Major Comments:

1. **DEC Comment: Ribbed Mussels.** [Note: The overall text of DEC's comment on Ribbed Mussels contains a number of specific points to which DEP has responded below. The specific points in DECs comment, as identified by DEP, are highlighted in the text below, and provided with a superscript letter that keys to the specific DEP response.] Under the selected alternative, the City has proposed construction of ribbed mussel beds in both Bergen and Thurston Basins to reduce bacterial load from CSOs and storm water discharges to these waterbodies. Ribbed mussels have not been considered under any other LTCP and represent a novel yet unproven technology. The ribbed mussel beds are the primary component of the selected alternative that will be used to reduce bacterial loads to both Basins (the other components have no or negligible impact on water quality) and the analysis presented in Appendix D assumes that the ribbed mussels will remove 10 percent of the bacterial load in the waterbodies. Based on that assumption, attainment levels in the Basins for the fecal coliform water quality standard will improve by up to 5 percent on an annual and recreational season basis.

   At present, the Department is reluctant to accept the City's analysis of the ribbed mussel performance. The information provided in Appendix D of the LTCP does not support the 10 percent removal efficiency assumption and a review of existing research on ribbed mussels by the Department did not reveal a solid basis for assuming a 10 percent removal efficiency either. [A]<u>Overall, the existing research indicates that ribbed mussels are capable of filtering particles from water columns, including plankton, organic matter, and bacteria. However, specific research on the use of ribbed mussels to remove fecal coliform in-situ is very limited.</u> Moreover, the research conditions differed notably from what will be experienced in Bergen and Thurston Basins, which will be year-round, submerged deployment of very dense mussel beds in ambient waters with intermittent high volume flows of CSOs and stormwater.

   Overall, the very limited available bench-top arid small scale field-level research on the use of mussels for fecal coliform removal is insufficient to make a leap to full-scale engineering application with significant assumptions on bacterial removal and improvements in water quality. As such, implementation of the ribbed mussel project needs to include further assessment steps leading from planning and bench scale studies to a large-scale field study prior to proceeding to a full scale engineered application. The Department offers the following conceptual outline for an overall research and planning process to include ribbed mussels in the proposed alternative that provide a solid basis for full scale application and water quality benefits:

Research and Planning Process

- [B]First, the City must develop a method or system for reliably culturing a large number of mussels for the mussel beds. The City has estimated it will need about 50 million mussels for the mussel beds but the LTCP does not provide any information on where the mussels will be obtained. According to the Department's Marine Resources experts, the mussels cannot be taken from adjacent marshes as they are integral to the marshes function and help to hold marsh peat in place. Although some research has been undertaken on culturing ribbed mussels, the state of that science is not sufficient to produce the quantity of mussels needed for the City's full-scale project. As the City is probably aware, one of the findings from the small-scale study by Galimany, et al. (2017)[1] that examined the use of mussels for bioextraction in the Bronx River estuary was that "[s]pat collection efforts from shore and within the water column were unsuccessful; this was identified as a key bottleneck to future large-scale implementation." Thus, a first key step is developing a reliable method for culturing the mussels.

- [C]Once the City has established a method for culturing the mussels, it must undertake studies to confirm that the mussels are capable of removing fecal coliform via lab bench-top studies, including cytometry filtration and aquaculture studies. This phase should also include experiments to determine actual removal efficiencies for the mussels under conditions likely to be experienced in the field. Building on these bench-top tests, the City will then need to undertake mesocosm-level experiments to simulate field conditions.

- [D]Following bench-top and mesocosm-level experiments, the City must undertake an in-situ pilot study (in accordance with all applicable laws and regulations). The in-situ study should be used to identify the key design factors that influence the performance of the mussel beds in filtering the targeted bacteria, including location within the waterbody, design of the placement of the mussels, mussel size and filtering capacity, waterbody retention times, existing water quality and particulate size, types of bacteria encountered, and mussel survivability and die off over time. The results from the various experiments and studies should be used to further develop appropriate models to represent the mussels and these models should be peer reviewed.

- [E]Finally, based on in-situ study results, the City will need to consider measures to be taken to minimize bird attraction. The City eliminated from consideration tidal wetland/marsh restoration near the airport due to potential hazards from birds with aircraft. A subtidal deployment of ribbed mussels would presumably avoid bird attraction but would need to remain submerged even at low tide. Any infrastructure (rafts, racks, etc.) used to maintain the mussels sub-tidally must also be subtidal.

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[1] Eve Galimany, Gary H. Wikfors, Mark S. Dixon, Carter R. Newell, Shannon L. Meseck, Dawn Henning, Yaqin Li, and Julie M. Rose (2017). Cultivation of the Ribbed Mussel (Geukensia demissa) for Nutrient Bioextraction in an Urban Estuary. *Environmental Sc/ence* A Dec/ono/opt, 51, 13311-13318.

If the mussel bed will be intertidal, it would be exposed and needs to be outfitted with effective bird deterrents as birds are known to aggregate in large numbers to floating gear used for shellfish farming, or to any other structure that offers a perch in a marsh or estuary. Birds also result in additional fecal coliform loads, so their presence needs to be minimized for that reason as well.

In sum, for the ribbed mussel component of the selected alternative, the City needs to include a plan to undertake a series of experiments and studies that will gradually build upon each other and establish a solid basis for the design of a full-scale engineered application of ribbed mussels for improving water quality in Bergen and Thurston Basins. This plan should outline the major phases of research and study, including timeframes and milestones, and culminating in the submittal of an approvable engineering report. The approvable engineering report shall include any recommendations for full-scale application and updated projections on water quality impacts.

Until the City presents and commits to complete a more comprehensive process for confirming the performance of the mussels as outlined above, including submission of an engineering report for the full-scale application, the Department cannot approve a full- scale engineered application of the ribbed mussels as a primary component of the LTCP. The Department is not opposed to the use of ribbed mussels for reducing bacterial load in the Basins, but feels it would be premature to approve construction of the mussel beds without first validating their performance, including their ability to filter high volumes of CSO, with peak flows as high as 555 MGD in Bergen Basin, within short periods of time.

Based on the foregoing, [F]<u>the City must provide a more detailed description and schedule in the LTCP for conducting a planning and research process</u> as outlined above to validate the performance of mussel beds, rather than proceeding to full-scale implementation. The process must include the [G]<u>submittal of an approvable engineering report documenting the basis for the design of the full-scale application along with projected water quality improvements</u>. For assessment purposes under the LTCP analysis, a zero percent removal efficiency should be assumed for the ribbed mussels until the planning and research process is completed. Lastly, to better understand the assumptions made in the Appendix D analysis, the City must provide a [H]<u>copy of the engineering analysis completed to size the ribbed mussel beds presented in Figures 8-10 and 8-17.</u>

DEP Response: *DEP acknowledges the complexities of installing and cultivating ribbed mussel colonies within Bergen Basin and Thurston Basin at such a large scale; challenges to restoring marsh islands within Jamaica Bay were also encountered but were ultimately resolved. The discussion below addresses the comments provided by DEC and outlines the strategy and collaborative research efforts proposed by DEP to achieve the 10% reduction in bacterial concentrations in Bergen and Thurston basins through ribbed mussel deployment as targeted in the Jamaica Bay and Tributaries LTCP. The discussion focuses specifically on:*

- *Completed literature review to showcase impressive filtration capabilities*
- *Completed initial bench scale experiments to confirm literature review*
- *Proposed lab and in-situ experiments of increasing complexity, simulating the conditions of Bergen and Thurston Basins, to inform the design of full-scale engineering application*
- *Timeframes and milestones for completing proposed experiments, culminating in the submittal of an approvable engineering report*
- *Studied cultivation techniques and secured partnerships with multiple hatcheries for spawning large mussel populations*

Discussion of Completed Research

Literature Review

A

DEP has completed a literature review to explore and confirm the water filtration capabilities of ribbed mussels. Papers that were referenced include research studies on the general biology and ecology of ribbed mussels and other similarly functioning bivalves, filtration capabilities that focused on bacteria uptake, and aquaculture techniques for spawning mussels. General takeaways from the compilation of this research show the ***extensive filtration capabilities of ribbed mussels, pointedly to their abilities to filter smaller particle sizes in the range of fecal coliform****, and these studies would be used to direct a series of lab experiments to inform the ultimate design of the proposed deployment. Between the compilation of literature and results of preliminary bench-scale testing, the City believes that* ***a 10% removal efficiency is a conservative estimate*** *and is eager to explore the range of possibilities of this biofiltration system.*

An extensive array of research literature exists focusing on the ecological role of the ribbed mussel. To contextualize this data within the localities of interest, DEP reviewed several papers that examined ribbed mussel populations in Jamaica Bay (Franz, 1993, 1997, and 2001) and in a subtidal setting in the Bronx River Estuary at Hunts Point (Galimany et al. 2013a and b, 2017), another highly eutrophic, urban waterbody. The natural presence of the mussel populations in these waterbodies, combined with the aforementioned studies, ***demonstrate the suitability of the proposed waterbodies to accommodate the large-scale engineering application of ribbed mussels****.*

A few notable studies have been conducted looking specifically at the filtration of bacteria by ribbed mussels. Based on these papers, (Kemp et al. 1990, Langdon and Newell 1990, Newel and Krambeck 1995, Riisgard 1988, and Wright et al 1982) it has become accepted that ribbed mussels are capable of filtering out smaller particles (<2µm) with greater efficiency than other species such as oyster and clam, with ***efficiency rates as high as 86%****. Wright et al. (1982) also analyzed the gill structure of ribbed mussel in comparison with other bivalve species and inferred that the structural differences are what enables the ribbed mussel to filter out particles as small as 0.2µm in size. Kemp et al. (1990) looked at the ranges of mussel size classes and how their filtration rates changed in response to different particle size. Other studies, as noted above, also corroborated the findings of Wright et al. and examined how the bacteria were* *being removed by the ribbed mussel. A table of particle sizes and associated efficiency rates for various studies can be seen below in* ***Table 1****.* ***These studies are invaluable in demonstrating the efficacy of ribbed mussels in the proposed application and would help to form the design of microcosm bench-top testing, mesocosm lab testing, the in-situ pilot study, and the full-scale engineering application.***

Table 1 Filtration Efficiency Rates of Specific Particle Sizes from Literature Review

Reference	Particle Size[1]	Efficiency
Langdon & Newell (1990)	< 2 µm	15.8%
Newell & Krambeck (1995)	Not specified	30-35%
Riisgard (1988)	2 µm	70%
Wright et al (1982)	0.2-0.4µm	30%
	0.4-0.6µm	86%

[1] *For comparison, E. coli ranges in size from 1-3 µm and Enterococcus ranges in size from* 1-2.5 µm*.*

A study by Bernard (1989) was influential and informative as it studied metrics and variables that were directly related to preliminary bench-scale testing completed in a joint effort by Cornell Cooperative Extension (CCE) and Stony Brook University (SBU). Bernard looked at the capabilities of various species of bivalve in filtering E. coli specifically, and included water temperature as a variable to observe the trends of filtration. It is important to note that while this west-coast study was conducted with bivalves native to the Pacific Northwest including the blue mussel, Mytilus edulis, the research of Wright et al. (1982) documented that the ribbed mussel gill structure has a greater density of gill filaments than the blue mussel and is likely to filter out E. coli more effectively.

The compilation of these studies serves to confirm ***that ribbed mussels have been looked to as an efficient and effective biofiltration method for decades*** *and infers that filtration rates could far exceed what has been displayed in deployments of other bivalve species in similar efforts. These studies have informed and propelled the next step of lab testing that will be used to design the full-scale engineering application of ribbed mussels in Thurston and Bergen basins.*

Completed Laboratory Experiments

A multi-phased approach has been proposed to further the study of water filtration with ribbed mussels and inform the design of the full-scale engineering application; Initial bench scale testing has already been completed.

The initial bench scale experiments focused on determining the filtration of E. coli bacteria by the ribbed mussel using small-scale laboratory experiments to identify baseline levels of clearance rates. Once prepped, a single mussel was suspended in 12 separate 2 L replicate beakers containing 1600 mL of filtered and sterilized seawater. Two additional treatments were tested as controls: (A) live ribbed mussel with no bacteria to provide a reference for *filtration capabilities and test whether or not natural levels of bacteria may have been introduced by the ribbed mussels themselves, and (B) empty ribbed mussel shell with the same bacterial introduction as the experimental beakers to identify whether or not the bacterial loads and microcapsule concentration in experimental containers change over time as a result of particle settling and bacteria natural multiplication or decay, if any.*

The design of the initial bench scale experiments was set up in a way to isolate and capture the experience of (1) a pulsed addition of bacteria (to simulate a CSO flow), (2) a constant flow of bacteria (to simulate normal tidal flow), and (3) the combination of constant flow and pulsed bacteria. *This last experiment's settings most closely mimic the relationship of mussels and bacteria in the vicinity of a CSO outfall. The results of these experiments displayed E. coli removal efficiency rates at 88% for experiment (1), and 62% for experiments (2) and (3). While this testing was acknowledged by all to be a preliminary, isolated experiment without hydrodynamic engineering controls, it served to confirm the impressive filtration capabilities of these bivalves and verify some of the filtration efficiencies as per the literature on similarly sized particles in the range of fecal coliform (<2 µm). With the acknowledgement of the contact time and other variable distinctions between bench-top testing and the full-scale engineering application,* ***the 62-88% removal efficiency results far exceed the 10% removal efficiency that was proposed as part of the Jamaica Bay and Tributaries LTCP****. This experiment also provided a baseline framework to move forward with further experiments that include the addition of a host of variables that are key physical and biological components of the proposed field setting.*

C

Discussion of Scale-Up Strategies

As highlighted by DEC, "the City needs to include a plan to undertake a series of experiments and studies that will gradually build upon each other and establish a solid basis for the design of a full-scale engineering application of ribbed mussels for improving water quality in Bergen and Thurston Basins." Accordingly, DEP is proposing a comprehensive series of experiments guiding the scale up towards a full-scale deployment of ribbed mussels in Bergen and Thurston basins. These series of experiments consist of additional microcosm experiments (bench top tests), mesocosm experiments to simulate field conditions, and an in-situ pilot study as recommended by DEC. Data and results gathered from these studies will be used to shape the design of the full-scale engineering application. ***Figure 1*** *presents the overall plan, sequencing, and expected outcomes from the laboratory to the field.* ***Throughout this process, regular meetings and workshops will be scheduled with interested stakeholders and DEC so that decisions are made collaboratively.***

Microcosm Bench-Top Experiments

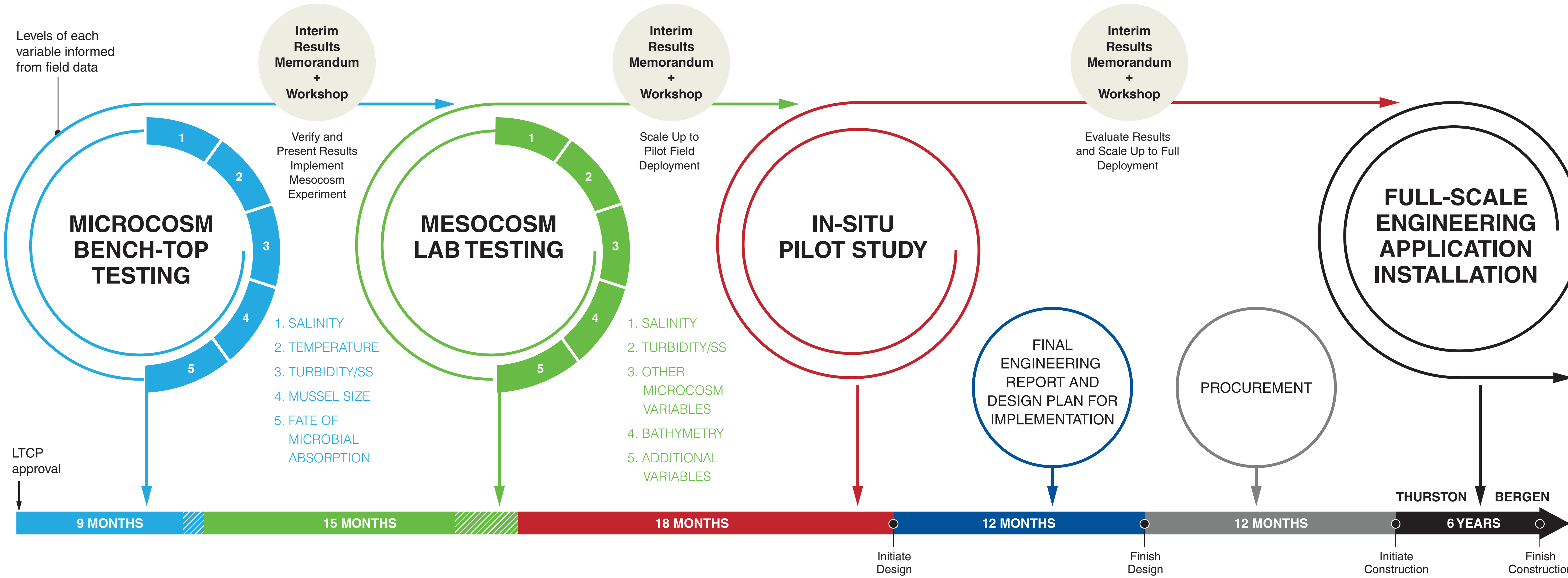
*Additional microcosm experiments would be conducted prior to and in concurrence with mesocosm experiments to study the effects of individual variables on the filtration capabilities of ribbed mussels (****see Table 2****). These variables include:*

- *temperature*
- *salinity*

Scale-Up Strategies For Full-Scale Engineering Application of Ribbed Mussels

DEP is proposing a comprehensive series of experiments guiding the scale up towards a full-scale engineering application of ribbed mussels in Bergen and Thurston basins. Periodic workshops would be held, concurrent with the studies, throughout the entire timeline.

Development of Interim Results Memorandum



MICROCOSM

- Purpose of Microcosm (lab) experiments is to study the effects of individual variables on the filtration efficiency of ribbed mussels.
- Test individual variables in isolated setting.
- Will inform design of Mesocosm experiments.

MESOCOSM

- Establish the flowrates and retention times to replicate the bathymetry and hydrodynamics of Bergen/Thurston basins.
- Vary the salinity and turbidity to emulate the ambient and CSO events to inform the placement of mussels.

IN-SITU

- Will take results of Microcosm and Mesocosm experiments and will verify filtration rates in similar site conditions (including all environmental/water quality variables).
- Additionally, mussels will be installed in cages to document the adaptability, recruitment, and mortality within Bergen and Thurston basins.

INSTALLATION

- Mussels would be installed in stages throughout the six years, achieving the full complement of mussels by the end of the proposed timeline.
- Thurston Basin would be completed first, followed by Bergen Basin.

Environmental Protection

Figure 1

- *turbidity*
- *mussel size*
- *fate of microbial absorption (composition of feces and pseudofeces for E. coli assimilation)*

Each of these variable parameters would be determined by site conditions at Bergen and Thurston basins. *To start, three levels of each variable would be tested to determine if a strong correlation appears between the variable and mussel filtration rates. For any variables that could be altered through the design of the full-scale engineering application, a feedback loop would be established to determine if additional levels should be tested at the microcosm scale (**see Figure 2**). Bacteria strains will include Escherichia coli (E. coli) and a lab-safe strain of Enterococcus.*

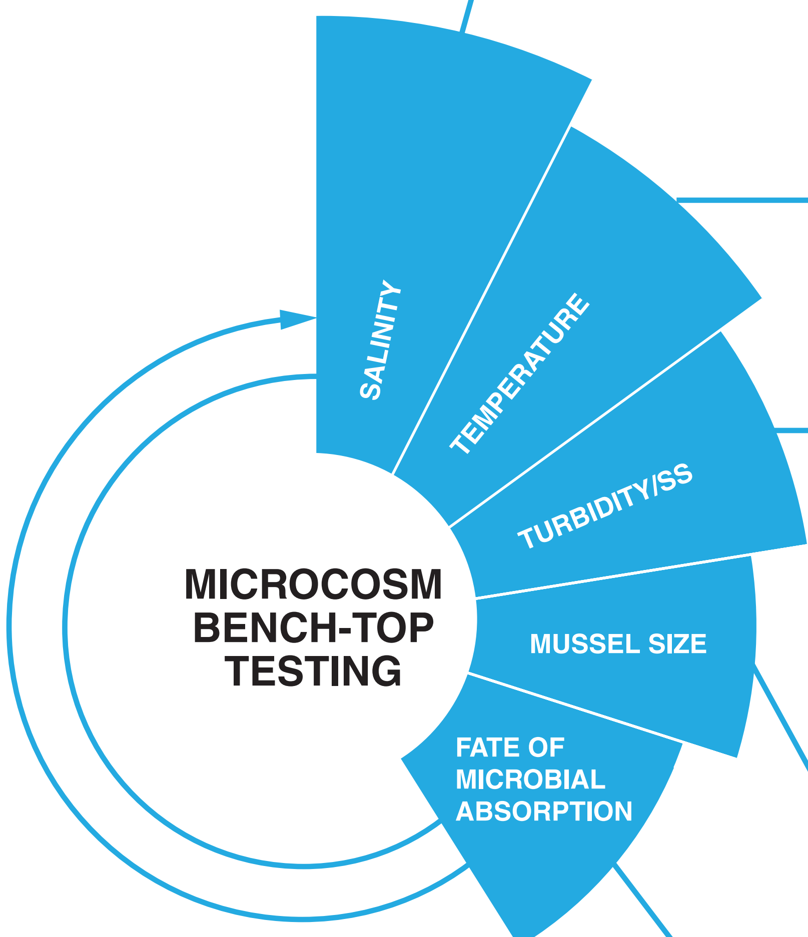
Table 2 Microcosm Experiment Variables and Implications

Microcosm Parameter	**Variables**	**Implications**	**Impact Design? (Full-scale engineering application)**
Salinity	10th percentile* 50th percentile* 90th percentile*	Define lower limit efficacy and establish efficiency pattern	Yes
Temperature	10th percentile** 50th percentile** 90th percentile**	Define lower limit efficacy and establish efficiency pattern	No
Turbidity/SS	10th percentile* 50th percentile* 90th percentile*	Define upper limit efficacy and establish efficiency pattern	Yes
Mussel Size	30mm 50mm 70mm	Establish mussel size in relation to particle size filtration and efficiency	Yes
Fate of Microbial Absorption	None	Will speak to feasibility of experiment	No
***As defined by Bergen and Thurston Harbor Survey Data from 2015-2017** ****As defined by Bergen and Thurston Harbor Survey Data from 2015-2017 during recreational months only**			

*For **salinity**, tests would include three percentile levels determined by data gathered from Bergen and Thurston basins. These percentiles would capture salinity concentrations that would be lowered, as it would following a CSO event both close to the outfall and further out in the basin, and would be complemented by the average salinity of the basin during the*

Microcosm Bench-Top Experiments

Microcosm experiments will be conducted to study the effects of individual variables on the filtration capabilities of ribbed mussels in a laboratory setting. Each of these variable parameters would be determined by site conditions at Bergen and Thurston basins.



FACTORS	SAMPLES	RESULTS
SALINITY Expect that this could be a significant factor, which would affect placement and engineering applications for field deployment	• 10th percentile (from field data) • 50th percentile (from field data) • 90th percentile (from field data)	Establish lower limit efficacy Strong pattern Does not have a strong pattern Test additional concentrations
TEMPERATURE Not expected to be a significant factor, however, at lower temperatures the filtration efficiency may be reduced. Establish performance under range of ambient temperatures capturing the recreation season.	• 10th percentile (from field data during recreation season) • 50th percentile (from field data during recreation season) • 90th percentile (from field data during recreation season)	Establish lower limit efficacy
TURBIDITY/SS Define impact of turbidity/ss on ribbed mussel filtration efficiency. Study the sensitivity towards different ratios of organic and inorganic particulate matter. Identify any upper thresholds that render the filtration ineffective. The results from this would inform the placement and design of the full-scale deployment.	• 10th percentile (from field data) • 50th percentile (from field data) • 90th percentile (from field data)	High organic/ Low inorganic High inorganic/ Low organic Strong pattern Does not have a strong pattern Test additional concentrations Establish upper level efficacy
MUSSEL SIZE Will only govern how we will deploy mussels. Three specific sizes tested at microcosm scale	• 30mm • 50mm • 70mm	
FATE OF MICROBIAL ABSORPTION Will speak to feasibility of the proposed full-scale deployment and will inform the modeling of water quality benefits. Will only be tested in microcosm.		

MESOCOSM LAB TESTING

recreational season (May 1st to October 31st) as a point of comparison. Results of these tests would aid in the determination of the ideal placement of the full-scale engineering application in regards to distance from the CSO outfall and the anticipated physiological response of the ribbed mussels.

*Tests on **temperature** would be similarly designed using three percentile levels determined by field data, however, these data would be isolated to include only logged temperatures during the recreational season (May 1st to October 31st). While the results of this experiment would not affect the overall design of the full-scale engineering application, the variable temperature experiments would enhance the resolution of expected efficiency rates, which are expected to be above the 10% removal rate.*

*Tests on **turbidity** levels would also include three percentile levels but would be further broken down to isolate different combinations of turbidity particulate matter. Different mixes of organic and inorganic suspended solids will be tested, as it is understood that every CSO flow is unique. The results from this experiment will define the upper limit efficacy of the ribbed mussels in response to a turbid CSO flow and would inform the ideal distance from the outfalls of the full-scale design in both basins.*

*Three different **mussel sizes** would be tested at the microcosm scale to determine the overall filtration capacities of mussels at different life stages. It is also expected that smaller sized mussels are capable of filtering smaller particulate matter due to their gill structure, so these experiments would serve to further that understanding. The results of these experiments would implicate the design of the full-scale engineering application in facilitating the stage at which the mussels would be moved from the hatcheries to the field site.*

C

*Microcosm bench top experiments would also be conducted to look at the **fate of microbial absorption**. While this test would not hold implications for the design of the final engineering application, it is necessary in understanding the cycle and final fate of the bacteria, and would address the feasibility of the overall experiment and guide the subsequent larger-scale experiments.*

After the completion of microcosm bench-top experiments, a detailed report including an analysis of results will be prepared to provide the basis of design for the mesocosm experiments. A workshop will also be scheduled to discuss results and strategy with DEC and other stakeholders. It is expected that further resolution may be needed for specific parameters that would weigh heavily on the design of the full-scale engineering application. As needed, these additional microcosm experiments will be conducted simultaneously with mesocosm experiments.

Mesocosm Experiments

*Once the preliminary results of the microcosm tests are produced, the mesocosm experiments would be carried out. **Designs for a large, custom built mesocosm setup are progressing and***

include features such as bathymetry, flow rates, and retention times all scaled proportionately from data gathered at Bergen and Thurston basins. *3D printing options based on NOAA navigational charts are being considered to accurately capture cross sections of the bathymetry of each basin. Experiments in the custom-built, flume system would involve multiple key variables at levels informed from microcosm results.*

The purpose of these mesocosm tests is to develop specific design parameters by isolating independent variables in a laboratory setting. As the middle step of the scale up strategy, these experiments will bring the field conditions into the laboratory. Data from Bergen and Thurston basins will be run through existing engineering models to develop the flow rates and retention times that will be represented in the mesocosm set-up. Ultimately, as discussed in the following scale-up step, these experiments will be replicated in the in-situ pilot study to verify the results in the actual field conditions.

As seen in ***Figure 3,*** *mesocosm experiments would be carried out in three rounds, first to expose the microcosm variables in conjunction with the site-specific bathymetry while varying the retention times and flow rates. The retention times and flow rates would be developed using existing models and data to map the hydrodynamics of Bergen and Thurston basins. The next mesocosm experiment would keep the retention times and flow rates constant while varying the turbidity and salinity. Isolating these parameters would determine the expected efficacy and efficiency at the flow rates and retention times during ambient and CSO events, and would hold valuable information for the design of the full-scale engineering application, which could be widely varied based on its placement in each basin. The third round would include testing the positioning of mussels in different locations and physical orientations in the modeled systems to optimize bacterial uptake under the replicated hydrodynamics of Bergen and Thurston basins.*

Again, similar to the completion of the microcosm bench-top testing, a detailed analysis report will be prepared to present the findings from the mesocosm experiments and discuss how they will impact the full-scale engineering application of ribbed mussels in Bergen and Thurston basins. A workshop will also be conducted with DEC and other stakeholders to inform the implementation of the in-situ pilot testing and the full-scale engineering application.

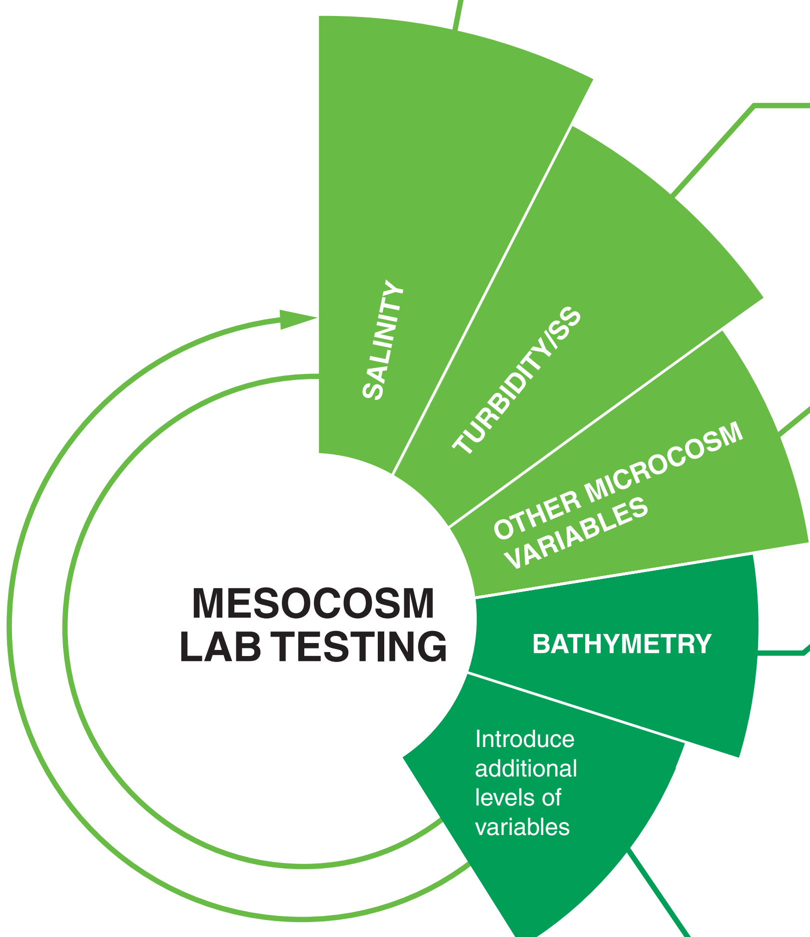
In-situ Pilot Study

*The next phase of experimental testing toward final design would be to design an in-situ pilot study (****see Figure 4)****. The primary objective of the in-situ pilot study would be to replicate and verify the filtration rates and bacterial removal rates achieved in the mesocosm (lab) testing in Bergen and/or Thurston basins. Based on the prior mentioned literature review, experimental flow-through systems or other similar installations will be evaluated to isolate the inflow and outflow to test for removal efficiency and would include parallel setups within the aforementioned basins as well as control setups with no mussels. These parallel setups with isolated inflow and outflow would provide verifiable results and a much better understanding of the quantifiable water quality benefits that can be scaled up to represent the*

Mesocosm Laboratory Experiments

MICROCOSM MESOCOSM IN-SITU

Using the results of the microcosm laboratory experiments, these tests will expose the ribbed mussels to modeled conditions replicating the conditions at Bergen and Thurston basins.



FACTORS	ROUND 1	ROUND 2	ROUND 3
SALINITY Use conditions as defined by the microcosm experiments.	Constant	Vary	Constant
TURBIDITY/SS Will experiment with implementing a quick onset of high suspended solids to simulate CSO flow conditions to understand the length of time the mussel filtration ability is lessened.	Constant	Vary	Constant
OTHER MICROCOSM VARIABLES Use conditions as defined by the Microcosm experiments for other variables such as temperature and mussel size.	Constant	Constant	Constant
BATHYMETRY Will be a constant throughout experiment. Will use NOAA navigation charts and potentially 3D print technology to replicate the waterbody bathymetry.	Scaled Representation	Scaled Representation	Scaled Representation
FLOW RATE Based on field data replicating the hydrodynamics of the waterbodies.	Vary	Constant	Constant
RETENTION TIMES Based on field data replicating the hydrodynamics of the waterbodies.	Vary	Constant	Constant
PHYSICAL PLACEMENT/ ORIENTATION OF MUSSELS Will experiment with orientation of mussels within the waterbody using the scaled simulation.	Constant	Constant	Vary

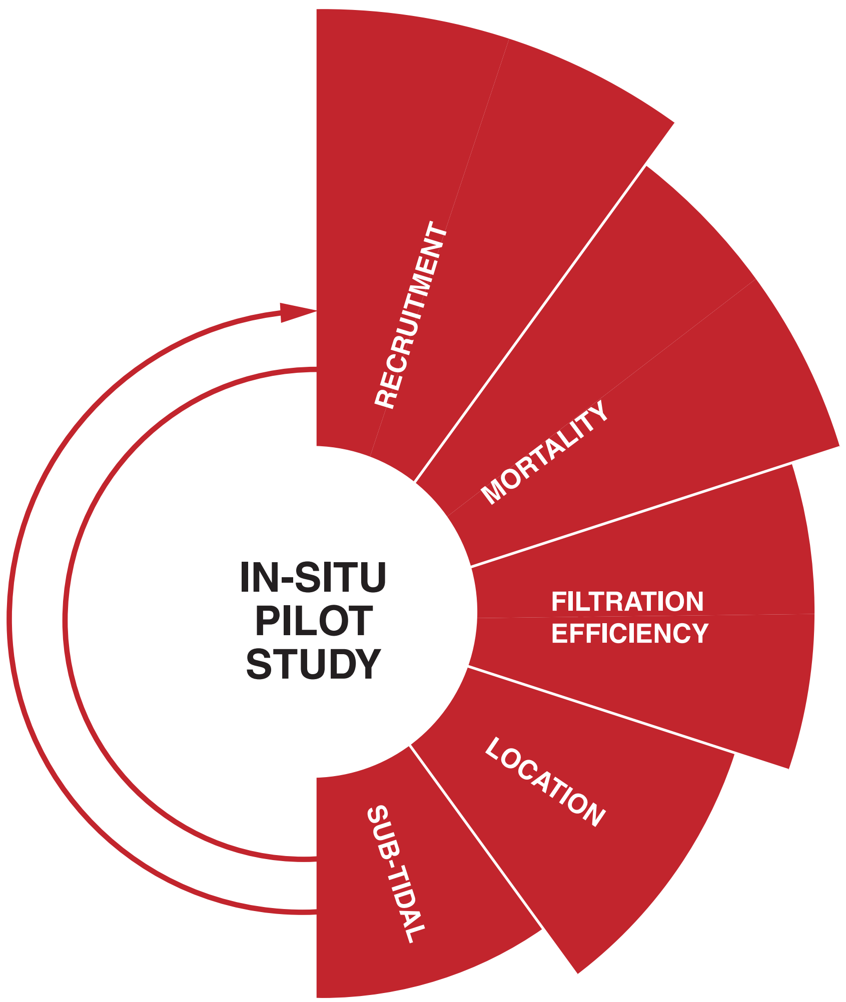
RESULTS

- We will establish the flowrates and retention times to simulate the conditions in Bergen and Thurston basins.
- We will verify the efficiencies at the various flowrates and retention times.
- Following that we will also vary the turbidity and salinity to simulate the time variable patterns incorporating the hydrodynamics in the basins.
- We shall use the existing models and data to inform the experimental parameters.
- We will bracket the location range for deploying mussels within the water column.

