

Calibration and Validation of the Pathogen Water Quality Model (PWQM) Report

Prepared on behalf of the following participating Permittees by Passaic Valley Sewerage Commission (NJ0021016) to Satisfy Permit Condition Part IV.D.3.d:

**Bayonne City (NJ0109240) PVSC
East Newark Borough (NJ0117846) PVSC
Harrison Town (NJ0108871) PVSC
Jersey City MUA (NJ0108723) PVSC
Kearny Town (NJ0111244) PVSC
Newark City (NJ0108758) PVSC
North Bergen MUA (NJ0108898) PVSC
Paterson City (NJ0108880) PVSC
Joint Meeting of Essex and Union Counties (NJ0024741) JMEUC
Middlesex County Utilities Authority (NJ0020141) MCUA
North Bergen MUA (Woodcliff) (NJ029084) NBMUA
Guttenberg Town (NJ0108715) NBMUA
North Hudson Sewage Authority - Adams Street STP (NJ0026085) NHSA
North Hudson Sewage Authority - River Road STP (NJ0025321) NHSA
Fort Lee Borough (NJ0034517) BCUA
Hackensack City (NJ0108766) BCUA
Ridgefield Park Village (NJ0109118) BCUA
Elizabeth City (NJ0108782) JMEUC
Perth Amboy City (NJ0156132) MCUA
Bergen County Utilities Authority (NJ0020028) BCUA**



**Passaic Valley Sewerage Commission
Essex County
600 Wilson Avenue
Newark, New Jersey**

September 2020

CERTIFICATIONS

Title: Calibration and Validation of the Pathogen Water Quality Model (PWQM) for the Passaic Valley Sewerage Commission

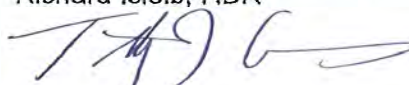
Preparer:

Modeling Project Manager:


Richard Isleib, HDR

9/11/2020
Date

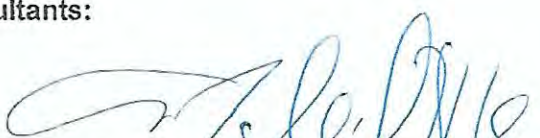
Modeling QA Officer:


Timothy J. Groninger, HDR

9/11/2020
Date

PVSC LTCP Consultants:

LTCP Consultant Project Officer:


Michael J. Hope, P.E., Greeley and Hansen

9/11/2020
Date


LTCP Consultant QA Officer:


Timothy J. Dupuis, P.E., CDM Smith

9/11/2020
Date

Passaic Valley Sewerage Commission:

PVSC Program Manager:


Thomas A. Laustsen, PE, Chief Operating Officer, PVSC

9/10/2020
Date

PVSC QA Officer:


Marques Eley, PVSC

9/10/2020
Date

New Jersey Department of Environmental Protection:

DEP Permits:

Joseph Mannick, CSO Coordinator

Date

DEP QA

Mark Ferko, Office of Quality Assurance


Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0021016 (Passaic Valley Sewage Commission)

Approval of Report:

Permittee:  9/10/2020
 Thomas A. Laustsen, PE Date
 Chief Operating Officer, Passaic Valley Sewage Commission

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:  9/10/2020
 Thomas A. Laustsen, PE Date
 Chief Operating Officer, Passaic Valley Sewage Commission

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0109240 (Bayonne City)

Approval of Report:

Permittee:

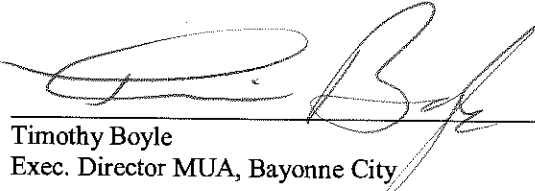

 Timothy Boyle
 Exec. Director MUA, Bayonne City

8.28.20
 Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:


 Timothy Boyle
 Exec. Director MUA, Bayonne City

8.28.20
 Date


CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**


NJPDES Number NJ0117846 (East Newark Borough)

Approval of Report:

Permittee:



 Frank Pestana
 Licensed Operator, Borough of East Newark




 Date


NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:



 Frank Pestana
 Licensed Operator, Borough of East Newark



 Date


CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

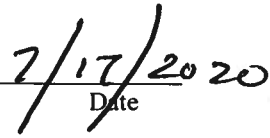
Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0108871 (Harrison Town)

Approval of Report:

Permittee:

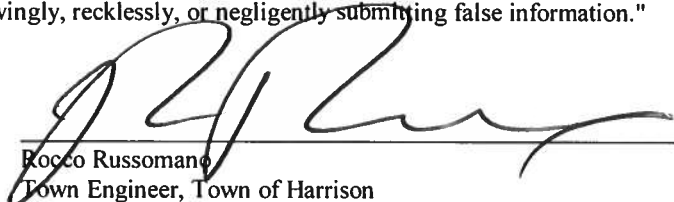

Rocco Russomano
Town Engineer, Town of Harrison



Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:


Rocco Russomano
Town Engineer, Town of Harrison



Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**


NJPDES Number NJ0108723 (Jersey City MUA)

Approval of Report:

Permittee:  July 9 2020
Rich Haytas Date
Senior Engineer, Jersey City MUA

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."


Permittee:  July 9 2020
Rich Haytas Date
Senior Engineer, Jersey City MUA

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0111244 (Kearny Town)

Approval of Report:

Permittee:  9/4/2020
Michael J. Neglia, P.E., P.L.S., C.M.E. Date
Town Engineer, Town of Kearny

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:  9/4/2020
Michael J. Neglia, P.E., P.L.S., C.M.E. Date
Town Engineer, Town of Kearny

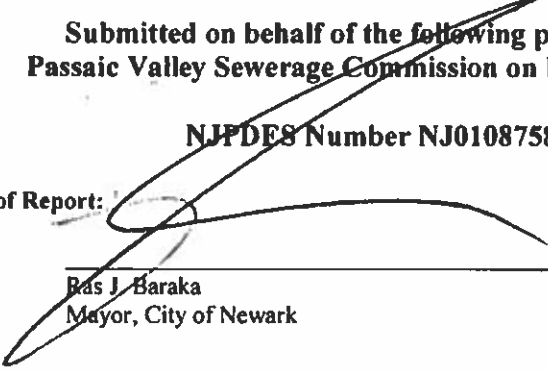
CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0108758 (Newark City)

Approval of Report:

Permittee:

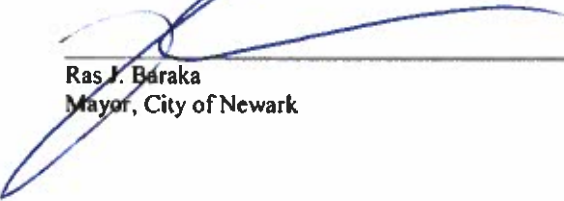

Ras J. Baraka
Mayor, City of Newark

9/10/20
Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:


Ras J. Baraka
Mayor, City of Newark

9/10/20
Date

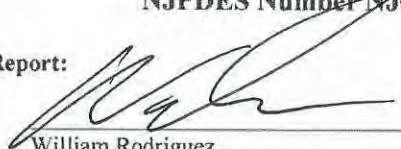
CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number ~~NJ~~0108880 (Paterson City)

Approval of Report:

Permittee:



William Rodriguez
Director Public Works, City of Paterson

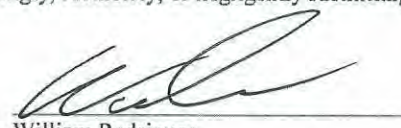


Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:



William Rodriguez
Director Public Works, City of Paterson



Date


CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0108898 (North Bergen MUA)

Approval of Report:

Permittee:



Frank Pestana
Exec. Director, North Bergen MUA

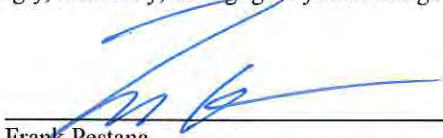


Date

NJPDES Certification:

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Permittee:



Frank Pestana
Exec. Director, North Bergen MUA




Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

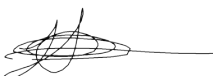
NJPDES Number NJ0024741 (Joint Meeting of Essex and Union Counties)

Approval of Report:

Permittee:	 <hr style="border: 0.5px solid black;"/> Hanifa Z. Johnson Exec. Director, Joint Meeting of Essex and Union Counties	7/10/20 Date
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NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:	 <hr style="border: 0.5px solid black;"/> Hanifa Z. Johnson Exec. Director, Joint Meeting of Essex and Union Counties	7/10/20 Date
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CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0020141 (Middlesex County Utilities Authority)

Approval of Report:

Permittee:

Joseph Cryan
Executive Director, Middlesex County Utilities Authority

9/6/20
Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:

Joseph Cryan
Executive Director, Middlesex County Utilities Authority

9/6/20
Date


CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

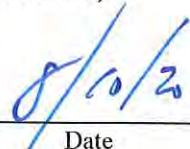
NJPDES Number NJ0029084 (North Bergen Woodcliff)

Approval of Report:

Permittee:



Frank Pestana
Executive Director, North Bergen MUA

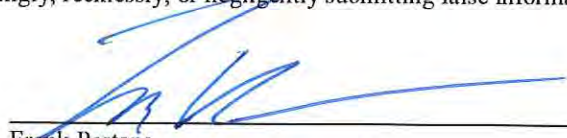


Date

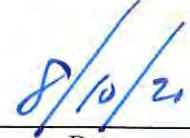
NJPDES Certification:

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Permittee:



Frank Pestana
Executive Director, North Bergen MUA



Date


CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0108715 (Guttenberg Town)

Approval of Report:

Permittee:



Frank Pestana
Licensed Operator, Town of Guttenberg



Date

NJPDES Certification:

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Permittee:



Frank Pestana
Licensed Operator, Town of Guttenberg



Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0025321 (North Hudson Sewerage Authority)

Approval of Report:

Permittee: *Fredric J. Poci* *July 7, 2020*
 Fredric J. Poci, P.E. Date
 Authority Engineer, North Hudson Sewerage Authority

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee: *Fredric J. Poci* *July 7, 2020*
 Fredric J. Poci, P.E. Date
~~Executive Director~~, North Hudson Sewerage Authority
Authority Engineer

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**


NJPDES Number NJ0034517 (Fort Lee Borough)

Approval of Report:

Permittee:  8/20/20
 Alfred R. Restaino Date
 City Administrator, City of Fort Lee

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:  8/20/20
 Alfred R. Restaino Date
 City Administrator, City of Fort Lee

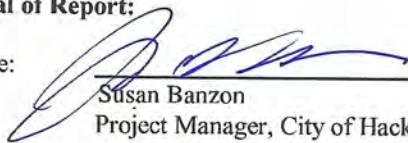
CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0108766 (Hackensack City)

Approval of Report:

Permittee:

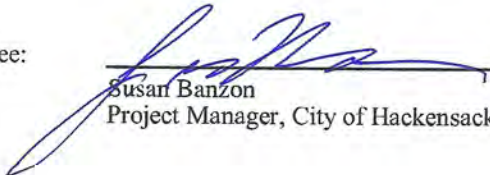

Susan Banzon
Project Manager, City of Hackensack

8/28/20
Date

NJPDES Certification:

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Permittee:


Susan Banzon
Project Manager, City of Hackensack

8/28/20
Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0109118 (Ridgefield Park Village)

Approval of Report:

Permittee:  8/16/2020
Mark Olson Date
Commissioner, Village of Ridgefield Park

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:  8/16/2020
Mark Olson Date
Commissioner, Village of Ridgefield Park

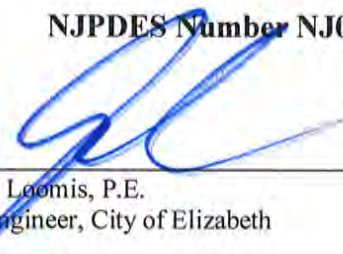
CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT

**Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group**

NJPDES Number NJ0108782 (Elizabeth City)

Approval of Report:

Permittee:



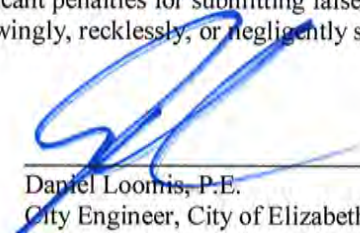
Daniel Loomis, P.E.
City Engineer, City of Elizabeth

7/13/2020
Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:



Daniel Loomis, P.E.
City Engineer, City of Elizabeth

7/13/2020
Date

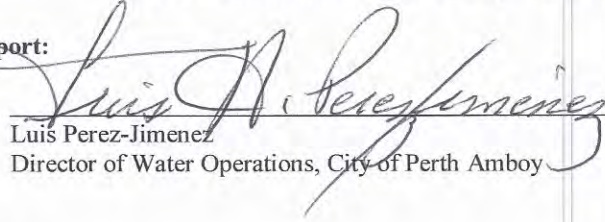
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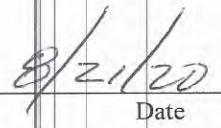
Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0156132 (Perth Amboy City)

Approval of Report:

Permittee:

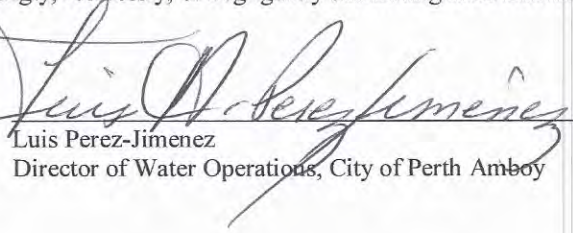

Luis Perez-Jimenez
Director of Water Operations, City of Perth Amboy

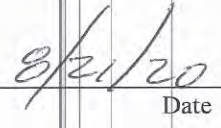

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NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:


Luis Perez-Jimenez
Director of Water Operations, City of Perth Amboy


Date

CALIBRATION AND VALIDATION OF THE PATHOGEN WATER QUALITY MODEL (PWQM) REPORT


Submitted on behalf of the following participating Permittee by
Passaic Valley Sewerage Commission on behalf of the NJ CSO Group

NJPDES Number NJ0020028 (Bergen County Utilities Authority)

Approval of Report:

Permittee:


Robert E. Laux
Executive Director, Bergen County Utilities Authority


Date

NJPDES Certification:

"I certify under penalty of law that this document and all attachments were prepared either: (a) under my direction or supervision; or (b) as part of a cooperative performed by members of the NJ CSO group effort in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for purposely, knowingly, recklessly, or negligently submitting false information."

Permittee:


Robert E. Laux
Executive Director, Bergen County Utilities Authority


Date

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1 Introduction

1.1 Purpose of this Report

This report presents the documentation of the development, calibration, and validation of the Pathogens Water Quality Model (PWQM) that will be used to provide support for the development of Long-Term Control Plans (LTCPs) for the NJ CSO Group. This report also provides some information for the basis of the Baseline Conditions to show that the calibration, validation, and baseline inputs were developed in a consistent manner.

1.2 Background

Northern New Jersey contains many older communities that have combined sewer systems. These combined sewers deliver sewage (sanitary flow) to sewage/wastewater treatment plants for treatment. The combined sewers also transport rainfall runoff to prevent flooding and for treatment. During precipitation events, the combined sewer system may contain more flow than can be handled at the treatment plant, so regulators were designed to divert flow into nearby waterbodies under high flow conditions. These discharges are called combined sewer overflows. These outfalls require permits from the New Jersey Department of Environmental Protection (NJDEP).

The New Jersey Pollutant Discharge Elimination System (NJPDDES) permits issued to Passaic Valley Sewerage Commission (PVSC) and each Combined Sewer Overflow (CSO) Permittee include requirements to cooperatively develop a CSO Long Term Control Plan (LTCP). PVSC has undertaken the construction of a water quality model on behalf of these permittees to support the development of a LTCP.

The NJ CSO Group was originally formed to work cooperatively to fulfill the requirements of the last CSO General Permit. The group was expanded to include more permittees that discharge to the tidally connected waterbodies in the NY/NJ Harbor Estuary. Member utilities provide services to multiple municipalities and the interrelationships are numerous and varied. For example:

- The utilities responsible for providing treatment typically do not have permitted CSOs, which are the responsibility of the municipalities;
- The municipalities with permitted CSOs may not be able to reduce their discharges without the treatment utility modifying its treatment and/or conveyance system;
- Certain municipalities own and operate their own combined sewer systems, interceptors, CSO control facilities, and pumping stations; while others do not own their collection systems; and
- Combinations of utilities and municipalities may jointly own force mains, pumping stations, and other appurtenances, but remain independently permitted by the State of New Jersey.

Because of these complex interrelationships, the NJ CSO Group elected to have PVSC lead the technical work required for CSO permit compliance with participating members paying for the program through reimbursement to PVSC for their proportionate share of sampling, model development, and report writing.

1.3 Purpose and Objectives

The pathogen water quality model (PWQM) was prepared to facilitate development of CSO LTCPs for the NJ CSO Group. Table 1-1 shows the members of the NJ CSO Group. The model is not a NJPDES permit requirement, but rather is being developed to allow the CSO permittees to employ the Demonstrative Approach to LTCP development, should they choose to do so. The model can also be used to support that meeting one of the Presumptive Approach criteria provides an adequate level of control to meet the water quality-based requirements of the Clean Water Act. The PWQM is the product of upgrading and recalibrating an existing hydrodynamic and water quality model (PATH) that was previously developed. More recent data collected based on the System Characterization Quality Assurance Project Plan (QAPP) and the Baseline Compliance Monitoring QAPP provided major sources of information in the development of the updated model.

The enhanced, validated model will be used to calculate bacteria concentrations in the waters of the NY/NJ Harbor complex under existing and anticipated future conditions to demonstrate attainment of applicable water quality standards. The previously developed Harbor Estuary Program (HEP) pathogen model (PATH) developed by HydroQual (now part of HDR) was the platform for model refinement. PATH consists of two major components - a hydrodynamic module (Estuarine Coastal and Ocean Model - ECOMSED) that defines the transport of the estuarine water throughout the Harbor-Bight-Sound complex, and a water quality module (Row-Column AESOP - RCA) which tracks the fate of bacteria in the water column. The water quality component of PATH built to track the fate of fecal indicator bacteria (FIB, E. coli, fecal coliform and enterococci) by incorporating sewer system model calculated outputs of CSO and stormwater discharges as inputs, along with boundary tidal, flow, and meteorological conditions. The model projects varying pollutant concentrations spatially, vertically, and temporally. The PATH model was reviewed by a model evaluation group (MEG) comprised of independent modeling experts assembled in a manner similar to the one outlined in the PWQM modeling QAPP. The creation of PWQM builds on the PATH work and updates it to present day water quality modeling standards.

1.4 Physical Setting

The primary study area of the PVSC LTCP Project (Project hereafter) are waters located in the northern part of the State of New Jersey affected by CSO discharges. These areas are adjacent to waters located in the southern part of the State of New York. The approximate study area is shown in Figure 1-1, and includes the Passaic, Hackensack, lower Hudson, Raritan and Elizabeth Rivers, Raritan Bay, the Upper and Lower Bays of NY-NJ Harbor System, connecting waterways Kill van Kull and Arthur Kill, and Newark Bay.

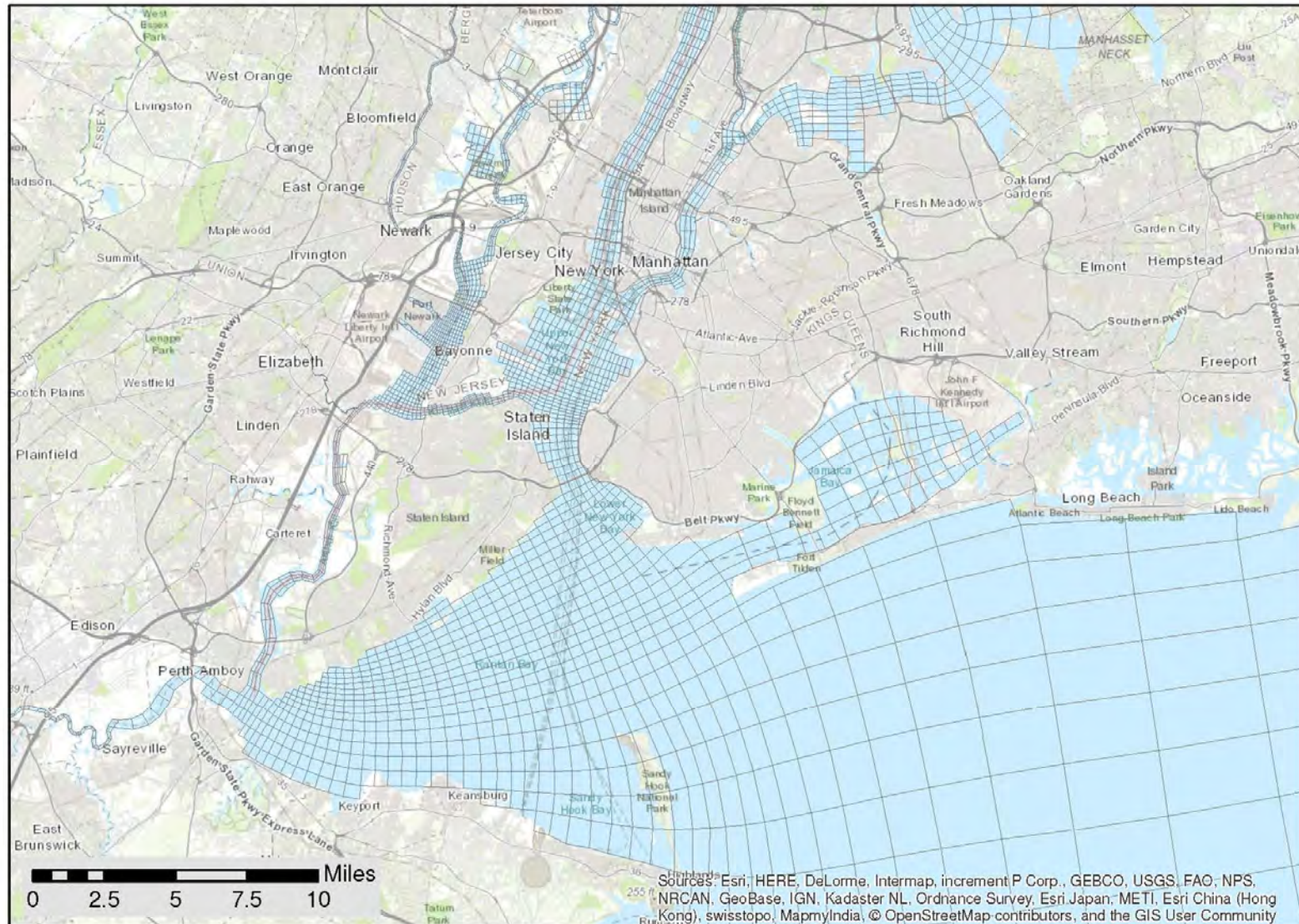


Figure 1-1. Project Area

The NY-NJ Harbor System is among the more complex estuarine systems in the United States, a network of multiple tidal straits connecting Raritan Bay, Newark Bay, Jamaica Bay, and the Long Island Sound with the New York Bight. These straits exchange freshwater from the several rivers of the estuarine system with the more saline waters from the Atlantic Ocean brought in through the tides.

The bathymetry of the NY-NJ Harbor system is characterized by complex networks of deep shipping channels from the New York Bight Apex (i.e., Ambrose Channel) through the Narrows and branches to Upper Bay and to Newark Bay through the Kill van Kull. The U.S. Army Corps of Engineers (USACE) maintains the navigability of the shipping channels to facilitate the movement of container ships in and out of Newark Bay and Upper Bay in support of New York-New Jersey Port operations. These shipping channels add additional complexity to the dynamics of the system because they are deep (13 -18 m) relative to near-shore depths, and because recent multi-phased Harbor Deepening Projects have changed many (but not all) channel depths.

The hydrodynamics of the NY-NJ Harbor system is predominantly controlled by three forcing mechanisms: freshwater flows, tides, and winds. The major sources of freshwater inflows are rivers. The Hudson River is the largest freshwater contributor by far (about 460 m³/sec or 16,200 cfs as measured at Green Island), followed by the Lower Passaic River (36 m³/sec or 1,300 cfs as measured at Little Falls), the Raritan River (34 m³/s or 1,200 cfs as measured at Bound Brook). The Hackensack River contributes as well, although only 1.9 m³/s (70 cfs) due to flow diversion at Oradell Dam for drinking water.

Tidal influence has significant importance within the NY-NJ Harbor estuarine system. A harmonic analysis of water elevation data measured at the Battery NOAA tide station suggests that the semi-diurnal constituents (M₂ and S₂) dominate the system. A spectral analysis of the water elevations also indicated that maximum variance occurred at an interval of approximately 12.4 hours, suggesting a dominant semi-diurnal tidal signal. The resultant tidal harmonic constituents are provided in Table 1-. The table indicates that the study area has predominant semi-diurnal tides.

Table 1-2. Characteristics of Principal Tidal Constituents at the Battery

Constituents	Period (Hrs)	Amplitude (m)	Phase (deg, EST)
O ₁	25.82	0.05	107
K ₁	23.93	0.10	104
M ₂	12.42	0.67	234
S ₂	12.00	0.13	253
N ₂	12.66	0.16	218

NOAA predicted tidal currents in the Upper Bay are found to be moderate, with average maximum amplitudes of 0.75 m/sec (2.5 ft/s) during ebb and 0.5 m/sec (1.6 ft/s) during flood. Due to strong estuarine circulation effects, during high-flow periods the surface currents, directed towards the ocean (ebb currents), become much stronger than the bottom currents, indicating the presence of strong vertical shear. During high freshwater flow, classical two-layer estuarine circulation is observed in the NY-NJ Harbor System, with surface currents carrying freshwater seaward and bottom currents conveying saline water upstream.

Strong and persistent wind events in the region can have a strong effect on the circulation in the estuary, and in some extreme cases can disrupt the normal pattern of estuarine circulation. Modeling analysis (Pence, 2004, Pecchioli et al., 2006) suggests that strong winds from the west will flush water and water borne constituents from Newark Bay out through the Kill van Kull, with weaker flow in through the Arthur Kill. Model computations indicate that this flow pattern changes direction when strong winds blow from the east, i.e., flow enters the Kill van Kull from the upper portion of NY-NJ Harbor and then enters Newark Bay (Pecchioli et al., 2006).

2 Observational Data Supporting Model

2.1 Quality and Quantity

2.1.1 Hydrodynamic Model Supporting Data

Model calibration for a model as large as the PVSC LTCP requires extensive field data, including surface water elevation, current velocity, temperature, and salinity. Since there is no unique data source with enough spatial and temporal coverage to be used as the sole basis of model calibration, a number of datasets were collected, reduced and analyzed. For the present study, emphasis is placed only on the years for which extensive data are available. The available datasets were compiled from HDR's previous modeling studies of NY-NJ Harbor System. These datasets include long-term water quality surveys conducted by the NJ Dischargers Group, the New York City Department of Environment Protection (NYCDEP), Meadowlands Environmental Research Institute (MERI) programs, the Hudson River Environmental Condition Observing System, the U.S. Environmental Protection Agency, and NOAA tide gages per the following:

- Monthly or weekly field survey data collected by NJ Harbor Dischargers Group from 2000 to 2018: Temperature/Salinity (T/S), (PVSC, 2019);
- Field survey data collected by HDR in 2016 and 2017 as part of the Baseline Compliance Monitoring: T/S (PVSC, 2018);
- Monthly or weekly field survey data collected by NYC DEP from 1970s to present: T/S, (NYCDEP, 2019);
- Quarterly and in-situ T/S data collected by MERI in the Hackensack River from 1993 to present (<https://meri.njmeadowlands.gov/>);

- In-situ T/S mooring data as part of Hudson River Environmental Conditions Observing System (HRECOS): PVSC plant, Castle Point, Pier 84, Yonkers, and Piermont Pier (<https://hrecos.org/>);
- Field data collected by Tierra Solutions Inc. (TSI) in 2009-2010 in the Lower Passaic River, Hackensack River, Newark Bay, Kill van Kull, Arthur Kill: in-situ moorings (T/S, and current meters); and
- NOAA tide gages at Sandy Hook, Bergen Point, the Battery, and Kings Point (<https://tidesandcurrents.noaa.gov/index.html>).

The sampling locations for available water elevations, current meter, temperature, and salinity data are presented in Figure 2-1 and Figure 2-3.

The monthly or weekly T/S monitoring data collected at more than 30 locations in NY-NJ Harbor by NJ Dischargers Group and NYC DEP were available in the Passaic and Hackensack Rivers, Hudson River, Upper and Lower Bays, as well as the Kills. These data sets provide long-term spatial and temporal variations of temperature and salinity conditions at most of the water bodies within NY-NJ Harbor system. HDR field survey team also performed water quality surveys during wet weather events in 2016 and 2017 period (Figure 2-1).

The Physical Water Column Monitoring data collected between 2009 and 2010 in five locations in Lower Passaic River, one location in Hackensack River, two locations in Newark Bay, and one each in Hackensack River, Kill van Kull, and Arthur Kill provided valuable hydrodynamic information in the western side of NY-NJ Harbor system consisting of surface and bottom moorings that measured water elevations, temperature, and conductivity as well as vertical profile of bottom mounted Acoustic Doppler Current Profilers. These locations are shown in Figure 2-2.

The HRECOS data sets consist of in-situ measurements of water temperature and salinity at five location within NY-NJ Harbor system, which provide concurrent T/S information: PVSC Plant at the mouth of Lower Passaic River, Castle Point, Pier 84, Yonkers, and Piermont Pier. Data collected in 2016 were used for the validation of model for the Newark Bay area. These HRECOS stations are shown in Figure 2-1.

Water elevation data from NOAA tide gages through NY-NJ Harbor system were also incorporated in model calibration. These are high-quality water elevation data sets and their records go back to more than 100 years. NOAA tide stations are shown in Figure 2-3.

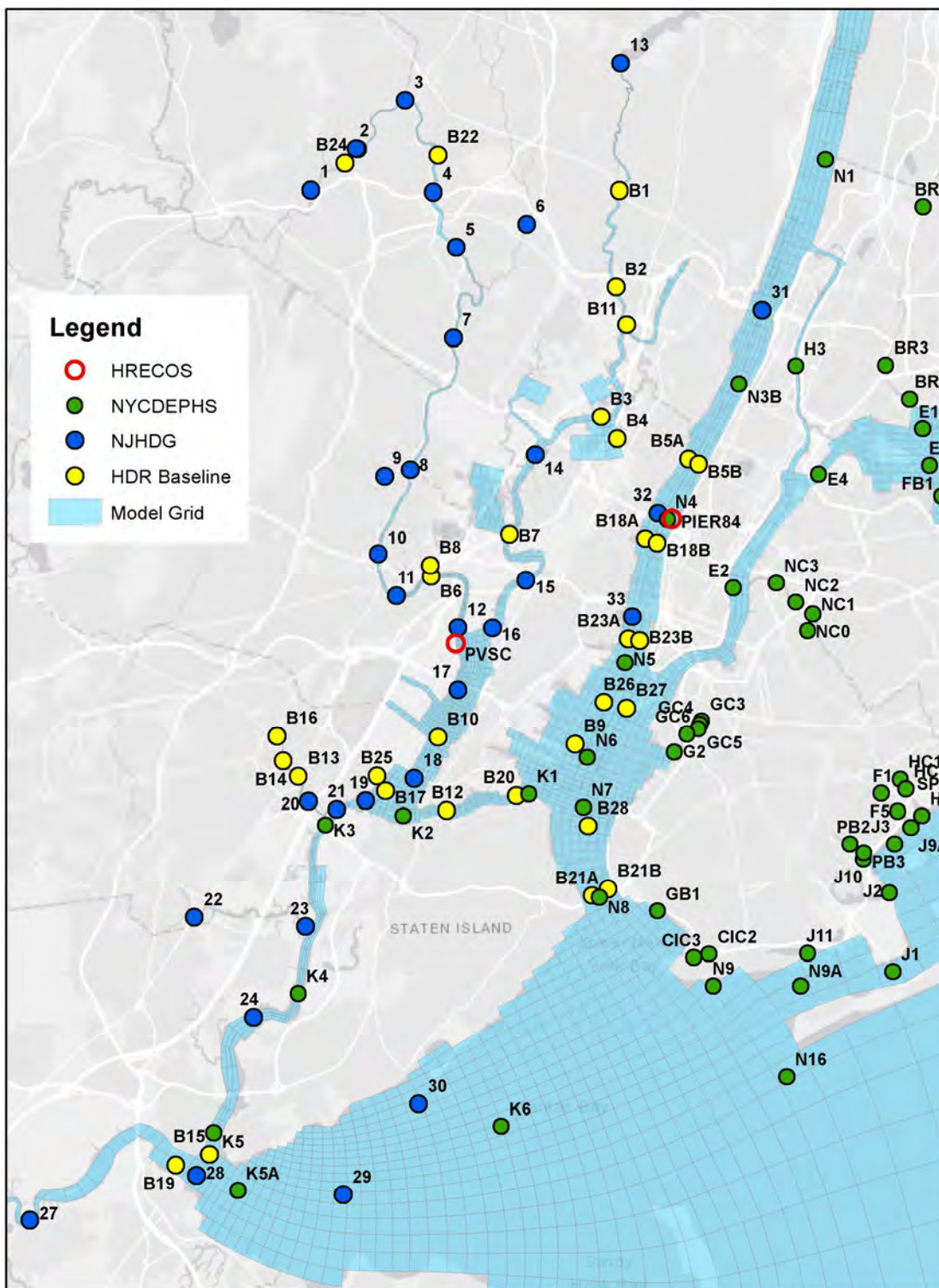


Figure 2-1. NJ Dischargers Group, HDR, and MERI Water Quality Survey Stations

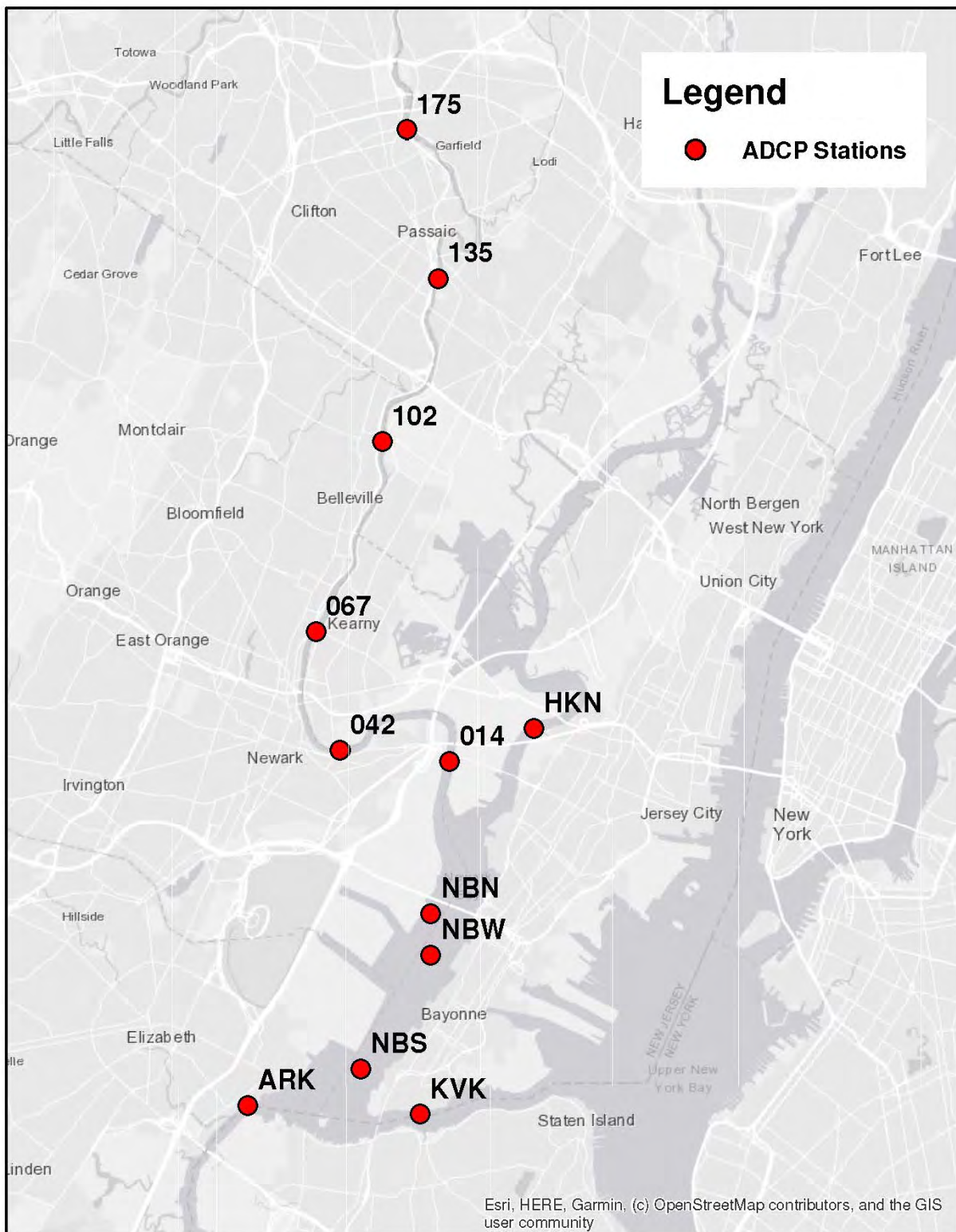


Figure 2-2. Map of ADCP Mooring Stations: 2009-2010

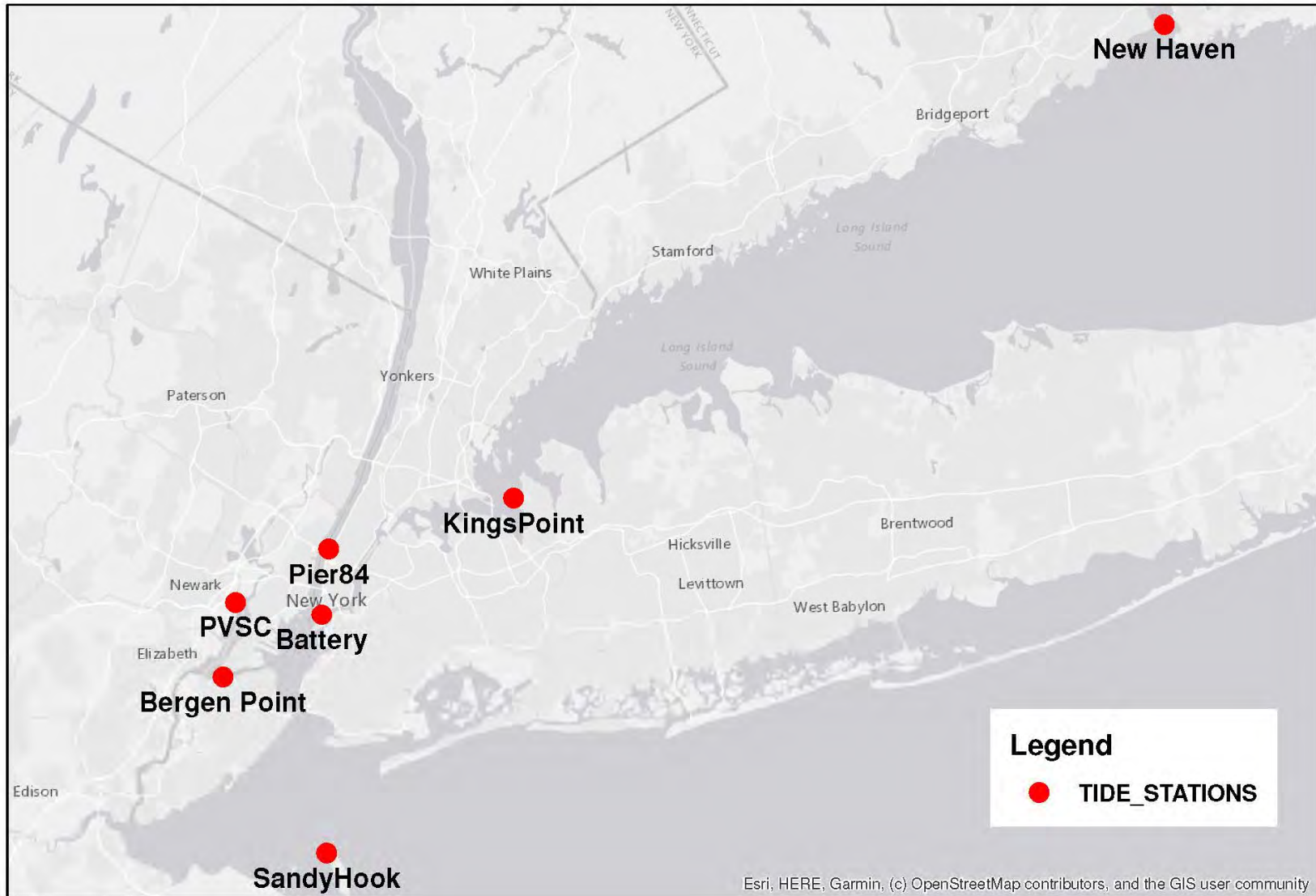


Figure 2-3. NOAA Tide Stations

Data from all of the above studies were processed and prepared for numerical model calibration/validation and for the evaluation of the physical mechanisms driving the flow through the NY-NJ Harbor System. Preliminary model calibration was done using 2009-2010 in-situ mooring data for water elevations and currents and model validation was done comparing model results in 2016 and 2017 period.

2.1.2 Water Quality Model Supporting Data

The Baseline Compliance Monitoring Program (BCMP) memorandum and its attachments (PVSC, 2018) summarize the data that HDR collected in support of PVSC's LTCP modeling. The BCMP was modeled, in part, on the program performed by the New Jersey Harbor Dischargers Group (NJHDG). NJHDG is an allied collaborative undertaking that includes nine (9) sewerage agencies representing eleven (11) wastewater treatment plants in northeastern New Jersey that discharge into the New Jersey portion of the NY/NJ Harbor Estuary. PVSC, Bergen County Utilities Authority (BCUA), Joint Meeting of Essex & Union Counties (JMEUC), Middlesex County Utilities Authority (MCUA), North Bergen Municipal Utilities Authority (NBMUA), and North Hudson Sewerage Authority (NHSA) are overlapping members of NJHDG and the NJ CSO Group. These agencies collaborate, jointly fund, and perform various water quality studies in the region, including the Long-Term Water Quality Monitoring Program initiated in 2003. PVSC has taken the lead for the NJHDG monitoring program which is modeled after the successful NYCDEP Harbor Survey. The purpose of NJHDG's long-term water quality monitoring program is to develop ambient water quality data for the Hackensack River, Passaic River, Rahway River, Elizabeth River, Raritan River, Raritan Bay, Newark Bay, and the New Jersey portions of the Hudson River, Upper New York Harbor, and the Arthur Kill, allowing long-term evaluation of water quality in these areas by providing baseline and annual information on water quality in these waterbodies as it relates to current water quality standards. This evaluation identifies changes in water quality over time under varying seasonal conditions, providing a basis for documenting pollution sources and water quality improvements resulting from the implementation of pollution control programs.

The BCMP was designed to generate sufficient data to establish existing ambient water quality conditions for pathogens in the CSO receiving waters and to update, calibrate, and validate a pathogen water quality model of the receiving water bodies. The resulting model is being used to support the development of CSO LTCPs by PVSC and participating members of the NJ CSO Group.

The BCMP included three parallel data collection efforts:

1. Baseline Sampling was modeled after and intended to supplement the approved routine sampling program of the NJHDG. The sampling frequency matched NJHDG, varying with time of year as follows:
 - a. Spring (May-Jun): Biweekly (4 dates);
 - b. Summer (Jul-Sep): Weekly (12 dates); and
 - c. Winter (Oct-Apr): Monthly (7 dates).

Baseline sampling was conducted at 65 stations.

2. Source Sampling targeted the major influent streams within the study area to establish non-CSO loadings and coincided with the NJHDG and Baseline Sampling. Any discussion of field activities applicable to Baseline Sampling is also applicable to Source Sampling because both sets of stations were sampled during the same field efforts. Source sampling was conducted at 7 Stations.
3. Event Sampling was timed to coincide with rainfall to capture three discrete wet-weather events over the course of the year on each segment of the NY/NJ Harbor complex impacted by CSOs. Event sampling was conducted at 25 of the 65 Baseline Sampling stations.

Field work for these three elements was completed on April 28, 2017. A total of 23 baseline and source sampling events were completed. The goal of the event sampling was to capture three significant wet weather events (precipitation >0.5 inches in 24 hours) at each targeted station, which was completed across four sampling events (one set of samples was collected across two precipitation events).

Table 2-1 provides a breakdown of the station locations. Stations with numbered designations are original NJHDG stations. Station names beginning with the letter B are added stations for the Baseline Compliance Monitoring. Stations names beginning with the letter S are Source Sampling stations. Figure 2-2 presents NJHDG stations along with those sampled under the Baseline Compliance Monitoring Program. Field measurement, sampling methods, and laboratory procedures are generally the same for all three parallel data collection efforts.

Table 2-1. Baseline Compliance Monitoring Stations

Station	Waterbody	Coordinates		Samples ³	Location Type ⁴	Additional Location Information	
		Lat	Lon				
Passaic River & Tributaries	PAS-C	Passaic River	40.88217	-74.34000	1	NJHDG	Horseneck Rd Bridge
	POM-A	Pompton River	40.91442	-74.27100	1	NJHDG	US 202/Mountainview Blvd
	PAS-B	Passaic River	40.89700	-74.27300	1	NJHDG	Two Bridges Rd Bridge
	PAS-A	Passaic River	40.88773	-74.24700	1	NJHDG	Rt 23 / Newark-Pompton Tpk Bridge
	1 ⁵	Passaic River	40.90416	-74.20066	1	NJHDG	Totowa Rd Bridge
	B24 ⁵	Passaic River	40.91521	-74.18198	1	HDR	
	2	Passaic River	40.92120	-74.17550	1	NJHDG(i)	Northwest St Bridge
	3 ⁵	Passaic River	40.94130	-74.14820	1	NJHDG	Lincoln Ave Bridge
	B22	Passaic River	40.91816	-74.13024	1	HDR	Bridge
	4 ⁵	Passaic River	40.90266	-74.13300	1	NJHDG	Market St Bridge
	5	Passaic River	40.87950	-74.12066	1	NJHDG	Dundee Dam Bridge
	6	Saddle River	40.88900	-74.08166	1	NJHDG	
	7 ⁵	Passaic River	40.84149	-74.12275	1	NJHDG	Union Ave Bridge
	S7	Third River	40.82598	-74.13306	1	HDR	
	8 ⁵	Passaic River	40.78616	-74.14733	2 ⁵	NJHDG	Near Mouth
9	Second River	40.78350	-74.16150	1	NJHDG		

Table 2-1. Baseline Compliance Monitoring Stations

Station	Waterbody	Coordinates		Samples ³	Location Type ⁴	Additional Location Information	
		Lat	Lon				
10 ^{5,6}	Passaic River	40.75120	-74.16530	2 ⁵	NJHDG	Clay St Bridge	
11	Passaic River	40.73366	-74.15566	1	NJHDG(i)	Jackson Ave Bridge	
B8	Franks Creek	40.74632	-74.13747	1	HDR	Kearny	
B6 ⁵	Passaic River	40.74148	-74.13632	2	HDR	Frank's Creek Bridge	
12	Passaic River	40.71983	-74.12183	2	NJHDG	Kearny Point Bridge	
Hackensack River & Tributaries	13	Hackensack River	40.95610	-74.02880	1	NJHDG	Head of Tide
	B1 ⁵	Hackensack River	40.89880	-74.03164	1	HDR	
	B2 ⁵	Hackensack River	40.86212	-74.03270	1	HDR	
	B11	Overpeck Creek	40.84610	-74.02701	1	HDR	
	S1	Berry's Creek	40.82810	-74.07955	1	HDR	
	B3	Cromakill Creek	40.80765	-74.04169	2	HDR	
	S2	Cromakill Creek	40.80487	-74.03663	1	HDR	
	B4	Cromakill Creek	40.79623	-74.03449	1	HDR	
	14 ⁵	Hackensack River	40.79190	-74.07837	2	NJHDG	
	S3	Sawmill Creek	40.76080	-74.09551	1	HDR	
	B7	Hackensack River	40.75899	-74.09297	2	HDR	Saw Mill Creek
	S5	Penhorn Creek	40.75247	-74.07553	1	HDR	
	15 ⁵	Hackensack River	40.73950	-74.08400	2	NJHDG	
	16	Hackensack River	40.71950	-74.10283	2	NJHDG	
Newark Bay & Tributaries	17 ⁵	Newark Bay	40.69383	-74.12216	2	NJHDG	
	B10	Newark Bay	40.67388	-74.13346	2	LTCP	
	18 ^{5,6}	Newark Bay	40.65666	-74.14683	2	NJHDG	
	B17	Newark Bay	40.65158	-74.16262	1	LTCP	
	19	Newark Bay	40.64750	-74.17350	2	NJHDG	At Arthur Kill
	21	Arthur Kill	40.64395	-74.18961	2	NJHDG	River Mouth
	B16	Elizabeth River	40.67500	-74.22218	1	LTCP	
	B14	Elizabeth River	40.66462	-74.21881	1	LTCP	
	B13	Elizabeth River	40.65809	-74.21040	1	LTCP	
	20 ⁵	Elizabeth River	40.64766	-74.20517	1	NJHDG	River Mouth sampled from bridge
	S4	Peripheral Ditch	40.68989	-74.16420	1	LTCP	Stormwater pump station
B25	Great Ditch	40.66104	-74.17414	1	LTCP	Great Ditch culvert (sampled from manhole)	

Table 2-1. Baseline Compliance Monitoring Stations

Station	Waterbody	Coordinates		Samples ³	Location Type ⁴	Additional Location Information	
		Lat	Lon				
Hudson River, Upper Bay	31 ⁵	Hudson River	40.85160	-73.95220	2	NJHDG	
	B5A	Hudson River	40.78941	-73.99374	2	LTCP	
	B5B	Hudson River	40.78733	-73.98818	2	LTCP	
	32 ⁵	Hudson River	40.76701	-74.01083	2	NJHDG	
	B18A	Hudson River	40.75645	-74.01805	2	LTCP	
	B18B	Hudson River	40.75461	-74.01151	2	LTCP	
	33 ^{5,6}	Hudson River	40.72351	-74.02553	2	NJHDG	
	B23A	Hudson River	40.71426	-74.02801	2	LTCP	
	B23B	Hudson River	40.71356	-74.02189	2	LTCP	
	B9	Upper Bay	40.67040	-74.05809	2	LTCP	
	B20	Upper Bay	40.64912	-74.09055	2	LTCP	Kill Van Kull
	B12 ⁵	Kill Van Kull	40.64313	-74.12917	2	LTCP	
	B21B	Upper Bay	40.60962	-74.04062	2	LTCP	
	B21A	Upper Bay	40.60679	-74.04946	2	LTCP	
	B26 ⁵	Upper Bay	40.68783	-74.04179	2	LTCP	
	B27 ⁵	Upper Bay	40.68537	-74.02946	2	LTCP	
B28 ⁵	Upper Bay	40.63601	-74.05145	2	LTCP		
Arthur Kill, Raritan River/Bay & Tributaries	22	Rahway River	40.59926	-74.26855	1	NJHDG	Remote sites sampled from bridge
	23	Arthur Kill	40.59497	-74.20745	2	NJHDG	River Mouth
	24 ⁵	Arthur Kill	40.55710	-74.23637	2	NJHDG(i)	
	S6	Woodbridge Creek	40.53999	-74.25541	1	LTCP	
	B15 ⁵	Arthur Kill	40.49985	-74.26120	2	LTCP	
	28	Raritan Bay	40.49097	-74.26856	2	NJHDG	Near Raritan River and Arthur Kill
	29 ⁵	Raritan Bay	40.48232	-74.18808	2	NJHDG	
	30	Raritan Bay	40.52000	-74.14600	2	NJHDG	
	25	Raritan River	40.56610	-74.52551	2	NJHDG	Head of Tide sampled from bridge
	26	Raritan River	40.49000	-74.40000	2	NJHDG	
	27	Raritan River	40.47300	-74.36000	2	NJHDG	
	B19	Raritan River	40.50847	-74.29026	2	LTCP	

Notes:

1. NJHDG Members Passaic Valley Sewerage Commission (PVSC), Middlesex County Utilities Authority (MCUA), Rahway Valley Sewerage Authority (RVSA), and Joint Meeting of Essex and Union Counties (JMEUC).
3. Number of samples at location: 1 = single sample at mid-depth; 2 = sample at surface and at bottom.
4. Station is either an existing NJHDG station or a station chosen for the LTCP. The letter "i" denotes a currently inactive NJHDG station.
5. Event station.
6. Stations sampled 4 times per day during Event sampling.

The following parameters were directly measured in the field:

- Dissolved Oxygen (DO)
- Temperature
- pH
- Salinity
- Secchi depth (where applicable)
- Turbidity

Laboratory Testing

The following parameters were analyzed in a laboratory:

- Fecal Coliform (all locations)
- Enterococcus (all locations)
- E. coli (freshwater locations only; Elizabeth River & Upper Passaic River)

Samples at two independent depths were collected at selected sites as noted in Table 2-1 to assess possible water column stratification differences. For the LTCP near-surface sample was collected between 1 and 2 feet below the surface to avoid surface debris and other interferences. The second sample was collected at mid-depth. A single sample was collected at sites located in rivers from the middle of the river channel at mid-depth, where the water is deepest to be representative of the most stable conditions of the river. NJHDG samples at 1 to 2 feet above the bottom instead of mid-depth when two samples are taken.

Additional information on the sampling program is provided in the BCMP memorandum.

2.2 Achievement of Acceptance Criteria

The data collected under the Baseline Compliance Monitoring Program is sufficient for the intended goal of calibrating the water quality model to be used for PVSC and NJCSO communities' LTCPs. Data quality met QAPP objectives, i.e.:

- The data completeness goal of valid data from 90% of collected samples was achieved. Over 99% of targeted samples were collected and analyzed, representing nearly 4,700 points of pathogen data. Of this data, 29% were reportable as estimates based on laboratory plate counts being outside of the recommended window, and less than 1% were qualified based on holding times. The review of flagged data shows that it is consistent with comparable non-flagged data and is likely to be informative to the model calibration process.
- The sample duplicate goal of calculated relative percent difference (RPD) being less than 30% on a log-basis was achieved in 92% of duplicates analyzed, which excludes pairs disqualified after collection and analysis for failure to meet reporting

or method detection limit requirements, a determination that cannot be made prior to collecting and analyzing samples.

- The field and equipment blanks were below the method detection limit (MDL) for 86% of all blanks analyzed. The overwhelming majority of the remaining 14% were in the range of 1 to 10 colonies per 100 mL, indicating that sample contamination was very low in those cases and not likely to have altered the results.
- The BCMP was not designed to provide an adequate data volume for assessing attainment of water quality standards, which would have required five samples per month at each sampling location to compute monthly geometric means.

2.3 Excluded Data

Bacteria data can be highly variable, making it difficult to determine the reliability of any individual measurement. The bacteria data were collected with the intent to use as much data as possible, and exclude only selected data that appeared to be outliers, when compared to the model, which also had a basis for exclusion (e.g., measurement after holding time limits or field or equipment blank with concentrations greater than the MDL). While the vast majority of BCMP data were acceptable for use for the calibration and validation of the PWQM, a few data points were excluded from the analysis. Initial screening of the data assessed bacteria measurements that were significantly different than the model calculations. However, no data were excluded solely because of disagreement between the model and data. Data identified in the initial screening were then reviewed to determine if the data had qualifiers or if the field and/or equipment blanks indicated contamination (i.e. concentrations > MDL). Excluded samples are listed in Table 2-2 with the reasons for exclusion.

Table 2-2. Excluded Data

Station	Date	Parameter	Depth	Concentration (cfu/100mL)	Reason for Exclusion
14	June 6, 2016	Fecal Coliform	Surface	2,800	Field Blank = 1,400 cfu/100mL
14	June 6, 2016	Fecal Coliform	Mid	2,400	Field Blank = 1,400 cfu/100mL
B6	June 6, 2016	Fecal Coliform	Surface	21,000	Analyzed outside holding time
B6	June 6, 2016	Enterococci	Surface	720	Analyzed outside holding time

Despite the need to exclude some of the collected data, the remaining data are deemed adequate for use in the calibration and validation of the PWQM.

3 Model Description

3.1 Model Selection

Complex estuarine systems with irregular coastlines and bathymetric features, such as the NY-NJ Harbor System, often pose a significant challenge to modelers seeking solutions when resolution of micro-scale physics (order of meters to kilometers) becomes dynamically important. For a credible scientific analysis, however, one must have a high-resolution representation of the model domain in order to resolve the coastline and bathymetry of the system, as well as other important physical, chemical and biological processes and their evolution within the system. The major challenge, however, comes from a computational perspective, even with the fastest and largest computers available to-date balancing desired spatial resolution with reasonable computational burden or “run-times” necessary to complete a model simulation. Thus, in order to provide an effective management tool, a balance must be struck between properly representing the system and its constituents while providing tractable solution times necessary to perform model calibration/validation, sensitivity analyses, and production runs.

Due to the complexities of the NY-NJ Harbor System, as described in a previous section, a hydrodynamic model of the system should encompass the Lower Passaic River, the Hackensack River, Newark Bay, the Arthur Kill and the Kill van Kull. The model domain should also include portions of New York Harbor and Raritan Bay as necessary to avoid boundary effects that would contaminate the model results in the region of interest. Since a hydrodynamic model of the NY-NJ Harbor complex that has been calibrated/validated and peer-reviewed (Blumberg et al., 1999) already exists, it was decided to use that model as the basis for the development of the PVSC LTCP hydrodynamic model. Most of the inputs required for setting up a hydrodynamic model of the NY-NJ Harbor System have already been developed and tested for previous modeling projects covering the NY-NJ Harbor System.

The hydrodynamic transport model applied for PWQM is based on the Estuarine, Coastal, and Ocean Model (ECOMSED) (Blumberg and Mellor, 1987) source code. The model is driven by measured water level, meteorological forcing, spatially and temporally varying surface heat flux and freshwater fluxes from the numerous rivers, wastewater treatment plants, combined sewer overflows, and stormwater/runoff from the land that enter the NY-NJ Harbor Estuary. The hydrodynamic model solves a coupled system of differential, prognostic equations describing conservation of mass, momentum, heat and salt.

The water quality model source code underlying PWQM is Row Column AESOP (RCA). RCA originates from the Water Analysis Simulation Program (WASP) developed by Hydrosience (HydroQual’s predecessor firm) in the 1970’s (DiToro et al., 1981, DiToro and Paquin, 1984). RCA code has been used to develop numerous models inside and outside of the NY-NJ Harbor region.

The principal attributes of the RCA source code include:

- RCA is a general purpose code used to evaluate a myriad of water quality problem settings. The user is able to customize an RCA sub-routine to address water quality issues that are specific to a given water body.
- RCA formulates mass balance equations for each model segment for each water quality constituent or state-variable of interest. These mass balance equations include all horizontal, lateral and vertical components of advective flow and diffusive/dispersive mixing between model segments; physical, chemical and biological transformations between the water quality variables within a model segment; and point, nonpoint, fall line, and atmospheric inputs of the various water quality variables of interest.
- The partial differential equations, which form the water quality model, together with their boundary conditions, are solved using several mass conserving finite difference techniques.

RCA's kinetic subroutine can be modified so that the constituents, or state-variables, of interest are calculated by the model. For this LTCP application, the following state-variables were modeled:

1. Salinity
2. Conservative Tracer
3. E. Coli
4. Fecal Coliform
5. Enterococcus

Salinity provides a check that the hydrodynamic model and water quality model are interfacing properly. The conservative tracer can be used to determine dilution. The three fecal indicator bacteria (FIB) were chosen because each one is used for a water quality criterion in the study area.

4 Model Input

4.1 Grid

The hydrodynamic and water quality models use the same model grid. A practical, numerically efficient and accurate approach was taken in order to discretize the Passaic River/Hackensack/Newark Bay and connecting waters. While the modeling focus is limited to the PVSC sewerage areas in LPR/Hackensack/Newark Bay system and its approaches including Kill van Kull, Arthur Kill and Upper New York Bay, it is important to locate the proper open boundary locations in order to avoid unwanted direct impact from the boundary forcing and maintain the robustness of the model performance. From the experience gained in previous modeling efforts in the region (HydroQual, 1999, 2001, and 2009), the modeling team identified the regional model grids developed by HDR: System Wide Eutrophication Model (SWEM) in the late 1990's and, subsequently for Contaminant

Assessment and Reduction Program (CARP) in early 2000's, and the EPA Superfund Study in Lower Passaic River (LPR) and Newark Bay in 2009, as the basis of the design of the grid for this study. The majority of the existing model grid was developed during the 1990s, and comprises the hydrodynamically connected coastal waters from the eastern Long Island Sound to Cape May, NJ and out to the continental shelf. In 2015, HDR made several refinements to the grid, in part to account for the recent harbor deepening, but also for the specific purpose of supporting NJ CSO LTCP development. Specifically upgrades included:

- Enhancing longitudinal segmentation in the Passaic River and extending the model from Dundee Dam upstream to the Great Falls;
- Adding Overpeck Creek and the Elizabeth River;
- Enhancing longitudinal segmentation of the Hackensack River and refining the Meadowlands complex;
- Increasing resolution in the Elizabeth River, Newark Bay, Arthur Kill, and Kill Van Kull;
- Enhancing lateral segmentation in the Hudson River to improve near-shore resolution;
- Enhancing lateral segmentation in Newark Bay to account for channel deepening; and
- Modifying bathymetry to account for the Harbor Deepening Project.

Figure 4-1 shows the model grid; Table 4-1 summarizes the change in resolution. The ECOM and RCA model components use the same segmentation, with model cells averaging about 500 meters on a side, but as small as 30 meters in the coastal areas of New Jersey. The model contains 10 vertical sigma layers, meaning that all areas of the model will have 10 vertical layers, but the depth of the layers will vary depending on the local depth.

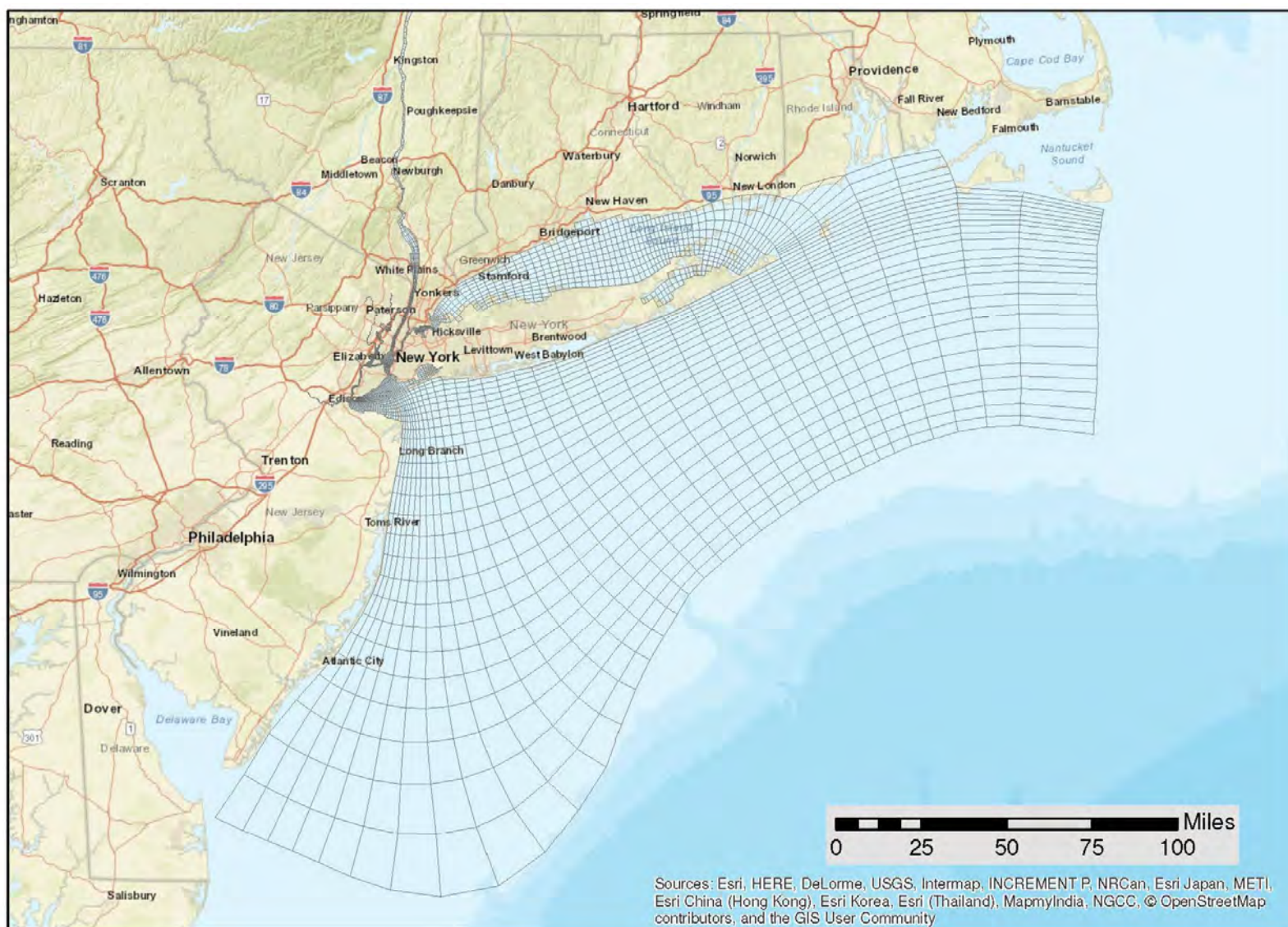


Figure 4-1. PVSC LTCP Model Grid

Table 4-1. Grid Resolution Improvements, 1990 to 2015

Model	Number of Grid Cells	Smallest Grid Cell Size (m²)	Largest Grid Cell Size (km²)	Average Grid Cell Size (km²)
1990s Grid	1,654	39,280	1,520	40
2015 Grid	3,953	940	1,520	20
Change	+139%	-98%	0%	-50%

Bathymetry data for configuration of model grid were compiled from several historical bathymetric surveys conducted by the USACE in multiple years and NOAA NOS Sounding Database. Following is a brief summary of data used for this study:

- Lower Passaic River: high resolution USACE survey data compiled in 2010 for the entire length of the LPR;
- Hackensack River and Meadowlands wetland: USACE survey data compiled in mid-1990;
- Approaches to Newark Bay including the Kill van Kull, upper section of the Arthur Kill, and Newark Bay, including the Port Elizabeth Channel: Survey data from Harbor Deepening Projects between 2005 and 2010;
- NY State Department of Environmental Conservation Hudson River Bathymetric Survey Database: 2007; and
- NOAA NOS Harbor Sounding Database for general areas.

4.2 Model Inflows, Loads, and Forcing Functions

4.2.1 Hydrodynamic Model (ECOM)

Comprehensive input for point and non-point freshwater sources were compiled for the project. Inputs included wastewater flows from 98 sewage treatment plants (STP), and discharges from combined sewer overflows (CSO) and stormwater (SW) runoff at 1,346 locations for a total of 1,452 inputs. In some cases, multiple outfalls that are physically located close to each other are placed in the same computational cell of the hydrodynamic model. Figure 4-2 presents the locations of these inputs.

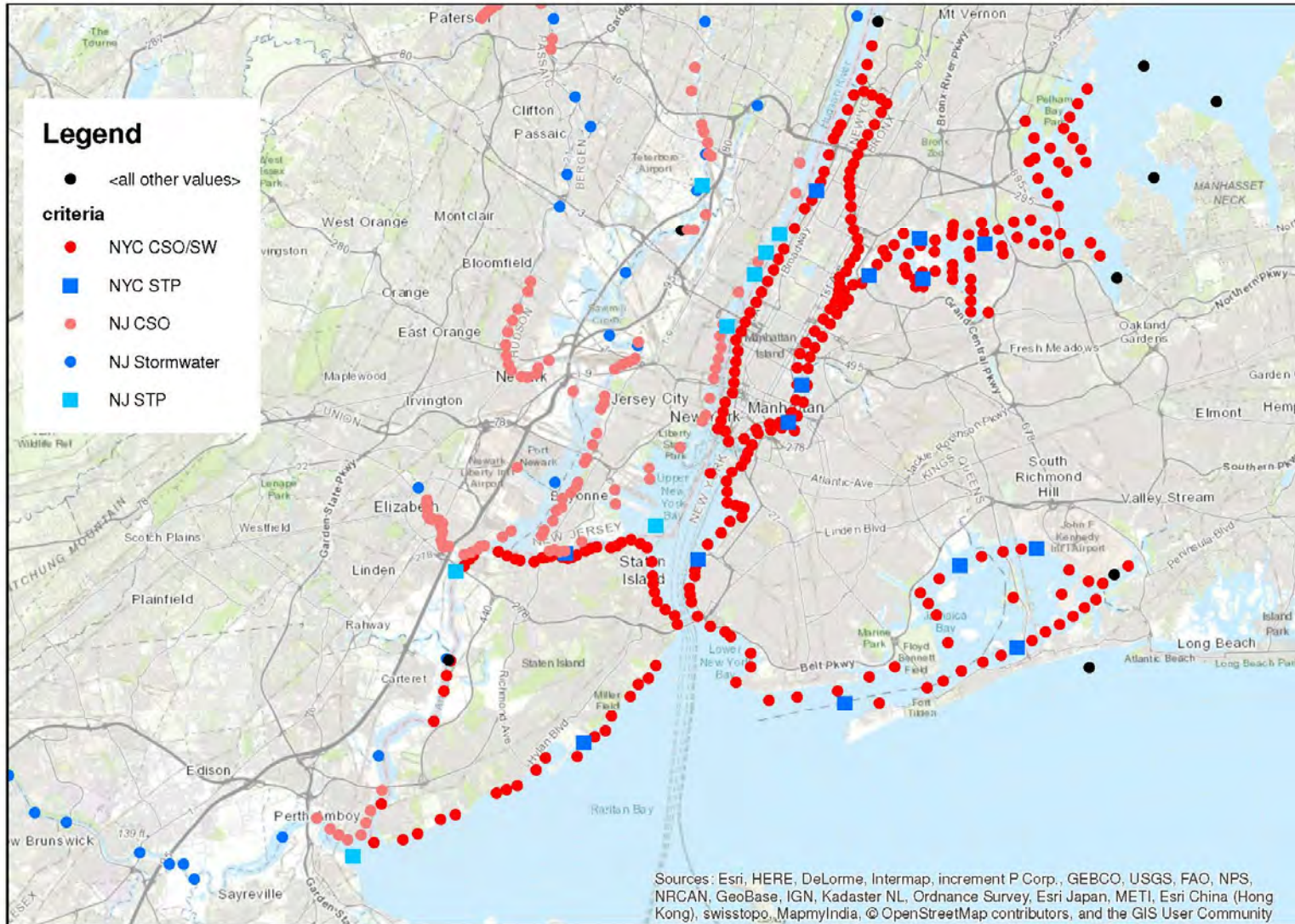


Figure 4-2. Location of CSO/Stormwater and STP Flows

4.2.1.1 CSO Flow

There are 182 NJ CSO outfalls in assigned in the model. As part of the CSO LTCP process, hydrologic and hydraulic (H&H or landside) models of the northern New Jersey communities' combined sewer systems were upgraded and integrated for use in the system characterization of the sewer systems. Several H&H models were developed by the permittees or groups of permittees. The majority of the H&H models used the InfoWorks ICM modeling platform, but PCSWMM (Jersey City) and SWMM 5 (Perth Amboy) were also used. The H&H models were calibrated to available sewer system flow monitoring data. Additional information related to these models can be found in the various System Characterization Reports submitted by the various CSO permittees. These reports can be found at <https://www.state.nj.us/dep/dwq/cso-ltcp-submittals.htm>.

The landside models provided time-variable flow information for each permitted CSO on a 15-minute basis. Flows were developed for the calibration period (2016), validation period (2017), and baseline period (2004). These flows were applied to the hydrodynamic model, so the freshwater flow could be accounted for, and later used to develop bacteria loads for the water quality model.

4.2.1.2 Stormwater Flow

An InfoWorks stormwater model covering the separated portion of the study area was developed to calculate flows and runoff from the separated areas of northern NJ that flow into the CSO affected waterbodies. The model included the area from the New York border south to the Raritan River. The model included 73 subcatchments corresponding to National Hydrography Dataset boundaries (Figure 4-3). Elevations and slopes were developed from the USGS 3D Elevation Program. Imperviousness was based on the National Land Cover Database. Soils were based on the National Resources Conservation Service SSURGO. Rain gauges from a number of sources were used to assign precipitation (Table 4-2). A constant monthly evaporation was assigned based on data from Newark Liberty International Airport. Upstream boundary flows were assigned based on USGS flow gages as presented in Table 4-3 and Figure 4-4.

