Exploring Localized Mixing Dynamics During Wet Weather in a Tidal Fresh Water System

Ramona McCullough & Phil Duzinski

Delaware Estuary Science & Environmental Summit

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Philadelphia Water Department

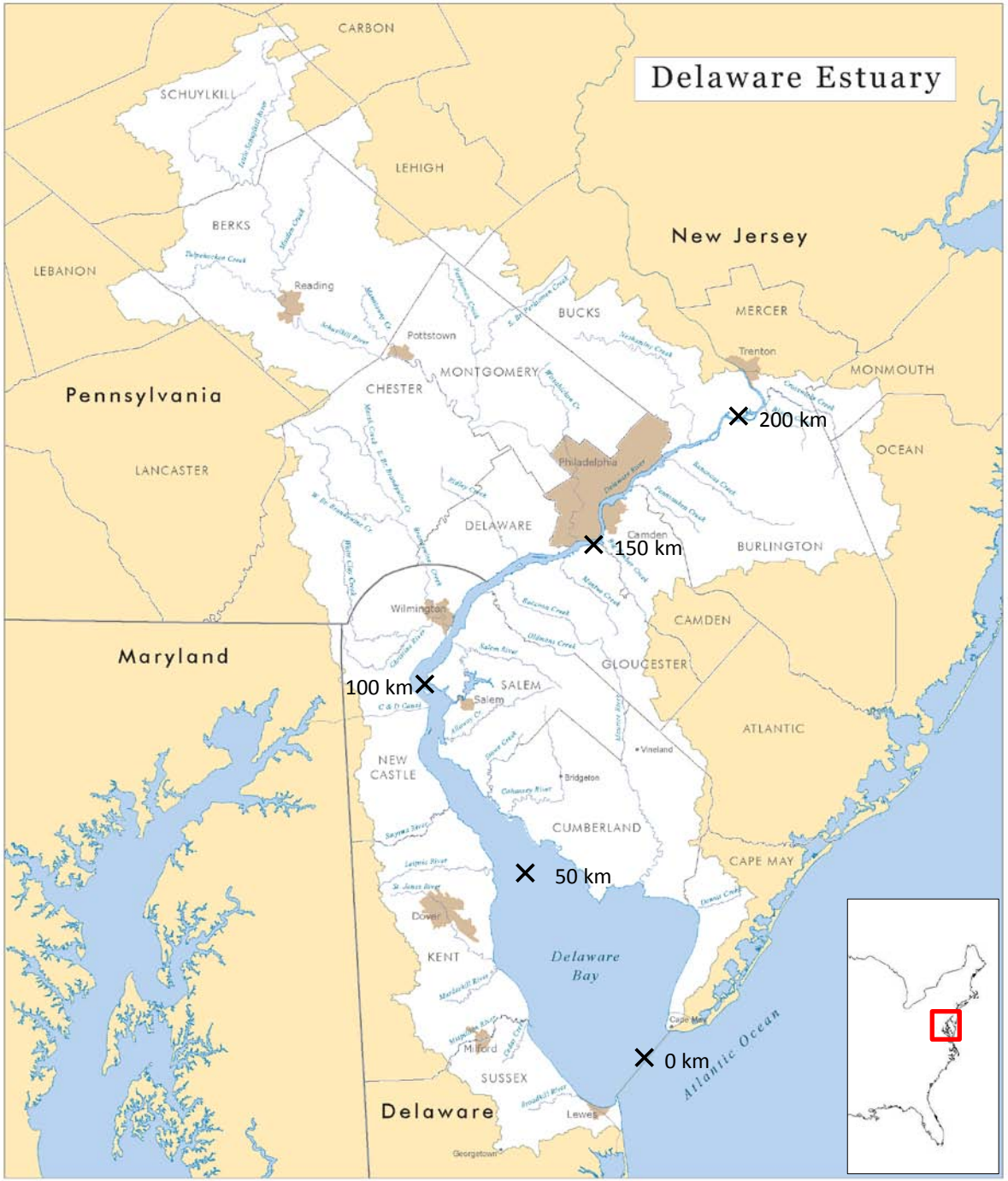
Office of Watersheds

Background and objectives

- City of Philadelphia regulated on discharges to tidal Delaware and Schuylkill Rivers
- Mission to model water quality in receiving waters to meet regulatory requirements
- Use 3-D model and dye study to characterize the hydrodynamics of tidal Delaware River and impact of stormwater and combined sewer (CSO) discharges

Delaware Estuary

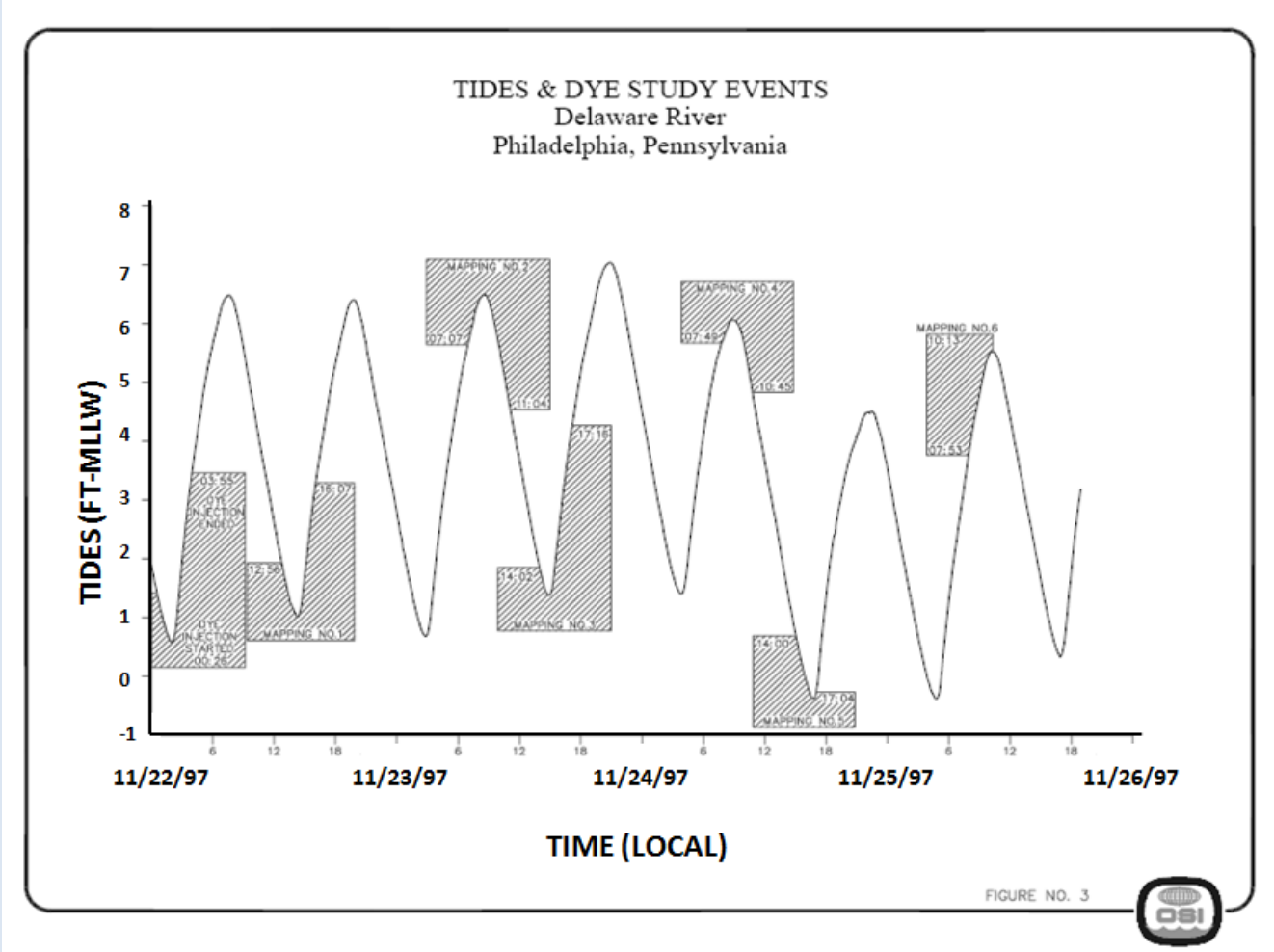
- Estuary length = 215 km
- Model domain
  - River km 99 – 215
- Chesapeake & Delaware Canal: km 94
- Turbidity max: km 50 – 120
- Salt intrusion mean: km 97
- Philadelphia: km 147 – 180
  - 4,800 km of sewer pipe
  - 455 stormwater outfalls
  - 164 CSO outfalls
  - 1 drinking water intake



