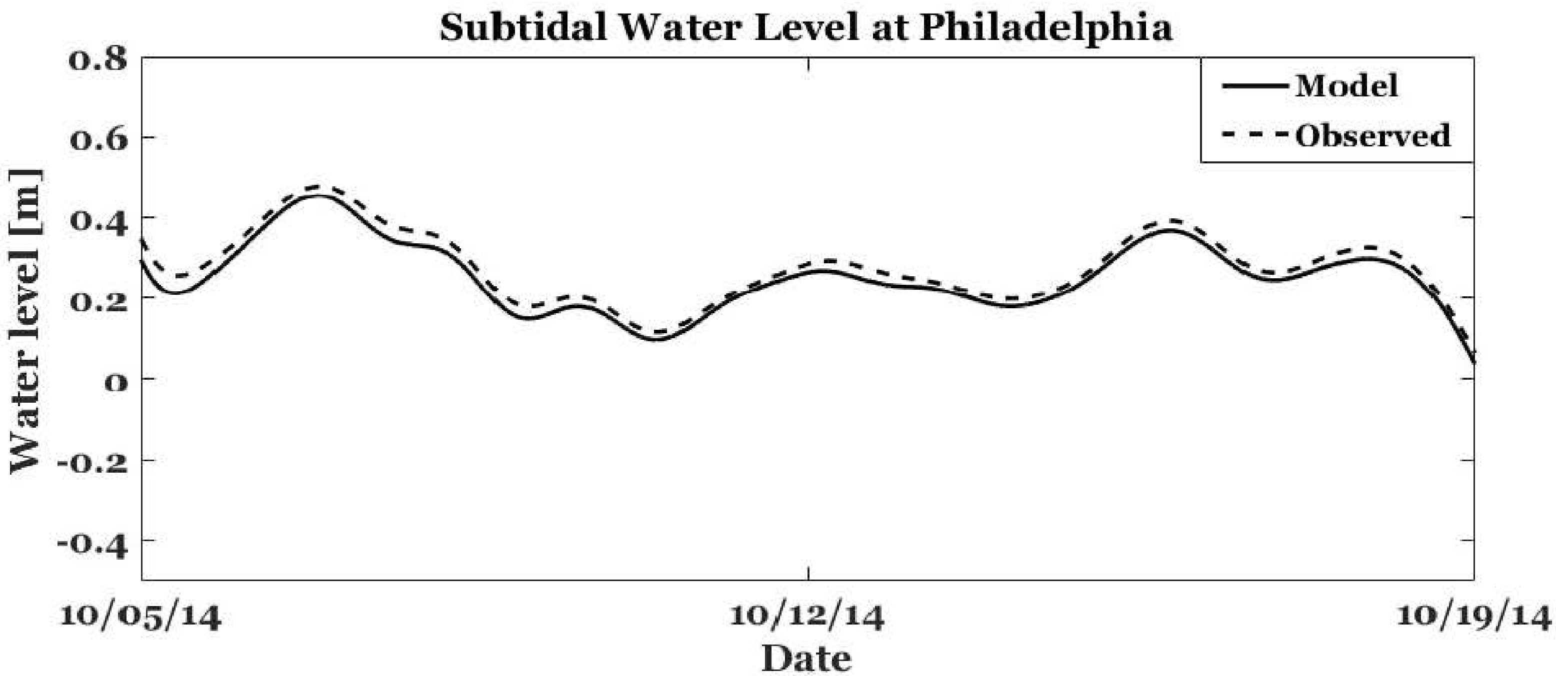
Tidal Constituent	Period [hr]	Amplitude Error [m/s]	Phase Error [hr]
M2	12.42	0.014	-0.22
S2	12.00	0.003	-0.15
M4	6.21	0.015	-0.17
M6	4.14	-0.008	-0.09