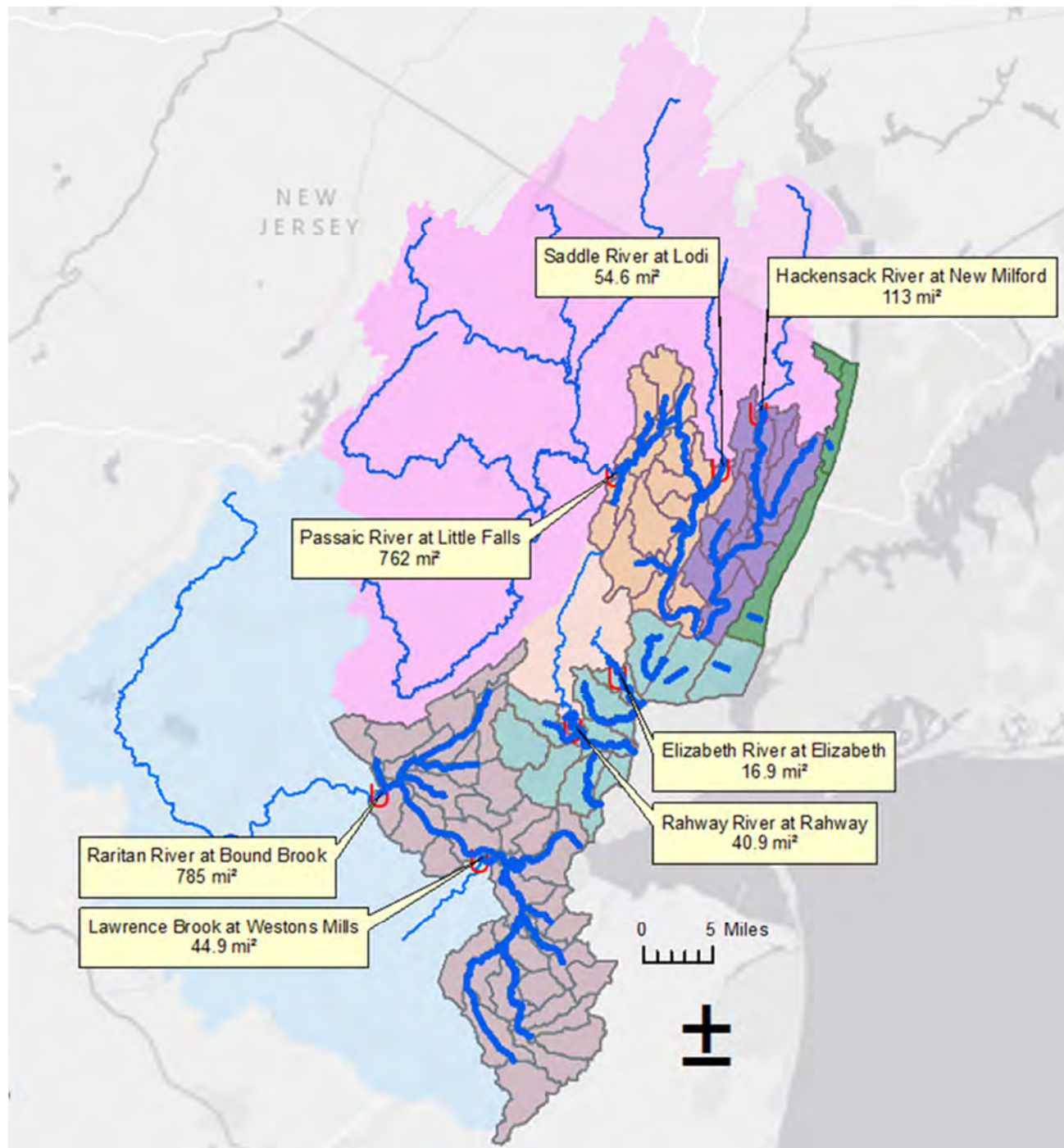


Figure 4-3. Stormwater/Runoff Model Coverage Area

Table 4-2. Precipitation Data

Location	Source
West Paterson (CW0529)	Citizen Weather Observer Program
Teterboro Airport (KTEB)	National Weather Service
Newark Liberty International Airport (KEWR)	National Weather Service
Bound Brook (MDSN4)	USGS
New Brunswick (NJ13)	Rutgers University
Manalapan (EW7636)	Citizen Weather Observer Program

Table 4-3. USGS Gages used for Stormwater Model Boundaries

USGS ID	Name	Drainage Area (mi²)
01378500	Hackensack River at New Milford	113
01389500	Passaic River at Little Falls	762
01391500	Saddle River at Lodi	55
01393450	Elizabeth River at Elizabeth	17
01395000	Rahway River at Rahway	41
01403060	Raritan River at Bound Brook	774
01405030	Lawrence Brook at Weston Mills	45

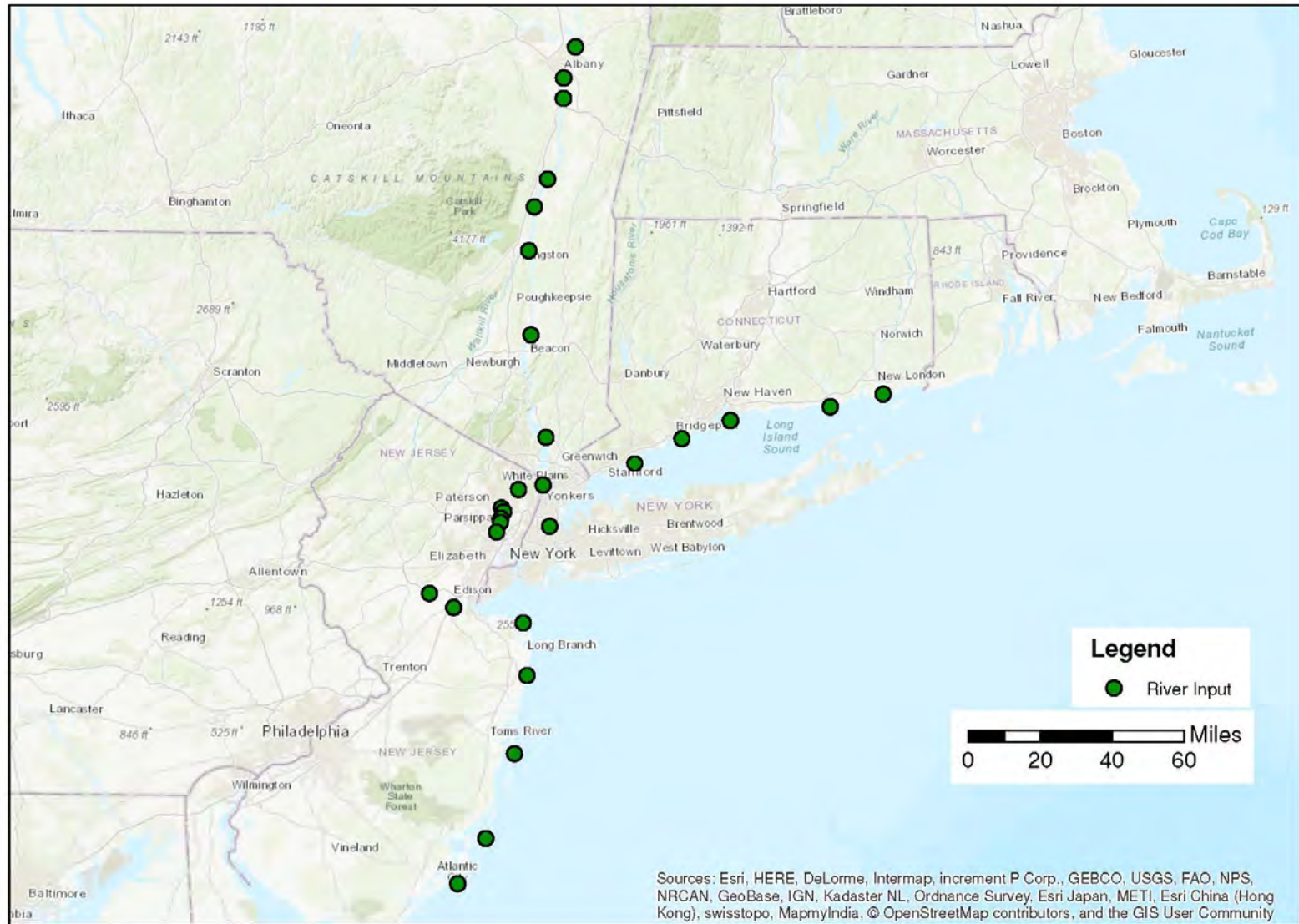


Figure 4-4. River Inflow Locations

The model was calibrated against 2016 data from USGS gages at locations within the model domain. These gages are listed in Table 4-4. Output from the model was used to supply flow inputs for the 2016 calibration period, 2017 validation period and 2004 baseline period.

Table 4-4. USGS Gages used for Stormwater Model Calibration

USGS ID	Name
01389550	Peckman River
01392500	Second River
01403400	Green Brook
01403900	Bound Brook
01405400	Manalapan Brook
01406050	Deep Run

4.2.1.3 WWTP Flow

Twelve wastewater treatment plants were included in the northern NJ portion of the model. Flows were based on plant records or landside model output. Table 4-5 presents the wastewater treatment plants (WWTP) or sewage treatment plants (STP) that were included in the project area and the daily average flow for the calibration, validation and baseline periods.

Table 4-5. Annual STP Flow

Permit	Facility	2016 Flow (MGD)	2017 Flow (MGD)	2004 Flow (MGD)
NJ0024643	Rahway Valley Sewage Authority	25.2	25.1	25.2
NJ0024953	Linden Roselle Sewage Authority	12.2	12.2	12.2
NJ0020591	BCUA Edgewater STP	3.0	3.4	3.0
NJ0025038	Secaucus MUA	3.1	3.1	3.1
NJ0020141	Middlesex County UA	91.6	99.4	108
NJ0020028	BCUA Little Ferry STP	64.5	70.8	76.5
NJ0034339	North Bergen MUA	6.0	6.0	6.0
NJ0025321	North Hudson River Road STP	8.3	8.8	6.9
NJ0026085	North Hudson Adams Street STP	13.0	12.6	14.4
NJ0029084	Woodcliff STP	2.9	2.9	2.9
NJ0024741	JMEUC	49.7	53.6	58.9
NJ0021016	PVSC WRRF	209	211	212

4.2.1.4 River Flow

River discharge data were compiled from 36 verified USGS surface water gauges for New York, New Jersey and Connecticut. Fresh water inflows from 24 rivers and tributaries are included in the model. Figure 4-4 shows their locations. If there was no gauge on a river, then a nearby gauge was used to calculate the river flow using the ratio of the ungauged drainage area to the gauged drainage area. For example, the ungauged Catskill Creek includes drainage basins in Green and Columbia Counties. The inflow was calculated based on specific discharge (discharge flow/area) from the adjacent Walkkill and Esopus Creeks. A similar procedure was used to determine discharge from ungauged Normans Kill and Moodener Kill based on specific discharge from nearby Wappinger Creek basin.

The statistics of river discharge data from 2002 to 2017 are listed in Table 4-6. The annual mean flow from the rivers listed in Table 4-6 is 1,650 m³/sec (or 58,200 cfs). The highest discharge is from the Connecticut River, followed by the Hudson River at Green Island. The mean flow of the Hudson is about 84 percent of the Connecticut River. These two rivers account for 61 percent of the total flow into the model domain. The tributaries of the Hudson in the New York areas contribute an additional flow of 310 m³/s (or 11,000 cfs). The long-term contributions of the freshwater discharges from Hudson, Lower Passaic, Hackensack, and Raritan River basins to the NY-NJ Harbor system is about 850 m³/s (or 30,000 cfs)

**Table 4-6. List of Rivers And Discharge Statistics
(Calendar Year 2002-2017)**

River	Gauging Station	Discharge (m ³ /sec)		
		Maximum	Minimum	Mean
1. Hudson River at Green Island	01358000 ⁽¹⁾	4471.4	69.6	458.5
2. Hackensack River	01378500	297.1	0.0	1.9
3. Passaic River	01389500	673.5	0.2	36.1
4. Saddle River	01391500	110.7	0.4	3.2
5. Raritan River	01403060	1460.3	2.7	34.2
6. Normans Kill (Wappinger)	01372500 ⁽²⁾	44.7	0.7	4.6
7. Moordener Kill (Wappinger)	01372500 ⁽²⁾	88.2	0.1	1.3
8. Esopus Creek	01364500	1487.1	1.5	65.4
9. Roundout Creek+Walkkill River	01367500/01371500	2701.3	4.1	134.1
10. Wappinger Creek+Fishkill	01372500	794.4	0.5	30.7
11. Croton River	01375000	528.8	0.8	24.5
12. Saw Mill River	01376500 ⁽²⁾	470.8	0.5	20.0

**Table 4-6. List of Rivers And Discharge Statistics
(Calendar Year 2002-2017)**

River	Gauging Station	Discharge (m ³ /sec)		
		Maximum	Minimum	Mean
13. Bronx River	01302000	65.2	0.1	3.0
14. Navesink +Shrewsbury	01407500	252.8	0.1	3.1
15. Catskill River (Wappinger)	01372500	599.4	0.8	31.8
16. Norwalk River	01209700	64.2	0.1	1.7
17. Housatonic River + Naugatuck River	01205500/01208500	1660.6	4.8	98.5
18. Quinnipiac River	01196500	125.1	0.7	6.8
19. Connecticut River	01184000	3452.6	52.1	543.1
20. Thames River(Shetucket + Quinebaug)	01122500/01127000	859.5	2.0	58.9
21. Manasquan + Shark Rivers	01408000/01407705	345.2	0.6	4.4
22. Metedeconk + Toms Rivers	01408120/01408500	344.4	4.1	21.7
23. Mulica River + Westconk River (Oswego, Batso, Bass)	01409400/01410000/ 01409500/01410150	402.5	6.3	29.9
24. Great Egg Harbor + Tuckahoe River	01411000/01411300	371.0	4.0	30.2

Daily surface water temperature data measured at the USGS Pompton River at Two Bridges, NJ (01389005) and USGS Poughkeepsie (01372058) were used for the specification of temperature associated with nearby tributaries such as Lower Passaic River and its tributaries, Hackensack River, Raritan River, and Hudson River and its tributaries. For other rivers outside of NY-NJ Harbor proper, daily water temperature observed at the NOAA Battery tide gage station were used. The temporal variation of four river discharges of Hudson and Lower Passaic and Hackensack Rivers used for the model calibration/validation for 2016 and 2017 are shown in Figure 4-5 and Figure 4-6, respectively. Black lines indicate the discharge flow and red lines indicate water temperature assigned to the river input.

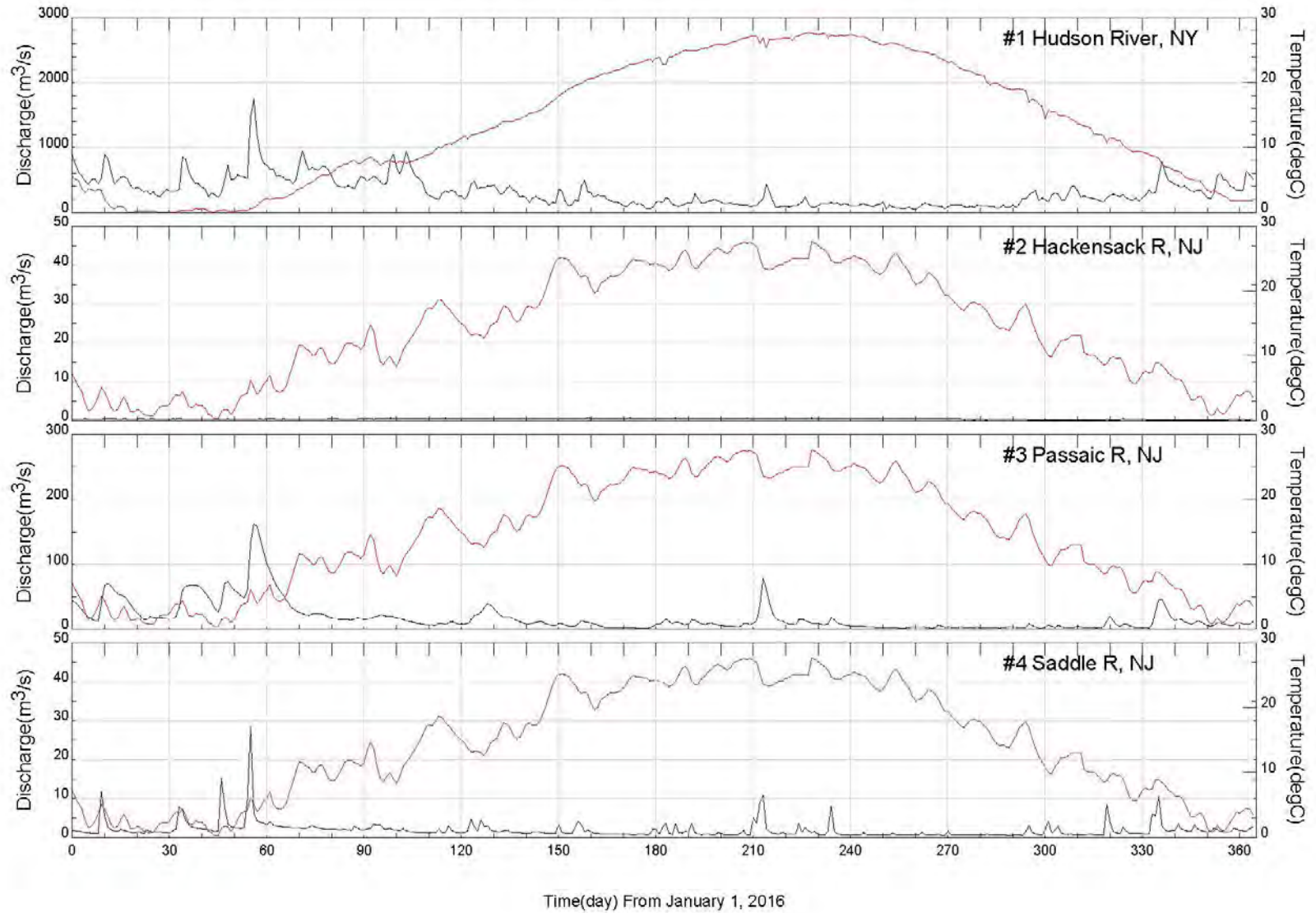


Figure 4-5. 2016 River Flow Input and Its Water Temperature

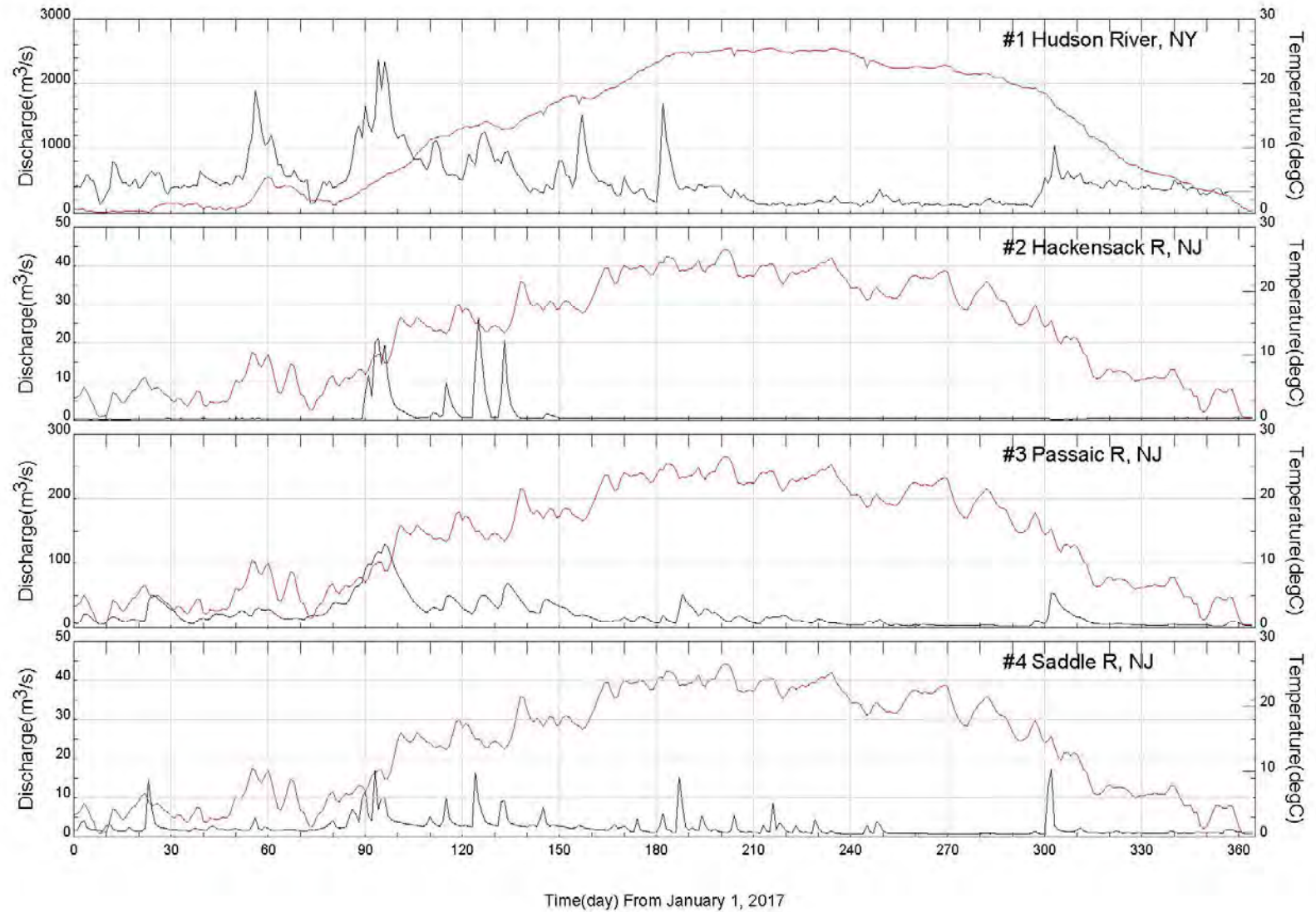


Figure 4-6. 2017 River Flow Input and Its Water Temperature

During the initial model calibration efforts, model calculated salinity in the Hackensack River was higher than observed salinity at all Hackensack River stations. The model over-calculated salinity by as much as 5 psu. A careful examination of model configuration and input data, such as freshwater inflows, was conducted. There is confidence that the model accounts for all available freshwater sources, such as the flow over the Oradell Dam, wastewater effluent from the three municipal sewage treatment plants including the Bergen County Utility Authority, Secaucus, and North Bergen plants, as well as CSO/SWO runoff estimates based on landside models.

Possible groundwater inflow associated with post-rainfall infiltration to the course of the river bed along the length of the river may be unaccounted for in the Hackensack River below the Oradell Dam. This may be a reasonable assumption given the low percent imperviousness of the Hackensack River basin and given elevation gradients within the watershed. A number of sensitivity runs were conducted to estimate the freshwater deficit. It was found that if the model was configured with an additional 150 cfs of freshwater inflow to the Hackensack River (in addition to the flow over the Oradell Dam, three sewage treatment inflows, and CSO/SWO inflows calculated by landside models), the model calculated salinity would compare favorably to the observed data. As a consequence, all model runs presented in this study assume the existence of the additional, as yet undefined, source of freshwater, added as groundwater. Further investigation of the freshwater budget in the Hackensack River basin would be required to better quantify and support this model assumption.

Another area where flow was added to the model was the Elizabeth River. In order to accurately model the salinity gradient in the river, the model required the river to be sloped to prevent saltwater from moving too far upstream. This also appropriately prevents water elevation changes due to tides from moving too far upstream. In order to prevent the river from drying out, due to the river slope, under low flow conditions, a minimum flow of 21 cfs (0.6 m³/s) was assigned. This results in an approximately 23% increase in the annual flow volume under baseline conditions. This compromise was necessary to maintain model stability and produce more reasonable salinity concentrations and water elevations in the river. Since this flow is added only under low flow conditions, it should not affect the assessment of CSO loads, which generally occur under higher flow conditions.

4.2.1.5 Boundary Conditions

To produce a simulation of the tidal scale circulation, including the effects of baroclinicity, it is necessary to prepare a data base containing the astronomical dynamics and climatological thermodynamic properties prevailing in New York Bight. The low frequency dynamics in the shelf break are important to the circulation in New York Bight. This phenomenon has already been addressed, among others, by Hopkins and Dieterle (1983, 1987) and Blumberg and Galperin (1990). Low frequency dynamics of continental shelves are associated, among others, with a geostrophic balance. Hence, the cross-shelf slope of the sea surface elevation at the boundaries is highly significant. Because low frequency cross-shelf sea surface elevation records at the boundaries are not available, a practical approach is developed in order to adequately define forcing conditions at these locations.

For the model simulation period, the sea surface elevation $\eta(x,t)$ at the boundary is assumed to be composed of three parts. The first part drives the long-term circulation (geostrophic currents) due to the cross-shelf slope ($\eta_g(x,t)$); the second part deals with the tidal fluctuations ($\eta_I(x,t)$); and the third part represents sub-tidal (meteorological) forcing ($\eta_M(t)$). The resulting water surface elevation is given by:

$$\eta(x,t) = \eta_g(x,t) + \eta_I(x,t) + \eta_M(x,t) \quad (4-1)$$

The effect of the along-shelf elevation gradient imposed at the shelf break on the barotropic circulation in New York Bight has been studied by Hopkins and Dieterle (1983). They found that the parabolic elevation gradient at the shelf-break affects the total transport through the cross-shelf boundaries. For August 1978, a typical summertime period, a diabathic gradient of 13 cm across a Narragansett Bay shelf-break section and an 11 cm gradient across a Cape May shelf-break section could produce the observed summer along-shelf flux of water. Following the findings of Hopkins and Dieterle (1983 and 1987), Blumberg and Galperin (1990) adopted the same approach to specifying the boundary elevation in a summer average circulation study in the New York Bight.

In the present study, a 13 cm gradient along the northeastern Nantucket Shoals boundary, an 11 cm gradient across the Cape May shelf-break southern boundary and a zero gradient along the shelf boundary are imposed.

Astronomical tide, $\eta_T(x,t)$ due to eight primary harmonic constituents (M_2 , S_2 , N_2 , K_2 , K_1 , O_1 , P_1 and Q_1), is obtained from a global model of ocean tide, TPXO.2, developed by Oregon State University (Egbert et al., 1994). The input to the tidal synthesis program is gridded data of the harmonic constants. The output is η_T as function of time and space (longitude and latitude). The tidal synthesis program uses interpolation of the tidal admittances in the diurnal and semi-diurnal bands to include 9 additional mirror constituents ($2N_2$, MU_2 , NU_2 , L_2 , T_2 , J_1 , NO_1 , OO_1 , RHO_1). The synthesis program also adds the long period constituents MF, MM, SSA using the standard equilibrium forms.

Previous modeling studies conducted by HDR (HydroQual, 2001 and 2002) indicates that the response of water surface to meteorological forcing are essentially in phase throughout the New York Bight and the adjacent estuarine waters. The differences in amplitude at different locations, due to local bathymetry and coastline, are also small. Therefore, in this study $\eta_M(t)$ is expressed as:

$$\eta_M(t) = \alpha \eta_{35h}(t) \quad (4-2)$$

Where α is a calibration parameter and $\eta_{35h}(t)$ is the 35-hour low-passed water surface elevation at Sandy Hook. As a tidal wave propagates over the continental shelf, its amplitude is increased by shoaling and shallow water effects. As a result α is expected to have a value less than one. Its value ($\alpha = 0.5$) has been determined previously by

performing a series of simulation runs and comparing model results with data (HydroQual, 2001).

Also a modified form of the Sommerfield radiation boundary conditions (Blumberg and Kantha, 1985) is applied across the Cape May shelf-break section with a function, which tends to force the elevation to a specified (elevation) boundary condition within a given time scale. Thus, long waves are allowed to propagate and they are free to advect through the boundary.

Temperature and salinity boundary conditions are obtained from climatological data from World Ocean Atlas 2013 (WOA2013, <https://www.nodc.noaa.gov/OC5/woa13/>), published by NOAA. The published data set contains gridded monthly temperature and salinity at one-degree latitude-longitude. This data set consists of monthly temperature and salinity data tabulated at 19 levels from 0 to 1000 m. At the PVSC LTCP model boundary, temperature and salinity are linearly interpolated from the surrounding gridded data.

As climatological data do not represent true monthly variations of temperature and salinity for the periods of the model calibration, it was necessary to adjust the boundary conditions defined from WOA2013 so that calculated temperature and salinity matched the monthly mean temperature and salinity in the Long Island Sound, the New York Harbor and the Hudson River. Only the temporal variations of the salinity at the continental shelf break was adjusted by 2 psu. They are defined as follows:

$$S(x, t) = S_L(x, t) - 2.0 \quad (4-3)$$

Where S_L is climatological salinity in psu from WOA2013. Offshore open boundary conditions for water temperature and salinity used for 2016 and 2017 period is shown in Figure 4-7. T/S data shown in Figure 4-7 is from one grid cell in offshore area in the middle of the model domain where water depth is about 100m.

4.2.1.6 Meteorological Forcings

Meteorological forcings applied to the water surface are wind stress and heat flux. Wind stress is calculated from wind speed and wind direction. Heat flux computations require the specification of air temperature, relative humidity, barometric pressure, shortwave solar radiation and cloud cover, and water column light extinction coefficient. These parameters were extracted from the NOAA's North American Regional Reanalysis (NARR) dataset (www.esrl.noaa.gov/psd/data/gridded/data.narr.html). NARR dataset consists of 32 km resolution gridded data at 3 hourly interval. Figure 4-8 shows the locations of the meteorological data points in the model domain. Data from 69 data points were spatially and temporarily interpolated to be used as model input. Examples of the meteorological input data for 2016 and 2017 are shown in Figure 4-9 and Figure 4-10, respectively. Additional figures can be found in Appendix A.

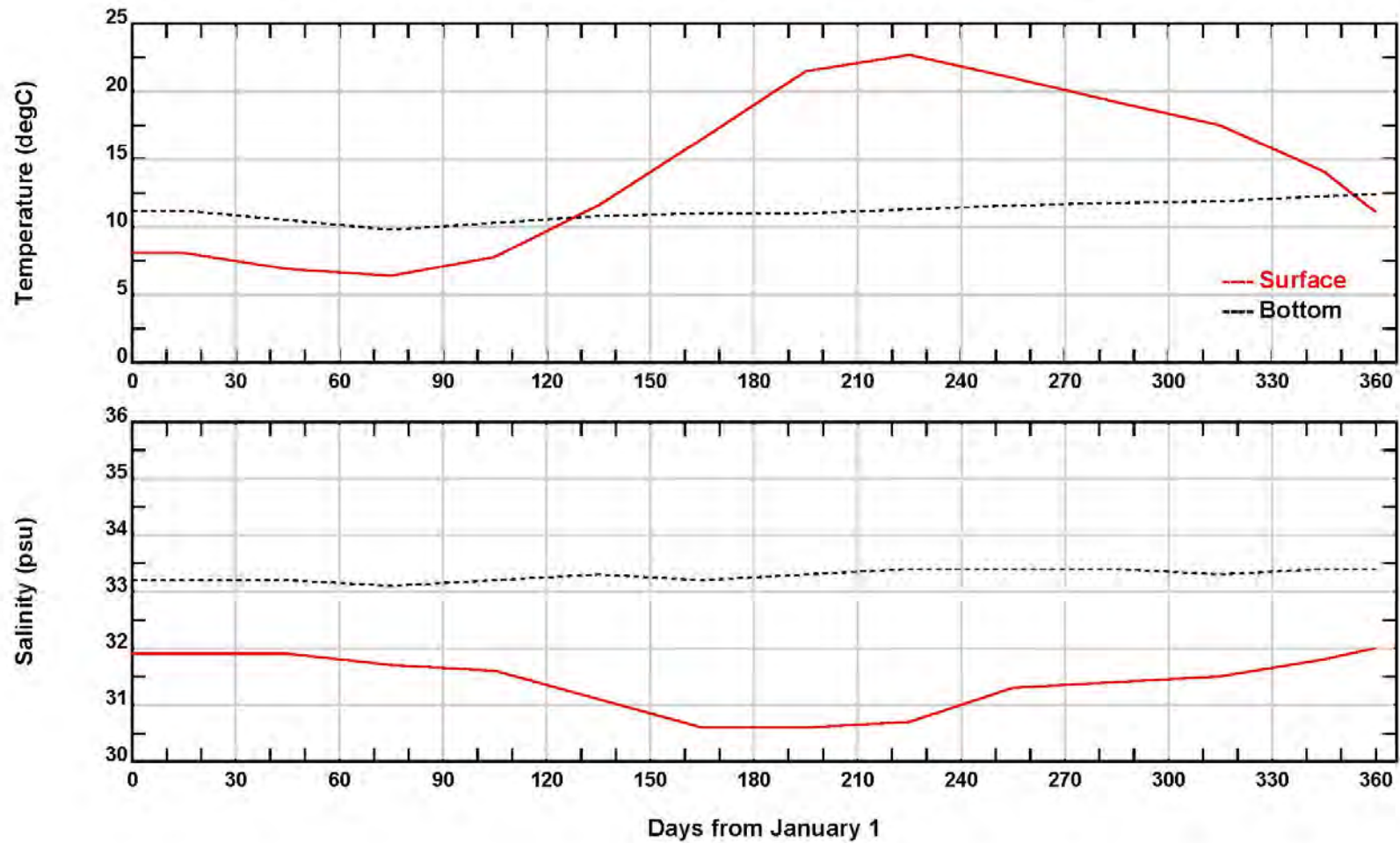


Figure 4-7. Offshore Temperature and Salinity Boundary Conditions

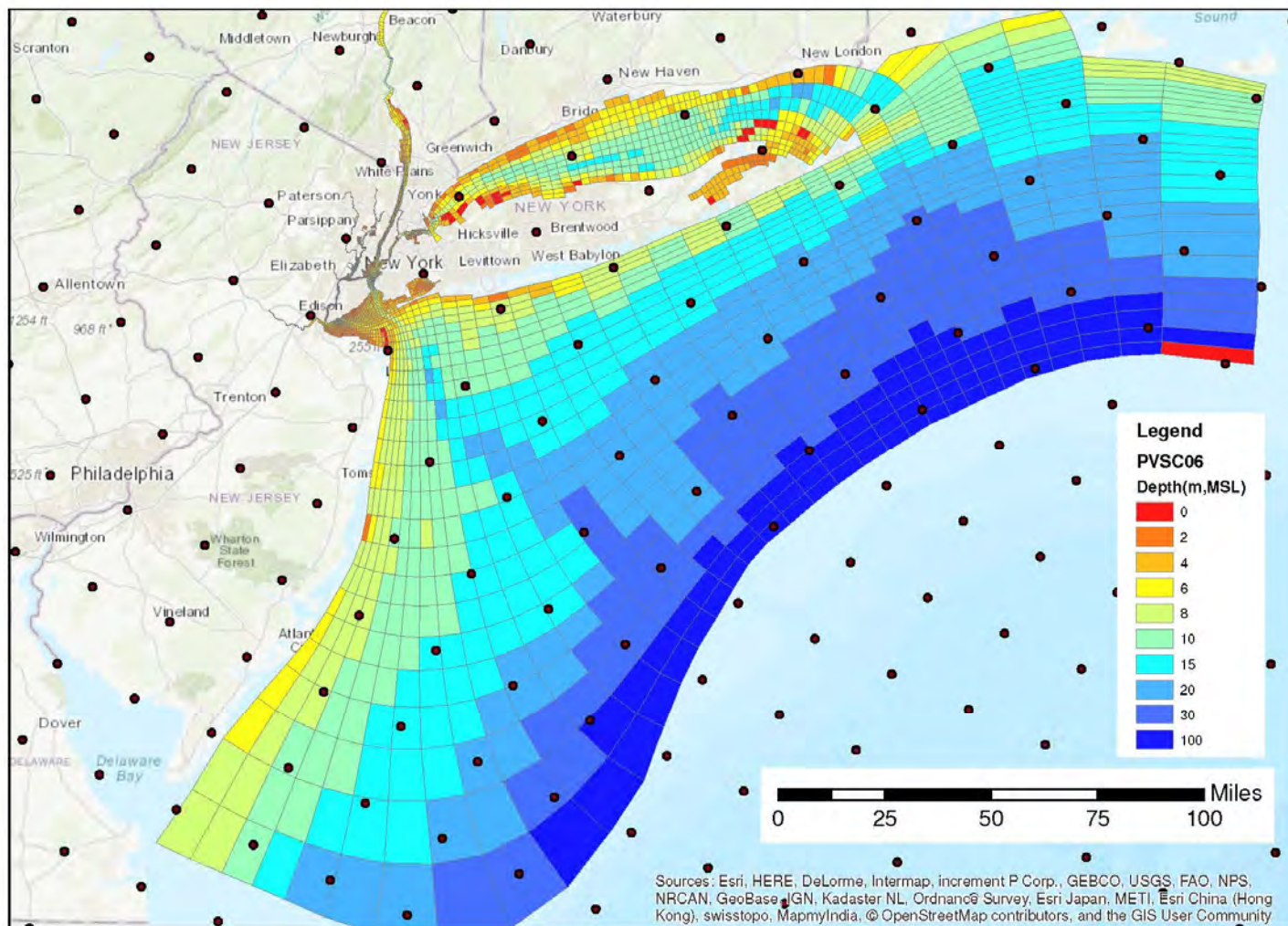
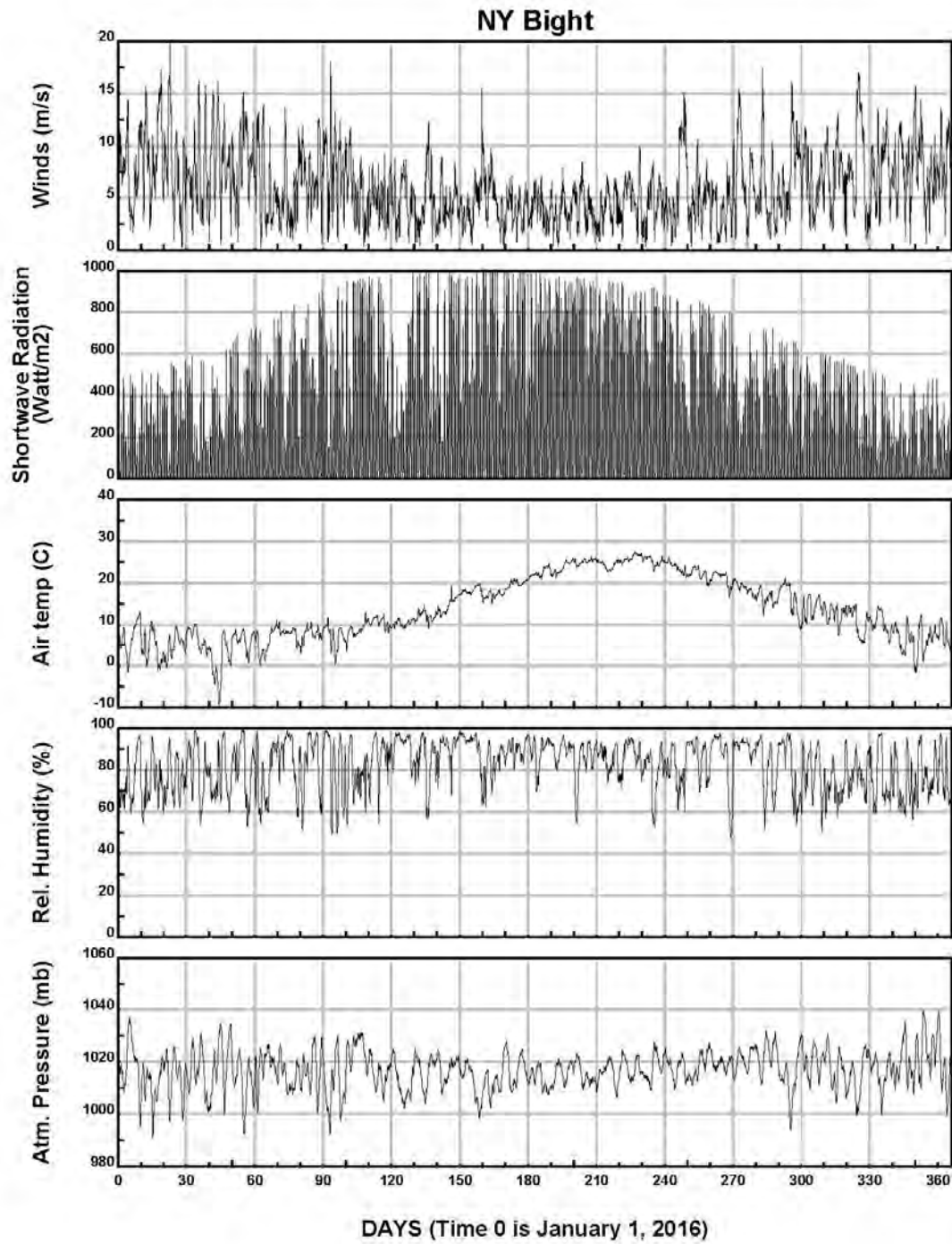
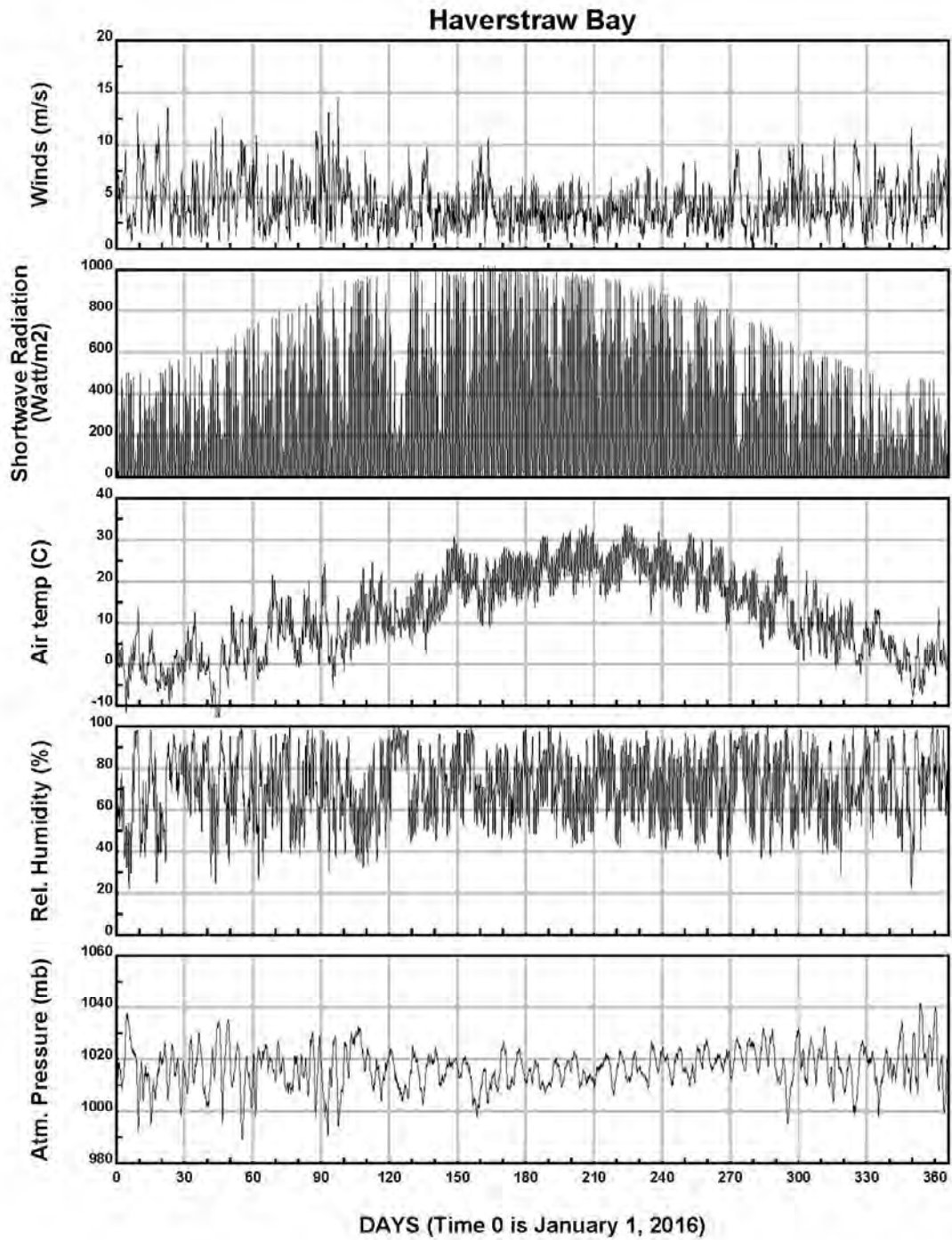


Figure 4-8. NOAA NARR Data Locations



2016

Figure 4-9. 2016 Meteorological Input Data



2016

Figure 4-10. 2017 Meteorological Input Data

4.2.2 Water Quality Model (RCA)

Aside from model constants, described in Section 5.1, the primary inputs to the water quality model are fecal indicator bacteria (FIB) loads and boundary conditions, which act as loads. Loads include: CSOs, stormwater, WWTP/STP/WRRF, rivers/boundary conditions, dry-weather loads, and other sources. Loads were developed for three periods: calibration, validation, and baseline. The calibration period is the calendar year 2016, the period when the majority of the baseline compliance monitoring occurred. The validation period is the calendar year 2017, when additional baseline compliance monitoring occurred. The baseline period, and the period that projections were based on is 2004. 2004 represents a “typical” rainfall year based on precipitation data from Newark Liberty International Airport. The landside models run for the baseline period used infrastructure and populations based on 2015.

4.2.2.1 CSO Loads

CSO loads were based on total flow and sanitary flow fraction calculated by the various landside models, and fecal indicator bacteria concentrations measured in the influent of the PVSC WRRF, and at eight storm sewer sites. Daily PVSC WRRF influent (sanitary) data was provided from July 11, 2016 through February 8, 2018. The fecal indicator bacteria influent data are presented in Figure 4-11. The fecal coliform and E. coli data show a seasonal cycle with higher concentrations in the late summer and early fall, and lower concentrations in the late winter and spring. The enterococci data show less of a seasonal trend.

The stormwater data were collected at locations meant to represent three types of land use: low-density residential, high-density residential, and industrial/commercial. Figure 4-12 and Table 4-7 present the location and land use of the stations. The stormwater data showed as much, if not more, variability within each land use type than variability between land use type. Figure 4-13 presents the stormwater fecal indicator bacteria data as probability distributions. Based on the similarity of the data between land use types, the stormwater data were lumped together and treated as a single stormwater data set, and a maximum likelihood estimator (MLE) was calculated for each of the fecal indicator bacteria.

Table 4-7. Stormwater Sampling Locations

Station	Land Use	City	Location
S1-PAT-LR1	Low Density Residential	Paterson	End of Short St.
S1-NWK-LR2	Low Density Residential	Newark	Intersection of Ivy St. and Eastern Pkwy.
S1-HAW-LR3	Low Density Residential	Hawthorne	Intersection of N 7 th St. and Rt. 504
S1-OAK-LR4	Low Density Residential	Oakland	Oswego Ave. between Hiawatha Blvd. and Calumet Ave.
S1-NWK-HR1	High Density Residential	Newark	Intersection of 3 rd Ave W and N 9 th St.
S1-NWK-HR2	High Density Residential	Newark	Intersection of Goldsmith St. and Aldine St.
S1-PAT-CI1	Commercial/Industrial	Paterson	Shady St. between 6 th Ave. and Peel St.
S1-NWK-CI2	Commercial/Industrial	Newark	Intersection of NJRR Ave. and Vanderpool St.

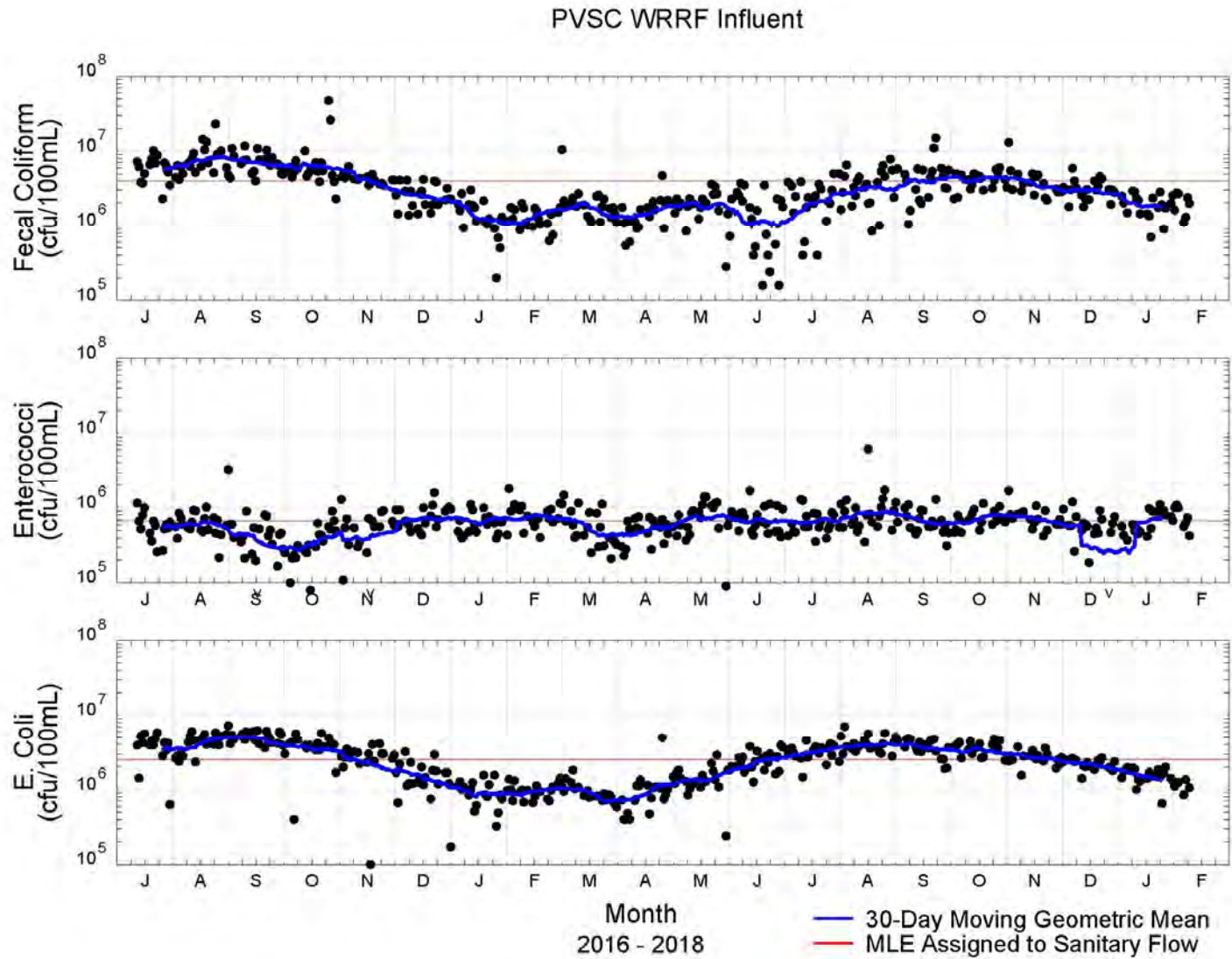


Figure 4-11. PVSC WRRF Influent FIB Concentrations

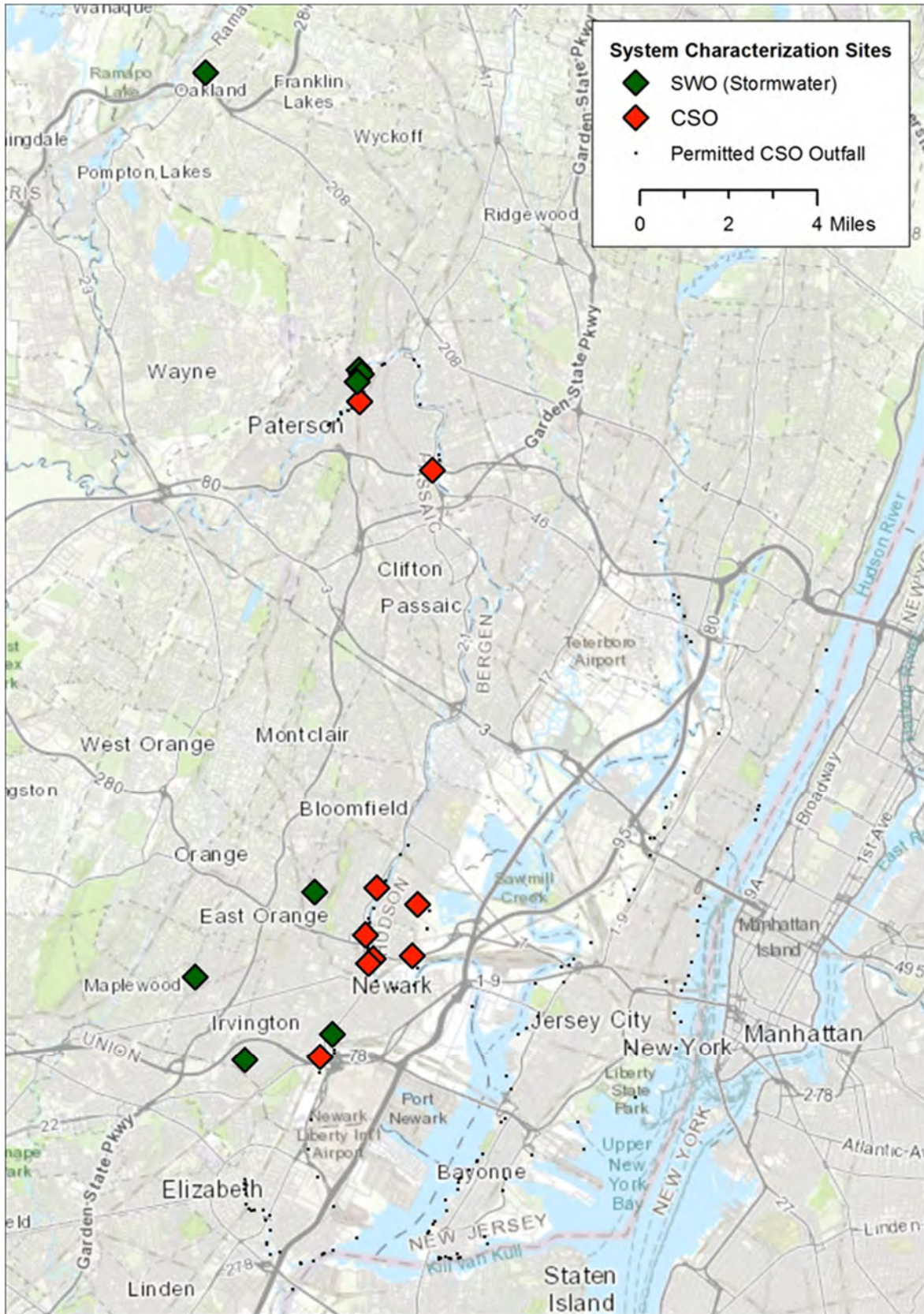


Figure 4-12. CSO and Stormwater Sampling Locations

Probability Plot of Stormwater Pathogen Data
By Land Use
2016-2017

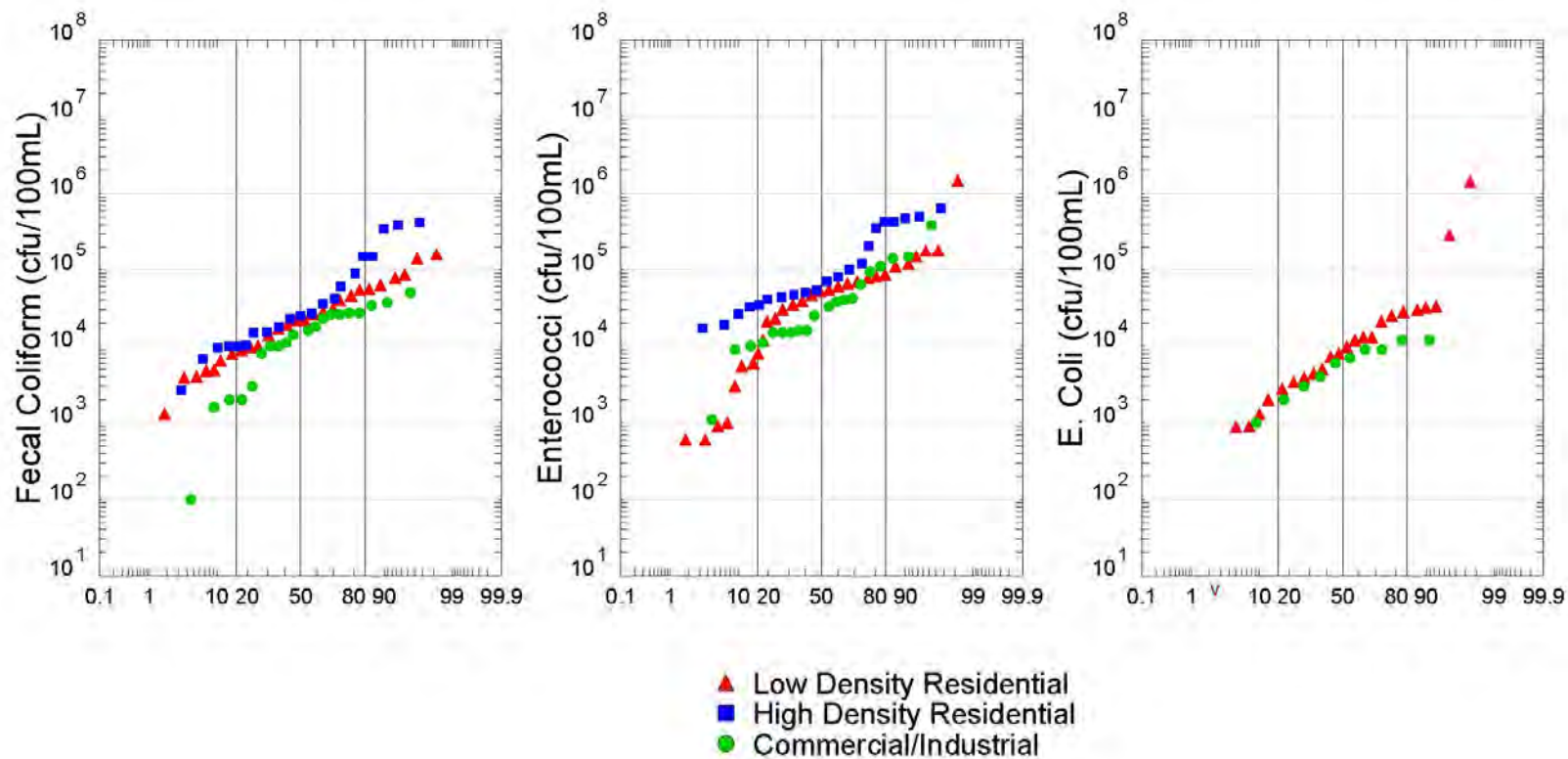


Figure 4-13. Stormwater FIB Concentrations by Land Use

The sanitary and stormwater concentration data, along with the sanitary flow fraction from the landside models were used to calculate the CSO concentrations based on Equation 4-4:

$$C_{CSO} = C_{San} * fr_{San} + C_{SW} * fr_{SW} \quad (4-4)$$

Where C_{CSO} is the CSO bacteria concentration (cfu/100mL), C_{San} is the sanitary bacteria concentration (cfu/100mL), fr_{San} is the fraction of flow that is sanitary flow, C_{SW} is the stormwater bacteria concentrations (cfu/100mL), and fr_{SW} is the fraction of flow that is stormwater. Two approaches were used to determine the appropriate sanitary fecal indicator bacteria concentrations: time-variable concentrations based on the apparent seasonal variability in the fecal coliform and E. coli influent data, and constant concentrations based on calculated MLEs.

Available CSO data collected at 11 locations (Figure 4-13) were used to assess which approach best fit the measured data. Figure 4-14 presents an example of measured concentrations compared to calculated concentrations using the two mass balance approaches. The first approach used constant sanitary concentrations, and the second approach used a sanitary-temperature relationship to assign the sanitary concentration. Additional figures can be found in Appendix B. Based on these comparisons, using the constant MLE concentrations compared more favorably to the measured CSO data. Since the sanitary data showed temporal variability, and the data covered a 19 month period, only the first 12 months were used to calculate the MLEs to avoid biasing the MLE to a period with higher or lower concentrations. Table 4-8 presents the concentrations used in the mass balance approach to calculate CSO concentrations. Since the landside models calculate time-variable fractions of sanitary and stormwater flow, and these fractions vary from outfall to outfall, the CSO bacteria concentrations in the model are temporally and spatially variable.

Table 4-8. Sanitary and Stormwater FIB Concentrations used to Calculate CSO FIB Concentrations

Fecal Indicator Bacteria	Sanitary Concentration (cfu/100mL)	Stormwater Concentration (cfu/100mL)
Fecal Coliform	4,000,000	41,000
Enterococci	675,000	110,000
E. Coli	2,500,000	38,000

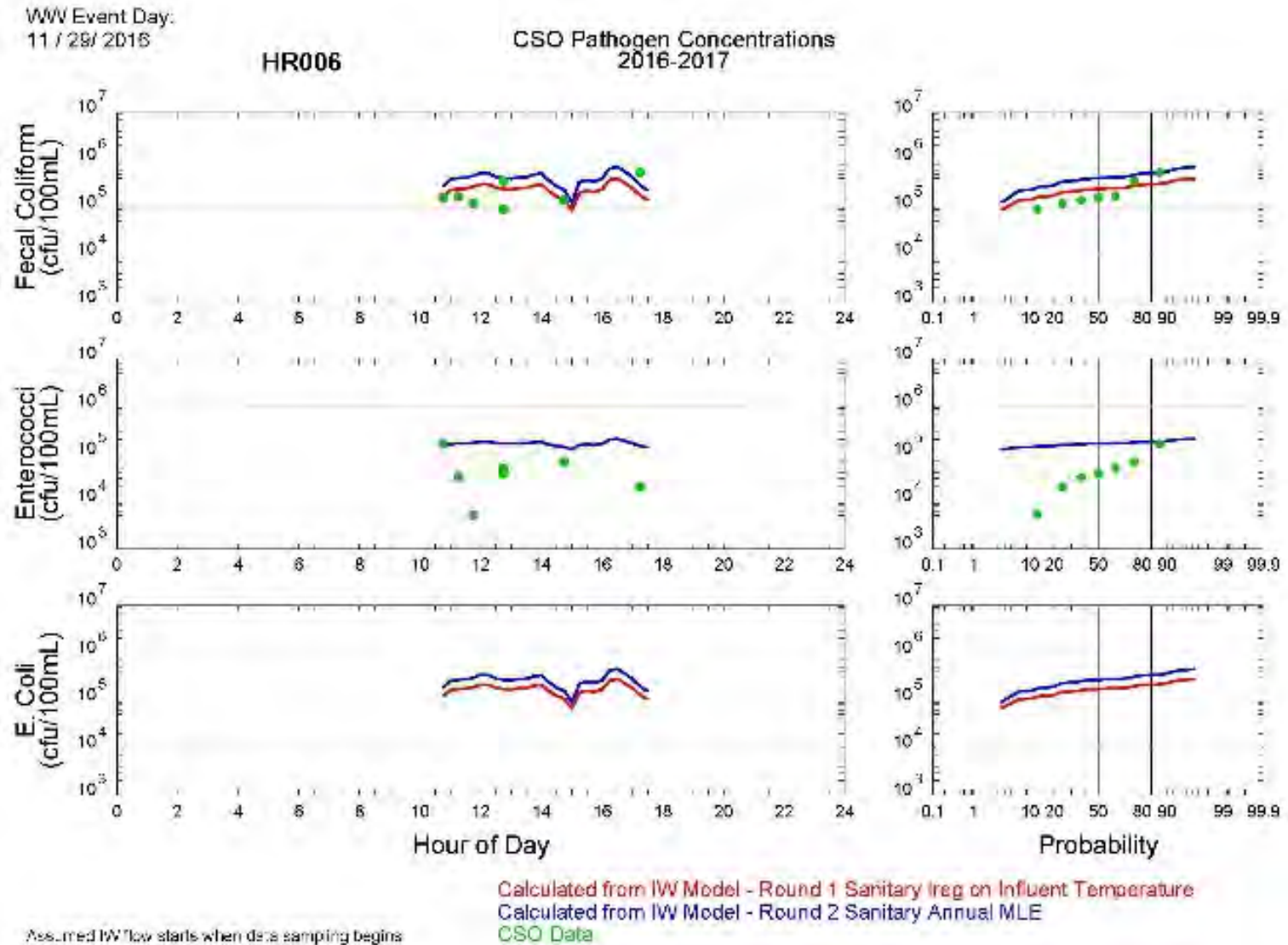


Figure 4-14. Comparison of Calculated CSO FIB Concentrations versus Measured FIB Concentrations

The calculated CSO load for each CSO under calibration, baseline, and validation periods is presented in Appendix C.

4.2.2.2 Stormwater Loads

An InfoWorks stormwater model covering the separated portion of the study area was developed to calculate flows and runoff from the separated areas of northern NJ that flow into the CSO affected waterbodies, as described in Section 4.2.1.2. As described in Section 4.2.2.1, stormwater FIB MLE concentrations were calculated based on measured stormwater concentrations. These concentrations, shown in Table 4-8, were assigned to flows above the river baseflows assigned in the model

Output from the stormwater model included 36 “outfalls”, five of which were treated as rivers. One additional location was added because the Franks Creek drainage area was not adequately covered by the stormwater model. Due to the number of stormwater “outfalls” assigned in the stormwater model. The loads for each subwatershed in the stormwater model are presented in Appendix C.

4.2.2.3 WWTP Loads

Limited WWTP effluent bacteria concentration data were available. PVSC provided two-plus years of data for fecal coliform beginning in 2016. Fecal coliform concentrations were generally less than 20 cfu/100mL. However, since data from other WWTPs were lacking, and to be conservative, the fecal indicator bacteria were assigned higher, constant, concentrations similar to concentrations used in previous modeling efforts for NYCDEP. Table 4-9 presents the assigned WWTP effluent concentrations. Table 4-10 through Table 4-12 present the WWTP loads associated with the calibration period, validation period and baseline period, respectively.

Table 4-9. WWTP Effluent Concentrations

Fecal Indicator Bacteria	Concentration (cfu/100mL)
Fecal Coliform	50
Enterococci	10
E. Coli	10

Table 4-10. Calibration Period WWTP Loads

Permit	Facility	Fecal Coliform (10 ¹² cfu/yr)	Enterococci (10 ¹² cfu/yr)	E. Coli (10 ¹² cfu/yr)
NJ0024643	Rahway Valley Sewage Authority	17.4	3.5	3.5
NJ0024953	Linden Roselle Sewage Authority	8.5	1.7	1.7
NJ0020591	BCUA Edgewater STP	2.1	0.4	0.4
NJ0025038	Secaucus MUA	2.1	0.4	0.4
NJ0020141	Middlesex County UA	63.4	12.7	12.7
NJ0020028	BCUA Little Ferry STP	44.7	8.9	8.9
NJ0034339	North Bergen MUA	4.2	0.8	0.8
NJ0025321	North Hudson River Road STP	5.8	1.2	1.2
NJ0026085	North Hudson Adams Street STP	9.0	1.8	1.8
NJ0029084	Woodcliff STP	2.0	0.4	0.4
NJ0024741	JMEUC	34.4	6.9	6.9
NJ0021016	PVSC	145	28.9	28.9

Table 4-11. Validation Period WWTP Loads

Permit	Facility	Fecal Coliform (10 ¹² cfu/yr)	Enterococci (10 ¹² cfu/yr)	E. Coli (10 ¹² cfu/yr)
NJ0024643	Rahway Valley Sewage Authority	17.4	3.5	3.5
NJ0024953	Linden Roselle Sewage Authority	8.4	1.7	1.7
NJ0020591	BCUA Edgewater STP	2.4	0.5	0.5
NJ0025038	Secaucus MUA	2.1	0.4	0.4
NJ0020141	Middlesex County UA	68.6	13.7	13.7
NJ0020028	BCUA Little Ferry STP	48.9	9.8	9.8
NJ0034339	North Bergen MUA	4.2	0.8	0.8
NJ0025321	North Hudson River Road STP	6.1	1.2	1.2
NJ0026085	North Hudson Adams Street STP	8.7	1.7	1.7
NJ0029084	Woodcliff STP	2.0	0.4	0.4
NJ0024741	JMEUC	37.0	7.4	7.4
NJ0021016	PVSC	145	29.1	29.1

Table 4-12. Baseline WWTP Loads

Permit	Facility	Fecal Coliform (10 ¹² cfu/yr)	Enterococci (10 ¹² cfu/yr)	E. Coli (10 ¹² cfu/yr)
NJ0024643	Rahway Valley Sewage Authority	17.4	3.5	3.5
NJ0024953	Linden Roselle Sewage Authority	8.5	1.7	1.7
NJ0020591	BCUA Edgewater STP	2.1	0.4	0.4
NJ0025038	Secaucus MUA	2.1	0.4	0.4
NJ0020141	Middlesex County UA	74.5	14.9	14.9
NJ0020028	BCUA Little Ferry STP	53.0	10.6	10.6
NJ0034339	North Bergen MUA	4.2	0.8	0.8
NJ0025321	North Hudson River Road STP	4.8	1.0	1.0
NJ0026085	North Hudson Adams Street STP	10.0	2.0	2.0
NJ0029084	Woodcliff STP	2.0	0.4	0.4
NJ0024741	JMEUC	40.8	8.2	8.2
NJ0021016	PVSC	147	29.4	29.4

4.2.2.4 River Loads and Boundary Conditions

River loads were based on a randomly ordered Monte Carlo distribution assigned during dry-weather and a constant concentration during wet-weather. The dry-weather concentration distributions were based on 2016 data for the calibration period, 2016-2017 data for the validation period, and 2012-2017 data for the baseline period. The distributions are generated using bacteria concentration log-normal geometric means and standard deviations. Table 4-13 through Table 4-15 present these geometric means and standard deviations. The arithmetic geometric means are also shown to provide perspective. Figure 4-15 presents a comparison of probability distributions created by the Monte Carlo approach and measured data used to calculate the geometric means and standard deviations used to create the Monte Carlo distribution. The wet-weather concentrations were based on MLEs of the data for the period of 2012-2017. An MLE concentration was suggested by Model Evaluation Group (MEG) members because a strong correlation between precipitation and bacteria concentration was not observed. The MLEs used for wet-weather are presented in Table 4-16 through Table 4-18.

Table 4-13. Calibration Dry-Weather Monte Carlo Distribution River Input

River	Fecal Coliform (cfu/100mL)			Enterococci (cfu/100mL)			E. Coli (cfu/100mL)		
	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.
Hudson River	28.0	3.33	1.32	7.6	2.03	1.12	N/A	N/A	N/A
Hackensack River	63.7	4.15	0.66	10.0	2.31	1.05	51.5	3.94	0.55
Passaic River	150.8	5.02	0.88	34.1	3.53	1.82	118.7	4.78	1.01
Saddle River	472.2	6.16	0.58	152.6	5.03	0.46	331.3	5.80	0.49
Raritan River	71.0	4.26	1.39	50.2	3.92	1.06	56.6	4.04	1.03
Second River	3944	8.28	0.63	867.4	6.77	0.67	3026	8.02	0.85
Elizabeth River	404.0	6.00	1.97	62.5	4.13	1.82	272.6	5.61	1.73
Third River	215.4	5.37	1.47	71.4	4.27	1.42	122.1	4.80	1.72
McDonalds Brook	3944	8.28	0.63	867.4	6.77	0.67	3026	8.02	0.85

Table 4-14. Validation Dry-Weather Monte Carlo Distribution River Input

River	Fecal Coliform (cfu/100mL)			Enterococci (cfu/100mL)			E. Coli (cfu/100mL)		
	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.
Hudson River	26.1	3.26	1.30	8.0	2.08	1.21	N/A	N/A	N/A
Hackensack River	58.0	4.06	1.05	19.2	2.95	1.36	41.5	3.73	1.08
Passaic River	131.9	4.88	0.98	43.6	3.78	1.84	105.6	4.66	1.13
Saddle River	336.1	5.82	0.80	158.8	5.07	0.87	291.0	5.67	0.73
Raritan River	95.2	4.56	1.10	80.3	4.39	1.15	96.8	4.57	1.11
Second River	3417	8.14	0.63	1074.4	6.98	0.72	3306	8.10	0.69
Elizabeth River	274.9	5.62	2.01	56.3	4.03	1.79	179.3	5.19	1.84
Third River	185.5	5.22	1.47	63.4	4.15	1.41	96.6	4.57	1.79
McDonalds Brook	3417	8.14	0.63	1074.4	6.98	0.72	3306	8.10	0.69

Table 4-15. Baseline Dry-Weather Monte Carlo Distribution River Input

River	Fecal Coliform (cfu/100mL)			Enterococci (cfu/100mL)			E. Coli (cfu/100mL)		
	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.	GM	Ln GM	Ln std. dev.
Hudson River	28.0	3.33	1.32	7.6	2.03	1.12	N/A	N/A	N/A
Hackensack River	63.7	4.15	0.66	10.0	2.31	1.05	51.5	3.94	0.55
Passaic River	150.8	5.02	0.88	34.1	3.53	1.82	118.7	4.78	1.01
Saddle River	472.2	6.16	0.58	152.6	5.03	0.46	331.3	5.80	0.49
Raritan River	71.0	4.26	1.39	50.2	3.92	1.06	56.6	4.04	1.03
Second River	3944	8.28	0.63	867.4	6.77	0.67	3026	8.02	0.85
Elizabeth River	404.0	6.00	1.97	62.5	4.13	1.82	272.6	5.61	1.73
Third River	215.4	5.37	1.47	71.4	4.27	1.42	122.1	4.80	1.72
McDonald Brook	3944	8.28	0.63	867.4	6.77	0.67	3026	8.02	0.85

Table 4-16. Calibration Wet-Weather River Load Concentrations

River	Fecal Coliform (cfu/yr)	Enterococci (cfu/yr)	E. Coli (cfu/yr)
Hudson River	199	106	N/A
Hackensack River	217	125	171
Passaic River	1,114	2,398	1,133
Saddle River	2,968	7,034	3,287
Raritan River	1,355	1,644	1,355
Second River	5,499	4,963	9,036
Elizabeth River	28,481	7,822	29,278
Third River	14,575	17,378	10,190
McDonalds Brook	5,499	4,963	9,036

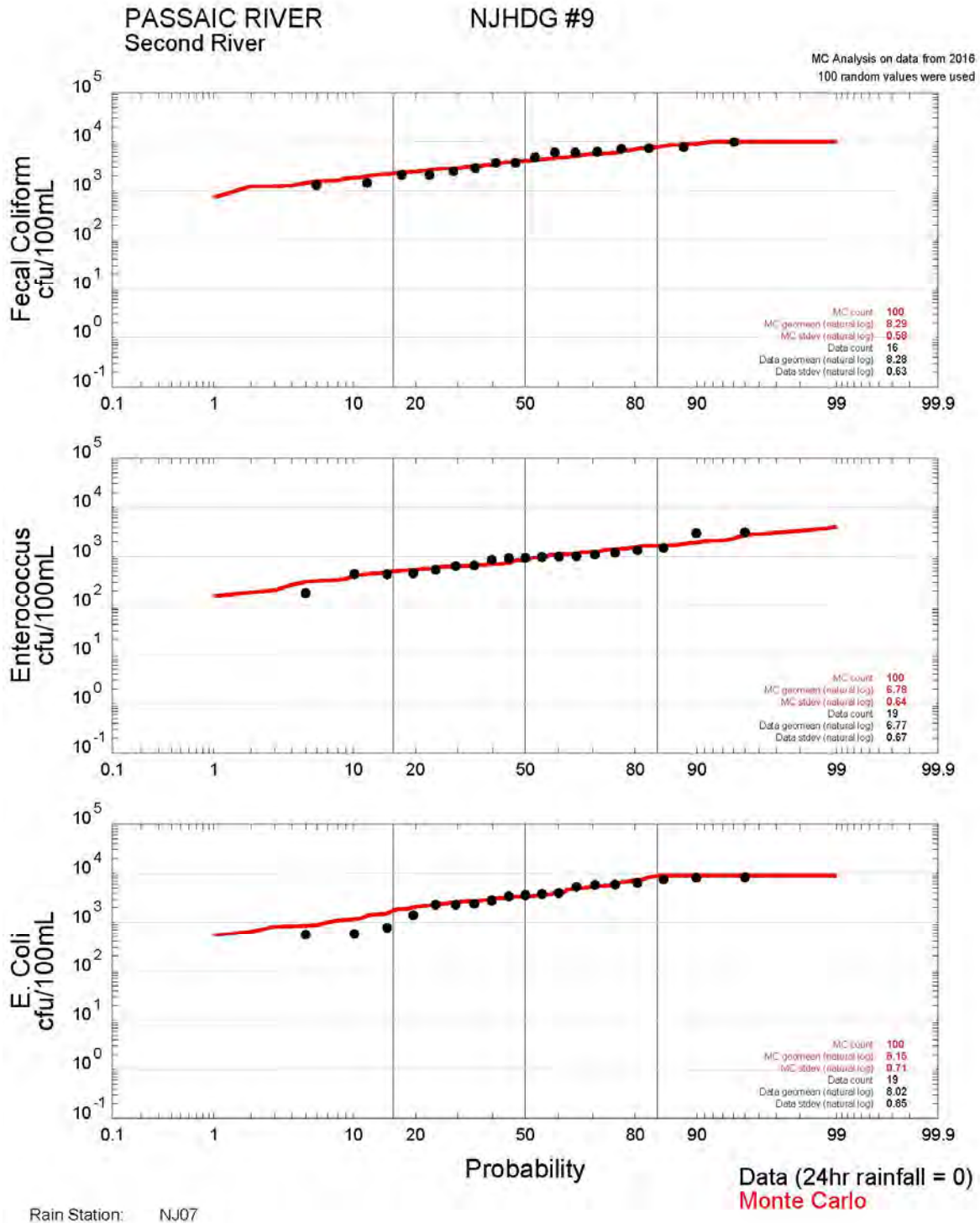


Figure 4-15. Example of Monte Carlo Bacteria Distributions used for Assigning Dry-Weather River Concentrations

The Hudson River loads were assigned in a different manner than the other rivers. The PWQM extends up the Hudson River to the Troy Dam in Albany, NY. Rather than trying to model all of the bacteria inputs between Albany and NJ, data were used to develop a Monte Carlo based random concentration distribution to assign a load upstream of the study area to reproduce the concentration data observed at NJHDG Station 31. Loads for E. coli in the Hudson River since E. coli is not a criterion used in saline waters. Table 4-17 through Table 4-19 present the river loads associated with the calibration period, validation period and baseline period, respectively.

