Appendix O

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

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	9/11/2020 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: [signature] 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: [signature] 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: ______________________ 8.23.20
Timothy Boyle Date
Exec. Director MUA, Bayonne City

NJPDES Certification:

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Permittee: ______________________ 8.28.20
Timothy Boyle Date
Exec. Director MUA, Bayonne City

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: ______________________ 8/10/20

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: ______________________ 8/10/20

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: ______________________________ 2/17/2020

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: ______________________________ 2/17/2020

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: [signature] July 9 2020

Rich Haytas
Senior Engineer, Jersey City MUA
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: [signature] July 9 2020

Rich Haytas
Senior Engineer, Jersey City 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 NJ0111244 (Kearny Town)

Approval of Report:

Permittee: [signature] 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: [signature] 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: ______________________________ 9/10/20

Ras J. Baraka
Mayor, City of 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: ______________________________ 9/10/20

Ras J. Baraka
Mayor, City of 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 NJ0108880 (Paterson City)

Approval of Report:

Permittee: William Rodriguez, Director Public Works, City of Paterson — Date: 8/6/20

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: 8/6/20

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: 8/10/20

Frank Pestana Date
Exec. Director, North Bergen 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: 8/10/20

Frank Pestana Date
Exec. Director, North Bergen 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 NJ0024741 (Joint Meeting of Essex and Union Counties)

Approval of Report:

Permittee: ______________________________ 7/10/20

Hanifa Z. Johnson Date
Exec. Director, Joint Meeting of Essex and Union Counties

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: ______________________________ 7/10/20

Hanifa Z. Johnson Date
Exec. Director, Joint Meeting of Essex and Union Counties

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: ______________________ 9/ 6/20
Date

Joseph Cryan
Executive Director, Middlesex County Utilities 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: ______________________ 9/6/20
Date

Joseph Cryan
Executive Director, Middlesex County Utilities Authority

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: 8/10/20

Frank Pestana
Executive Director, North Bergen MUA
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: 8/10/21

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: ____________________ 8/10/20

Frank Pestana — Date
Licensed Operator, Town of Guttenberg

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: ____________________ 8/11/20

Frank Pestana — Date
Licensed Operator, Town of Guttenberg

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. Pocci (signature) July 7, 2020

Fredric J. Pocci, 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. Pocci (signature) July 7, 2020

Fredric J. Pocci, 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: [signature] 8/20/20

Alfred R. Restaino
City Administrator, City of Fort Lee
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: [signature] 8/20/20

Alfred R. Restaino
City Administrator, City of Fort Lee
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 NJ0108766 (Hackensack City)

Approval of Report:

Permittee: ______________________________ 8/28/20

Susan Banzon Date
Project Manager, City of Hackensack

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: ______________________________ 8/28/20

Susan Banzon Date
Project Manager, City of Hackensack

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: [signature] 8/16/2020

Mark Olson
Commissioner, Village of Ridgefield Park
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: [signature] 8/16/2020

Mark Olson
Commissioner, Village of Ridgefield Park
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 NJ0108782 (Elizabeth City)

Approval of Report:

Permittee: ______________________________ 7/13/2020

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

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: ______________________________ 7/13/2020

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

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 NJ0156132 (Perth Amboy City)

Approval of Report:

Permittee: [signature] 8/21/20
Luis Perez-Jimenez
Director of Water Operations, City of Perth Amboy
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: [signature] 8/21/20
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: ______________________ 7/23/20

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: ______________________ 7/23/20

Robert E. Laux
Executive Director, Bergen County Utilities Authority
Date

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Tables

Figures

Appendices

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 (NJPDES) 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.

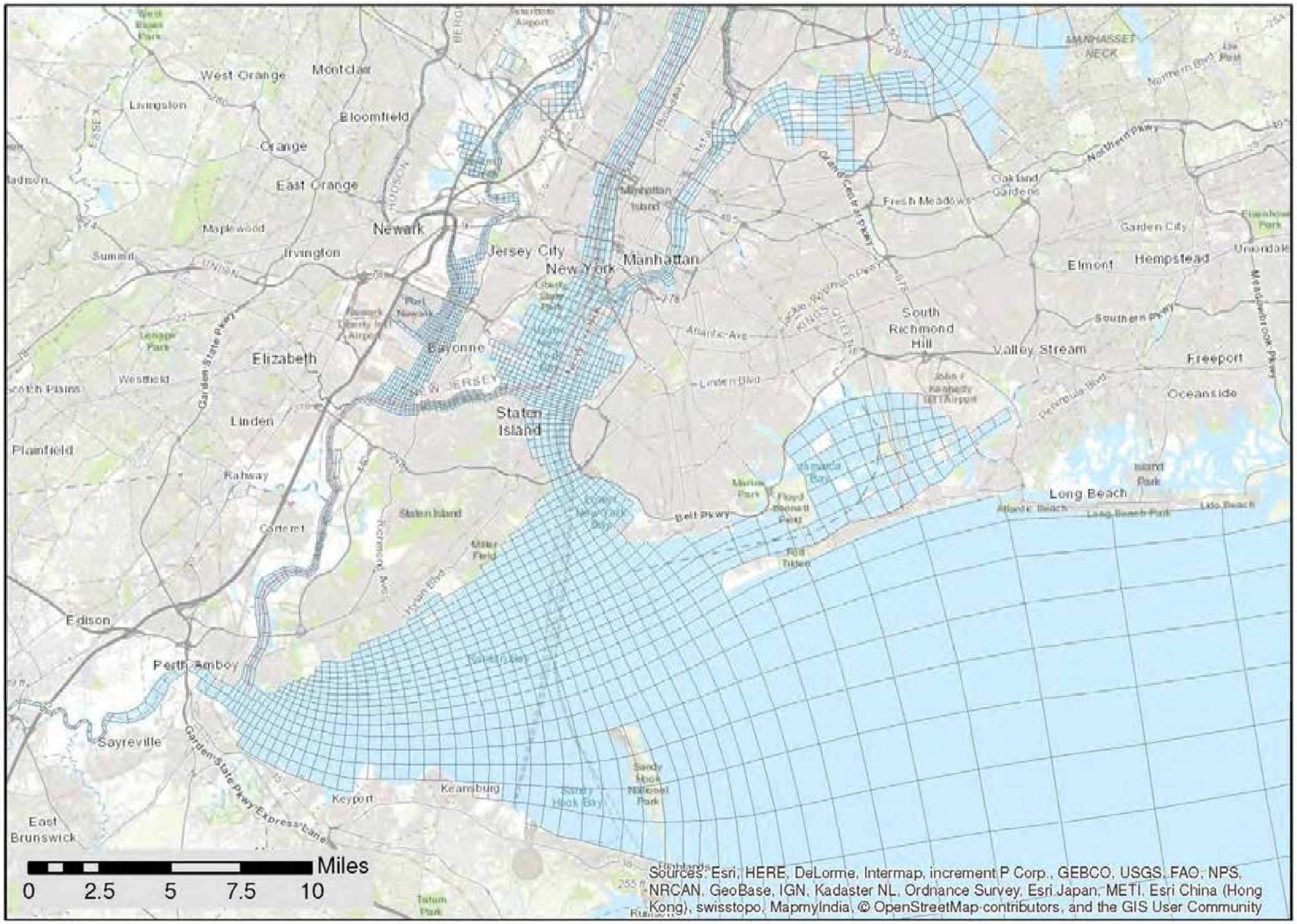


Figure 1-1. Project Area

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 m^3/sec or 16,200 cfs as measured at Green Island), followed by the Lower Passaic River (36 m^3/sec or 1,300 cfs as measured at Little Falls), the Raritan River (34 m^3/s or 1,200 cfs as measured at Bound Brook). The Hackensack River contributes as well, although only 1.9 m^3/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 (M_2 and S_2) 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.

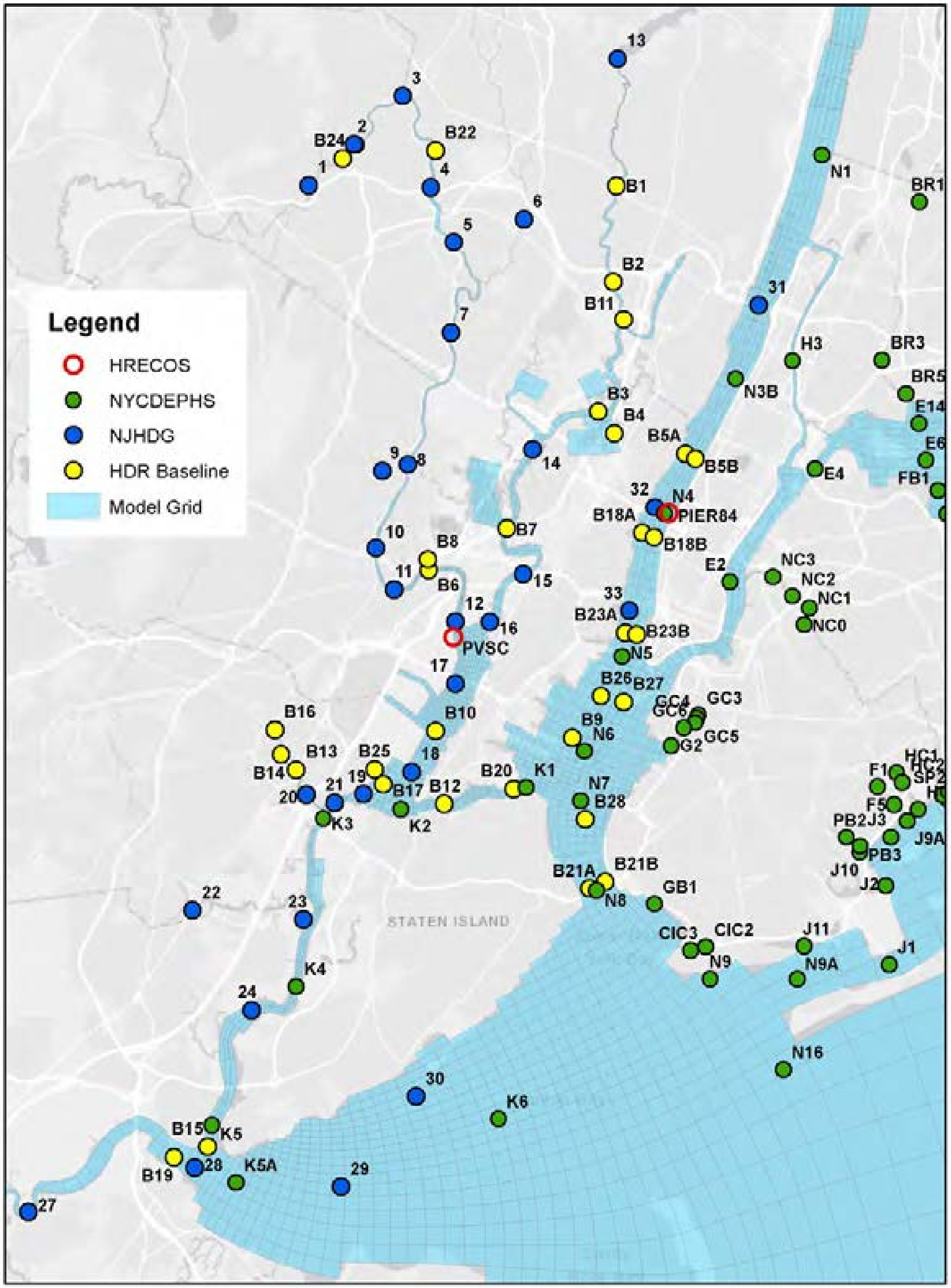


Figure 2-1. NJ Dischargers Group, HDR, and MERI Water Quality Survey Stations

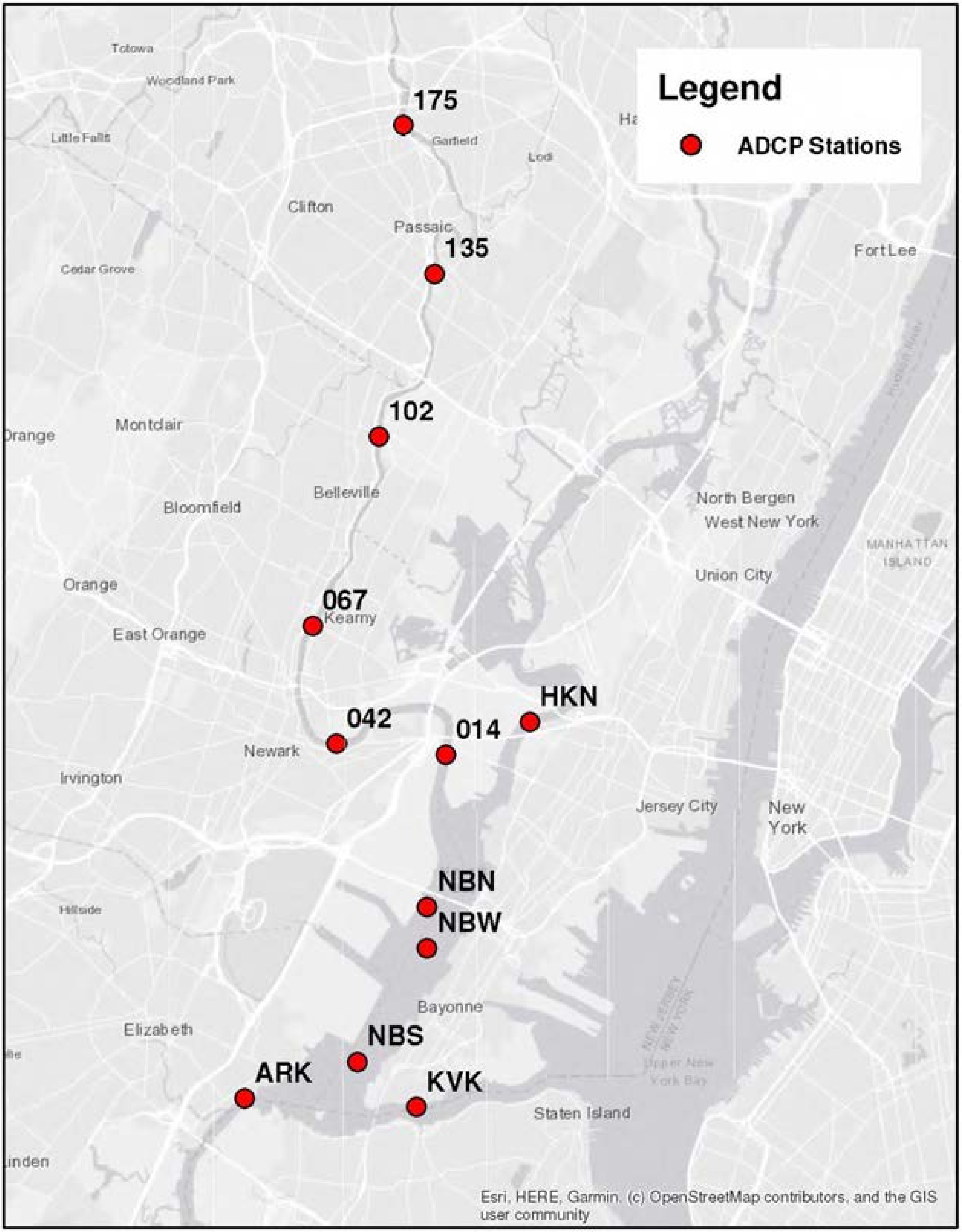


Figure 2-2. Map of ADCP Mooring Stations: 2009-2010

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
Hackensack River & Tributaries	B1[5]	Hackensack River	40.89880	-74.03164	1	HDR	
Hackensack River & Tributaries	B2[5]	Hackensack River	40.86212	-74.03270	1	HDR	
Hackensack River & Tributaries	B11	Overpeck Creek	40.84610	-74.02701	1	HDR	
Hackensack River & Tributaries	S1	Berry's Creek	40.82810	-74.07955	1	HDR	
Hackensack River & Tributaries	B3	Cromakill Creek	40.80765	-74.04169	2	HDR	
Hackensack River & Tributaries	S2	Cromakill Creek	40.80487	-74.03663	1	HDR	
Hackensack River & Tributaries	B4	Cromakill Creek	40.79623	-74.03449	1	HDR	
Hackensack River & Tributaries	14[5]	Hackensack River	40.79190	-74.07837	2	NJHDG	
Hackensack River & Tributaries	S3	Sawmill Creek	40.76080	-74.09551	1	HDR	
Hackensack River & Tributaries	B7	Hackensack River	40.75899	-74.09297	2	HDR	Saw Mill Creek
Hackensack River & Tributaries	S5	Penhorn Creek	40.75247	-74.07553	1	HDR	
Hackensack River & Tributaries	15[5]	Hackensack River	40.73950	-74.08400	2	NJHDG	
Hackensack River & Tributaries	16	Hackensack River	40.71950	-74.10283	2	NJHDG	
Newark Bay & Tributaries	17[5]	Newark Bay	40.69383	-74.12216	2	NJHDG	
Newark Bay & Tributaries	B10	Newark Bay	40.67388	-74.13346	2	LTCP	
Newark Bay & Tributaries	18[5,6]	Newark Bay	40.65666	-74.14683	2	NJHDG	
Newark Bay & Tributaries	B17	Newark Bay	40.65158	-74.16262	1	LTCP	
Newark Bay & Tributaries	19	Newark Bay	40.64750	-74.17350	2	NJHDG	At Arthur Kill
Newark Bay & Tributaries	21	Arthur Kill	40.64395	-74.18961	2	NJHDG	River Mouth
Newark Bay & Tributaries	B16	Elizabeth River	40.67500	-74.22218	1	LTCP	
Newark Bay & Tributaries	B14	Elizabeth River	40.66462	-74.21881	1	LTCP	
Newark Bay & Tributaries	B13	Elizabeth River	40.65809	-74.21040	1	LTCP	
Newark Bay & Tributaries	20[5]	Elizabeth River	40.64766	-74.20517	1	NJHDG	River Mouth sampled from bridge
Newark Bay & Tributaries	S4	Peripheral Ditch	40.68989	-74.16420	1	LTCP	Stormwater pump station
Newark Bay & Tributaries	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 Hydroscience (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.

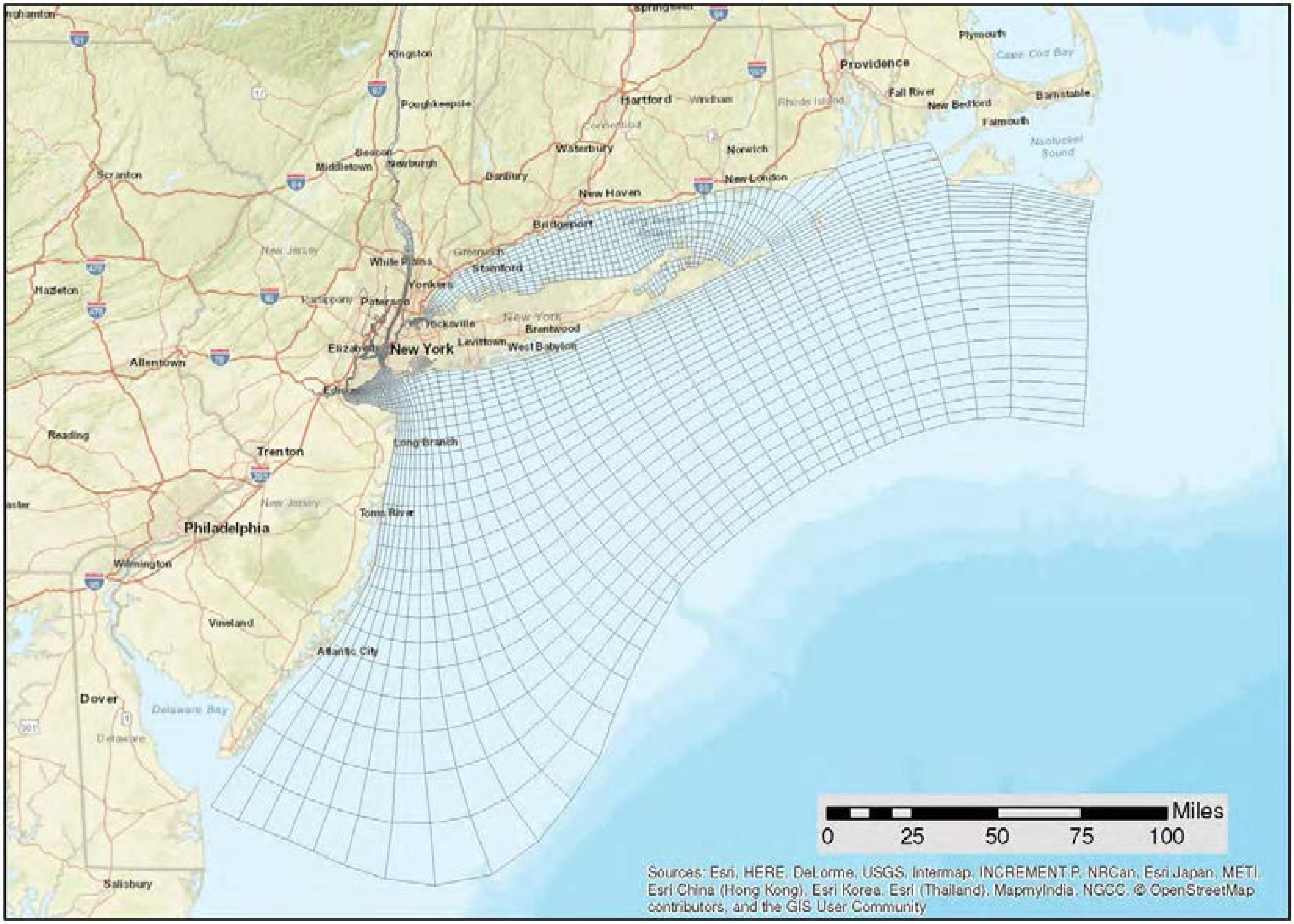


Figure 4-1. PVSC LTCP Model Grid

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

Model	Number of Grid Cells	Smallest Grid Cell Size (m^2)	Largest Grid Cell Size (km^2)	Average Grid Cell Size (km^2)
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.

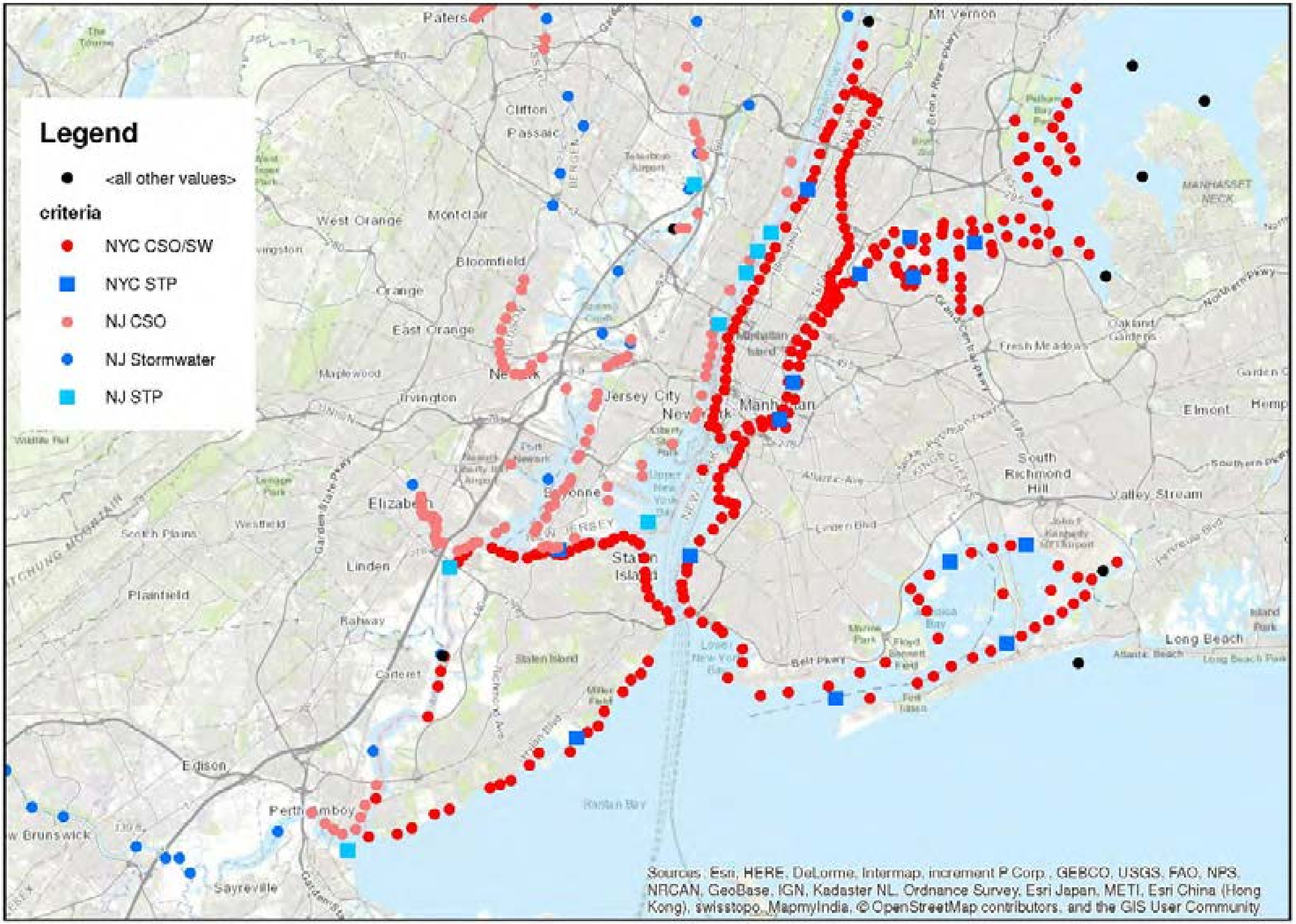


Figure 4-2. Location of CSO/Stormwater and STP Flows

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-ltcpsubmittals.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.

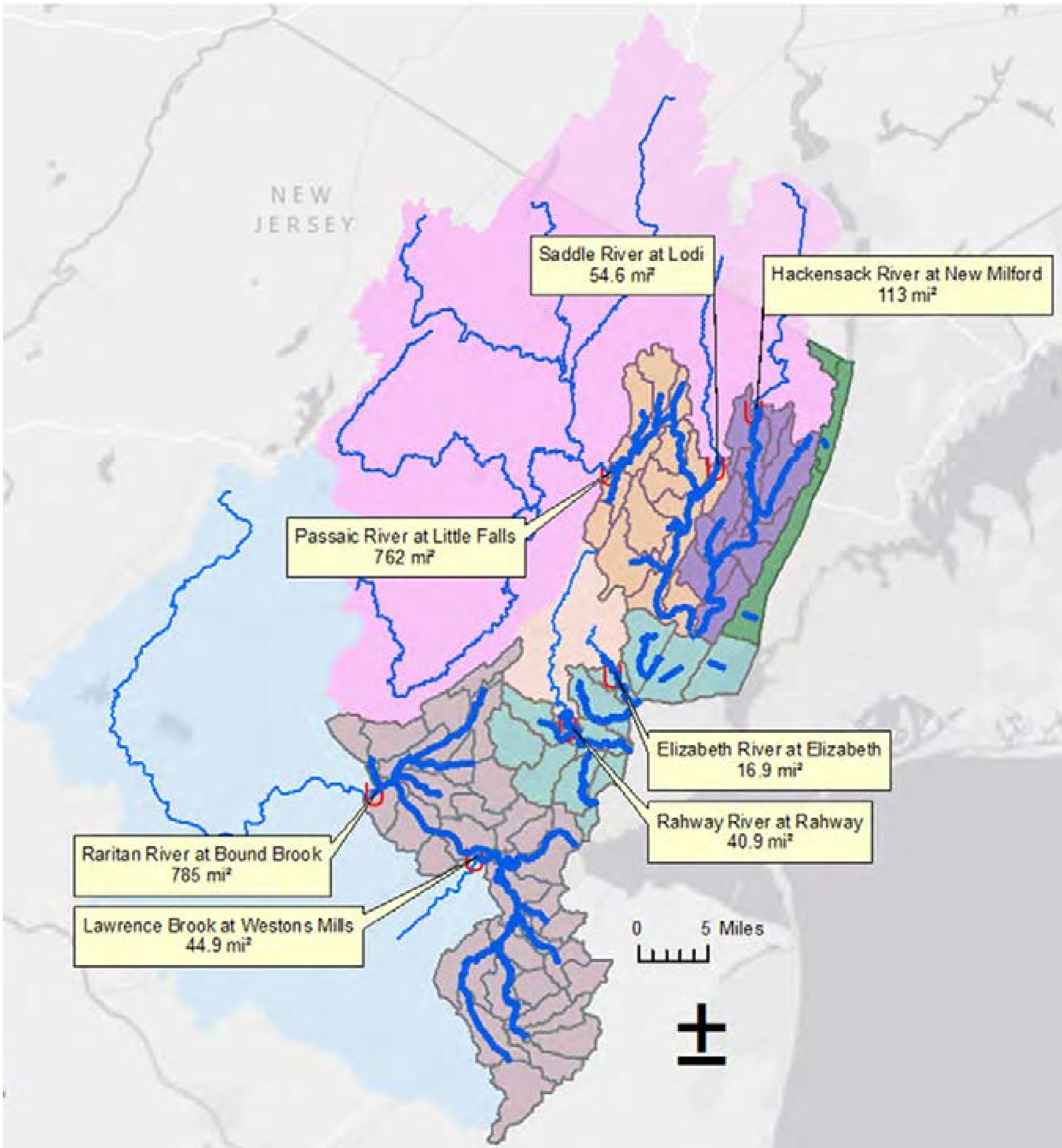


Figure 4-3. Stormwater/Runoff Model Coverage Area

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 (mi^2)
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

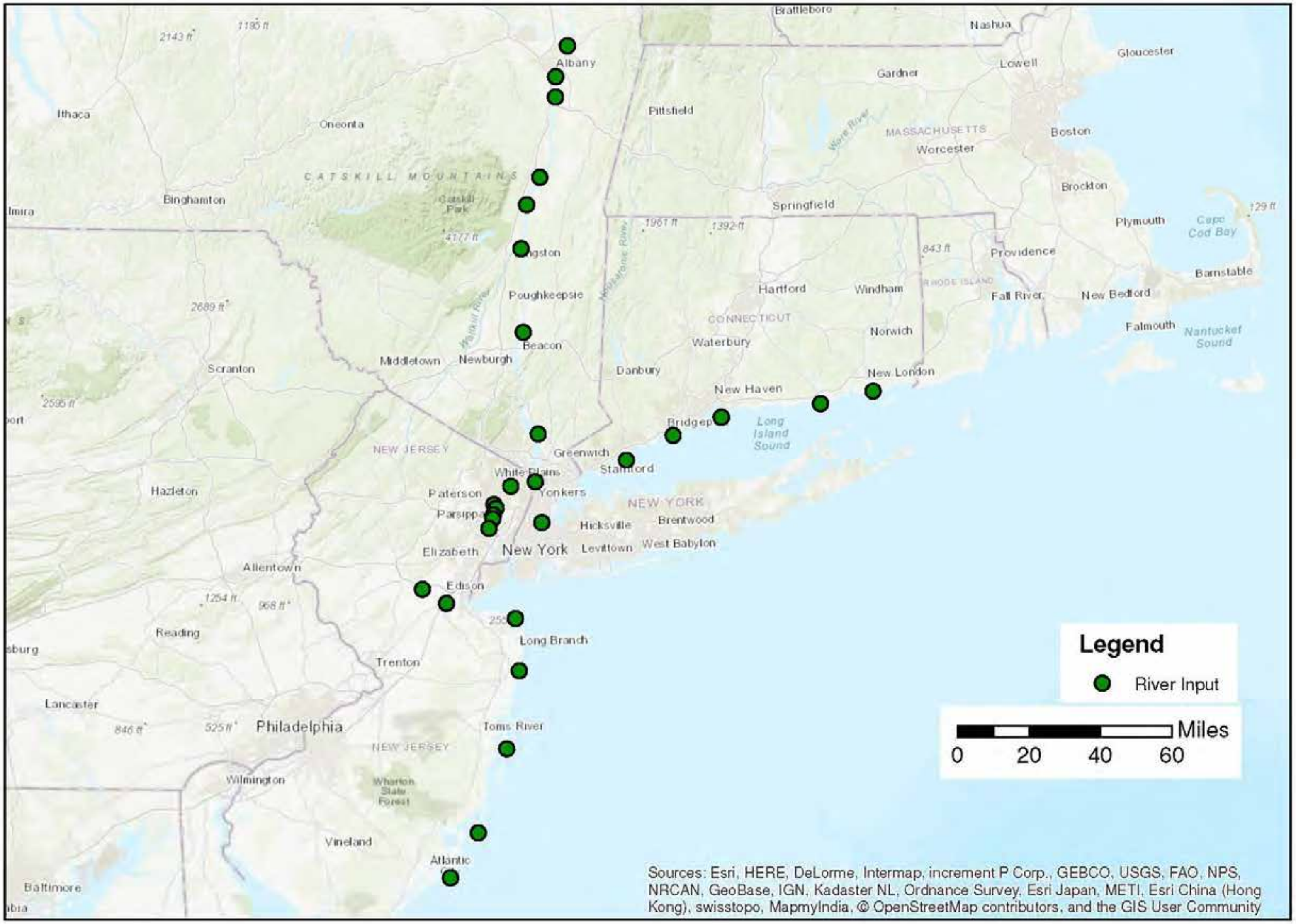


Figure 4-4. River Inflow Locations

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 Wallkill 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 m^3/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 m^3/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 m^3/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+Wallkill 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.

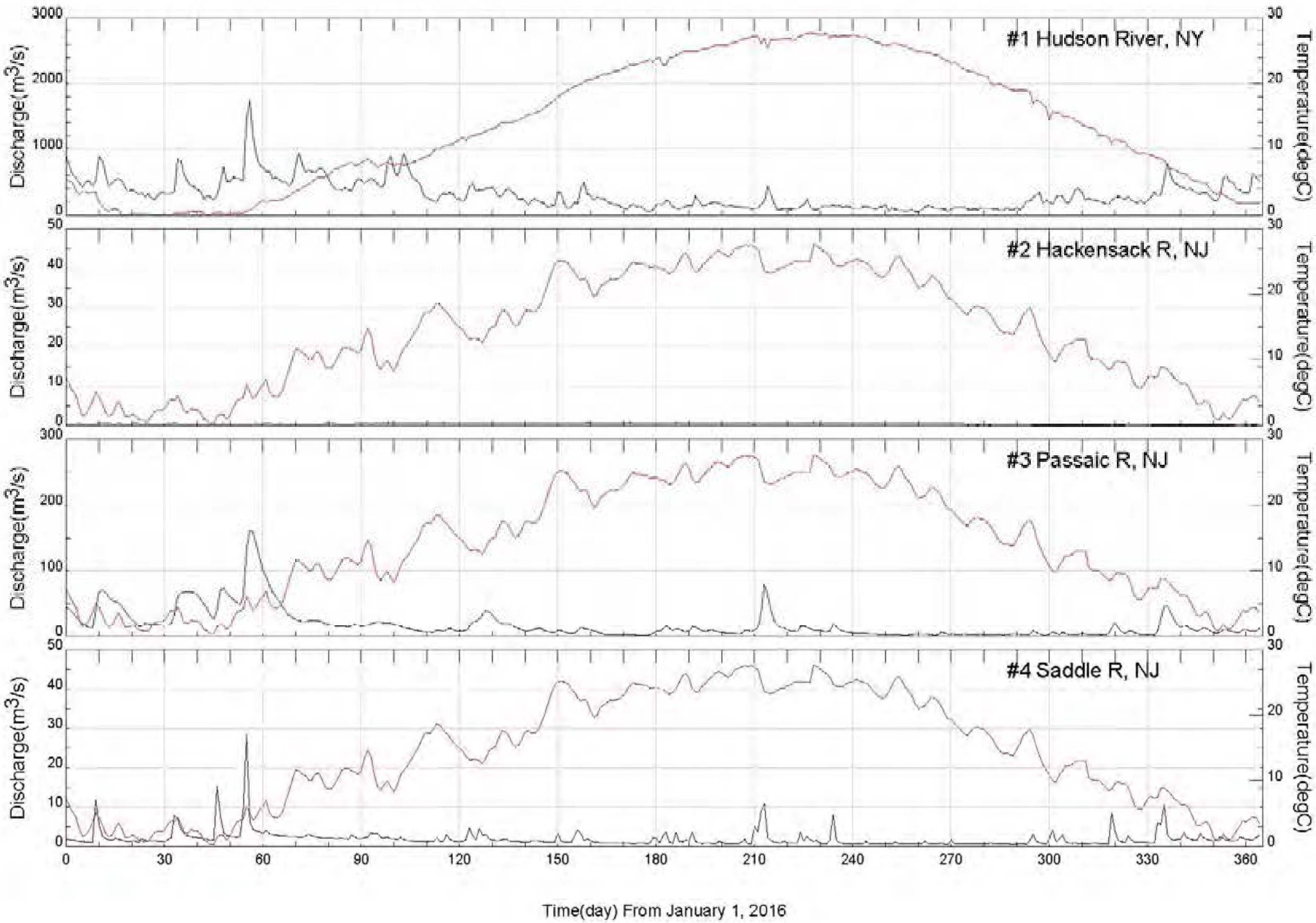


Figure 4-5. 2016 River Flow Input and Its Water Temperature

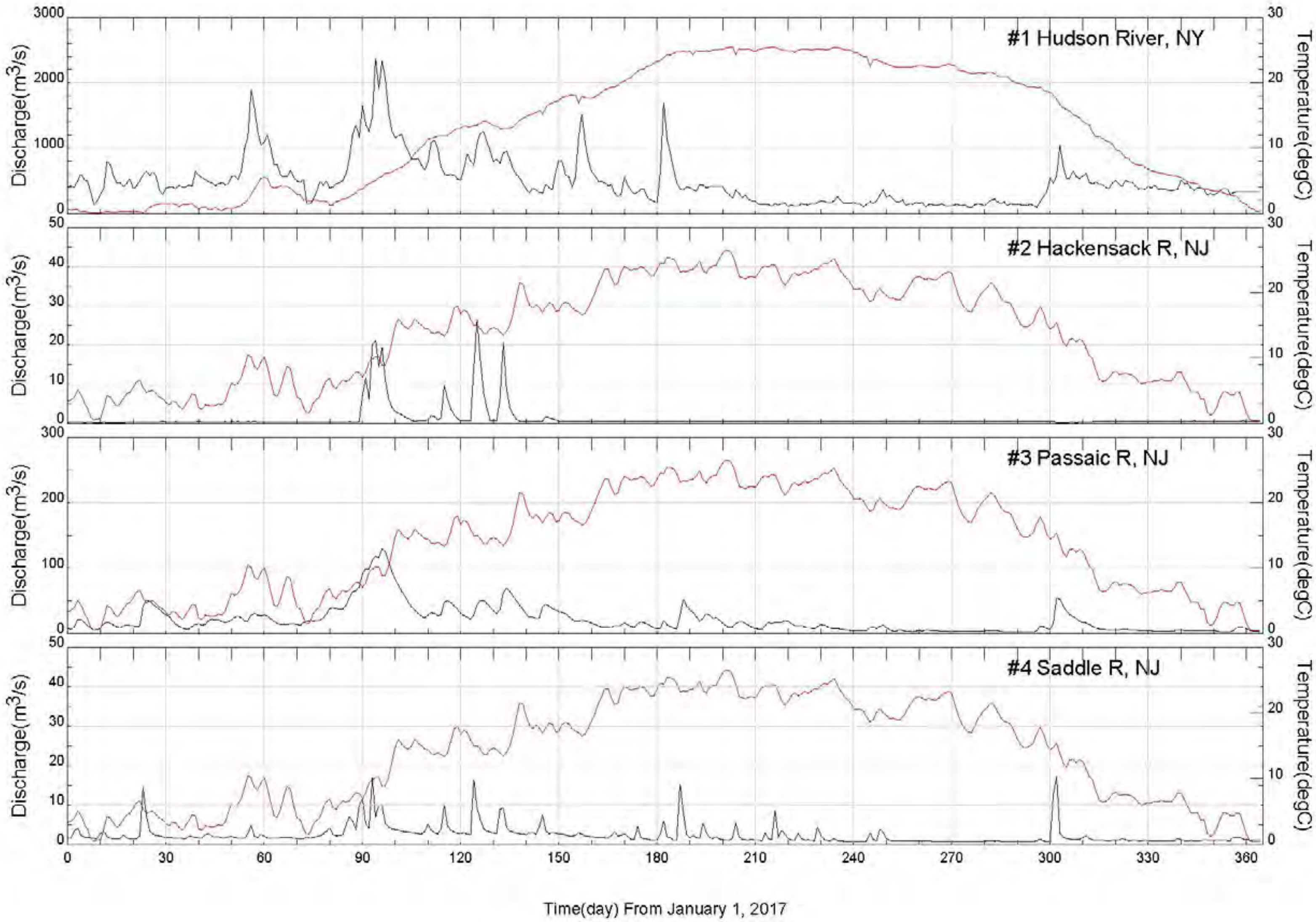


Figure 4-6. 2017 River Flow Input and Its Water Temperature

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 m^3/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:

$$\eta(x,t) = \eta_g(x,t) + \eta_T(x,t) + \eta_M(x,t) \qquad (4\text{-}1)$$

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 parabathic 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:

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

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 (α = 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:

$$S(x,t) = S_L(x,t) - 2.0 \tag{4-3}$$

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.

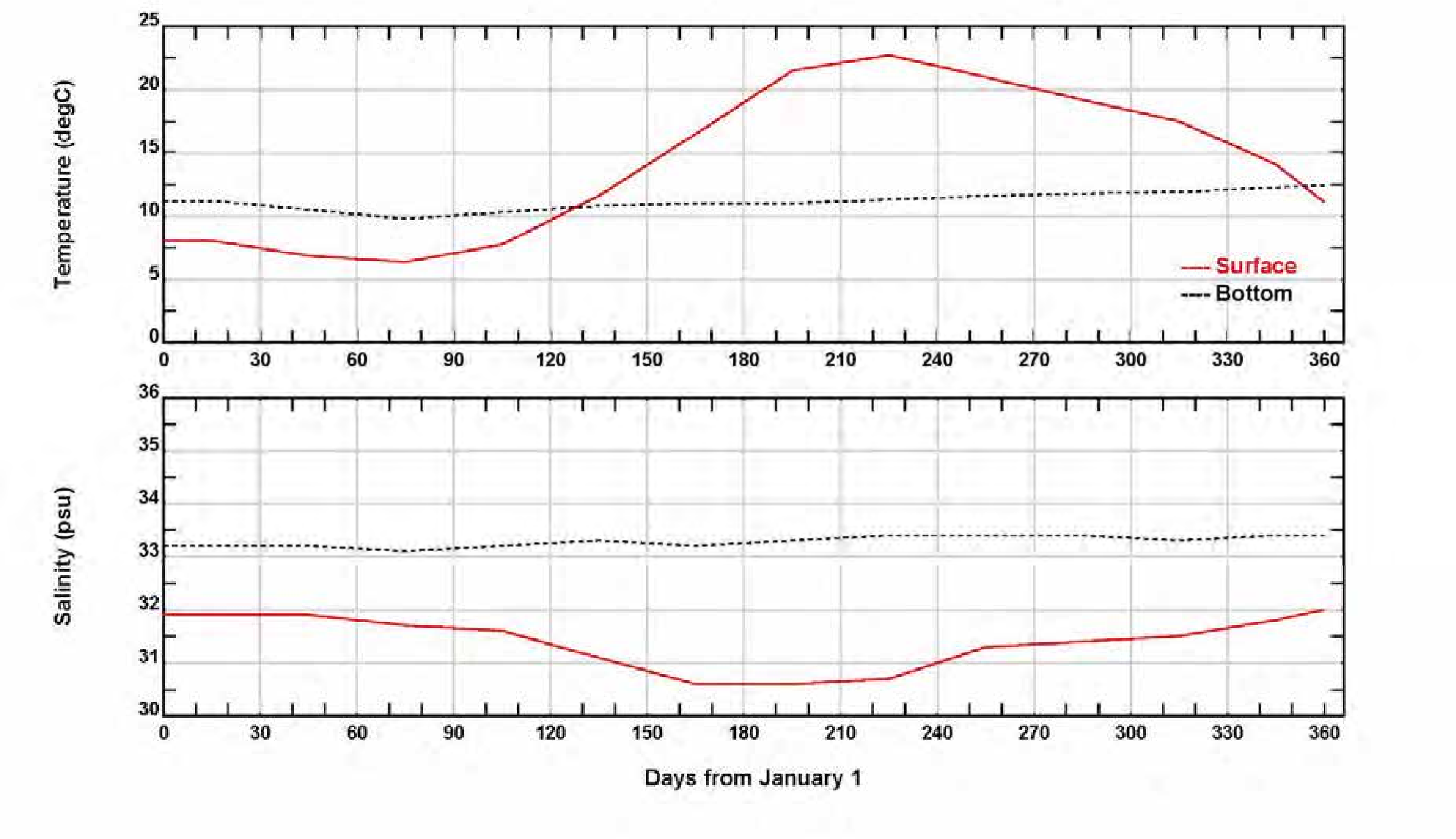


Figure 4-7. Offshore Temperature and Salinity Boundary Conditions

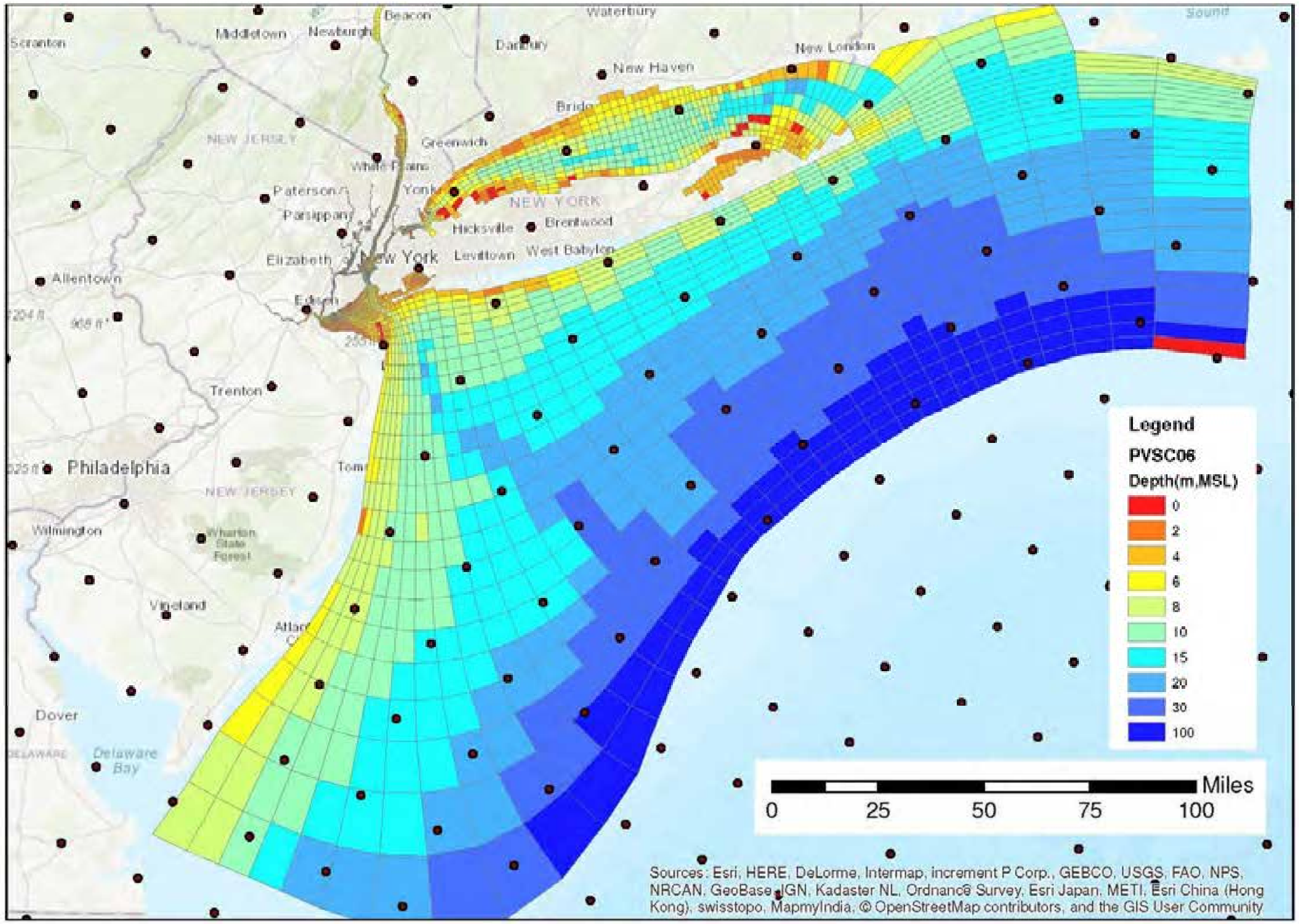


Figure 4-8. NOAA NARR Data Locations

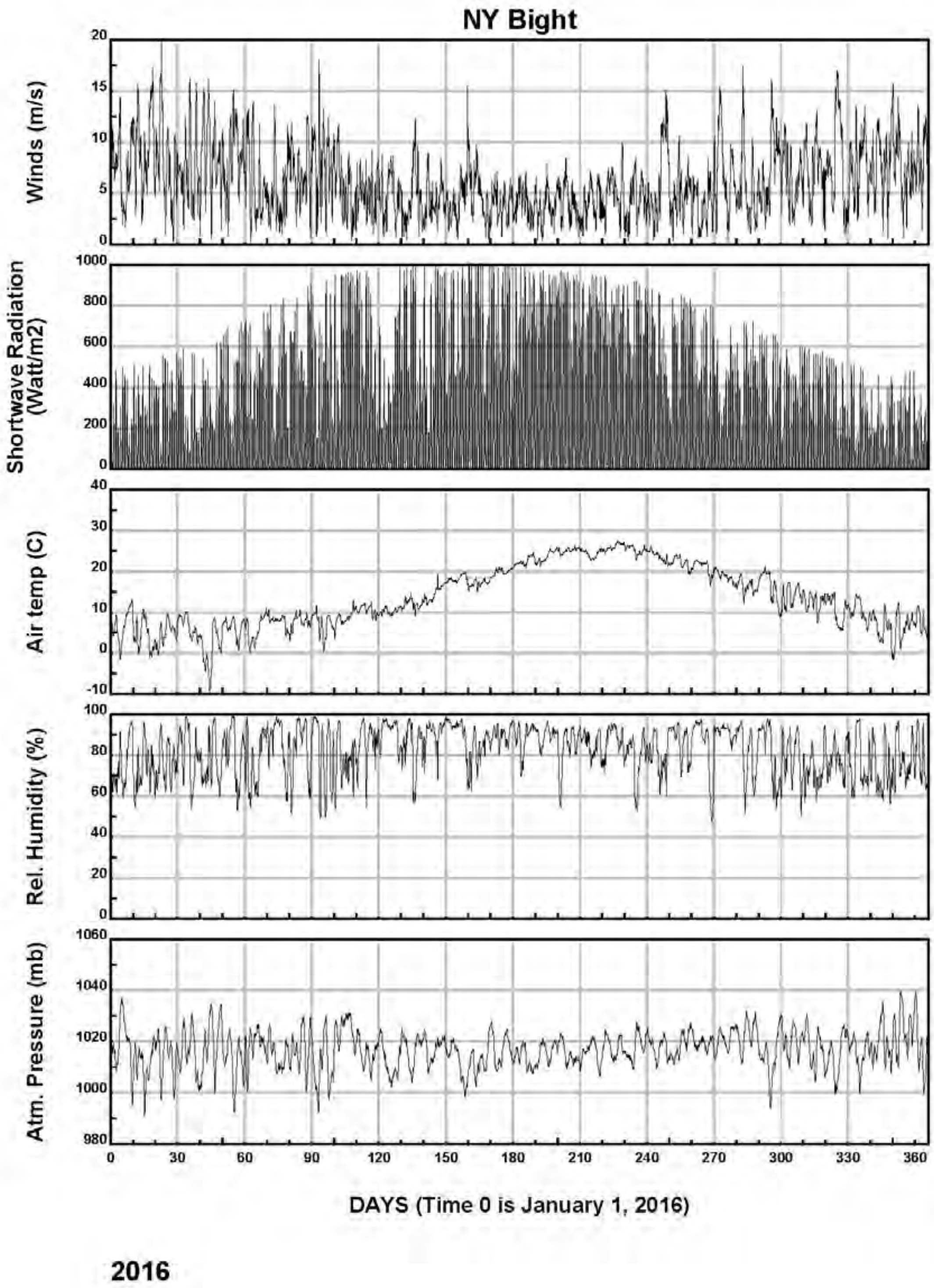


Figure 4-9. 2016 Meteorological Input Data

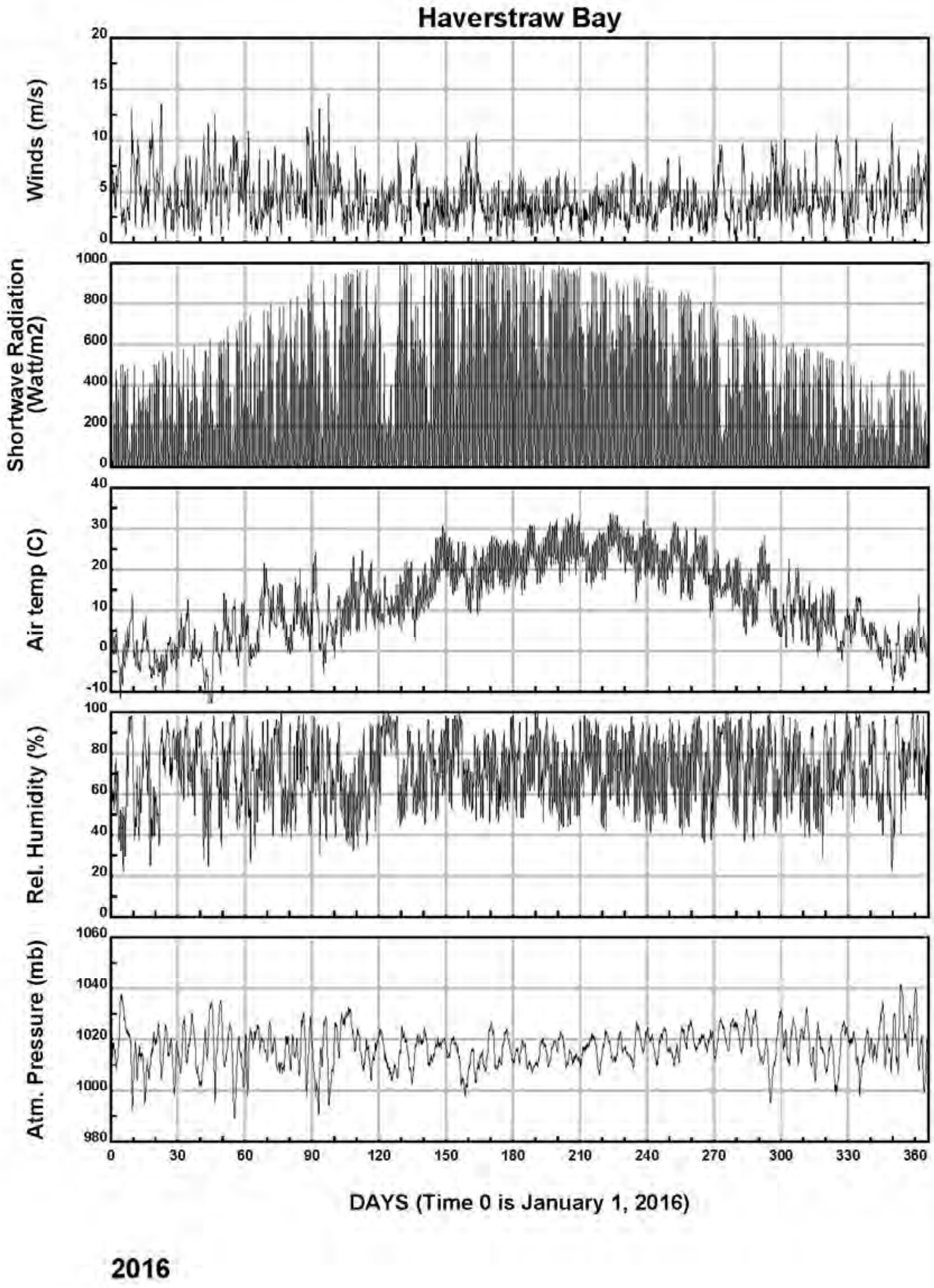


Figure 4-10. 2017 Meteorological Input Data

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 7th 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 3rd Ave W and N 9th St.
S1-NWK-HR2	High Density Residential	Newark	Intersection of Goldsmith St. and Aldine St.
S1-PAT-CI1	Commercial/Industrial	Paterson	Shady St. between 6th Ave. and Peel St.
S1-NWK-CI2	Commercial/Industrial	Newark	Intersection of NJRR Ave. and Vanderpool St.

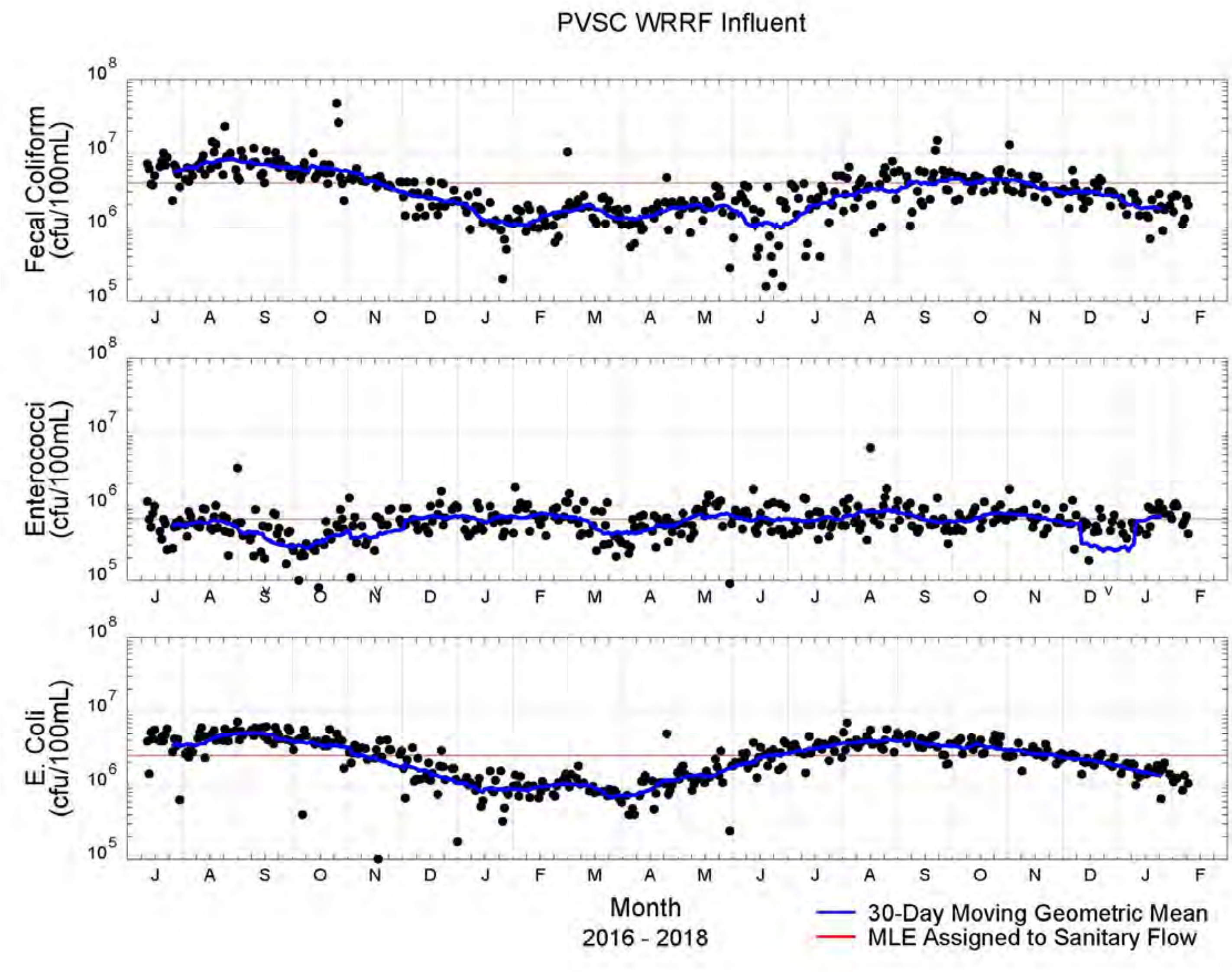


Figure 4-11. PVSC WRRF Influent FIB Concentrations

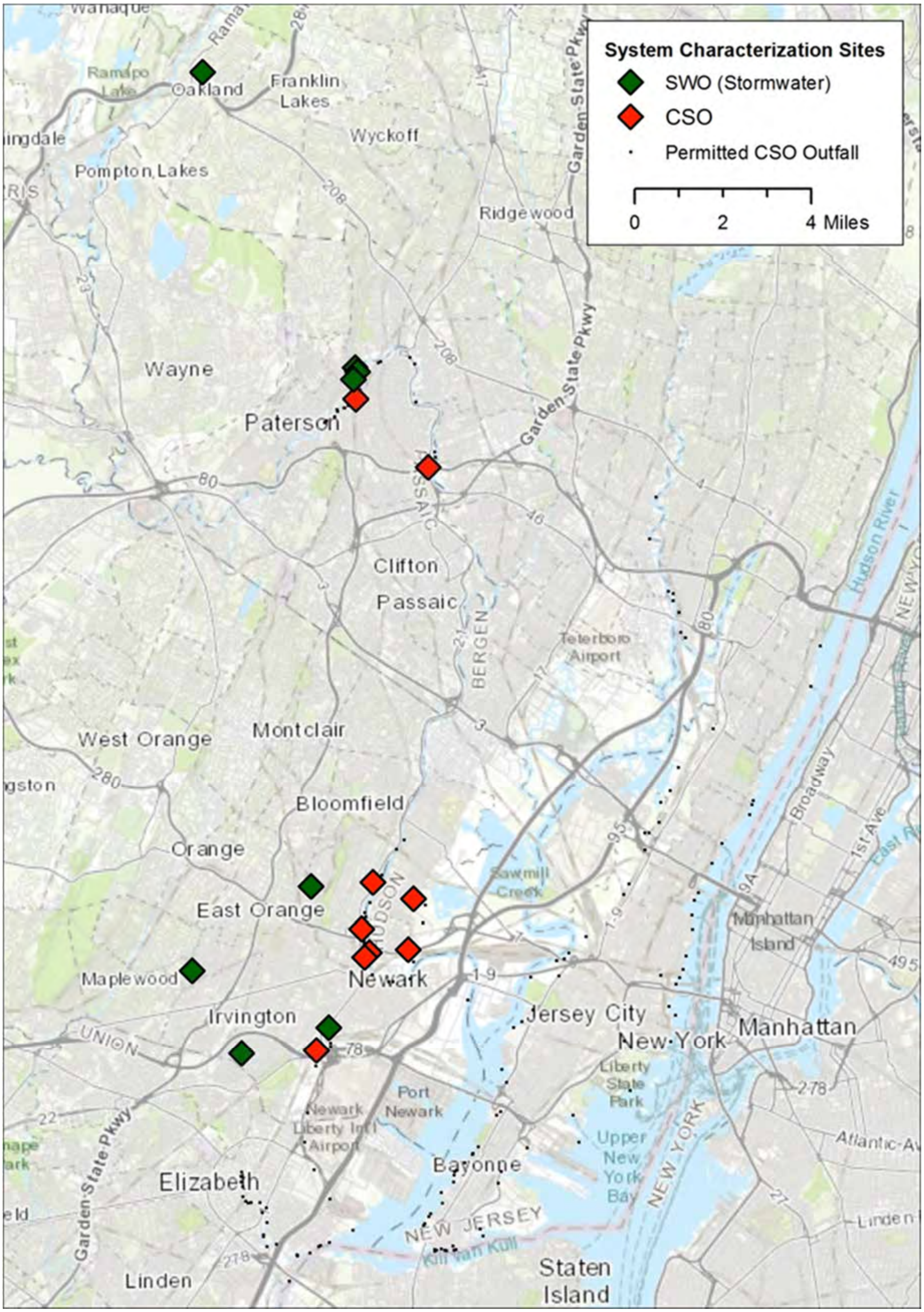


Figure 4-12. CSO and Stormwater Sampling Locations

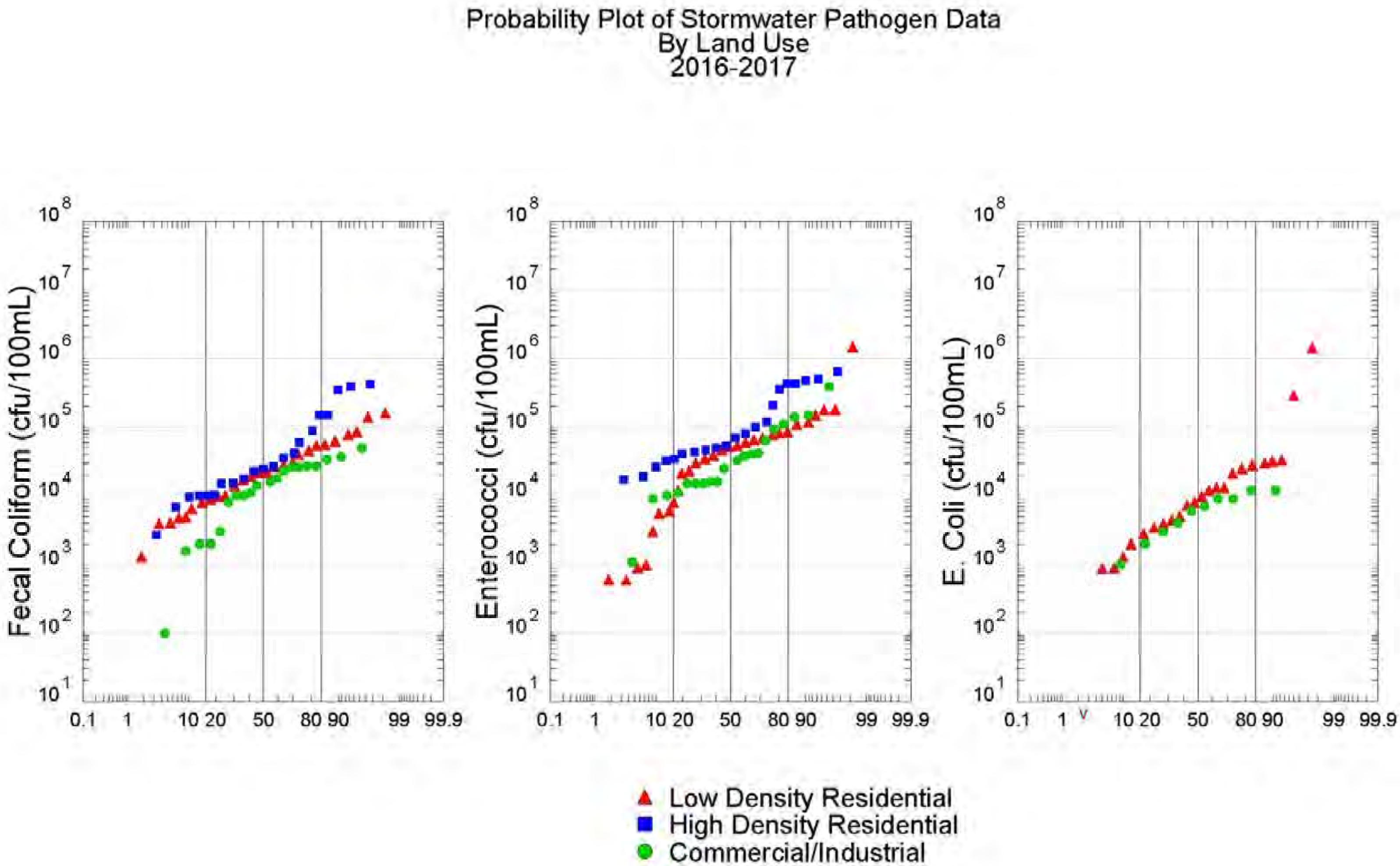


Figure 4-13. Stormwater FIB Concentrations by Land Use

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:

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

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 approached 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

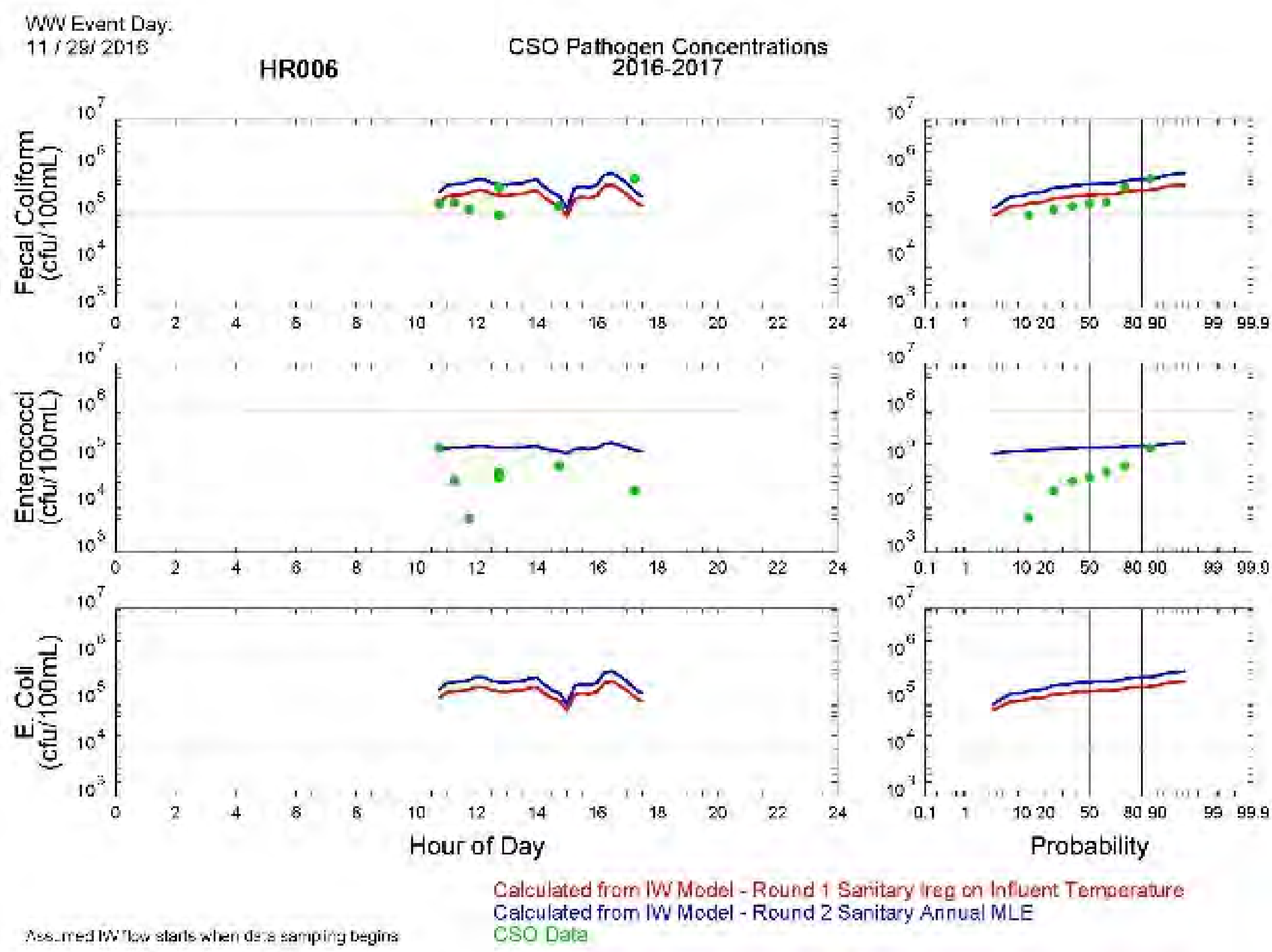


Figure 4-14. Comparison of Calculated CSO FIB Concentrations verses Measured FIB Concentrations

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

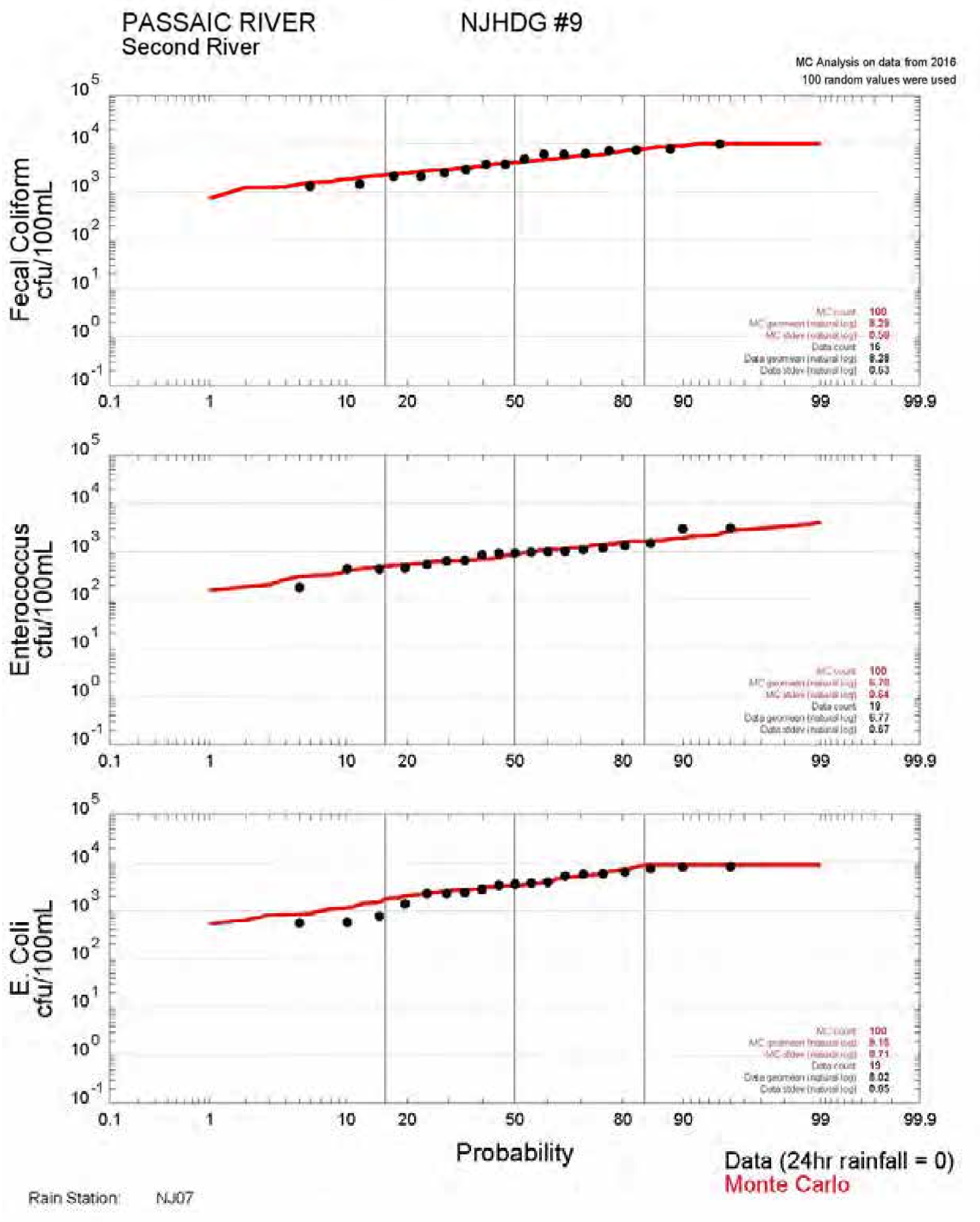


Figure 4-15. Example of Monte Carlo Bacteria Distributions used for Assigning Dry-Weather River Concentrations

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 (10^{12} cfu/yr)	Enterococci (10^{12} cfu/yr)	E. Coli (10^{12} 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 (10^{12} cfu/yr)	Enterococci (10^{12} cfu/yr)	E. Coli (10^{12} 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 it 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:

$$N = N_0 e^{(-Kbt)} \tag{5-1}$$

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:

$$\begin{aligned} K_b &= [0.8 + 0.006(\%\text{seawater})]1.07^{(T-20)} \\ &+ \alpha I_0(t)/K_e H[1-\exp(-K_e H)] \\ &+ V_s/H \qquad \text{(Mancini, 1978)} \end{aligned} \tag{5-2}$$

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 ℃). 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 ℃	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 ℃	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.