- 2016 validation results at Buoy C

Tidal Constituent	Period [hr]	Amplitude Error [m/s]	Phase Error [hr]
M2	12.42	-0.004	-0.14
S2	12.00	0.001	-0.13
M4	6.21	-0.008	0.04
M6	4.14	-0.005	-0.01

 Results well below the industry recommendation of 0.26 m/s

Validation – Water Level Metrics



Station	Mean Error [m]		RMSE [m]		Skill Factor [-]	
	2014	2016	2014	2016	2014	2016
Marcus Hook	-0.020	NA	0.038	NA	0.999	NA
Philadelphia	-0.026	-0.026	0.081	0.069	0.996	0.997
Burlington	-0.042	-0.048	0.113	0.112	0.995	0.995
Newbold	0.001	0.014	0.119	0.112	0.995	0.996

 Results are well below the industry recommendation of 0.15 m

Validation – Water Level Harmonic Analysis

- 2014 validation results at Philadelphia

Tidal Constituent	Period [hr]	Amplitude Error [m]	Phase Error [hr]
M2	12.42	0.091	-0.16
S2	12.00	0.015	-0.05
M4	6.21	0.000	0.07
M6	4.14	-0.005	-0.11

- 2016 validation results at Philadelphia

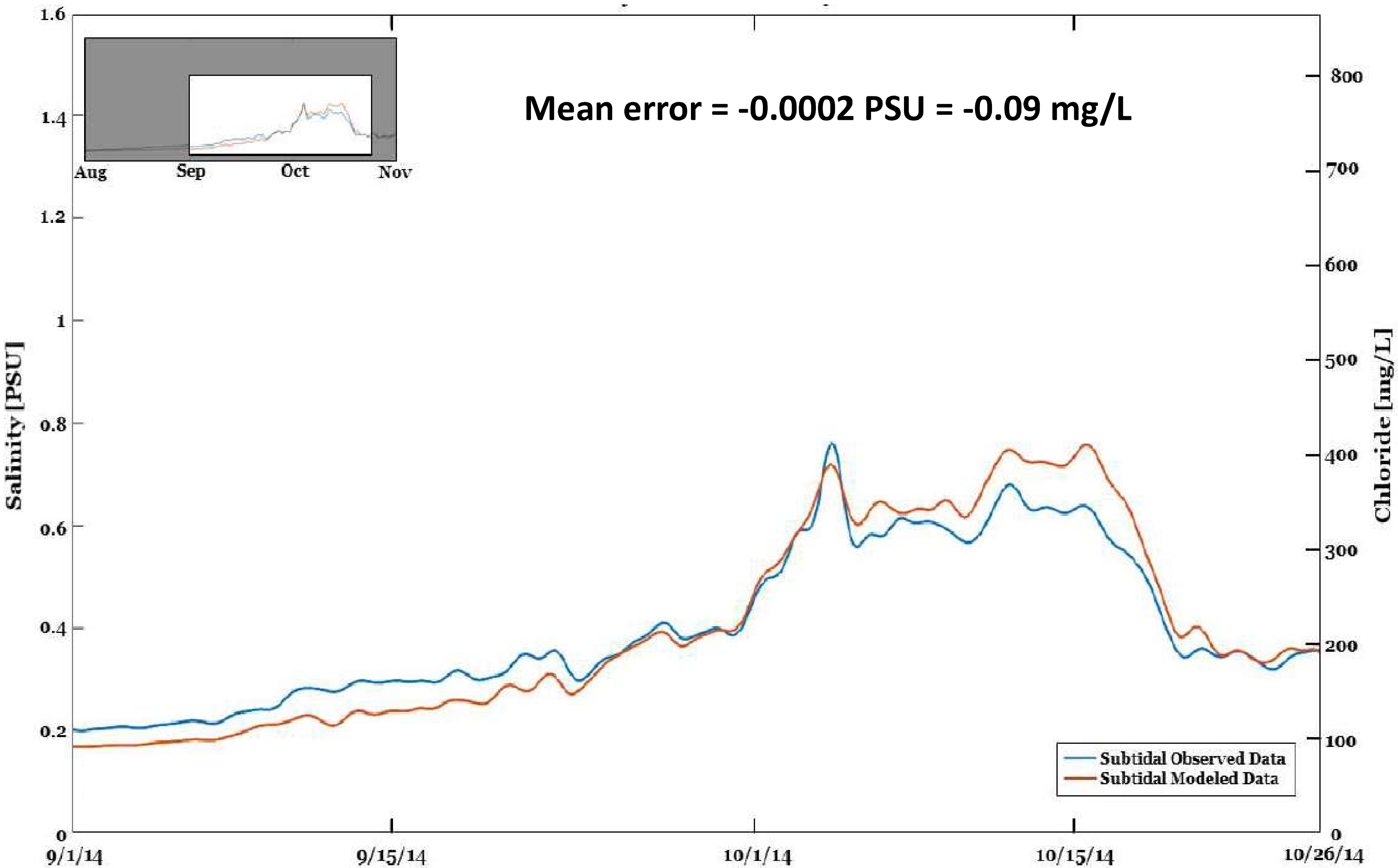
Tidal Constituent	Period [hr]	Amplitude Error [m]	Phase Error [hr]
M2	12.42	0.075	-0.03
S2	12.00	0.014	0.02
M4	6.21	-0.002	0.17
M6	4.14	-0.005	0.01