Table 4-17. Calibration Period River Loads

River	Average Flow (cfs)	Fecal Coliform (10¹² cfu/yr)	Enterococci (10¹² cfu/yr)	E. Coli (10¹² cfu/yr)
Hudson River	55,700	39,600	14,600	19,800
Elizabeth River	34.8	4,300	1,110	4,180
Hackensack River	12.9	12.0	4.5	9.2
Passaic River	612	2,200	3,900	2,330
Saddle River	66.2	785	1,390	769
Second River	29.6	1,400	1,020	2,050
Third River	25.6	2,420	2,870	1,690
McDonalds Brook	23.7	967	816	1,530
Raritan River	648	3,190	3,200	2,770

Table 4-18. Validation Period River Loads

River	Average Flow (cfs)	Fecal Coliform (10¹² cfu/yr)	Enterococci (10¹² cfu/yr)	E. Coli (10¹² cfu/yr)
Hudson River	55,900	40,900	14,700	20,500
Elizabeth River	35.1	4,640	1,230	4,650
Hackensack River	38.4	47	27	39
Passaic River	700	2,600	5,140	2,780
Saddle River	80.4	824	1,570	865
Second River	30.5	1,410	1,130	2,190
Third River	26.5	2,680	3,160	1,890
McDonalds Brook	25.5	1,050	914	1,690
Raritan River	764	3,250	3,560	3,260

Table 4-19. Baseline River Loads

River	Average Flow (cfs)	Fecal Coliform (10^{12} cfu/yr)	Enterococci (10^{12} cfu/yr)	E. Coli (10^{12} cfu/yr)
Hudson River	53,300	46,600	13,500	23,300
Elizabeth River	35.6	4,700	1,200	4,500
Hackensack River	102	161	75	128
Passaic River	1,230	3,960	5,770	3,850
Saddle River	125	1,370	2,260	1,390
Second River	38.0	1,820	1,400	2,710
Third River	38.1	3,820	4,480	2,670
McDonalds Brook	33.9	1,460	1,200	2,260
Raritan River	1,300	7,630	8,030	7,380

In addition to river boundary conditions, ocean bacteria boundary conditions were assigned. The ocean boundaries are very far from the study area and from most bacteria sources. A FIB concentration of 1 cfu/100mL was assigned to the ocean boundaries to provide a non-zero concentration to avoid model instabilities.

4.2.2.5 Dry-Weather Loads

In some locations, the receiving water data indicated that unaccounted for dry-weather sources were contributing to a background bacteria concentration. These dry-weather sources are some of the most difficult to assign due to the uncertainty in their location, magnitude, and temporal variability. To account for this source, or sources, a dry-weather load was assigned to multiple model segments along several rivers in the model. These sources were assigned as constant loads. Appendix B contains figures that show where dry-weather loads were assigned in the model. Table 4-20 presents the loads for these sources. Equivalent daily flows have been added to the table based on an assumption that the source has sanitary sewage concentrations. The dry-weather sources may not be sanitary sewage. The equivalent flows were added to provide perspective against the other sources. This analysis does indicate that a relatively small sanitary flow can result in fairly significant bacteria loads.

Table 4-20. Dry-Weather Loads

River	No. of model cells	Equivalent Flow (gpd)	Fecal Coliform (10^{12} cfu/yr)	Enterococci (10^{12} cfu/yr)	E. Coli (10^{12} cfu/yr)
Elizabeth River	20	45,000	2,500	421	1,560
Hackensack River	81	182,250	10,100	1,700	6,320
Passaic River	37	83,250	4,620	779	2,880
Raritan River	19	42,750	2,370	400	1,480

4.2.2.6 Other Loads

Little effort was applied to assign bacteria loads within the model domain that are a great distance from the study area and do not impact the study area (e.g. discharges to Long Island Sound). One source of bacteria that is close enough to the study area to potentially have an impact is New York City. The NYC Department of Environmental Protection (NYCDEP) has InfoWorks models of its 14 WRRF sewersheds that include both combined and separately sewered areas of the City. NYCDEP provided InfoWorks output for the calibration, validation and baseline periods. NYCDEP is in the process of completing its own CSO LTCPs. The concentrations used for CSO, stormwater, and direct drainage areas in the LTCP plans were used in PWQM to assign the NYC bacteria loads. AECOM and Hazen (2020) and NYCDEP (2020) will provide additional information.

4.2.2.7 Loading Summary

Table 4-21 presents the total contribution of each source from the New Jersey side (with the exception of the Hudson River) within the project area for the calibration period. CSOs, stormwater runoff, and rivers all contribute similar levels of bacteria. CSOs contribute 26 to 43 percent of the total bacteria loading during the calibration period. Table 4-22 and Table 4-23 present the loading summary for the validation and baseline periods, respectively. CSO loads are higher during the validation and baseline periods than during the calibration period, but their relative bacteria loading contribution remains similar to the calibration period.

While fecal coliform generally has the highest load from each source, with the notable exception of stormwater, the ratio between the different fecal indicator bacteria is no greater than 6:1 from any one source. Total loads from each fecal indicator bacteria are close to 1:1.

Table 4-21. Calibration Bacteria Contribution by Source

Source	Flow (MG)	E. Coli (10 ¹⁴ cfu/100mL)	Fecal Coliform (10 ¹⁴ cfu/100mL)	Enterococci (10 ¹⁴ cfu/100mL)
NJ CSO	6,120	550	837	361
NJ Stormwater/Runoff	83,200	326	363	697
River Boundary ^a	13,500,000	257	458	231
Internal River Loads ^b	56,700	98	95	62
NJ STP	179,000	0.7	3.4	0.7
Dry	129 ^c	122	196	33
Total	13,830,000^d	1,354	1,952	1,385

a – Hudson R., Hackensack R., Passaic R., Saddle R., and Raritan R.

b – Second, Third, Elizabeth, South Rivers and McDonalds Brook

c - Equivalent flow. Flow not actually included in model.

d – Rounded

Table 4-22. Validation Bacteria Contribution by Source

Source	Flow (MG)	E. Coli (10 ¹⁴ cfu/100mL)	Fecal Coliform (10 ¹⁴ cfu/100mL)	Enterococci (10 ¹⁴ cfu/100mL)
NJ CSO	7,700	656	996	446
NJ Stormwater/Runoff	101,000	428	474	922
River Boundary ^a	13,600,000	274	477	249
Internal River Loads ^b	70,800	111	105	72
NJ STP	186,000	0.7	3.5	0.7
Dry	129 ^c	122	196	33
Total	13,970,000^d	1,592	2,251	1,723

a – Hudson R., Hackensack R., Passaic R., Saddle R., and Raritan R.

b – Second, Third, Elizabeth, South Rivers and McDonalds Brook

c - Equivalent flow. Flow not actually included in model.

d – Rounded

Table 4-23. Baseline Bacteria Contribution by Source

Source	Flow (MG)	E. Coli (10 ¹⁴ cfu/100mL)	Fecal Coliform (10 ¹⁴ cfu/100mL)	Enterococci (10 ¹⁴ cfu/100mL)
NJ CSO	7,800	967	1,500	521
NJ Stormwater/Runoff	118,000	520	577	1,030
River Boundary ^a	13,300,000	360	597	296
Internal River Loads ^b	90,500	133	130	96
NJ STP	194,000	0.7	3.6	0.7
Dry	129 ^c	122	196	33
Total	13,710,000^d	2,104	2,999	1,976

a – Hudson R., Hackensack R., Passaic R., Saddle R., and Raritan R.

b – Second, Third, Elizabeth, South Rivers and McDonald Brook

c - Equivalent flow. Flow not actually included in model.

d – Rounded

4.3 Key Assumptions

The PWQM is based on the principle of mass balance. As such, a key component of the model is to account for all of the sources of bacteria to the receiving waters to the project area. The sources of bacteria include CSOs, stormwater, rivers, STPs and other sources including illicit connections and domestic/wild animals. Bacteria concentrations can be highly variable, and this variability is not predictable. The Monte Carlo approach applied to river concentrations, and the mass balance approach applied to the CSO loads account for some of the variability, but based on source data, the actual bacteria concentration variability is greater than the variability applied in the model. A key assumption then is that using MLE concentrations for bacteria sources adequately accounts for the total loading of bacteria. Based on the model calibration/validation presented below, this assumption appears valid.

A second key assumption for both the hydrodynamic model and the water quality model, is that the landside models accurately calculate the flow and sanitary fraction discharged from the CSOs. Since the water quality model is based on the principle of mass balance, the landside models must accurately account for the volume of CSO being discharged and the fraction of that volume that is sanitary flow. Again, based on the calibration/validation presented below, the landside models appear to adequately account for the CSO bacteria loads.

5 Calibration and Validation

5.1 Objectives, Activities, and Methods

Previous calibration of the HEP PATH TMDL model was based on conditions from the mid-to-late 1980s, and then was recalibrated to data from 2002 and 2004. However, substantial environmental improvements have occurred since that time and are likely to continue to occur. The NYCDEP Harbor Survey Data shows dramatic improvement in bacteria levels, particularly in the Hudson River, over the past 10 years. In addition, dredging of portions of the NY/NJ Harbor has continued changing the circulation patterns within sections, particularly Newark Bay. Therefore, a calibration/validation of the bacteria calculations were performed using primary data collected during this project under a related QAPP data collected under the Baseline Compliance Monitoring Program QAPP, the NJHDG Annual Program, and the NYCDEP Harbor Survey. The model was considered calibrated/validated when the comparison of results and data met the standard of best professional judgment.

5.2 Parameter Values and Sources, Rationale

5.2.1 Hydrodynamic Model

The hydrodynamic model calibration was performed by adjusting bottom friction (C_D) and horizontal eddy diffusion coefficients to reproduce measured water elevations, current velocities, salinities and temperatures at different locations inside the model domain. In addition, fluxes through the East River, Kill van Kill and Arthur Kill section, and Newark

Bay were compared with estimates of fluxes from previous NY-NJ Harbor studies. The calibrated value of Smagorinsky (1963) horizontal diffusion formulation is equal to 0.01 throughout the model domain. The minimum bottom friction coefficient (C_D) was set equal to 0.003, except for the East River and Harlem River where C_D is equal to 0.06.

5.2.2 Water Quality Model

The fecal indicator bacteria are modeling using a first-order decay as described in Equation 5-1:

$$N = N_0 e^{-K_b t} \tag{5-1}$$

where N is the bacteria concentration in cfu/100mL, N_0 is the bacteria at time 0, K_b is the decay rate in units of /day and t is time in days. K_b is based on the equation developed by Mancini (1978) and shown as Equation 5-2:

$$K_b = [0.8 + 0.006(\%seawater)] 1.07^{(T-20)} + \alpha I_0(t) / K_e H [1 - \exp(-K_e H)] + V_s / H \tag{5-2}$$

(Mancini, 1978)

The first part of Equation 5-2 represents a base die-off rate (0.8/day) that is modified by percent seawater (with the constant 0.006/day) and temperature (1.07 raised to the $T-20$ with T in °C). The constants: 0.8, 0.006, and 1.07, can all be modified as part of the model calibration process. The second part of equation represents the die-off associated with solar radiation, where α is a proportionality constant, I_0 is the surface solar radiation, K_e is the extinction coefficient in /m, and H is the depth in m. Alpha (α) can be used as part of the calibration process. The last part of Equation 5-2 is the loss of bacteria due to settling where V_s is the settling rate in m/d. V_s can also be adjusted as part of the calibration process.

Table 5-1 presents the final constants used for the calibration. E. coli and fecal coliform were assigned the same constants. E. coli are a subset of the bacteria in the fecal coliform group. Enterococci were assigned similar but higher loss rate constants. This was primarily due to the observation that fecal coliform to enterococci ratios in the water column were greater than the fecal coliform to enterococci ratios measured in the sources (CSO, stormwater, sanitary).

Table 5-1. Water Quality Model Constants

Constant	Symbol	Value	Units
Base temperature dependent fecal coliform and E. coli die-off rate at 20 °C	K_{fcb} , K_{ecb}	0.5	/day
Temperature coefficient for fecal coliform and E. coli die-off rate	θ	1.07	unitless
Fecal coliform/E. coli die-off rate due to sea water	K_{sw}	0.006	/day

Table 5-1. Water Quality Model Constants

Constant	Symbol	Value	Units
Fecal coliform/E. coli proportionality constant (solar radiation)	α	0.003	/ly-day
Base temperature dependent enterococci die-off rate at 20 °C	K_{enb}	0.8	/day
Temperature coefficient for enterococci die-off rate	θ	1.07	unitless
Enterococci die-off rate due to sea water	K_{sw}	0.006	/day
Enterococci proportionality constant (solar radiation)	α	0.00824	/ly-day
Light extinction coefficient	K_e	1-10	/m

The final enterococci constants were true to the original Mancini equation constants with a proportionality constant based on Auer et al. (1993). The fecal coliform and E. coli constants for the base die-off rate and proportionality constant were reduced from the original Mancini equation constants to better represent the data. The light extinction coefficient was assigned to be spatially varying based on limited Secchi depth data. There was not enough data to justify assigning a temporally varying light extinction coefficients. Figure 5-1 presents a map of the assigned K_e . The colored circles with station numbers show the average K_e calculated from the data, so the data can be compared to what was assigned. In some cases, the assigned K_e was adjusted from the data to better match water column bacteria concentrations.

5.3 Calibration Results

5.3.1 Hydrodynamic Model

Model calibration is an iterative procedure whereby model parameters are refined by comparing model results with observed data until the model is able to produce realistic results comparing well with observed data under various forcing conditions. When more calibration data are available, the model is more likely to represent physical processes of the study area after the calibration is completed. This section focuses on the model calibration procedures and the calibration results of the PVSC LTCP hydrodynamic model.

5.3.1.1 Water Elevations

Figure 5-2 shows the comparison of the calculated surface water elevations with observed data over a one-month period at five NOAA stations and one at PVSC HRECOS station in 2016. In this figure, observations are shown as red lines, while the model results are shown as black lines. The figure indicates that the model results agree very well with the observed data at all locations. The ranges between spring and neap tidal cycles, and times of high and low waters are very well reproduced. Model results for another 30-day period, in 2017, is shown in Figure 5-3.

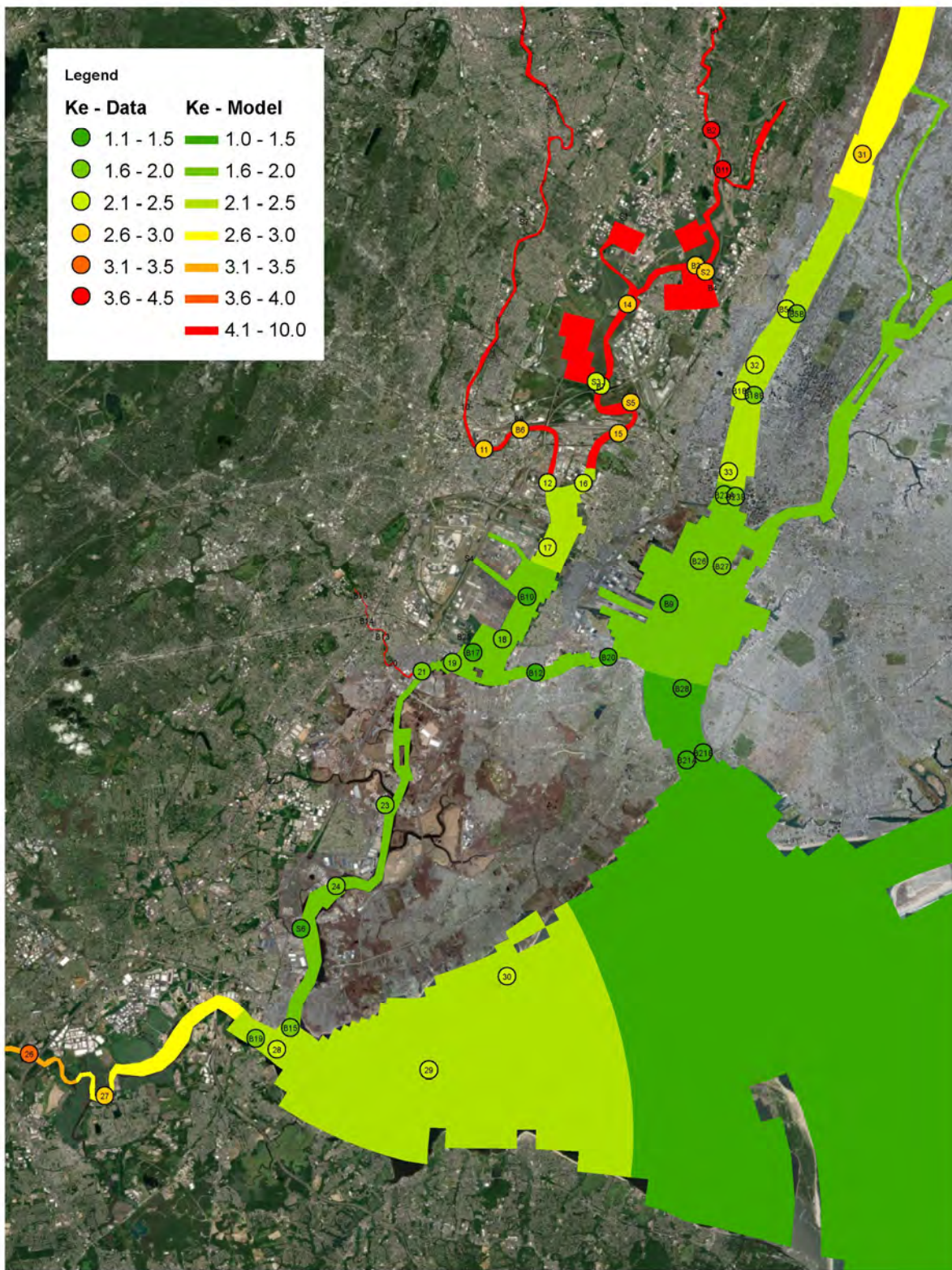


Figure 5-1. Assigned Spatially Varying Light Extinction Coefficients (Ke)

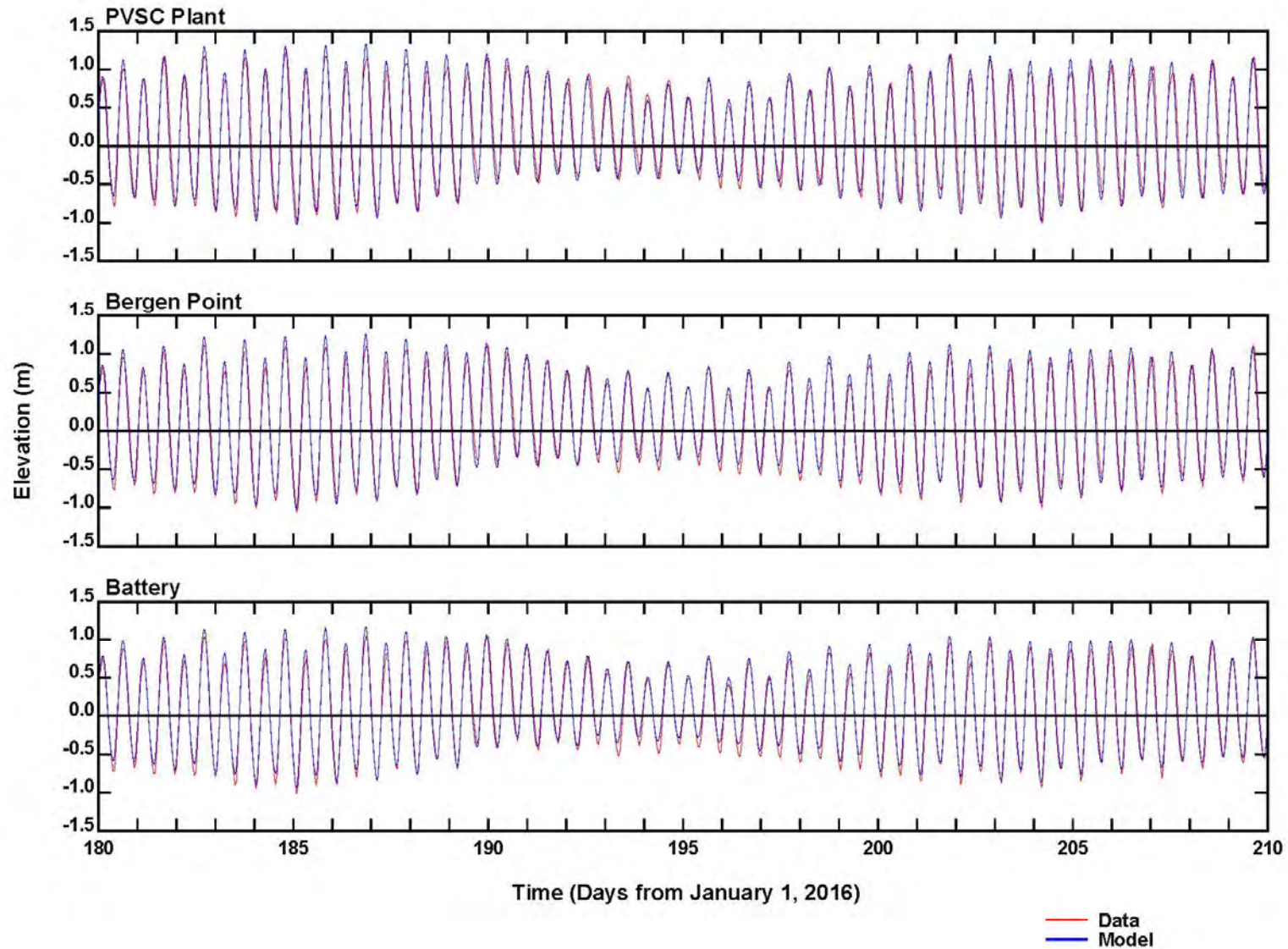


Figure 5-2. 2016 Comparison of Hourly Tidal Water Elevations

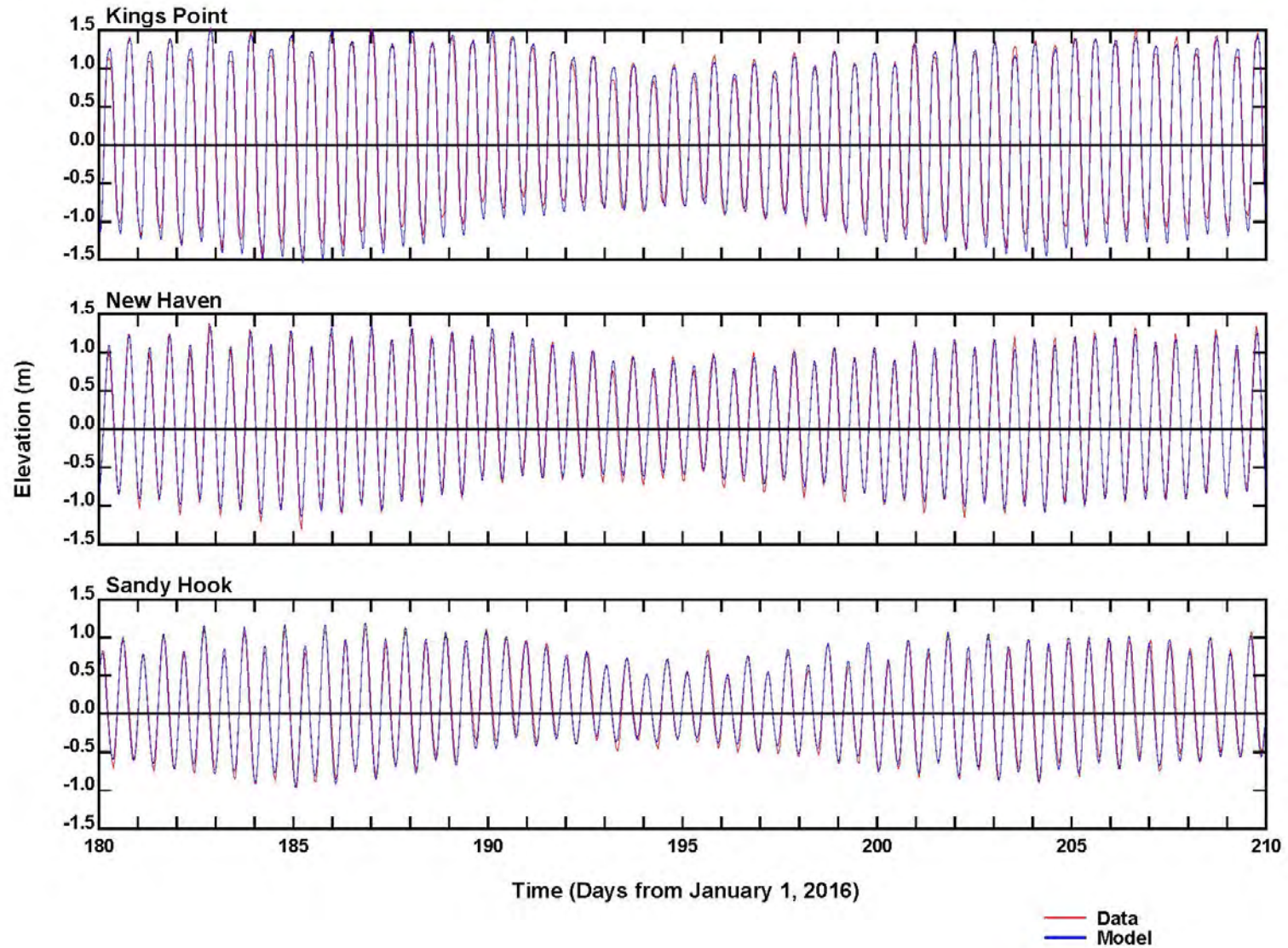


Figure 5-2. 2016 Comparison of Hourly Tidal Water Elevations (Continued)

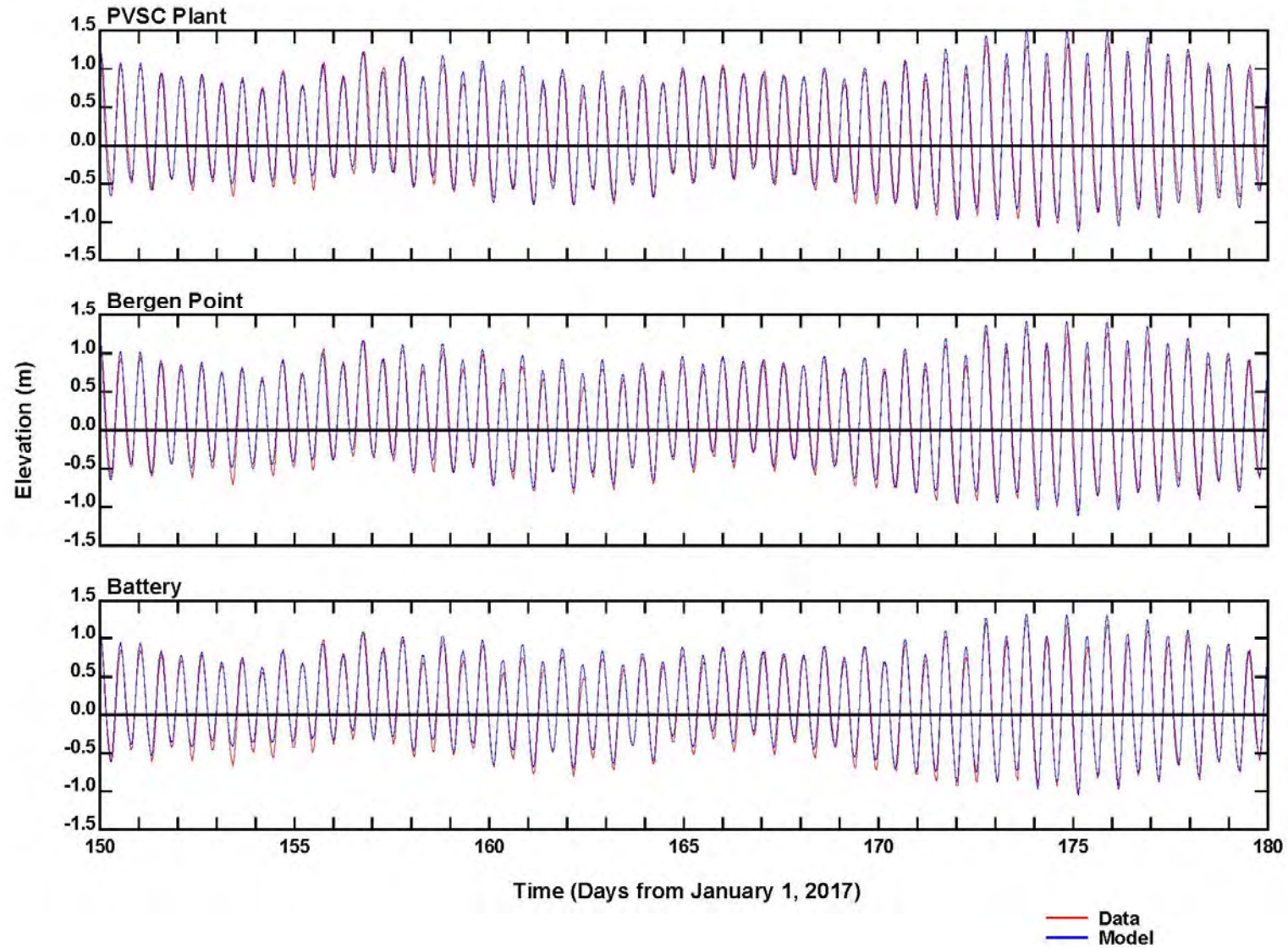


Figure 5-3. 2017 Comparison of Hourly Tidal Water Elevations

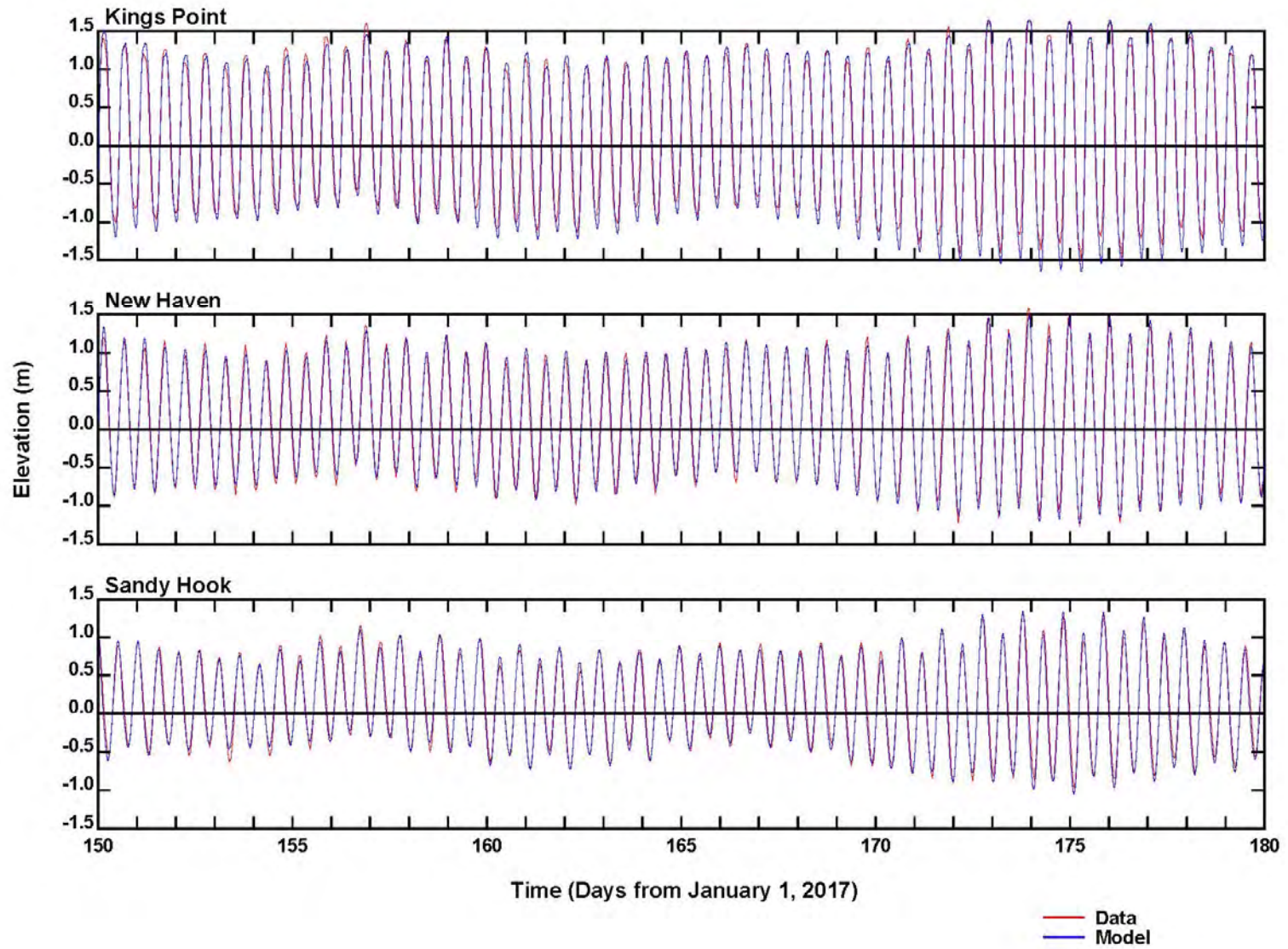


Figure 5-3. 2017 Comparison of Hourly Tidal Water Elevations (Continued)

At the same tide stations, 35-hour low-pass filtered data are compared over a period of one year. Figure 5-4 and Figure 5-5 show the results for 2016 and 2017, respectively. These 35-hour low-pass filtered elevations represent sub-tidal fluctuations of water levels (i.e. frequency longer than 12-24 hour tidal signals) caused mainly due to meteorological forcings such as wind stress and barometric pressure gradients. The figures show that at any given time, subtidal water levels vary from astronomical tides (tides caused by gravity alone) by about 0.5m during the course of the year. Most of the highs and lows (i.e. storm surge or set-down processes) are reproduced by the model. Since off-shore boundary conditions are used to force the model, the discrepancies between model results and data are mainly due to the approximate nature of the derived elevation boundary conditions as discussed in Section 4.2.1.5 (off-shore boundary forcings). Considering these approximations, the model manages to reproduce the subtidal variations in water surface elevations reasonably well. It should be noted that during winter periods (i.e. Days 0-60 and Day 300-365) sub-tidal fluctuations are more frequent and larger than those in summer months. This is mainly due to relatively strong wind patterns in NY-NJ-CT area. Please refer to Figure 4-6 and Figure 4-7 for seasonal variation of wind speeds at different parts of the model domain.

5.3.1.2 Current Velocities

Model calculated tidal currents in LPR and Hackensack Rivers, Newark Bay, Kill van Kull, and Arthur Kill were compared with bottom mounted ADCP mooring data measured in 2009 and 2010 period at nine (9) different locations. Locations of these ADCP mooring stations are shown in Figure 2-2. Figure 5-6 shows examples of the comparison between model calculated and observed tidal current at six (6) depths at two locations for a 12-day period to show the behavior of the tidal currents in the Passaic River and Hackensack River. Additional figures are presented in Appendix D. Positive values indicate current moving in the upstream direction in LPR, Hackensack, and Newark Bay stations. In Kill van Kull and Arthur Kill stations, positive values indicate current moving toward eastward. Red lines indicate observed currents and black lines are model calculated currents.

While there are substantial variations of magnitudes of current velocities at different locations, the model calculated currents are in line with observed values both in amplitude (i.e., range of high and low velocities) and phase (i.e. timing of high and low velocities) at most locations. As shown in Appendix D, observed surface currents at Kill van Kull exceed 100 cm/s whereas in Arthur Kill station, which is near Goethals Bridge at the northern end of Arthur Kill, surface currents reduce to below 50 cm/s. Model calculated currents match observed current velocities very well. Also note that, at the Kill van Kill station, there is substantial reduction in range of observed currents between near surface and near bottom. Amplitude of the surface currents is about 100 cm/s and bottom currents is about 50 cm/s, which is a reduction of about 50%. Model calculated currents at this location also depict the similar reduction, which implies that the model accounts for proper variation of vertical current profile due to frictional effect at depths. However, at Stations 042 in LPR and HKN in Hackensack River, model calculated currents are slightly higher than observed data.

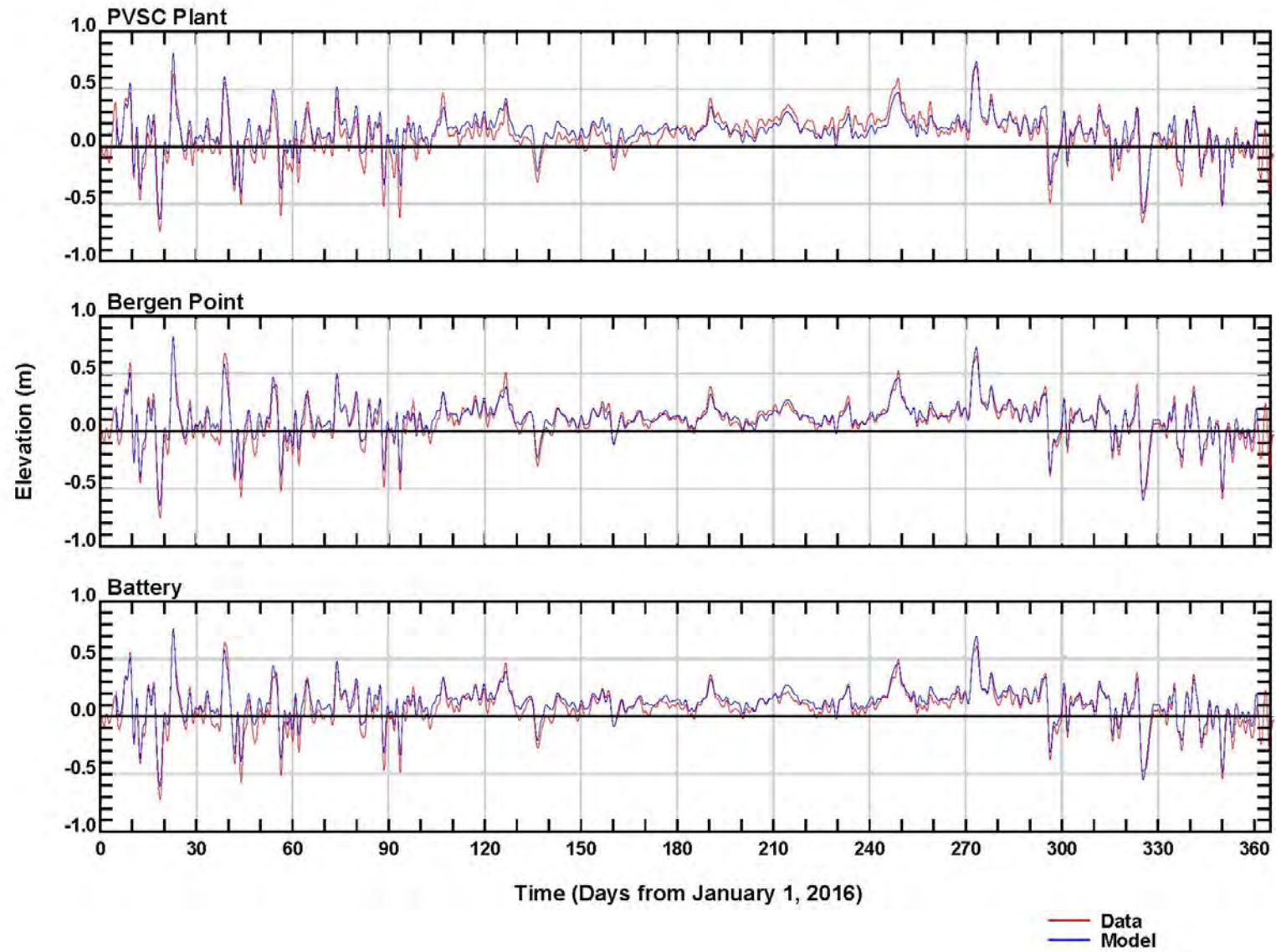


Figure 5-4. 2016 Comparison of 35hr Low-Passed Elevations

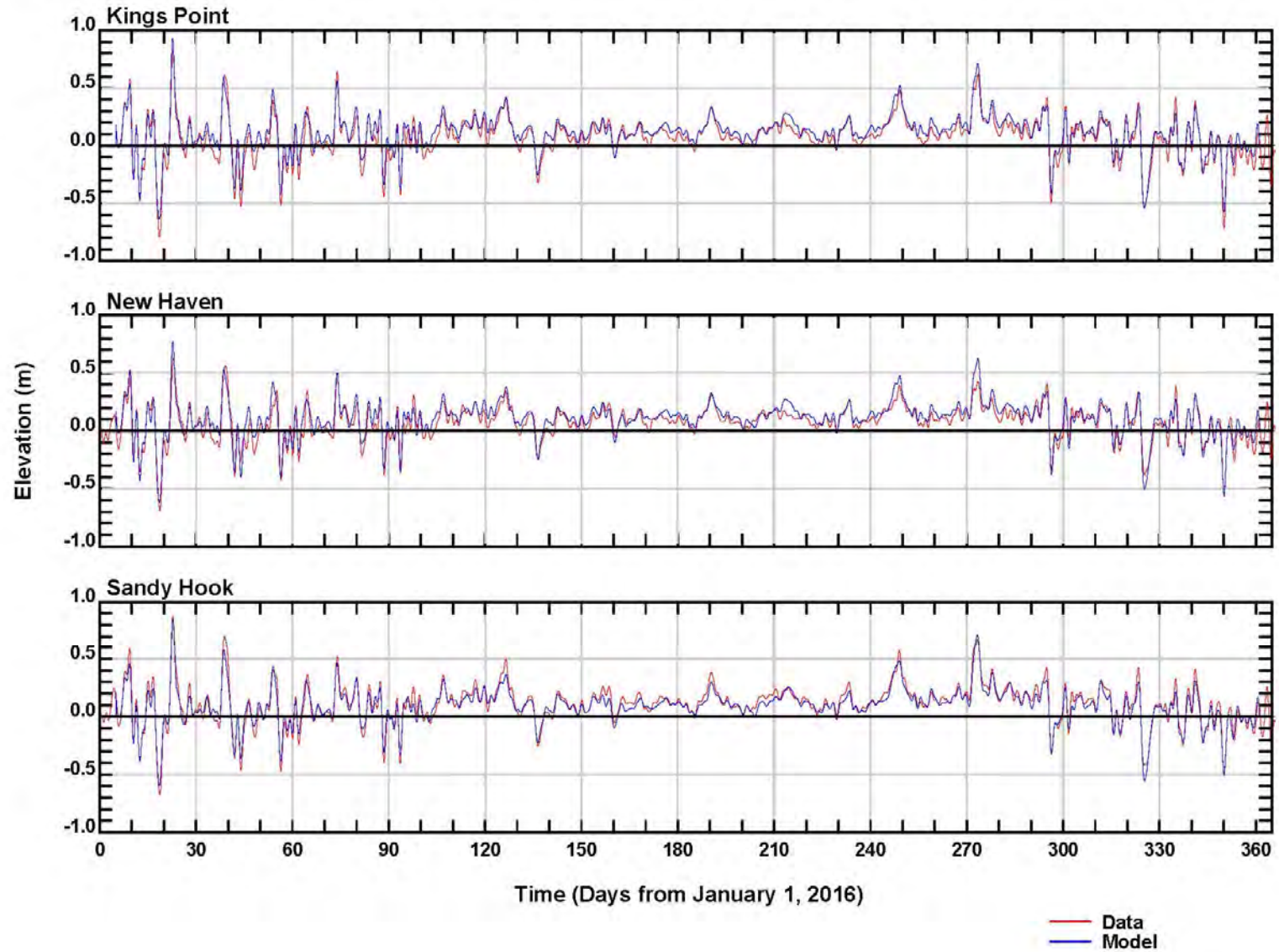


Figure 5-4. 2016 Comparison of 35hr Low-Passed Elevations (Continued)

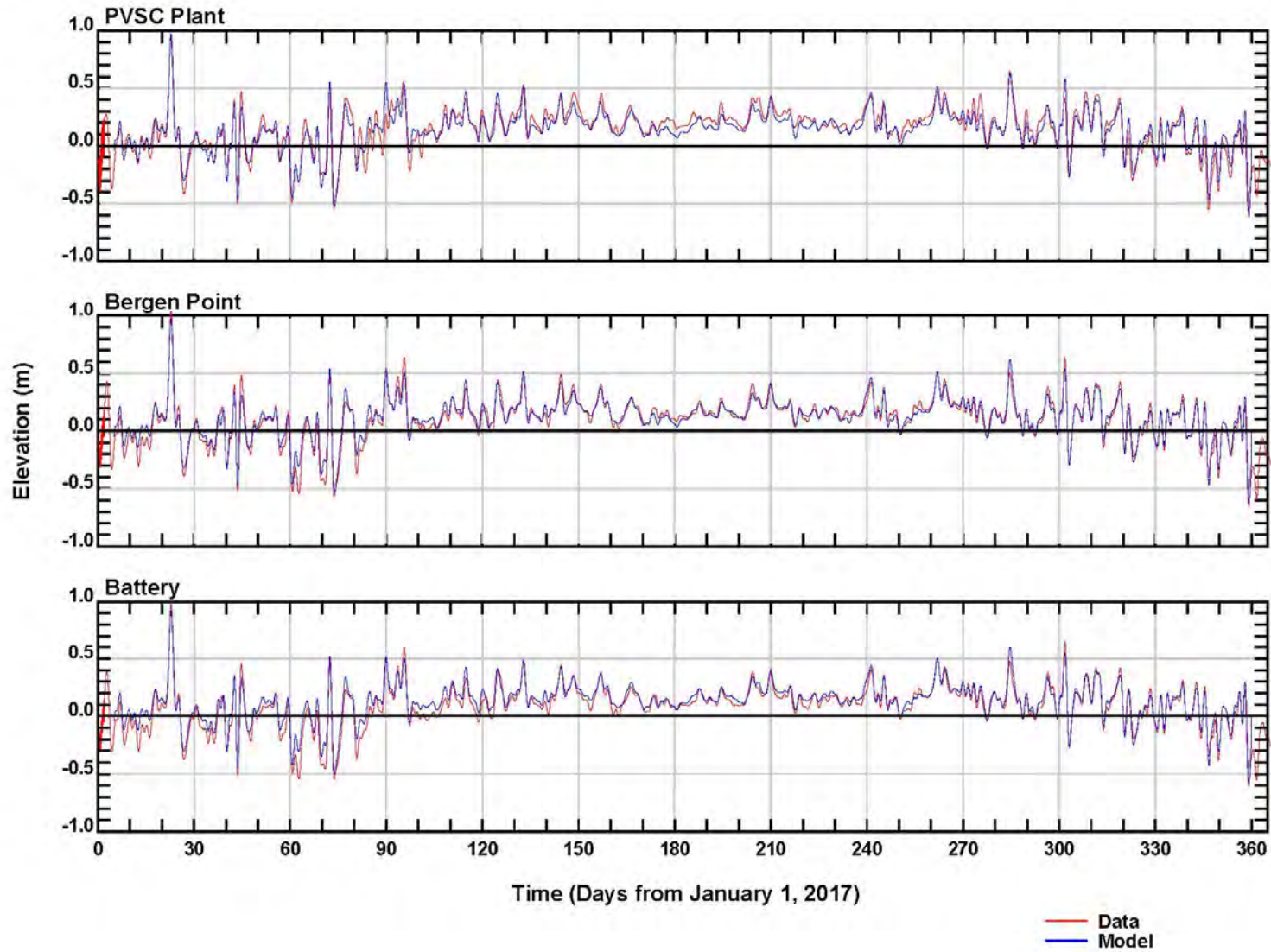


Figure 5-5. 2017 Comparison of 35hr Low-Passed Elevations

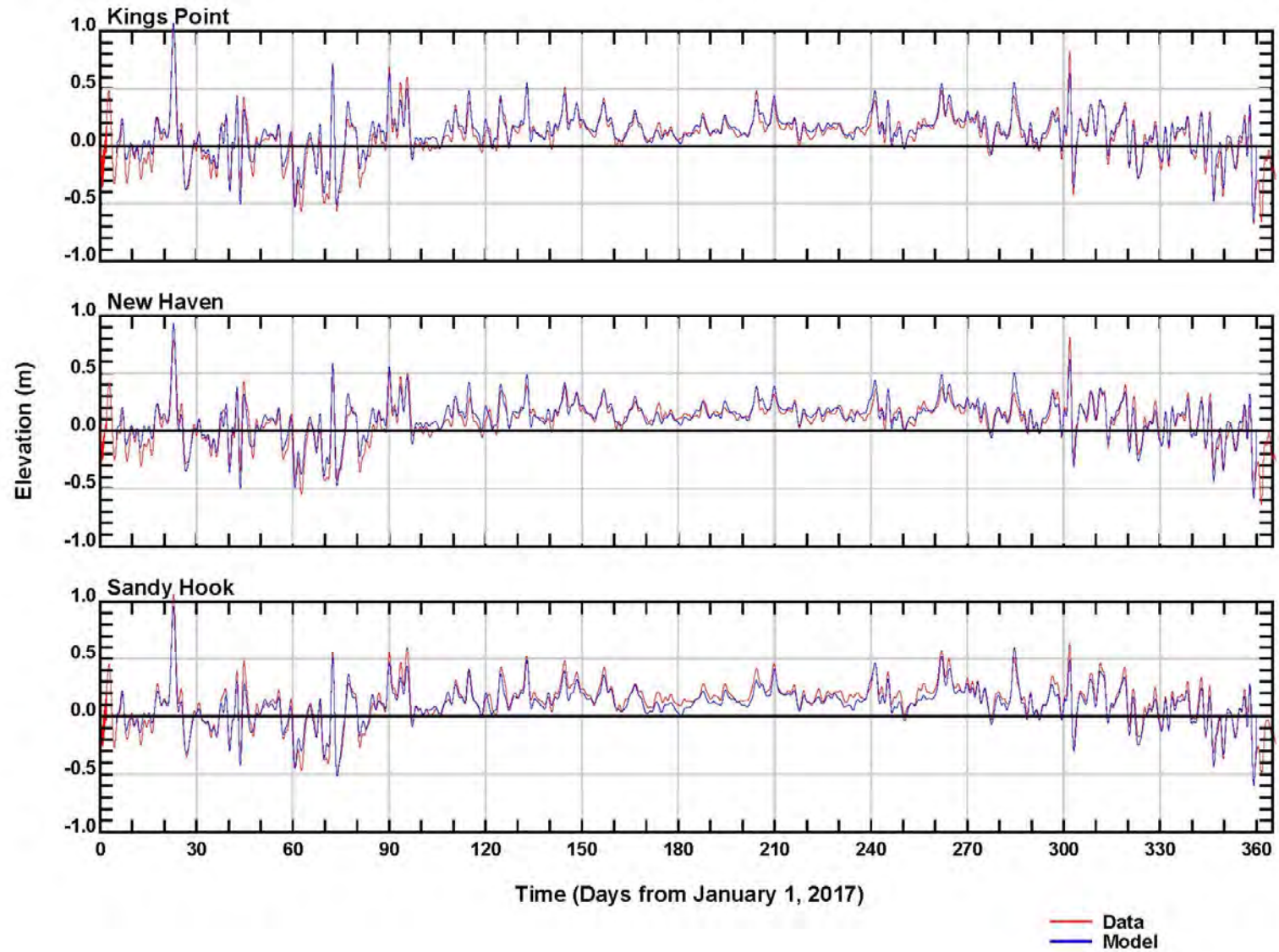


Figure 5-5. 2017 Comparison of 35hr Low-Passed Elevations (Continued)

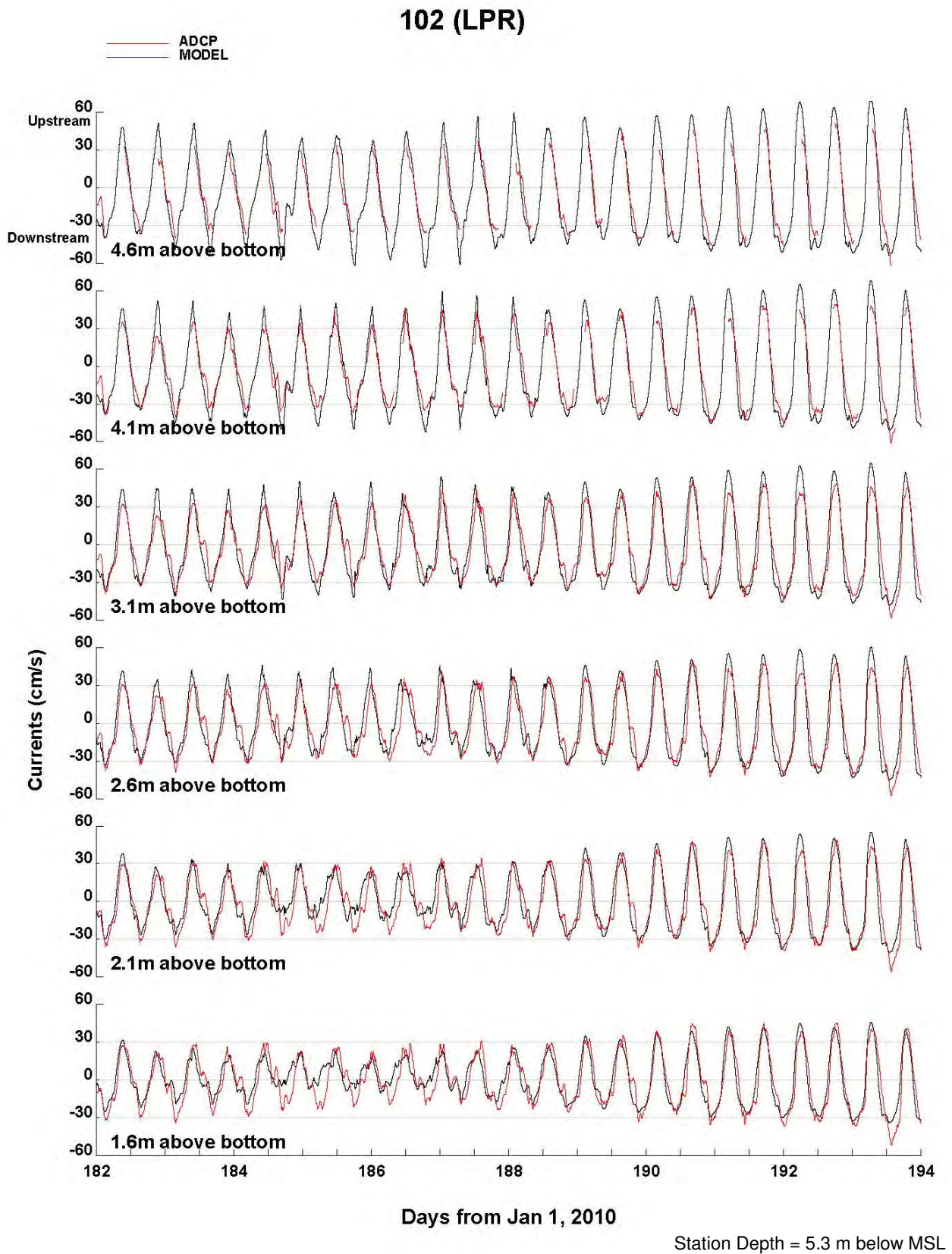


Figure 5-6. 2010 Comparison of Tidal Currents

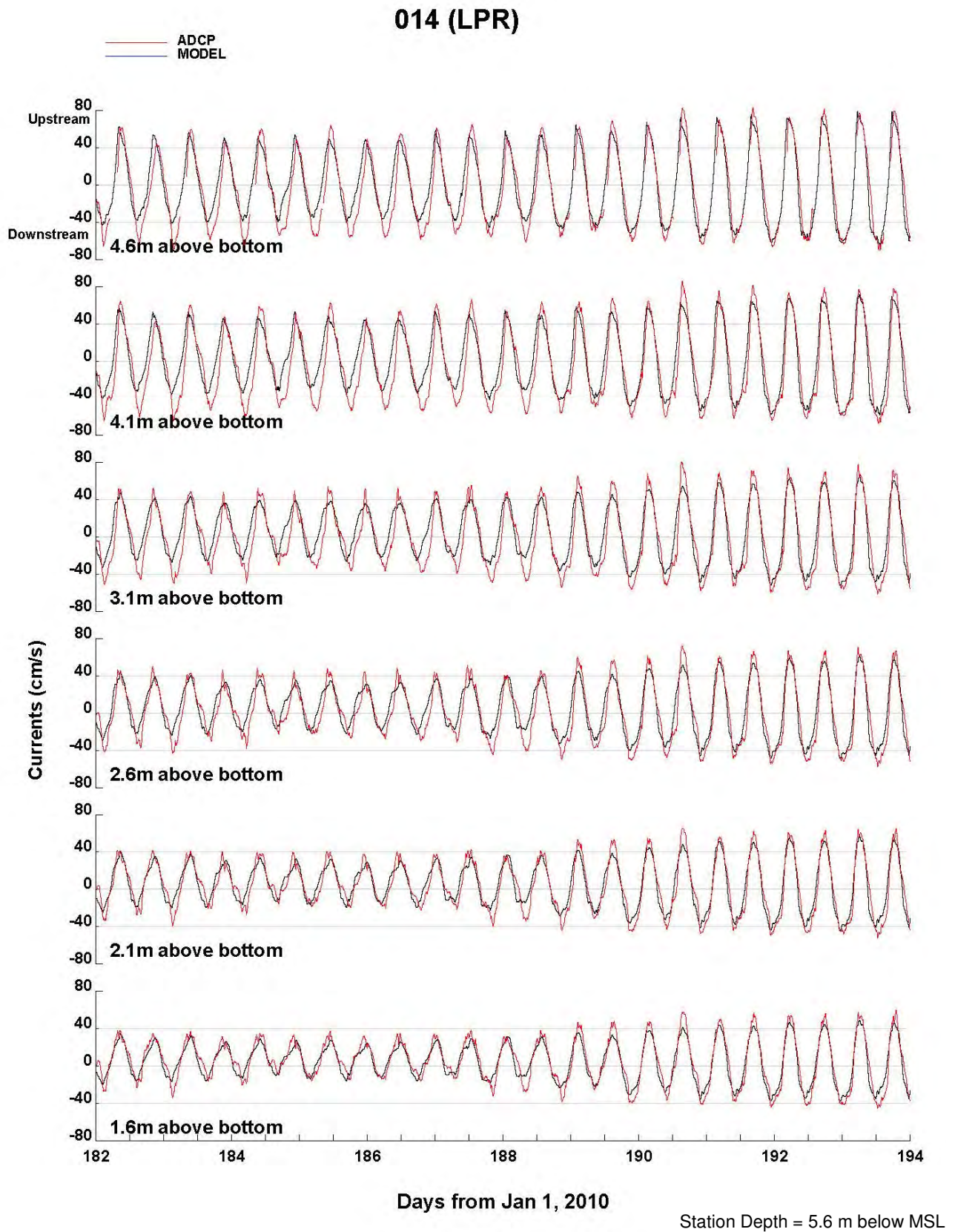


Figure 5-6. 2010 Comparison of Tidal Currents (Continued)

5.3.1.3 Temperature and Salinity

The model was calibrated against various water temperature and salinity data collected in 2016 and 2017. These data sets include surveys done by NJ Dischargers Group, HDR, NYC DEP Harbor Survey, MERI, and HRECOS as described in Section 2.1.1. There are more than 60 locations covered by these various sampling programs. For the brevity of this report, nine (9) sampling stations were selected which represent lower Hudson River/Upper Bay area, Lower Passaic, Hackensack, and Newark Bay area, and Kill van Kull and Arthur Kill area. Comprehensive model-data comparison plots are included in Appendix D.

Figure 5-7 and Figure 5-8 show the model-data comparison of hourly surface and bottom water temperature in 2016 and 2017, respectively. As mentioned earlier, nine (9) locations within NY-NJ Harbor system were selected to show the model and data comparisons. Three stations in the first page of Figure 5-7 show the model-data comparison in the lower Hudson River near Lincoln Tunnel, in the middle of Upper Bay, and at the Narrows. The first panel contains data collected by four different agencies: NYC Harbor Survey Station N4, HDR Station 32, and NJ Dischargers Group Station 32, and HRECOS mooring at Pier 84. The results indicate that the model reproduced the surface and bottom temperature at this location very well throughout the year. The other two locations (middle and bottom panels) also show very good agreement between model and data. The second page shows model-data comparison at two locations in the Lower Passaic River (one at Station 10 near Rt 280 in Newark and another at HRECOS station at the PVSC plant) and one location in the Hackensack River (Station 14 near Berrys Creek). Unlike at the stations in the Hudson River, these three stations in the LPR and Hackensack River show highly variable temperatures throughout the year. It appears that the shallow and narrow river system responds more readily with rapidly changing weather conditions, and the model is tracking the temperature variations very well, particularly at continuous observation data at the PVSC plant. The last page of Figure 5-7 shows model-data comparison at the middle of Newark Bay (Station 18), at the eastern end of Kill van Kull (HDR Station B20 and NYC DEP Harbor Survey Station K1), and at the northern end of Arthur Kill near Goethals Bridge (NJ Dischargers Group Station 21 and NYC DEP Harbor Survey Station K3). Again the agreement between model calculated and observed water temperature at these stations is very good.

Figure 5-8 shows the model and data comparison of water temperature in 2017. Again, the figure shows very good agreement of model calculated and observed water temperature at those stations in 2017. It appears that spatially variable NOAA NARR meteorological data provided accurate surface heat flux to for the model to accurately calculate water temperature.