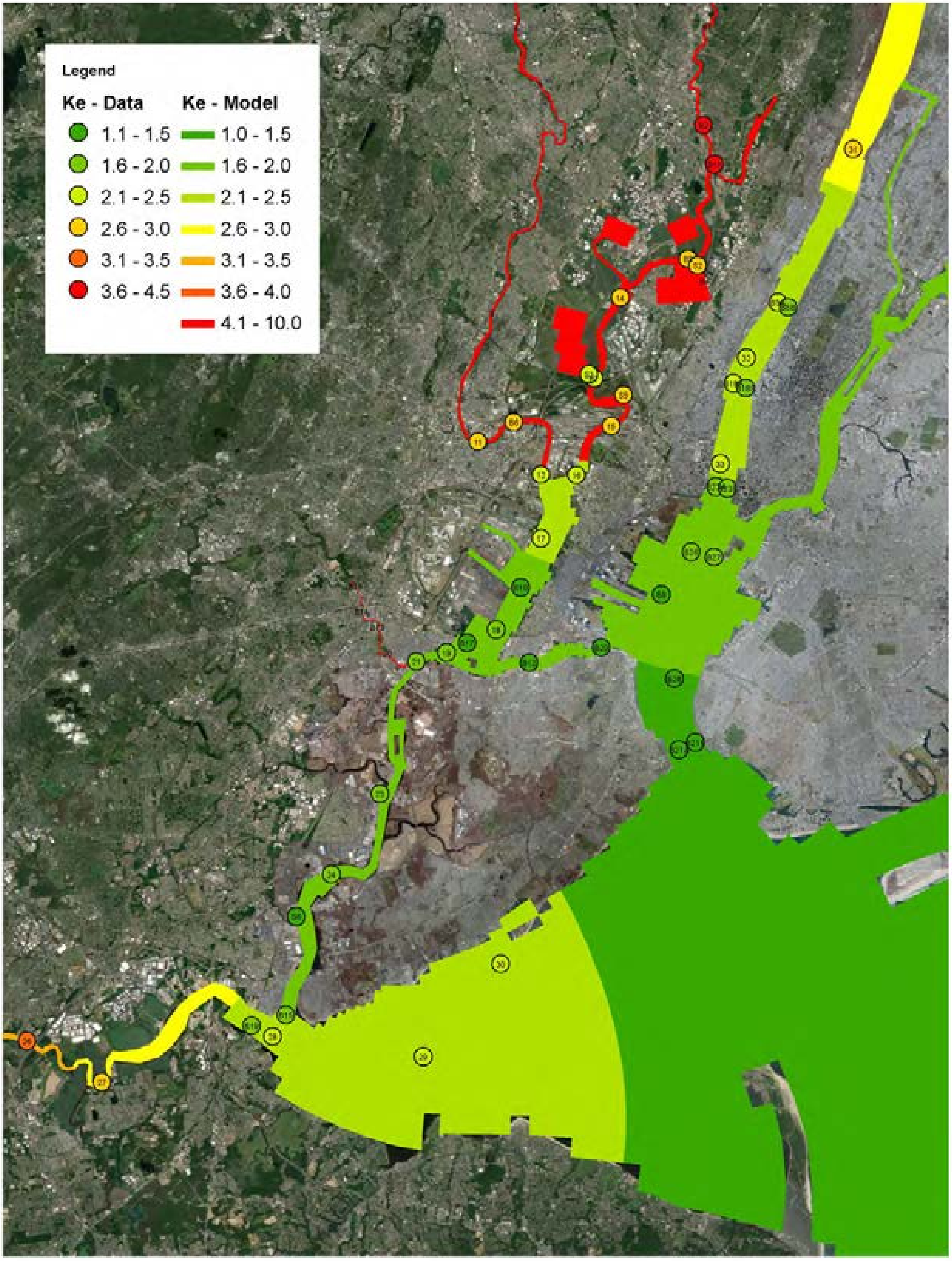


Figure 5-1. Assigned Spatially Varying Light Extinction Coefficients (Ke)

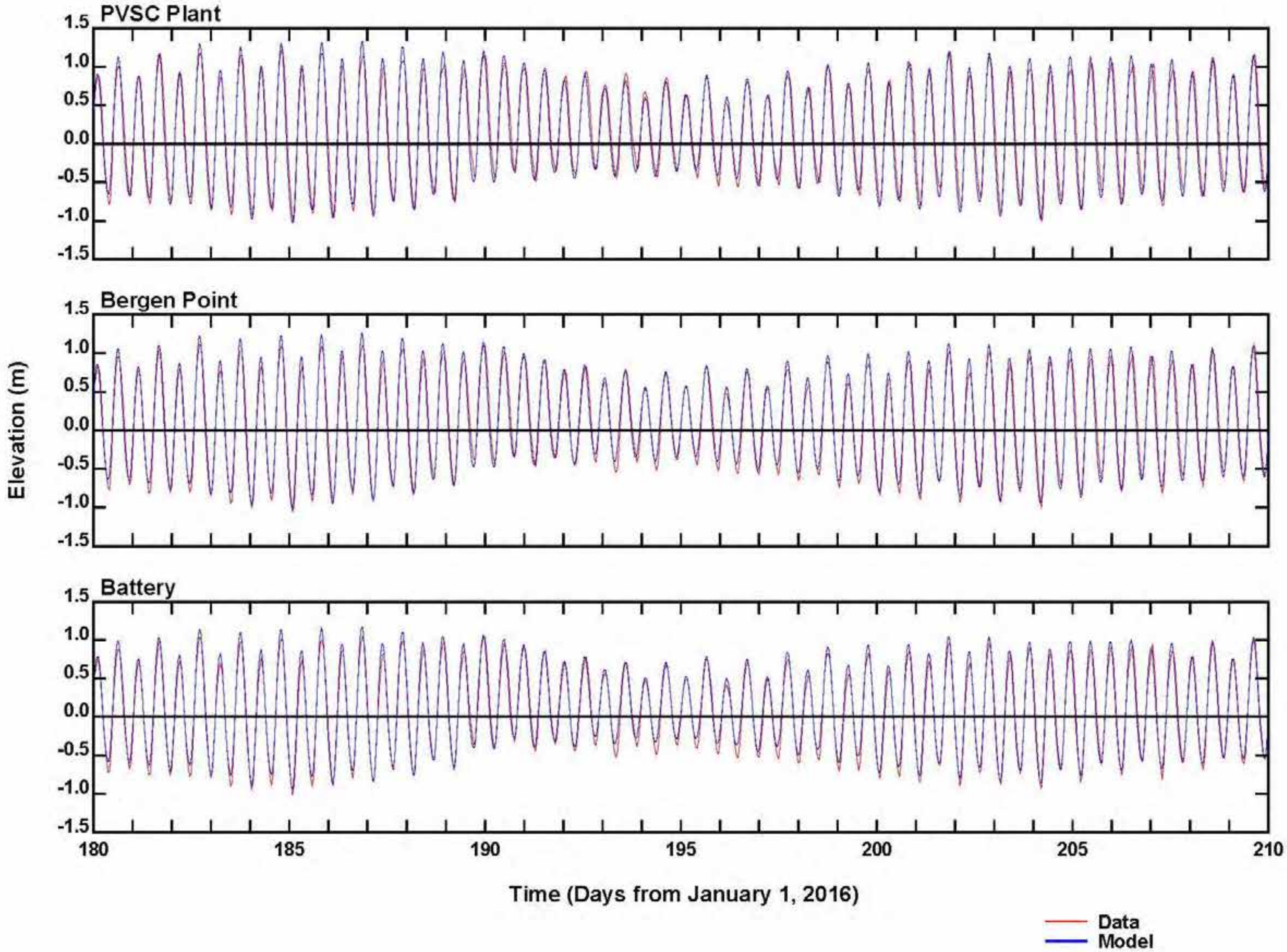


Figure 5-2. 2016 Comparison of Hourly Tidal Water Elevations

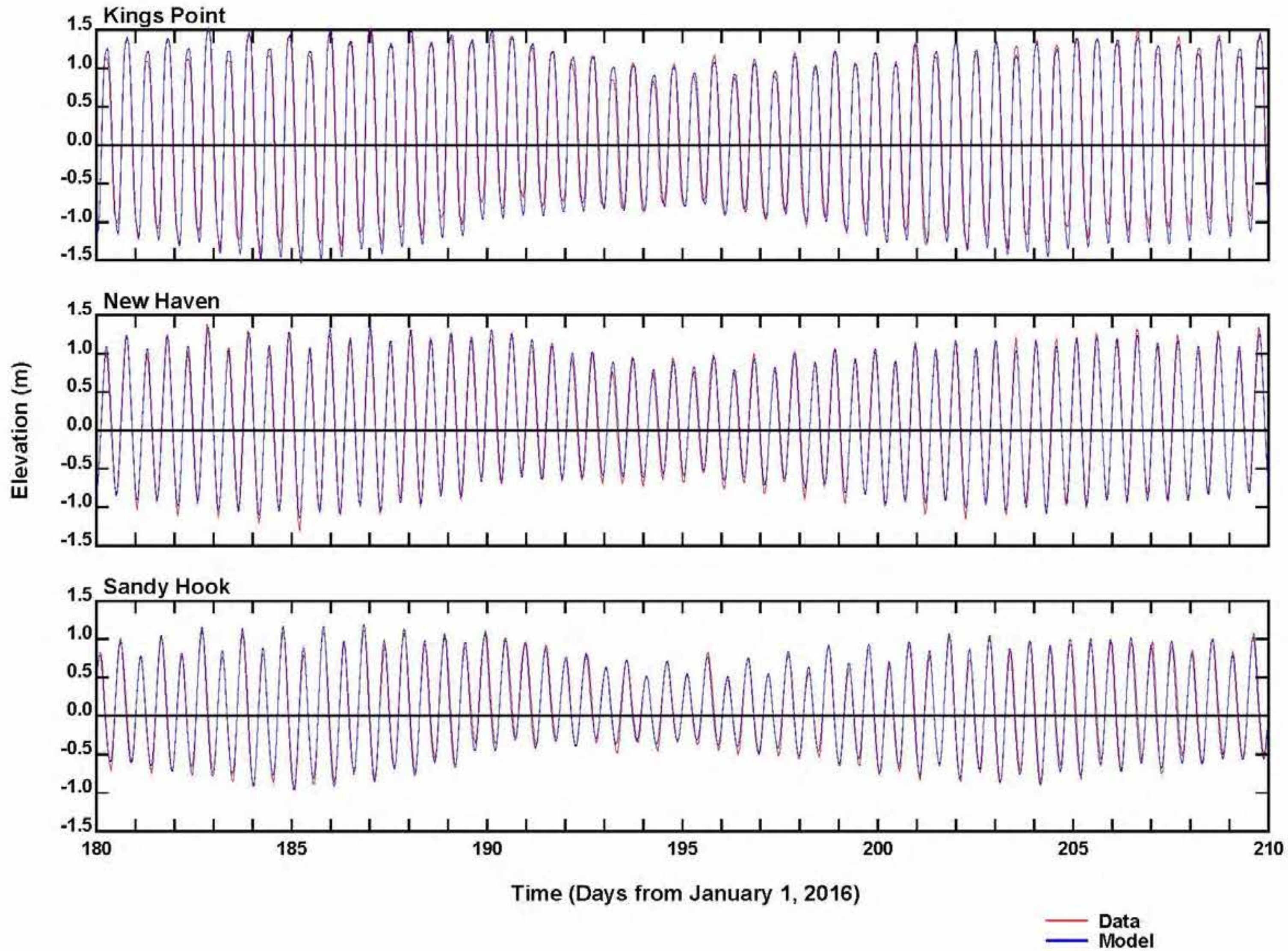


Figure 5-2. 2016 Comparison of Hourly Tidal Water Elevations (Continued)

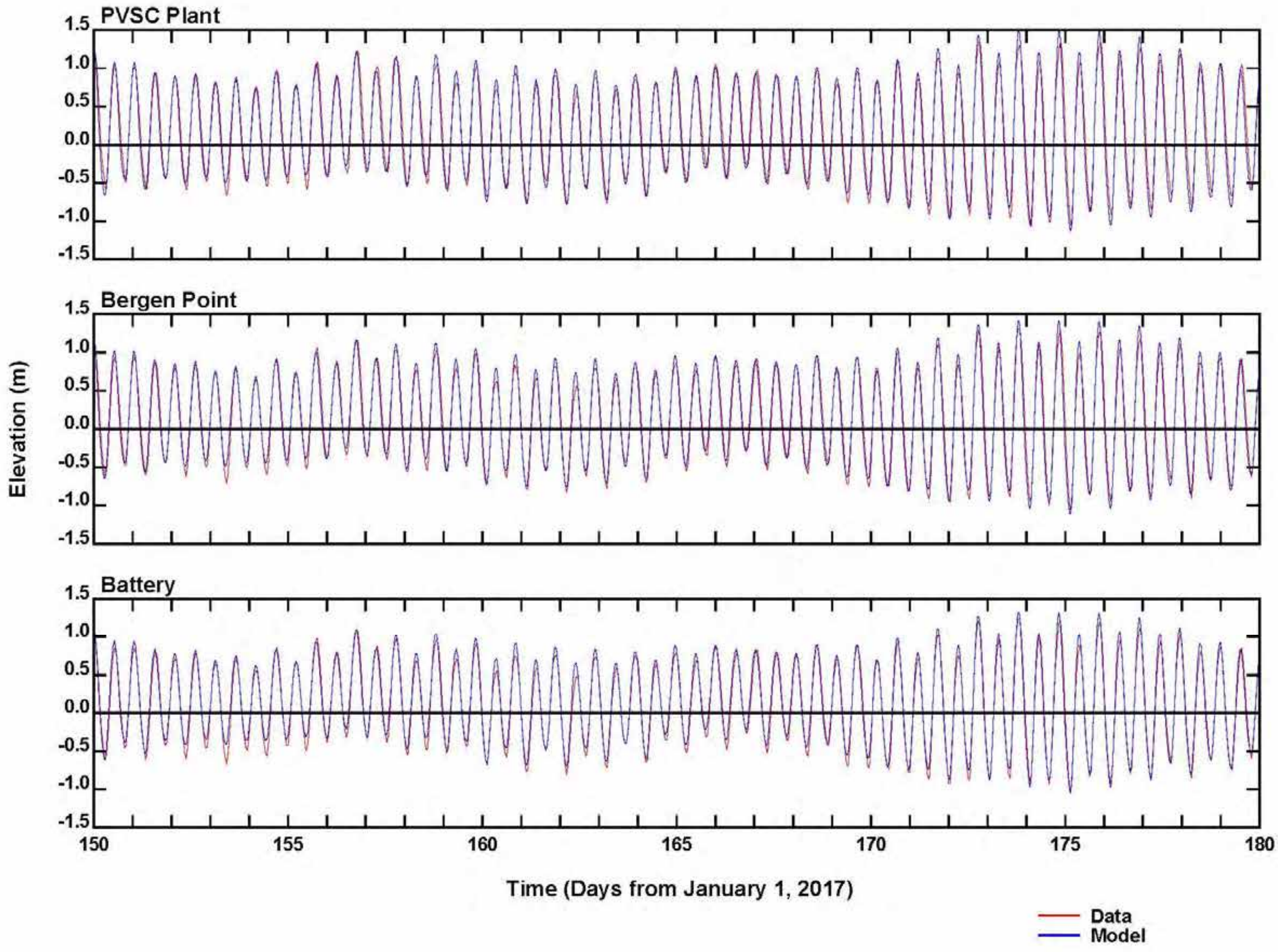


Figure 5-3. 2017 Comparison of Hourly Tidal Water Elevations

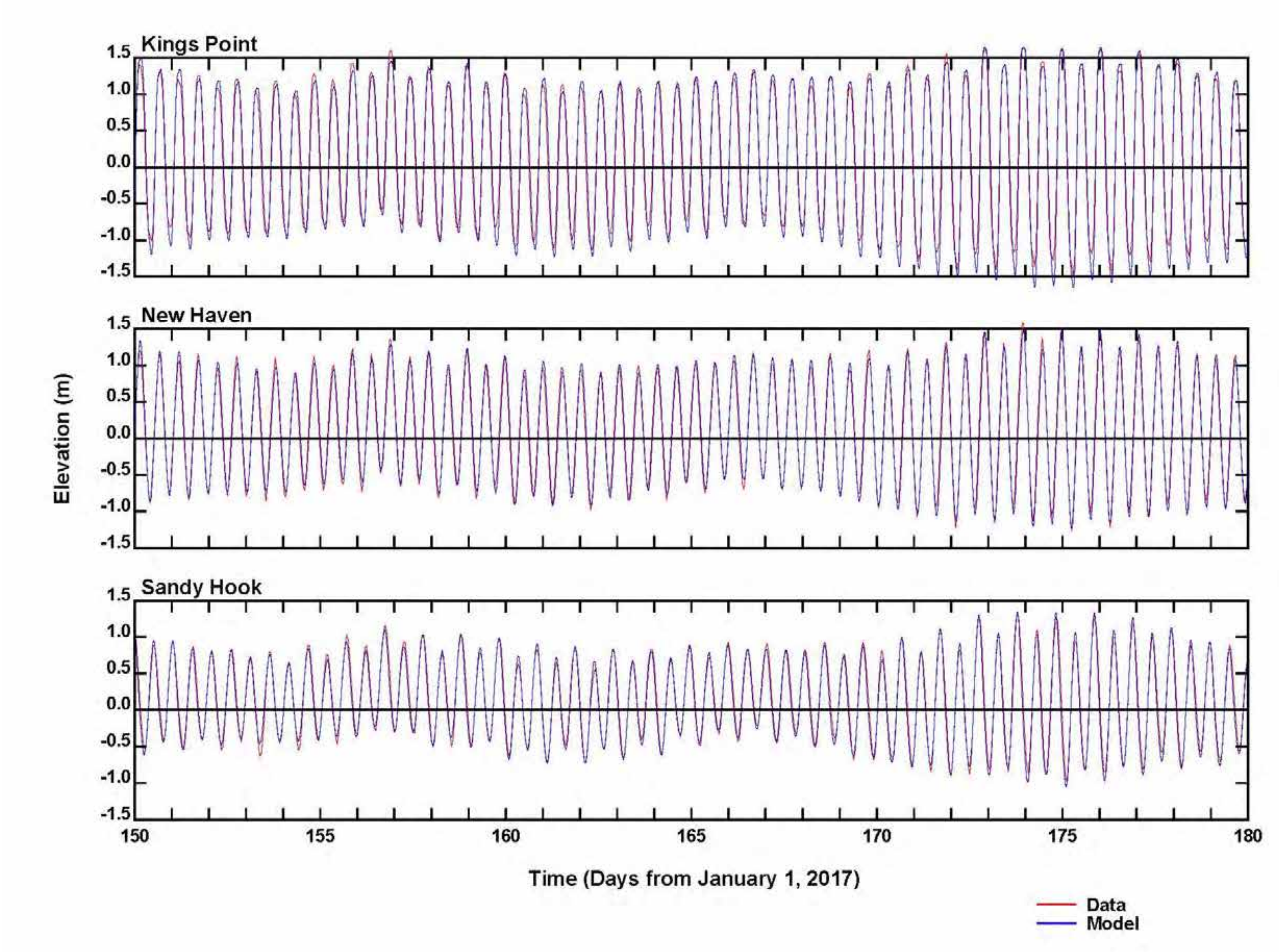


Figure 5-3. 2017 Comparison of Hourly Tidal Water Elevations (Continued)

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.

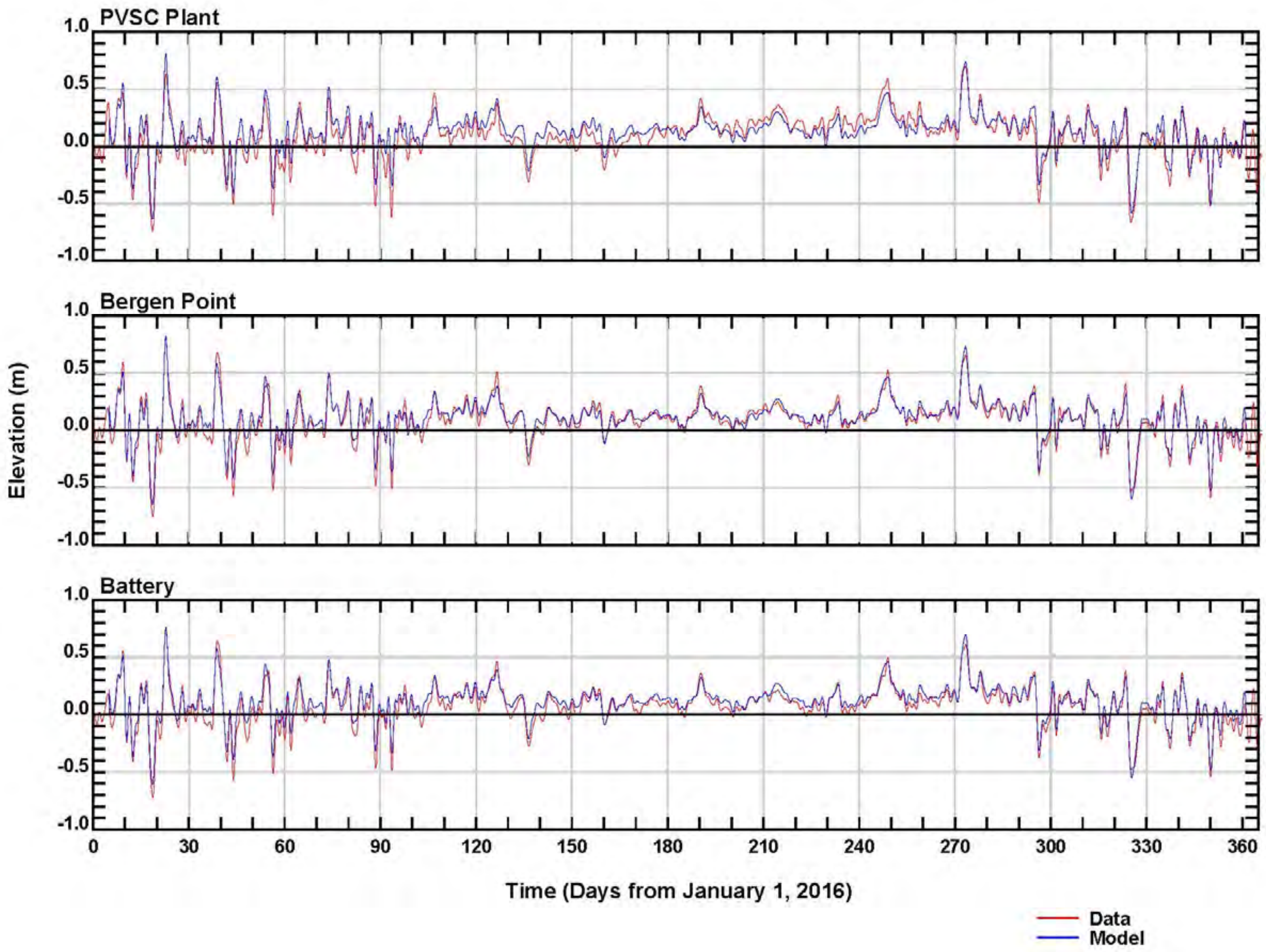


Figure 5-4. 2016 Comparison of 35hr Low-Passed Elevations

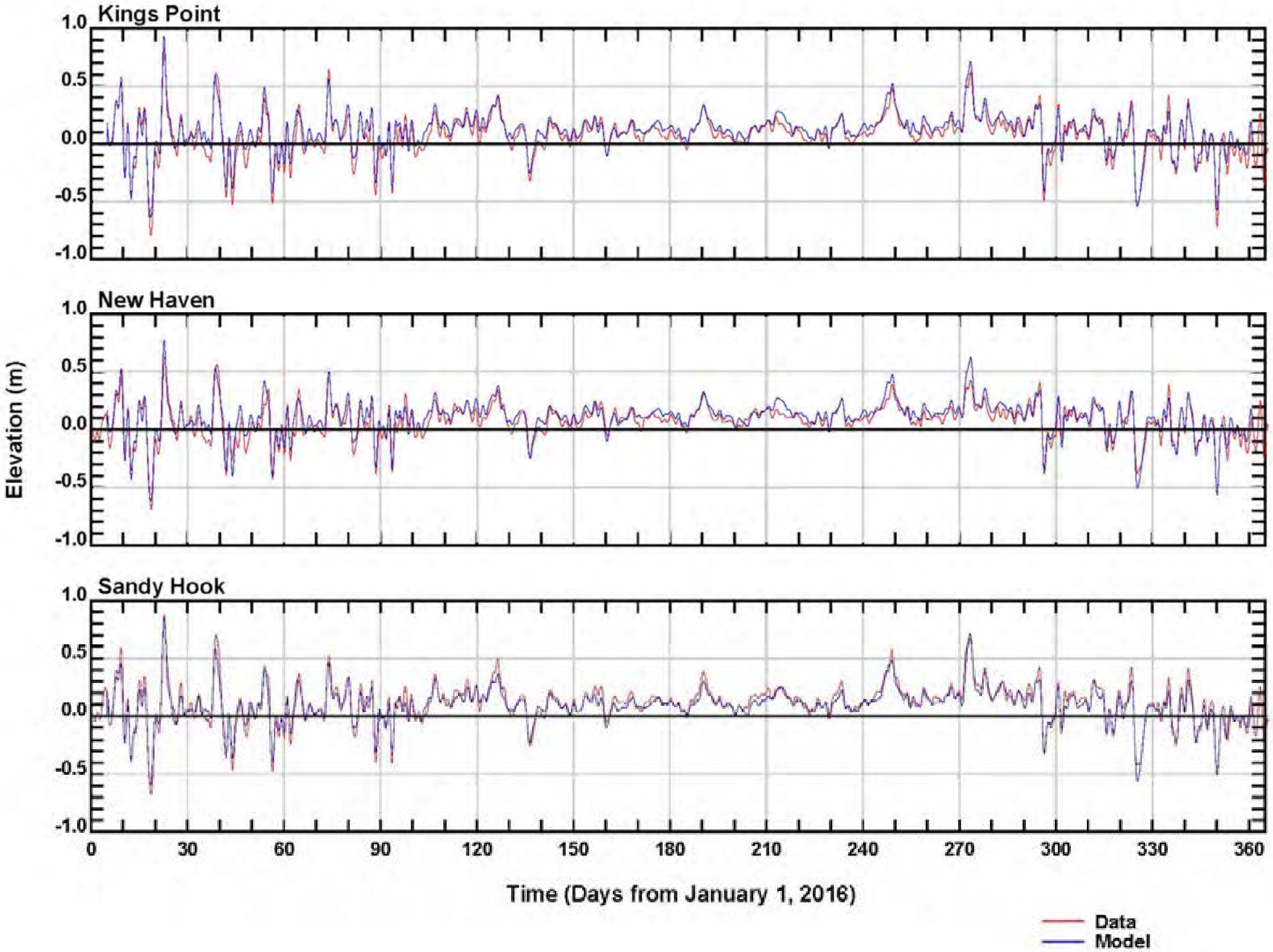


Figure 5-4. 2016 Comparison of 35hr Low-Passed Elevations (Continued)

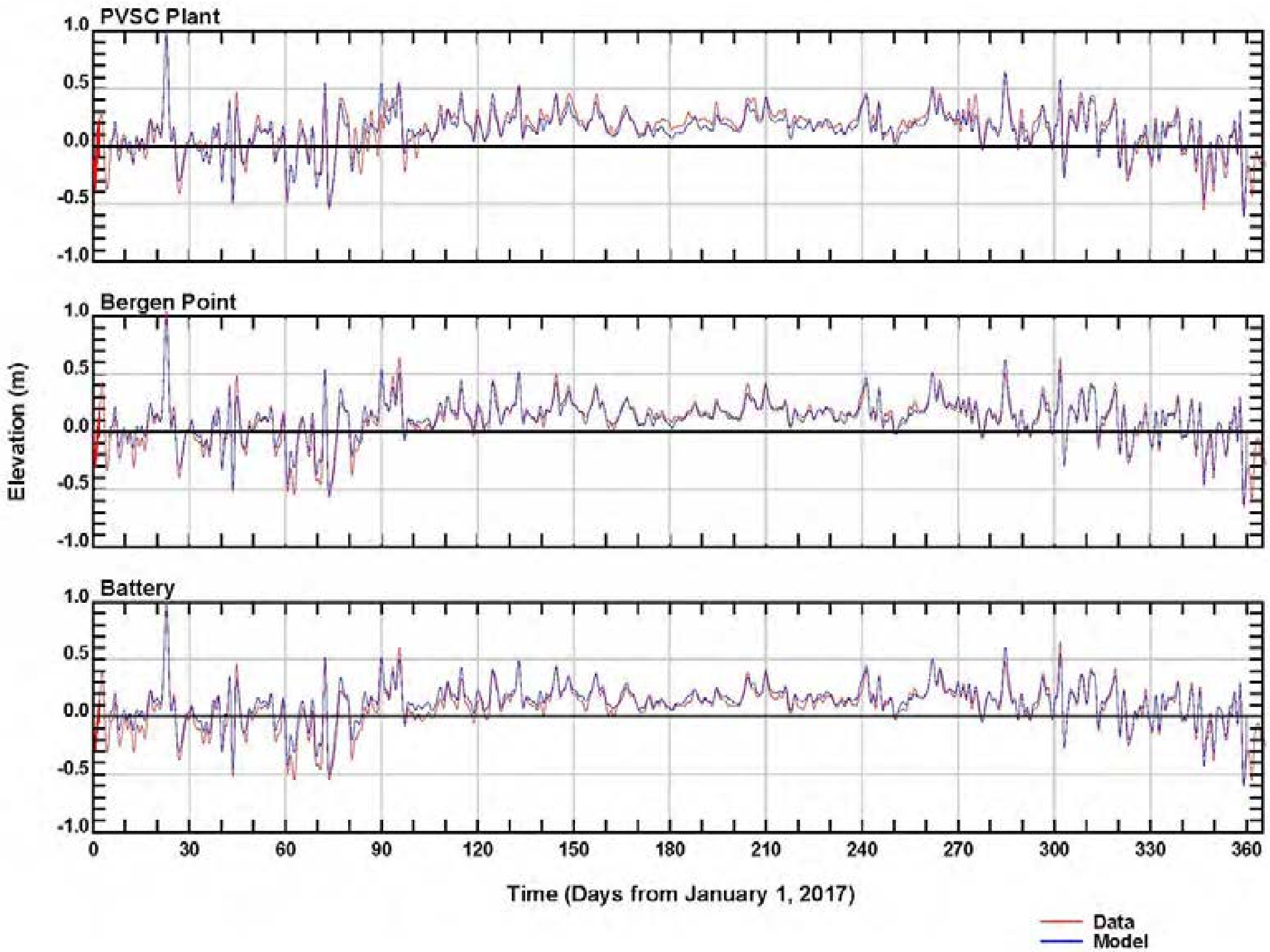


Figure 5-5. 2017 Comparison of 35hr Low-Passed Elevations

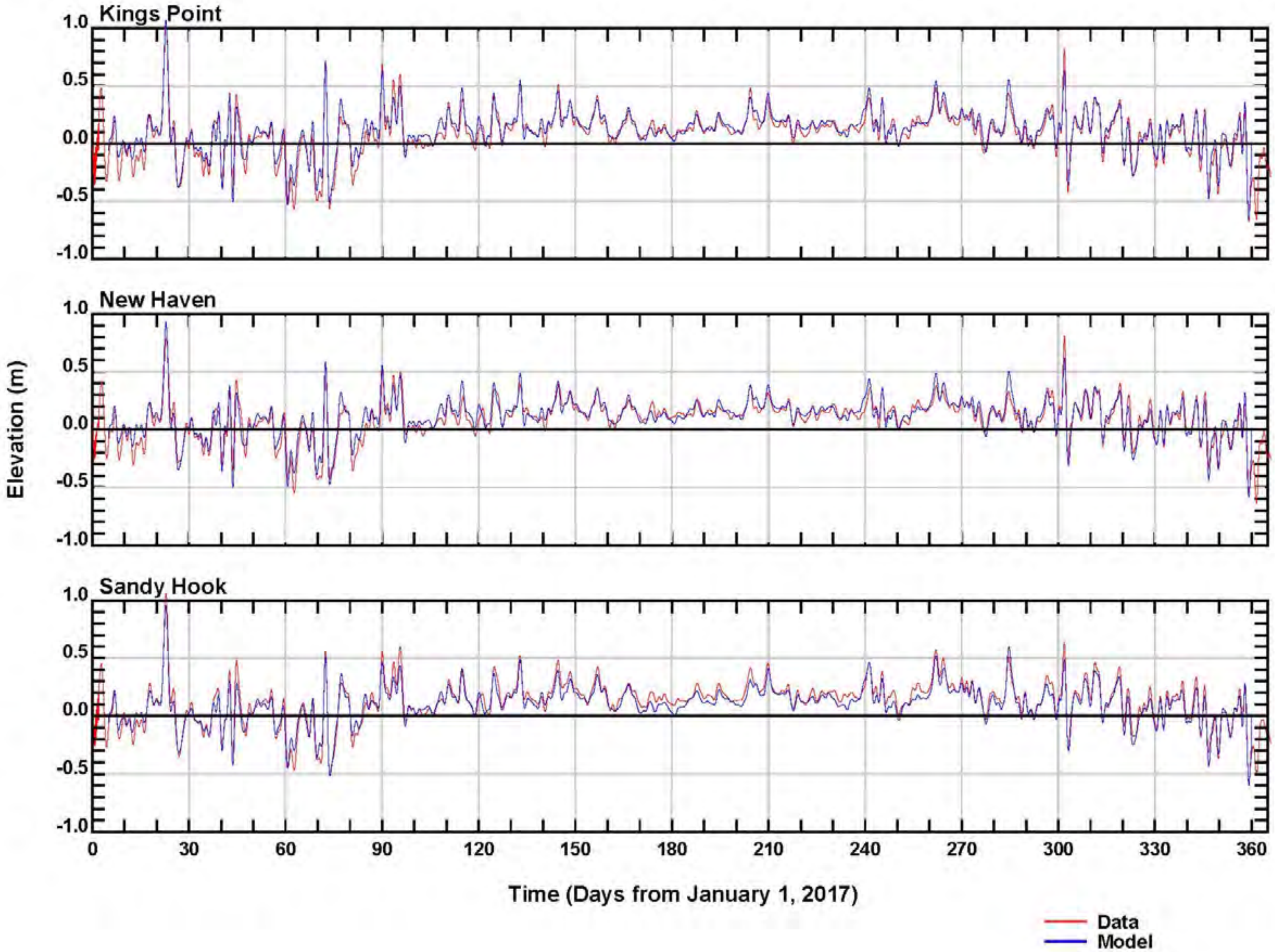
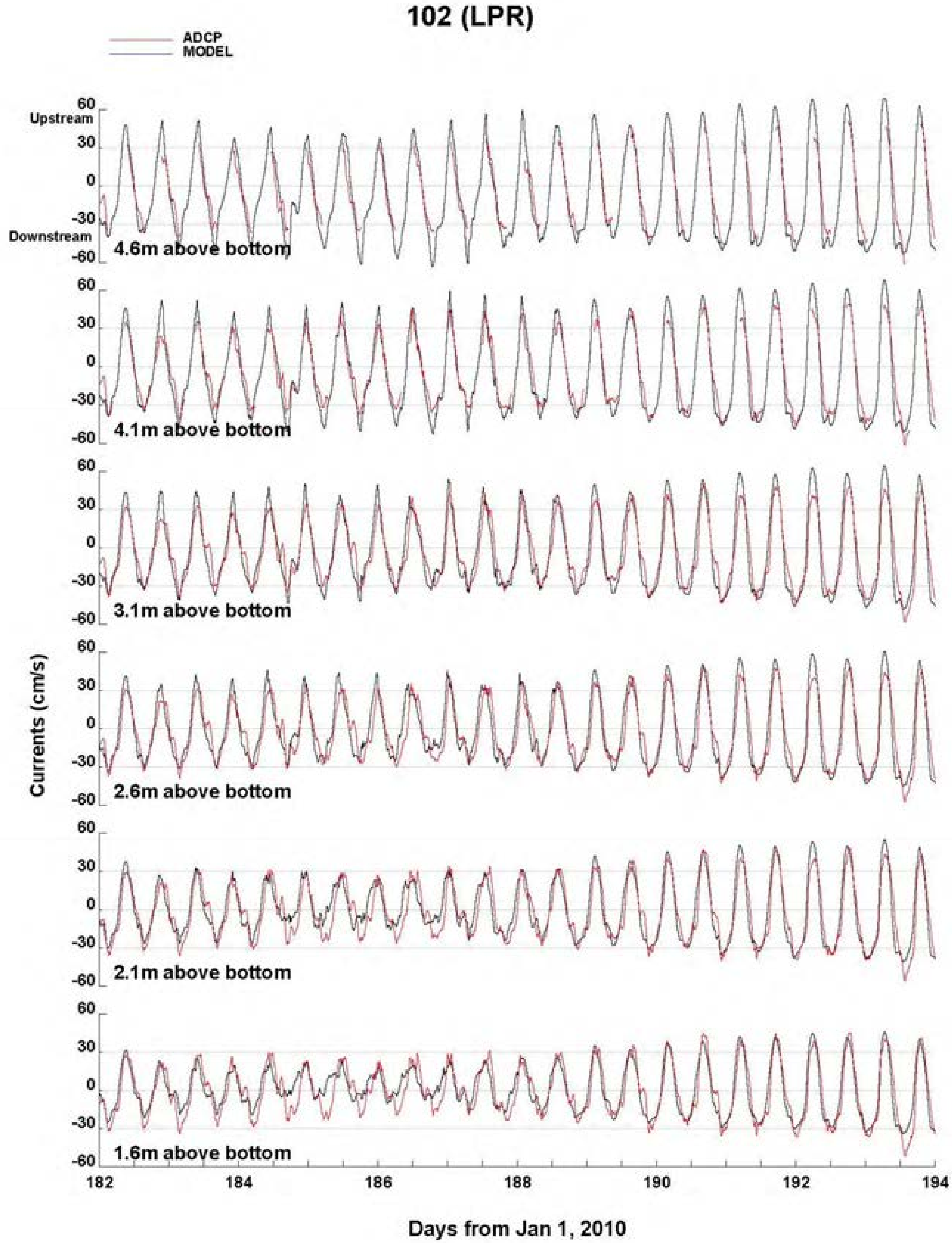
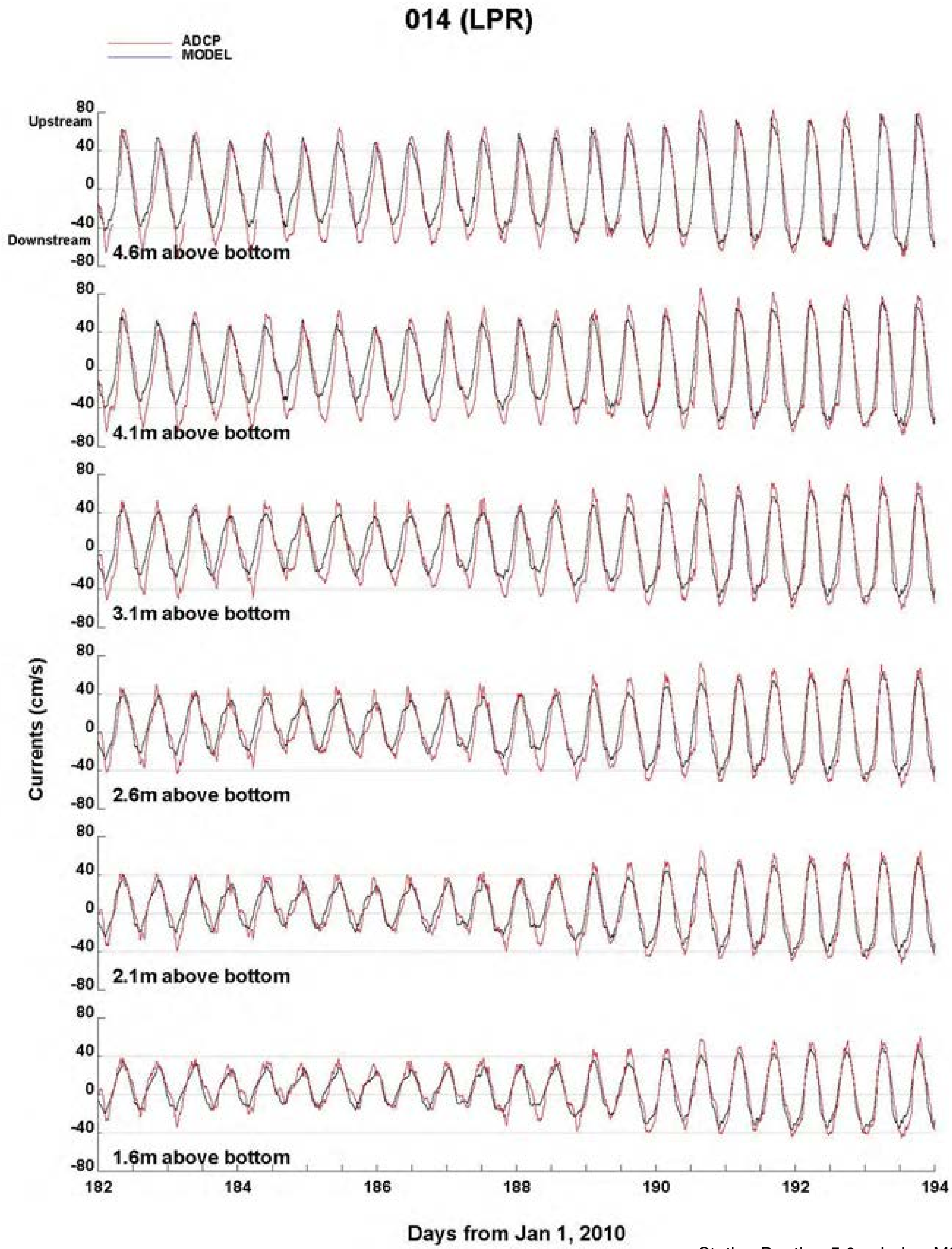


Figure 5-5. 2017 Comparison of 35hr Low-Passed Elevations (Continued)



Station Depth = 5.3 m below MSL

Figure 5-6. 2010 Comparison of Tidal Currents



Station Depth = 5.6 m below MSL

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.

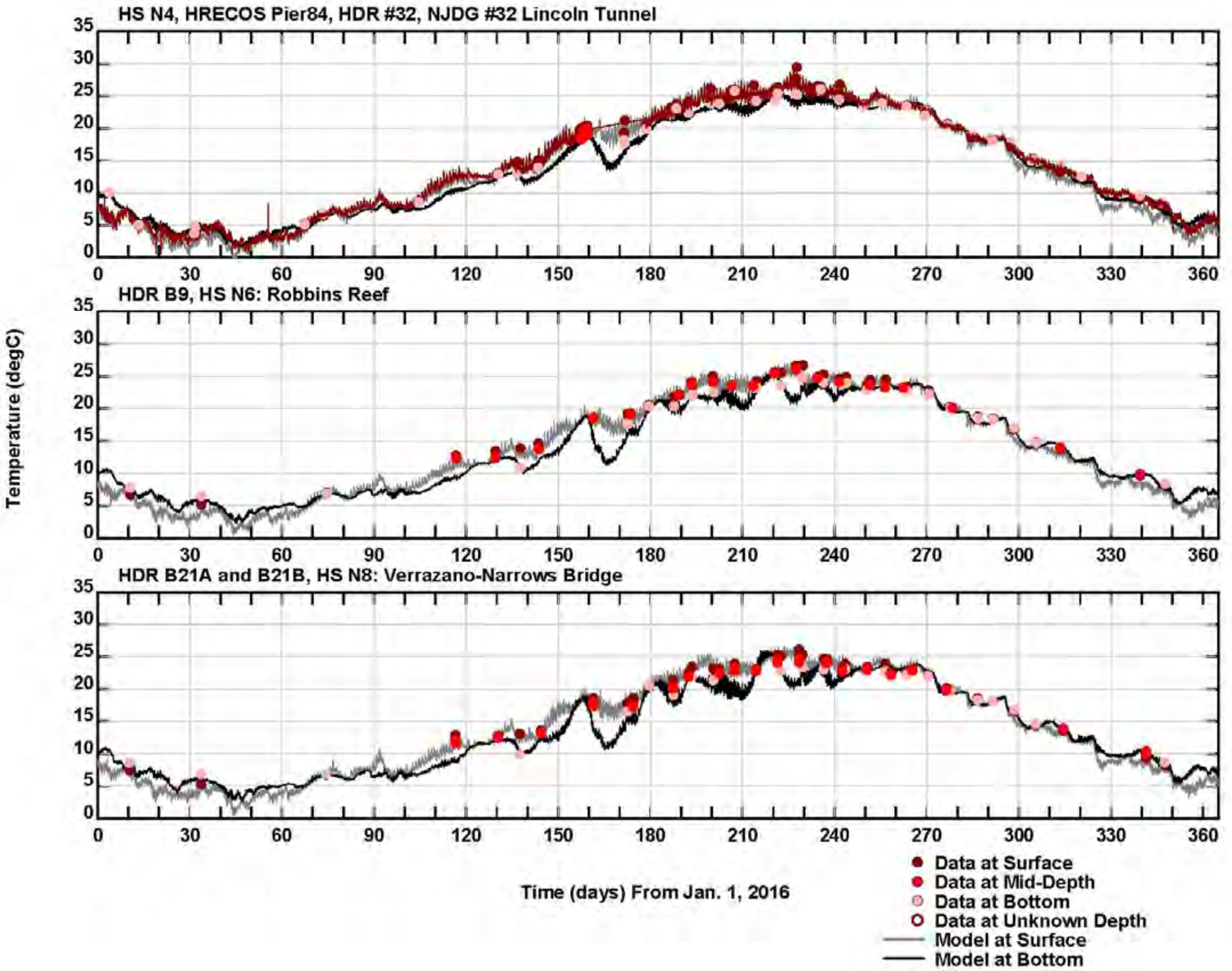


Figure 5-7. 2016 Comparison of Model Computed Water Temperature

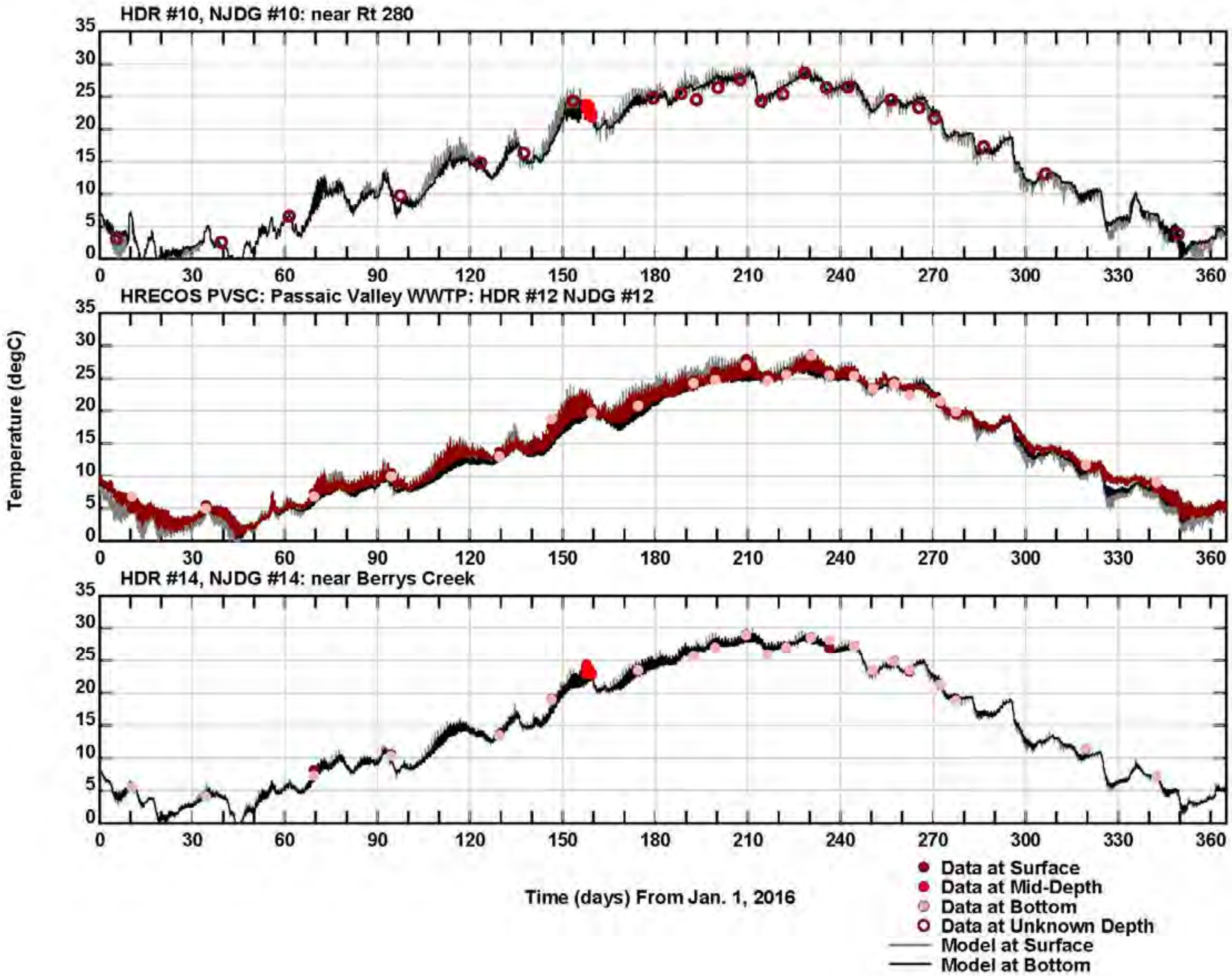


Figure 5-7. 2016 Comparison of Model Computed Water Temperature (Continued)

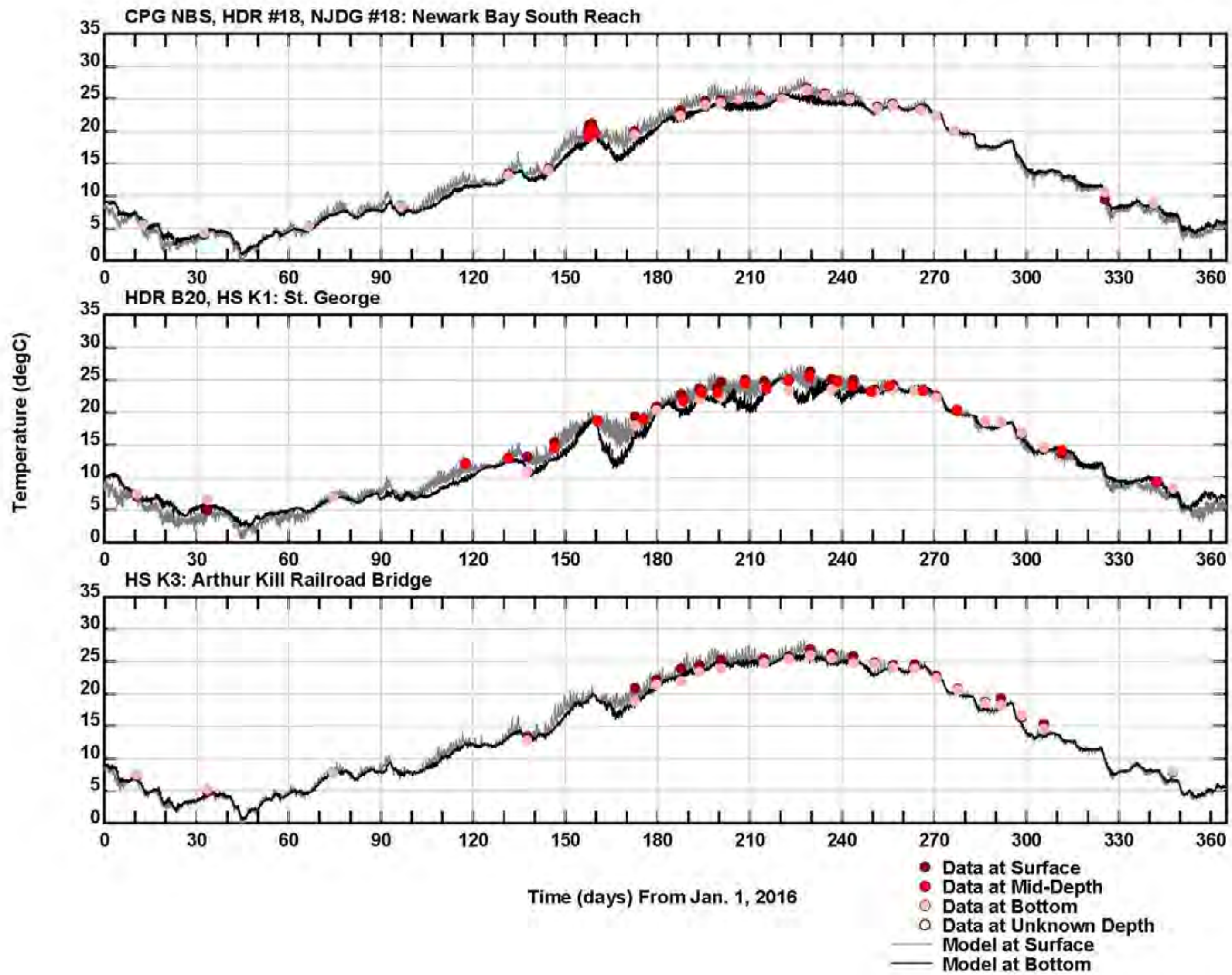


Figure 5-7. 2016 Comparison of Model Computed Water Temperature (Continued)

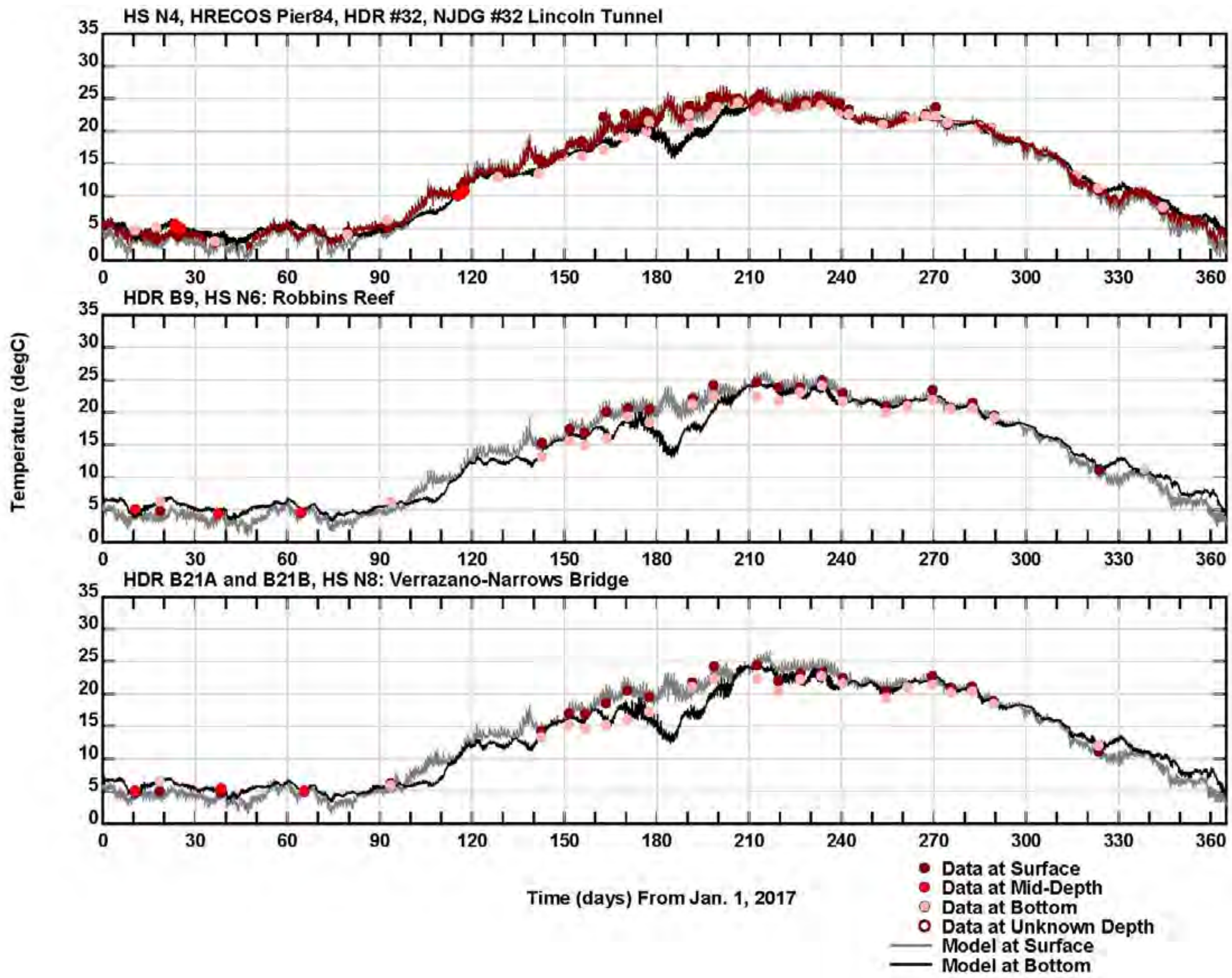


Figure 5-8. 2017 Comparison of Model Computed Water Temperature

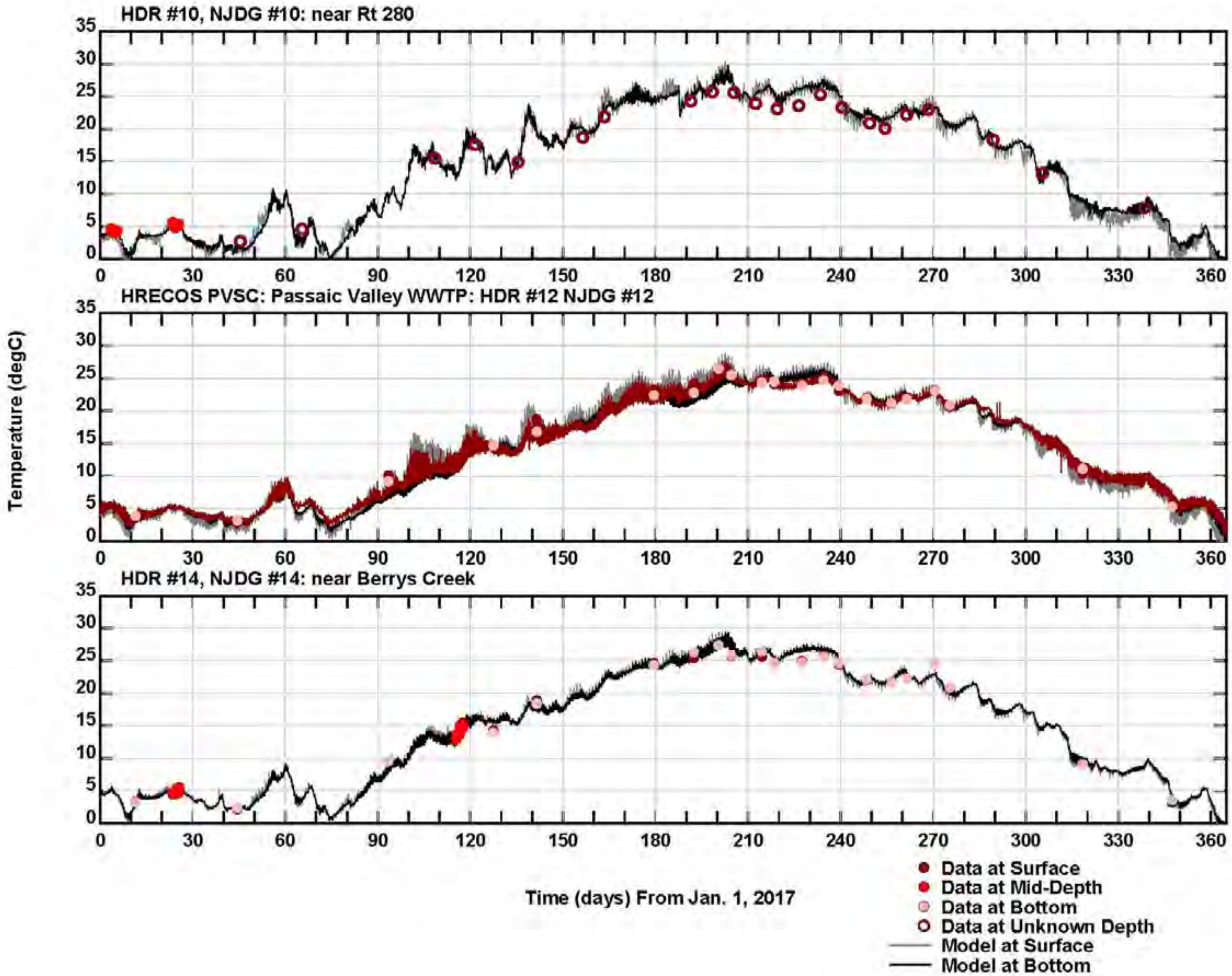


Figure 5-8. 2017 Comparison of Model Computed Water Temperature (Continued)

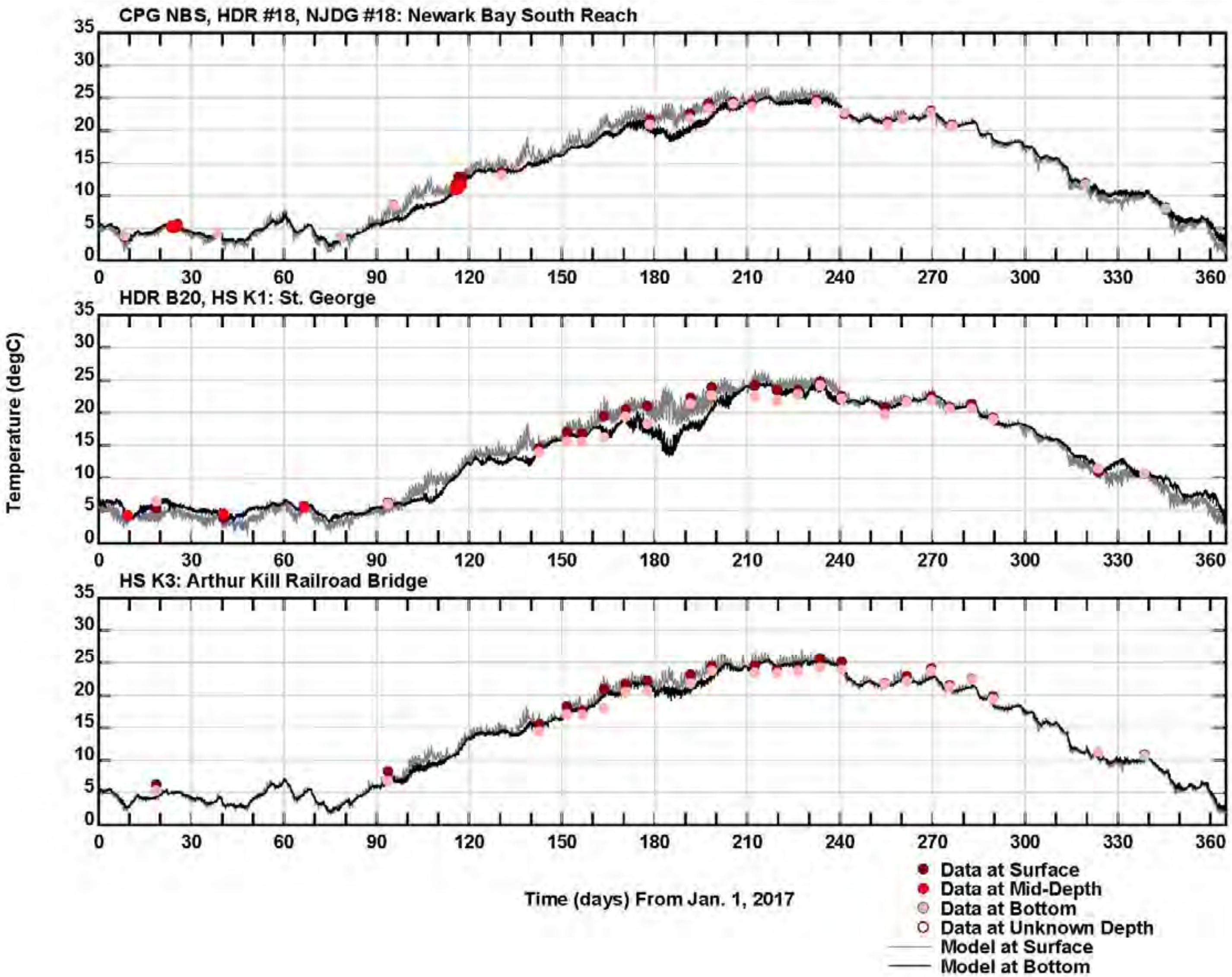


Figure 5-8. 2017 Comparison of Model Computed Water Temperature (Continued)

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.

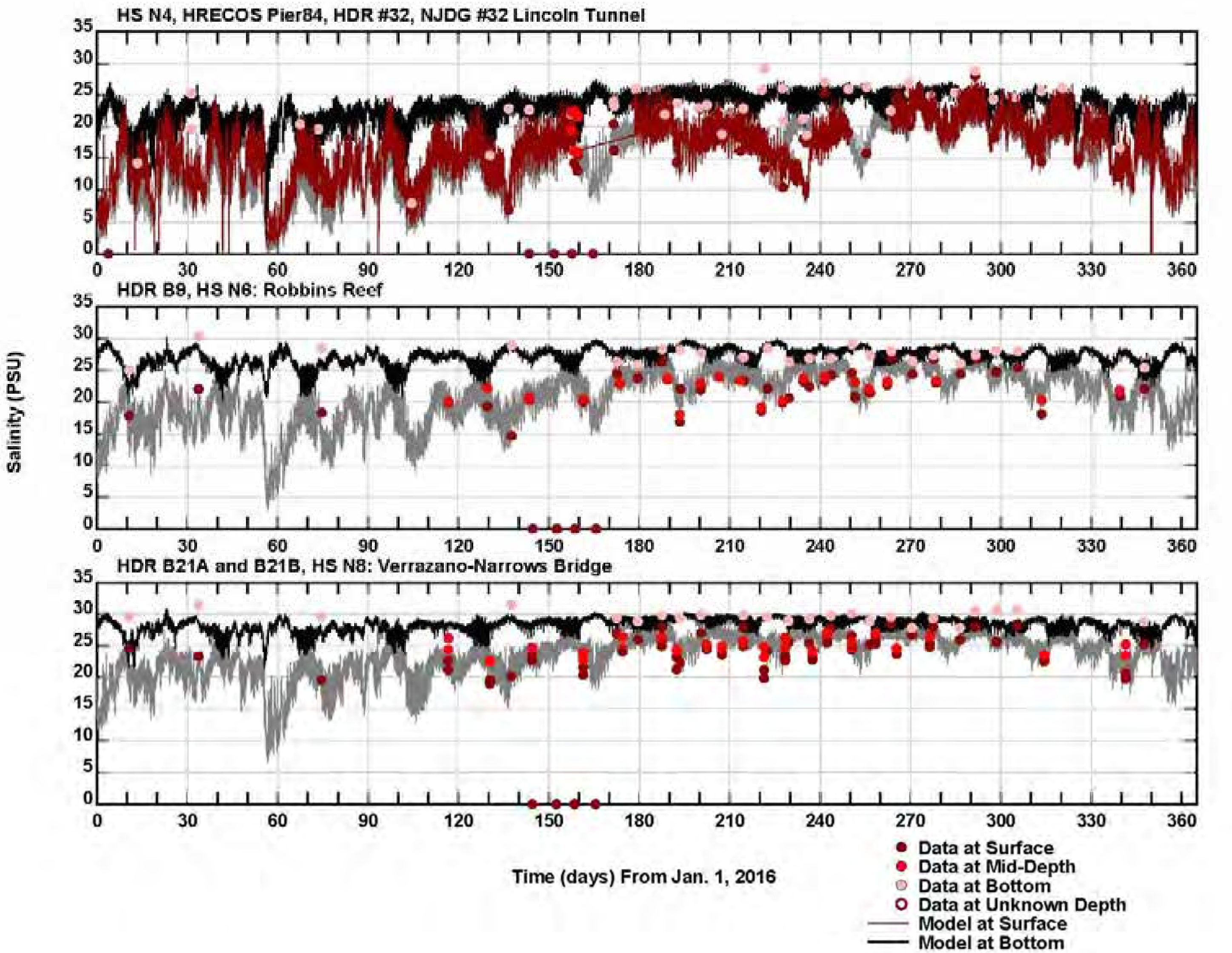


Figure 5-9. 2016 Comparison of Model Computed Salinity

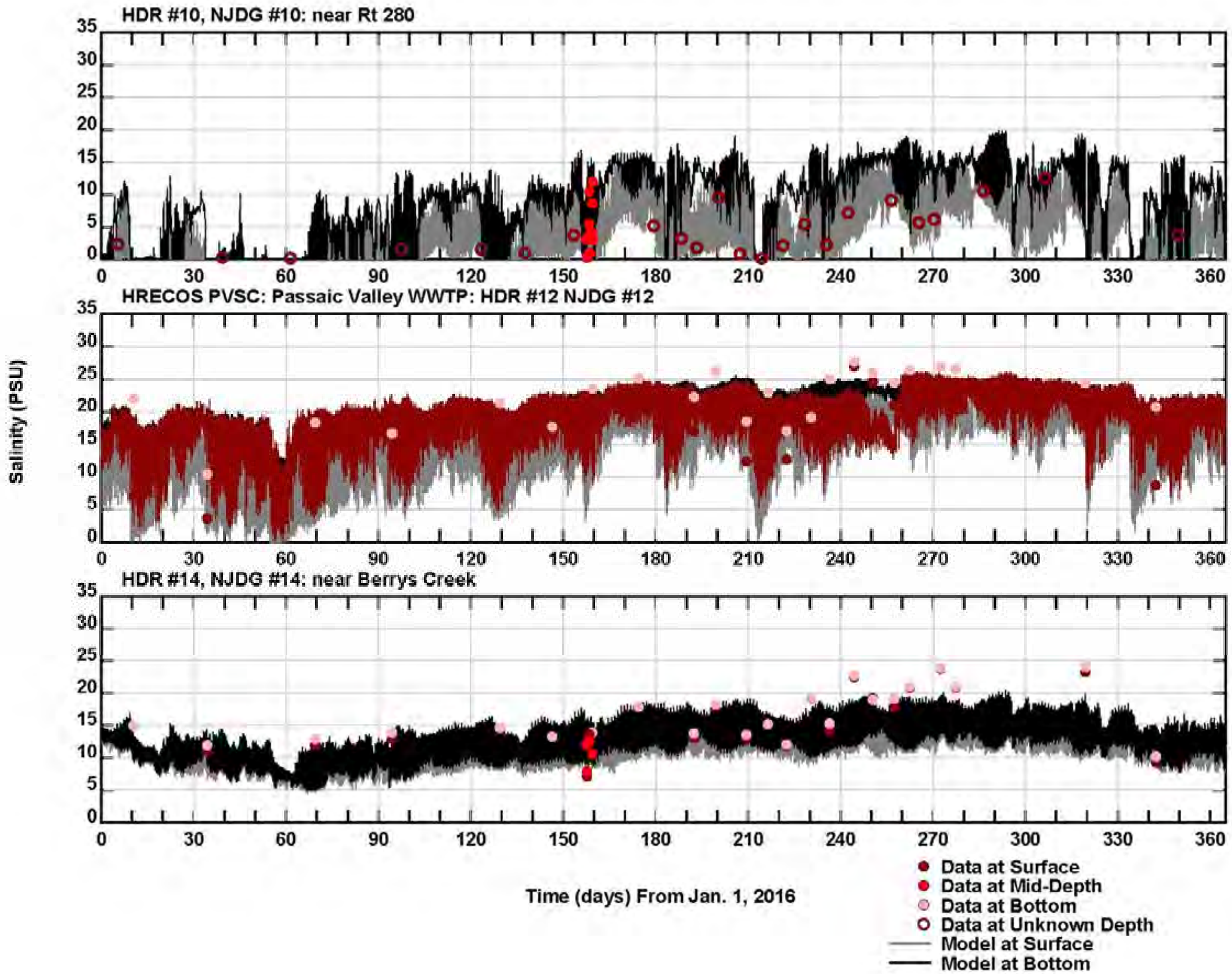


Figure 5-9. 2016 Comparison of Model Computed Salinity (Continued)

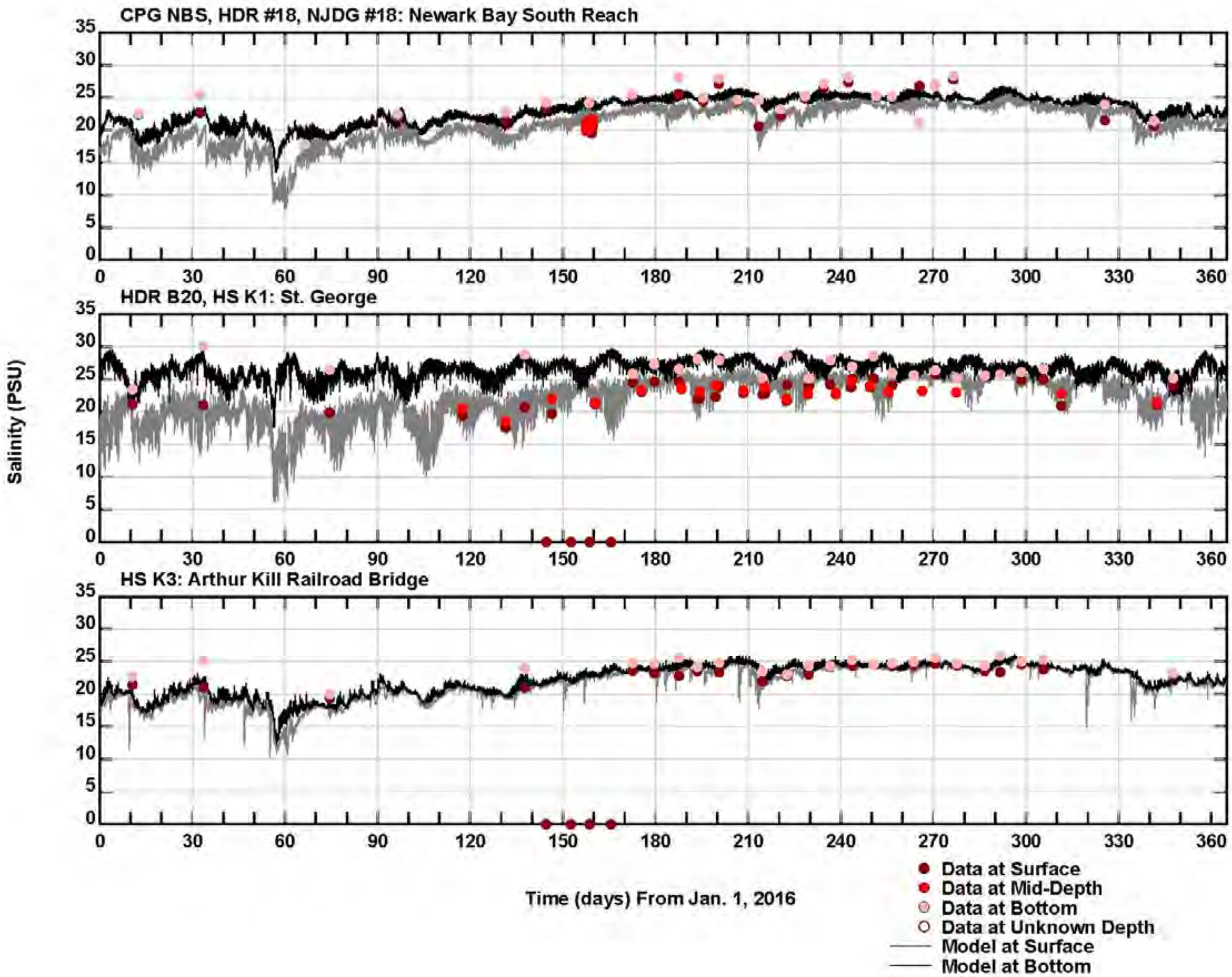


Figure 5-9. 2016 Comparison of Model Computed Salinity (Continued)

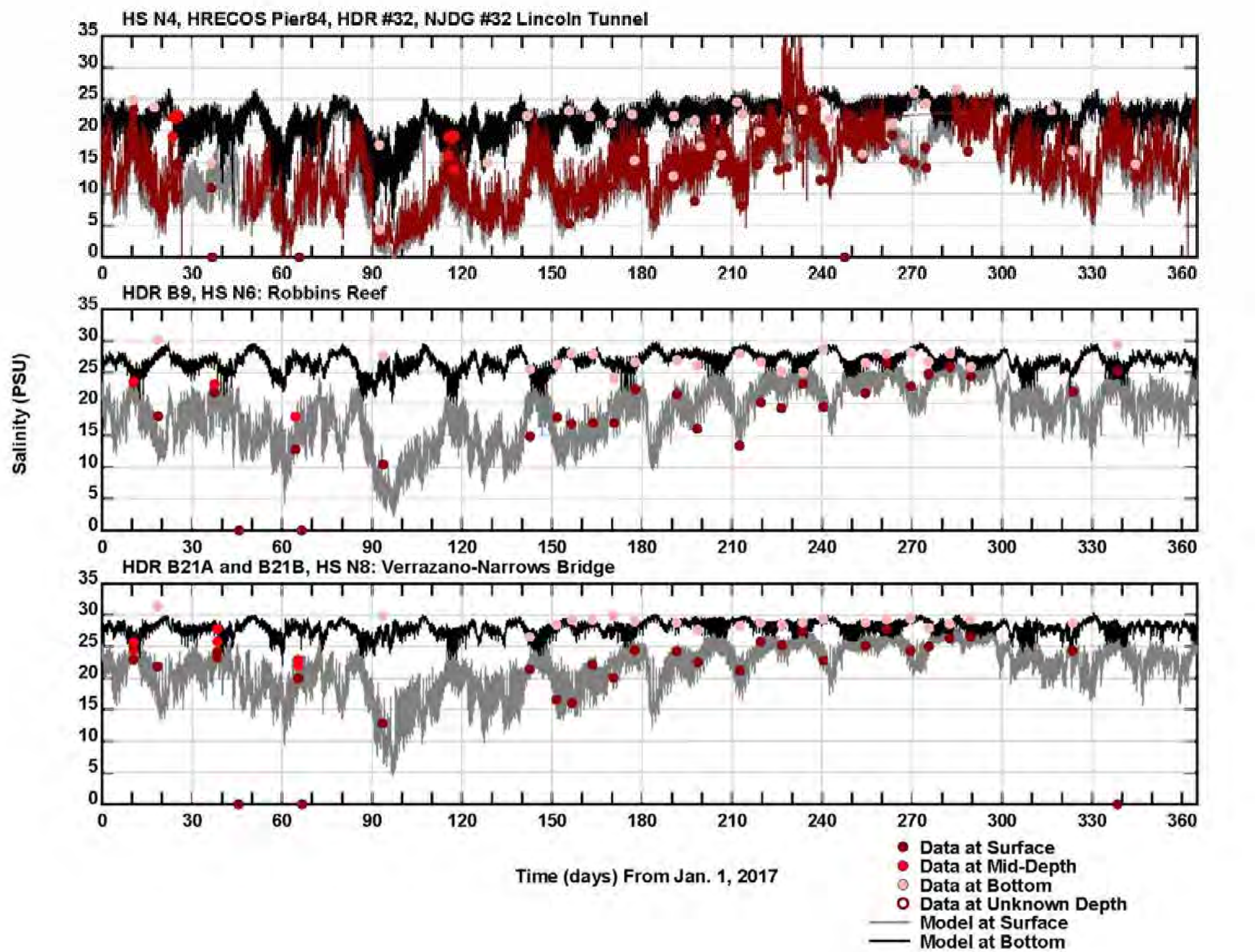


Figure 5-10. 2017 Comparison of Model Computed Salinity

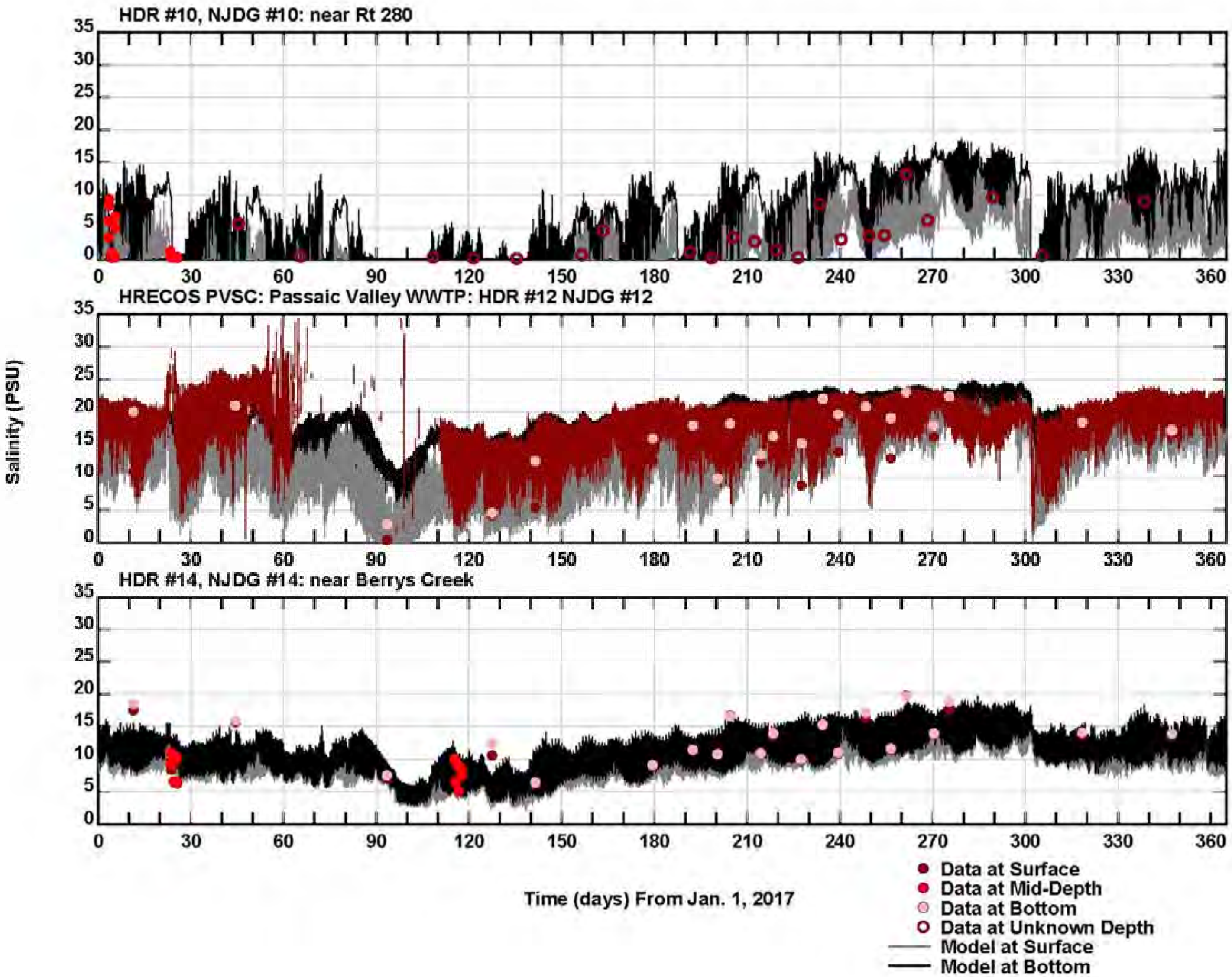


Figure 5-10. 2017 Comparison of Model Computed Salinity (Continued)

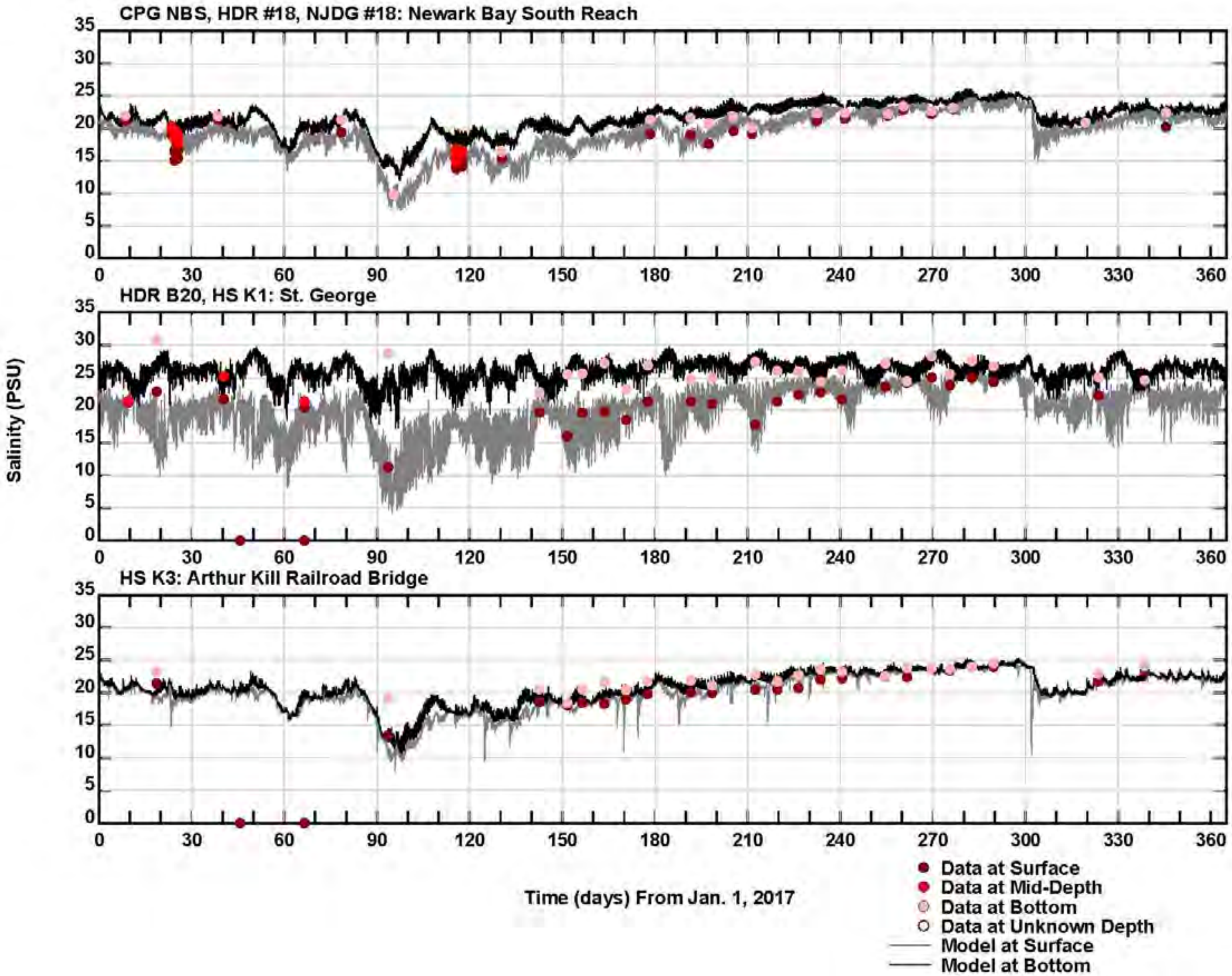


Figure 5-10. 2017 Comparison of Model Computed Salinity (Continued)

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.