 Results are well below the industry recommendation of 0.15 m

Validation – Salinity

Station	Mean Error [PSU]		Mean Error [mg/L]		RMSE [PSU]		RMSE [mg/L]	
	2014	2016	2014	2016	2014	2016	2014	2016
Buoy C	0.083	-0.034	46.0	-19.22	0.268	0.302	148.9	167.7
Chester	-0.0002	-0.066	-0.09	-36.59	0.143	0.170	79.7	94.5
Buoy B	-0.023	-0.049	-12.8	-27.11	0.025	0.053	14.0	29.6
Ben Franklin	-0.007	-0.014	-3.8	-7.56	0.009	0.017	5.3	9.6
Baxter	-0.002	-0.005	-1.3	-2.74	0.003	0.006	1.9	3.6

Validation – Salinity Chester 2014



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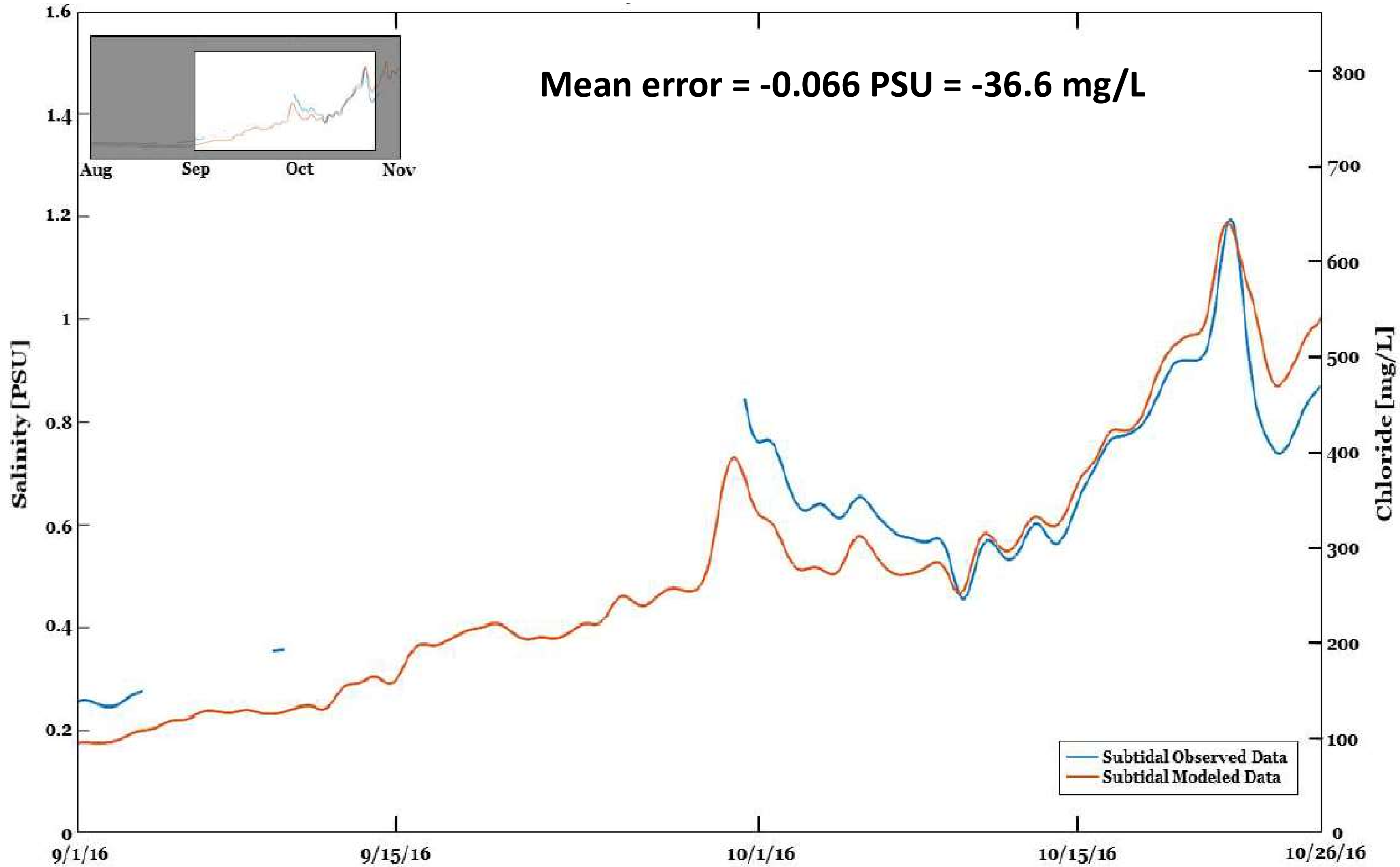
Validation – Salinity Chester 2016