→ **IN-SITU PILOT STUDY**

In-Situ Pilot Study Experiments

This phase of experimental testing towards final design would be to conduct in-situ testing using an experimental flow-through system installed in the waterbodies to verify the filtration and removal efficiencies.



- Will take results of micro and mesocosm experiments and will test filtration rates in site-specific conditions (all environmental/water quality variable combined).
- Will be done in limited areas of basin (one or both). At this point we will have a good understanding of expected results based on prior two phases, then in-situ serves as a check to the prior experiments

D

full-scale engineering application. Additionally, individual groups (lots) of mussels with varying ratios of juveniles to adults would be installed in cages or other structures as deemed appropriate and best for the practice to document adaptability and examine recruitment and mortality trends within Bergen and Thurston basins. ***These in-situ pilot studies, planned in either Bergen or Thurston Basins, would provide real-world simulations and would allow the testing of different locations and strategies for the full-scale engineering application****. This would also finalize the design basis and document the various environmental factors that would be considered and addressed as part of the full-scale engineering application.*

Throughout all testing on ribbed mussels, regular meetings between DEP and DEC would allow for informed decision making and collaborative progression of the proposed project.

Planning and Design for Full-Scale Development

E

Key design parameters for the full-scale engineering application would be informed by all prior experiment phases, as described above. Additionally, variables such as filtration capacity in relation to mussel size and mussel survivability will be explored to have a firm understanding of what maintenance and operations would be required once installation is complete. Concerns regarding bird attraction would be eliminated through the use of a sub-tidal deployment, which as an added benefit would maximize the effectiveness of filtration, both during CSO events and in ambient conditions. The subtidal deployment strategy will be introduced at the mesocosm scale, so results gathered from that phase of testing and replicated in the in-situ pilot will properly inform the full-scale engineering application. This will be achieved by using a similar channel flow system design that was used in a previous DEP experiment with oysters to determine nitrogen uptake using fluorometry measurements. As for options for housing the mussels, plastic mesh bags, oyster cages, and gabion cages are being explored and our recommendations will be documented in the approvable engineering report. Navigation issues and hazards will be evaluated as part of the design as needed.

H

The sizing of the mussel beds was developed using the information from the existing hydrodynamic model of Jamaica Bay and its tributaries (provided by HDR) on the volume of water that is exchanged within each basin for each tidal cycle. Knowing that volume for each tidal exchange and the filtering capacity of a single adult mussel to be 5.1 L/hour and assuming a medium-low density of 2,000 mussels per square meter produces the calculated number of acres needed to filter that entire water volume. It is important to note that the density of mussels in Jamaica Bay can reach 10,000 mussels per square meter, so 2,000 mussels per square meter is a very reasonable number.

$$\text{1 Mussel Filtration Capacity} = \frac{5.1\,L}{1\,hour} = \frac{61.2\,L}{\underset{(12\,hours)}{Tidal\ Cycle}} \rightarrow \frac{3{,}000{,}000{,}000\,L\,(apprx.)}{\underset{(Bergen\ and\ Thurston\ Basins)}{Tidal\ Cycle}} \approx \text{50,000,000 mussels}$$

$$50{,}000{,}000\ mussels \div \frac{2{,}000\ mussels\ (med - low\ density)}{1\ sq\ meter} = 25{,}000\ sq\ meters \approx 6.2\ acres \rightarrow rounded\ to\ 7\ acres$$

Following the interim results memoranda from the experimental phases, the estimated pathogen removal efficiencies will be refined. The initial 10% removal efficiency rate has been informed from multiple factors. First, as the mussel installations would be subtidal, the contact time of the bivalves would be 100%. Second, the number of mussels for the full-scale deployment was calculated to filter the full tidal cycle of Bergen and Thurston basins. And lastly, these details, paired with the literature review showing removal efficiency rates up to 86%, informed the decision of the conservative 10% removal efficiency rate. Furthermore, the final engineering report and design plan will include a knee-of-the-curve analysis to provide the highest water quality benefit with the lowest cost. Assuming the described experimental phases will serve to prove that ribbed mussel filtration rates are above 10%, this analysis will be used in consultation with DEC to inform the optimum number of mussels and their associated acreage for the deployment.

Timeframes and Milestones

The proposed timeline begins with the approval of the LTCP and ends with the full complement of mussels installed for the full-scale engineering application. First, microcosm bench-top testing would be initiated. This experiment phase would be carried out over a period of 9 months. The final month of the microcosm bench-top tests would be dedicated to producing an interim results memorandum, which would be disseminated to DEC and other stakeholders. Next, the mesocosm lab testing would be carried out over a period of 15 months, with an interim results memorandum produced in the final three months. The in-situ pilot study would follow and is expected to be carried out over 18 months. Following the in-situ pilot study, a detailed engineering report will be developed and DEP will initiate procurement prior to the start of construction. The report, produced over the course of 12 months, would document the basis for the design of the full-scale application along with projected water quality improvements. Construction procurement will be initiated following the DEC approval of the engineering report. The remaining six years would then be utilized for installation and deployment of the ribbed mussels for the full-scale engineering application. Installation would occur first in Thurston Basin, followed by Bergen Basin. Mussels would be installed in stages throughout the six years, ultimately achieving the full complement of mussels by the end of the proposed timeline.

*The milestone of initiating design would officially begin at the completion of the in-situ pilot study, however, preliminary designs have already commenced following the completion of initial bench-scale experiments. The final engineering design will be completed with the delivery of the final engineering report, and construction will be initiated following procurement. These schedule milestones are presented in **Figure 1**. Concurrent with the* *studies, periodic workshops would be held, quarterly or as needed, with DEC and other stakeholders.*

The full engineering design report will document the results of all experiments. Based on these results it will provide a basis of design including a set of input design parameters, detailed description of all environmental factors and a schedule of implementation for the full-scale engineering application. The design report will also include the projected water quality benefits for the full-scale application and document the mussel procurement and culturing strategy to reach the desired mussel numbers for the full-scale engineering application.

Initiatives for Culturing and Procuring Large Ribbed Mussel Populations

DEP agrees with DEC that the *first key step is developing a reliable method for culturing the mussels. Accordingly, Cornell Cooperative Extension (CCE) and Stony Brook University scientists have been developing methodologies on large scale cultivation techniques to ensure adequate stock is available per the proposed installation schedule. The research team will be refining multiple annual spawning cultivation techniques at CCE's hatchery, while simultaneously engaging other hatcheries in conversation on a collaborative spawning effort. In addition, CCE's newly constructed hatchery in Southold will enable for mass production of ribbed mussels once the cultivation techniques have been optimized. To achieve the full required population of ribbed mussels for the full-scale engineering application, a ramping-up strategy would be utilized where mussels would be installed in stages over the course of several years. This strategy is beneficial in many ways as it maximizes available square footage devoted to mussel cultivation at the participating hatcheries, diversifies the sizes of mussels in the field, and it allows for mussel recruitment. Additionally, this technique will provide a production buffer in case small numbers of larvae are produced from each spawn. The approach outlines the potential for consistent spawning to provide continuous batches for production.*

Collaborations with other hatcheries have already been established and these partnerships would allow for exponential spawning growth opportunities, as needed. They include the Aquatic Innovation Center (AIC) at Rutgers University and Martha's Vineyard Shellfish Group. Canvassing of additional facilities is ongoing, and the collection of partnerships is expected to produce an adequate supply of ribbed mussels for the proposed full-scale deployment. Some of the additional hatcheries include the Aquatic Research and Environmental Assessment Center (AREAC) at Brooklyn College, Roger Williams University in Rhode Island, and the Aquaculture Research Corporation in Massachusetts.

In summation, DEP has undertaken a significant effort to showcase the immense filtration capacity of ribbed mussel populations and is confident in the applicability of the proposed full-scale engineering application in reducing a conservative 10% of bacterial concentrations in Bergen Basin and Thurston Basin. DEP looks forward to frequent communication and requests for feedback from DEC throughout the proposed experiment and design process. As part of the Supplemental Document, DEP will update "Appendix D: Modeling Approach for Estimating *the Pathogen Bioextraction in Jamaica Bay and Tributaries, June 19, 2018" to include additional information on how the preliminary ribbed mussel area was calculated and additional justification of bacterial extraction capabilities of ribbed mussels.*

2. **DEC Comment**: **Southeast Queens (SEQ) Storm Sewer Buildout and High Level Sewer Separation (HLSS) in Springfield/Laurelton.** The SEQ storm sewer buildout and HLSS in Springfield and Laurelton have been long-standing projects planned by the City to alleviate flooding and sewer backups in this area of Queens as well as to reduce CSOs to Thurston Basin. The City has discussed the storm sewer buildout and HLSS in past planning documents but has never committed to complete the projects within the context of the CSO Order due to uncertainty of project funding and the long timeframe for implementation. However, the City has recently allocated $1.9 billion to implement a portion of the storm sewer buildout over the next 10 years. While this funding may not result in the complete buildout of the storm sewers, it should allow for measurable progress on this project.

   Given that the City has received substantial funding to complete a significant portion of the storm sewer buildout project within an intermediate timeframe of 10 years and that buildout will reduce CSOs, it seems reasonable that the City could include the pending construction as part of the selected alternative. The City has publicly stated on several occasions that the "bulk of the funding will go towards the construction of large trunk sewer spines along 150th" Street, Guy Brewer Boulevard, Farmers Boulevard, and Springfield Boulevard." These trunk lines are major components of the buildout that can readily be incorporated into the LTCP.

   Moreover, future phases of the project, which may occur after 10 years, are well within the timeframe for this LTCP. Other LTCPs have included large tunnel projects that will take up to 25 years to complete, which is a comparable timeframe for the SEQ storm sewer buildout and HLSS in Springfield/Laurelton projects. As such, the City must consider including some or all of the SEQ storm sewer buildout and HLSS in Springfield/Laurelton projects within the selected alternative. The milestones can be structured to accommodate the uncertainty associated with future phases of the project, such as by incorporating more specific schedules for construction at future dates once they are known.

   To facilitate further discussion on including the storm sewer building and HLSS projects as part of the selected alternative, the City must provide detailed information on the work to be undertaken with the $1.9 billion, including scopes of work for construction, maps where the work will be completed, and implementation schedules. Additionally, the City must provide water quality model projections for CSO overflows, storm water discharges, and water quality attainment assuming the full completion of the SEQ storm sewer buildout and HLSS in Springfield and Laurelton projects.

DEP Response: *The October 2011 Jamaica Bay and CSO Tributaries Waterbody Watershed Facilities Plan Report references both High Level Sewer Separation and High Level Storm Sewers. The term High Level Storm Sewers (HLSS) is used in relation to partial sewer separation methods that are limited to the diversion of stormwater sources located within public street and rights-of-way. This technology was retained for consideration on a site specific basis and was believed to be most cost-effective in areas near the shorelines where there is no need to build large diameter and long storm sewers to convey the separated stormwater to the receiving waterbody. The term sewer separation includes the diversion of stormwater sources from private residences or buildings such as rooftops and parking lots. Complete separation is almost impossible to attain in the city since it requires re-plumbing of apartment, office and commercial buildings where roof drains are often interconnected with the building's interior plumbing. Due to the risks and legal issues associated with a public entity entering, inspecting and performing construction on private properties, DEP has limited the practices of diverting stormwater from the combined sewer system to the application of HLSS.*

The SEQ Storm Sewer Buildout is an extensive long-term drainage program covering approximately 7,000 acres, with a primary goal of relieving flooding issues throughout Southeast Queens through the construction of storm sewers. The Springfield/Laurelton High Level Storm Sewer (HLSS) component of the program as currently envisioned is expected to result in CSO reductions at JAM 005/007. However as discussed below, not only is this portion of the SEQ work not included in DEP's 10-year capital plan, it's primary purpose is not CSO control.

Project phasing, budgetary and schedule considerations must be prioritized based upon expediting relief to areas which have a history of flooding. While $1.9 billion has been budgeted in DEP's current 10-year capital plan, full build-out of the program is anticipated to cost several billion dollars more and take several decades to complete. As future planning, design and funding will be dependent upon the policy and budgets of future administrations, DEP cannot commit to a schedule for construction of the SEQ Buildout.

*The current 10-year capital plan primarily consists of the construction of major storm sewer spines illustrated in **Figure 5** and neighborhood projects to address localized flooding. No collector storm sewer connections will be made to the major sewer spines under the current 10-year capital plan. Collector sewers will be developed under future phases and are not shown in **Figure 5**. At this point in the project planning, it is not known when the new spines will be activated. The HLSS proposed for the Springfield/Laurelton Area is similarly not included in the current 10-year capital plan, as downstream infrastructure must be constructed first, to accommodate the storm flow to be diverted from the combined sewer system to the new storm sewers.*

Completion of the major storm sewer spines is not anticipated to initially result in a change in stormwater or CSO volumes, since the collector storm sewers will not be connected and the Springfield/Laurelton HLSS will not be completed under the 10-year capital plan. As implementation progresses beyond the 10-year capital plan, stormwater conveyance capacity is projected to increase as new collector storm sewers are constructed and tied into the new spines. As surface flooding and ponding is reduced, stormwater volumes discharged from the new spines are expected to increase.

Once the Springfield/Laurelton HLSS project is in service, a portion of the stormwater will be redirected from the combined sewers to new storm sewers. The remaining combined flow will be diverted to a new regulator to be constructed at the intersection of 147 Avenue and 229th Street. The SEQ Buildout will result in a redistribution of wet weather flow throughout the Jamaica Water Resource Recovery Facility (WRRF) sewershed and ultimately a projected reduction of CSO discharges and a further increase in stormwater discharges.

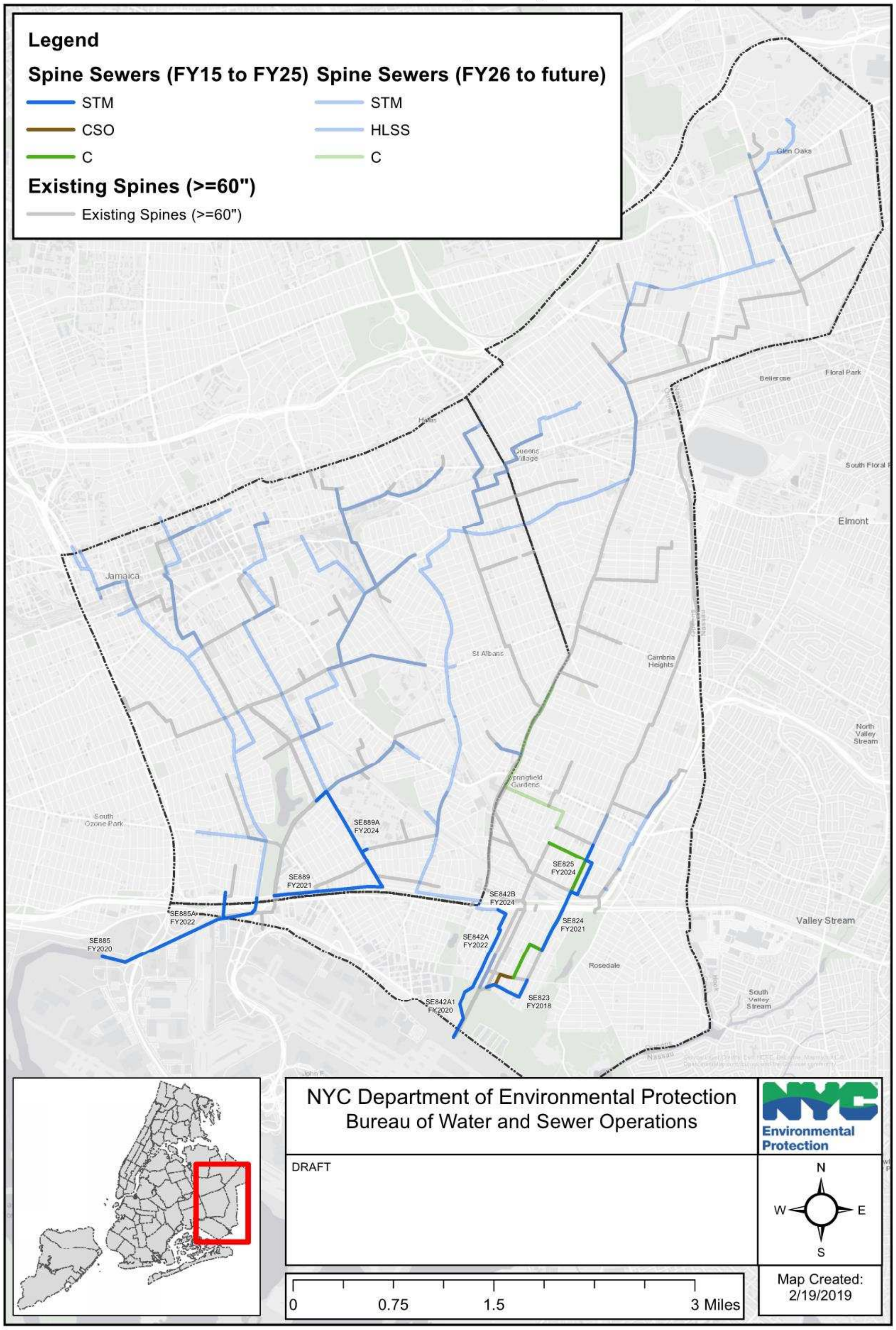
The primary objective of the SEQ Buildout is to relieve historical flooding throughout southeast Queens. As a result, any CSO reductions (outside of the Springfield/Laurelton HLSS Project) will be incidental and are not expected to have any impact on the City's ability to achieve recreational season attainment for fecal coliform in either Thurston or Bergen Basin. As the gap analysis summarized in Table 6-7 of Section 6 of the LTCP indicates that recreational season water quality attainment will not be achieved for fecal coliform in Thurston Basin even with a modeled 100% CSO control, the CSO reductions associated with the SEQ Buildout will not result in attainment of water quality standards.

As requested by DEC, conceptual modeling is being developed for the purposes of simulating the changes in CSO and stormwater volume discharges to Thurston and Bergen Basins upon completion of the SEQ storm sewer buildout. The landside modeling results will be incorporated into the water quality model to assess the potential impacts to water quality attainment. Tables, figures and commentary summarizing the findings of this evaluation will be provided in the Supplemental Document.

Figure 5 – Southeast Queens Spine Prioritization

Southeast Queens Spine Prioritization

First Phase SEQ Projects (FY15-FY25)



3. **DEC comment: Additional Options to Improve Water Quality.** The analysis of alternatives included in the LTCP examined a broad range of alternatives and the alternative that was selected appeared to be the most cost-effective and feasible of those considered. The selected alternative, however, is not solely focused on CSO reduction and while it provides important non-water quality benefits, the associated improvements to water quality are minimal and uncertain. Thus, the City must reconsider or evaluate other alternatives that might enhance the water quality of the Bay or tributaries by either further reducing or mitigating CSOs, consistent with the CSO Control Policy, or by reducing other sources of impairment to the waterbodies on a voluntary basis similar to the tidal wetland restoration projects proposed in the LTCP. The following provides examples of some alternatives that should be further considered and the Department encourages the City to identify other options that may not have yet been considered.

DEP Response: *Section 4 of the LTCP outlines over $1.03 billion in grey CSO infrastructure projects implemented under previous CSO control programs and facility plans, such as the Jamaica Bay Waterbody Watershed Facilities Plan. These projects are included in the Baseline Conditions for the Jamaica Bay and Tributaries CSO LTCP and their implementation has resulted in high levels of water quality standards attainment for pathogens and dissolved oxygen in Paerdegat Basin, Spring Creek, Fresh Creek, Hendrix Creek and Shellbank Basin. In consideration of the water quality improvements to these waterbodies, the evaluation of alternatives in Section 8 primarily focused on higher levels of CSO control for Bergen and Thurston Basins to further complement the recommendations of past studies, as well as other investments in Jamaica Bay outside of the CSO LTCP. These investments include over $600 million in BNR upgrades to the WRRFs tributary to Jamaica Bay, $300 million in existing and planned green infrastructure under the OneNYC Plan, $32 million in ecosystem restoration and research efforts for pathogen reduction and DO improvements and the multi-billion dollar Southeast Queens Sewer Buildout Program.*

The CSO control alternatives analysis in Section 8 considered each of the CSO control technologies and strategies identified in the CSO Toolbox (Figure 8-4). Although approximately 70 alternatives were presented for control of CSOs throughout Jamaica Bay and its tributaries, the evaluation process considered over 100 alternatives, most of which were focused on Bergen and Thurston Basins. The initial evaluations were initially narrowed down after multiple iterations and consideration of reductions in CSO volume and frequency, impacts to hydraulic grade line, availability of property, constructability and other factors. Appendix A includes presentation slides outlining remaining alternatives just prior to the final cut performed in advance of selecting the alternatives to be presented in Section 8. These presentation slides summarize the recommendations for 40 basin specific controls evaluated specifically for Bergen and Thurston Basins, which were then reduced to the 27 basin specific alternatives for presentation in the LTCP. The *analyses outlined in the LTCP further evaluated these alternatives based upon cost-performance, constructability, operability and other factors resulting in the seven specific alternatives retained for Bergen and Thurston Basin as outlined in Table 8-20.*

The LTCP considered a wide range of grey infrastructure, however, the primary issue throughout the analysis was that the improvements in water quality attainment were minimal regardless of the level of CSO control. As indicated by the gap analysis presented in Section 6, water quality attainment for fecal coliform cannot be achieved with 100% CSO Control at the upstream ends of Bergen Basin (73% at BB5) and Thurston Basin (87% at TBH1 and 93% at TBH3). The very small gap (1-3%) in attainment between Baseline Conditions and 100% CSO Control results in a very low cost-benefit ratio for the grey alternatives considered for these waterbodies.

The Recommended Plan, consisting of Additional GI and Environmental Improvements, provides the highest cost-benefit ratio of the alternatives evaluated. In addition to the Triple-Bottom Line Benefits outlined in Table 8-33, the Recommended Plan will further the many ecosystem goals outlined in the City's OneNYC Plan providing additional quality of life and ecological improvements throughout Jamaica Bay and its tributaries.

a. **DEC Comment: HLSS at Fresh Creek.** Fresh Creek continues to receive around 300 million gallons per year of CSO and the head end of the waterbody does not attain the fecal coliform water quality standard on an annual (86 percent) or recreational season (93 percent) basis. The City is currently completing HLSS in the CSO drainage basin that overflows to Fresh Creek, but the 440 or so acres that are currently being separated represent only a portion of the area that is planned for separation. Another approximately 2400 acres is planned for separation. As such, the City must consider undertaking additional HLSS for Fresh Creek, to further improve water quality.

DEP Response: *As set forth in the LTCP, DEP evaluated attainment with current New York State water quality standards for fecal coliform in the tributaries to Jamaica Bay, including Fresh Creek. Table 6-7 of the LTCP summarizes model-calculated fecal coliform attainment for 10-year baseline and 100% CSO control conditions. As indicated in Table 6-7, all monitoring stations in Fresh Creek except for FC1 are projected to be in attainment of the Primary Contact WQ Criteria for fecal coliform greater than 95% of the time under Baseline Conditions, on both an annual and recreational season basis. At station FC1, located at the upstream end of the tributary, attainment is projected to be 86% on an annual basis, and 93% for the recreational season. The gap analysis indicates that 100% CSO control to FC-1 would result in 91% attainment on an annual basis, and 98% attainment for the recreational season.*

Upon reviewing the landside models in response to this comment, the LTCP modeling team found that the Baseline Conditions Models had some inconsistencies related to the simulation of HLSS and green infrastructure within the 26th Ward Sewershed. Specifically, these discrepancies were related to drainage area size inconsistencies in the landside modeling for Fresh Creek, Hendrix Creek and Spring Creek. Both HLSS and GI are represented in the model by reducing the runoff area tributary to the combined sewer system, and in the case of HLSS, runoff area is added to the separate storm drain system. It was determined that the runoff area adjustments did not appropriately account for flow reductions associated with both the HLSS and GI. Upon updating the respective subcatchment areas and confirming that the total drainage areas were correct, both prior to and after the addition of HLSS and GI, CSO discharges were found to be reduced for Spring Creek, Hendrix Creek and Fresh Creek. The approximate reduction in volume, frequency and duration are shown below in Table 1 for Fresh Creek. All tables within the LTCP will be updated accordingly as part of the Supplemental Document. Some additional refinements still need to be made to the landside model to incorporate deviations to the Phase 1 invert elevations and recent refinements made to the upland HLSS areas based on constructability issues and this will be included in the supplemental JB LTCP along with updated projected water quality attainment for Fresh Creek.

Table 3 – 2008 Typical Year Model Predicted Statistics for Fresh Creek

Modeled Simulated Conditions	2008 Typical Year Model Predicted Statistics			
	Volume	Frequency	Duration	Fecal Coliform Load
	Total Discharge (MG/yr)	Events per year	Hours	Total Org (10^12/yr)
LTCP Baseline Conditions	300	15	91	4,014
Corrected LTCP Baseline Conditions	223	12	78	2,980*
100% CSO Control from LTCP	0	0	0	0

* Approximate fecal coliform load. Load to be updated in the supplemental document upon refinements to the 26W HLSS drainage area and completion of the WQ modeling.

Figure 7-7 of the October Jamaica Bay and CSO Tributaries Waterbody Watershed Facilities Plan (WWFP) identifies a total area of 2400 acres tributary to Fresh Creek which includes the drainage areas proposed for HLSS. The WWFP evaluated variations of HLSS throughout the Fresh Creek drainage area. The preferred alternative was identified based upon a preliminary evaluation of constructability. The WWFP preferred alternative consists of three phases of HLSS spanning a combined sewer drainage area of 443 acres.

As DEP advanced design and construction of Phases 1, 2 and 3 of the HLSS, several *constructability issues related to conflicts with existing utilities have been encountered and addressed. HLSS utilizes shallow constructed storm sewers to divert catch basins and other inflow sources from the combined sewer system. Due to the shallow construction, there is a high risk of conflict with gas, water, communications and other utilities that are all competing for space within the same road right-of-ways and are generally constructed within five feet of ground surface. To address these conflicts, the conceptual routes have been modified to route the proposed storm sewers around the conflicts identified during design and construction.*

Previous evaluations of additional opportunities expand HLSS upstream of Fresh Creek beyond Phases 1, 2, and 3 identified the following constructability and maintenance issues:

- *In order to convey additional HLSS flow to Fresh Creek, larger storm sewers would need to be constructed and cross Buckeye Fuel Lines running along Cozine Avenue. The depth of these fuel lines conflict with the elevation of the proposed HLSS, which could force the city to utilize siphons to cross Cozine Avenue. Siphons are not desirable for stormwater conveyance. Due to the intermittent flow patterns which are dependent upon precipitation, storm sewer siphons are susceptible to accumulation of debris, thereby requiring more frequent maintenance to maintain capacity and protect against flooding. Additionally, once the siphon is installed, if constructability issues are identified with later upstream phases of the HLSS work and sufficient head is not provided, the siphons may not function as designed.*
- *The design of the HLSS conveyance system is based on the assumption that streets are built to legal grade. In the area surrounding Fresh Creek, much of the area was not built to legal grade. Therefore, in order to install additional HLSS, streets will need to be raised, in some instances by multiple feet as opposed to inches above existing grade. This is very challenging as it may reduce accessibility of property owners to garages and basements.*

In summary, based on the anticipated constructability issues and impacts to private property owners, application of additional HLSS within the Fresh Creek watershed will not be considered further.

b. **DEC Comment: Floatables Control at Fresh Creek.** The City's annual floatables monitoring report indicates that floatables may be a problem for this tributary (station J9A). As such, the City must consider undertaking floatables control for Fresh Creek, to further improve water quality and aesthetics.

***DEP Response**: Monitoring Station J9A is located at the confluence of Fresh Creek with Jamaica Bay. DEP operates and maintains a netting facility at CSO Outfall 26W-003 (located at the upstream end of Fresh Creek). The CSO BMP Annual Report dated May 2018 indicates that 21.25 cubic yards (cy) of floatables were captured by the existing* *floatables containment nets in Fresh Creek in 2017.*

Floatables downstream of the nets are in part associated with tidal changes in the creek and non-CSO discharges. Floatables have also been observed in the creek in relation to shoreline erosion downstream of the nets.

c. **DEC Comment: Disinfection at Thurston Basin.** The City evaluated the construction of a disinfection facility (comprised of chlorination and dechlorination) for CSO Outfalls JAM-005 and JAM-007 that discharge into Thurston Basin, however, this alternative was deter- mined to be infeasible due to siting issues and other technical challenges associated with construction and operation. For this alternative, both the chlorination and dechlorination facilities were sited close to the discharge end of the CSO outfalls. However, the CSO being discharged at these two outfalls overflows at regulators located much further upstream, and there is a large quantity of stormwater discharged downstream of the CSO regulators as well as some tidal influence in the outfalls, which is also subject to chlorination and dechlorination. In order to alleviate some of the challenges associated with siting the disinfection facility at the downstream reach of the CSO outfall and reduce the amount of flow that would be subject to disinfection to only CSO, the City must consider siting the disinfection facility further upstream and utilize the length of the outfall for contact time and consumption of the chlorine through mixing with the stormwater and tidal water. To facilitate further discussion on this alternative, the City must provide a to-scale schematic illustrating the location of the stormwater discharges into the Thurston Basin CSO outfalls vis a vis location of the CSO regulators and outfall discharges and a preliminary analysis of the feasibility of this disinfection configuration.

DEP Response: D*isinfection of CSO Outfalls JAM-005 and JAM-007 was evaluated in Section 8 of the LTCP with further details provided in a technical memo in Appendix E. The following text further emphasizes the concerns with successful operation of this CSO control alternative and addresses the request to evaluate application of disinfectant at points closer to Regulators JA-06 and JA-07, as well as a new regulator to be constructed at 147 Avenue and 229th Street under the SEQ Storm Sewer Buildout Program. While moving the disinfection application point upstream increases available contact time, it further complicates system operation as a result of the additional storm sewers that connect to the multiple barrel sewers between the points for application of chlorination and dechlorination chemicals.*

***Figure 6** provides a scaled map of the collection system downstream of Regulators JA-06, JA-07 and JA-08. The figure identifies over a dozen interconnections (48" or larger) contributing CSO and stormwater to the multiple barrel CSO Outfalls JAM-005 and JAM-007. In addition, numerous smaller connections (not shown in the figure) exist along each of the outfalls. Due to the configuration of the collection system, siting of* *chemical storage and feed equipment will require multiple property acquisitions. Potential sites for chlorination and dechlorination facilities are shown. Sites for tide gates are also shown for each outfall.*

Controlling the application of chlorination and dechlorination chemicals will be a major operations issue for the following reasons:

- *As there are several points where CSO and stormwater enter the outfalls, there would be a need to introduce disinfectant at numerous upstream locations or heavily dose with disinfectant at the upstream end to achieve the required contact times.*
- *Since the flow rates and composition of CSO and stormwater may vary significantly within each sewer barrel, multiple pumps and feed lines would be required, each with meters and controls to pace application of disinfectant at each injection point.*
    - *Sensors and means of estimating CSO discharges over regulator weirs would also need to be incorporated in the disinfectant feed control logic to adjust feed for the higher load associated with CSO.*
    - *Dechlorination chemicals would need to be introduced to multiple outfall barrels, all having varying flow rates. The dechlorination system will require similar chemical feed equipment and operations as used for the application of disinfectant.*
    - *Due to the intermittent application, chemical feed equipment and distribution lines must be flushed following each storm event to prevent crystallization of chemicals and blockage of the feed lines. As flushing will be performed during dry weather conditions, procedures will need to be developed to minimize the introduction of chemicals to the outfalls and impact of chlorination byproducts.*
- *As the outfalls are tidally influenced, the discharge will be impacted by the tide level and storm surge. These conditions will be highly variable within each of the outfall barrels and would require potential safeguards to prevent activation of chemical feed equipment as a result of the movement of water within the outfall barrels as CSO and stormwater enter the outfall during high tide. The chemical feed control logic would need to account for negative or extremely low flow rates that will occur in the outfalls until there is sufficient head to overcome the tide and open downstream tide gates.*

During the typical rainfall year (2008), CSO discharges occur about 25 times annually, while stormwater is introduced during each of the 118 rain events. To achieve the bacteria and total residual chlorine limits that DEP expects to be included in future SPDES permits, DEP will likely need to activate these facilities for the majority of precipitation events to avoid the risk of missing a CSO event. This increases the level of maintenance by nearly five times that of a typical tank installation. The multiple injection points further increases the level of maintenance.