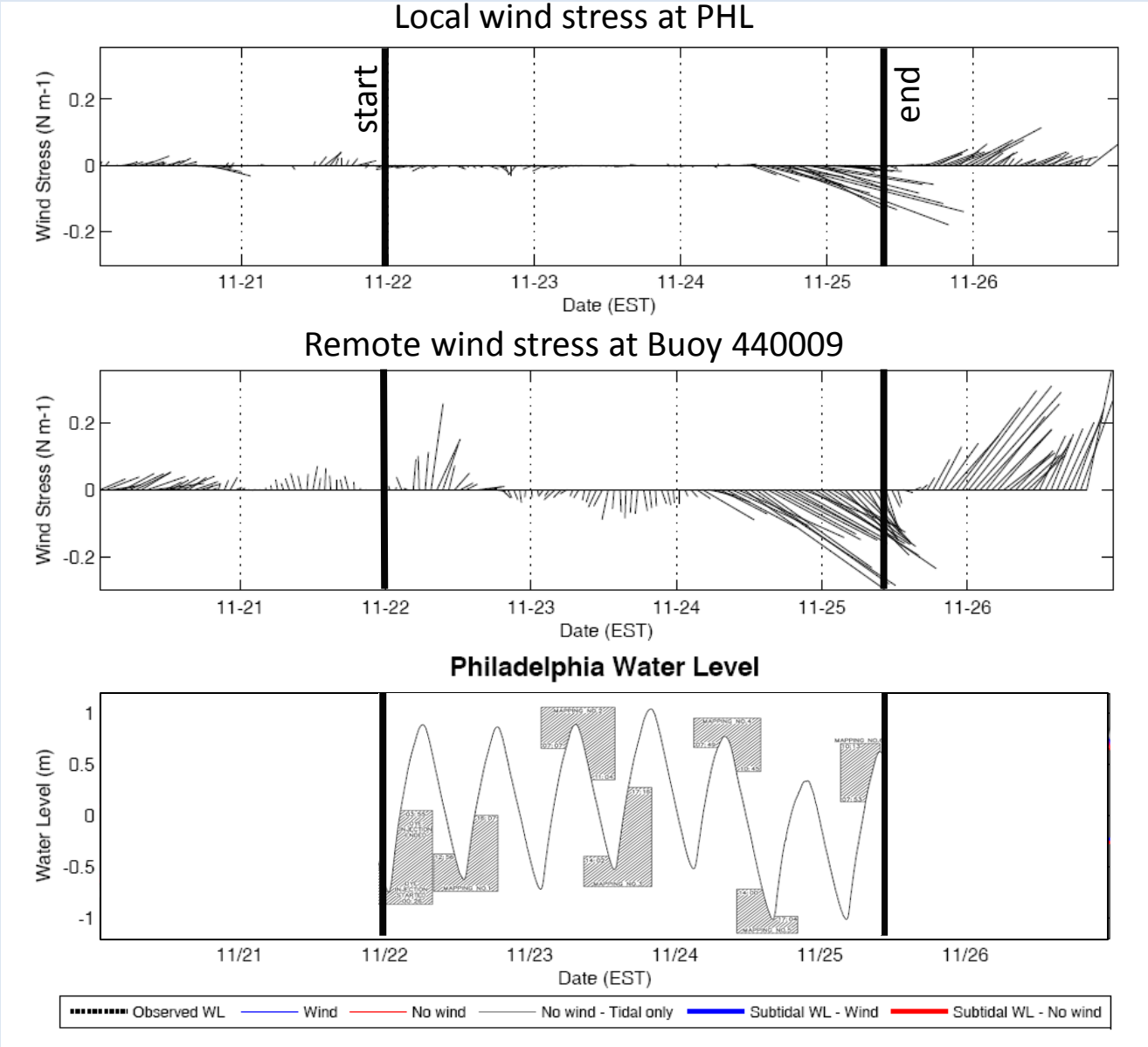
Delaware River Basin Commission

1997 CSO Mixing Zone Study

- Characterize CSO discharge plume
- Targeted wet weather event (1.1” rainfall)
- Dye injected in sewer line
- C_0 = 236 ppb
- Modeled Q_0



Meteorological Conditions



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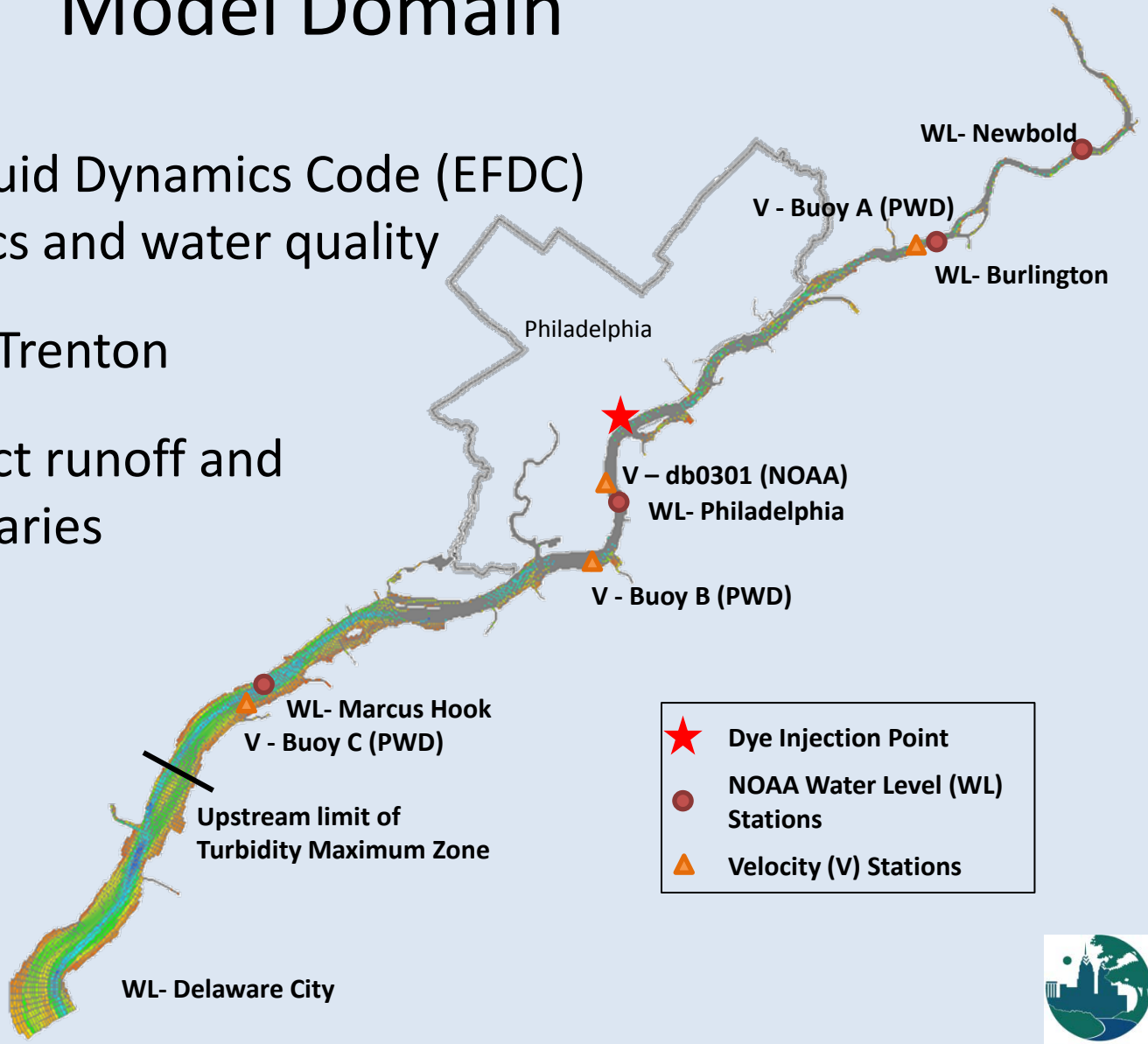
Tidal Delaware & Schuylkill River Model Domain

- Environmental Fluid Dynamics Code (EFDC) for hydrodynamics and water quality
- Delaware City to Trenton
- CSO, WWTP, direct runoff and freshwater tributaries