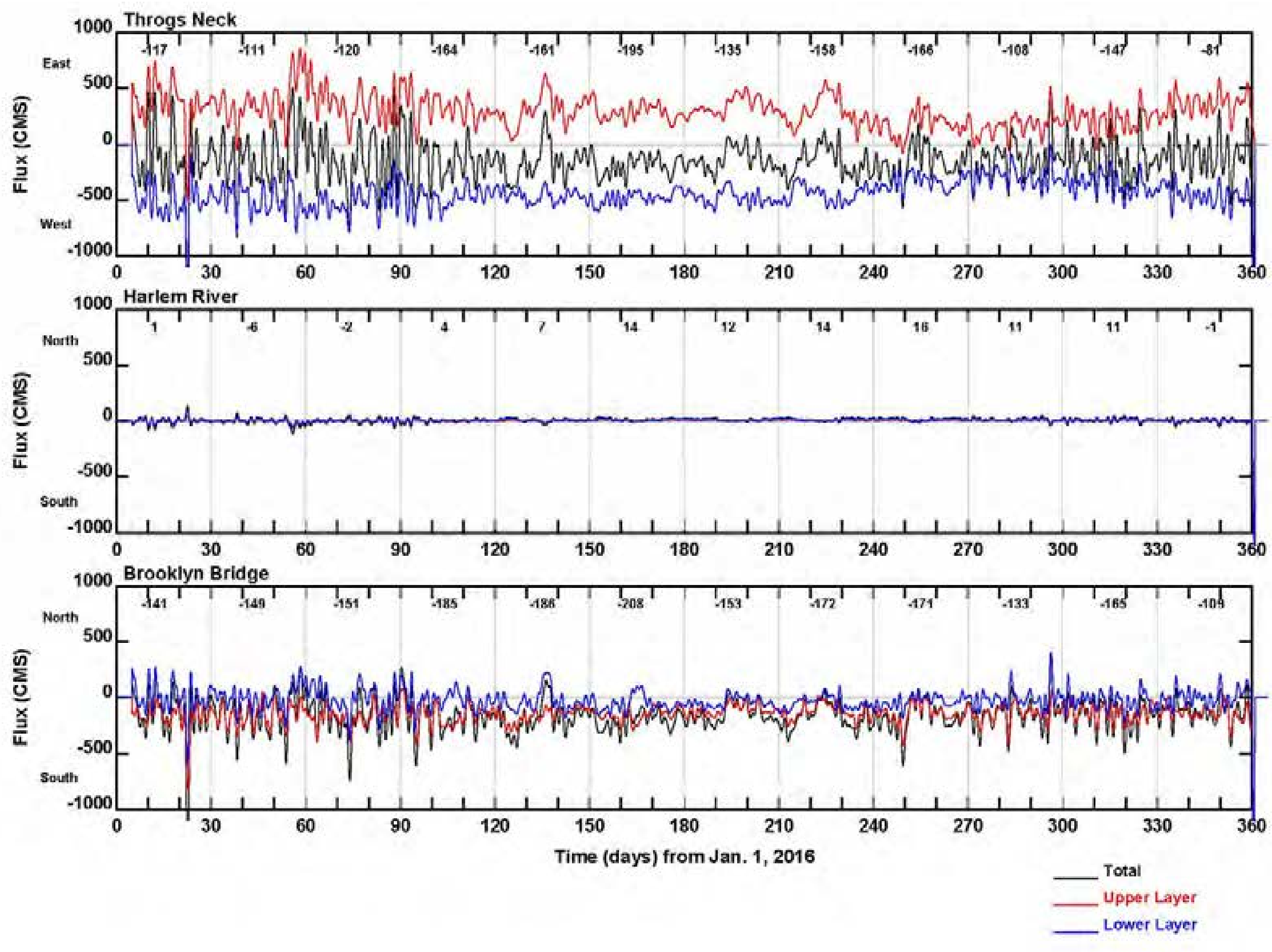


Figure 5-11. 2016 Cross Sectional Fluxes

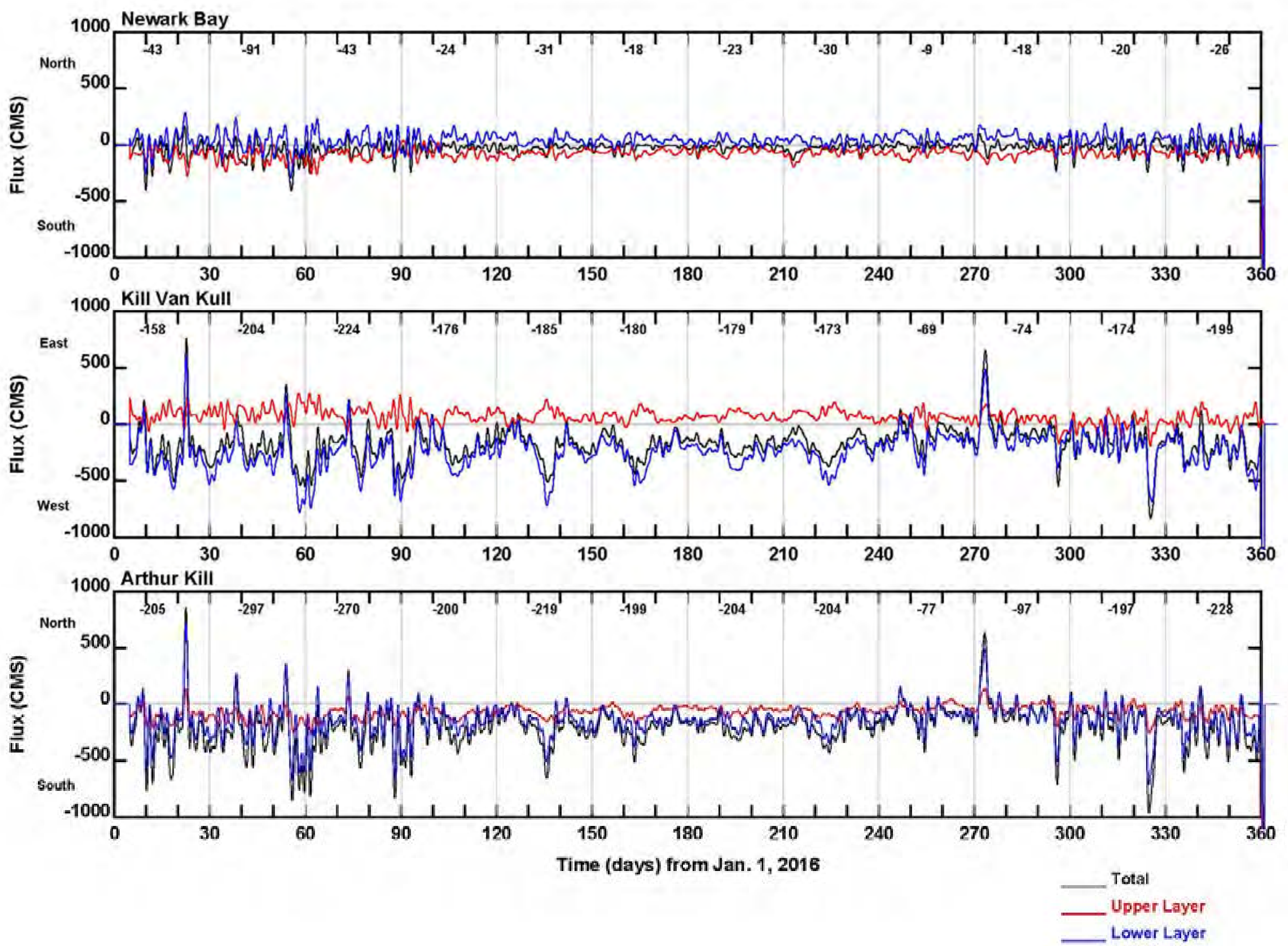


Figure 5-11. 2016 Cross Sectional Fluxes (Continued)

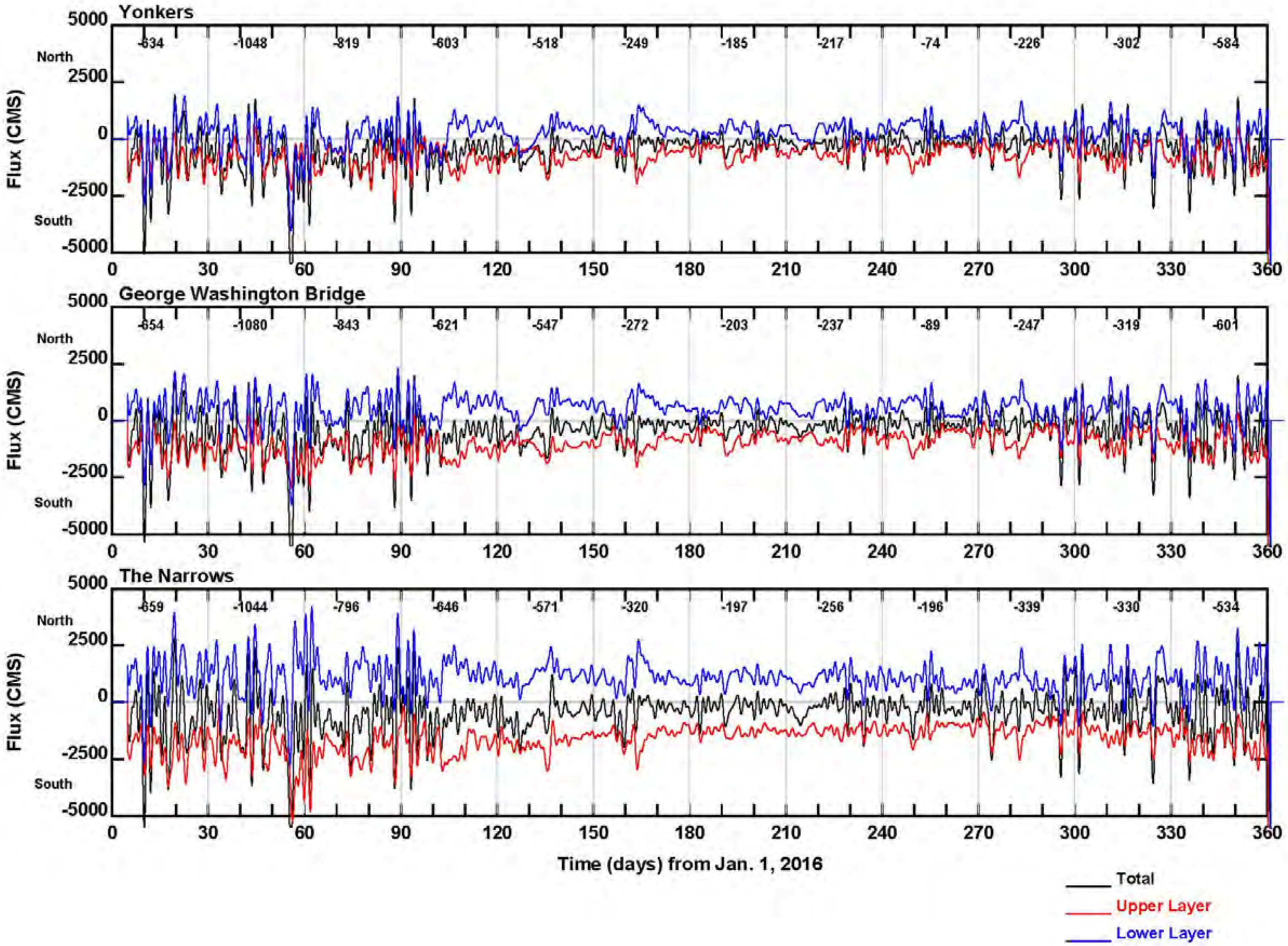


Figure 5-11. 2016 Cross Sectional Fluxes (Continued)

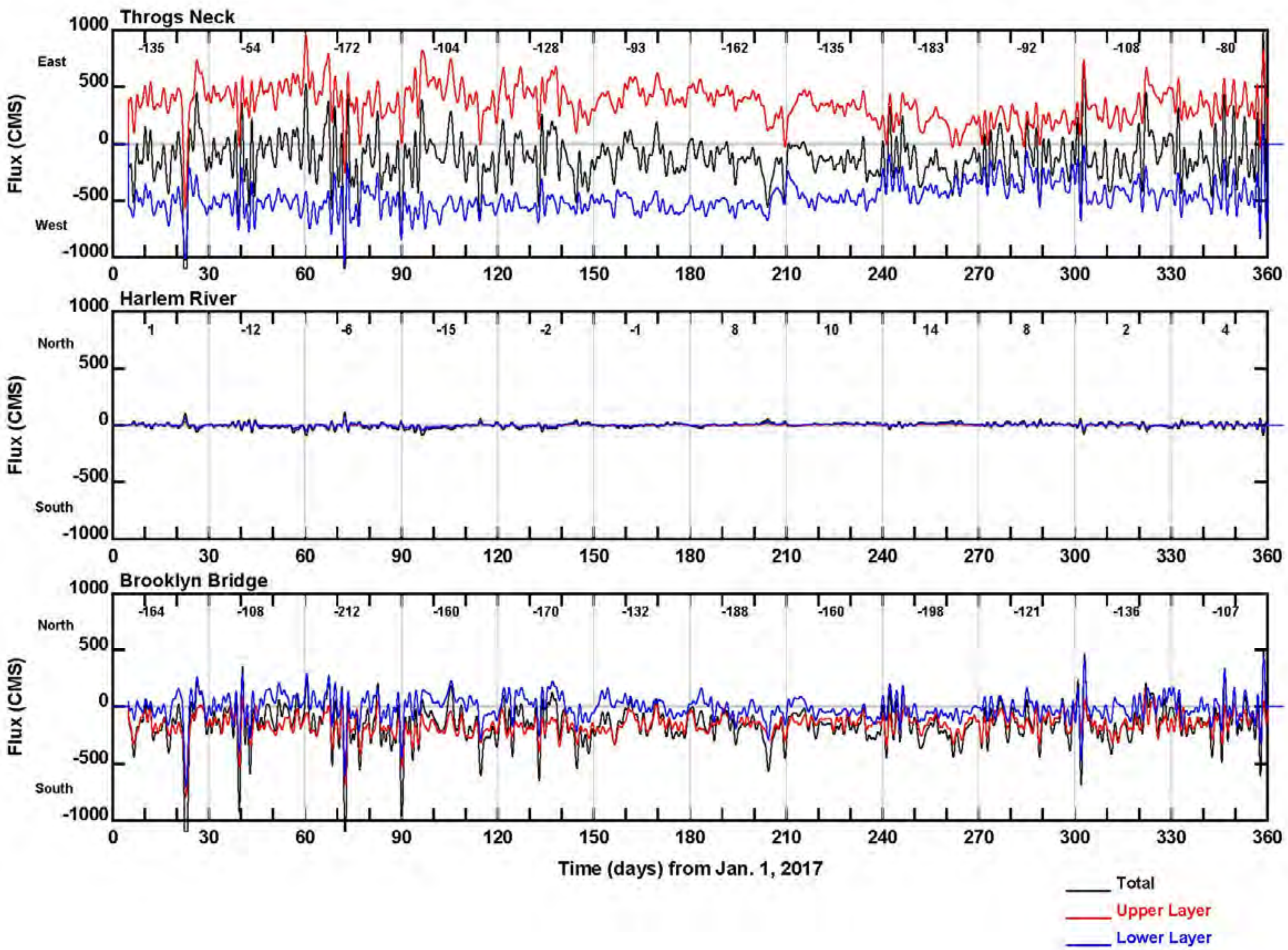


Figure 5-12. 2017 Cross Sectional Fluxes

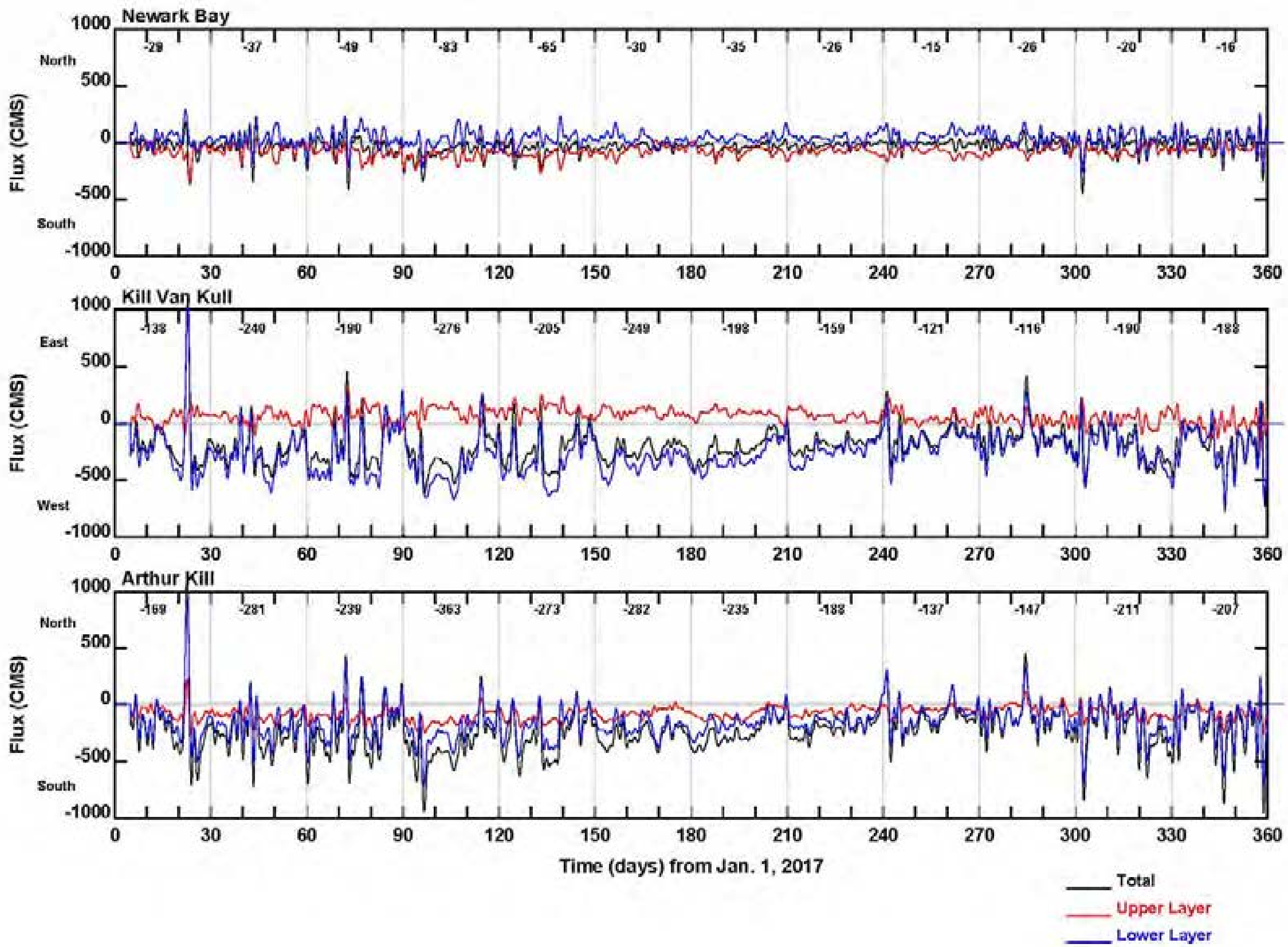


Figure 5-12. 2017 Cross Sectional Fluxes (Continued)

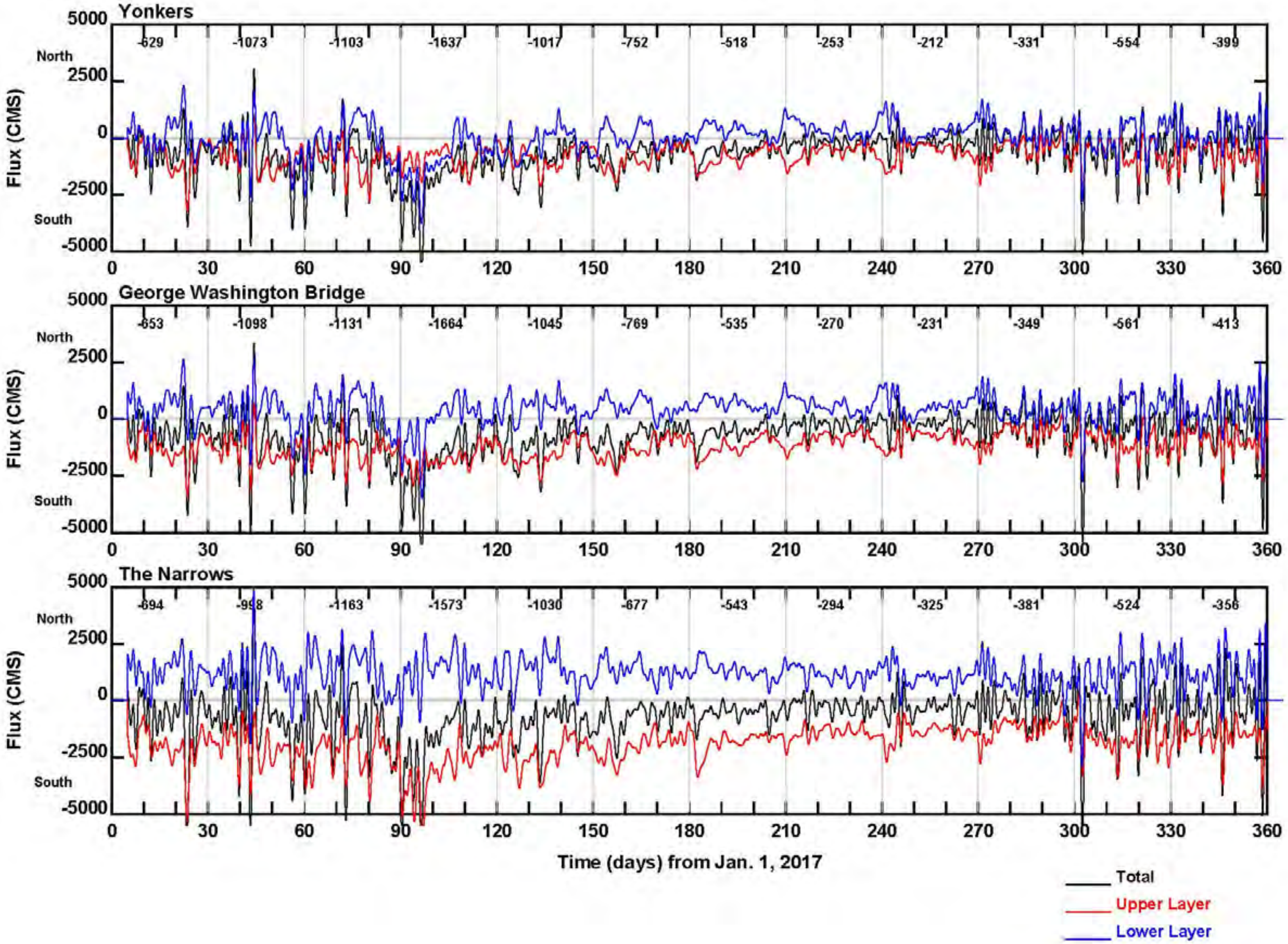


Figure 5-12. 2017 Cross Sectional Fluxes (Continued)

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 if 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.

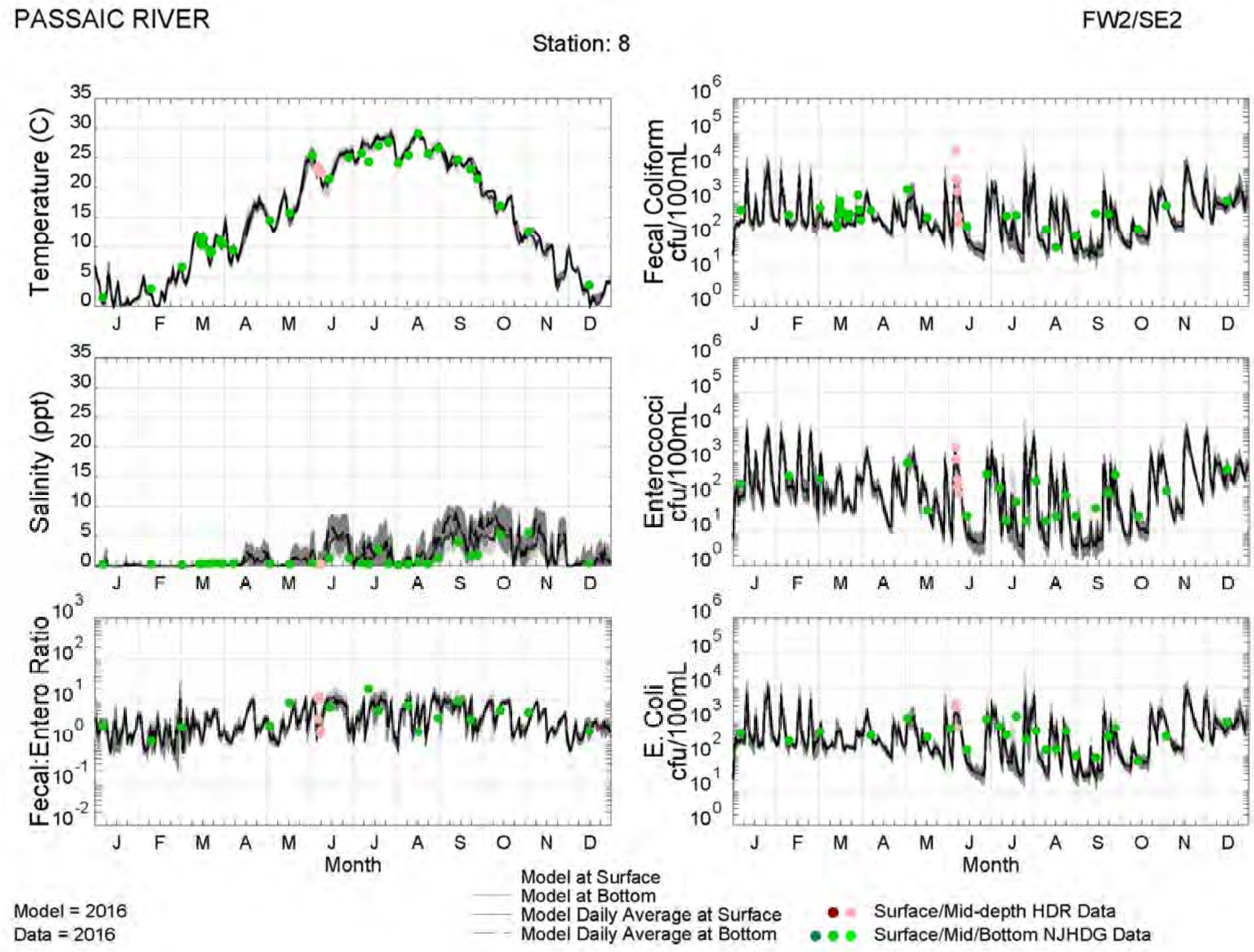


Figure 5-13. 2016 Annual Time-Series Model versus Data Comparison at Station 8, Passaic River

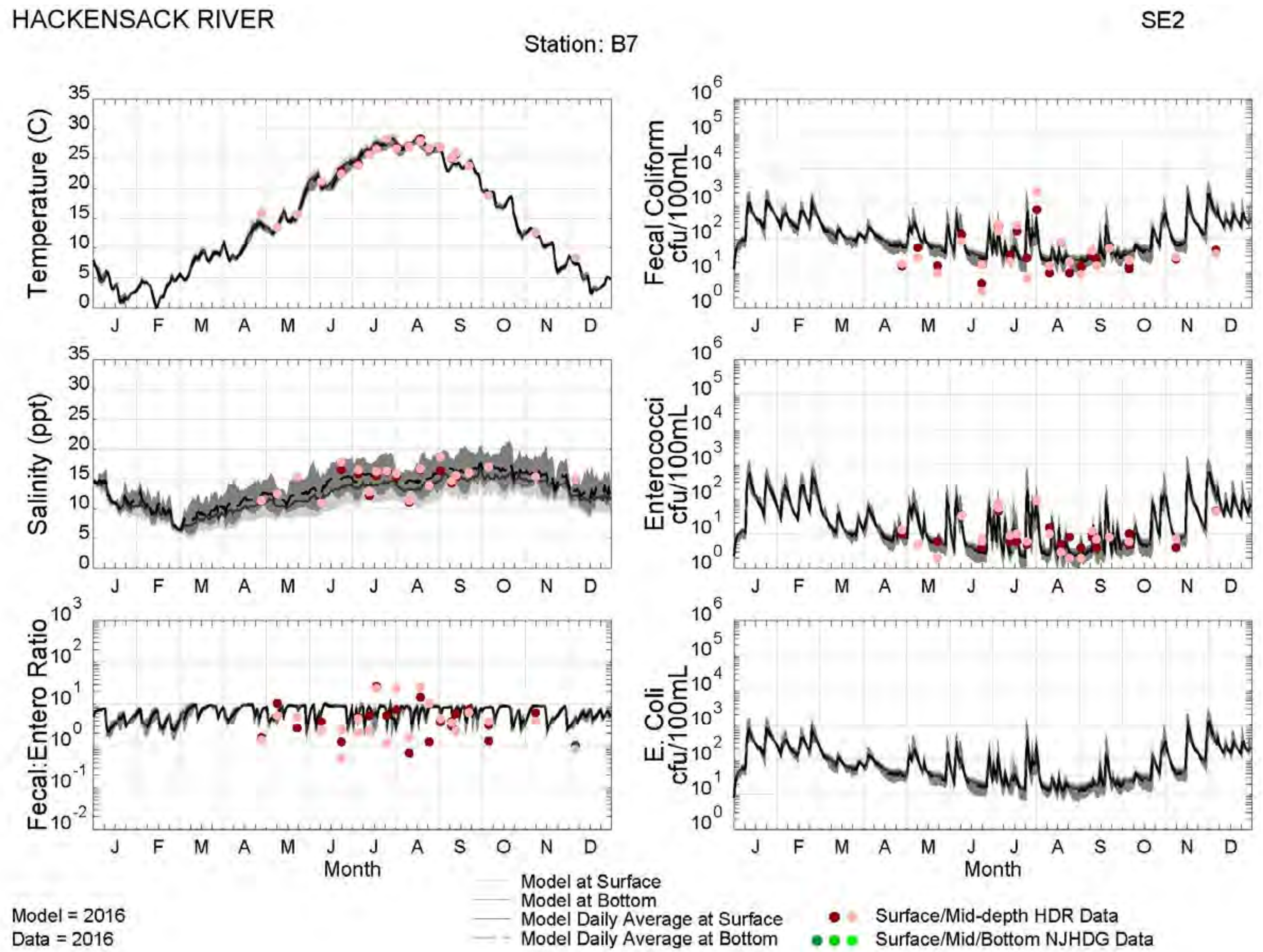


Figure 5-14. 2016 Annual Time-Series Model versus Data Comparison at Station B7, Hackensack River

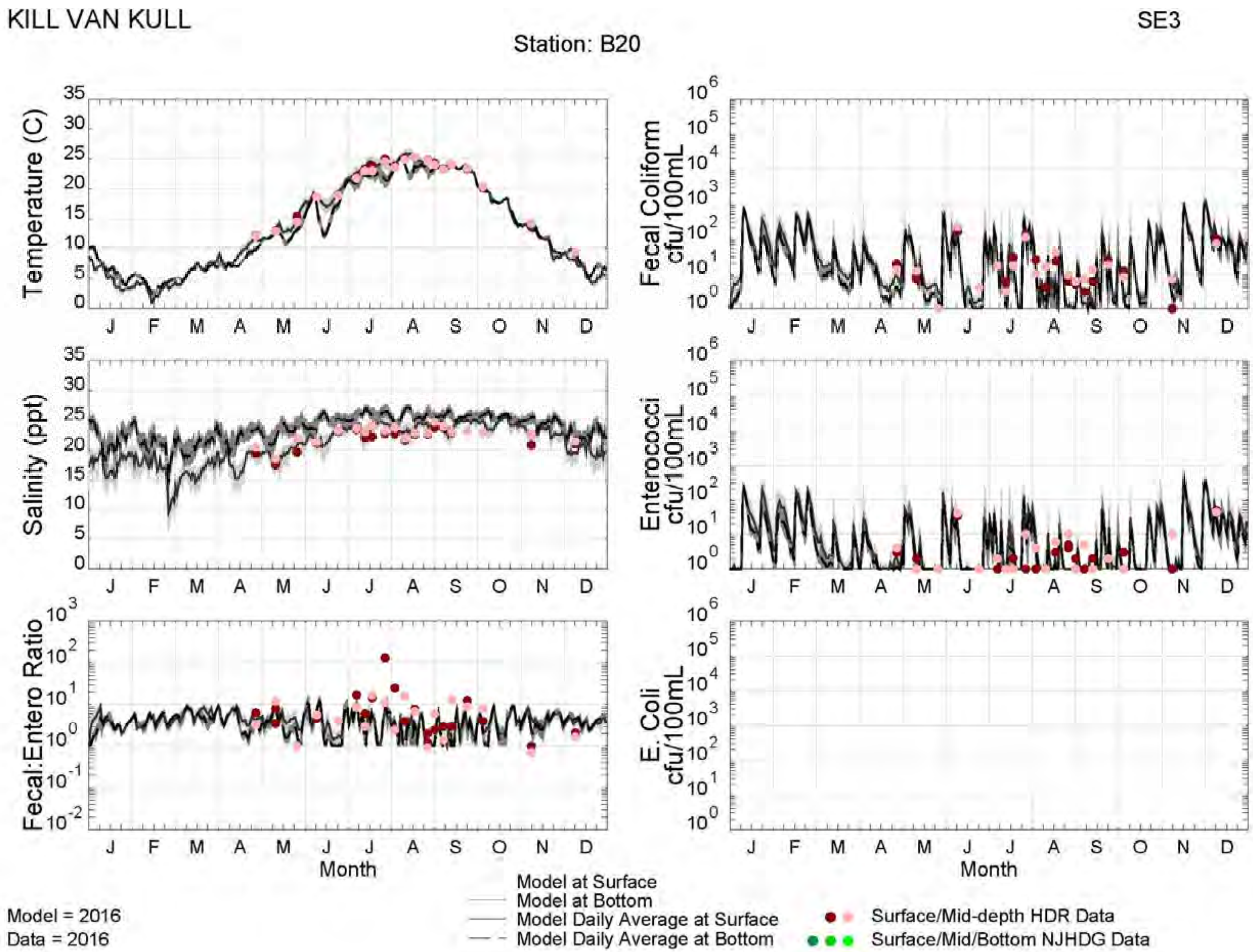


Figure 5-15. 2016 Annual Time-Series Model versus Data Comparison at Station B20, Kill van Kull

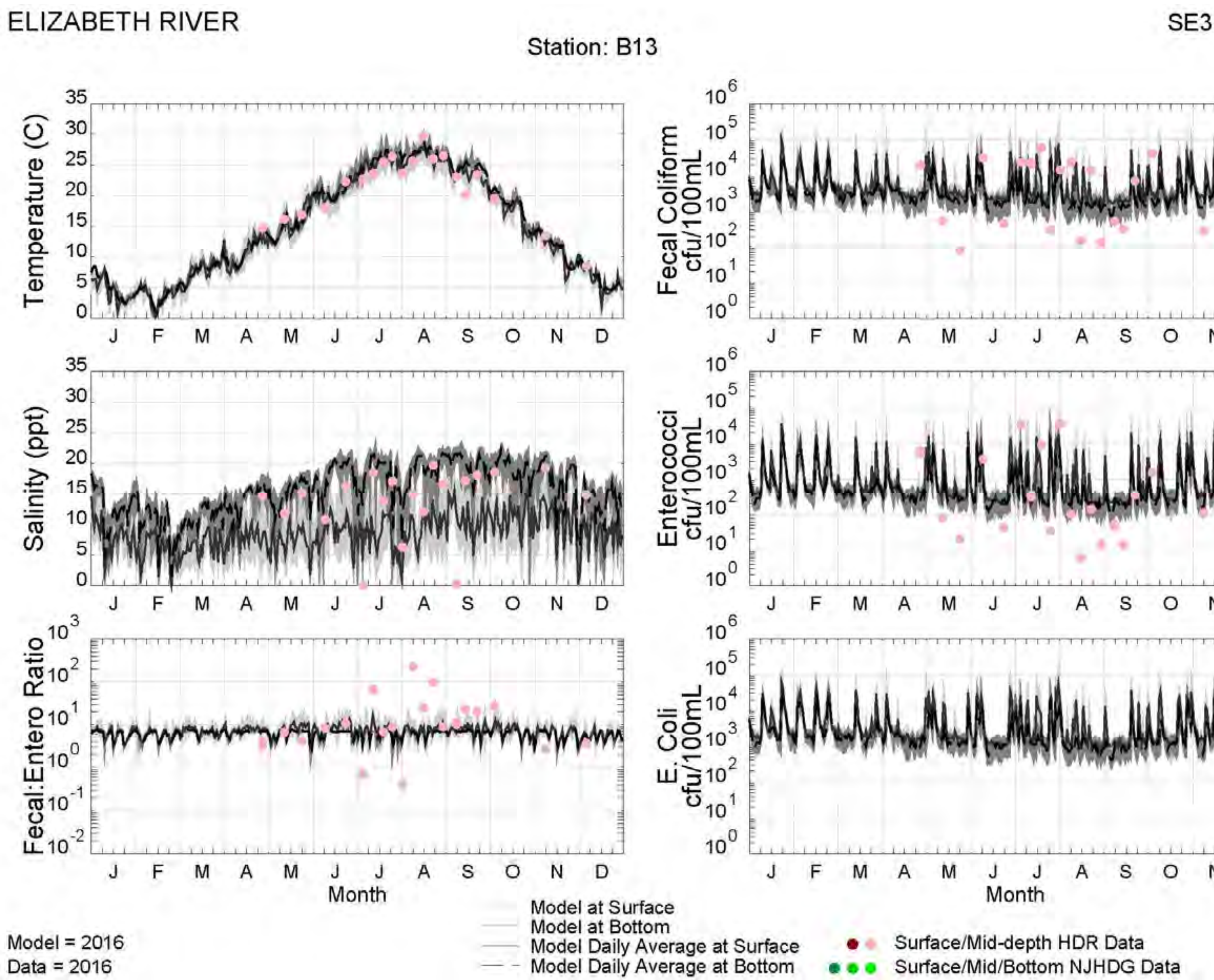


Figure 5-16. 2016 Annual Time-Series Model versus Data Comparison at Station B13, Elizabeth River

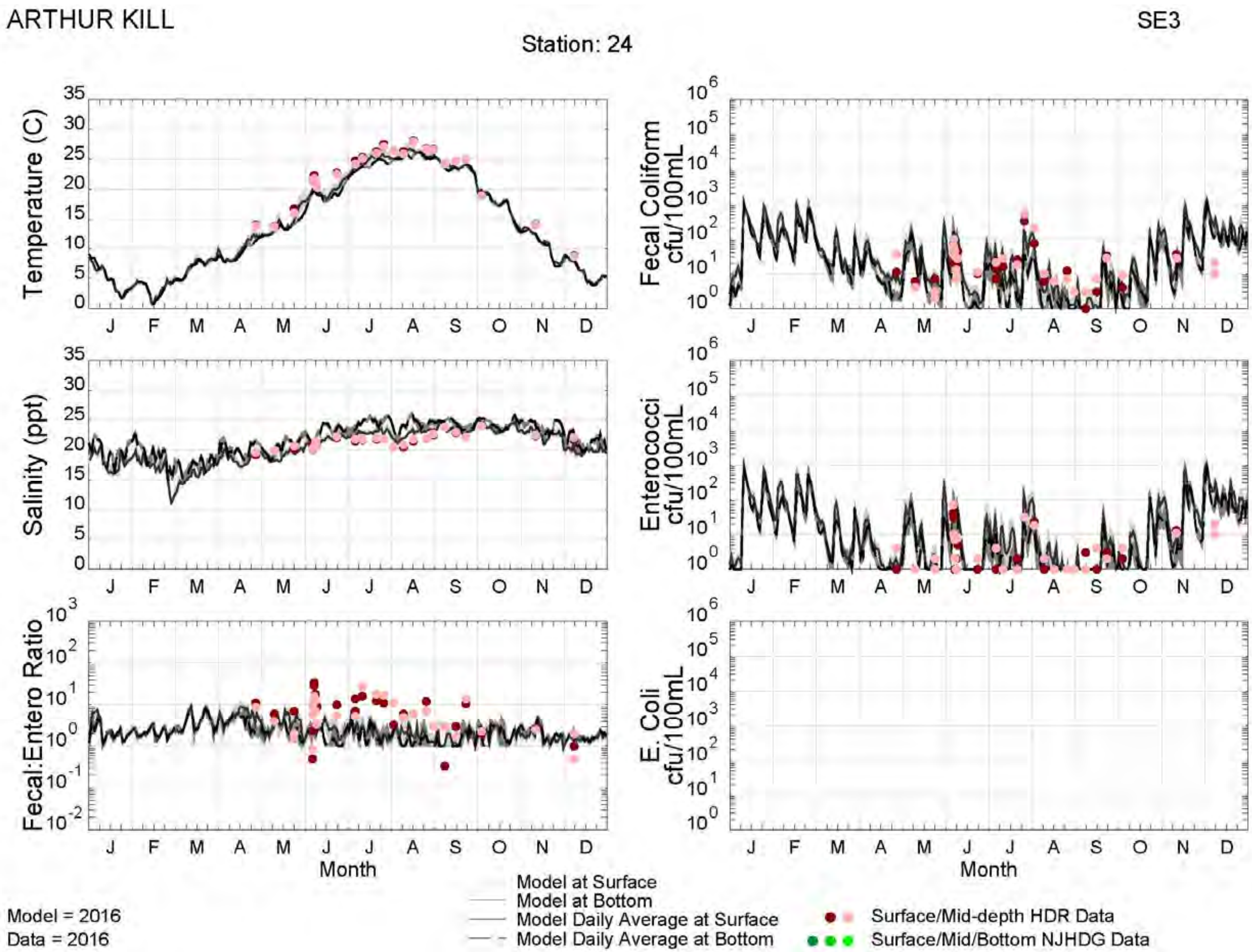


Figure 5-17. 2016 Annual Time-Series Model versus Data Comparison at Station 24, Arthur Kill

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.

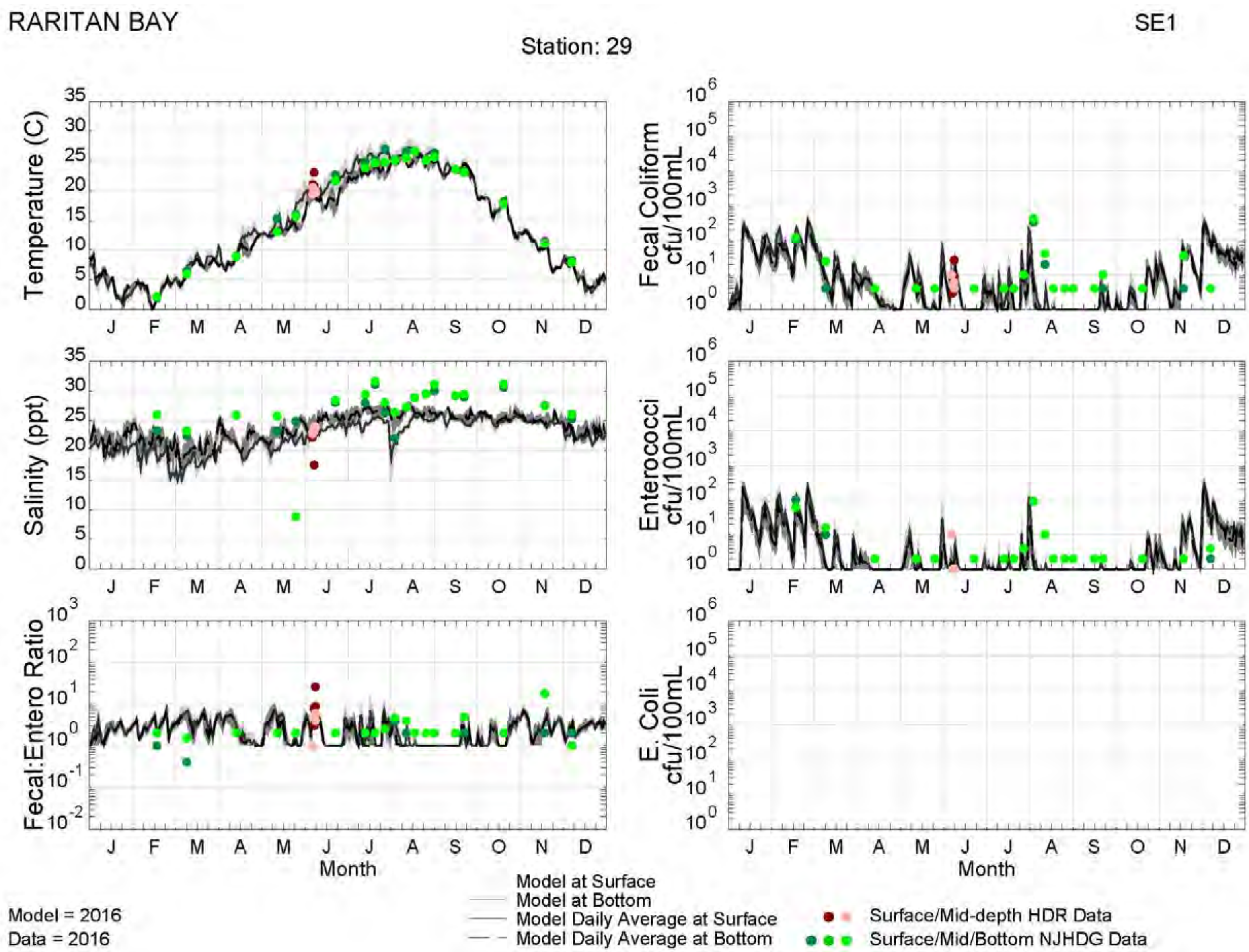


Figure 5-18. 2016 Annual Time-Series Model versus Data Comparison at Station 29, Raritan Bay

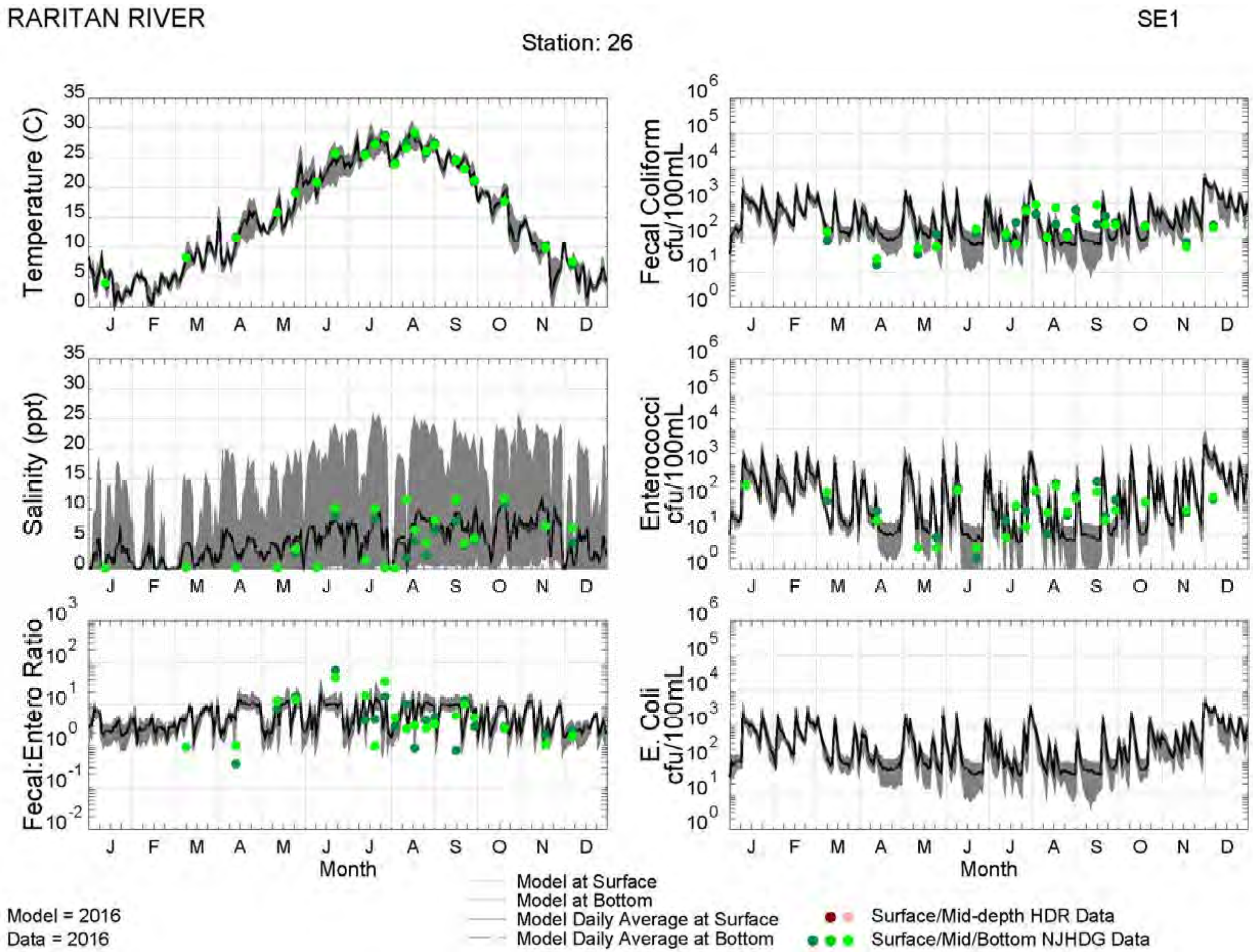


Figure 5-19. 2016 Annual Time-Series Model versus Data Comparison at Station 26, Raritan River

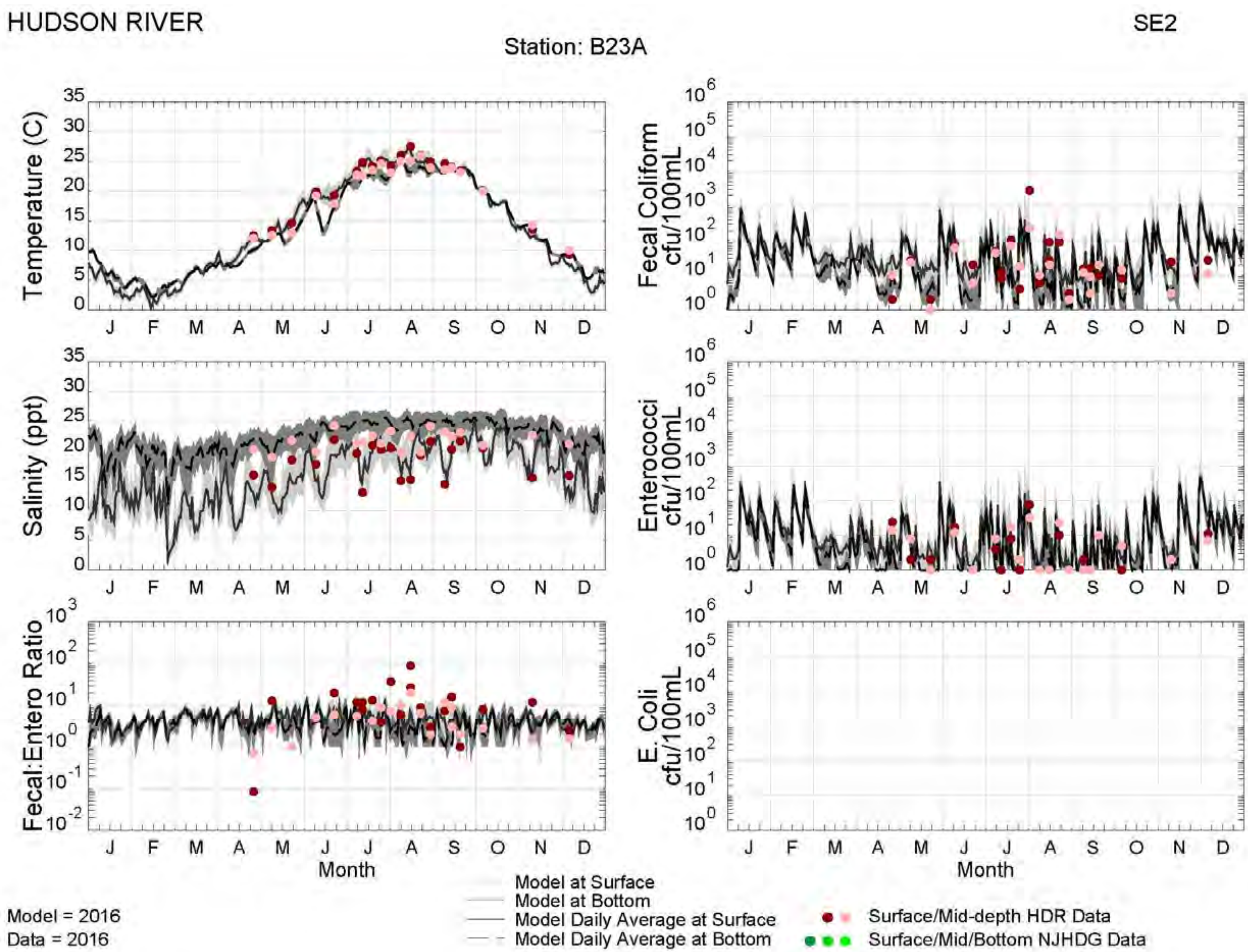


Figure 5-20. 2016 Annual Time-Series Model versus Data Comparison at Station B23A, Hudson River

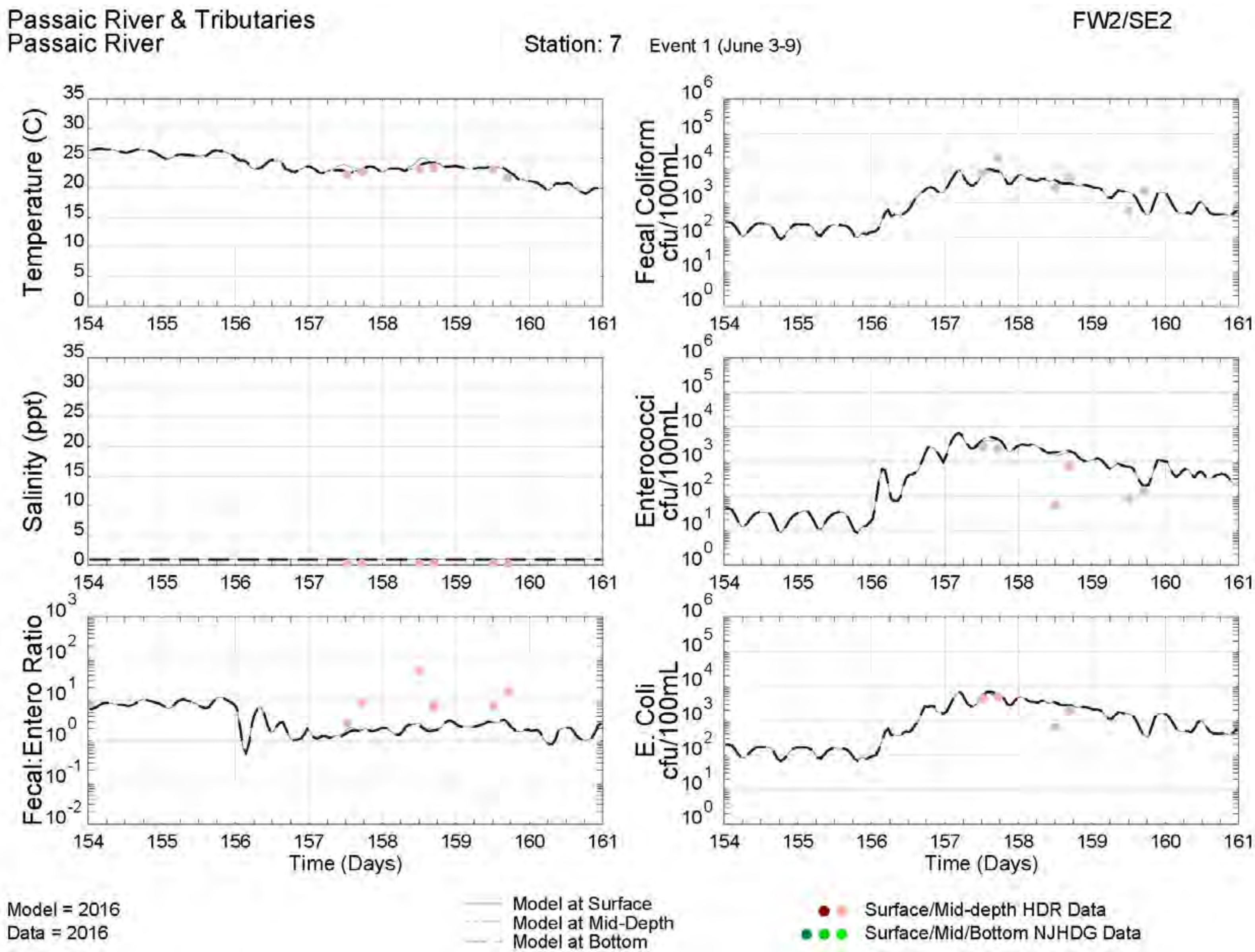


Figure 5-21. June 2016 Wet-Weather Event Model versus Data Comparison at Station 7, Passaic River

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.

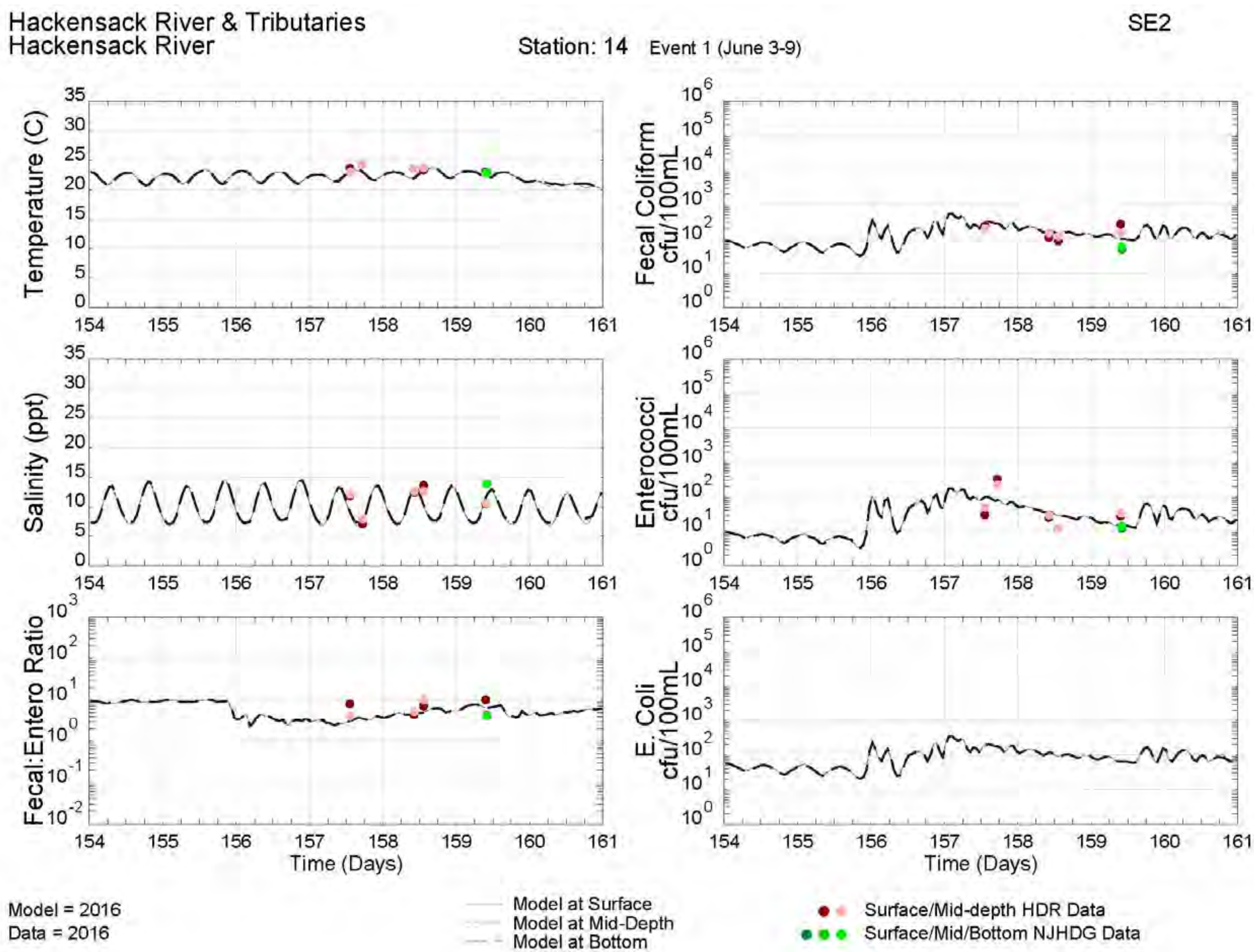


Figure 5-22. June 2016 Wet-Weather Event Model versus Data Comparison at Station 14, Hackensack River

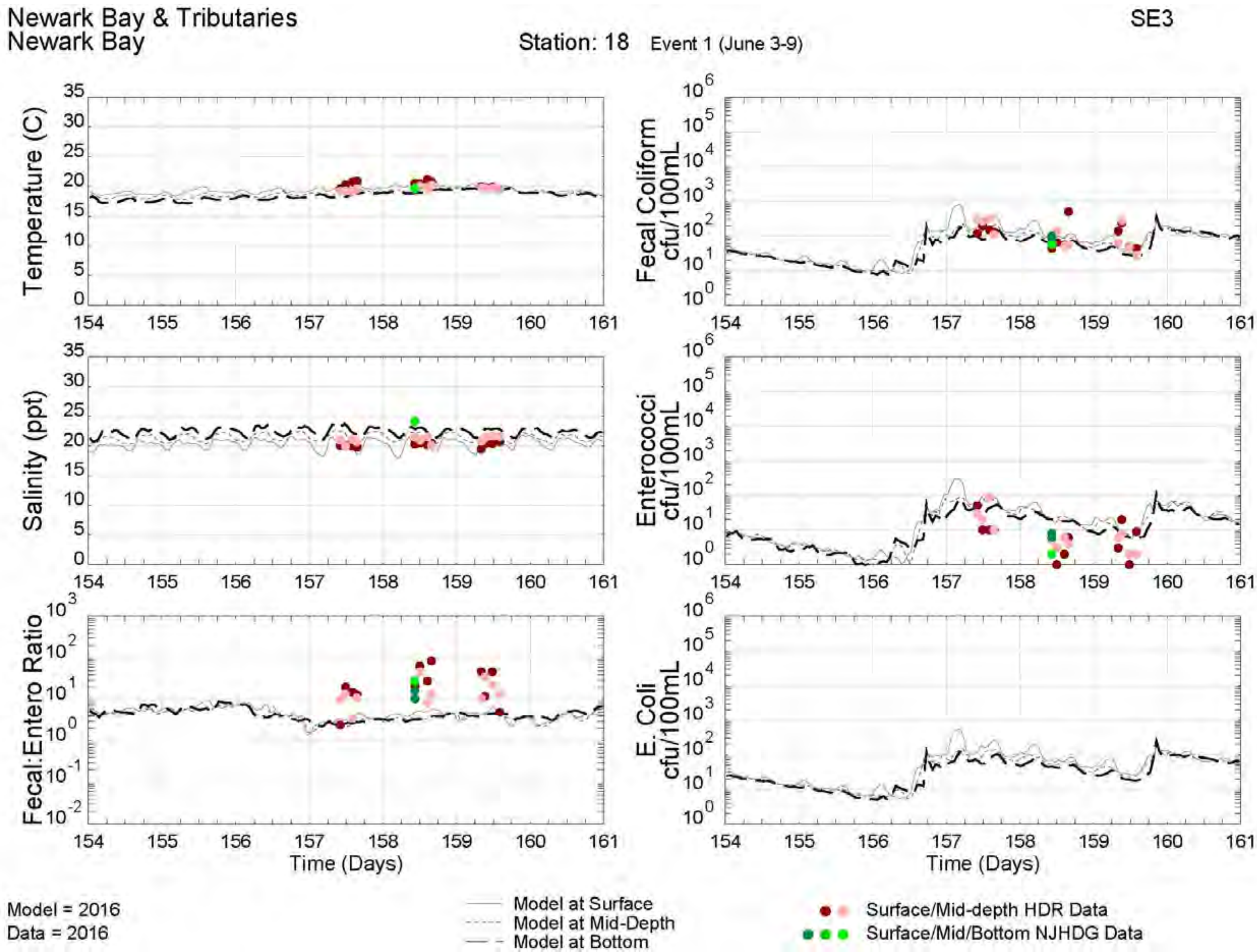


Figure 5-23. June 2016 Wet-Weather Event Model versus Data Comparison at Station 18, Newark Bay

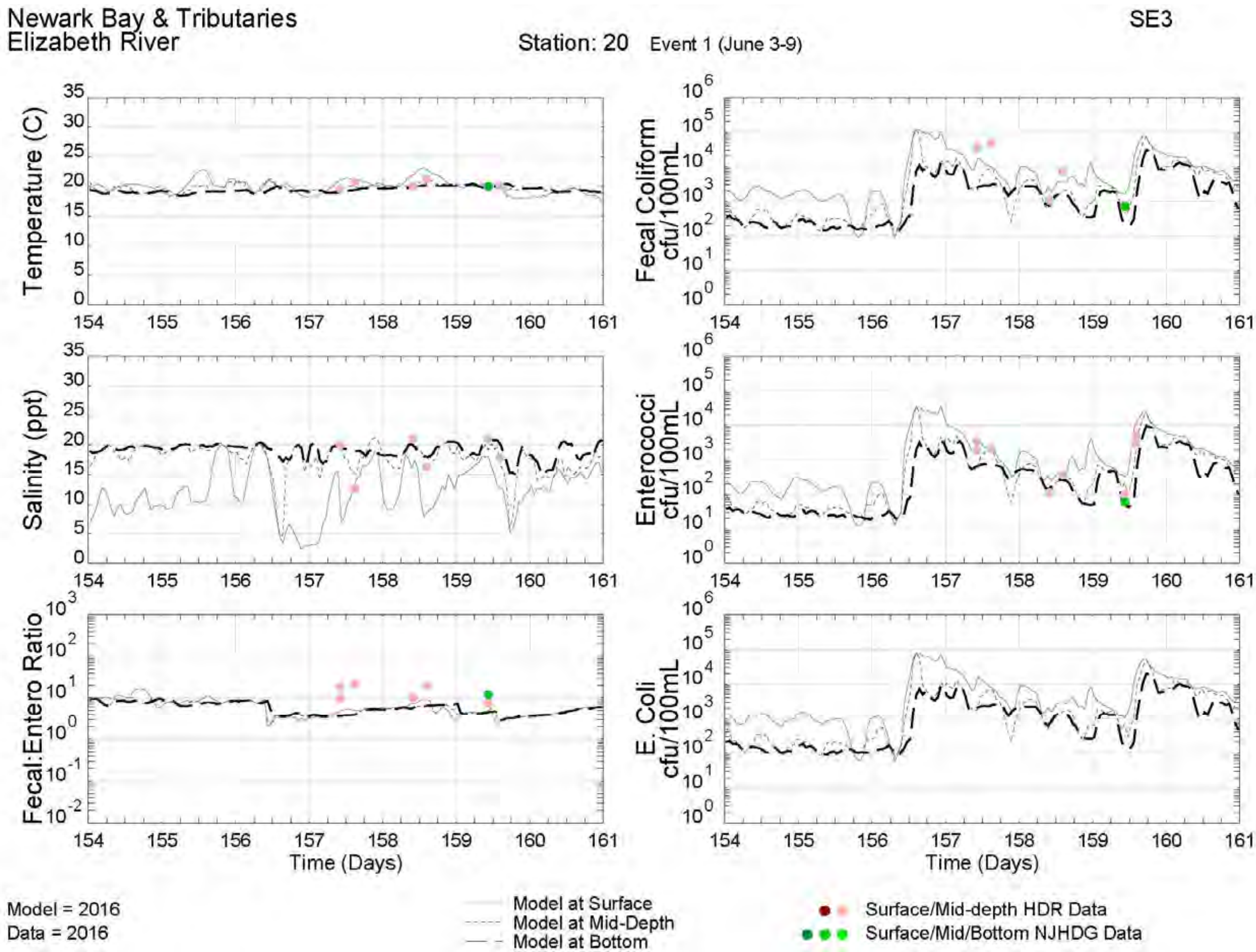


Figure 5-24. June 2016 Wet-Weather Event Model versus Data Comparison at Station 20, Elizabeth River

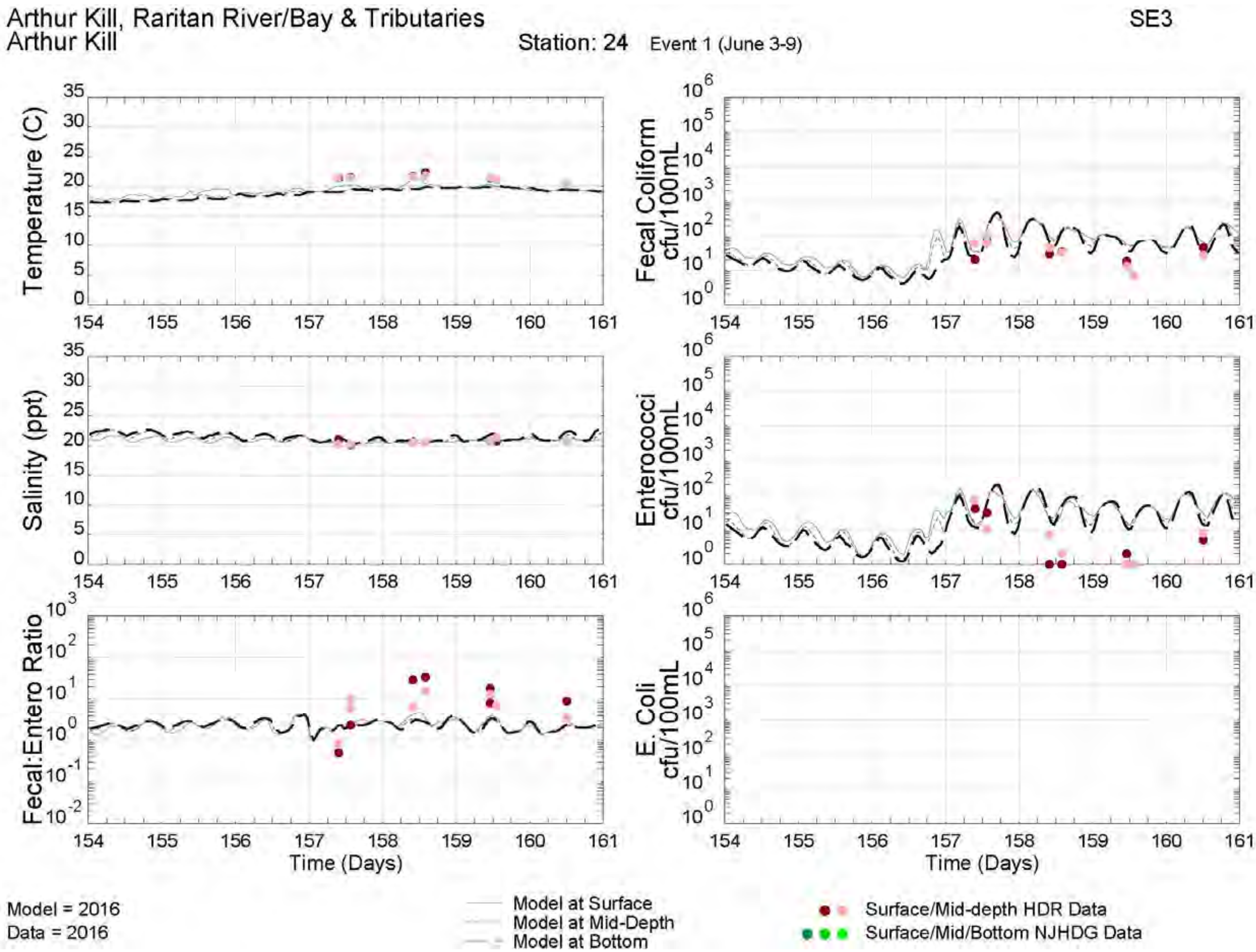


Figure 5-25. June 2016 Wet-Weather Event Model versus Data Comparison at Station 24, Raritan River

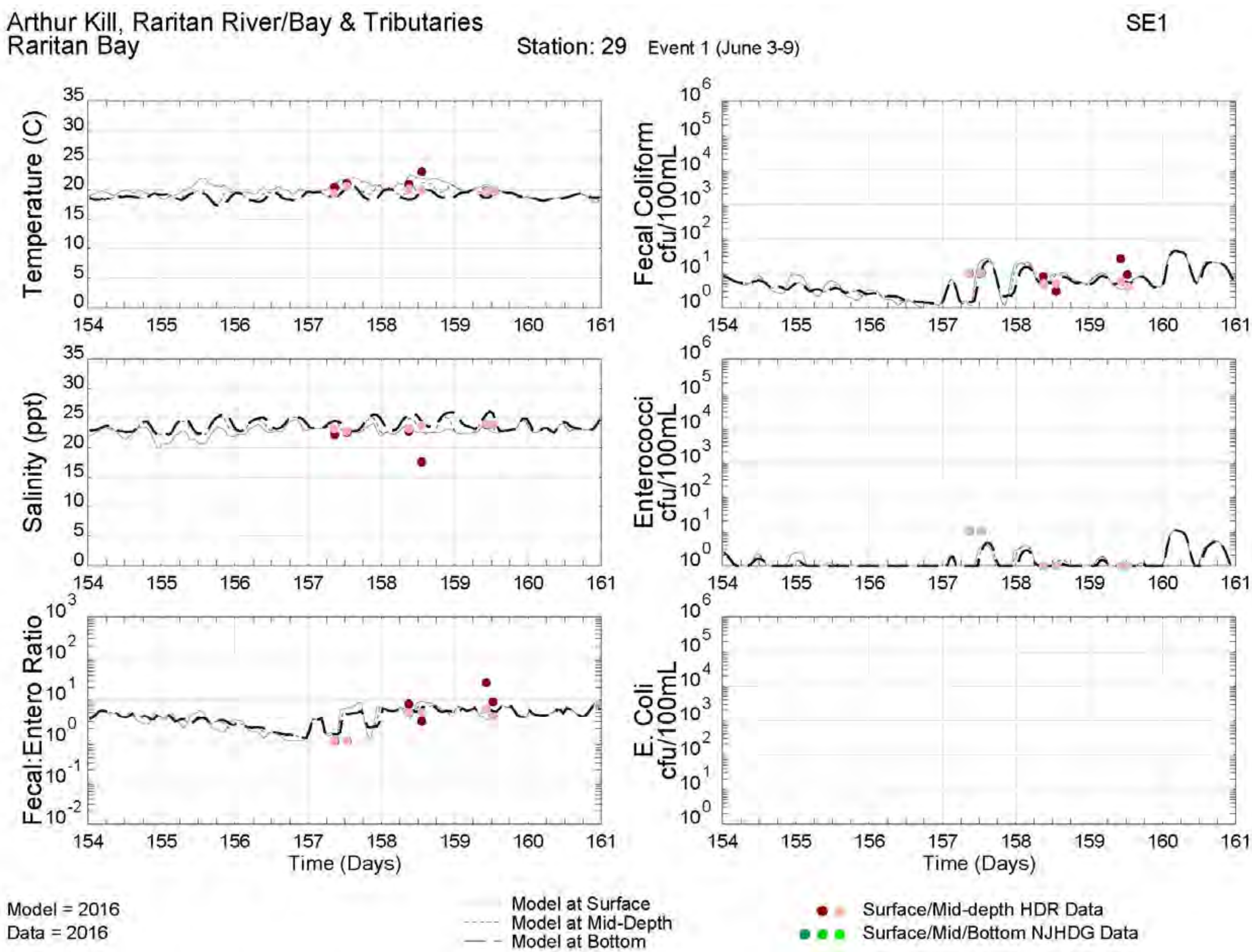


Figure 5-26. June 2016 Wet-Weather Event Model versus Data Comparison at Station 29, Raritan Bay

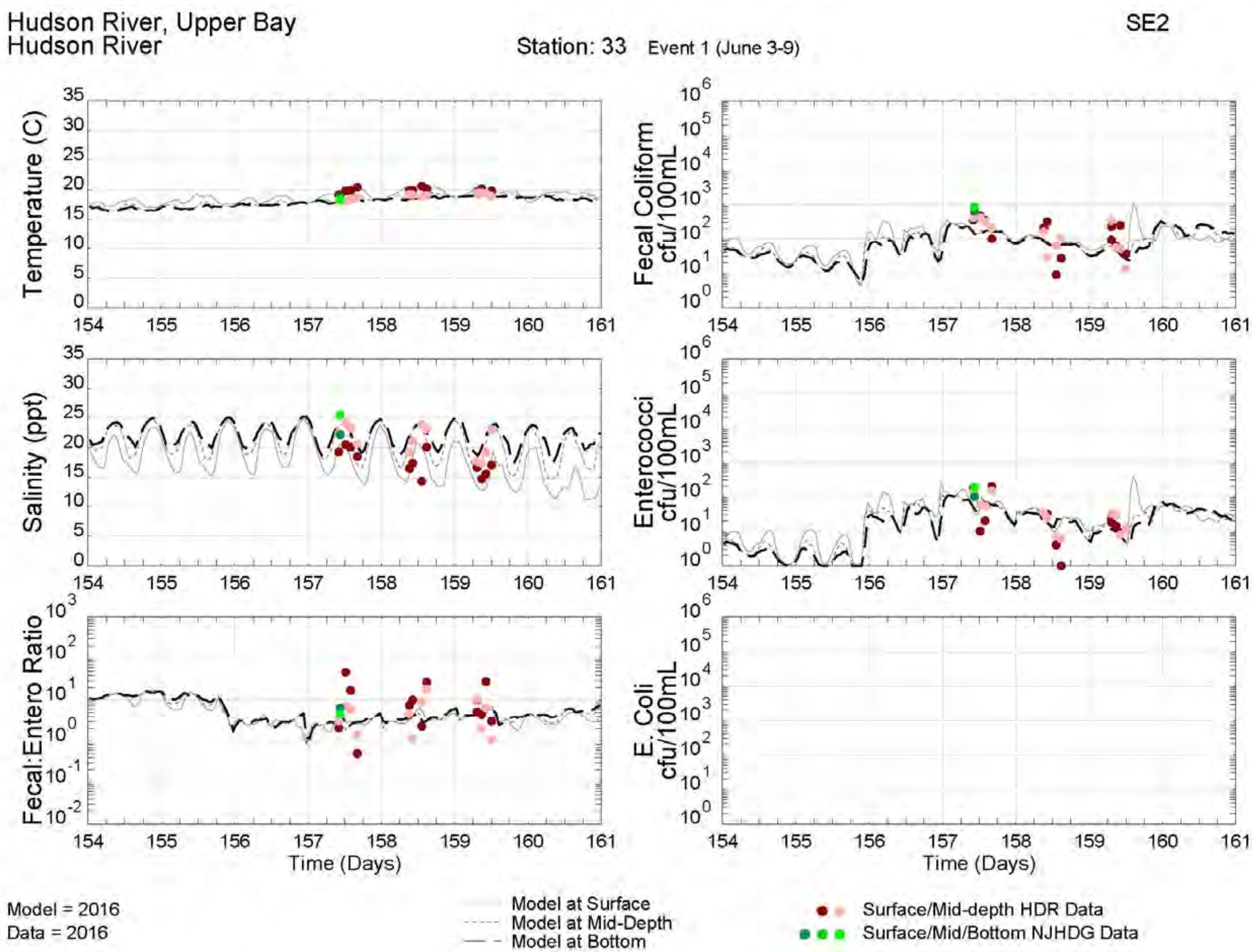


Figure 5-27. June 2016 Wet-Weather Event Model versus Data Comparison at Station 33, Hudson River

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.

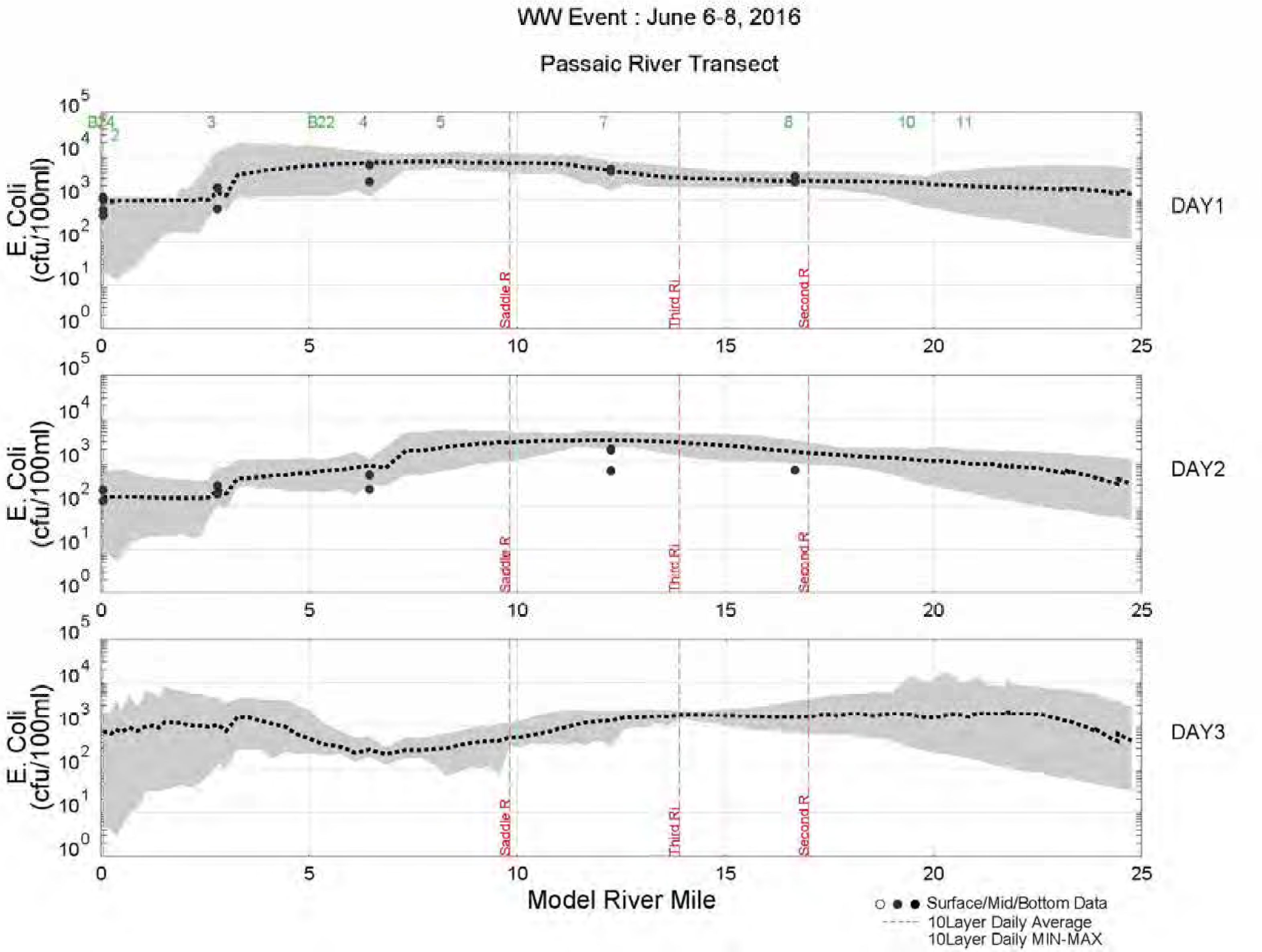


Figure 5-28. June 2016 Passaic River Model versus Data Transect Comparison for E. Coli

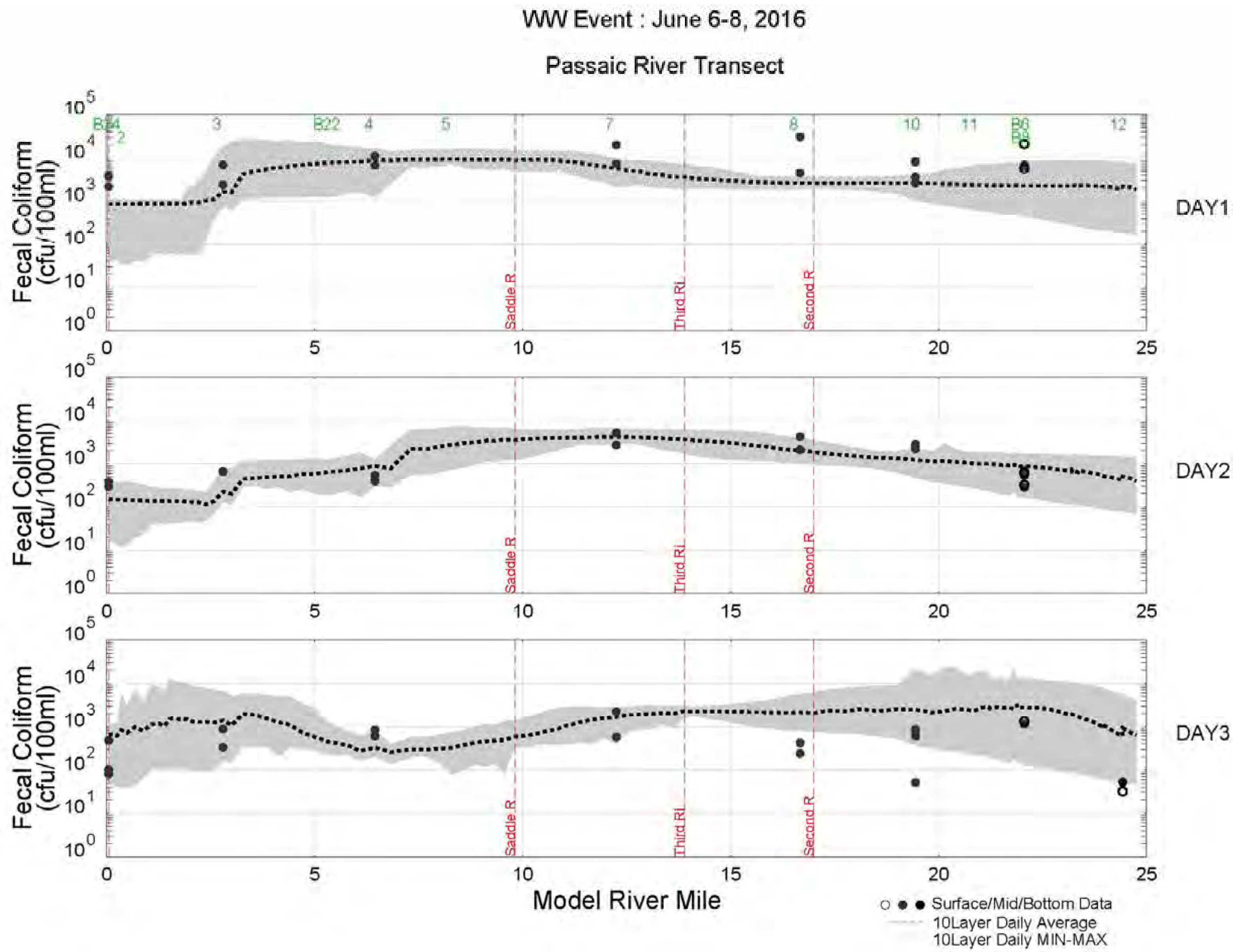


Figure 5-29. June 2016 Passaic River Model versus Data Transect Comparison for Fecal Coliform

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 50^{th} percentile represent the median concentration. For a log-normally distributed data set, the 50^{th} percentile represents the geometric mean. Therefore, if the model can be shown to reproduce the 50^{th} 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 in crosses a single sample maximum concentration or 90^{th} percentile concentration, then the model can be used to assess these criteria as well.