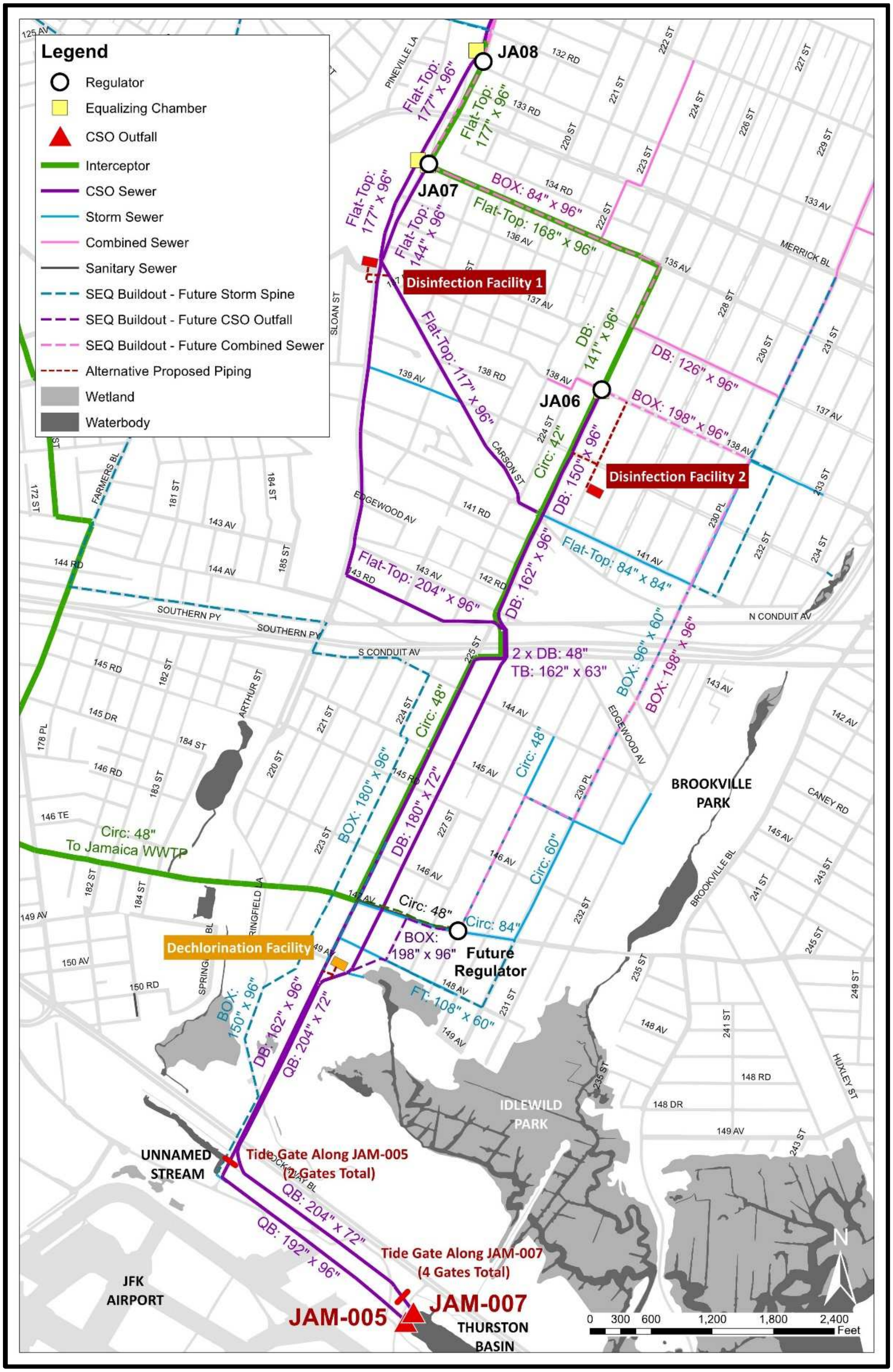
The disinfection system will need to consider future phased expansion and/or modification to account for the wide variations in flow and load as future connections are made as the SEQ buildout is implemented. For example, as the storm sewer buildout program advances, additional stormwater will be contributed to the upstream sewers and CSO will be reduced and ultimately eliminated from some of the outfall sewer barrels.

In summary, the primary challenges and risks include:

- *Chemical feed facilities that would need to be constructed and maintained at multiple locations;*
- *As these facilities would be located in residential and commercial areas, the health and safety risk of spills and public exposure is much higher in comparison to a typical WRRF application, and public opposition to siting is also likely to be higher;*
- *The trunk and outfall sewers consist of multiple barrel pipes with additional connecting sewers along their alignments resulting in highly variable flow conditions from event to event;*
- *Multiple feed lines must be provided and individually controlled for application of chemicals to each of the individual sewer barrels;*
- *To address the highly variable flow conditions and multiple feed points, an extremely high degree of system automation and sophistication will be required to operate this facility;*
- *As the chemicals are being applied to multiple sewers in comparison to a tank with multiple channels, it is virtually impossible to simulate the highly variable operational conditions for accurate calibration of instrumentation and controls;*
- *There is a high risk of overdosing to overcome operational complexities and achieve anticipated permit limits for pathogens and chlorine residual;*
- *Thorough flushing of multiple chemical feed lines will be required after each storm event with management of flush water to protect against contaminating the downstream waterbody,*
- *The gap analysis indicated that even with 100% control of CSOs, recreational season water quality attainment for fecal coliform is not achieved at the upstream end of Thurston Basin. As a result, outfall disinfection will not achieve water quality attainment for pathogens.*

In consideration of the highly variable operating conditions, successful operation of an outfall disinfection system for Thurston Basin would be extremely complicated and pose a high risk of not consistently achieving permit limits. As a result, outfall disinfection is not considered to be feasible for Thurston Basin.

Figure 6 – JAM-005/007 Outfall Disinfection Alternative



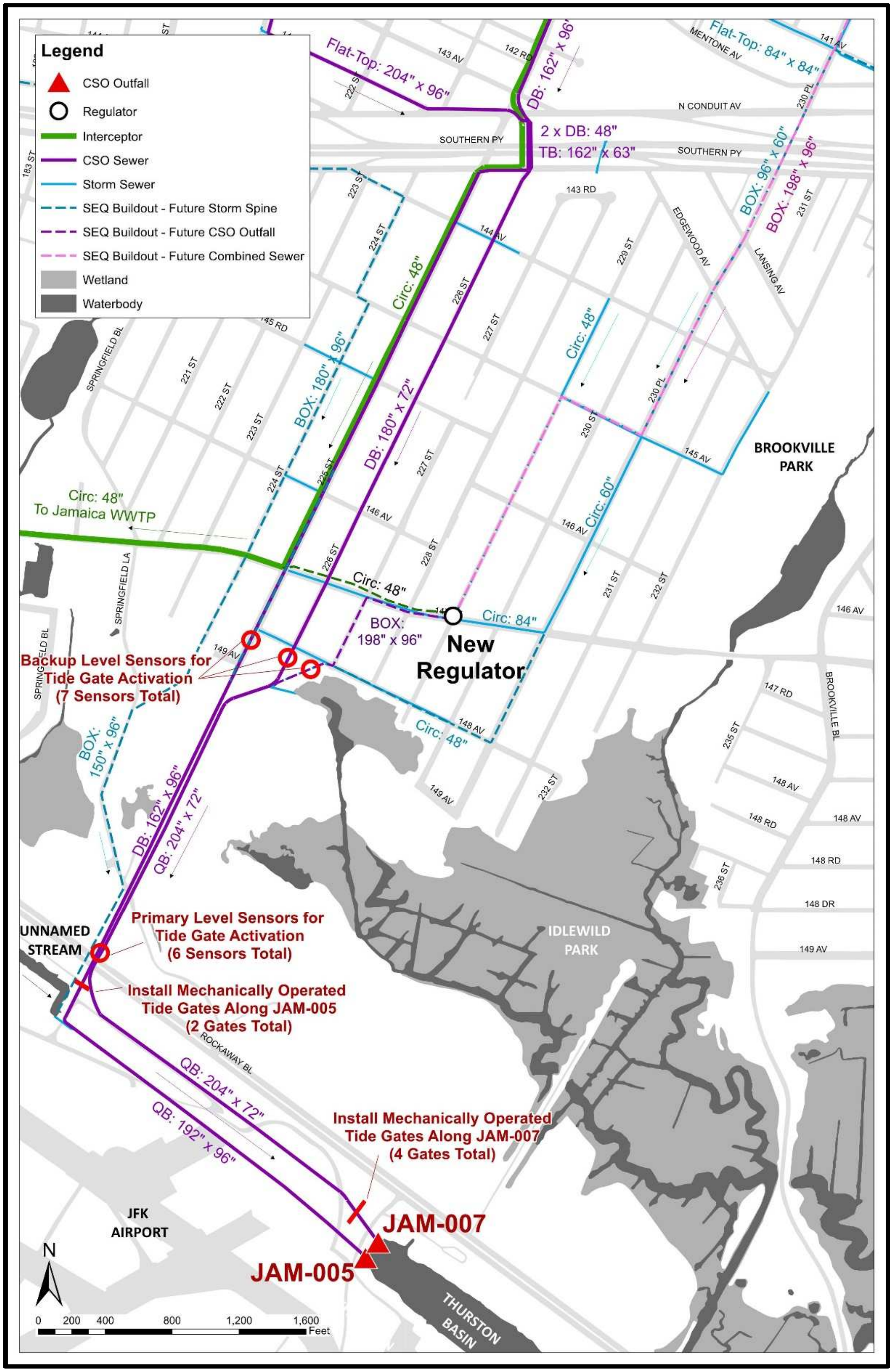
d. **DEC Comment: In-Line Storage.** The City evaluated in-line storage to reduce CSOs to Bergen and Thurston Basins, but eliminated this alternative for various technical reasons. However, for Thurston Basin, the City must consider installation of tide gates to reduce the tidal influence for these outfalls for the in-line storage option.

DEP Response: *Installation of gates would be required at multiple locations as indicated in **Figure 7** to isolate tidal inflow from Thurston Basin, as well as an existing unnamed stream that connects to Outfall JAM-005 approximately 2200 feet upstream of the outfall discharge. The gates would be located at the discharge end of each of the four barrels of JAM-007 and on two outfall sewer barrels of JAM-005 just upstream of the connection of the unnamed stream as shown in **Figure 7.** The gates on JAM-005 are necessary to prevent backflow of the stream along the outfall which would reduce in-line storage capacity during high tide conditions and increase the risk of deposition of debris and sediment. Deposition of stream debris within the outfall will also increase the risk of clogging the dewatering pumps and reduce storage and conveyance capacity.*

To create and maximize in-line storage within the outfall over the range of tides, mechanically operated gates and controls would be necessary, rather than the traditional hinged tide gates used at most of the City's CSO outfalls. During low tide conditions, the design would need to include automated or remote gate controls to induce storage of CSO within the outfall until the stored CSO can be pumped back to the interceptor. During large storms, which generate runoff in excess of storage capacity of the outfalls or when a 5 year storm occurs, automated control or remote operation of the gates would be needed to open the gates to release the flow to the receiving waters when depths reach a maximum set point. Malfunction of mechanically operated gates poses a high risk for sewer backup and flooding as experienced at the Spring Creek AWWTP on April 30, 2014. Failure of the mechanically operated gates resulted in basement backups and flooding in parts of the New Lots and Lindenwood neighborhoods. As a result, DEP is removing the mechanically operated sluice gates at this facility and replacing them with standard passive hinged tide gates.

Considering the potential for similar equipment malfunctions and the history of flooding throughout SEQ, DEP will not consider CSO control alternatives that would require automated electro-mechanical systems to store or control flow within a sewer or tank. Maintaining existing drainage to this community is a high priority for DEP as evidenced by the SEQ Storm Sewer Buildout Program.

Figure 7 – JAM-005/007 In-line Storage Alternative



e. **DEC Comment - Floatables Control.** The City evaluated floatables control at the largest outfalls that only have floatables booms, in particular JAM-003A, JAM-005, JAM-007, and 26W-003, and indicated that the alternatives were abandoned due to adverse impacts to hydraulic grade line in upstream sewers. However, the only floatables control technology considered was underflow baffles. Netting facilities downstream of the regulator should not have any impact on the HGL, so the City may want to consider that technology as well. Additionally, for floatables control at Fresh Creek and Hendrix Creek, the LTCP states the alternative was abandoned due to no CSO benefits. While floatables control does not reduce CSO volumes, it does mitigate floatables from CSO and improve attainment with the water quality standard for floatables, so it should not be eliminated because it does not reduce CSO volume. As such, the City must reconsider underflow baffles for floatables control at the largest outfalls where it does not impact the HGL.

DEP Response*: Floatables control facilities are operated in each of the Jamaica Bay tributaries that receive CSO discharges, as follows:*

- *Floatables containment booms are located downstream of the CSO outfalls in Thurston Basin for JAM-005/007, Bergen Basin for JAM-003/003A and JAM-006, and Hendrix Creek for 26W-004. Skimmer boats are utilized to retrieve the floatables captured by the booms. In addition to floatables from CSOs, the booms in Thurston and Bergen Basins are sited such that floatables are also captured from storm sewers and vast majority of wet weather flow being discharged into Bergen and Thurston Basin is stormwater. The Thurston Basin boom also provides floatables capture for two unnamed streams conveying runoff from areas surrounding Springfield Park and Idlewild Park. In addition, the Port Authority maintains a containment upstream of DEP's boom which is believed to have resulted in a reduction in the capture recorded at the DEP boom. Replacing the booms with netting facilities or underflow baffles would eliminate these ancillary water quality benefits.*
- *A netting facility is operated at CSO 26W-003 for capture of floatables at this CSO outfall, which discharges to Fresh Creek.*
- *Floatables are currently captured in the CSO Retention Facilities at the head ends of Spring Creek and Paerdegat Basin.*
- *DEP has also replaced or modified catch basins to include hoods and sumps for capture of floatables. These collection system upgrades, in addition to the increased frequency of catch basin cleaning and street sweeping has significantly reduced the volume of floatables that are captured at the containment booms.*
- *DEP is evaluating floatables control under its MS4 program and is looking to implement additional programmatic controls to eliminate floatables from their source.*

Each of the above floatables control technologies are identified as accepted practices in the USEPA Guidance for NMCs and Floatables Control Technology Fact Sheet. The fact sheet *specifically references boom and skimming operations in Jamaica Bay, as well as catch basin modifications throughout New York City. Considering the well documented effectiveness of the current BMP programs for floatables capture, DEP believes that the existing approach to floatables control in the tributaries to Jamaica Bay meets the intent of the BMP requirements for floatables control, and that additional investment in alternative floatables control technologies would not provide substantial improvements in floatables capture.*

However, to be responsive to DEC's comment, DEP has further investigated alternatives for providing end-of-pipe nets in Bergen Basin at JAM005/007, Thurston Basin at JAM003/003A, and Hendrix Creek at 26W-004. The following summarizes the findings of these investigations.

***JAM005/007 (Thurston Basin). Figure 8-17** from Section 8 of the LTCP, shown below, indicates the location of the JAM005/007 outfalls relative to other key features of Thurston Basin. An end-of-pipe netting system would extend approximately 80 feet into Thurston Basin from the outfall headwall at the upstream end of Thurston Basin. Published design criteria for the end-of-pipe floating net systems indicate that a minimum of 2 to 3 feet of water depth should be available for the netting system. Based on available information, dredging would likely be required at the end of the outfalls at this location to provide the required depth at low tide. The dredging would have to extend into Thurston Basin until the existing bottom provides 2 to 3 feet of depth at low tide.*

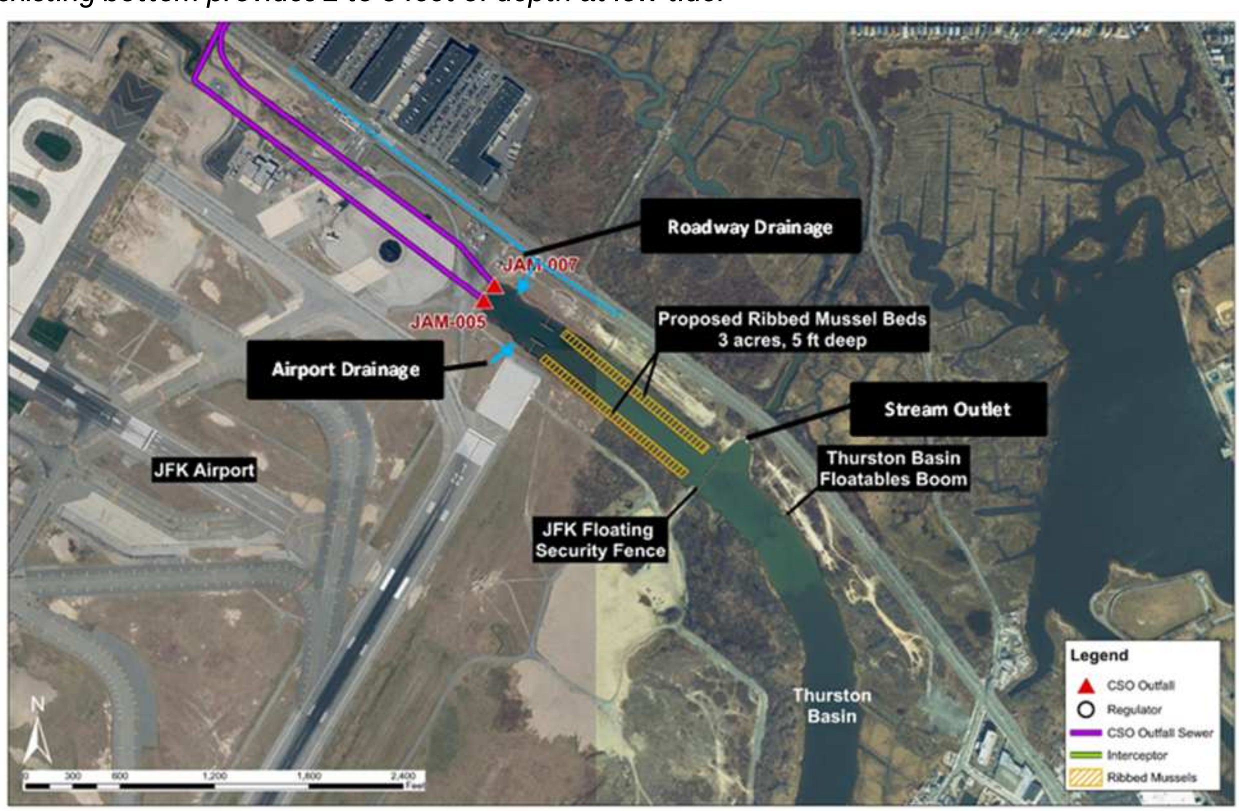


Figure 8-17. Ribbed Mussel Installation in Thurston Basin

*This location is immediately adjacent to an active runway from JFK Airport. The floating security fence shown in **Figure 8-17** prevents access to this location by water, so the nets would need to be replaced from the land side. The only access road to this location is on JFK Airport property, where access is restricted due to its proximity to the runway. The nets need to be pulled out of their frames using a jib crane or boom truck, and this type of operation would also be severely restricted in such close proximity to the active runway. In summary, the physical location of a floating net system for outfall JAM005/007 creates severe restrictions in terms of access and equipment use for regular maintenance activities. For these reasons, a floating netting system is not recommended for JAM005/007. The existing containment boom located downstream of the floating security fence would continue to provide floatables control for these CSO outfalls, as well as for storm drain outfalls and a stream that discharge to Thurston Basin upstream of the boom as indicated in Figure 8-17.*

JAM003/003A (Bergen Basin). Figure 8 *shows a conceptual sketch of a 12-net end-of-pipe netting arrangement for outfalls JAM003/003A. The sizing was based on providing a design velocity of 5 fps through the nets for the 90th percentile peak flow from the typical year. As noted above, end-of-pipe floating net systems need a minimum of 2 to 3 feet of water depth. It is likely that some dredging would be required at the end of the outfalls at this location to provide the required depth at low tide. The dredging would extend into Bergen Basin until the existing bottom provides 2 to 3 feet of depth at low tide.*

*As indicated in **Figure 8**, limited space is available between Pan Am Road and the shoreline of Bergen Basin for construction and operation of the facilities. Temporary road closures would be required for construction, while access to the nets for replacement would likely be via boat. Access to this reach of Bergen Basin is restricted by JFK Airport security, but the location is just upstream of the floatables control boom across Bergen Basin as shown in **Figure 9**, so access requirements would likely be similar to the requirements for access to the existing boom.*

As noted above, if a netting facility for outfalls JAM003/003A were to replace the existing floating boom, then floatables associated with the stormwater discharges at JAM006 and the airport drain at the upstream end of Bergen Basin would no longer be captured. If the existing boom were to remain in place, then the benefit of a new structural floatables control system for Outfall JAM003/003A in terms of reducing floatables in Bergen Basin would be limited. In summary, although a floating end-of-pipe netting facility for outfalls JAM003/003A appears to be technically feasible, it is unlikely to provide a significant improvement in the floatables captured by the existing boom in Bergen Basin (26 cy in 2017), and is therefore not recommended.

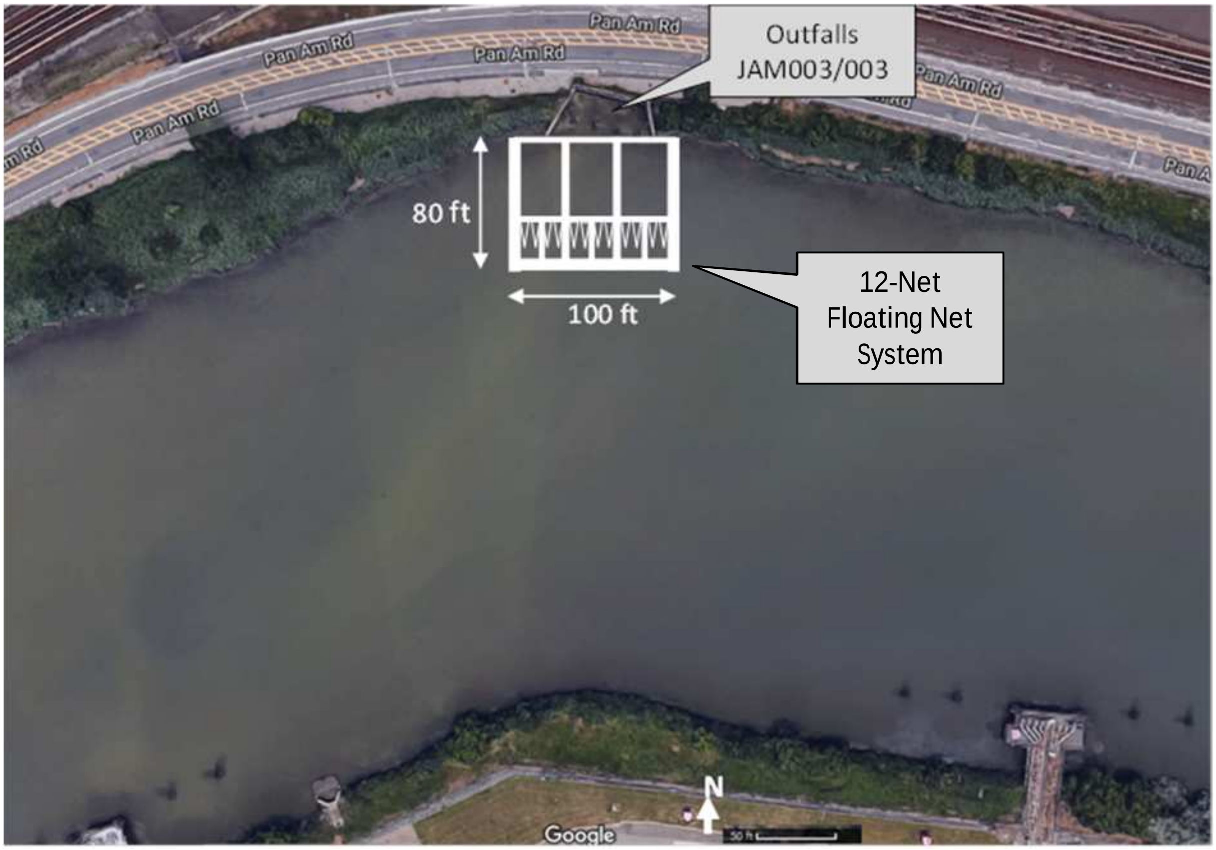


Figure 8. Conceptual Layout of Floating Netting Facility for Outfalls JAM003/003A

Figure 9. Location of Outfalls Relative to Existing Containment Boom in Bergen Basin

26W-004 (Hendrix Creek). *As noted above, published design criteria for floating end-of-pipe netting installations call for having a minimum water depth of 2 to 3 feet at the nets. Outfall 26W-004 is located at the upstream end of Hendrix Creek (See **Figure 10**), where a previous dredging project established the creek bed at an elevation of -6.1 BSD, which approximately matches the minimum low tide elevation during the typical year. Under lowest tide conditions, the depth in Hendrix Creek at the end of the outfall would be less than 2 to 3 feet, and therefore a floating end-of-pipe netting system would require extensive re-dredging of the upstream end of Hendrix Creek. Since the existing boom across Hendrix Creek effectively provides floatables control for Outfall 26W-004 (5 cy in 2017), a floating end-of-pipe net system is not recommended.*

Figure 10. Location of Outfall 26W-004 and Existing Floatables Boom in Hendrix Creek

f. **DEC Comment - Nitrogen Reduction.** In the 2006 Jamaica Bay Comprehensive Plan, the City evaluated the nitrogen contributions from CSO to the Bay and their impacts on water quality, in particular dissolved oxygen. At that time, the CSOs did not have a significant impact in comparison to the wastewater treatment plants. However, the nitrogen loads from the treatment plants has been reduced under the Biological Nutrient Removal program, and it seems reasonable for the City to reevaluate the CSO nitrogen contributions under the LTCP to determine if they have a more measurable impact on dissolved oxygen in the Bay. In conjunction with this evaluation, the City might also consider other projects that further reduce nutrient load to the Bay, not directly related to CSOs. The City has completed numerous upgrades to the wastewater treatment plants to reduce nitrogen loading to Jamaica Bay, however, the level of chlorophyll-a has remained relatively unchanged over time in the water- body (based on post-construction monitoring data). Thus, the City must examine alternatives that might further reduce nutrient loading to the Bay, either from CSOs or from the treatment plants, such as reducing the transshipment of sludge to 26th Ward wastewater treatment plant.

DEP Response: ***Table 4*** *provides a summary of model predicted fecal coliform, Enterococcus, and Biochemical Oxygen Demand (BOD) discharged to Jamaica Bay and its tributaries from WRRFs and CSO Outfalls under Baseline Conditions for the 2008 typical year. Total Nitrogen (TN) loads for the WRRFs and CSO Outfalls are provided for 2017 DMR and CSO TN Reporting. The table illustrates that fecal coliform and Enterococcus loads are predominantly from CSOs making pathogens the primary focus of the CSO LTCP, while BOD and TN are primarily associated with WRRF effluent discharges.*

In addition, TN loading is consistent with the findings of other LTCPs which indicate that CSOs typically contribute negligible nutrient loads to receiving waters. The annual system-wide nutrient load for CSOs is typically comparable to the daily load from the WRRFs. The analysis below indicates that the model predicted load from CSOs is significantly less than the annual TN contribution from the four WRRFs combined. Considering the extremely small TN loads contributed by CSOs to Jamaica Bay and its tributaries, it is not cost-effective to address TN related water quality issues through CSO control. Reduction of TN loads related to non-CSO sources are outside the scope of this LTCP and continue to be addressed through the nitrogen management program and the SPDES Permit for each WRRF.

Table 4 – Loads for Baseline Conditions

Parameter	*Jamaica*[1]	*26th Ward*[1]	*Rockaway*[2]	*Coney Island*[2]	*CSOs*
Fecal Coliform ($x10^{12}$ cfu/100 ml)[3]	*43*	*31*	*13*	*26*	*68,250*
Enterococcus ($x10^{12}$ cfu/100 ml)[3]	*22*	*15*	*6*	*4*	*37,430*
BOD (lbs/yr)[3]	*1,816,374*	*951,515*	*332,734*	*2,800,572*	*425,593*
TN (lbs/day)[4]	*5,777*	*3,382*	*2,070*	*17,347*	*230*
TN (lbs/yr)[4]	*2,108,741*	*1,234,481*	*755,591*	*6,331,804*	*83,950*

Notes:

1. *BNR upgrades with carbon addition are fully operational.*
2. *BNR upgrades are under construction.*
3. *Based on LTCP model predicted loads for typical 2008 rainfall year.*
4. *Based on 2017 DMR data and 2017 CSO TN report.*

4. **DEC Comment: Green Infrastructure.** According to the LTCP, the City's baseline commitment for green infrastructure for Jamaica Bay and its tributaries was to manage 1-inch of storm water runoff from 877 acres, which will reduce CSOs to these waterbodies by about 202 MGY for an average rainfall year (note: see additional comment below on the baseline green infrastructure commitment). The selected alternative includes additional green infrastructure beyond the baseline commitment in both CSO and separately sewer areas that drain to Bergen and Thurston Basins. Specifically, the City will manage 1-inch of storm water runoff from 147 acres in the Thurston Basin drainage area, which will reduce CSO by 6 MGY and storm water by 22 MGY to this waterbody, as well as manage 1-inch of storm water runoff from 232 acres in the Bergen Basin drainage area, which will reduce CSO by 9 MGY and storm water by 211 MGY to this waterbody.

   The LTCP does not provide detailed information on how these CSO and storm water reductions were calculated or their estimated cost. At first glance, based on capture ratios alone, it does not appear that the additional green infrastructure is cost-effective, because there is very little CSO reduction achieved despite the sizable amount of green infrastructure proposed for both basins. For the baseline green infrastructure commitment, the ratio of CSO reduction per impervious acre managed (MG/Ac) is about 0.23 MG/Ac, and this ratio is consistent with citywide ratio of 0.22 MG/Ac presented in the June 2006 GI Metrics Report. However, the additional green infrastructure has a ratio of only 0.04 MG/Ac, about a fifth of the citywide ratio and a tenth of the ratio for green infrastructure with high percentage of retention assets, which is 0.4 MG/Ac.

   While the additional green infrastructure will also reduce storm water discharges to Bergen and Thurston Basins, the overall level of reduction is minimal compared to the volume of storm water being discharged. As such, it appears that there is very little benefit from constructing additional green infrastructure in the drainage areas for these two basins. To better understand the technical basis for the GI, the City must provide a more detailed explanation of how the projected reductions for CSO and storm water for the additional green infrastructure in Thurston and Bergen Basins were calculated, their estimated costs, and their projected water quality benefits.

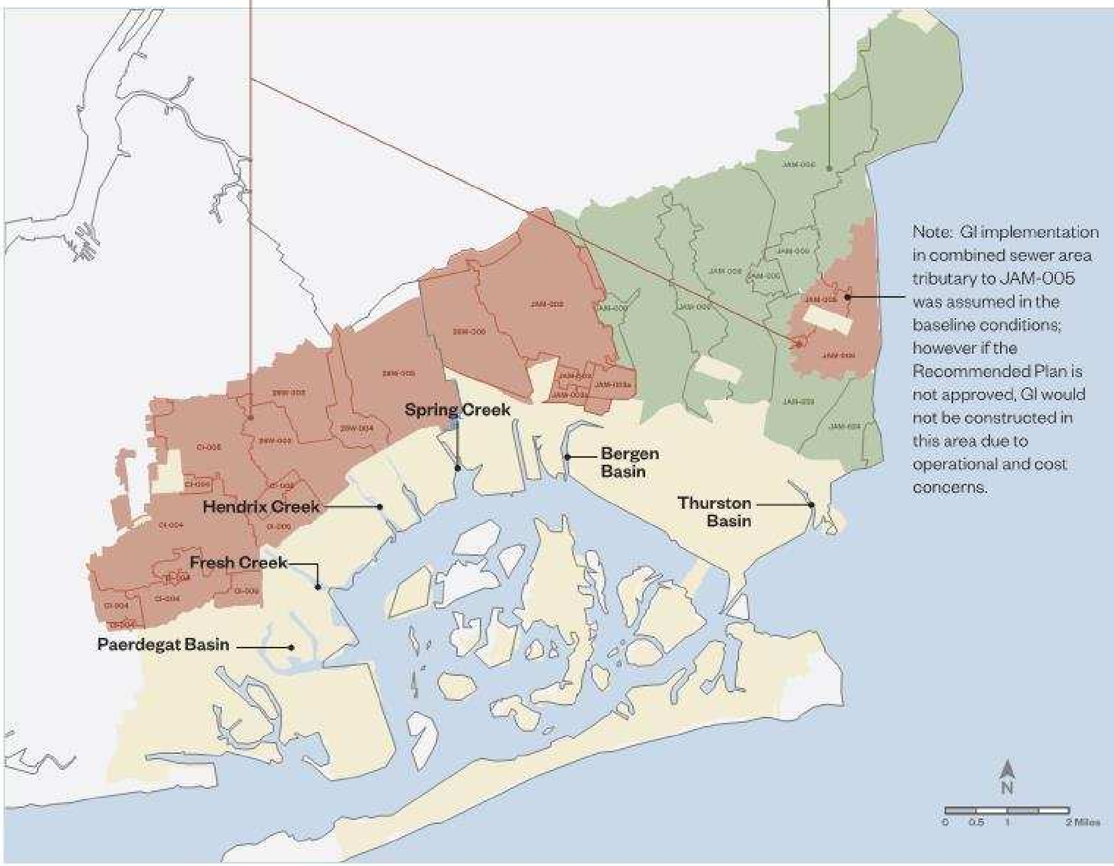
   DEP Response: *As illustrated in LTCP Figure ES-6 (below), the majority of the Baseline GI will be implemented within the portions of the collections system tributary to the 26th Ward and Coney Island WRRFs. The drainage systems have been built-out in this area resulting in a ratio of CSO reduction per impervious area managed that is consistent with the City-Wide projections. However, the additional GI proposed under the LTCP Recommended Plan is located in the areas where SEQ Sewer Buildout is being performed and the calibrated landside model for this drainage area had unusually low runoff coefficients that are likely attributable to the lack of storm sewers in the area. As a result, the projected initial* *benefits of GI in reducing wet weather volumes is much lower than is typically anticipated. However, the GI will provide ancillary benefits in capturing storm flow such as upland flood relief, reduction in carbon footprint, ecosystem habitat creation, heat island reduction and property value benefits. Further, as sewers are built out over the long term the GI will provide much more substantial reductions in wet weather loadings in stormwater discharges. The DEP is currently making modifications to the landside model to represent future full buildout conditions and will rerun the GI scenario under these future conditions to better assess its efficacy in reducing wet weather loadings into Bergen and Thurston Basins.*

As noted in the response to Comment 2, modeling will be performed to simulate conditions upon completion and activation of the SEQ Sewer Buildout. Ratios of CSO and stormwater reduction per impervious acre managed (MG/Ac) will be calculated using the results of these model simulations and compared to the City-Wide ratio of 0.22 MG/Ac. The impacts of the SEQ Sewer Buildout on CSO reduction ratios, cost-effectiveness of GI and model calculated water quality attainment projections for Baseline Conditions and the SEQ buildout will be addressed in the Supplemental Document.

Figure ES-1. GI CSO Baseline and GI Expansion in Recommended Plan

CSO GREEN INFRASTRUCTURE (GI) BASELINE (Current and Future)	
Greened Acres	877 ac.
CSO Reduction	201 MGY
Stormwater Reduction	Not applicable

RECOMMENDED PLAN		
Additional Benefits	**Thurston Basin**	**Bergen Basin**
Greened Acres	147 ac.	232 ac.
CSO Reduction	6 MGY	9 MGY
Stormwater Reduction	22 MGY	211 MGY



Miscellaneous Comments:

5. **DEC Comment: Chapter 8.** Provide figures (similar to Figure ES-8) that show attainment levels for the entire Jamaica Bay as well as tributaries for fecal coliform, enterococcus, and dissolved oxygen standards for the selected alternative. The figures provided, such as Figure ES-2, only show the tributaries and the northern half of the Bay. Additionally, provide a similar figure in the Executive Summary for the baseline, 100 percent CSO reduction, and selected alternative showing the attainment levels for the proposed enterococci 130 cfu/100 ml STV standard.