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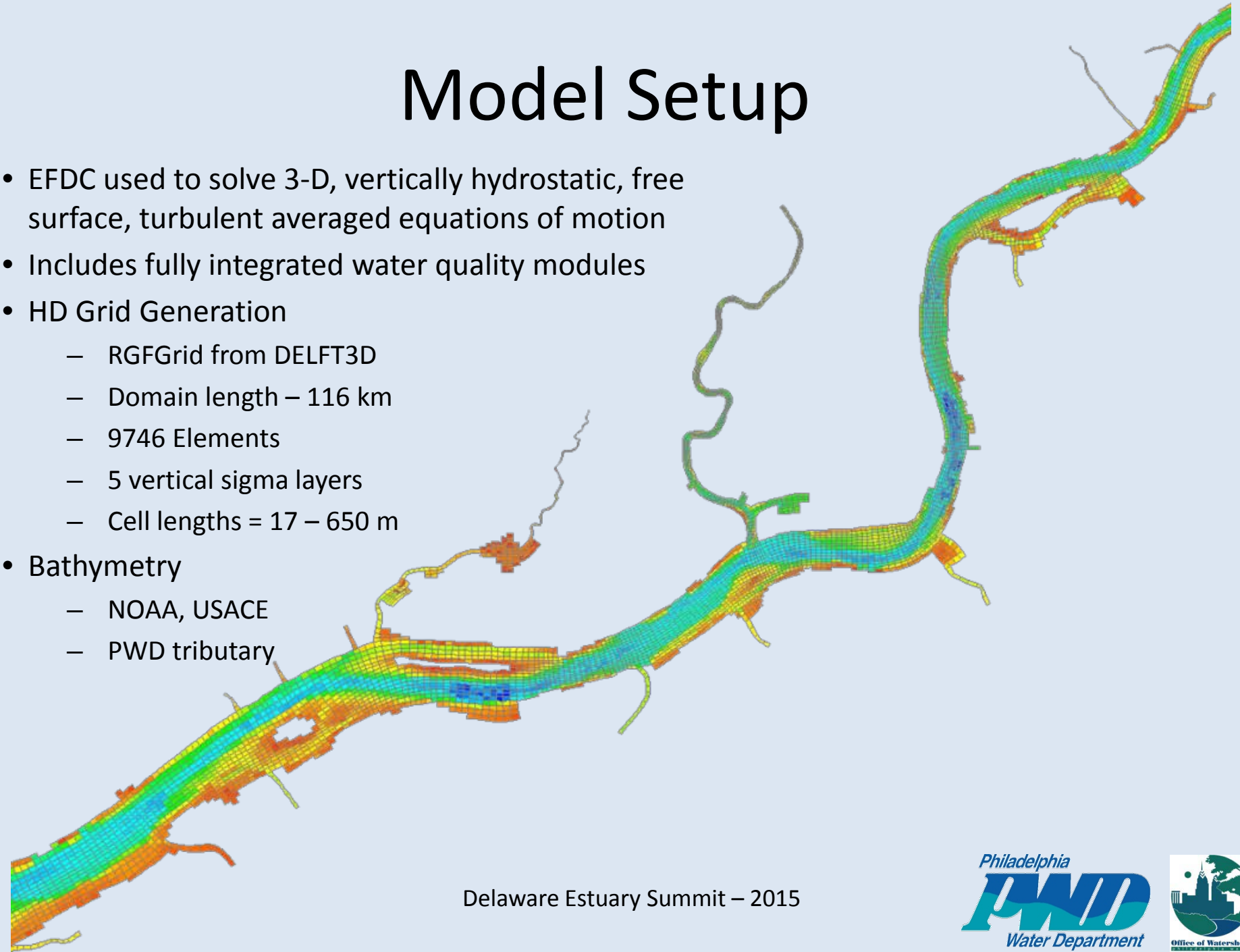
Model Setup

- EFDC used to solve 3-D, vertically hydrostatic, free surface, turbulent averaged equations of motion
- Includes fully integrated water quality modules
- HD Grid Generation
  - RGFGrid from DELFT3D
  - Domain length – 116 km
  - 9746 Elements
  - 5 vertical sigma layers
  - Cell lengths = 17 – 650 m
- Bathymetry
  - NOAA, USACE
  - PWD tributary



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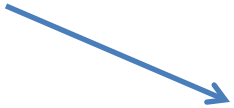
WASP models of non-tidal Tacony and Cobbs Creeks

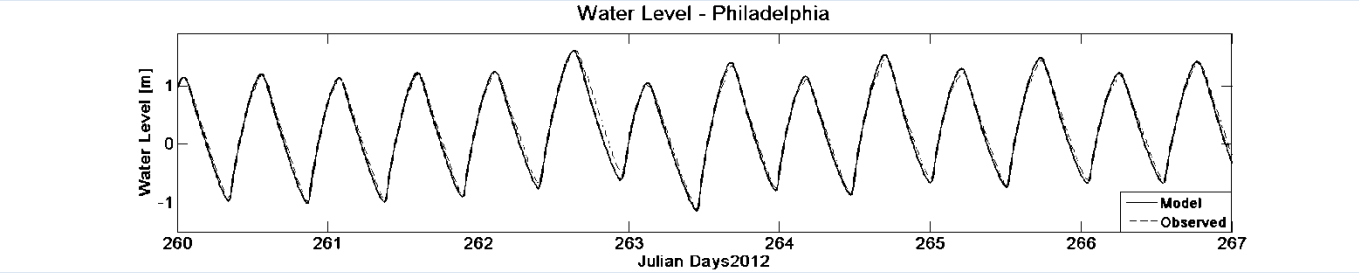


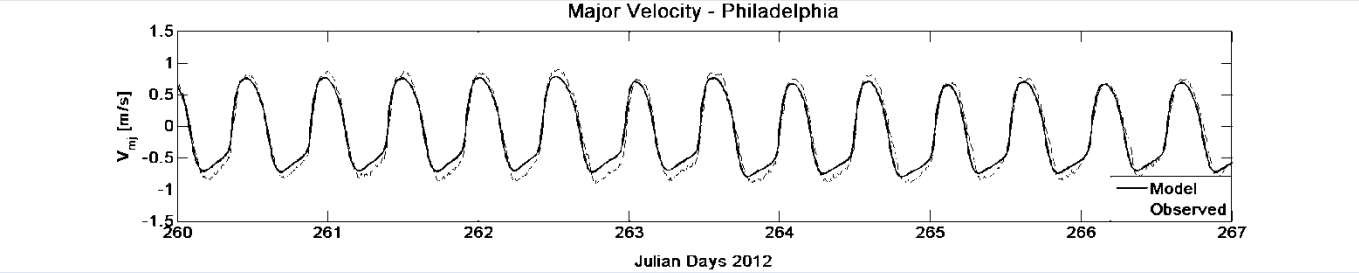
Model Validation

- Validation periods of 1984 & 2012
- NOAA water levels
- Currents
  - 1984-85 NOS Circulation Survey (tidal only & hindcast)
  - PWD ADCP data 2012 to present (hindcast)
- Bottom friction adjustments guided by detailed University of Delaware sediment morphology study (Sommerfield & Madsen, 2003)

2012 water level & velocity results

	Total Model		M2 Amplitude			M2 Phase		
Station	**RMSE**	**Skill**	**Obs**	**Mod**	**Error**	**Obs**	**Model**	**Error**
	[m]	[-]	[m]	[m]	[m]	[hr]	[hr]	[hr]
WL-Marcus Hook	0.038	0.999	0.776	0.754	-0.022	0.042	0.128	0.087
WL-Philadelphia	0.049	0.999	0.824	0.838	0.015	1.384	1.333	-0.051
WL-Burlington	0.073	0.998	1.002	1.003	0.001	2.404	2.333	-0.071
WL-Newbold	0.085	0.997	1.084	1.067	-0.016	2.555	2.482	-0.074
	[m/s]	[-]	[m/s]	[m/s]	[m/s]	[hr]	[hr]	[hr]
Vmj-Philadelphia	0.091	0.993	0.775	0.707	-0.068	11.713	11.522	-0.191
Vmj-Buoy A	0.121	0.978	0.579	0.435	-0.144	11.874	11.806	-0.069
Vmj-Buoy B	0.073	0.994	0.624	0.575	-0.049	11.102	11.116	0.014