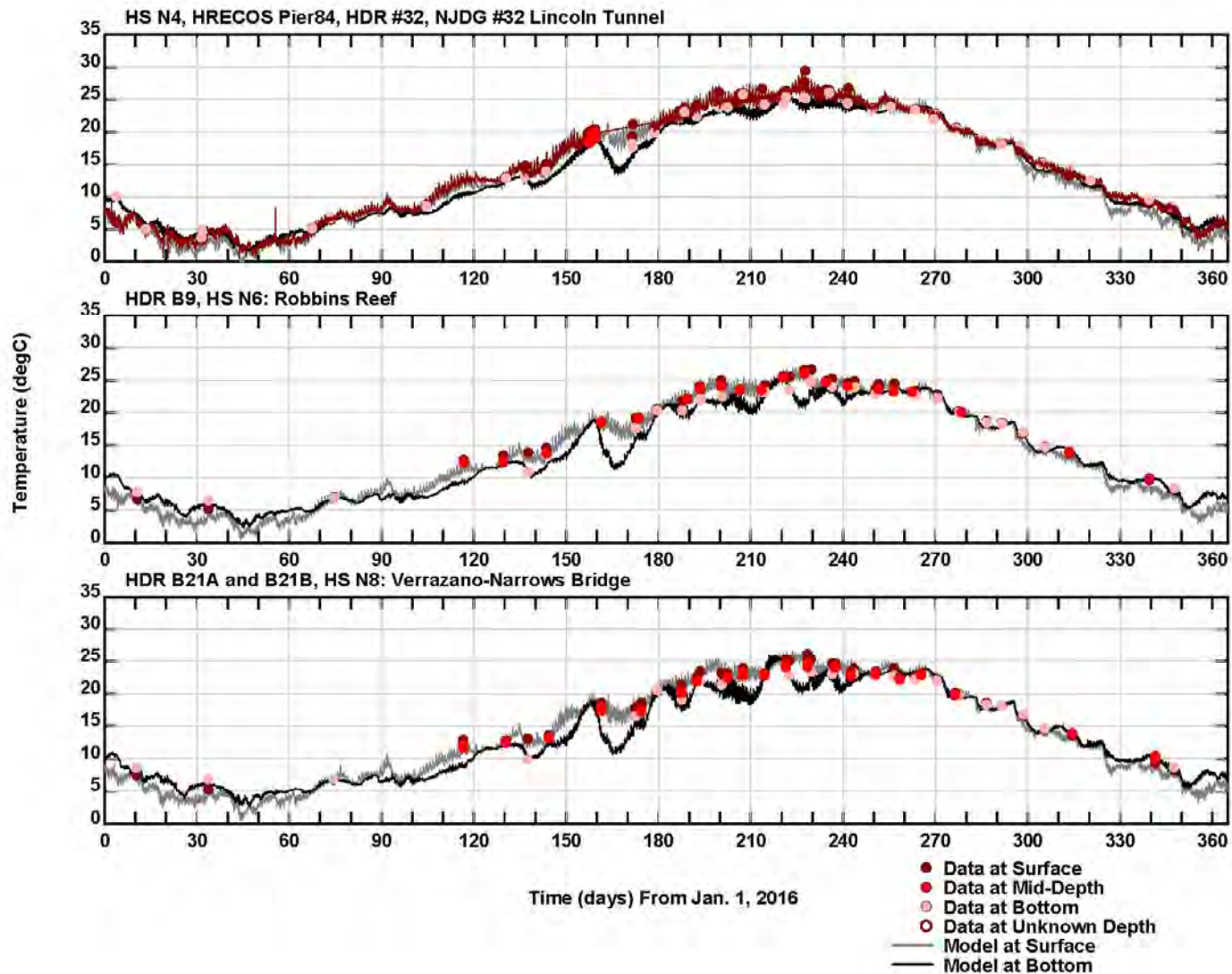


Figure 5-7. 2016 Comparison of Model Computed Water Temperature

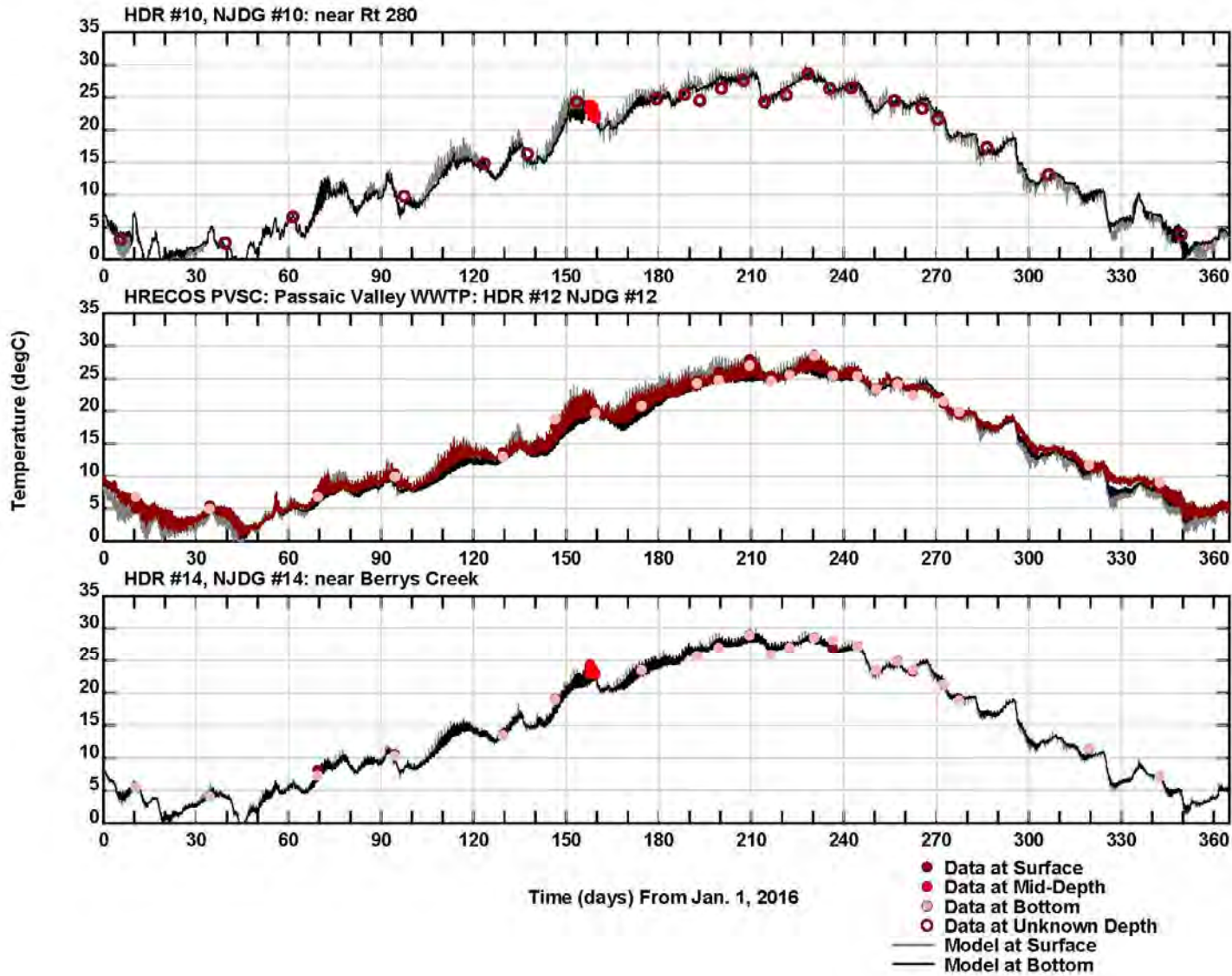


Figure 5-7. 2016 Comparison of Model Computed Water Temperature (Continued)

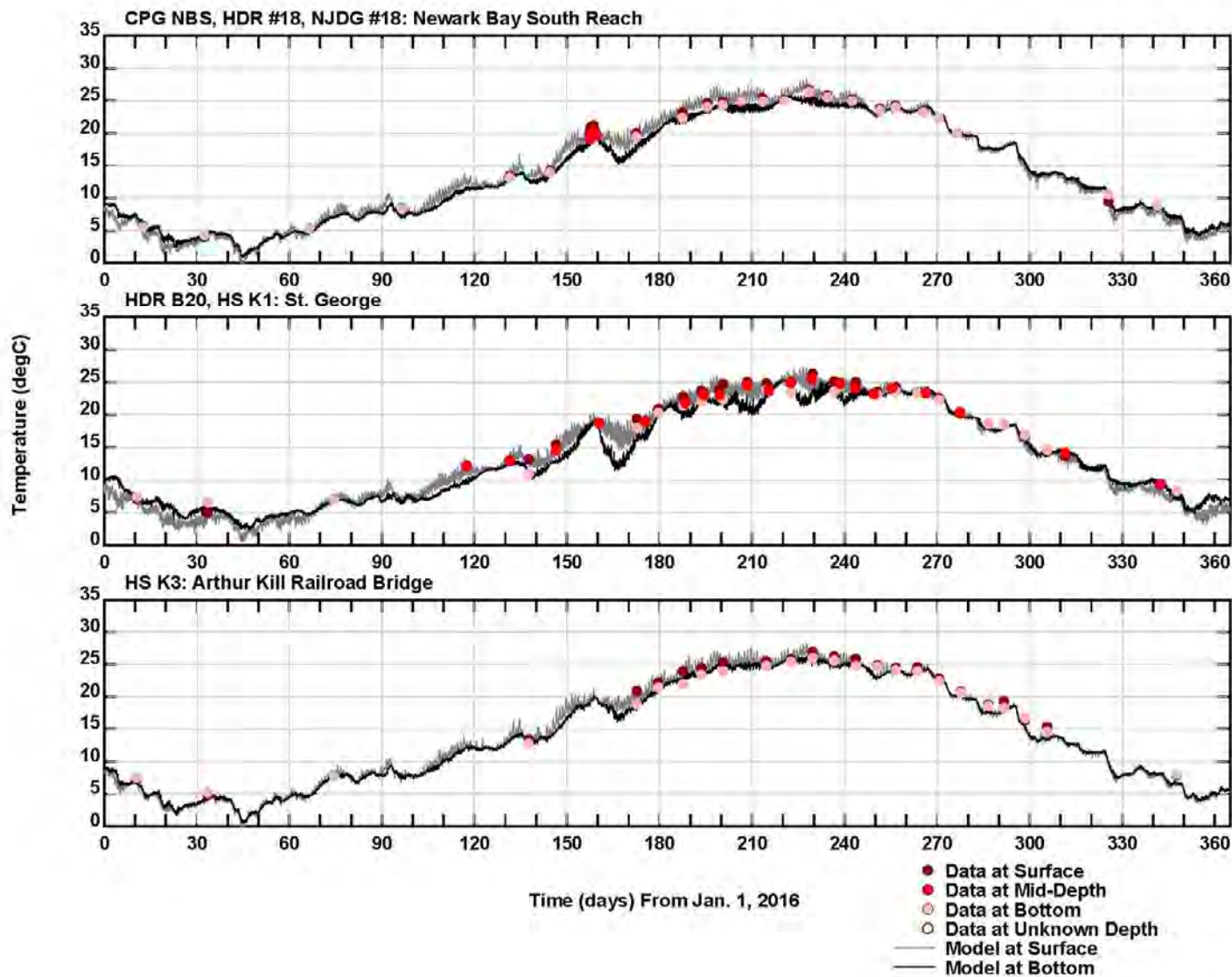


Figure 5-7. 2016 Comparison of Model Computed Water Temperature (Continued)

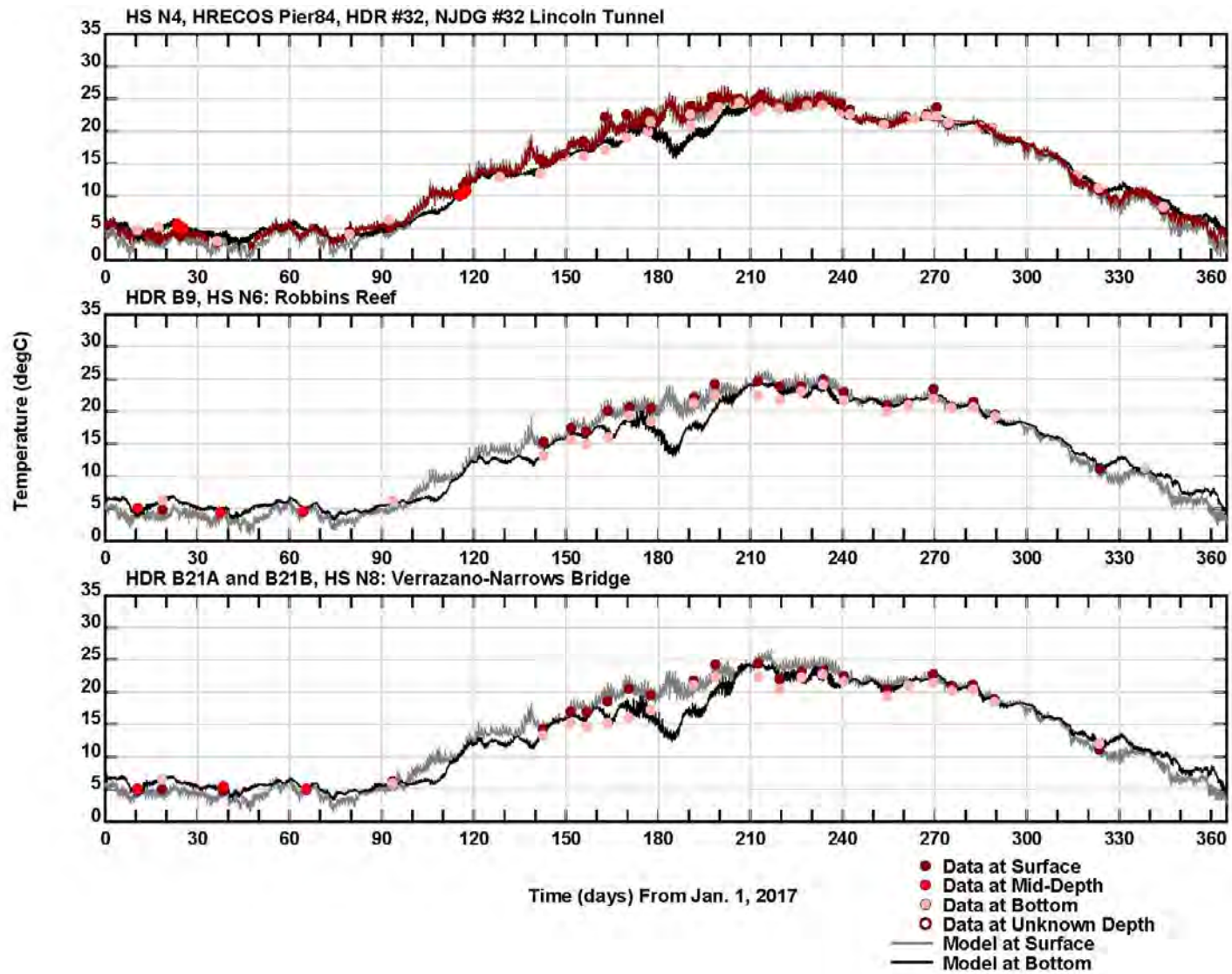


Figure 5-8. 2017 Comparison of Model Computed Water Temperature

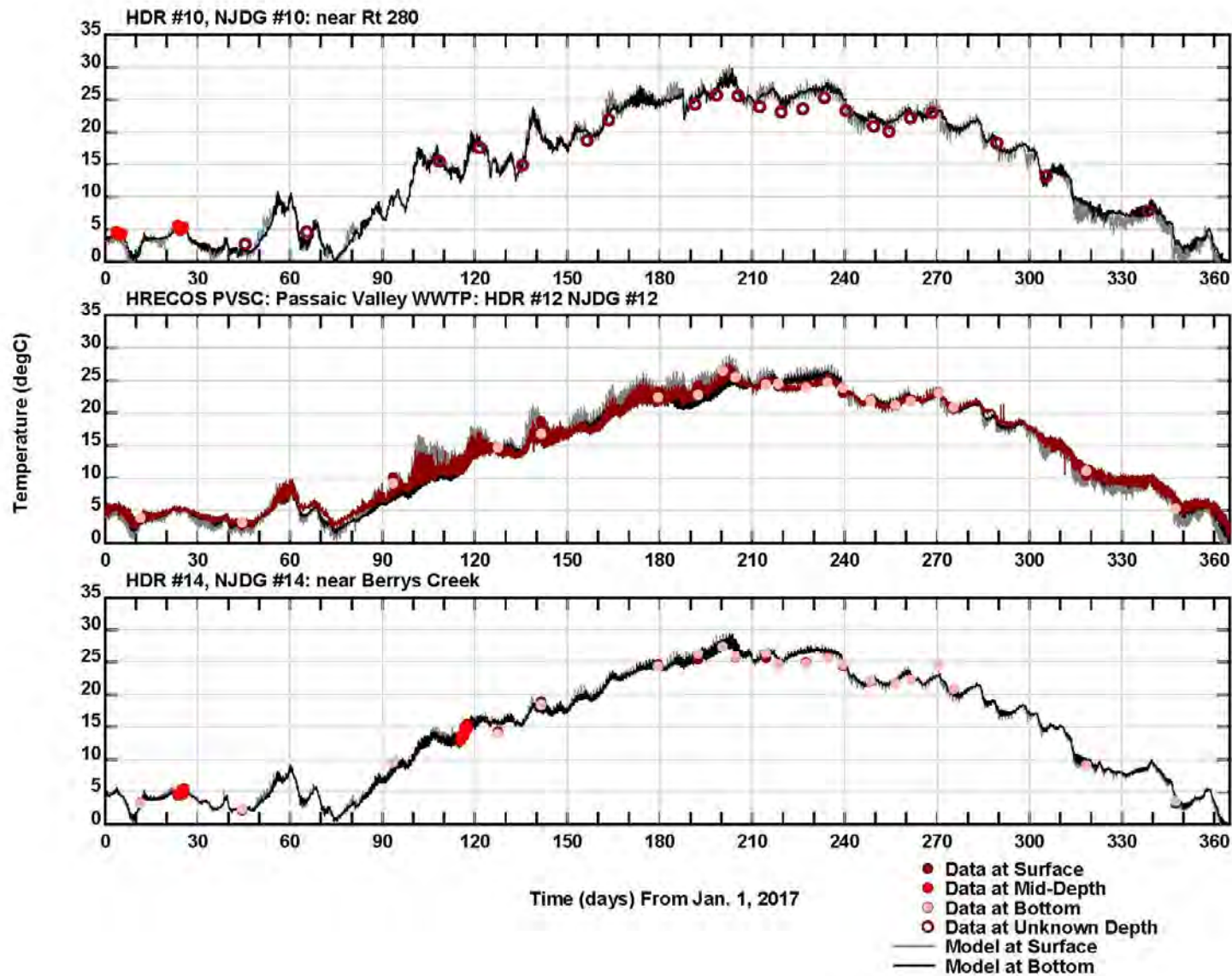


Figure 5-8. 2017 Comparison of Model Computed Water Temperature (Continued)

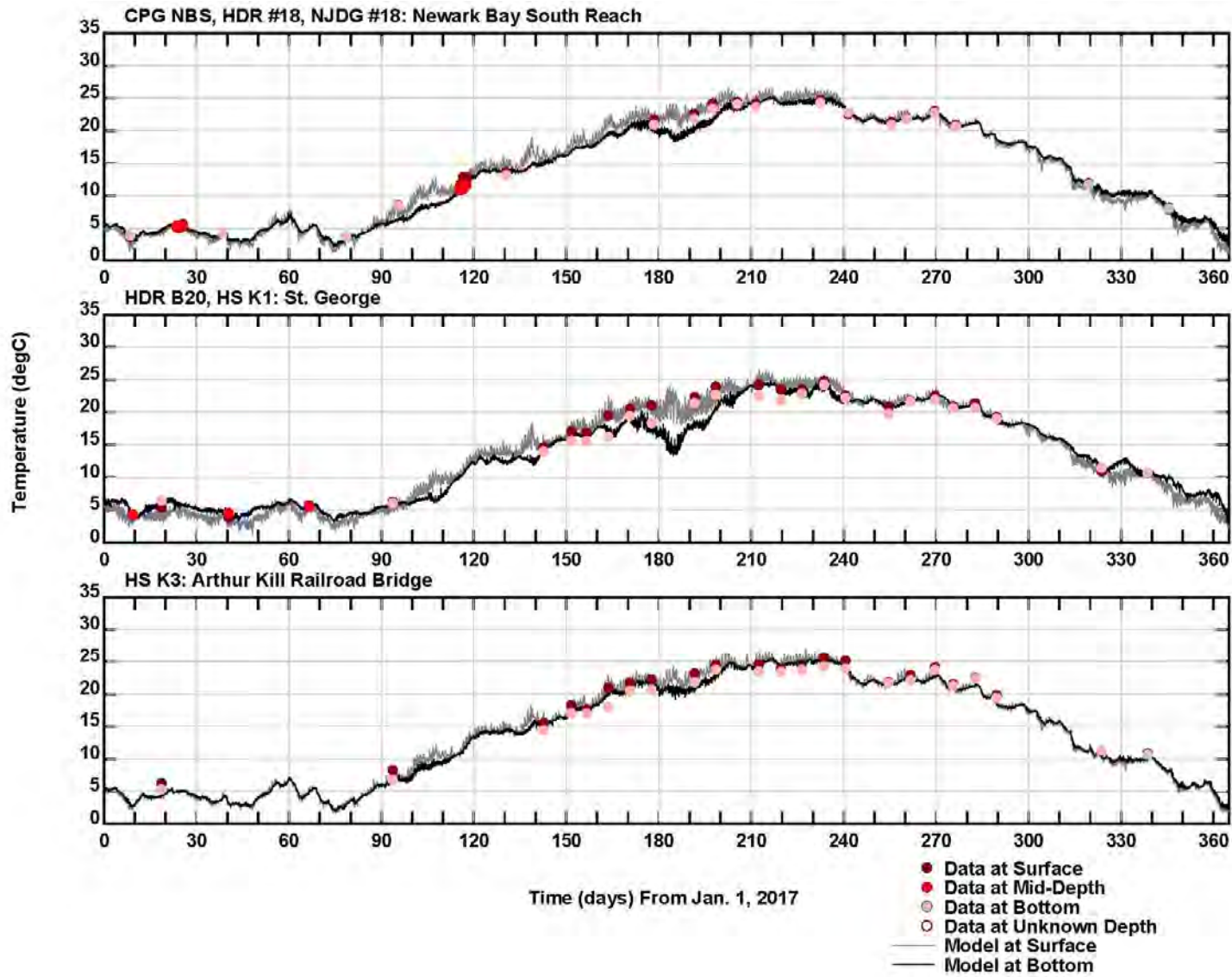


Figure 5-8. 2017 Comparison of Model Computed Water Temperature (Continued)

Model calculated salinity at the same nine stations for the water temperature were compared with observed salinity data during the 2016 and 2017 periods. Figure 5-9 and Figure 5-10 show the results for 2016 and 2017, respectively. Salinity is a good indicator to gauge the model's ability to reproduce advective and diffusive processes occurring in the system. Due to the conservative nature of salinity variation, the interaction between inland freshwater sources and oceanic salt displays a range of transport processes. The first page of Figure 5-9 shows the salinity variations in the lower Hudson River (top panel), the Upper Bay (middle panel), and the Narrows (bottom panel). Model calculated surface salinity is shown in light grey colored lines and bottom salinity is shown as dark black lines. Data are shown in different color shades. Surface and bottom samples are presented as light red shaded circles (i.e. pink) and dark red circles, respectively. Some data collected by HDR survey crew were from mid-depth. These data are shown as bright red circles. When the sampling depth was unspecified data are shown as open red circles. The model-data comparison near the Lincoln Tunnel (i.e. top frame of the first page of Figure 5-9) shows highly variable surface salinity throughout the year, which vary from near zero psu (i.e. freshwater) to 25 psu with relatively short period of time. Conversely, it appears that bottom salinity remained within a relatively narrow range between 20 and 25 psu. Observed salinity data were generally in good agreement with model calculated salinity. Model calculated surface salinity tracks very well with the continuous observations at HRECOS Pier 84 (shown as a dark brown line).

The surface and bottom salinity at Station 32 shows periodic separation of surface and bottom salinity throughout the year. There are three physical processes controlling these stratification and de-stratification processes in the Harbor: tidal forcing, freshwater discharge events, and wind-mixing. Bi-weekly (i.e. ~ 15 day interval), separation and collapse of surface-bottom salinity are due to spring and neap cycles of tidal currents in the Harbor. The tides in the NY-NJ Harbor system are predominantly semi-diurnal, which results in seven days of relatively high ranges of water elevations (i.e. spring tide) followed by seven days of relatively low ranges of water elevations (i.e. neap tide). During spring tides when water elevation ranges are greater, tidal currents in the NY-NJ Harbor system increase and the relatively strong tidal currents induce vertical water column mixing, which reduces the differences between surface and bottom salinity. Conversely, when the tidal current becomes relatively weak during neap periods, lower density water (i.e. freshwater) remains on surface and creates highly stratified conditions. There are few distinct low salinity events observed at this station in 2016: around Day 60, Day 80, and Day 110. It appears that these low salinity events coincide with relatively high flow events in the Hudson River.

The second page of Figure 5-9 shows the salinity comparison in the Lower Passaic and Hackensack Rivers. The figure shows that salinity in LPR varies from 0 psu to 15-20 psu in 2016. Low salinity events at Station 10 coincide with a relatively high river discharge event. At the PVSC WRRF (second frame in the figure), the model calculated salinity reproduces the highly variable salinity patterns measured by the moored sensor. It should be noted that, in 2016, salinity values continuously increase from Day 60 and onward. It can be attributed to relatively dry condition that persisted during that year.

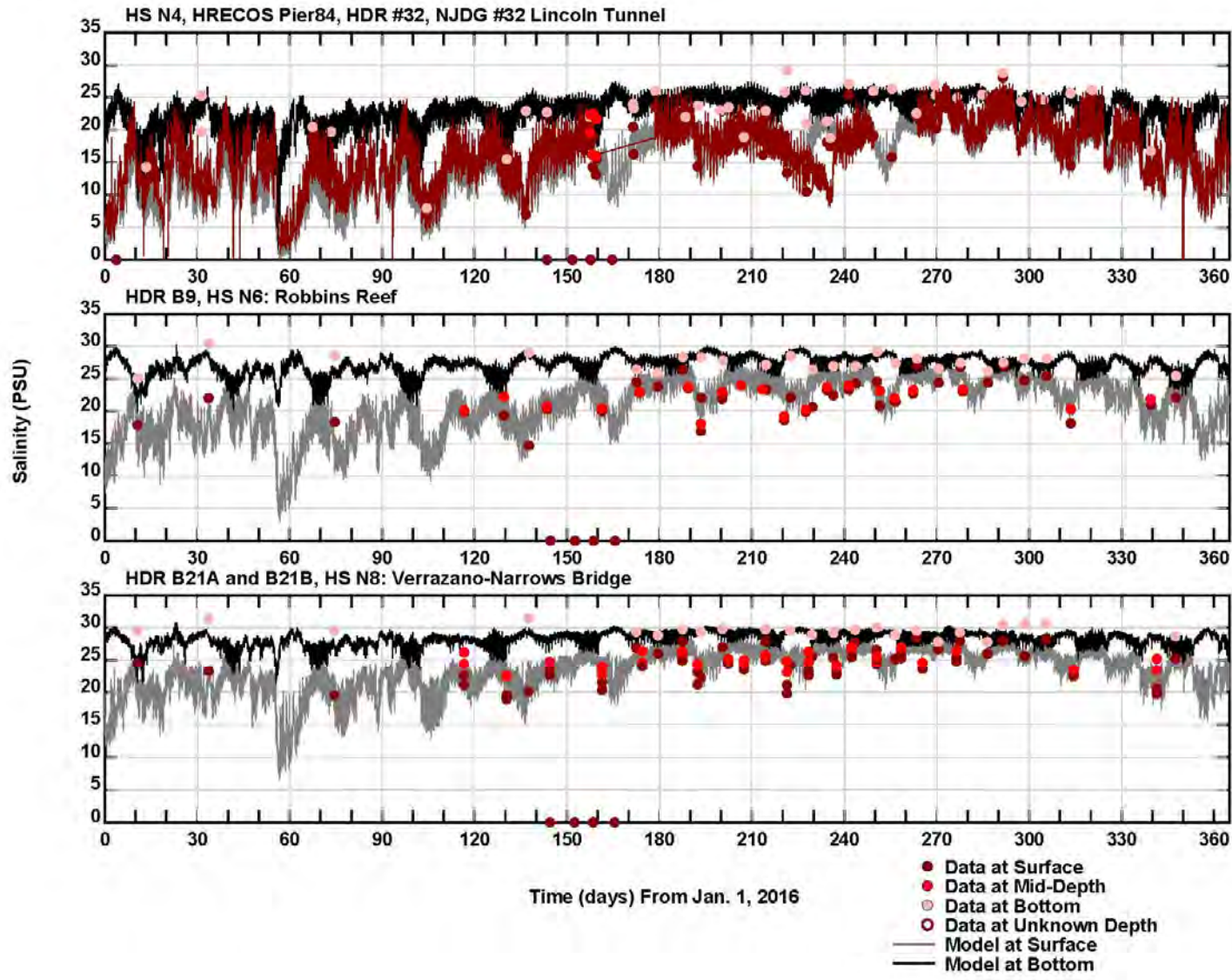


Figure 5-9. 2016 Comparison of Model Computed Salinity

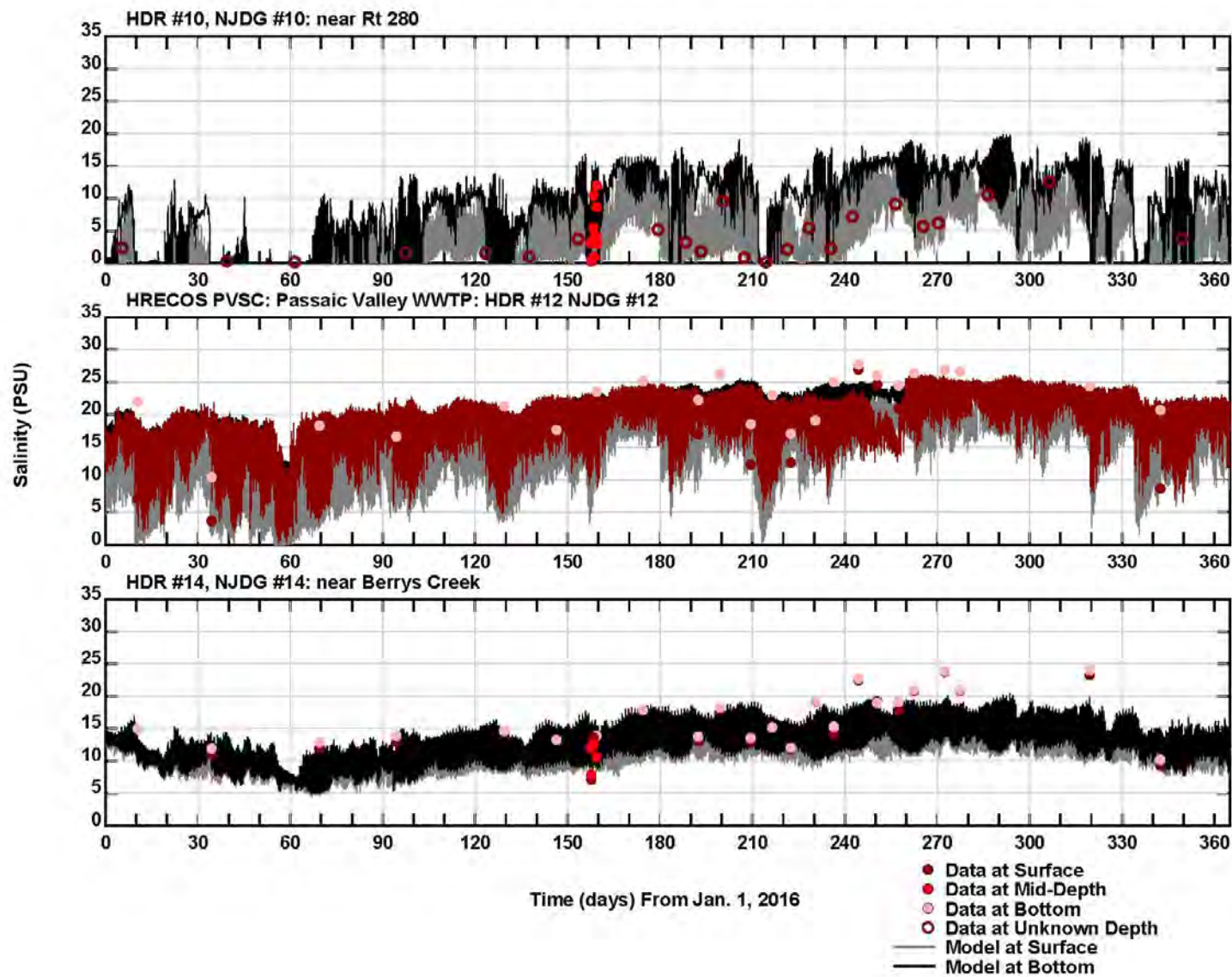


Figure 5-9. 2016 Comparison of Model Computed Salinity (Continued)

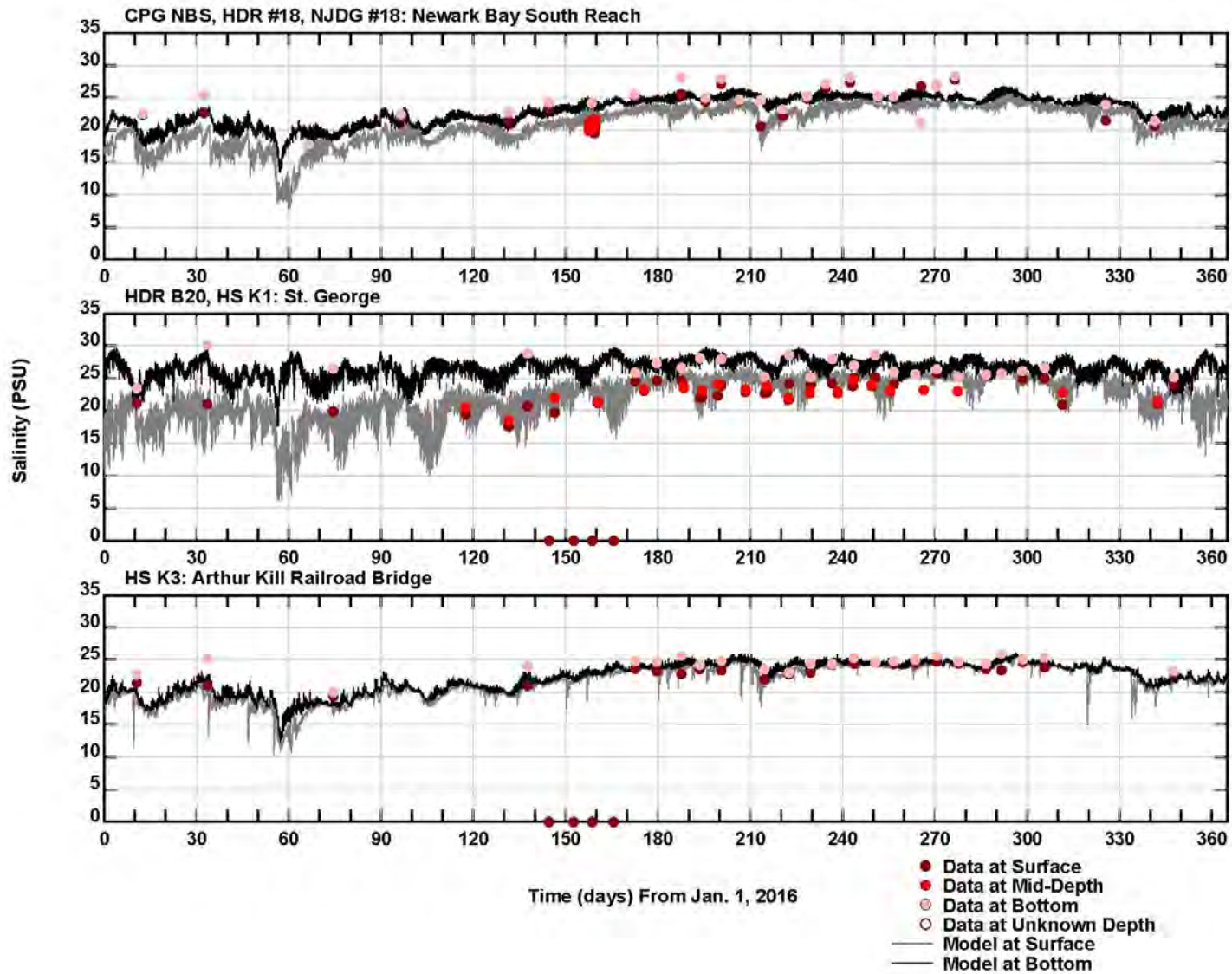


Figure 5-9. 2016 Comparison of Model Computed Salinity (Continued)

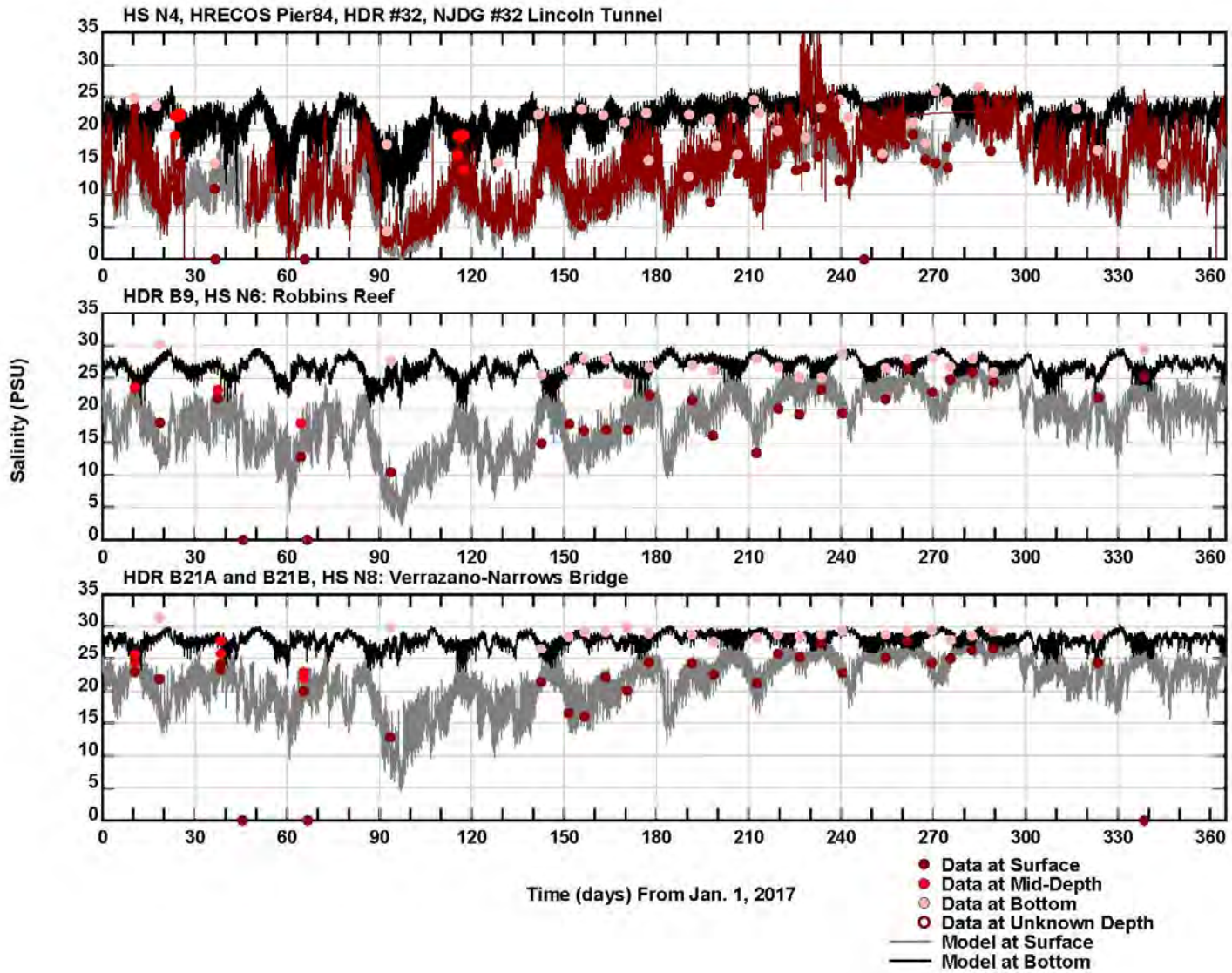


Figure 5-10. 2017 Comparison of Model Computed Salinity

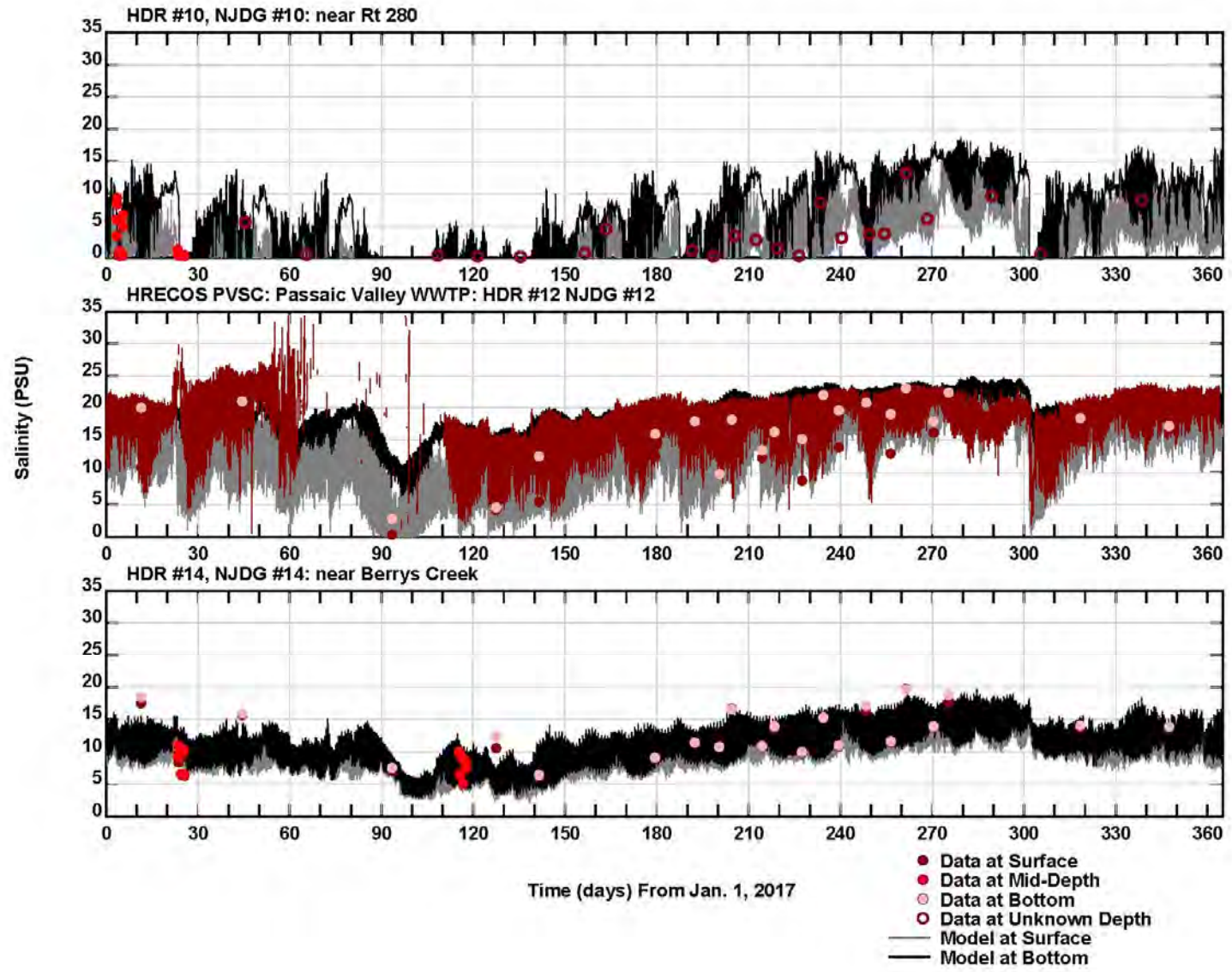


Figure 5-10. 2017 Creek Comparison of Model Computed Salinity (Continued)

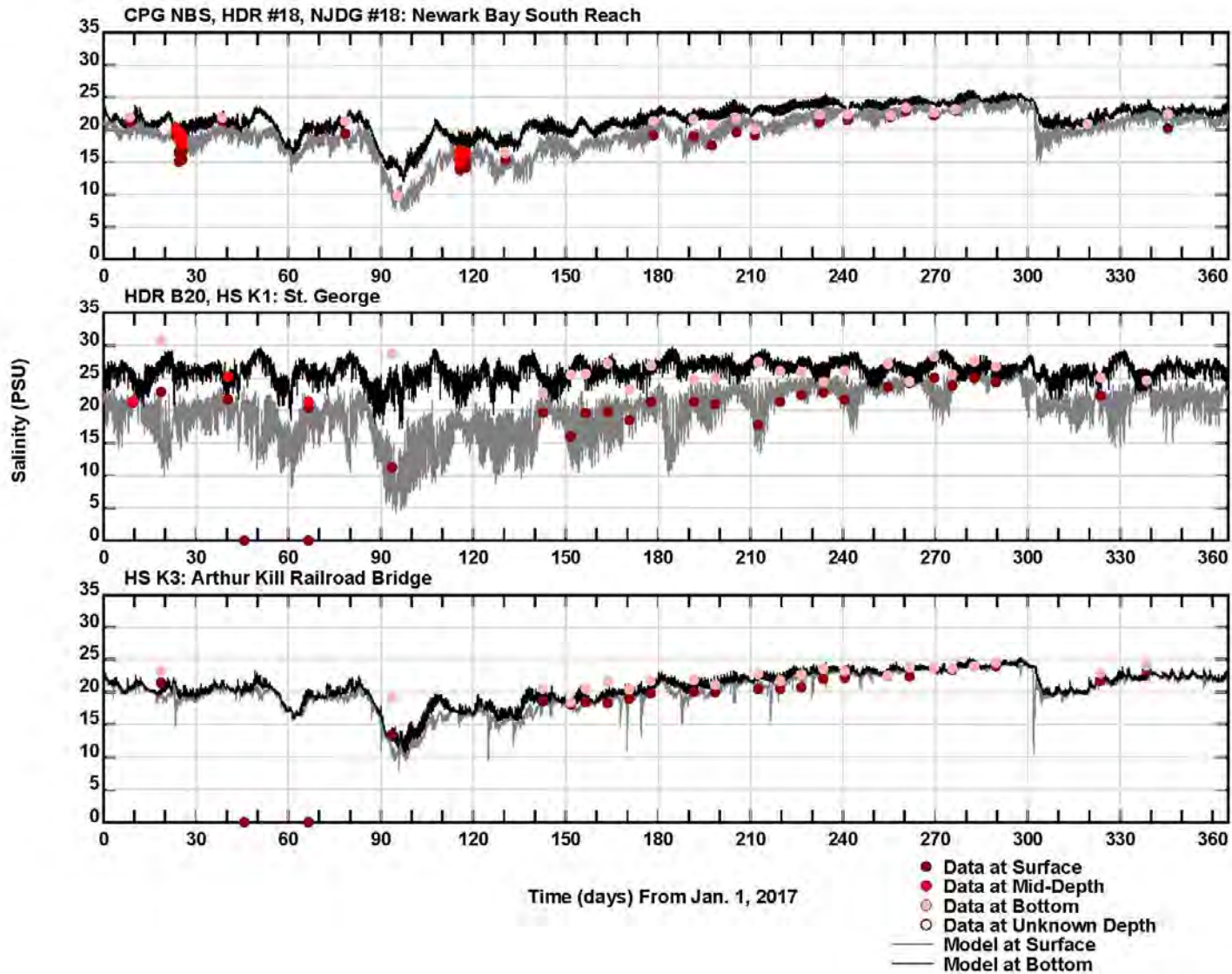


Figure 5-10. 2017 Comparison of Model Computed Salinity (Continued)

The third page of Figure 5-9 shows the salinity in the Newark Bay, Kill van Kull and Arthur Kill sections. The figure shows that the salinity variation is relatively flat compared to other section of the Harbor except at the entrance of Kill van Kull near St. George, where the salinity is greatly influenced by the Hudson River. At Arthur Kill, the water column is well mixed.

Figure 5-10 shows the comparison of model calculated salinity and observed data in 2017. Again, the model calculated salinity is in good agreement with the observed data, which suggests that model is to reproduce transport of patterns within the NY-NJ Harbor system.

5.3.1.4 Net Fluxes in NY-NJ Harbor System

Sub-tidal volume fluxes reflect the system's response to meteorological events such as storms, floods, or low-frequency perturbation of offshore coastal oceans or freshwater discharge events. The time series of fluxes at various sections in NY-NJ Harbor system are shown in Figure 5-11 and 5-12 for 2016 and 2017, respectively. The fluxes shown in the figures are low-pass filtered with a cut-off period of 35 hours to remove the tidal component of volume exchanges. The figures show the vertically averaged total flux in black, upper layer flux in red, and lower layer flux in blue. The monthly mean fluxes in m^3/sec are posted in the upper part of each frame in the figures.

Volume fluxes in the East River section that are shown in the first page of Figure 5-11 vary from 100 to 200 m^3/s in 2016. Negative fluxes indicate water moving toward the east (i.e. from Long Island Sound to the Battery). There is very little volume exchange through the Harlem River, which remains one order of magnitude less than the volume fluxes in the East River. The results are consistent with previous modeling efforts (Blumberg et al, 1999). The second page of Figure 5-11 shows the flux balances in Newark Bay, Kill van Kull, and Arthur Kill. The downstream volume fluxes out of Newark Bay are consistently balanced by the sum of the Passaic and Hackensack Rivers inflows. The third page shows the volume fluxes through the Hudson River section from Yonkers to the Narrows. In the 35-hour sub-tidal band, the total volume flux in the Hudson River and Newark Bay sections are almost always in the downstream direction, reflecting the dominant freshwater inflows from upstream.

In the Kill van Kull and the Arthur Kill, the flux is predominantly toward Raritan Bay (i.e. counter-clock-wise around Staten Island). The flux in the Arthur Kill is quite similar to the one in the Kill van Kull. The results indicate that there is very limited two layer circulation in the Kill van Kull with no evidence of two layer circulation in the Arthur Kill. During this period, the average net volume fluxes in the Kills are about 200 m^3/sec toward Raritan Bay. The magnitude and its direction are consistent with earlier SWEM and CARP modeling studies (HydroQual, 2002).

Figure 5-12 shows the cross sectional fluxes in 2017. The figure shows that the magnitude and direction of net volume fluxes at those transects remained the same for both years except during high flow events in the Hudson River and LPR, which suggests that dynamic balances of the NY-NJ Harbor system remain more or less the same in 2016 and 2017.

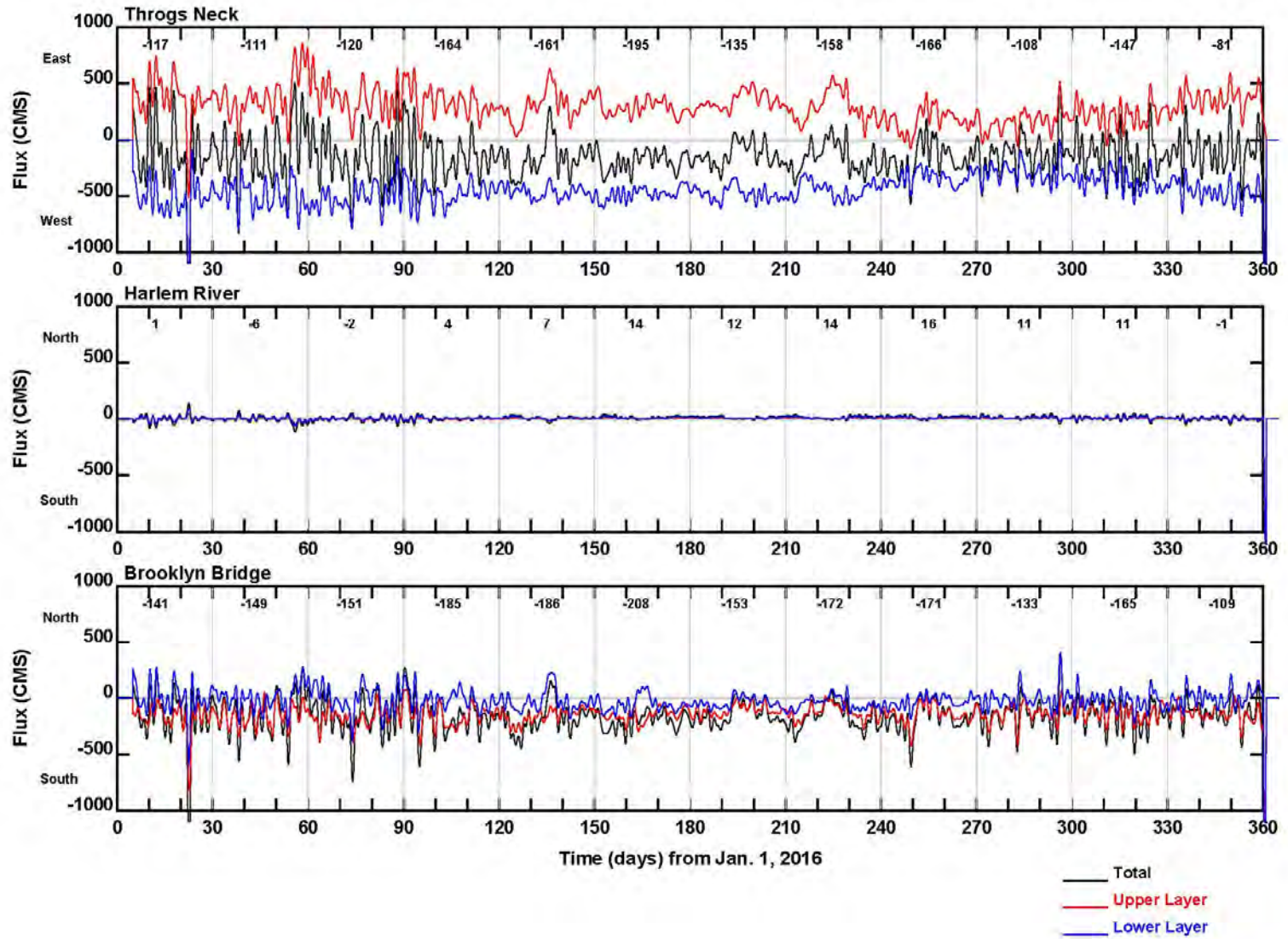


Figure 5-11. 2016 Cross Sectional Fluxes

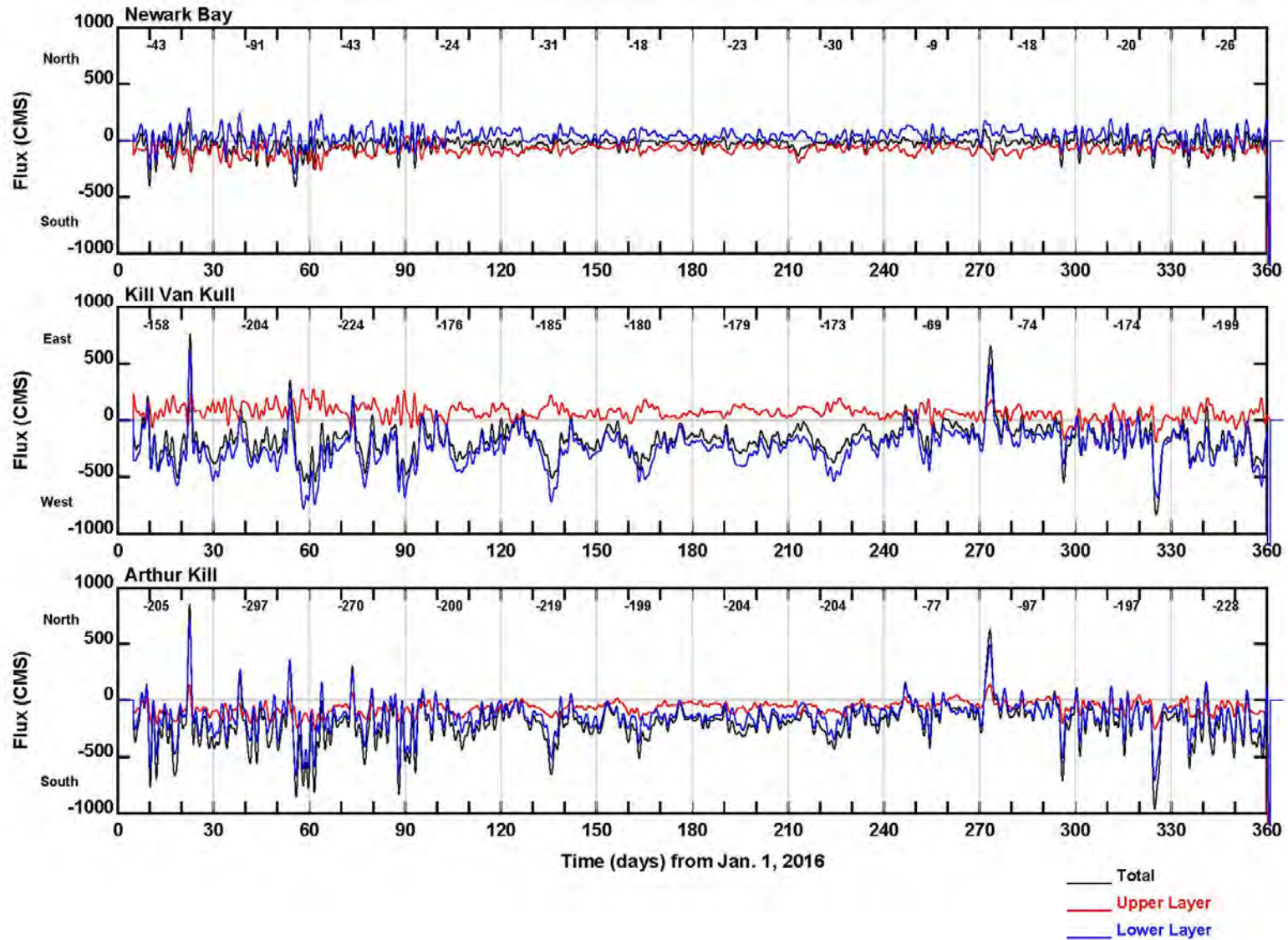


Figure 5-11. 2016 Cross Sectional Fluxes (Continued)

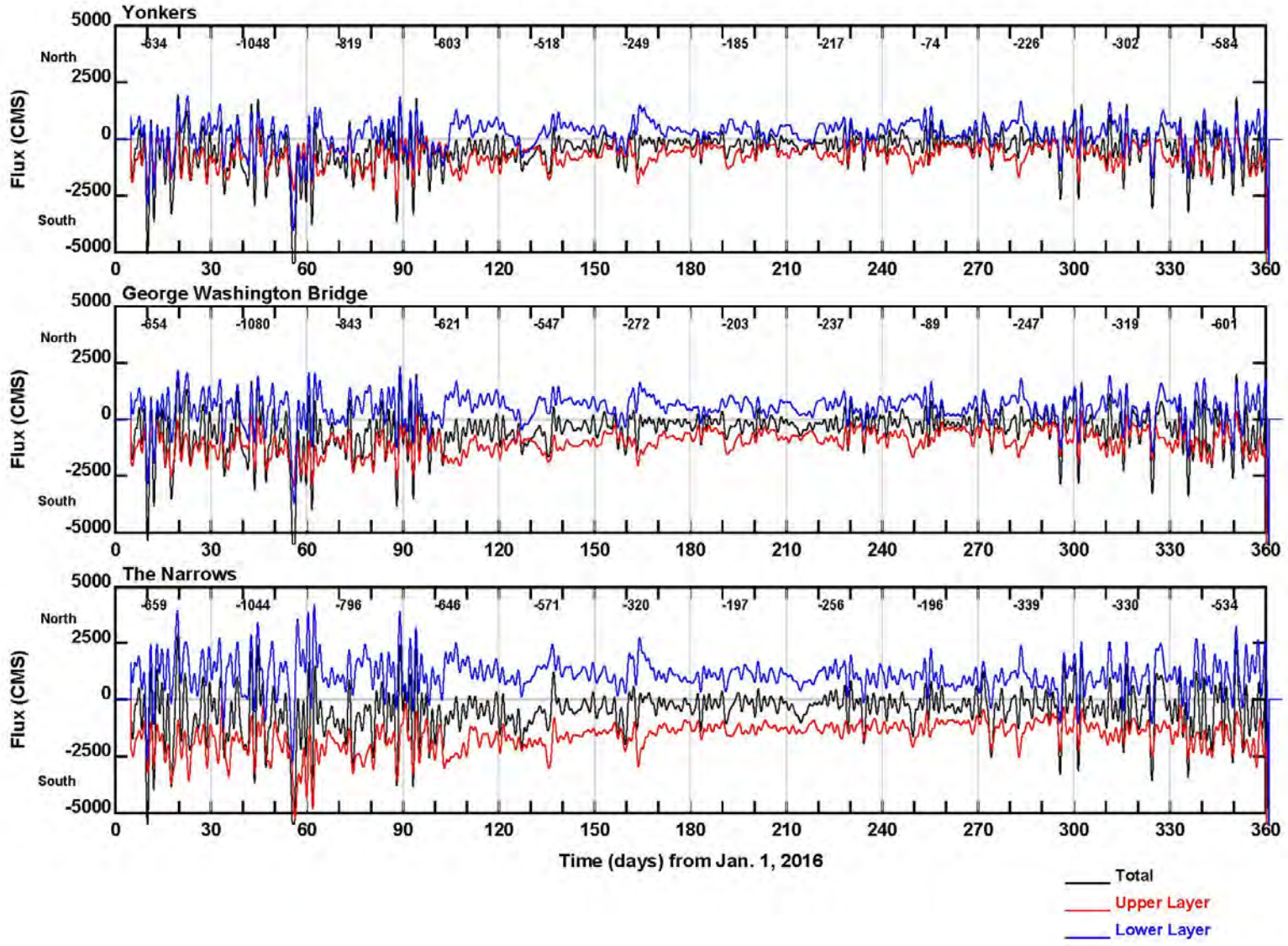


Figure 5-11. 2016 Cross Sectional Fluxes (Continued)

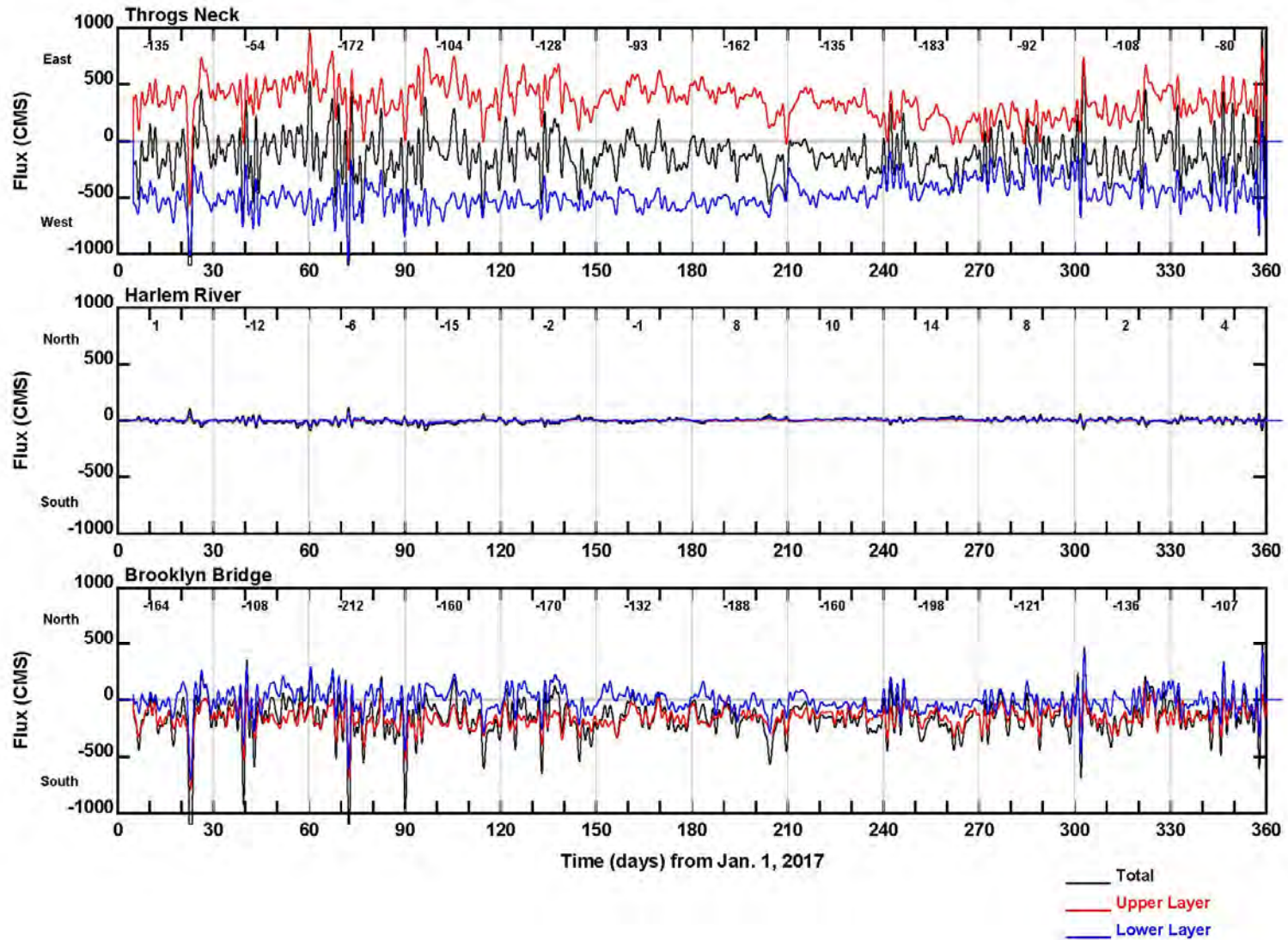


Figure 5-12. 2017 Cross Sectional Fluxes

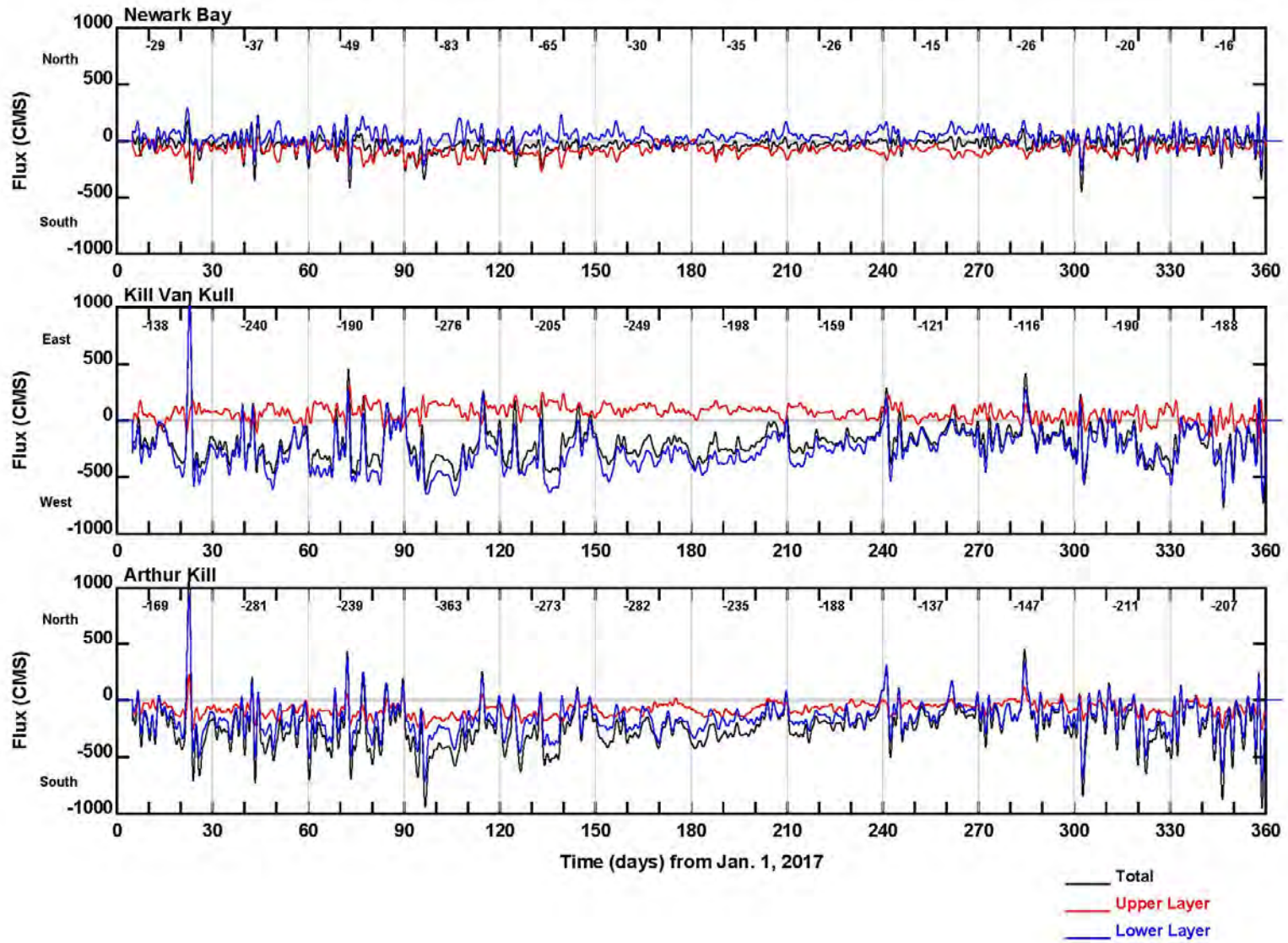


Figure 5-12. 2017 Cross Sectional Fluxes (Continued)

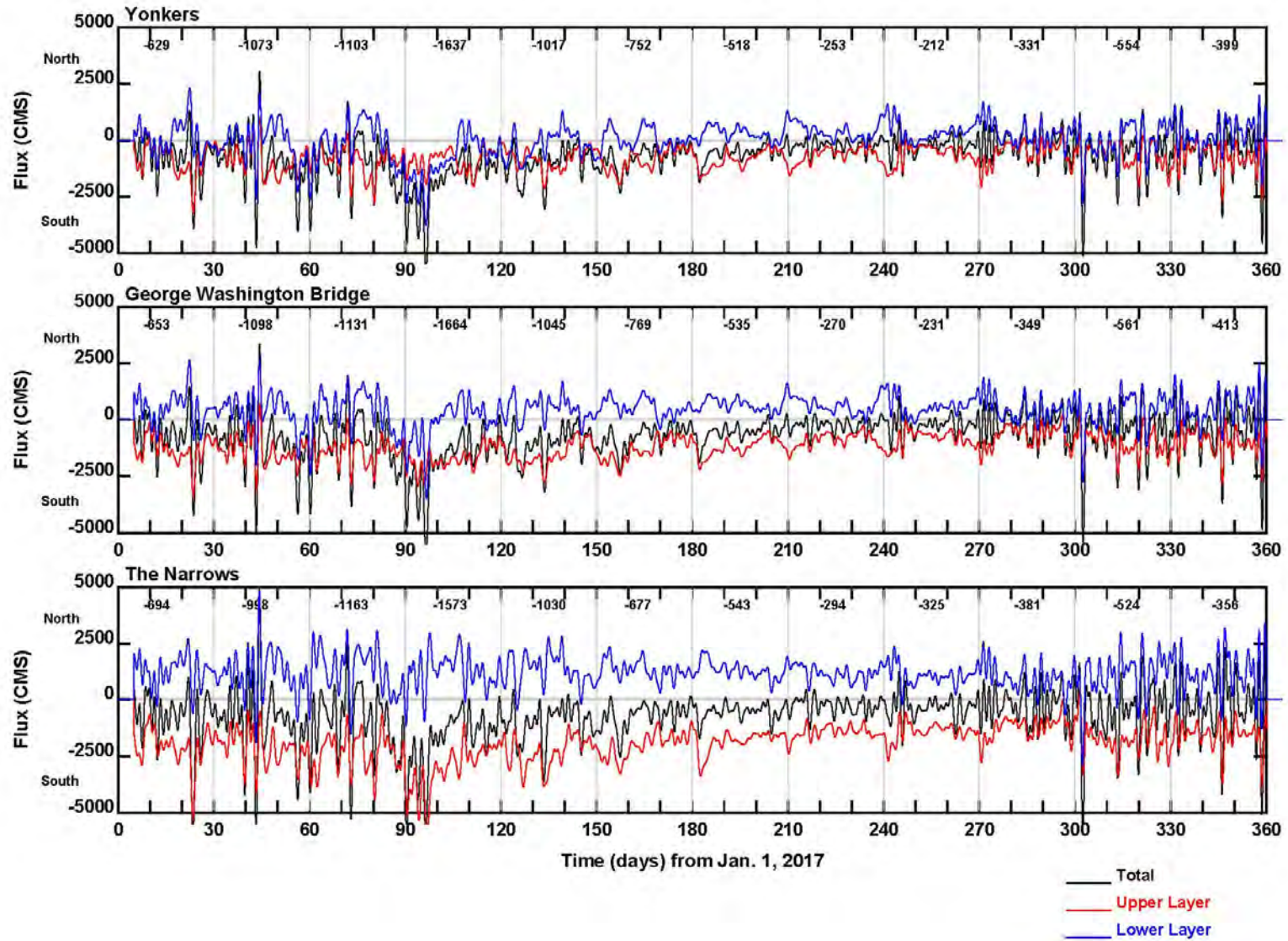


Figure 5-12. 2017 Cross Sectional Fluxes (Continued)

5.3.2 Water Quality Model

The model performance criteria reside largely in the experience and judgment of the modeler. The model "goodness of fit" measure may be either qualitative or quantitative. Qualitative measures that will be used in the development of the water quality model include several types of analysis, including:

- Graphical time-series plots of observed and predicted data at individual stations using primary data;
- Spatial transect plots of model output versus observed data at an instant in time or under time-averaged conditions; and
- Comparisons between observed and calculated probability distributions from the same time window.

5.3.3 Time-Series Comparisons

Time-series figures were generated at the locations where water quality data were collected, so that model output could be compared to the data. The figures included annual figures to assess the model's ability to reproduce seasonal trends, and wet-weather event figures to assess if the model could reproduce the increase and decrease in bacteria concentrations during and after a wet-weather event. The calibration period is the calendar year 2016.

5.3.3.1 Annual

Annual time-series figures were generated for 60 stations. Figures presenting results for representative stations for the major CSO affected waterbodies will be presented in this section with the remaining figures included in Appendix E. The figures present the waterbody in the upper left corner, the station number, and the waterbody classification in the upper right corner. The data are presented as circles with the varying colors representing surface, mid-depth, or bottom data, and the data source, either NJHDG or HDR. Model daily average concentrations are represented by a solid line for the surface results and a dashed line for bottom results. Shading around the model lines represents the range of concentration calculated by the model over the day.

The figures present the model calibration for temperature, salinity, fecal coliform, enterococci, and E. coli. A fecal coliform to enterococci ratio was included to help determine the differences in the fecal coliform and enterococci decay rates.

Figure 5-13 presents the calibration results for Station 8, which located in the Passaic River just north of Newark. The Passaic River is classified as FW2/SE2 in this location because during high flow periods the salt wedge is pushed downstream and the river is fresh at this location. During drier conditions, the salt wedge is able to push up the river, and the river becomes more saline under these conditions. The model is able to reproduce the seasonal changes in temperature, and does a good job reproducing the salinity during both wet and dry conditions. The model is also to generally reproduce the magnitude and

timing of the fecal indicator bacteria changes during the year. The bacteria data indicate the presence of dry-weather sources because the bacteria concentrations remain relatively high even during dry conditions. The model reproduces the dry-weather concentrations. In this location the model also reproduces the magnitude of the fecal coliform to enterococci ratio fairly well.

Model calibration results at Station B7, near Kearny on the Hackensack River, are presented in Figure 5-14. This area of the Hackensack River is classified as SE2, so it is subject to a fecal coliform criterion. The model is able to reproduce the temperature and salinity very well. The model reproduces the higher fecal coliform concentrations reasonably well, but over estimates some of the lower concentrations, and reproduces the enterococci concentrations very well. *E. coli* was not sampled at this location because *E. coli* criteria only apply to waterbodies that are freshwater. The panel that shows the fecal coliform to enterococci ratios indicates some of the challenges of modeling multiple fecal indicator bacteria that have sources that can have considerable variability. This ratio can change very rapidly and the model can only reproduce some of this variability. As part of the model calibration process, when it was a challenge to reproduce both the fecal coliform and enterococci concentrations, an effort was made to either reproduce the fecal indicator bacteria that was relevant to that particular waterbody or slightly over predict the concentration in order to be conservative.

Figure 5-15 presents model versus data comparisons for Station B20 in the Kill Van Kull located off of the southeast corner of Kearny. This location is classified as SE3. The model reproduces all of the constituents very well as shown by the model line running through most of the data points.

The model versus data comparison at Station B13 in the Elizabeth River, about halfway through the city of Elizabeth, is shown in Figure 5-16. The model reproduces the temperature and salinity, even though there can be large swings in the salinity. The model reproduces the highest fecal coliform and enterococci concentrations, but sometimes over estimates the lower concentrations. The model results show the influence of adding dry-weather loads to help the model reproduce some of the high dry-weather concentrations. It is likely that some of the dry-weather loads are intermittent or time-variable rather than constant, but due to the apparent randomness of these sources the timing of these sources cannot be predicted. A constant dry-weather source allows the model to be conservative.

Figure 5-17 presents the model versus data comparison at Station 24 in the Arthur Kill, north of Perth Amboy. This is another location where the model reproduces all of the constituents very well, although the fecal coliform to enterococci ratio is sometimes under estimated. Again, part of the challenge in reproducing this ratio is that this same level of ratio variability is not reflected in the loads. However, since the model is able to reproduce the fecal coliform concentrations in this SE3 waterbody, the model is useful as a tool to assess attainment of the water quality criterion.