   DEP Response: *LTCP Table ES-2 and Figures ES-2 and ES-3 summarize model calculated attainment of existing and potential future WQ Criteria for the Recommended Plan. Figures ES-14 through ES-16 summarize model calculated attainment of Baseline Conditions and 100% CSO Control. As model calculated WQS compliance is attained throughout Jamaica Bay for existing Fecal Coliform, Potential Future Enterococcus and Existing Dissolved Oxygen Standards, all figures were truncated to focus on the tributaries. As requested, updated copies of Figures ES-2, ES-3, ES-14, ES-15 and ES-16 will be revised to show the southern portion of Jamaica Bay and the Rockaway Shoreline. The updated figures will be included in the Supplemental Document.*

6. **DEC Comment: Page 1-4.** The Interstate Environmental Commission is not part of NEIWPCC as of September 2018, it is an independent organization.

   DEP Response: *The following sentence will be deleted from Section 1.2c New York State Policies and Regulations: "The IEC was recently incorporated into, and is now part of, the New England Interstate Water Pollution Control Commission (NEIWPCC), a similar multi-state compact of which NYS is a member."*

7. **DEC Comment**: Figures 2-3 and 6-2. Explain the difference between areas designated as "storm drainage" and "MS4 drainage". In previous LTCPs, the City has not similarly differentiated the separately sewered areas in the drainage basins.

   DEP Response: *"MS4 drainage" consists of areas that are tributary to the outfalls identified in the City's MS4 SPDES Permit. "Storm drainage" consists of all areas tributary to stormwater conveyance that go to an outfall, but excludes those outfalls that are designated as DEP MS4 as well as permitted transportation and airport stormwater sources. "Direct drainage" consists of all drainage areas that enter a waterbody directly via overload flow and are not tributary to a storm sewer.*

8. **DEC Comment: Section 2.2.a.5.** Provide a figure showing the specific sensitive areas in Jamaica Bay and its tributaries, such as locations associated with endangered species and any public bathing beaches.

   DEP Response: *Figure 2-29 provides the location of public access points including parks, boat launches and beaches. An additional figure will be developed and incorporated in the Supplemental Document to illustrate the locations where endangered species were reported.*

9. **DEC Comment:** Provide a copy of CSO-LTCP: Basis for Modeling - Jamaica Bay and Tributaries and Jamaica Bay LTCP Sewer System and Water Quality Modeling Report.

   DEP Response: *The Basis of Design Memo is provided in Appendix B and the Sewer System and Water Quality Modeling Report is provided in Appendix C.*

10. **DEC Comment: Section 6.3.** The gap analysis does not need to examine attainment with DO for the next higher use classification. For Class I waterbodies, examine attainment with only the existing DO water quality standard, which is never less than 4.0 mg/l.

    DEP Response: *Table 6-9 provides DO attainment of Existing WQ Criteria for Baseline and 100% CSO Control for the Class I tributaries and Jamaica Bay which is Class SB. The gap analyses provided in Table 6-10 was performed consistent with prior LTCPs. However, if DEC still desires this change in the LTCP, the table can be modified in the Supplemental Document.*

11. **DEC Comment: Section 8.1.C.** The use of a NPV factor 24.505, based on a 100-year useful life, does not seem reasonable given the nature of the projects included in the selected alternative. A useful life of 20 years, as has been used for other LTCPs, seems more reasonable.

    DEP Response: *All CSO controls must be evaluated on the same basis. As tunnels have a useful life of 100 years, the cost of operations and maintenance, as well as rehabilitation of equipment and facilities with shorter useful lives must be accounted for in properly comparing the net present value of the other CSO control alternatives with the various tunnel alternatives.*

12. **DEC Comment: Section 8.1.i.** The justification for elimination of the mechanical aeration does not make any sense. Aeration can be used even though elimination of the CSOs does not notably improve attainment levels, in fact, that very rationale would support use of instream mechanical aeration. Additionally, Figure 8-4 does not show that the technology has been eliminated from consideration. Please confirm that the narrative and figure are correct.

    DEP Response: *The narrative and figure are correct. The legend for Figure 8-4 indicates that mechanical aeration was completed in accordance with the Waterbody/Watershed Facilities Plan (WWFP). The Shellbank Basin Destratification System was recommended in the Jamaica WWFP and implemented to address DO attainment issues. Section 4.2 provides the following project summary and status for this project:*

    - *<u>Project Summary</u>: Due to the variable depth throughout Shellbank Basin, temperature stratification presented a major water quality issue resulting in depleted dissolved oxygen levels, aquatic species deaths, and odor complaints. The destratification project included the installation of air compressors, diffuser piping, and associated equipment at the head of Shellbank Basin to provide mixing of the entire water column to address temperature stratification issues.*
    - *<u>Status</u>: Project was completed in November 2010.*

Model calculated DO WQ attainment for the typical 2008 year rainfall is summarized in LTCP Table 6-8 for Baseline Conditions. Attainment results were projected to fall just short of the 95% attainment goal at monitoring stations in Thurston Basin (90% at TBH1 & TBH3), Bergen Basin (89% at BB5) and Hendrix Creek (94% at HC1). While LTCP Table 8-36 summarizes model calculated attainment for the Recommended Plan, the water quality model is not equipped to estimate the dissolved oxygen improvements associated with the GI, environmental dredging, wetlands restoration or ribbed mussel colony creation proposed for each of these respective watersheds. Considering the attainment levels for DO in these waterbodies under Baseline Conditions, DEP does not believe that there is sufficient justification to install in-stream mechanical aeration. No further projects should be considered until the Recommended Plan is implemented and post construction compliance monitoring has been performed to evaluate the improvements in the water quality attainment for dissolved oxygen criteria.

13. **DEC** Comment: Section 8-4.k. Provide a detailed breakdown of the cost estimate for each component of the selected alternative (e.g. wetlands, dredging, mussels, and green infrastructure).

DEP Response: Table 5 *provides a detailed cost breakdown of the Recommended Plan segregated by waterbody in support of the Probable Bid Costs identified in Table 8-31.*

Table 5 - Recommended Plan Cost Breakdown

Waterbody	GI Cost ($ Millions)	Environmental Dredging Cost ($ Millions)	Ribbed Mussel Cost ($ Millions)	Tidal Wetlands Restoration Cost ($ Millions)	Total Cost ($ Millions)
Thurston Basin	$104.0	$0.0	$5.8	$0.0	**$109.8**
Bergen Basin	$106.4	$27.0	$4.6	$0.0	**$138.0**
Spring Creek	$0.0	$0.0	$0.0	$16.3	**$16.3**
Hendrix Creek	$0.0	$0.0	$0.0	$3.1	**$3.1**
Fresh Creek	$0.0	$0.0	$0.0	$17.0	**$17.0**
Paerdegat Basin	$0.0	$0.0	$0.0	$5.6	**$5.6**
Jamaica Bay	$0.0	$0.0	$0.0	$20.5	**$20.5**
PBC Total (2018 $)	**$210.4**	**$27.0**	**$10.4**	**$62.5**	**$310.3**

14. **DEC Comment: Section 8.2.a.2.** Describe in more detail the alternatives B-1f and 26W-1, "Real time control of existing private building retention facilities" considered for Bergen Basin, Spring Creek, Hendrix Creek, and Fresh Creek and why they were eliminated from consideration.

DEP Response: *Many private properties with large impervious surfaces currently operate and maintain facilities to manage stormwater in conformance with DEP guidelines for the design and construction of stormwater management systems. Landside model runs were performed to simulate the implementation of modifications to these facilities to provide for longer retention times. The model run focused on private building retention facilities serving large impervious surfaces associated with private properties of greater than 5 acres. The reduction in peak flows contributing to CSOs were found to have a negligible impact on the frequency and volume of CSO discharges. The additional cost to the City to maintain these facilities and the risk of potentially damaging private plumbing systems were additional concerns. DEP thus eliminated this CSO control alternative from further consideration.*

15. **DEC Comment**: **Page 8-54.** The discussion under Spring Creek alternatives indicates that the CSO chlorination study is still ongoing, although the City has stated before that it is complete. Confirm that the statements regarding the pilot study are correct or revise as needed.

DEP Response: *The Spring Creek study was completed in June 2018 and the report was posted to DEP's website around the same time that the LTCP was drafted. This statement will be amended in the Supplemental Document.*

16. **DEC Comment**: Confirm if the City has bathymetry for the head-end of Bergen Basin or provide photos of the exposed sediments during low tide if readily available.

DEP Response: *Bathymetry and current photos are not readily available. Photos of the conditions in Bergen Basin will be included with the Supplemental Document, while bathymetry will be performed under the dredging design contract.*

17. **DEC Comment: Inflow and Infiltration.** The LTCP indicates that inflow and infiltration are a problem within some of the sewersheds covered under this LTCP (e.g. Coney Island Creek WWTP, 26th Ward WWTP, and Jamaica WWTP). Specifically, the LTCP states that the Paerdegat CSO retention facility and Spring Creek AWWTP both receive I&I, and the southeast Queens area contributes inflow to the Jamaica WWTP due to a lack of storm sewers. The Department requests more specific information on the magnitude of the I&I in these sewersheds and the extent to which the City has monitored its collection system to identify the specific areas where the great contributions of I&I are occurring. Section 7.2.2 of the 2011 Jamaica Bay/Tribs Waterbody/Watershed Facility Plan states that I&I control would be reevaluated during the development of Jamaica Bay/Tribs LTCP, but the LTCP does not indicate if any further I&I assessments were completed. Lastly, confirm that the original baseline conditions for the InfoWorks model included I&I for Paerdegat and Spring Creek CSO storage tanks.

DEP Response: *DEP monitors and appropriately addresses infiltration/inflow in compliance with its SPDES Permits. By definition, combined sewers receive stormwater inflow from catch basins, yard drains, roof leaders and other sources. The Baseline Conditions for the InfoWorks modeling for the LTCP takes into account the reduction of inflow sources associated with HLSS and GI recommended under the Jamaica Bay/Tribs WWFP. In addition, infiltration/inflow to the Paerdegat Basin CSO Facility and the Spring Creek AWWTP, as well as each WRRF sewershed, is also accounted for in the InfoWorks modeling. Additional source controls, such as HLSS, additional green infrastructure and other measures, were evaluated to further reduce stormwater inflow to the collection system sewersheds covered under the LTCP.*

The SEQ Storm Sewer Buildout Program is being implemented to address the general lack of stormwater drainage in the areas of Southeast Queens tributary to the Jamaica WRRF. While this project is ongoing and expected to require several decades to complete, it will divert stormwater (inflow sources) from the collection system over time to new storm sewer spines sized to address drainage capacity needs throughout the Jamaica WRRF sewershed. SEQ Buildout Conditions modeling, that DEP will perform in response to other DEC comments on the LTCP, will account for the diversion of inflow sources from the collection system tributary to the Jamaica WRRF.

18. **DEC Comment: Table 9-16.** It would be more appropriate if the cost estimates for the CSO program were all presented in the same year dollars or include a footnote that indicates otherwise.

    DEP Response: *The following revisions to* ***Table 9-16*** *of LTCP Section 9 will be provided in the Supplemental Document.*

Table 9-16. Financial Commitment to CSO Reduction

New York City's CSO Program	Financial Commitment ($B)
Waterbody/Watershed Facility Plan and other CSO Projects	$2.7^{(1)}$
Green Infrastructure Program	$1.5^{(2)}$
LTCP/Submitted and Approved	$5.0^{(3)}$
Total	**$9.2**

Note:

(1) Reflects costs incurred or committed to date for implementation of projects identified in the WWFP or the cost to complete other CSO projects to date.
(2) Reflects costs incurred or committed to date for the GI Program.
(3) Reflects costs escalated to midpoint construction for submitted and approved LTCP plans as shown in Table 9-14. Total LTCP costs are not currently known. A conceptual $5.7B in LTCP spending through 2045 is assumed for the affordability assessment. The total LTCP cost estimates will evolve over the next year and will be updated when the Citywide LTCP is completed.

19. **DEC Comment**: Confirm if the City examined the collection system for Jamaica WWTP, 26th Ward WWTP, and Coney Island Creek WWTP using the Optimizer software.

DEP Response: *DEP has not evaluated the collection systems tributary to the Jamaica WRRF, 26th Ward WRRF or the Coney Island WRRF using Optimizer software. InfoWorks modeling of the collection systems tributary to these WRRFs performed as part of the Jamaica Bay and Tributaries CSO LTCP alternatives evaluations found the hydraulic grade lines within these systems to be very sensitive to regulator modifications and other low cost measures for optimizing system performance. The modeling is reflective of the projects recommended and implemented in accordance with the recommendations contained in Jamaica Bay Waterbody Watershed Facilities Plan which identified low cost collection system improvements to reduce CSOs by maximizing wet weather flow to the WRRFs.*

20. **DEC Comment**: During past discussions related to the Rockaway sewershed, the City has stated that the collection system in this sewershed is completely separated. However, in the LTCP the City states that sewershed has CSOs, implying that a portion of sewershed had a combined sewer system. The City and Department are currently confirming the configuration of the sewer system as part of negotiations to resolve the Rockaway 2xDDWF notice of violation. Any references to CSOs from the Rockaway sewershed should be revised to be consistent with these discussions between the Department and City.

DEP Response: *For the record, DEP has and continues to operate the Rockaway collection system as a combined sewer system consistent with its SPDES Permit. References in the LTCP to the Rockaway WRRF sewershed are consistent with the current status of storm sewer construction and the SPDES permit for the Rockaway WRRF. There are currently 10 CSO Outfalls identified on page 3 of the SPDES Permit. While landside modeling of the collection system indicates that none of the permitted CSOs activate during 2008 rainfall conditions, flow monitoring indicates that infiltration and inflow impact wastewater flows during wet weather conditions. As discussed with DEC, DEP intends to conduct an I/I study to identify any remaining portions of the Rockaway WRRF sewershed served by combined sewers. DEP's efforts to resolve the referenced notice of violation for the Rockaway WRRF are ongoing with DEC.*

21. **DEC Comment**: According to a "June 14, 2016 Green Infrastructure Performance Metrics Report Briefing for DEC", presented by the City, the baseline GI commitment for Jamaica Bay and its tributaries was to manage 1-inch of storm water runoff from 1153 acres, or about 14.6 percent of the impervious surface, which would result in a reduction in CSO of about 248 MG. The LTCP presents different values for both the acres of impervious surface managed and CSO reduction and the City needs to explain in more detail the reasons for the differences in baseline values.

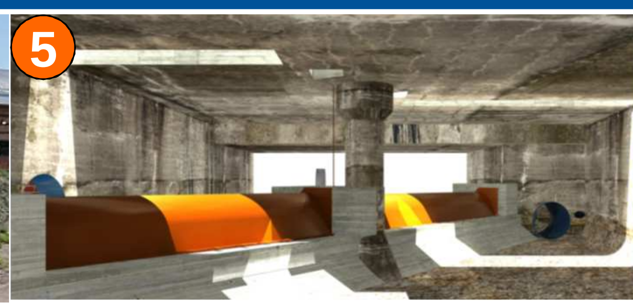
DEP Response: *As DEP continues to implement the Green Infrastructure (GI) Program throughout the City, projects are tracked from planning stages through implementation and activation. From the time the 2016 GI Performance Metrics Report was issued to the submission of this LTCP, some of the projects originally planned were eliminated or relocated and new projects have been identified to work towards achieving the program's overall goals. Additional information is collected, as planned projects advance to design, which may influence the feasibility of implementation. Siting and type of facilities may change due to groundwater conditions, permeability of soils, conflicts with utilities, public feedback, and other impacts. The LTCP reflects the latest information available based upon the project tracking performed under the GI Program.*

Appendix A
Evaluation of CSO Control Alternatives

Evaluation of Retained Alternatives

Jamaica CSO Mitigation Projects

Recommended Project	Status
1 26th Ward WWTP Drainage Area Sewer Cleaning	Completed in 2010
2 Hendrix Creek Canal Dredging	Completed in 2012
3 Spring Creek Auxiliary WWTP Upgrade	In Operation Since 2007
Warnerville Pump Station and Force Main	In Operation Since 2009
4 Paerdegat Basin CSO Facility	In Operation Since 2011
Shellbank Destratification	In Operation Since 2012
5 Bending Weirs	In Operation Since 2017
6 New Parallel Sewer West Interceptor	Construction Completed in 2016
Bergen Basin Lateral Sewer	Ongoing Construction
26th Ward WWTP Wet Weather Stabilization	Ongoing Construction
26th Ward High Level Storm Sewers	Ongoing Construction
Total Cost	**$1.03 Billion**



Jamaica LTCP Alternatives Toolbox

Source Control	Additional GI		High Level Storm Sewers	
System Optimization	Fixed Weir Modifications	Bending Weirs / Control Gates	Pump Station Modifications	Parallel Interceptor
CSO Relocation	Gravity Flow Tipping to Other Watersheds		Flow Tipping with Conduit/Tunnel and Pumping	
Water Quality / Ecological Enhancement	Floatables Control	Environmental Dredging	Mechanical Aeration	Tidal Wetlands, Bioextractors
Treatment *Satellite:*	Outfall Disinfection	Retention Treatment Basin (RTB)		~~High Rate Clarification (HRC)~~
Centralized:	WWTP Upgrades			
Storage	In-System	~~Shaft~~	Tank	Tunnel

Completed or Underway Per WWFP

Completed/Underway Per WWFP & Identified for Evaluation

CSO Controls Identified for Evaluation

Bergen Basin – Alternatives Evaluations

Alt.	Description	Impacted Outfalls	AAOV (MG)	Const. Cost	Recommendations
B-2b	Inline storage with designated pump stations for East and West Interceptors	JAM-003 & 003A	-	-	Abandon due to HGL Increase for West Int.
B-2c	Extend Howard Beach PS force main to Jamaica WWTP	JAM-003 & 003A	-	-	Abandon due to HGL Increase for East Int.
B-2d	Parallel sewer from Regulators JA-03 & JA-14 to the Jamaica WWTP	JAM-003 & 003A	-	-	Abandon - HGL Increase East & West Int.
B-2e	**Abandon Howard Beach PS and construct gravity sewer to 26th Ward WWTP**	**JAM-003 & 003A**	**325**	**$716 M**	**Abandon – High cost to benefit ratio**
B-2f	**Combination of B-2d and B-2e. Parallel sewer along tunnel route.**	**JAM-003 & 003A**	**~260**	**$984 M**	**Abandon – High cost to benefit ratio**
B-2g	**Extend sewer for B-2e to Outfalls JAM-003 and 003A (25% Capture)**	**JAM-003 & 003A**	**277**	**$956 M**	**Abandon – High cost to benefit ratio**
	Extend sewer for B-2e to Outfalls JAM-003 and 003A (50% Capture)	**JAM-003 & 003A**	**185**	**$1,088 M**	**Abandon – High cost to benefit ratio**
	Extend sewer for B-2e to Outfalls JAM-003 and 003A (75% Capture)	**JAM-003 & 003A**	**92**	**$1,348 M**	**Abandon – High cost to benefit ratio**
	Extend sewer for B-2e to Outfalls JAM-003 and 003A (100% Capture)	**JAM-003 & 003A**	**0**	**$1,988 M**	**Abandon – High cost to benefit ratio**
B-2h	Divert all flow from Regulator JA-02 to 26th Ward WWTP Sewer Service Area	JAM-003 & 003A	347	-	Abandon – Insufficient depth differential
B-3	Outfall disinfection of CSO Outfalls JAM-003 & 003A	JAM-003 & 003A	369	-	Abandon – Insufficient contact time
B-4	CSO storage tank along Outfalls JAM-003 and 003A (25% - 100% CSO Control)	JAM-003 & 003A	0-277	-	Abandon – Impacts to JFK Airport facilities
B-6	**CSO tunnel from Outfalls JAM-003/003A to Jamaica WWTP (25% Control)**	**JAM-003 & 003A**	**277**	**$216 M**	**Abandon – High cost to benefit ratio**
	CSO tunnel from Outfalls JAM-003/003A to Jamaica WWTP (50% Control)	**JAM-003 & 003A**	**185**	**$255 M**	**Abandon – High cost to benefit ratio**
	CSO tunnel from Outfalls JAM-003/003A to Jamaica WWTP (75% Control)	**JAM-003 & 003A**	**92**	**$329 M**	**Abandon – High cost to benefit ratio**
	CSO tunnel from Outfalls JAM-003/003A to Jamaica WWTP (100% Control)	**JAM-003 & 003A**	**0**	**$608 M**	**Abandon – High cost to benefit ratio**
B-7	RTB at storage tank sites for Alternative B-4 (25% - 100% Control)	JAM-003 & 003A	0-277	-	Abandon – Impacts to JFK Airport facilities
B-10	Install new regulator along Outfall JAM-006 to divert CSO and SW to the WWTP	JAM-006	-	-	Abandon - HGL Increase in East & West Int.
B-11	Combination of Alternatives B-6 and B-10	JAM-003, 003A & 006	-	-	Abandon - HGL Increase in East & West Int.
B-12	Jamaica WWTP Capacity Upgrade	JAM-003, 003A & 006	369	-	Abandon - No CSO reduction

Thurston Basin – Alternatives Evaluations

Alt.	Description	Impacted Outfall	AAOV (MG)	Const. Cost	Recommendations
T-2a, 2b, 2c	Parallel interceptor from new regulator to Jamaica WWTP	JAM-005/007	-	-	Abandon – HGL increase for West Int.
T-2d, 2e, 2f	Replace East Interceptor from new regulator to Jamaica WWTP	JAM-005/007	-	-	Abandon – HGL increase for West Int.
T-3	Outfall disinfection of CSO and stormwater (25% - 100% Control)	JAM-005/007	611	-	Abandon – Impacts to JFK facilities
T-4a & 4b	CSO storage tank south of 148 Ave or Idlewild Park (25% - 100% Control)	JAM-005/007	0 – 458	-	Abandon – Impacts to wetlands
T-4c	CSO storage tank at site south of Rockaway Blvd (25% - 100% Control)	JAM-005/007	0 - 458	-	Abandon – Impacts to JFK facilities
T-6	**CSO storage tunnel JAM-005/007 to Jamaica WWTP (25% Control)**	**JAM-005/007**	**458**	**$904 M**	**Abandon – High cost to benefit ratio**
	CSO storage tunnel JAM-005/007 to Jamaica WWTP (50% Control)	**JAM-005/007**	**306**	**$913 M**	**Abandon – High cost to benefit ratio**
	CSO storage tunnel JAM-005/007 to Jamaica WWTP (75% Control)	**JAM-005/007**	**153**	**$954 M**	**Abandon – High cost to benefit ratio**
	CSO storage tunnel JAM-005/007 to Jamaica WWTP (100% Control)	**JAM-005/007**	**0**	**$1,204 M**	**Abandon – High cost to benefit ratio**
T-7a & 7b	Retention treatment basins at site south of 148 Ave. or Idlewild Park	JAM-005/007	611	-	Abandon – Impacts to wetlands
T-7c	Retention treatment basin south of Rockaway Blvd (25% - 100% Control)	JAM-005/007	611	-	Abandon – Impacts to JFK facilities
T-9	Laurelton Area high level storm sewers	JAM-005/007	-	-	Abandon – Cannot meet LTCP schedule[1]
T-10	Inline storage	JAM-005/007	-	-	Abandon – HGL increase in East and West Int.
T-11	Wetlands treatment of stormwater	JAM-005/007	-	-	Abandon – Cannot meet LTCP schedule
T-13	**Environmental Dredging**	**JAM-005/007**	**611**	**$27 M**	**Retain – Removes deposited CSO solids**

Notes:
1) Implementation of high level storm sewers requires completion of downstream storm sewer spines to provide sufficient capacity to convey the diverted storm water to Thurston Basin. This work is included in the storm sewer buildout plans for Thurston Basin, but cannot be completed within the 2040 timeline established for the LTCP.

Appendix B
Basis of Modeling Memo

CSO-LTCP: Basis for Modeling	
Location:	**Jamaica Bay and Tributaries**
Version:	**September 22, 2015; Revised July 17, 2018**

The 2012 Combined Sewer Overflow (CSO) Consent Order (DEC Case No. CO2-20110512-25) requires the New York City Department of Environmental Protection (DEP) to develop 11 approvable CSO Long Term Control Plans (LTCPs). One critical step in developing an LTCP is establishing modeling conditions. DEP has had numerous technical meetings with the New York State Department of Environmental Conservation (DEC) over the duration of the project to discuss and confirm the proposed conditions and modeling results that are required in the City's LTCPs. This Basis for Modeling for Jamaica Bay and Tributaries document summarizes modeling assumptions, simulation approaches and post-processing results.

Major points are:

1. The tributaries included in this analysis that received CSO and stormwater discharges were: Paerdegat Basin, Fresh Creek, Hendrix Creek, Spring Creek, Bergen Basin, and Thurston Basin. Tributaries included in the analysis that received stormwater discharges only were: Head of Bay, Shellbank Basin and Hawtree Basin in addition to Jamaica Bay. Waterbodies receiving WWTP effluent included Jamaica Bay, Rockaway Inlet, Bergen Basin, and Hendrix Creek.

2. The CSO flow and quality data collected during 2015, and supplemental data collected in 2016 and 2017, was used to update the model inputs.

3. CSO, DEP MS4 stormwater, airport outfalls, other stormwater discharges, direct drainage, and other component loads were identified. It should be noted that, except as further described below, tributary drainage areas for direct drainage, highway runoff and sources of stormwater had not been fully delineated by DEP or obtained from other agencies. These drainage areas were estimated based on GIS mapping, aerial photographs, land use maps, and topographic maps rather than detailed topographic surveys and sewer maps. The InfoWorks CS™ (IW) watershed model, therefore, had a lumped representation of stormwater areas and features. Hence, urban stormwater flows and loads represented estimates rather than definitive values. BWSO MS4 delineations for the Jamaica and 26th Ward sewersheds were included in the LTCP IW modeling in an effort to provide for better estimates of the stormwater and consistency between DEP's MS4 work and this LTCP work. In addition, the LTCP team re-assessed the JFK airport delineations and created a separate airport/transportation category.

4. The four WWTPs (26th Ward, Coney Island, Jamaica, and Rockaway) were modeled based on the nitrogen removal upgrades specified in the First Amended Nitrogen Consent Judgment.

5. Two CSO retention facilities (Paerdegat Basin and Spring Creek) were explicitly included in the InfoWorks models.

6. Planned High Level Storm Sewers (HLSS) in the Fresh Creek drainage area was included (referred to as "full build-out")

7. The modeling approach and simulations were based on the modified approach approved by DEC on the February 13, 2015 conference call.

8. In cases where high fecal coliform-to-*Enterococci* ratios existed, and the source of high fecal coliform concentrations was not resolved, the bacteria model calibration/validation was based on the *Enterococci* data. Fecal coliform was based on model results using a calibration guided by the *Enterococci* calibration and fecal coliform loads as outlined below.

9. The model included a representation of the potential recommended conveyance alternative for the Jamaica WWTP Drainage Area Facility Planning project, including a limited recalibration based on metered data from the three sanitary trunks feeding the East Interceptor

The results for the modeling are presented in Sections 6 and 8 of the LTCP: Section 6 is entitled "BASELINE CONDITIONS AND PERFORMANCE GAP" and Section 8 is entitled "EVALUATION OF ALTERNATIVES." Both sections of the LTCP include results from the computer modeling work.

The tables and figures that summarized the output from these modeling results, and were included in Sections 6 and 8 and Appendix A, are described in the Post-Processing discussion below.

Modeling Assessment Conditions

Models

The InfoWorks CS™ collection system model was used to generate CSO and stormwater flows and volumes, and the Jamaica Bay Eutrophication Model (JEM) was used to compute pathogen and DO concentrations in the receiving waters. Each of these models is described below.

InfoWorks CS™

- InfoWorks CS™ – The commercially available InfoWorks (IW) model was applied to the sewersheds to develop CSO, stormwater and direct drainage loadings to Jamaica Bay. Three distinct IW models were used to cover the Owls Head, Coney Island, 26th Ward, Jamaica and Rockaway WWTP drainage areas. The Owls Head and Coney Island WWTP areas were integrated into a single IW model network due to certain hydraulic interconnections. Similarly, the 26th Ward and Jamaica areas were integrated into a combined 26th Ward/Jamaica IW model. The starting point for the IW models was the recalibrated (2012) models that include the following updates:
    - The InfoWorks Citywide Recalibration Report, Updates to and Recalibration of the October 2007 Landside Models, New York City, Department of Environmental Protection, June 2012.
    - Latest information on build out for HLSS in the Fresh Creek area.
    - Latest information on the Bergen Basin Parallel Sewer to Jamaica WWTP project (additional sewer crossing Belt Parkway) and Improvements to Regulators JA-03, JA-06 and JA-14 project.
    - Latest information on the Jamaica WWTP Drainage Area Facility Planning project, including a limited recalibration based on metered data from the three sanitary trunks feeding the East Interceptor
- While the Owls Head/Coney Island, 26th Ward/Jamaica, and Rockaway IW models contained detailed representations of CSO drainage areas, as well as CSO regulator/outfall dimensions and configurations, they contained a limited, lumped representation of separate storm sewer and direct drainage areas and features. As noted previously, the drainage areas tributary to permitted stormwater outfalls, as well as direct drainage areas (and any other areas contributing separate storm loadings to the receiving water), were not necessarily calibrated to flow monitoring data, nor were they intended to have the same level of detail or resolution as CSO features in the model. In many cases, while the drainage areas were included for loading purposes, multiple stormwater outfall pipes were lumped together in the model as single, larger outfalls for simplicity. This approach provided a means to roughly estimate the loading of stormwater to the receiving water, but provided a limited ability to extract information pertaining to specific stormwater outfalls located in the study area.

- For the purposes of this LTCP, the project team incorporated BWSO desktop MS4 delineation mapping information for the Jamaica and 26th Ward WWTP sewersheds, which was provided to the LTCP team in October 2017. These delineations were included in the initial modeling assessments and all results provided in LTCP Sections 6 and 8, as well as Appendix A loading tables.
- Updates made as part of the below efforts were also included:
    - o The IW models were recalibrated at JAM-001, JAM-003 (at Regulator JA-03), JAM-003A (at Regulator JA-14), JAM-005 (at Regulator JA-06), JAM-007 (at Regulator JA-07), 26W-003 and 26W-004, utilizing flow meter data collected for the LTCP in 2015.
    - o The model included a recalibration to support the Jamaica WWTP Drainage Area Facility Planning project.
    - o Recalibration activities will be reported in a stand-alone technical memorandum entitled "Jamaica Bay and Tributaries Water Quality and Sewer System Modeling Technical Memorandum." It is anticipated that this document will be submitted in July 2018 after the modeling work and LTCP submission are completed.

Jamaica Bay Eutrophication Model

- The Jamaica Bay Eutrophication Model (JEM), as developed for larval transport analysis and used for post-construction monitoring (PCM) modeling at the Paerdegat Basin CSO Facility and Spring Creek Auxiliary Wastewater Treatment Plant (AWWTP), was the starting point for the water quality modeling of Jamaica Bay and its tributaries. Water quality data used in JEM water quality model recalibration efforts included 2015 DEP Harbor Survey data, DEP Sentinel Monitoring Data, National Park Service and data collected as part of the LTCP project in 2015. Recalibration/verification of the water quality model will also be presented in the "Jamaica Bay and Tributaries Water Quality and Sewer System Modeling Technical Memorandum."

Baseline Conditions

A set of conditions was developed for evaluation of future water quality conditions, with and without additional CSO controls. A separate technical memorandum entitled "LTCP2 Baseline Conditions" describes these baseline conditions and the reasons why they were selected. The following are excerpts from that memo and specifics related to those conditions for Jamaica Bay and Tributaries.

Rainfall Conditions*:*

- Calendar year 2008 rainfall conditions from JFK Airport rain gauge for single year evaluations.
- Calendar year 2002 through 2011 from JFK Airport rain for continuous water quality simulations.
    - o Based on recent LTCPs, the time-to-recovery analysis was based on the 2002 through 2011 JFK rainfall, instead of the August 15, 2008 storm.
- Future alternative analyses used JFK Airport rainfall spread equally to all catchments and subcatchments citywide.

WWTP Projected Sanitary Flows*:*

- Revised 2040 projected sanitary flow based on BEPA July 2014 projections. (July 14, 2014 memo Angela Licata and Pinar Balci – NYC DEP to Distribution, 2014 Water Demand and Wastewater Flow Projections.)
    - o Coney Island WWTP sanitary flow = 78.8 MGD

- o 26th Ward WWTP sanitary flow = 44.9 MGD
- o Jamaica WWTP sanitary flow = 76.5 MGD
- o Rockaway WWTP sanitary flow = 20.7 MGD

WWTP Wet Weather Flows:

- Two Times Design Dry Weather Flow (2xDDWF) as plant wet weather flows to estimate CSO capture volumes.

Grey Infrastructure - CSO Controls:

- Existing CSO control structures included the Spring Creek AWWTP and the Paerdegat Basin CSO Facility. Both facilities store CSO that overflows regulator weirs and discharge flow to the receiving waterbody once the storage volume is exceeded. Pump back of the captured CSO volume after a storm event was modeled explicitly for each facility.

- CSO controls included all cost-effective grey (CEG) infrastructure included in the 2012 CSO Order on Consent.

  - o For the Jamaica WWTP sewershed these projects included:
    - ▪ Regulator Modifications at JA-03, JA-06 and JA-14
      - – bending weirs at all three regulators
      - – increased orifice opening size at Regulator JA-03 from 36"x48" to 61.5"x74"
    - ▪ Bergen Basin Parallel Interceptor Sewer Project
      - – relief sewers for existing twin-36" sewers: a new 54" single sewer, followed by twin-36" sewers (in series)
    - ▪ Automation of Regulator JA-02
      - – actuator to control flow at the regulator; under dry conditions, the regulator conveys flow to the Jamaica WWTP via the Howard Beach Pump Station; under wet weather conditions, the regulator diverts flow to the Spring Creek AWWTP for retention
  - o For the 26th Ward WWTP sewershed these projects included:
    - ▪ HLSS in Fresh Creek tributary area
  - o Infiltration and inflow (I&I) from the storm and combined sewers tributary to the Paerdegat Basin CSO Facility and the Spring Creek AWWTP was included in the analyses. I&I flows were based on existing conditions.

Planned BWSO Sewer Projects:

- The potential gravity trunk sewer to support redevelopment of downtown Jamaica was included in the Baseline Conditions. It is possible that the retained alternative for the Jamaica WWTP Drainage Area Facility Planning project may be a pump station/force main, but no alternative had been selected at the time the Baseline Conditions were finalized. The parameters adjusted during the calibration to support the Jamaica WWTP Drainage Area Facility Planning project were also updated in the Baseline Conditions model.

- It is recognized that BWSO storm sewer build-out planning is ongoing and capital projects planned within the 2040 LTCP Baseline Conditions planning period may change as the LTCP development progresses. Given the uncertainty over the schedule and specific scope of these projects, the Southeast Queens storm sewer buildout was not included in the baseline conditions.