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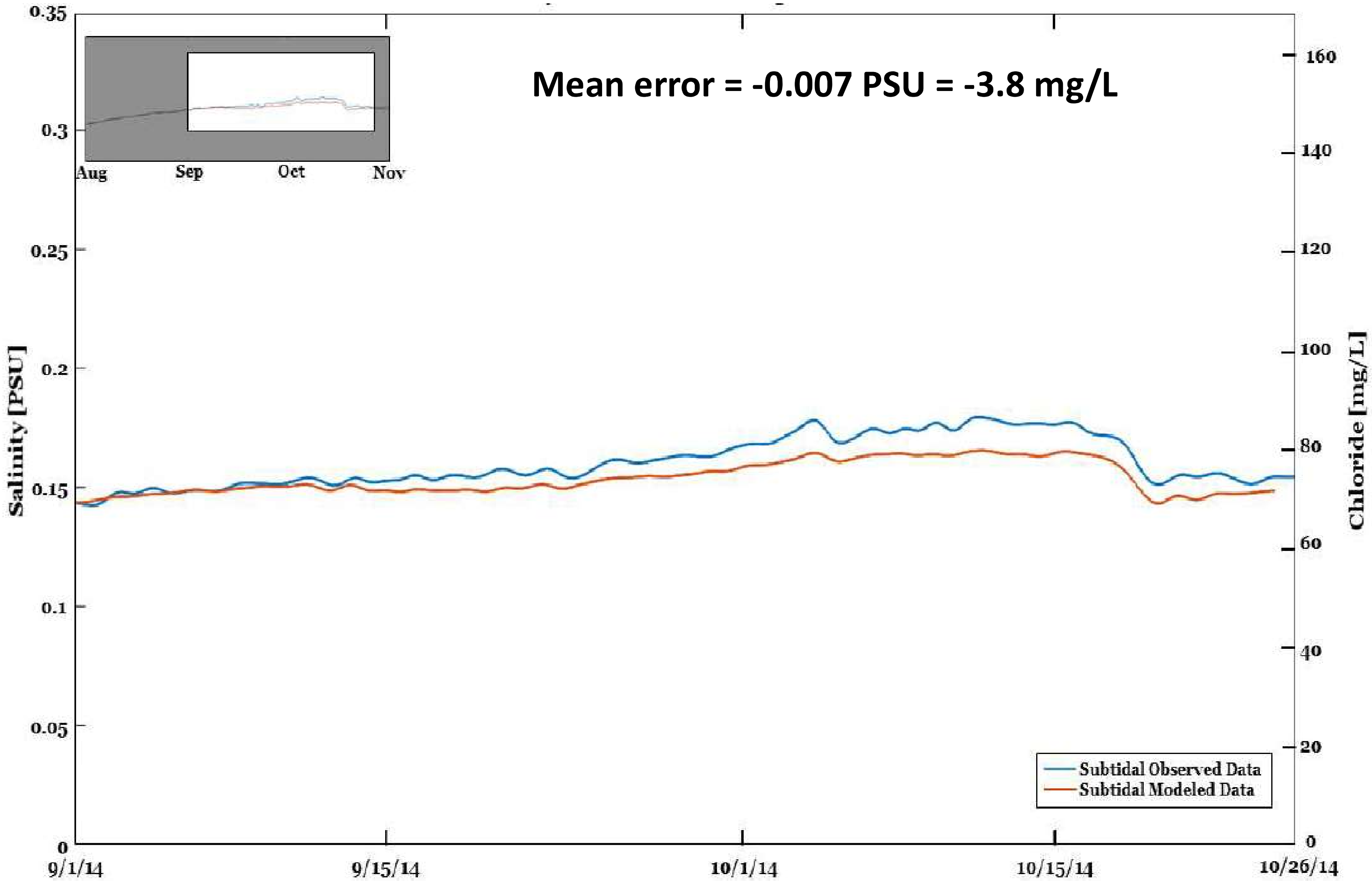
Validation – Salinity Ben Franklin 2014