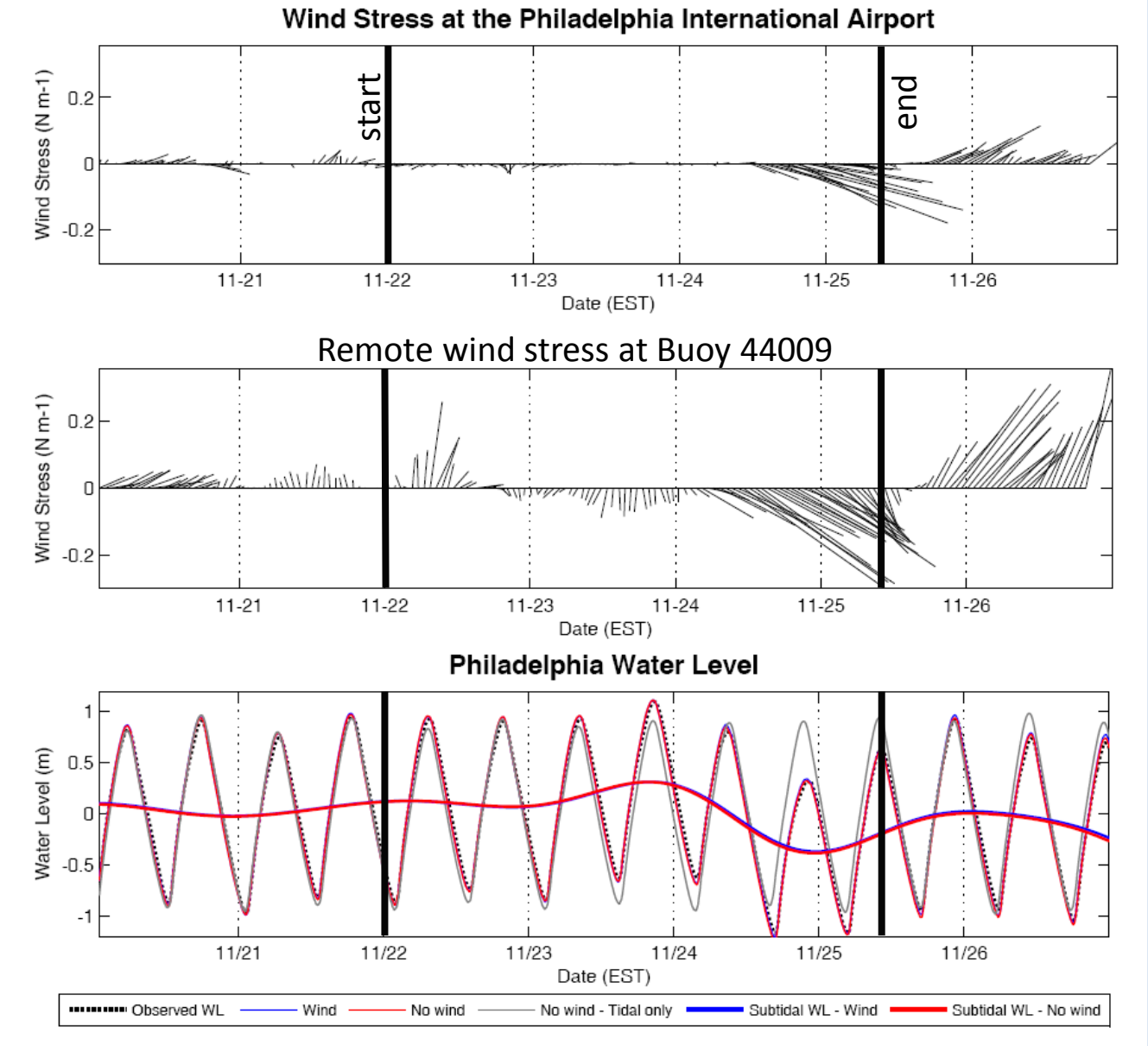


Target RMSE: WL ±0.15 m; Vel ±0.25 m/s (Patchen, NOAA/NOS, ECM10, 2008)

Dye results

- Scenarios
  1. Observed water level (domain wind field on)
  2. Observed water level (wind field off)
  3. Predicted water level (wind field off)
- Analyzed:
  - Day 2: low slack tide dye contour
  - Day 3: impact of local set-down event on dye transport

Meteorological Conditions



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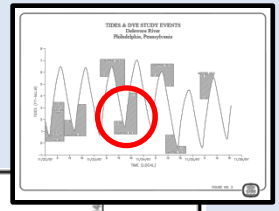
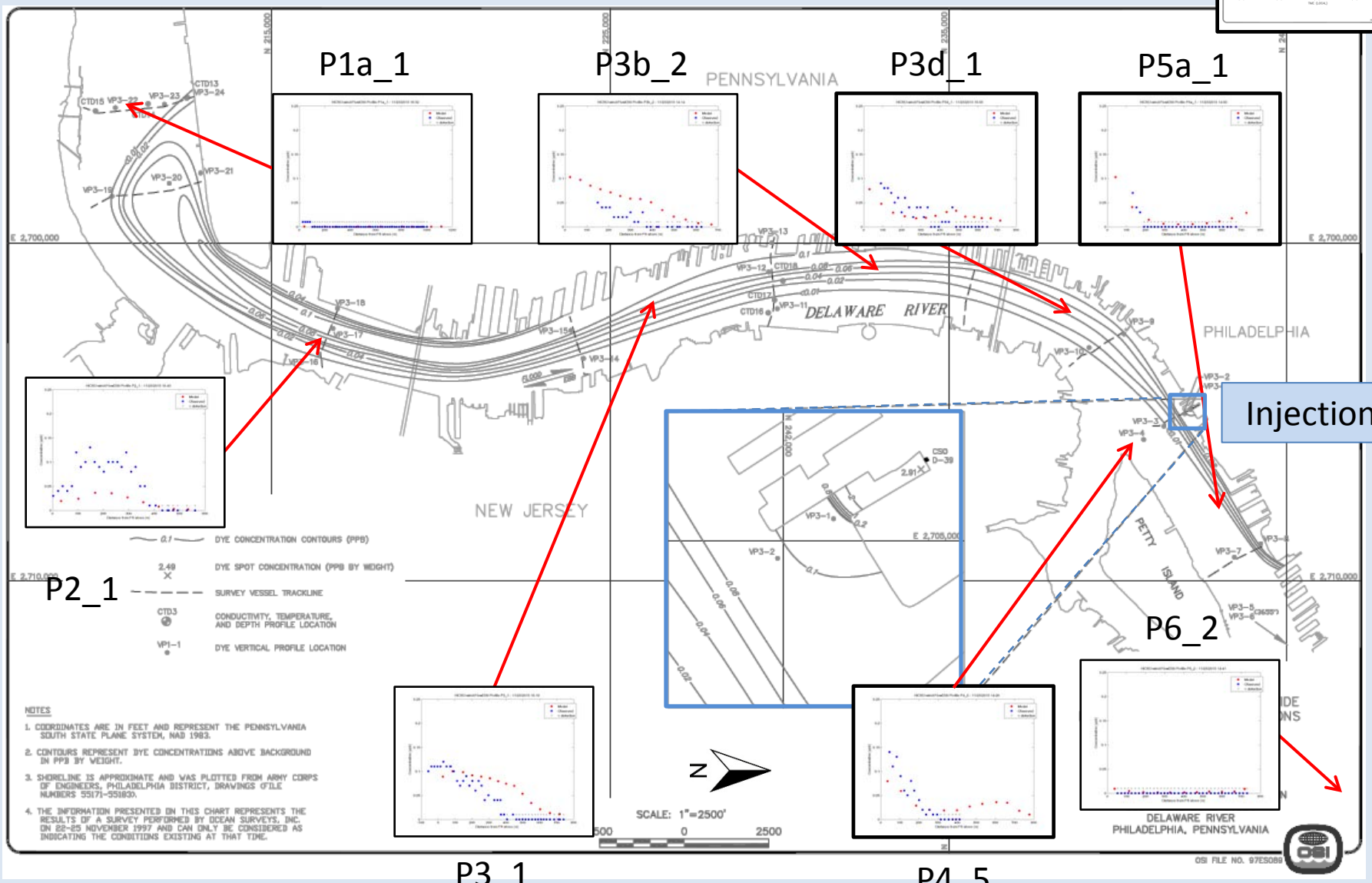
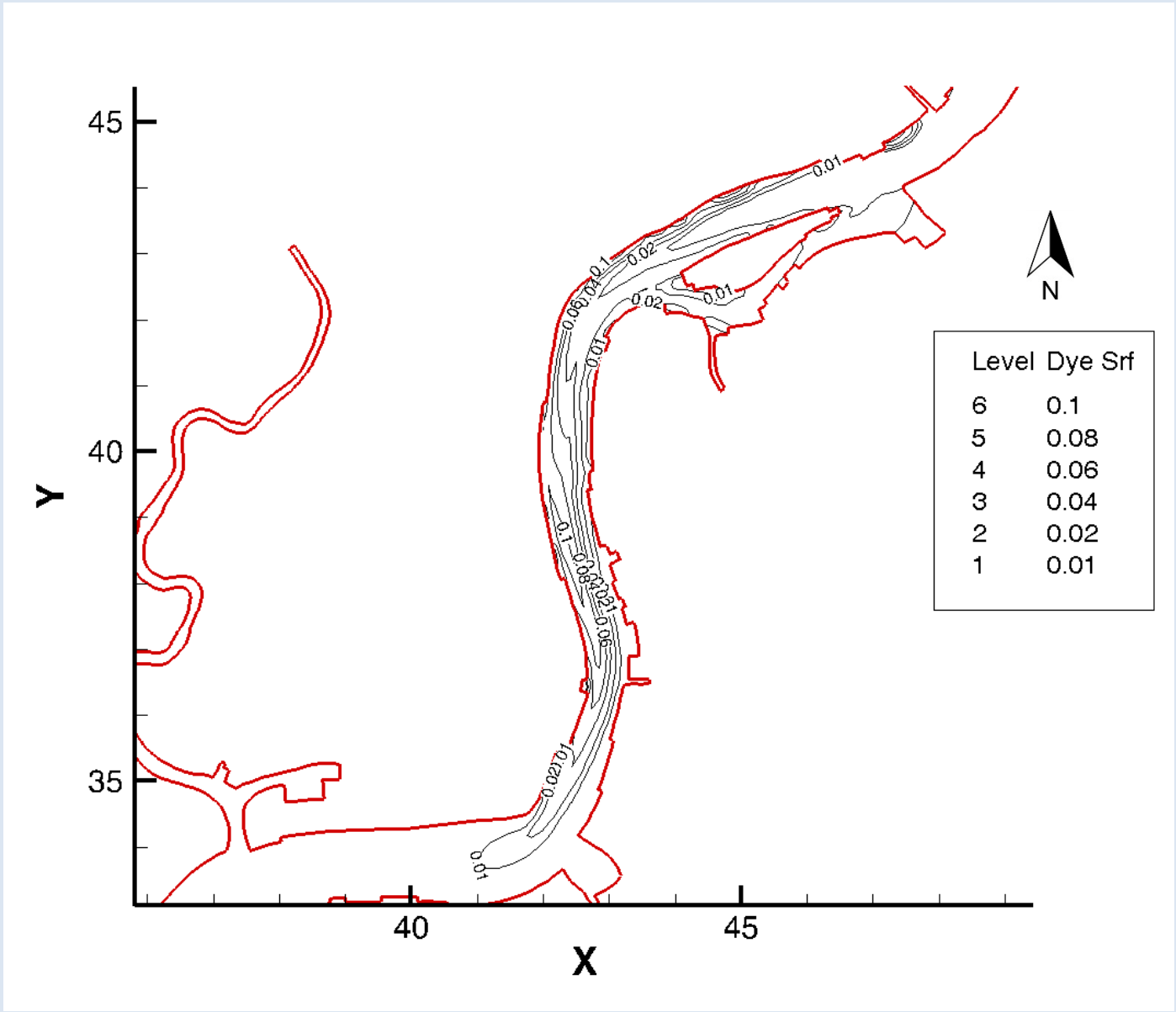
Dye Contour Day 2 (rotated 90° cw)