Sewer Sediments:

- Sediment conditions were representative of post cleaning observations from Citywide Interceptor Cleaning Program.
- No sediments in sewers except as measured during model calibration.

Green Infrastructure (GI):

The NYCDEP Bureau of Engineering Design and Construction (BEDC) and the Bureau of Environmental Planning and Assessment (BEPA) have completed or are in the midst of implementing GI projects within a number of sewersheds tributary to Jamaica Bay.

BEPA and their GI modeling consultants provided Hazen and Sawyer with an InfoWorks CS model incorporating all Baseline Condition GI on May 7, 2018. This model included three major types of GI implementation:

1) Lumped detention: Physical location and size of the detention practice has not yet been identified. The total impervious area managed by detention across an outfall is applied to the model. A portion of flow is restricted, so that its release to the sewer system is delayed.

2) Distributed retention: The physical location and size of the retention practice is known and modeled. Additionally, individual infiltration rates obtained during field investigations are applied to each practice. The runoff generated across the impervious area managed by the practice is removed by infiltration and completely bypasses the sewer system.

3) Lumped retention: Physical location and size of the retention practice has not yet been identified. The total impervious area managed by retention across an outfall is applied to the model. The runoff generated across the impervious area managed by the practice is removed by infiltration and completely bypasses the sewer system.

The impervious area managed by GI in this model is summarized in Table 1 below:

Table 1. Baseline Condition: Impervious Area Managed by Green Infrastructure

Waterbody/ Designation/ GI Type	**Bergen Basin**		**Thurston Basin**		**Fresh /Hendrix Creek**	**Spring Creek**	**Paerdegat Basin**	**Grand Total**
	Combined	**Storm**	**Combined**	**Storm**	**Combined**	**Combined**	**Combined**	
Lumped Detention	134.1	0	33.4	0	117.5	38.0	55.7	378.7
Distributed Retention	442.2	1.6	0.0	0	243.9	249.1	7.0	943.9
Lumped Retention	11.4	0	78.7	0	10.5	14.2	78.6	193.4
Total Acres Managed by Waterbody	**587.7**	**1.6**	**112.1**	**0**	**372.0**	**301.3**	**141.23**	**1515.9**

Ambient Conditions

- WWTP effluent loadings were assumed to represent future conditions consistent with the Nitrogen Consent Judgment. Effluent limits for BOD and nitrogen at the Jamaica, 26th Ward, Rockaway, and Coney Island WWTPs were set so that nitrogen removal was fully operational.
- For tides, winds and ambient conditions (river flows), used 2008 conditions.
- For 2002 to 2011, continuous bacteria simulations used tides and ambient conditions from 2002-2011.
- Sea Level Rise based on 2050 projections was included only when sea level rise sensitivity was assessed.

Water Quality Standards

- Existing Water Quality (Tributaries) Criteria – Class I
    - Fecal GM ≤ 200 cfu/100mL - calendar month – annual
    - DO never less than 4.0 mg/L at any time
- Primary Contact Water Quality (existing Class SB Criterion in Jamaica Bay and upgraded fishable-swimmable criteria in tributaries)
    - Fecal GM ≤ 200cfu/100mL - calendar month – annual
    - DO Chronic Standard: Daily average ≥ 4.8 mg/l*
    - DO Acute Standard: never less than 3.0 mg/L

  * Chronic standard based on daily average. The DO concentration may fall below 4.8 mg/L for a limited number of days, as defined by the formula:

$$DO_i = \frac{13.0}{2.80 + 1.84e^{-0.1t_i}}$$

  where DO_i = DO concentration in mg/L between 3.0 – 4.8 mg/L and t_i = time in days. This equation is applied by dividing the DO range of 3.0 – 4.8 mg/L into a number of equal intervals. DO_i is the lower bound of each interval (i) and t_i is the allowable number of days that the DO concentration can be within that interval. The actual number of days that the measured DO concentration falls within each interval (i) is divided by the allowable number of days that the DO can fall within interval (t_i). The sum of the quotients of all intervals (i …n) cannot exceed 1.0: i.e.

$$\sum_{i=1}^{n} \frac{t_i(\text{actual})}{t_i(\text{allowed})} < 1.$$

- Proposed *Enterococci* WQ Criteria*
    - *Enterococci* 90-day rolling GM ≤ 35 cfu/100mL – May 1st through October 31st (Recreational Season)
    - *Enterococci* standard threshold value (STV) 90th percentile ≤ 130 cfu/100mL (Recreational Season)
- Compliance was defined as being at 95 percent attainment of the standard or higher
- The Proposed *Enterococci* WQ Criteria* were not yet been promulgated as of the date of submittal of the LTCP. As such, the assessment of attainment of the Proposed *Enterococci* WQ Criteria* was completed for comparison purposes only.

CSO, Stormwater, Highway Runoff, Direct Drainage and other Urban Stormwater Loadings

Bacteria Loading

*Proposed *Enterococci* WQ Criteria, if adopted as proposed, would only apply to Class SB and SA waters.

In order to develop loads for the Jamaica Bay model, the pathogen concentrations were first defined for each of the outfalls that discharge into the model domain. Each outfall has a defined land surface which drains stormwater runoff. Each of these outfall drainage areas was visually inspected using aerial photographs from USDA taken in 2015. The drainage areas were categorized as either residential, impervious non-residential, or undeveloped. Typical concentrations for direct drainage were used for the undeveloped drainage basins. The same concentrations that were used for LaGuardia Airport in the Flushing Bay LTCP model were used for all areas defined as impervious non-residential. The remaining basins were defined as residential, and the stormwater concentrations were dependent on the WWTP sewershed in which they resided.

Pathogen concentration data were collected at several CSO outfalls during the calibration period. For those outfalls, the data was analyzed, and a determination was made as to whether the concentration data was log-normally distributed. A Monte Carlo distribution of 100 unique concentrations was developed based on the mean and the standard deviation of the log of the data from each outfall. The Monte Carlo analysis produced a unique randomized concentration for each hour, with the overall statistical distribution of all the values matching the statistical distribution of the data. Pathogen loadings were calculated for each hour by multiplying the concentration generated by the Monte Carlo analysis by the flow generated by the IW model. The Monte Carlo concentrations were used for all outfalls where the loading was capable of reproducing the receiving water data. In some cases, the data was insufficient to represent the overflow concentrations from certain outfalls. In these cases the mass balance concentrations were applied.

Pathogen data were collected at the Thurston Basin regulators, so the normal loading approach would be to use the Monte Carlo approach at this location. However, due to the interactions between CSO and stormwater in the outfalls to Thurston Basin, and to have a consistent loading approach for the calibration and projection runs, the mass balance approach was used to assign concentrations at the Thurston Basin CSO outfalls.

Loadings to the water quality model were developed from IW flows and associated concentrations:

- Bacteria loading from the WWTPs was based on Monte Carlo analysis of the 2015 plant effluent data for fecal coliform. Since *Enterococci* is not measured in the effluent, a concentration equal to half of the fecal coliform concentration was assigned. The geometric mean of the fecal coliform concentration at each WWTP is presented in Table 2.

Table 2. Geometric Mean Fecal Coliform Concentrations at Each WWTP

WWTP	Fecal Coliform (#/100mL)
26th Ward	12
Coney Island	21
Jamaica	13
Rockaway	9

- Direct drainage concentrations reflected recent updates to direct drainage bacteria concentrations derived from the low end concentrations from the 2005 Memo (HydroQual 2005, May 4, 2005, NY/NJ Harbor Estuary Program Model Application of Stormwater Sampling Results, Technical Memorandum from Charles Dujardin and William Leo to Chris Villari - NYC DEP), from the NYS Stormwater Manual and from experience in the Charles River watershed.
    - Fecal coliform = 4,000 #/100mL
    - *Enterococci* = 6,000 #/100mL
- The stormwater bacteria concentrations were based upon the HydroQual 2005 Memo for all waterbodies except Bergen and Thurston Basins. The 2005 memo classified the 26th Ward and Coney Island WWTPs as high level urban concentration sewersheds and the Jamaica and

Rockaway WWTPs as low level urban concentration sewersheds. Stormwater sampling performed in Bergen Basin and Thurston Basin found bacteria concentrations to be higher than those recommended in the 2005 Memo and were increased accordingly.

- Stormwater loading will be based on the assigned concentrations and calculated flows from InfoWorks.

- IW catchments will be examined to determine whether parks and cemeteries and other open and non-urban areas are properly classified as direct drainage catchments and not stormwater catchments and necessary adjustments will be made.

- The Nassau County drainage area that discharges into Head of Bay and the eastern end of Jamaica Bay will be added to InfoWorks to account for the volume of runoff from Nassau County. Nassau County stormwater concentrations will be based on the direct drainage concentrations used in the calibration process.

- CSO concentrations at outfalls where CSO sampling data were collected were based on 2015 and 2016 measurements:

  - The Monte Carlo approach was used to calculate CSO bacteria concentrations for Outfalls 26W-003, JAM-003, JAM-003A, and PB-CSO.

  - Rounded geometric means of the LTCP sampling results from CSOs that form the basis of the Monte Carlo approach are provided in Table 3.

Table 3. Geometric Means of CSO Sampling Data

Outfall	Fecal Coliform, #/100 ml	*Enterococcus*, #/100 ml
26W-003	215,000	155,000
JAM-003 & JAM-003A	665,000	545,000
PB-CSO	970,000	515,000

- Monitoring data collected at the Paerdegat Basin CSO Facility was used to developed overflow concentrations using the Monte Carlo methodology.

- CSO monitoring covered many of the major CSOs that are expected to overflow. For other CSOs that overflow, the mass balance approach was used based on sanitary concentrations in the HydroQual (2005) memorandum:
  - Sanitary fecal coliform = 4,000,000 cfu/100mL
  - Sanitary *Enterococci* = 1,000,000 cfu/100mL

- For the mass balance modeling simulations, CSO concentrations were calculated using the stormwater and sanitary concentrations, multiplied by the flow calculated by the IW model. The model provided a calculated fraction of flow from stormwater and flow from sanitary sources, as follows:

$$C_{cso} = fr_{san} * C_{san} + fr_{sw} * C_{sw}$$

where: C_{cso} = CSO concentration

C_{san} = sanitary concentration

C_{sw} = stormwater concentration

fr_{san} = fraction of flow that is sanitary

fr_{sw} = fraction of flow that is stormwater

Further details will be provided in the modeling technical memorandum entitled "Jamaica Bay and Tributaries Water Quality and Sewer System Modeling Technical Memorandum."

- The flow monitoring at 26W-003, 26W-004, JAM-003, JAM-003A, JAM-005, JAM-007 under this LTCP contract was used to assess the calibration of the InfoWorks model.

Table 4 summarizes the bacteria source concentrations used for water quality modeling.

Table 4. Bacteria Source Concentrations Used for Water Quality Modeling

Source	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)	BOD_5 (mg/L)
Urban SW - Bergen Basin(1)	45,000	55,000	15
Urban SW - Rockaway(2)	35,000	15,000	
Urban SW - All Others(2)	120,000	50,000	
Sanitary for Mass Balance CSOs(3)	4,000,000	1,000,000	Mass Balance (Sanitary=110)
CSOs (26W-003, JAM-003, JAM-003A, PB-CSO)(4)	Monte Carlo	Monte Carlo	Mass Balance (Sanitary =110)
CSOs (All others)	Mass Balance	Mass Balance	Mass Balance (Sanitary=110)
Highway/ Airport Runoff (5)	20,000	8,000	15
Direct Drainage(6)	4,000	6,000	15
WWTP Effluent(7)	Monte Carlo	Monte Carlo	Quarterly

Notes:

(1) Stormwater bacteria concentrations based on 2015-2017 Jamaica Bay and Tributaries LTCP measurements. Stormwater BOD_5 based on Jamaica Bay Waterbody/Watershed Report (2012).
(2) Stormwater bacteria concentrations based HydroQual Memo to DEP, 2005a. Stormwater BOD_5 based on Jamaica Bay Waterbody/Watershed Report (2012).
(3) Sanitary bacteria concentrations from the HydroQual Memo to DEP, 2005a. BOD concentrations based on Jamaica Bay Waterbody/Watershed Report (2012).
(4) Monte Carlo based on 2015 LTCP CSO data.
(5) Highway/Airport runoff concentrations based on airport drainage data used in the Flushing Bay LTCP model estimated from NYS Stormwater Manual, Charles River LTCP, National Stormwater Data Base.
(6) Direct drainage bacteria concentrations based on NYS Stormwater Manual, Charles River LTCP, and National Stormwater Data Base for commercial and industrial land uses. Direct drainage BOD_5 concentrations specified as stormwater.
(7) WWTP effluent bacteria concentrations based on 2016 DMR measurements: Monte Carlo selection of daily averages for fecal coliform and median of several months for *Enterococci*. BOD concentrations based on quarterly BioWin model results from the FANCJ analysis.

Eutrophication Loading

- The sanitary and stormwater concentrations used for the eutrophication modeling were based on the previous Jamaica Bay Eutrophication Study. The applied concentrations are shown in Table 5.

Table 5. Sanitary and Stormwater Concentrations for Eutrophication Model

Constituent	26th Ward Sanitary (mg/L)	Coney Island Sanitary (mg/L)	Jamaica Sanitary (mg/L)	Rockaway Sanitary (mg/L)	Stormwater (mg/L)
Organic P	1.22	1.65	1.09	1.34	0.16
Phosphate	2.27	1.63	2.39	1.75	0.11
Organic N	9.28	10.81	12.47	8.00	1.3
Ammonia	16.26	10.85	19.20	10.54	0.27
Nitrite + Nitrate	0.18	0.40	0.28	0.72	0.51
Silica	6.96	7.22	10.03	7.82	1.45
Organic Carbon	58.8	88.0	83.4	42.2	16.5
Dissolved Oxygen	1.0	1.0	1.0	1.0	6.3

- The WWTP effluent concentrations used for the eutrophication modeling were based on BioWin results for the First Amended Nitrogen Consent Judgment and 2015 data. Concentrations varied on a monthly basis and ranges are presented in Table 6.

- Note the model directly modeled carbon and not the indirect measurement of carbon that is BOD. BOD can be calculated based on the carbon concentrations and the carbon oxidation rates used in the model. Conversely, carbon concentrations for loads can be calculated from BOD concentrations using the carbon oxidation rates.

Table 6. WWTP Effluent Concentrations for Eutrophication Model

Constituent	26th Ward WWTP Range (mg/L)	Coney Island WWTP Range (mg/L)	Jamaica WWTP Range (mg/L)	Rockaway WWTP Range (mg/L)
Organic P	0.4-1.5	0.2-1.6	0.3-1.4	0.2-1.6
Phosphate	1.6-4.1	0.8-2.6	0.4-1.8	1.5-2.2
Organic N	1.0-3.7	1.7-8.0	2.0-3.4	0.7-2.1
Ammonia	2.6-11.3	8.8-21.6	1.9-8.8	1.8-7.7
Nitrite + Nitrate	2.3-7.2	0.8-2.6	0.9-3.7	2.9-11.9
Silica	6.96	7.22	10.03	7.82
Organic Carbon	4.9-13.0	7.7-66.7	6.3-15.4	3.9-10.3
Dissolved Oxygen	3.9-6.2	1.3-3.0	4.4-6.4	6.2-7.9

Assessments

IW Model Assumptions

- Runoff coefficients, roughness, etc., were based on the 2012 Recalibration Report (InfoWorks Citywide Recalibration Report, Updates to and Recalibration of the October 2007 Landside Models, New York City, Department of Environmental Protection, June 2012) unless otherwise modified through local calibration as part of LTCP2. These parameters were updated as needed during the IW calibration analysis based on the 2015 flow measurements.

- Evapotranspiration was based on monthly values as per the 2012 Recalibration.

- BEPA and their GI modeling consultants provided Hazen and Sawyer with an InfoWorks CS model incorporating all Baseline Condition GI on May 7, 2018. A total of approximately 1,616 impervious acres are managed by GI across all waterbodies tributary to Jamaica Bay

Jamaica Bay WQ Model Assumptions

- The larval transport version of the JEM model was used to calculate water quality in the Bay.

- The model grid was not further refined.

- The WWTPs were modeled based on the nitrogen removal upgrades specified in the First Amended Nitrogen Consent Judgment.

Water Quality Evaluations

- Alternative CSO control evaluations, dissolved oxygen evaluations, Section 6 (Appendix A) loading table, and Section 6 bacteria component analysis were all developed using calendar year 2008 rainfall conditions from JFK Airport rain gauge.

- Fecal coliform and *Enterococci* Baseline and 100% CSO Control evaluations were run for 2008 conditions and continuous water quality simulations using calendar year 2002 through 2011 from JFK Airport rain gauge. The preferred alternative continuous water quality simulations used calendar year 2002 through 2011 from JFK Airport rain gauge.

- Component analyses was performed to develop the fecal coliform (max. month during year) and *Enterococci* (max. 90-day period during recreational season) GM components for 2008 conditions. The components that were evaluated included CSO, DEP MS4 stormwater and direct drainage, and boundary conditions.

- Only CSO load reduction alternatives that provide input to the Knee-of-the-Curve analyses were assessed.

- The gap analysis was completed using a Baseline and a 100% CSO reduction scenario.

- Simulations consisted of the following:
  - 2002-2011 baseline bacteria simulation
  - 2002-2011 100% CSO control bacteria simulation

- o 2008 baseline DO simulation
- o 2008 100% control DO simulation
- o 2008 bacteria component analysis
- o 2002-2011 recreation binned precipitation time to recover for fecal coliform

- Alternatives analysis included:
  - o Up to six one-year bacteria simulations
  - o Up to four one-year DO simulations
  - o 2002-2011 bacteria simulation for the preferred alternative

Post-Processing

- Models were post-processed for the following:
  - o All IW 2008 model simulations were post-processed for annual average CSO, stormwater and direct drainage overflow volumes.
    - ▪ Discharge volume (annual average overflow – AAOV) tables were prepared for each CSO outfall, stormwater and direct drainage location.
  - o IW model outputs for the 2002 to 2011 preferred alternative run were prepared with water quality outputs and were used to drive the JEM WQ model of Jamaica Bay and its CSO tributaries.
    - ▪ No AAOV tables for the 2002 to 2011 run were prepared for use in the report but AAOV tables were prepared for internal use.
  - o WQ models were post-processed for annual attainment (fecal coliform and DO) and recreational season attainment (fecal coliform and *Enterococci*) including:
    - ▪ Existing WQ Criteria (Tributaries) – Class I
      - – Fecal GM ≤ 200cfu/100mL - calendar month – annual and May 1st through October 31st (Recreational Season)
      - – DO never less than 4.0 mg/L
    - ▪ Primary Contact WQ Criteria (existing Class SB Criterion in Jamaica Bay and upgraded fishable-swimmable criteria in tributaries)
      - – Fecal GM ≤ 200cfu/100mL - calendar month – annual and May 1st through October 31st (Recreational Season)
      - – DO Chronic Standard: Daily average >= 4.8 mg/L, and
      - – DO Acute Standard: never less than 3.0 mg/L
    - ▪ Proposed *Enterococci* WQ Criteria*

* Proposed *Enterococci* WQ Criteria, if adopted as proposed, would only apply to Class SB and SA waters.

– *Enterococci* 90-day rolling GM ≤ 35 cfu/100mL – May 1st through October 31st (Recreational Season)

– *Enterococci* STV 90th percentile ≤ 130 cfu/100mL (Recreational Season)

– *Enterococci* was evaluated for comparative purposes only as DEC had not promulgated the *Enterococci* standards as of the submittal of the LTCP.

- Fecal coliform time-to-recovery tables were calculated based on the 2002-2011 recreation season binned precipitation for Baseline Conditions, the 100% CSO control scenario, and the preferred alternative. Results were presented or "binned" based upon a range of storm sizes.

- Preferred alternative WQ results were prepared from the 10-year simulation for bacteria (fecal coliform and *Enterococci*) and from the 2008 simulation for DO.

Appendix C
Sewer System and Water Quality Modeling Report

The City of New York
Department of Environmental Protection
Bureau of Wastewater Treatment

CSO Long Term Control Planning II

Jamaica Bay and Tributaries LTCP

Sewer System and Water Quality Modeling

August 2018

AECOM
with Hazen

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1.0 INTRODUCTION

Collection system and receiving-water quality models were used to support the development and evaluation of combined sewer overflow (CSO) control alternatives as part of the process of developing the Long Term Control Plan (LTCP) for Jamaica Bay and its tributaries. These models were initially developed to represent existing conditions in the collection system and in the receiving waters. Flow metering and sampling programs were then undertaken to provide a basis for calibrating the models against actual measured conditions. Once the collection system models were calibrated, they were further modified to represent the LTCP Baseline Conditions. The baseline conditions models provided the basis for comparing the performance of CSO control alternatives, and included a defined set of future conditions including base sanitary flow, implementation of previously-defined cost-effective grey CSO control projects, and implementation of green infrastructure (GI) over a previously-defined percentage of impervious tributary area.

The collection system and receiving-water quality models used to support the Jamaica Bay and Tributaries LTCP were based on versions of previously-calibrated models used as part of earlier CSO planning efforts. These earlier models were updated with new information and validated with flow and water quality data for use in support of the Jamaica Bay and Tributaries LTCP. This report provides information related to the update and validation of the collection system and water quality models for Jamaica Bay and its tributaries. Section 2 covers the collection system model, and Section 3 covers the water quality models.

Figure 1-1 presents the Jamaica Bay watershed area and Figure 1-2 presents the project area. Figure 1-2 presents the drainage area separated into combined sewer areas, separate sewer areas, and direct drainage, and the CSO and storm sewer outfall names and locations are identified. . It should be noted that areas shown in Figure 1-2 as separated (stormwater) and direct drainage are based on information available at the time the model was developed, and should be considered approximate in some locations.

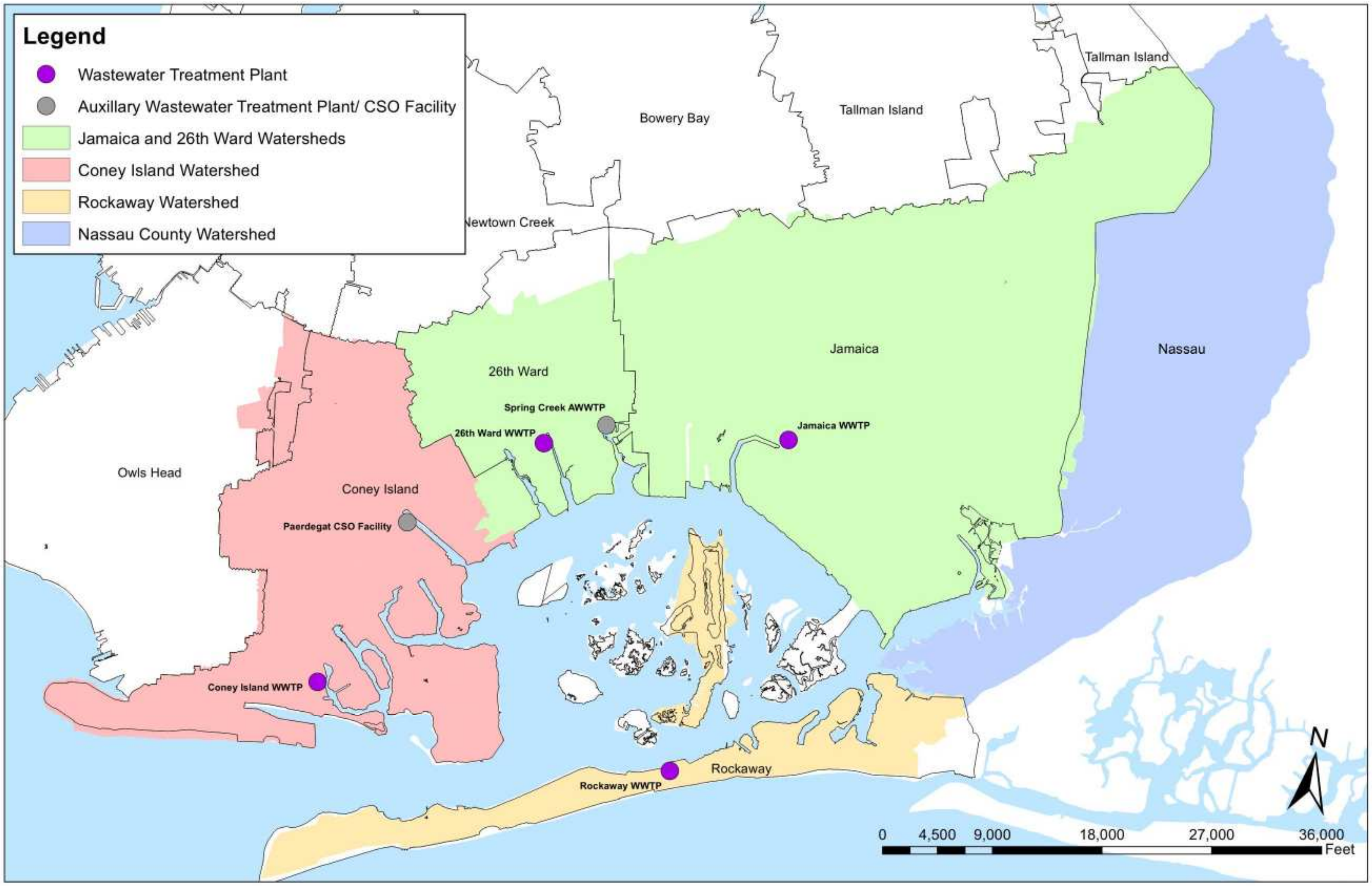

Figure 1-1. Jamaica Bay Watershed Area

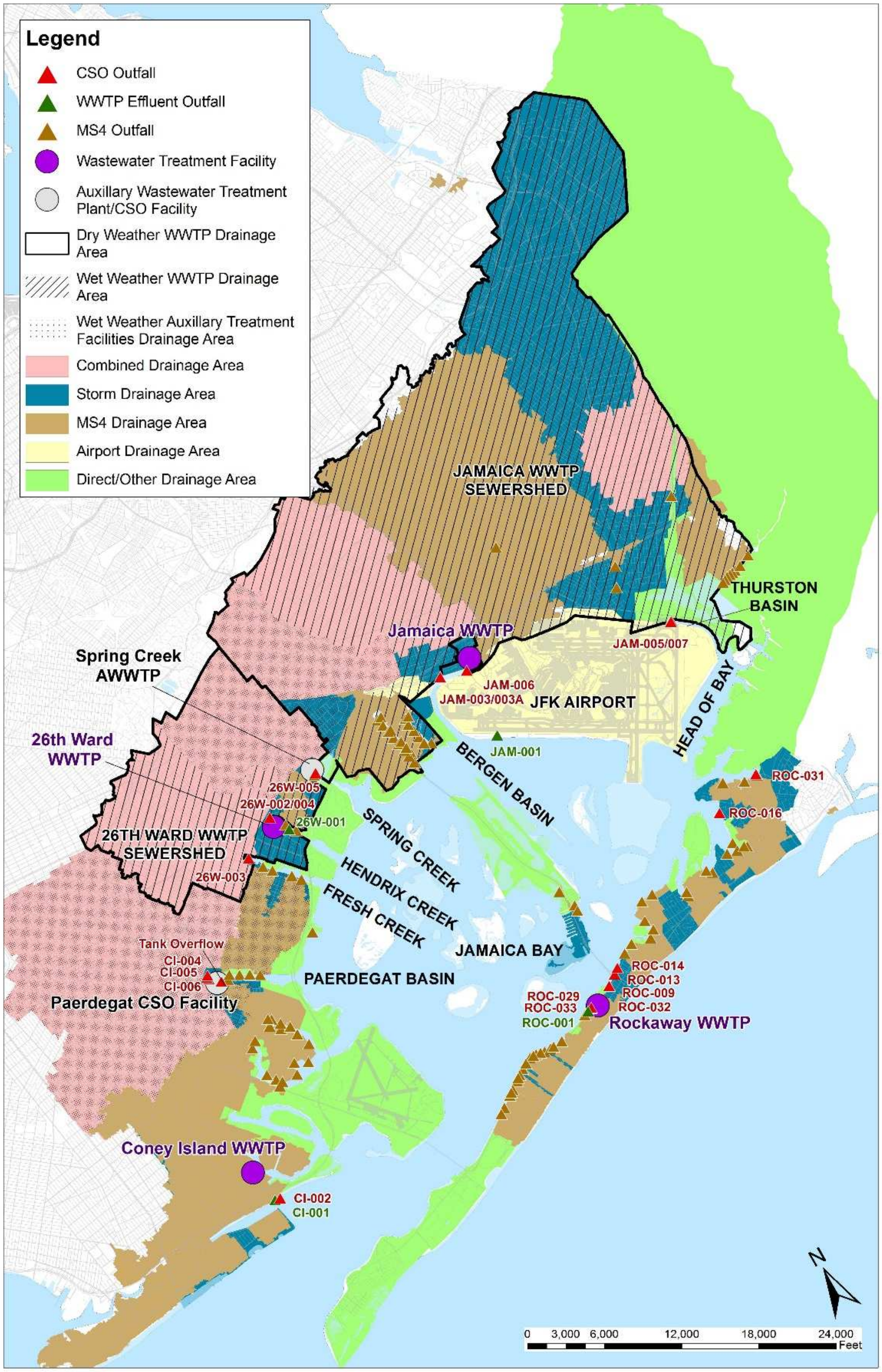

Figure 1-2. Jamaica Bay Project Area

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2.0 CSO AND STORMWATER MODELING

2.1 Model Description

The Jamaica, 26th Ward, Rockaway and Coney Island Wastewater Treatment Plant (WWTP) service areas were modeled using InfoWorks CS™ (IW) version 10.5, a link-node hydrologic and hydraulic model that combines a relational database with geographical analysis to provide a single environment for integrated analysis. The hydraulic component of the software incorporates full solution modeling of backwater effects and reverse flow, open channels, sewers, detention ponds, complex pipe connections, and complex ancillary structures such as culverts, orifices, and weirs. The hydrologic component of the IW model incorporates the routines from the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM), a non-linear reservoir routing model developed for the EPA, to route overland runoff. Three distinct IW models were used to cover the Owls Head, Coney Island, 26th Ward, Jamaica and Rockaway WWTP drainage areas. The Owls Head and Coney Island WWTP areas were integrated into a single IW model network due to certain hydraulic interconnections. Similarly, the 26th Ward and Jamaica WWTP areas were integrated into a combined 26th Ward/Jamaica IW model. The Rockaway WWTP service area is addressed as a separate IW model.

All three of the models include: plant headworks, interceptors, branch interceptors, major trunk sewers, all sewers greater than 48 inches in diameter plus other smaller, significant sewers, and control structures such as pump stations, diversion chambers, tipping locations, regulators and tide gates. Figure 2-1, Figure 2-2, and Figure 2-3 present schematics of the model networks.

2.1.a **Previous Modeling Overview**

<u>2007 Model Version</u>

During development of Waterbody/Watershed Facility Plans (WWFP) submitted in the late 2000s to the New York State Department of Environmental Conservation (DEC), IW models were employed for each WWTP service area, as documented in a series of model calibration reports dated October 2007[1]. The reports documented the development process and status of the collection/conveyance system models as of October 2007 and presented results showing the goodness-of-fit between flows and depths calculated by the model and measurements within the collection system conducted at various times prior to 2007. The model versions employed by DEP as documented in these reports were IW versions 6.5 and 7.0.

[1] There were 14 volumes of the report entitled "City-Wide Long Term CSO Control Planning Project, Landside Modeling Report"; each volume developed for an individual WWTP conveyance system (the 26th Ward, Coney Island, Jamaica, and Rockaway WWTP systems were documented in Volumes 1, 3, 5, and 12, respectively).