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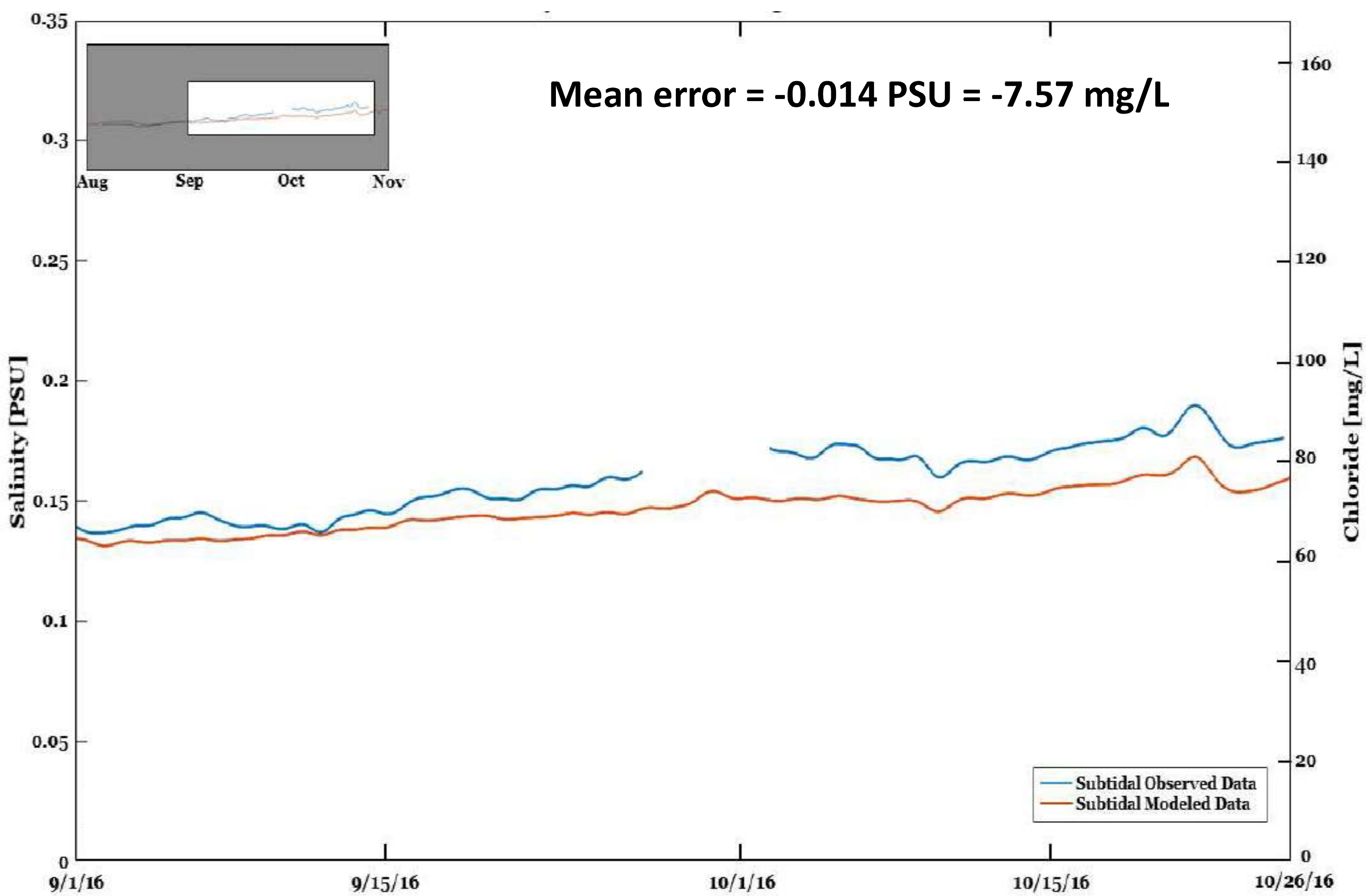
Validation – Salinity Ben Franklin 2016