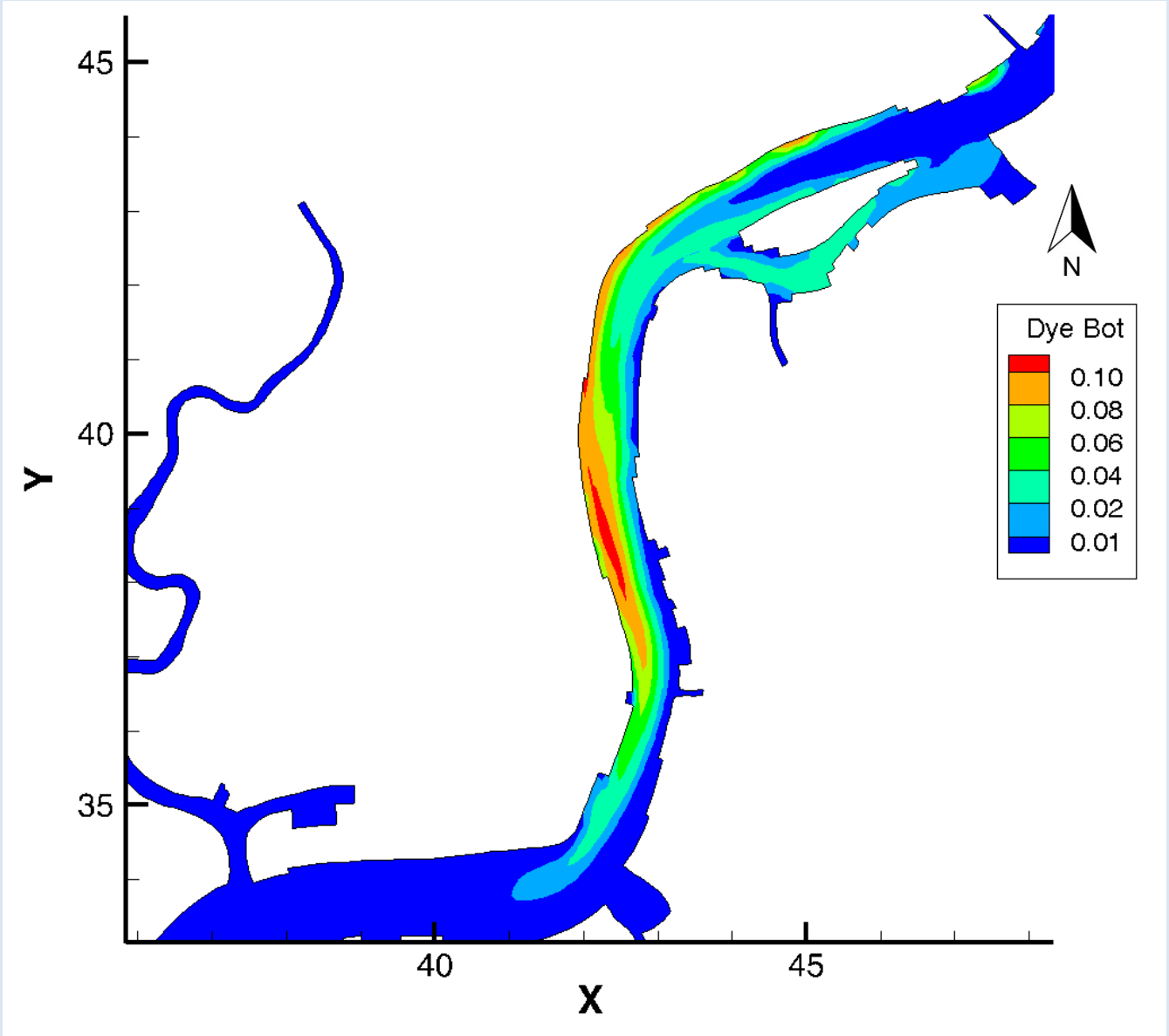


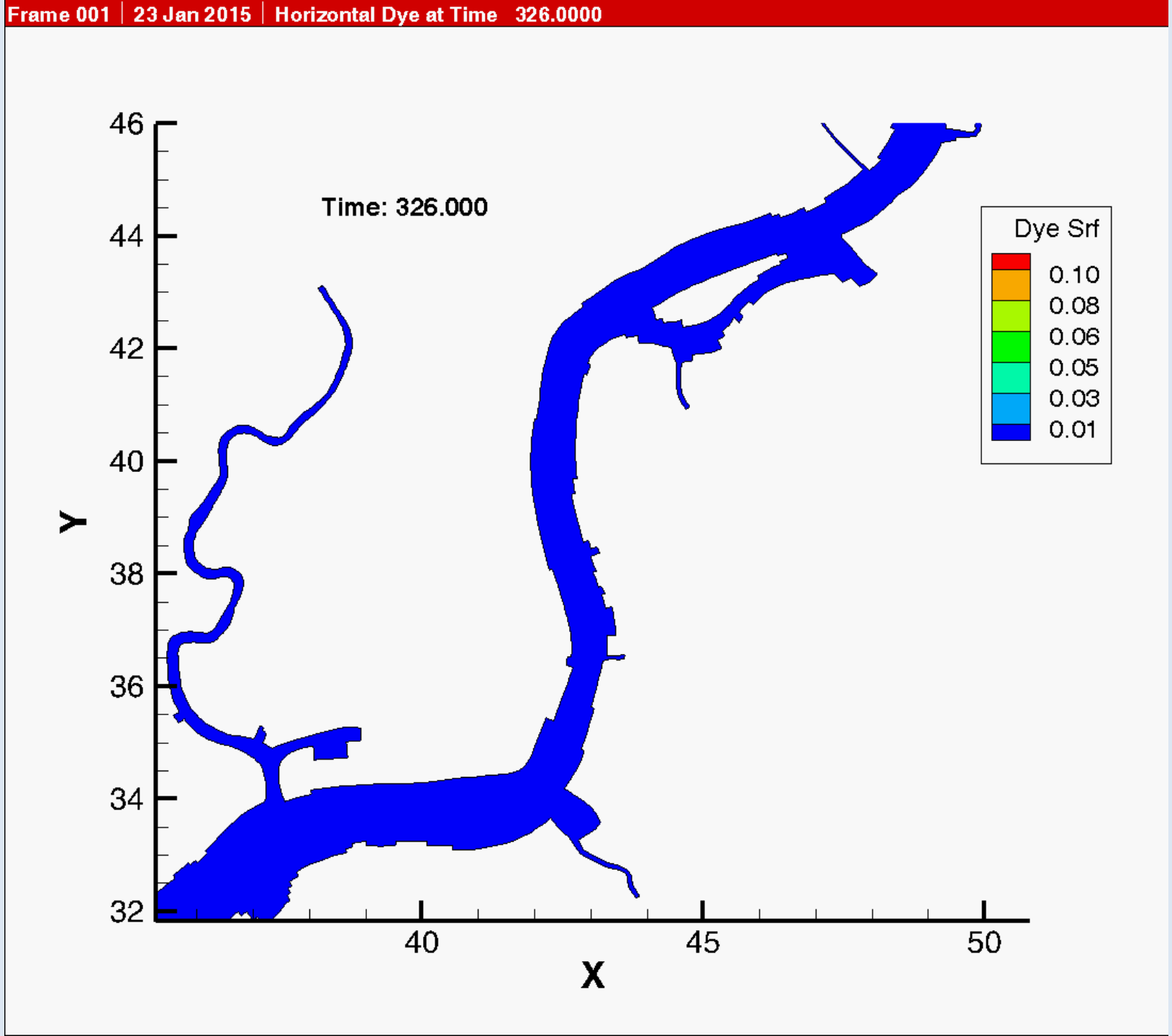
11/23/1997 Low Slack

Dye result “Map 3”

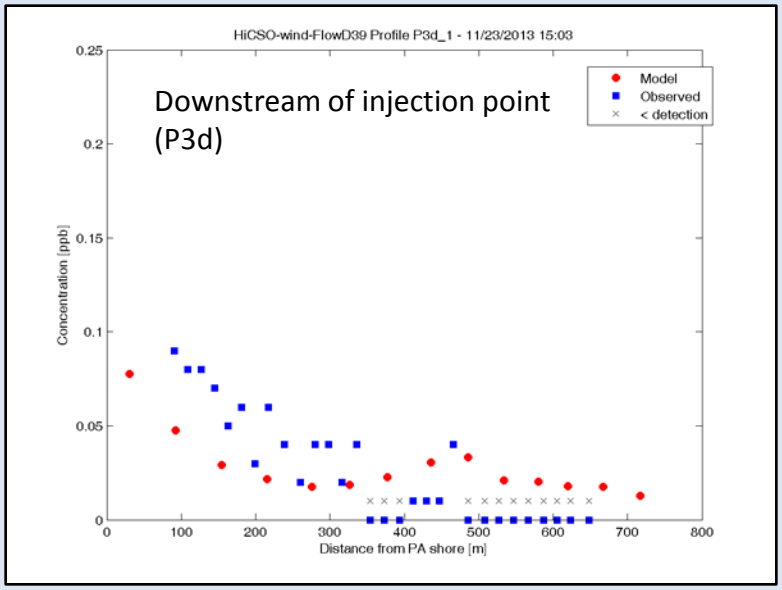


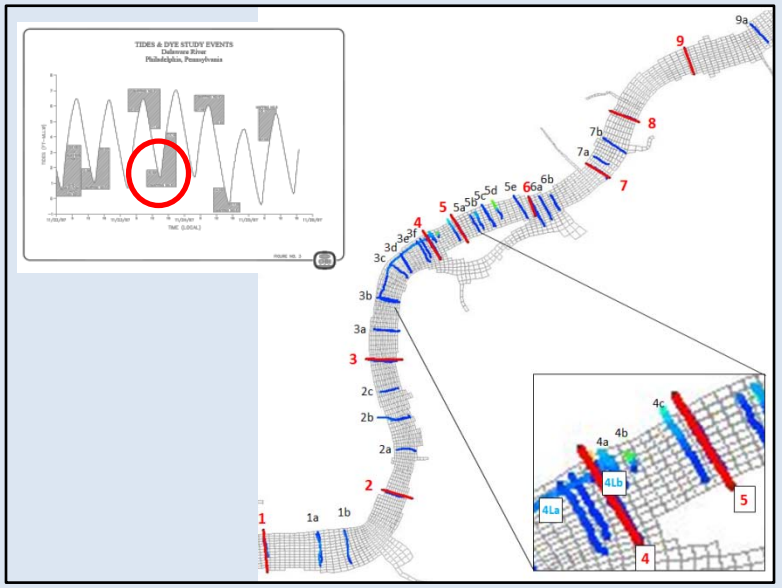
Dye result “Map 3”