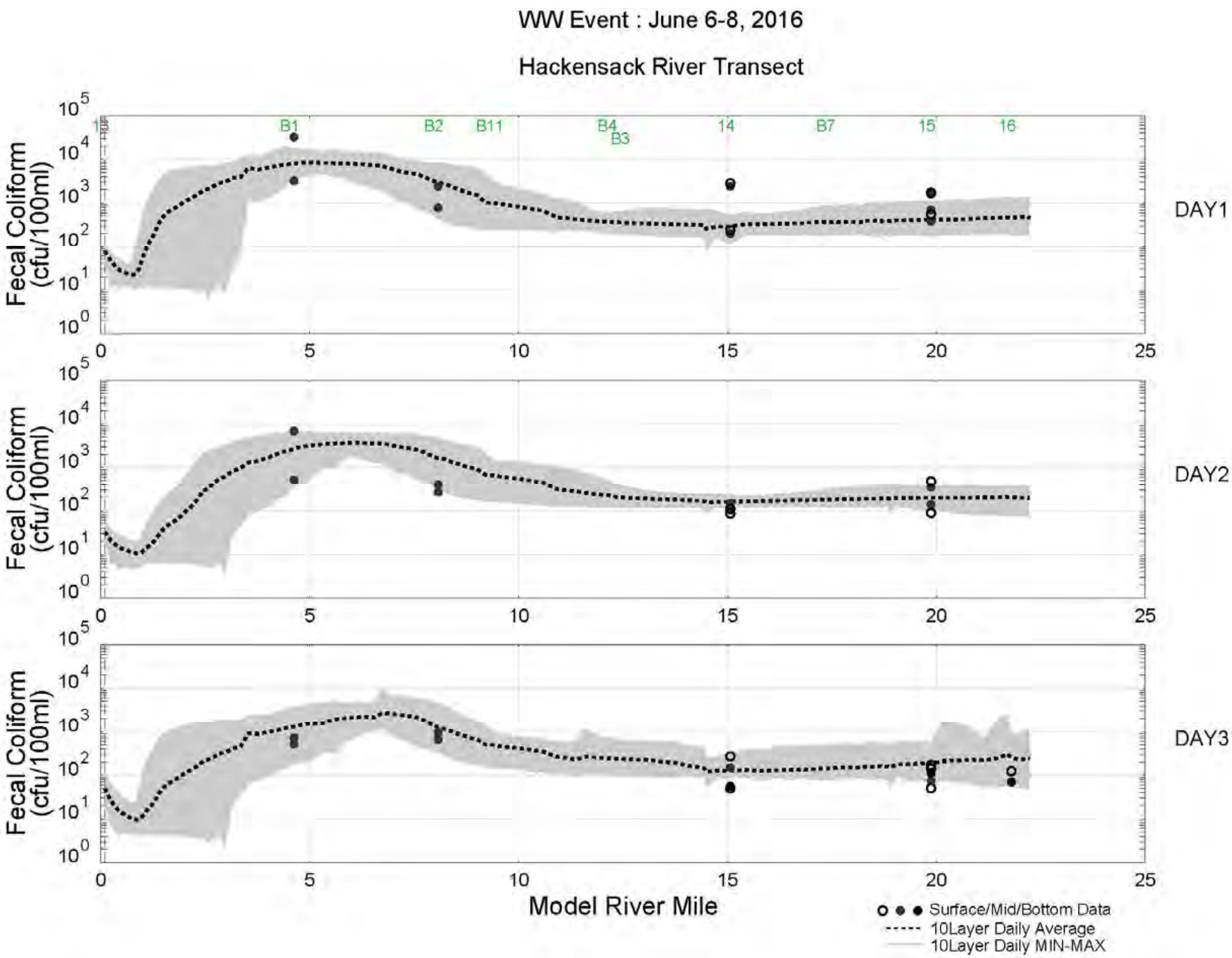


Figure 5-30. June 2016 Hackensack River Model versus Data Transect Comparison for Fecal Coliform

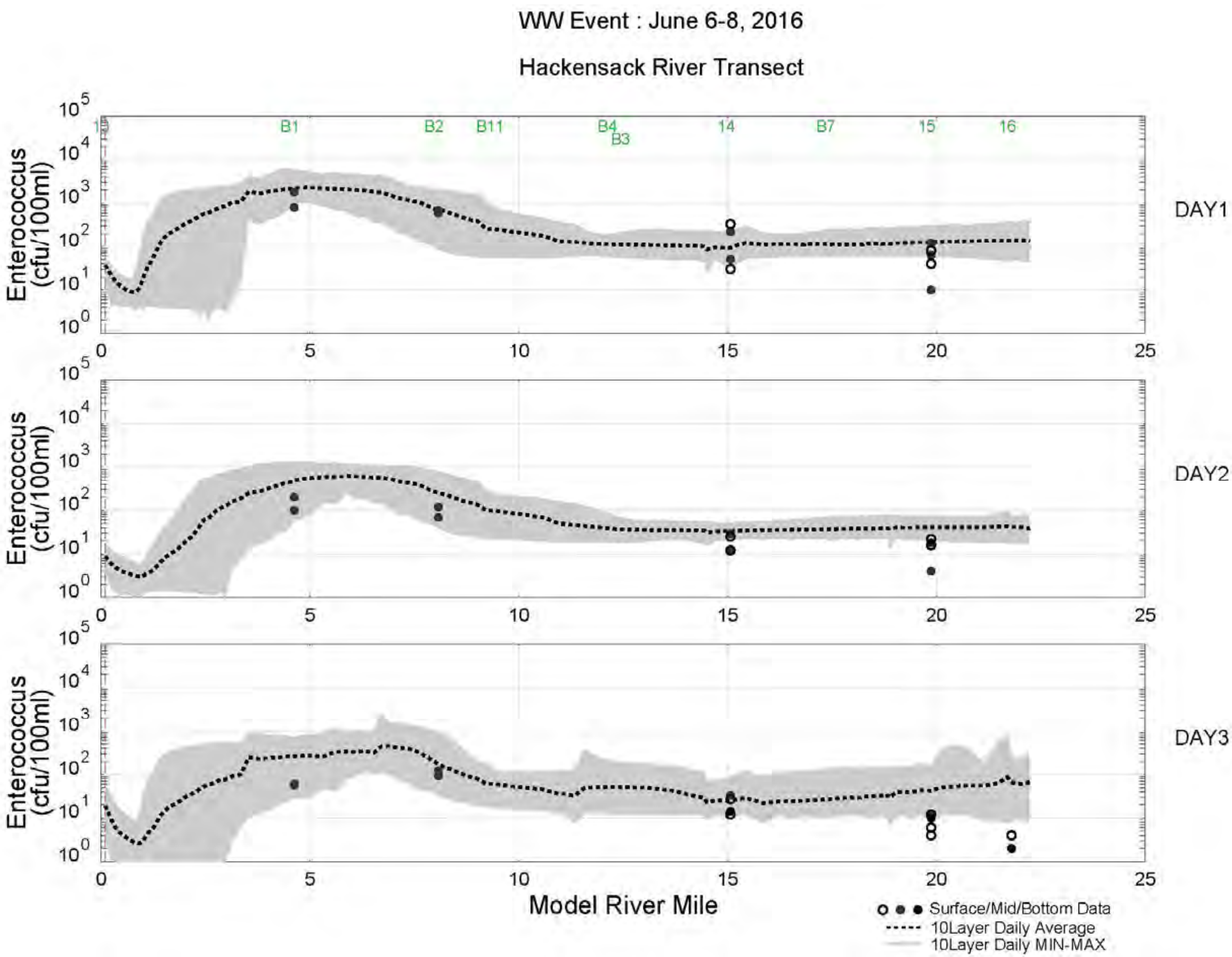


Figure 5-31. June 2016 Hackensack River Model versus Data Transect Comparison for Enterococci

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 where 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 a 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.

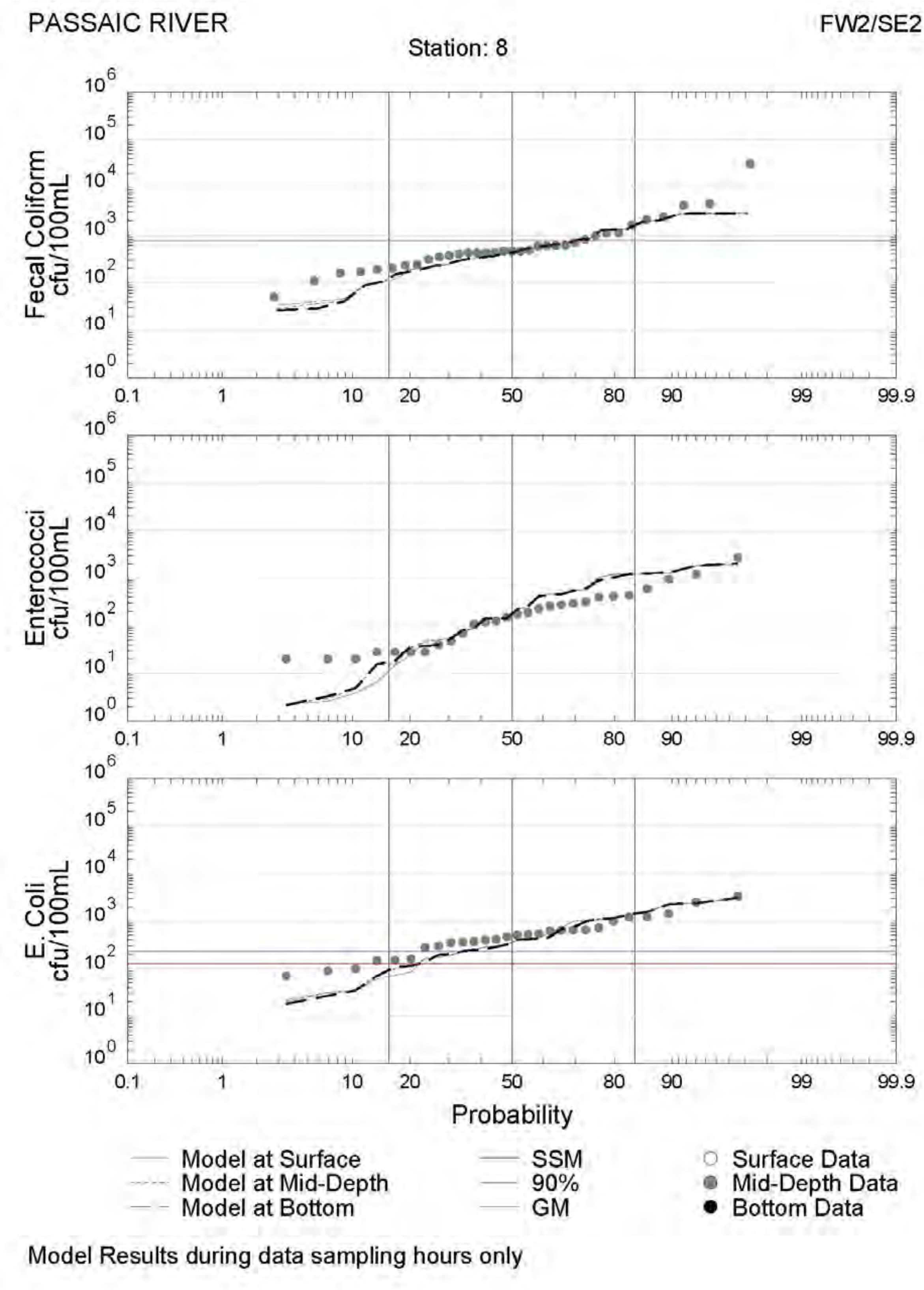


Figure 5-32. 2016 Annual Model versus Data Probability Distribution Comparison at Station 8, Passaic River

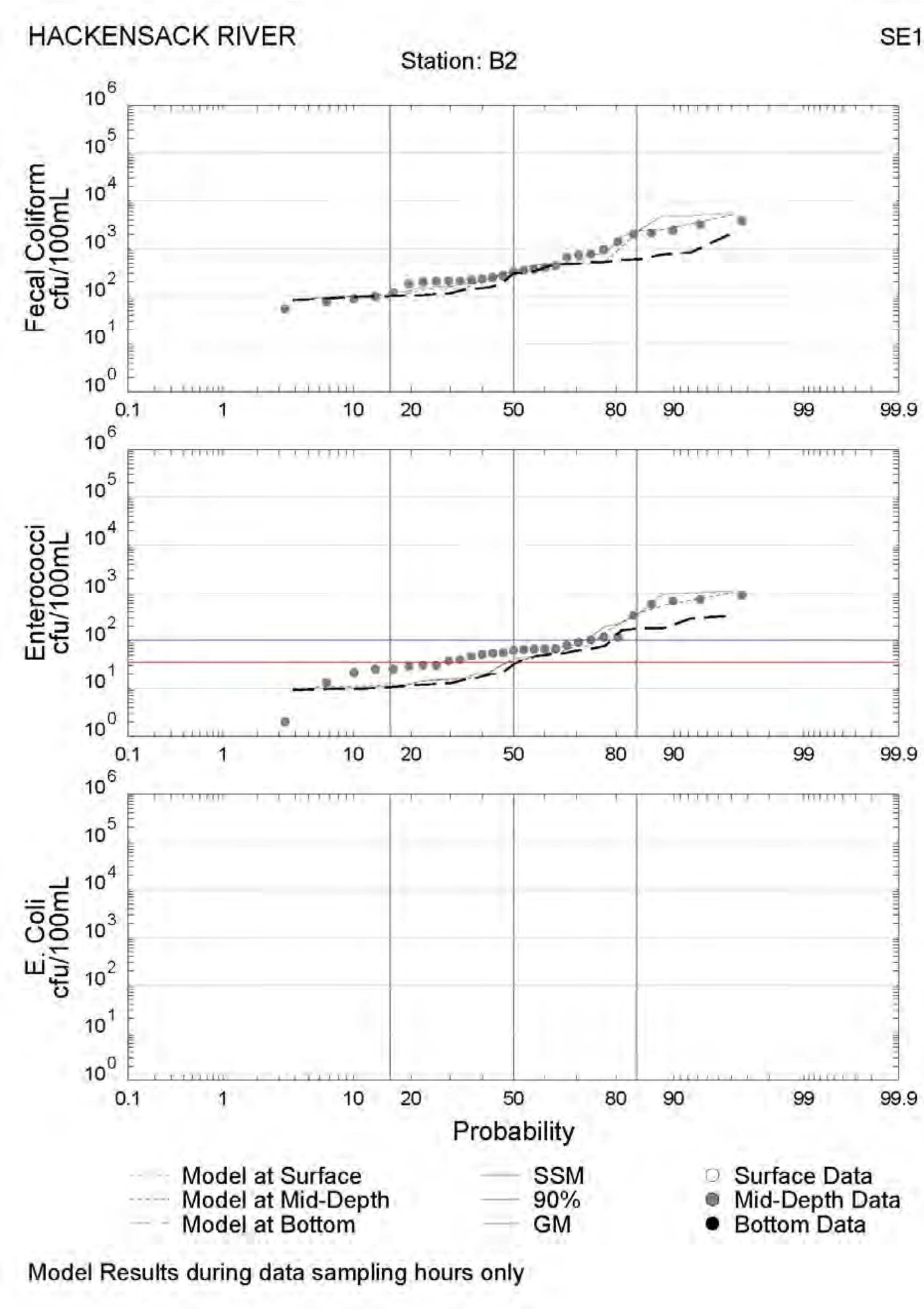


Figure 5-33. 2016 Annual Model versus Data Probability Distribution Comparison at Station B2, Hackensack River

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 is 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.

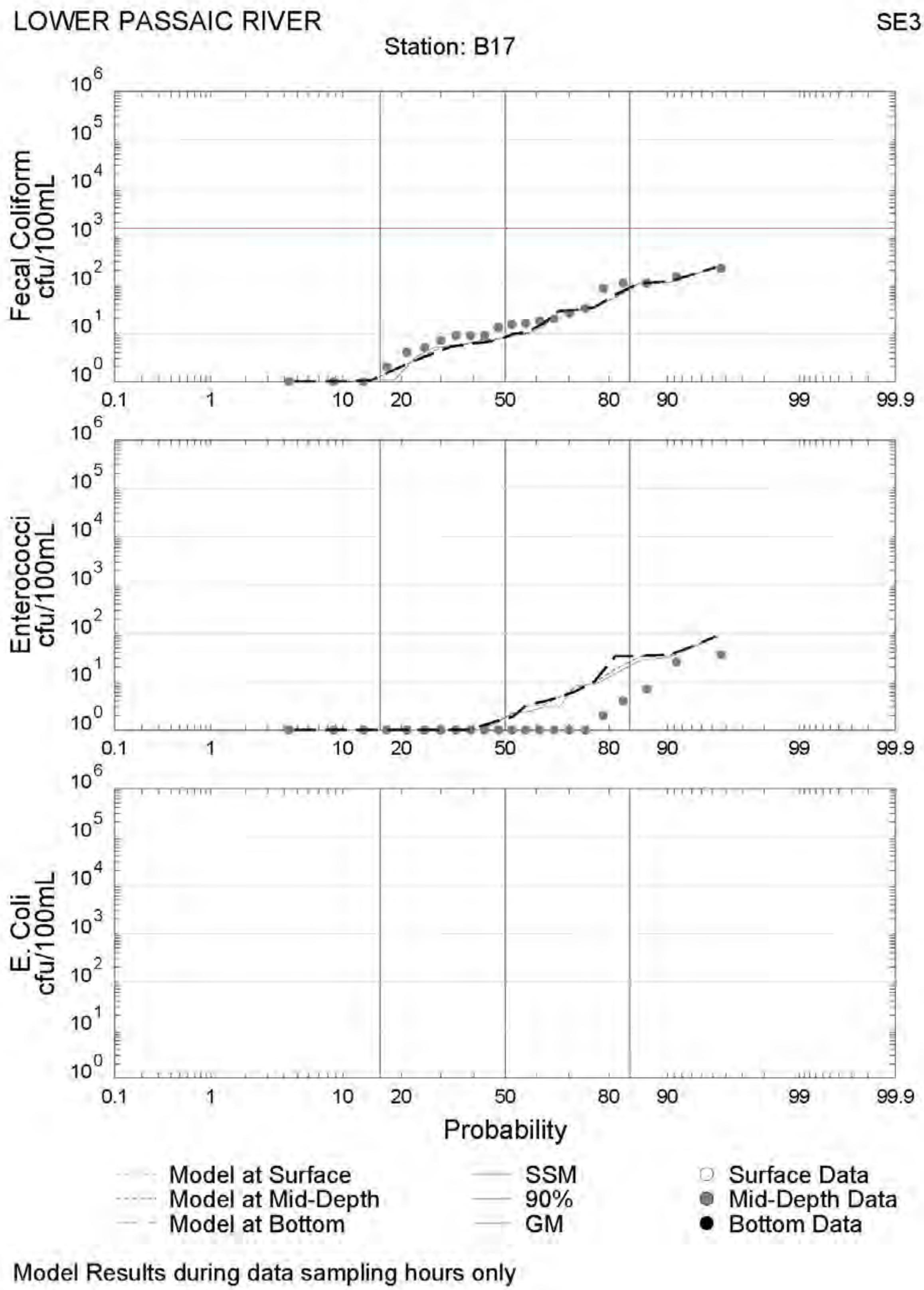


Figure 5-34. 2016 Annual Model versus Data Probability Distribution Comparison at Station B17, Newark Bay

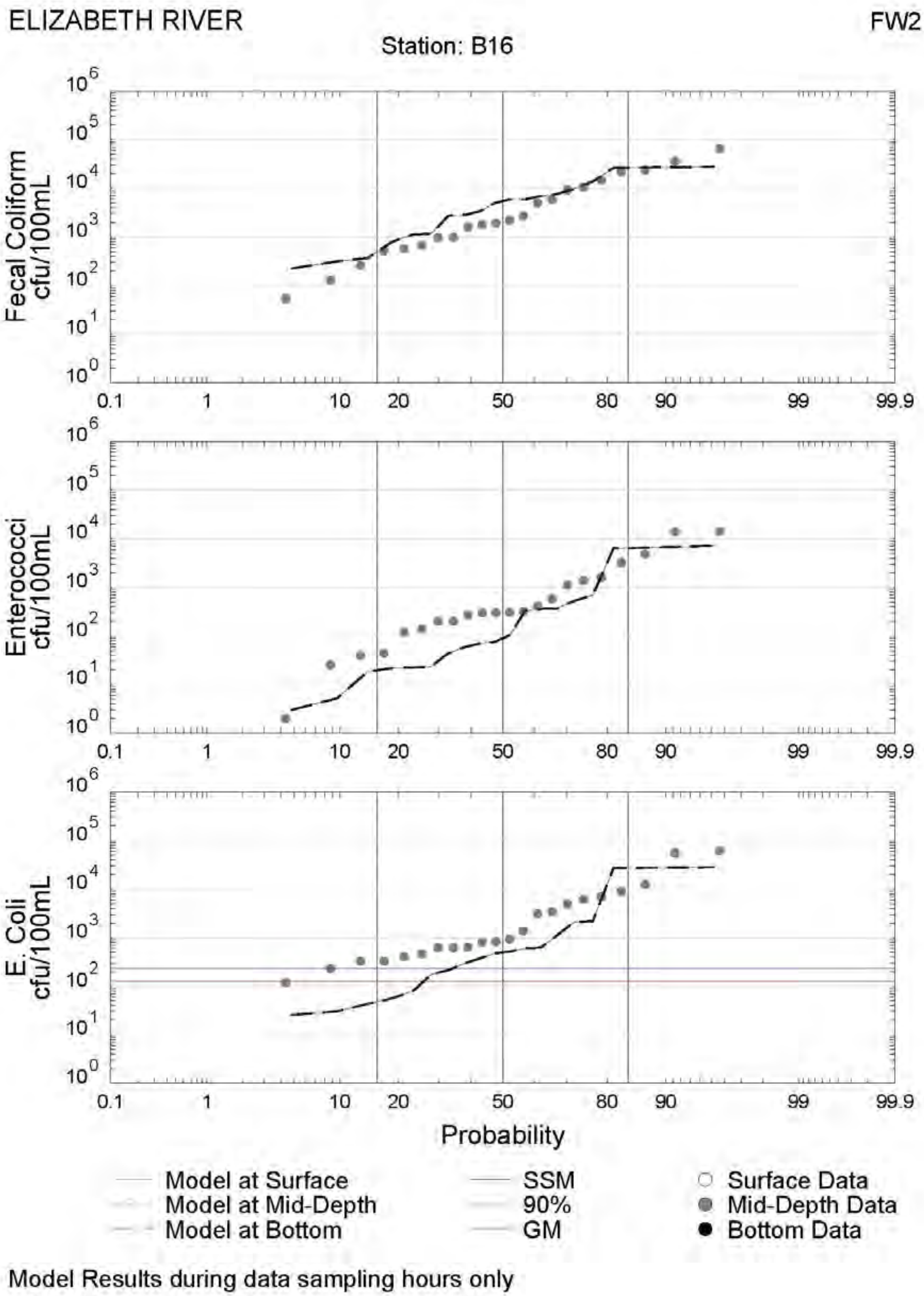


Figure 5-35. 2016 Annual Model versus Data Probability Distribution Comparison at Station B16, Elizabeth River

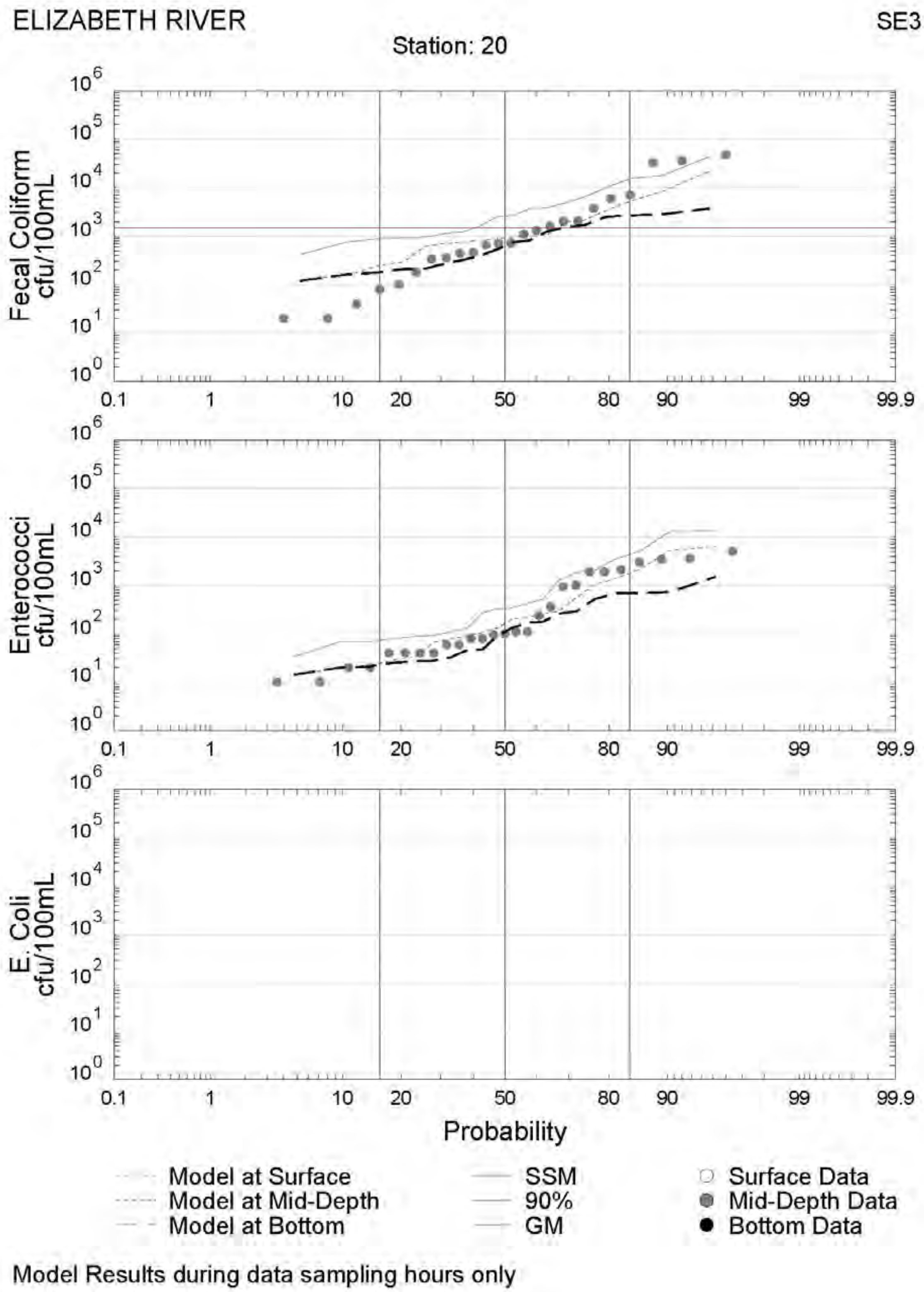


Figure 5-36. 2016 Annual Model versus Data Probability Distribution Comparison at Station 20, Elizabeth River

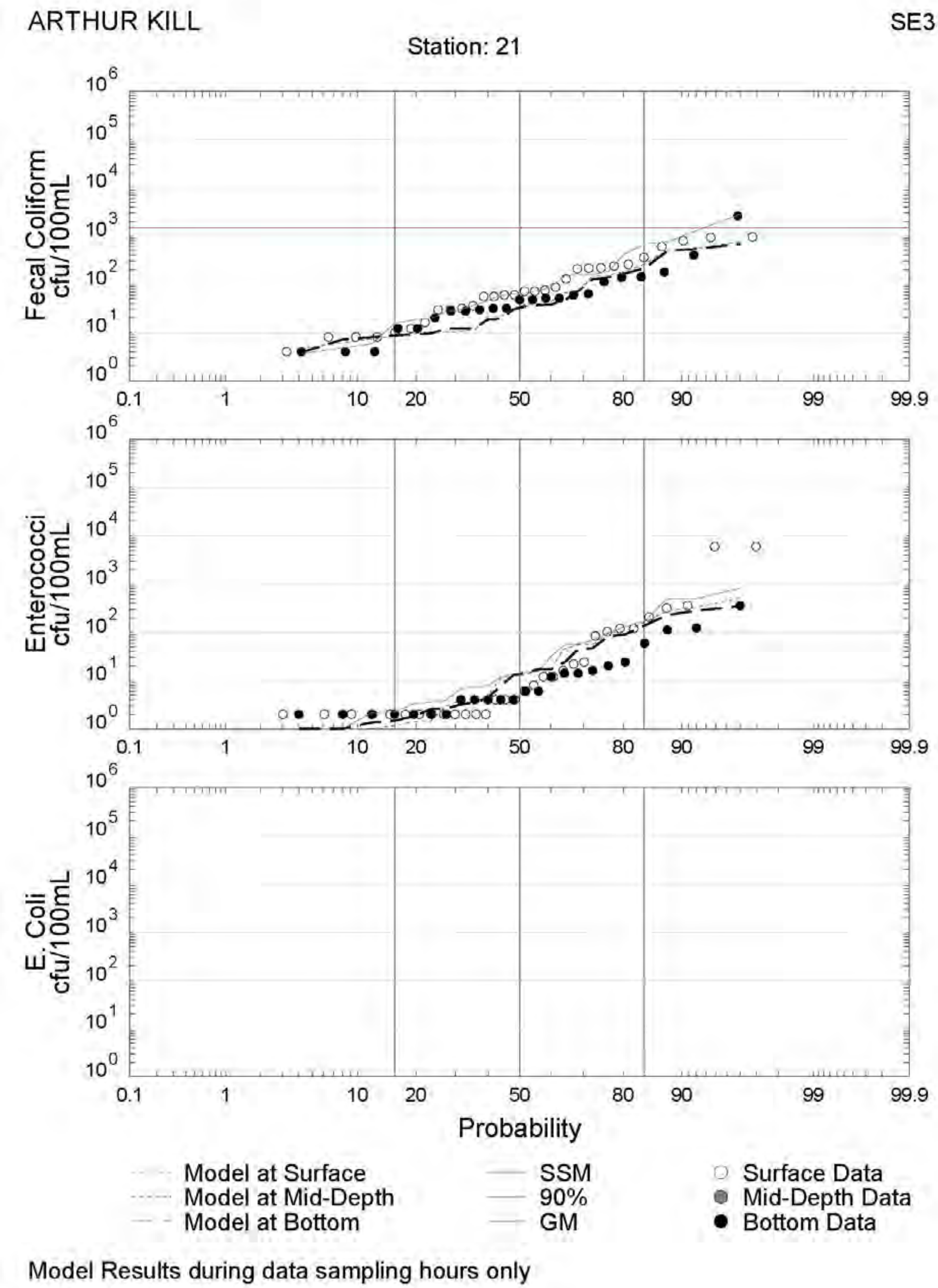


Figure 5-37. 2016 Annual Model versus Data Probability Distribution Comparison at Station 21, Arthur Kill

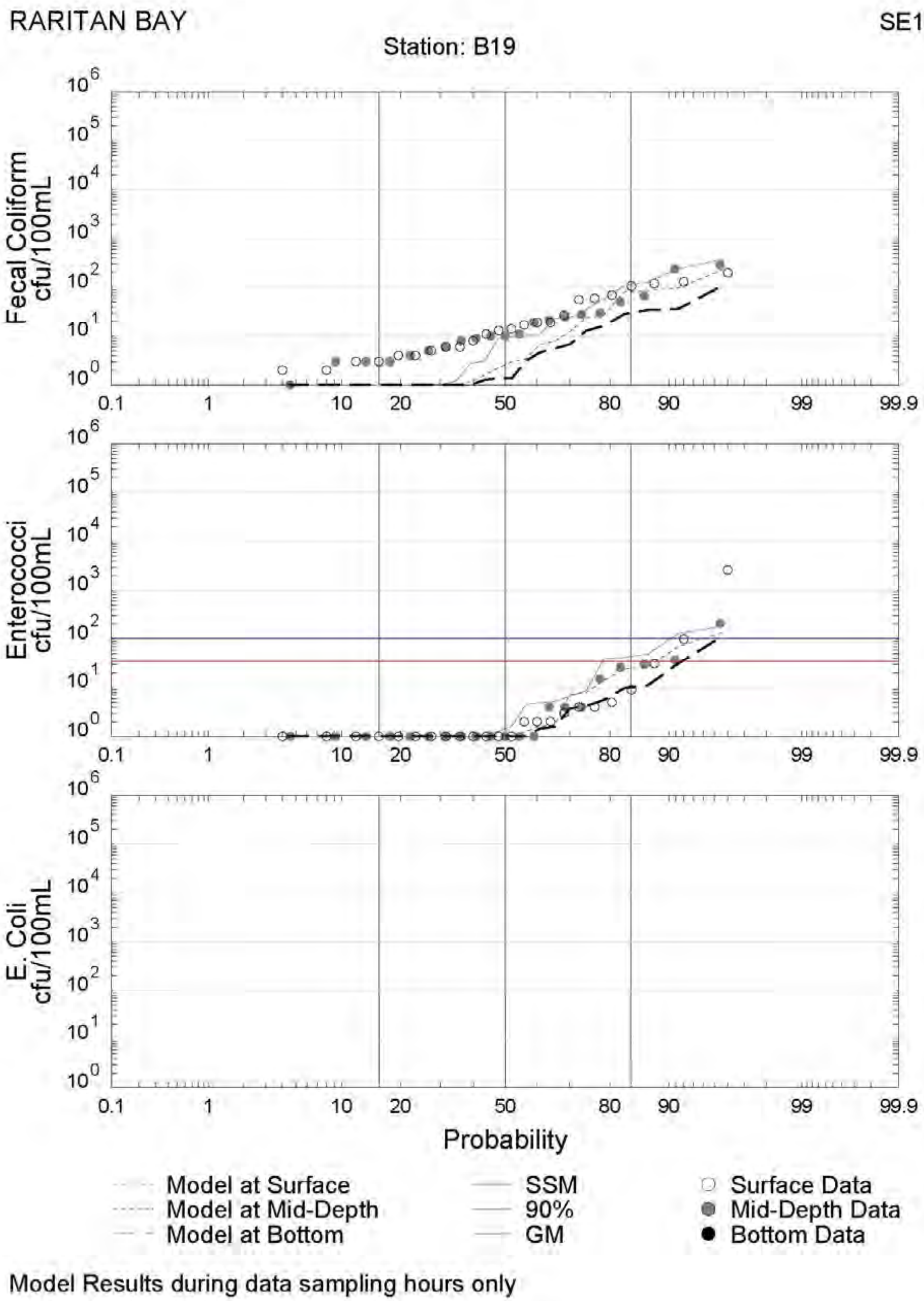


Figure 5-38. 2016 Annual Model versus Data Probability Distribution Comparison at Station B19, Raritan Bay

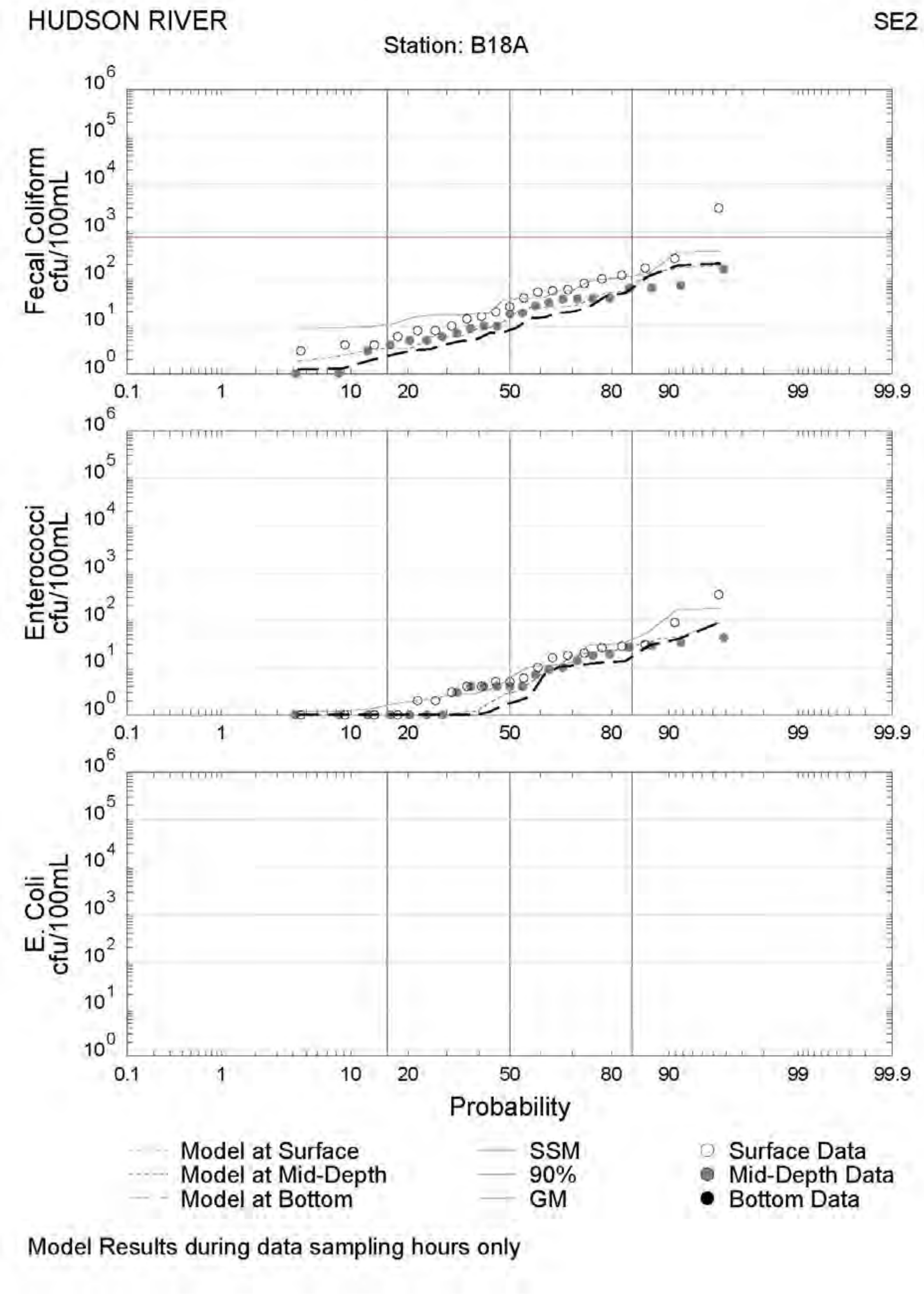


Figure 5-39. 2016 Annual Model versus Data Probability Distribution Comparison at Station B18A, Hudson River

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.

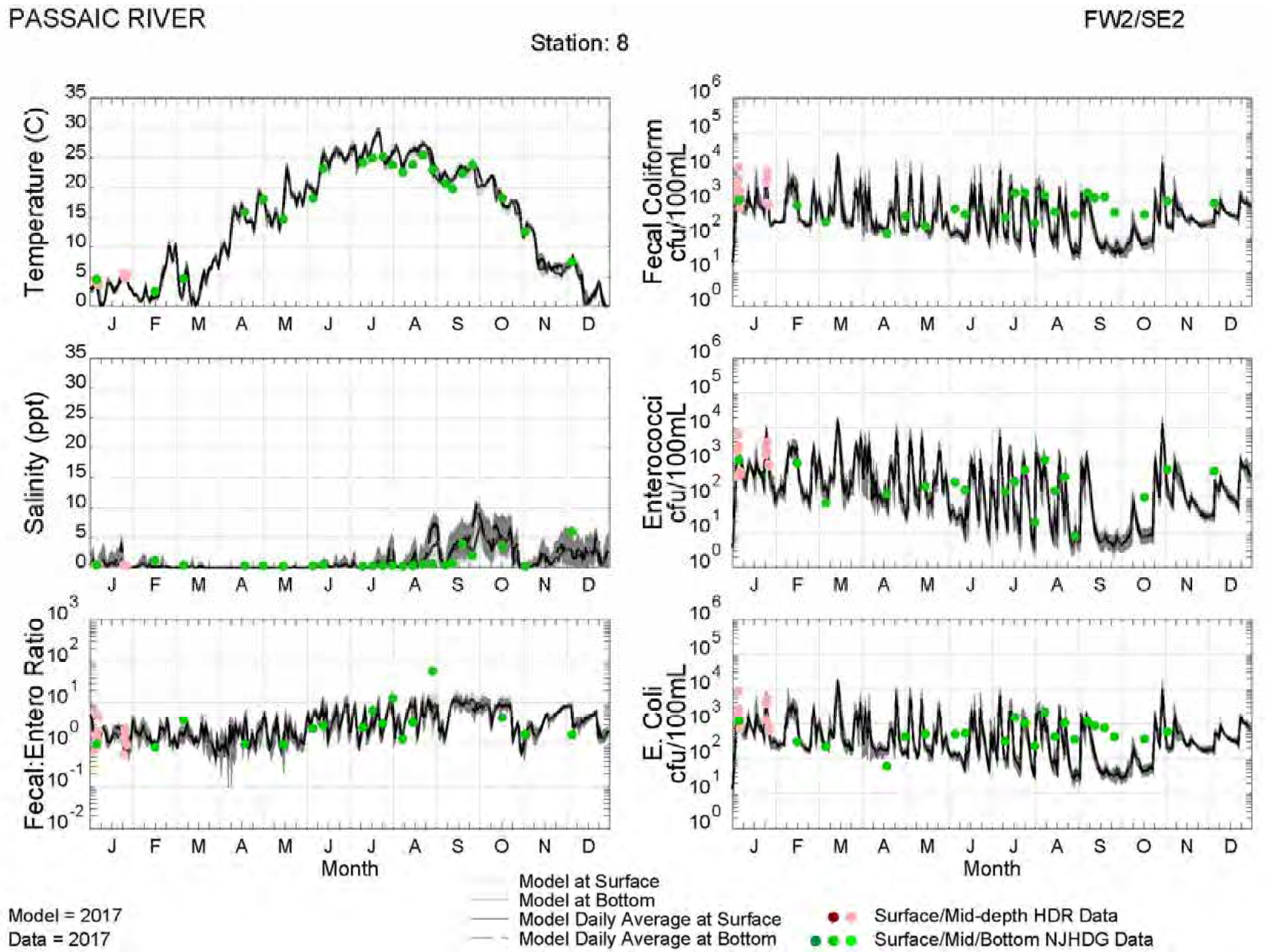


Figure 5-40. 2017 Annual Time-Series Model versus Data Comparison at Station 8, Passaic River

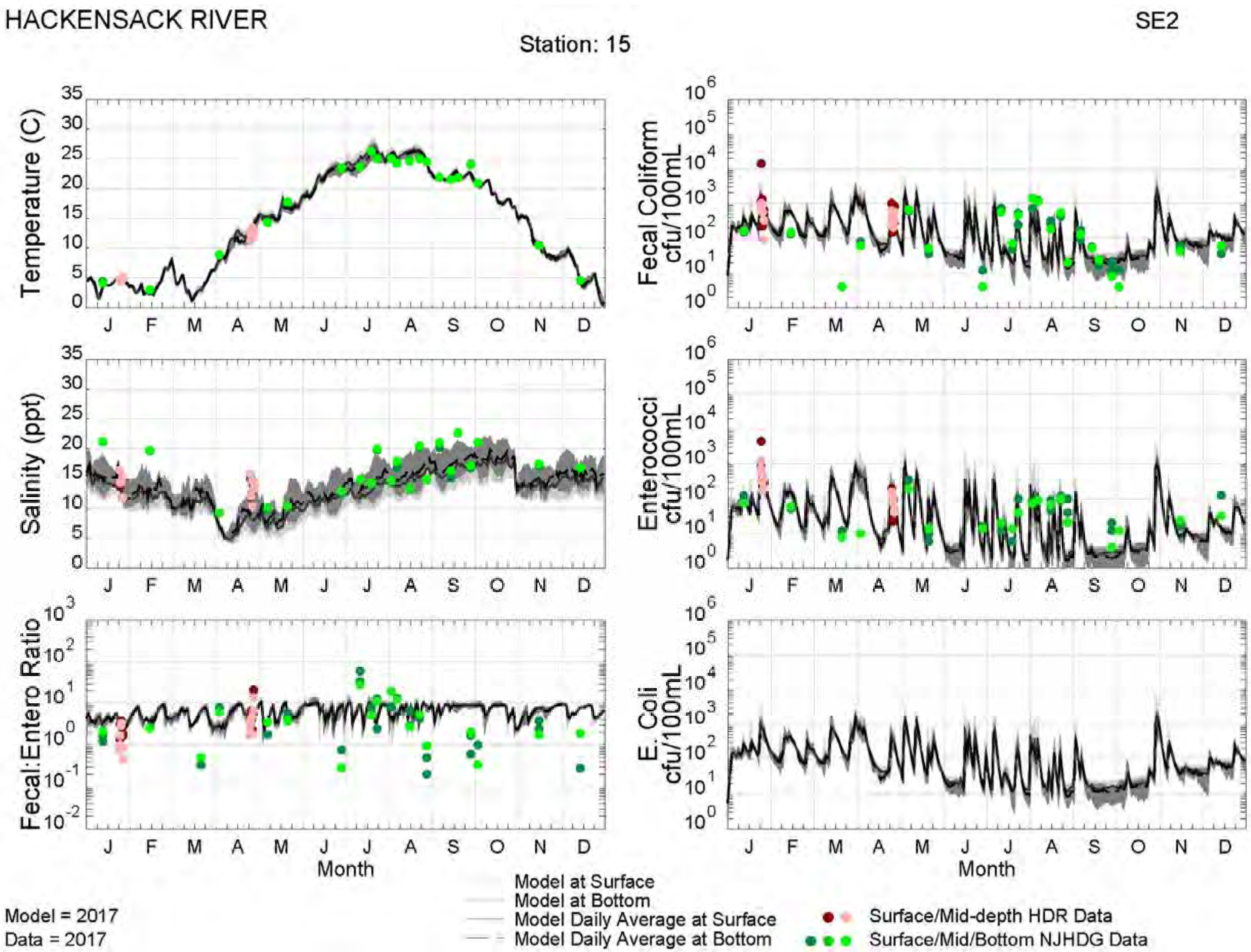


Figure 5-41. 2017 Annual Time-Series Model versus Data Comparison at Station 15, Hackensack River

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.

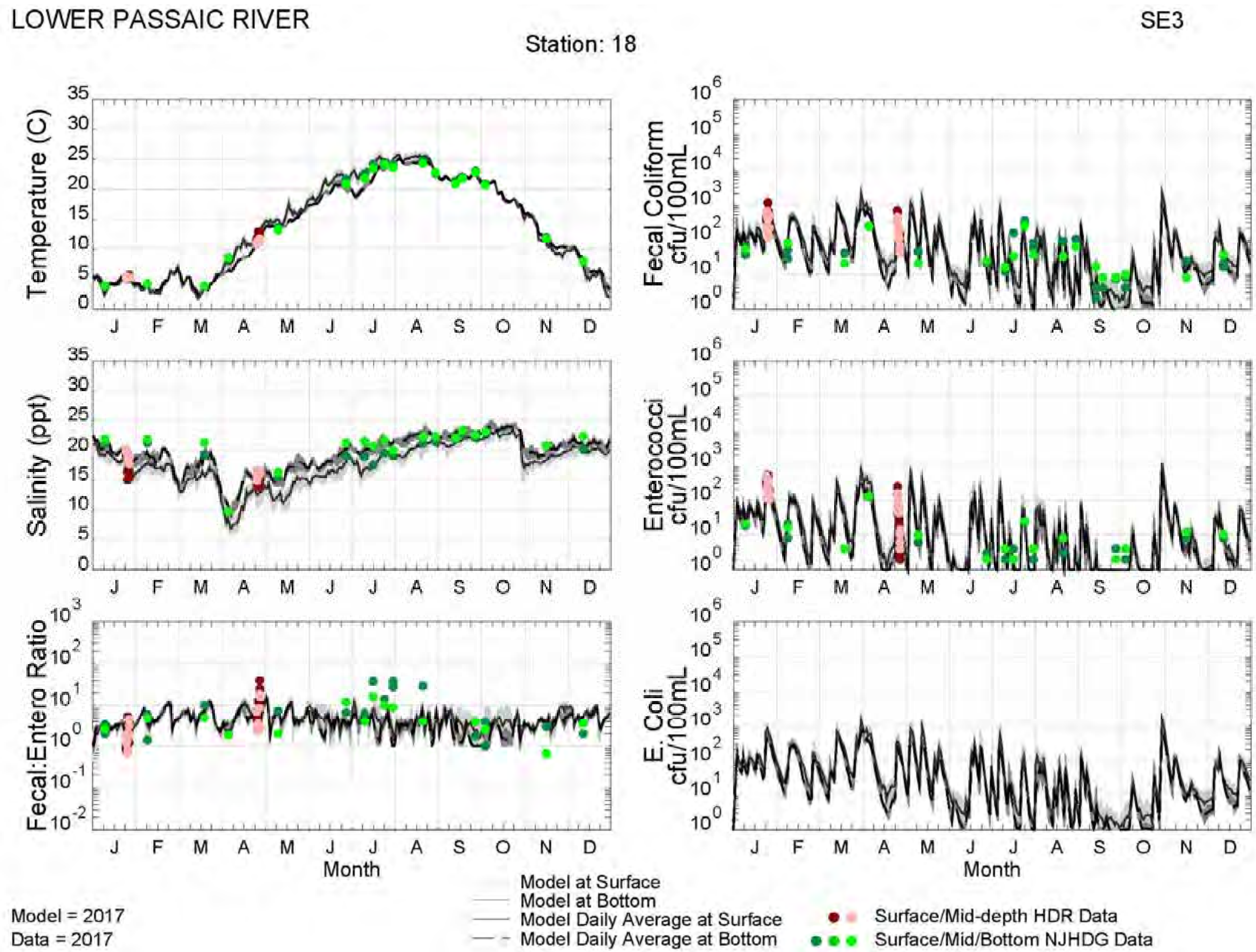


Figure 5-42. 2017 Annual Time-Series Model versus Data Comparison at Station 18, Kill van Kull

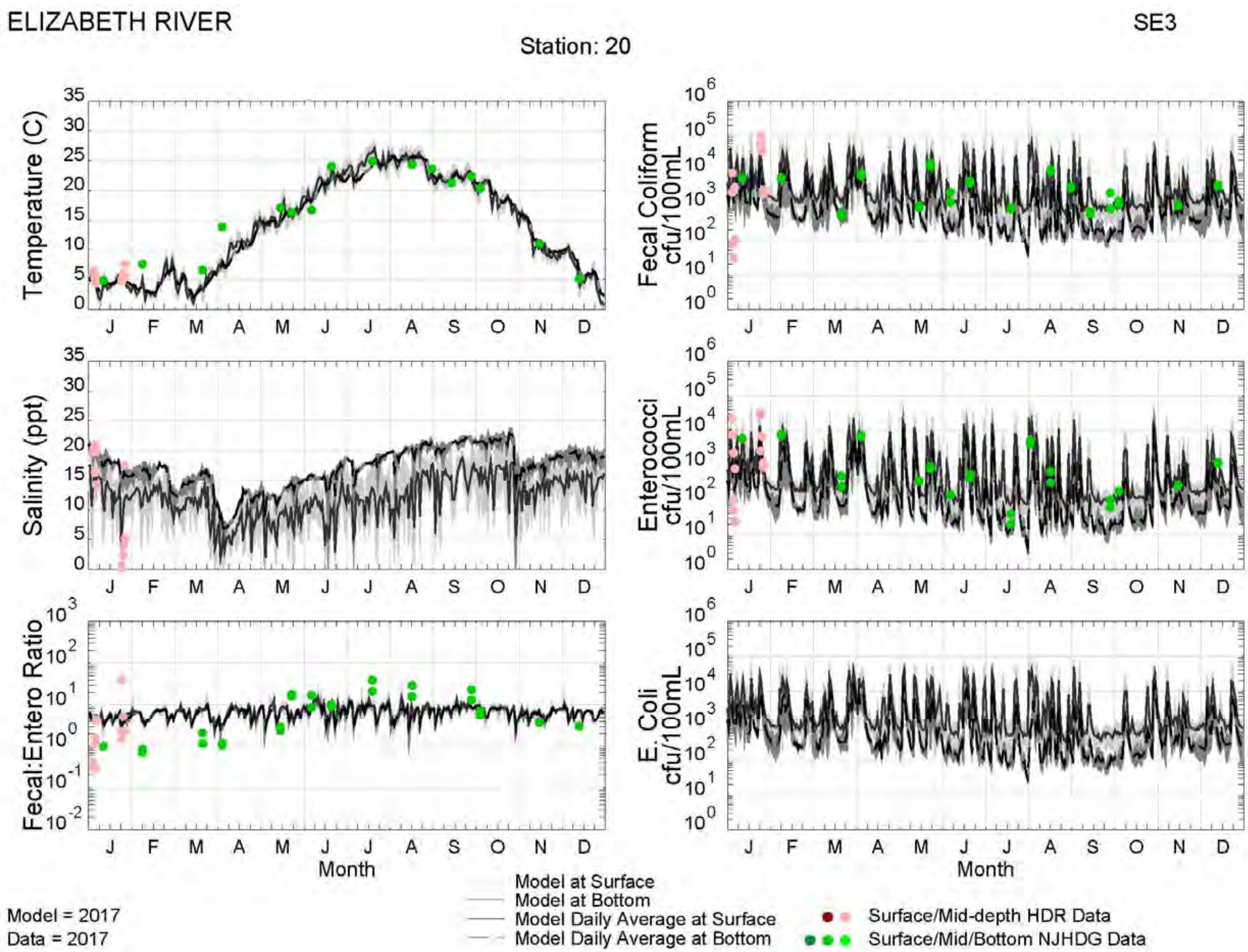


Figure 5-43. 2017 Annual Time-Series Model versus Data Comparison at Station 20, Elizabeth River

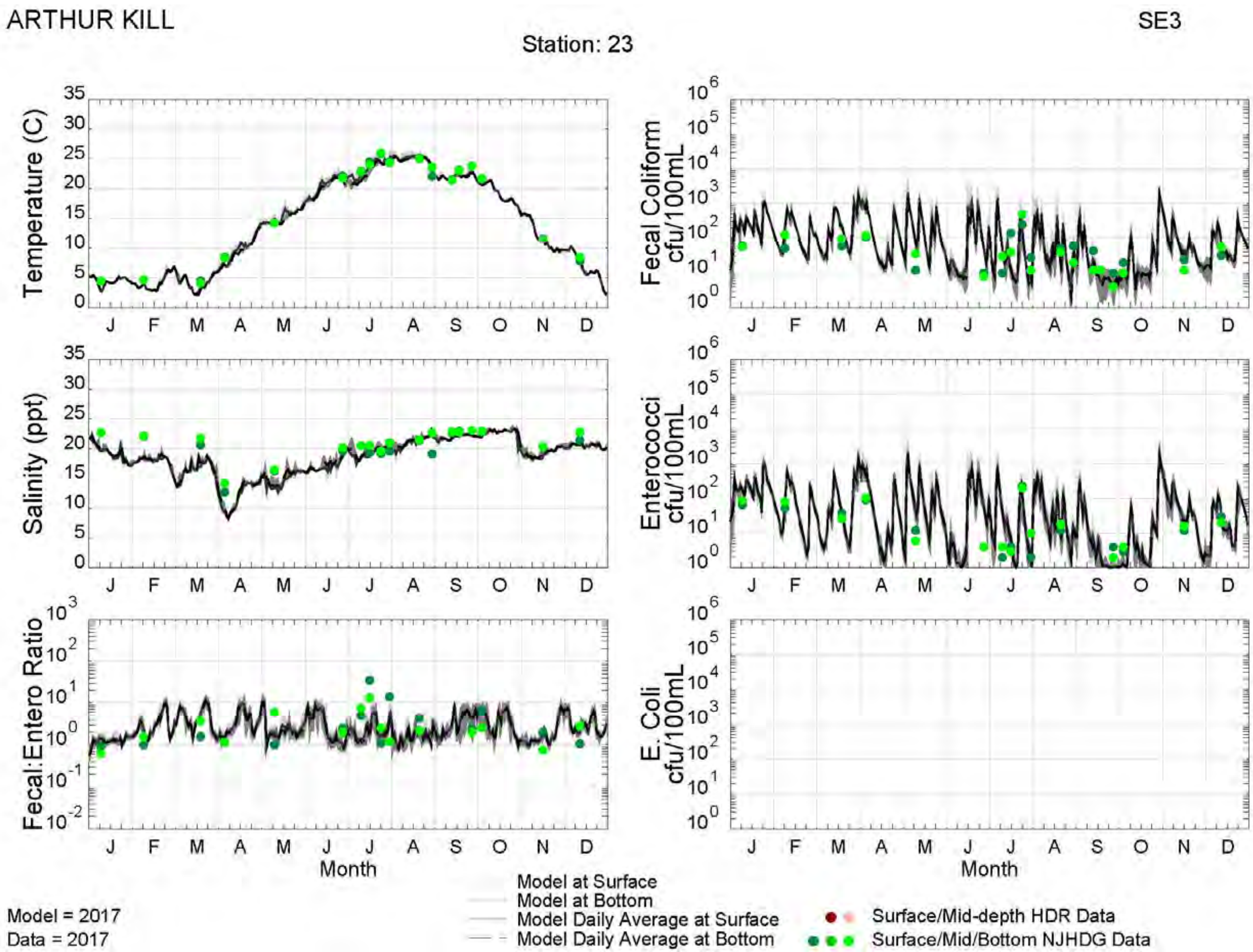


Figure 5-44. 2017 Annual Time-Series Model versus Data Comparison at Station 23, Arthur Kill

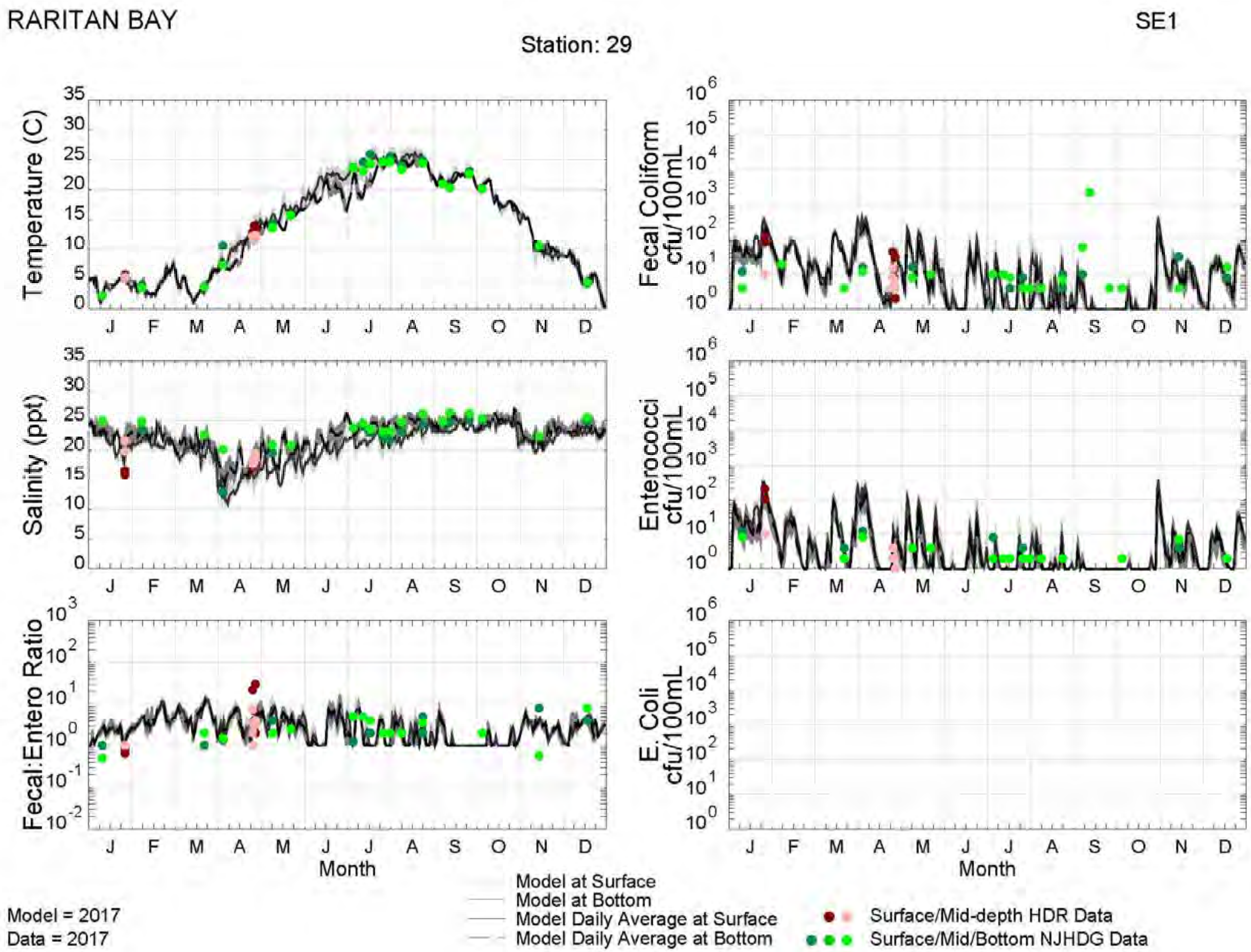


Figure 5-45. 2017 Annual Time-Series Model versus Data Comparison at Station 29, Raritan Bay

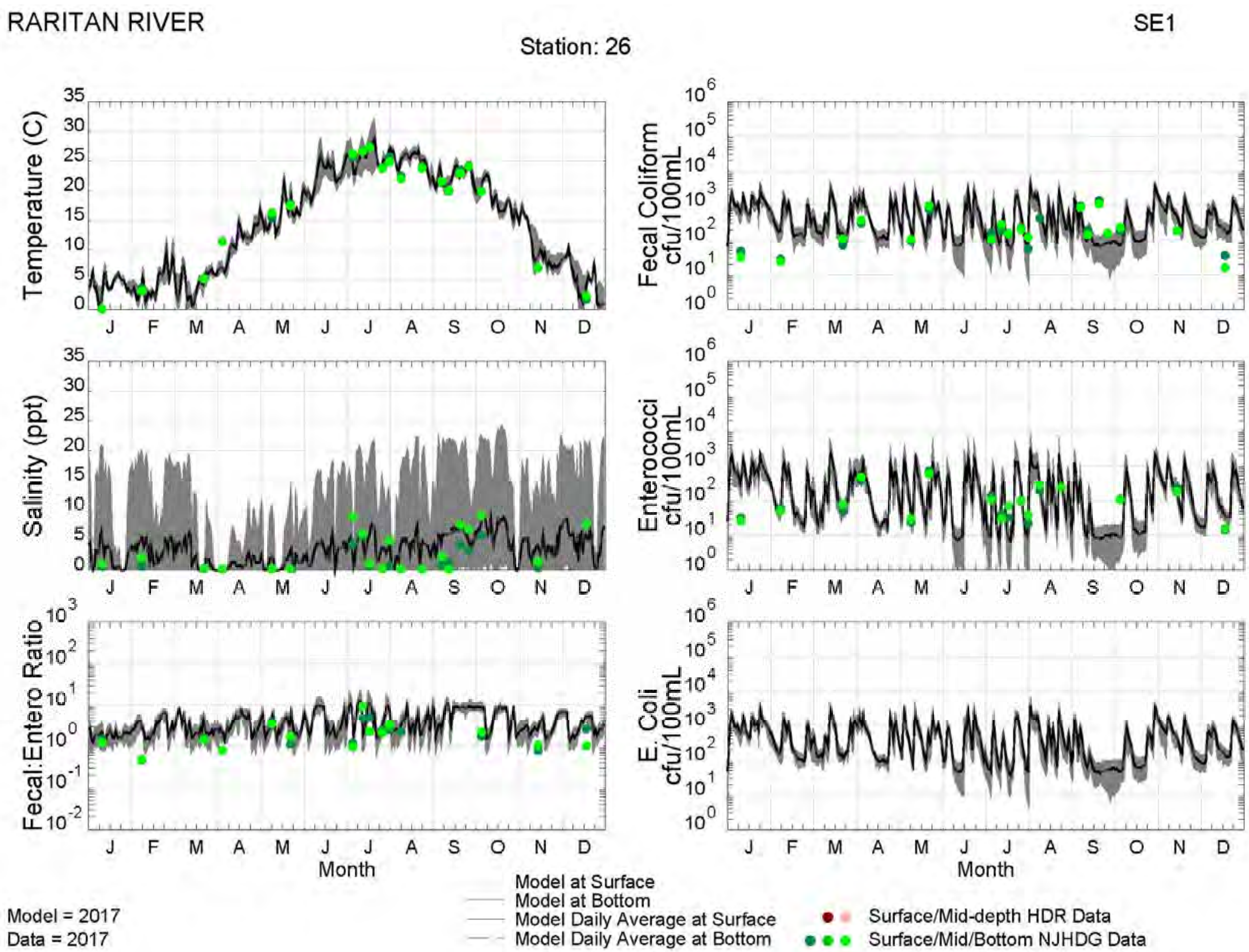


Figure 5-46. 2017 Annual Time-Series Model versus Data Comparison at Station 26, Raritan River

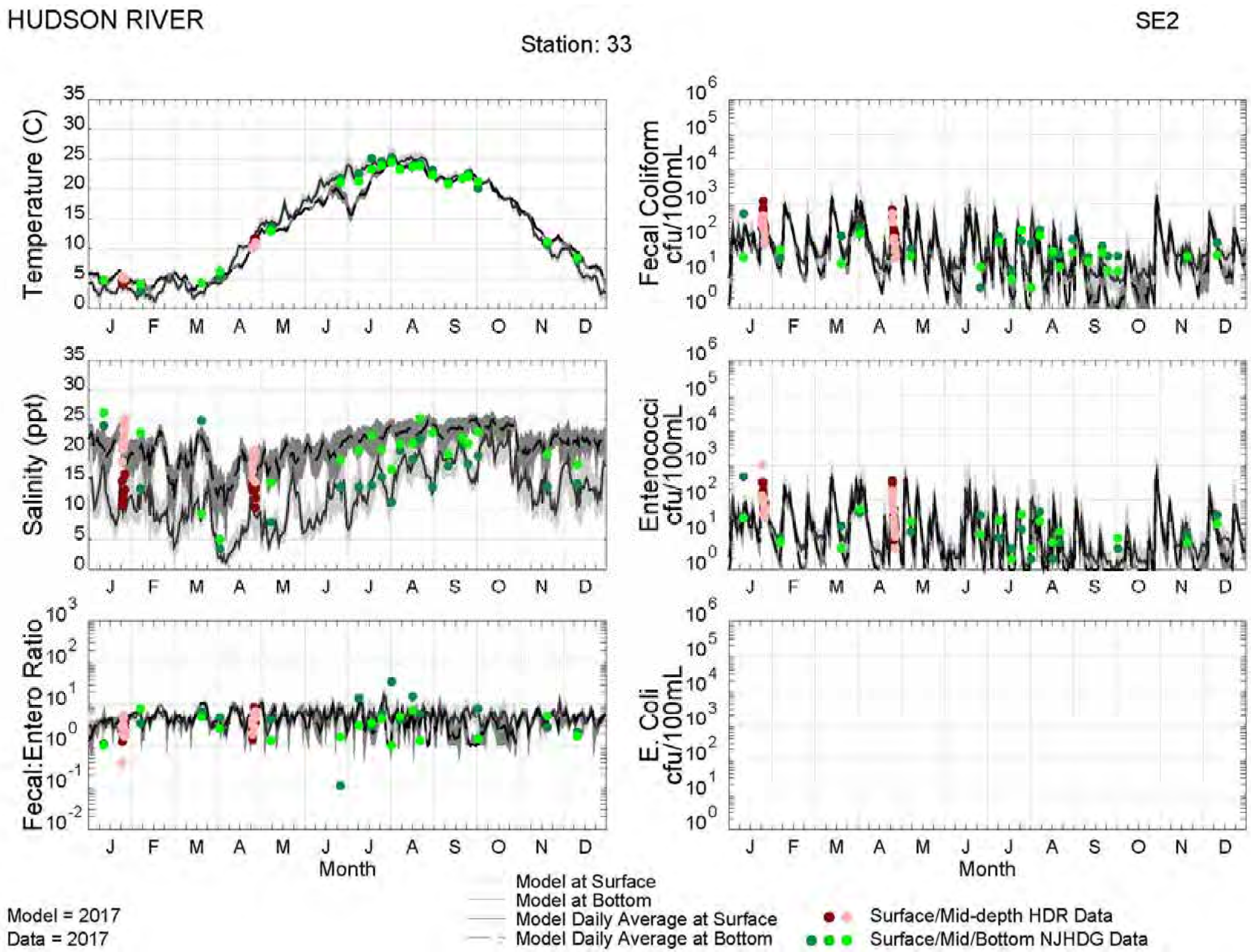


Figure 5-47. 2017 Annual Time-Series Model versus Data Comparison at Station 33, Hudson River

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.

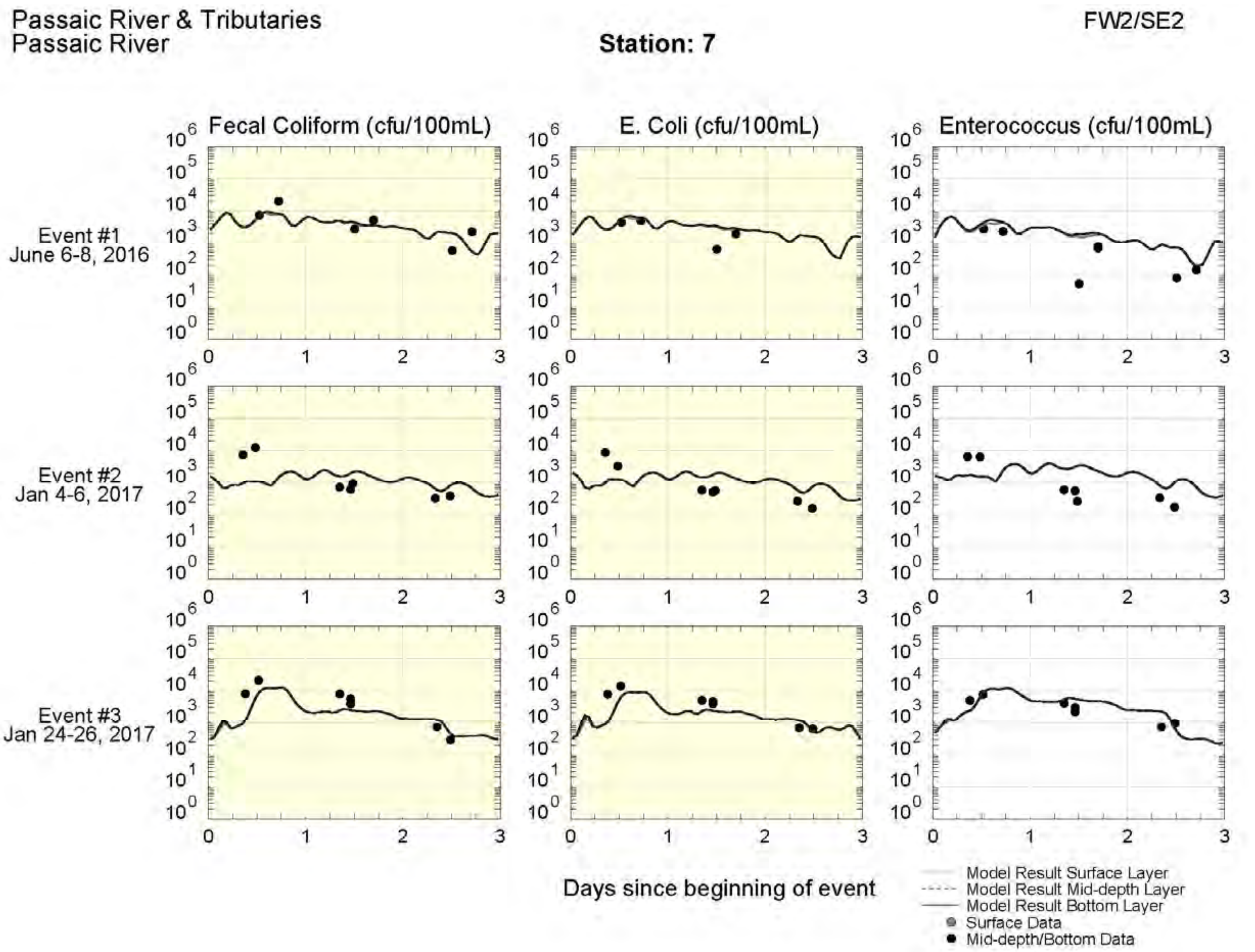


Figure 5-48. Wet-Weather Events Model versus Data Comparison at Station 7, Passaic River

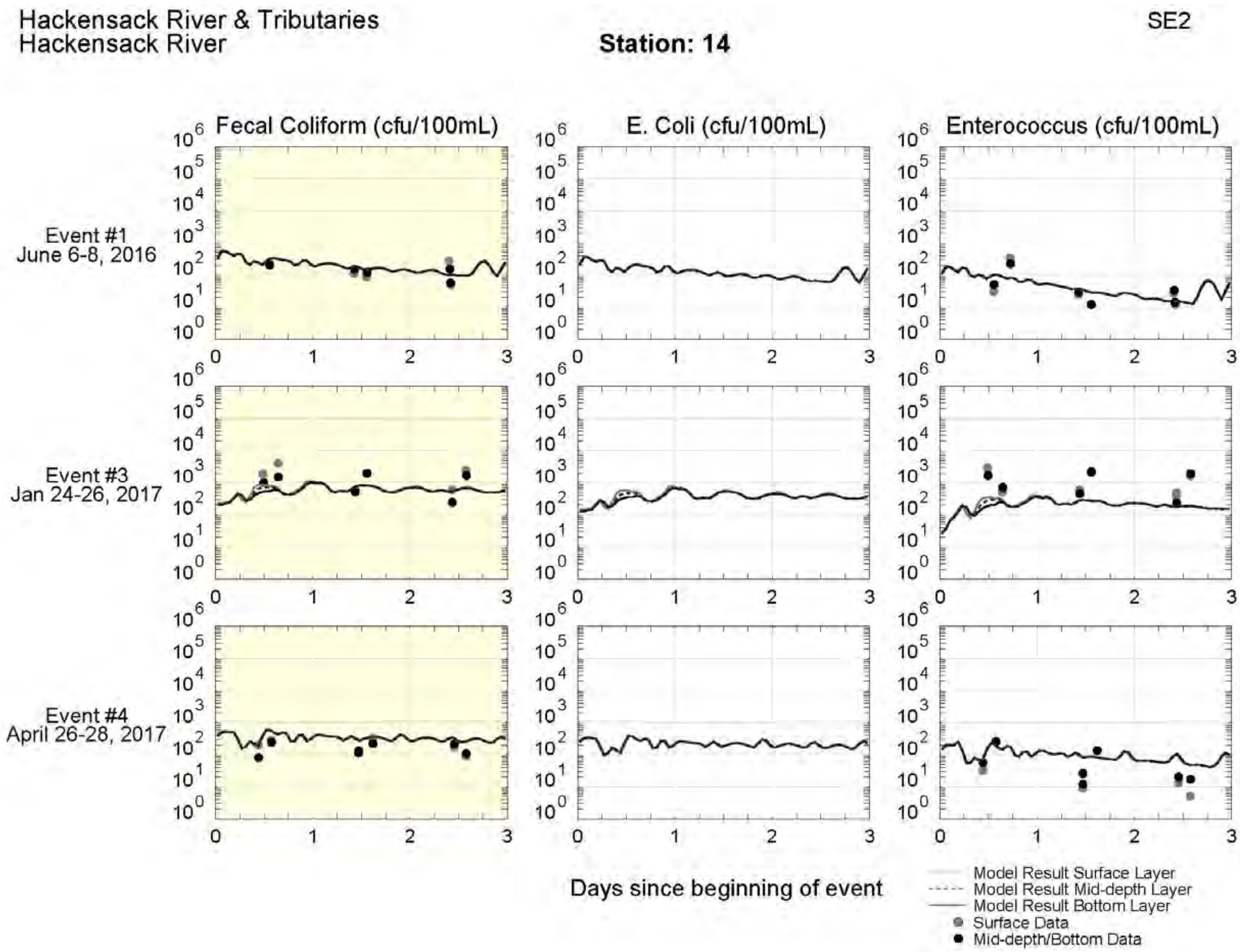


Figure 5-49. Wet-Weather Events Model versus Data Comparison at Station 14, Hackensack River

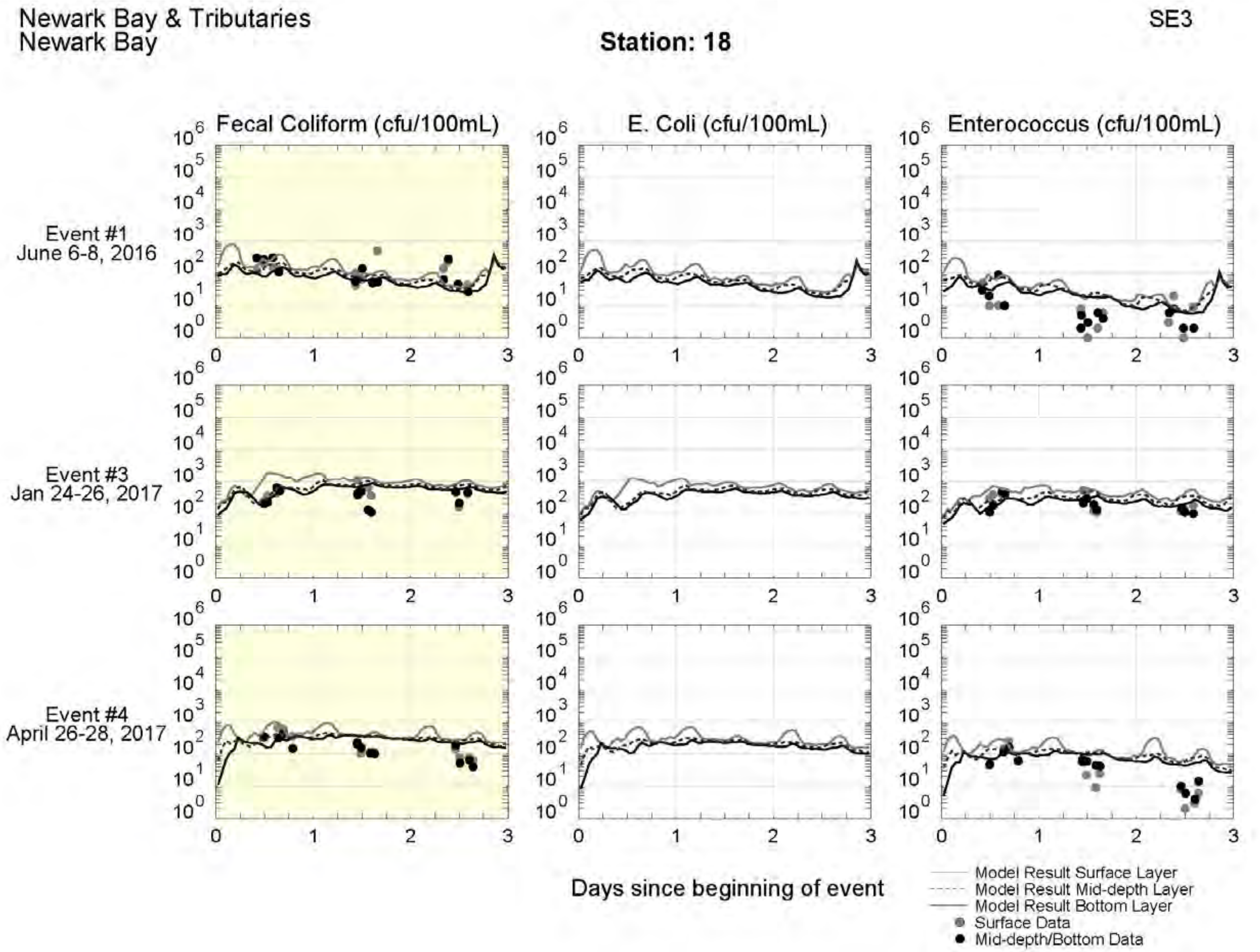


Figure 5-50. Wet-Weather Events Model versus Data Comparison at Station 18, Newark Bay

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.