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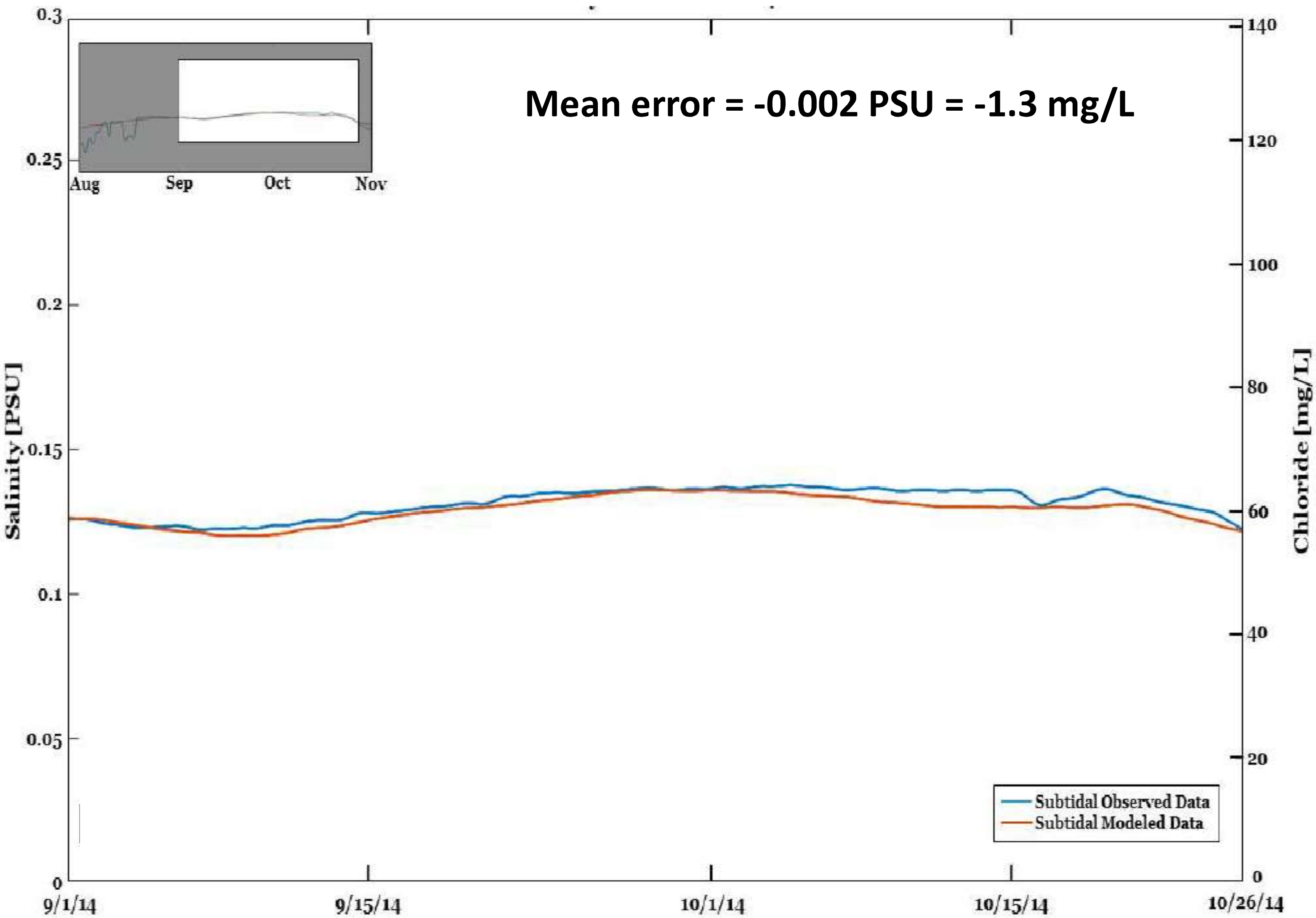
Validation – Salinity Baxter 2014