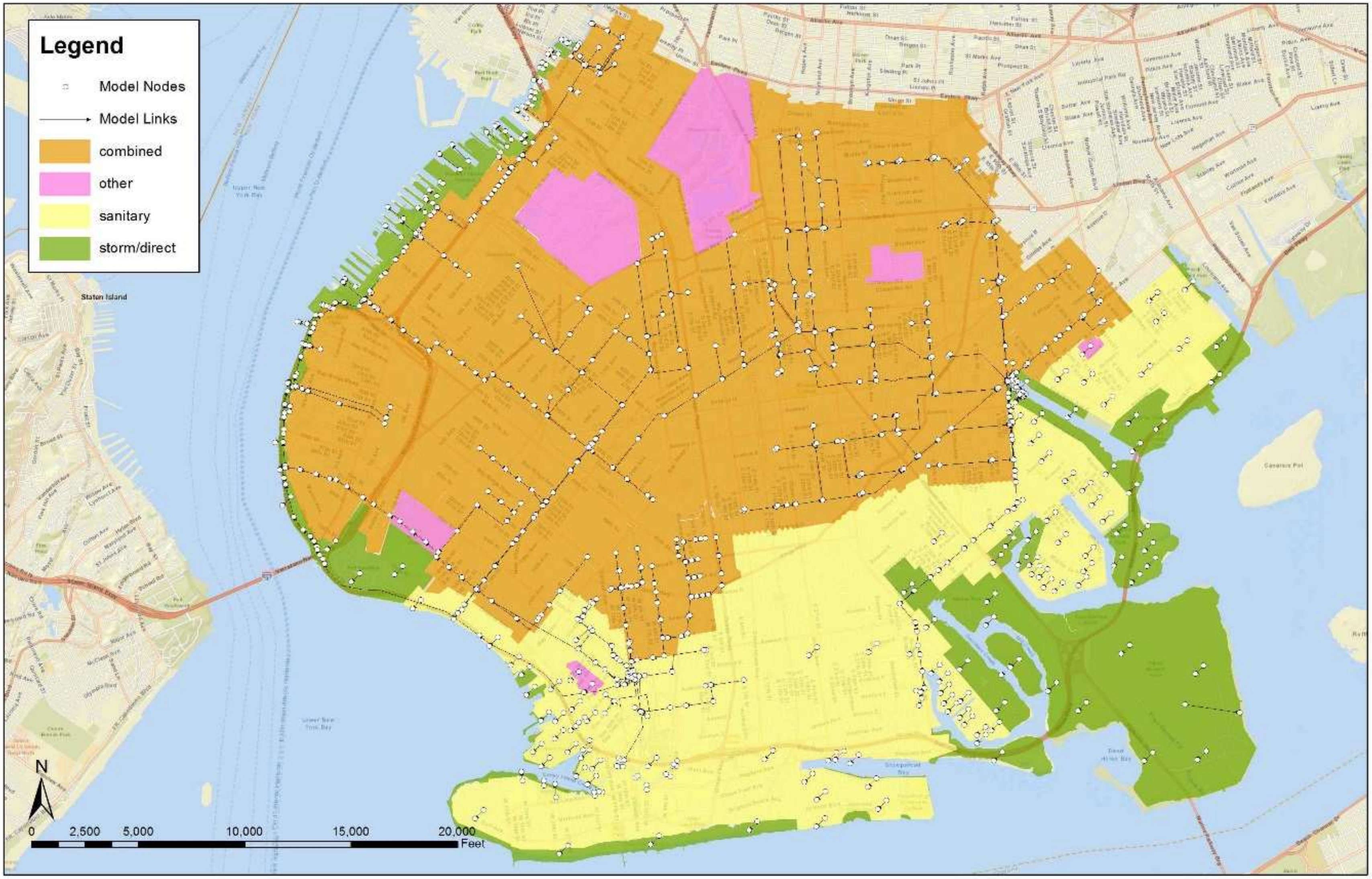

Figure 2-1. Coney Island and Owl's Head WWTP Model Network

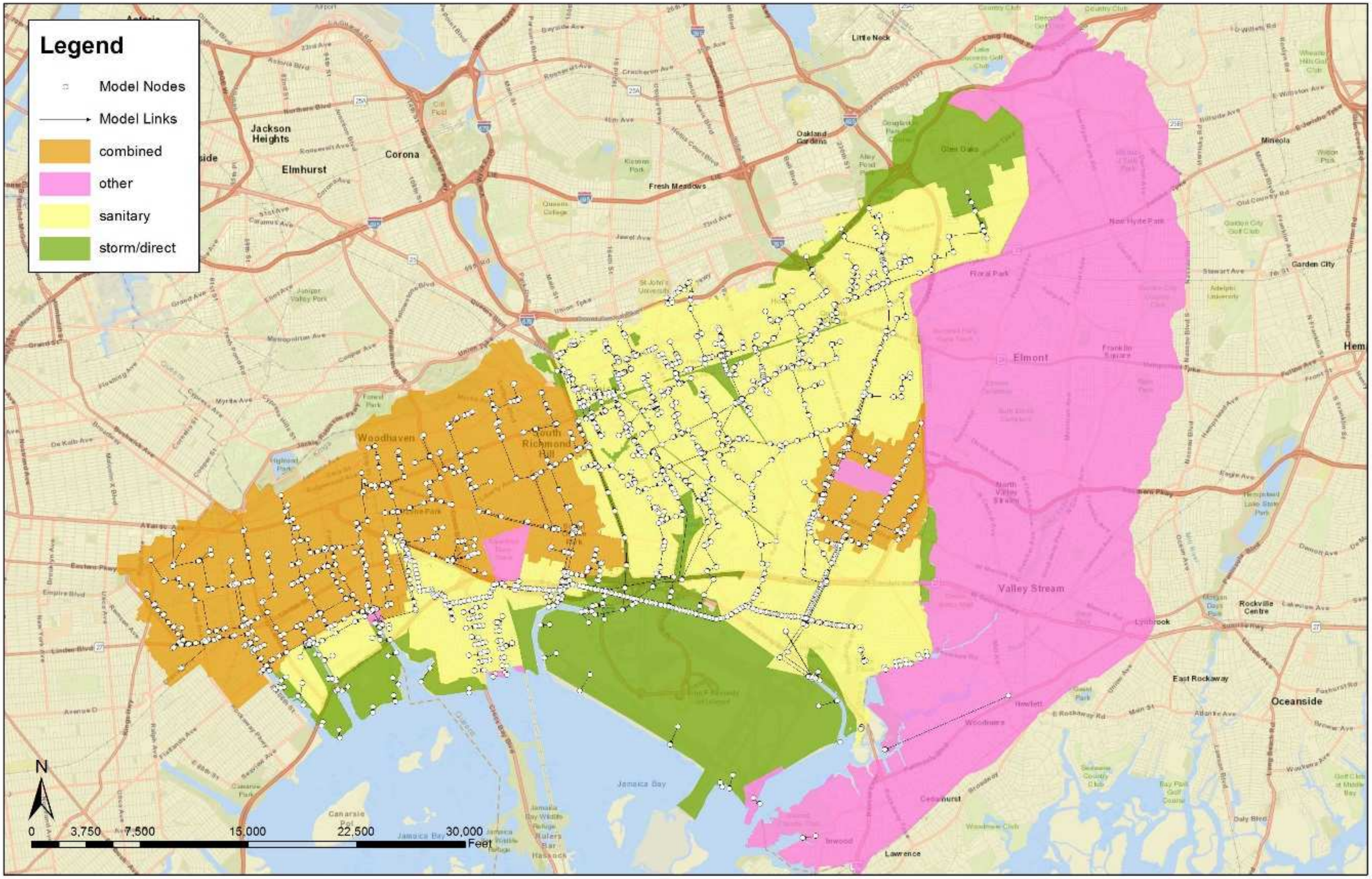

Figure 2-2. Jamaica and 26th Ward WWTP Model Network

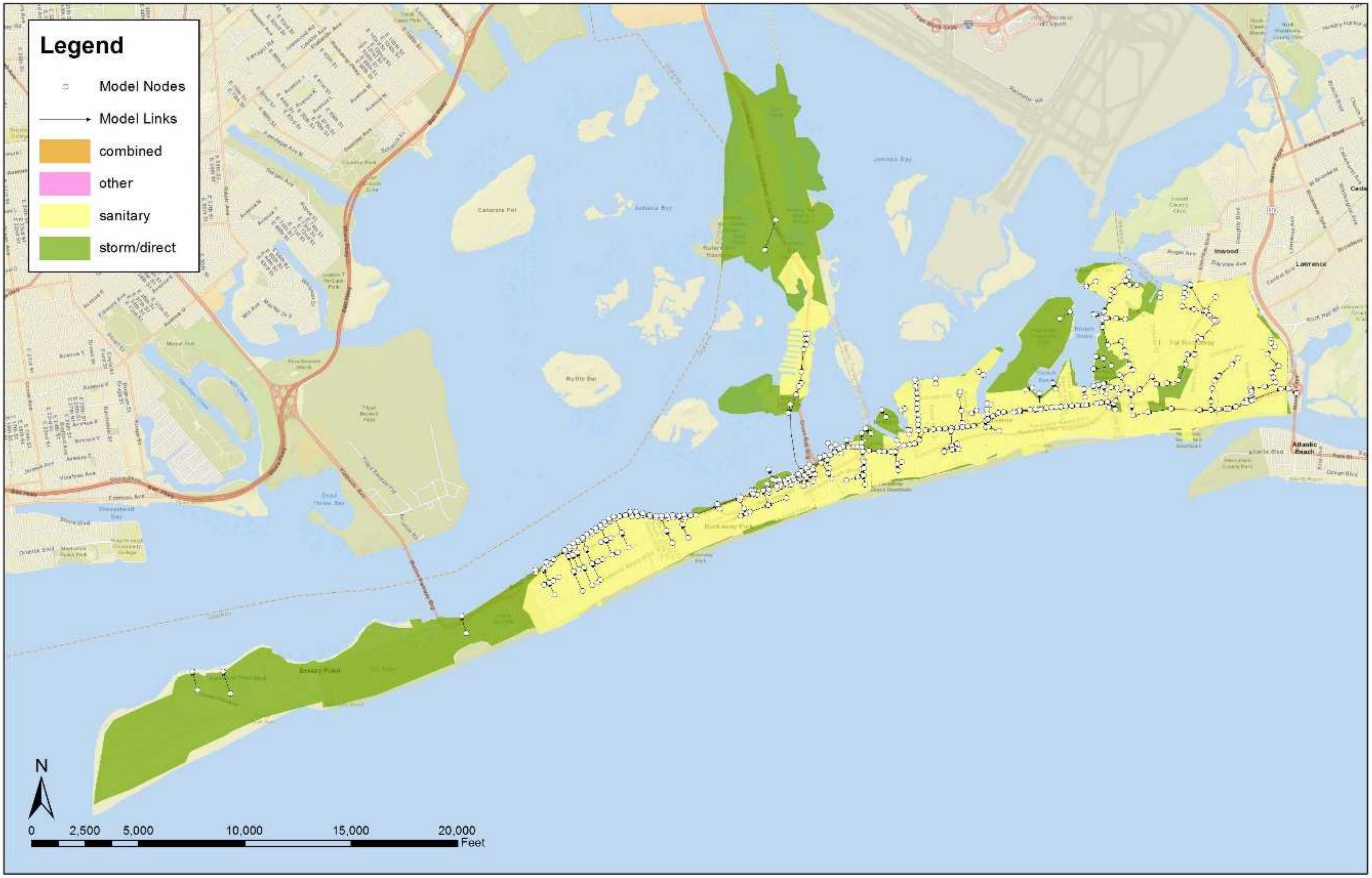

Figure 2-3. Rockaway WWTP Model Network

2012 Model Version

In 2012, the previous models underwent a major recalibration to serve as a better tool for green infrastructure evaluations, among other improvements. The majority of the 2012 model updates focused on the hydrology (i.e., runoff) portion of the model, but other updates were made as described further below. The 2012 update and recalibration is documented in the "InfoWorks Citywide Recalibration Report, Updates to and Recalibration of October 2007 NYC Landside Models, June 2012." The models were recalibrated using a phased approach as follows:

1. Use of site-scale flow monitoring data (to eliminate bias from downstream facilities and hydraulic structures) at a sampling of locations in the City as a localized representation of hydrology only.

2. Use of flow monitoring data located downstream in the system on larger trunk sewers and interceptors as an area-wide representation of both hydrology and hydraulics.

3. Use of facility (e.g., WWTP or CSO storage/treatment facilities) flow data to validate model predictions.

Previously, pervious surfaces were considered to infiltrate rainfall into soils based on the Horton equation. The basic premise of the Horton equation is that the amount of infiltration within the soils is based on the soil properties and that rainfall would continue to infiltrate as long as the intensity was less than the soil absorption capacity. More intense rainfall would produce runoff that would enter the collection system.

In the updated setup, the runoff coefficient approach was adopted for the model after researching the types of soil and infiltration data available from the NYC Water and Soil Conservation Service. In short, the available data would not provide additional insight on surface infiltration characteristics to allow refinement or continued use of the Horton equation approach to characterizing runoff behavior from pervious surfaces. As such, two types of pervious surfaces were developed for each sub-catchment and appropriate land areas developed from Geographical Information System (GIS) analyses: open space pervious surfaces and non-open space pervious surfaces. Open space pervious surfaces included parks, cemeteries, highway medians, and similar surfaces where surface soils were not subjected to consolidation by constant use. Non-open space pervious surfaces were defined as front and back yards in developed areas where soils would likely be consolidated through use. Open space and non-open space pervious surfaces were assigned runoff coefficients consistent with DEP drainage planning design values, as well as common usage in other similar modeling assessments.

In IW, a sub-catchment can have both total impervious area and the fraction of directly connected impervious area (DCIA) specified in the model. DCIA is a term that describes the impervious area that actually produces the runoff that reaches the collection system. Previously, the runoff coefficient for impervious surfaces was assigned an initial value of 1.0, and then the GIS-based imperviousness values were adjusted during calibration. This meant that the total impervious value was adjusted during calibration and it was assumed that all impervious area was directly connected to the sewer system. However, it was recognized that it is more appropriate (particularly to support the future use of the model in evaluating green infrastructure controls) to keep the total impervious area constant and adjust DCIA. This adjustment was made by reducing the runoff coefficient for the total impervious area. The impervious area runoff coefficient was treated as the primary calibration parameter during the recalibration analyses. As a result, the starting value for the impervious surfaces was the area provided by the Columbia University analysis (described in further detail in the 2012 Recalibration Report). This analysis was comprised of procurement of high quality satellite imagery (2.4 meter pixel resolution), followed by translation of each pixel of that imagery to measurements of pervious and impervious fractions. The final value for the DCIA in acres would then be the area provided by the Columbia University analysis multiplied by the final runoff coefficient for the impervious area developed during the recalibration process. This resulted in an approach that utilized the detailed imperviousness data, while controlling the runoff predicted from those surfaces through a coefficient, such that modeled output matched observed data.

In addition, to simulate runoff from impervious areas that have little or no initial rainfall losses (depression storage), one fourth of the impervious areas was assumed to have no initial losses. This assumption was made based on site-scale data analyses (as described above). Thus, the total drainage area in a sub-catchment was subdivided into four types of surfaces: impervious surface without depression storage; impervious surface with depression storage; pervious non-open surface; and pervious open surface.

IW software version 10.5, a more up-to-date version of the model, was employed in the 2012 recalibration effort.

In the 2007 version of the model, an average of 0.1 in/hr evaporation rate was used for model calibration, while no evaporation rate was used in the future condition simulations, as a conservative measure. The Northeast Regional Climate Center (NRCC) affiliated with Cornell University has developed a semi-physical model which estimates hourly evapotranspiration (ET). Continuous hourly ET estimates were obtained from Cornell for the NYC National Oceanic and Atmospheric Administration (NOAA) climate stations (JFK, EWR, CPK and LGA) for an 11-year period from 2000 to 2011. The data were then used to calculate monthly average ET. The monthly average ET rates developed from these long term data were then used in the models. The “June 2012 InfoWorks City-wide Recalibration Report,” provides additional information on the revised evaporation rates used in the model.

Finally, detailed pipe sediment data were incorporated into the modeled interceptors to represent a more realistic representation of the pipe conditions after the DEP completed a citywide inspection and cleaning program.

2.1.b 2016 Modifications to Model

Rainfall and Tides

Previous evaluations of the Jamaica Bay watershed used the 1988 precipitation characteristics as the representative typical precipitation year. However, for this LTCP, the precipitation characteristics for 2008 were used for the baseline condition, as well as for alternative evaluations. In addition to the 2008 precipitation pattern, the observed tide conditions that existed in 2008 were also applied in the models as the tidal boundary conditions at the CSO outfalls that discharge to tidally influenced waterbodies. For longer term 10-year evaluations, the period from 2002 through 2011 was analyzed.

Sanitary Flow Rates

Consistent with previous studies, the dry-weather sanitary sewage flows used in the baseline modeling were escalated to reflect anticipated growth in the City. In the past, flow estimates were based on the 2000 census, and growth rates were estimated by the Mayor’s Office and New York City Department of City Planning (DCP), to arrive at projected 2045 sanitary flow rates. These flows were then applied to the model, although they were conservative and did not account for flow conservation measures. The updated analyses uses the 2010 census data to reassign population values to the watersheds in the model and project up to 2040 sanitary flows. These projections also reflect water conservation measures that have already significantly reduced flows to the WWTPs and freed up capacity in the conveyance system.

Other Updates

Certain structures within the Jamaica, 26th Ward, Coney Island, and Rockaway WWTP collection systems have been modeled in more than one configuration, depending on the particular evaluations at the time. Some of these updates are not physically located within the Jamaica Bay watershed, but they may impact flows in this watershed due to hydraulic interconnectivities. Thus, they are summarized below:

- Added two 12" diameter piped interconnections upstream of Regulators JA-03 and JA-14 in the Bergen Basin drainage area of the model.
- Updated the Nassau County drainage area representation in the Jamaica WWTP model.
- Implemented the BWSO drainage area delineations where available in the Jamaica WWTP model.

2.2 Quantity Modeling

2.2.a Monitoring Program and Available Data

Temporary flow monitors were installed to collect flow data at Regulators JA-03 (Bergen Basin), JA-14 (Bergen Basin), JA-06 (Thurston Basin), JA-07 (Thurston Basin), and 26W-01 (Fresh Creek), to validate the current model's CSO discharge predictions. The flow and rainfall monitoring program ran from September 25, 2015 to December 31, 2015. Flow data was obtained at 5-minute intervals. The diagram in Figure 2-4 shows the locations of the flow meters used for the monitoring program.

Rainfall data was collected at the NOAA JFK gauge, as well as at the Jamaica and 26th Ward WWTP rain gauges, and a temporary gauge located near Outfall 26W-003. Radar rainfall data was also obtained and utilized in the model calibration and validation process. Table 2-1 summarizes the storm events observed during the monitoring period for this local gauge.

Figure 2-4. Monitoring Program Overview

Table 2-1. Observed Storm Events at 26W-003 Local (Temporary) Gauge

#	Rain Start	Rain End	Duration (hr)	Peak Intensity (in/hr)	Total Depth (in)
1	9/29/2015 23:20	9/30/2015 5:15	5.9	2.04	1.01
2	10/1/2015 16:55	10/3/2015 13:05	44.2	0.36	2.39
3	10/9/2015 17:45	10/9/2015 19:45	2.0	0.36	0.28
4	10/28/2015 10:50	10/29/2015 8:55	22.1	1.56	1.68
5	11/10/2015 8:55	11/11/2015 8:50	23.9	0.36	0.70
6	11/19/2015 18:00	11/20/2015 1:10	7.2	0.60	0.79
7	12/1/2015 3:25	12/1/2015 22:55	19.5	0.24	0.37
8	12/14/2015 20:15	12/15/2015 2:30	6.2	0.84	0.47
9	12/17/2015 11:05	12/17/2015 17:45	6.7	0.48	1.12
10	12/22/2015 9:05	12/22/2015 16:05	7.0	0.24	0.24
11	12/23/2015 11:00	12/23/2015 23:10	12.2	1.56	1.21
12	12/28/2015 19:20	12/29/2015 11:05	15.8	0.36	0.82
13	12/30/2015 21:00	12/31/2015 0:45	3.8	0.24	0.39

2.2.b **IW Model Quantity Assessment**

The model was used to simulate sewer flows for the rainfall conditions observed during the temporary monitoring period, and calculations were compared to the measured data to evaluate model accuracy. This effort was performed to validate the model's predictive capability for use in typical year LTCP simulations. A validation confirms that the model parameters are appropriate for predicting flows and volumes within reasonable ranges without changing model parameters (as opposed to a calibration, which specifically optimizes model parameters to match measured data).

A "triangulation" approach was utilized, where modeling output, flow monitoring data, and SCADA data (where available), were evaluated with respect to CSO events. Tables 2-2 and 2-3 summarize the comparison for the monitoring period.

Based on the initial comparisons of model-predicted output and measurements, the following modifications were made to the model:

- Dry-weather flow rate was modified to match measured data for the monitoring period.

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- Sediment was removed from the Regulator JA-06 influent pipe and branch pipe, to avoid an artificial dry-weather overflow and better match data.
- The runoff coefficient for Thurston Basin upstream separate storm areas where seepage pits were noted was decreased from 0.5 to 0.1. Figure 2-5 shows the approximate locations of seepage pits based on GIS data and conversations with DEP staff.
- The runoff coefficient for a 38-acre local area tributary to JA-06 (influent pipe measured at monitoring location "M2") was decreased from 0.5 to 0.2.
- The runoff coefficient in the 26W-003 tributary area was increased from 0.5 to 0.7.

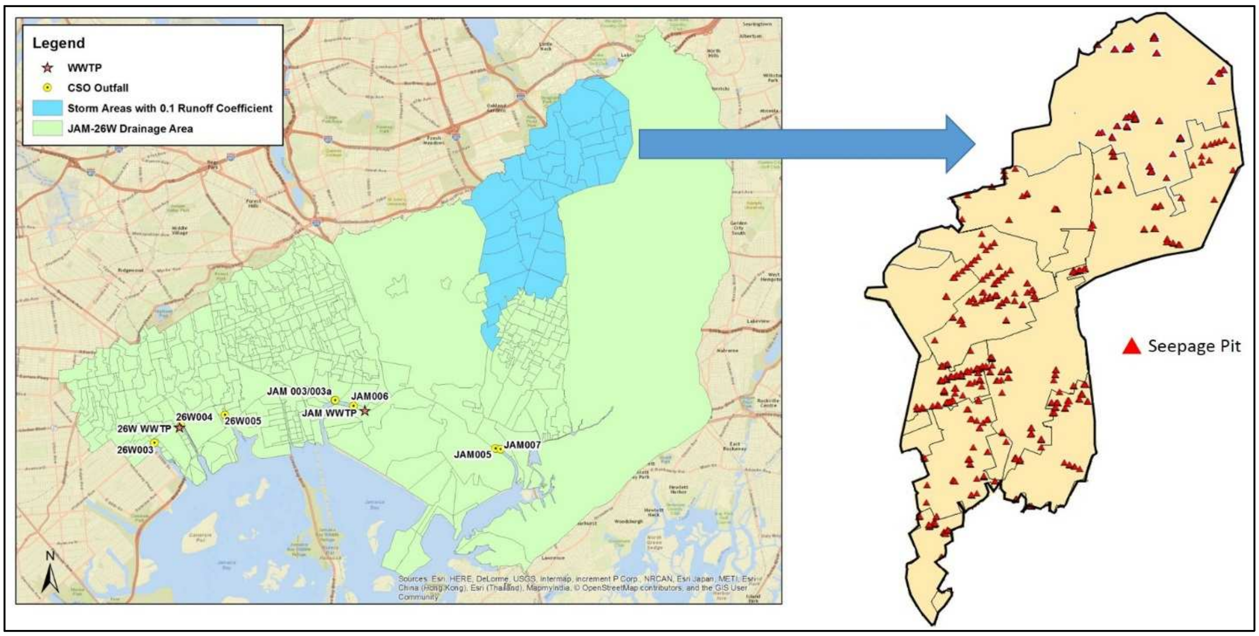

Figure 2-5. Approximate Seepage Pit Locations to Support Model Adjustment

Table 2-2. Triangulation of Data Sources for Model Calibration

Rain Events During Flow Monitoring Period						CSO Events at 26W-R2 (003)						CSO Events at JA-R6 (005)				CSO Events at JA-R7 (005/007)		
Event #	Rain Start	Rain End	Rain Duration (Hour)	Peak Intensity (Inch/Hour)	Total Depth (Inch)	26W003 Switch1	26W003 Switch2	ADS Metering Data[1]	DEP SCADA[2]	Model Prediction - Local Gauge	Model Prediction - RADAR	ADS Metering Data[5]	DEP SCADA	Model Prediction - Local Gauge	Model Prediction - RADAR	DEP SCADA	Model Prediction - Local Gauge	Model Prediction - RADAR
1	9/29/2015 23:20	9/30/2015 5:15	5.9	2.04	1.01	Y	N	Y	Y	Y	Y	Y		Y	Y		Y	Y
2	10/1/2015 16:55	10/3/2015 13:05	44.2	0.36	2.39	N	N	Y	Y	Y	Y	Y		Y	Y		Y	Y
3	10/9/2015 17:45	10/9/2015 19:45	2.0	0.36	0.28	N	N	N	N	N	N	Y		Y	Y		N	N
4	10/28/2015 10:50	10/29/2015 8:55	22.1	1.56	1.68	N	N	Y	Y	Y	Y	Y		Y	Y		Y	Y
5	11/10/2015 8:55	11/11/2015 8:50	23.9	0.36	0.70	N	N	N	N	N	N	N		Y	Y		N	N
6	11/19/2015 18:00	11/20/2015 1:10	7.2	0.60	0.79	N	N	Y	Y	Y	Y	Y		Y	Y		Y	Y
7	12/1/2015 3:25	12/1/2015 22:55	19.5	0.24	0.37	N	N	N	N	N	N	N	No Data	Y	Y	No Data	N	N
8	12/14/2015 20:15	12/15/2015 2:30	6.2	0.84	0.47	N	N	N	N	N	N	Y		Y	Y		Y	N
9	12/17/2015 11:05	12/17/2015 17:45	6.7	0.48	1.12	N	N	Y	Y	Y	Y	Y		Y	Y		Y	Y
10	12/22/2015 9:05	12/22/2015 16:05	7.0	0.24	0.24	N	N	N	N	N	N	N		Y	Y		N	N
11	12/23/2015 11:00	12/23/2015 23:10	12.2	1.56	1.21	Y	Y	Y	Y	Y	Y	Y		Y	Y		Y	Y
12	12/28/2015 19:20	12/29/2015 11:05	15.8	0.36	0.82	Y	Y	N	N	N	N	Y		Y	Y		Y	N
13	12/30/2015 21:00	12/31/2015 0:45	3.8	0.24	0.39	Y	Y	N	N	N	N	Y		Y	Y		N	N

Table 2-3. Triangulation of Data Sources for Model Calibration (Continued)

Rain Events During Flow Monitoring Period						CSO Events at JA-R9 (005/007)			CSO Events at JA-R3 (003)				CSO Events at JA-14 (003A)					
Event #	Rain Start	Rain End	Rain Duration (Hour)	Peak Intensity (Inch/Hour)	Total Depth (Inch)	DEP SCADA[2]	Model Prediction - Local Gauge	Model Prediction - RADAR	ADS Metering Data[4]	DEP SCADA	Model Prediction - Local Gauge	Model Prediction - RADAR	JAM003a Switch1	JAM003a Switch2	ADS Metering Data[3]	DEP SCADA[2]	Model Prediction - Local Gauge	Model Prediction - RADAR
1	9/29/2015 23:20	9/30/2015 5:15	5.9	2.04	1.01	N	Y	Y	Y	Data Not Reliable due to Construction	Y	Y	Y	Y	Y	Y	Y	Y
2	10/1/2015 16:55	10/3/2015 13:05	44.2	0.36	2.39	N	N	N	Y		Y	Y	Y	N	Y	Y	Y	Y
3	10/9/2015 17:45	10/9/2015 19:45	2.0	0.36	0.28	N	N	N	Y		Y	Y	Y	Y	Y	Y	Y	Y
4	10/28/2015 10:50	10/29/2015 8:55	22.1	1.56	1.68	N	N	N	Y		Y	Y	Y	No Data	Y	Y	Y	Y
5	11/10/2015 8:55	11/11/2015 8:50	23.9	0.36	0.70	N	N	N	N		Y	Y	Y		N	Y	Y	Y
6	11/19/2015 18:00	11/20/2015 1:10	7.2	0.60	0.79	N	N	N	Y		Y	Y	Y		Y	Y	Y	Y
7	12/1/2015 3:25	12/1/2015 22:55	19.5	0.24	0.37	N	N	N	N		Y	Y	N		N	Y	Y	Y
8	12/14/2015 20:15	12/15/2015 2:30	6.2	0.84	0.47	N	N	N	Y		Y	Y	Y		Y	Y	Y	Y
9	12/17/2015 11:05	12/17/2015 17:45	6.7	0.48	1.12	N	N	N	Y		Y	Y	Y		Y	Y	Y	Y
10	12/22/2015 9:05	12/22/2015 16:05	7.0	0.24	0.24	N	N	N	N		Y	Y	N		N	Y	Y	Y
11	12/23/2015 11:00	12/23/2015 23:10	12.2	1.56	1.21	N	Y	Y	Y		Y	Y	Y		Y	N	Y	Y
12	12/28/2015 19:20	12/29/2015 11:05	15.8	0.36	0.82	N	N	N	Y		Y	Y	Y		Y	Y	Y	Y
13	12/30/2015 21:00	12/31/2015 0:45	3.8	0.24	0.39	N	N	N	Y		Y	Y	No Data		Y	Y	Y	Y

The model was run for the calibration period and the model was evaluated using the criteria suggested in the Wastewater Planning Users Group (WaPUG, 2002) guidance document. The criteria were:

- The timing of the peaks and troughs should be similar, having regard to the duration of the event.
- The difference between observed and modeled peak flow rates at each significant peak should be in the range +25 percent to -15 percent and should be generally similar throughout the complete simulation of each event.
- The differences between observed and modeled volume of flow should be in the range +20 percent to -10 percent.
- The differences between observed and modeled depth of surcharge should be in the range +16 inches to –4 inches.
- The differences between observed and modeled un-surcharged depth at any key points, where un-surcharged depth is important in regard to the objectives of the model (e.g., at combined sewer overflows), should be within the range ±4 inches.

For each validation event, modeled versus observed hydrographs were generated to evaluate the model's performance. In addition, the goodness-of-fit was also examined by comparing the modeled event volume, peak flow and maximum water depth of the events to the observed data in goodness-of-fit scatter plots. The upper and lower WaPUG calibration criteria bounds were marked for comparison in goodness-of-fit plots (see Figure 2-6 for an example).

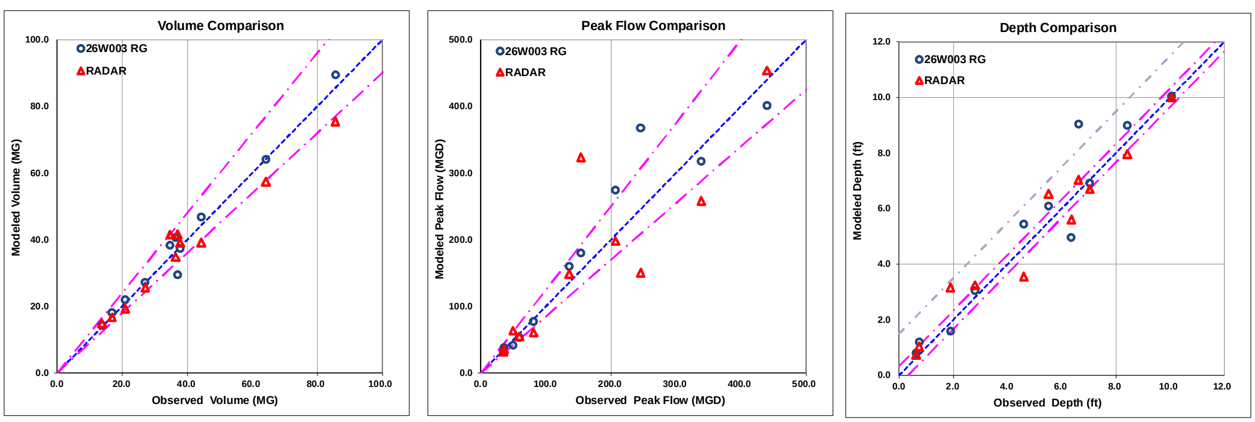

Figure 2-6. Example Model Performance Evaluation (26W-003 Influent)

The validation plots of measured versus modeled data for each monitoring location are presented in Appendix A. Plots showing model performance in comparison to the WaPUG criteria are presented in Appendix B. The validation results at each monitoring location are discussed below.

CSO 26W-003

The model-predicted versus observed influent peak flow, volume, and depth comparisons were almost all within the guidance error tolerances. The CSO comparisons were more scattered, but the volumes were nearly all within the error ranges (except for one storm), when using the local rain gauge. From the triangulation comparison, it can be seen that there was strong agreement and consistency among all three data sources (model output, SCADA data, flow monitoring data), for the occurrence of CSO events.

CSO JAM-003 and 003A

Outfalls 003 and 003A combine together at a common discharge point into the head end of Bergen Basin. Each of these outfalls is fed by overflow from Regulators JA-3 and JA-14, respectively. The model-predicted versus observed influent peak flow and volume comparisons were almost all within the guidance error ranges for influent flow to Regulator 3, but they were on the higher side of the range, while depth was consistently under-predicted. For Regulator JA-14, the opposite was true. This suggests that potentially the flow distribution between the two regulators is less than perfect, but it is greatly improved since the inclusion of the 2-12" diameter interconnections that were located via GIS data review. The CSO comparisons were scattered, but errors were minimized as some events were over-predicted and others under-predicted, at both Outfalls JAM-003 and JAM-003A. It should be noted that the CSO observations are based on a weir equation calculation (using measured depth). Tide gate switches were installed at JAM-003A. From the triangulation comparison, it can be seen that there was generally reasonable agreement and consistency among all three data sources (model output, SCADA data, flow monitoring data), for the occurrence of CSO events. One major factor affecting the comparison of predicted and measured CSOs at these two outfalls is the construction that was ongoing for the bending weir installation contract at each of the CSO regulator structures during the monitoring period.

JAM-005 and 007

Outfalls JAM-005 and JAM-007 receive CSO and separate stormwater flow from upstream tributary areas that are interconnected in many locations (both upstream and downstream of CSO regulators). This discussion focuses on the quantitative comparisons at the regulator structure since that is where the monitoring occurred (versus at the outfalls at the head end of Thurston Basin). Influent flow to Regulator JA-06 was measured at two locations (referred to as “M1” and “M2”). One of these locations (M2) was an influent pipe that served a very small (38-acre) tributary area. At this location, there was reasonable agreement between model-predicted peak flows, volumes and depths and measured values, for most of the storm events. At location M1, the same was true, except volumes were slightly over-predicted. At both locations, the agreement between model-predicted and measured values was closest when using the local point rain gauge (versus radar rainfall data). Influent flow to Regulator JA-7 was also measured at two locations (referred to as “M1P1”and “M1P2”). Comparisons of model-predicted peak flows and volumes for location M1P1 were very close, with nearly all events falling within the error ranges. Depth comparisons were also good for the majority of the storm events. At location M1P2, volume comparisons were well balanced, but peak flow and depth were often under-predicted.

CSO volumes were based on a weir equation calculation (using measured depth). Calculated CSO volumes from Regulator JA-07 were not logical and thus initial comparisons were discarded. Calculations of CSO from Regulator JA-06 produced viable results. Both volume and peak flow were well balanced (some slightly over-predicted and some under-predicted). From the triangulation comparison, it can be seen that all three data sources (model output, SCADA data, flow monitoring data) were never available at any one regulator (only 2 out of 3). For example, SCADA data was not available at either Regulator JA-06 or JA-07, but it was available at Regulator JA-09; thus, comparisons were made between model predictions and SCADA data at this location, for CSO activations. This regulator is further upstream from Regulators JA-06 and JA-07. At Regulators JA-06 and JA-07, comparisons for CSO activations could only be made between model output and flow monitoring data. In total, there was reasonable agreement among data sources for Outfalls JAM-005 and JAM-007, when considering all the available data sources.

3.0 RECEIVING WATERBODY MODELING

3.1 Model Description

Jamaica Bay water quality was simulated using the refined Jamaica Bay Eutrophication Model (JEM), which was originally developed and applied as part of DEP's Jamaica Bay Eutrophication Study in 1996. Updates to the grid were made in 2013 during the development of a larval transport model for the Harbor Estuary Program. The model domain includes Jamaica Bay, its CSO tributaries (Paerdegat Basin, Fresh Creek, Hendrix Creek, Spring Creek, Bergen Basin, and Thurston Basin), as well as the bay's other tributaries and basins. As part of this LTCP work, the model was refined, validated and applied to assess CSO control alternatives.

3.1.a **Previous Modeling Overview**

JEM is a spatially continuous, three-dimensional, time dependent, receiving water model of Jamaica Bay and its tributaries and is comprised of a hydrodynamic model (ECOMSED) coupled to a eutrophication (i.e., water quality) model (RCA). JEM was developed to assess eutrophication and nitrogen controls in Jamaica Bay and has been used as an assessment and prediction tool to support the DEP CSO Long Term Control Planning early 2007 Waterbody Watershed Facility Planning. The original model segmentation of JEM is presented in Figure 3-1. The representation of the Jamaica Bay tributaries was considered too coarse for the analysis of tributaries, so two additional models were used: the North Channel Model (NCM), which includes Fresh, Hendrix and Spring Creeks (Figure 3-2); and a modified JEM segmentation (JEM-BT), which includes finer resolution in Bergen and Thurston Basins (Figure 3-3).

The original calibration and validation of JEM focused on nutrients, chlorophyll-a, and dissolved oxygen (DO) based on data collected during 1995-96 and the model was validated against 1988 data. JEM was later calibrated to bacteria against 2005 data. Both NCM and JEM-BT were also calibrated for bacteria and DO with 2005 data.