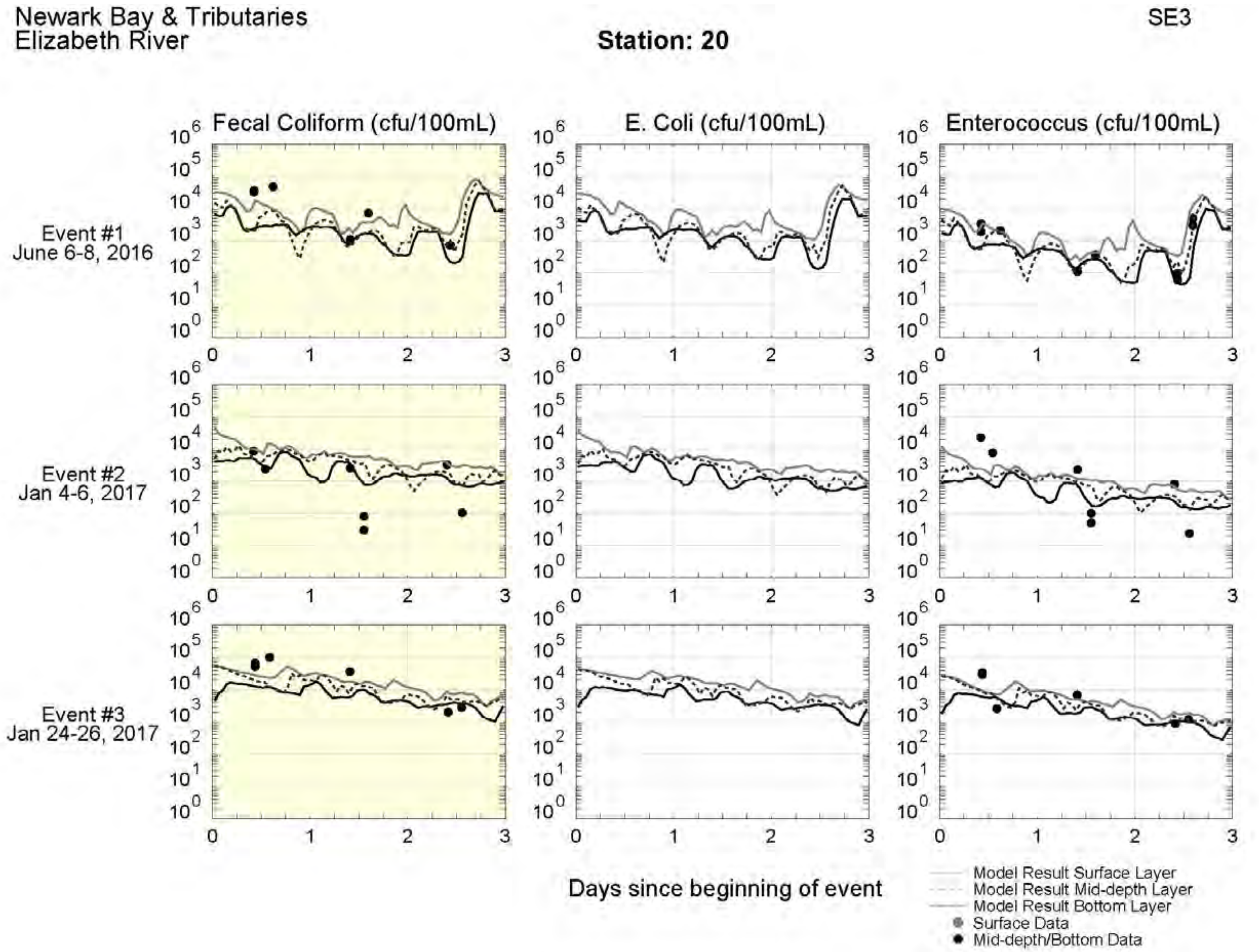


Figure 5-51. Wet-Weather Events Model versus Data Comparison at Station 20, Elizabeth River

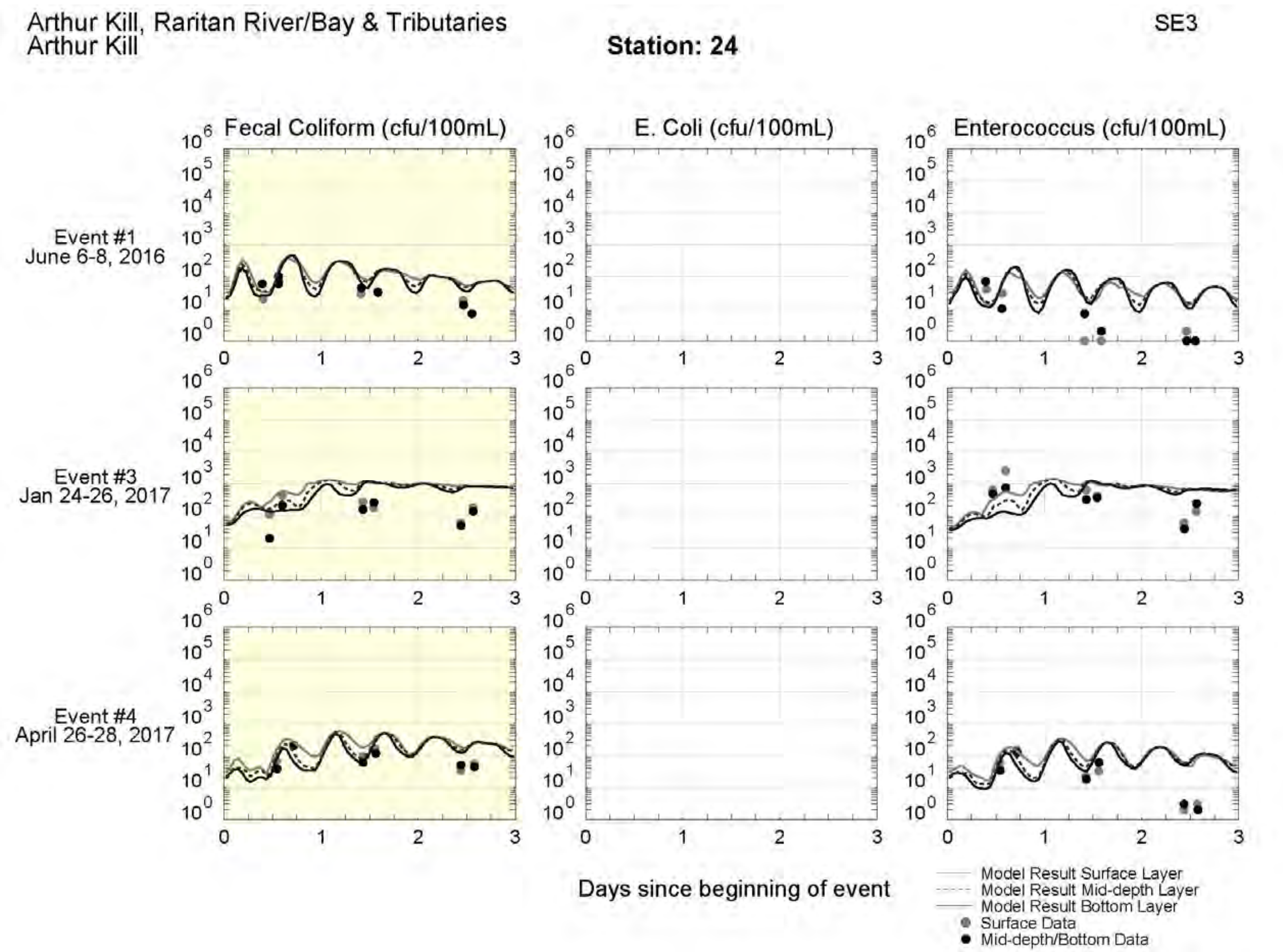


Figure 5-52. Wet-Weather Events Model versus Data Comparison at Station 24, Raritan River

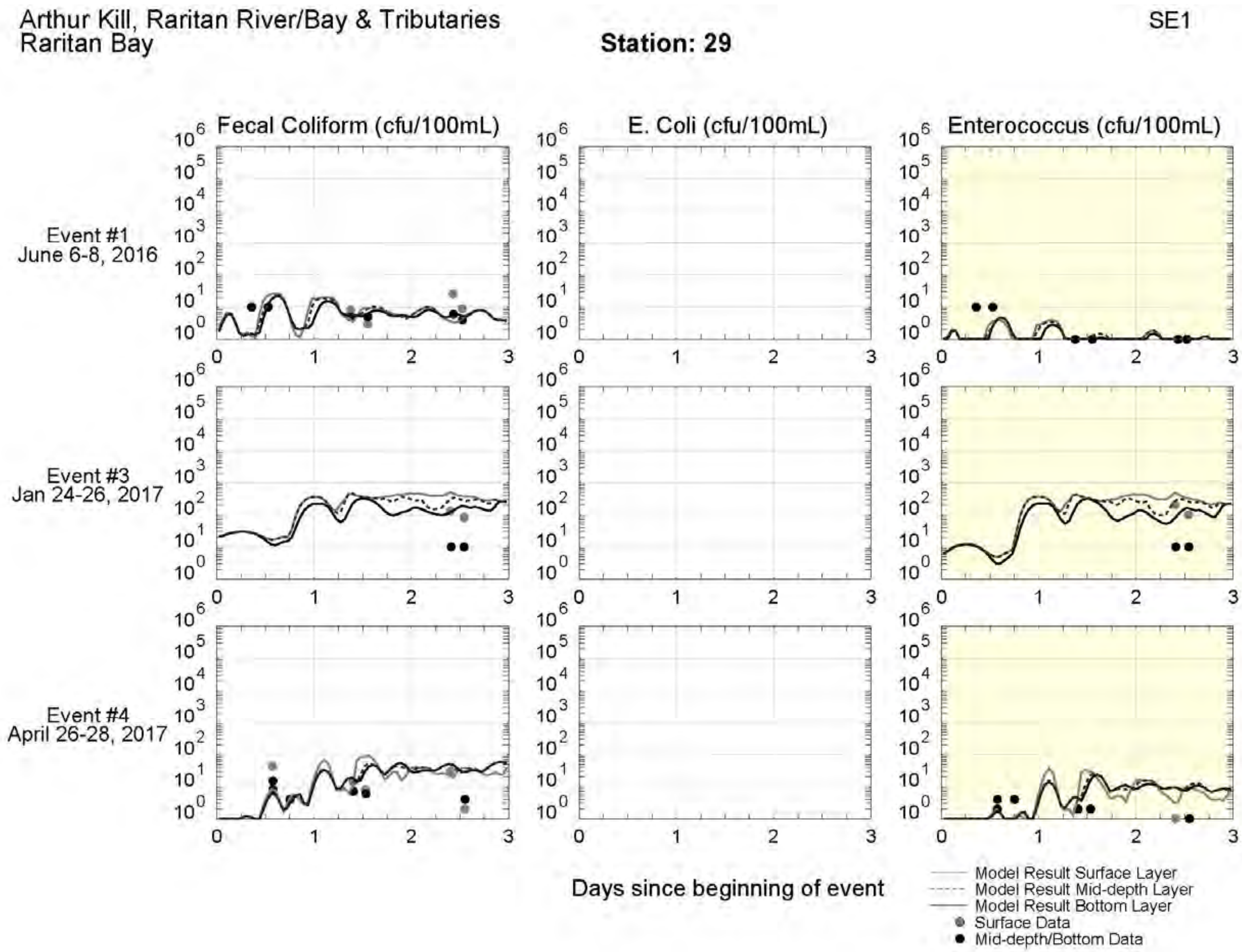


Figure 5-53. Wet-Weather Events Model versus Data Comparison at Station 29, Raritan Bay

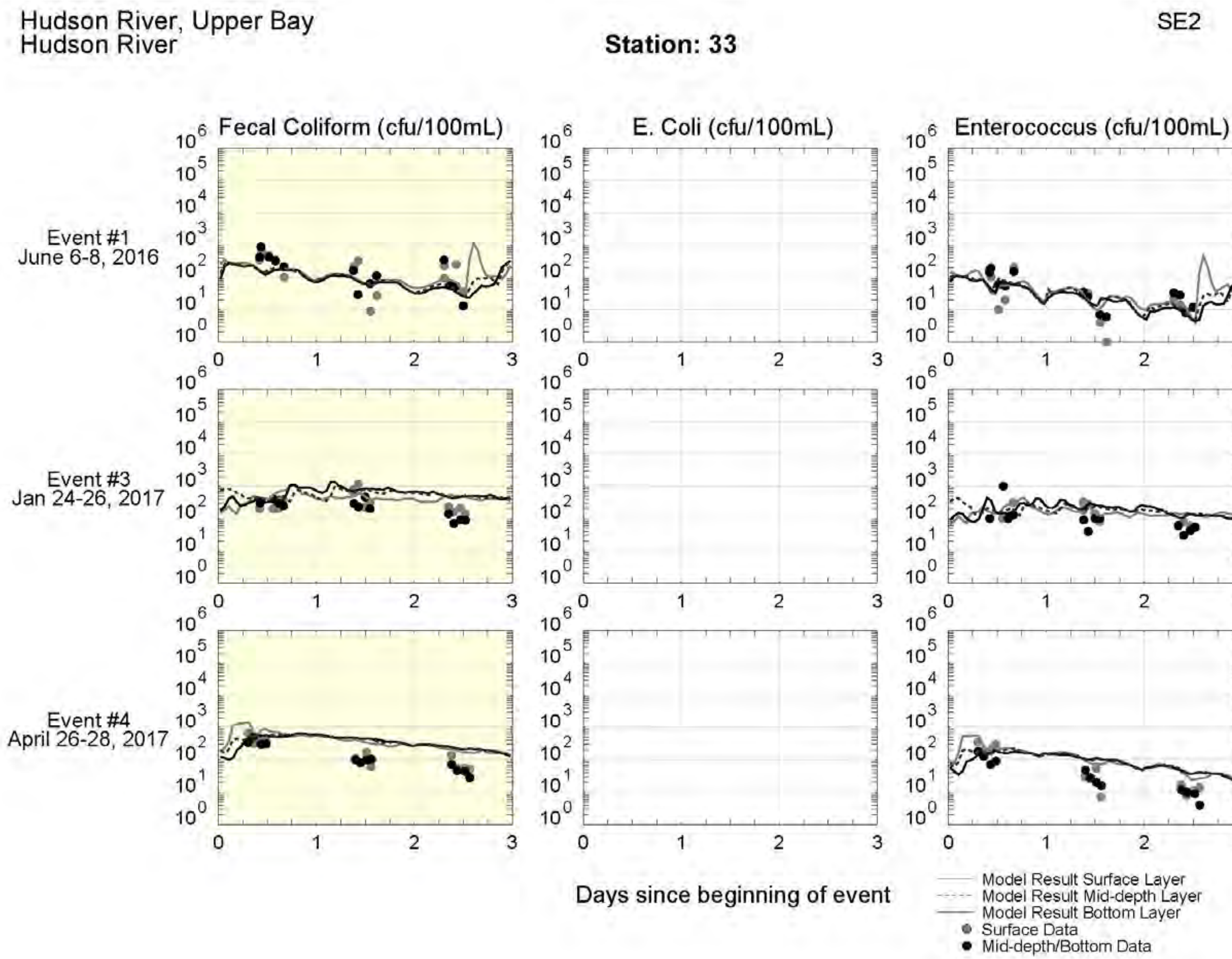


Figure 5-54. Wet-Weather Events Model versus Data Comparison at Station 33, Hudson River

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.

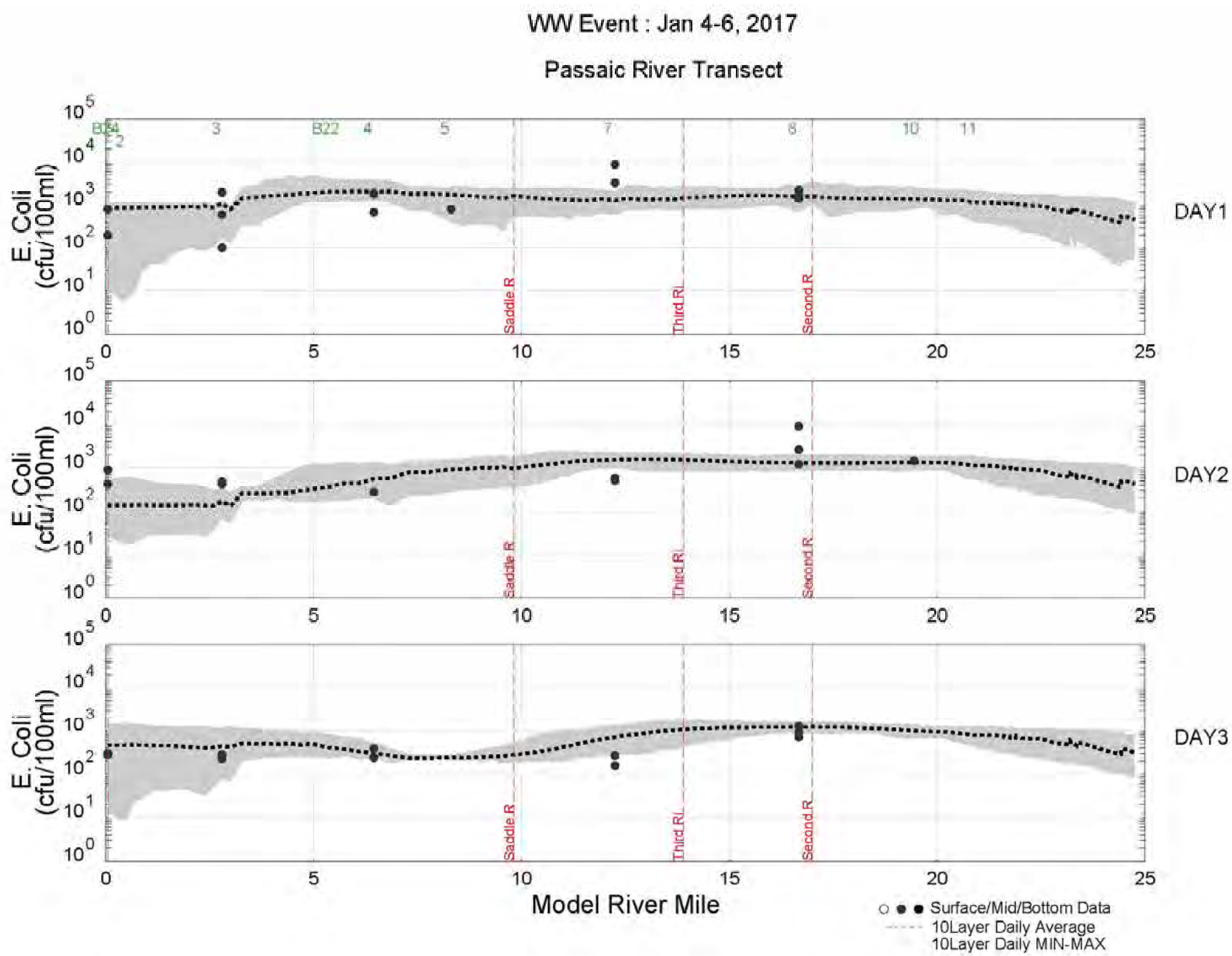


Figure 5-55. January 4-6, 2017 Passaic River Model versus Data Transect Comparison for E. Coli

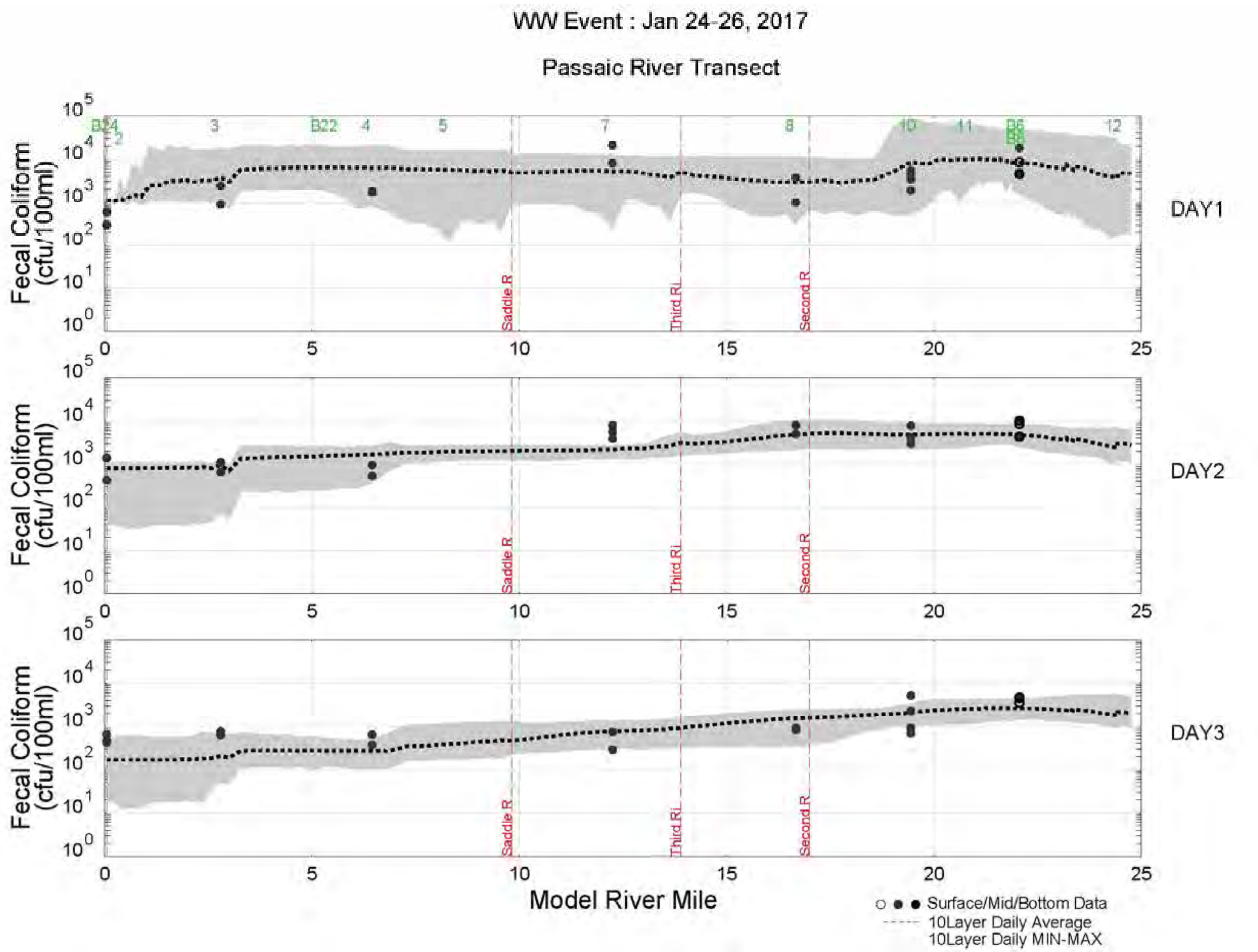


Figure 5-56. January 24-26, 2017 Passaic River Model versus Data Transect Comparison for Fecal Coliform

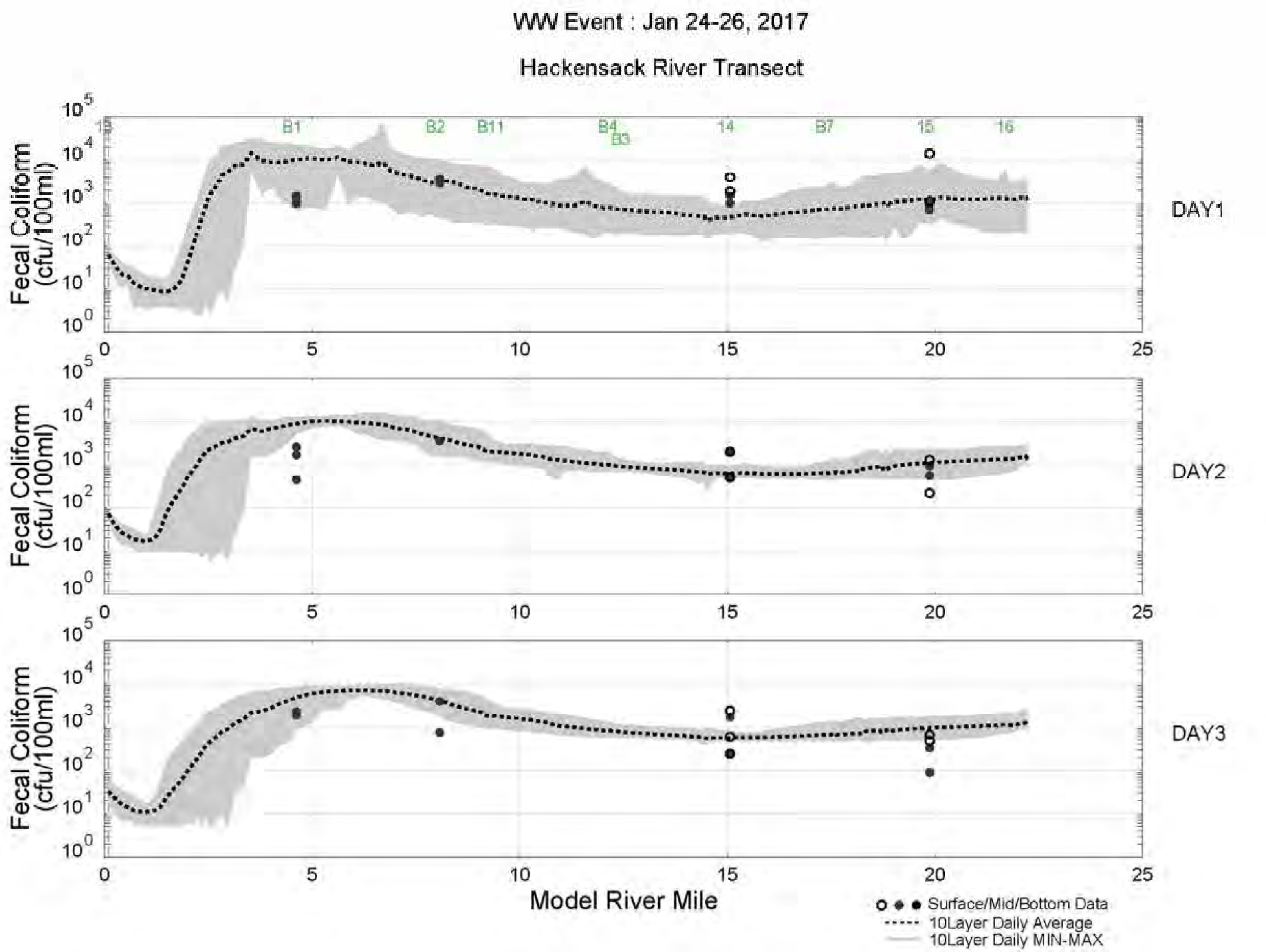


Figure 5-57. January 24-26, 2017 Hackensack River Model versus Data Transect Comparison for Fecal Coliform

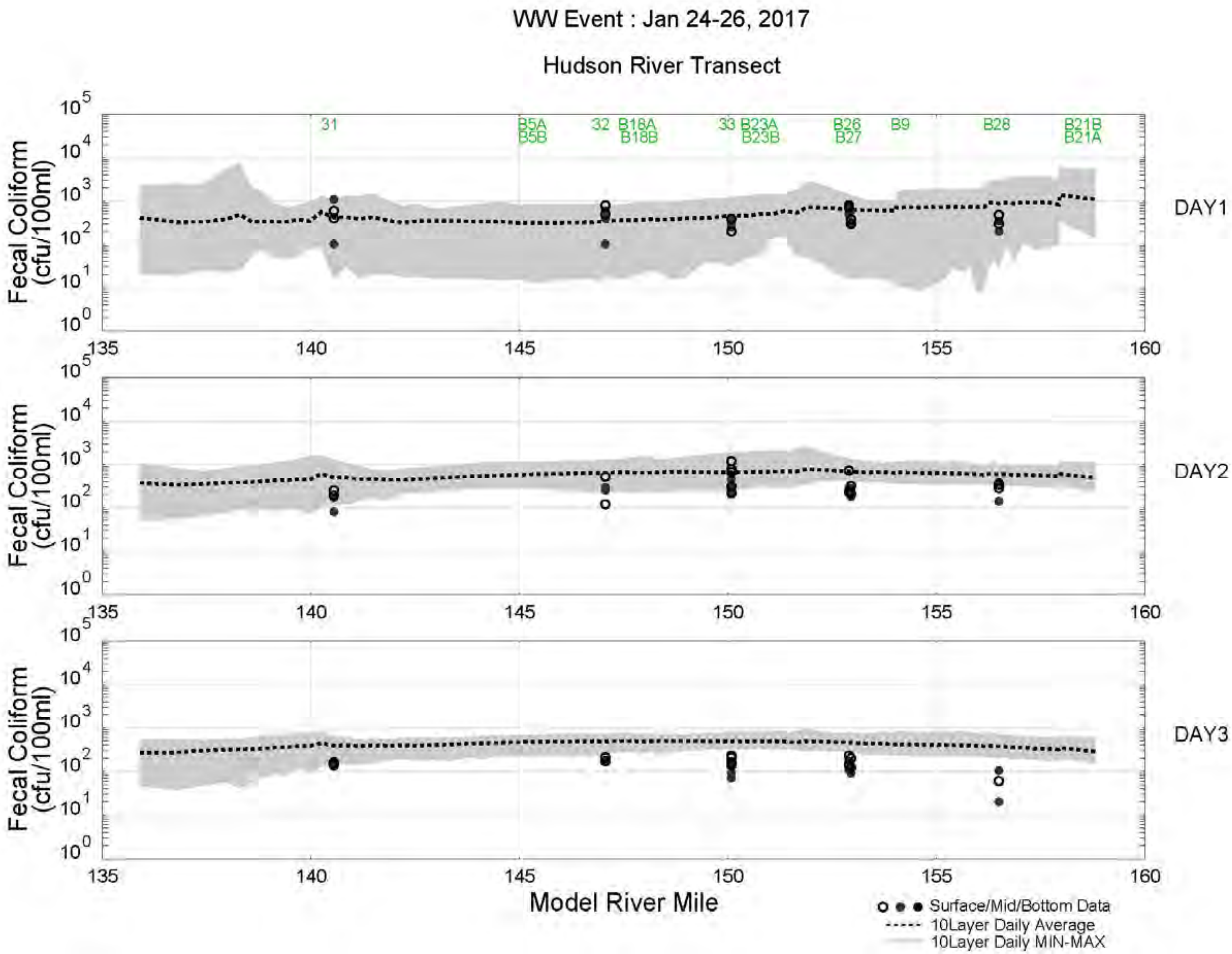


Figure 5-58. January 24-26, Hudson River Model versus Data Transect Comparison for Fecal Coliform

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 an 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.

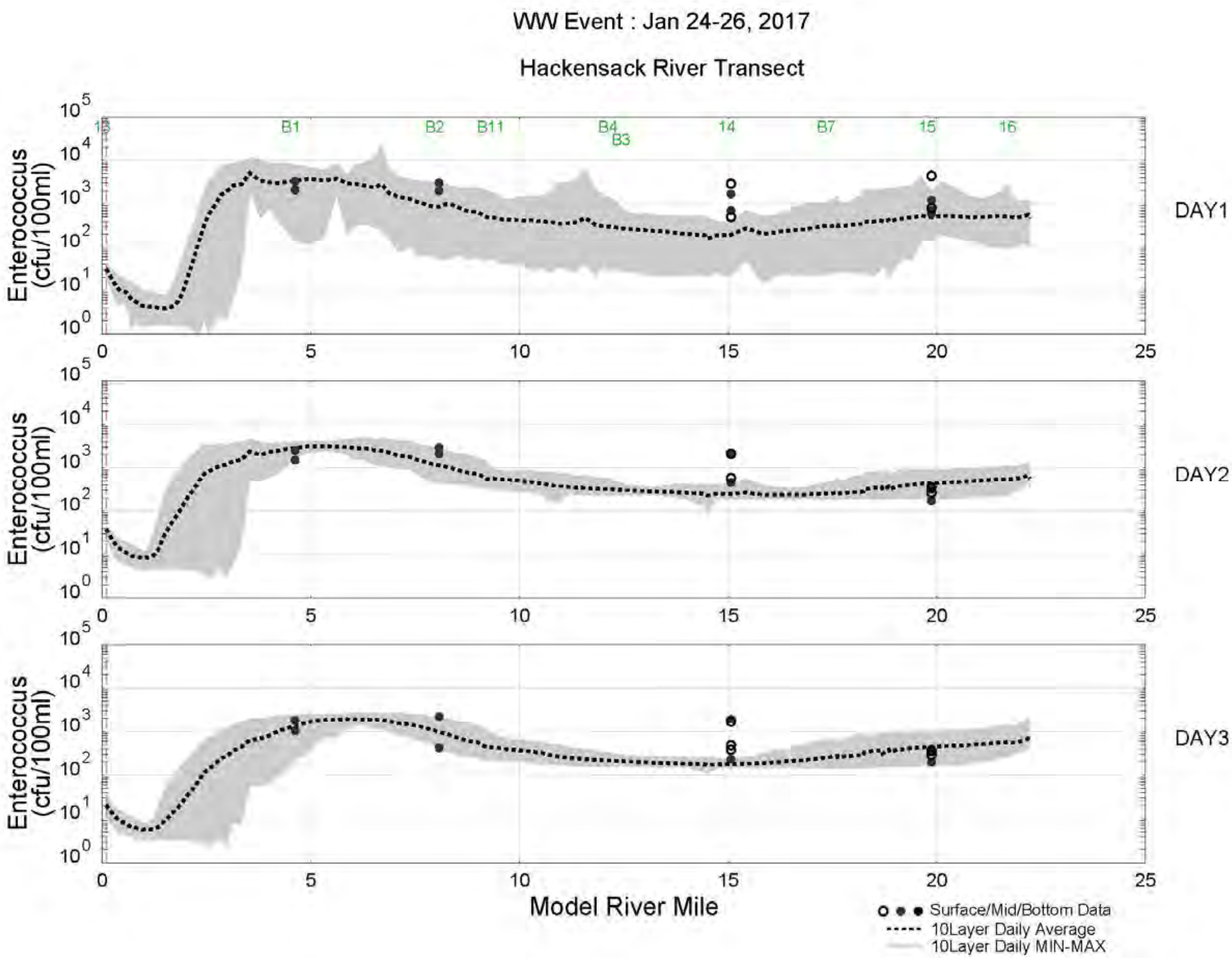


Figure 5-59. January 24-26, Hackensack River Model versus Data Transect Comparison for Enterococci

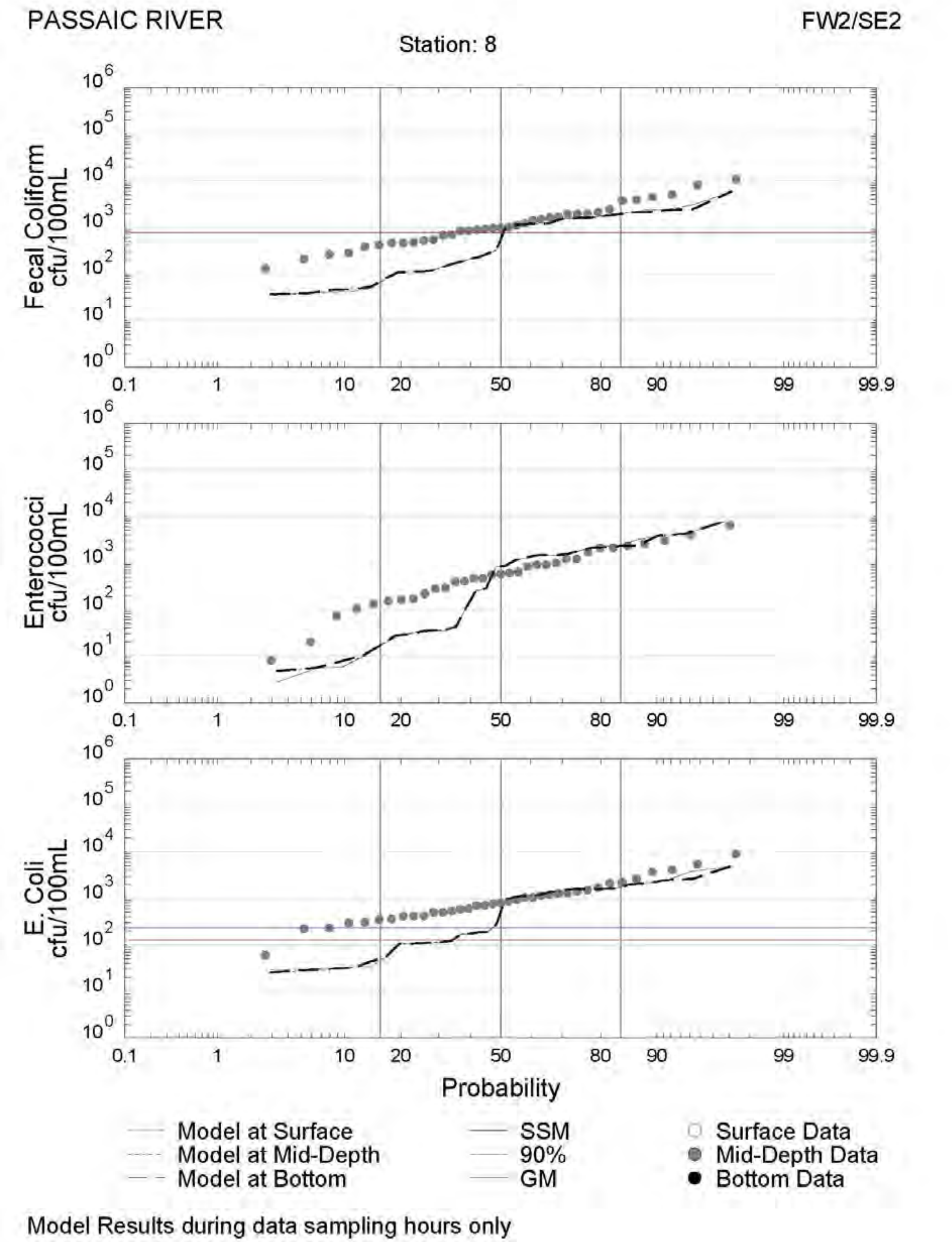


Figure 5-60. 2017 Annual Model versus Data Probability Distribution Comparison at Station 8, Passaic River

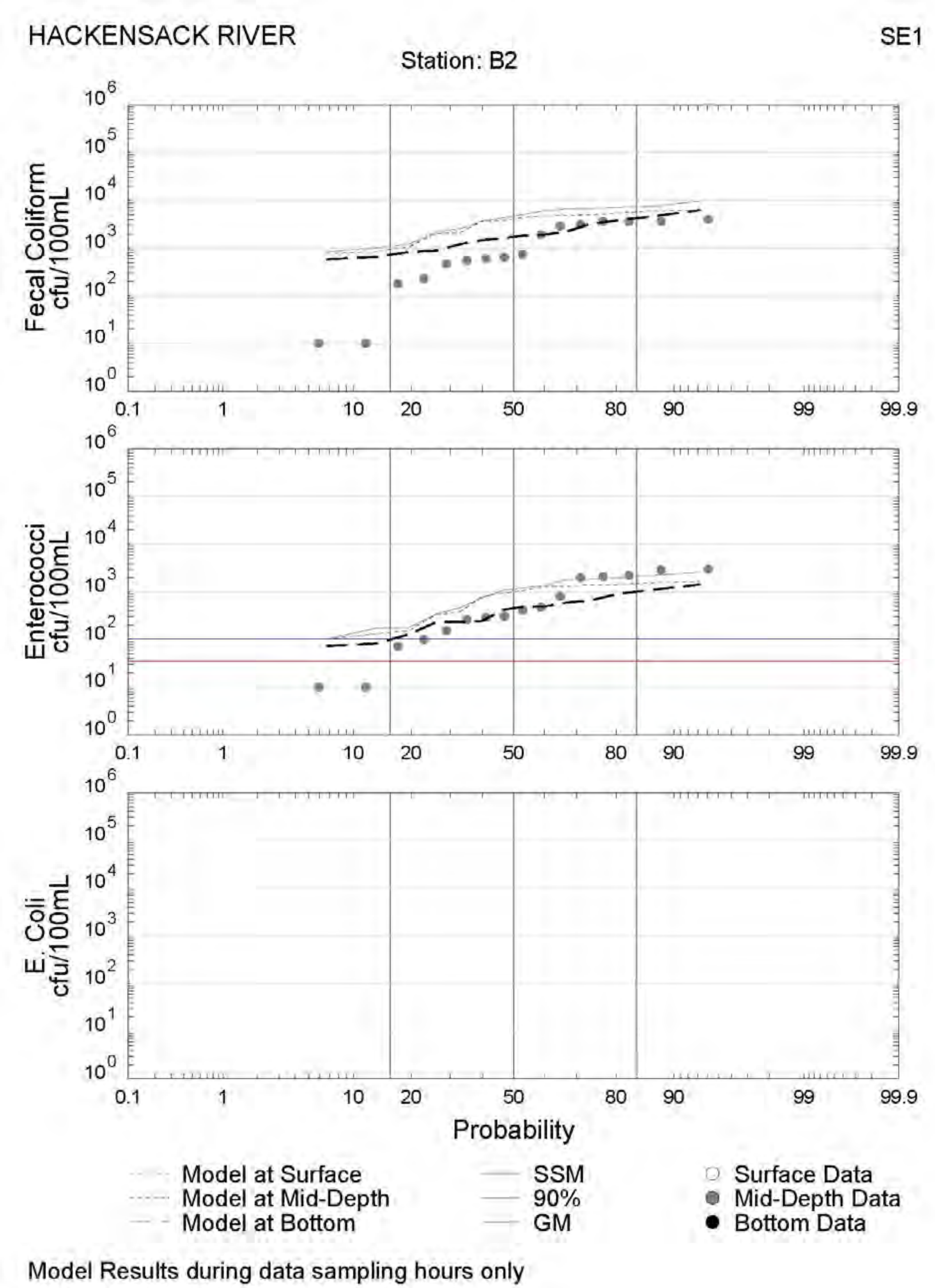


Figure 5-61. 2017 Annual Model versus Data Probability Distribution Comparison at Station B2, Hackensack River

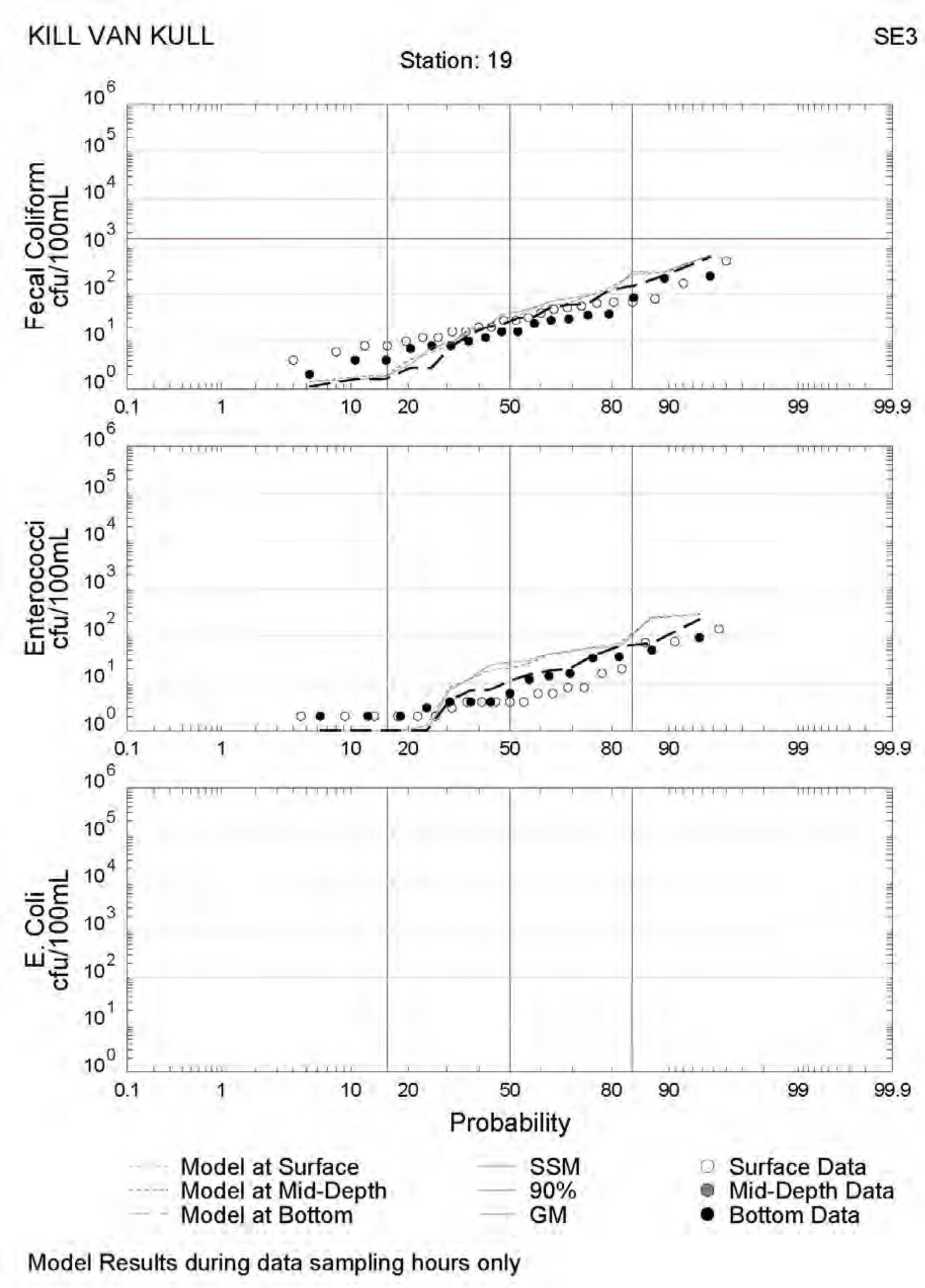


Figure 5-62. 2017 Annual Model versus Data Probability Distribution Comparison at Station 19, Newark Bay

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.

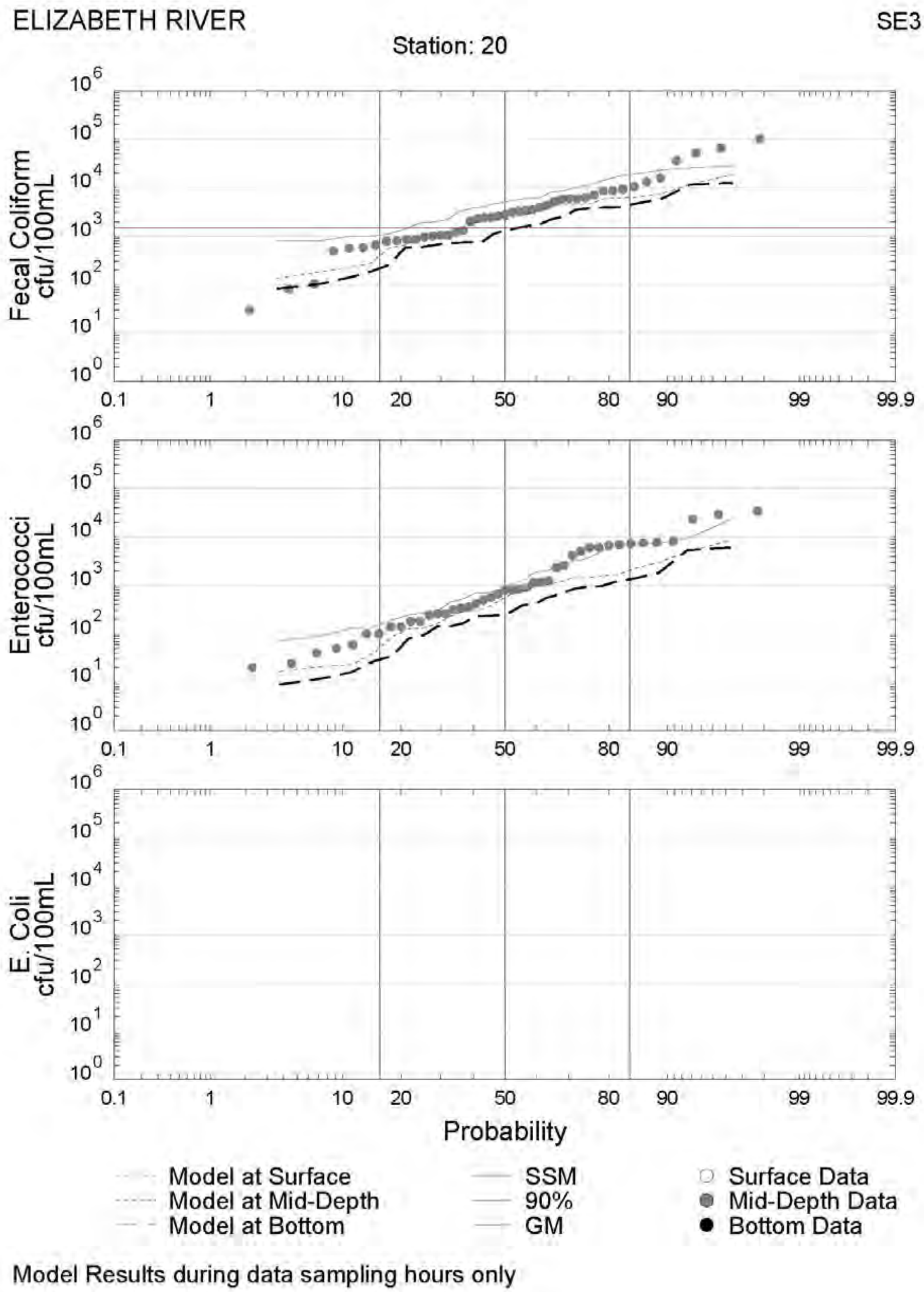


Figure 5-63. 2017 Annual Model versus Data Probability Distribution Comparison at Station 20, Elizabeth River

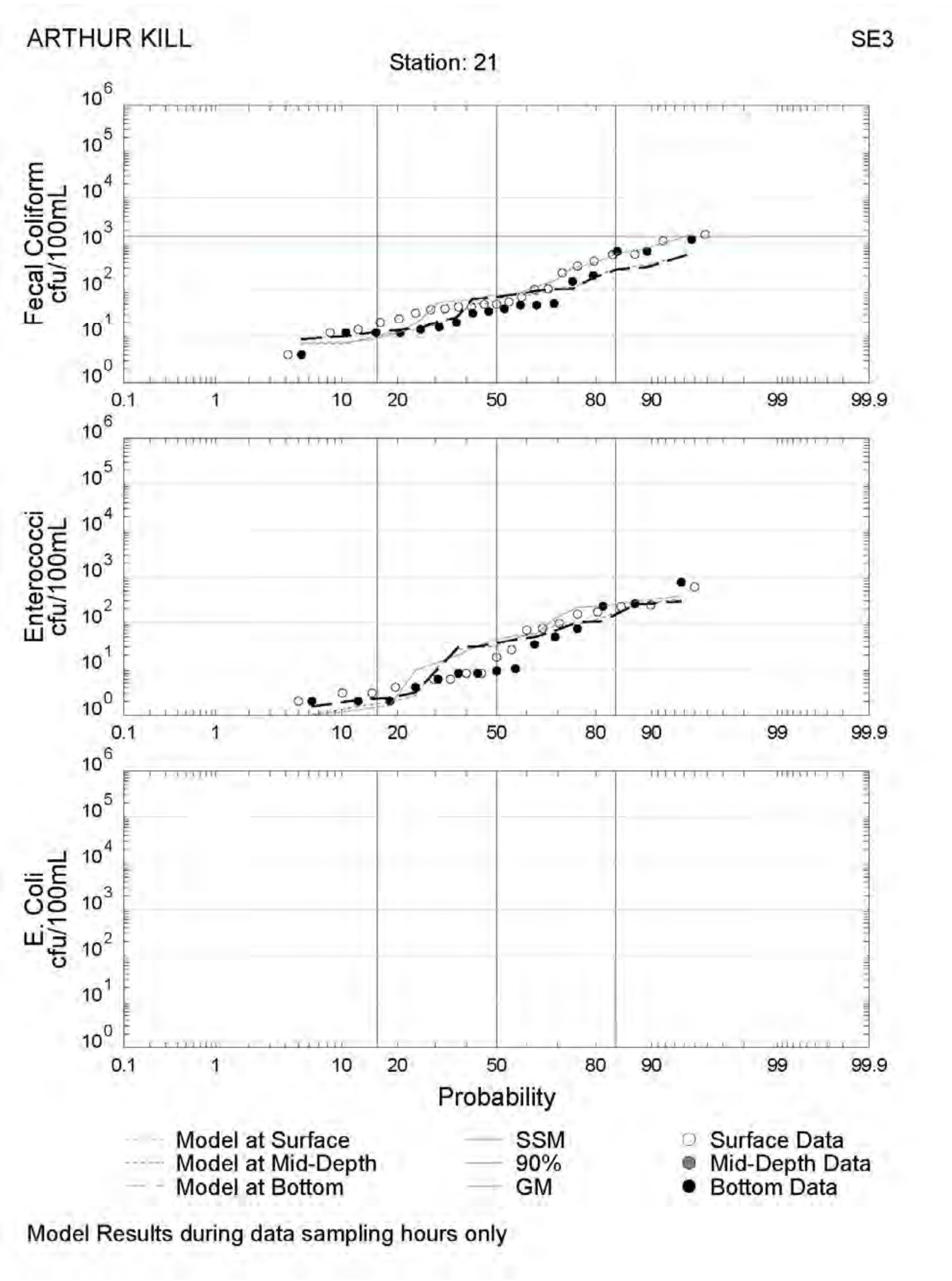


Figure 5-64. 2017 Annual Model versus Data Probability Distribution Comparison at Station 21, Arthur Kill

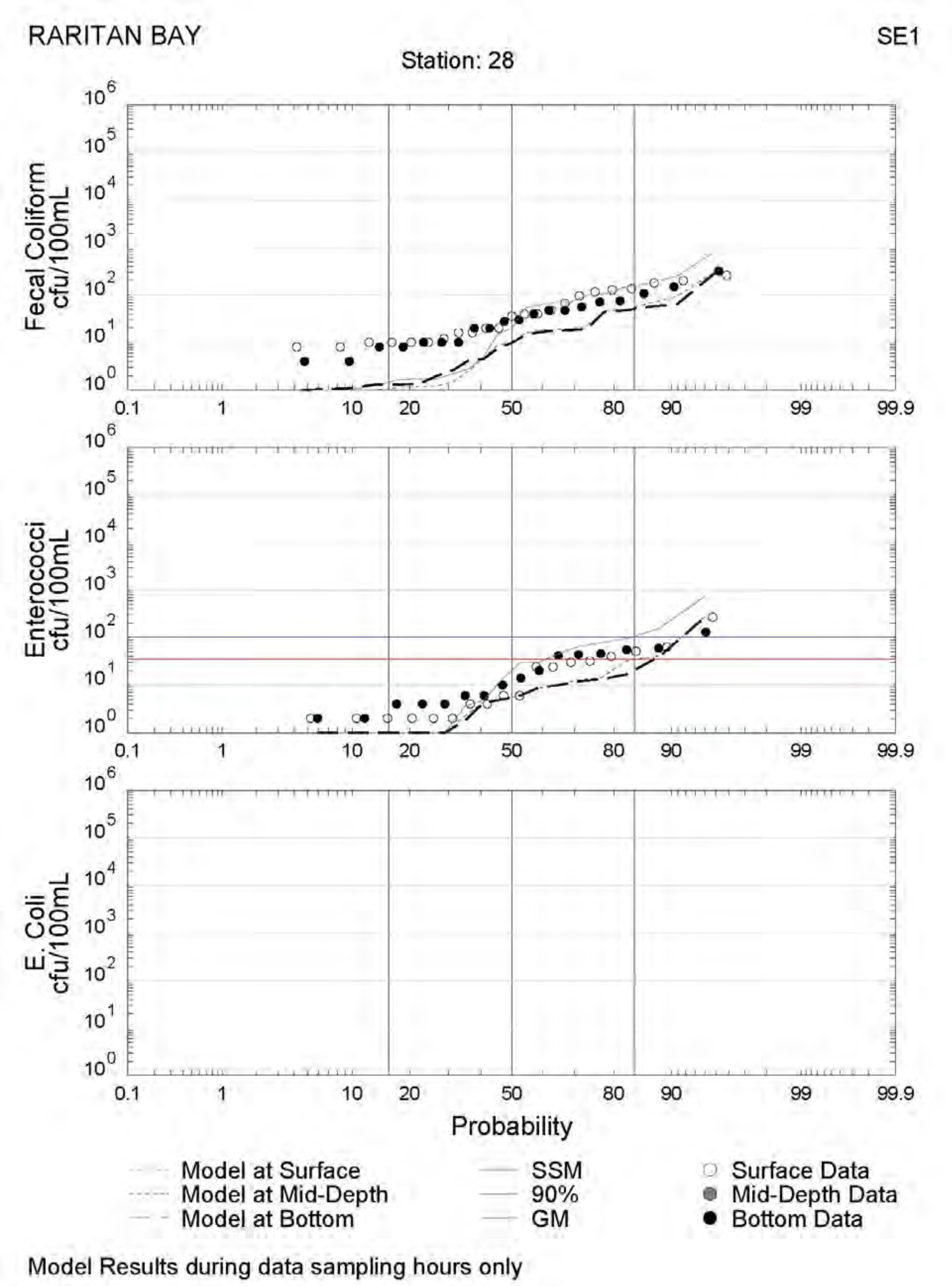


Figure 5-65. 2017 Annual Model versus Data Probability Distribution Comparison at Station 28, Raritan Bay

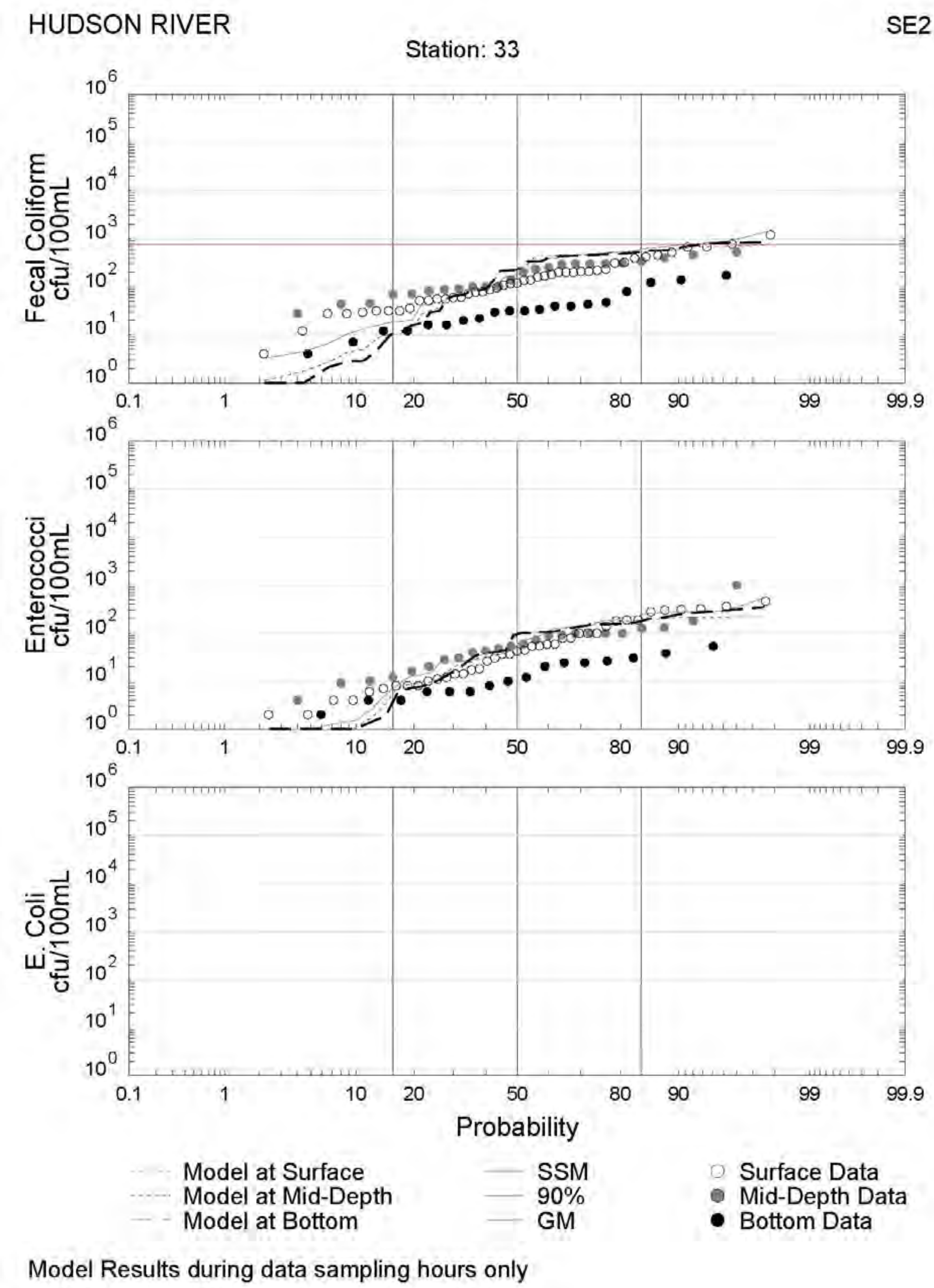


Figure 5-66. 2017 Annual Model versus Data Probability Distribution Comparison at Station 33, Hudson River

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. In 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.

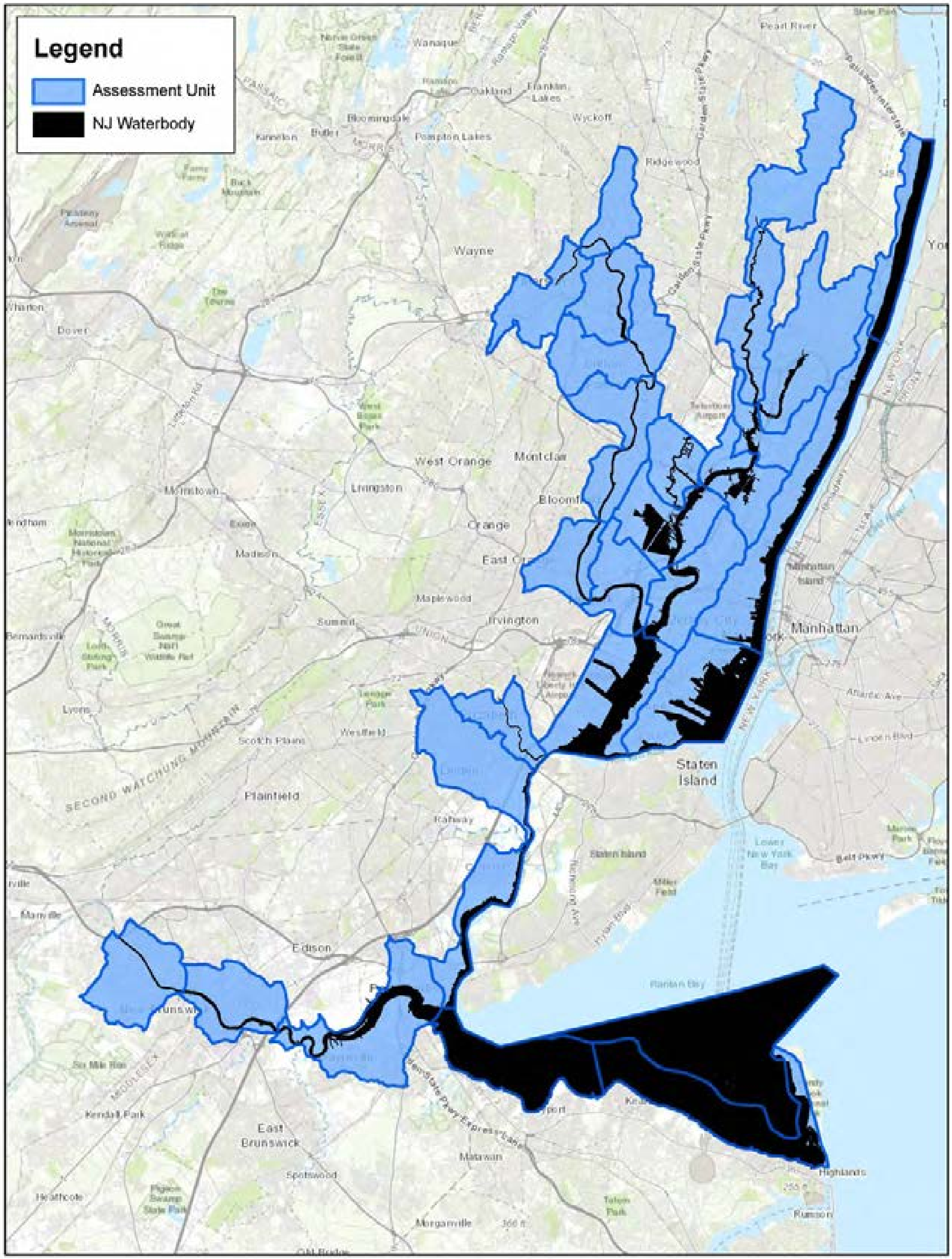


Figure 6-1. Assessment Units used for Spatial Attainment Calculations

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 stn)	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 (4th St br to Second R)	02030103150040-01	100.0	100.0
Passaic R Lwr (Nwk Bay to 4th 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 be 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 to 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.

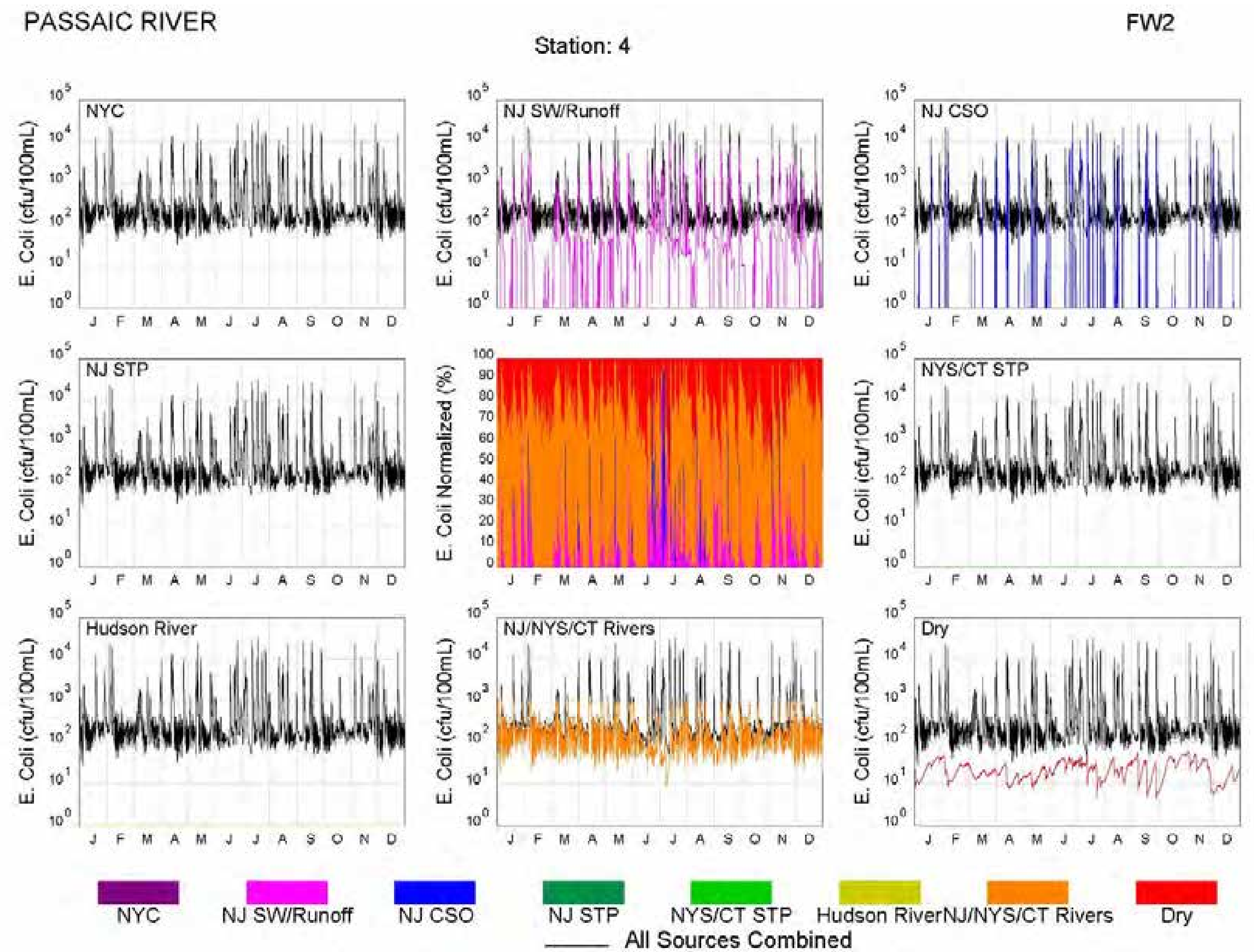


Figure 6-2. Component Analysis for E. Coli at Station 4

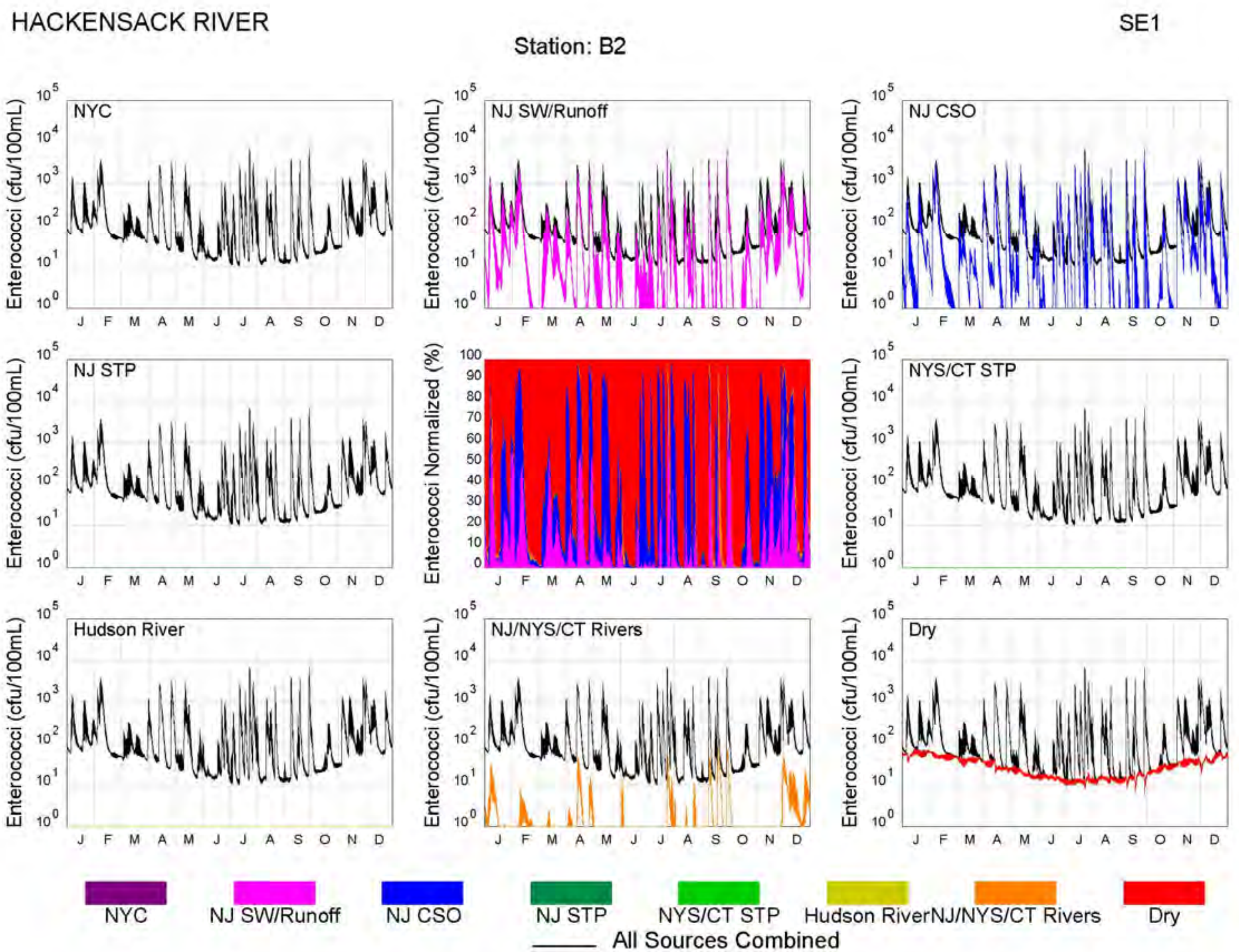


Figure 6-3. Component Analysis for Enterococci at Station B2

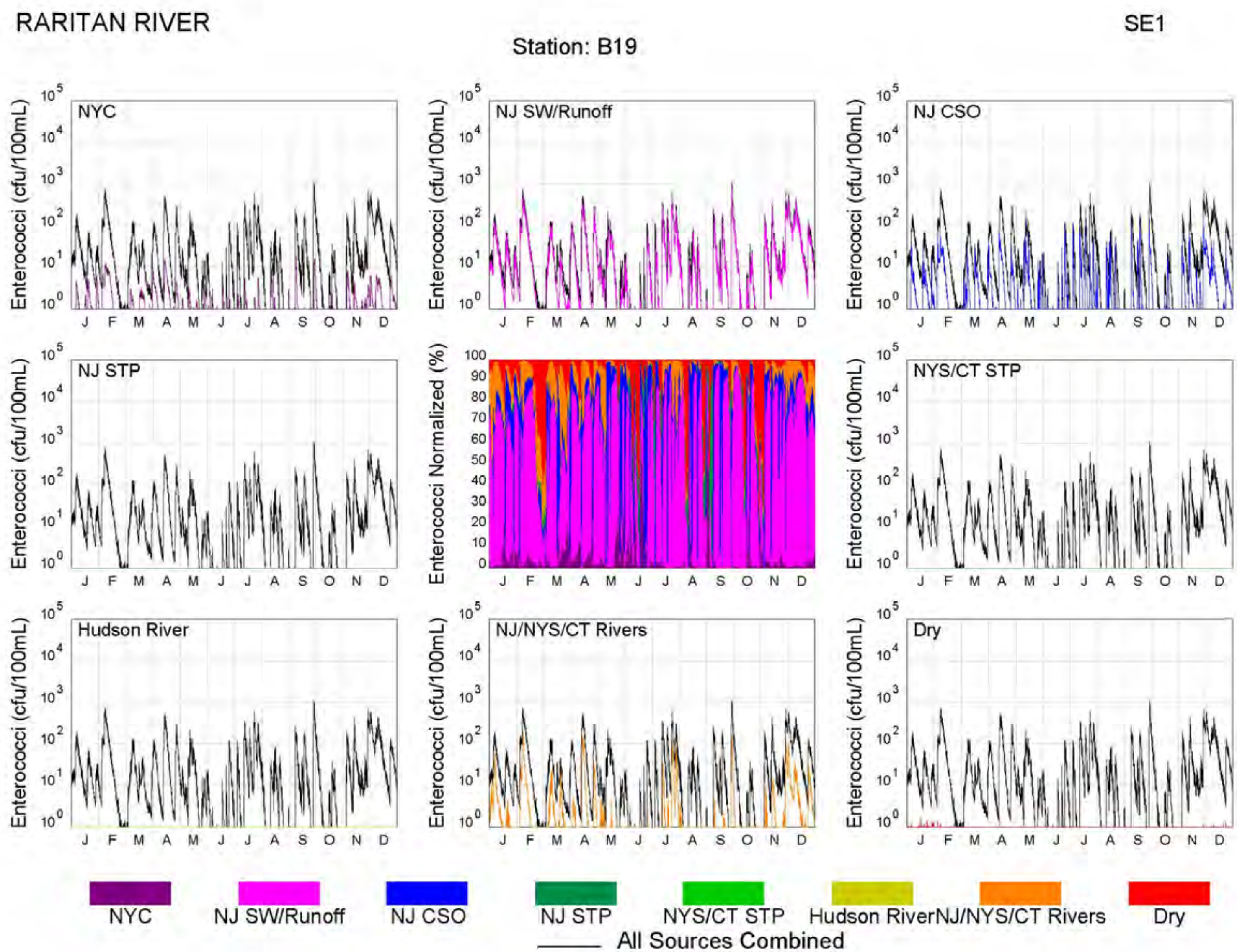


Figure 6-4. Component Analysis for Enterococci at Station B19

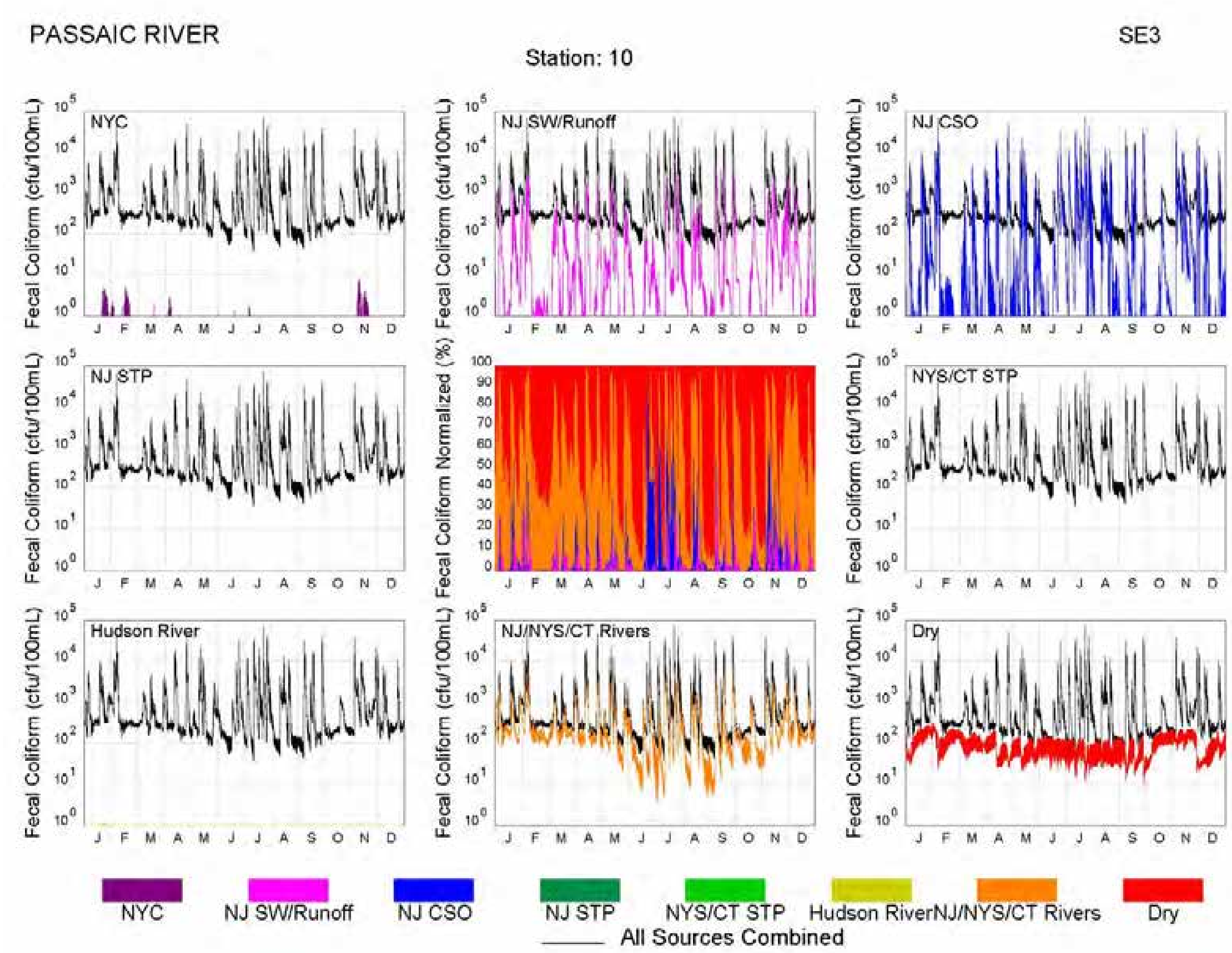


Figure 6-5. Component Analysis for Fecal Coliform at Station 10

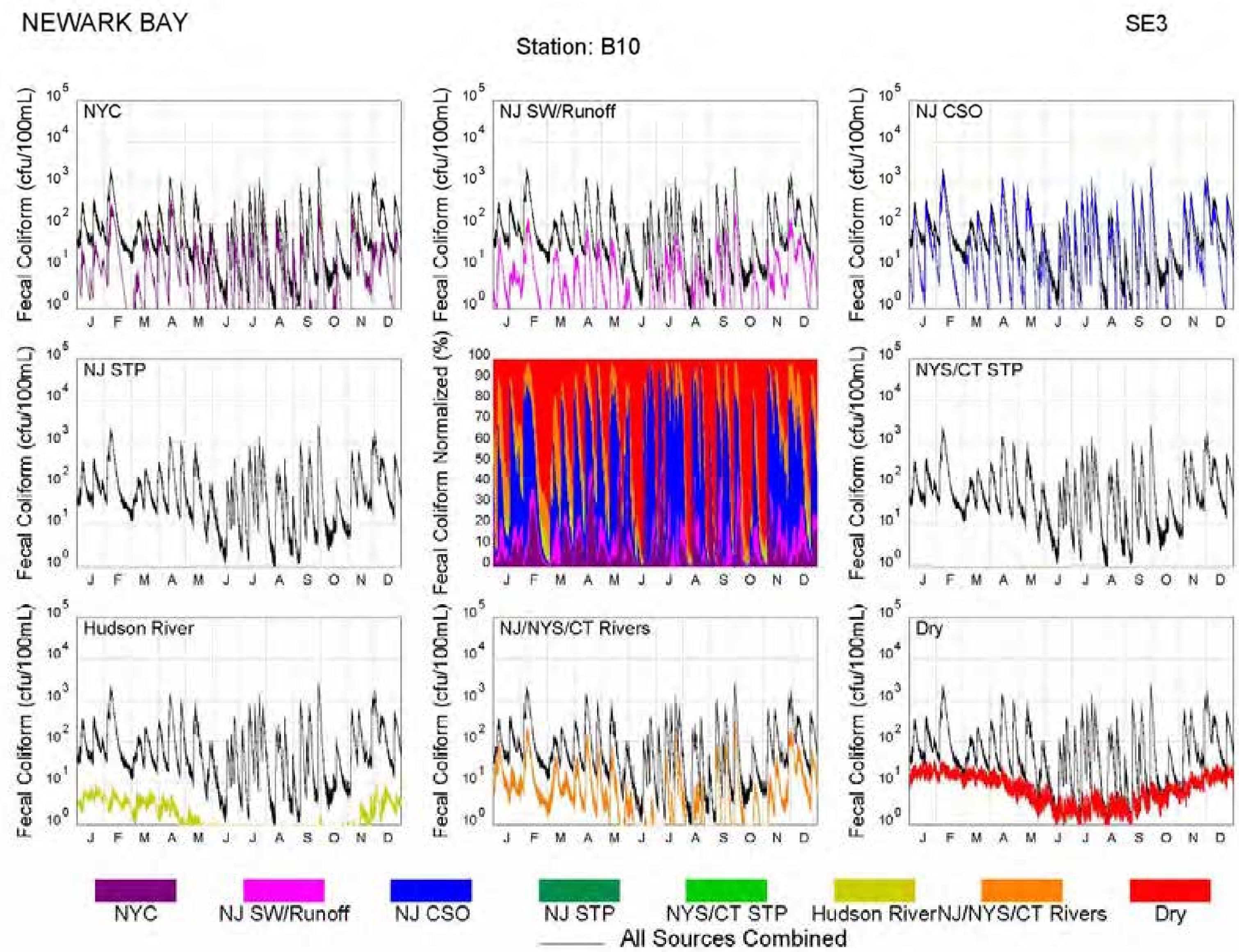


Figure 6-6. Component Analysis for Fecal Coliform at Station B10

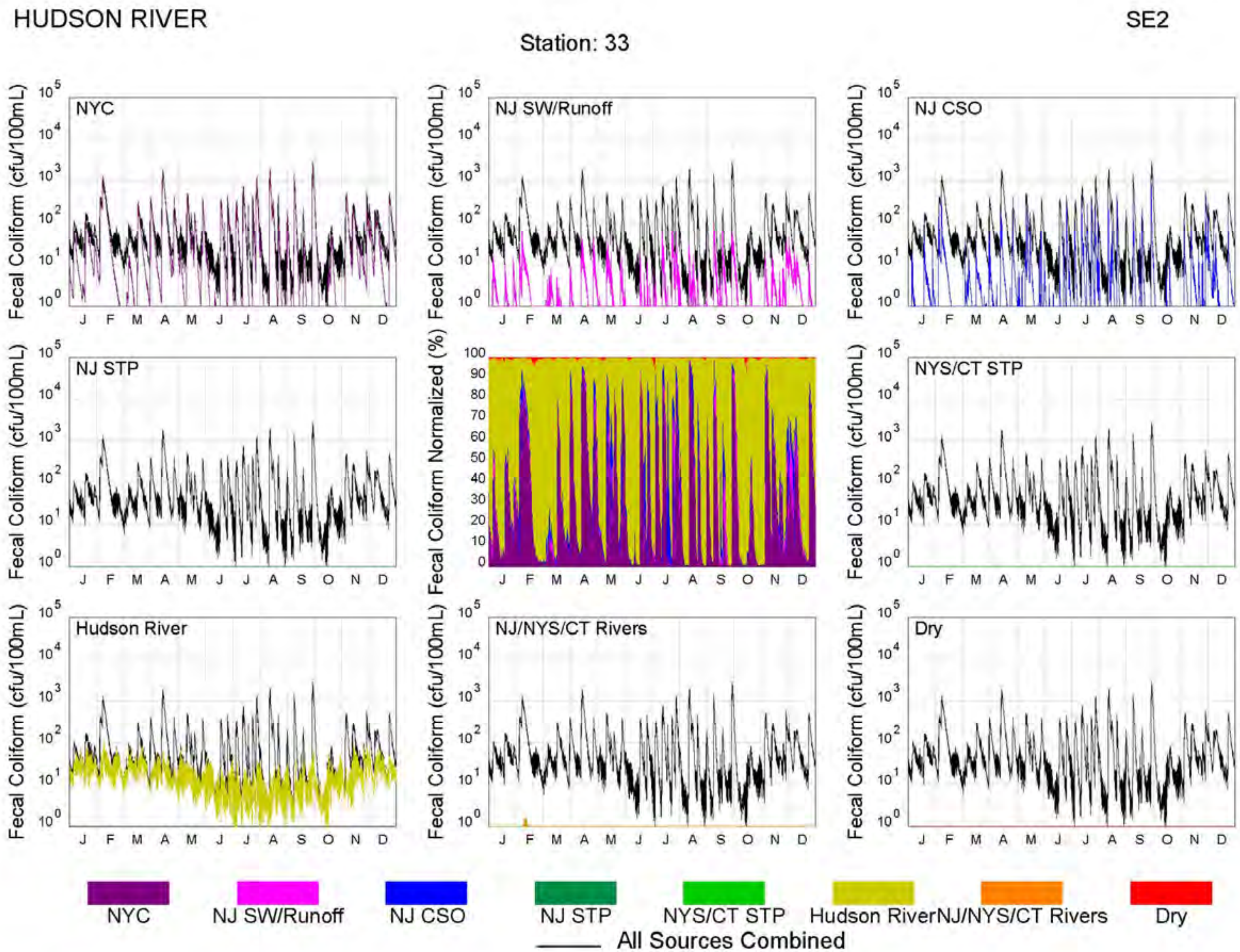


Figure 6-7. Component Analysis for Fecal Coliform at Station 33

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 be used to assess controls for stormwater or the elimination of illicit connections, additional field sampling and model verification is recommended.