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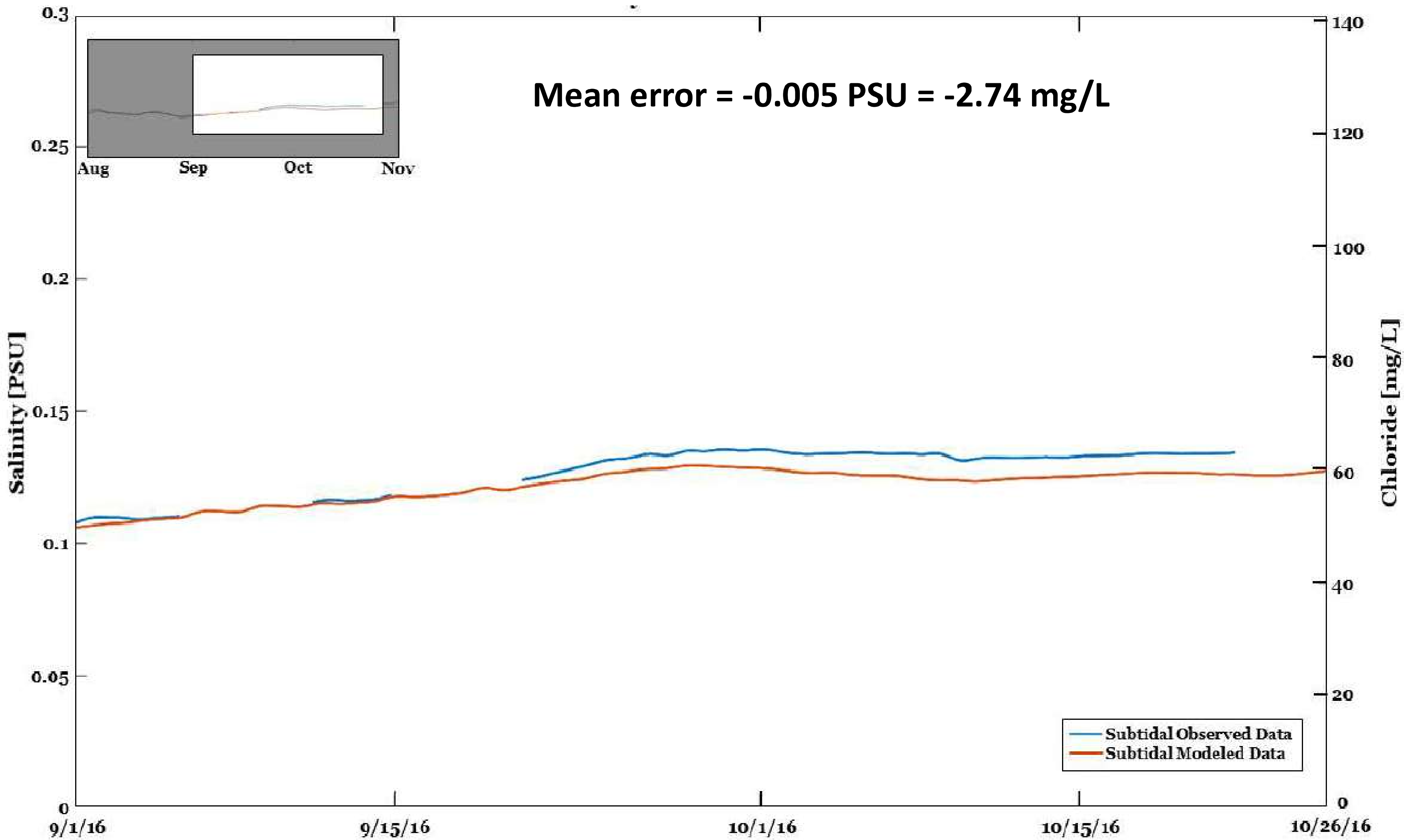
Validation – Salinity Baxter 2016



Validation Summary

- The Philadelphia Water Department's EFDC model simulates the hydrodynamics of the tidal Delaware River to a high degree of model skill
- The model well represents salinity transport processes during periods of salinity intrusion
- The model is in use by the Philadelphia Water Department as a planning tool to study the influences of streamflow and other factors on the salinity distribution in the tidal Delaware River
- A 3-Dimensional model is required to represent adequately the fundamentally important hydrodynamic processes that govern material transport in the tidal river

Salinity Modeling – Objectives

Support infrastructure planning

- Inform Baxter Water Treatment Plant capital planning initiatives exploring plant modifications and technology decisions

Support Pennsylvania PADEP and RFAC

- Provide high quality analyses of how FFMP policy changes will impact the supply to the largest drinking water utility in Pennsylvania
- Share findings and results with stakeholders interested in salinity impacts to aquatic and fishery resources

Ongoing Work

- Numerical experiments, post processing
- Begin PST2 refinements, research into alternative policies
- Sea level rise salinity model set up and numerical experiments
- Numerical experiments with PST2 and synthesis of findings

Series of Presentations

1. **Planning Introduction (May 2018)**
2. **Salinity Intrusion in the Delaware Estuary (April 2019)**
3. **Model Setup and Validation (today)**
4. **Numerical Experiments**

And much more to come!

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THANK YOU!

www.phila.gov/water/sustainability

Inquiries may be directed to:

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