PASSAIC RIVER

Station: 8

FW2/SE2

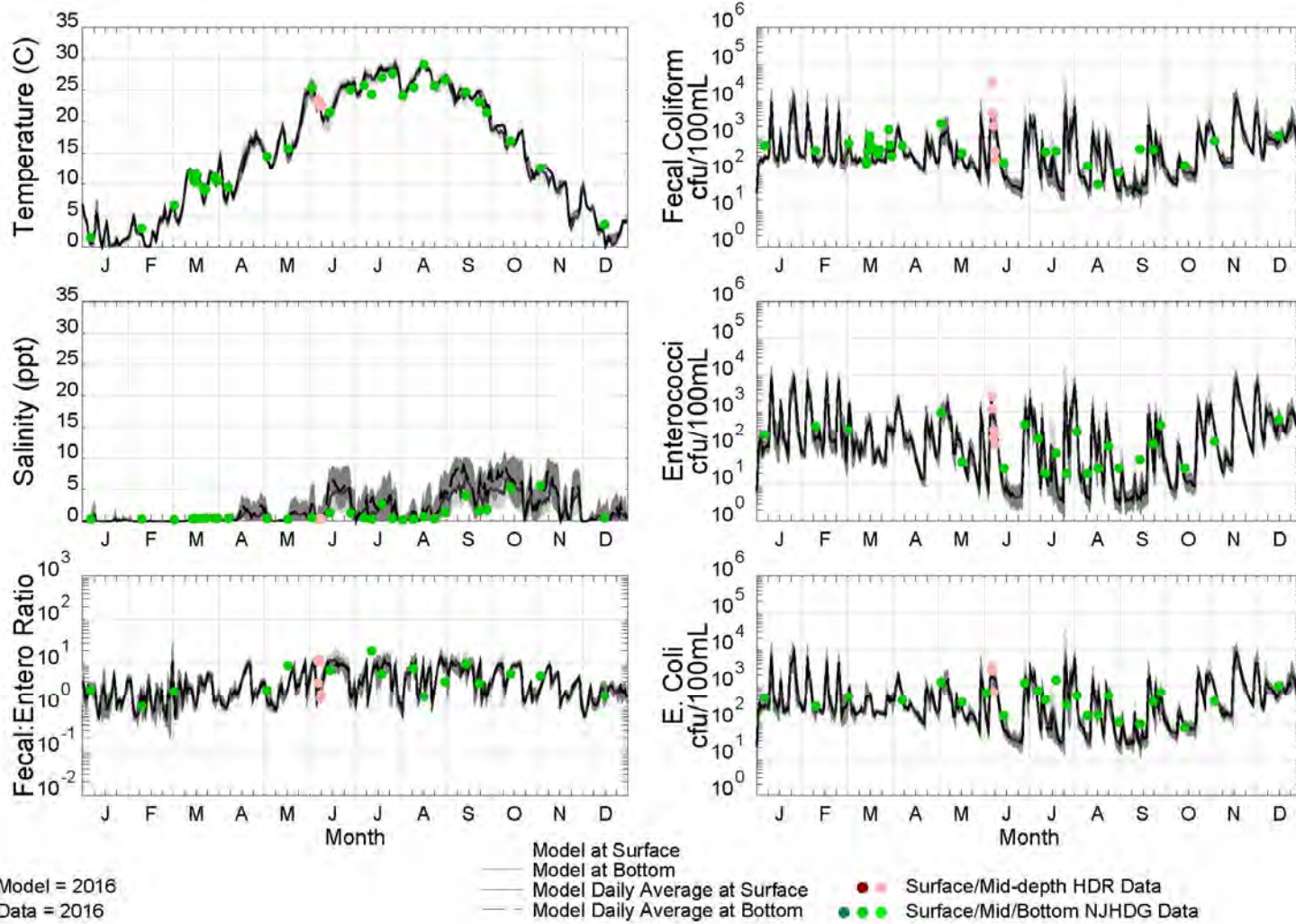


Figure 5-13. 2016 Annual Time-Series Model versus Data Comparison at Station 8, Passaic River

HACKENSACK RIVER

Station: B7

SE2

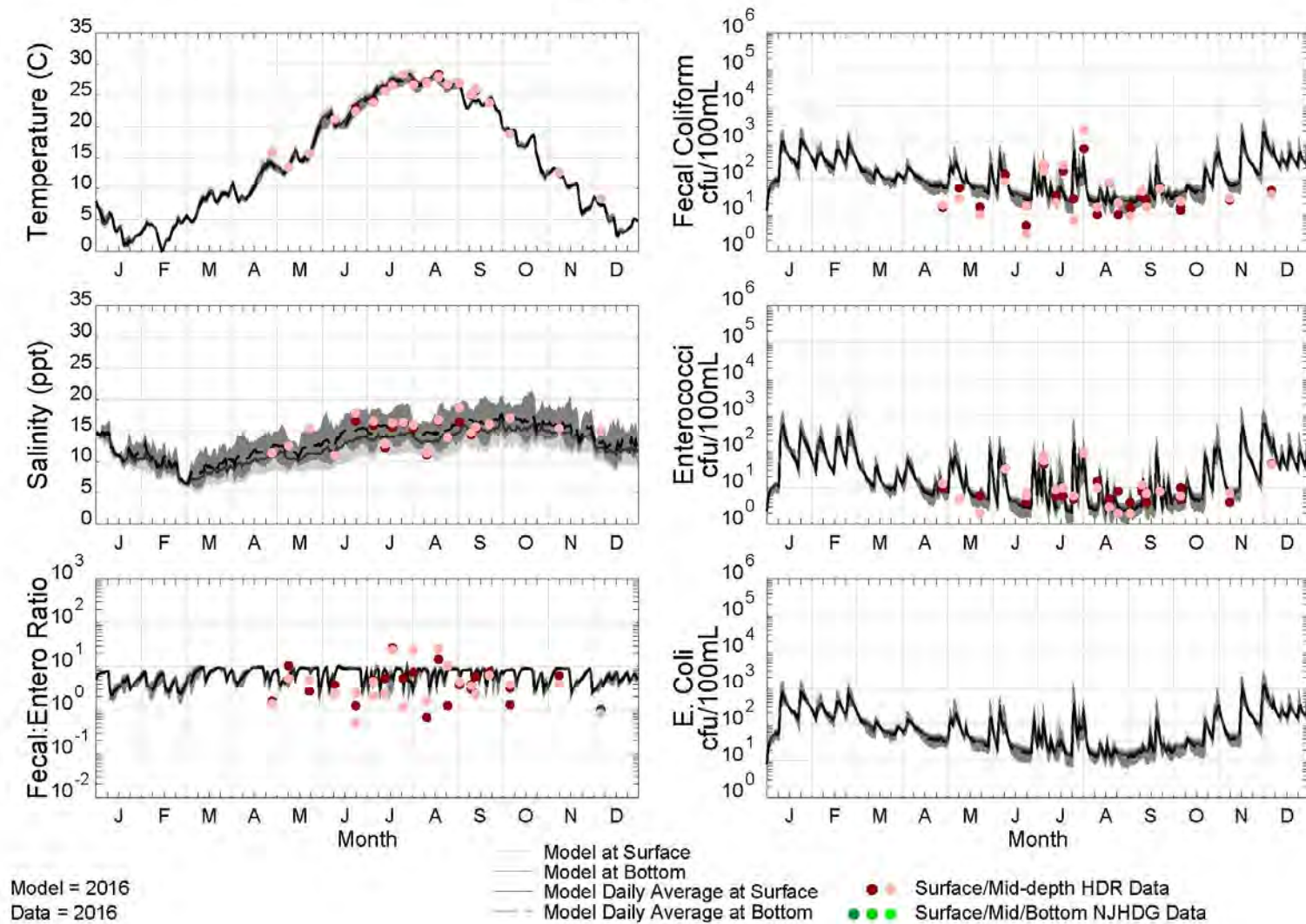


Figure 5-14. 2016 Annual Time-Series Model versus Data Comparison at Station B7, Hackensack River

KILL VAN KULL

Station: B20

SE3

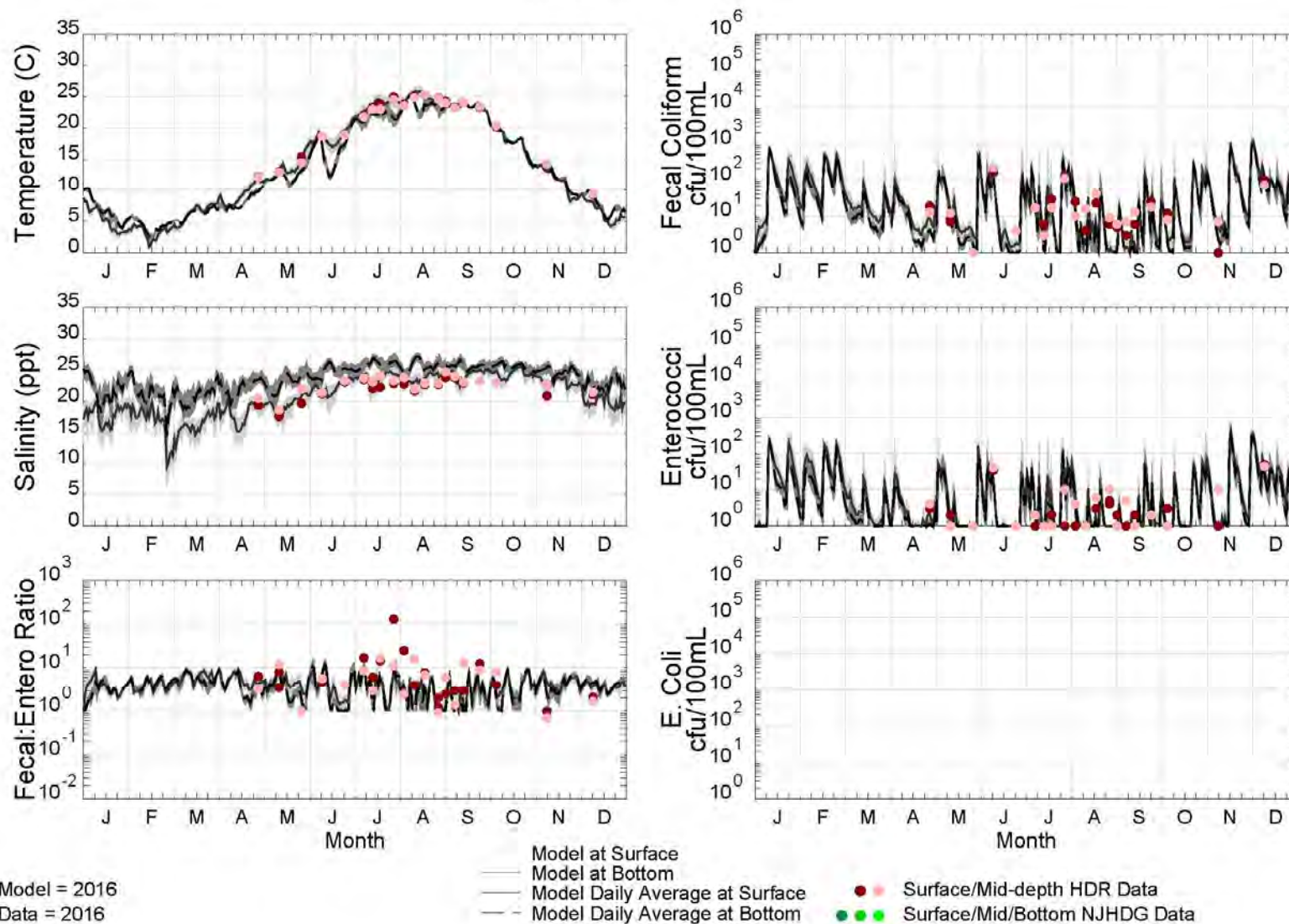


Figure 5-15. 2016 Annual Time-Series Model versus Data Comparison at Station B20, Kill van Kull

ELIZABETH RIVER

Station: B13

SE3

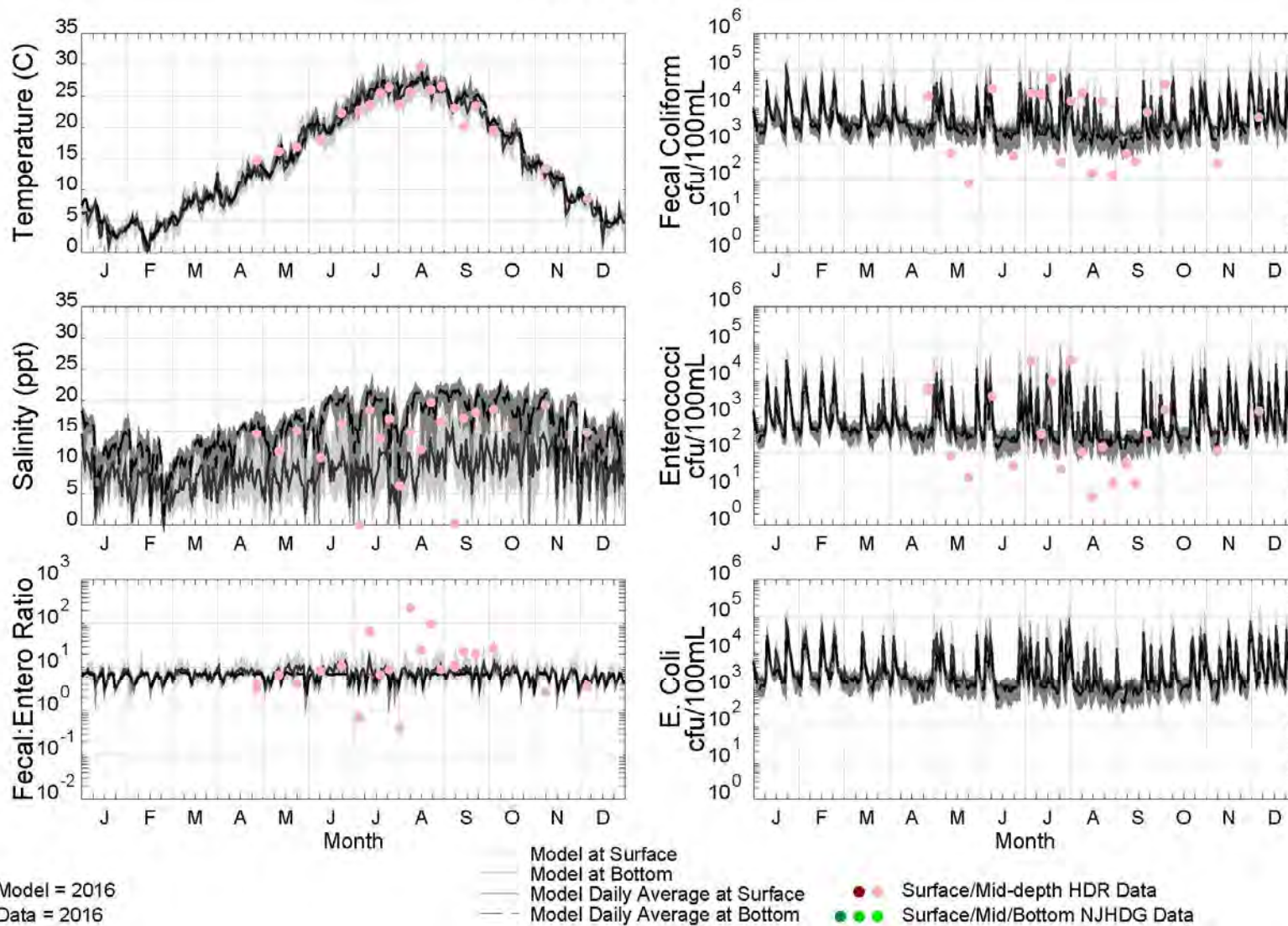


Figure 5-16. 2016 Annual Time-Series Model versus Data Comparison at Station B13, Elizabeth River

ARTHUR KILL

Station: 24

SE3

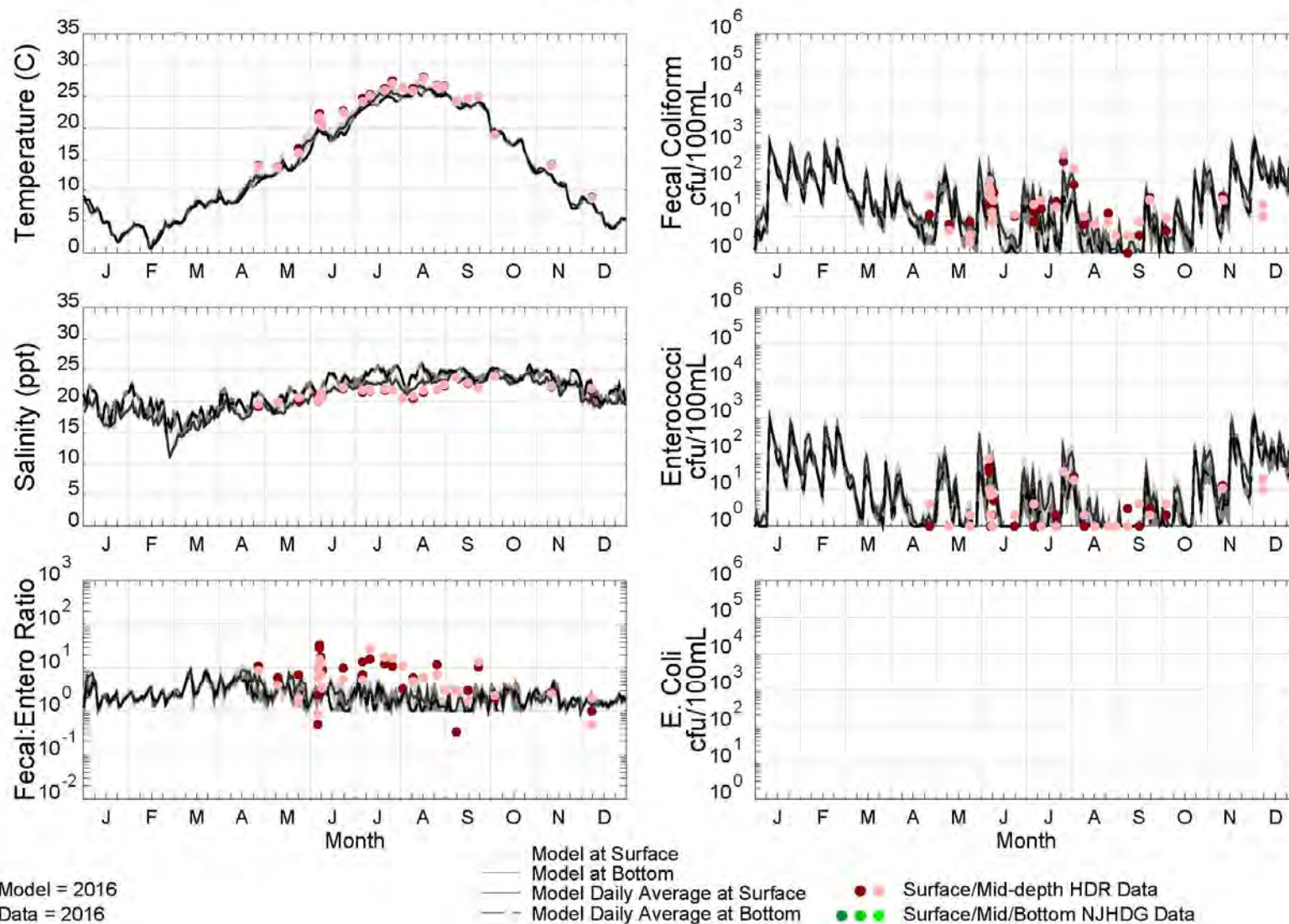


Figure 5-17. 2016 Annual Time-Series Model versus Data Comparison at Station 24, Arthur Kill

The annual model versus data time-series comparison for Station 29 in Raritan Bay is presented in Figure 5-18. The model reproduces the temperature data very well. There is some concern that the NJHDG salinity data during 2016 is not accurate. In most cases, the model matches the HDR salinity data very well, but the NJHDG data tends to be higher. Based on a review of data from other sources, the model calibration ignored the NJHDG salinity data from 2016. The model reproduces the fecal coliform and enterococci data very well. For both the fecal coliform and enterococci data there are periods when the data are reported at the detection limit, and these data are plotted at the detection limit.

Figure 5-19 presents the model versus data comparison for Station 26 in the Raritan River east of New Brunswick. This area is not impacted by CSOs. The model does reproduce all of the constituents at this location quite well. This is an indication that the hydrodynamics, boundary conditions, and loads from sources other than CSOs are accurate and provide reasonable background conditions for areas downstream that are impacted by CSO discharges.

Results from the model to data comparison in the Hudson River are presented in Figure 5-20 at Station B23A near Jersey City. On an annual basis, the model reproduces the temperature, salinity, fecal coliform, and enterococci data fairly well.

Overall, the model is reasonably well calibrated based on a comparison to data on an annual basis. The model is able to reproduce the majority of the data both spatially and temporally. The model is able to reproduce data under both wet and dry conditions. The remaining annual time series figures are presented in Appendix E.

5.3.3.2 Wet-Weather Events

Shorter, week-long, event-based time-series figures were generated for 25 locations to assess the model's ability to reproduce bacteria concentrations during wet-weather events. Seven example stations from different regions of the project area will be presented here, with the remaining presented in Appendix E. Only one wet-weather event was captured during the 2016 calibration period (June 6-8). The remaining wet-weather events were captured during 2017 and will be presented in Section 5.4.1.2.

Figure 5-21 presents a model versus data comparison for Station 7, located in the Passaic River near the town of Passaic. The figure is set up in the same format as the annual time-series figures, except they show only seven days, in this case June 3–9. The model accurately reproduces the temperature and salinity. During this time period, at this location, the Passaic River is completely freshwater. The waterbody classification is both FW2 and SE2 in this location, and the model reasonably reproduces the magnitude and timing of the fecal coliform and *E. coli* concentrations.

RARITAN BAY

Station: 29

SE1

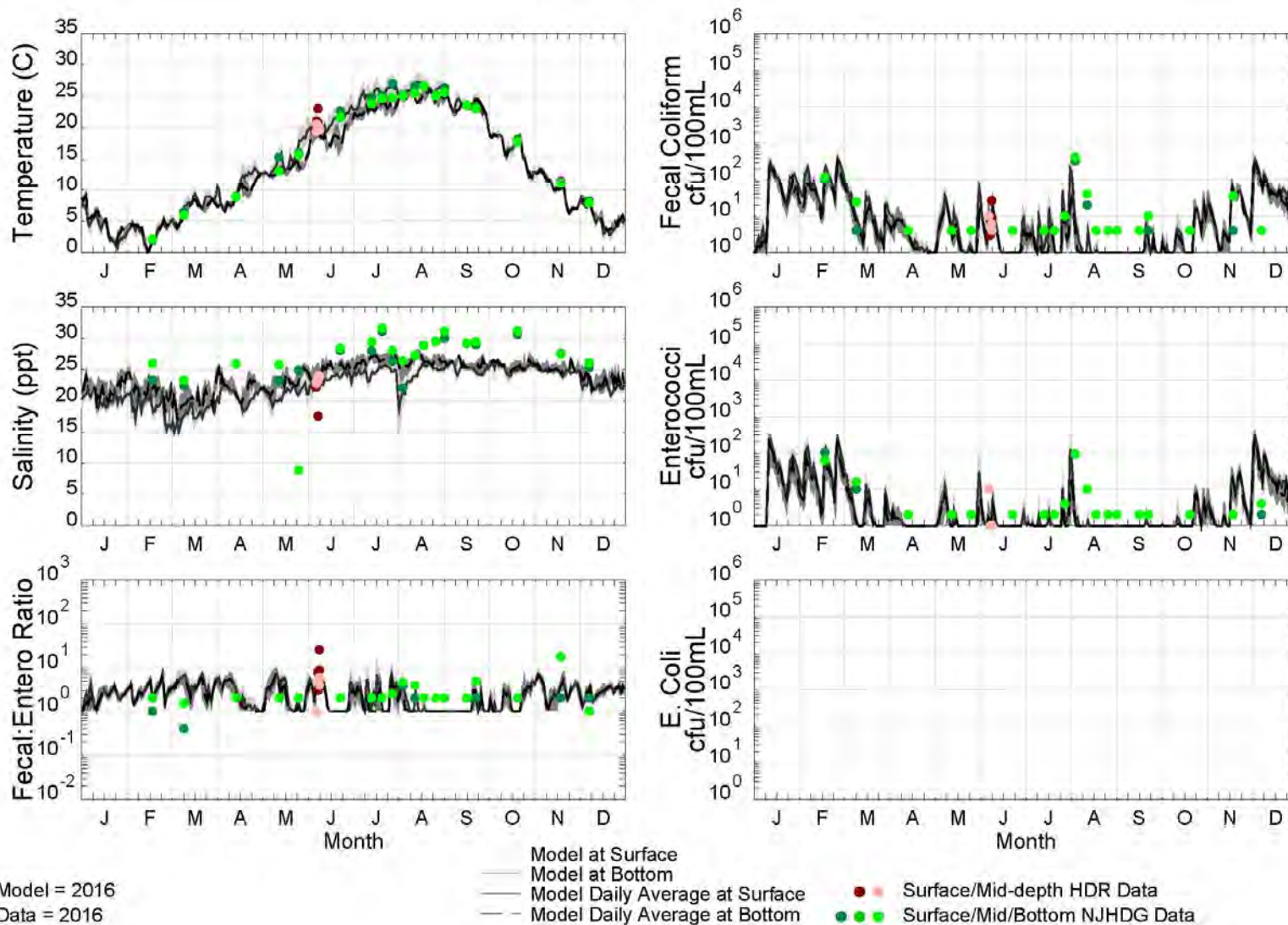


Figure 5-18. 2016 Annual Time-Series Model versus Data Comparison at Station 29, Raritan Bay

RARITAN RIVER

Station: 26

SE1

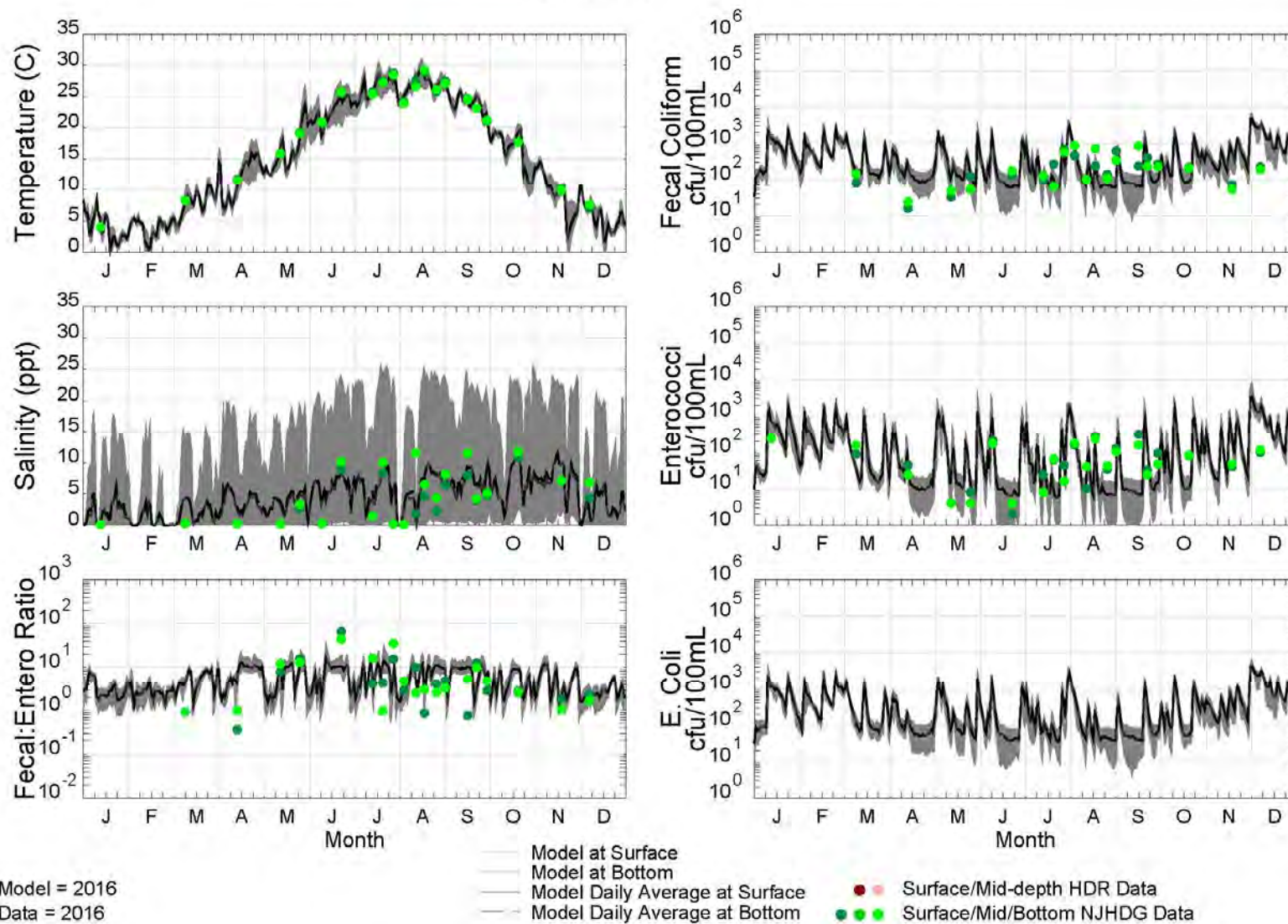


Figure 5-19. 2016 Annual Time-Series Model versus Data Comparison at Station 26, Raritan River

HUDSON RIVER

Station: B23A

SE2

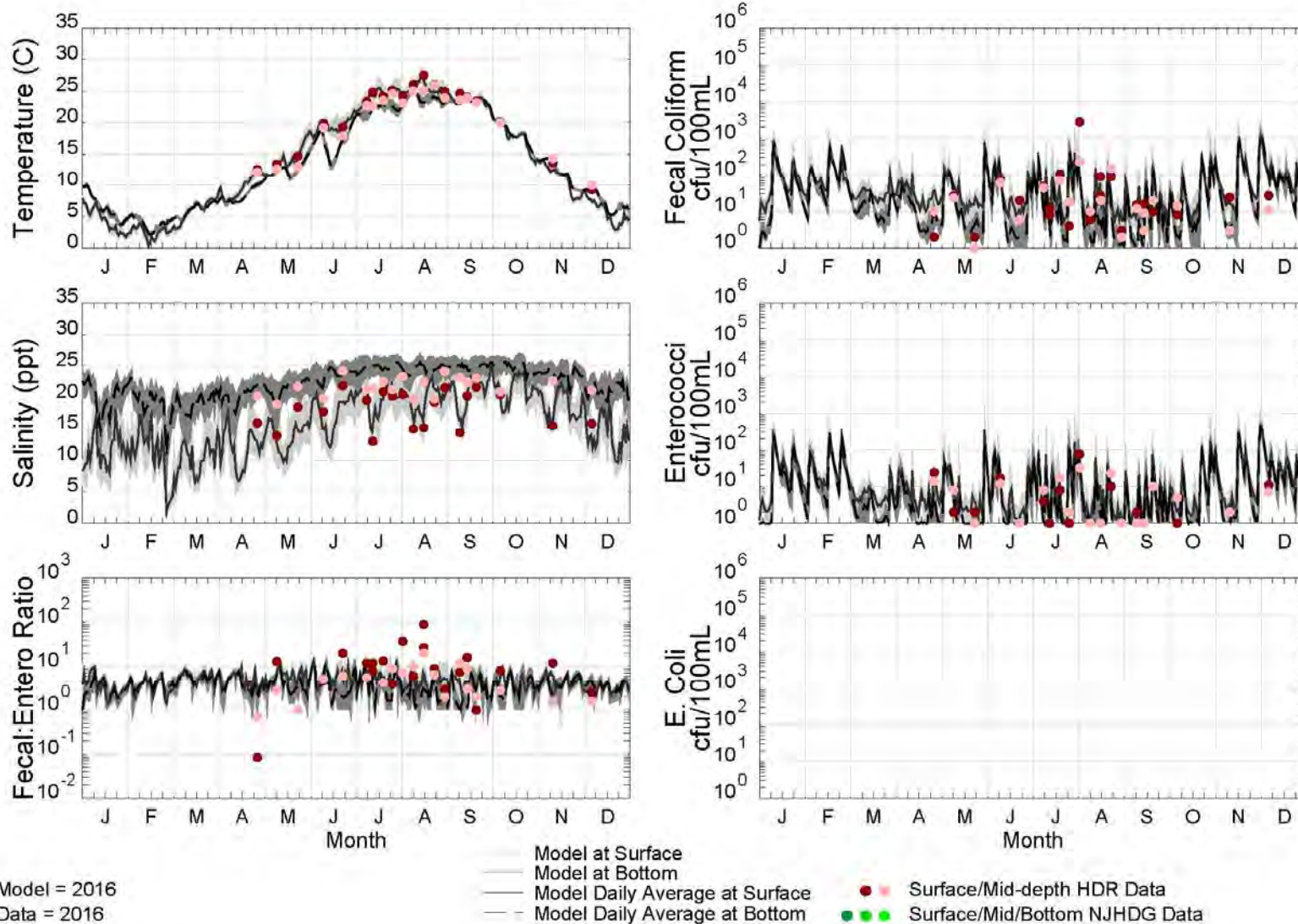


Figure 5-20. 2016 Annual Time-Series Model versus Data Comparison at Station B23A, Hudson River

Passaic River & Tributaries
Passaic River

Station: 7 Event 1 (June 3-9)

FW2/SE2

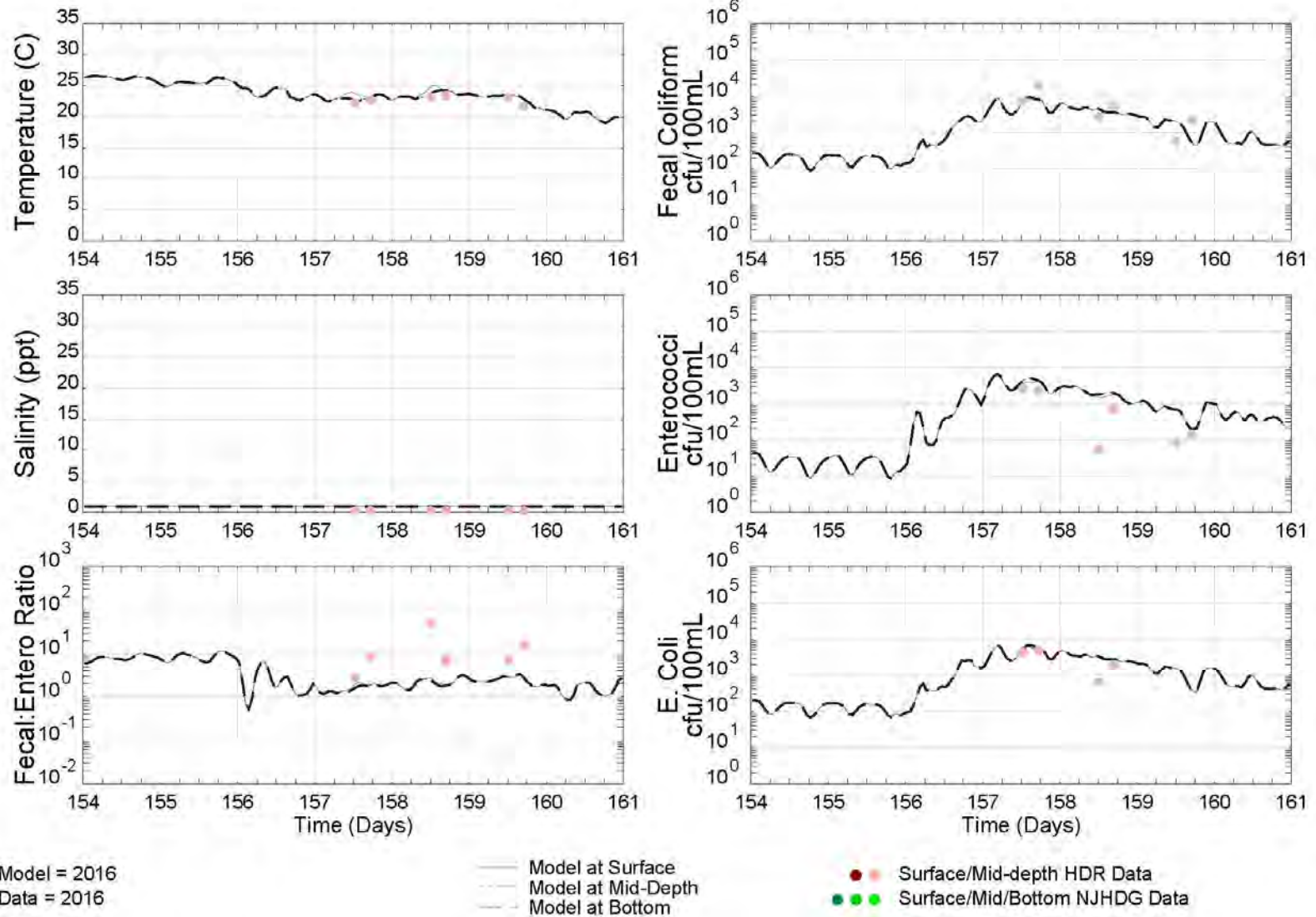


Figure 5-21. June 2016 Wet-Weather Event Model versus Data Comparison at Station 7, Passaic River

Station 14, in the Hackensack River near Berrys Creek, model versus data comparisons for the June event is presented in Figure 5-22. Again, the hydrodynamic model is able to represent the temperature and salinity quite well. The model is also able reasonably reproduce the fecal coliform and enterococci data while also generally reproducing the ratio between the two. The model does not match every data point, but does reproduce the majority of the measured bacteria concentrations.

Figure 5-23 presents a model versus data comparison for Station 18 in Newark Bay, for the June 2016 wet-weather event. The model reproduces the temperature and salinity very well. The model reproduces the fecal coliform quite well, but over estimates the enterococci data. This area is classified as SE3 which uses fecal coliform to assess attainment with bacteria criteria. The ratio shows that the fecal coliform to enterococci ratio ranges over an order of magnitude and is much higher than the ratios measured in the source data.

Figure 5-24 presents the model to data comparison for the June 2016 storm event at Station 20 in the Elizabeth River towards the mouth. At this location, the model is able to reproduce all the constituents rather well. It is apparent that the model is reasonably well calibrated, and flexible enough to reproduce data collected in rivers of varying size.

The model to data comparison to the wet-weather event in the Arthur Kill, at Station 24, is presented in Figure 5-25. Here, the model slightly underestimates the temperature, and does a good job reproducing the salinity. The model matches the fecal coliform data well, and over estimates the enterococci data. This is a class SE3 waterway where fecal coliform is used to assess attainment with the water quality criteria for bacteria.

The model to data comparison for Raritan Bay Station 29 is shown in Figure 5-26. The model is able to match the available data for this event quite well for all constituents. This is an area where the enterococci criteria is applied, and the model reproduces the low enterococci concentrations.

The final wet-weather event station to be presented is Station 33 in the Hudson River (Figure 5-27). The model matches the temperature data well, and also matches the semi-diurnal changes in the salinity. The model does not match the variability in the bacteria data, but the model line generally goes through the middle of the range of data points.

The model has been shown to be able to reproduce the magnitude and timing of the June 2016 wet-weather event for the spatially varying conditions in the project area. The remaining June wet-weather time-series calibration figures can be found in Appendix E.

Hackensack River & Tributaries
Hackensack River

Station: 14 Event 1 (June 3-9)

SE2

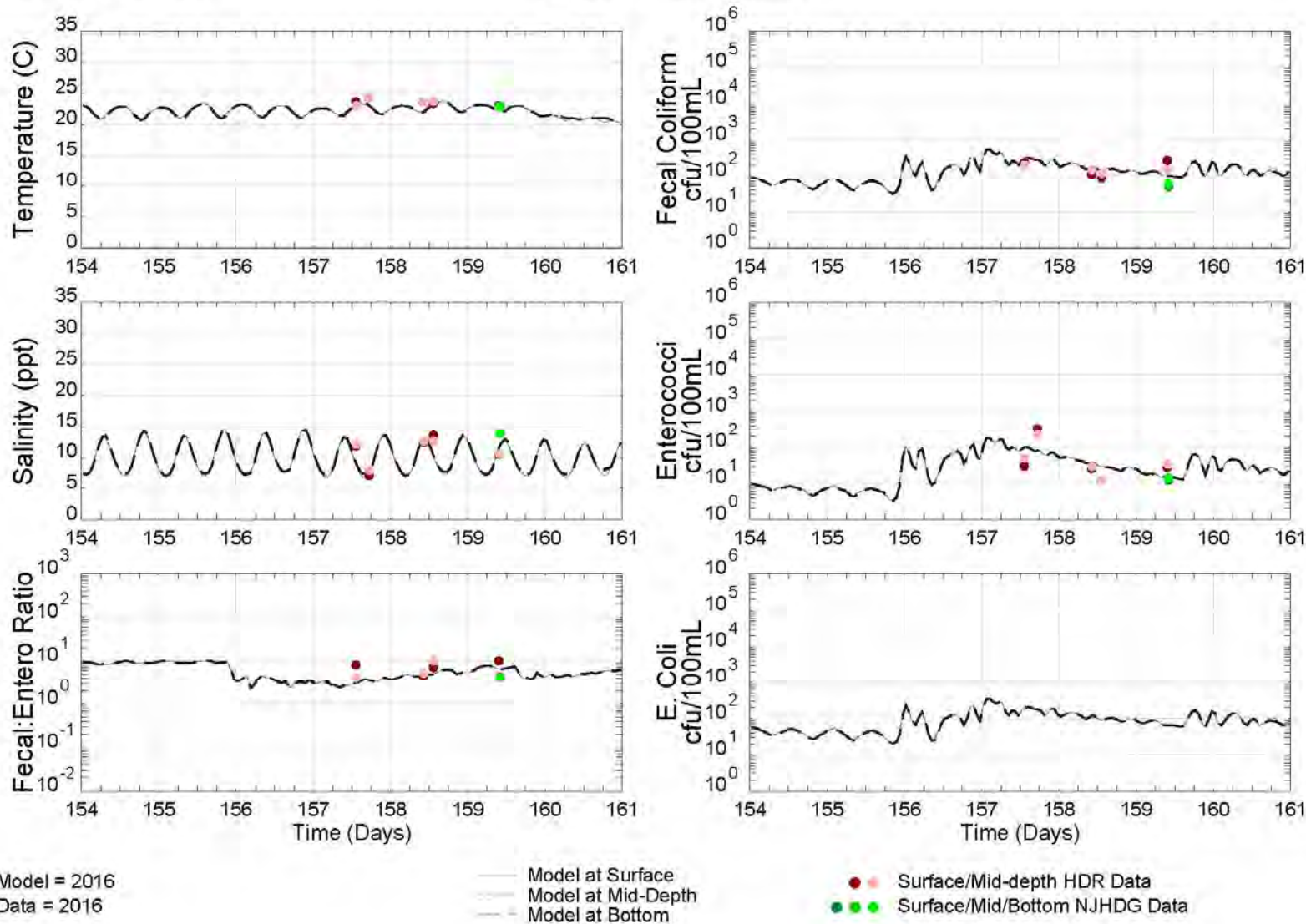


Figure 5-22. June 2016 Wet-Weather Event Model versus Data Comparison at Station 14, Hackensack River

Newark Bay & Tributaries
Newark Bay

Station: 18 Event 1 (June 3-9)

SE3

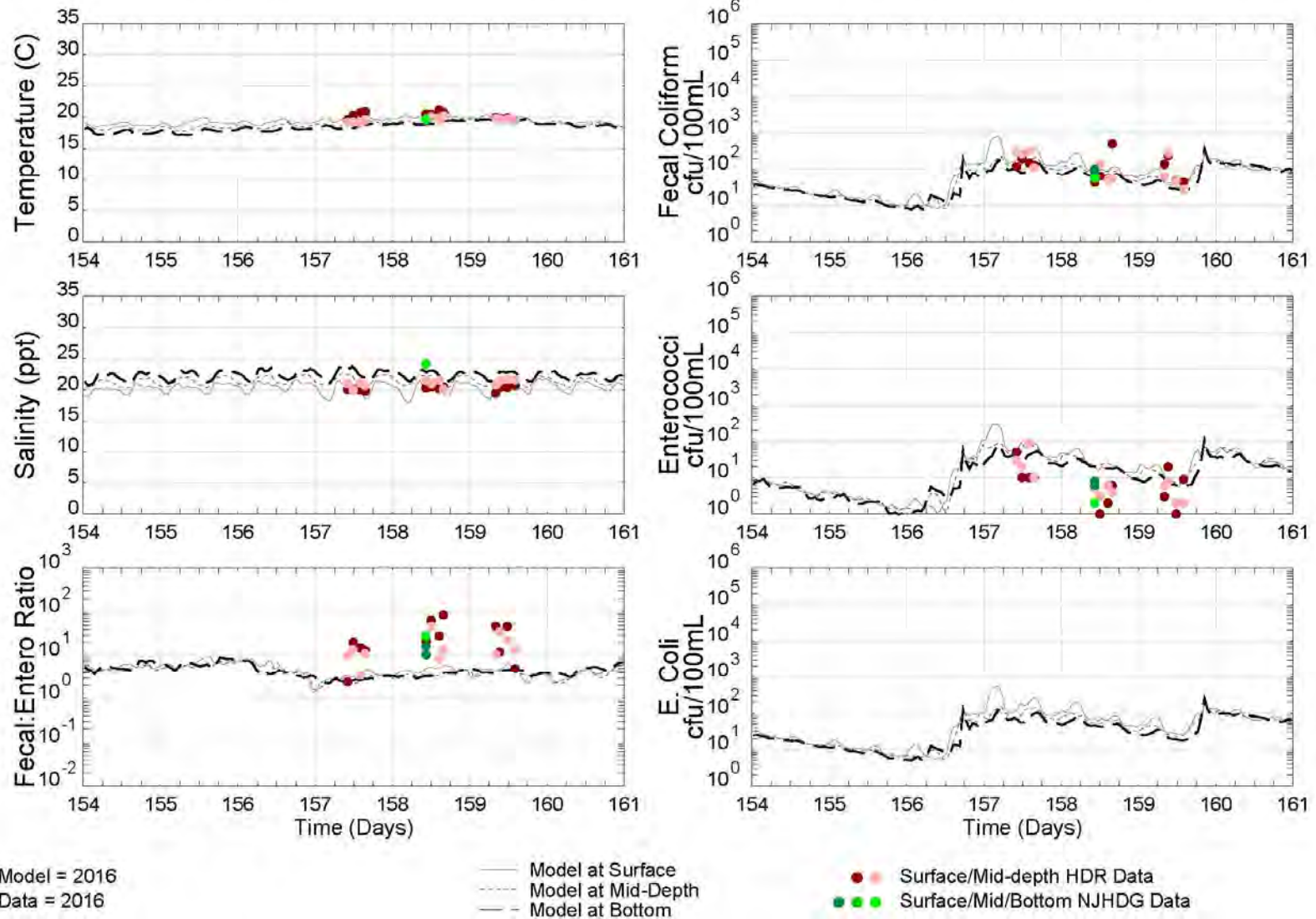


Figure 5-23. June 2016 Wet-Weather Event Model versus Data Comparison at Station 18, Newark Bay

Newark Bay & Tributaries
Elizabeth River

Station: 20 Event 1 (June 3-9)

SE3

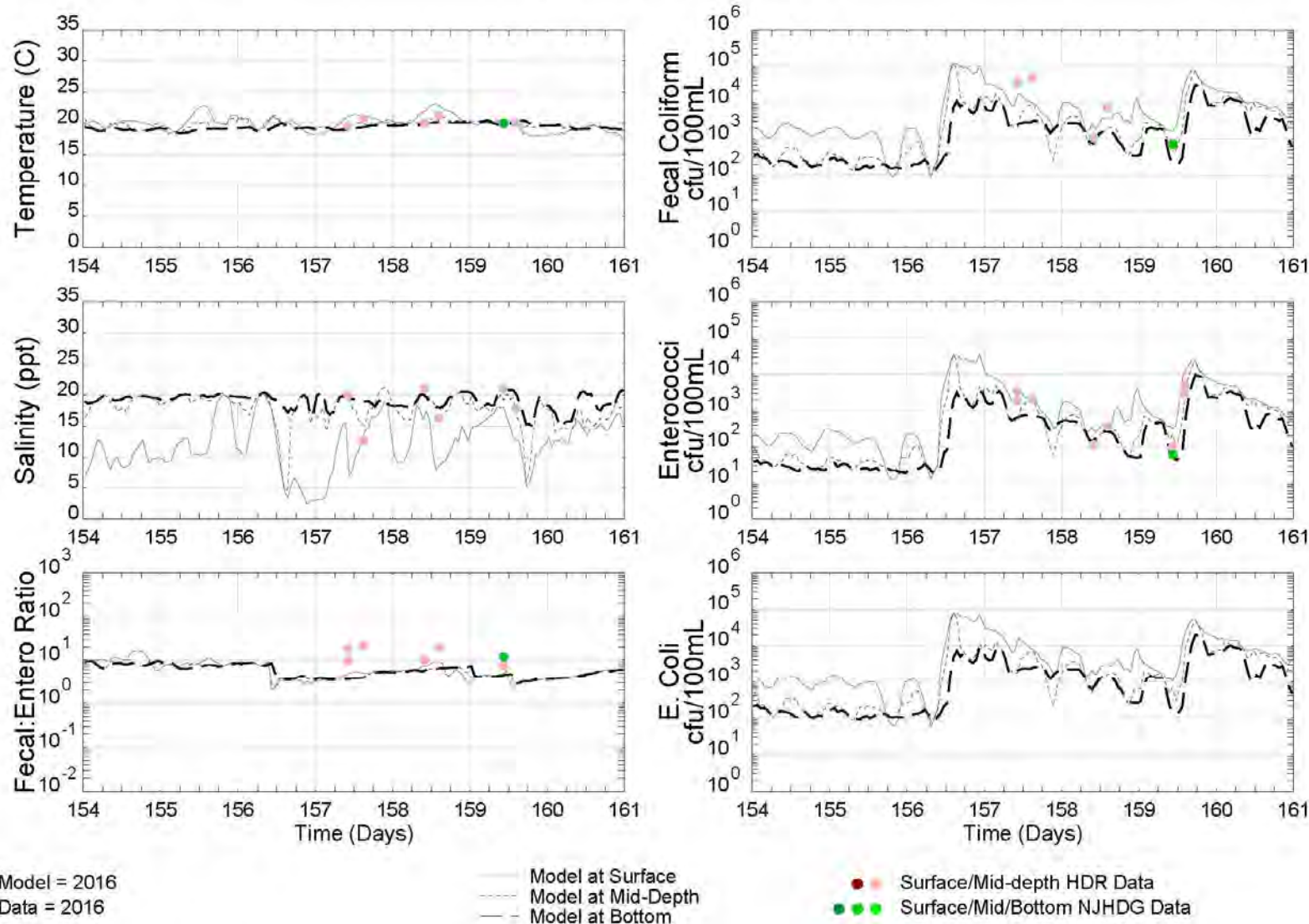


Figure 5-24. June 2016 Wet-Weather Event Model versus Data Comparison at Station 20, Elizabeth River

Arthur Kill, Raritan River/Bay & Tributaries
Arthur Kill

Station: 24 Event 1 (June 3-9)

SE3

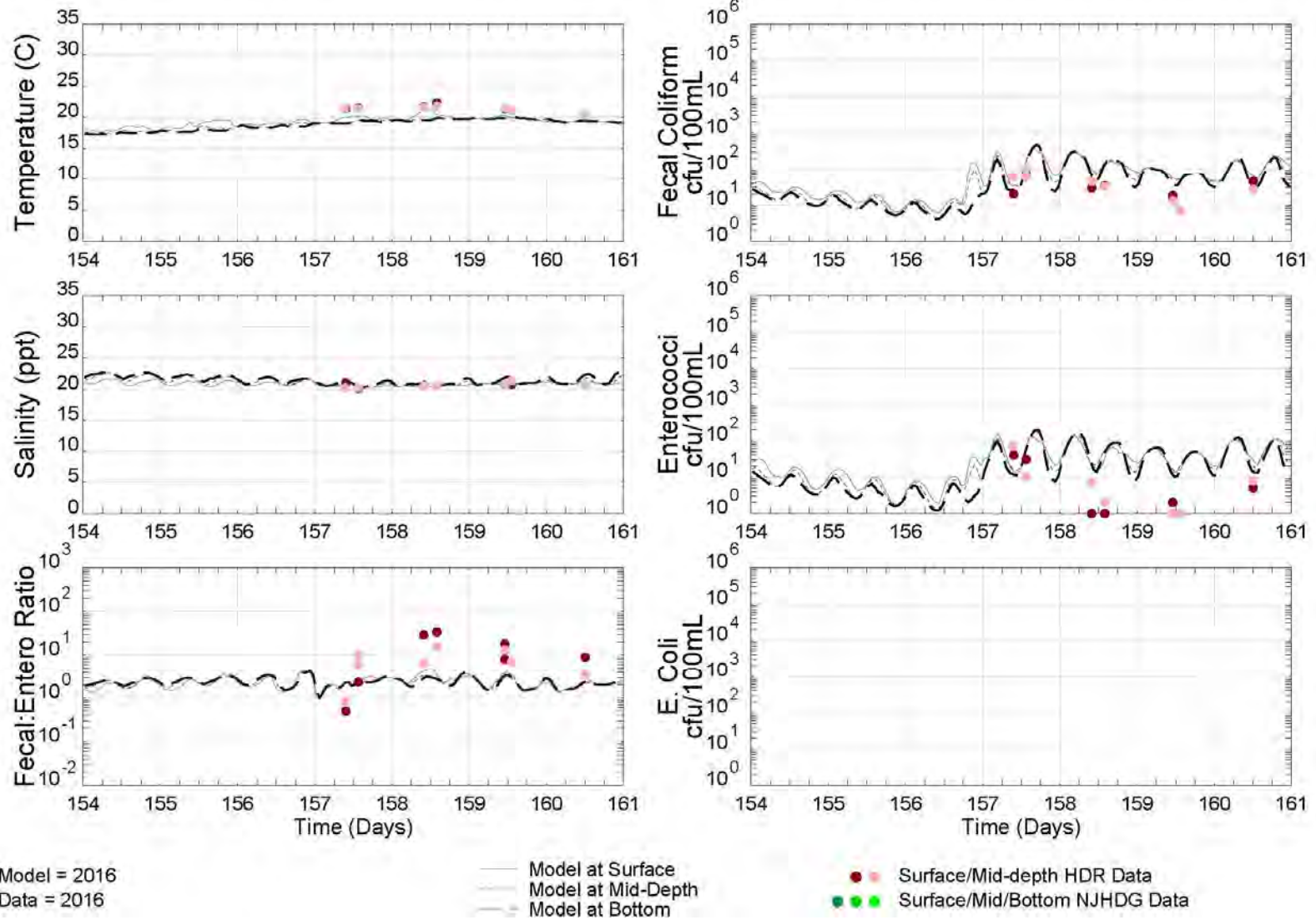


Figure 5-25. June 2016 Wet-Weather Event Model versus Data Comparison at Station 24, Raritan River

Arthur Kill, Raritan River/Bay & Tributaries
Raritan Bay

Station: 29 Event 1 (June 3-9)

SE1

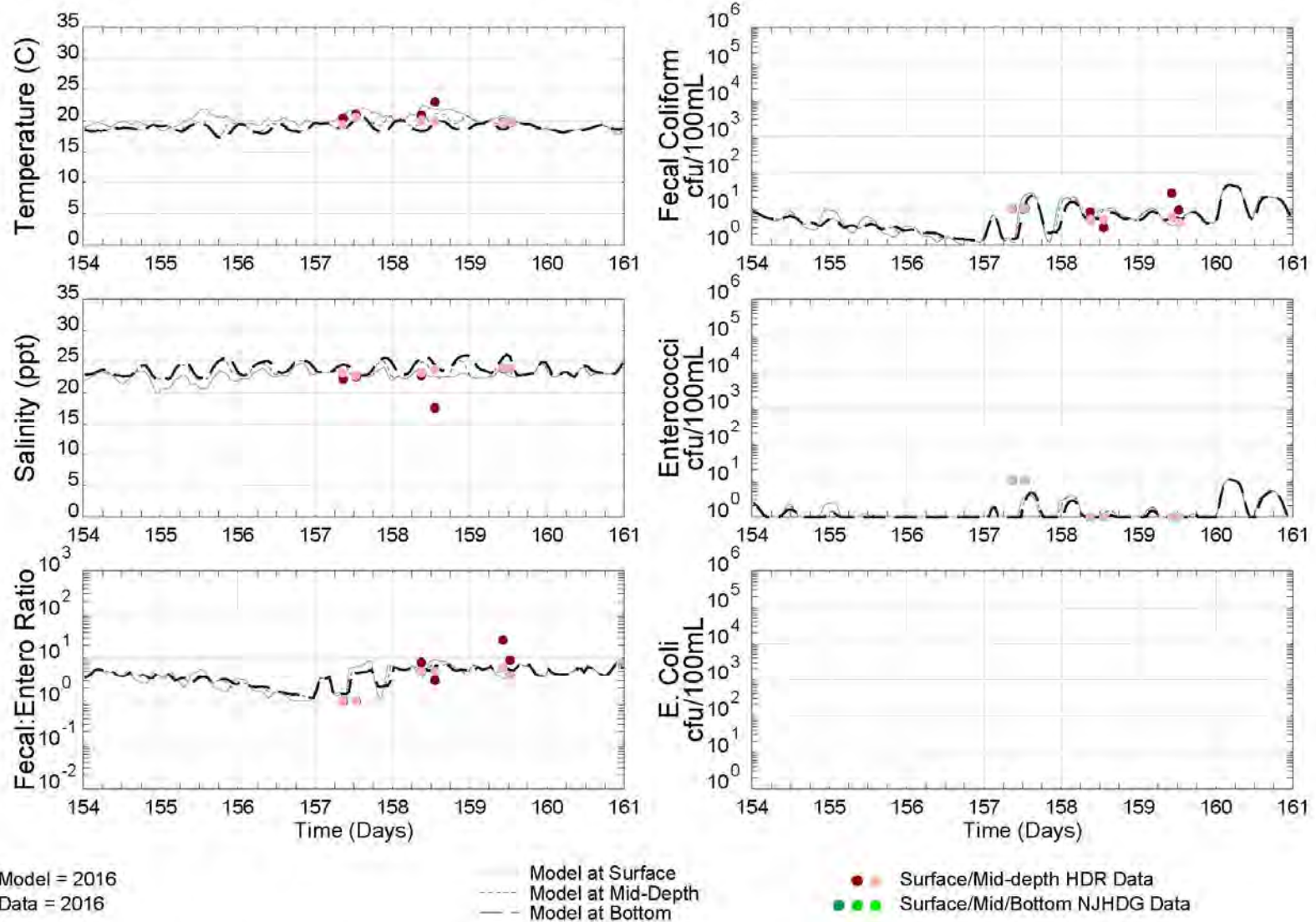
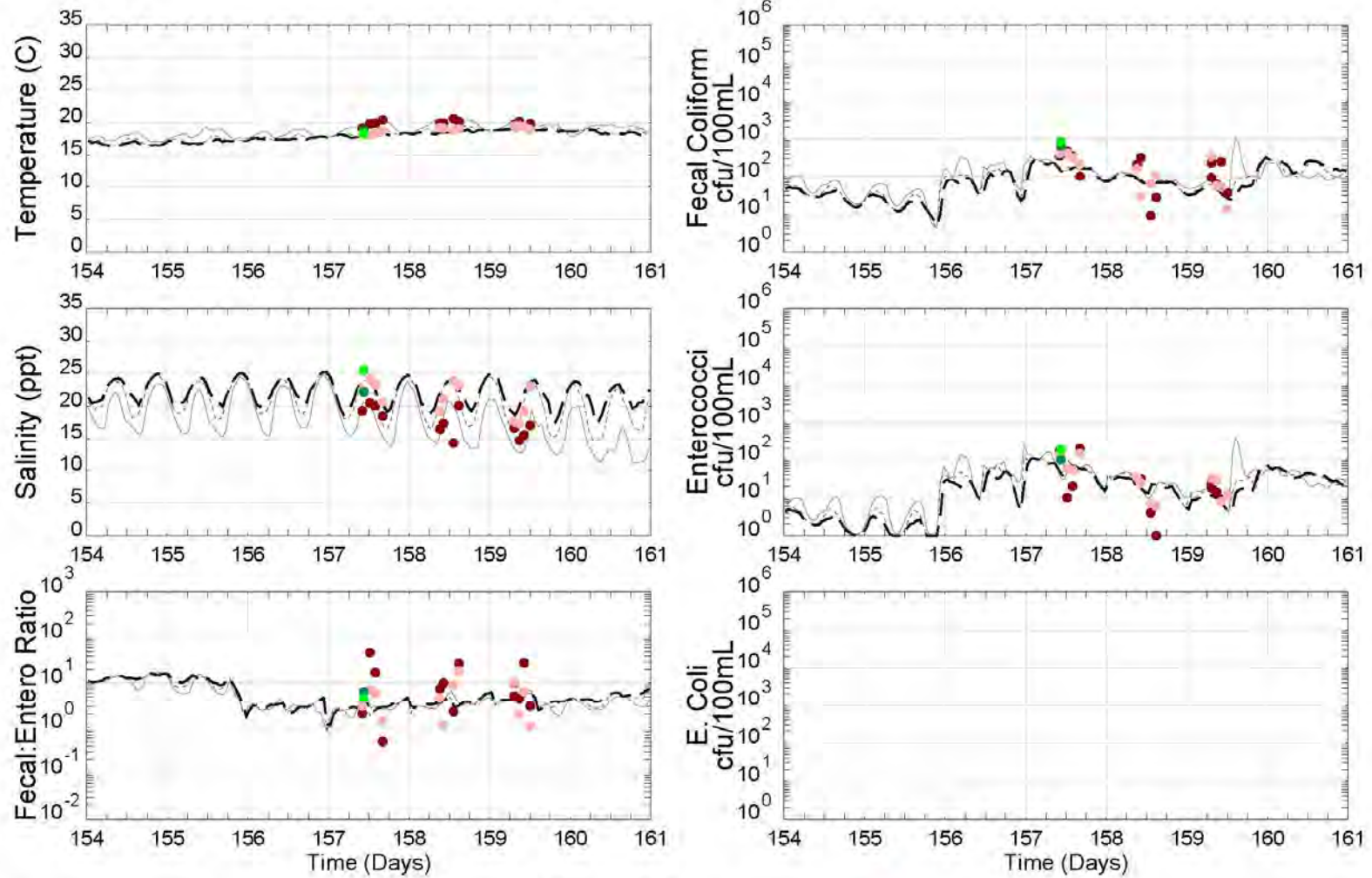


Figure 5-26. June 2016 Wet-Weather Event Model versus Data Comparison at Station 29, Raritan Bay

Hudson River, Upper Bay
Hudson River

Station: 33 Event 1 (June 3-9)

SE2



Model = 2016
Data = 2016

— Model at Surface
- - - Model at Mid-Depth
... Model at Bottom

● Surface/Mid-depth HDR Data
■ Surface/Mid/Bottom NJHDG Data

Figure 5-27. June 2016 Wet-Weather Event Model versus Data Comparison at Station 33, Hudson River

5.3.4 Spatial Transects

While time-series figures provide an understanding of how the model reproduces the data at a single point in space over a period of time, spatial transects provide an understanding of how the model reproduces spatial variations of concentration over a short time-frame. Spatial transect figures were generated for *E. coli*, fecal coliform and enterococci for the wet-weather events in rivers where data were available.

5.3.4.1 *E. coli*

E. coli sampling was limited to freshwater areas, so the only river with enough data to generate a transect plot is the Passaic River for the June 6 – 8 wet-weather event, during the calibration period. Figure 5-28 presents the model comparison to data for *E. coli*. Each panel represents one day of the survey. The northern end of the river is on the left side of the panel, and travels downstream from left to right. The data are presented as circles. Two samples were collected each day at the intensive survey stations. The green numbers at the top of the top panel identify the sampling stations. The *E. coli* samples for June 8, 2016 sampling date were lost due to a lab error. The dashed line represents a 10-layer model daily average, and the shading represents the daily range of the 10-layer averaged concentrations.

The model and data both show an increase in the *E. coli* concentration from the upstream boundary to approximately Station 4 south of Paterson. This is followed by a gradual decrease in concentration. The model then calculates lower concentrations closer to Newark Bay, where more dilution can occur due to tidal exchange. The model matches the Day 1 data very well. On Day 2 the model reproduces the data at the upstream end, but then tends to overestimate the more downstream data. While it is preferred that the model reproduce all of the data, when it cannot, it is preferred that the model overestimate the data, so that the modeling results can be considered conservative.

5.3.4.2 Fecal Coliform

Fecal coliform data is available in more waterbodies because it is used as the criteria in more of the project areas. Figure 5-29 presents the transect figure for the Passaic River during the June 6 – 8 sampling event for fecal coliform. The figure is in the same format as the *E. coli* transect figure.

The model is able to reproduce the fecal coliform, as signified by the majority of the data falling within the shaded area based on model output. Some of the downstream peak concentrations are underestimated on Day 1. The model reproduces the majority of the data on Day 2, and overestimates some of the downstream data on Day 3. However, overall the model reproduces the majority of the data and reproduces the spatial distribution of the data during this three-day period.

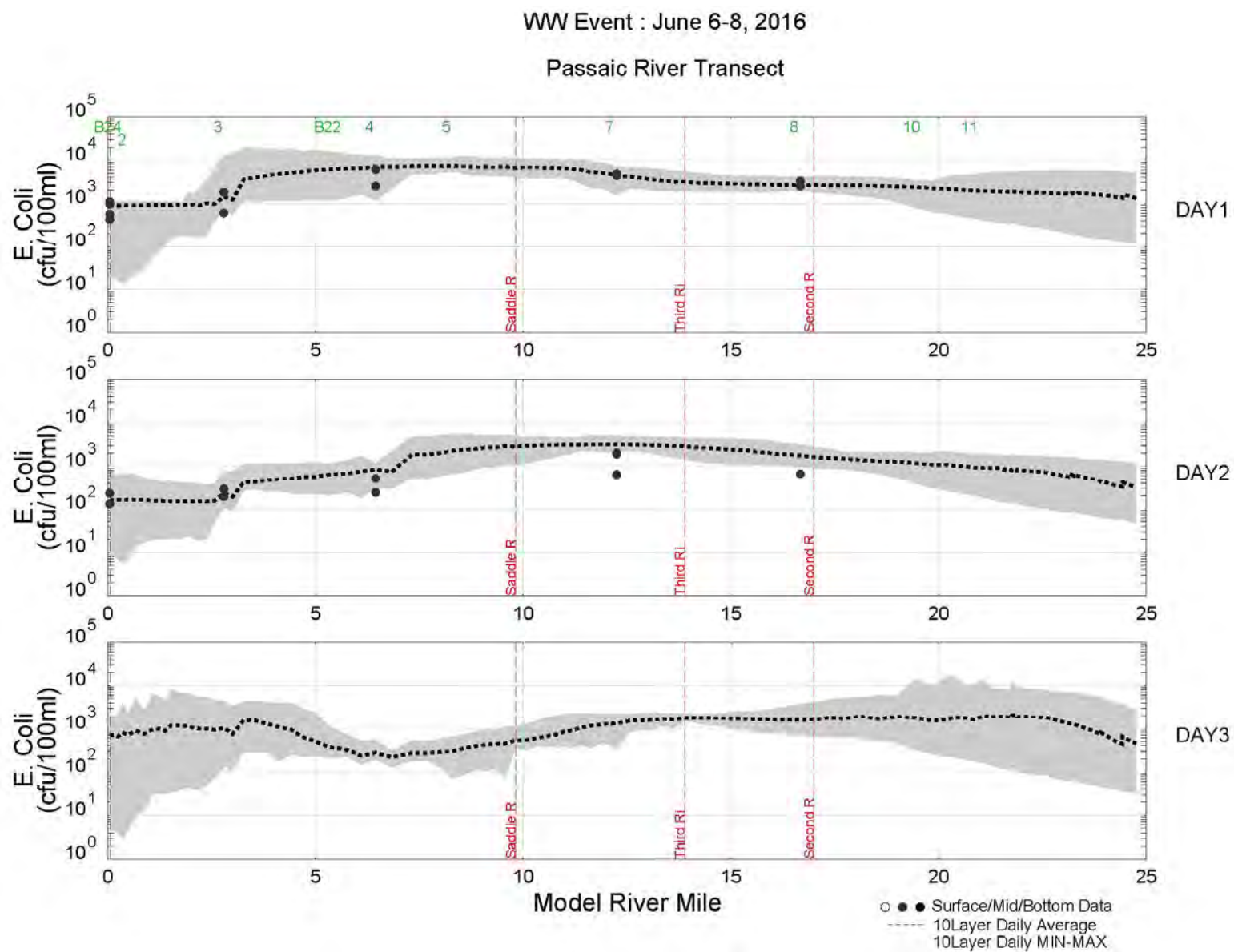


Figure 5-28. June 2016 Passaic River Model versus Data Transect Comparison for E. Coli

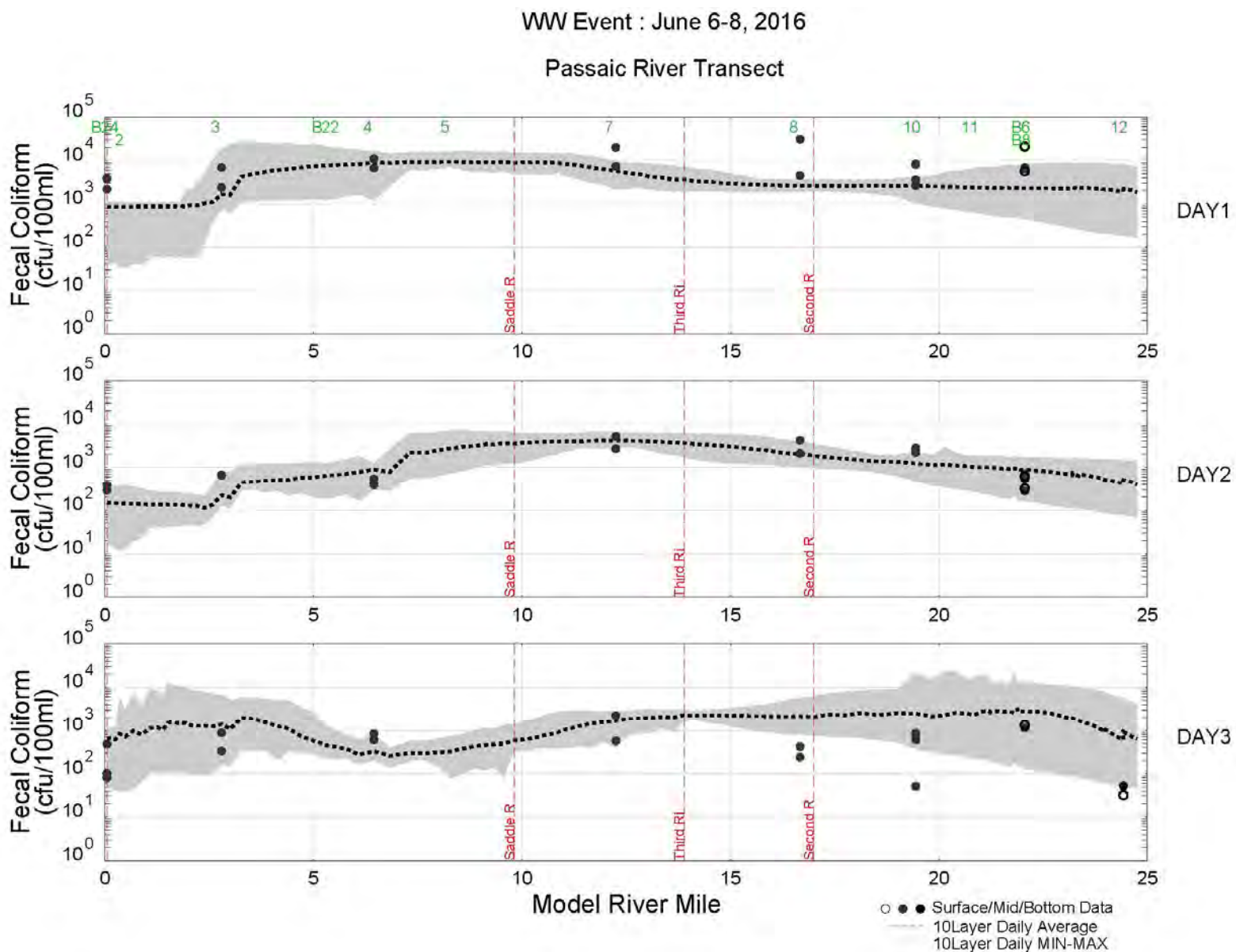


Figure 5-29. June 2016 Passaic River Model versus Data Transect Comparison for Fecal Coliform

Another example for fecal coliform is presented in Figure 5-30, which shows the model to data comparison for the Hackensack River. The model indicates lower concentrations at the northern boundary, on the left in these panels, and then both model and data indicate the highest concentrations during this event were near Station B1. This followed by a decline in concentrations over the next 5-10 miles until the concentrations remain relatively constant. The model is able to match the spatial pattern in the data rather well over the three-day period.

Additional examples of fecal coliform transect figures are presented in Appendix E.

5.3.4.3 Enterococci

An enterococci transect figure, similar to those presented for *E. coli* and fecal coliform, is presented in Figure 5-31 for the Hackensack River. Enterococci is used as the bacteria criteria in very few locations in the project area, but the Hackensack River is one of them. The model reproduces the data trends in space and time very well. Peak concentrations occur at Station B1 and the peak concentration decreases over the three-day period. Additionally, concentrations decrease toward the mouth of the river. The model is able to reproduce these features.

Additional examples of enterococci transect figures are presented in Appendix E.

5.3.5 Probability Distributions and Water Quality Criteria Attainment

The model has been shown to reproduce the measured bacteria concentrations during the calibration period of 2016. However, some of the water quality criteria are based on 30-day geometric mean concentrations. Bacteria concentrations in receiving waters are generally log-normally distributed. This means that if the bacteria concentrations are plotted on a log-probability figure, the data will plot as a straight line. For a normally distributed data set, data at the 50th percentile represent the median concentration. For a log-normally distributed data set, the 50th percentile represents the geometric mean. Therefore, if the model can be shown to reproduce the 50th percentile on a log-probability plot, it can be assumed that the model can be used to assess attainment of geometric mean standards. If the model can be shown to reproduce the probability distribution of a dataset when it crosses a single sample maximum concentration or 90th percentile concentration, then the model can be used to assess these criteria as well.

WW Event : June 6-8, 2016
 Hackensack River Transect

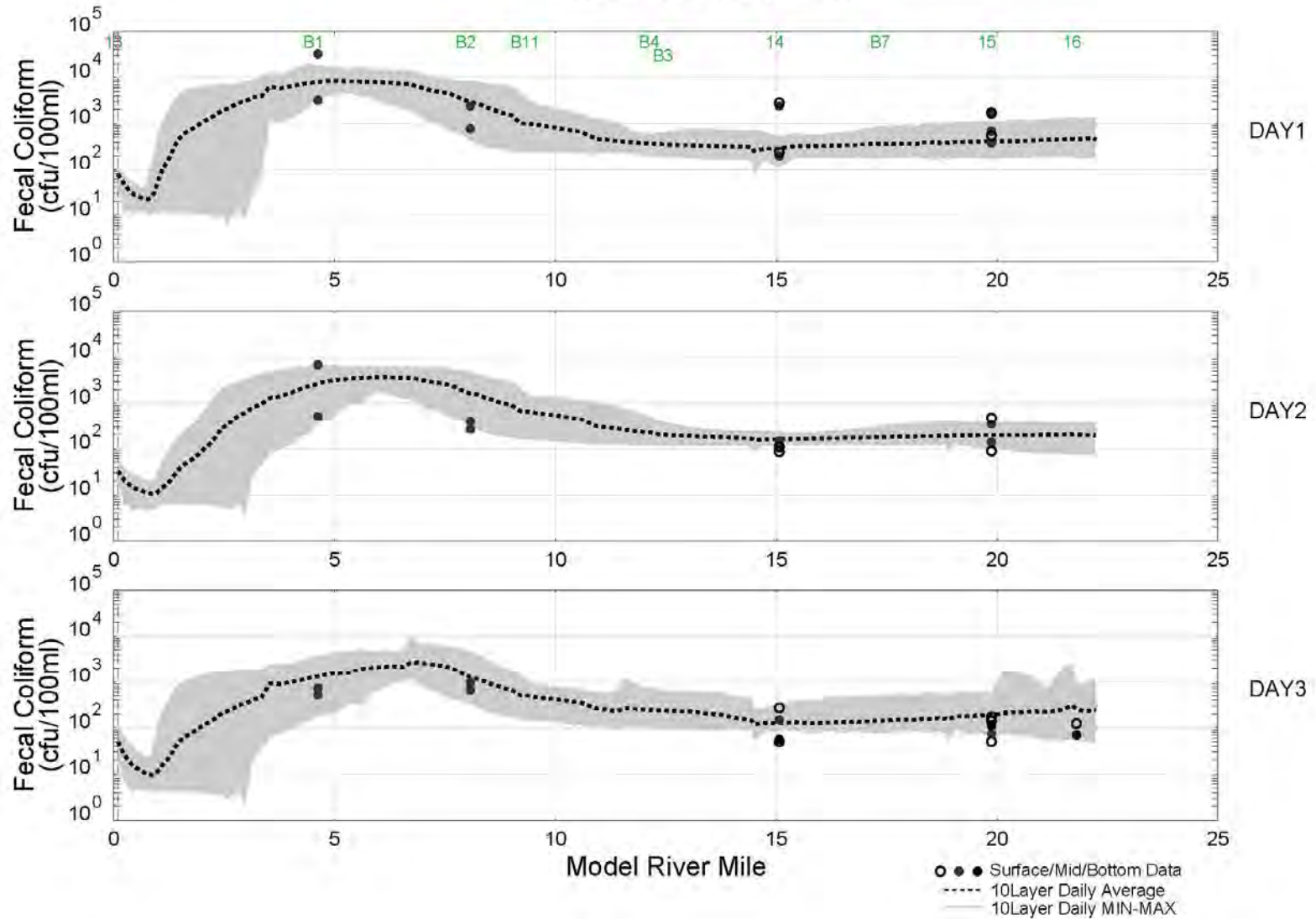


Figure 5-30. June 2016 Hackensack River Model versus Data Transect Comparison for Fecal Coliform

WW Event : June 6-8, 2016
 Hackensack River Transect

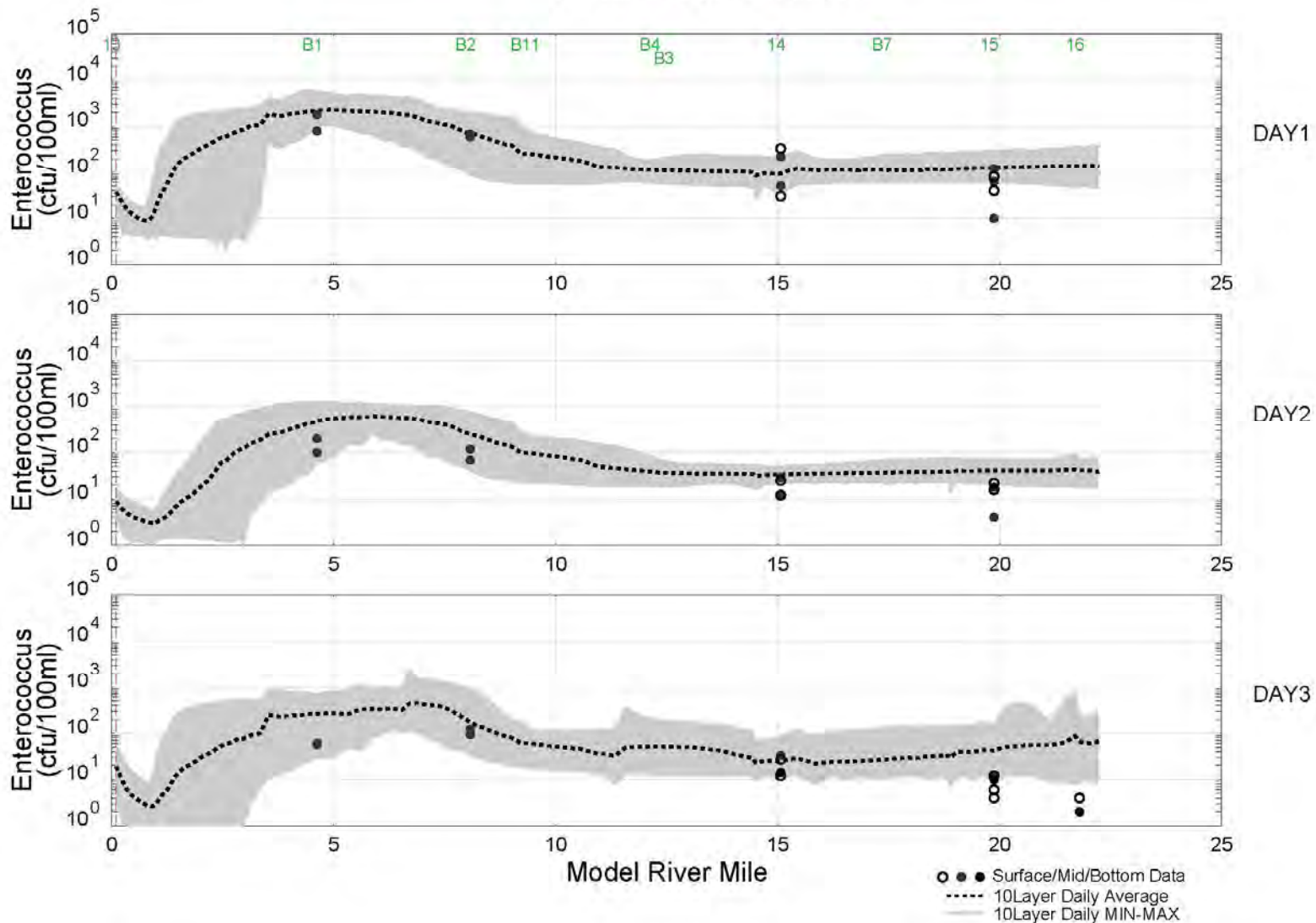


Figure 5-31. June 2016 Hackensack River Model versus Data Transect Comparison for Enterococci

The bacteria standards require a minimum of 5 samples per a 30-day period to assess attainment. In general, sampling does not occur often enough to meet the 5 sample requirement, so the model cannot be compared to 30-day periods when enough data are collected. In order to test the model, all of the data collected during the calibration period were plotted on a single log-probability plot and model output from the hour that each sample was collected was plotted to compare against the data. The idea here is that if the model can reproduce the variation in concentrations on an annual basis, it can reasonably be assumed that the model should be able to reproduce the variability over 30-day periods. The following figures provide examples of the model's ability to reproduce the bacteria probability distributions on an annual basis. The location presented are generally removed from the model boundary, so the boundary conditions are not unduly influencing the model's ability to reproduce the data. Additional figures are included in Appendix E.