Results of the model calibrations can be found in "A Water Quality Model for Jamaica Bay: Calibration of the Jamaica Bay Eutrophication Model (JEM) (2002)," "NYCDEP City-Wide Long Term CSO Control Planning Project, Receiving Water Quality Modeling Report, Volume 5, Jamaica Bay Eutrophication Model (JEM) (October 2007)," and the "City-Wide Long Term CSO Control Planning Project, Receiving Water Quality Modeling Report, Volume 7, North Channel Model (NCM) (October 2007)." This calibrated model was the starting point for the modeling conducted for Jamaica Bay as part of the CSO LTCP. Unless specified differently herein, model coefficients and kinetic coefficients used in the calibration analysis described herein remained unchanged from those described in the calibration reports.

3.1.b **Modifications to the Model**

The primary modifications to JEM for the development of the Jamaica Bay LTCP were the enhancement of the model grid, and the addition of a settling loss term for bacteria. Figure 3-4 presents the model domain used for this analysis. Rather than using three separate models for this analysis, the finer resolution of the model grid developed for larval transport assessment was used. This segmentation has resolution that is similar to, or finer than, the resolution included in the NCM and JEM-BT models. This enhancement to the model grid resulted in finer resolution of water quality impacts in the tributaries and Jamaica Bay.

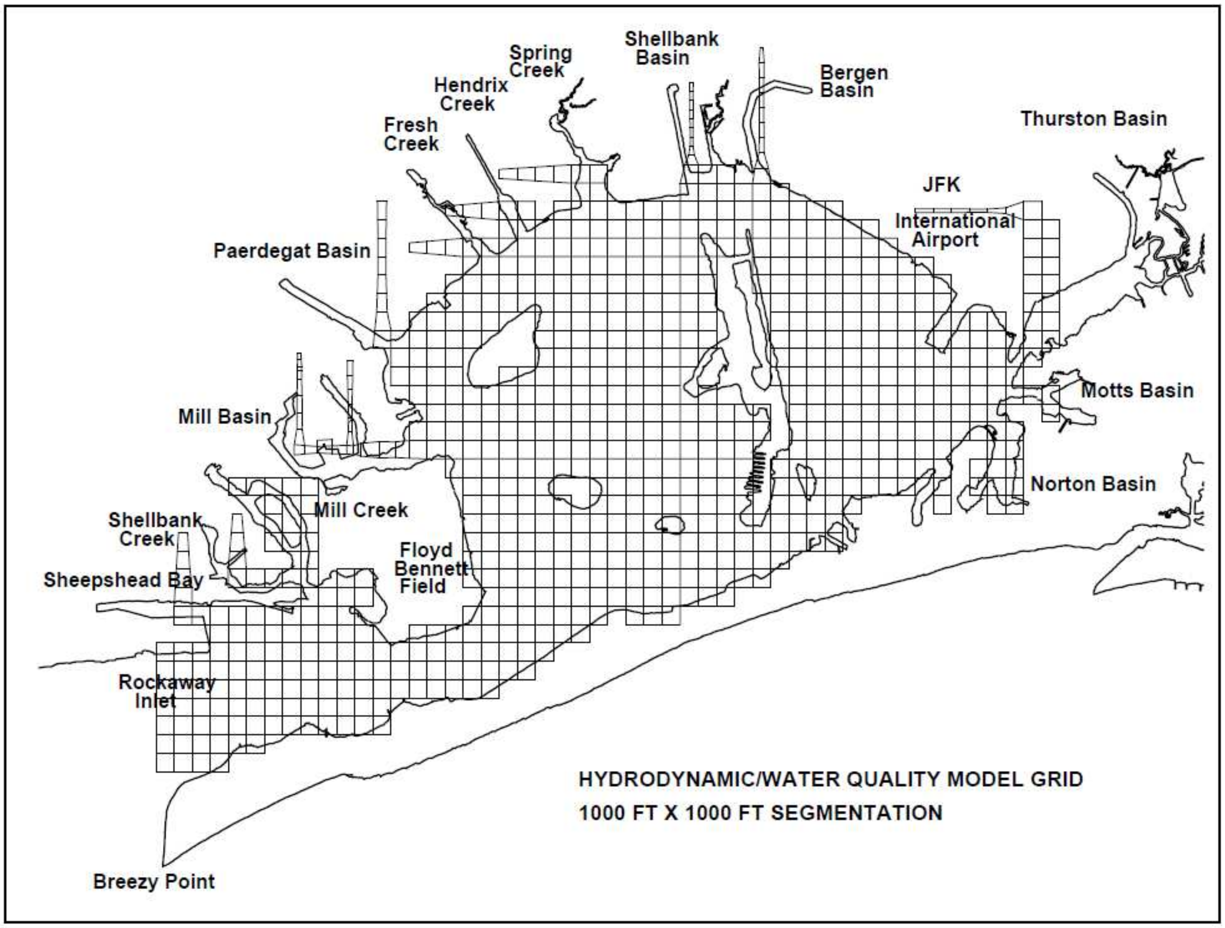

Figure 3-1. Original Jamaica Bay Eutrophication Model (JEM) Domain

During the calibration process, it was noted that the model under-estimated the loss rate of bacteria after rain events, which resulted in over-estimating bacteria concentrations. It is known that sediment mounds form around CSO outfalls, so some fraction of bacteria associated with particulate matter must settle to the sediment. Not all bacteria are associated with particulate matter, and it is likely that during some conditions, sediment can be re-suspended. Rather than trying to estimate the fraction of bacteria associated with particulate matter, the settling rate of the particulate matter, and the amount of resuspension that might occur, a simpler net settling rate was applied. This net settling rate was meant to account for all the factors that affect bacteria associated with settling and resuspension in one term.

The net settling rate (V_{snet}) is a multiplier between 0.0 and 1.0 applied to the settling rate. A V_{snet} of 1.0 represents a condition where all of the bacteria that settles to the bottom is incorporated into the sediment, and none is re-suspended. With a V_{snet} less than 1.0, the value of V_{snet} represents the fraction of the bacteria that settles to the bottom that gets incorporated into the sediment and the rest (1- V_{snet}) remains in the water column (i.e. is re-suspended). Shallower areas, where re-suspension is more likely, were assigned lower values. Deeper areas were assigned higher values. Additional information on the settling rate and impact on bacteria concentrations is presented in Section 3.3.c.

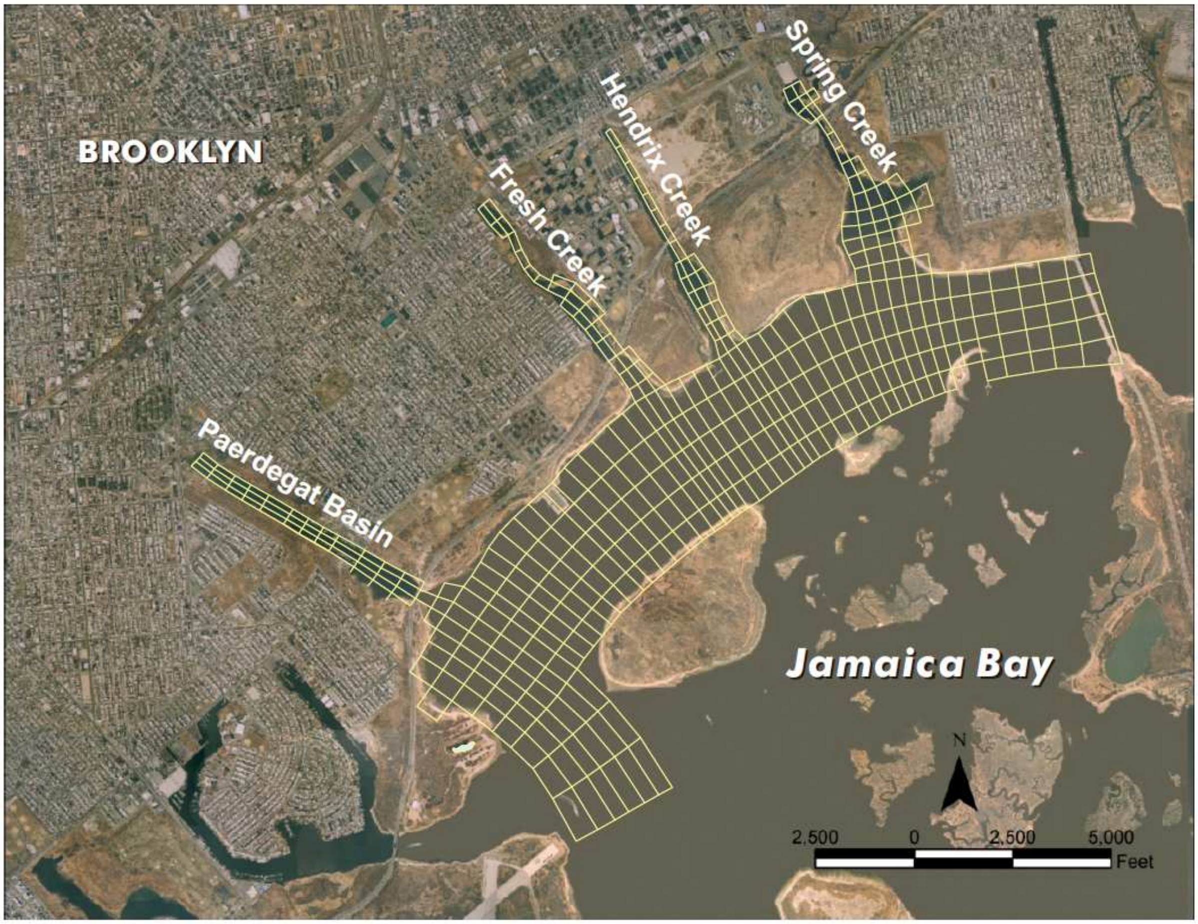

Figure 3-2. North Channel Model (NCM) Domain

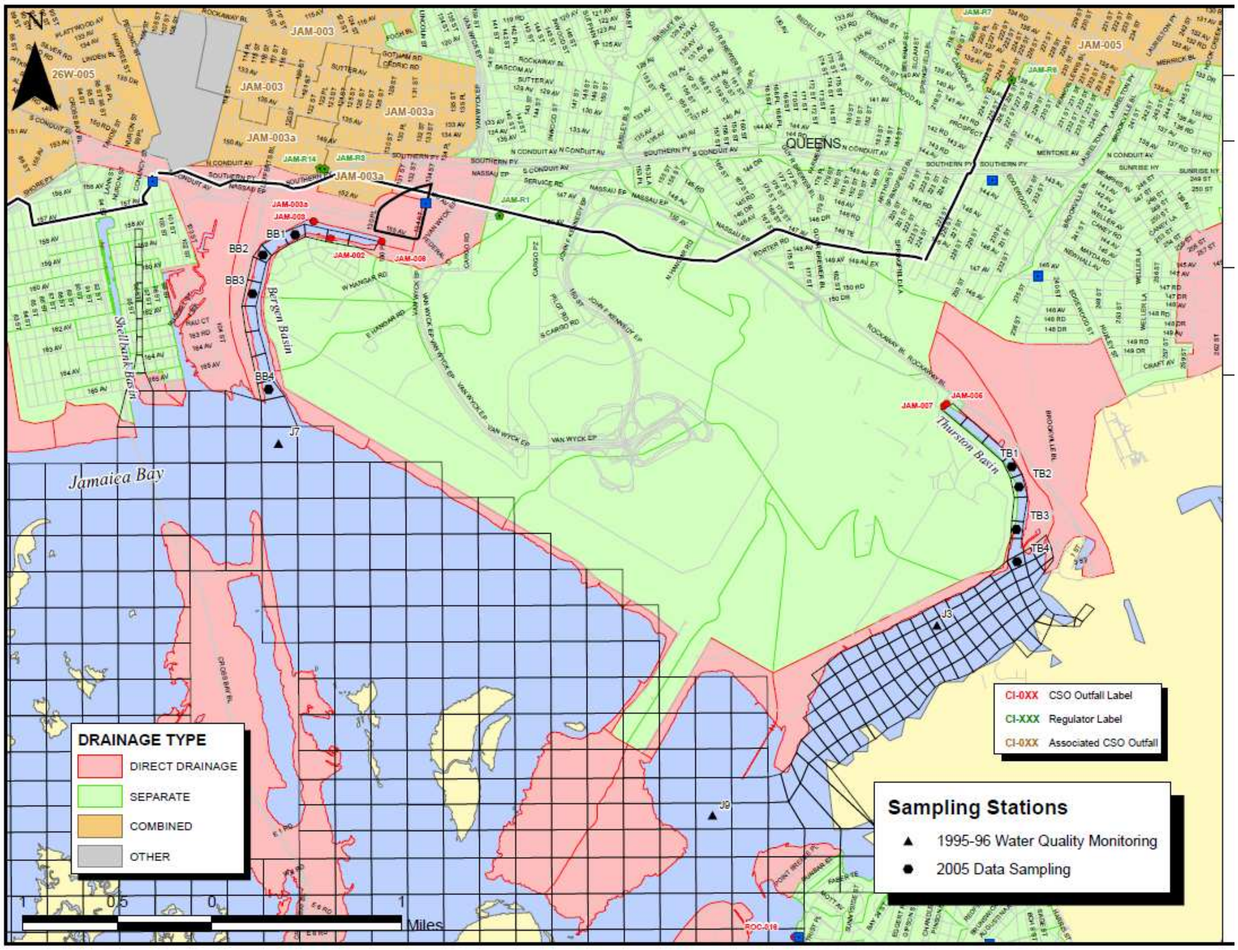

Figure 3-3. JEM-BT Domain

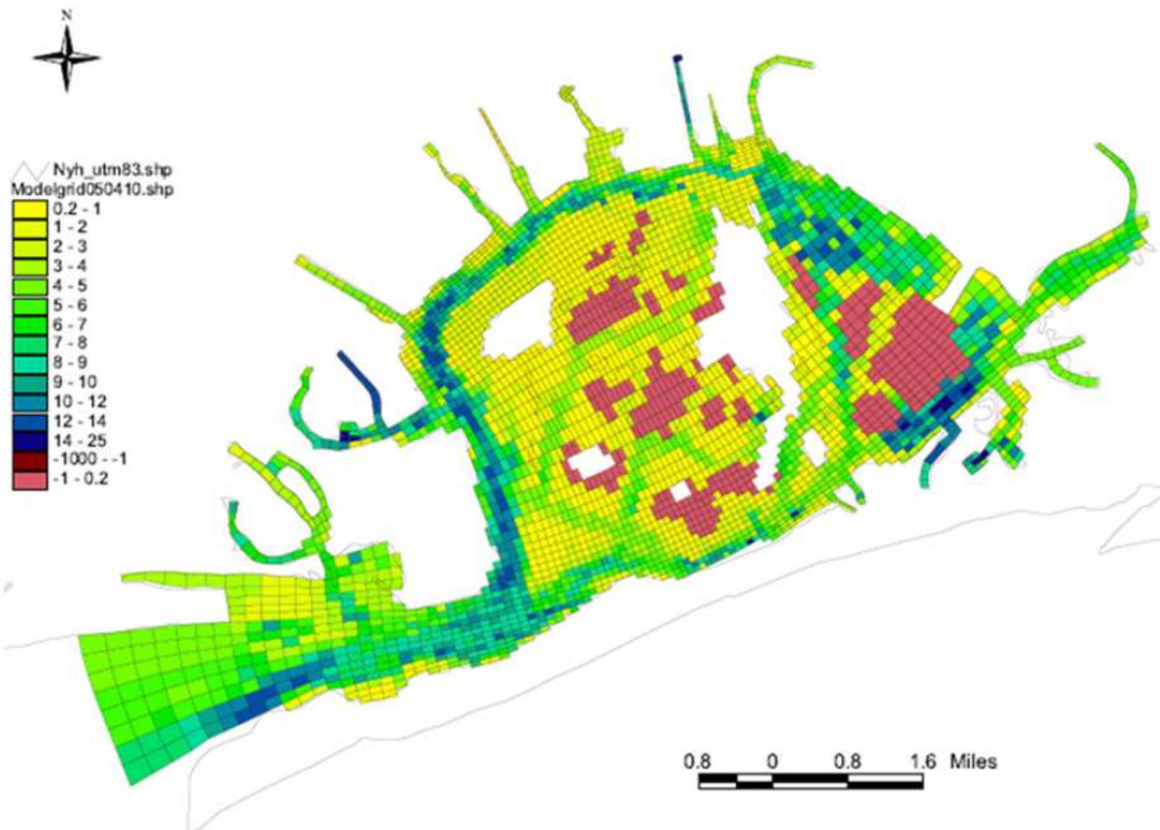

Figure 3-4. Updated Jamaica Bay Eutrophication Model (JEM) Domain

3.2 Hydrodynamic Modeling

3.2.a Monitoring Program and Available Data

Model verification was conducted for the calendar year 2015. Data collected as part of the Harbor Survey Program and data collected as part of the LTCP monitoring program for Fresh Creek, Bergen Basin and Thurston Basin/Head of Bay for this period was used to compare against the model calculations.

The Harbor Survey program collects water quality data for various constituents within the area of interest that can be used to compare against the model. Figure 3-5 shows the locations of the Harbor Survey Stations in Jamaica Bay. Harbor Survey data are collected more frequently during the warmer months at the Harbor Survey Stations and are collected on a predetermined schedule with no regard for trying to capture wet-weather or dry-weather conditions. In 1998, the DEP began supplementing Harbor Survey data with the Sentinel Monitoring Program, in which stations are sampled quarterly for fecal coliform bacteria, and the results are compared with baseline conditions to trigger intensive surveillance of the adjacent shoreline if high fecal coliform concentrations are observed during dry-weather conditions. The Sentinel Monitoring Program includes Stations S76 in Fresh Creek, S27 in Hendrix Creek, S78 in Bergen Basin, and S31 in Thurston Basin.

To supplement the water quality sampling information that is available from DEP, a sampling program was conducted during the development of the LTCP for Jamaica Bay. This sampling was targeted at developing a better understanding of the spatial variability of the water quality along the length of the Fresh Creek, Bergen Basin, and Thurston Basin. Sampling in tributaries was conducted during both Wet-Weather Conditions (WWC) and Dry-Weather Conditions (DWC) at 12 distinct sampling stations. Figure 3-6 through Figure 3-8 show the locations of the LTCP2 stations in Fresh Creek, Bergen Basin, and Thurston Basin, respectively. Samples were collected at these locations in both dry- and wet-weather periodically during October and November 2015. Results of the sampling can be found in the “Data Collection Memorandum for Jamaica Bay” (AECOM, March 1, 2017).

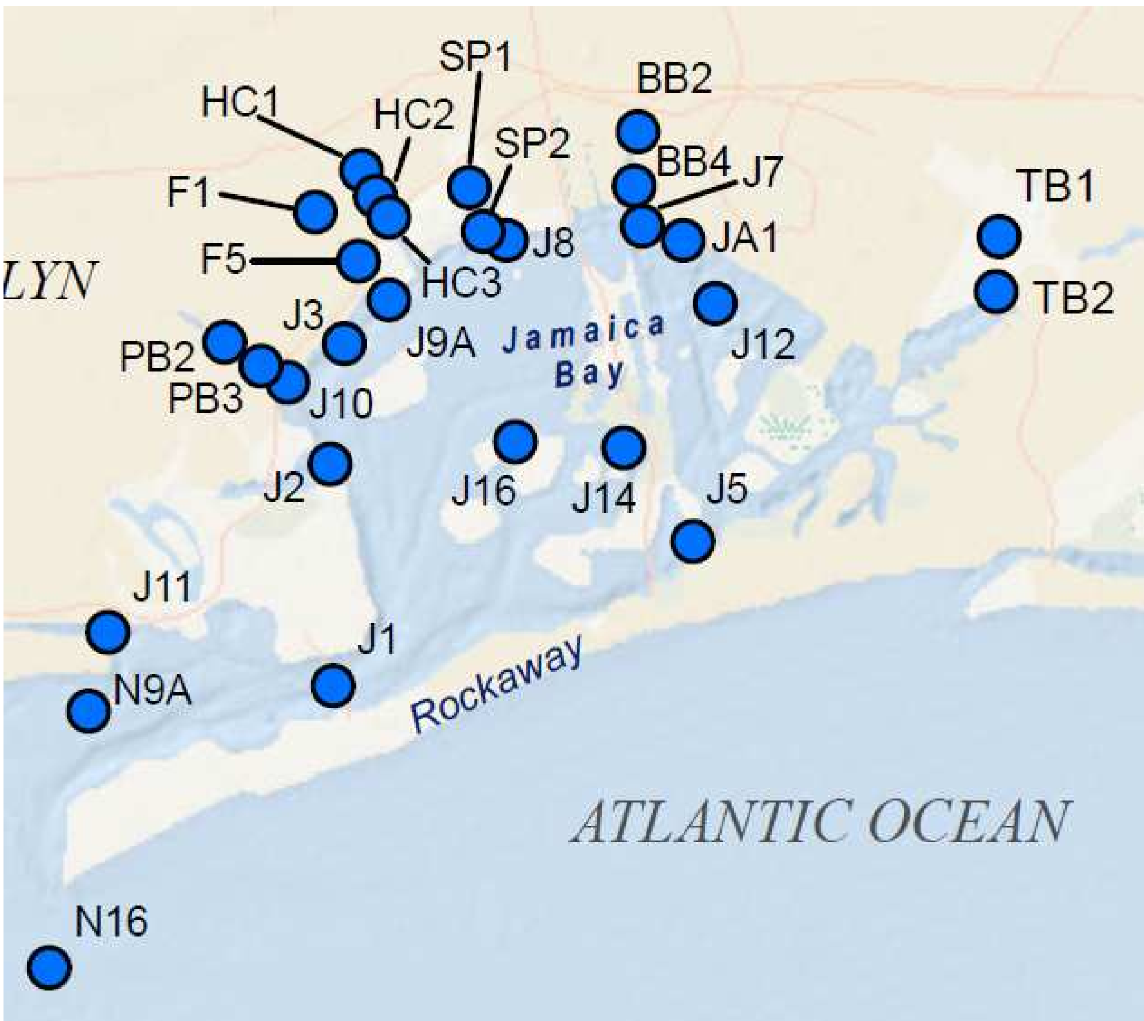

Figure 3-5. Harbor Survey Water Quality Sampling Stations in Jamaica Bay

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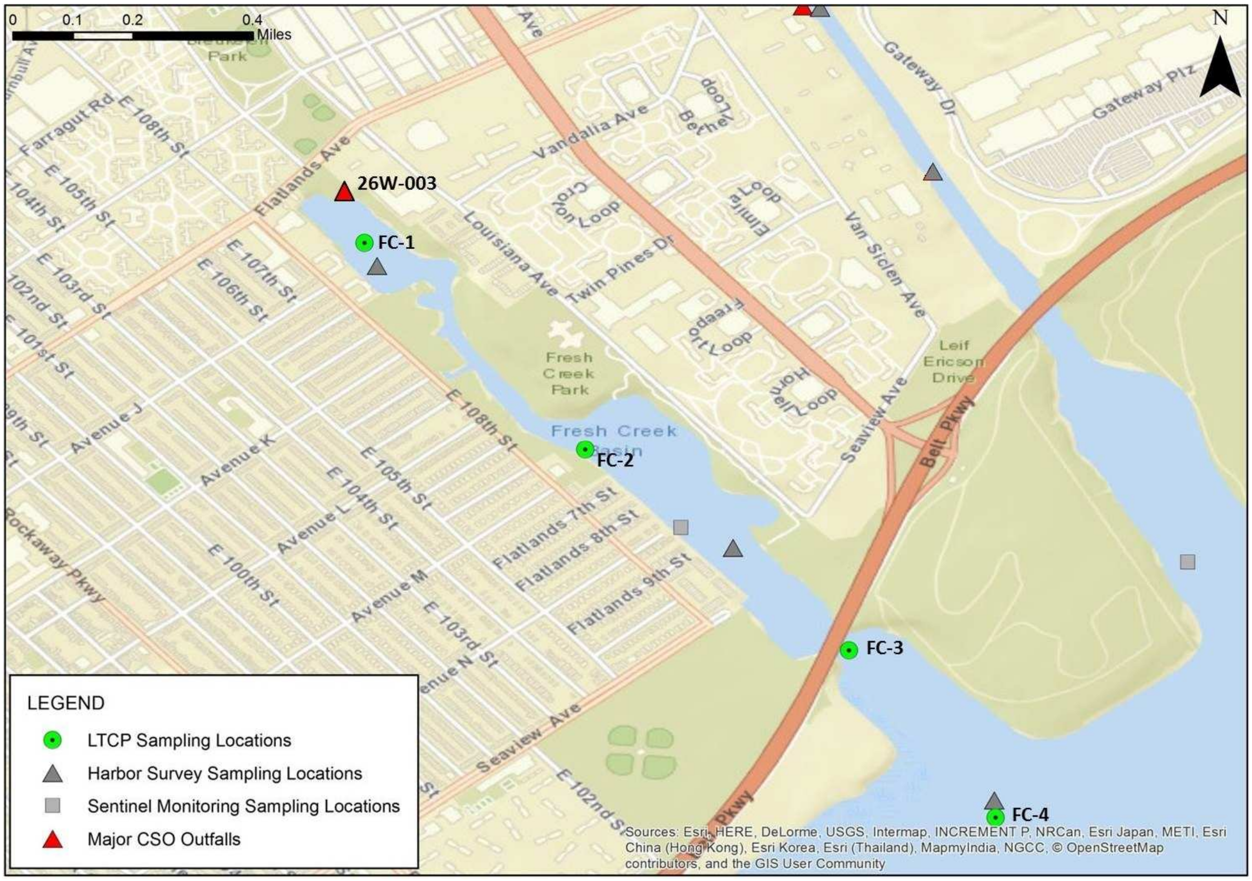

Figure 3-6. LTCP2 Water Quality Sampling Stations in Fresh Creek

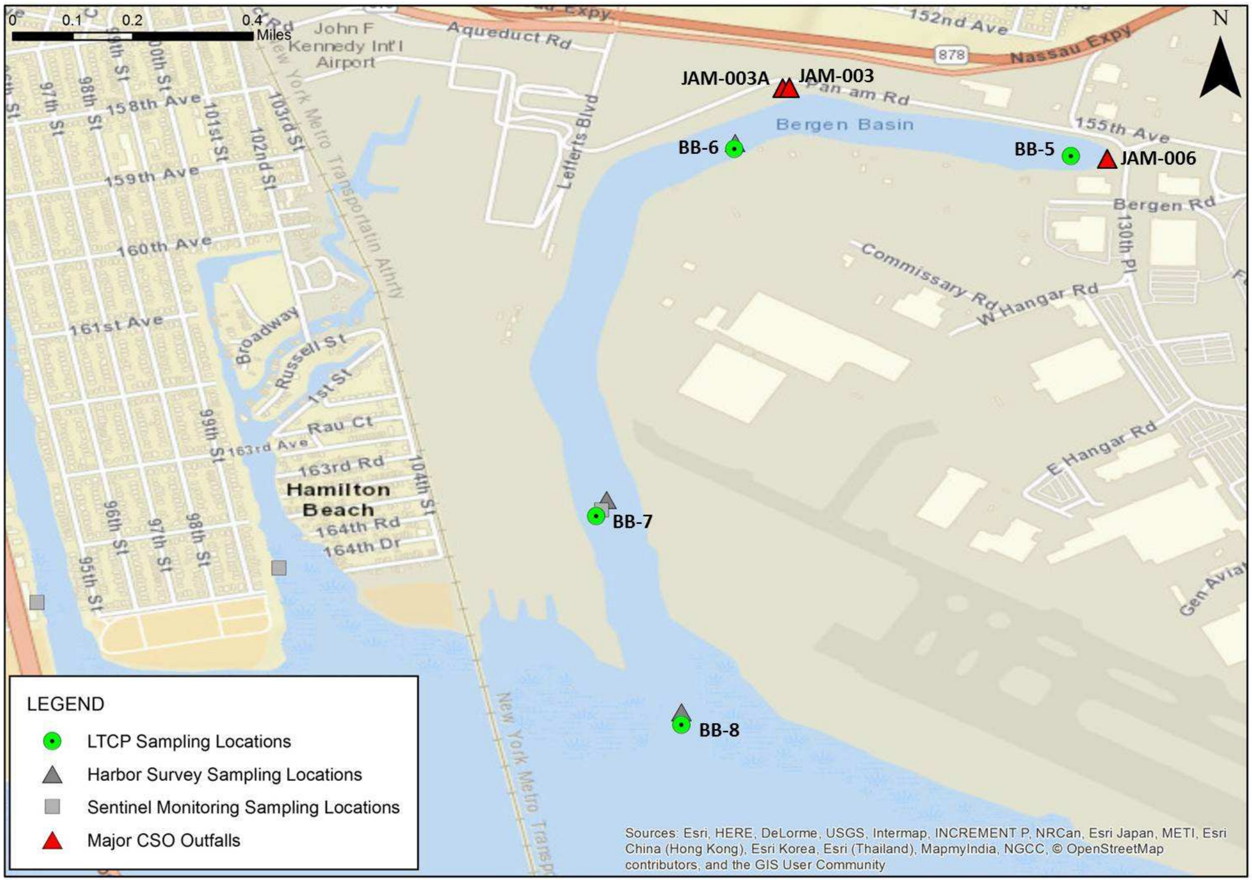

Figure 3-7. LTCP2 Water Quality Sampling Stations in Bergen Basin

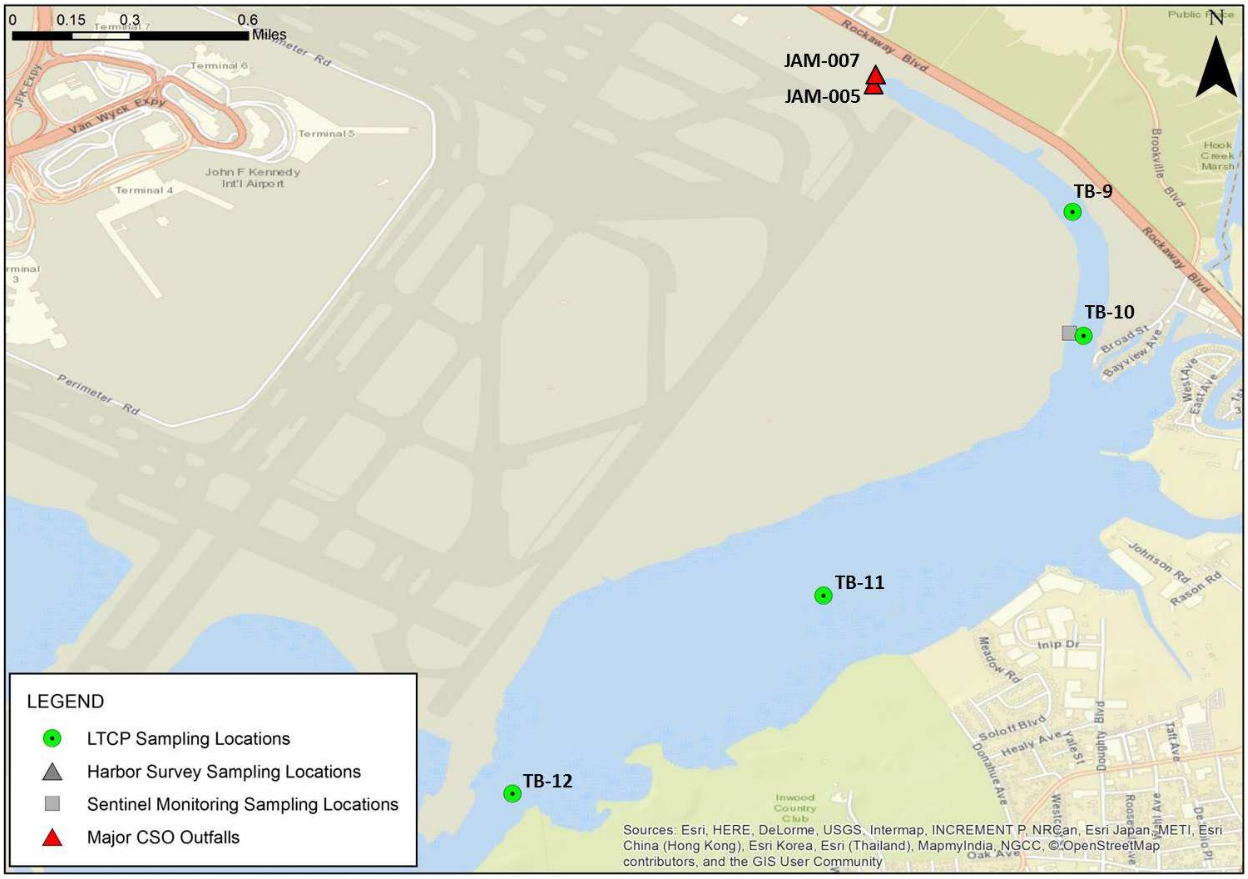

Figure 3-8. LTCP2 Water Quality Sampling Stations in Thurston Basin and Head of Bay

3.2.b **Hydrodynamic Model Inputs**

Input for the hydrodynamic model falls into three general categories: boundary conditions, freshwater flow, and meteorological conditions. Boundary conditions include water elevation, temperature, and salinity. Water elevations were obtained from the regional SWEM model at the Rockaway Inlet. Temperature and salinity boundary conditions were based on U.S. Geographical Survey Floyd Bennett Field measurements. Boundary figures are included in Appendix C.

Freshwater flows from Wastewater Treatment Plants (WWTPs), CSOs, storm sewers and direct drainage for New York City were obtained from the IW model as described in Section 2.

Meteorology input was based on the NOAA's weather station at JFK International Airport (USAF 744860 WBAN_ID 94789). Figures presenting the meteorological inputs are presented in Appendix C.

3.2.c **Hydrodynamic Model Calibration**

The data available to compare against the hydrodynamic model results were somewhat limited. Temperature and salinity data were available from numerous Harbor Survey sampling and LTCP2 sampling stations. Figure 3-9 through Figure 3-16 present model versus data comparisons for temperature in the CSO tributaries and Jamaica Bay proper. The results are presented starting in Paerdegat Basin and then clockwise around the bay in the CSO tributaries followed by results in the bay. The temperature data show a typical seasonal pattern for a temperate region with the highest temperatures observed in August and September. The temperature data show very little temperature difference between the surface and bottom, indicating minimal temperature stratification. The model compares to the temperature data reasonably well throughout the bay. There are a few exceptions where the model over-estimates the summer temperatures, most often in shallow areas at the head ends of tributaries and the center of the bay.