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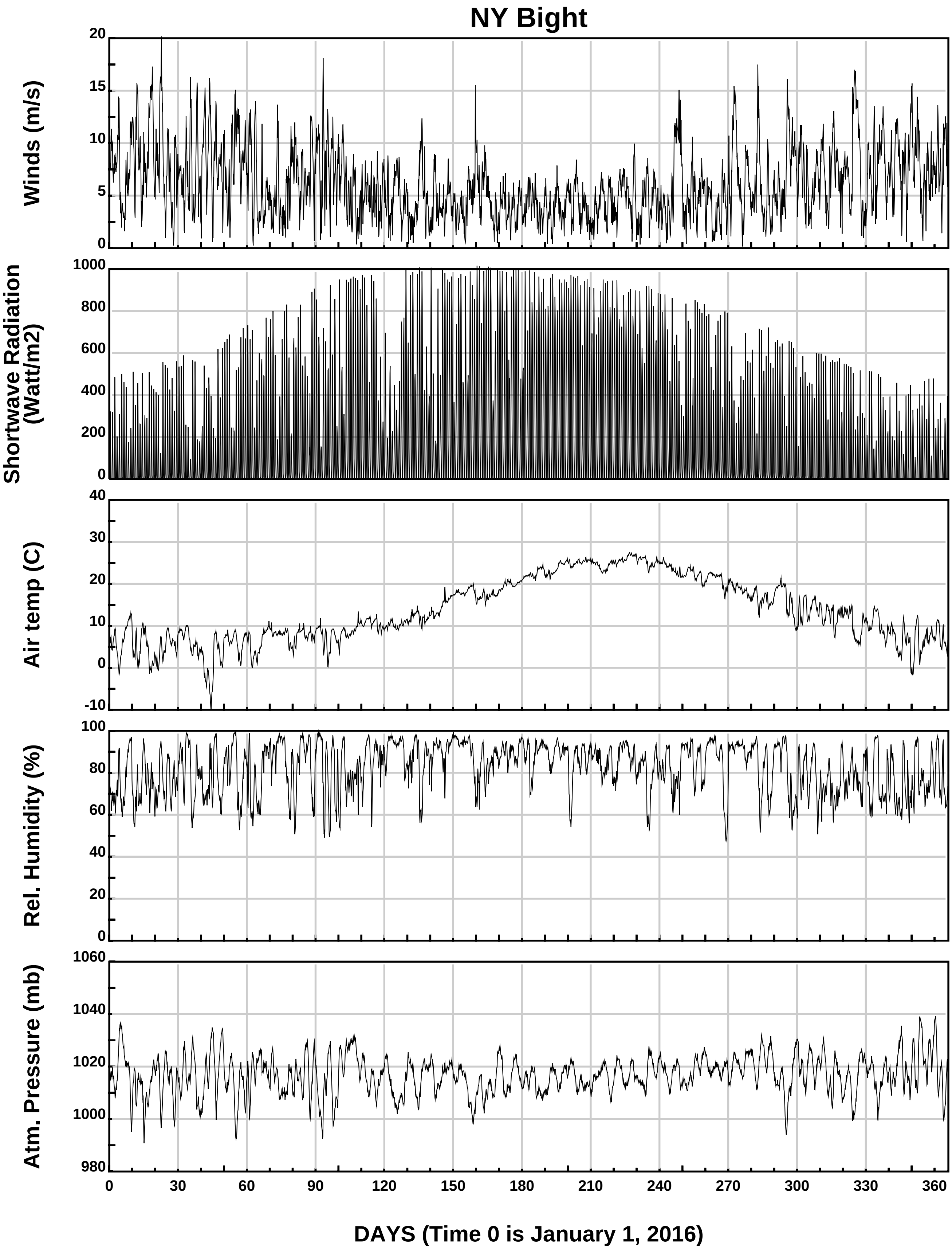
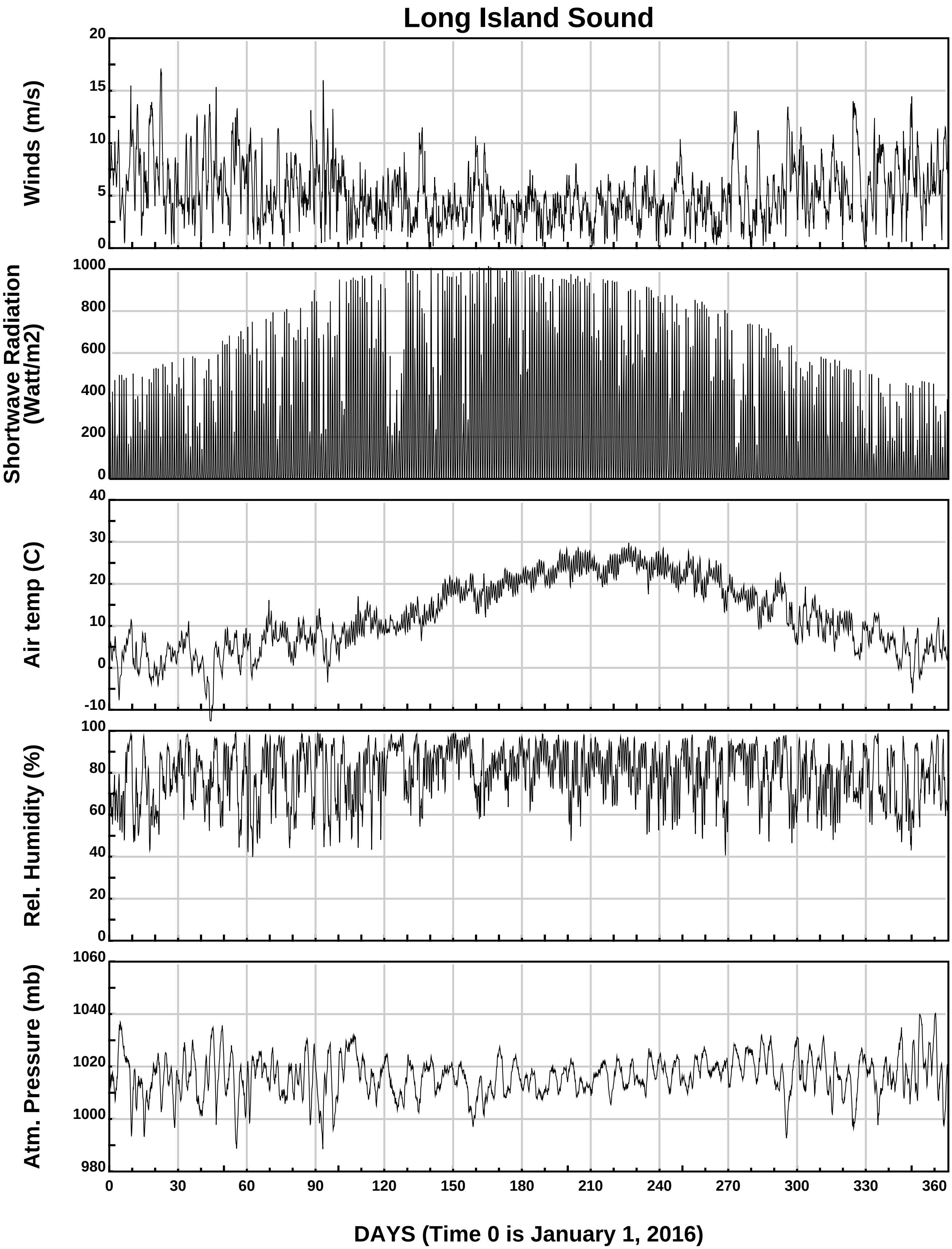
Appendix A

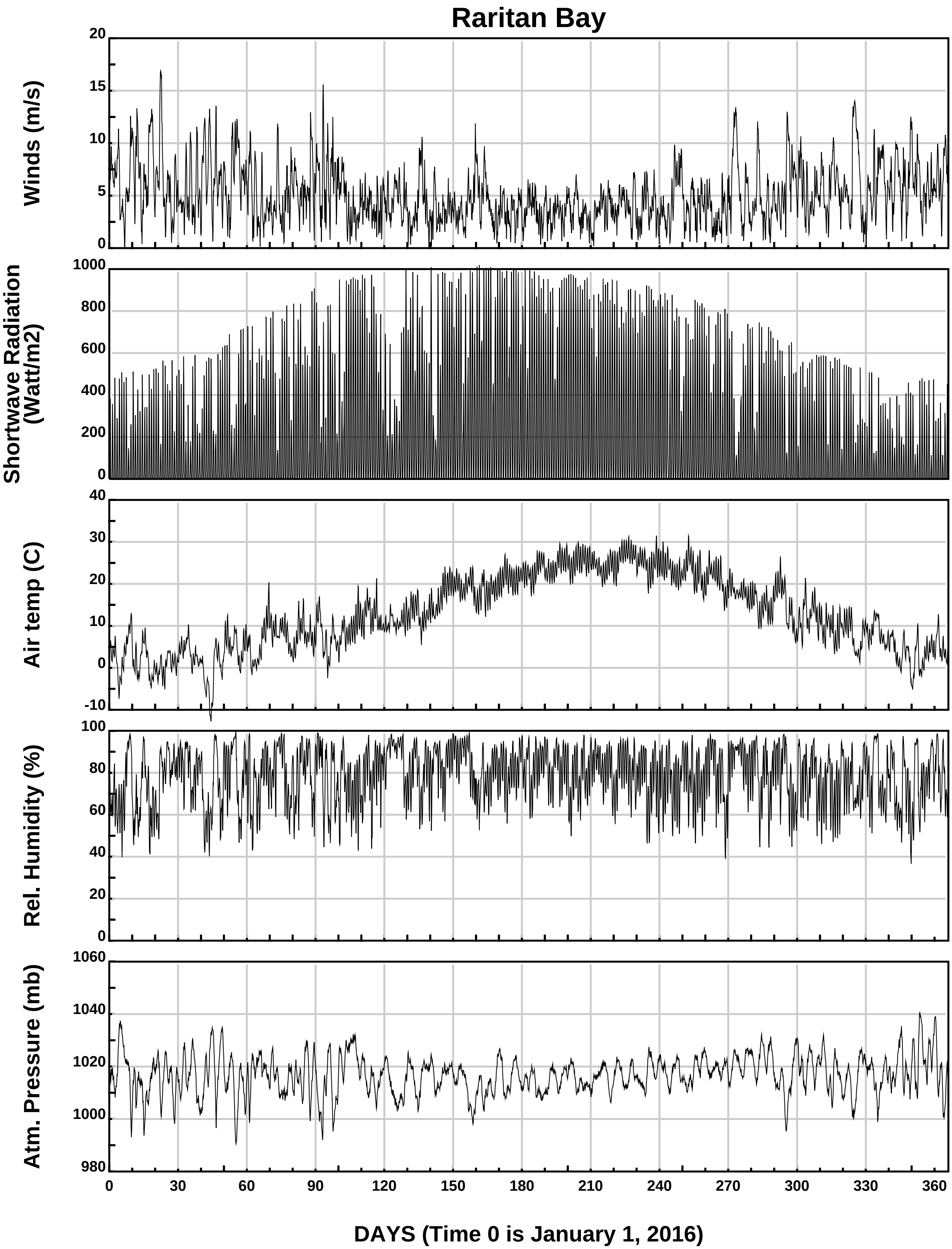
Additional Hydrodynamic Model Input Figures


NY Bight
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
0
30
60
90
120
150
180
210
240
270
300
330
360
DAYS (Time 0 is January 1, 2016)

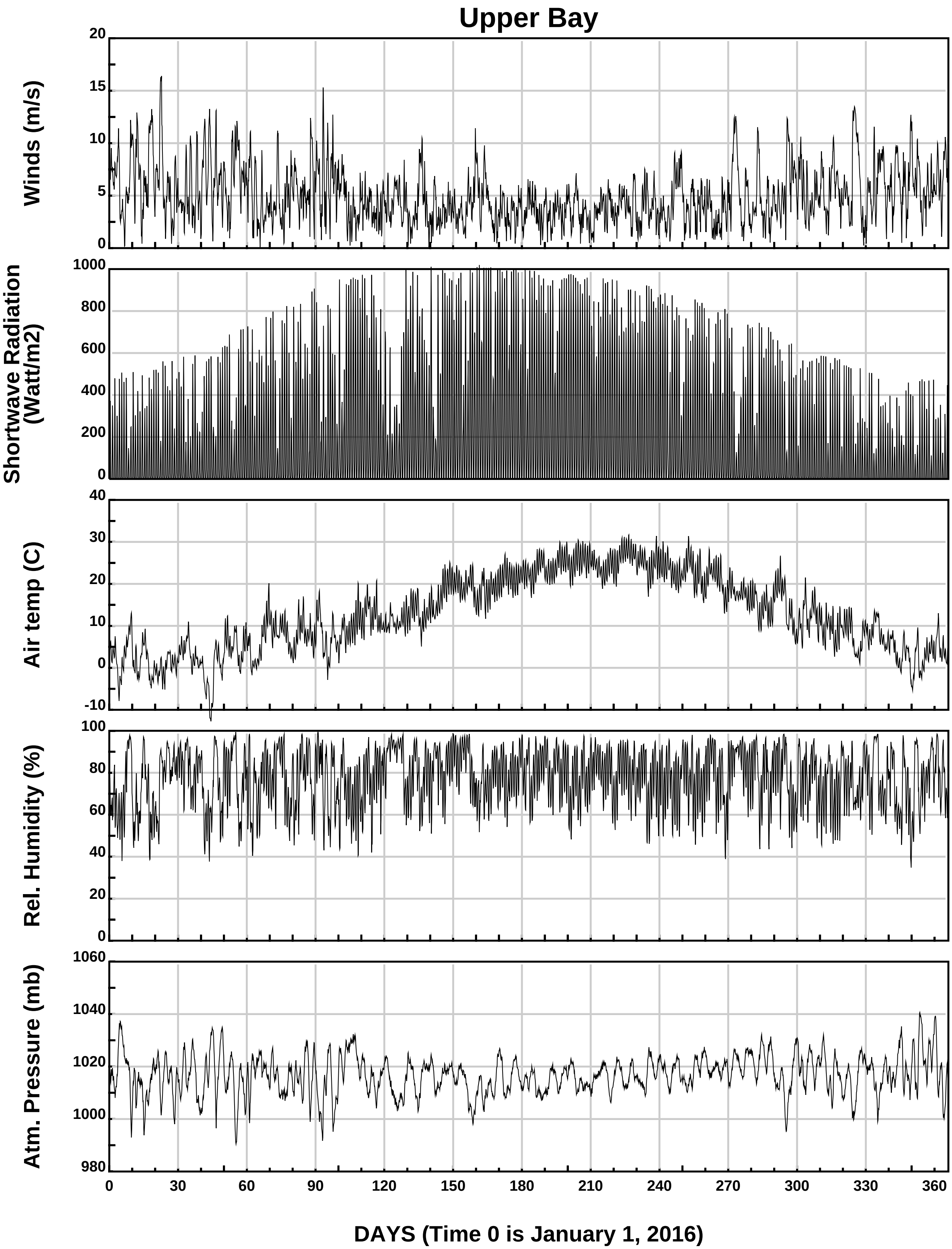
2016


Long Island Sound
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
0
30
60
90
120
150
180
210
240
270
300
330
360
DAYS (Time 0 is January 1, 2016)

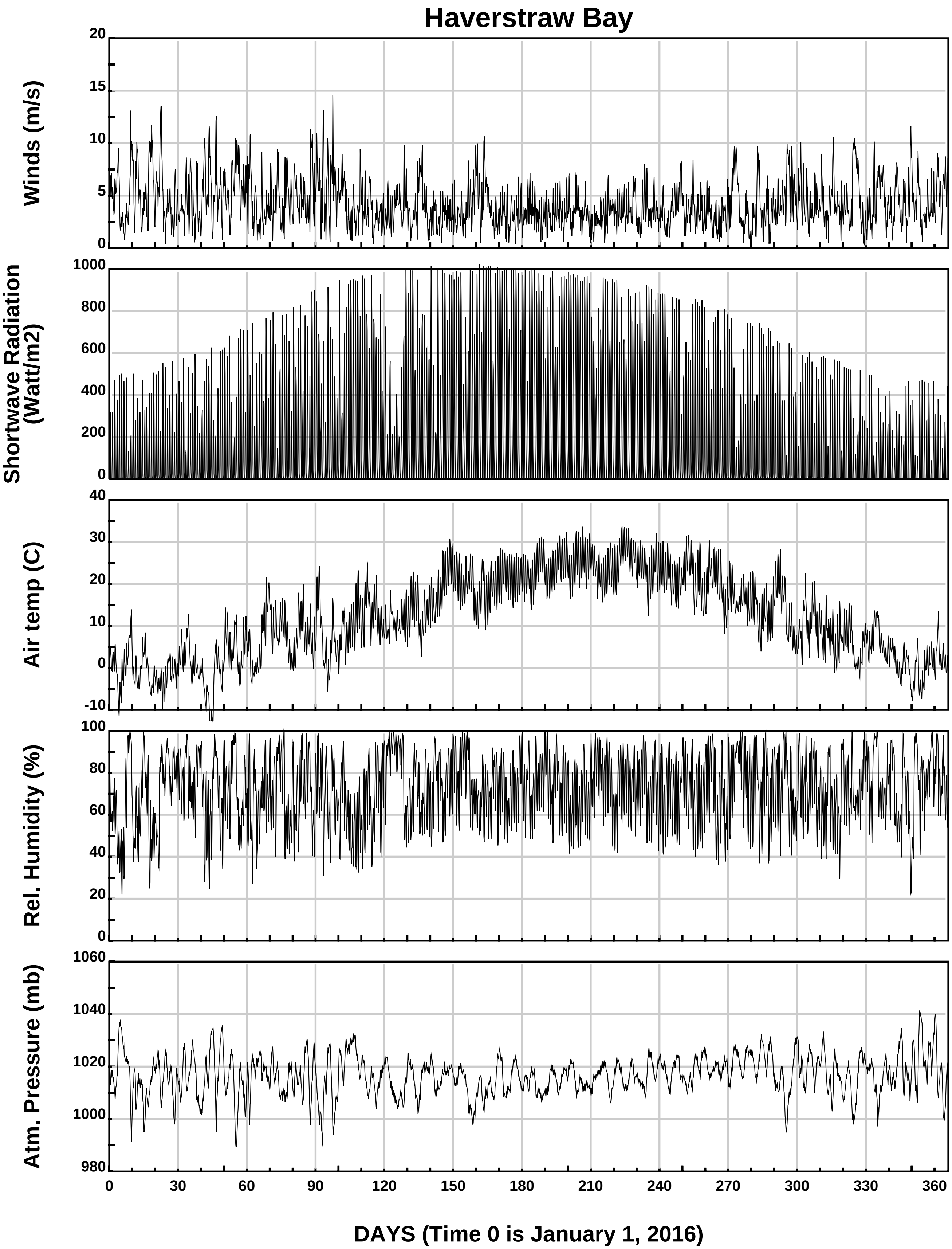
2016


Raritan Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2016)

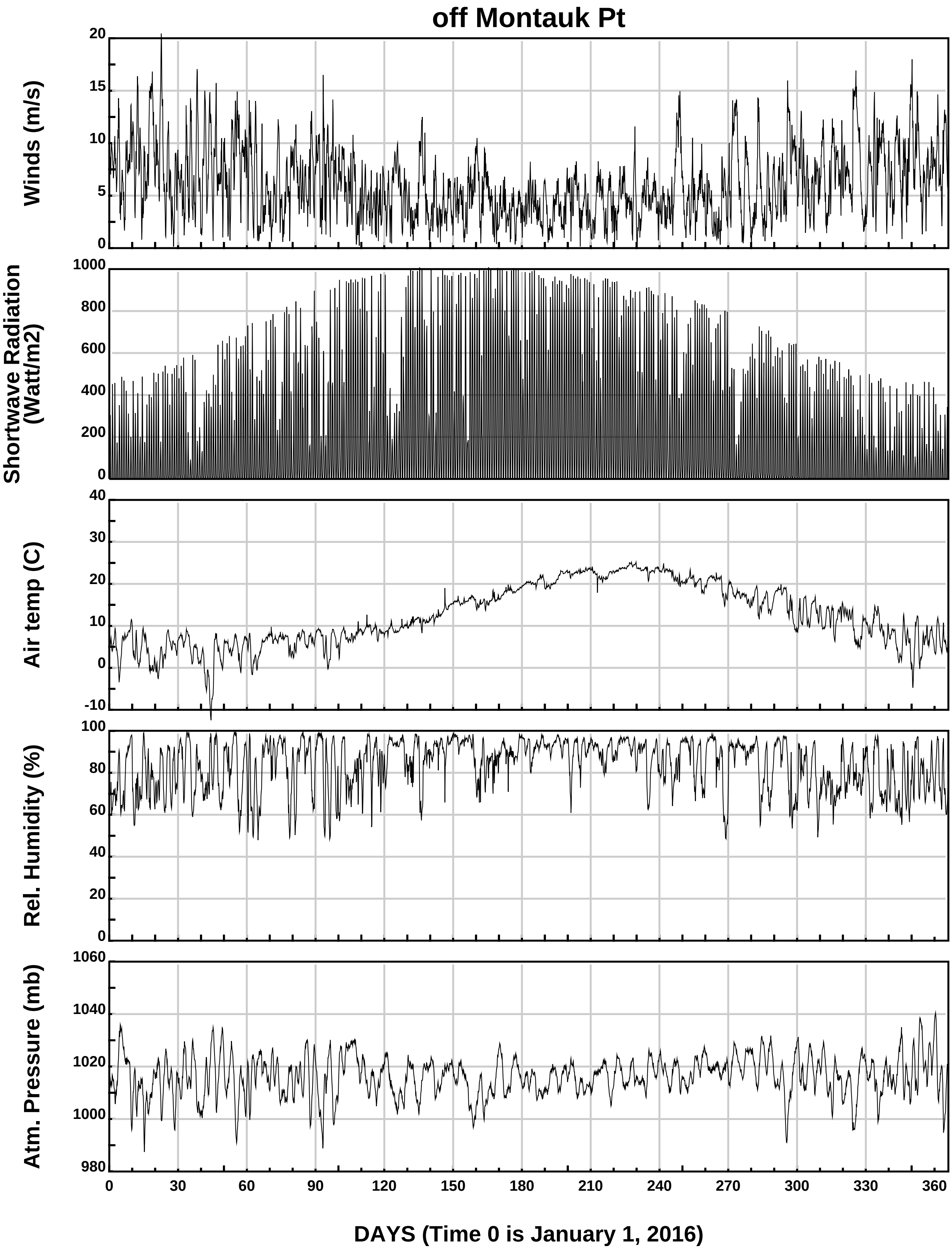
2016


Upper Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2016)

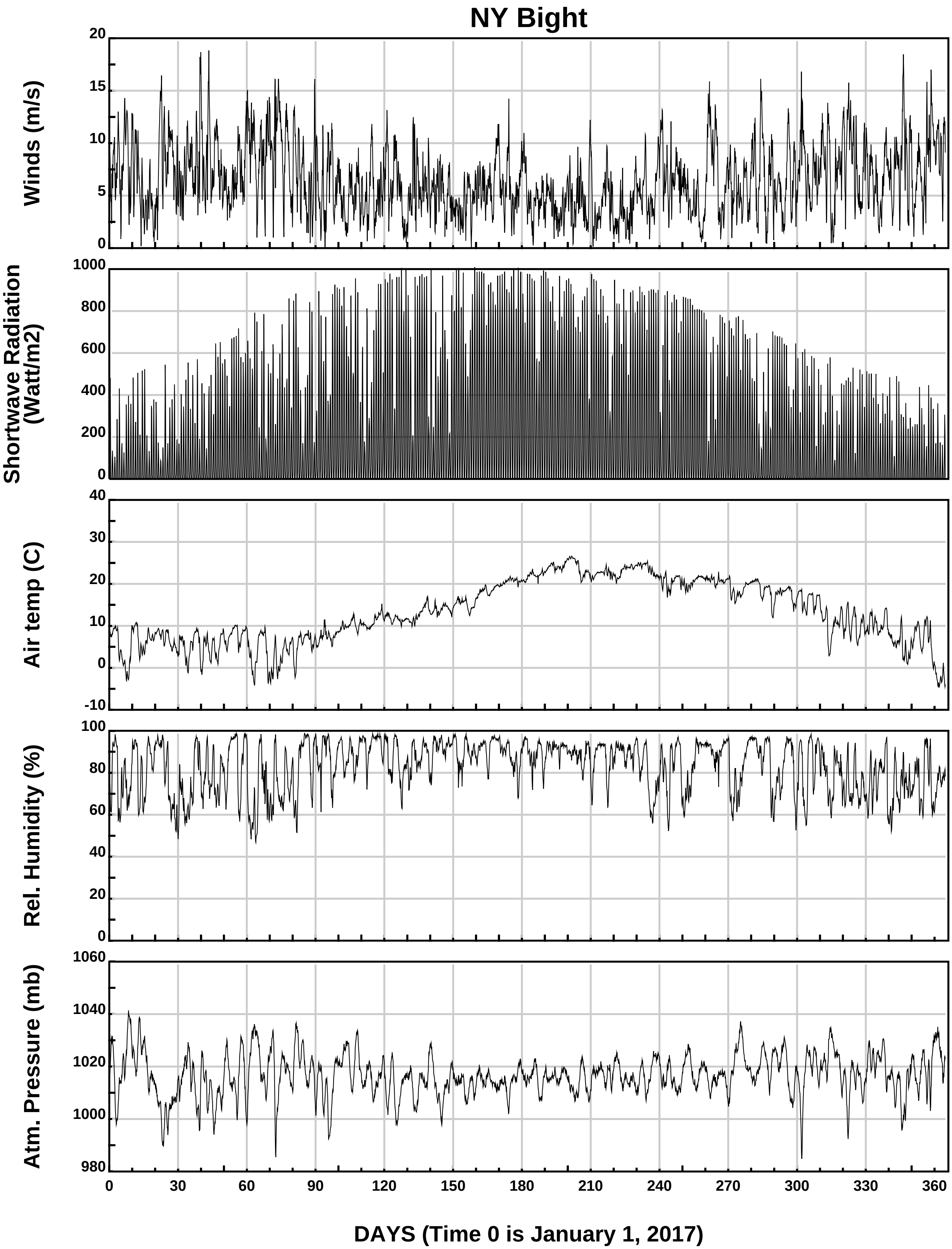
2016


Haverstraw Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2016)

2016


off Montauk Pt
Winds (m/s)
20
15
10
5
0
Shortwave Radiation (Watt/m2)
1000
800
600
400
200
0
Air temp (C)
40
30
20
10
0
-10
Rel. Humidity (%)
100
80
60
40
20
0
Atm. Pressure (mb)
1060
1040
1020
1000
980
0
30
60
90
120
150
180
210
240
270
300
330
360
DAYS (Time 0 is January 1, 2016)

2016


NY Bight
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
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90
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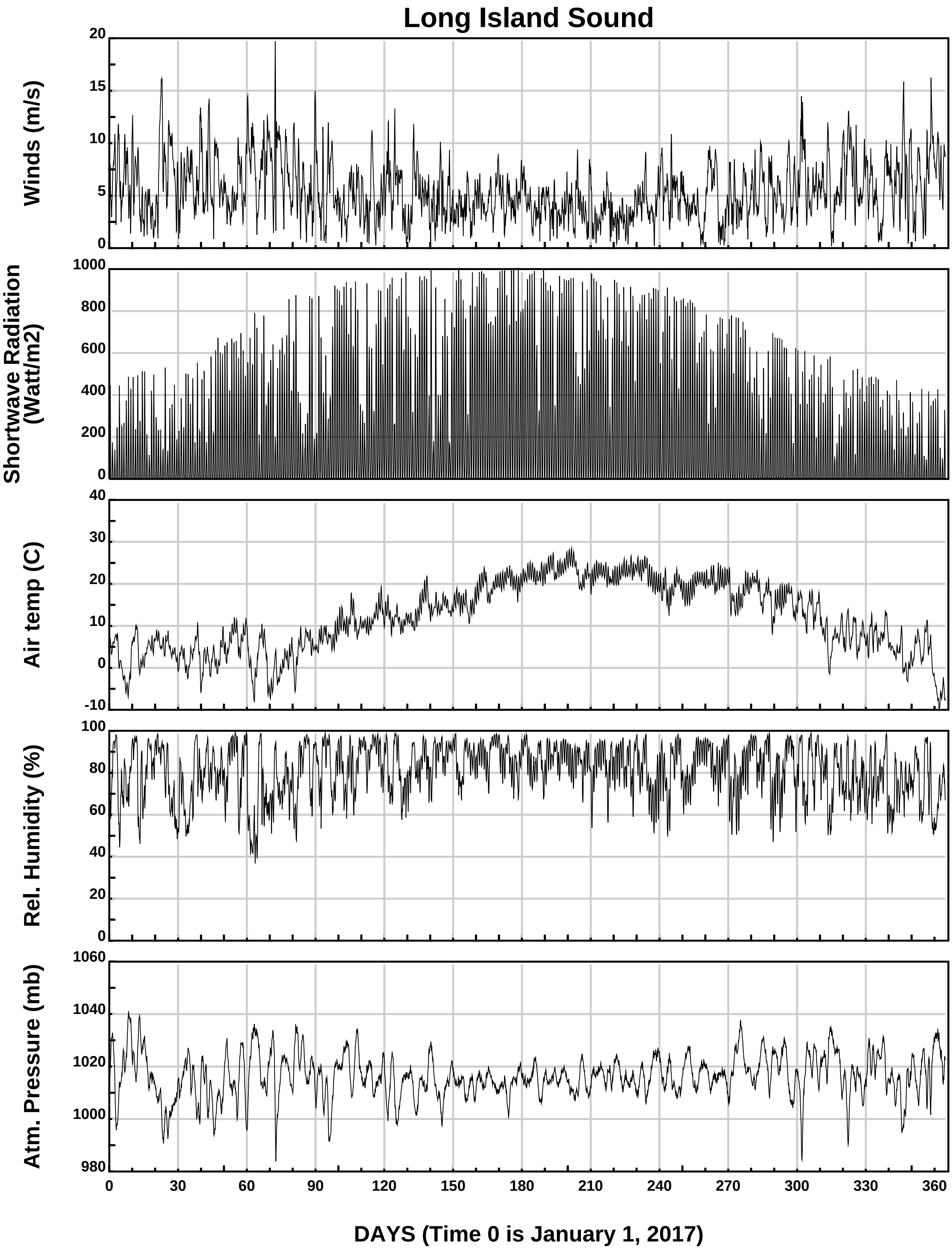
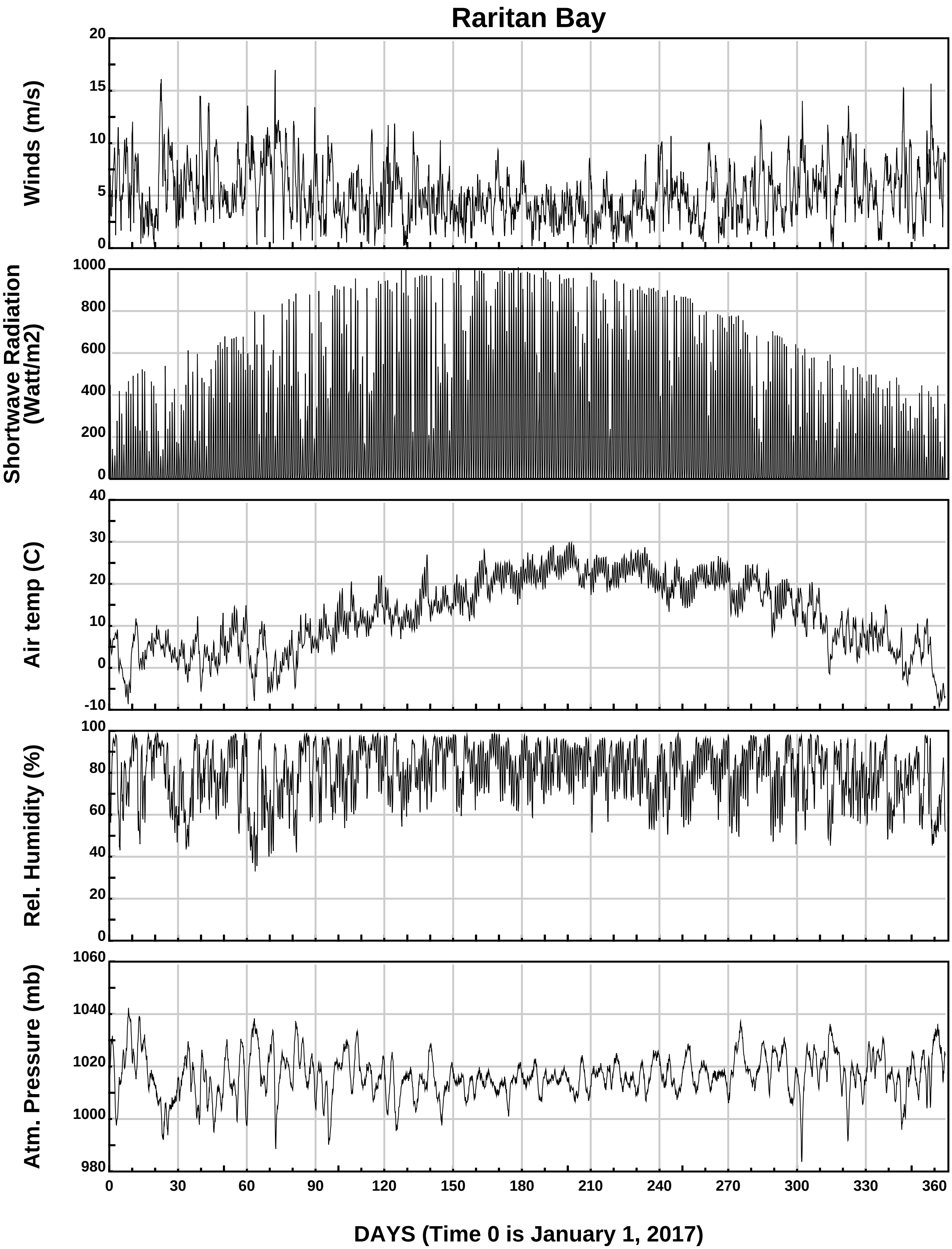
180
210
240
270
300
330
360
DAYS (Time 0 is January 1, 2017)

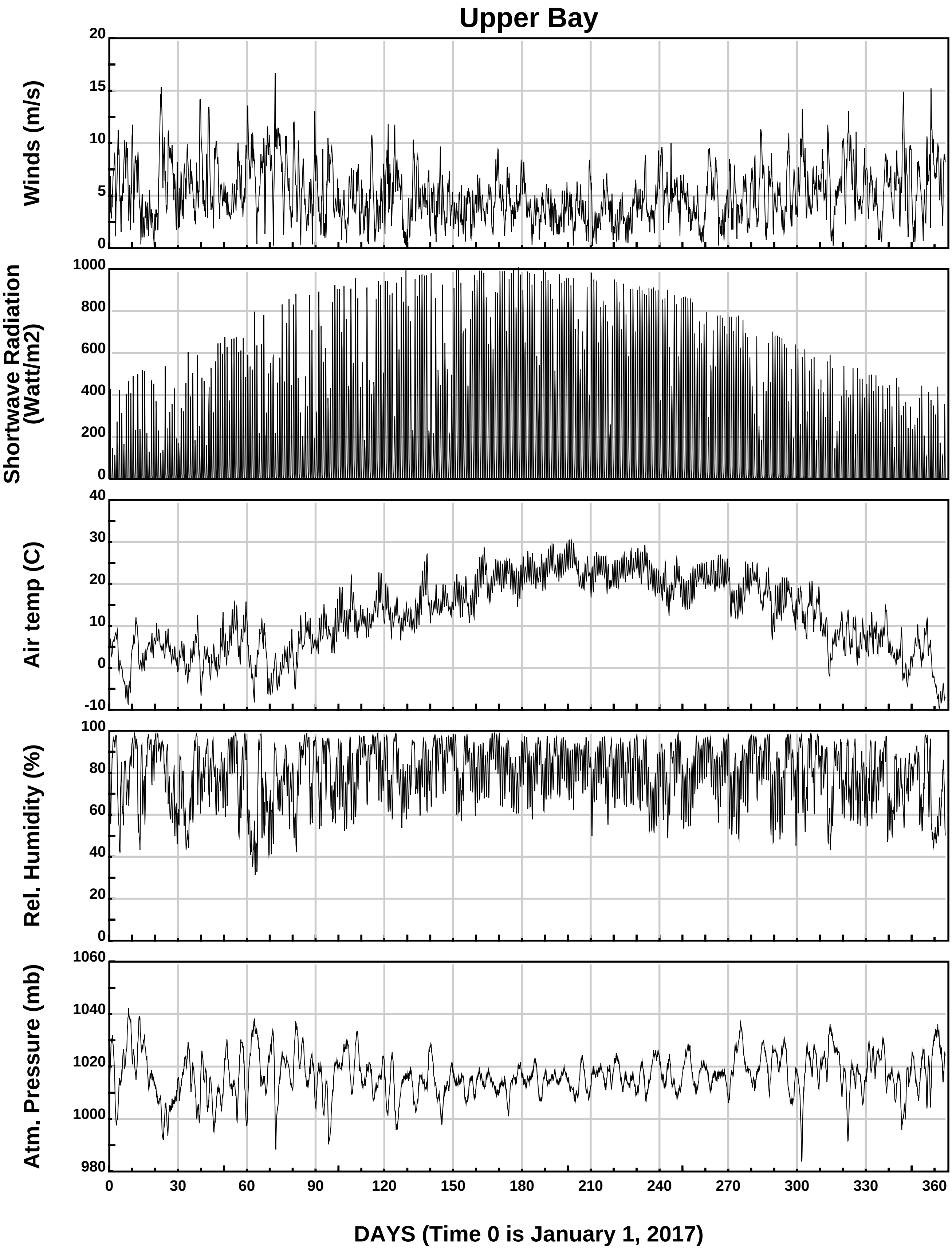
2017


Long Island Sound
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2017)

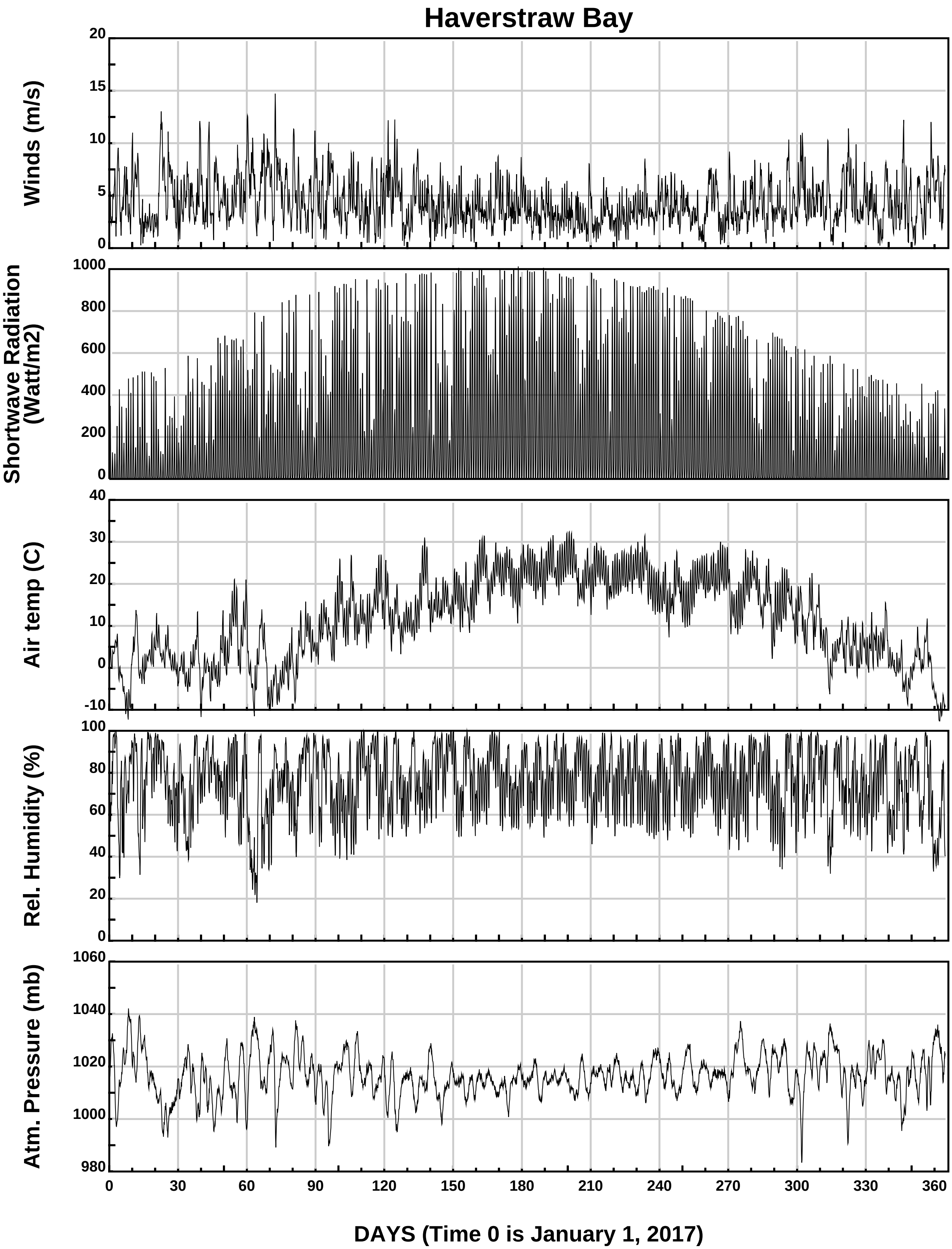
2017


Raritan Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2017)

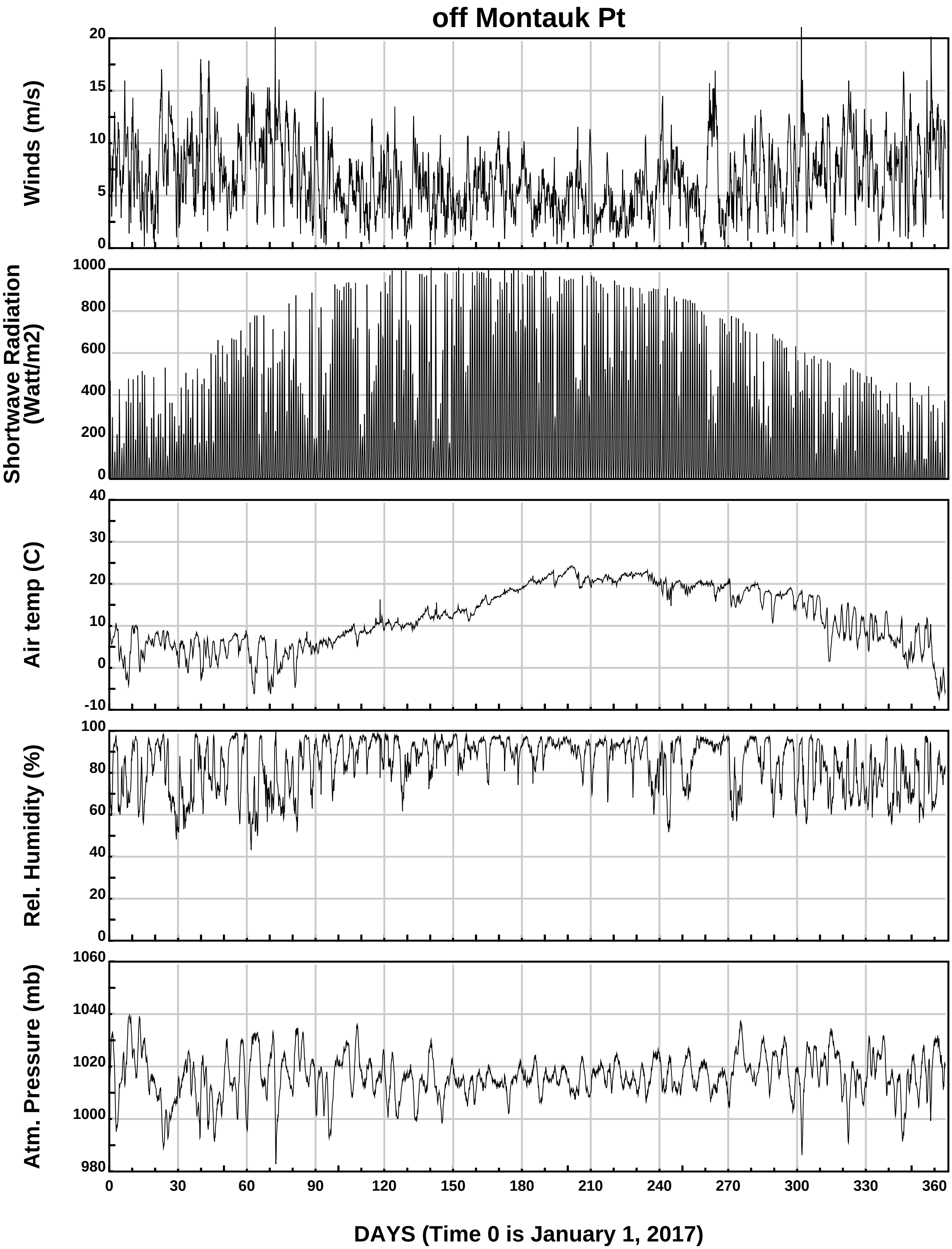
2017


Upper Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
0
30
60
90
120
150
180
210
240
270
300
330
360
DAYS (Time 0 is January 1, 2017)

2017


Haverstraw Bay
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
0 30 60 90 120 150 180 210 240 270 300 330 360
DAYS (Time 0 is January 1, 2017)

2017


off Montauk Pt
Winds (m/s)
Shortwave Radiation (Watt/m2)
Air temp (C)
Rel. Humidity (%)
Atm. Pressure (mb)
DAYS (Time 0 is January 1, 2017)

2017

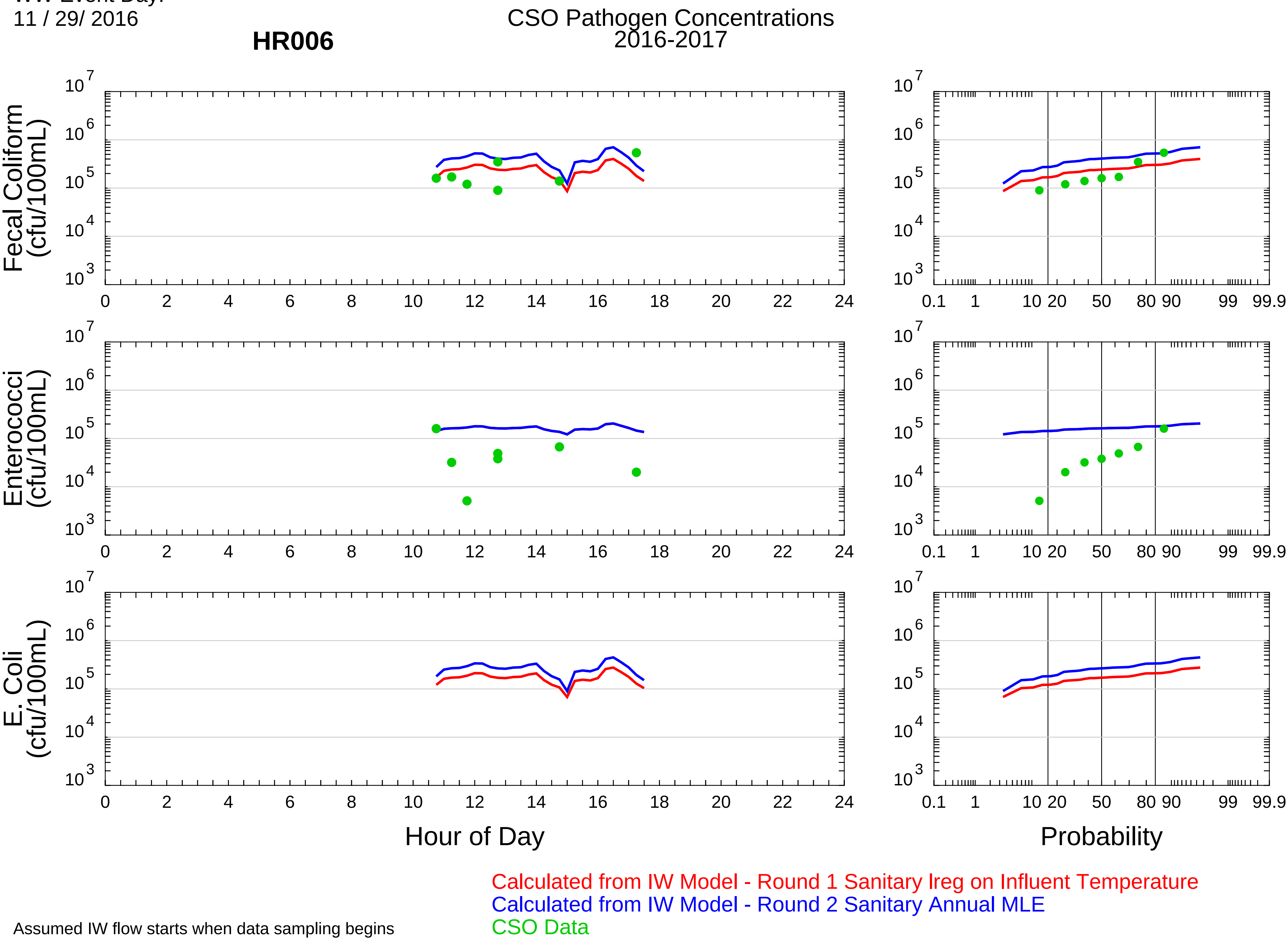
Appendix B

Additional Water Quality Model Loading Figures

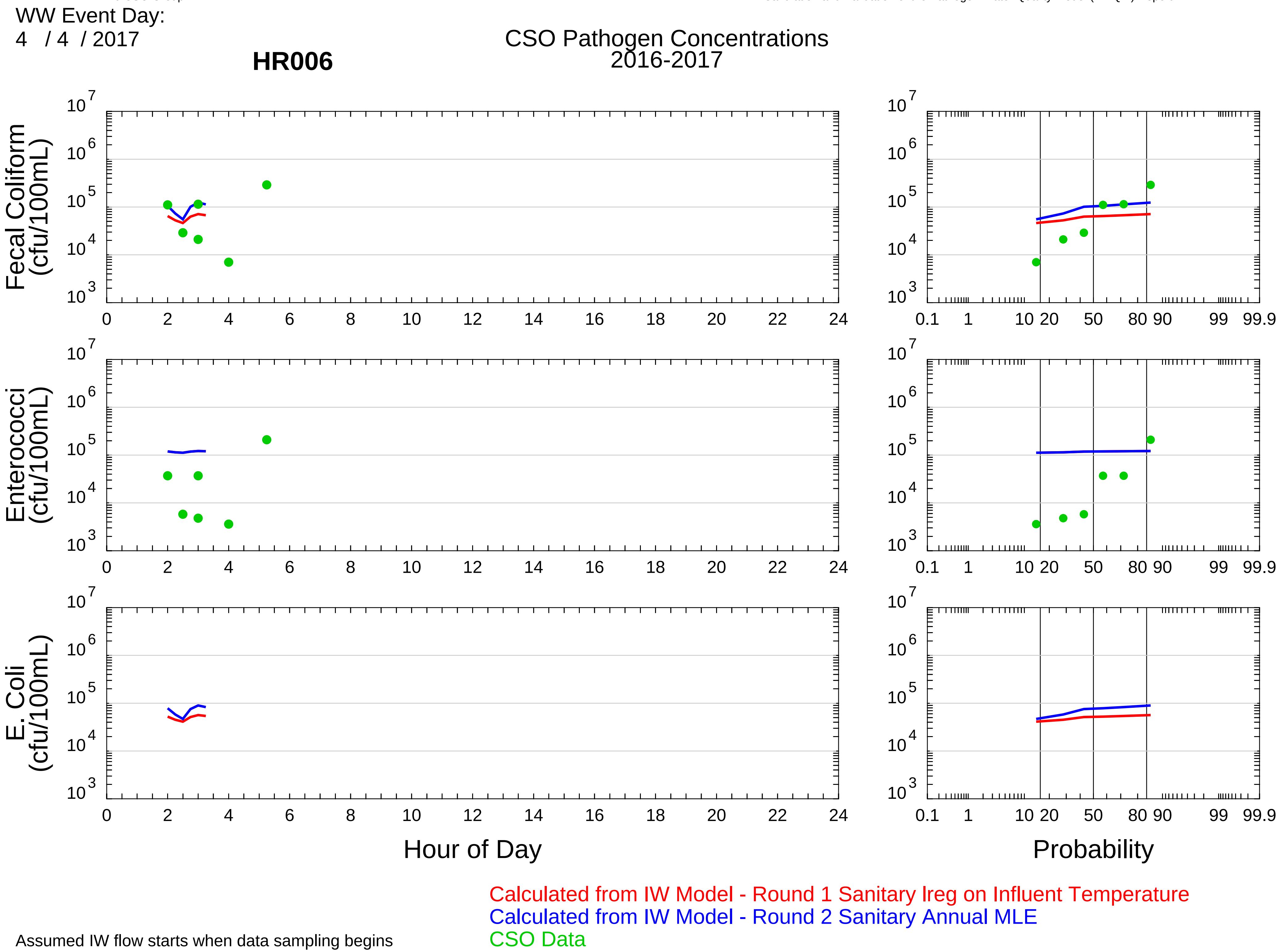
Appendix B-1

Assessment of CSO Mass Balance Approach

WW Event Day:
11 / 29/ 2016



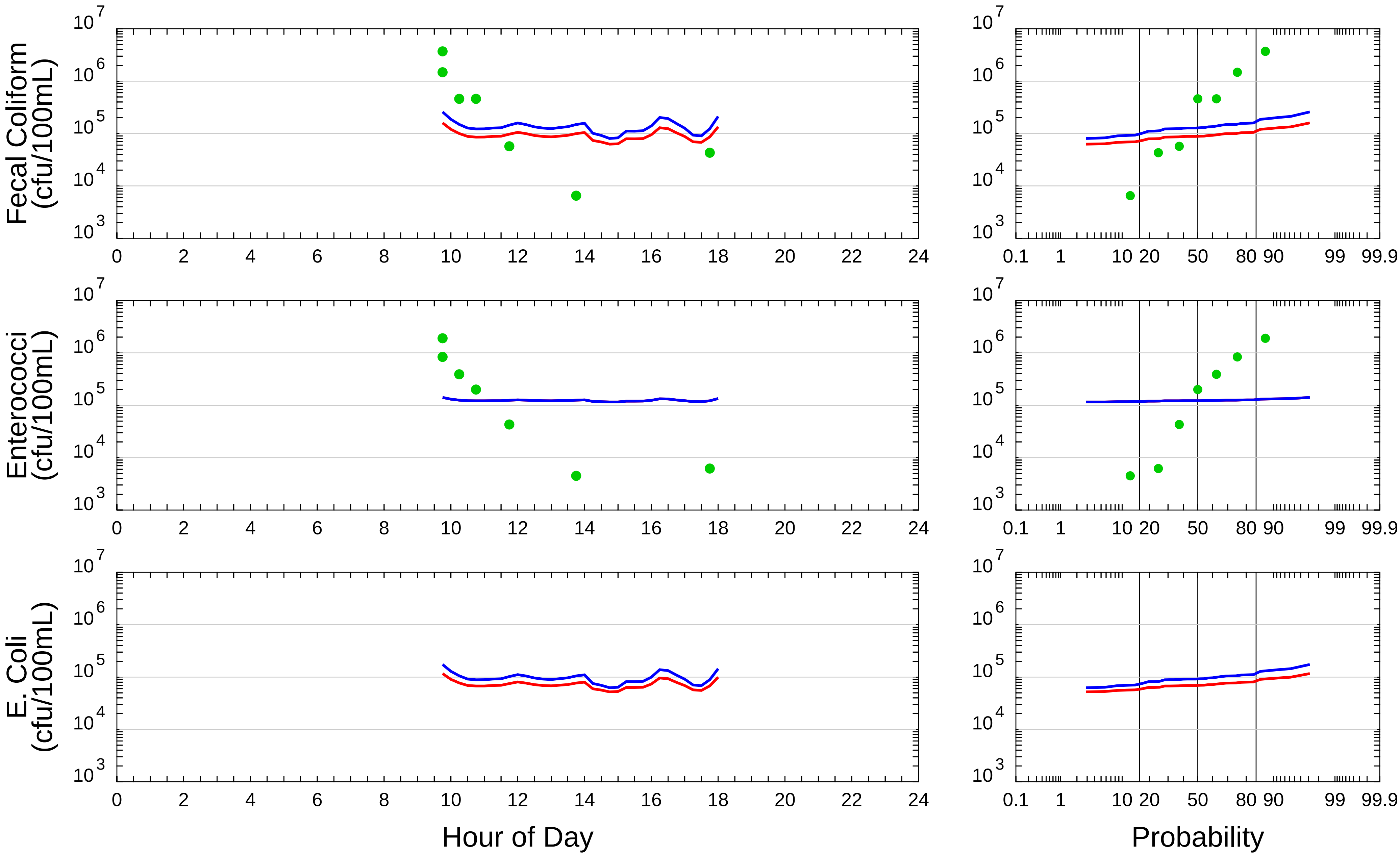
Assumed IW flow starts when data sampling begins


WW Event Day:
4 / 4 / 2017
HR006
CSO Pathogen Concentrations
2016-2017
Fecal Coliform (cfu/100mL)
Enterococci (cfu/100mL)
E. Coli (cfu/100mL)
10^3 10^4 10^5 10^6 10^7
0 2 4 6 8 10 12 14 16 18 20 22 24
0.1 1 10 20 50 80 90 99 99.9
Hour of Day
Probability
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data
Assumed IW flow starts when data sampling begins

WW Event Day:
11 / 29/ 2016

HR007

CSO Pathogen Concentrations 2016-2017



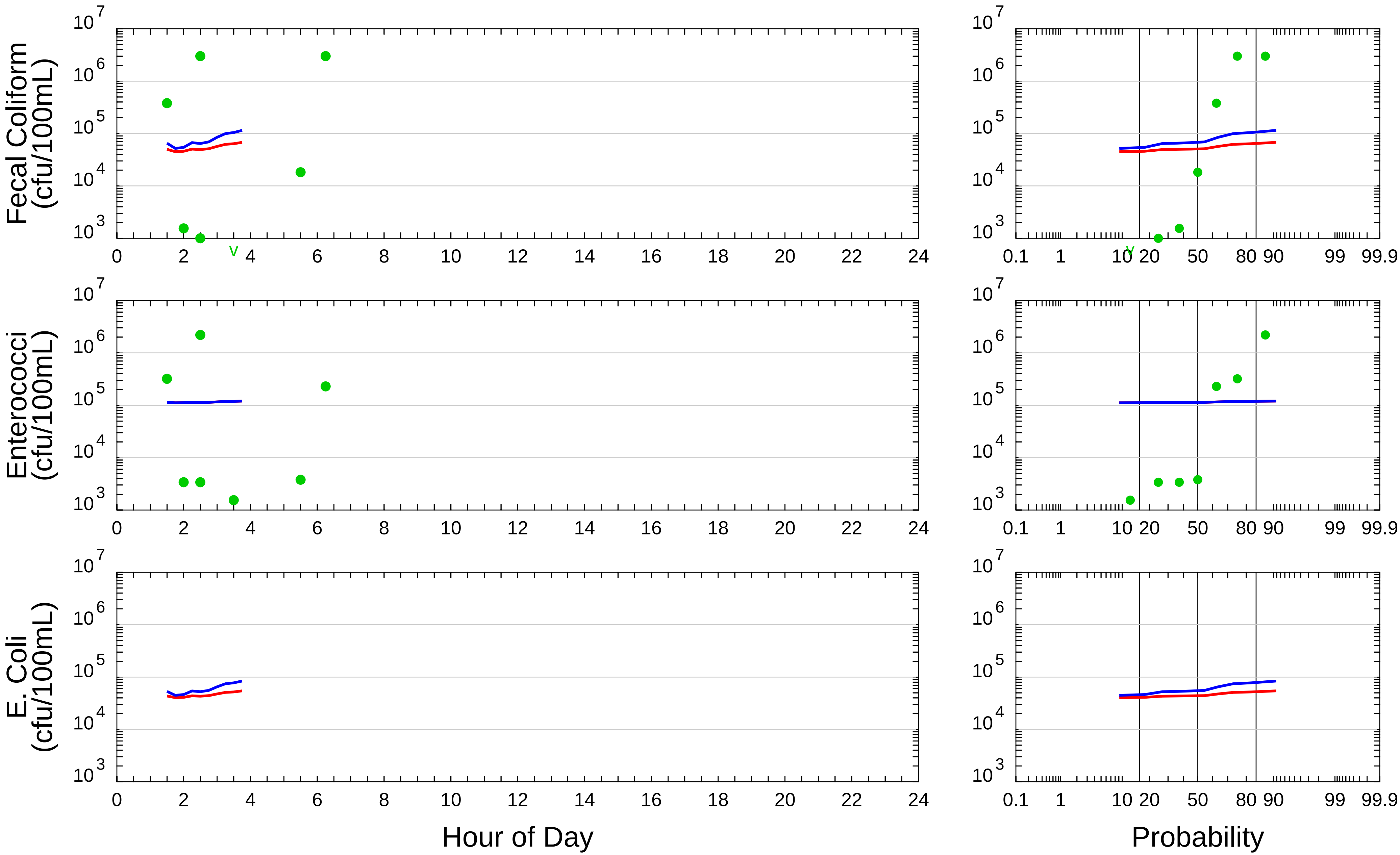
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 4 / 2017

CSO Pathogen Concentrations 2016-2017

HR007



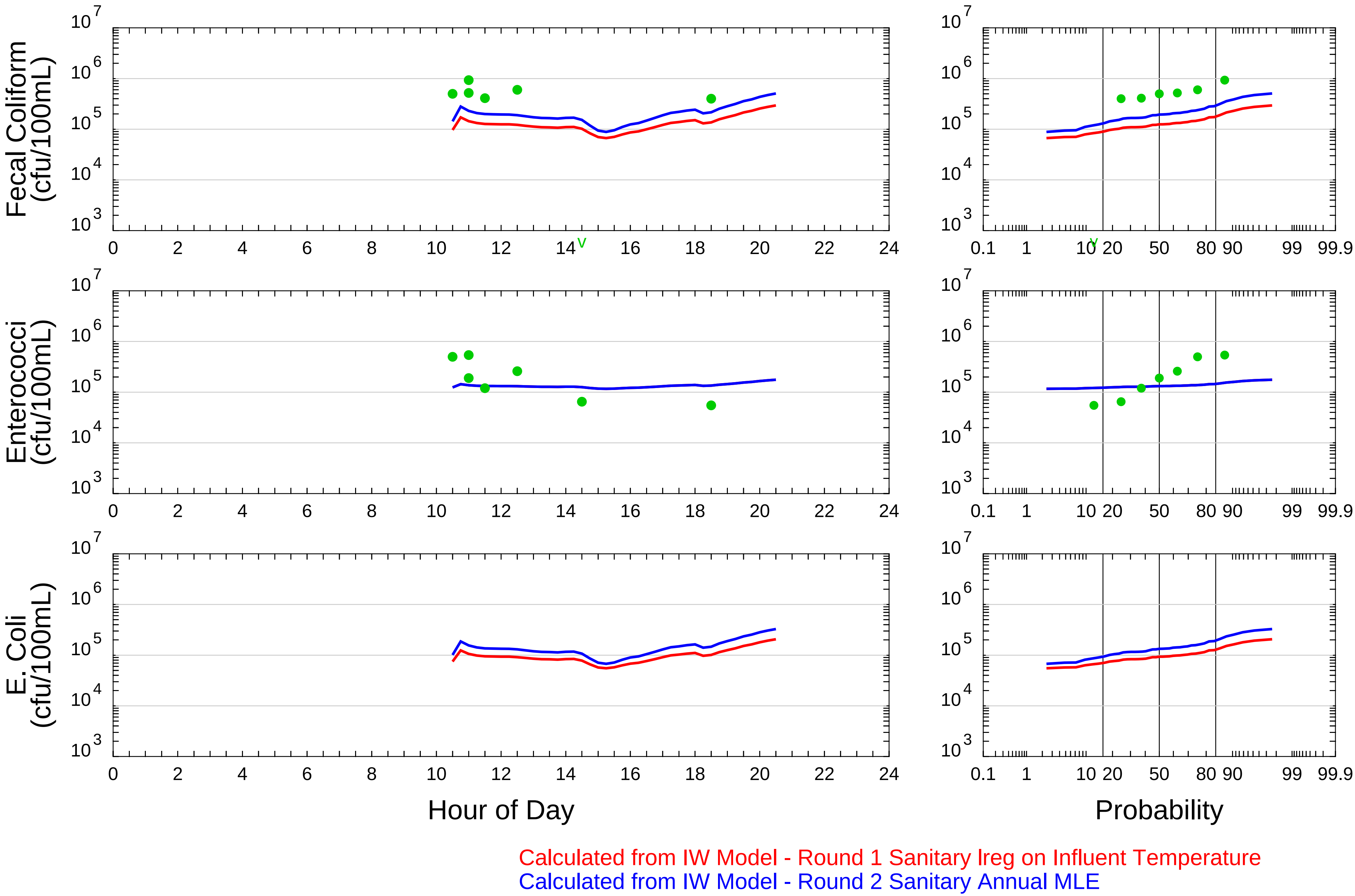
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
11 / 29/ 2016

KE007

CSO Pathogen Concentrations
2016-2017

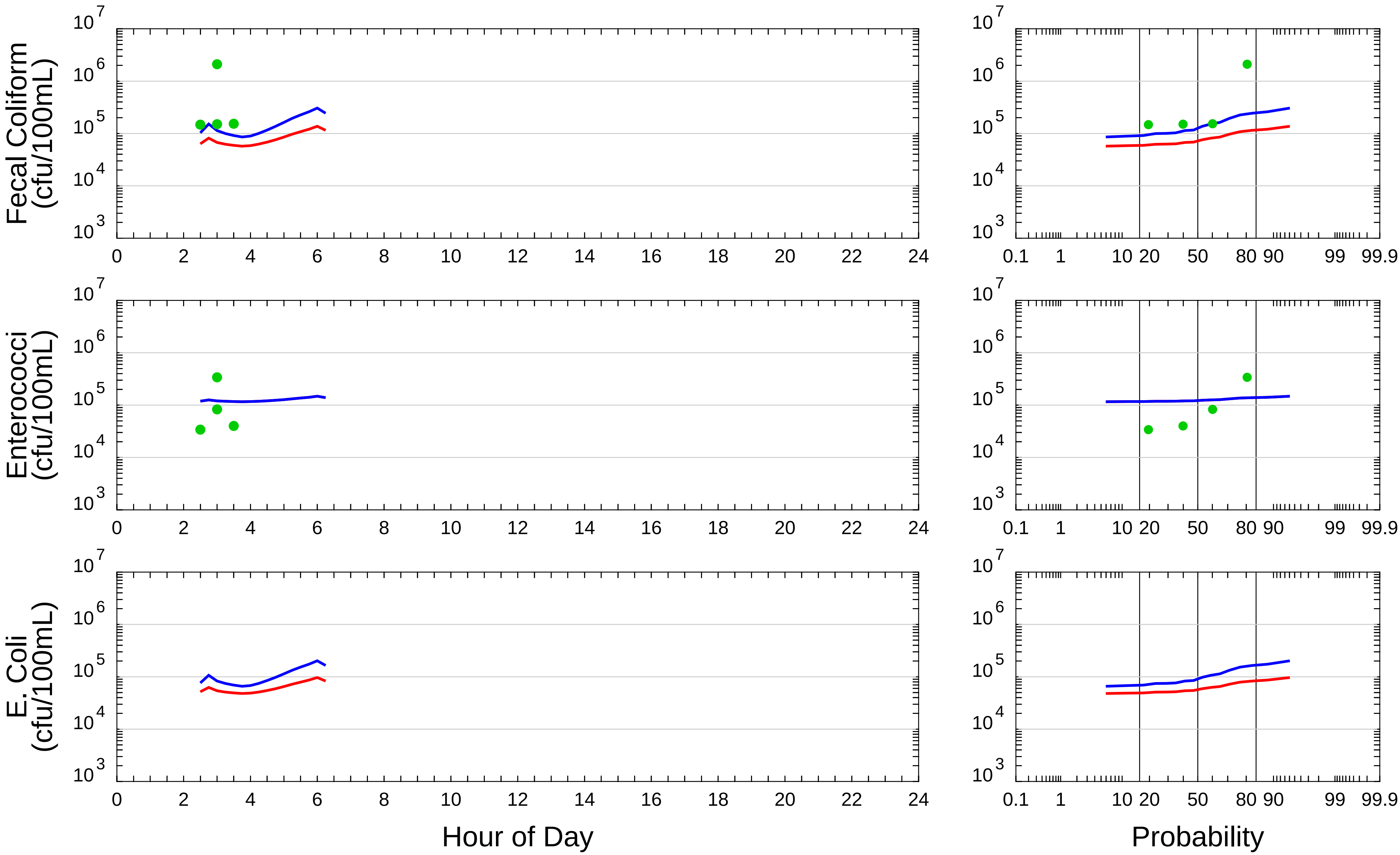


Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 4 / 2017

CSO Pathogen Concentrations 2016-2017

KE007



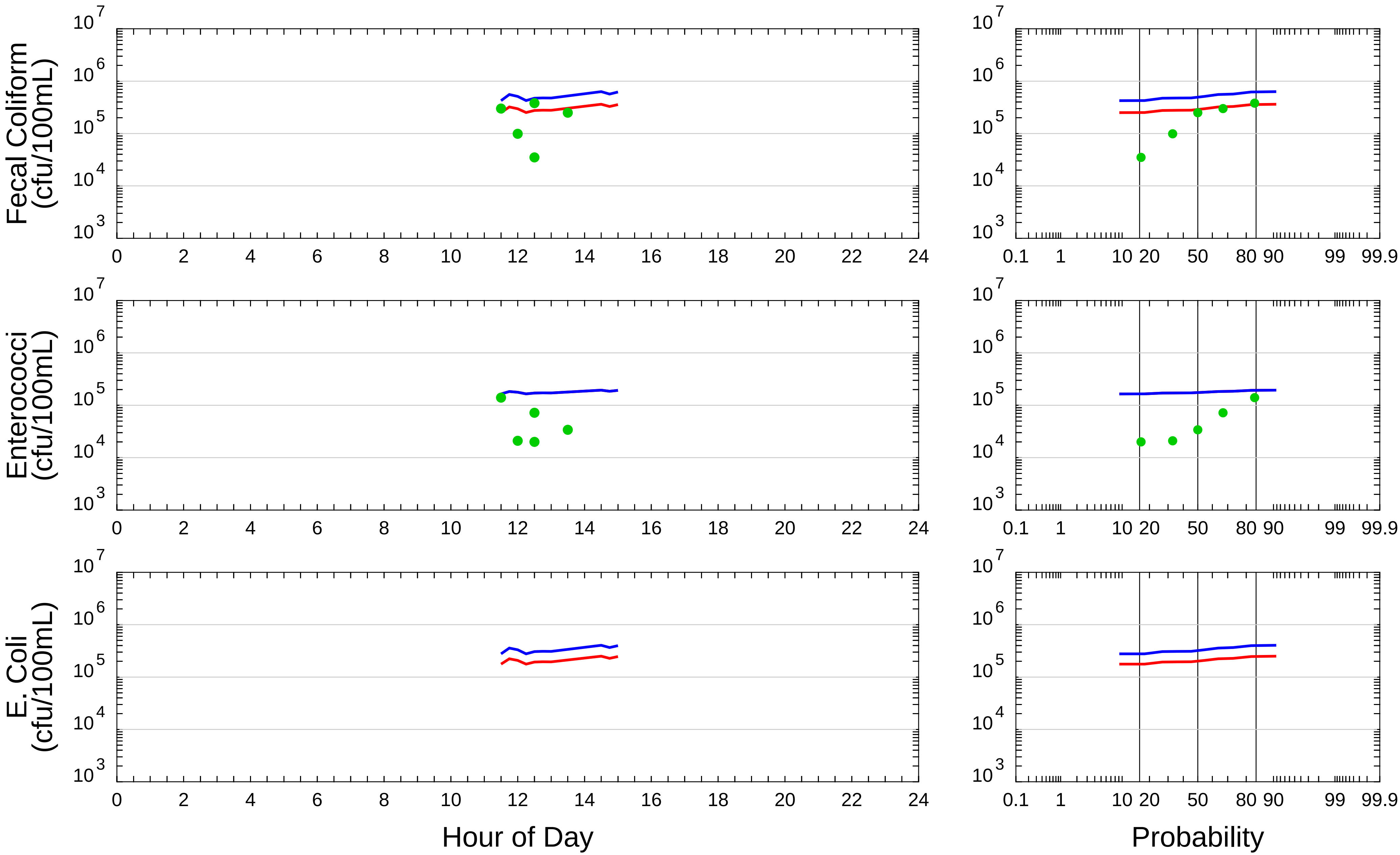
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
11 / 29/ 2016

NE004

CSO Pathogen Concentrations
2016-2017



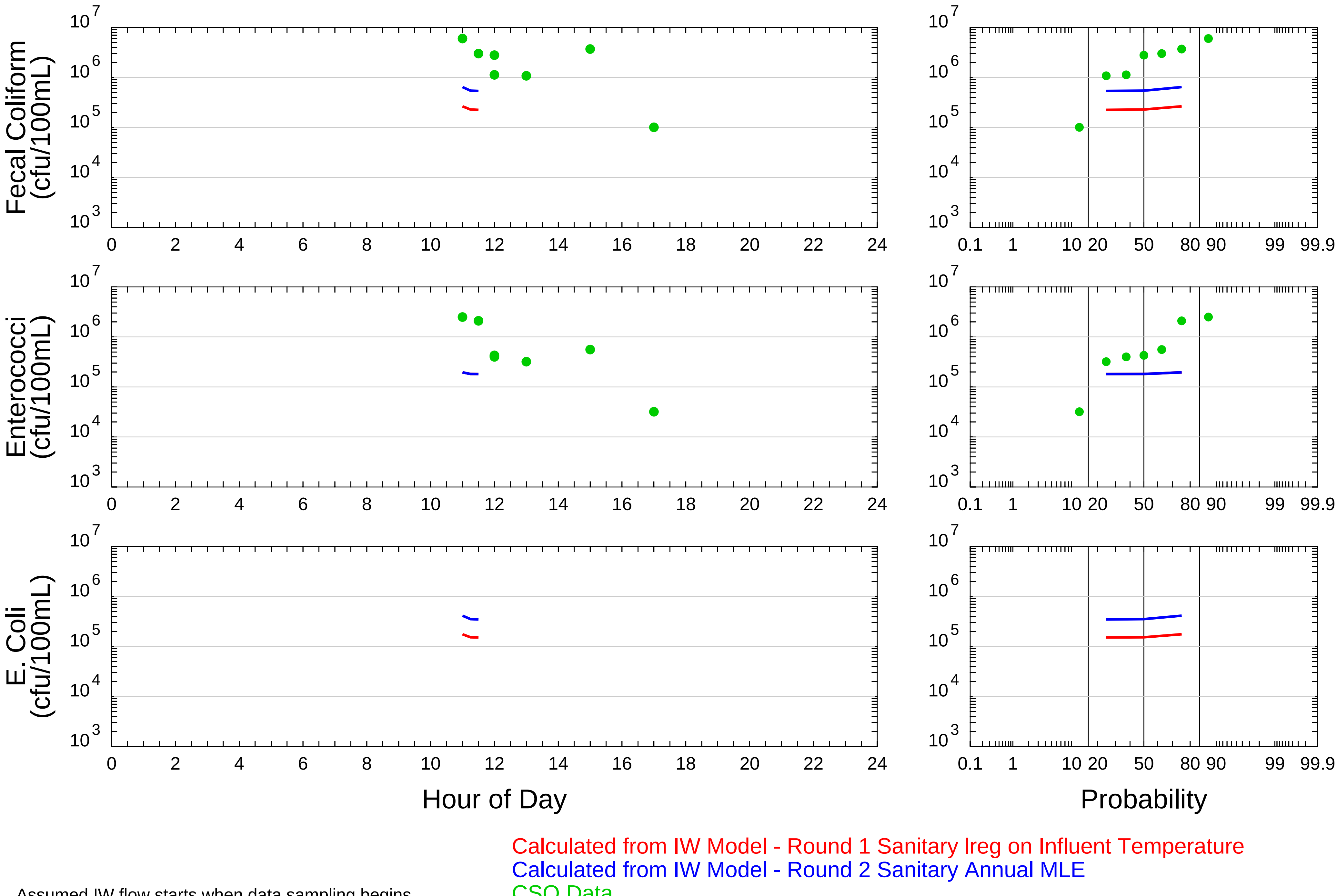
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 6 / 2017