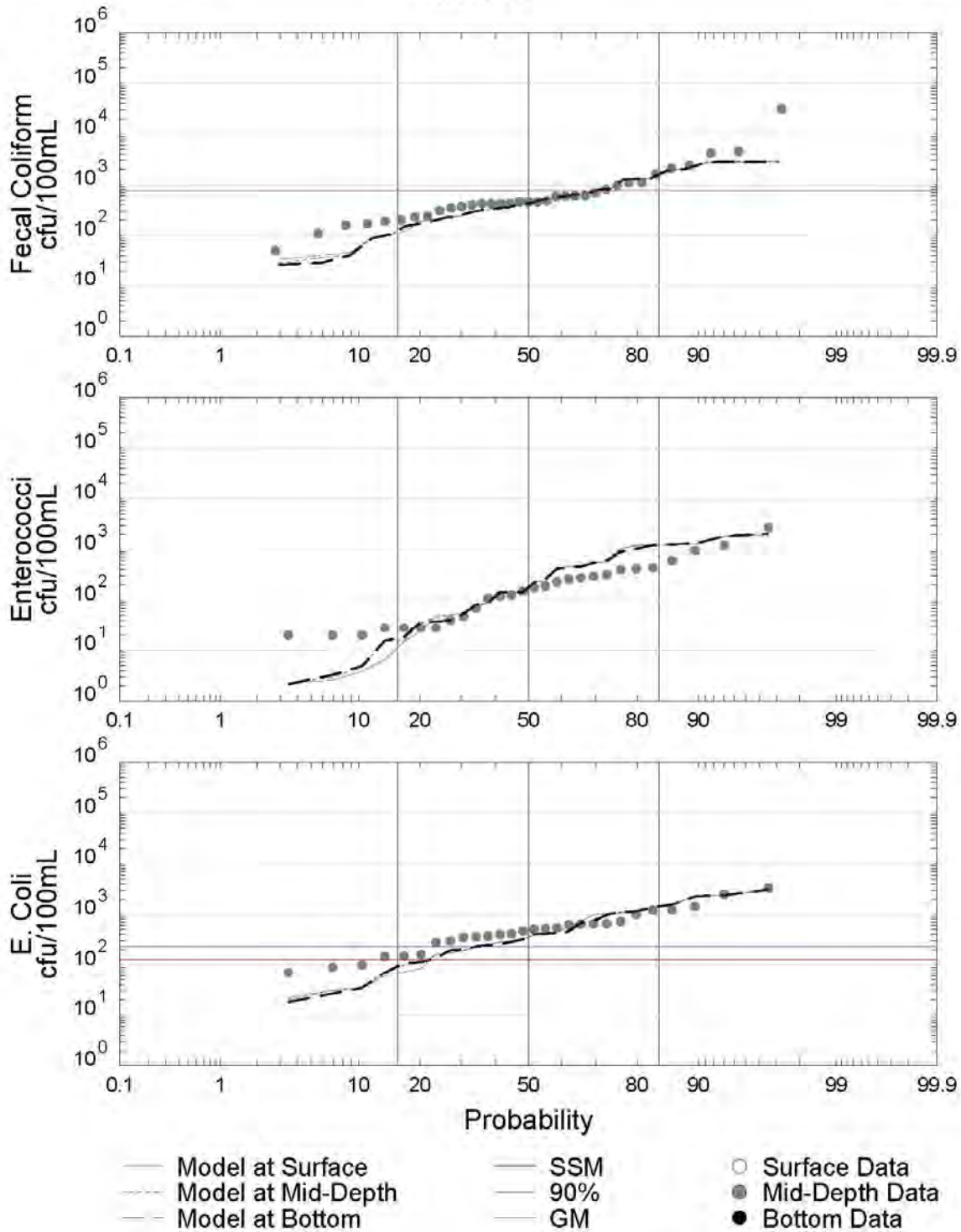
Figure 5-32 presents the model comparison to data for the annual probability distribution at Station 8 in the Passaic River near the Second River. The figure includes comparisons for fecal coliform, enterococci, and *E. coli*. Data are presented as circles and the model results are presented as solid or dashed lines depending on the model layer. Horizontal lines are added to panels to show the numerical criteria for the fecal indicator bacteria based on the waterbody classification at the station shown. Station 8 is located in a section of the Passaic River that is classified as FW2/SE2, so criteria lines are shown on both the fecal coliform and *E. coli* panels. In the top panel of the figure, the model line matches the data very well, and crosses the 50th percentile line at about the same concentration as the data. If this sample set were from a 30-day period, both the model and data would indicate there is attainment of the SE2 fecal coliform criterion at this location. In the bottom panel, the model also matches the *E. coli* data very well and crosses the 50th percentile line and the criteria lines at about the same points. If these data were for a 30-day period, the model and data would indicate that this station is not in attainment of the geometric mean or single sample maximum criteria.

A model to data comparison for the probability distributions at Station B2 in the Hackensack River is presented in Figure 5-33. The waterbody classification in this part of the river is SE1, so enterococci is the fecal indicator bacteria that is used for the bacteria criteria in this location. The lower end of the probability distributions, especially for fecal coliform indicate there is a source that exists even during dry-weather because the bacteria concentrations remain elevated even during dry-weather when the lowest bacteria concentrations occur. This required the addition of dry-weather loads to this area in the model. The model reproduces the fecal coliform data very well, but underestimates the enterococci in the lower half of the probability distribution. This indicates that the model performs better during wet-weather at this location. Despite this, the model still indicates non-attainment at this location based on the geometric mean criteria, as does the data. The model and data cross the single sample maximum line at the approximately the same point, indicating the model reproduces this criterion very well at this station.

PASSAIC RIVER

Station: 8

FW2/SE2



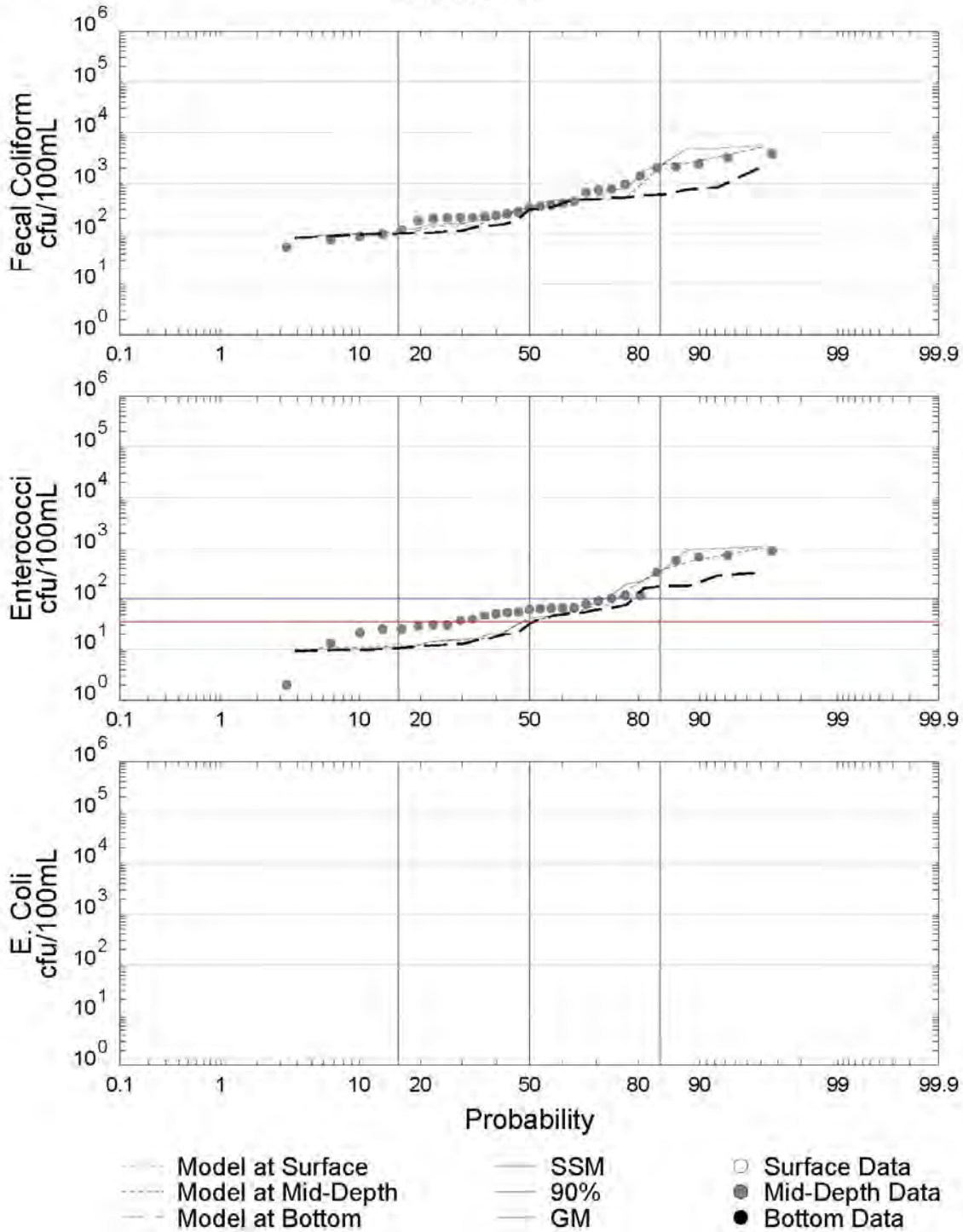
Model Results during data sampling hours only

Figure 5-32. 2016 Annual Model versus Data Probability Distribution Comparison at Station 8, Passaic River

HACKENSACK RIVER

Station: B2

SE1



Model Results during data sampling hours only

Figure 5-33. 2016 Annual Model versus Data Probability Distribution Comparison at Station B2, Hackensack River

The probability comparison results for Station B17 in Newark Bay is presented in Figure 5-34. Newark Bay is classified as and SE3 waterbody and fecal coliform are used for the bacteria criterion. The model reproduces the fecal coliform distribution very well. It is clear from both the model and data that the geometric mean of the fecal coliform concentrations is well below the criterion and this area of Newark Bay is in attainment of the criterion. The model overestimates the enterococci concentrations. This points out a phenomenon observed throughout the project area. Despite the loading of fecal coliform and enterococci being similar, there are many instances when the fecal coliform to enterococci concentration in the receiving water is greater than 10:1. This suggests the net loss of fecal coliform bacteria is slower than the net loss of enterococci at least in some parts of the project area, and provides a rationale for assigning a lower die-off rate for fecal coliform than enterococci.

Figure 5-35 and Figure 5-36 present model versus data probability distributions for the freshwater (FW2) (Station B16), and saltwater (SE3) (Station 20) portions of the Elizabeth River, respectively. The Elizabeth River was one of the more difficult areas of the model to calibrate because, as can be seen in the data, the bacteria concentrations are elevated most of the time, which indicate there are dry-weather sources. This makes it difficult to assess the model's response to wet-weather events because the bacteria concentrations are always high. The model under predicts the *E. coli* data at Station B16, but still indicates the geometric mean concentration is well above the criterion. This area is upstream of any CSO and not impacted by the tides. The fecal coliform data at Station 20 is reproduced very well. The model is also able to show non-attainment at Station B16 and attainment at Station 20 as indicated by the data, if all of the data were collected within a 30-day period.

The model versus data comparison for Station 21 in the Arthur Kill is presented in Figure 5-37. This area is designated as SE3. The model distribution line compares favorably to both the fecal coliform and enterococci data. In many portions of the study area data are either collected at mid-depth, or the data do not show much difference between the surface and bottom concentrations. At this location in the Arthur Kill, there is some stratification between the surface and bottom concentrations in the upper end of the fecal coliform distribution, and the model is able to reproduce this feature.

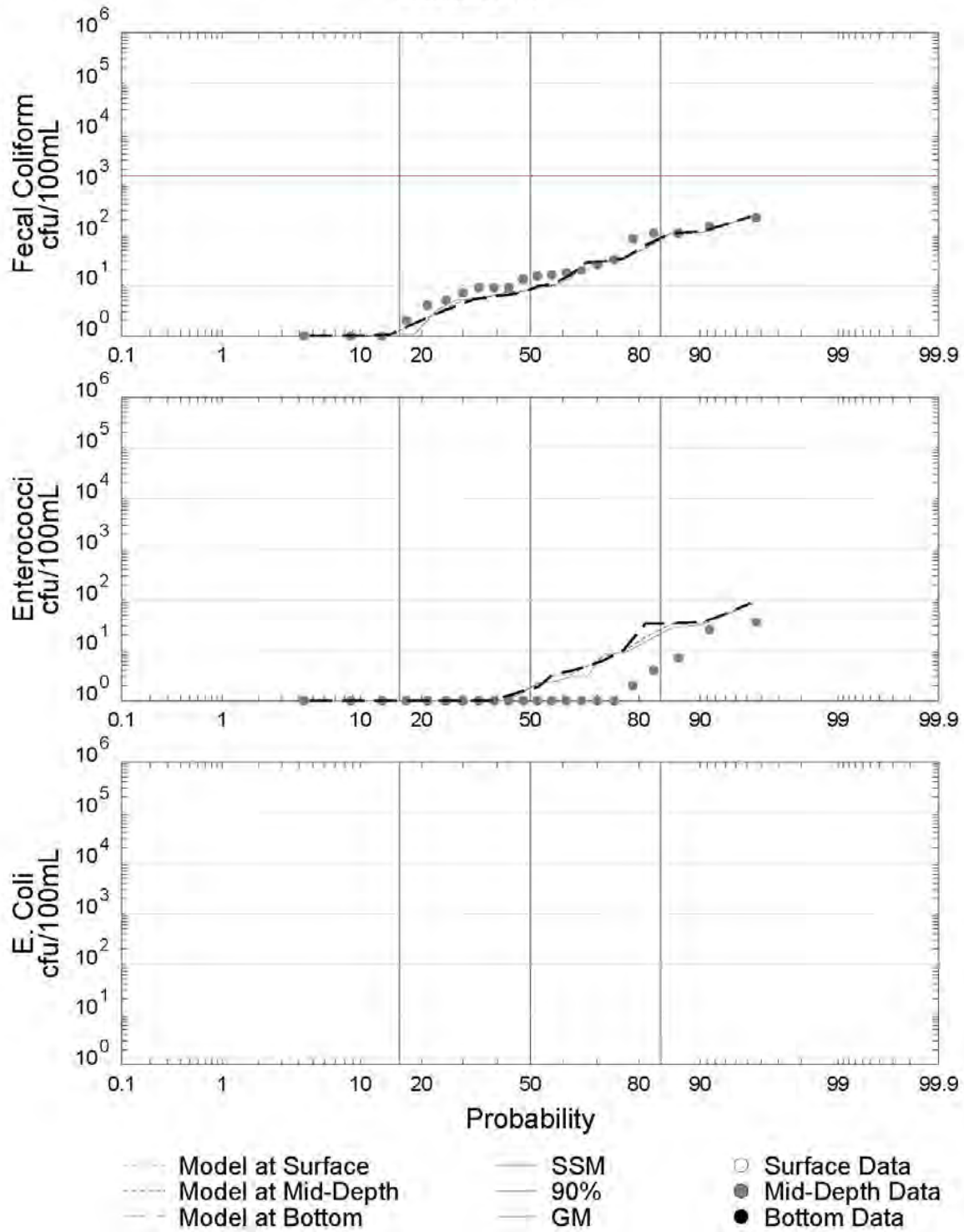
Figure 5-38 presents the probability distribution comparison between model and data for Station B19 in Raritan Bay near the mouth of the Raritan River (SE1). The model underestimates fecal coliform concentrations on the lower end of the distribution, but matches the enterococci concentrations, which are used to assess bacteria criteria attainment in this location, quite well. The data suggest attainment of the geometric mean criterion with occasional exceedances of the single sample maximum criterion. The model reproduces this very well.

Figure 5-39 presents the model versus data comparison for the bacteria probability distributions at Station B18A in the Hudson River (SE2). The model compares very favorably to both the fecal coliform data, which are used to assess attainment, and the enterococci data. Both the model and data show that bacteria concentrations in the Hudson River at this location are well below the criterion.

LOWER PASSAIC RIVER

SE3

Station: B17



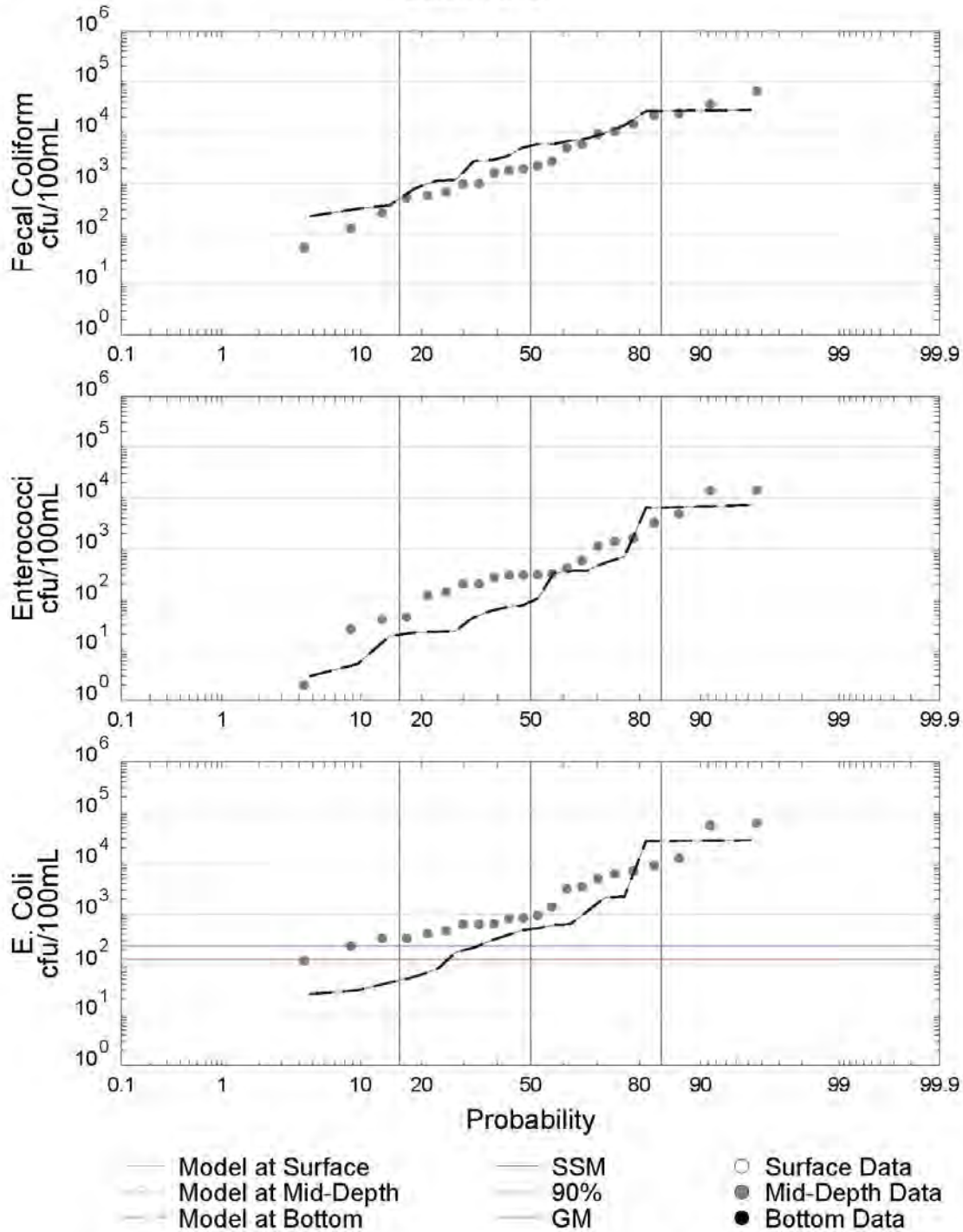
Model Results during data sampling hours only

Figure 5-34. 2016 Annual Model versus Data Probability Distribution Comparison at Station B17, Newark Bay

ELIZABETH RIVER

Station: B16

FW2



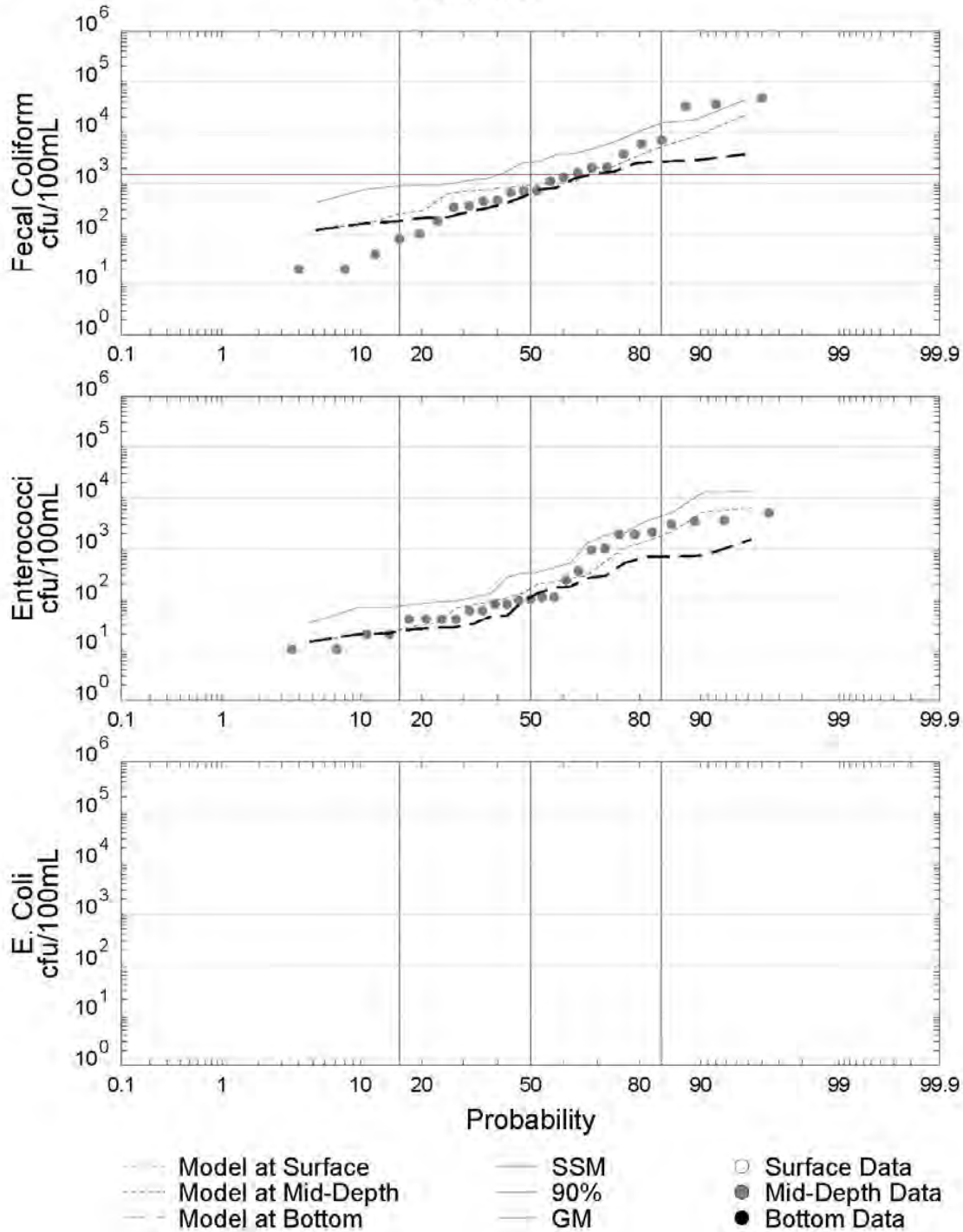
Model Results during data sampling hours only

Figure 5-35. 2016 Annual Model versus Data Probability Distribution Comparison at Station B16, Elizabeth River

ELIZABETH RIVER

Station: 20

SE3



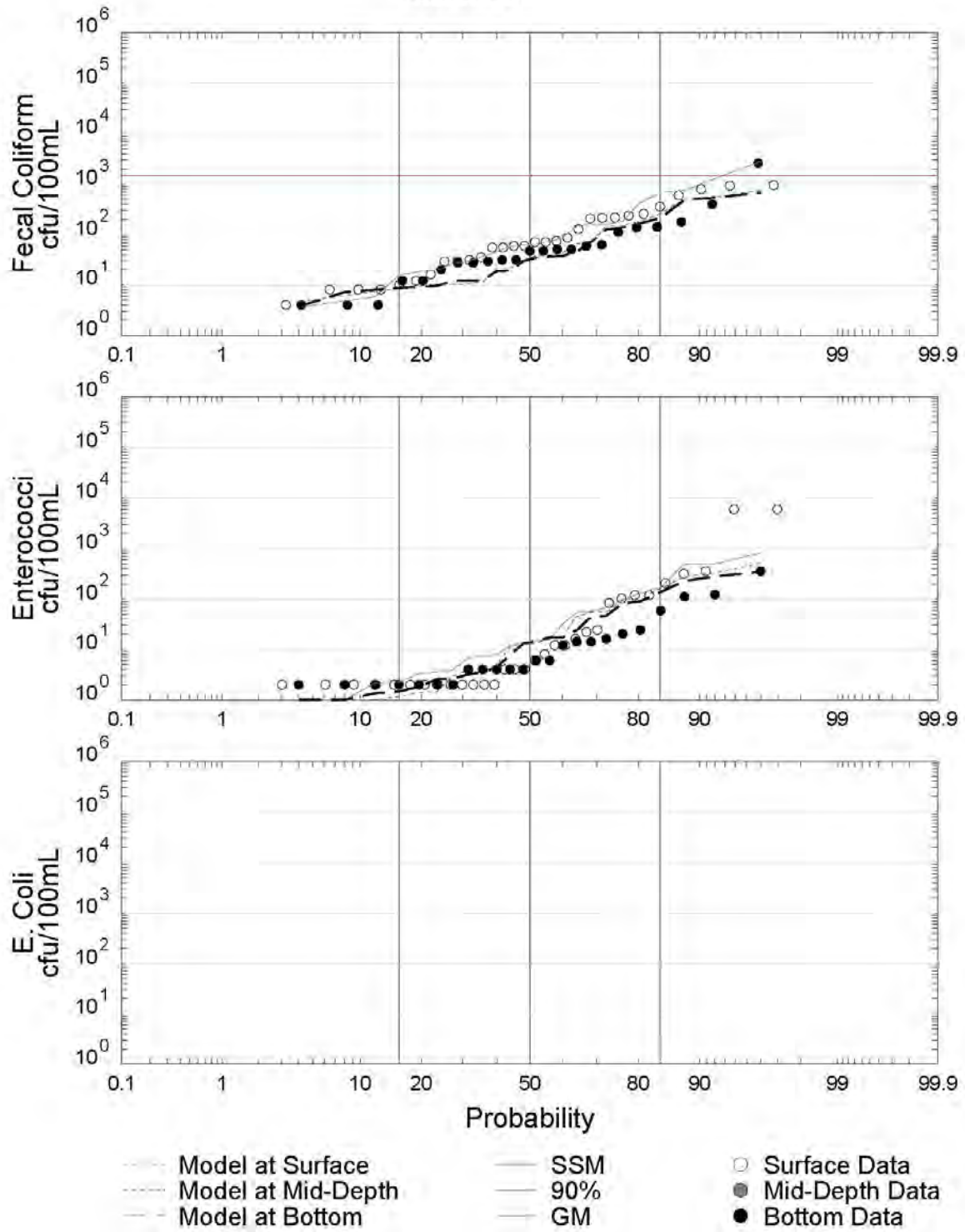
Model Results during data sampling hours only

Figure 5-36. 2016 Annual Model versus Data Probability Distribution Comparison at Station 20, Elizabeth River

ARTHUR KILL

SE3

Station: 21



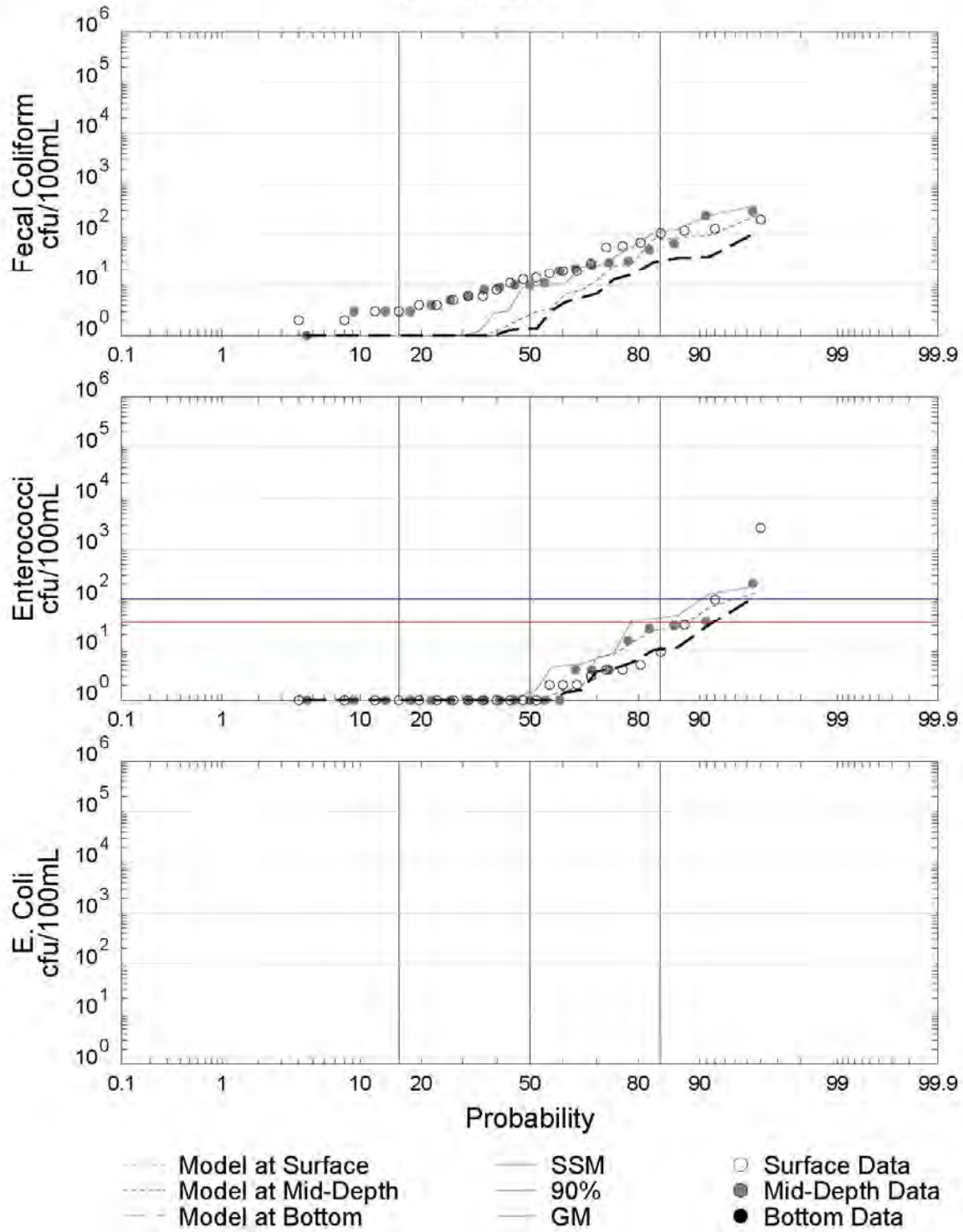
Model Results during data sampling hours only

Figure 5-37. 2016 Annual Model versus Data Probability Distribution Comparison at Station 21, Arthur Kill

RARITAN BAY

Station: B19

SE1



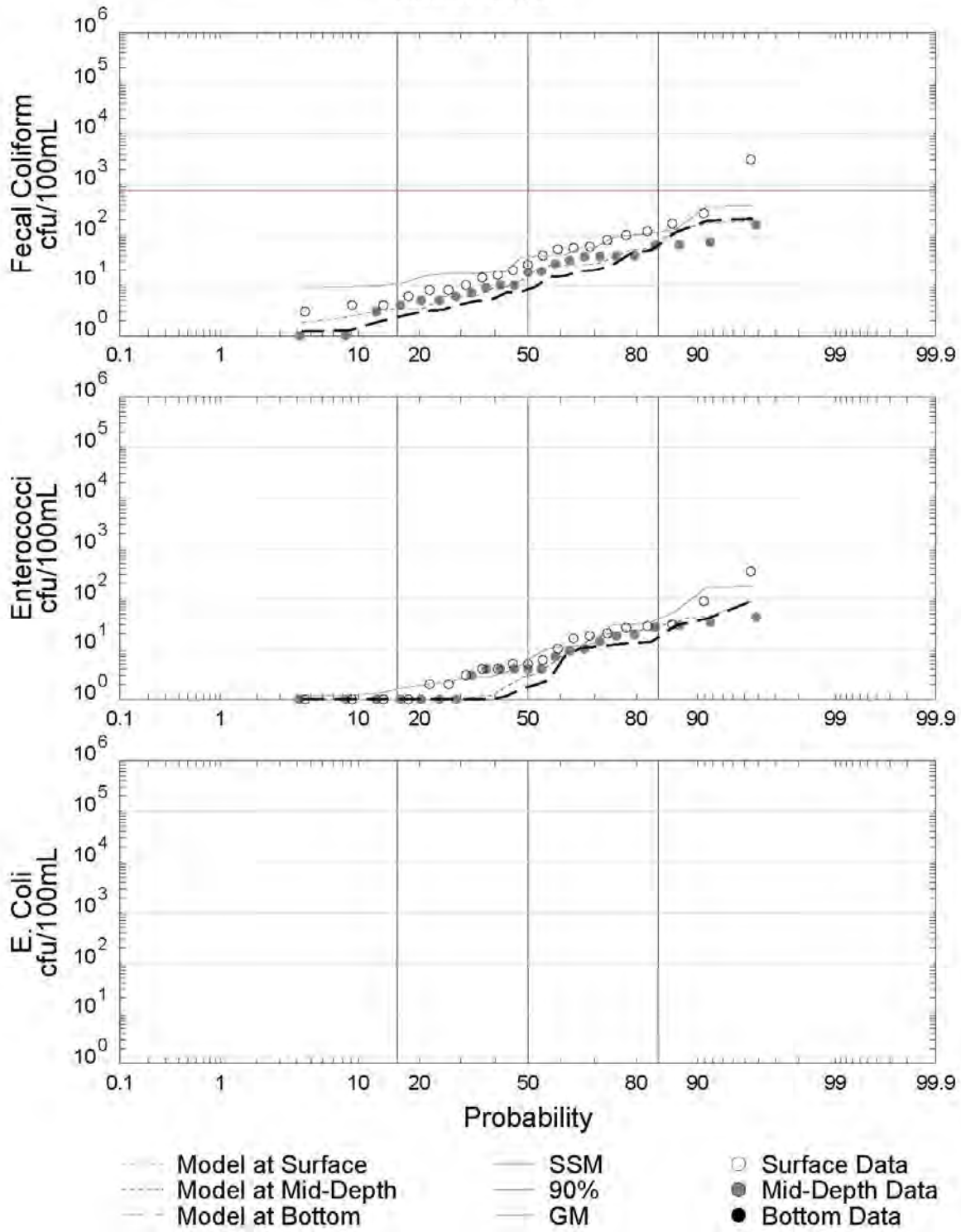
Model Results during data sampling hours only

Figure 5-38. 2016 Annual Model versus Data Probability Distribution Comparison at Station B19, Raritan Bay

HUDSON RIVER

Station: B18A

SE2



Model Results during data sampling hours only

Figure 5-39. 2016 Annual Model versus Data Probability Distribution Comparison at Station B18A, Hudson River

Additional probability distribution figures are included in Appendix E.

These probability figures indicate that the model can reasonably calculate attainment of the fecal indicator bacteria throughout the project area. There is still some uncertainty that every model cell will be accurate simply because data doesn't exist to test the model everywhere. This means the model can be used to assess attainment of water quality criteria, but decisions based on attainment should not emphasize the results in one particular model cell.

5.4 Validation Results

The baseline compliance monitoring sampling continued into April 2017, so 2017 was chosen as the validation year for the model because sufficient data were available. 2017 also included two wet-weather intensive surveys. The validation comparison between the model and data used the same model constants as the calibration year. Only the meteorological, flow and loading conditions were changed to represent 2017 conditions.

5.4.1 Time-Series Comparisons

Some of the stations in this section will be the same as shown for the calibration period in Section 5.3.1, so that it can be observed the model is able to reproduce the data in both years reasonably well. In other cases, there are limited data to compare against the model, so a NJHDG station will be presented.

5.4.1.1 Annual

Figure 5-40 presents the model versus data time-series comparison for 2017 at Station 8 in the Passaic River. The model reproduces the temperature data quite well, with the possible exception of an overestimation of August temperature. The model also reproduces the salinity quite well. The model indicates that the salt wedge reached this location less often than during 2016, and the saltiest period occurred during late-August through October. The higher salinity corresponds to a period when the model calculates lower bacteria levels. This indicates a drier period occurred during this time. The model reproduces the bacteria data during most of the year, but there are some higher concentrations during the dry period that the model under predicts.

A model versus data comparison for the Hackensack River at Station 15, upstream of the mouth, is presented in Figure 5-41. Again, the model is able to reproduce the temperature and salinity data. The model is able to reproduce seasonal trends in the data as well as range of salinity changes caused by tidal action. The model is also generally able to reproduce the magnitude and timing of the fecal coliform and enterococci data. However, the fecal coliform to enterococci ratio panel does show the challenges in reproducing the data. The data indicate that this ratio can change by up to two orders of magnitude. This is difficult for the model to reproduce, in part, because there is more variability in the loading than the model input accounts for. Despite this, the model reproduces both the fecal coliform and enterococci concentrations reasonably well most of the time.

PASSAIC RIVER

Station: 8

FW2/SE2

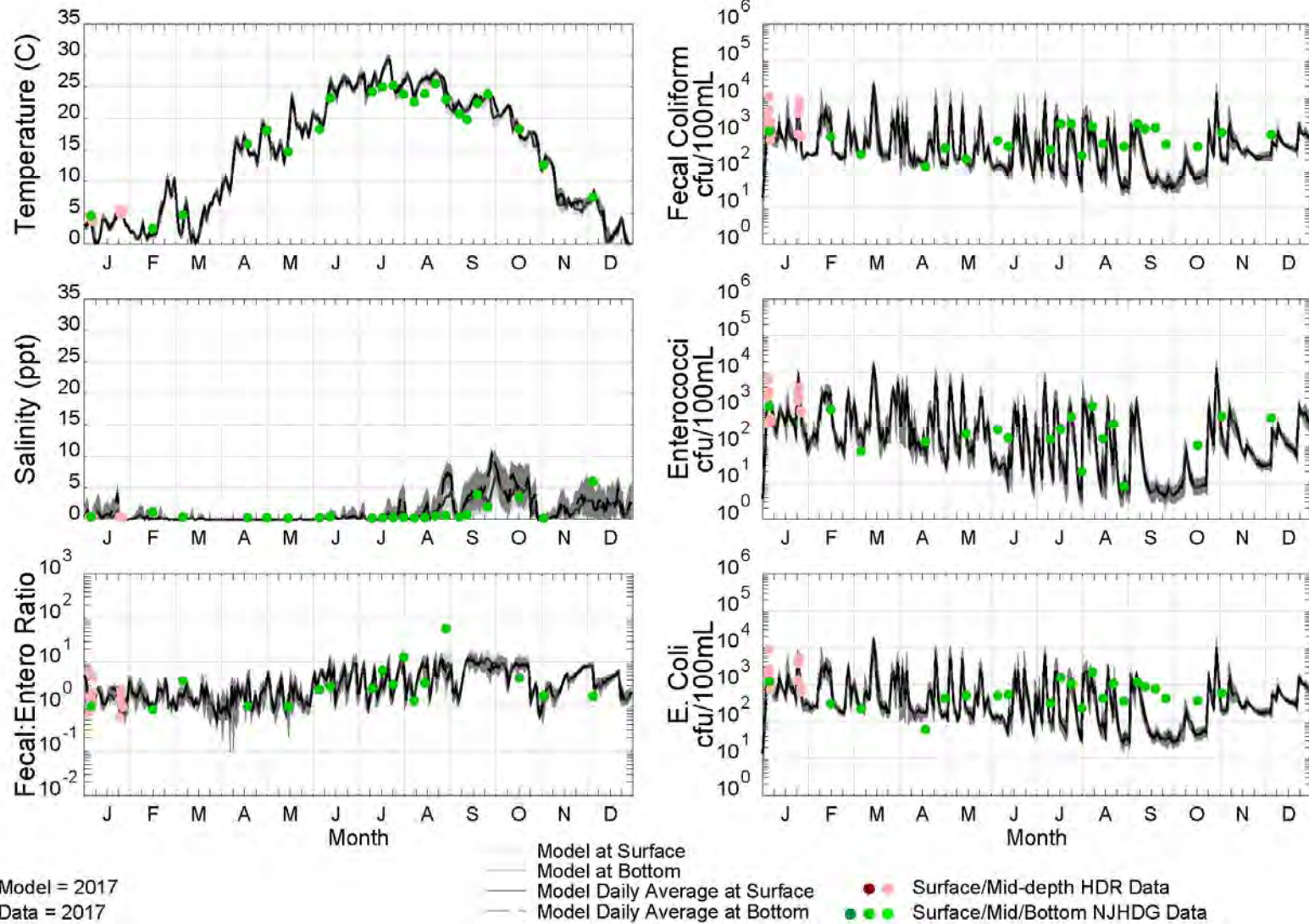


Figure 5-40. 2017 Annual Time-Series Model versus Data Comparison at Station 8, Passaic River

HACKENSACK RIVER

Station: 15

SE2

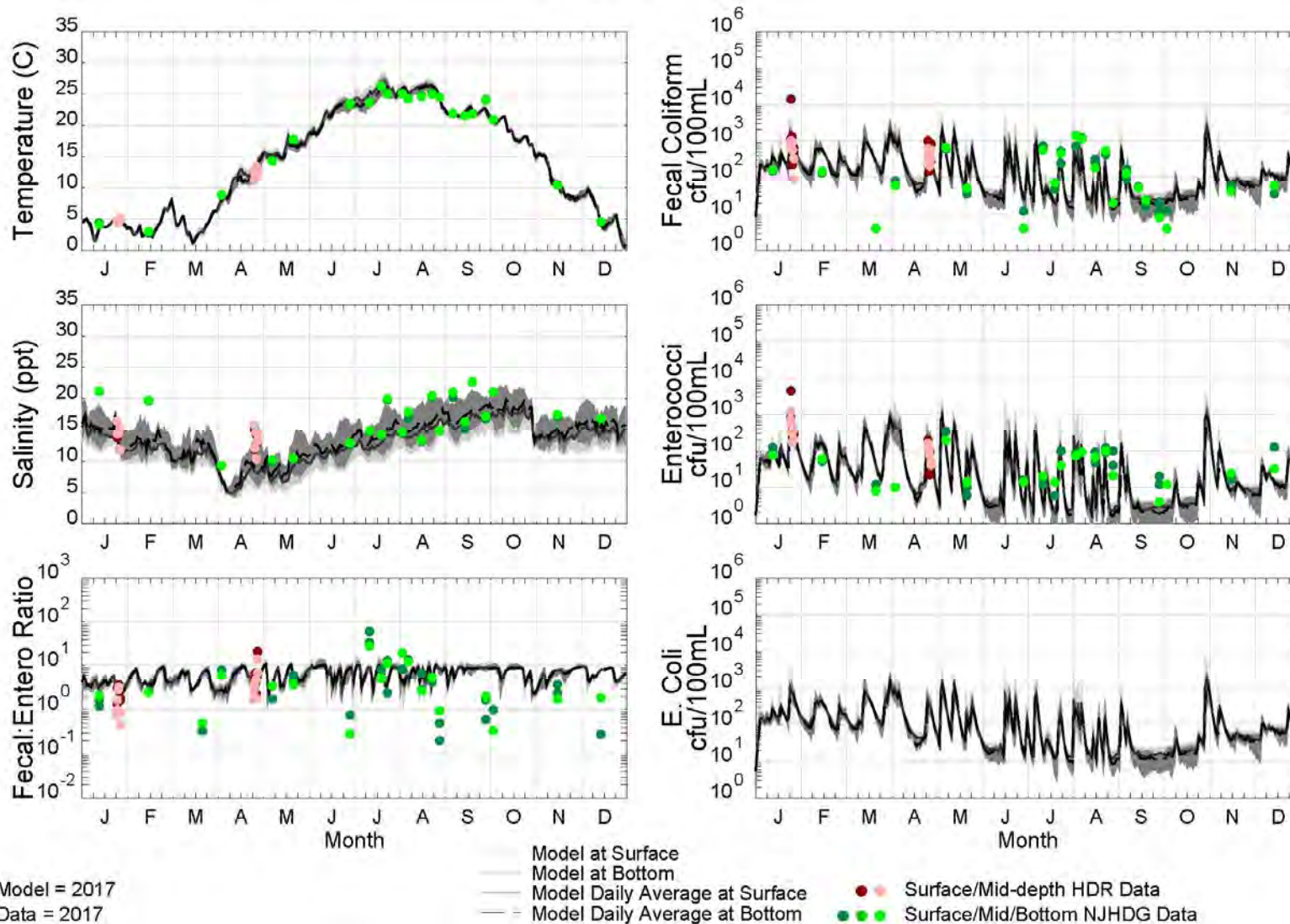


Figure 5-41. 2017 Annual Time-Series Model versus Data Comparison at Station 15, Hackensack River

Figure 5-42 presents a time-series comparison of model versus data for Station 18 in lower Newark Bay. The model is able to reproduce the seasonal changes in temperature and salinity. The model is also able to reproduce the fecal coliform and enterococci data, and even the fecal coliform to enterococci ratio for most of the year.

Model and data comparisons at Station 20, in the Elizabeth River, are presented in Figure 5-43. The model compares favorably to temperature. There are only wet-weather intensive salinity data to compare against the model during January, so it is not clear how well the model compares to salinity during the remainder of the year. The model appears to reproduce the magnitude and variation of the fecal coliform and enterococci concentrations during 2017.

Figure 5-44 presents the model versus data time-series comparison for Station 23 in the Arthur Kill. The model reproduces the temperature data very well. The salinity data are also reproduced well with the exception of the beginning of the year where the model under predicts the salinity. The model also reproduces the fecal coliform and enterococci data, as well as the ratio between them, very well.

The model versus data time-series comparison for Station 29 in Raritan Bay during 2017 is presented in Figure 5-45. The model reproduces the temperature data. The model also compares favorably to the salinity data. This differs from the comparison to 2016 data at this location where there is a question about the accuracy of the 2016 salinity data. With few exceptions, the model also reproduces the magnitude of the bacteria data as well as the ratio between the fecal coliform to enterococci concentrations.

The model versus data comparison for Station 26 in the Raritan River is presented in Figure 5-46. Again, this is a location upstream of any CSOs, but it is important that the model reproduce the data in waterbodies like this because they contribute to the bacteria concentrations in areas downstream that are impacted by CSO. The model compares well to the observed data in this location during 2017.

The last station to be presented is Station 33 in the Hudson River (Figure 5-47). The model is able to reproduce the temperature and the complex and extreme changes in salinity in the river. The model also reproduces the bacteria quite well.

Additional figures can be found in Appendix F.

What can be observed from a review of the time-series figures from both the calibration and validation periods is that the model can reproduce the measured temperature, salinity, and bacteria data temporally throughout the project area.

LOWER PASSAIC RIVER

Station: 18

SE3

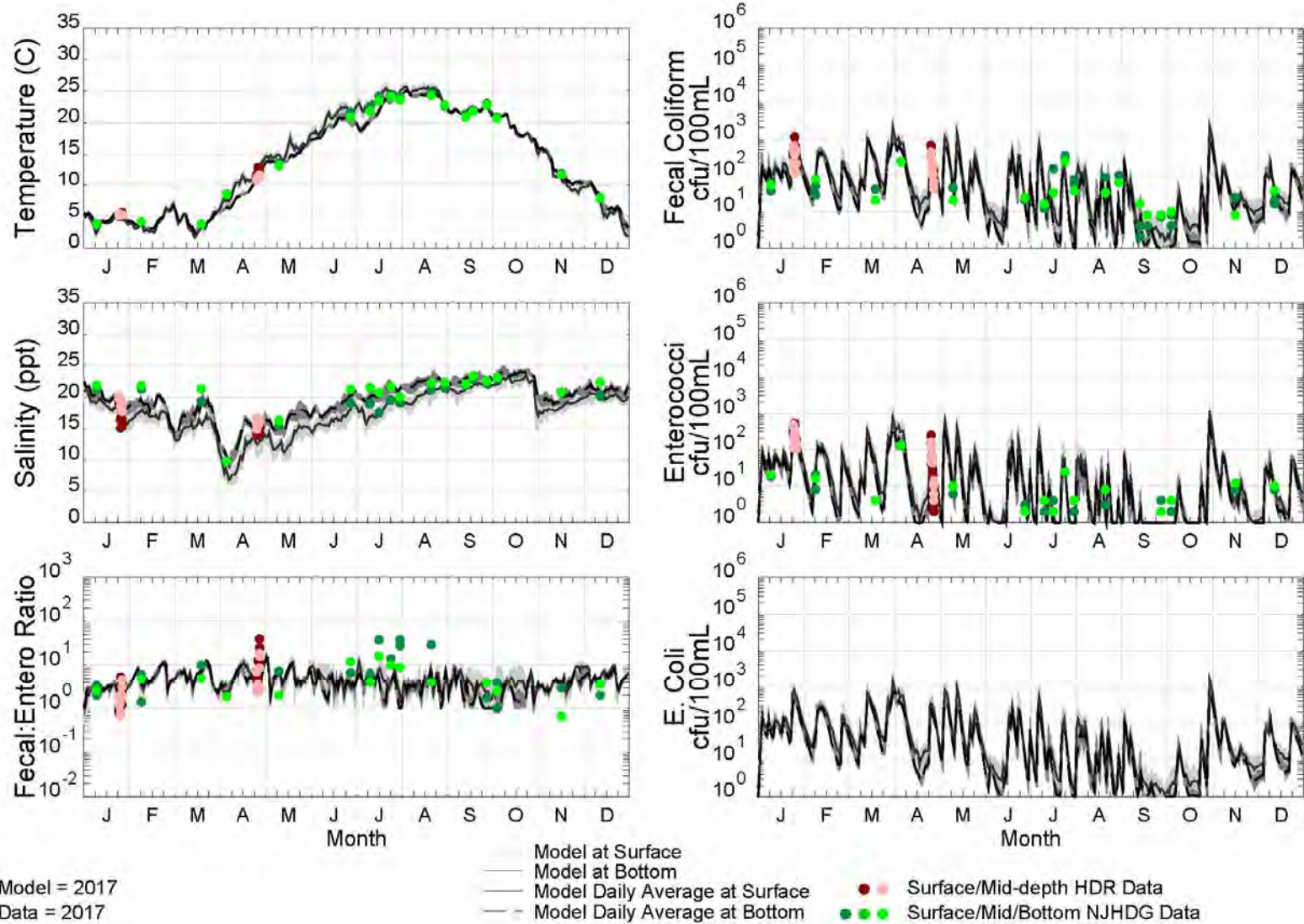


Figure 5-42. 2017 Annual Time-Series Model versus Data Comparison at Station 18, Kill van Kull

ELIZABETH RIVER

Station: 20

SE3

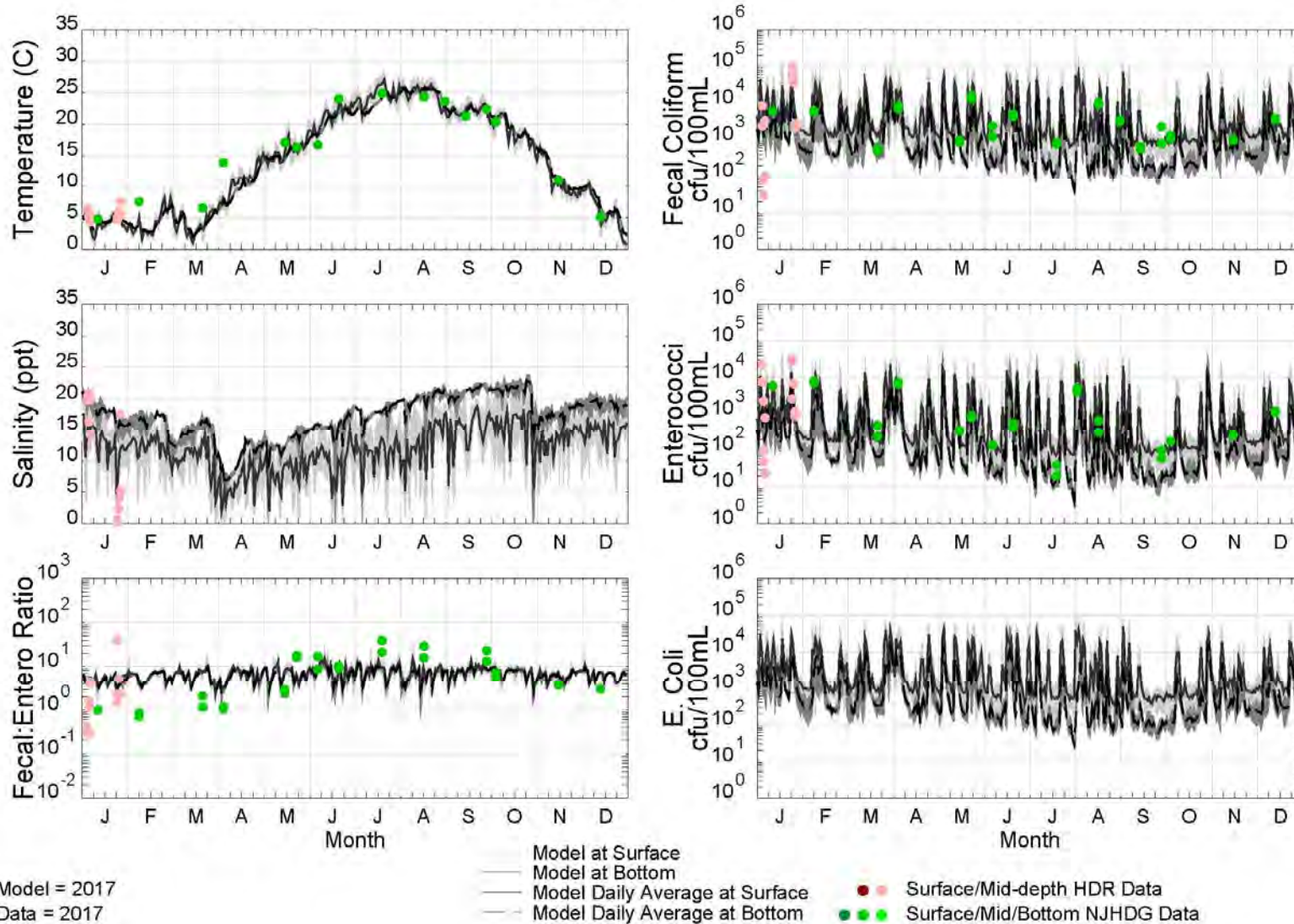


Figure 5-43. 2017 Annual Time-Series Model versus Data Comparison at Station 20, Elizabeth River

ARTHUR KILL

Station: 23

SE3

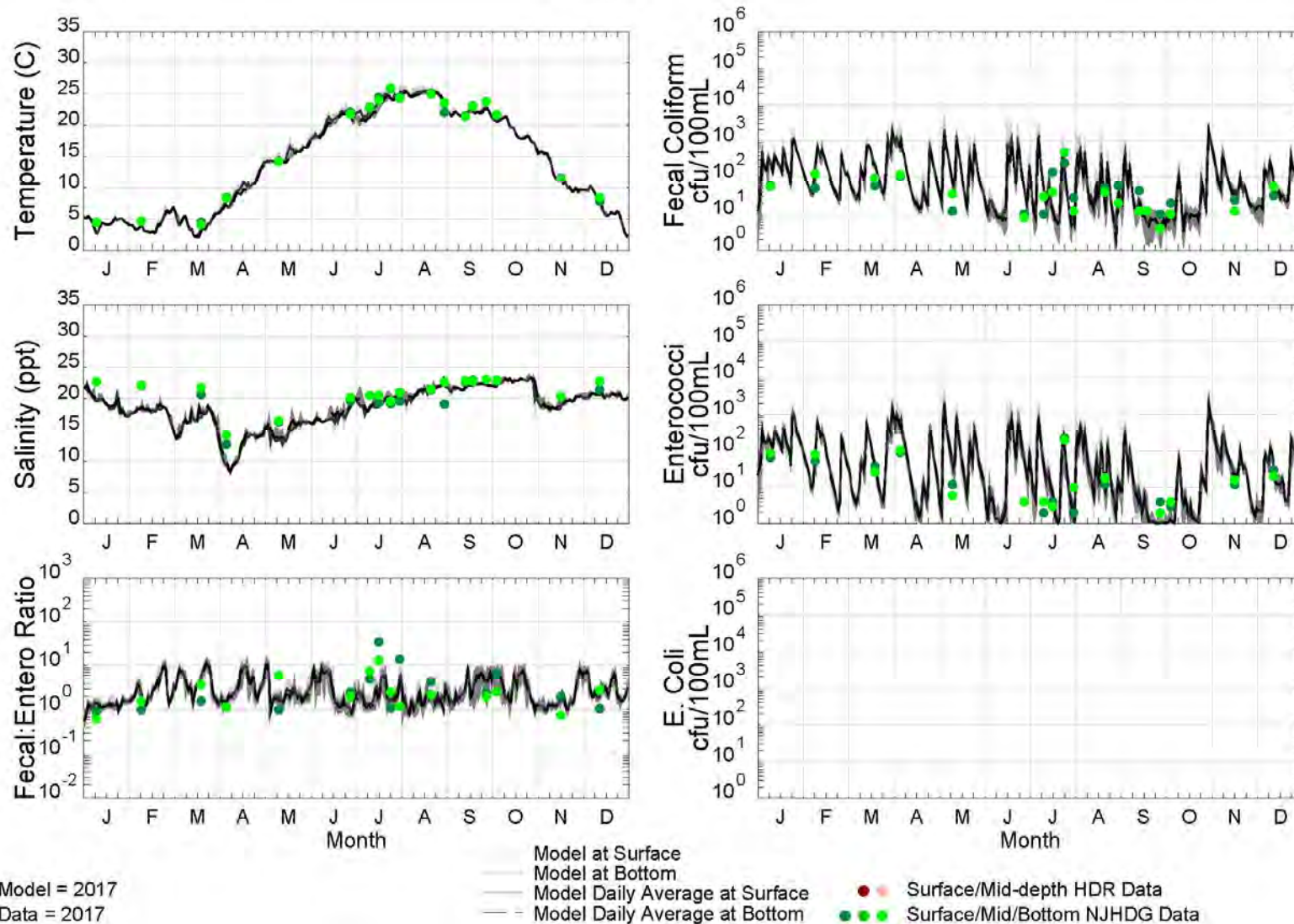


Figure 5-44. 2017 Annual Time-Series Model versus Data Comparison at Station 23, Arthur Kill

RARITAN BAY

Station: 29

SE1

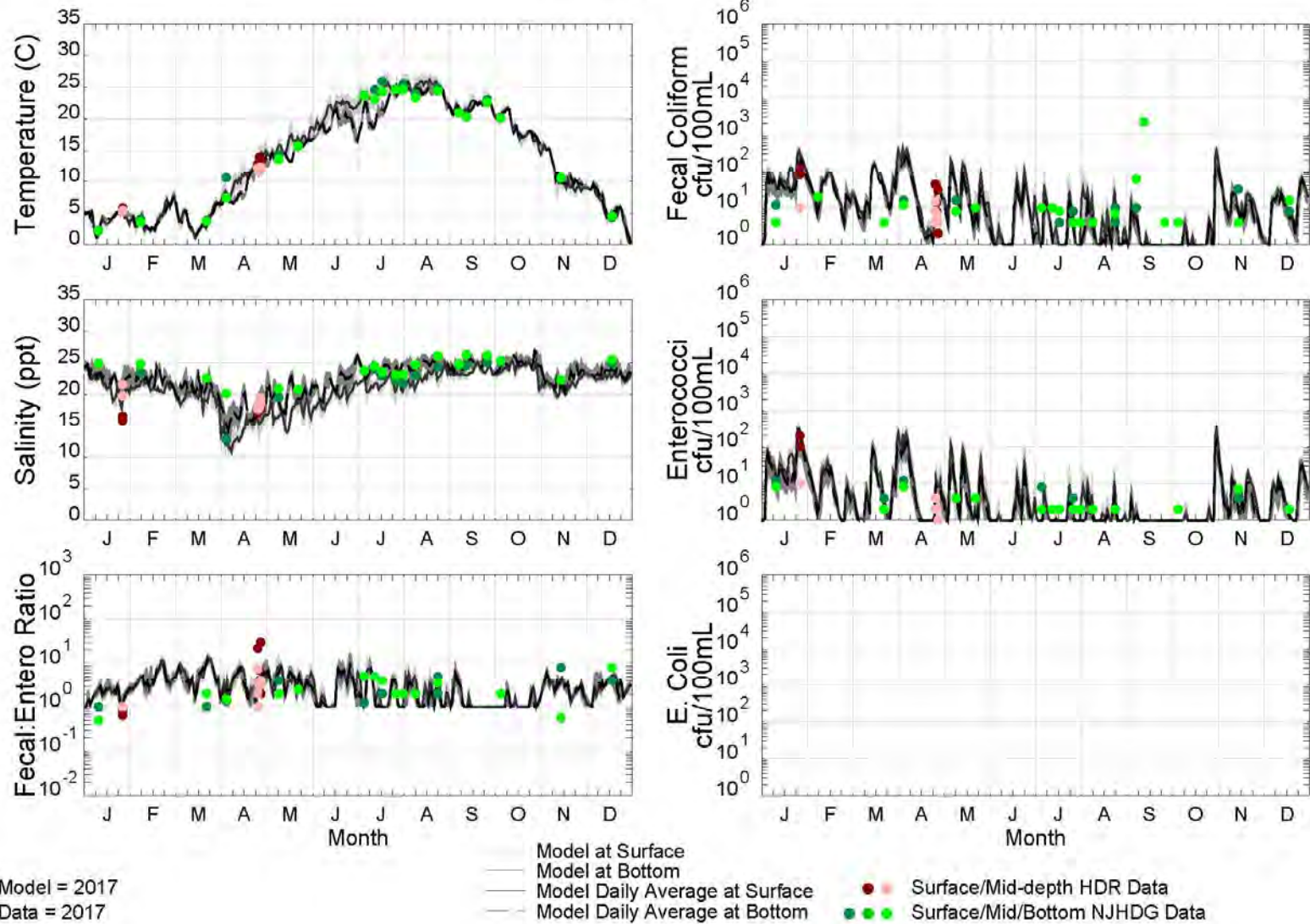


Figure 5-45. 2017 Annual Time-Series Model versus Data Comparison at Station 29, Raritan Bay

RARITAN RIVER

Station: 26

SE1

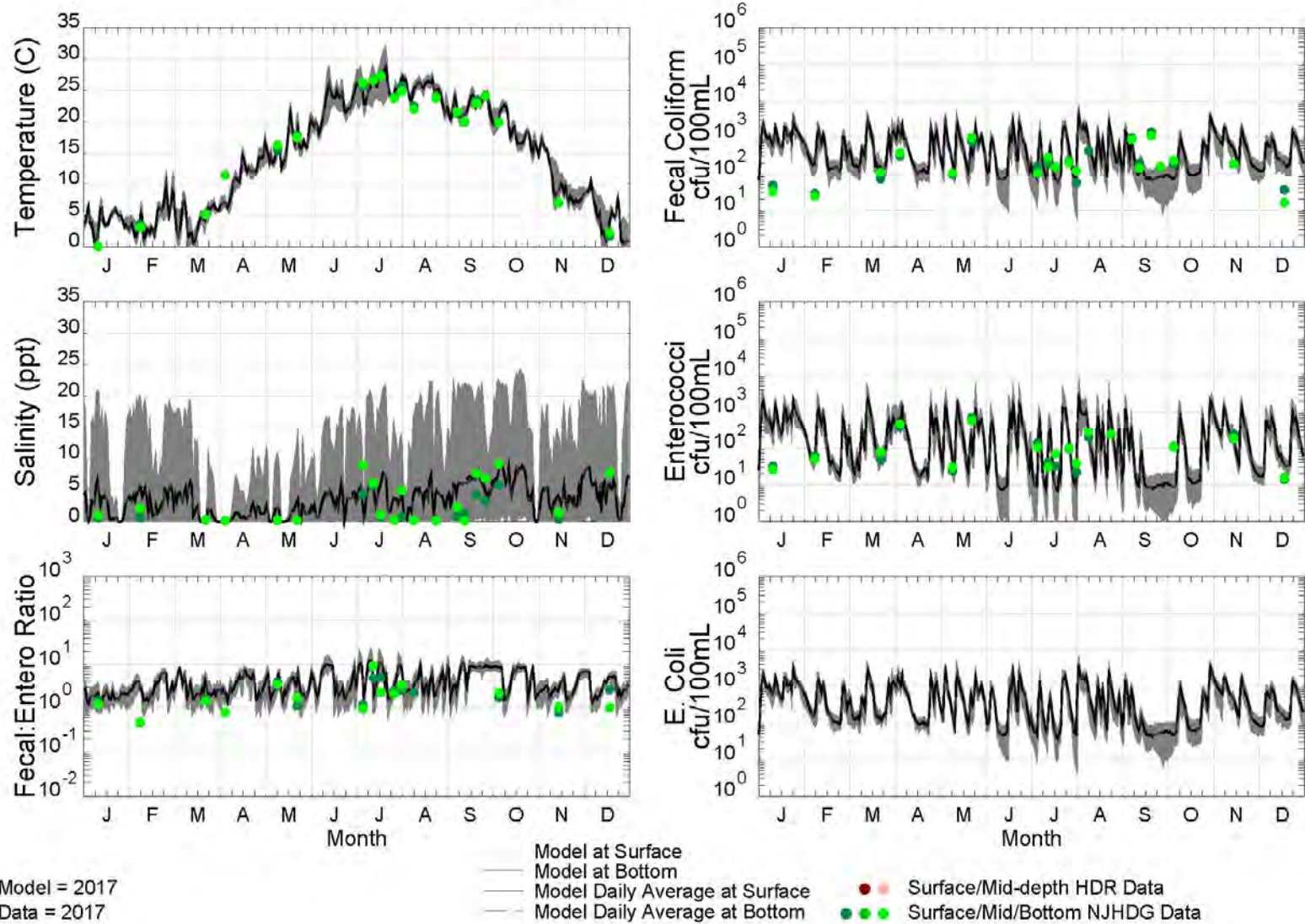


Figure 5-46. 2017 Annual Time-Series Model versus Data Comparison at Station 26, Raritan River

HUDSON RIVER

Station: 33

SE2

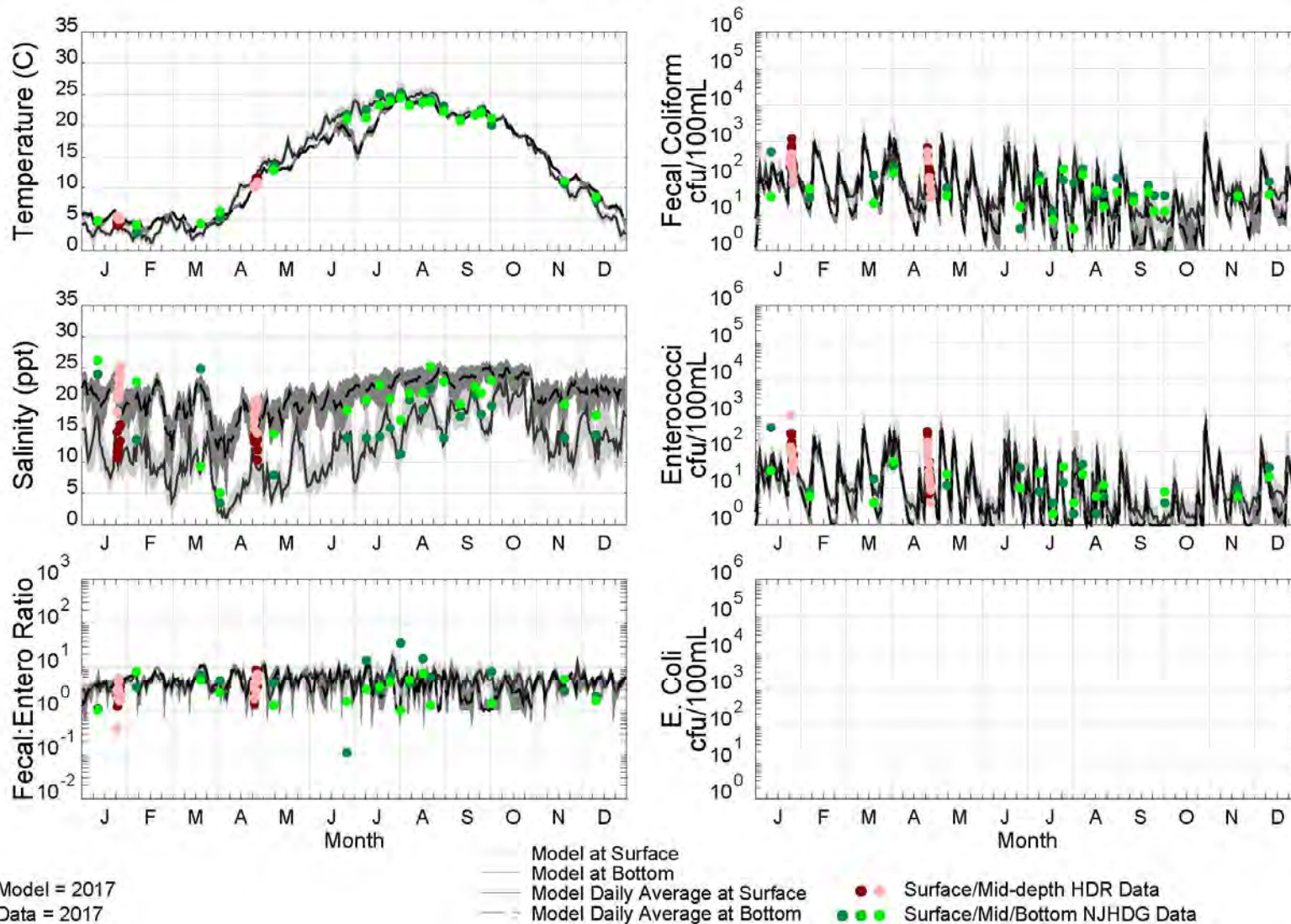


Figure 5-47. 2017 Annual Time-Series Model versus Data Comparison at Station 33, Hudson River

5.4.1.2 Wet-Weather Events

Three wet-weather events were sampled during the 2016-2017 Baseline Compliance Monitoring at each wet-weather intensive survey station. One event was sampled during the 2016 calibration period, and two events were sampled during 2017. (Note: the last sampling event was split into two precipitation events, one in January and one in April in order to cover all of the stations.) Results presented in this section will differ from the way they were presented in Section 5.3.1.2 to show a comparison of model versus data for the fecal bacteria indicators during all three wet-weather events for the same stations presented for the calibration. The additional stations will be presented in Appendix F. Since each wet-weather event is unique and in many cases each storm has independent impacts on water quality, each storm can be considered a validation of the model's ability to reproduce fecal indicator bacteria concentrations. Challenges to reproducing individual storms come from the landside model's ability to reproduce the flow from each event, and the assumption that MLE sanitary and stormwater concentrations can be used to assign loads when there is known variability in CSO and stormwater concentrations.