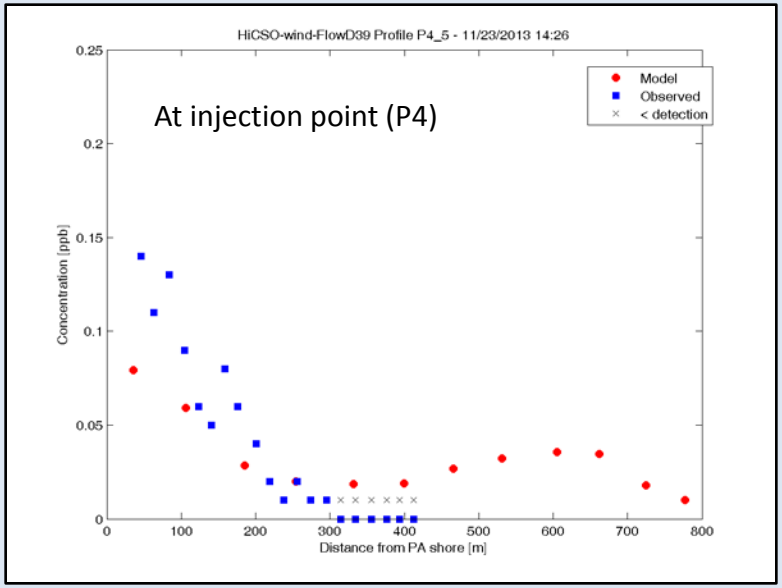


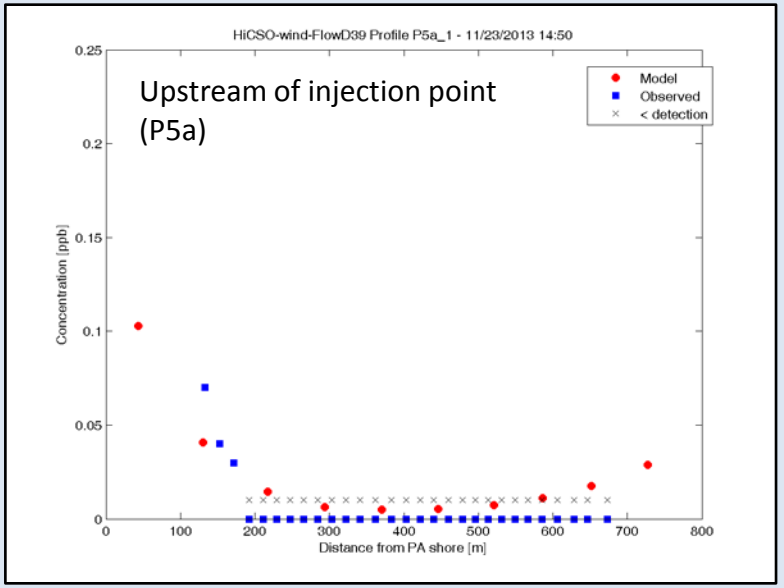

Frame 001 | 23 Jan 2015 | Horizontal Dye at Time 326.0000
Time: 326.000
Dye Srf
0.10
0.08
0.06
0.05
0.03
0.01
46
44
42
40
38
36
34
32
Y
40
45
50
X