NE004

CSO Pathogen Concentrations
2016-2017

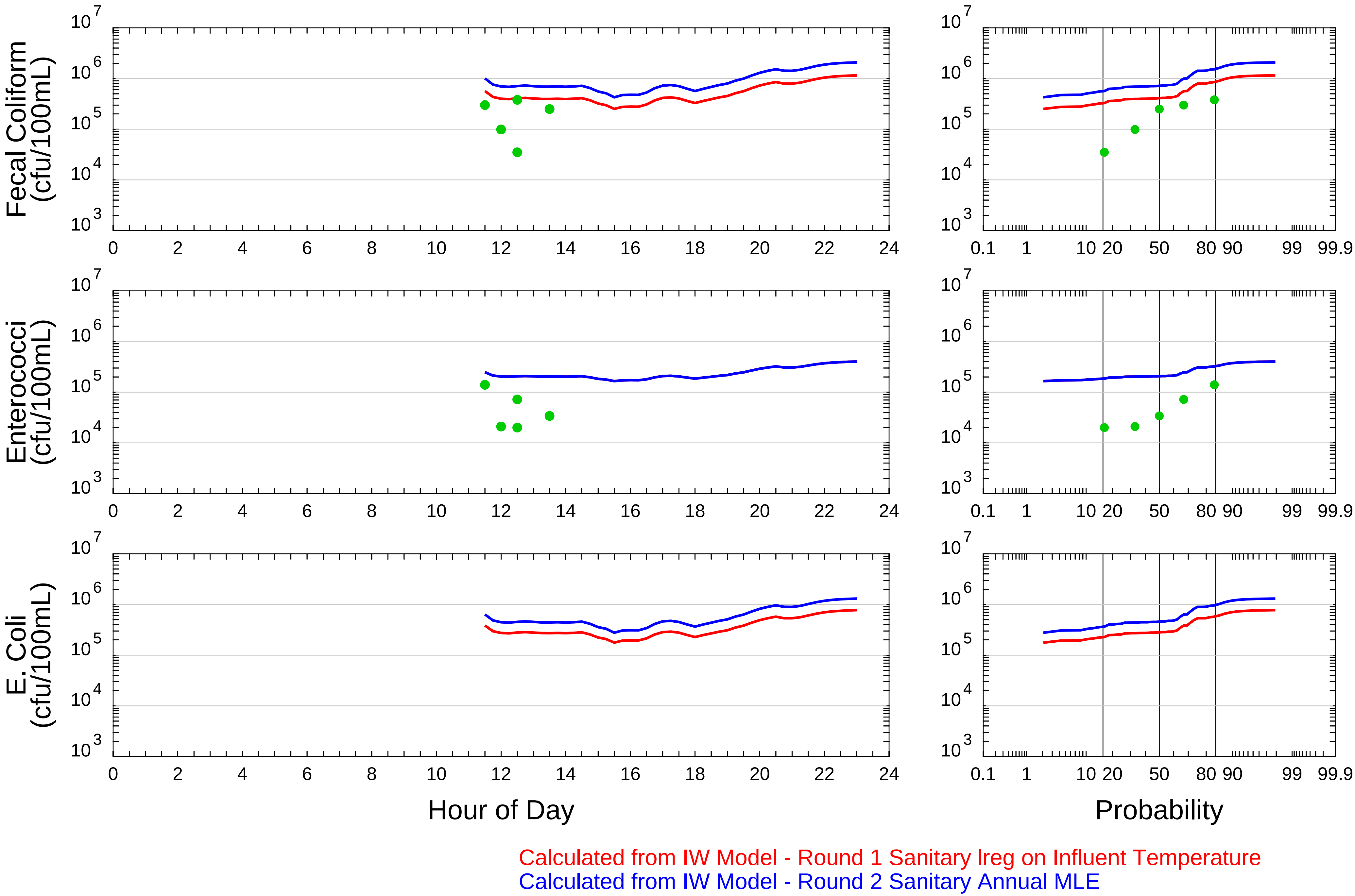


Assumed IW flow starts when data sampling begins

WW Event Day:
11 / 29/ 2016

NE005

CSO Pathogen Concentrations
2016-2017

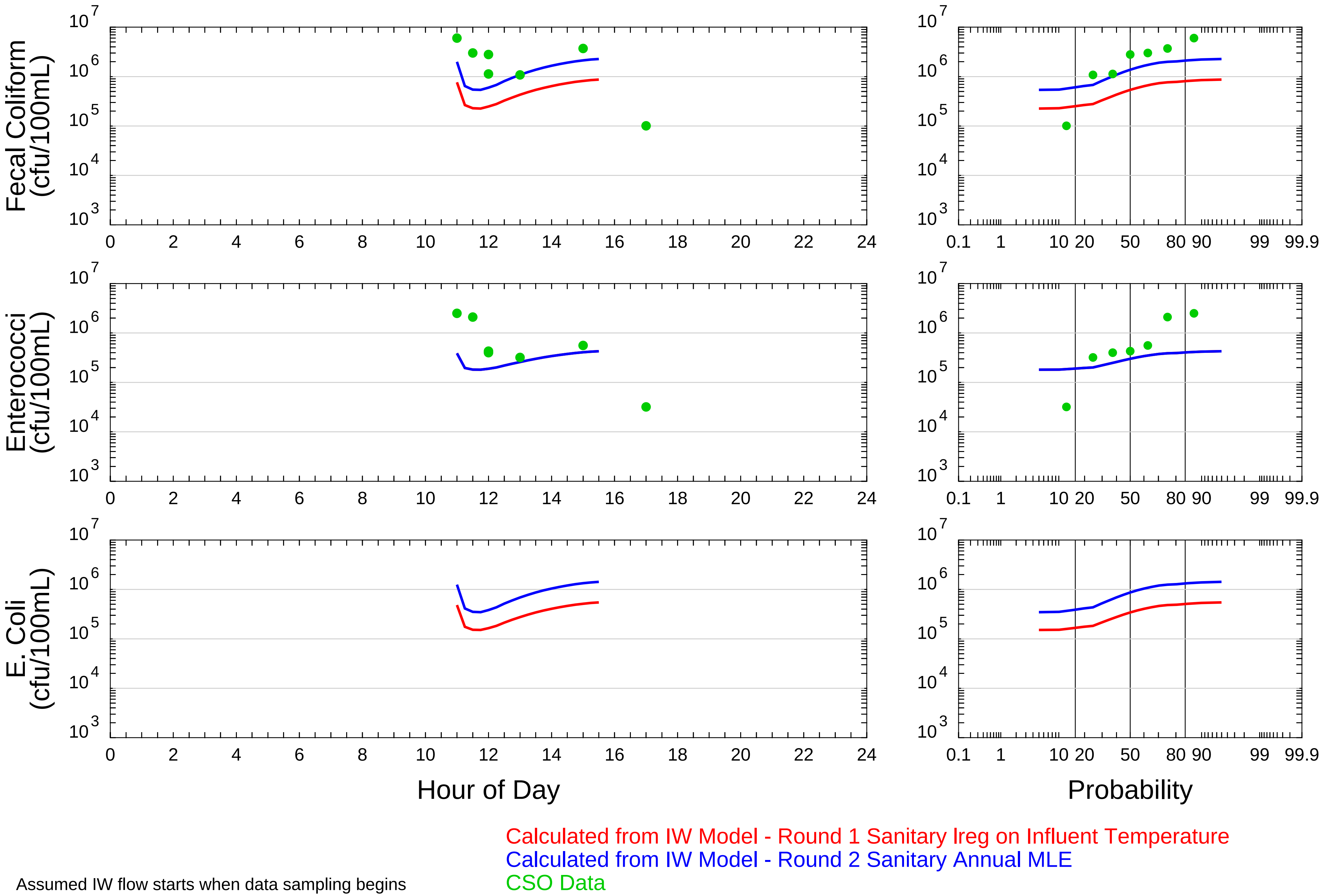


Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 6 / 2017

NE005

CSO Pathogen Concentrations 2016-2017

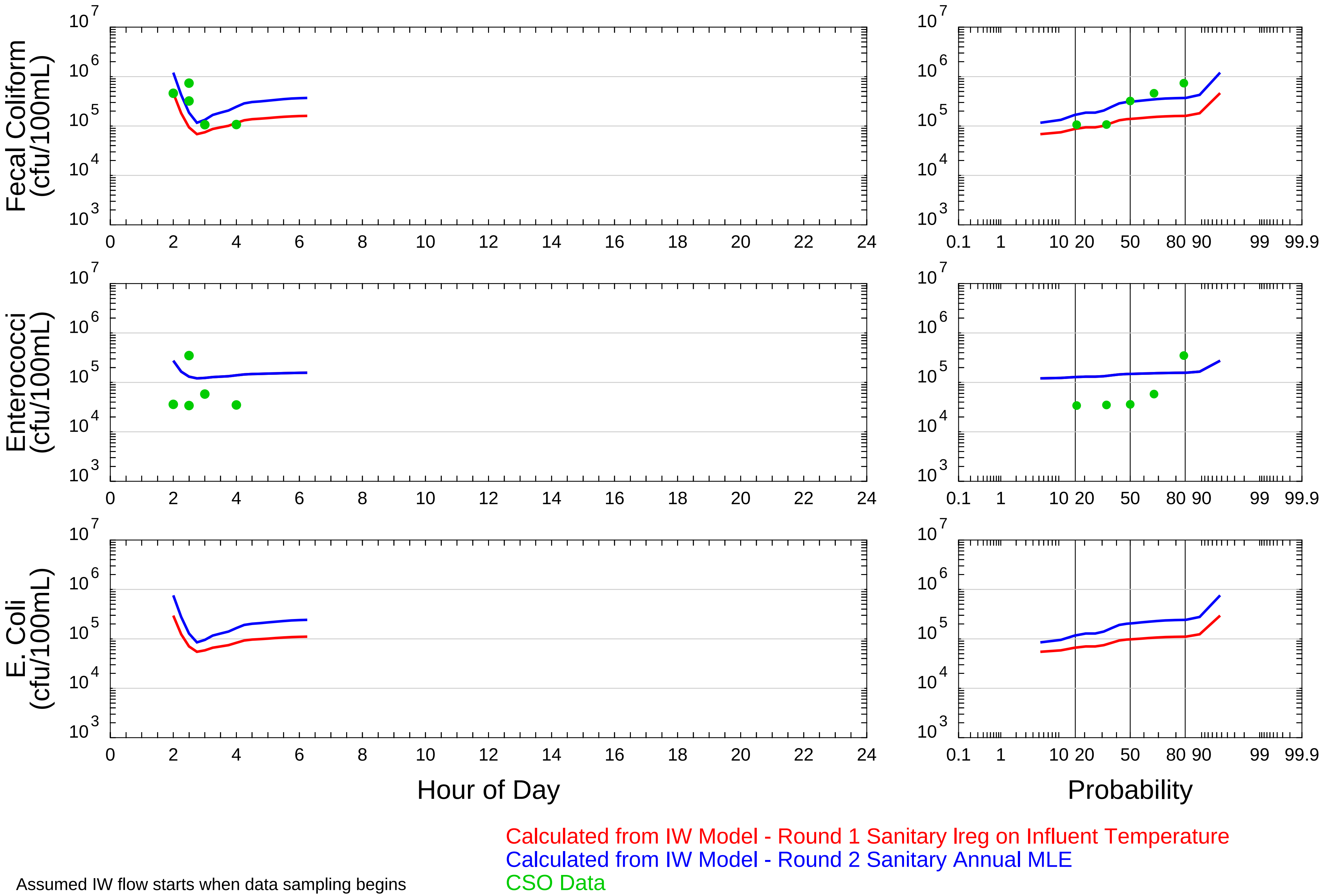


Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 4 / 2017

CSO Pathogen Concentrations 2016-2017

NE009

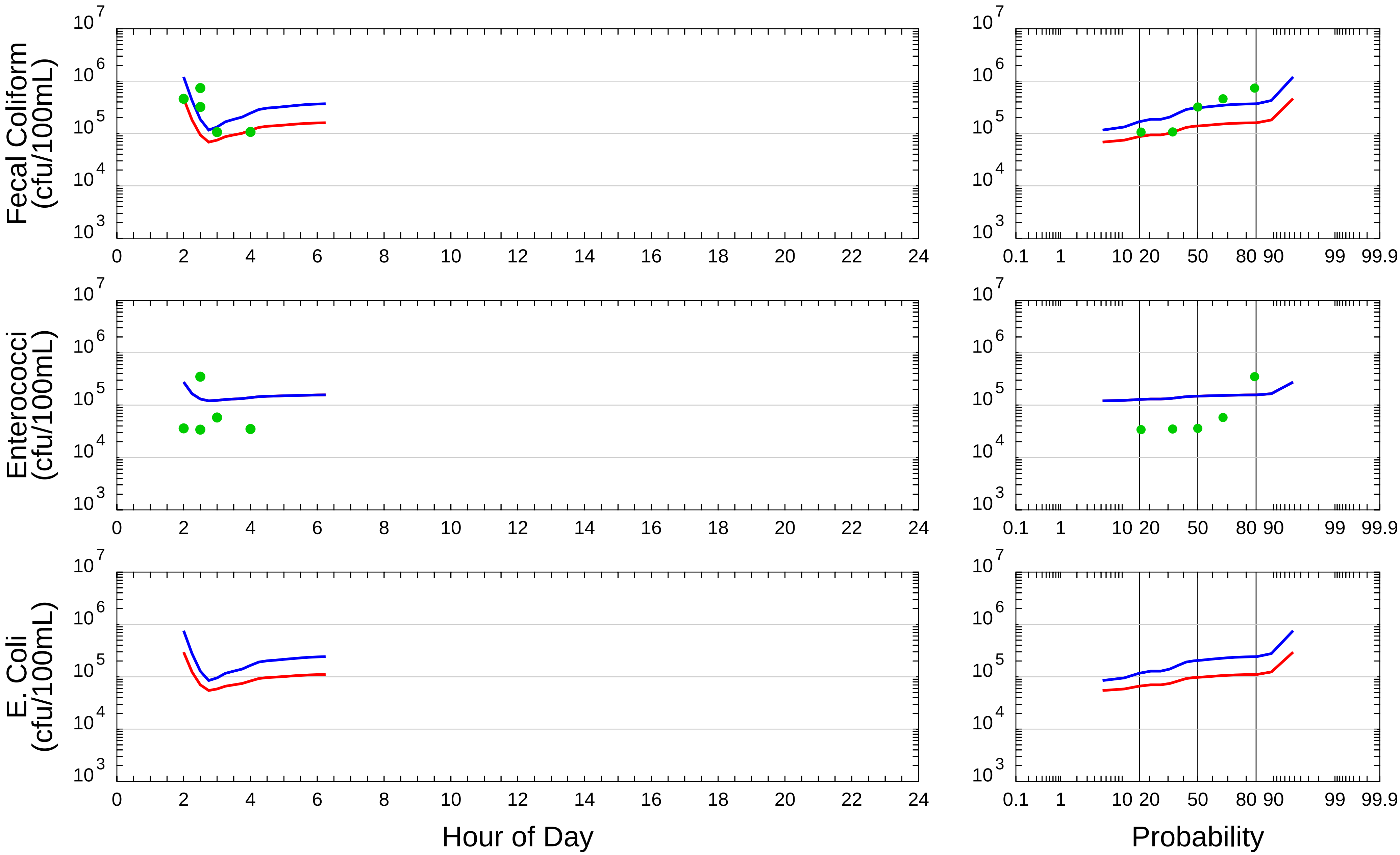


Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 4 / 2017

CSO Pathogen Concentrations 2016-2017

NE010



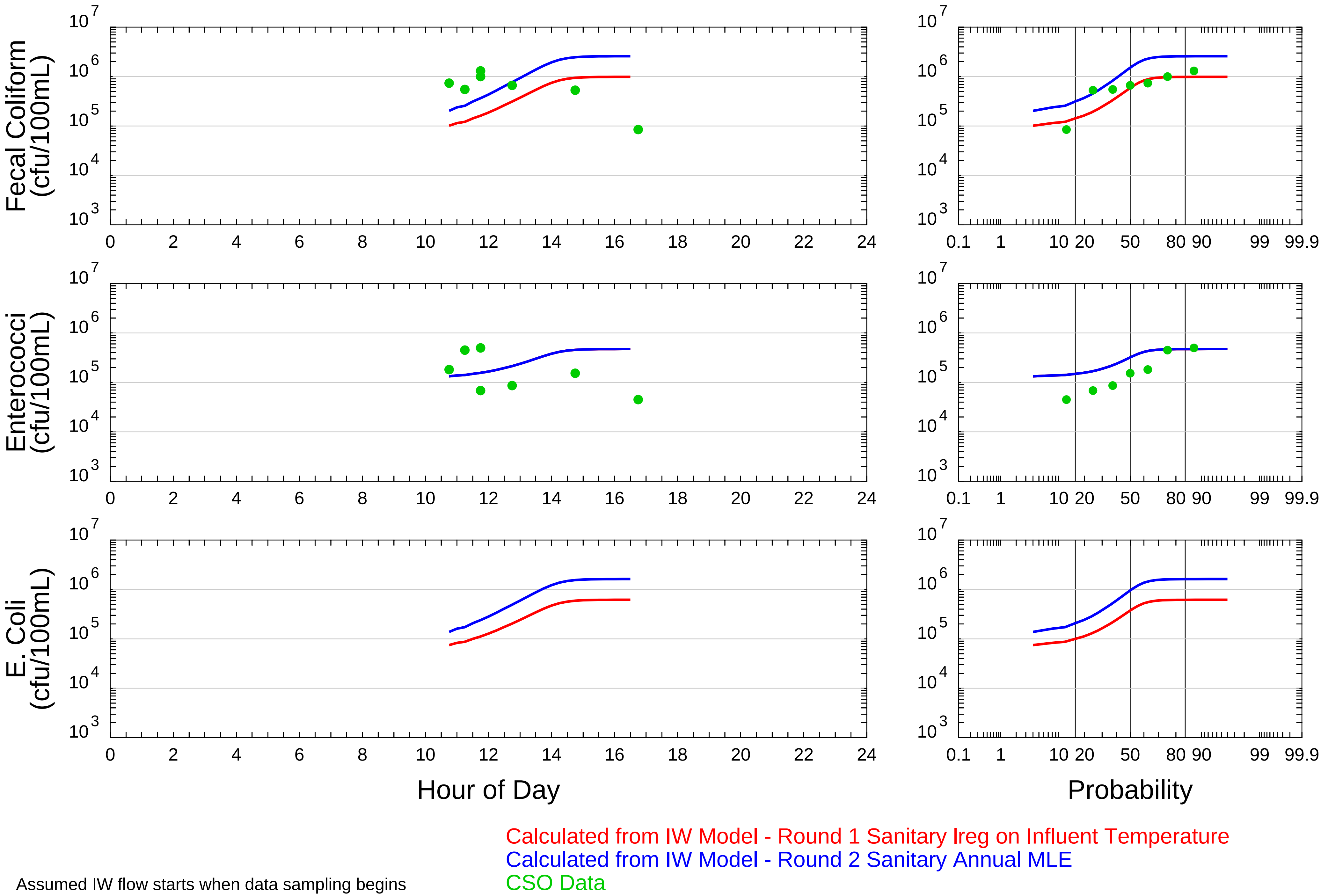
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 6 / 2017

NE014

CSO Pathogen Concentrations 2016-2017

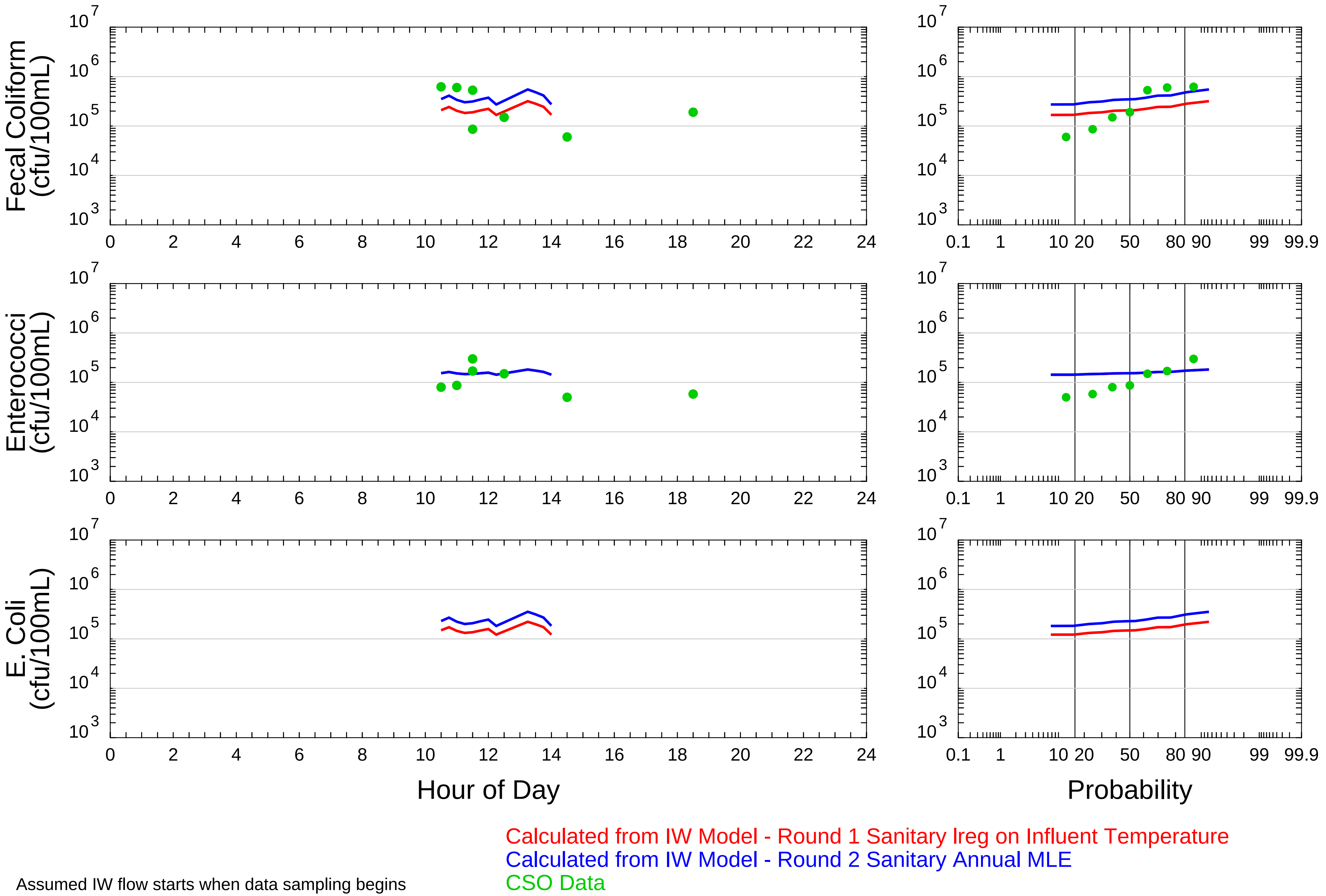


Assumed IW flow starts when data sampling begins

WW Event Day:
11 / 29/ 2016

NE025

CSO Pathogen Concentrations
2016-2017

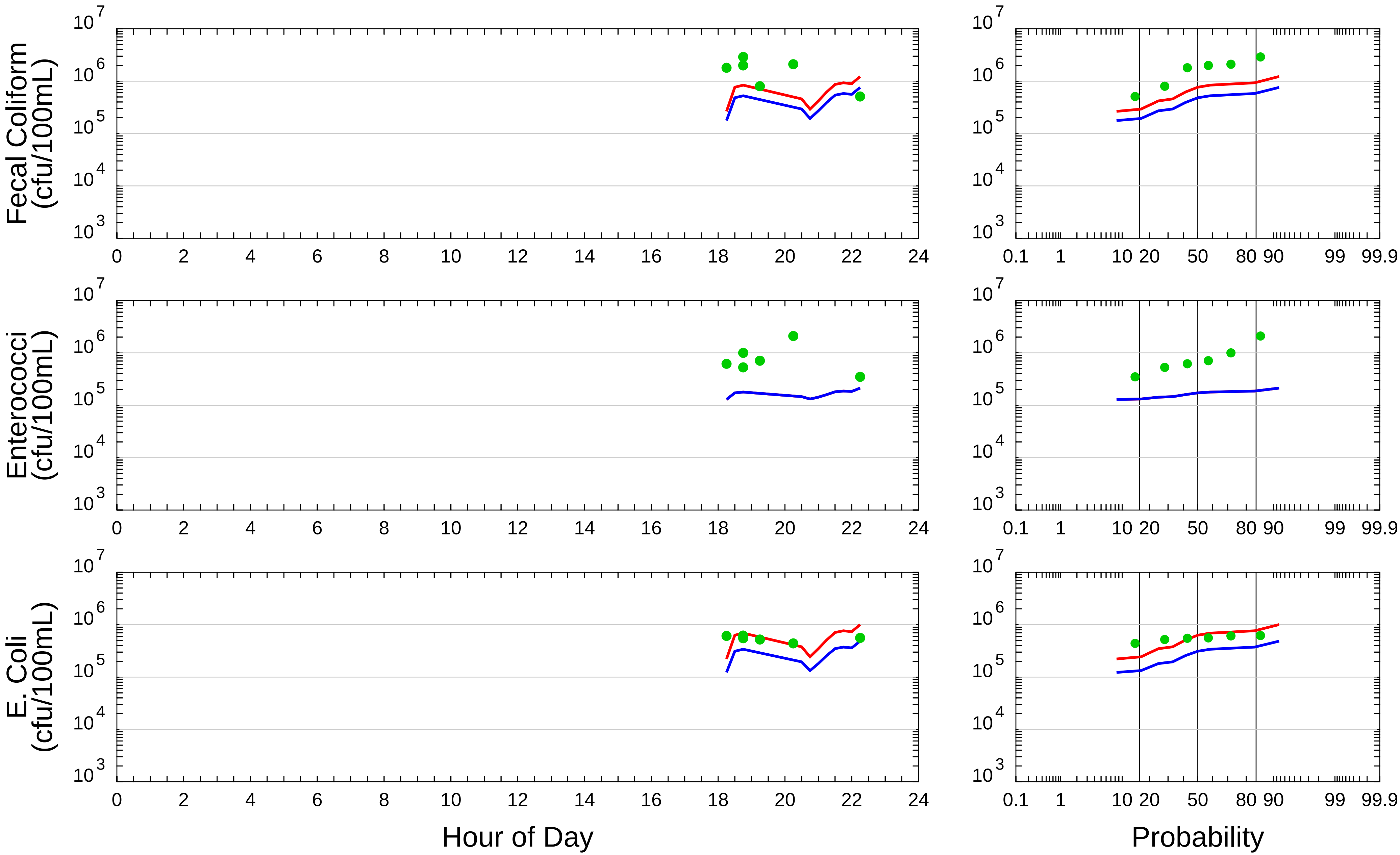


Assumed IW flow starts when data sampling begins

WW Event Day:
8 / 21/ 2016

CSO Pathogen Concentrations 2016-2017

PT006



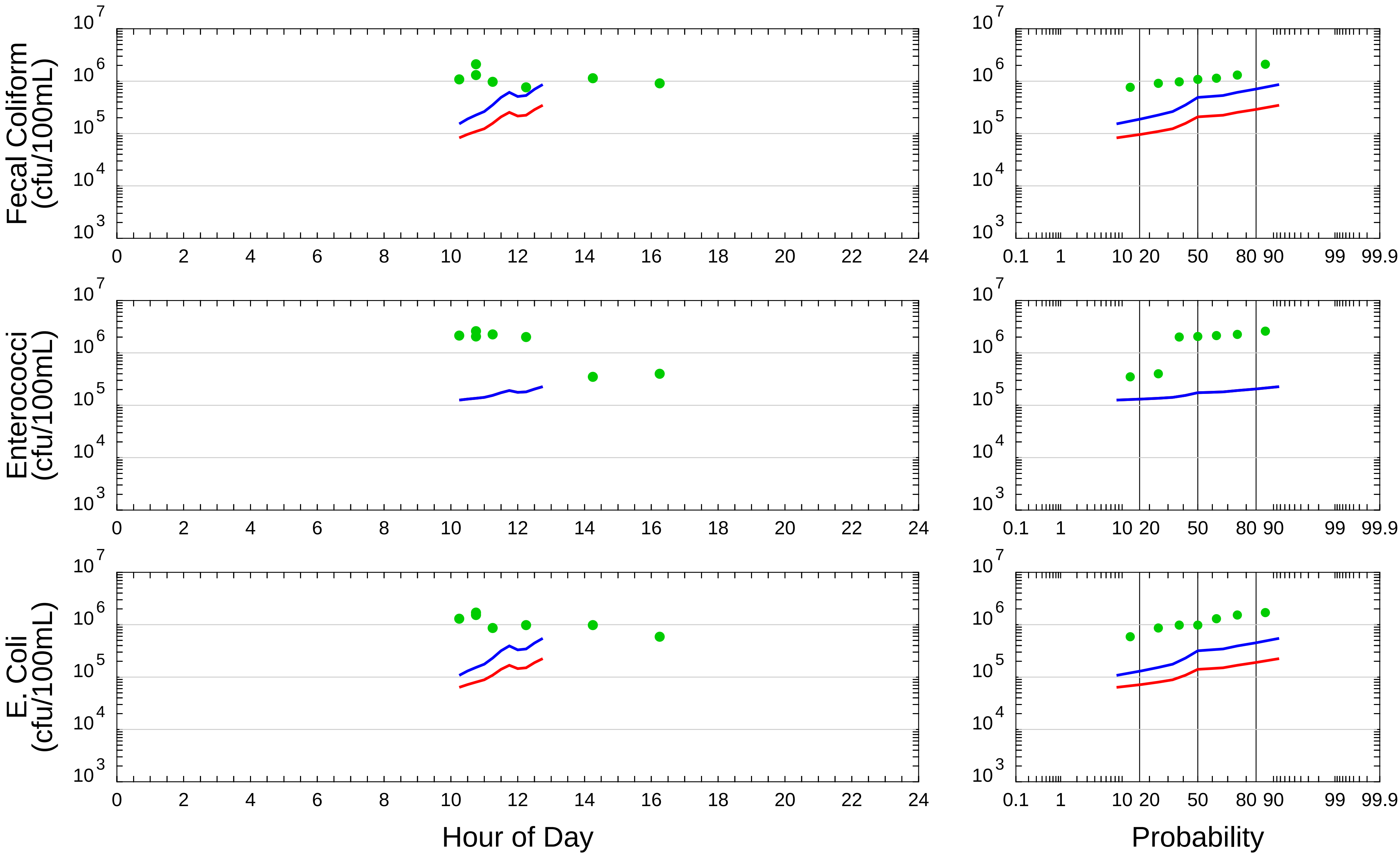
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 6 / 2017

PT006

CSO Pathogen Concentrations
2016-2017



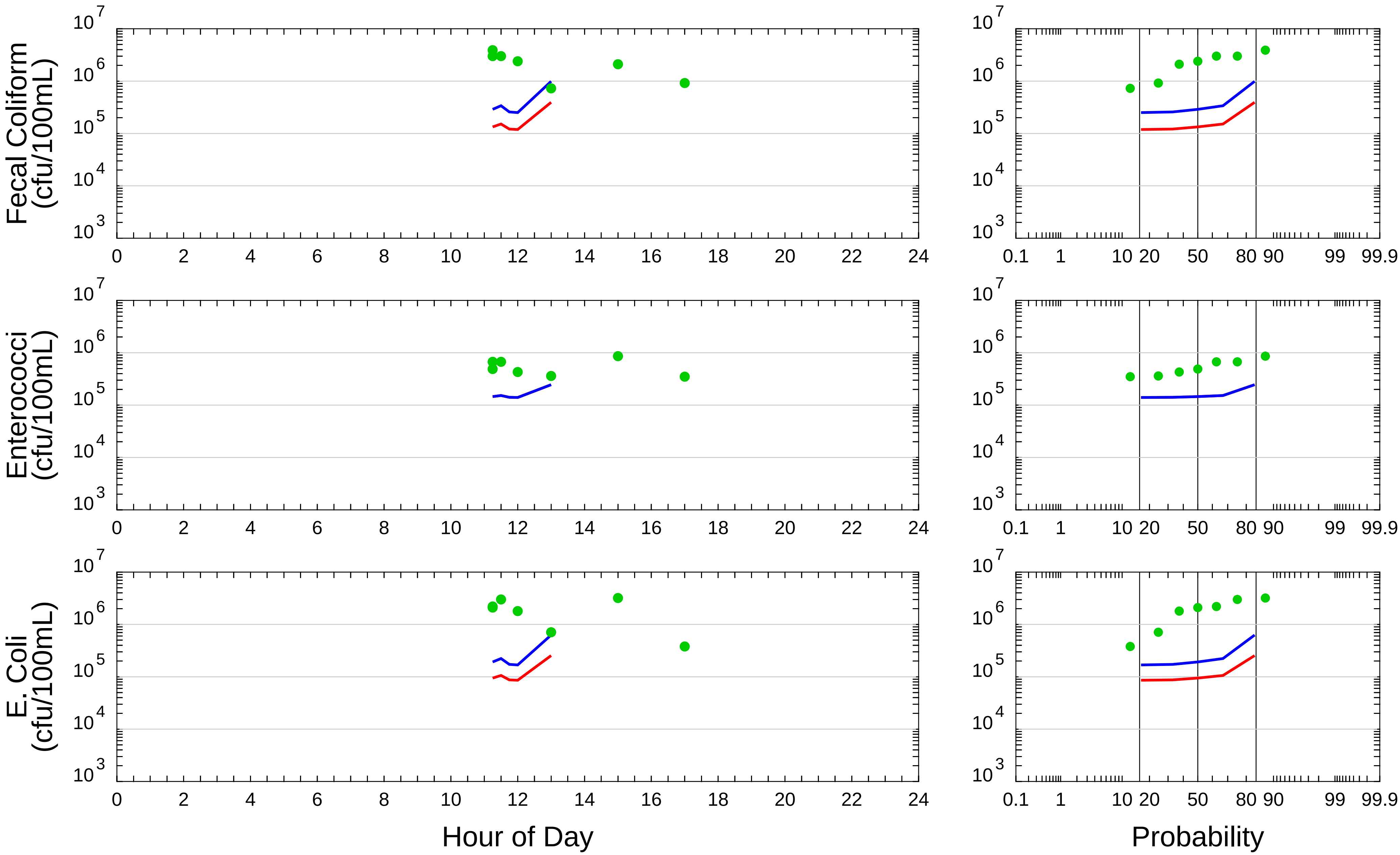
Calculated from IW Model - Round 1 Sanitary Ireg on Influent Temperature
Calculated from IW Model - Round 2 Sanitary Annual MLE
CSO Data

Assumed IW flow starts when data sampling begins

WW Event Day:
4 / 6 / 2017

PT027

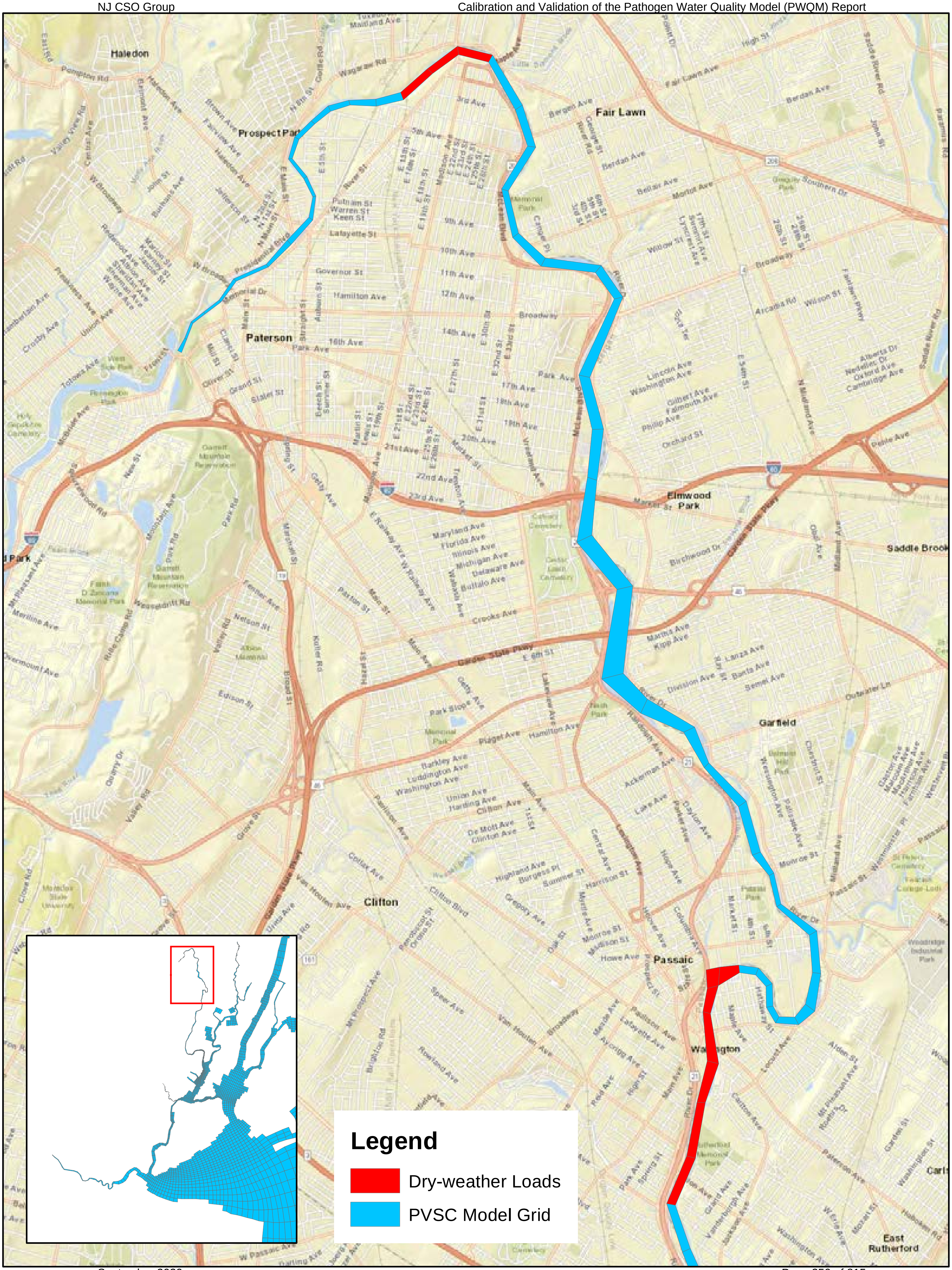
CSO Pathogen Concentrations
2016-2017

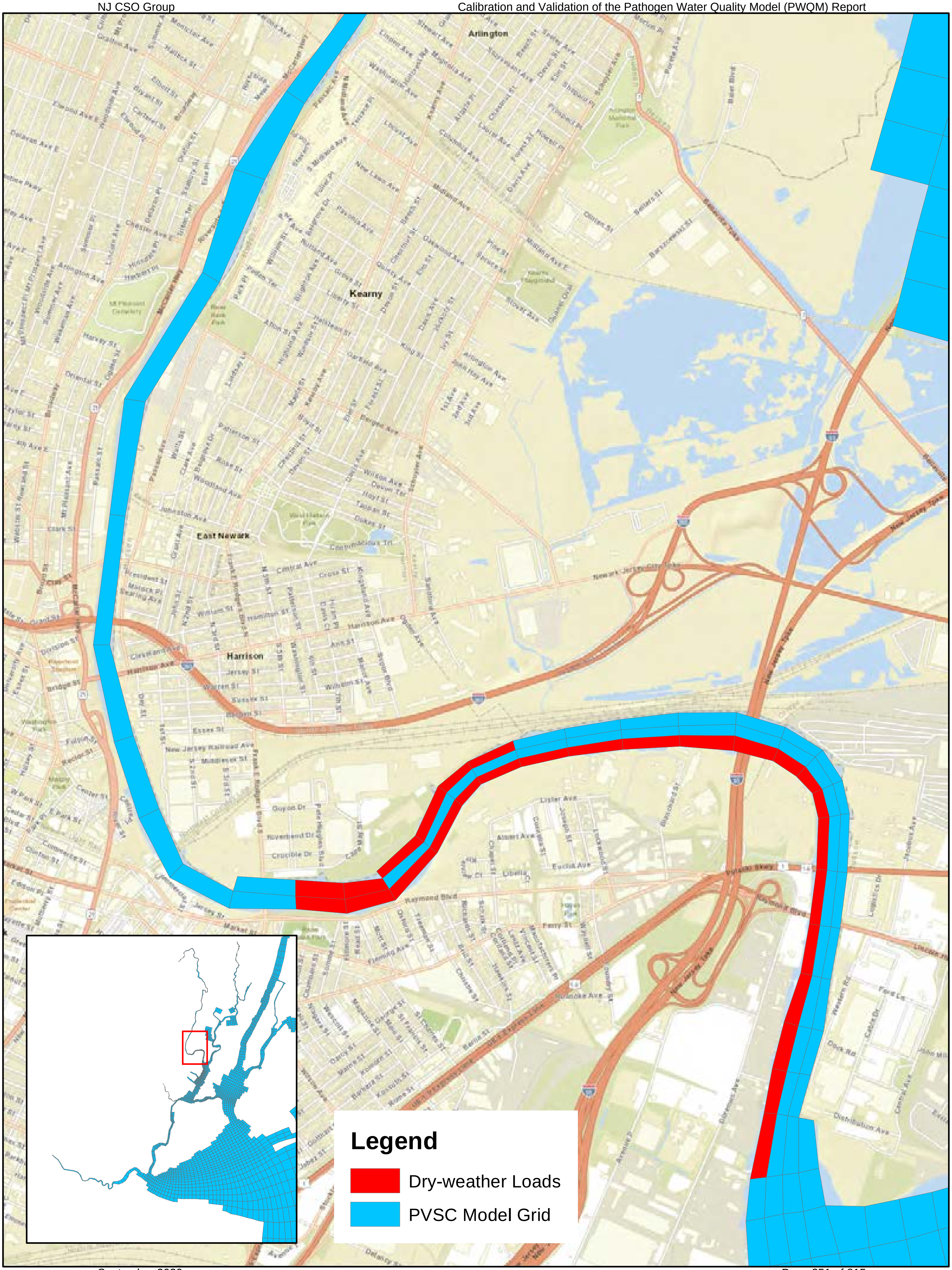


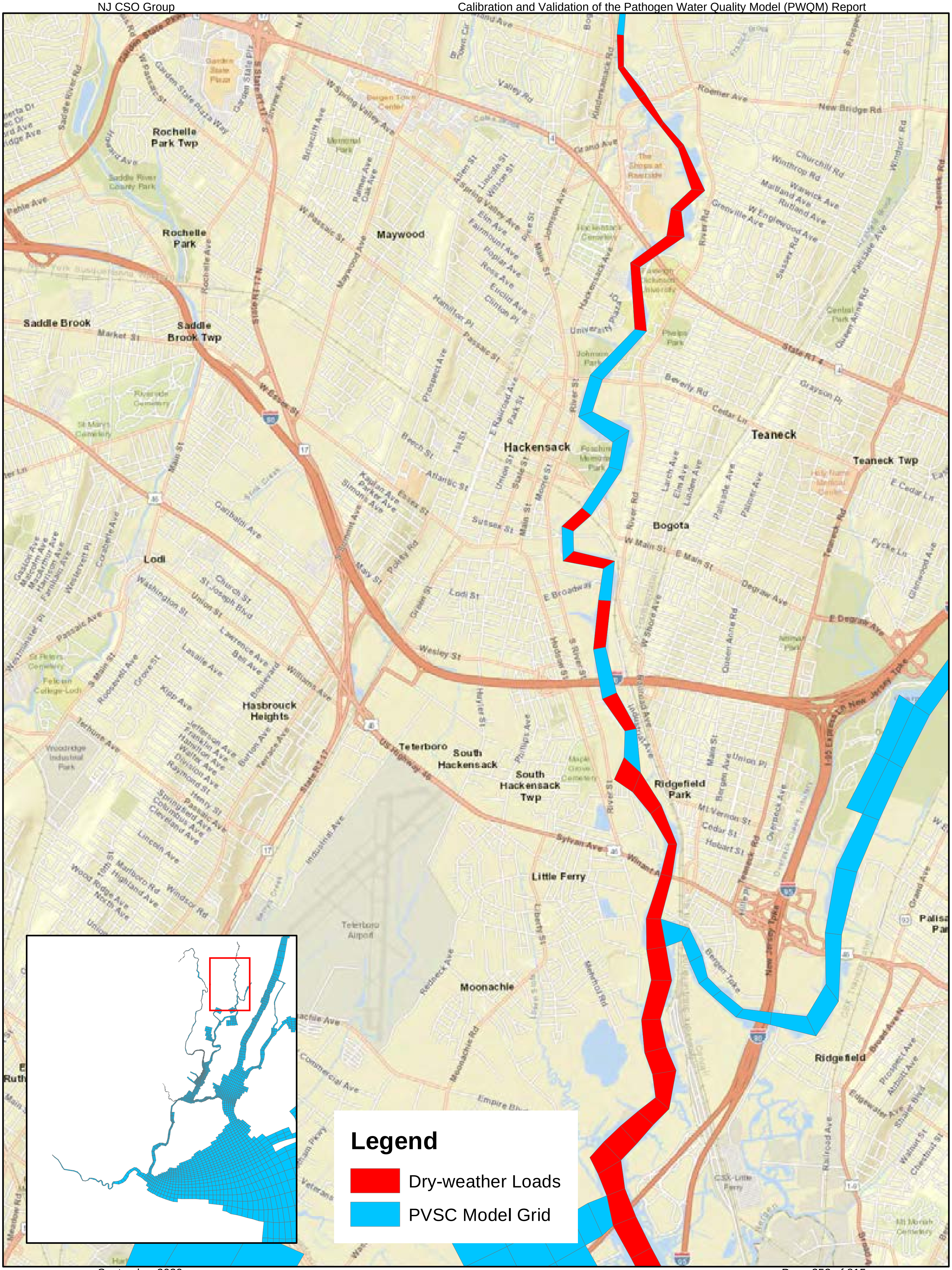
Assumed IW flow starts when data sampling begins

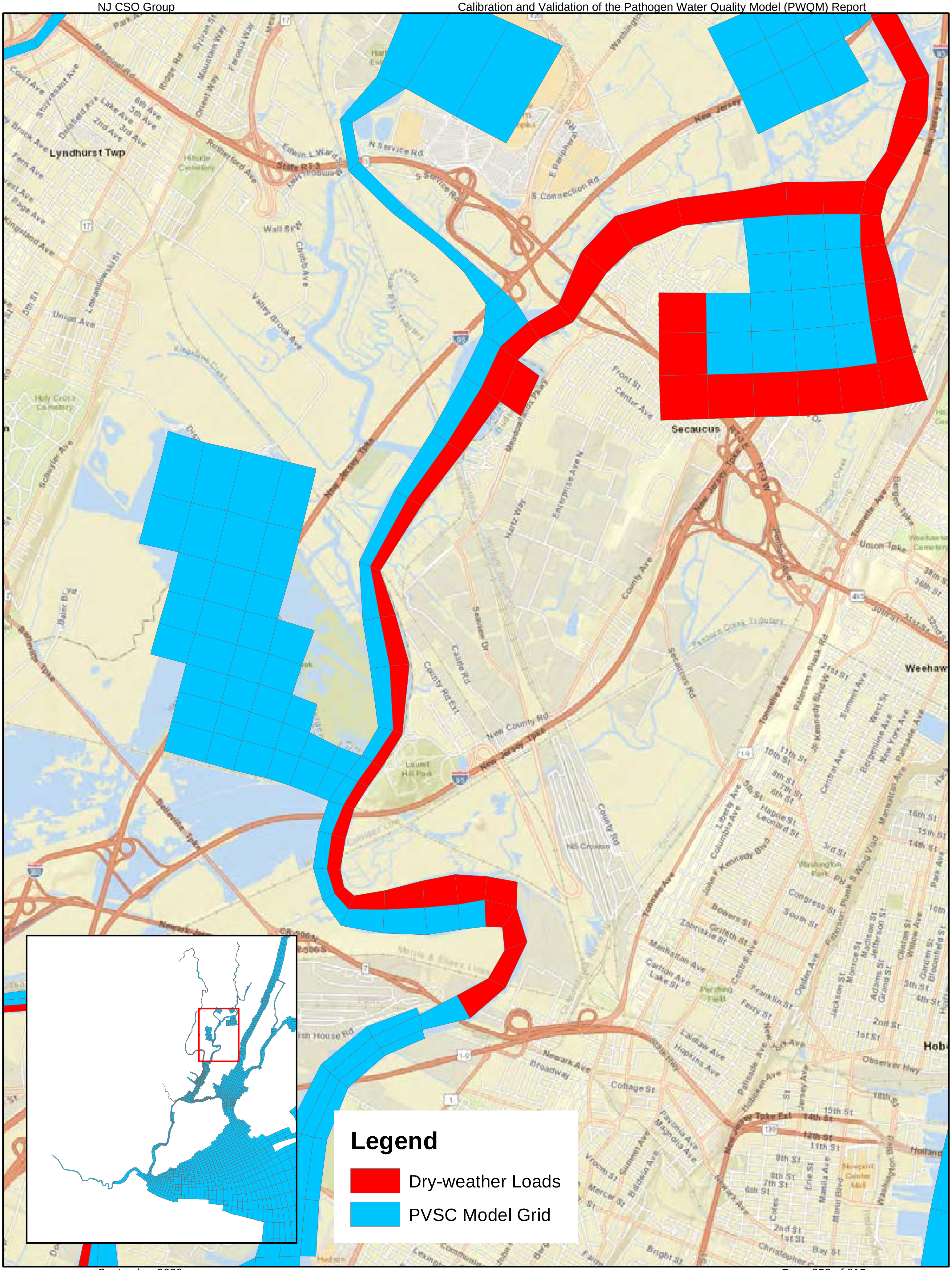
Appendix B-2

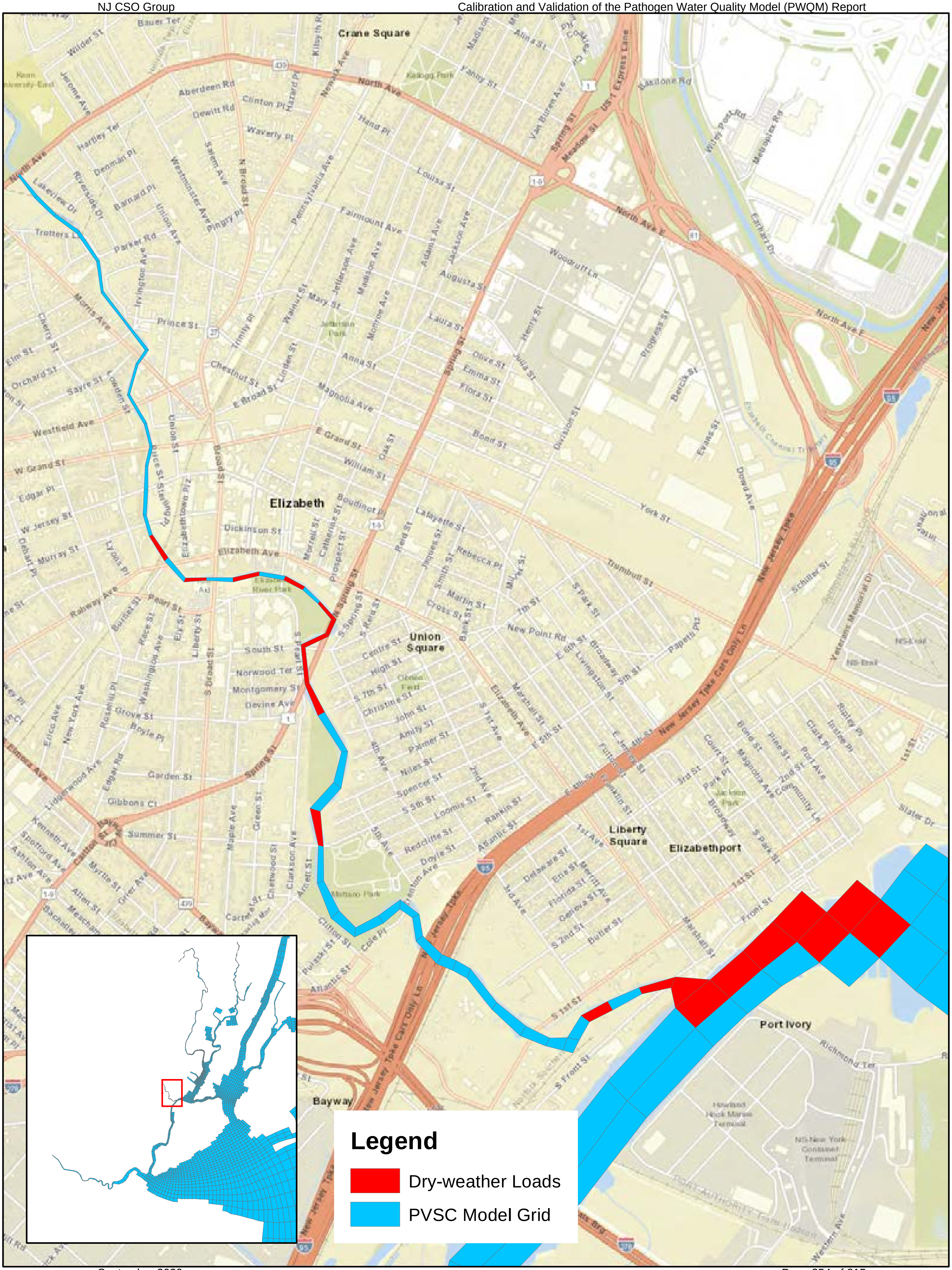
Locations of Assigned Dry-Weather Flows

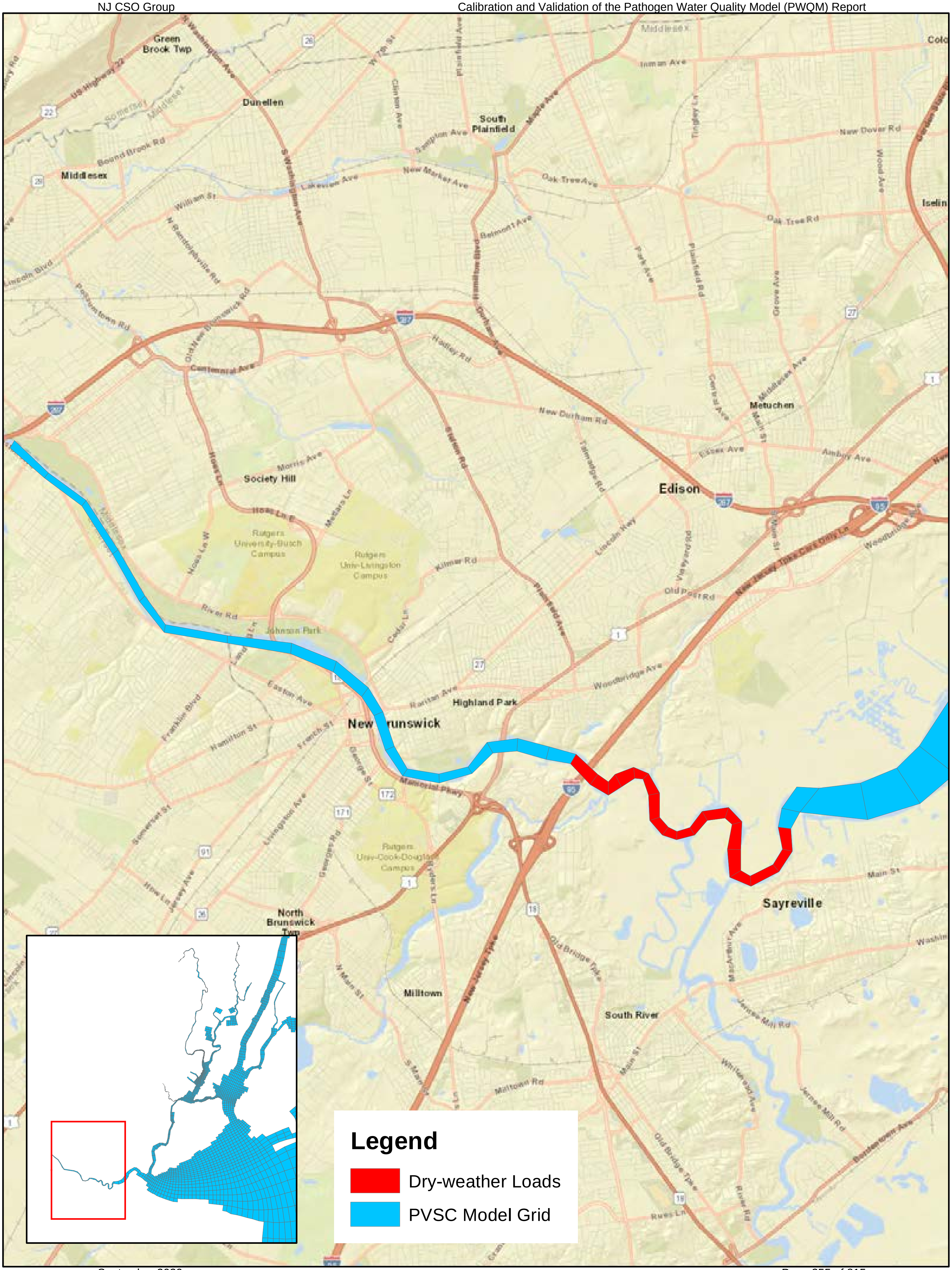

Legend
Dry-weather Loads
PVSC Model Grid


Arlington
Kearny
East Newark
Harrison
Legend
Dry-weather Loads
PVSC Model Grid


Legend
Dry-weather Loads
PVSC Model Grid
Rochelle Park Twp
Rochelle Park
Maywood
Saddle Brook
Saddle Brook Twp
Hackensack
Teaneck
Teaneck Twp
Bogota
Lodi
Hasbrouck Heights
Teterboro
South Hackensack
South Hackensack Twp
Ridgefield Park
Little Ferry
Moonachie
Ridgefield


Legend
Dry-weather Loads
PVSC Model Grid
Lyndhurst Twp
Secaucus
Weehaw
Hob


Legend
Dry-weather Loads
PVSC Model Grid
Crane Square
Elizabeth
Union Square
Liberty Square
Elizabethport
Port Ivory
Bayway


Legend
Dry-weather Loads
PVSC Model Grid
New Brunswick
Edison
Sayreville
Highland Park
Metuchen
South Plainfield
Dunellen
Middlesex
Green Brook Twp
Society Hill
North Brunswick Twp
Milltown
South River
Iselin

Appendix C

Water Quality Model Loads

Appendix C-1

Calibration Loads

Volume

Combined Sewer Outfalls		
Waterbody	Outfall	Total Discharge (MG/Yr)
Arthur Kill	EL030	3
Arthur Kill	EL031	13
Arthur Kill	EL032	7
Arthur Kill	EL037	61
Arthur Kill	PA002	51
Arthur Kill	PA003	27
Arthur Kill	PA004	8
Arthur Kill	PA005	8
Arthur Kill	PA006	16
Arthur Kill	PA007	4
Arthur Kill	PA008	2
Arthur Kill	PA009	2
Arthur Kill	PA010	2
Elizabeth River	EL003	56
Elizabeth River	EL005	89
Elizabeth River	EL008	9
Elizabeth River	EL010	16
Elizabeth River	EL011	16
Elizabeth River	EL012	5
Elizabeth River	EL014	1
Elizabeth River	EL016	16
Elizabeth River	EL021	2
Elizabeth River	EL022	66
Elizabeth River	EL026	52
Elizabeth River	EL027	33
Elizabeth River	EL028	32
Elizabeth River	EL029	34
Elizabeth River	EL035	34
Elizabeth River	EL036a	17
Elizabeth River	EL036b	20
Elizabeth River	EL038	8
Elizabeth River	EL040	12
Elizabeth River	EL041	175
Elizabeth River	EL042	36
Elizabeth River	EL043	1
Hackensack River	HK001	81
Hackensack River	HK002	115
Hackensack River	JC001	68
Hackensack River	JC002	29
Hackensack River	JC003	45
Hackensack River	JC004	20
Hackensack River	JC005	8
Hackensack River	JC006	67
Hackensack River	JC007	33
Hackensack River	JC008	97
Hackensack River	JC009	38
Hackensack River	JC010	25
Hackensack River	NB003	150

Fecal Coliform

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	12
Arthur Kill	EL031	147
Arthur Kill	EL032	29
Arthur Kill	EL037	1,046
Arthur Kill	PA002	1,128
Arthur Kill	PA003	971
Arthur Kill	PA004	94
Arthur Kill	PA005	224
Arthur Kill	PA006	372
Arthur Kill	PA007	39
Arthur Kill	PA008	16
Arthur Kill	PA009	6
Arthur Kill	PA010	5
Elizabeth River	EL003	186
Elizabeth River	EL005	1,386
Elizabeth River	EL008	193
Elizabeth River	EL010	80
Elizabeth River	EL011	79
Elizabeth River	EL012	58
Elizabeth River	EL014	2
Elizabeth River	EL016	152
Elizabeth River	EL021	35
Elizabeth River	EL022	1,350
Elizabeth River	EL026	1,238
Elizabeth River	EL027	169
Elizabeth River	EL028	162
Elizabeth River	EL029	375
Elizabeth River	EL035	476
Elizabeth River	EL036a	137
Elizabeth River	EL036b	182
Elizabeth River	EL038	79
Elizabeth River	EL040	123
Elizabeth River	EL041	1,985
Elizabeth River	EL042	324
Elizabeth River	EL043	4
Hackensack River	HK001	1,525
Hackensack River	HK002	2,289
Hackensack River	JC001	1,050
Hackensack River	JC002	282
Hackensack River	JC003	384
Hackensack River	JC004	128
Hackensack River	JC005	56
Hackensack River	JC006	2,323
Hackensack River	JC007	263
Hackensack River	JC008	998
Hackensack River	JC009	286
Hackensack River	JC010	190
Hackensack River	NB003	1,812

Enterococcus

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	12
Arthur Kill	EL031	73
Arthur Kill	EL032	32
Arthur Kill	EL037	389
Arthur Kill	PA002	363
Arthur Kill	PA003	247
Arthur Kill	PA004	44
Arthur Kill	PA005	65
Arthur Kill	PA006	115
Arthur Kill	PA007	23
Arthur Kill	PA008	11
Arthur Kill	PA009	8
Arthur Kill	PA010	7
Elizabeth River	EL003	246
Elizabeth River	EL005	547
Elizabeth River	EL008	61
Elizabeth River	EL010	74
Elizabeth River	EL011	73
Elizabeth River	EL012	27
Elizabeth River	EL014	4
Elizabeth River	EL016	85
Elizabeth River	EL021	13
Elizabeth River	EL022	452
Elizabeth River	EL026	380
Elizabeth River	EL027	154
Elizabeth River	EL028	150
Elizabeth River	EL029	188
Elizabeth River	EL035	201
Elizabeth River	EL036a	87
Elizabeth River	EL036b	104
Elizabeth River	EL038	43
Elizabeth River	EL040	64
Elizabeth River	EL041	972
Elizabeth River	EL042	189
Elizabeth River	EL043	6
Hackensack River	HK001	537
Hackensack River	HK002	780
Hackensack River	JC001	419
Hackensack River	JC002	154
Hackensack River	JC003	230
Hackensack River	JC004	99
Hackensack River	JC005	40
Hackensack River	JC006	594
Hackensack River	JC007	166
Hackensack River	JC008	524
Hackensack River	JC009	191
Hackensack River	JC010	126
Hackensack River	NB003	849

E. Coli

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	8
Arthur Kill	EL031	98
Arthur Kill	EL032	21
Arthur Kill	EL037	679
Arthur Kill	PA002	726
Arthur Kill	PA003	617
Arthur Kill	PA004	62
Arthur Kill	PA005	143
Arthur Kill	PA006	239
Arthur Kill	PA007	26
Arthur Kill	PA008	11
Arthur Kill	PA009	5
Arthur Kill	PA010	4
Elizabeth River	EL003	142
Elizabeth River	EL005	904
Elizabeth River	EL008	124
Elizabeth River	EL010	57
Elizabeth River	EL011	57
Elizabeth River	EL012	38
Elizabeth River	EL014	2
Elizabeth River	EL016	102
Elizabeth River	EL021	23
Elizabeth River	EL022	871
Elizabeth River	EL026	794
Elizabeth River	EL027	121
Elizabeth River	EL028	116
Elizabeth River	EL029	249
Elizabeth River	EL035	312
Elizabeth River	EL036a	94
Elizabeth River	EL036b	122
Elizabeth River	EL038	53
Elizabeth River	EL040	82
Elizabeth River	EL041	1,317
Elizabeth River	EL042	219
Elizabeth River	EL043	3
Hackensack River	HK001	987
Hackensack River	HK002	1,478
Hackensack River	JC001	685
Hackensack River	JC002	189
Hackensack River	JC003	260
Hackensack River	JC004	89
Hackensack River	JC005	39
Hackensack River	JC006	1,476
Hackensack River	JC007	179
Hackensack River	JC008	666
Hackensack River	JC009	196
Hackensack River	JC010	130
Hackensack River	NB003	1,198

Hackensack River	NB005	27
Hackensack River	NB006	0
Hackensack River	NB007	6
Hackensack River	NB008	13
Hackensack River	NB009	23
Hackensack River	NB010	1
Hackensack River	NB011	4
Hackensack River	NB014	0
Hackensack River	RP001	9
Hackensack River	RP002	1
Hackensack River	RP003	11
Hackensack River	RP004	14
Hackensack River	RP005	6
Hackensack River	RP006	1
Hudson River	FL001	57
Hudson River	FL002	1
Hudson River	GU001	10
Hudson River	JC020	49
Hudson River	JC025	35
Hudson River	JC026	9
Hudson River	JC028	64
Hudson River	JC029	171
Hudson River	NB004	11
Hudson River	NH002A1	186
Hudson River	NH002A2	157
Hudson River	NH003A	91
Hudson River	NH005A	41
Hudson River	NH006A	30
Hudson River	NH008A	19
Hudson River	NH012A	7
Hudson River	NH013A	134
Hudson River	NH015A	25
Kill Van Kull	BA001	363
Kill Van Kull	BA002	14
Kill Van Kull	BA003	8
Kill Van Kull	BA004	0
Kill Van Kull	BA008	4
Kill Van Kull	BA009	2
Kill Van Kull	BA010	7
Kill Van Kull	BA011	4
Kill Van Kull	BA022	0
Kill Van Kull	BA024	0
Kill Van Kull	BA037	2
Newark Bay	BA012	9
Newark Bay	BA013	0
Newark Bay	BA014	11
Newark Bay	BA015	37
Newark Bay	BA016	3
Newark Bay	BA017	41
Newark Bay	BA018	11
Newark Bay	BA019	24
Newark Bay	BA020	7

Hackensack River	NB005	289
Hackensack River	NB006	0
Hackensack River	NB007	105
Hackensack River	NB008	101
Hackensack River	NB009	270
Hackensack River	NB010	4
Hackensack River	NB011	50
Hackensack River	NB014	1
Hackensack River	RP001	156
Hackensack River	RP002	18
Hackensack River	RP003	49
Hackensack River	RP004	129
Hackensack River	RP005	89
Hackensack River	RP006	4
Hudson River	FL001	1,375
Hudson River	FL002	45
Hudson River	GU001	123
Hudson River	JC020	738
Hudson River	JC025	804
Hudson River	JC026	139
Hudson River	JC028	825
Hudson River	JC029	1,258
Hudson River	NB004	138
Hudson River	NH002A1	1,939
Hudson River	NH002A2	4,030
Hudson River	NH003A	949
Hudson River	NH005A	880
Hudson River	NH006A	161
Hudson River	NH008A	76
Hudson River	NH012A	12
Hudson River	NH013A	2,011
Hudson River	NH015A	216
Kill Van Kull	BA001	5,555
Kill Van Kull	BA002	51
Kill Van Kull	BA003	45
Kill Van Kull	BA004	1
Kill Van Kull	BA008	25
Kill Van Kull	BA009	9
Kill Van Kull	BA010	44
Kill Van Kull	BA011	11
Kill Van Kull	BA022	0
Kill Van Kull	BA024	1
Kill Van Kull	BA037	6
Newark Bay	BA012	39
Newark Bay	BA013	1
Newark Bay	BA014	59
Newark Bay	BA015	408
Newark Bay	BA016	18
Newark Bay	BA017	1,050
Newark Bay	BA018	142
Newark Bay	BA019	175
Newark Bay	BA020	38

Hackensack River	NB005	146
Hackensack River	NB006	0
Hackensack River	NB007	37
Hackensack River	NB008	64
Hackensack River	NB009	128
Hackensack River	NB010	5
Hackensack River	NB011	22
Hackensack River	NB014	1
Hackensack River	RP001	56
Hackensack River	RP002	8
Hackensack River	RP003	51
Hackensack River	RP004	73
Hackensack River	RP005	35
Hackensack River	RP006	3
Hudson River	FL001	421
Hudson River	FL002	11
Hudson River	GU001	56
Hudson River	JC020	297
Hudson River	JC025	253
Hudson River	JC026	57
Hudson River	JC028	369
Hudson River	JC029	854
Hudson River	NB004	62
Hudson River	NH002A1	1,008
Hudson River	NH002A2	1,194
Hudson River	NH003A	495
Hudson River	NH005A	288
Hudson River	NH006A	140
Hudson River	NH008A	87
Hudson River	NH012A	31
Hudson River	NH013A	816
Hudson River	NH015A	129
Kill Van Kull	BA001	2,223
Kill Van Kull	BA002	64
Kill Van Kull	BA003	37
Kill Van Kull	BA004	2
Kill Van Kull	BA008	19
Kill Van Kull	BA009	11
Kill Van Kull	BA010	32
Kill Van Kull	BA011	17
Kill Van Kull	BA022	0
Kill Van Kull	BA024	2
Kill Van Kull	BA037	7
Newark Bay	BA012	43
Newark Bay	BA013	2
Newark Bay	BA014	52
Newark Bay	BA015	206
Newark Bay	BA016	13
Newark Bay	BA017	310
Newark Bay	BA018	65
Newark Bay	BA019	120
Newark Bay	BA020	35

Hackensack River	NB005	192
Hackensack River	NB006	0
Hackensack River	NB007	68
Hackensack River	NB008	69
Hackensack River	NB009	178
Hackensack River	NB010	3
Hackensack River	NB011	33
Hackensack River	NB014	0
Hackensack River	RP001	101
Hackensack River	RP002	12
Hackensack River	RP003	36
Hackensack River	RP004	87
Hackensack River	RP005	58
Hackensack River	RP006	3
Hudson River	FL001	882
Hudson River	FL002	28
Hudson River	GU001	81
Hudson River	JC020	482
Hudson River	JC025	517
Hudson River	JC026	91
Hudson River	JC028	543
Hudson River	JC029	863
Hudson River	NB004	91
Hudson River	NH002A1	1,293
Hudson River	NH002A2	2,580
Hudson River	NH003A	633
Hudson River	NH005A	567
Hudson River	NH006A	114
Hudson River	NH008A	57
Hudson River	NH012A	11
Hudson River	NH013A	1,314
Hudson River	NH015A	146
Kill Van Kull	BA001	3,627
Kill Van Kull	BA002	39
Kill Van Kull	BA003	32
Kill Van Kull	BA004	1
Kill Van Kull	BA008	18
Kill Van Kull	BA009	7
Kill Van Kull	BA010	31
Kill Van Kull	BA011	8
Kill Van Kull	BA022	0
Kill Van Kull	BA024	1
Kill Van Kull	BA037	4
Newark Bay	BA012	29
Newark Bay	BA013	1
Newark Bay	BA014	42
Newark Bay	BA015	272
Newark Bay	BA016	12
Newark Bay	BA017	672
Newark Bay	BA018	94
Newark Bay	BA019	121
Newark Bay	BA020	27

Newark Bay	BA026	1
Newark Bay	BA028	0
Newark Bay	BA029	6
Newark Bay	BA030	1
Newark Bay	BA034	0
Newark Bay	EL001	74
Newark Bay	EL002	31
Newark Bay	EL034	70
Newark Bay	EL039	9
Newark Bay	JC011	57
Newark Bay	JC013	76
Newark Bay	NE023	13
Newark Bay	NE023_Stor	190
Newark Bay	NE025	58
Newark Bay	NE027	12
Newark Bay	NE030	10
Newark Bay	NE030_Stor	37
Passaic River	EN001	13
Passaic River	HR001	1
Passaic River	HR002	2
Passaic River	HR003	11
Passaic River	HR005	14
Passaic River	HR006	6
Passaic River	HR006_Stor	5
Passaic River	HR007	11
Passaic River	KE001	3
Passaic River	KE004	10
Passaic River	KE006	92
Passaic River	KE007	61
Passaic River	KE010	20
Passaic River	NE002	73
Passaic River	NE003	0
Passaic River	NE003_Stor	48
Passaic River	NE004	2
Passaic River	NE005	17
Passaic River	NE008	74
Passaic River	NE009	121
Passaic River	NE010	121
Passaic River	NE014	143
Passaic River	NE015	57
Passaic River	NE016	41
Passaic River	NE017	82
Passaic River	NE018	59
Passaic River	NE022	32
Passaic River	PT001	16
Passaic River	PT003	1
Passaic River	PT005	3
Passaic River	PT006	49
Passaic River	PT007	31
Passaic River	PT010	5
Passaic River	PT013	8
Passaic River	PT014	0

Newark Bay	BA026	2
Newark Bay	BA028	0
Newark Bay	BA029	32
Newark Bay	BA030	3
Newark Bay	BA034	1
Newark Bay	EL001	837
Newark Bay	EL002	301
Newark Bay	EL034	937
Newark Bay	EL039	30
Newark Bay	JC011	158
Newark Bay	JC013	1,908
Newark Bay	NE023	65
Newark Bay	NE023_Stor	294
Newark Bay	NE025	448
Newark Bay	NE027	63
Newark Bay	NE030	74
Newark Bay	NE030_Stor	57
Passaic River	EN001	123
Passaic River	HR001	10
Passaic River	HR002	8
Passaic River	HR003	30
Passaic River	HR005	66
Passaic River	HR006	69
Passaic River	HR006_Stor	8
Passaic River	HR007	37
Passaic River	KE001	10
Passaic River	KE004	25
Passaic River	KE006	977
Passaic River	KE007	454
Passaic River	KE010	107
Passaic River	NE002	748
Passaic River	NE003	0
Passaic River	NE003_Stor	74
Passaic River	NE004	20
Passaic River	NE005	675
Passaic River	NE008	2,065
Passaic River	NE009	2,819
Passaic River	NE010	2,819
Passaic River	NE014	4,372
Passaic River	NE015	1,122
Passaic River	NE016	539
Passaic River	NE017	951
Passaic River	NE018	1,202
Passaic River	NE022	176
Passaic River	PT001	549
Passaic River	PT003	4
Passaic River	PT005	47
Passaic River	PT006	742
Passaic River	PT007	607
Passaic River	PT010	37
Passaic River	PT013	73
Passaic River	PT014	0

Newark Bay	BA026	5
Newark Bay	BA028	0
Newark Bay	BA029	29
Newark Bay	BA030	6
Newark Bay	BA034	1
Newark Bay	EL001	411
Newark Bay	EL002	167
Newark Bay	EL034	411
Newark Bay	EL039	38
Newark Bay	JC011	249
Newark Bay	JC013	571
Newark Bay	NE023	62
Newark Bay	NE023_Stor	790
Newark Bay	NE025	291
Newark Bay	NE027	58
Newark Bay	NE030	48
Newark Bay	NE030_Stor	153
Passaic River	EN001	68
Passaic River	HR001	6
Passaic River	HR002	10
Passaic River	HR003	46
Passaic River	HR005	64
Passaic River	HR006	33
Passaic River	HR006_Stor	22
Passaic River	HR007	48
Passaic River	KE001	13
Passaic River	KE004	42
Passaic River	KE006	502
Passaic River	KE007	306
Passaic River	KE010	94
Passaic River	NE002	395
Passaic River	NE003	0
Passaic River	NE003_Stor	200
Passaic River	NE004	9
Passaic River	NE005	163
Passaic River	NE008	585
Passaic River	NE009	881
Passaic River	NE010	881
Passaic River	NE014	1,189
Passaic River	NE015	385
Passaic River	NE016	238
Passaic River	NE017	459
Passaic River	NE018	406
Passaic River	NE022	151
Passaic River	PT001	140
Passaic River	PT003	5
Passaic River	PT005	18
Passaic River	PT006	300
Passaic River	PT007	208
Passaic River	PT010	24
Passaic River	PT013	41
Passaic River	PT014	1

Newark Bay	BA026	2
Newark Bay	BA028	0
Newark Bay	BA029	23
Newark Bay	BA030	2
Newark Bay	BA034	1
Newark Bay	EL001	556
Newark Bay	EL002	202
Newark Bay	EL034	616
Newark Bay	EL039	23
Newark Bay	JC011	126
Newark Bay	JC013	1,222
Newark Bay	NE023	47
Newark Bay	NE023_Stor	273
Newark Bay	NE025	306
Newark Bay	NE027	45
Newark Bay	NE030	51
Newark Bay	NE030_Stor	53
Passaic River	EN001	82
Passaic River	HR001	6
Passaic River	HR002	6
Passaic River	HR003	23
Passaic River	HR005	48
Passaic River	HR006	46
Passaic River	HR006_Stor	7
Passaic River	HR007	28
Passaic River	KE001	7
Passaic River	KE004	20
Passaic River	KE006	651
Passaic River	KE007	311
Passaic River	KE010	76
Passaic River	NE002	500
Passaic River	NE003	0
Passaic River	NE003_Stor	69
Passaic River	NE004	13
Passaic River	NE005	428
Passaic River	NE008	1,319
Passaic River	NE009	1,811
Passaic River	NE010	1,811
Passaic River	NE014	2,787
Passaic River	NE015	725
Passaic River	NE016	355
Passaic River	NE017	630
Passaic River	NE018	776
Passaic River	NE022	124
Passaic River	PT001	349
Passaic River	PT003	3
Passaic River	PT005	31
Passaic River	PT006	485
Passaic River	PT007	392
Passaic River	PT010	25
Passaic River	PT013	49
Passaic River	PT014	0

Passaic River	PT015	0
Passaic River	PT016	9
Passaic River	PT017	5
Passaic River	PT021	5
Passaic River	PT022	14
Passaic River	PT023	3
Passaic River	PT024	7
Passaic River	PT025	69
Passaic River	PT026	0
Passaic River	PT027	39
Passaic River	PT028	7
Passaic River	PT029	70
Passaic River	PT030	4
Passaic River	PT031	9
Passaic River	PT032	16
Raritan River	PA011	9
Raritan River	PA013	27
Raritan River	PA014	10
Raritan River	PA015	11
Raritan River	PA016	86
Raritan River	PA017	8
Raritan River	PA019	51
Upper NY Bay	BA006	9
Upper NY Bay	BA006_stor	21
Upper NY Bay	BA007	40
Upper NY Bay	BA021	43
Upper NY Bay	JC014	17
Upper NY Bay	JC015	7
Upper NY Bay	JC016	57
Upper NY Bay	JC018	120
Total CSO		**6,118**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Discharge, (MG/Yr)**
Arthur Kill	49a.1	22,699
Arthur Kill	50.1	5,780
Arthur Kill	64.1	4,711
Elizabeth River	56a.d	0
Hackensack River	126.d	750
Hackensack River	136.d	1,584
Hackensack River	145.d	600
Hackensack River	146.d	475
Hackensack River	151.d	724
Hackensack River	152.d	2,824
Hackensack River	160.d	377
Hackensack River	BerrysCka.	3,515
Hudson River	Hudson1.1	1,652
Hudson River	Hudson2.1	2,593
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	2,021
Overpeck Creek	165.1	1,302

Passaic River	PT015	1
Passaic River	PT016	37
Passaic River	PT017	52
Passaic River	PT021	104
Passaic River	PT022	566
Passaic River	PT023	47
Passaic River	PT024	69
Passaic River	PT025	465
Passaic River	PT026	1
Passaic River	PT027	550
Passaic River	PT028	56
Passaic River	PT029	1,098
Passaic River	PT030	8
Passaic River	PT031	78
Passaic River	PT032	116
Raritan River	PA011	140
Raritan River	PA013	603
Raritan River	PA014	172
Raritan River	PA015	274
Raritan River	PA016	884
Raritan River	PA017	27
Raritan River	PA019	278
Upper NY Bay	BA006	52
Upper NY Bay	BA006_stor	32
Upper NY Bay	BA007	197
Upper NY Bay	BA021	443
Upper NY Bay	JC014	80
Upper NY Bay	JC015	22
Upper NY Bay	JC016	960
Upper NY Bay	JC018	420
Total CSO		**83,722**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	1,347
Arthur Kill	50.1	14
Arthur Kill	64.1	5,830
Elizabeth River	56a.d	0
Hackensack River	126.d	2
Hackensack River	136.d	135
Hackensack River	145.d	7
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	3,570
Hackensack River	160.d	0
Hackensack River	BerrysCka.	662
Hudson River	Hudson1.1	1,644
Hudson River	Hudson2.1	1,842
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,376
Overpeck Creek	165.1	0

Passaic River	PT015	2
Passaic River	PT016	42
Passaic River	PT017	29
Passaic River	PT021	33
Passaic River	PT022	135
Passaic River	PT023	18
Passaic River	PT024	39
Passaic River	PT025	338
Passaic River	PT026	2
Passaic River	PT027	232
Passaic River	PT028	37
Passaic River	PT029	434
Passaic River	PT030	18
Passaic River	PT031	47
Passaic River	PT032	80
Raritan River	PA011	56
Raritan River	PA013	192
Raritan River	PA014	63
Raritan River	PA015	84
Raritan River	PA016	466
Raritan River	PA017	35
Raritan River	PA019	241
Upper NY Bay	BA006	45
Upper NY Bay	BA006_stor	86
Upper NY Bay	BA007	188
Upper NY Bay	BA021	232
Upper NY Bay	JC014	77
Upper NY Bay	JC015	31
Upper NY Bay	JC016	360
Upper NY Bay	JC018	531
Total CSO		**36,070**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	1,764
Arthur Kill	50.1	7
Arthur Kill	64.1	15,639
Elizabeth River	56a.d	0
Hackensack River	126.d	0
Hackensack River	136.d	5
Hackensack River	145.d	4
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	1,306
Hackensack River	160.d	0
Hackensack River	BerrysCka.	680
Hudson River	Hudson1.1	4,411
Hudson River	Hudson2.1	4,941
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	3,691
Overpeck Creek	165.1	0

Passaic River	PT015	1
Passaic River	PT016	28
Passaic River	PT017	35
Passaic River	PT021	67
Passaic River	PT022	359
Passaic River	PT023	31
Passaic River	PT024	47
Passaic River	PT025	322
Passaic River	PT026	1
Passaic River	PT027	361
Passaic River	PT028	39
Passaic River	PT029	716
Passaic River	PT030	7
Passaic River	PT031	53
Passaic River	PT032	80
Raritan River	PA011	92
Raritan River	PA013	387
Raritan River	PA014	112
Raritan River	PA015	176
Raritan River	PA016	591
Raritan River	PA017	21
Raritan River	PA019	197
Upper NY Bay	BA006	37
Upper NY Bay	BA006_stor	30
Upper NY Bay	BA007	141
Upper NY Bay	BA021	296
Upper NY Bay	JC014	58
Upper NY Bay	JC015	17
Upper NY Bay	JC016	624
Upper NY Bay	JC018	318
Total CSO		**54,961**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	673
Arthur Kill	50.1	7
Arthur Kill	64.1	5,402
Elizabeth River	56a.d	0
Hackensack River	126.d	1
Hackensack River	136.d	67
Hackensack River	145.d	3
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	3,309
Hackensack River	160.d	0
Hackensack River	BerrysCka.	331
Hudson River	Hudson1.1	1,524
Hudson River	Hudson2.1	1,707
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,275
Overpeck Creek	165.1	0

Passaic River	104.1	2,277
Passaic River	111.d	297
Passaic River	115.d	903
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	3,724
Passaic River	Frank's Cr	297
Raritan River	12a.d	3,037
Raritan River	14.1	7,984
Raritan River	18.d	2,288
Raritan River	31.d	6,091
Raritan River	7.1	0
Raritan River	9.d	2,759
Raritan River	10.d	1,975
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**83,239**

River Discharges		
Waterbody	**Outfall**	**Total Discharge (MG/Yr)**
Hudson River	Hudson R	13,171,352
Hackensack River	Hackensa	3,058
Passaic River	Passaic	144,737
Passaic River	Saddle R	15,654
Raritan River	Raritan	153,336
Hudson River	Norman K	26,515
Hudson River	Mooorden	4,017
Hudson River	Esopus C	274,052
Hudson River	Wallkill	582,631
Hudson River	Wappinge	146,124
Hudson River	Croton R	112,553
Hudson River	Sawmill	94,066
Hudson River	Catskill	137,420
Passaic River	1392500.1	7,009
Elizabeth River	1393450.1	8,244
Passaic River	110.1	6,053
Passaic River	120a.d	5,600
Raritan River	23.1	29,820
	Total River	**14,922,241**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Discharge (MG/Yr) Equivalent**
Elizabeth River	Elizabeth	16
Hackensack River	Hackensack	67
Passaic River	Passaic	30
Raritan River	Raritan	16
	Total Dry Load	**129**

WWTP Discharges		
Waterbody	**Outfall**	**Total Discharge (MG/Yr)**
Upper NY Bay	WPCF	76,438

Passaic River	104.1	2,988
Passaic River	111.d	74
Passaic River	115.d	71
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	148
Passaic River	Frank's Cr	17
Raritan River	12a.d	3,594
Raritan River	14.1	201
Raritan River	18.d	2,776
Raritan River	31.d	6,914
Raritan River	7.1	0
Raritan River	9.d	3,022
Raritan River	10.d	50
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**36,284**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	39,588
Hackensack River	Hackensa	12
Passaic River	Passaic	2,203
Passaic River	Saddle R	785
Raritan River	Raritan	3,189
Hudson River	Norman K	1
Hudson River	Mooorden	0
Hudson River	Esopus C	10
Hudson River	Wallkill	22
Hudson River	Wappinge	6
Hudson River	Croton R	4
Hudson River	Sawmill	4
Hudson River	Catskill	5
Passaic River	1392500.1	1,399
Elizabeth River	1393450.1	4,301
Passaic River	110.1	2,417
Passaic River	120a.d	967
Raritan River	23.1	421
	Total River	**55,334**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Elizabeth River	Elizabeth	2,500
Hackensack River	Hackensack	10,100
Passaic River	Passaic	4,620
Raritan River	Raritan	2,370
	Total Dry Load	**19,590**

WWTP Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Upper NY Bay	WPCF	145

Passaic River	104.1	8,011
Passaic River	111.d	198
Passaic River	115.d	191
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	112
Passaic River	Frank's Cr	28
Raritan River	12a.d	1,315
Raritan River	14.1	214
Raritan River	18.d	7,446
Raritan River	31.d	18,551
Raritan River	7.1	0
Raritan River	9.d	1,105
Raritan River	10.d	57
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**69,676**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	14,618
Hackensack River	Hackensa	4
Passaic River	Passaic	3,903
Passaic River	Saddle R	1,387
Raritan River	Raritan	3,203
Hudson River	Norman K	1
Hudson River	Mooorden	0
Hudson River	Esopus C	10
Hudson River	Wallkill	22
Hudson River	Wappinge	6
Hudson River	Croton R	4
Hudson River	Sawmill	4
Hudson River	Catskill	5
Passaic River	1392500.1	1,022
Elizabeth River	1393450.1	1,108
Passaic River	110.1	2,868
Passaic River	120a.d	816
Raritan River	23.1	425
	Total River	**29,407**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Elizabeth River	Elizabeth	421
Hackensack River	Hackensack	1,700
Passaic River	Passaic	779
Raritan River	Raritan	400
	Total Dry Load	**3,300**

WWTP Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Upper NY Bay	WPCF	29

Passaic River	104.1	2,768
Passaic River	111.d	69
Passaic River	115.d	66
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	91
Passaic River	Frank's Cr	9
Raritan River	12a.d	3,332
Raritan River	14.1	182
Raritan River	18.d	2,572
Raritan River	31.d	6,409
Raritan River	7.1	0
Raritan River	9.d	2,800
Raritan River	10.d	48
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**32,644**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	19,793
Hackensack River	Hackensa	9
Passaic River	Passaic	2,327
Passaic River	Saddle R	769
Raritan River	Raritan	2,765
Hudson River	Norman K	1
Hudson River	Mooorden	0
Hudson River	Esopus C	10
Hudson River	Wallkill	22
Hudson River	Wappinge	6
Hudson River	Croton R	4
Hudson River	Sawmill	4
Hudson River	Catskill	5
Passaic River	1392500.1	2,049
Elizabeth River	1393450.1	4,177
Passaic River	110.1	1,695
Passaic River	120a.d	1,532
Raritan River	23.1	368
	Total River	**35,537**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Elizabeth River	Elizabeth	1,560
Hackensack River	Hackensack	6,320
Passaic River	Passaic	2,880
Raritan River	Raritan	1,480
	Total Dry Load	**12,240**