Figure 5-48 presents model versus data time-series comparisons for fecal coliform, *E. coli* and enterococcus at Station 7, in the Passaic River, for the three wet-weather event periods. The figure presents the three days of each event. At Station 7, the three dates were June 6-8, 2016; January 4-6, 2017; and January 24-26, 2017. Fecal coliform and *E. coli* are highlighted in this figure because these are the two fecal indicator bacteria used to assess attainment in this waterbody classified as FW2/SE2. As would be expected, the data, presented as circles, indicate higher bacteria concentrations immediately after the rainfall event, followed by a decrease in concentrations as a result of flushing and bacteria die-off. The model does not reproduce the peak concentrations during the first January event, but is able to generally reproduce the magnitude and timing of the change in concentrations during each of the three wet-weather events. The model constants, shown in Table 5-1, were the same for both the 2016 and 2017 model runs.

Results for Station 14, in the Hackensack River, are presented in Figure 5-49. Note that *E. coli* were not measured in any saline waters. At this location, the third wet-weather event was during April 26-28, 2017 rather than early-January. The data indicate a slow to no decrease in fecal coliform concentrations over the three-day sampling events. The model is consistent with the magnitude and trend of the data. The enterococci data show a more discernable decrease in concentrations, and the model reproduces this observation.

Figure 5-50 presents the event time-series comparison between model and data at Station 18 in Newark Bay, which is classified as SE3. The model reproduces the June fecal coliform rather well. For the other events, the beginning of the storm is well represented by the model, but the data indicates a faster decrease in concentrations than the model. This indicates the model may be conservative during storms in this location. The model reproduces the January event very well for enterococci, but overestimates concentrations during the other storms.

Passaic River & Tributaries
Passaic River

Station: 7

FW2/SE2

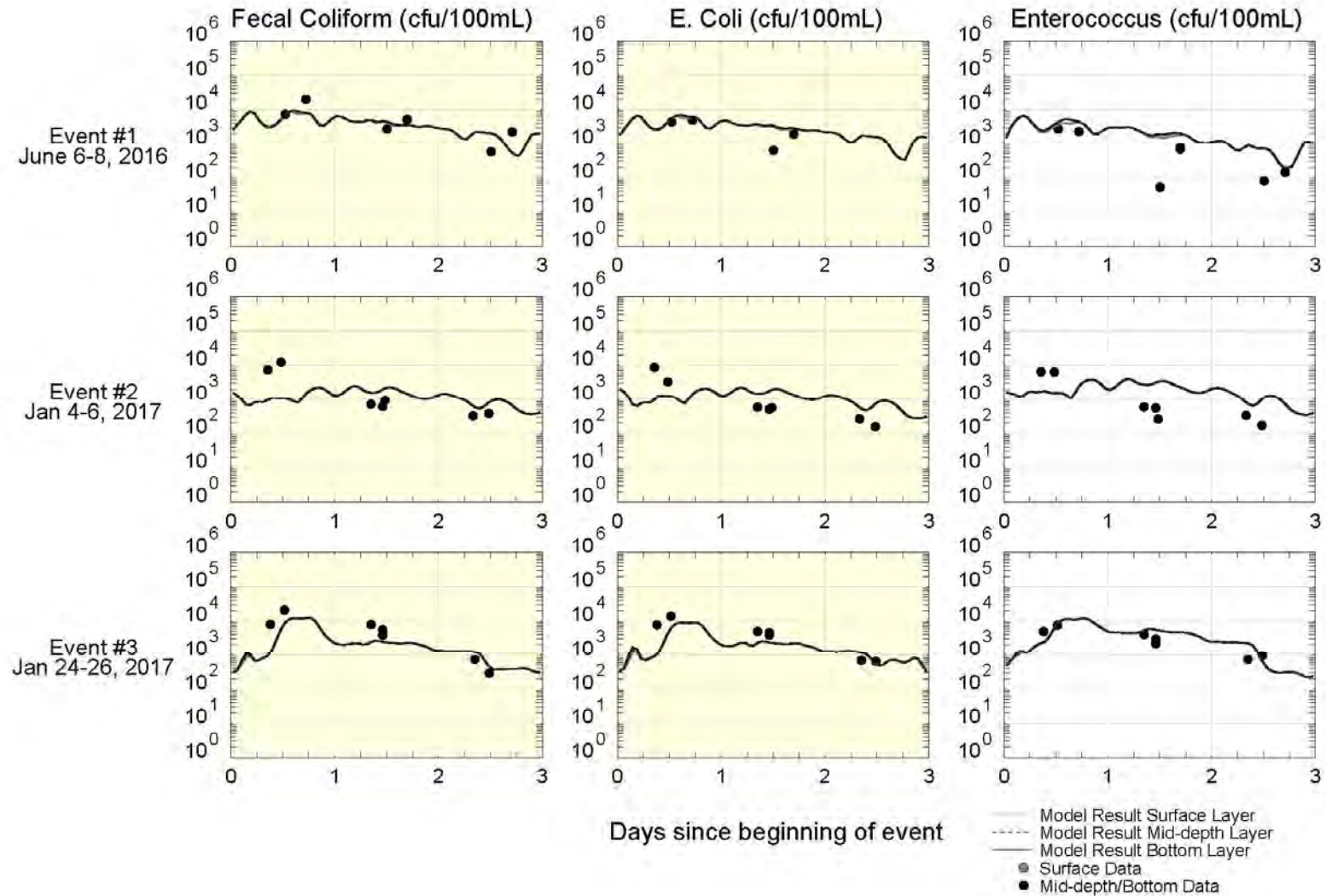


Figure 5-48. Wet-Weather Events Model versus Data Comparison at Station 7, Passaic River

Hackensack River & Tributaries
Hackensack River

Station: 14

SE2

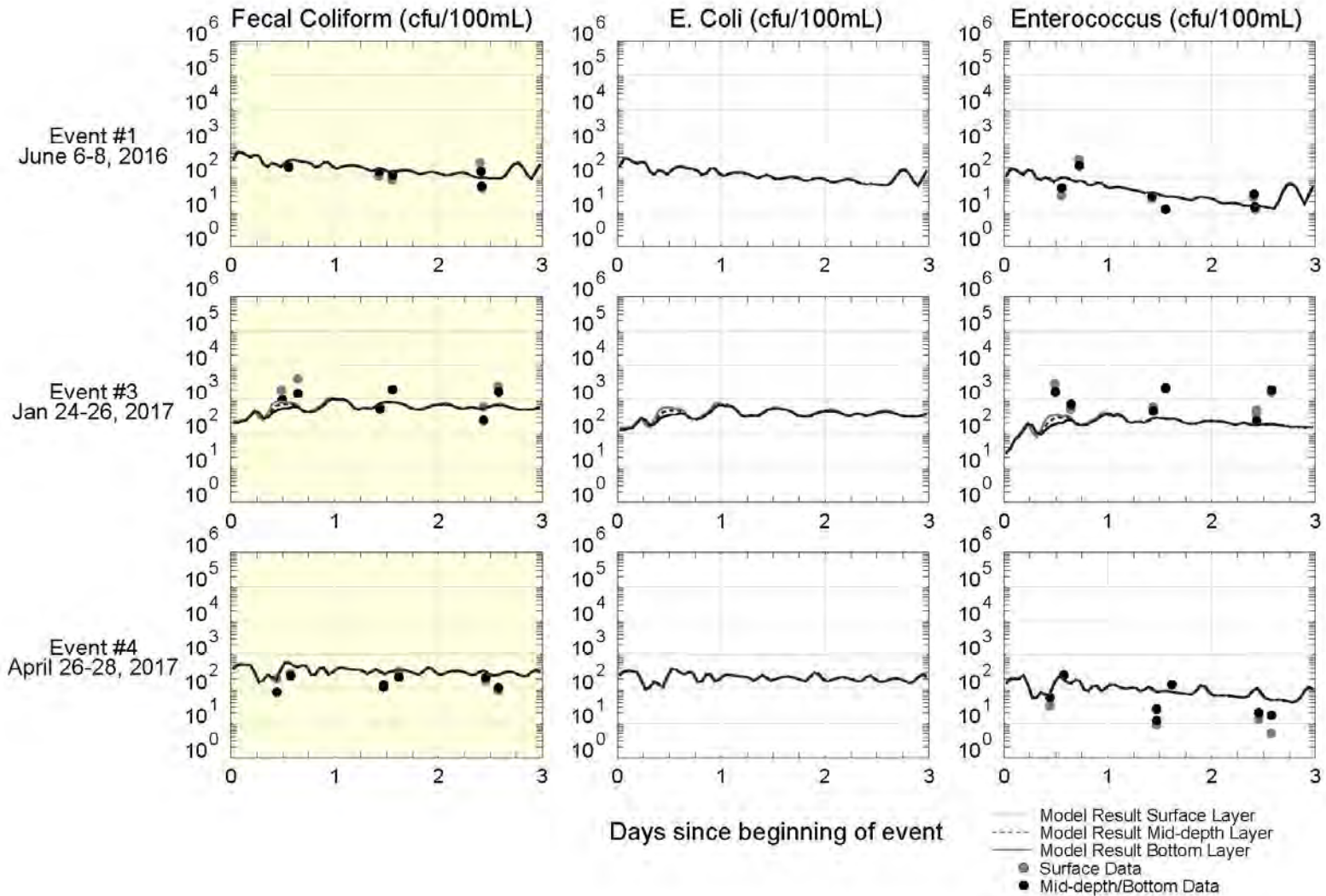


Figure 5-49. Wet-Weather Events Model versus Data Comparison at Station 14, Hackensack River

Newark Bay & Tributaries
Newark Bay

Station: 18

SE3

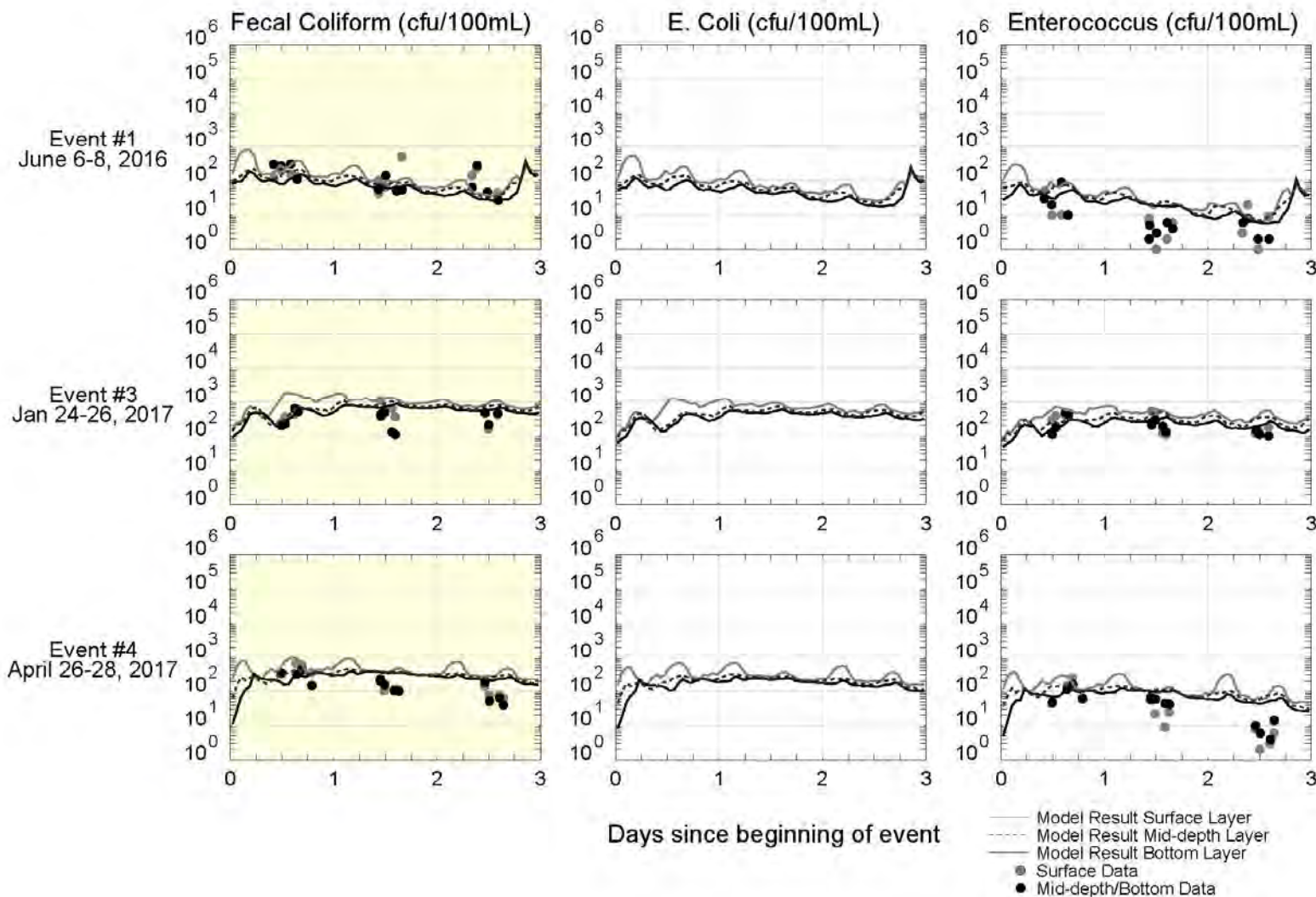


Figure 5-50. Wet-Weather Events Model versus Data Comparison at Station 18, Newark Bay

The model versus data comparison for the three wet-weather events at Station 20, in the Elizabeth River, is presented in Figure 5-51. As with the other locations, the model is generally able to reproduce the bacteria concentrations during the three wet-weather events. Not every sampled concentration is reproduced by the model, but the model is able to reproduce the magnitude and trends in the data. The bacteria concentrations in the Elizabeth River tend to be higher than many of the waterbodies in the project area, and the model reproduces this spatial variation.

Figure 5-52 shows the model versus data comparison for the three wet-weather events at Station 24 in the Arthur Kill. The model comparison here is similar to that observed in Newark Bay. The model reproduces the first day of the storm rather well, but by the third day of the storm, the model overestimates the fecal coliform and enterococci concentrations. This is an indication that the model results may be conservative in this area during wet-weather.

The three event time-series model versus data comparison for Station 29 in Raritan Bay is presented in Figure 5-53. The data indicate that bacteria concentrations at this location are fairly low, even during wet-weather, in this SE1 waterbody. The model reproduces the low fecal coliform and enterococci concentrations at this station for these surveys.

The last station to be discussed here is Station 33 in the Hudson River. The model versus data time-series for the three wet-weather events is shown in Figure 5-54. The model generally reproduces the fecal coliform and enterococci concentrations during the initial portion of the events. The model reproduces the July 2016 event as whole quite well. The model reproduces the January 2017 reasonably well, but generally the model bacteria concentrations decrease more slowly than the data concentrations. During April, the slower model decrease in bacteria concentrations is more evident. As with some of the other open water stations reviewed, the model tends to be more conservative, that is calculate higher concentrations, than the observed data. This has the potential for the model to under estimate attainment of the fecal indicator bacteria criteria in the open waters.

These figures and the figures included in Appendix F indicate that the model is able to reproduce the change in concentrations of bacteria during four different wet-weather events at stations that represent differing waterbodies within the project area. In general, when the model comparison to data is less favorable, the model calculated concentrations are higher than the data. This makes the model an accurate, but conservative tool to assess attainment with bacteria criteria in the project area.

Newark Bay & Tributaries
Elizabeth River

Station: 20

SE3

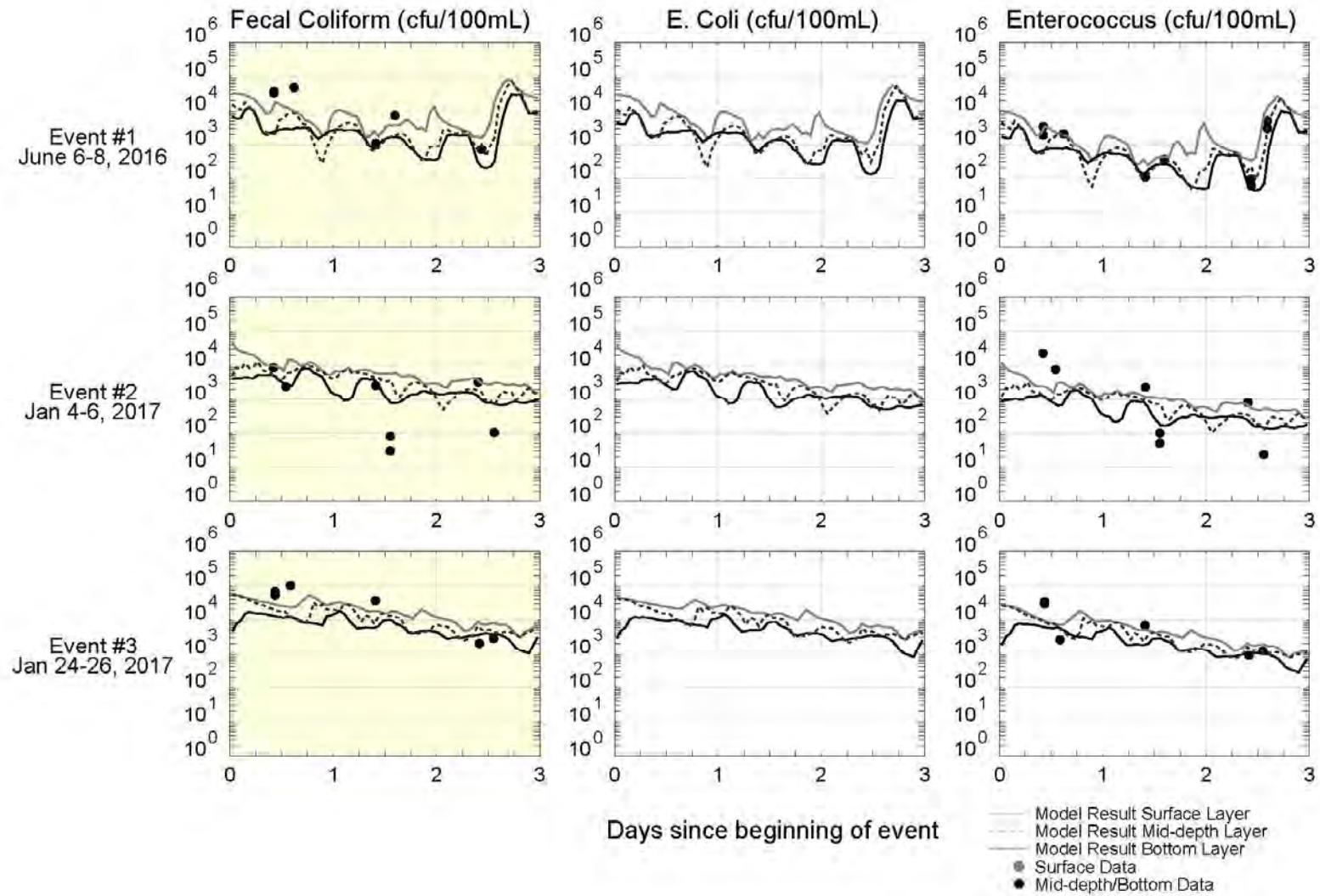


Figure 5-51. Wet-Weather Events Model versus Data Comparison at Station 20, Elizabeth River

Arthur Kill, Raritan River/Bay & Tributaries
Arthur Kill

Station: 24

SE3

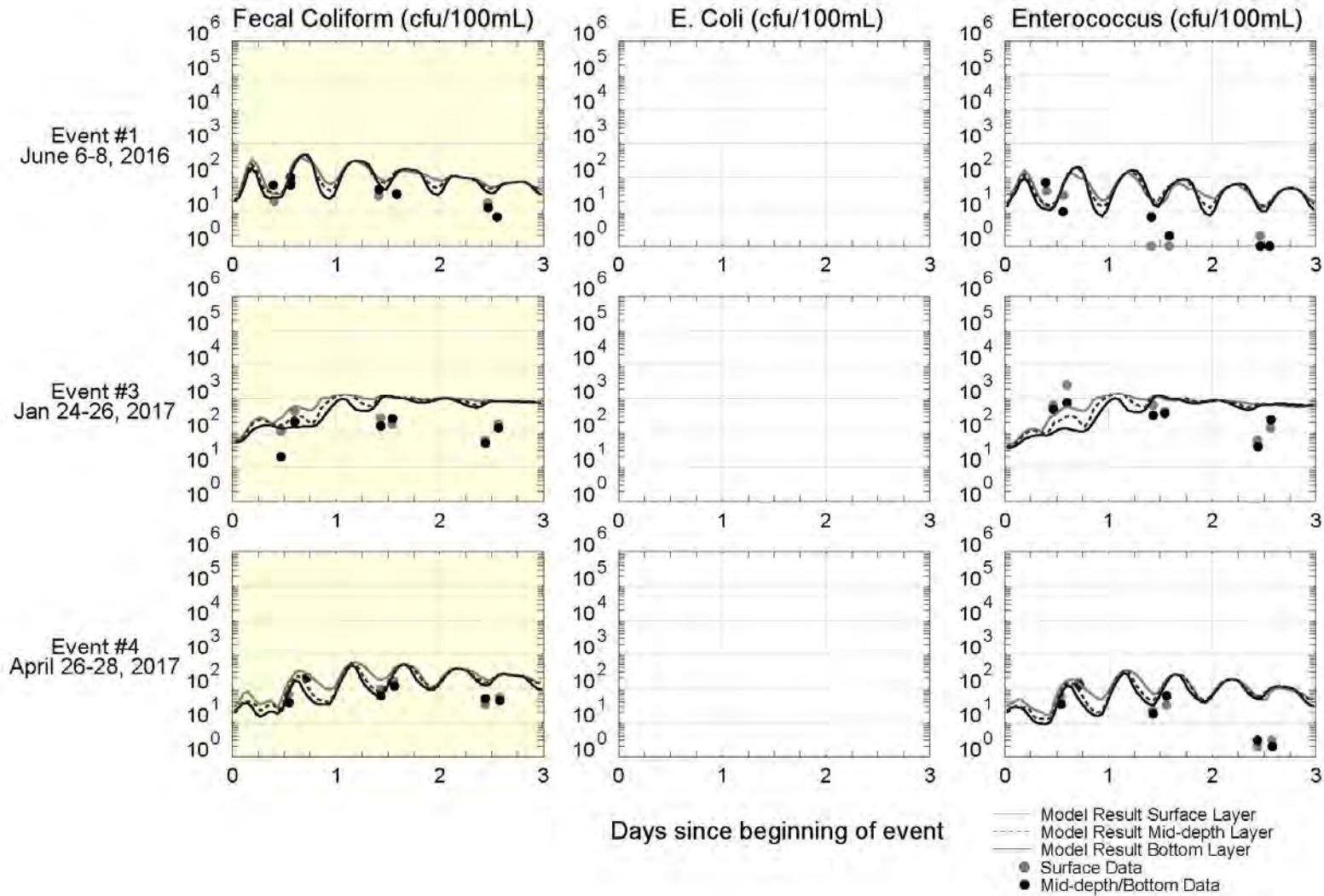


Figure 5-52. Wet-Weather Events Model versus Data Comparison at Station 24, Raritan River

Arthur Kill, Raritan River/Bay & Tributaries
Raritan Bay

Station: 29

SE1

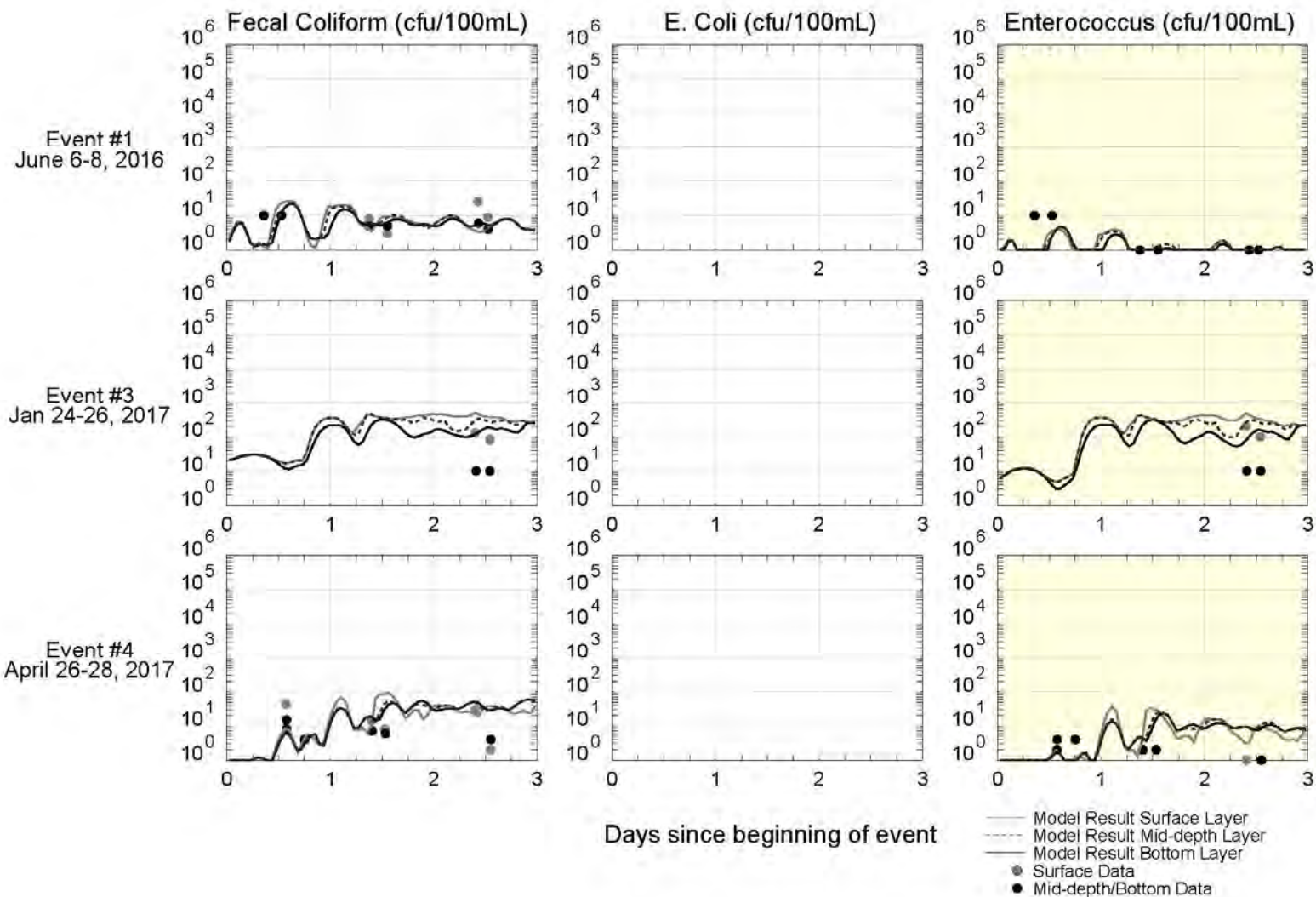


Figure 5-53. Wet-Weather Events Model versus Data Comparison at Station 29, Raritan Bay

Hudson River, Upper Bay
Hudson River

Station: 33

SE2

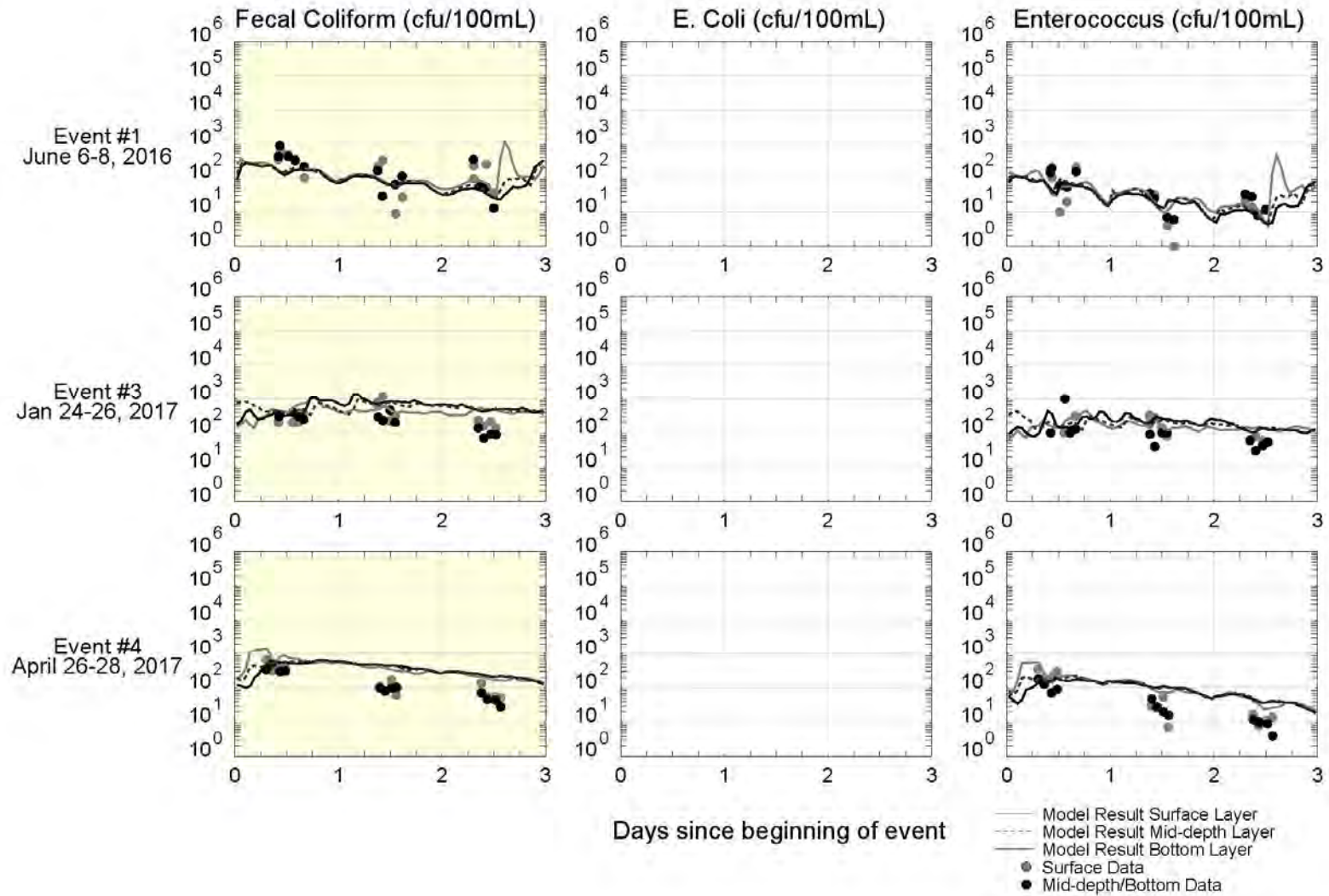


Figure 5-54. Wet-Weather Events Model versus Data Comparison at Station 33, Hudson River

5.4.2 Spatial Transects

Examples of model versus bacteria spatial transects along the rivers will be presented here in a similar way as presented in section 5.3.2. Since there were more wet-weather surveys during the validation period there are more transects to choose from. Additional examples are presented in Appendix F.

5.4.2.1 E. Coli

Figure 5-55 presents the spatial transect for E. coli in the Passaic River during the January 4-6, 2017 sampling event. The data during Day 1 show relatively high concentrations throughout the river with peak concentrations near Station 7. The majority of the measured E. coli concentrations fall within the modeled range. During Day 2 the data are lower in the upstream portion of the Passaic River being modeled, and the peak concentrations were measured at Station 8. The model is able to reproduce the spatial distribution of the E. coli concentrations. The model is able to reproduce the Day 3 E. coli data as well. Overall, the model is able to reproduce the spatial distribution of the E. coli data in the Passaic River during both the calibration and validation periods.

5.4.2.2 Fecal Coliform

Fecal coliform is the basis for the bacteria criterion in more rivers in the project area than the other fecal indicator bacteria, so there more relevant transects to review. Figure 5-56 presents the spatial transect comparison between model and data for fecal coliform during the January 24-26, 2017 sampling in the Passaic River. The model matches the data very well. During all three days that were sampled, the vast majority of the data falls within the range calculated by the model.

Figure 5-57 shows the model data comparison for the January 24-26, 2017 sampling event in the Hackensack River. The data indicate that fecal coliform concentrations were generally above 1,000 cfu/100mL across the length of the river for the first two days of sampling, with slightly lower concentrations toward the mouth on the third day. The model suggests there was more of a spatial pattern in concentrations with variations along the length of the river, but when the model line reaches a data point it generally matches the data.

The model versus data comparison for the Hudson River for the January 24-26, 2017 sampling period is presented in Figure 5-58. Both the model and data show relatively similar fecal coliform concentrations along the length of the river presented with most data between 100 and 1,000 cfu/100mL. The data have a faster decrease in concentration over time than the model output. The range in concentrations calculated by the model decreases during the three-day sampling event.

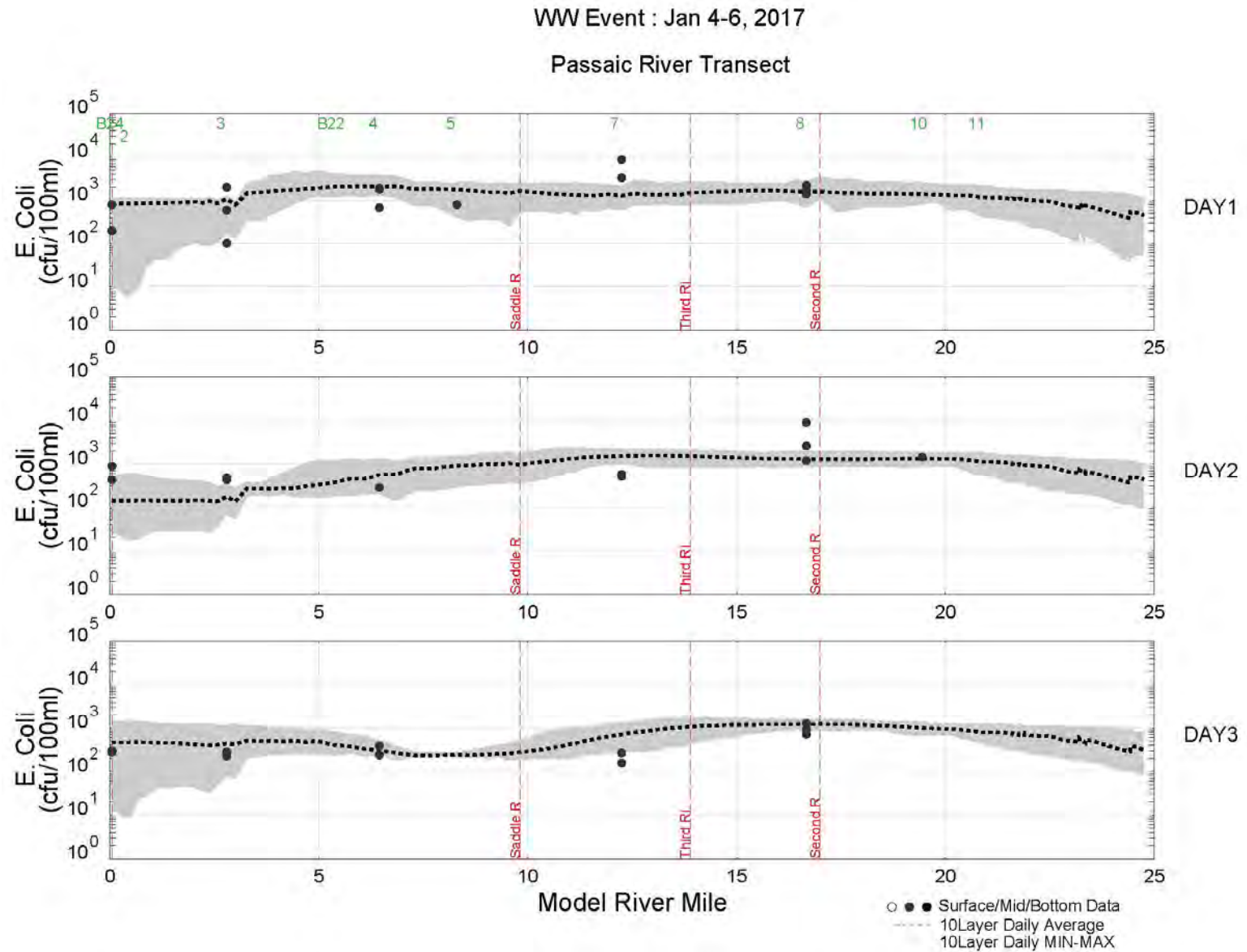


Figure 5-55. January 4-6, 2017 Passaic River Model versus Data Transect Comparison for E. Coli

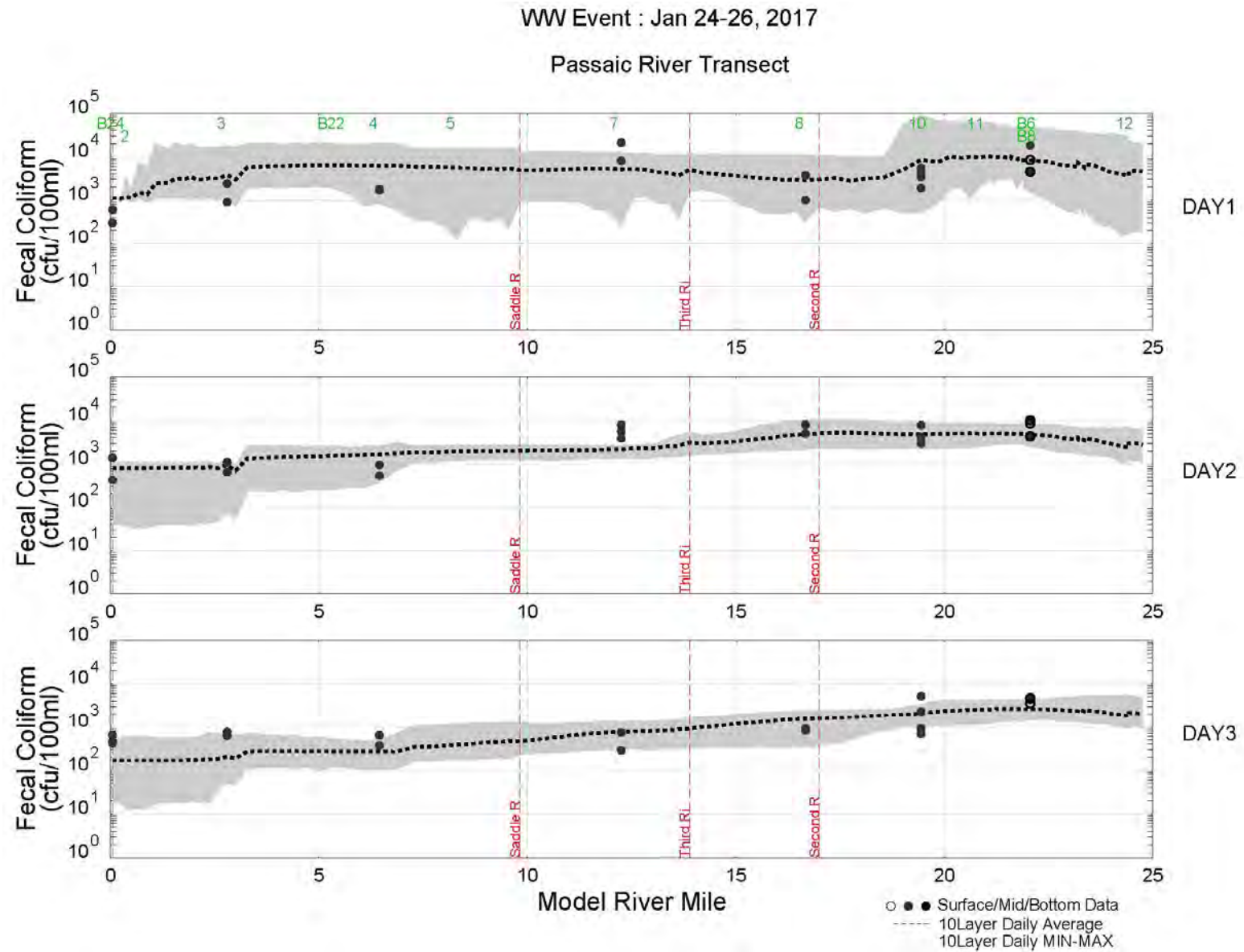


Figure 5-56. January 24-26, 2017 Passaic River Model versus Data Transect Comparison for Fecal Coliform

WW Event : Jan 24-26, 2017

Hackensack River Transect

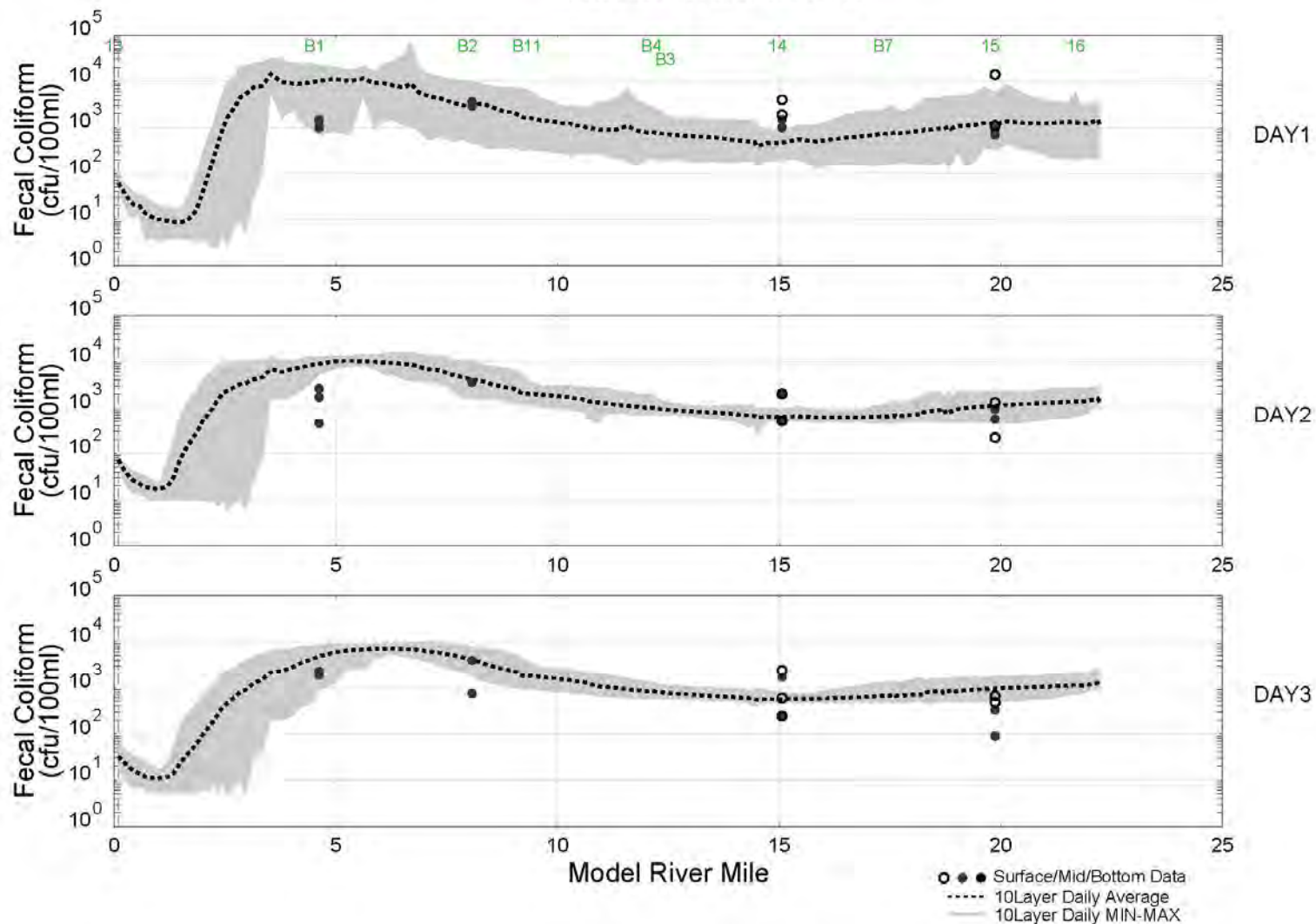


Figure 5-57. January 24-26, 2017 Hackensack River Model versus Data Transect Comparison for Fecal Coliform

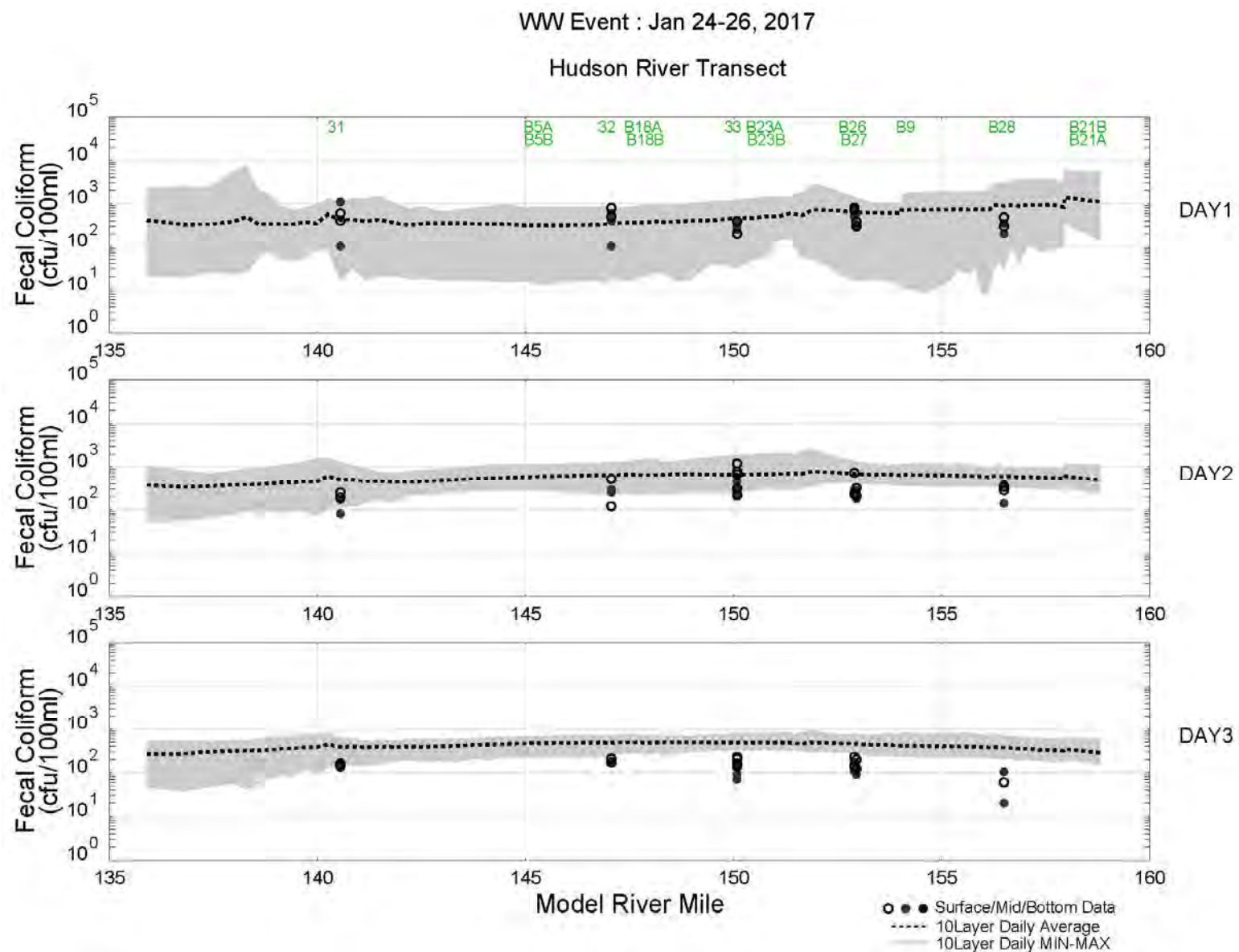


Figure 5-58. January 24-26, Hudson River Model versus Data Transect Comparison for Fecal Coliform

5.4.2.3 Enterococcus

Figure 5-59 present the model versus data transect comparison for enterococcus in the Hackensack River for the January 24-26, 2017. The Hackensack River was chosen because it is one of the few rivers where the enterococcus criteria applies in the project area that also has CSOs. As observed with the other fecal indicator bacteria, the model generally matches the data during all three days of the sampling event. The model does underestimate the concentrations at Station 14, but the remaining locations show a good match between the model and data.

Overall, the spatial transect comparisons between the model and data for all three fecal indicator bacteria are good in both the calibration and validation periods. This is an indicator that the model is well calibrated.

5.4.3 Probability Distributions and Water Quality Attainment

Probability distributions comparing the model output to the bacteria data will be presented here as it was in Section 5.3.3 for the calibration period. In a few cases the stations presented will differ from the calibration period because the majority of the Baseline Compliance Monitoring samples were collected during the 2016 calibration period. Choosing a NJHDG station in 2017 allows for a better model versus data comparison.

Figure 5-60 presents a model versus data comparison for the fecal indicator bacteria probability distributions at Station 8 in the Passaic River. The model reproduces the upper half of the fecal coliform and *E. coli* data distributions quite well. Using the concept that the annual data could represent a 30-day period, the model and data both indicate that there would be an exceedance of the fecal coliform and *E. coli* geometric mean criteria. Generally, higher bacteria concentrations are measured during wet-weather, which indicates the model is reproducing concentrations during wet periods. The model tends to under estimate the lower half of the fecal coliform and *E. coli* distributions. As part of the model validation process, the dry-weather concentrations at the boundary of the Passaic River and dry-weather loads to the Passaic River were unchanged from the calibration period. It is possible that dry-weather loads differed between 2016 and 2017.

The model versus data probability distribution comparison as Station B2 is shown in Figure 5-61. The majority of the data points on this figure are from the two wet-weather sampling events during 2017. The model results match the enterococci data well indicating the model can reproduce wet-weather concentrations in this portion of the Hackensack River.

Figure 5-62 presents the model versus data probability distribution comparison for Station 19 at the western end of the Kill van Kull. Here the model compares favorably to the fecal coliform data. Both the model and data indicate that the fecal coliform concentrations and associated geometric mean concentrations are well below the water quality criteria at this location.

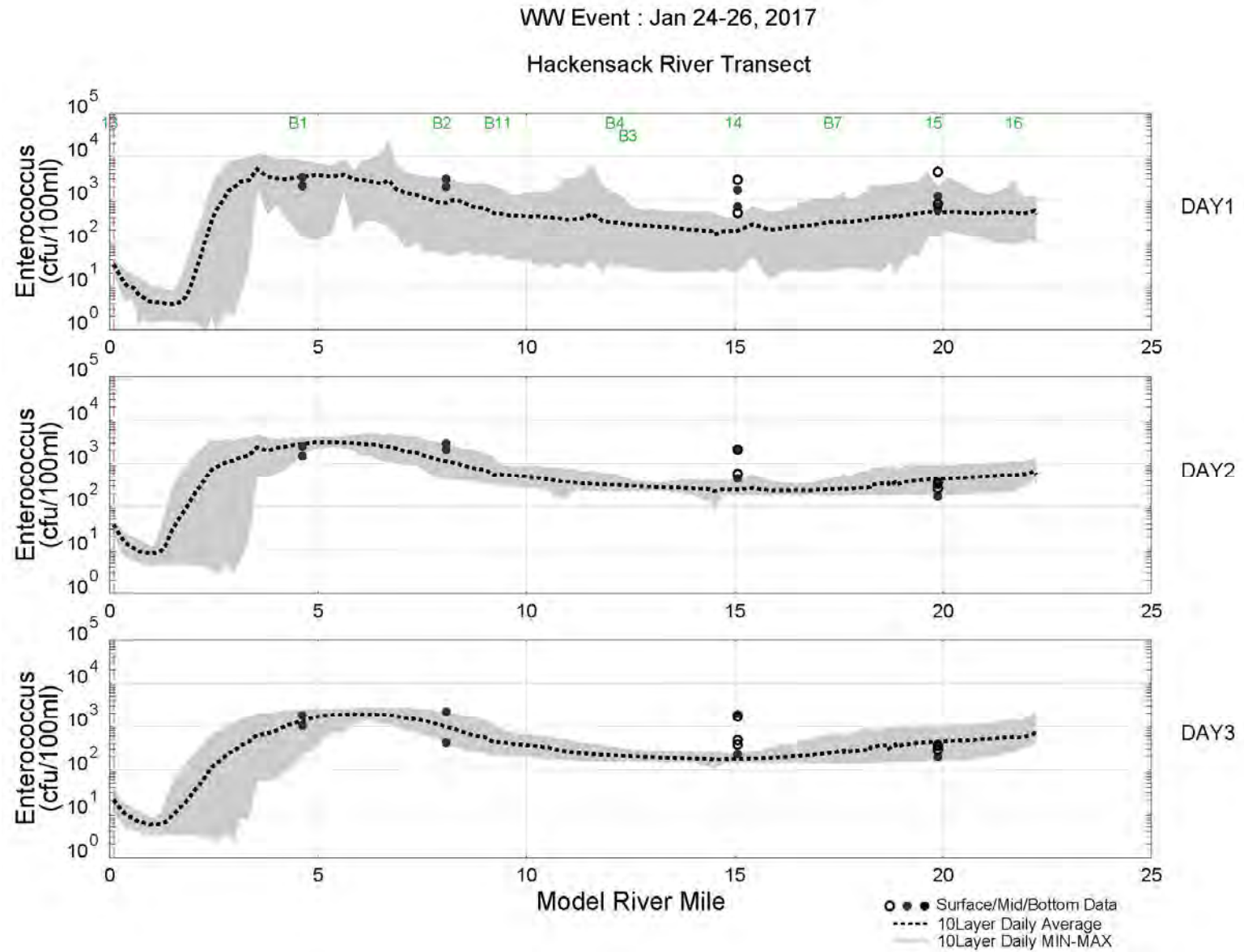


Figure 5-59. January 24-26, Hackensack River Model versus Data Transect Comparison for Enterococci

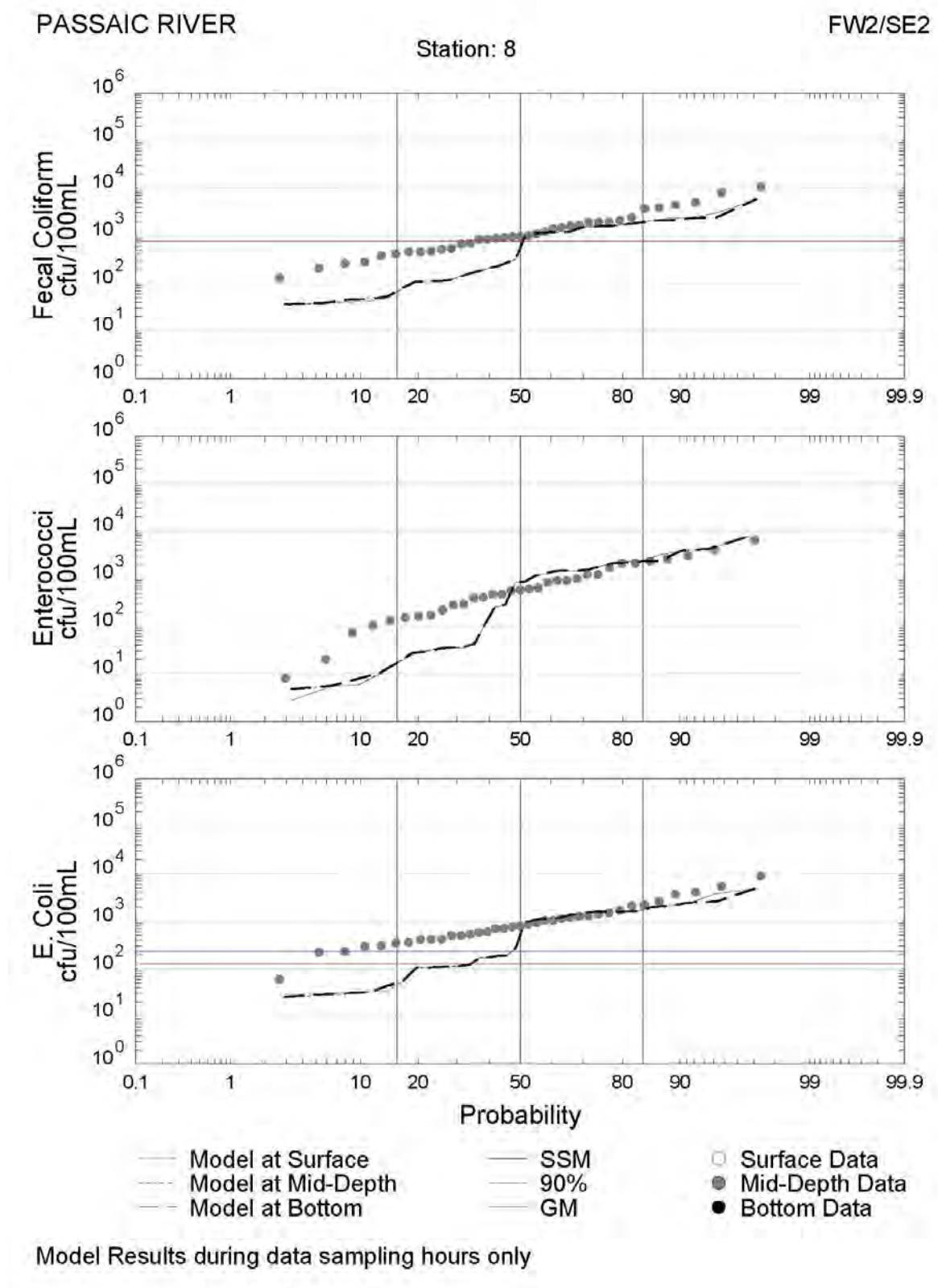
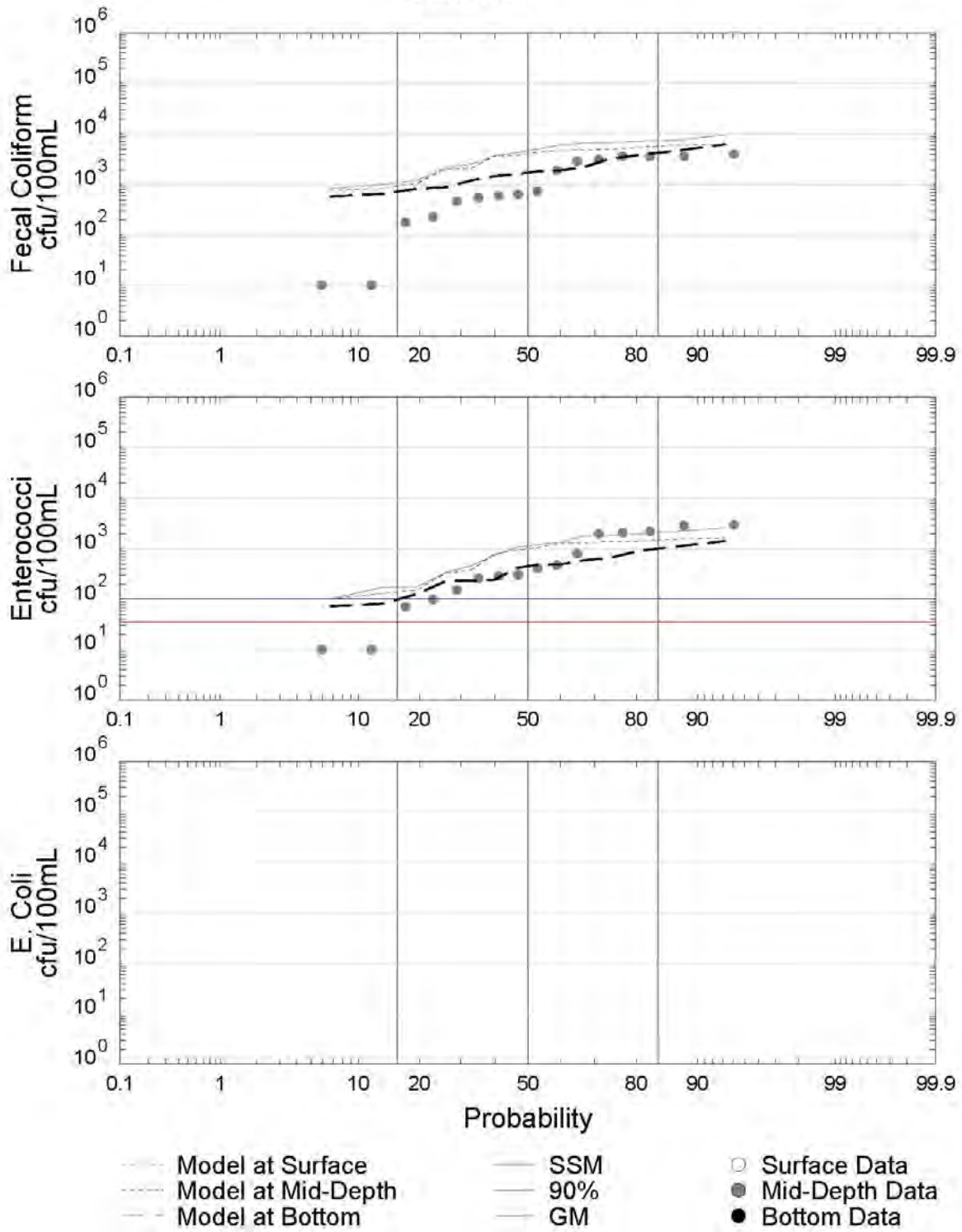


Figure 5-60. 2017 Annual Model versus Data Probability Distribution Comparison at Station 8, Passaic River

HACKENSACK RIVER

Station: B2

SE1



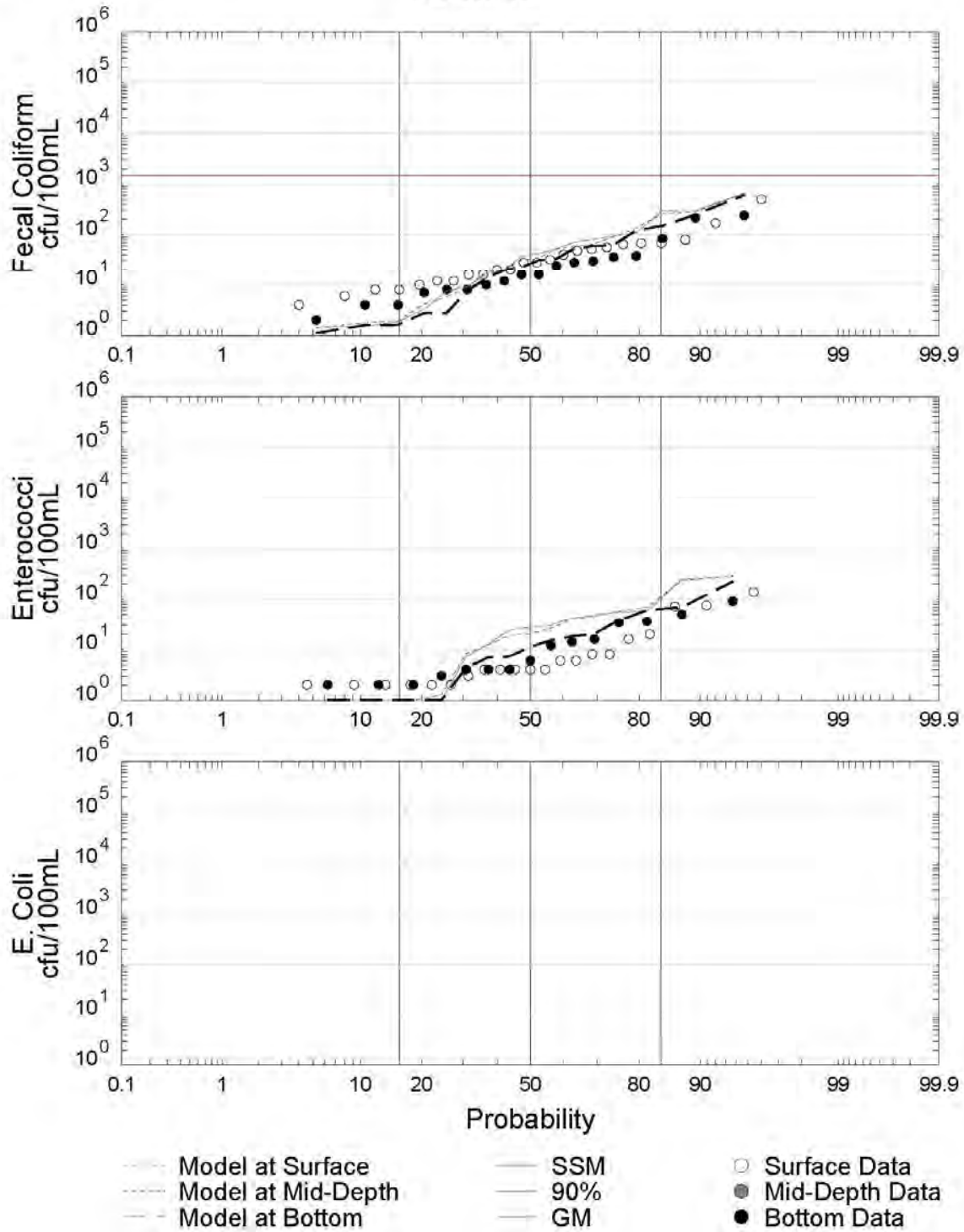
Model Results during data sampling hours only

Figure 5-61. 2017 Annual Model versus Data Probability Distribution Comparison at Station B2, Hackensack River

KILL VAN KULL

SE3

Station: 19



Model Results during data sampling hours only

Figure 5-62. 2017 Annual Model versus Data Probability Distribution Comparison at Station 19, Newark Bay

Station 20 comparisons are presented in Figure 5-63. The Elizabeth River has consistently high bacteria concentrations. The model matches the fecal coliform and enterococci concentrations very well. Both the model and data indicate that the Elizabeth River would have exceedances of the fecal coliform geometric mean criteria in this SE3 waterbody during 2017 if these data represented a 30-day period.

Figure 5-64 presents the model versus data probability distribution comparison at Station 21 in the Arthur Kill. Similar to Station 19, the model is able to reproduce the fecal coliform and enterococci concentrations quite well. Both the model and data indicate the bacteria concentrations are well below the level that would result in exceedances of the fecal coliform criteria.

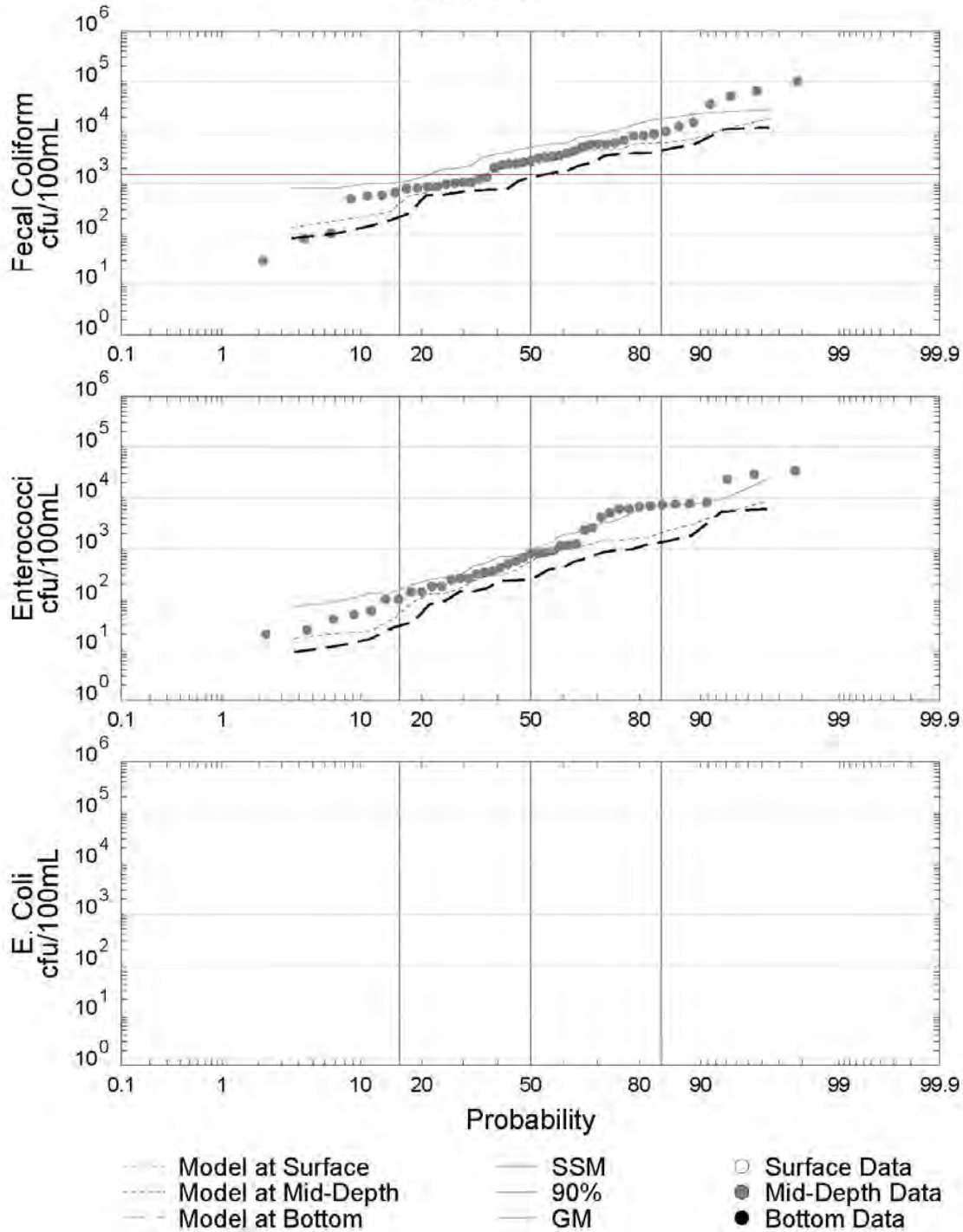
Figure 5-65 shows the model versus data probability distribution comparison at Station 28 in Raritan Bay at the mouth of the Raritan River. The model reproduces the measured fecal coliform and enterococci concentrations at the upper end of the probability distribution and also generally matches where the data crosses the criteria lines. The model underestimates the lower end of the distribution.

The model versus data comparison of probability distributions in the Hudson River is presented in Figure 5-66 for Station 33. The model generally matches the surface data fairly well, but overestimates the bottom bacteria concentrations. It has been established earlier that the model tends to be conservative in the open waters during wet-weather, and this figure shows the model can be conservative at other times as well. Both model and data show that Hudson River bacteria concentrations are below the level that would result in exceedances of the fecal coliform criteria.