Dye Scenario 1



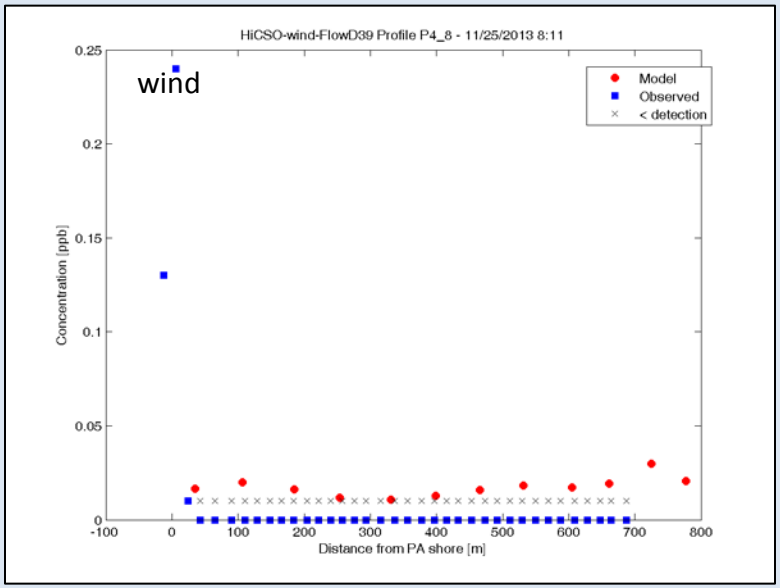


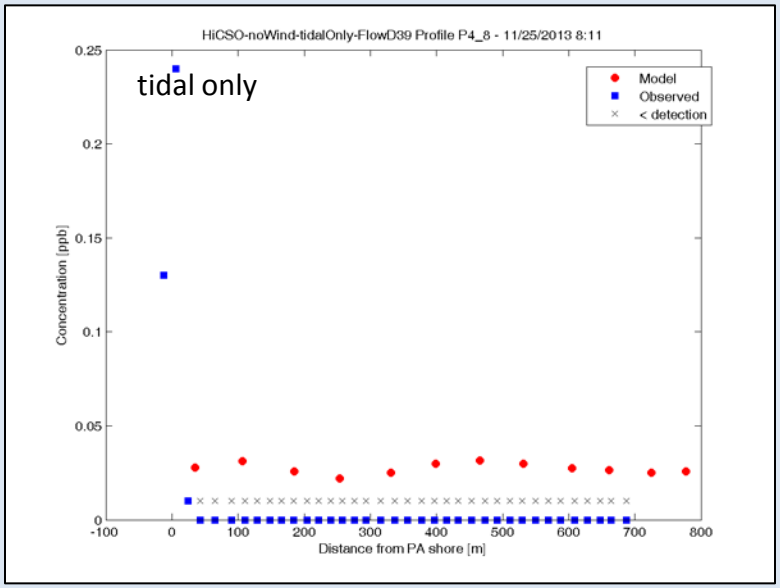


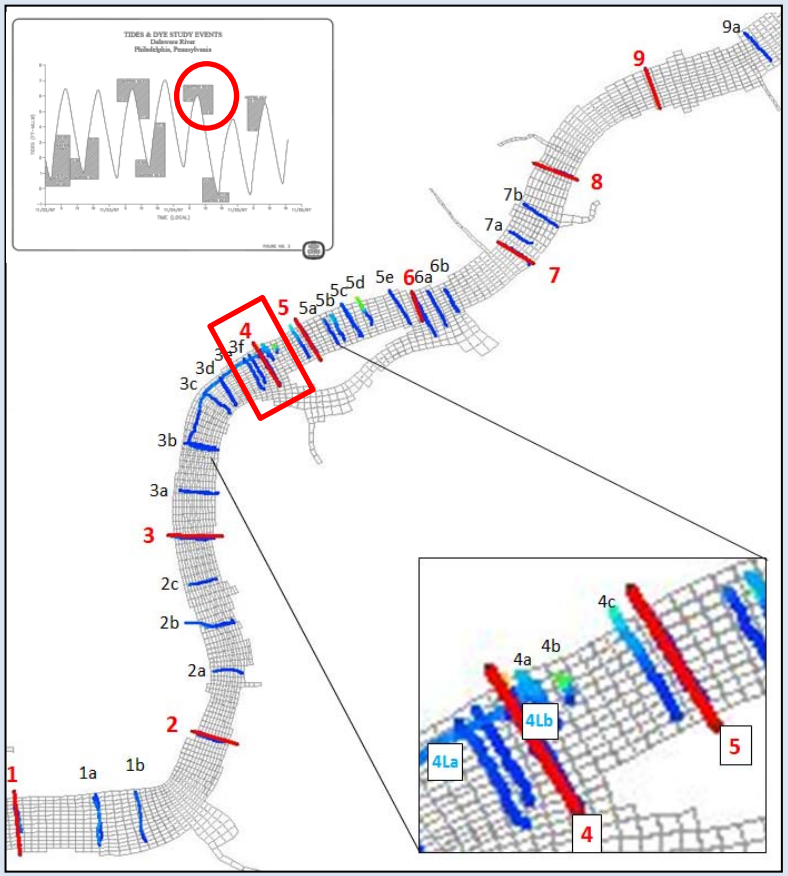


Scenarios 1 and 3: Wind vs. tidal only

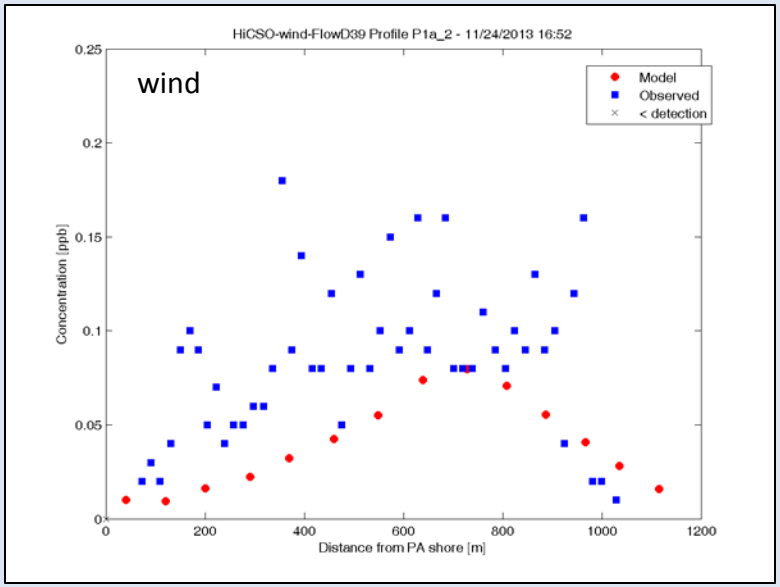
at injection point (P4)