WWTP Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Upper NY Bay	WPCF	29

Hackensack River	BCUA001	23,611
Arthur Kill	JMEUC	18,196
Raritan River	MCUA	33,508
Hudson River	NHSA001	3,044
Hudson River	Woodcliff	1,051
Hudson River	NHSA002	4,745
Hudson River	BCUA002	1,098
Arthur Kill	NJ0024643	9,190
Arthur Kill	NJ0024953	4,471
Hackensack River	NJ0025038	1,121
Hackensack River	NJ0034339	2,206
Total WWTP		**178,680**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Discharge (MG/Yr)**
Arthur Kill		65,252
Elizabeth River		8,988
Hackensack River		41,800
Hudson River		14,564,011
Kill Van Kull		404
Newark Bay		2,811
Passaic River		188,071
Raritan River		241,017
Upper NY Bay		76,752

Totals by Source		
Source	**Outfall**	**Total Discharge (MG/Yr)**
CSO		6,118
Storm		83,239
River		14,922,241
Dry		129
WWTP		178,680

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Discharge (MG/Yr)**
Arthur Kill	CSO	204
	Storm	33,190
	River	0
	Dry	0
	WWTP	31,858
Elizabeth River	CSO	728
	Storm	0
	River	8,244
	Dry	16
	WWTP	0
Hackensack River	CSO	889
	Storm	10,849
	River	3,058
	Dry	67
	WWTP	26,938

Hackensack River	BCUA001	45
Arthur Kill	JMEUC	34
Raritan River	MCUA	63
Hudson River	NHSA001	6
Hudson River	Woodcliff	2
Hudson River	NHSA002	9
Hudson River	BCUA002	2
Arthur Kill	NJ0024643	17
Arthur Kill	NJ0024953	8
Hackensack River	NJ0025038	2
Hackensack River	NJ0034339	4
Total WWTP		**338**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		11,338
Elizabeth River		15,576
Hackensack River		27,388
Hudson River		58,864
Kill Van Kull		5,750
Newark Bay		8,519
Passaic River		40,504
Raritan River		24,978
Upper NY Bay		2,350

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		83,722
Storm		36,284
River		55,334
Dry		19,590
WWTP		338

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	4,088
	Storm	7,190
	River	0
	Dry	0
	WWTP	60
Elizabeth River	CSO	8,774
	Storm	0
	River	4,301
	Dry	2,500
	WWTP	0
Hackensack River	CSO	12,849
	Storm	4,376
	River	12
	Dry	10,100
	WWTP	51

Hackensack River	BCUA001	9
Arthur Kill	JMEUC	7
Raritan River	MCUA	13
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	BCUA002	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
Total WWTP		**68**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		18,810
Elizabeth River		5,651
Hackensack River		9,048
Hudson River		30,594
Kill Van Kull		2,415
Newark Bay		7,826
Passaic River		28,730
Raritan River		33,867
Upper NY Bay		1,579

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		36,070
Storm		69,676
River		29,407
Dry		3,300
WWTP		68

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	1,389
	Storm	17,410
	River	0
	Dry	0
	WWTP	12
Elizabeth River	CSO	4,122
	Storm	0
	River	1,108
	Dry	421
	WWTP	0
Hackensack River	CSO	5,338
	Storm	1,996
	River	4
	Dry	1,700
	WWTP	10

Hackensack River	BCUA001	9
Arthur Kill	JMEUC	7
Raritan River	MCUA	13
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	BCUA002	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
Total WWTP		**68**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		8,733
Elizabeth River		11,539
Hackensack River		18,462
Hudson River		33,373
Kill Van Kull		3,768
Newark Bay		6,092
Passaic River		30,391
Raritan River		21,543
Upper NY Bay		1,549

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		54,961
Storm		32,644
River		35,537
Dry		12,240
WWTP		68

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	2,639
	Storm	6,082
	River	0
	Dry	0
	WWTP	12
Elizabeth River	CSO	5,801
	Storm	0
	River	4,177
	Dry	1,560
	WWTP	0
Hackensack River	CSO	8,411
	Storm	3,712
	River	9
	Dry	6,320
	WWTP	10

Hudson River	CSO	1,097
	Storm	4,245
	River	14,548,731
	Dry	0
	WWTP	9,938
Kill Van Kull	CSO	404
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	790
	Storm	2,021
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	1,490
	Storm	7,498
	River	179,053
	Dry	30
	WWTP	0
Raritan River	CSO	203
	Storm	24,135
	River	183,156
	Dry	16
	WWTP	33,508
Upper NY Bay	CSO	313
	Storm	0
	River	0
	Dry	0
	WWTP	76,438

Hudson River	CSO	15,719
	Storm	3,486
	River	39,640
	Dry	0
	WWTP	19
Kill Van Kull	CSO	5,750
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	7,143
	Storm	1,376
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	24,815
	Storm	3,298
	River	7,771
	Dry	4,620
	WWTP	0
Raritan River	CSO	2,379
	Storm	16,557
	River	3,610
	Dry	2,370
	WWTP	63
Upper NY Bay	CSO	2,205
	Storm	0
	River	0
	Dry	0
	WWTP	145

Hudson River	CSO	6,568
	Storm	9,352
	River	14,670
	Dry	0
	WWTP	4
Kill Van Kull	CSO	2,415
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	4,136
	Storm	3,691
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	9,415
	Storm	8,539
	River	9,996
	Dry	779
	WWTP	0
Raritan River	CSO	1,138
	Storm	28,688
	River	3,628
	Dry	400
	WWTP	13
Upper NY Bay	CSO	1,550
	Storm	0
	River	0
	Dry	0
	WWTP	29

Hudson River	CSO	10,293
	Storm	3,231
	River	19,845
	Dry	0
	WWTP	4
Kill Van Kull	CSO	3,768
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	4,816
	Storm	1,275
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	16,138
	Storm	3,001
	River	8,372
	Dry	2,880
	WWTP	0
Raritan River	CSO	1,575
	Storm	15,342
	River	3,133
	Dry	1,480
	WWTP	13
Upper NY Bay	CSO	1,520
	Storm	0
	River	0
	Dry	0
	WWTP	29

Appendix C-2

Validation Loads

Volume

Combined Sewer Outfalls		
Waterbody	Outfall	Total Discharge (MG/Yr)
Arthur Kill	EL030	5
Arthur Kill	EL031	19
Arthur Kill	EL032	11
Arthur Kill	EL037	77
Arthur Kill	PA002	72
Arthur Kill	PA003	34
Arthur Kill	PA004	11
Arthur Kill	PA005	11
Arthur Kill	PA006	21
Arthur Kill	PA007	6
Arthur Kill	PA008	3
Arthur Kill	PA009	3
Arthur Kill	PA010	3
Elizabeth River	EL003	86
Elizabeth River	EL005	111
Elizabeth River	EL008	11
Elizabeth River	EL010	22
Elizabeth River	EL011	21
Elizabeth River	EL012	6
Elizabeth River	EL014	2
Elizabeth River	EL016	21
Elizabeth River	EL021	4
Elizabeth River	EL022	85
Elizabeth River	EL026	67
Elizabeth River	EL027	41
Elizabeth River	EL028	48
Elizabeth River	EL029	44
Elizabeth River	EL035	44
Elizabeth River	EL036a	27
Elizabeth River	EL036b	30
Elizabeth River	EL038	13
Elizabeth River	EL040	15
Elizabeth River	EL041	222
Elizabeth River	EL042	51
Elizabeth River	EL043	1
Hackensack River	HK001	85
Hackensack River	HK002	116
Hackensack River	JC001	90
Hackensack River	JC002	37
Hackensack River	JC003	57
Hackensack River	JC004	27
Hackensack River	JC005	9
Hackensack River	JC006	81
Hackensack River	JC007	38
Hackensack River	JC008	118
Hackensack River	JC009	48
Hackensack River	JC010	35
Hackensack River	NB003	154

Fecal Coliform

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	18
Arthur Kill	EL031	214
Arthur Kill	EL032	43
Arthur Kill	EL037	1,280
Arthur Kill	PA002	1,442
Arthur Kill	PA003	1,140
Arthur Kill	PA004	116
Arthur Kill	PA005	238
Arthur Kill	PA006	401
Arthur Kill	PA007	46
Arthur Kill	PA008	30
Arthur Kill	PA009	10
Arthur Kill	PA010	11
Elizabeth River	EL003	279
Elizabeth River	EL005	1,635
Elizabeth River	EL008	233
Elizabeth River	EL010	124
Elizabeth River	EL011	109
Elizabeth River	EL012	69
Elizabeth River	EL014	5
Elizabeth River	EL016	208
Elizabeth River	EL021	57
Elizabeth River	EL022	1,747
Elizabeth River	EL026	1,599
Elizabeth River	EL027	203
Elizabeth River	EL028	237
Elizabeth River	EL029	481
Elizabeth River	EL035	607
Elizabeth River	EL036a	196
Elizabeth River	EL036b	253
Elizabeth River	EL038	127
Elizabeth River	EL040	148
Elizabeth River	EL041	2,443
Elizabeth River	EL042	444
Elizabeth River	EL043	3
Hackensack River	HK001	1,548
Hackensack River	HK002	2,272
Hackensack River	JC001	1,486
Hackensack River	JC002	390
Hackensack River	JC003	443
Hackensack River	JC004	182
Hackensack River	JC005	58
Hackensack River	JC006	2,638
Hackensack River	JC007	317
Hackensack River	JC008	1,081
Hackensack River	JC009	372
Hackensack River	JC010	240
Hackensack River	NB003	1,649

Enterococcus

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	21
Arthur Kill	EL031	107
Arthur Kill	EL032	49
Arthur Kill	EL037	484
Arthur Kill	PA002	488
Arthur Kill	PA003	296
Arthur Kill	PA004	59
Arthur Kill	PA005	76
Arthur Kill	PA006	138
Arthur Kill	PA007	31
Arthur Kill	PA008	18
Arthur Kill	PA009	12
Arthur Kill	PA010	13
Elizabeth River	EL003	380
Elizabeth River	EL005	673
Elizabeth River	EL008	78
Elizabeth River	EL010	104
Elizabeth River	EL011	98
Elizabeth River	EL012	32
Elizabeth River	EL014	7
Elizabeth River	EL016	113
Elizabeth River	EL021	23
Elizabeth River	EL022	584
Elizabeth River	EL026	491
Elizabeth River	EL027	191
Elizabeth River	EL028	225
Elizabeth River	EL029	242
Elizabeth River	EL035	260
Elizabeth River	EL036a	136
Elizabeth River	EL036b	153
Elizabeth River	EL038	68
Elizabeth River	EL040	82
Elizabeth River	EL041	1,224
Elizabeth River	EL042	265
Elizabeth River	EL043	4
Hackensack River	HK001	556
Hackensack River	HK002	780
Hackensack River	JC001	569
Hackensack River	JC002	201
Hackensack River	JC003	287
Hackensack River	JC004	133
Hackensack River	JC005	43
Hackensack River	JC006	697
Hackensack River	JC007	196
Hackensack River	JC008	619
Hackensack River	JC009	243
Hackensack River	JC010	171
Hackensack River	NB003	841

E. Coli

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	14
Arthur Kill	EL031	142
Arthur Kill	EL032	32
Arthur Kill	EL037	832
Arthur Kill	PA002	931
Arthur Kill	PA003	725
Arthur Kill	PA004	77
Arthur Kill	PA005	153
Arthur Kill	PA006	259
Arthur Kill	PA007	31
Arthur Kill	PA008	20
Arthur Kill	PA009	8
Arthur Kill	PA010	8
Elizabeth River	EL003	215
Elizabeth River	EL005	1,070
Elizabeth River	EL008	150
Elizabeth River	EL010	88
Elizabeth River	EL011	78
Elizabeth River	EL012	46
Elizabeth River	EL014	4
Elizabeth River	EL016	140
Elizabeth River	EL021	37
Elizabeth River	EL022	1,127
Elizabeth River	EL026	1,026
Elizabeth River	EL027	146
Elizabeth River	EL028	170
Elizabeth River	EL029	320
Elizabeth River	EL035	399
Elizabeth River	EL036a	135
Elizabeth River	EL036b	171
Elizabeth River	EL038	85
Elizabeth River	EL040	99
Elizabeth River	EL041	1,624
Elizabeth River	EL042	300
Elizabeth River	EL043	2
Hackensack River	HK001	1,003
Hackensack River	HK002	1,467
Hackensack River	JC001	967
Hackensack River	JC002	260
Hackensack River	JC003	302
Hackensack River	JC004	126
Hackensack River	JC005	40
Hackensack River	JC006	1,679
Hackensack River	JC007	215
Hackensack River	JC008	728
Hackensack River	JC009	254
Hackensack River	JC010	165
Hackensack River	NB003	1,098

Hackensack River	NB005	28
Hackensack River	NB006	0
Hackensack River	NB007	6
Hackensack River	NB008	14
Hackensack River	NB009	23
Hackensack River	NB010	1
Hackensack River	NB011	6
Hackensack River	NB014	1
Hackensack River	RP001	10
Hackensack River	RP002	2
Hackensack River	RP003	14
Hackensack River	RP004	19
Hackensack River	RP005	7
Hackensack River	RP006	1
Hudson River	FL001	68
Hudson River	FL002	5
Hudson River	GU001	13
Hudson River	JC020	59
Hudson River	JC025	43
Hudson River	JC026	11
Hudson River	JC028	77
Hudson River	JC029	216
Hudson River	NB004	12
Hudson River	NH002A1	190
Hudson River	NH002A2	200
Hudson River	NH003A	95
Hudson River	NH005A	41
Hudson River	NH006A	41
Hudson River	NH008A	21
Hudson River	NH012A	8
Hudson River	NH013A	141
Hudson River	NH015A	27
Kill Van Kull	BA001	431
Kill Van Kull	BA002	26
Kill Van Kull	BA003	10
Kill Van Kull	BA004	1
Kill Van Kull	BA008	7
Kill Van Kull	BA009	4
Kill Van Kull	BA010	8
Kill Van Kull	BA011	6
Kill Van Kull	BA022	0
Kill Van Kull	BA024	1
Kill Van Kull	BA037	3
Newark Bay	BA012	13
Newark Bay	BA013	1
Newark Bay	BA014	15
Newark Bay	BA015	47
Newark Bay	BA016	4
Newark Bay	BA017	51
Newark Bay	BA018	14
Newark Bay	BA019	33
Newark Bay	BA020	11

Hackensack River	NB005	270
Hackensack River	NB006	0
Hackensack River	NB007	116
Hackensack River	NB008	99
Hackensack River	NB009	281
Hackensack River	NB010	6
Hackensack River	NB011	73
Hackensack River	NB014	2
Hackensack River	RP001	171
Hackensack River	RP002	19
Hackensack River	RP003	68
Hackensack River	RP004	197
Hackensack River	RP005	110
Hackensack River	RP006	6
Hudson River	FL001	1,601
Hudson River	FL002	155
Hudson River	GU001	148
Hudson River	JC020	801
Hudson River	JC025	851
Hudson River	JC026	156
Hudson River	JC028	863
Hudson River	JC029	1,593
Hudson River	NB004	157
Hudson River	NH002A1	2,096
Hudson River	NH002A2	4,424
Hudson River	NH003A	979
Hudson River	NH005A	885
Hudson River	NH006A	223
Hudson River	NH008A	77
Hudson River	NH012A	13
Hudson River	NH013A	1,919
Hudson River	NH015A	222
Kill Van Kull	BA001	6,839
Kill Van Kull	BA002	86
Kill Van Kull	BA003	57
Kill Van Kull	BA004	3
Kill Van Kull	BA008	31
Kill Van Kull	BA009	18
Kill Van Kull	BA010	43
Kill Van Kull	BA011	15
Kill Van Kull	BA022	0
Kill Van Kull	BA024	2
Kill Van Kull	BA037	11
Newark Bay	BA012	50
Newark Bay	BA013	1
Newark Bay	BA014	77
Newark Bay	BA015	499
Newark Bay	BA016	19
Newark Bay	BA017	1,308
Newark Bay	BA018	188
Newark Bay	BA019	239
Newark Bay	BA020	57

Hackensack River	NB005	147
Hackensack River	NB006	0
Hackensack River	NB007	41
Hackensack River	NB008	69
Hackensack River	NB009	132
Hackensack River	NB010	5
Hackensack River	NB011	35
Hackensack River	NB014	3
Hackensack River	RP001	65
Hackensack River	RP002	10
Hackensack River	RP003	66
Hackensack River	RP004	102
Hackensack River	RP005	44
Hackensack River	RP006	4
Hudson River	FL001	497
Hudson River	FL002	40
Hudson River	GU001	72
Hudson River	JC020	346
Hudson River	JC025	291
Hudson River	JC026	65
Hudson River	JC028	425
Hudson River	JC029	1,079
Hudson River	NB004	71
Hudson River	NH002A1	1,050
Hudson River	NH002A2	1,421
Hudson River	NH003A	516
Hudson River	NH005A	290
Hudson River	NH006A	194
Hudson River	NH008A	93
Hudson River	NH012A	33
Hudson River	NH013A	828
Hudson River	NH015A	139
Kill Van Kull	BA001	2,674
Kill Van Kull	BA002	116
Kill Van Kull	BA003	49
Kill Van Kull	BA004	4
Kill Van Kull	BA008	31
Kill Van Kull	BA009	18
Kill Van Kull	BA010	39
Kill Van Kull	BA011	25
Kill Van Kull	BA022	0
Kill Van Kull	BA024	3
Kill Van Kull	BA037	13
Newark Bay	BA012	57
Newark Bay	BA013	3
Newark Bay	BA014	68
Newark Bay	BA015	255
Newark Bay	BA016	17
Newark Bay	BA017	387
Newark Bay	BA018	83
Newark Bay	BA019	165
Newark Bay	BA020	50

Hackensack River	NB005	181
Hackensack River	NB006	0
Hackensack River	NB007	75
Hackensack River	NB008	68
Hackensack River	NB009	186
Hackensack River	NB010	4
Hackensack River	NB011	48
Hackensack River	NB014	1
Hackensack River	RP001	111
Hackensack River	RP002	13
Hackensack River	RP003	49
Hackensack River	RP004	131
Hackensack River	RP005	72
Hackensack River	RP006	4
Hudson River	FL001	1,028
Hudson River	FL002	98
Hudson River	GU001	98
Hudson River	JC020	526
Hudson River	JC025	550
Hudson River	JC026	102
Hudson River	JC028	573
Hudson River	JC029	1,093
Hudson River	NB004	103
Hudson River	NH002A1	1,394
Hudson River	NH002A2	2,846
Hudson River	NH003A	654
Hudson River	NH005A	570
Hudson River	NH006A	158
Hudson River	NH008A	58
Hudson River	NH012A	12
Hudson River	NH013A	1,260
Hudson River	NH015A	151
Kill Van Kull	BA001	4,457
Kill Van Kull	BA002	66
Kill Van Kull	BA003	40
Kill Van Kull	BA004	2
Kill Van Kull	BA008	23
Kill Van Kull	BA009	13
Kill Van Kull	BA010	31
Kill Van Kull	BA011	12
Kill Van Kull	BA022	0
Kill Van Kull	BA024	2
Kill Van Kull	BA037	8
Newark Bay	BA012	37
Newark Bay	BA013	1
Newark Bay	BA014	55
Newark Bay	BA015	332
Newark Bay	BA016	14
Newark Bay	BA017	838
Newark Bay	BA018	124
Newark Bay	BA019	164
Newark Bay	BA020	41

Newark Bay	BA026	2
Newark Bay	BA028	0
Newark Bay	BA029	10
Newark Bay	BA030	2
Newark Bay	BA034	1
Newark Bay	EL001	103
Newark Bay	EL002	43
Newark Bay	EL034	94
Newark Bay	EL039	14
Newark Bay	JC011	75
Newark Bay	JC013	91
Newark Bay	NE023	20
Newark Bay	NE023_Stor	237
Newark Bay	NE025	102
Newark Bay	NE027	21
Newark Bay	NE030	18
Newark Bay	NE030_Stor	46
Passaic River	EN001	18
Passaic River	HR001	2
Passaic River	HR002	3
Passaic River	HR003	16
Passaic River	HR005	19
Passaic River	HR006	9
Passaic River	HR006_Stor	7
Passaic River	HR007	14
Passaic River	KE001	3
Passaic River	KE004	13
Passaic River	KE006	120
Passaic River	KE007	63
Passaic River	KE010	27
Passaic River	NE002	94
Passaic River	NE003	0
Passaic River	NE003_Stor	60
Passaic River	NE004	3
Passaic River	NE005	21
Passaic River	NE008	94
Passaic River	NE009	173
Passaic River	NE010	173
Passaic River	NE014	183
Passaic River	NE015	81
Passaic River	NE016	54
Passaic River	NE017	105
Passaic River	NE018	75
Passaic River	NE022	42
Passaic River	PT001	22
Passaic River	PT003	2
Passaic River	PT005	5
Passaic River	PT006	62
Passaic River	PT007	37
Passaic River	PT010	8
Passaic River	PT013	10
Passaic River	PT014	0

Newark Bay	BA026	4
Newark Bay	BA028	0
Newark Bay	BA029	49
Newark Bay	BA030	5
Newark Bay	BA034	1
Newark Bay	EL001	1,037
Newark Bay	EL002	391
Newark Bay	EL034	1,215
Newark Bay	EL039	47
Newark Bay	JC011	196
Newark Bay	JC013	2,074
Newark Bay	NE023	76
Newark Bay	NE023_Stor	368
Newark Bay	NE025	698
Newark Bay	NE027	115
Newark Bay	NE030	134
Newark Bay	NE030_Stor	71
Passaic River	EN001	193
Passaic River	HR001	15
Passaic River	HR002	15
Passaic River	HR003	54
Passaic River	HR005	87
Passaic River	HR006	75
Passaic River	HR006_Stor	10
Passaic River	HR007	52
Passaic River	KE001	10
Passaic River	KE004	34
Passaic River	KE006	1,219
Passaic River	KE007	473
Passaic River	KE010	142
Passaic River	NE002	907
Passaic River	NE003	0
Passaic River	NE003_Stor	93
Passaic River	NE004	28
Passaic River	NE005	814
Passaic River	NE008	2,462
Passaic River	NE009	3,704
Passaic River	NE010	3,704
Passaic River	NE014	5,275
Passaic River	NE015	1,374
Passaic River	NE016	633
Passaic River	NE017	1,090
Passaic River	NE018	1,451
Passaic River	NE022	219
Passaic River	PT001	712
Passaic River	PT003	15
Passaic River	PT005	114
Passaic River	PT006	1,009
Passaic River	PT007	743
Passaic River	PT010	90
Passaic River	PT013	134
Passaic River	PT014	0

Newark Bay	BA026	8
Newark Bay	BA028	0
Newark Bay	BA029	48
Newark Bay	BA030	10
Newark Bay	BA034	2
Newark Bay	EL001	553
Newark Bay	EL002	227
Newark Bay	EL034	545
Newark Bay	EL039	60
Newark Bay	JC011	325
Newark Bay	JC013	655
Newark Bay	NE023	90
Newark Bay	NE023_Stor	988
Newark Bay	NE025	503
Newark Bay	NE027	97
Newark Bay	NE030	88
Newark Bay	NE030_Stor	191
Passaic River	EN001	100
Passaic River	HR001	8
Passaic River	HR002	16
Passaic River	HR003	71
Passaic River	HR005	86
Passaic River	HR006	47
Passaic River	HR006_Stor	27
Passaic River	HR007	64
Passaic River	KE001	12
Passaic River	KE004	55
Passaic River	KE006	649
Passaic River	KE007	316
Passaic River	KE010	126
Passaic River	NE002	500
Passaic River	NE003	0
Passaic River	NE003_Stor	249
Passaic River	NE004	16
Passaic River	NE005	200
Passaic River	NE008	721
Passaic River	NE009	1,211
Passaic River	NE010	1,211
Passaic River	NE014	1,473
Passaic River	NE015	516
Passaic River	NE016	302
Passaic River	NE017	568
Passaic River	NE018	503
Passaic River	NE022	198
Passaic River	PT001	188
Passaic River	PT003	9
Passaic River	PT005	35
Passaic River	PT006	390
Passaic River	PT007	251
Passaic River	PT010	43
Passaic River	PT013	60
Passaic River	PT014	1

Newark Bay	BA026	4
Newark Bay	BA028	0
Newark Bay	BA029	35
Newark Bay	BA030	4
Newark Bay	BA034	1
Newark Bay	EL001	693
Newark Bay	EL002	264
Newark Bay	EL034	800
Newark Bay	EL039	35
Newark Bay	JC011	158
Newark Bay	JC013	1,333
Newark Bay	NE023	57
Newark Bay	NE023_Stor	341
Newark Bay	NE025	482
Newark Bay	NE027	81
Newark Bay	NE030	92
Newark Bay	NE030_Stor	66
Passaic River	EN001	129
Passaic River	HR001	10
Passaic River	HR002	11
Passaic River	HR003	41
Passaic River	HR005	63
Passaic River	HR006	51
Passaic River	HR006_Stor	9
Passaic River	HR007	39
Passaic River	KE001	7
Passaic River	KE004	27
Passaic River	KE006	815
Passaic River	KE007	324
Passaic River	KE010	101
Passaic River	NE002	609
Passaic River	NE003	0
Passaic River	NE003_Stor	86
Passaic River	NE004	19
Passaic River	NE005	517
Passaic River	NE008	1,575
Passaic River	NE009	2,386
Passaic River	NE010	2,386
Passaic River	NE014	3,366
Passaic River	NE015	893
Passaic River	NE016	419
Passaic River	NE017	727
Passaic River	NE018	938
Passaic River	NE022	156
Passaic River	PT001	453
Passaic River	PT003	10
Passaic River	PT005	73
Passaic River	PT006	657
Passaic River	PT007	479
Passaic River	PT010	60
Passaic River	PT013	88
Passaic River	PT014	0

Passaic River	PT015	1
Passaic River	PT016	11
Passaic River	PT017	7
Passaic River	PT021	5
Passaic River	PT022	16
Passaic River	PT023	3
Passaic River	PT024	7
Passaic River	PT025	73
Passaic River	PT026	1
Passaic River	PT027	36
Passaic River	PT028	9
Passaic River	PT029	76
Passaic River	PT030	6
Passaic River	PT031	9
Passaic River	PT032	24
Raritan River	PA011	12
Raritan River	PA013	33
Raritan River	PA014	12
Raritan River	PA015	14
Raritan River	PA016	108
Raritan River	PA017	13
Raritan River	PA019	66
Upper NY Bay	BA006	14
Upper NY Bay	BA006_stor	26
Upper NY Bay	BA007	61
Upper NY Bay	BA021	59
Upper NY Bay	JC014	27
Upper NY Bay	JC015	12
Upper NY Bay	JC016	71
Upper NY Bay	JC018	164
Total CSO		**7,697**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Discharge, (MG/Yr)**
Arthur Kill	49a.1	28,081
Arthur Kill	50.1	7,116
Arthur Kill	64.1	5,837
Elizabeth River	56a.d	0
Hackensack River	126.d	748
Hackensack River	136.d	1,794
Hackensack River	145.d	598
Hackensack River	146.d	473
Hackensack River	151.d	721
Hackensack River	152.d	3,057
Hackensack River	160.d	377
Hackensack River	BerrysCka.	3,732
Hudson River	Hudson1.1	1,747
Hudson River	Hudson2.1	2,693
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	2,286
Overpeck Creek	165.1	1,297

Passaic River	PT015	2
Passaic River	PT016	57
Passaic River	PT017	85
Passaic River	PT021	114
Passaic River	PT022	617
Passaic River	PT023	66
Passaic River	PT024	83
Passaic River	PT025	542
Passaic River	PT026	1
Passaic River	PT027	547
Passaic River	PT028	115
Passaic River	PT029	1,112
Passaic River	PT030	14
Passaic River	PT031	74
Passaic River	PT032	192
Raritan River	PA011	162
Raritan River	PA013	661
Raritan River	PA014	178
Raritan River	PA015	286
Raritan River	PA016	1,034
Raritan River	PA017	47
Raritan River	PA019	335
Upper NY Bay	BA006	67
Upper NY Bay	BA006_stor	40
Upper NY Bay	BA007	307
Upper NY Bay	BA021	556
Upper NY Bay	JC014	124
Upper NY Bay	JC015	37
Upper NY Bay	JC016	1,031
Upper NY Bay	JC018	649
Total CSO		**99,563**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	1,783
Arthur Kill	50.1	18
Arthur Kill	64.1	7,592
Elizabeth River	56a.d	0
Hackensack River	126.d	2
Hackensack River	136.d	163
Hackensack River	145.d	13
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	3,936
Hackensack River	160.d	0
Hackensack River	BerrysCka.	751
Hudson River	Hudson1.1	1,794
Hudson River	Hudson2.1	2,005
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,794
Overpeck Creek	165.1	0

Passaic River	PT015	2
Passaic River	PT016	50
Passaic River	PT017	40
Passaic River	PT021	36
Passaic River	PT022	152
Passaic River	PT023	21
Passaic River	PT024	40
Passaic River	PT025	364
Passaic River	PT026	2
Passaic River	PT027	220
Passaic River	PT028	52
Passaic River	PT029	458
Passaic River	PT030	26
Passaic River	PT031	45
Passaic River	PT032	122
Raritan River	PA011	71
Raritan River	PA013	226
Raritan River	PA014	73
Raritan River	PA015	97
Raritan River	PA016	572
Raritan River	PA017	60
Raritan River	PA019	310
Upper NY Bay	BA006	64
Upper NY Bay	BA006_stor	107
Upper NY Bay	BA007	283
Upper NY Bay	BA021	313
Upper NY Bay	JC014	123
Upper NY Bay	JC015	51
Upper NY Bay	JC016	426
Upper NY Bay	JC018	741
Total CSO		**44,556**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	2,402
Arthur Kill	50.1	10
Arthur Kill	64.1	20,368
Elizabeth River	56a.d	0
Hackensack River	126.d	0
Hackensack River	136.d	6
Hackensack River	145.d	3
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	1,440
Hackensack River	160.d	0
Hackensack River	BerrysCka.	742
Hudson River	Hudson1.1	4,813
Hudson River	Hudson2.1	5,379
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	4,811
Overpeck Creek	165.1	0

Passaic River	PT015	2
Passaic River	PT016	40
Passaic River	PT017	56
Passaic River	PT021	73
Passaic River	PT022	391
Passaic River	PT023	42
Passaic River	PT024	55
Passaic River	PT025	372
Passaic River	PT026	1
Passaic River	PT027	357
Passaic River	PT028	76
Passaic River	PT029	727
Passaic River	PT030	11
Passaic River	PT031	50
Passaic River	PT032	131
Raritan River	PA011	107
Raritan River	PA013	427
Raritan River	PA014	116
Raritan River	PA015	184
Raritan River	PA016	694
Raritan River	PA017	36
Raritan River	PA019	240
Upper NY Bay	BA006	48
Upper NY Bay	BA006_stor	37
Upper NY Bay	BA007	220
Upper NY Bay	BA021	374
Upper NY Bay	JC014	90
Upper NY Bay	JC015	29
Upper NY Bay	JC016	674
Upper NY Bay	JC018	481
Total CSO		**65,559**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	891
Arthur Kill	50.1	9
Arthur Kill	64.1	7,036
Elizabeth River	56a.d	0
Hackensack River	126.d	1
Hackensack River	136.d	81
Hackensack River	145.d	6
Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	3,647
Hackensack River	160.d	0
Hackensack River	BerrysCka.	375
Hudson River	Hudson1.1	1,663
Hudson River	Hudson2.1	1,858
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,662
Overpeck Creek	165.1	0

Passaic River	104.1	2,361
Passaic River	111.d	297
Passaic River	115.d	901
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	3,882
Passaic River	Frank's Cr	297
Raritan River	12a.d	4,257
Raritan River	14.1	10,899
Raritan River	18.d	3,240
Raritan River	31.d	8,423
Raritan River	7.1	0
Raritan River	9.d	3,088
Raritan River	10.d	2,789
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**100,994**

River Discharges

Waterbody	Outfall	Total Discharge (MG/Yr)
Hudson River	Hudson R	13,219,695
Hackensack River	Hackensa	9,088
Passaic River	Passaic	165,430
Passaic River	Saddle R	19,020
Raritan River	Raritan	180,612
Hudson River	Norman K	40,616
Hudson River	Mooorden	8,670
Hudson River	Esopus C	414,037
Hudson River	Wallkill	883,444
Hudson River	Wappinge	199,851
Hudson River	Croton R	158,884
Hudson River	Sawmill	130,303
Hudson River	Catskill	210,561
Passaic River	1392500.1	7,223
Elizabeth River	1393450.1	8,311
Passaic River	110.1	6,251
Passaic River	120a.d	6,018
Raritan River	23.1	43,005
	Total River	**15,711,019**

Dry-weather Loads

Waterbody	Outfall	Total Discharge (MG/Yr) Equivalent
Elizabeth River	Elizabeth	16
Hackensack River	Hackensack	67
Passaic River	Passaic	30
Raritan River	Raritan	16
	Total Dry Load	**129**

WWTP Discharges

Waterbody	Outfall	Total Discharge (MG/Yr)
Upper NY Bay	WPCF	76,837

Passaic River	104.1	3,113
Passaic River	111.d	75
Passaic River	115.d	73
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	160
Passaic River	Frank's Cr	18
Raritan River	12a.d	5,488
Raritan River	14.1	259
Raritan River	18.d	4,254
Raritan River	31.d	10,540
Raritan River	7.1	0
Raritan River	9.d	3,536
Raritan River	10.d	75
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**47,442**

River Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Hudson River	Hudson R	40,923
Hackensack River	Hackensa	47
Passaic River	Passaic	2,597
Passaic River	Saddle R	824
Raritan River	Raritan	3,249
Hudson River	Norman K	2
Hudson River	Mooorden	0
Hudson River	Esopus C	16
Hudson River	Wallkill	33
Hudson River	Wappinge	8
Hudson River	Croton R	6
Hudson River	Sawmill	5
Hudson River	Catskill	8
Passaic River	1392500.1	1,411
Elizabeth River	1393450.1	4,636
Passaic River	110.1	2,680
Passaic River	120a.d	1,052
Raritan River	23.1	718
	Total River	**58,215**

Dry-weather Loads

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Elizabeth River	Elizabeth	2,500
Hackensack River	Hackensack	10,100
Passaic River	Passaic	4,620
Raritan River	Raritan	2,370
	Total Dry Load	**19,590**

WWTP Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	WPCF	145

Passaic River	104.1	8,348
Passaic River	111.d	200
Passaic River	115.d	194
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	125
Passaic River	Frank's Cr	30
Raritan River	12a.d	2,008
Raritan River	14.1	296
Raritan River	18.d	11,411
Raritan River	31.d	28,276
Raritan River	7.1	0
Raritan River	9.d	1,294
Raritan River	10.d	88
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**92,243**

River Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Hudson River	Hudson R	14,658
Hackensack River	Hackensa	27
Passaic River	Passaic	5,136
Passaic River	Saddle R	1,566
Raritan River	Raritan	3,563
Hudson River	Norman K	2
Hudson River	Mooorden	0
Hudson River	Esopus C	16
Hudson River	Wallkill	33
Hudson River	Wappinge	8
Hudson River	Croton R	6
Hudson River	Sawmill	5
Hudson River	Catskill	8
Passaic River	1392500.1	1,125
Elizabeth River	1393450.1	1,235
Passaic River	110.1	3,160
Passaic River	120a.d	914
Raritan River	23.1	809
	Total River	**32,269**

Dry-weather Loads

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Elizabeth River	Elizabeth	421
Hackensack River	Hackensack	1,700
Passaic River	Passaic	779
Raritan River	Raritan	400
	Total Dry Load	**3,300**

WWTP Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	WPCF	29

Passaic River	104.1	2,884
Passaic River	111.d	69
Passaic River	115.d	67
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	99
Passaic River	Frank's Cr	9
Raritan River	12a.d	5,086
Raritan River	14.1	258
Raritan River	18.d	3,942
Raritan River	31.d	9,768
Raritan River	7.1	0
Raritan River	9.d	3,277
Raritan River	10.d	75
Upper NY Bay	Hudson3.1	0
	Total Stormwater	**42,766**

River Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Hudson River	Hudson R	20,461
Hackensack River	Hackensa	39
Passaic River	Passaic	2,776
Passaic River	Saddle R	865
Raritan River	Raritan	3,257
Hudson River	Norman K	2
Hudson River	Mooorden	0
Hudson River	Esopus C	16
Hudson River	Wallkill	33
Hudson River	Wappinge	8
Hudson River	Croton R	6
Hudson River	Sawmill	5
Hudson River	Catskill	8
Passaic River	1392500.1	2,188
Elizabeth River	1393450.1	4,648
Passaic River	110.1	1,886
Passaic River	120a.d	1,692
Raritan River	23.1	714
	Total River	**38,604**

Dry-weather Loads

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Elizabeth River	Elizabeth	1,560
Hackensack River	Hackensack	6,320
Passaic River	Passaic	2,880
Raritan River	Raritan	1,480
	Total Dry Load	**12,240**

WWTP Discharges

Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	WPCF	29

Hackensack River	BCUA001	25,856
Arthur Kill	JMEUC	19,573
Raritan River	MCUA	36,268
Hudson River	NHSA001	3,199
Hudson River	Woodcliff	1,049
Hudson River	NHSA002	4,581
Hudson River	BCUA002	1,243
Arthur Kill	NJ0024643	9,165
Arthur Kill	NJ0024953	4,460
Hackensack River	NJ0025038	1,118
Hackensack River	NJ0034339	2,199
Total WWTP		**185,548**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Discharge (MG/Yr)**
Arthur Kill		74,507
Elizabeth River		9,300
Hackensack River		50,855
Hudson River		15,281,842
Kill Van Kull		497
Newark Bay		3,352
Passaic River		213,612
Raritan River		292,856
Upper NY Bay		77,270

Totals by Source		
Source	**Outfall**	**Total Discharge (MG/Yr)**
CSO		7,697
Storm		100,994
River		15,711,019
Dry		129
WWTP		185,548

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Discharge (MG/Yr)**
Arthur Kill	CSO	274
	Storm	41,035
	River	0
	Dry	0
	WWTP	33,198
Elizabeth River	CSO	972
	Storm	0
	River	8,311
	Dry	16
	WWTP	0
Hackensack River	CSO	1,027
	Storm	11,501
	River	9,088
	Dry	67
	WWTP	29,173

Hackensack River	BCUA001	49
Arthur Kill	JMEUC	37
Raritan River	MCUA	69
Hudson River	NHSA001	6
Hudson River	Woodcliff	2
Hudson River	NHSA002	9
Hudson River	BCUA002	2
Arthur Kill	NJ0024643	17
Arthur Kill	NJ0024953	8
Hackensack River	NJ0025038	2
Hackensack River	NJ0034339	4
Total WWTP		**351**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		14,445
Elizabeth River		18,345
Hackensack River		29,160
Hudson River		61,981
Kill Van Kull		7,105
Newark Bay		10,715
Passaic River		47,194
Raritan River		33,261
Upper NY Bay		2,956

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		99,563
Storm		47,442
River		58,215
Dry		19,590
WWTP		351

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	4,990
	Storm	9,392
	River	0
	Dry	0
	WWTP	63
Elizabeth River	CSO	11,209
	Storm	0
	River	4,636
	Dry	2,500
	WWTP	0
Hackensack River	CSO	14,092
	Storm	4,866
	River	47
	Dry	10,100
	WWTP	55

Hackensack River	BCUA001	10
Arthur Kill	JMEUC	7
Raritan River	MCUA	14
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	BCUA002	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
Total WWTP		**70**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		24,584
Elizabeth River		7,088
Hackensack River		9,988
Hudson River		32,382
Kill Van Kull		2,973
Newark Bay		10,287
Passaic River		33,432
Raritan River		49,567
Upper NY Bay		2,138

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		44,556
Storm		92,243
River		32,269
Dry		3,300
WWTP		70

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	1,792
	Storm	22,779
	River	0
	Dry	0
	WWTP	13
Elizabeth River	CSO	5,432
	Storm	0
	River	1,235
	Dry	421
	WWTP	0
Hackensack River	CSO	6,059
	Storm	2,191
	River	27
	Dry	1,700
	WWTP	11

Hackensack River	BCUA001	10
Arthur Kill	JMEUC	7
Raritan River	MCUA	14
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	BCUA002	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
Total WWTP		**70**

Totals by Waterbody		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill		11,182
Elizabeth River		13,639
Hackensack River		19,732
Hudson River		35,337
Kill Van Kull		4,653
Newark Bay		7,715
Passaic River		35,324
Raritan River		29,675
Upper NY Bay		1,982

Totals by Source		
Source	**Outfall**	**Total Load (10^{12} cfu/Yr)**
CSO		65,559
Storm		42,766
River		38,604
Dry		12,240
WWTP		70

Totals by Source by Waterbody		
Waterbody	**Source**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	CSO	3,233
	Storm	7,937
	River	0
	Dry	0
	WWTP	13
Elizabeth River	CSO	7,431
	Storm	0
	River	4,648
	Dry	1,560
	WWTP	0
Hackensack River	CSO	9,250
	Storm	4,112
	River	39
	Dry	6,320
	WWTP	11

Hudson River	CSO	1,269
	Storm	4,440
	River	15,266,062
	Dry	0
	WWTP	10,072
Kill Van Kull	CSO	497
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	1,066
	Storm	2,286
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	1,901
	Storm	7,739
	River	203,942
	Dry	30
	WWTP	0
Raritan River	CSO	259
	Storm	32,697
	River	223,616
	Dry	16
	WWTP	36,268
Upper NY Bay	CSO	433
	Storm	0
	River	0
	Dry	0
	WWTP	76,837

Hudson River	CSO	17,162
	Storm	3,799
	River	41,000
	Dry	0
	WWTP	19
Kill Van Kull	CSO	7,105
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	8,921
	Storm	1,794
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	30,571
	Storm	3,439
	River	8,564
	Dry	4,620
	WWTP	0
Raritan River	CSO	2,703
	Storm	24,152
	River	3,967
	Dry	2,370
	WWTP	69
Upper NY Bay	CSO	2,810
	Storm	0
	River	0
	Dry	0
	WWTP	145

Hudson River	CSO	7,450
	Storm	10,192
	River	14,735
	Dry	0
	WWTP	4
Kill Van Kull	CSO	2,973
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	5,476
	Storm	4,811
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	11,856
	Storm	8,897
	River	11,900
	Dry	779
	WWTP	0
Raritan River	CSO	1,408
	Storm	43,373
	River	4,372
	Dry	400
	WWTP	14
Upper NY Bay	CSO	2,109
	Storm	0
	River	0
	Dry	0
	WWTP	29

Hudson River	CSO	11,274
	Storm	3,521
	River	20,538
	Dry	0
	WWTP	4
Kill Van Kull	CSO	4,653
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	6,053
	Storm	1,662
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	19,909
	Storm	3,128
	River	9,407
	Dry	2,880
	WWTP	0
Raritan River	CSO	1,804
	Storm	22,406
	River	3,971
	Dry	1,480
	WWTP	14
Upper NY Bay	CSO	1,953
	Storm	0
	River	0
	Dry	0
	WWTP	29

Appendix C-3

Baseline Loads

Volume

Combined Sewer Outfalls		
Waterbody	Outfall	Total Discharge (MG/Yr)
Arthur Kill	EL030	2
Arthur Kill	EL031	15
Arthur Kill	EL032	7
Arthur Kill	EL037	55
Arthur Kill	PA002	64
Arthur Kill	PA003	33
Arthur Kill	PA004	9
Arthur Kill	PA005	10
Arthur Kill	PA006	19
Arthur Kill	PA007	5
Arthur Kill	PA008	3
Arthur Kill	PA009	2
Arthur Kill	PA010	2
Elizabeth River	EL003	59
Elizabeth River	EL005	85
Elizabeth River	EL008	8
Elizabeth River	EL010	17
Elizabeth River	EL011	17
Elizabeth River	EL012	4
Elizabeth River	EL014	1
Elizabeth River	EL016	16
Elizabeth River	EL021	1
Elizabeth River	EL022	66
Elizabeth River	EL026	53
Elizabeth River	EL027	35
Elizabeth River	EL028	34
Elizabeth River	EL029	41
Elizabeth River	EL035	40
Elizabeth River	EL036a	10
Elizabeth River	EL036b	33
Elizabeth River	EL038	8
Elizabeth River	EL040	14
Elizabeth River	EL041	172
Elizabeth River	EL042	37
Elizabeth River	EL043	0
Hackensack River	HK001	105
Hackensack River	HK002	151
Hackensack River	JC001	90
Hackensack River	JC002	49
Hackensack River	JC003	85
Hackensack River	JC004	34
Hackensack River	JC005	17
Hackensack River	JC006	92
Hackensack River	JC007	46
Hackensack River	JC008	130
Hackensack River	JC009	50
Hackensack River	JC010	37
Hackensack River	NB003	154

Fecal Coliform

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	8
Arthur Kill	EL031	160
Arthur Kill	EL032	30
Arthur Kill	EL037	362
Arthur Kill	PA002	1,534
Arthur Kill	PA003	1,152
Arthur Kill	PA004	110
Arthur Kill	PA005	261
Arthur Kill	PA006	423
Arthur Kill	PA007	44
Arthur Kill	PA008	30
Arthur Kill	PA009	7
Arthur Kill	PA010	12
Elizabeth River	EL003	192
Elizabeth River	EL005	935
Elizabeth River	EL008	144
Elizabeth River	EL010	97
Elizabeth River	EL011	85
Elizabeth River	EL012	44
Elizabeth River	EL014	2
Elizabeth River	EL016	171
Elizabeth River	EL021	17
Elizabeth River	EL022	1,325
Elizabeth River	EL026	1,294
Elizabeth River	EL027	170
Elizabeth River	EL028	161
Elizabeth River	EL029	419
Elizabeth River	EL035	434
Elizabeth River	EL036a	84
Elizabeth River	EL036b	265
Elizabeth River	EL038	74
Elizabeth River	EL040	146
Elizabeth River	EL041	1,250
Elizabeth River	EL042	287
Elizabeth River	EL043	0
Hackensack River	HK001	1,811
Hackensack River	HK002	2,697
Hackensack River	JC001	4,545
Hackensack River	JC002	2,271
Hackensack River	JC003	3,999
Hackensack River	JC004	1,375
Hackensack River	JC005	591
Hackensack River	JC006	4,338
Hackensack River	JC007	1,872
Hackensack River	JC008	3,555
Hackensack River	JC009	2,168
Hackensack River	JC010	1,718
Hackensack River	NB003	2,151

Enterococcus

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	9
Arthur Kill	EL031	81
Arthur Kill	EL032	34
Arthur Kill	EL037	270
Arthur Kill	PA002	470
Arthur Kill	PA003	295
Arthur Kill	PA004	52
Arthur Kill	PA005	77
Arthur Kill	PA006	136
Arthur Kill	PA007	27
Arthur Kill	PA008	15
Arthur Kill	PA009	8
Arthur Kill	PA010	8
Elizabeth River	EL003	262
Elizabeth River	EL005	467
Elizabeth River	EL008	54
Elizabeth River	EL010	81
Elizabeth River	EL011	79
Elizabeth River	EL012	24
Elizabeth River	EL014	4
Elizabeth River	EL016	88
Elizabeth River	EL021	8
Elizabeth River	EL022	450
Elizabeth River	EL026	393
Elizabeth River	EL027	163
Elizabeth River	EL028	157
Elizabeth River	EL029	220
Elizabeth River	EL035	220
Elizabeth River	EL036a	53
Elizabeth River	EL036b	167
Elizabeth River	EL038	44
Elizabeth River	EL040	76
Elizabeth River	EL041	858
Elizabeth River	EL042	187
Elizabeth River	EL043	0
Hackensack River	HK001	674
Hackensack River	HK002	982
Hackensack River	JC001	1,003
Hackensack River	JC002	517
Hackensack River	JC003	907
Hackensack River	JC004	329
Hackensack River	JC005	151
Hackensack River	JC006	980
Hackensack River	JC007	449
Hackensack River	JC008	1,020
Hackensack River	JC009	507
Hackensack River	JC010	392
Hackensack River	NB003	913

E. Coli

Combined Sewer Outfalls		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill	EL030	6
Arthur Kill	EL031	107
Arthur Kill	EL032	22
Arthur Kill	EL037	252
Arthur Kill	PA002	984
Arthur Kill	PA003	732
Arthur Kill	PA004	73
Arthur Kill	PA005	167
Arthur Kill	PA006	272
Arthur Kill	PA007	30
Arthur Kill	PA008	20
Arthur Kill	PA009	5
Arthur Kill	PA010	8
Elizabeth River	EL003	147
Elizabeth River	EL005	622
Elizabeth River	EL008	94
Elizabeth River	EL010	69
Elizabeth River	EL011	61
Elizabeth River	EL012	30
Elizabeth River	EL014	2
Elizabeth River	EL016	114
Elizabeth River	EL021	11
Elizabeth River	EL022	855
Elizabeth River	EL026	830
Elizabeth River	EL027	123
Elizabeth River	EL028	116
Elizabeth River	EL029	279
Elizabeth River	EL035	289
Elizabeth River	EL036a	57
Elizabeth River	EL036b	181
Elizabeth River	EL038	50
Elizabeth River	EL040	97
Elizabeth River	EL041	859
Elizabeth River	EL042	196
Elizabeth River	EL043	0
Hackensack River	HK001	1,176
Hackensack River	HK002	1,749
Hackensack River	JC001	2,871
Hackensack River	JC002	1,435
Hackensack River	JC003	2,528
Hackensack River	JC004	871
Hackensack River	JC005	375
Hackensack River	JC006	2,741
Hackensack River	JC007	1,186
Hackensack River	JC008	2,272
Hackensack River	JC009	1,372
Hackensack River	JC010	1,086
Hackensack River	NB003	1,410

Hackensack River	NB005	26
Hackensack River	NB006	0
Hackensack River	NB007	14
Hackensack River	NB008	24
Hackensack River	NB009	28
Hackensack River	NB010	1
Hackensack River	NB011	20
Hackensack River	NB014	7
Hackensack River	RP001	18
Hackensack River	RP002	4
Hackensack River	RP003	15
Hackensack River	RP004	19
Hackensack River	RP005	9
Hackensack River	RP006	1
Hudson River	FL001	73
Hudson River	FL002	13
Hudson River	GU001	38
Hudson River	JC020	69
Hudson River	JC025	46
Hudson River	JC026	2
Hudson River	JC028	84
Hudson River	JC029	230
Hudson River	NB004	13
Hudson River	NH002A1	191
Hudson River	NH002A2	26
Hudson River	NH003A	95
Hudson River	NH005A	65
Hudson River	NH006A	17
Hudson River	NH008A	15
Hudson River	NH012A	8
Hudson River	NH013A	243
Hudson River	NH015A	25
Kill Van Kull	BA001	380
Kill Van Kull	BA002	12
Kill Van Kull	BA003	8
Kill Van Kull	BA004	0
Kill Van Kull	BA008	6
Kill Van Kull	BA009	3
Kill Van Kull	BA010	15
Kill Van Kull	BA011	5
Kill Van Kull	BA022	0
Kill Van Kull	BA024	0
Kill Van Kull	BA037	1
Newark Bay	BA012	12
Newark Bay	BA013	1
Newark Bay	BA014	13
Newark Bay	BA015	45
Newark Bay	BA016	6
Newark Bay	BA017	52
Newark Bay	BA018	14
Newark Bay	BA019	35
Newark Bay	BA020	10

Hackensack River	NB005	329
Hackensack River	NB006	0
Hackensack River	NB007	495
Hackensack River	NB008	255
Hackensack River	NB009	376
Hackensack River	NB010	8
Hackensack River	NB011	206
Hackensack River	NB014	54
Hackensack River	RP001	373
Hackensack River	RP002	67
Hackensack River	RP003	77
Hackensack River	RP004	222
Hackensack River	RP005	141
Hackensack River	RP006	8
Hudson River	FL001	2,334
Hudson River	FL002	779
Hudson River	GU001	1,312
Hudson River	JC020	3,180
Hudson River	JC025	2,364
Hudson River	JC026	105
Hudson River	JC028	3,863
Hudson River	JC029	9,359
Hudson River	NB004	216
Hudson River	NH002A1	2,104
Hudson River	NH002A2	64
Hudson River	NH003A	980
Hudson River	NH005A	148
Hudson River	NH006A	32
Hudson River	NH008A	26
Hudson River	NH012A	12
Hudson River	NH013A	668
Hudson River	NH015A	41
Kill Van Kull	BA001	5,475
Kill Van Kull	BA002	47
Kill Van Kull	BA003	42
Kill Van Kull	BA004	1
Kill Van Kull	BA008	35
Kill Van Kull	BA009	12
Kill Van Kull	BA010	107
Kill Van Kull	BA011	13
Kill Van Kull	BA022	0
Kill Van Kull	BA024	1
Kill Van Kull	BA037	4
Newark Bay	BA012	47
Newark Bay	BA013	1
Newark Bay	BA014	68
Newark Bay	BA015	478
Newark Bay	BA016	49
Newark Bay	BA017	1,383
Newark Bay	BA018	175
Newark Bay	BA019	279
Newark Bay	BA020	48

Hackensack River	NB005	150
Hackensack River	NB006	0
Hackensack River	NB007	127
Hackensack River	NB008	132
Hackensack River	NB009	163
Hackensack River	NB010	6
Hackensack River	NB011	107
Hackensack River	NB014	36
Hackensack River	RP001	124
Hackensack River	RP002	24
Hackensack River	RP003	72
Hackensack River	RP004	107
Hackensack River	RP005	55
Hackensack River	RP006	4
Hudson River	FL001	622
Hudson River	FL002	161
Hudson River	GU001	338
Hudson River	JC020	728
Hudson River	JC025	517
Hudson River	JC026	22
Hudson River	JC028	884
Hudson River	JC029	2,241
Hudson River	NB004	83
Hudson River	NH002A1	1,053
Hudson River	NH002A2	110
Hudson River	NH003A	514
Hudson River	NH005A	278
Hudson River	NH006A	73
Hudson River	NH008A	63
Hudson River	NH012A	33
Hudson River	NH013A	1,052
Hudson River	NH015A	103
Kill Van Kull	BA001	2,279
Kill Van Kull	BA002	54
Kill Van Kull	BA003	36
Kill Van Kull	BA004	1
Kill Van Kull	BA008	28
Kill Van Kull	BA009	14
Kill Van Kull	BA010	76
Kill Van Kull	BA011	22
Kill Van Kull	BA022	0
Kill Van Kull	BA024	2
Kill Van Kull	BA037	5
Newark Bay	BA012	53
Newark Bay	BA013	3
Newark Bay	BA014	62
Newark Bay	BA015	247
Newark Bay	BA016	30
Newark Bay	BA017	402
Newark Bay	BA018	79
Newark Bay	BA019	178
Newark Bay	BA020	45

Hackensack River	NB005	217
Hackensack River	NB006	0
Hackensack River	NB007	314
Hackensack River	NB008	170
Hackensack River	NB009	247
Hackensack River	NB010	5
Hackensack River	NB011	137
Hackensack River	NB014	37
Hackensack River	RP001	240
Hackensack River	RP002	43
Hackensack River	RP003	55
Hackensack River	RP004	147
Hackensack River	RP005	92
Hackensack River	RP006	5
Hudson River	FL001	1,487
Hudson River	FL002	490
Hudson River	GU001	834
Hudson River	JC020	2,012
Hudson River	JC025	1,492
Hudson River	JC026	66
Hudson River	JC028	2,443
Hudson River	JC029	5,930
Hudson River	NB004	140
Hudson River	NH002A1	1,399
Hudson River	NH002A2	52
Hudson River	NH003A	655
Hudson River	NH005A	123
Hudson River	NH006A	28
Hudson River	NH008A	23
Hudson River	NH012A	11
Hudson River	NH013A	531
Hudson River	NH015A	37
Kill Van Kull	BA001	3,584
Kill Van Kull	BA002	35
Kill Van Kull	BA003	30
Kill Van Kull	BA004	1
Kill Van Kull	BA008	24
Kill Van Kull	BA009	9
Kill Van Kull	BA010	74
Kill Van Kull	BA011	10
Kill Van Kull	BA022	0
Kill Van Kull	BA024	1
Kill Van Kull	BA037	3
Newark Bay	BA012	35
Newark Bay	BA013	1
Newark Bay	BA014	48
Newark Bay	BA015	319
Newark Bay	BA016	33
Newark Bay	BA017	885
Newark Bay	BA018	115
Newark Bay	BA019	190
Newark Bay	BA020	34

Newark Bay	BA026	1
Newark Bay	BA028	0
Newark Bay	BA029	7
Newark Bay	BA030	2
Newark Bay	BA034	0
Newark Bay	EL001	83
Newark Bay	EL002	32
Newark Bay	EL034	74
Newark Bay	EL039	10
Newark Bay	JC011	79
Newark Bay	JC013	98
Newark Bay	NE023	23
Newark Bay	NE023_Stor	239
Newark Bay	NE025	65
Newark Bay	NE026	23
Newark Bay	NE027	14
Newark Bay	NE030	11
Newark Bay	NE030_Stor	46
Passaic River	EN001	17
Passaic River	HR001	2
Passaic River	HR002	3
Passaic River	HR003	13
Passaic River	HR004	0
Passaic River	HR005	20
Passaic River	HR006	8
Passaic River	HR007	14
Passaic River	KE001	4
Passaic River	KE004	13
Passaic River	KE006	122
Passaic River	KE007	90
Passaic River	KE010	27
Passaic River	NE002	98
Passaic River	NE003	0
Passaic River	NE003_Stor	60
Passaic River	NE004	2
Passaic River	NE005	24
Passaic River	NE008	99
Passaic River	NE009	191
Passaic River	NE010	191
Passaic River	NE014	194
Passaic River	NE015	84
Passaic River	NE016	57
Passaic River	NE017	114
Passaic River	NE018	81
Passaic River	NE022	45
Passaic River	PT001	14
Passaic River	PT002	0
Passaic River	PT003	1
Passaic River	PT004	0
Passaic River	PT005	2
Passaic River	PT006	25
Passaic River	PT007	34

Newark Bay	BA026	2
Newark Bay	BA028	0
Newark Bay	BA029	34
Newark Bay	BA030	3
Newark Bay	BA034	0
Newark Bay	EL001	841
Newark Bay	EL002	142
Newark Bay	EL034	476
Newark Bay	EL039	33
Newark Bay	JC011	3,174
Newark Bay	JC013	3,373
Newark Bay	NE023	188
Newark Bay	NE023_Stor	371
Newark Bay	NE025	631
Newark Bay	NE026	205
Newark Bay	NE027	90
Newark Bay	NE030	77
Newark Bay	NE030_Stor	72
Passaic River	EN001	173
Passaic River	HR001	17
Passaic River	HR002	10
Passaic River	HR003	35
Passaic River	HR004	1
Passaic River	HR005	89
Passaic River	HR006	59
Passaic River	HR007	53
Passaic River	KE001	16
Passaic River	KE004	42
Passaic River	KE006	1,631
Passaic River	KE007	762
Passaic River	KE010	137
Passaic River	NE002	1,248
Passaic River	NE003	0
Passaic River	NE003_Stor	93
Passaic River	NE004	22
Passaic River	NE005	1,110
Passaic River	NE008	3,002
Passaic River	NE009	5,872
Passaic River	NE010	5,872
Passaic River	NE014	6,822
Passaic River	NE015	2,292
Passaic River	NE016	858
Passaic River	NE017	1,621
Passaic River	NE018	1,964
Passaic River	NE022	280
Passaic River	PT001	479
Passaic River	PT002	2
Passaic River	PT003	3
Passaic River	PT004	2
Passaic River	PT005	24
Passaic River	PT006	390
Passaic River	PT007	672

Newark Bay	BA026	5
Newark Bay	BA028	0
Newark Bay	BA029	34
Newark Bay	BA030	7
Newark Bay	BA034	1
Newark Bay	EL001	449
Newark Bay	EL002	148
Newark Bay	EL034	360
Newark Bay	EL039	44
Newark Bay	JC011	765
Newark Bay	JC013	867
Newark Bay	NE023	118
Newark Bay	NE023_Stor	995
Newark Bay	NE025	345
Newark Bay	NE026	119
Newark Bay	NE027	68
Newark Bay	NE030	54
Newark Bay	NE030_Stor	193
Passaic River	EN001	93
Passaic River	HR001	10
Passaic River	HR002	14
Passaic River	HR003	56
Passaic River	HR004	1
Passaic River	HR005	93
Passaic River	HR006	41
Passaic River	HR007	64
Passaic River	KE001	18
Passaic River	KE004	55
Passaic River	KE006	715
Passaic River	KE007	464
Passaic River	KE010	125
Passaic River	NE002	565
Passaic River	NE003	0
Passaic River	NE003_Stor	251
Passaic River	NE004	9
Passaic River	NE005	254
Passaic River	NE008	819
Passaic River	NE009	1,593
Passaic River	NE010	1,593
Passaic River	NE014	1,740
Passaic River	NE015	657
Passaic River	NE016	348
Passaic River	NE017	679
Passaic River	NE018	598
Passaic River	NE022	219
Passaic River	PT001	122
Passaic River	PT002	1
Passaic River	PT003	4
Passaic River	PT004	1
Passaic River	PT005	13
Passaic River	PT006	155
Passaic River	PT007	230

Newark Bay	BA026	2
Newark Bay	BA028	0
Newark Bay	BA029	25
Newark Bay	BA030	3
Newark Bay	BA034	0
Newark Bay	EL001	562
Newark Bay	EL002	103
Newark Bay	EL034	331
Newark Bay	EL039	25
Newark Bay	JC011	2,012
Newark Bay	JC013	2,144
Newark Bay	NE023	128
Newark Bay	NE023_Stor	344
Newark Bay	NE025	423
Newark Bay	NE026	138
Newark Bay	NE027	63
Newark Bay	NE030	53
Newark Bay	NE030_Stor	67
Passaic River	EN001	116
Passaic River	HR001	11
Passaic River	HR002	7
Passaic River	HR003	28
Passaic River	HR004	1
Passaic River	HR005	65
Passaic River	HR006	41
Passaic River	HR007	40
Passaic River	KE001	12
Passaic River	KE004	32
Passaic River	KE006	1,072
Passaic River	KE007	517
Passaic River	KE010	98
Passaic River	NE002	823
Passaic River	NE003	0
Passaic River	NE003_Stor	87
Passaic River	NE004	15
Passaic River	NE005	702
Passaic River	NE008	1,914
Passaic River	NE009	3,742
Passaic River	NE010	3,742
Passaic River	NE014	4,334
Passaic River	NE015	1,465
Passaic River	NE016	561
Passaic River	NE017	1,062
Passaic River	NE018	1,259
Passaic River	NE022	195
Passaic River	PT001	304
Passaic River	PT002	1
Passaic River	PT003	2
Passaic River	PT004	1
Passaic River	PT005	16
Passaic River	PT006	255
Passaic River	PT007	434

Passaic River	PT010	5
Passaic River	PT012	2
Passaic River	PT013	10
Passaic River	PT014	0
Passaic River	PT015_Comb	1
Passaic River	PT015_Stor	0
Passaic River	PT016	13
Passaic River	PT017	7
Passaic River	PT021_Comb	7
Passaic River	PT021_Stor	0
Passaic River	PT022	22
Passaic River	PT023_Comb	9
Passaic River	PT023_Stor	0
Passaic River	PT024_Comb	16
Passaic River	PT024_Stor	0
Passaic River	PT025	97
Passaic River	PT026	1
Passaic River	PT027	48
Passaic River	PT028_Comb	0
Passaic River	PT028_Stor	80
Passaic River	PT029_Comb	12
Passaic River	PT029_Stor	193
Passaic River	PT030	3
Passaic River	PT031	8
Passaic River	PT032	16
Raritan River	PA011	10
Raritan River	PA013	33
Raritan River	PA014	12
Raritan River	PA015	14
Raritan River	PA016	103
Raritan River	PA017	9
Raritan River	PA019	62
Upper NY Bay	BA006	12
Upper NY Bay	BA006_stor	26
Upper NY Bay	BA007	56
Upper NY Bay	BA021	53
Upper NY Bay	JC014	22
Upper NY Bay	JC015	30
Upper NY Bay	JC016	75
Upper NY Bay	JC018	198
Total CSO		**7,804**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Discharge, (MG/Yr)**
Arthur Kill	49a.1	32,319
Arthur Kill	50.1	6,767
Arthur Kill	64.1	5,544
Elizabeth River	56a.d	0
Hackensack River	126.d	753
Hackensack River	136.d	1,771
Hackensack River	145.d	600

Passaic River	PT010	35
Passaic River	PT012	9
Passaic River	PT013	183
Passaic River	PT014	0
Passaic River	PT015_Comb	2
Passaic River	PT015_Stor	0
Passaic River	PT016	120
Passaic River	PT017	104
Passaic River	PT021_Comb	184
Passaic River	PT021_Stor	0
Passaic River	PT022	756
Passaic River	PT023_Comb	203
Passaic River	PT023_Stor	0
Passaic River	PT024_Comb	315
Passaic River	PT024_Stor	0
Passaic River	PT025	1,300
Passaic River	PT026	1
Passaic River	PT027	792
Passaic River	PT028_Comb	0
Passaic River	PT028_Stor	125
Passaic River	PT029_Comb	367
Passaic River	PT029_Stor	300
Passaic River	PT030	13
Passaic River	PT031	46
Passaic River	PT032	278
Raritan River	PA011	158
Raritan River	PA013	670
Raritan River	PA014	197
Raritan River	PA015	330
Raritan River	PA016	1,050
Raritan River	PA017	33
Raritan River	PA019	341
Upper NY Bay	BA006	72
Upper NY Bay	BA006_stor	40
Upper NY Bay	BA007	291
Upper NY Bay	BA021	555
Upper NY Bay	JC014	1,874
Upper NY Bay	JC015	2,498
Upper NY Bay	JC016	2,465
Upper NY Bay	JC018	5,147
Total CSO		**149,505**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	2,070
Arthur Kill	50.1	17
Arthur Kill	64.1	7,137
Elizabeth River	56a.d	0
Hackensack River	126.d	2
Hackensack River	136.d	169
Hackensack River	145.d	10

Passaic River	PT010	23
Passaic River	PT012	8
Passaic River	PT013	66
Passaic River	PT014	1
Passaic River	PT015_Comb	3
Passaic River	PT015_Stor	0
Passaic River	PT016	67
Passaic River	PT017	42
Passaic River	PT021_Comb	53
Passaic River	PT021_Stor	0
Passaic River	PT022	195
Passaic River	PT023_Comb	66
Passaic River	PT023_Stor	0
Passaic River	PT024_Comb	110
Passaic River	PT024_Stor	0
Passaic River	PT025	567
Passaic River	PT026	3
Passaic River	PT027	303
Passaic River	PT028_Comb	0
Passaic River	PT028_Stor	335
Passaic River	PT029_Comb	99
Passaic River	PT029_Stor	805
Passaic River	PT030	16
Passaic River	PT031	38
Passaic River	PT032	104
Raritan River	PA011	63
Raritan River	PA013	227
Raritan River	PA014	77
Raritan River	PA015	103
Raritan River	PA016	555
Raritan River	PA017	41
Raritan River	PA019	295
Upper NY Bay	BA006	56
Upper NY Bay	BA006_stor	108
Upper NY Bay	BA007	262
Upper NY Bay	BA021	289
Upper NY Bay	JC014	356
Upper NY Bay	JC015	475
Upper NY Bay	JC016	646
Upper NY Bay	JC018	1,515
Total CSO		**52,102**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	2,532
Arthur Kill	50.1	9
Arthur Kill	64.1	19,147
Elizabeth River	56a.d	0
Hackensack River	126.d	0
Hackensack River	136.d	6
Hackensack River	145.d	4

Passaic River	PT010	24
Passaic River	PT012	6
Passaic River	PT013	119
Passaic River	PT014	0
Passaic River	PT015_Comb	2
Passaic River	PT015_Stor	0
Passaic River	PT016	81
Passaic River	PT017	68
Passaic River	PT021_Comb	118
Passaic River	PT021_Stor	0
Passaic River	PT022	481
Passaic River	PT023_Comb	131
Passaic River	PT023_Stor	0
Passaic River	PT024_Comb	203
Passaic River	PT024_Stor	0
Passaic River	PT025	854
Passaic River	PT026	1
Passaic River	PT027	515
Passaic River	PT028_Comb	0
Passaic River	PT028_Stor	116
Passaic River	PT029_Comb	234
Passaic River	PT029_Stor	278
Passaic River	PT030	10
Passaic River	PT031	32
Passaic River	PT032	181
Raritan River	PA011	103
Raritan River	PA013	433
Raritan River	PA014	129
Raritan River	PA015	212
Raritan River	PA016	702
Raritan River	PA017	25
Raritan River	PA019	242
Upper NY Bay	BA006	50
Upper NY Bay	BA006_stor	37
Upper NY Bay	BA007	207
Upper NY Bay	BA021	371
Upper NY Bay	JC014	1,176
Upper NY Bay	JC015	1,568
Upper NY Bay	JC016	1,567
Upper NY Bay	JC018	3,294
Total CSO		**96,671**

Stormwater Outfalls		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Arthur Kill	49a.1	1,035
Arthur Kill	50.1	8
Arthur Kill	64.1	6,614
Elizabeth River	56a.d	0
Hackensack River	126.d	1
Hackensack River	136.d	85
Hackensack River	145.d	5

Hackensack River	146.d	475
Hackensack River	151.d	724
Hackensack River	152.d	4,133
Hackensack River	160.d	388
Hackensack River	BerrysCka.	4,802
Hudson River	Hudson1.1	2,427
Hudson River	Hudson2.1	3,322
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	2,222
Overpeck Creek	165.1	1,302
Passaic River	104.1	3,479
Passaic River	111.d	320
Passaic River	115.d	926
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	5,807
Passaic River	Frank's Cr	320
Raritan River	12a.d	5,210
Raritan River	14.1	14,102
Raritan River	18.d	3,137
Raritan River	31.d	8,269
Raritan River	7.1	0
Raritan River	9.d	5,332
Upper NY Bay	Hudson3.1	0
Raritan River	10.d	3,344
	Total Stormwater	**117,794**

River Discharges		
Waterbody	**Outfall**	**Total Discharge (MG/Yr)**
Hudson River	Hudson R	12,598,365
Hackensack River	Hackensa	24,024
Passaic River	Passaic	291,144
Passaic River	Saddle R	29,487
Raritan River	Raritan	307,549
Hudson River	Norman K	37,330
Hudson River	Mooorden	13,647
Hudson River	Esopus C	524,778
Hudson River	Wallkill	1,093,778
Hudson River	Wappinge	235,858
Hudson River	Croton R	198,145
Hudson River	Sawmill	157,328
Hudson River	Catskill	259,269
Passaic River	1392500.1	8,978
Elizabeth River	1393450.1	8,422
Passaic River	110.1	9,019
Passaic River	120a.d	8,023
Raritan River	23.1	56,047
	Total River	**15,861,188**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Discharge (MG/Yr) Equivalent**

Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	5,595
Hackensack River	160.d	0
Hackensack River	BerrysCka.	955
Hudson River	Hudson1.1	2,847
Hudson River	Hudson2.1	2,974
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,688
Overpeck Creek	165.1	0
Passaic River	104.1	4,846
Passaic River	111.d	110
Passaic River	115.d	107
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	240
Passaic River	Frank's Cr	24
Raritan River	12a.d	6,965
Raritan River	14.1	402
Raritan River	18.d	4,092
Raritan River	31.d	10,293
Raritan River	7.1	0
Raritan River	9.d	7,013
Upper NY Bay	Hudson3.1	0
Raritan River	10.d	111
	Total Stormwater	**57,669**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	46,597
Hackensack River	Hackensa	161
Passaic River	Passaic	3,960
Passaic River	Saddle R	1,371
Raritan River	Raritan	7,625
Hudson River	Norman K	1
Hudson River	Mooorden	1
Hudson River	Esopus C	20
Hudson River	Wallkill	41
Hudson River	Wappinge	9
Hudson River	Croton R	8
Hudson River	Sawmill	6
Hudson River	Catskill	10
Passaic River	1392500.1	1,820
Elizabeth River	1393450.1	4,702
Passaic River	110.1	3,817
Passaic River	120a.d	1,460
Raritan River	23.1	1,215
	Total River	**72,823**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**

Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	2,047
Hackensack River	160.d	0
Hackensack River	BerrysCka.	976
Hudson River	Hudson1.1	7,638
Hudson River	Hudson2.1	7,979
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	4,529
Overpeck Creek	165.1	0
Passaic River	104.1	12,994
Passaic River	111.d	294
Passaic River	115.d	287
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	188
Passaic River	Frank's Cr	38
Raritan River	12a.d	2,548
Raritan River	14.1	439
Raritan River	18.d	10,979
Raritan River	31.d	27,615
Raritan River	7.1	0
Raritan River	9.d	2,566
Upper NY Bay	Hudson3.1	0
Raritan River	10.d	129
	Total Stormwater	**102,942**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	13,508
Hackensack River	Hackensa	75
Passaic River	Passaic	5,771
Passaic River	Saddle R	2,255
Raritan River	Raritan	8,032
Hudson River	Norman K	1
Hudson River	Mooorden	1
Hudson River	Esopus C	20
Hudson River	Wallkill	41
Hudson River	Wappinge	9
Hudson River	Croton R	8
Hudson River	Sawmill	6
Hudson River	Catskill	10
Passaic River	1392500.1	1,396
Elizabeth River	1393450.1	1,206
Passaic River	110.1	4,483
Passaic River	120a.d	1,195
Raritan River	23.1	1,306
	Total River	**39,323**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**

Hackensack River	146.d	0
Hackensack River	151.d	0
Hackensack River	152.d	5,186
Hackensack River	160.d	0
Hackensack River	BerrysCka.	478
Hudson River	Hudson1.1	2,639
Hudson River	Hudson2.1	2,756
Newark Bay	82b.1	0
Newark Bay	NewarkBay1	1,565
Overpeck Creek	165.1	0
Passaic River	104.1	4,490
Passaic River	111.d	102
Passaic River	115.d	99
Passaic River	124.1	0
Passaic River	80.1	0
Passaic River	99.1	154
Passaic River	Frank's Cr	12
Raritan River	12a.d	6,456
Raritan River	14.1	390
Raritan River	18.d	3,793
Raritan River	31.d	9,540
Raritan River	7.1	0
Raritan River	9.d	6,499
Upper NY Bay	Hudson3.1	0
Raritan River	10.d	110
	Total Stormwater	**52,015**

River Discharges		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**
Hudson River	Hudson R	23,299
Hackensack River	Hackensa	128
Passaic River	Passaic	3,851
Passaic River	Saddle R	1,388
Raritan River	Raritan	7,377
Hudson River	Norman K	1
Hudson River	Mooorden	1
Hudson River	Esopus C	20
Hudson River	Wallkill	41
Hudson River	Wappinge	9
Hudson River	Croton R	8
Hudson River	Sawmill	6
Hudson River	Catskill	10
Passaic River	1392500.1	2,714
Elizabeth River	1393450.1	4,502
Passaic River	110.1	2,667
Passaic River	120a.d	2,264
Raritan River	23.1	1,188
	Total River	**49,474**

Dry-weather Loads		
Waterbody	**Outfall**	**Total Load (10^{12} cfu/Yr)**

Elizabeth River	Elizabeth	16
Hackensack River	Hackensack	67
Passaic River	Passaic	30
Raritan River	Raritan	16
	Total Dry Load	129

WWTP Discharges		
Waterbody	Outfall	Total Discharge (MG/Yr)
Upper NY Bay	PVSC	77,727
Hackensack River	BCUA001	27,997
Arthur Kill	JMEUC	21,570
Raritan River	NJ0020141	39,372
Hudson River	NHSA001	2,530
Hudson River	Woodcliff	1,062
Hudson River	NHSA002	5,265
Hudson River	NJ0020591	1,087
Arthur Kill	NJ0024643	9,190
Arthur Kill	NJ0024953	4,471
Hackensack River	NJ0025038	1,121
Hackensack River	NJ0034339	2,206
	Total WWTP	193,599

Totals by Waterbody		
Waterbody	Outfall	Total Discharge (MG/Yr)
Arthur Kill		80,088
Elizabeth River		9,192
Hackensack River		70,286
Hudson River		15,135,443
Kill Van Kull		431
Newark Bay		3,217
Passaic River		359,735
Raritan River		442,621
Upper NY Bay		78,199

Totals by Source		
Source	Outfall	Total Discharge (MG/Yr)
CSO		7,804
Storm		117,794
River		15,861,188
Dry		129
WWTP		193,599

Totals by Source by Waterbody		
Waterbody	Source	Total Discharge (MG/Yr)
Arthur Kill	CSO	227
	Storm	44,630
	River	0
	Dry	0
	WWTP	35,231

Elizabeth River	Elizabeth	2,500
Hackensack River	Hackensack	10,100
Passaic River	Passaic	4,620
Raritan River	Raritan	2,370
	Total Dry Load	19,590

WWTP Discharges		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	PVSC	147
Hackensack River	BCUA001	53
Arthur Kill	JMEUC	41
Raritan River	NJ0020141	74
Hudson River	NHSA001	5
Hudson River	Woodcliff	2
Hudson River	NHSA002	10
Hudson River	NJ0020591	2
Arthur Kill	NJ0024643	17
Arthur Kill	NJ0024953	8
Hackensack River	NJ0025038	2
Hackensack River	NJ0034339	4
	Total WWTP	366

Totals by Waterbody		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill		13,421
Elizabeth River		14,800
Hackensack River		52,755
Hudson River		80,122
Kill Van Kull		5,736
Newark Bay		13,929
Passaic River		63,159
Raritan River		42,940
Upper NY Bay		13,091

Totals by Source		
Source	Outfall	Total Load (10^{12} cfu/Yr)
CSO		149,505
Storm		57,669
River		72,823
Dry		19,590
WWTP		366

Totals by Source by Waterbody		
Waterbody	Source	Total Load (10^{12} cfu/Yr)
Arthur Kill	CSO	4,131
	Storm	9,224
	River	0
	Dry	0
	WWTP	67

Elizabeth River	Elizabeth	421
Hackensack River	Hackensack	1,700
Passaic River	Passaic	779
Raritan River	Raritan	400
	Total Dry Load	3,300

WWTP Discharges		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	PVSC	29
Hackensack River	BCUA001	11
Arthur Kill	JMEUC	8
Raritan River	NJ0020141	15
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	NJ0020591	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
	Total WWTP	73

Totals by Waterbody		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill		23,184
Elizabeth River		5,683
Hackensack River		14,750
Hudson River		38,099
Kill Van Kull		2,518
Newark Bay		10,199
Passaic River		44,182
Raritan River		55,389
Upper NY Bay		3,736

Totals by Source		
Source	Outfall	Total Load (10^{12} cfu/Yr)
CSO		52,102
Storm		102,942
River		39,323
Dry		3,300
WWTP		73

Totals by Source by Waterbody		
Waterbody	Source	Total Load (10^{12} cfu/Yr)
Arthur Kill	CSO	1,484
	Storm	21,687
	River	0
	Dry	0
	WWTP	13

Elizabeth River	Elizabeth	1,560
Hackensack River	Hackensack	6,320
Passaic River	Passaic	2,880
Raritan River	Raritan	1,480
	Total Dry Load	12,240

WWTP Discharges		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Upper NY Bay	PVSC	29
Hackensack River	BCUA001	11
Arthur Kill	JMEUC	8
Raritan River	NJ0020141	15
Hudson River	NHSA001	1
Hudson River	Woodcliff	0
Hudson River	NHSA002	2
Hudson River	NJ0020591	0
Arthur Kill	NJ0024643	3
Arthur Kill	NJ0024953	2
Hackensack River	NJ0025038	0
Hackensack River	NJ0034339	1
	Total WWTP	73

Totals by Waterbody		
Waterbody	Outfall	Total Load (10^{12} cfu/Yr)
Arthur Kill		10,348
Elizabeth River		11,144
Hackensack River		34,999
Hudson River		46,546
Kill Van Kull		3,771
Newark Bay		9,648
Passaic River		47,027
Raritan River		38,691
Upper NY Bay		8,300

Totals by Source		
Source	Outfall	Total Load (10^{12} cfu/Yr)
CSO		96,671
Storm		52,015
River		49,474
Dry		12,240
WWTP		73

Totals by Source by Waterbody		
Waterbody	Source	Total Load (10^{12} cfu/Yr)
Arthur Kill	CSO	2,677
	Storm	7,658
	River	0
	Dry	0
	WWTP	13

Elizabeth River	CSO	754
	Storm	0
	River	8,422
	Dry	16
	WWTP	0
Hackensack River	CSO	1,227
	Storm	13,645
	River	24,024
	Dry	67
	WWTP	31,324
Hudson River	CSO	1,252
	Storm	5,750
	River	15,118,497
	Dry	0
	WWTP	9,944
Kill Van Kull	CSO	431
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	995
	Storm	2,222
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	2,202
	Storm	10,852
	River	346,650
	Dry	30
	WWTP	0
Raritan River	CSO	244
	Storm	39,393
	River	363,596
	Dry	16
	WWTP	39,372
Upper NY Bay	CSO	472
	Storm	0
	River	0
	Dry	0
	WWTP	77,727

Elizabeth River	CSO	7,598
	Storm	0
	River	4,702
	Dry	2,500
	WWTP	0
Hackensack River	CSO	35,701
	Storm	6,733
	River	161
	Dry	10,100
	WWTP	59
Hudson River	CSO	27,589
	Storm	5,821
	River	46,692
	Dry	0
	WWTP	19
Kill Van Kull	CSO	5,736
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	12,241
	Storm	1,688
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	40,785
	Storm	5,327
	River	12,427
	Dry	4,620
	WWTP	0
Raritan River	CSO	2,780
	Storm	28,875
	River	8,840
	Dry	2,370
	WWTP	74
Upper NY Bay	CSO	12,944
	Storm	0
	River	0
	Dry	0
	WWTP	147

Elizabeth River	CSO	4,056
	Storm	0
	River	1,206
	Dry	421
	WWTP	0
Hackensack River	CSO	9,930
	Storm	3,033
	River	75
	Dry	1,700
	WWTP	12
Hudson River	CSO	8,875
	Storm	15,617
	River	13,603
	Dry	0
	WWTP	4
Kill Van Kull	CSO	2,518
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	5,670
	Storm	4,529
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	14,502
	Storm	13,800
	River	15,101
	Dry	779
	WWTP	0
Raritan River	CSO	1,360
	Storm	44,276
	River	9,338
	Dry	400
	WWTP	15
Upper NY Bay	CSO	3,707
	Storm	0
	River	0
	Dry	0
	WWTP	29

Elizabeth River	CSO	5,082
	Storm	0
	River	4,502
	Dry	1,560
	WWTP	0
Hackensack River	CSO	22,784
	Storm	5,754
	River	128
	Dry	6,320
	WWTP	12
Hudson River	CSO	17,752
	Storm	5,395
	River	23,394
	Dry	0
	WWTP	4
Kill Van Kull	CSO	3,771
	Storm	0
	River	0
	Dry	0
	WWTP	0
Newark Bay	CSO	8,083
	Storm	1,565
	River	0
	Dry	0
	WWTP	0
Passaic River	CSO	26,407
	Storm	4,856
	River	12,885
	Dry	2,880
	WWTP	0
Raritan River	CSO	1,844
	Storm	26,787
	River	8,565
	Dry	1,480
	WWTP	15
Upper NY Bay	CSO	8,270
	Storm	0
	River	0
	Dry	0
	WWTP	29