ELIZABETH RIVER

Station: 20

SE3



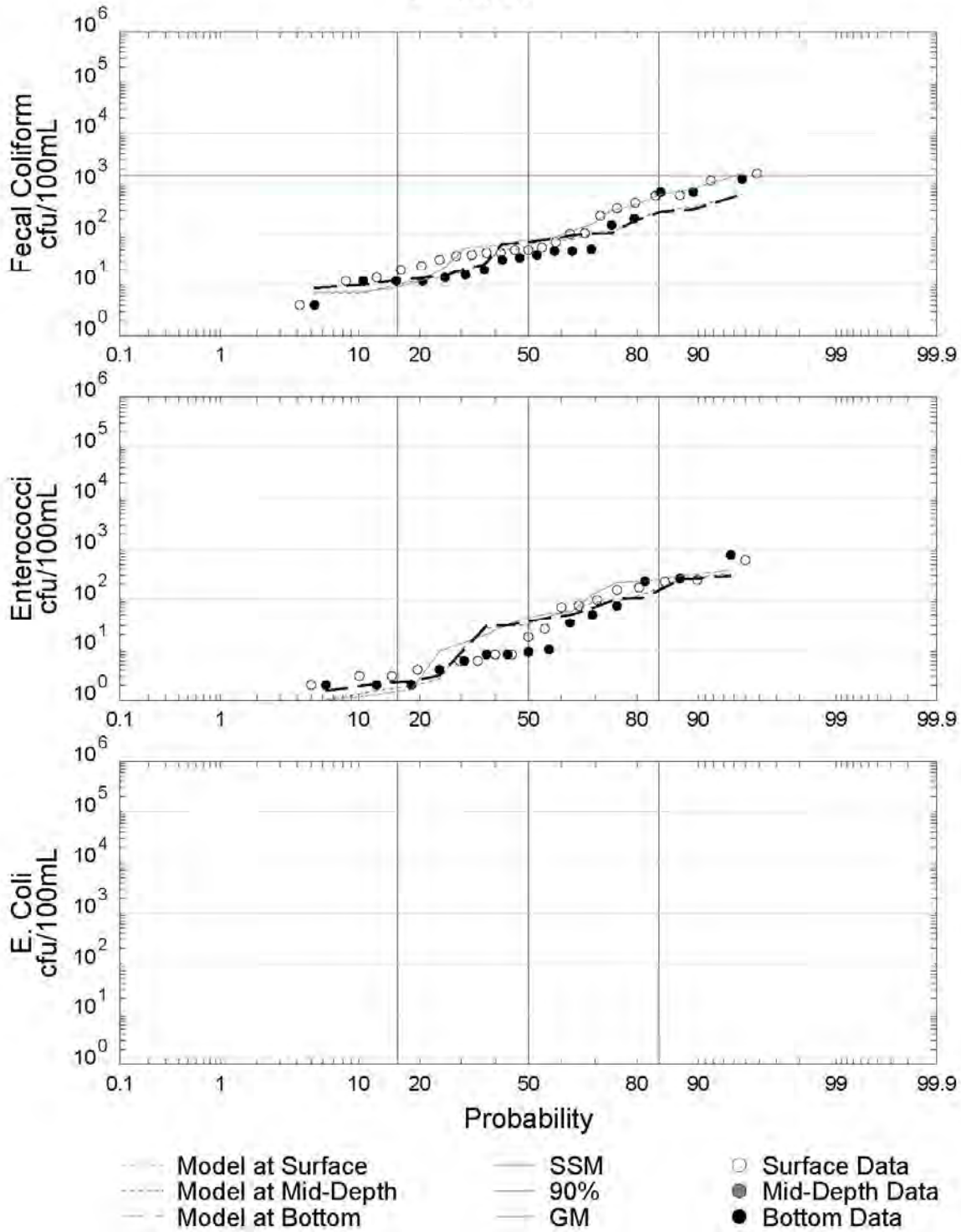
Model Results during data sampling hours only

Figure 5-63. 2017 Annual Model versus Data Probability Distribution Comparison at Station 20, Elizabeth River

ARTHUR KILL

SE3

Station: 21



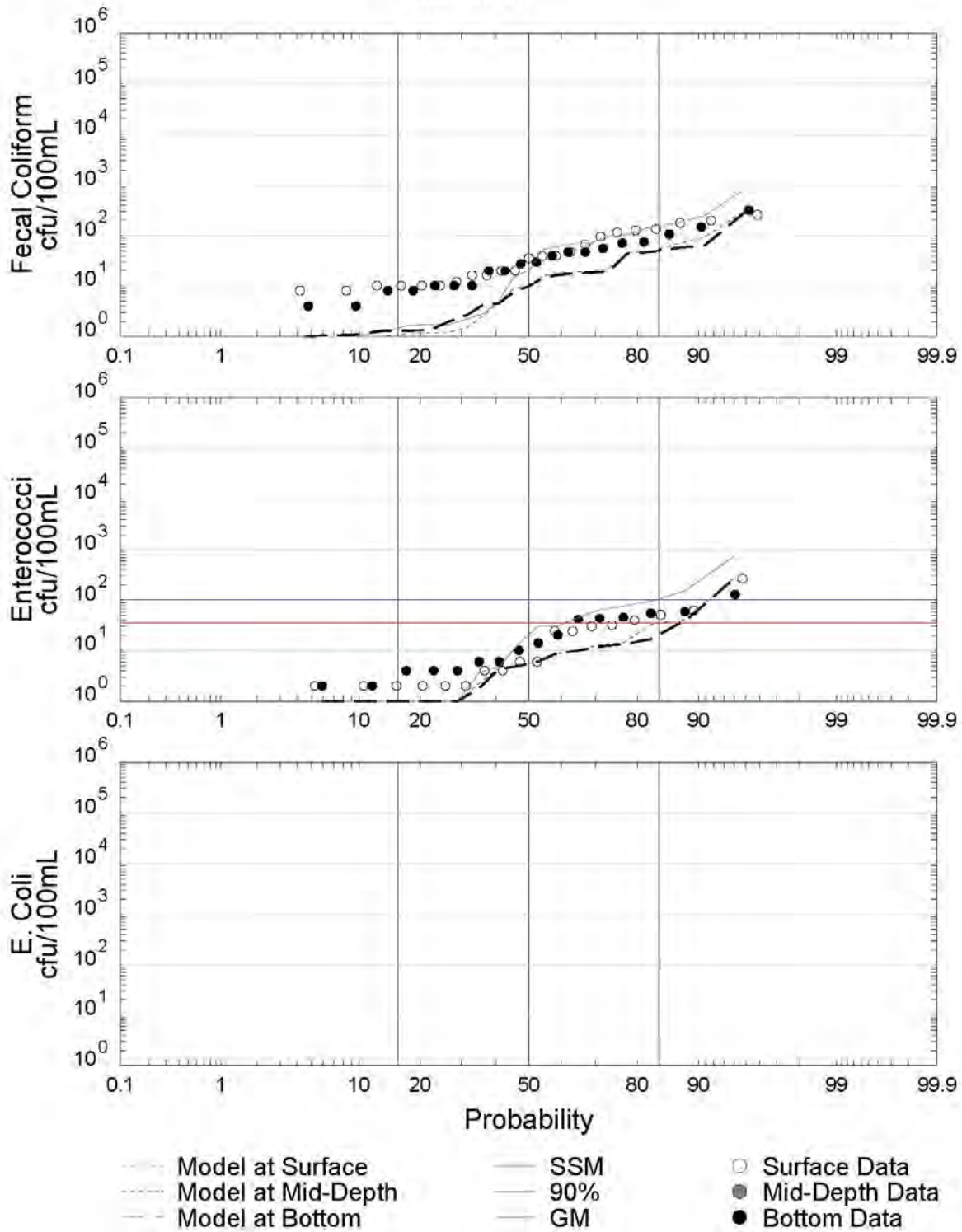
Model Results during data sampling hours only

Figure 5-64. 2017 Annual Model versus Data Probability Distribution Comparison at Station 21, Arthur Kill

RARITAN BAY

Station: 28

SE1



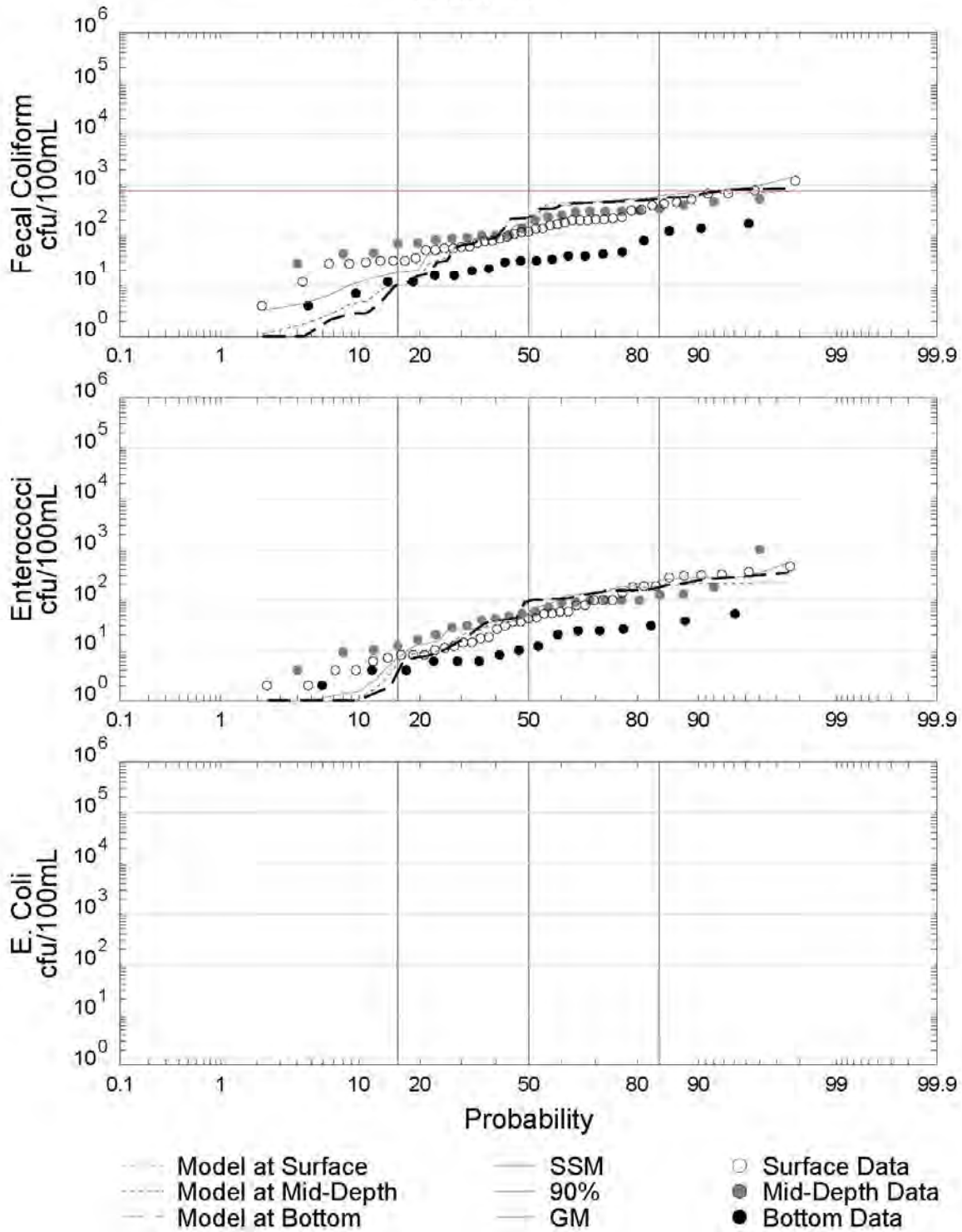
Model Results during data sampling hours only

Figure 5-65. 2017 Annual Model versus Data Probability Distribution Comparison at Station 28, Raritan Bay

HUDSON RIVER

Station: 33

SE2



Model Results during data sampling hours only

Figure 5-66. 2017 Annual Model versus Data Probability Distribution Comparison at Station 33, Hudson River

5.5 Error Analysis

In the last review of the modeling analysis, the Model Evaluation Group (MEG) (see Section 5.6) requested a statistical analysis of the model results. In order to satisfy this request, a percent difference was calculated between the geometric means of data and paired model results at each station and sampling depth. Since the model is being used to assess attainment of the water quality criteria, and the criteria used for assessment of compliance is based on 30-day geometric means, this model versus data comparison seemed most appropriate.

The data and paired model results are the same as those plotted in the probability distribution figures. Any stations with fewer than five measurements during a particular year and depth were omitted from the analysis. In some cases, especially at the baseline compliance monitoring stations (“B” stations) during 2017, the measurements are biased towards the wet-weather intensive sampling, so it would be expected that the model would have more difficulty reproducing geometric means based on short-term events with very high concentrations. The model is using constant concentrations for many of its bacteria loading sources, so it is challenging to reproduce the concentrations of an individual storm.

An additional item to note is that there is uncertainty in the measured fecal indicator bacteria concentrations. While the Baseline Monitoring Program did meet its quality goal with respect to precision (Target: Relative Percent Difference < 30% on a log basis), there is still uncertainty in the bacteria measurements. Within the duplicate data collected as part of the baseline compliance monitoring, the average difference between the duplicates was 40% for fecal coliform, 41% for enterococci, and 27% for *E. coli*. Therefore, some differences between the model and data are due to uncertainty in the data itself.

The intent of the model is to assess whether a location is in attainment of the FIB criteria. In this analysis, it is assumed that all of the data collected during a year at a particular depth represents a 30-day period, and the geometric mean of this data can then be compared to the criterion to determine attainment or non-attainment. Due to the variability of the source loading concentrations and the simplifying assumptions made in the model, a reasonable expectation for the model geometric mean is to be within a factor of two of the data geometric mean (-50% to 100%). However, there is no universal standard for goodness of fit for modeling fecal indicator bacteria. More importantly though is the assessment of attainment of the criteria, so if the data indicates non-attainment, so should the model. For example, in Table 5-2 below, station B16 has a data *E. coli* geometric mean of 1,690 cfu/100mL while the model has a geometric mean of only 649 cfu/100mL. However, the criterion is 126 cfu/100mL, so both the model and data indicate the geometric mean is well above the criterion. It is important to note as well, that in some cases, like this one, the stations are not impacted by CSOs because they are upstream of any outfall. Another example is station B10 in Table 5-7. These fecal coliform data were collected at mid-depth and have a geometric mean of 20 cfu/100mL. The geometric mean of the model is only 7.7 cfu/100mL, so there is an under estimation by the model of 62%. However, the criterion here is 1,500 cfu/100mL, so the underestimation by the model is inconsequential since both the model and data indicate fecal coliform concentrations are well below the criterion. Results of this error analysis are presented in Table 5-2 through Table 5-11

below. The tables break up the results into waterbody classifications (e.g., FW2, SE1, etc.) and sample depths to avoid creating one overwhelming table.

Table 5-2 presents the comparison of station E. coli data and model geometric means at the FW2 stations. All samples were collected at mid-depth. Both the model and data indicate the geometric means were higher than the criterion of 126 cfu/100mL, with the exception of station 25 2016 data in the Raritan River, which is well upstream of any CSO outfall. At this location, the model has only a 9% error in the geometric mean during 2016. The error is higher in 2017, but the FW2 criterion only applies to this station, so there error does not propagate downstream.

In the Passaic River the geometric mean comparisons are fairly good with some under estimation of the geometric means at stations 7 and 8 in 2017. These stations are intensive wet-weather sampling stations. There were two wet-weather sampling events during 2017, so these stations are biased high by these samples. Also, these stations are well down stream of Paterson and somewhat upstream of the Newark CSOs, so it is likely that other sources are contributing to these high E. coli concentrations. As mentioned before, the B16 E.coli geometric mean calculated near the model boundary in the Elizabeth River is low, but the model geometric mean at station B14 compares more favorably to the data. These E. coli geometric means are well above the criterion.

Table 5-2. Comparison of E. Coli Data and Model Geometric Means (cfu/100mL) in FW2 Waterbodies

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
B24 ¹	M	Passaic	126	155	201	30%	327	293	-10%
2	M	Passaic	126	214	258	21%	NA	NA	
3 ¹	M	Passaic	126	419	293	-30%	427	422	-1%
B22	M	Passaic	126	377	303	-20%	NA	NA	
4 ¹	M	Passaic	126	275	434	58%	344	355	3%
5	M	Passaic	126	244	248	2%	192	169	-12%
7 ¹	M	Passaic	126	548	446	-19%	1,060	447	-58%
8 ¹	M	Passaic	126	451	351	-22%	848	387	-54%
B16	M	Elizabeth	126	1,690	649	-62%	NA	NA	
B14	M	Elizabeth	126	1,900	2,530	33%	NA	NA	
25	M	Raritan	126	121	132	9%	132	267	102%

NA – Not Applicable, fewer than five samples

1 – Intensive wet-weather survey station

Table 5-3 presents a comparison of the model and data geometric means for surface data collected in SE2 waterbodies. At these stations, the 30-day geometric mean criterion is 770 cfu/100mL. The comparison between the geometric means is generally quite favorable. Most of the higher differences occur at the wet-weather intensive stations

during 2017. In most cases the model results are higher than the data, but all of the geometric means are well below the criterion.

Table 5-3. Comparison of Surface Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE2 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
B11	S	Hackensack	770	113	80.9	-28%	NA	NA	
B4	S	Hackensack	770	52.6	86.2	64%	162	182	12%
14 ¹	S	Hackensack	770	33.2	60.1	81%	NA	NA	
B7	S	Hackensack	770	60.2	79.1	31%	148	167	13%
15 ¹	S	Hackensack	770	52.6	86.2	64%	162	182	12%
B15 ¹	S	Arthur Kill	770	10.3	5.0	-52%	74.7	139	86%
31 ¹	S	Hudson	770	42.1	48.7	16%	44.4	78.7	77%
B5A	S	Hudson	770	23.4	33.3	42%	NA	NA	
B5B	S	Hudson	770	22.2	29.3	32%	NA	NA	
32 ¹	S	Hudson	770	59.7	46.4	-22%	99.6	86.7	-13%
B18A	S	Hudson	770	31.0	34.6	12%	NA	NA	
B18B	S	Hudson	770	24.7	30.5	23%	NA	NA	
33	S	Hudson	770	64.7	41.2	-36%	115	132	15%
B23A	S	Hudson	770	20.1	19.9	-1%	NA	NA	
B23B	S	Hudson	770	22.7	16.1	-29%	NA	NA	
B26 ¹	S	Hudson	770	19.6	16.1	-18%	129	240	86%
B27 ¹	S	Hudson	770	19.2	13.1	-32%	84.8	255	201%
B9	S	Hudson	770	11.5	7.5	-35%	NA	NA	
B28 ¹	S	Hudson	770	15.8	13.1	-17%	79.4	239	201%
B21A	S	Hudson	770	8.0	6.4	-20%	NA	NA	
B21B	S	Hudson	770	9.1	6.4	-30%	NA	NA	

NA – Not Applicable, fewer than five samples
1 – Intensive wet-weather survey station

Table 5-4 shows a comparison between the model and data calculated geometric means for fecal coliform samples collected at mid-depth in SE2 waterbodies. Stations 7 and 8, located downstream of Paterson and upstream of Newark are two locations where the model underestimates the geometric means. This suggests there is an unaccounted for or under accounted source located in this area. While the model would not predict non-attainment at these locations based on fecal coliform, the E. coli criterion also applies here because these are FW2-SE2 waterbodies, and the model does calculate non-attainment based on this criterion.

The model compares favorably to the data in the Hackensack River and most of the Hudson River where the geometric means are well below the criterion. The least favorable comparisons are for the intensive wet-weather stations during 2017. It should be noted that the CSO flows provided by New York City were significantly higher in 2017 than 2016.

Table 5-4. Comparison of Mid-depth Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE2 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
7 ¹	M	Passaic	770	970	593	-39%	1,130	521	-54%
8 ¹	M	Passaic	770	570	419	-26%	1,070	432	-60%
B11	M	Hackensack	770	216	141	-35%	NA	NA	
B3	M	Hackensack	770	94.0	78.7	-16%	NA	NA	
B4	M	Hackensack	770	289	145	-50%	NA	NA	
14 ¹	M	Hackensack	770	NA	NA		344	452	31%
B7	M	Hackensack	770	35.3	58.1	65%	NA	NA	
15 ¹	M	Hackensack	770	339	227	-33%	435	596	37%
B15 ¹	M	Arthur Kill	770	9.8	3.3	-66%	45.8	98.3	115%
31 ¹	M	Hudson	770	96.0	129	34%	158	457	189%
B5A	M	Hudson	770	15.8	25.4	61%	NA	NA	
B5B	M	Hudson	770	18.9	19.5	3%	NA	NA	
32 ¹	M	Hudson	770	122	102	-16%	152	443	191%
B18A	M	Hudson	770	14.3	15.9	11%	NA	NA	
B18B	M	Hudson	770	16.1	12.9	-20%	NA	NA	
33 ¹	M	Hudson	770	114.	81.7	-28%	153	445	191%
B23A	M	Hudson	770	13.3	8.7	-34%	NA	NA	
B23B	M	Hudson	770	13.4	6.6	-51%	NA	NA	
B26 ¹	M	Hudson	770	18.1	11.1	-39%	97.7	247	153%
B27 ¹	M	Hudson	770	19.6	8.1	-58%	84.7	261	208%
B9	M	Hudson	770	9.4	5.4	-43%	NA	NA	
B28 ¹	M	Hudson	770	11.4	9.6	-16%	56.2	233	315%
B21A	M	Hudson	770	6.7	3.0	-55%	NA	NA	
B21B	M	Hudson	770	10.5	4.6	-56%	NA	NA	

NA – Not Applicable, fewer than five samples
¹ – Intensive wet-weather survey station

A comparison of geometric means calculated for the model and data fecal coliform data collected at the bottom in SE2 waterbodies is presented in Table 5-5. Both the model and data show that the geometric means are low and well below the criterion of 770 cfu/100mL.

Table 5-5. Comparison of Bottom Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE2 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
14 ¹	B	Hackensack	770	48.5	77.8	60%	87.5	105	20%
15 ¹	B	Hackensack	770	46.3	53.7	16%	79.2	80.8	2%
31 ¹	B	Hudson	770	31.7	66.8	111%	37.4	73.6	97%
32 ¹	B	Hudson	770	41.8	17.7	-58%	41.5	20.7	-50%
33 ¹	B	Hudson	770	29.7	14.3	-52%	30.1	18.0	-40%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

Table 5-6 presents a comparison of fecal coliform geometric means using data and model results for surface samples in class SE3 waters. In the Passaic River, the model compares well to the data. Station B6 during 2017 is the only location with a geometric mean greater than the criterion of 1,500 cfu/100mL and the model calculates the geometric mean within 3% of the data. In the other locations, the model generally agrees with the data, and both the model and data geometric means are well below the criterion.

Table 5-6. Comparison of Surface Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE3 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
B6	S	Passaic	1500	325	238	-27%	2,990	3,090	3%
12	S	Passaic	1500	97.6	123	26%	284	242	-15%
16	S	Hackensack	1500	77.2	47.9	-38%	98.4	77.9	-21%
17 ¹	S	Newark B	1500	37.9	55.8	47%	141	182	29%
B10	S	Newark B	1500	12.5	11.6	-7%	33.7	NA	
18 ¹	S	Newark B	1500	35.0	29.5	-16%	79.7	145	82%
19	S	Newark B	1500	26.5	24.2	-9%	28.2	28.2	0%
21	S	Arthur Kill	1500	69.7	91.9	32%	81.0	104	28%
23	S	Arthur Kill	1500	40.8	39.4	-3%	34.9	43.7	25%
24	S	Arthur Kill	1500	13.9	14.1	1%	89.3	270	202%
B20	S	Kill Van Kull	1500	11.6	6.9	-41%	NA	NA	
B12	S	Kill Van Kull	1500	16.2	14.5	-10%	127	312	146%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

A comparison of the mid-depth fecal coliform geometric means in Class SE3 waters is presented in Table 5-7. The model tends to under predict the fecal coliform geometric mean near station 10, especially during 2017. In this part of the model domain dry-weather loads were added and calibrated against in 2016. These loads were unchanged for the 2017 validation. It is highly probable that these dry-weather loads are time-variable and could have been higher during 2017. However, it is not good modeling practice to change these types of loads for the model validation period because it then reduces the predictive power of the model for other modeling periods. Additionally, station 10 was a wet-weather intensive station, so the data contain more wet-weather samples than some of the other stations. In Newark Bay, the Elizabeth River, the Arthur Kill, and the Kill Van Kull the model generally reproduces the magnitude of the geometric means and accurately assesses attainment or non-attainment.

Table 5-7. Comparison of Mid-depth Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE3 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
10 ¹	M	Passaic	1500	905	566	-37%	1940	845	-56%
11	M	Passaic	1500	324	256	-21%	NA	NA	
B6	M	Passaic	1500	359	265	-26%	2,200	3,100	41%
17 ¹	M	Newark B	1500	134	158	18%	377	892	137%
B10	M	Newark B	1500	20.0	7.7	-62%	NA	NA	
18 ¹	M	Newark B	1500	98.3	78.6	-20%	208	431	107%
B17	M	Newark B	1500	13.4	10.4	-22%	NA	NA	
B13	M	Elizabeth	1500	3,050	2,100	-31%	NA	NA	
20 ¹	M	Elizabeth	1500	842	1,090	29%	2,620	1,930	-26%
24	M	Arthur Kill	1500	17.0	8.3	-51%	65.9	218	231%
B20	M	Kill Van Kull	1500	13.3	5.5	-59%	NA	NA	
B12	M	Kill Van Kull	1500	18.7	12.0	-36%	125	306	145%
NA – Not Applicable, fewer than five samples									
1 – Intensive wet-weather survey station									

A comparison of the bottom fecal coliform geometric means in Class SE3 waters is presented in Table 5-8. There are only a few places where bottom water samples were collected. These areas tend to be deep and more stratified with the freshwater floating on the surface over the denser saline water. This tends to lead to lower bacteria concentrations because the sources of bacteria are generally associated with fresh water. At the locations in Table 5-8, the model and data both show the fecal coliform geometric means are well below the criterion of 1,500 cfu/100mL.

Table 5-8. Comparison of Bottom Fecal Coliform Data and Model Geometric Means (cfu/100mL) in SE3 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
12	B	Passaic	1500	53.8	76.4	42%	247	125	-49%
16	B	Hackensack	1500	53.3	40.3	-24%	75.3	55.3	-27%
17 ¹	B	Newark B	1500	22.6	20.7	-8%	32.2	28.8	-11%
18 ¹	B	Newark B	1500	25.9	10.1	-61%	29.1	15.5	-47%
19	B	Newark B	1500	29.9	14.0	-53%	18.3	21.2	16%
21	B	Arthur Kill	1500	43.4	39.1	-10%	49.7	56.7	14%
23	B	Arthur Kill	1500	31.2	37.0	19%	30.4	39.2	29%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

Locations where surface waters were sampled in SE1 waters were limited to Raritan River and Raritan Bay. The model versus data enterococci geometric means for these locations are presented in Table 5-9. The model comparison to the data geometric means is good and indicates attainment and non-attainment at the same locations as the data. The percent differences at stations 28, 29, and 30 are biased high because the model geometric means are based on a minimum concentration of 1 cfu/100mL where the data have a reporting limit of 2 cfu/100mL.

Table 5-9. Comparison of Surface Enterococci Data and Model Geometric Means (cfu/100mL) in SE1 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
26	S	Raritan R	35	164	163	-1%	173	204	18%
27	S	Raritan R	35	94.5	110	16%	66.0	171	159%
B19	S	Raritan R	35	15.2	7.5	-51%	NA	NA	
28	S	Raritan B	35	24.2	12.6	-48%	34.7	17.9	-48%
29	S	Raritan B	35	6.9	2.0	-70%	10.0	9.5	-5%
30	S	Raritan B	35	6.7	1.3	-80%	6.0	2.0	-67%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

Table 5-10 presents a comparison of the geometric means for mid-depth enterococci samples and model output in Class SE1 waters. The model underestimates the geometric means at station 13 indicating the boundary conditions could have been set a little higher. During 2016 the model compares reasonably well to the data geometric mean at stations

B1 and B2 with both showing the geometric means to be well above the criterion of 35 cfu/100mL. During 2017 the model geometric means are well above the data, but these data sets are dominated by the two wet-weather sampling events. In Raritan Bay, both model and data indicate low geometric means and attainment of the criterion.

Table 5-10. Comparison of Mid-depth Enterococci Data and Model Geometric Means (cfu/100mL) in SE1 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
13	M	Hackensack	35	61.3	30.5	-50%	59.6	34.8	-42%
B1 ¹	M	Hackensack	35	576	890	55%	855	3,720	335%
B2 ¹	M	Hackensack	35	398	363	-9%	648	2,880	344%
B19	M	Raritan B	35	13.5	3.5	-74%	NA	NA	
29	M	Raritan B	35	6.3	4.8	-24%	7.3	33.5	359%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

Bottom water geometric means of enterococci data and model output at SE1 waterbodies is presented in Table 5-11. The model accurately predicts which locations would be in attainment and non-attainment of the geometric mean criterion. Like the surface calculations, the model calculated geometric means are biased low at station 28, 29, and 30 because the data detection limit is higher than the minimum model concentration used in the geometric mean calculation.

Table 5-11. Comparison of Bottom Enterococci Data and Model Geometric Means (cfu/100mL) in SE1 Waters

Station	Depth	Waterbody	Criterion	2016 Data	2016 Model	% Difference	2017 Data	2017 Model	% Difference
26	B	Raritan R	35	166	163	-2%	163	181	11%
27	B	Raritan R	35	65.7	76.3	16%	62.3	130	109%
28	B	Raritan B	35	17.9	7.5	-58%	27.2	9.7	-64%
29	B	Raritan B	35	9.4	1.0	-89%	10.2	2.7	-73%
30	B	Raritan B	35	6.4	1.5	-77%	6.9	2.3	-67%
NA – Not Applicable, fewer than five samples 1 – Intensive wet-weather survey station									

This statistical error analysis indicates the model can generally predict areas that would attain or not attain water quality criteria based on geometric means. The analysis also shows there is uncertainty in the model calculations. This indicates that, in some areas of the model, the model could over predict or under predict the attainment of water quality

criteria especially in places where the geometric means are close to the existing criteria. Therefore, caution should be used when interpreting model results on a model cell basis.

5.6 Model Evaluation Group

A Model Evaluation Group (MEG) was assembled to help assess the validity of the model, the modeling assumptions, and the model calibration/validation. The group consisted of three modeling experts with expertise covering the different modeling aspects of the project. These experts included: Dr. Wayne Huber, Professor Emeritus Oregon State University (landside modeling), Dr. Alan Blumberg, former Professor at Stevens Institute of Technology (hydrodynamic modeling), and Dr. Steven Chapra, Professor at Tufts University (water quality modeling).

The MEG met for a total of five meetings. The initial meetings focused more on the landside modeling, with the later meetings focusing on hydrodynamics and water quality. The following describes what was presented at each meeting related to the hydrodynamic and water quality modeling. The first meeting occurred on February 5, 2016 and focused on the water quality modeling approach and the approaches for developing model input. The second meeting occurred on March 17, 2017 and focused on the initial hydrodynamic modeling and the CSO and stormwater data that had been collected to that point. Meeting 3 was held on September 17, 2017 and the discussions included the near final hydrodynamic model calibration, the approaches and input for bacteria loading, and the initial water quality model calibration. The fourth MEG meeting occurred on December 5, 2018 and an overview of the water quality model calibration was presented. The final meeting was held on November 21, 2019 where a final overview of the water quality model was presented, and the MEG was given instructions on the review of the model. In addition, a draft of the modeling report was provided to the MEG members as part of their review.

The instructions involved answering the following six questions with more specific questions under each main question:

1. Is the water quality model software appropriate for use in this study?
2. Was the model developed and calibrated in order to meet or exceed industry standards?
3. Are the loads for stormwater, CSO, dry weather flow and upstream boundary conditions appropriate and supported by water quality sampling data collected under the approved QAPP?
4. Were reasonable assumptions applied in evaluating attainment of water quality standards?
5. Is the model's calibration adequate to reflect future wet weather flow improvements, which would include reductions in CSO flows and volumes and/or changes in pathogen concentrations associated with inflow and infiltration reduction, sewer separation, treatment, and storage technologies?
6. Is the model useful for assessing attainment of water quality standards?

The MEG’s responses were generally favorable, and can be seen in Appendix G. The responses did include some additional questions and comments that are addressed in Table 5-12 below, as well as throughout the report.

Ultimately, the MEG meetings helped steer the direction of the development of model input and the calibration. Some suggestions were implemented while others were reviewed and shown not to improve the model calibration. Suggestions from the MEG meetings that were used for the model calibration included:

- Using an MLE concentration for the stormwater bacteria;
- Adjustment of bacteria concentrations used at the WWTPs;
- Using a constant concentration at the river boundaries during wet-weather due to the lack of strong correlation between rainfall and concentration;
- Using a longer term (5 year) record of data to develop boundary conditions for the rivers; and
- The application of a solar radiation term in the bacteria die-off kinetics.

Overall, the MEG approved of the approaches used to develop the model input, and found the model calibration to be adequate for use to aid the development of the LTCP.

Table 5-12. Responses to MEG Comments

MEG Comment	Response
Comments related to modeling in the Elizabeth River	During the fifth MEG meeting, the modeling team reported issues with the modeling in the Elizabeth River related to the river slope and salinity modeling. These issues have been addressed and are discussed in this report.
Note that the reference to Figure 2-2 on page 11 is incorrect.	This has been corrected.
It is also curious that the river inflow temperature data shown in Figures 4-5 and 4-6 have interannual fluctuations while the Hudson River inflow temperature does not. Why?	Actually, the Hudson River inflows are subtly different in the two figures. Since the Hudson River is a large river, meteorological changes do not impact the water temperature as dramatically as it does in the smaller rivers.
The only issue for validation/verification is that the currents should have also been low-passed filtered as was done for water levels to afford a clearer assessment.	The modeling team had some concern as to whether this would be a fair assessment of the model. In some cases the model is only one segment wide and one representative depth, whereas in reality the river may have a center channel. While the model can reproduce

Table 5-12. Responses to MEG Comments

MEG Comment	Response
	the magnitude of the overall velocity, reproducing the subtle changes in velocity due to meteorological forcings is more challenging. Nevertheless, low-passed current velocity figures have been added to Appendix D without comment.
Note that Figures 5-6 should include the total water depth, so the reader knows where in the water column the observations came from.	Total water depth at the ADCP stations has been added to the figures.
The MEG would have been preferred that more was done to explore model sensitivity.	Model sensitivities can be useful in model assessment. The model calibration and component analysis provide some measure of model sensitivity. Additional model sensitivities are beyond the scope of the original modeling effort. Model sensitivities could be conducted if the CSO Team decides this is important, and would be included in a separate document.
The report talks about tides and tidal forcing. It really should be water levels.	Changes to the text were made where appropriate.
What is needed is a statistical quantification of the results, i.e., rmse and percent error.	Statistical assessment of a model calibration to fecal indicator bacteria is not commonplace, nor is there a standard numerical target as to what constitutes a “good” or “satisfactory” calibration. For log normally distributed FIB, rmse analysis does not seem appropriate. However, a percent error of the geometric means could provide some insight as to the model’s ability to assess attainment. As a response to this comment, Section 5.5 of this report was developed.

6 Projections

This report is meant to be a model calibration/validation report. However, some discussion on projections is provided primarily to show that the baseline loading and boundary

conditions were set up in a manner consistent with the calibration and validation conditions.

6.1 Calculation of Attainment with Water Quality Criteria

NJDEP provides some guidance as to how to calculate attainment of water quality criteria. The Water Quality Standards (NJAC 7:9B), include Statements of policy (7:9B-1.5). Paragraph (c) 7 states, in part:

“The Department shall utilize a geometric mean to assess compliance with the bacterial quality indicators ... The geometric mean shall be calculated using a minimum of five samples collected over a thirty-day period.”

The policy does not indicate where the samples are to be collected, or how to assess compliance when using a model.

The PVSC Team has decided on the following approach to calculate attainment of the criteria using the model. Results from the surface layer of the model will be used. The surface layer represents the top 10 percent of the water column. This approach is conservative since freshwater tends to stay on the surface because it is less dense than saline water, and most bacteria sources are associated with freshwater.

In addition, attainment will be based on spatial averaging over areas defined by NJDEP 14-digit Assessment Units (AU). All model surface cells within an AU are averaged, and then the attainment is based on the average concentrations. An alternative approach could have been to use single model cells at locations where there were data to calibrate against and there would be greater confidence in the model results. This single cell approach would have omitted some areas in the project area that were not samples. The AU approach allows for all locations within the project area to be assessed, and does not over emphasize single cells where data was not collected and there is more uncertainty in the model results. A map of the AUs is presented in Figure 6-1.

Finally, the model saves output as hourly averages, although this period could be lengthened or shortened. Thirty-day rolling periods, shifted on an hourly basis, are used to calculate the geometric mean, and then the number of thirty-day periods out of the year with geometric means that are lower than the criteria are used to calculate attainment of the criteria.

To sum up, attainment of the criteria will be based on surface layer model results, aggregated by AUs, and calculated using rolling 30-day geometric means shifted hourly over the year.

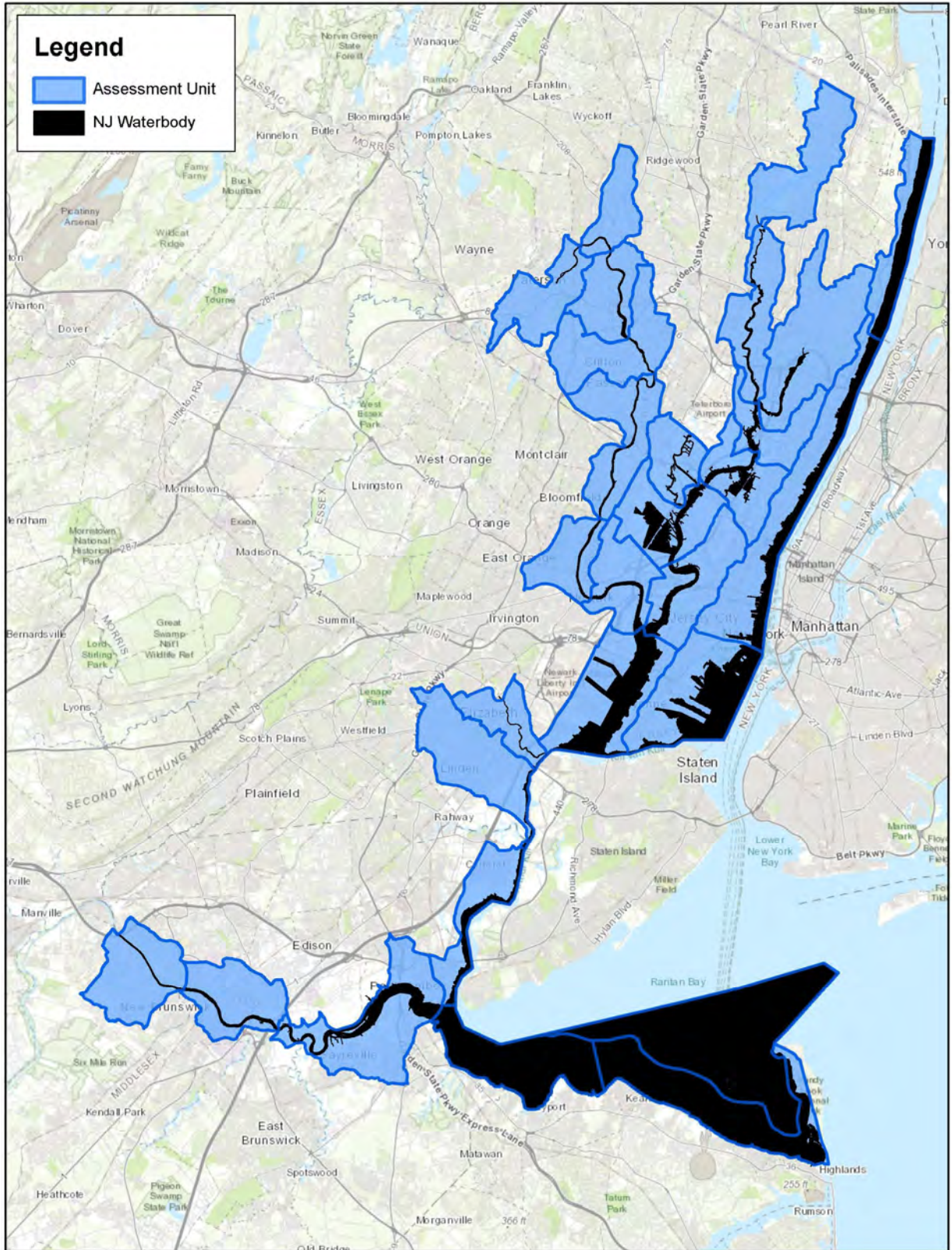


Figure 6-1. Assessment Units used for Spatial Attainment Calculations

6.2 Baseline

Baseline conditions are based on the use of a “typical” rainfall condition. Analysis of precipitation records indicated that 2004 rainfall conditions at Newark Liberty International Airport most closely reflected typical year conditions (PVSC 2018). Unlike the calibration and validation process, which used several rain gages to drive the landside models, the baseline conditions in the landside models all use Newark Airport precipitation. River flow was used in the analysis to choose the typical year, so river flow and water elevations for 2004 are part of the baseline condition.

Additionally, to create a consistent baseline, the InfoWorks models were set up using “existing” 2015 infrastructure. New NJPDES permits were issued in 2015, so any infrastructure upgrades after this date is considered part of the LTCP.

Finally, Baseline conditions assume that the non-CSO sources of bacteria to the project area remain unmitigated. This means that although the precipitation and river flows change to 2004 conditions from the calibration and validation conditions, the approach to developing the stormwater, river, and dry-weather loads remains the same, and no efforts were made to reduce bacteria loads from the other sources.

6.3 100% CSO Control

The use of a 100% CSO Control scenario is part of a “gap analysis.” 100% CSO control is obviously the maximum level of control that can be attained for CSOs and results in the maximum improvement in water quality conditions. If CSOs were the primary reason for non-attainment of water quality criteria, then some level of CSO control between baseline conditions and 100% control could conceivably result in attainment of the criteria. This level of CSO control would close the gap between attainment and non-attainment of water quality criteria. In many cases, other sources of bacteria, such as stormwater, are large enough that even 100% CSO control is not enough to meet criteria. In this case the 100% CSO Control scenario shows the highest level of water quality that can be achieved by CSO control only, and additional control scenarios can be analyzed that can be incorporated into a cost-benefit analysis.

6.4 Gap Analysis

Table 6-1 through Table 6-4 present model calculated attainment for the AUs under Baseline and 100% CSO control conditions for FW2 (FW2/SE2), SE1, SE2, and SE3 AUs, respectively. The results indicate that FW2 and FW2/SE2 generally have poor attainment of the criteria, and that CSO control will not improve attainment of the criteria in most cases. Note that in FW2/SE2 waterbodies the FW2 criterion always has lower attainment, so the FW2 criterion was considered the controlling criterion. SE1 waterbodies have more mixed results with some areas having poor attainment and others having high attainment. SE2 and SE3 waters generally fully attain the water quality criteria.

Table 6-1. AU Attainment in FW2 and FW2/SE2 Waterbodies under Baseline and 100% Control Conditions

Assessment Unit Name	Assessment Unit Number	Baseline % Attainment	100% Control % Attainment
Passaic R Lwr (Fair Lawn Ave to Goffle Road)	02030103120070-01	0.0	0.0
Passaic R Lwr (Dundee Dam to Fair Lawn Ave)	02030103120080-01	0.0	0.0
Passaic R Lwr (Saddle R to Dundee Dam)	02030103120090-01	0.0	0.0
Passaic R Lwr (Goffle Bk to Pump str)	02030103120110-01	0.0	0.0
Passaic R Lwr (Second R to Saddle R)	02030103150030-01	0.0	0.0
Overpeck Creek	02030103180040-01	50.0	67.0
Berrys Creek (below Paterson Ave)	02030103180070-01	79.0	94.0
Hackensack R (Amtrak Bridge to Rt 3) ¹	02030103180090-01	100.0	100.0
Elizabeth River (below Elizabeth CORP BDY) ¹	02030104020030-01	0.0	0.0
Raritan R Lwr (MileRun to I-287 Piscataway)	02030105120160-01	0.0	0.0
1. This Assessment Unit had to be divided into two pieces because it spanned two waterbody classifications.			

Table 6-2. AU Attainment in SE1 Waterbodies under Baseline and 100% Control Conditions

Assessment Unit Name	Assessment Unit Number	Baseline % Attainment	100% Control % Attainment
Hackensack R (Oradell to Old Tappan gage)	02030103170060-01	100.0	100.0
Hackensack R (Fort Lee Road to Oradell gage)	02030103180030-01	0.0	0.0
Raritan Bay (West of Thorns Ck)	02030104910010-01	93.0	94.0
Sandy Hook Bay (East of Thorns Ck)	02030104910020-01	100.0	100.0

Table 6-2. AU Attainment in SE1 Waterbodies under Baseline and 100% Control Conditions

Assessment Unit Name	Assessment Unit Number	Baseline % Attainment	100% Control % Attainment
Raritan Bay (Deep water)	02030104910030-01	100.0	100.0
Raritan R Lwr (Lawrence Bk to Mile Run)	02030105120170-01	8.0	8.0
Raritan r Lwr (below Lawrence Bk)	02030103180070-01	31.0	32.0

Table 6-3. AU Attainment in SE2 Waterbodies under Baseline and 100% Control Conditions

Assessment Unit Name	Assessment Unit Number	Baseline % Attainment	100% Control % Attainment
Hudson River (upper)	02030101170010-01	100.0	100.0
Hudson River (lower)	02030101170030-01	100.0	100.0
Hackensack R (Bellmans Ck to Fort Lee Rd)	02030103180050-01	92.6	100.0
Hackensack R (Rt 3 to Bellmans Ck)	02030103180080-01	100.0	100.0
Hackensack R (Amtrak Bridge to Rt 3) ¹	02030103180090-01	100.0	100.0
Hackensack R (below Amtrak bridge) ¹	02030103180100-01	100.0	100.0
Upper NY Bay / Kill Van Kull (74d07m30s) ¹	02030104010030-01	100.0	100.0
Arthur Kill waterfront (below Grasselli) ¹	02030103180070-01	100.0	100.0
1 This Assessment Unit had to be divided into two pieces because it spanned two waterbody classifications.			

Table 6-4. AU Attainment in SE3 Waterbodies under Baseline and 100% Control Conditions

Assessment Unit Name	Assessment Unit Number	Baseline % Attainment	100% Control % Attainment
Passaic R Lwr (4 th St br to Second R)	02030103150040-01	100.0	100.0
Passaic R Lwr (Nwk Bay to 4 th St br)	02030103150050-01	100.0	100.0
Hackensack R (below Amtrak bridge) ¹	02030104010020-01	100.0	100.0
Kill Van Kull West	02030103180080-01	100.0	100.0
Upper NY Bay / Kill Van Kull (74d07m30s) ¹	02030104010030-01	100.0	100.0
Elizabeth River (below Elizabeth CORP BDY) ¹	02030104020030-01	100.0	100.0
Morses Creek/Pile Creek	02030104030010-01	100.0	100.0
Arthur Kill waterfront (below Grasselli) ¹	02030103180070-01	100.0	100.0
1 This Assessment Unit had to be divided into two pieces because it spanned two waterbody classifications.			

6.5 Component Responses

Components are defined as the various sources of pollutants to the receiving water. A component analysis can quantify the impacts of the source categories (either geographical, type, or both) to assess which are most influential in a particular time or location. This phase is helpful to establish the level of load control to target during LTCP development. The PWQM was applied to simulate eight component analyses to assess the impacts of various source categories on water quality. The following source categories were evaluated: CSO, stormwater and runoff, the Hudson River, other rivers, NJ STPs, NY/CT STPs, dry-weather loads, and sources from New York City. Each source component was run separately and the individual pieces were summed to calculate the total concentration. The output provides information as to the importance of the various sources in locations throughout the model domain. The analysis was completed on a station basis using depth averaged concentrations. Several examples are presented below.

Figure 6-2 presents the component analysis for station 4 south of Paterson above the Dundee Dam on the Passaic River. The eight panels on the perimeter of the figure represent each of the eight individual components. The component concentrations are represented by a color and the black line is the total concentration. The center panel

presents the percent contribution of each source during each hour of the baseline year. In this location, the classification is FW2 and the criterion used to assess attainment is E. coli.

The upper right panel shows the contribution by CSOs, and it is apparent that CSO loads contribute to the highest E. coli concentrations, but only for a short duration. The stormwater concentrations in the upper center panel and the river concentrations presented in the lower center panel contribute to the E. coli concentrations at a higher frequency, and these sources are large enough that the E. coli criterion is exceeded even without the CSO load contributions.

Figure 6-3 presents the enterococci component analysis for station B2 in the Hackensack River. At this location in the Hackensack River the waterbody classification is SE1. At this location CSOs, stormwater, and dry-weather loads are the primary bacteria sources. CSO discharges at this location are enough to result in exceedances of the criterion.

The enterococci component analysis for another SE1 waterbody, Raritan Bay at station B19 near the mouth of the river, is presented in Figure 6-4. At this station, stormwater loading impacts dominate, followed by CSOs, and sources in the upper Raritan River outside the project area. Based on these results, the reduction in CSO loads will only have a limited effect on attainment in criteria due to the dominance of the stormwater and runoff.

Figure 6-5 presents the fecal coliform component analysis for station 10 in the Passaic River in the SE3 portion of the river. Several sources including CSOs, stormwater, rivers, and dry-weather loads contribute to the fecal coliform concentrations at this location. However, because the fecal coliform criterion is 1,500 cfu/100mL as a 30-day geometric mean, the combined sources do not contribute enough loading to exceed this criterion.

Figure 6-6 presents the fecal coliform component analysis for station B10 in Newark Bay, a SE3 waterbody. Several sources contribute to the fecal coliform concentrations in this location, with CSOs being the dominant source. However, modeling indicates the concentrations in the bay at this location rarely exceed 1,500 cfu/100mL and do not approach a 30-day geometric mean of 1,500 cfu/100mL.

Figure 6-7 presents the fecal coliform component analysis for station 33 in the Hudson River, a SE2 waterbody. At this location, CSO loading from New Jersey and New York City, stormwater, and upstream Hudson River sources are the primary contributors to the fecal coliform concentrations in this area. The sum of these sources results in fecal coliform concentrations that have 30-day geometric means below the criterion.

In general, the component analysis shows that different sources dominate the bacteria loading in the various locations of the project area. In some cases CSOs are a significant contributor to the bacteria concentrations, but these locations are often areas where the 30-day geometric mean concentrations are not exceeded, or exceedances occur due to contributions from other sources.

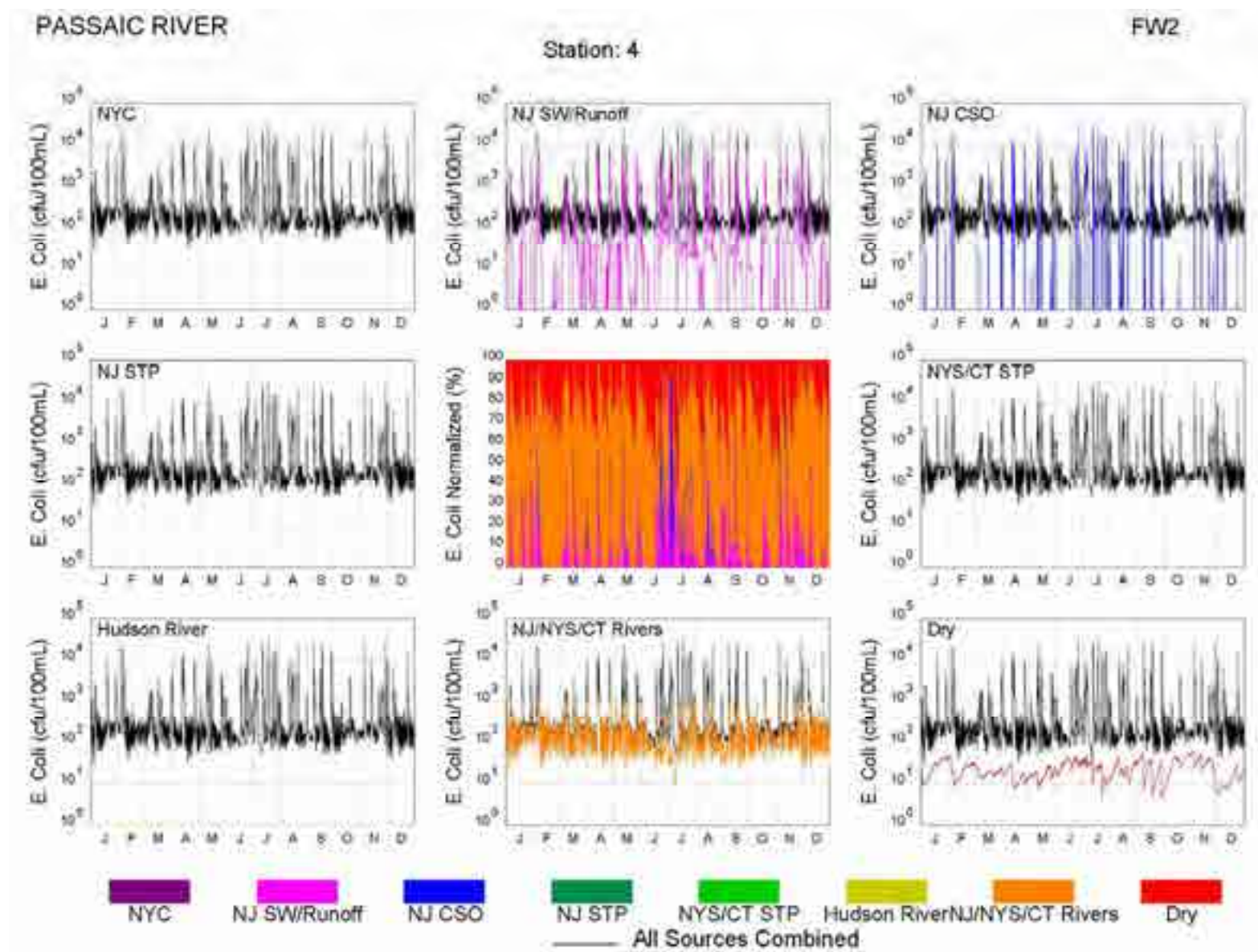


Figure 6-2. Component Analysis for E. Coli at Station 4

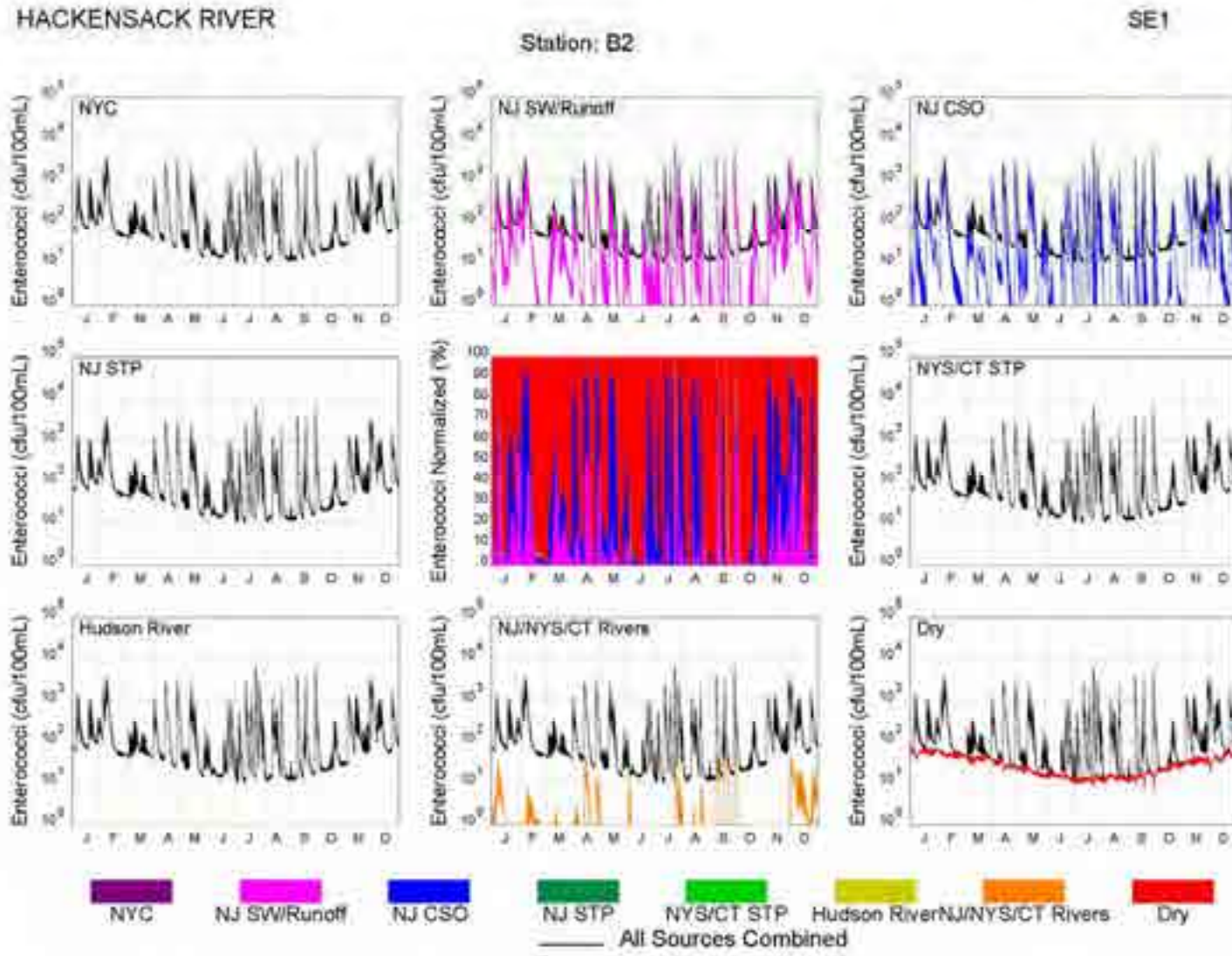


Figure 6-3. Component Analysis for Enterococci at Station B2

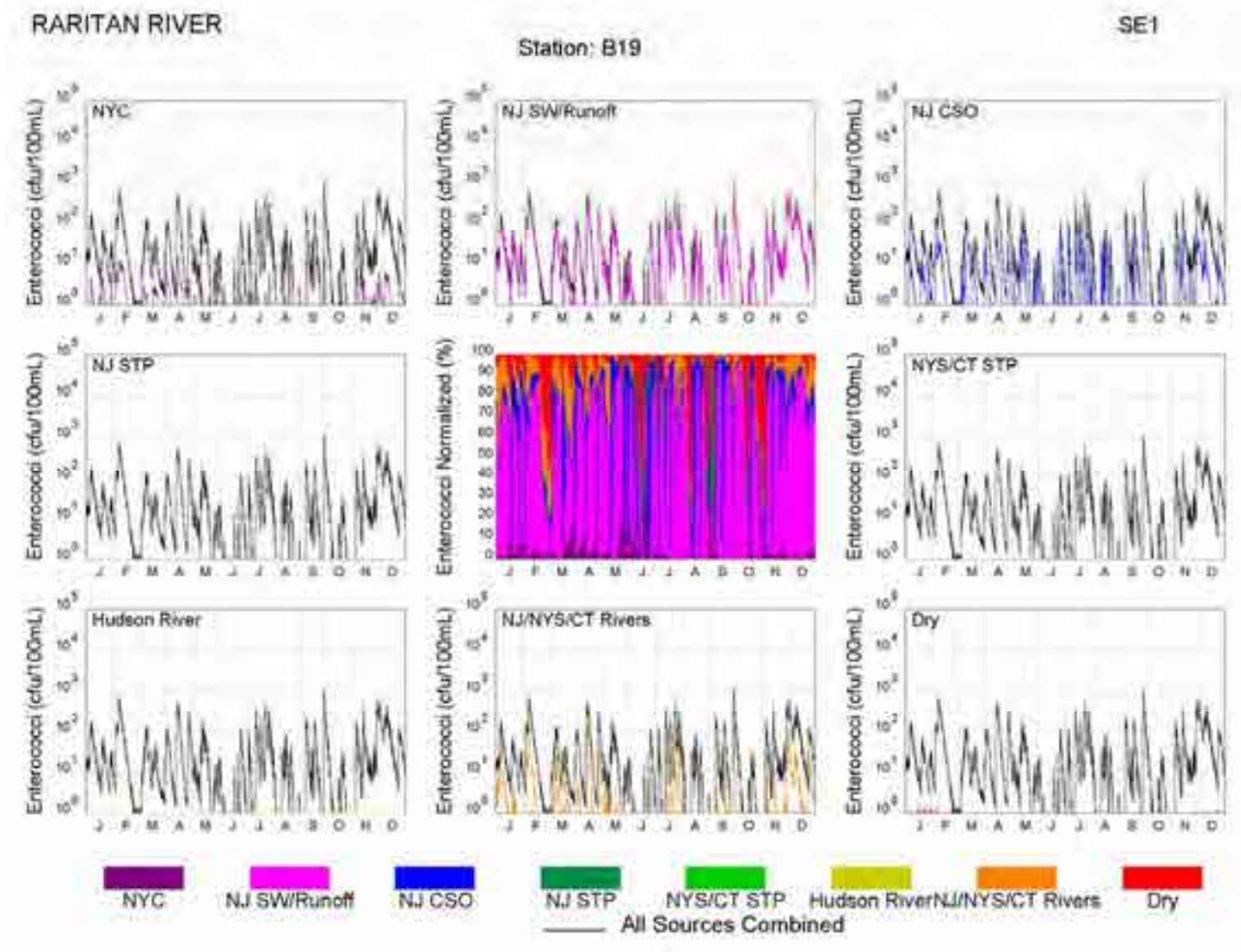


Figure 6-4. Component Analysis for Enterococci at Station B19

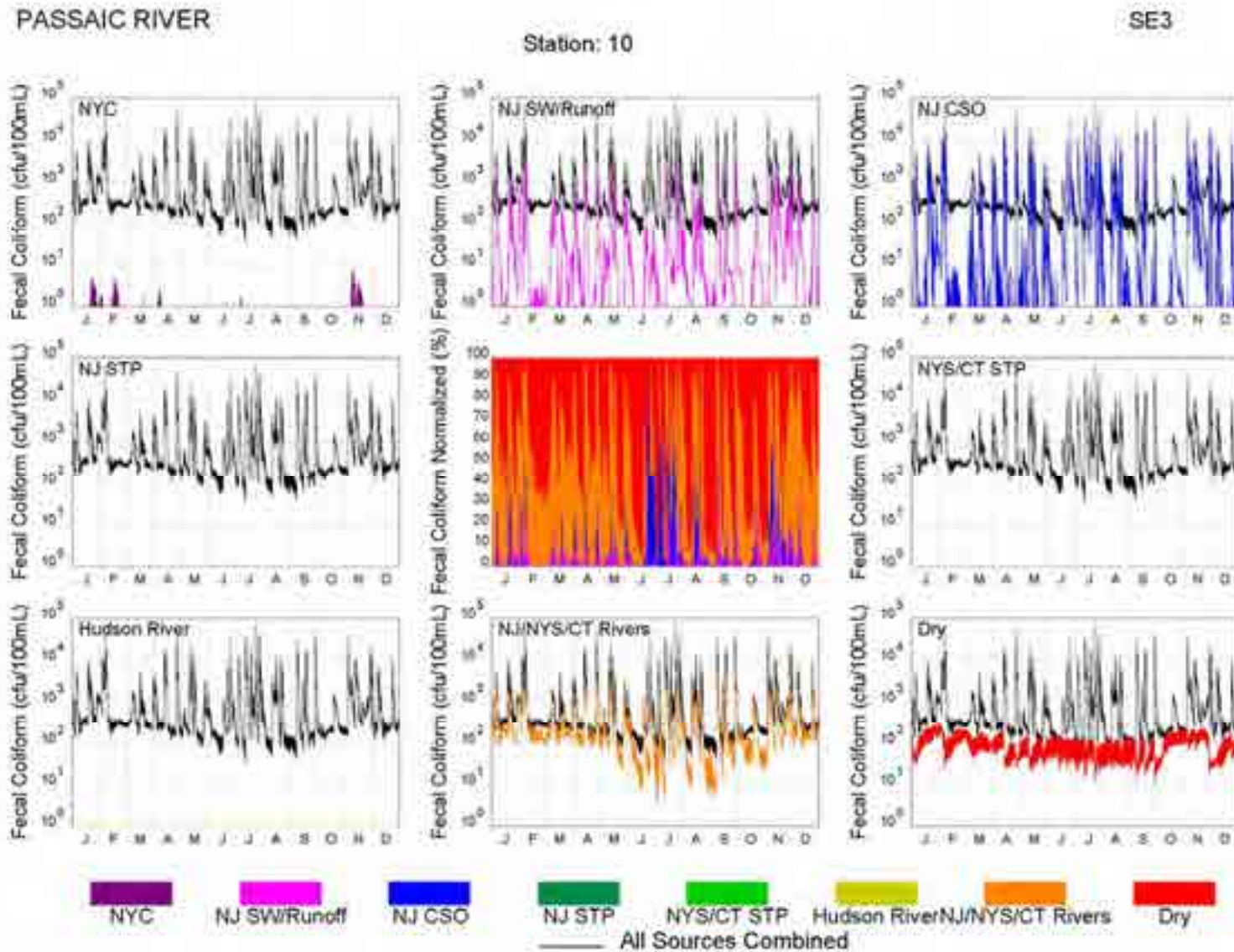


Figure 6-5. Component Analysis for Fecal Coliform at Station 10

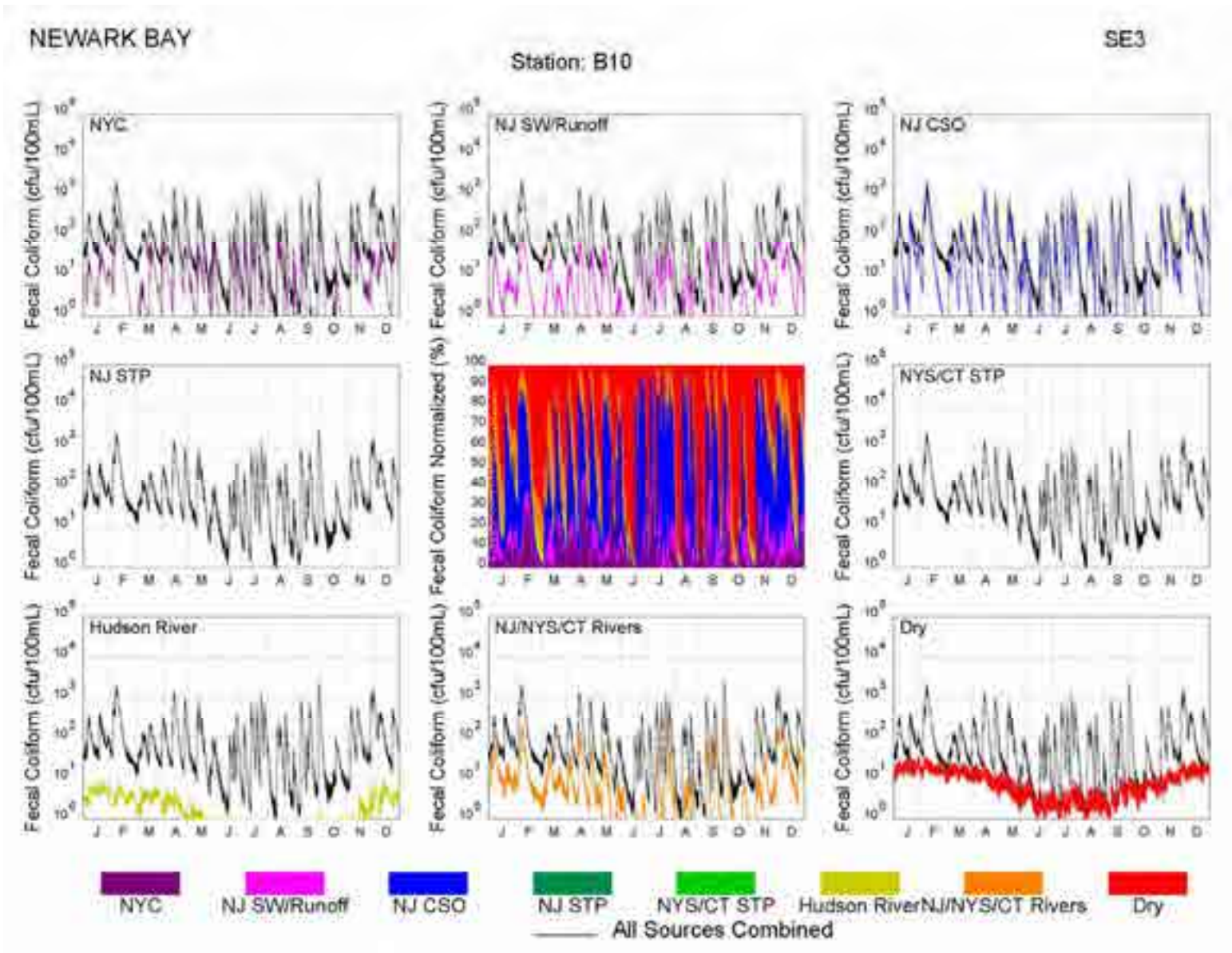


Figure 6-6. Component Analysis for Fecal Coliform at Station B10

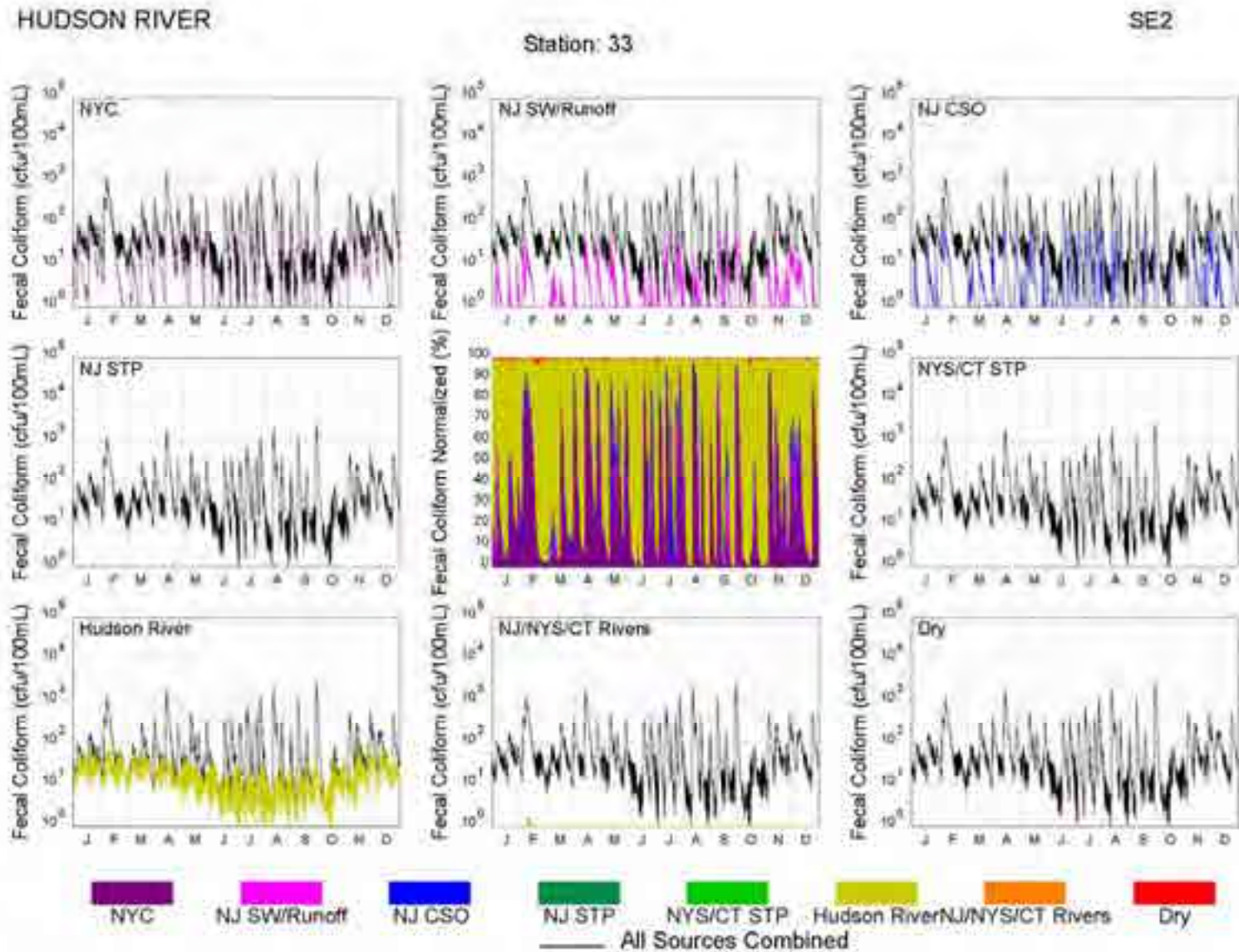


Figure 6-7. Component Analysis for Fecal Coliform at Station 33

7 Deviations from the QAPP

Over the course of the model development and calibration/validation process, certain deviations from the technical approach outlined in the water quality modeling QAPP became necessary. These deviations are discussed below.

7.1 Model Inputs

The QAPP outlines a process for developing stormwater loads based on land use types, and assigning different bacteria concentrations based on these land types. After analysis of the stormwater data that were collected, it was shown that bacteria concentrations did not vary appreciably between land use types. The decision was made to apply a single concentration for each FIB for all stormwater. This approach was discussed at MEG meetings and found acceptable to the MEG.

The QAPP also discussed the use of slightly different model coefficients for each of the three FIB: fecal coliform, *E. coli*, and enterococci. The calibration resulted in using the same constants for both fecal coliform and *E. coli*. Since *E. coli* is a subset of fecal coliform, this is a reasonable assumption.

7.2 Calibration Data

The QAPP discusses using Baseline Compliance Monitoring Program data, NJHDG data and NYCDEP Harbor Survey data to assess the model calibration. The combination of the Baseline Compliance Monitoring Program data and NJHDG data provided more than 60 locations to compare model results to data. This amount of data was adequate, so the NYCDEP Harbor Survey was not the focus during the calibration/validation process. Calibration/Validation figures with NYCDEP data are included in Appendices E and F.

7.3 Reporting

The QAPP presents a preliminary outline for this report. The focus of this report became the calibration and validation of the model, so limited projection information is provided in this report. Additionally, based on MEG recommendations, the use of statistical comparisons between model and data were not performed. Also, some of the elements in the outline, such as Application of Submodels, were not applicable. Consequently, this report has been modified from the preliminary outline.

8 Conclusions and Recommendations

The PWQM was developed to assist with the development of CSO LTCPs for the NJ CSO Group. The model builds on the previously developed PATH model. Data collected during 2016 and 2017 were adequate to develop model inputs and successfully calibrate and validate both the hydrodynamic and water quality components of the model. The model calibration and validation was assessed by visual comparison between model output and the collected data. The model versus data comparisons lead to the following conclusions:

- Time-series figures of water elevation and low-pass filtered water elevation data show the model captures the magnitude and timing of the water elevation changes due to tidal and meteorological effects,
- The hydrodynamic model accurately reproduces accurately captures the magnitude of current velocities of the available data, and captures the variation of velocity with depth,
- Annual time-series model versus data comparisons show the hydrodynamic model reproduces the observed temperature and salinity data over multiple years at multiple locations,
- Since the hydrodynamic model is able to reproduce water elevation, current velocity, temperature and salinity, the model can be expected to accurately account for the advection and dispersion of FIB within the project area and account for the effects of temperature and salinity on FIB die-off,
- Annual time-series model versus data comparisons show the water quality model reproduces the magnitude and temporal variations of the FIB data during multiple years and multiple locations.
- Short-term wet-weather event time-series figures show the water quality model adequately reproduces short-term events,
- Spatial transect figures shows the water quality model reproduces the spatial distribution of FIB concentrations within the rivers during wet-weather events,
- Probability distribution figures indicate that the model reproduces the distribution of the FIB data at multiple locations, and
- Based on the weight of evidence of the model versus data comparisons, PWQM adequately reproduces FIB concentrations both in space and time within the project area.

Since PWQM has been successfully calibrated and validated it can be used as a tool to assess how CSO controls affect water quality and attainment with water quality criteria. The model has been successfully calibrated to data collected at more the 60 locations, and can be reasonably expected to reproduce water quality conditions within the project area. However, while the monitoring stations provide extensive coverage of the project area, data cannot be collected at all locations and all times, so there may be areas within the model domain where it may not accurately reproduce water quality conditions. Therefore, the model cannot be expected to be completely accurate in each individual model segment at all times. Based on this, attainment of water quality criteria using the model should not be judged solely on the individual model cell with the lowest calculated attainment; rather, attainment based on model results should be determined using model cells that have been shown to be accurately calibrated (i.e., monitoring sites), or aggregations of model cells with similar conditions such as within NJDEP Assessment Units.

The PWQM was developed to assess the impact of CSO controls on water quality to assist in the development of CSO LTCPs. As such, the bacteria loads from CSO sources have been developed to a higher degree than any other load source. While adequate information was collected to estimate loads from other sources, it was with the intent of characterizing the influence of CSO reduction on water quality. Therefore, if this model were to be used to assess controls for stormwater or the elimination of illicit connections, additional field sampling and model verification is recommended.

9 References

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