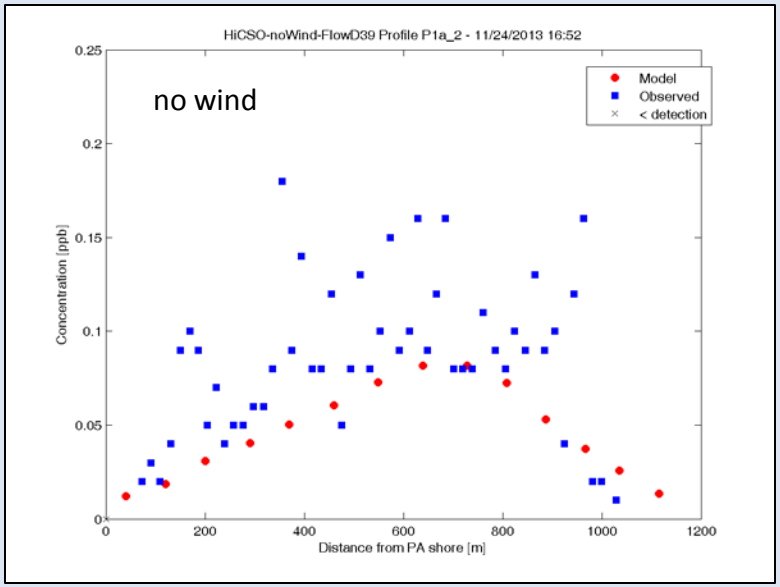


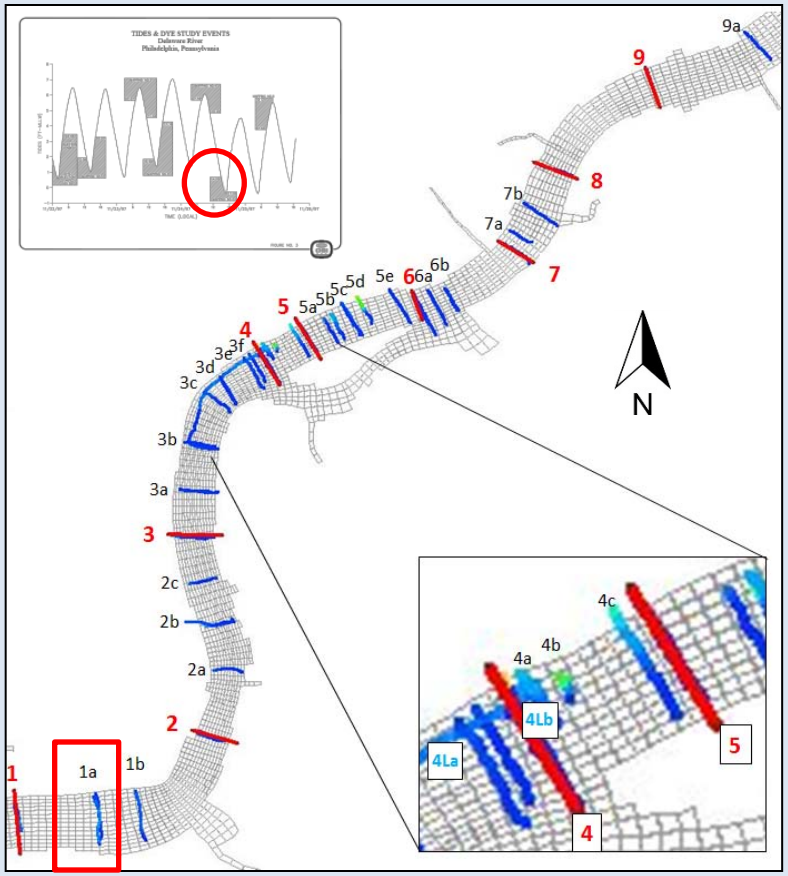




Scenarios 1 and 2: Wind vs. no local Wind







- Strong across channel oriented wind at profile location 1a
  - ➢ moves plume slightly to the south

Summary

- Modeled CSO discharge along with observed dye concentration resulted in good agreement with 1997 survey
- Down-bay wind results in set down in estuary
  - Model matches rapid advection of dye plume out of study area
- Local wind had negligible impact on water level as seen in subtidal plot
  - As expected in narrow, meandering riverine section
  - Minor impact of wind within the model domain only seen in one transect

Further hydrodynamic studies

- New dye study in Summer of 2014
  - Higher resolution data
  - 24 hour coverage over 3 days

Future PWD work

- Validation of EFDC water quality model for bacteria and dissolved oxygen
  - Predicting dissolved oxygen levels, including impacts from carbon, nutrients, sediments and algae
  - Predicting bacteria levels across a wide range of dry and wet weather conditions
- Use new dye study to investigate apparent tidally induced trapping from corrugated shoreline

Future model use

- Impacts of sea level rise and changing weather patterns on localized flooding and salt line intrusion
- Influences of a dynamic river on future capital infrastructure planning requirements

Acknowledgements

- Woods Hole Group * Academy of Natural Sciences of Drexel University * Chesapeake Biogeochemical Associates * University of Delaware * Rutgers University
- NOAA/NOS
- USEPA Region 3
- Delaware River Basin Commission (DRBC)
- USACE
- CDM Smith
- Tetra Tech

Thank you! Questions?

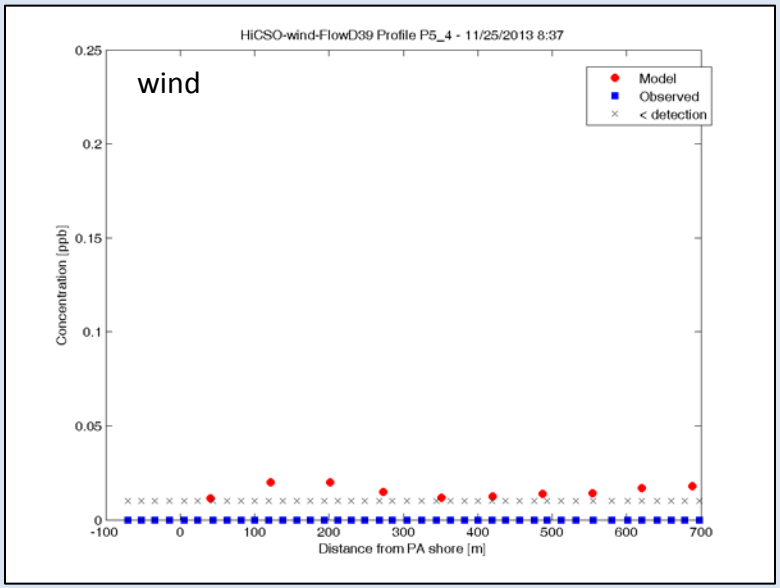
Contact info:

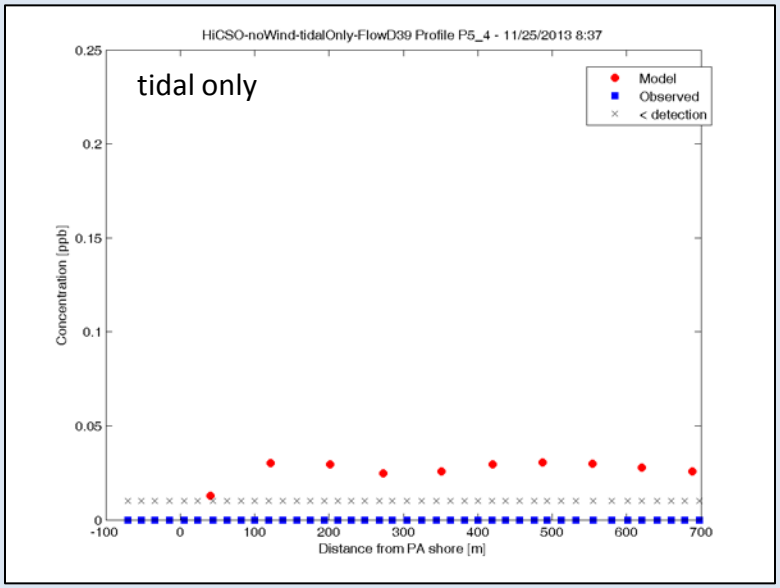
Phil.Duzinski@phila.gov

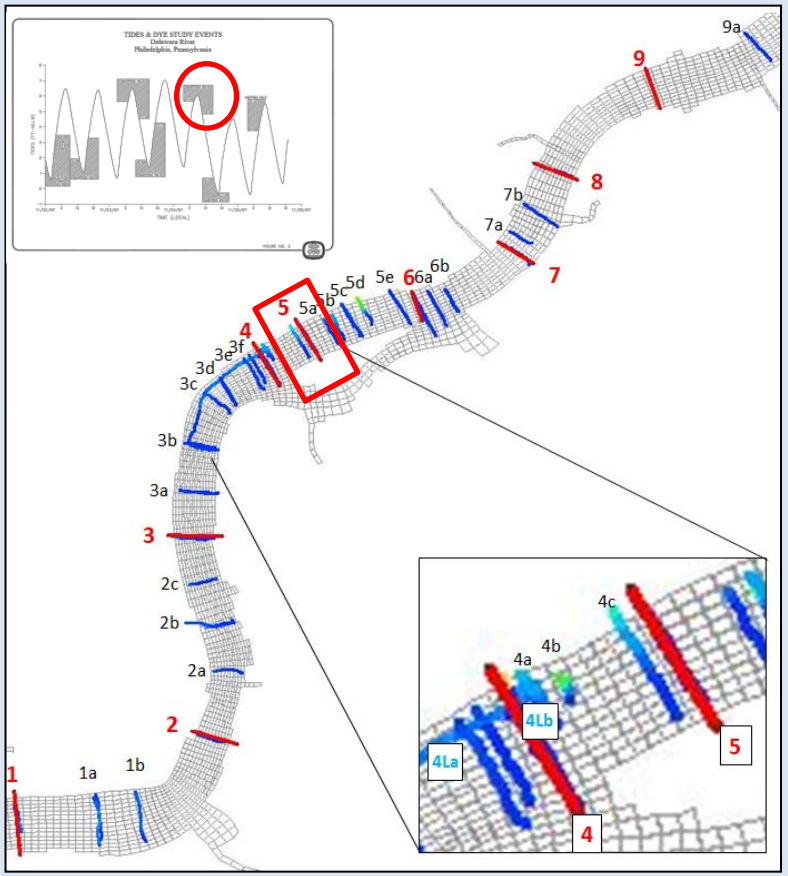
Ramona.McCullough@phila.gov

Scenarios 1 and 3: Wind vs. tidal only

upstream of injection point (P5)







Scenarios 1 and 3: Wind vs. tidal only

downstream of injection point (P3d)