Figure 3-9 presents the temperature calibration for Paerdegat Basin and the stations in Jamaica Bay near Paerdegat Basin. There is some over-estimation by the model of June and July temperatures closer to the head end, but during the other times and locations, the model reproduces the data very well. In Fresh Creek (Figure 3-10) the model also does a good job reproducing the data. The three LTCP2 event surveys are well represented by the model. In some cases, the model over-estimates the temperature during the warmest portion of the year. The data in Hendrix Creek is generally just surface data. As shown in Figure 3-11, the model reproduces the temperature very well. The discharge of wastewater from the 26th Ward WWTP has the impact of moderating the temperatures in Hendrix Creek. Figure 3-12 presents the model versus data comparison for Spring Creek. The model does a good job reproducing the data at these stations.

Bergen Basin model versus data comparisons are presented in Figure 3-13. Here the model can be compared to both Harbor Survey and LTCP2 data. The model compares very favorably to the data on a temporal and spatial basis. Thurston Basin and Head of Bay (Figure 3-14) have only LTCP2 data available, and the model reproduces these three survey events fairly well.

In the open waters of Jamaica Bay (Figure 3-15 and Figure 3-16) the model generally reproduces the temperature data. Over-estimation of the temperature data occurs in deep water at Station J12 and shallow water at Stations J14 and J16.

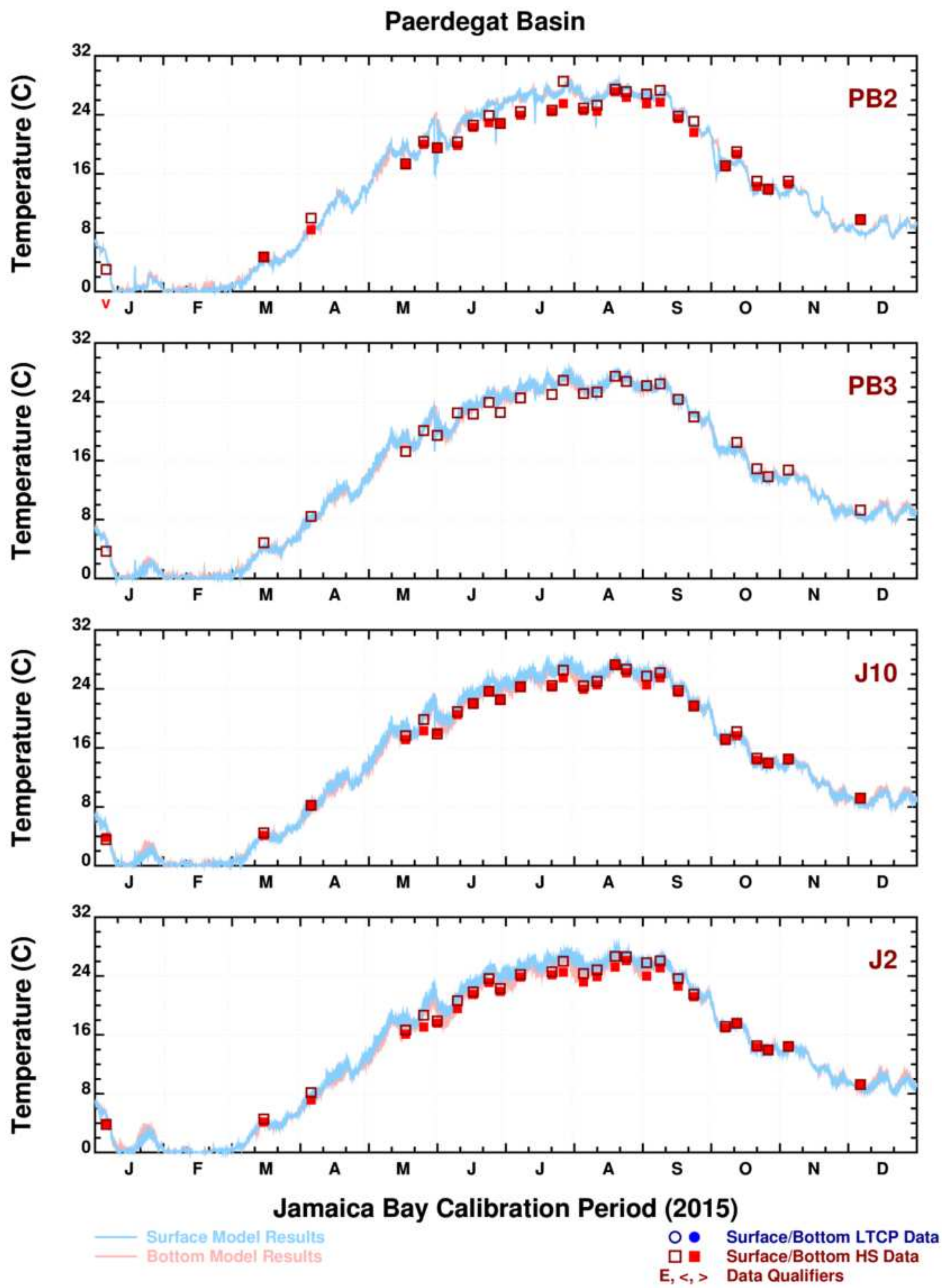

Figure 3-9. 2015 Temperature Calibration in Paerdegat Basin and Nearby Jamaica Bay

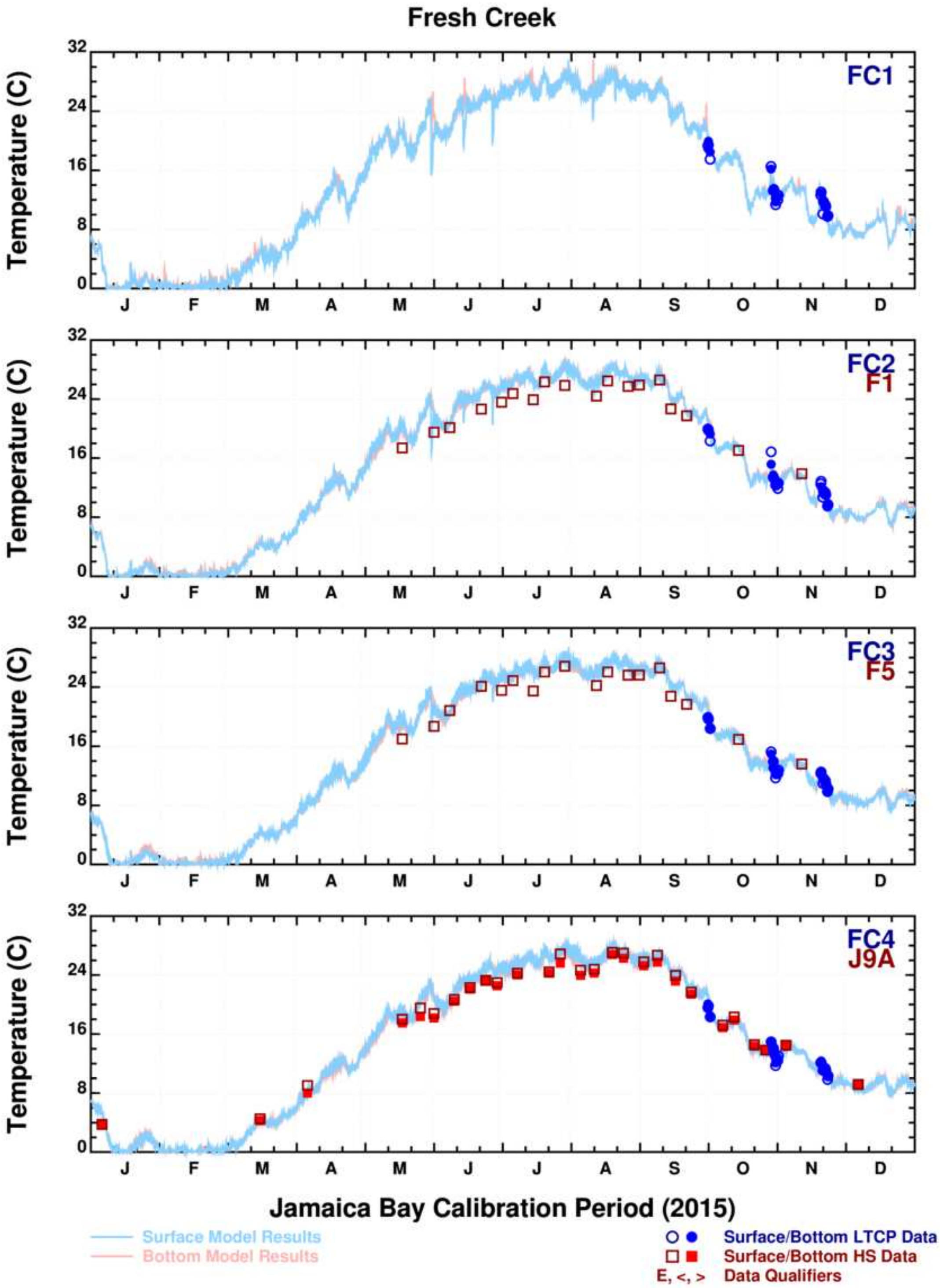

Figure 3-10. 2015 Temperature Calibration Fresh Creek and Nearby Jamaica Bay

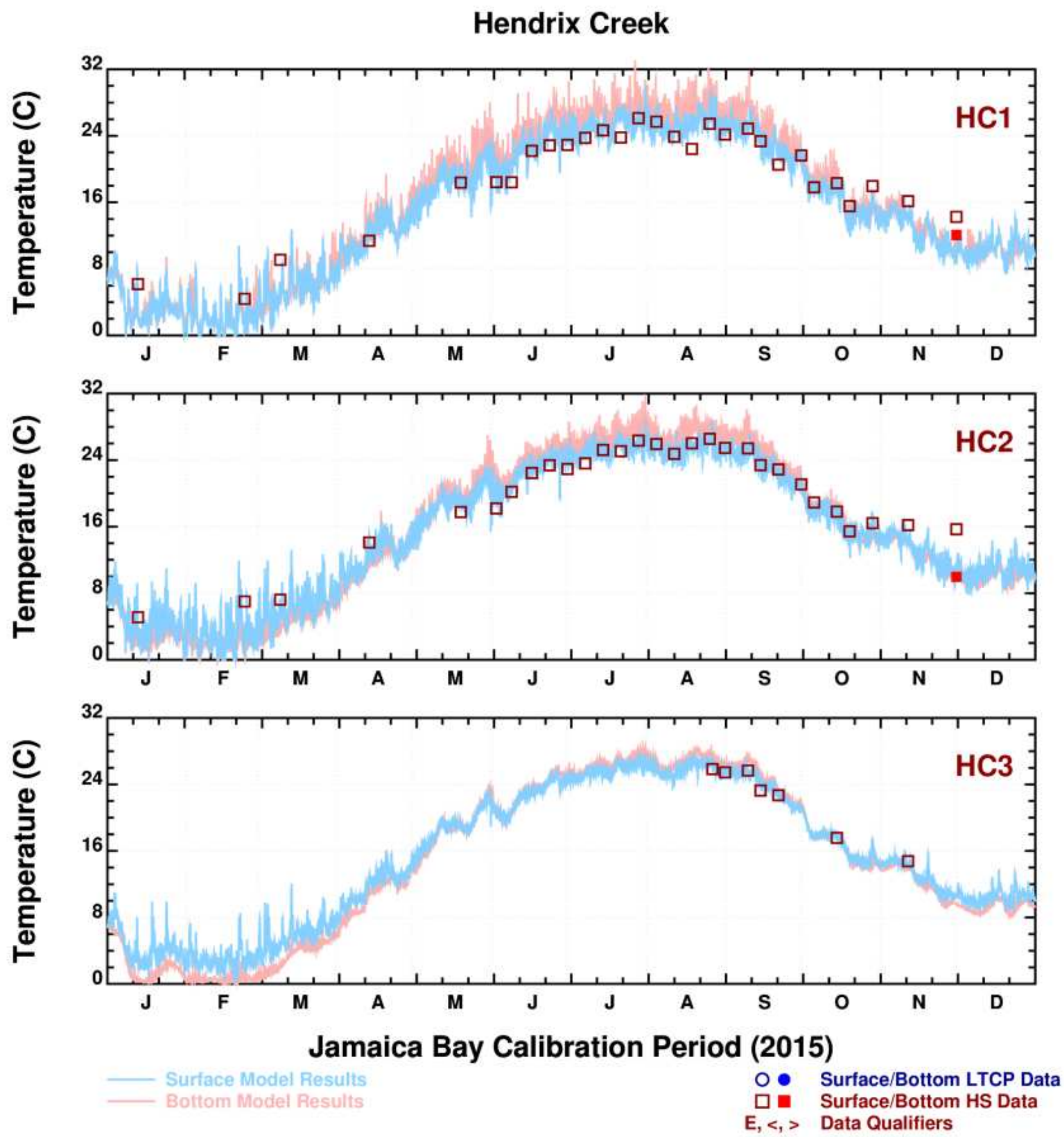

Figure 3-11. 2015 Temperature Calibration in Hendrix Creek

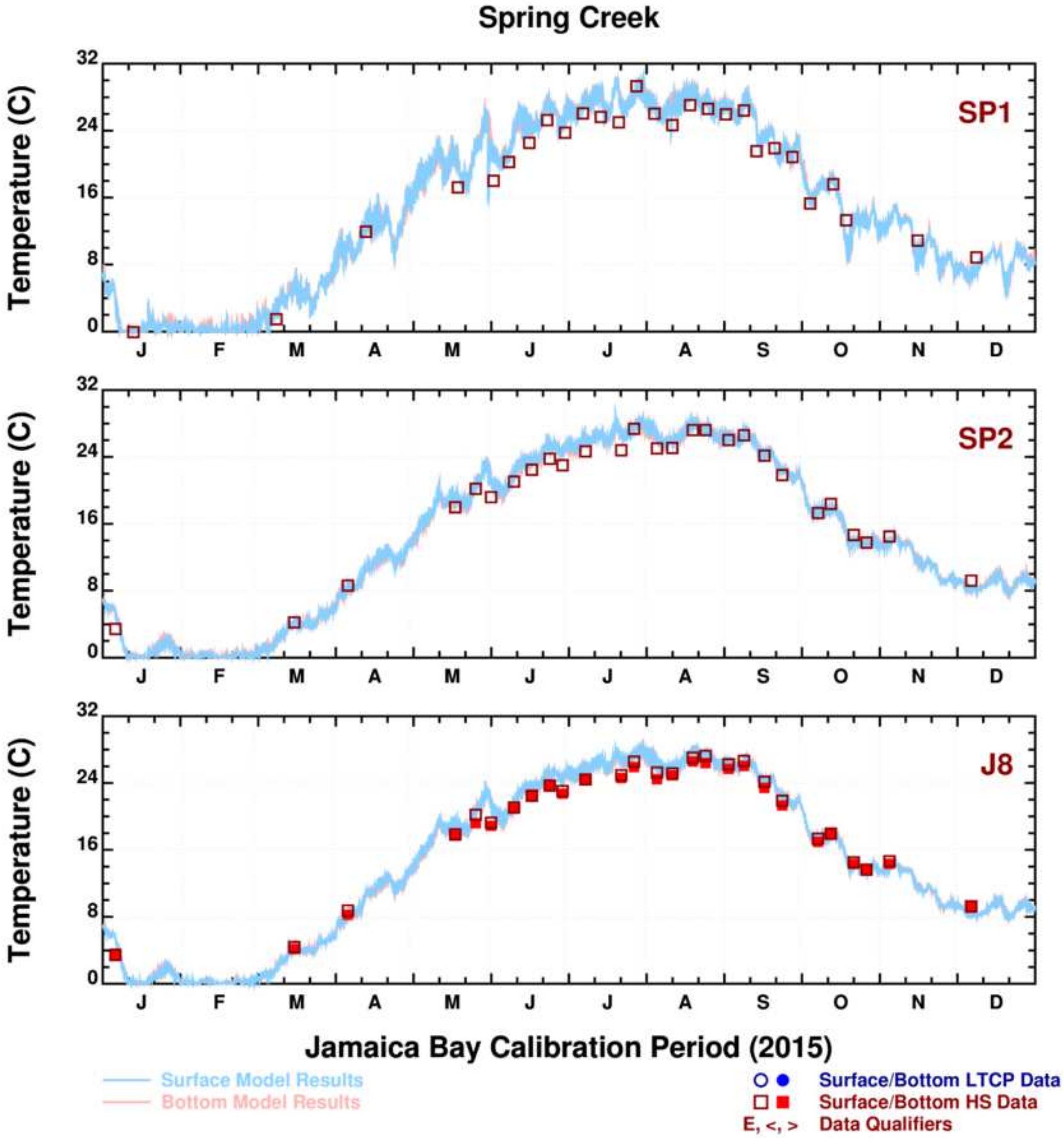

Figure 3-12. 2015 Temperature Calibration in Spring Creek and Nearby Jamaica Bay

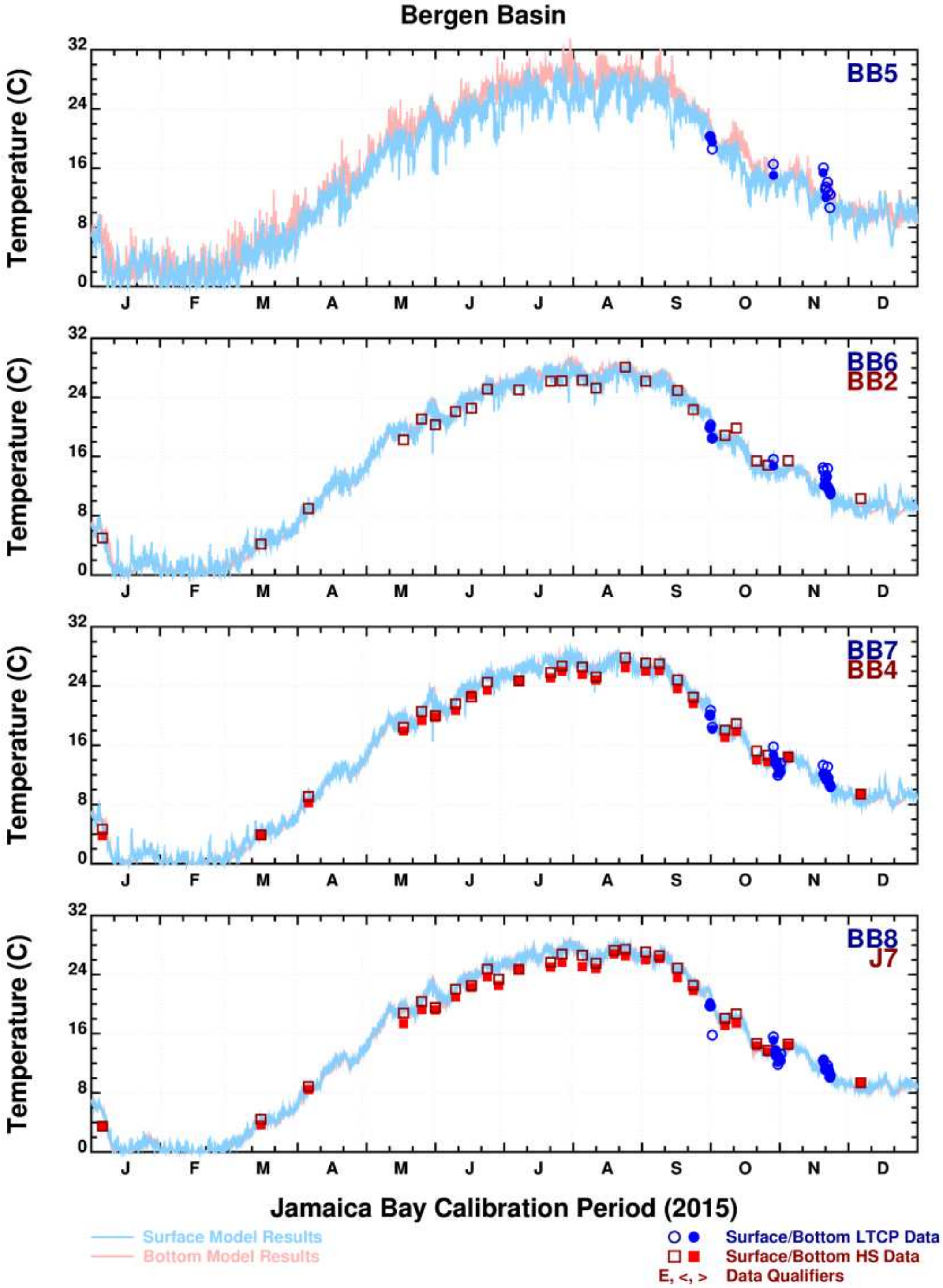

Figure 3-13. 2015 Temperature Calibration in Bergen Basin and Nearby Jamaica Bay

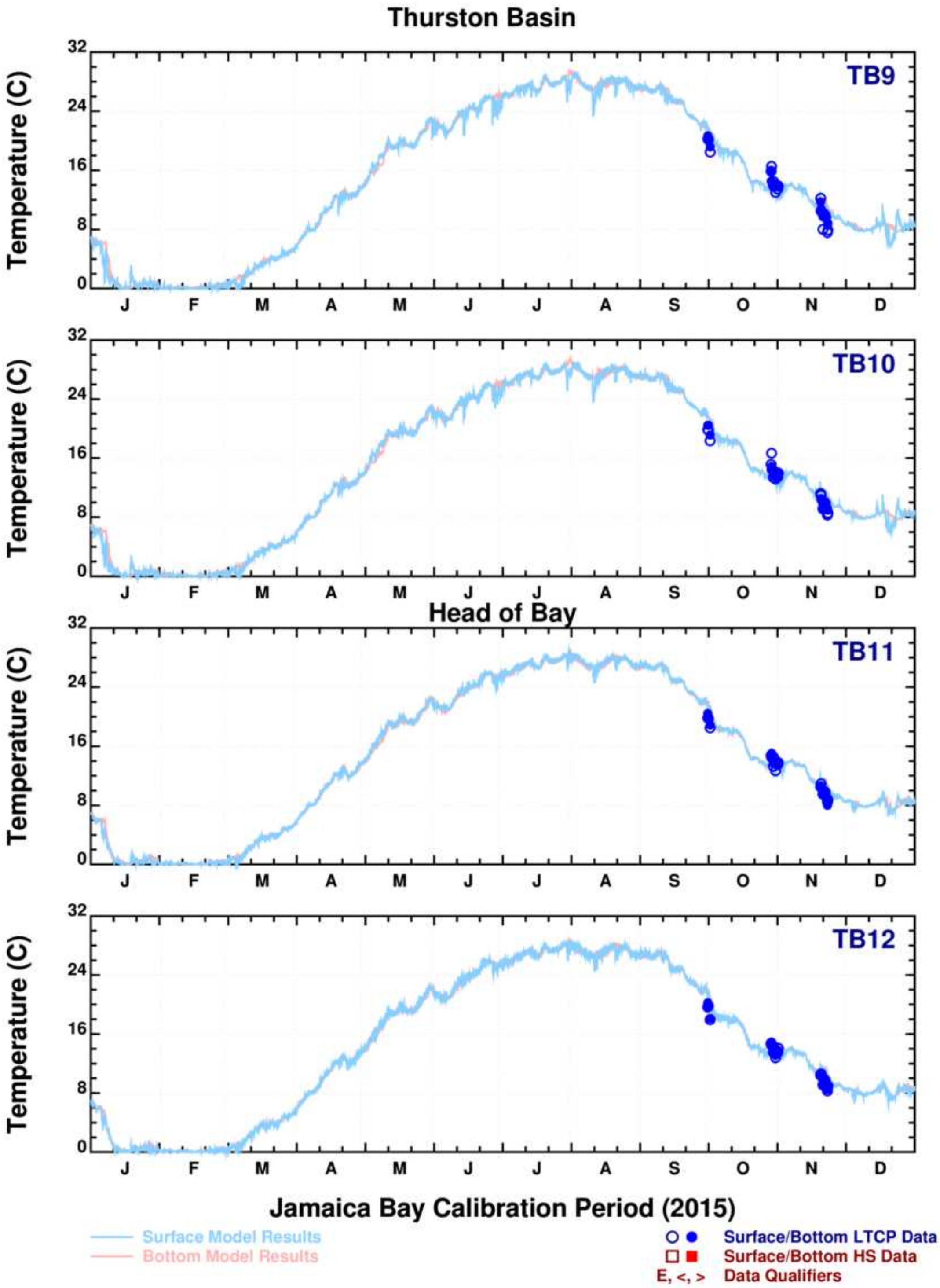

Figure 3-14. 2015 Temperature Calibration in Thurston Basin and Head of Bay

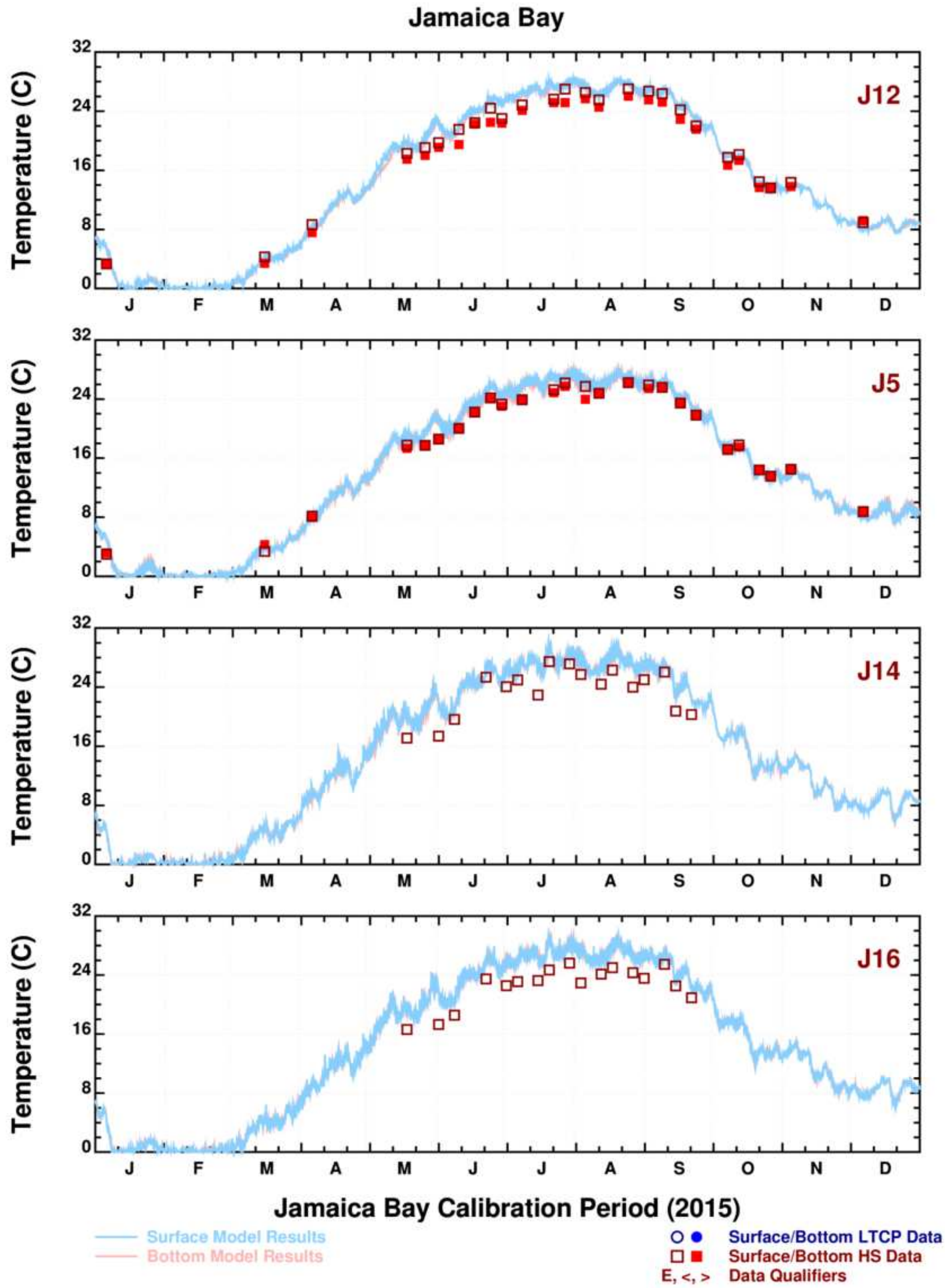

Figure 3-15. 2015 Temperature Calibration in Central and Eastern Jamaica Bay

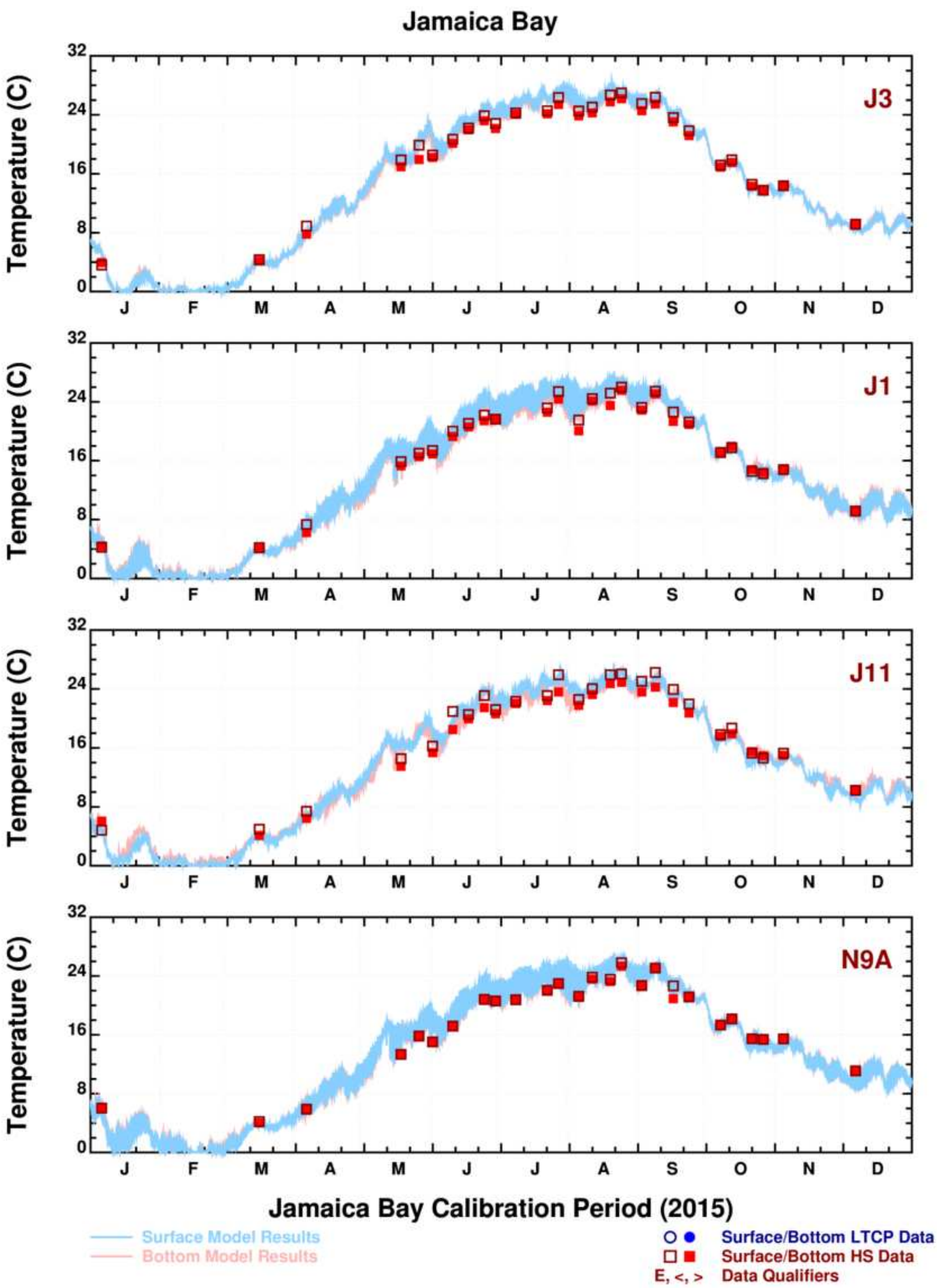

Figure 3-16. 2015 Temperature Calibration in Western Jamaica Bay

The model calibration to salinity data is presented in Figure 3-17 through Figure 3-24. The figures begin with Paerdegat Basin, followed by the other CSO tributaries in a clockwise direction around the bay: Fresh Creek, Hendrix Creek, Spring Creek, Bergen Basin and Thurston Basin. The figures present data from the head end to the mouth and on some occasions into Jamaica Bay. Two additional figures showing the model versus data comparison in the eastern and western bay are then presented. The calibration data includes surface and bottom Harbor Survey data as well as surface and bottom data collected during three, four-day surveys conducted by the LTCP2 Team. The LTCP2 surveys are meant to capture three wet-weather days followed by a dry day.

Figure 3-17 presents the Paerdegat Basin salinity calibration. The Harbor Survey salinity data are fairly consistent at approximately 28 ppt, and very little salinity stratification was measured. The model reproduces the data very well. Occasional low salinity spikes are calculated during the infrequent CSO discharges. The impact on salinity decreases from the head end of Paerdegat Basin towards the mouth and into Jamaica Bay.

The salinity calibration for Fresh Creek is presented in Figure 3-18. In Fresh Creek, the Harbor Survey data is supplemented by three surveys conducted by the LTCP2 Team. The model reproduces the Harbor Survey data very well. The model shows a rapid decrease in salinity during storm events, and low surface salinity during the peak of the storm. The sampling data does not always show these low salinities, but appears to miss the peak of the overflow. The model salinity appears to return to background more quickly than the data.

Figure 3-19 presents the salinity calibration for Hendrix Creek. Hendrix Creek has the freshwater contribution from the 26th Ward Wastewater Treatment Plant (WWTP). While the 26th Ward WWTP outfall is not at the head end of the Creek, the plume appears to trap freshwater in the head end and results in a somewhat chaotic mixture of freshwater and bay water. The model does a reasonable job of reproducing the magnitude and spatial distribution of the Hendrix Creek salinity.

The model calibration to the Spring Creek data is presented in Figure 3-20. The model reproduces the general pattern of the salinity data. Spring Creek does have a small freshwater creek entering the head end, which does contribute some flow, but this creek is not included in the model. The model shows occasional decreases in salinity towards the head end of the Creek during CSO overflow events.

Figure 3-21 shows the salinity calibration for Bergen Basin, which has both Harbor Survey and LTCP2 data available. Bergen Basin receives some freshwater discharge from the Jamaica WWTP. The Harbor Survey data is supplemented by the LTCP2 data in the basin. The salinity data show the effects of the freshwater discharge as is apparent from the greater salinity stratification than is observed in other portions of Jamaica Bay. The model generally reproduces the salinity data, but returns to dry-weather salinity levels more quickly than the data.

The Thurston Basin and Head of Bay model versus salinity comparisons are presented in Figure 3-22. Only LTCP2 data are available at these stations. In Thurston Basin, the model reproduces the timing and magnitude of the data. In Head of Bay, the model over-estimates the salinity during the middle storm and reasonably reproduces the salinity during the other events.

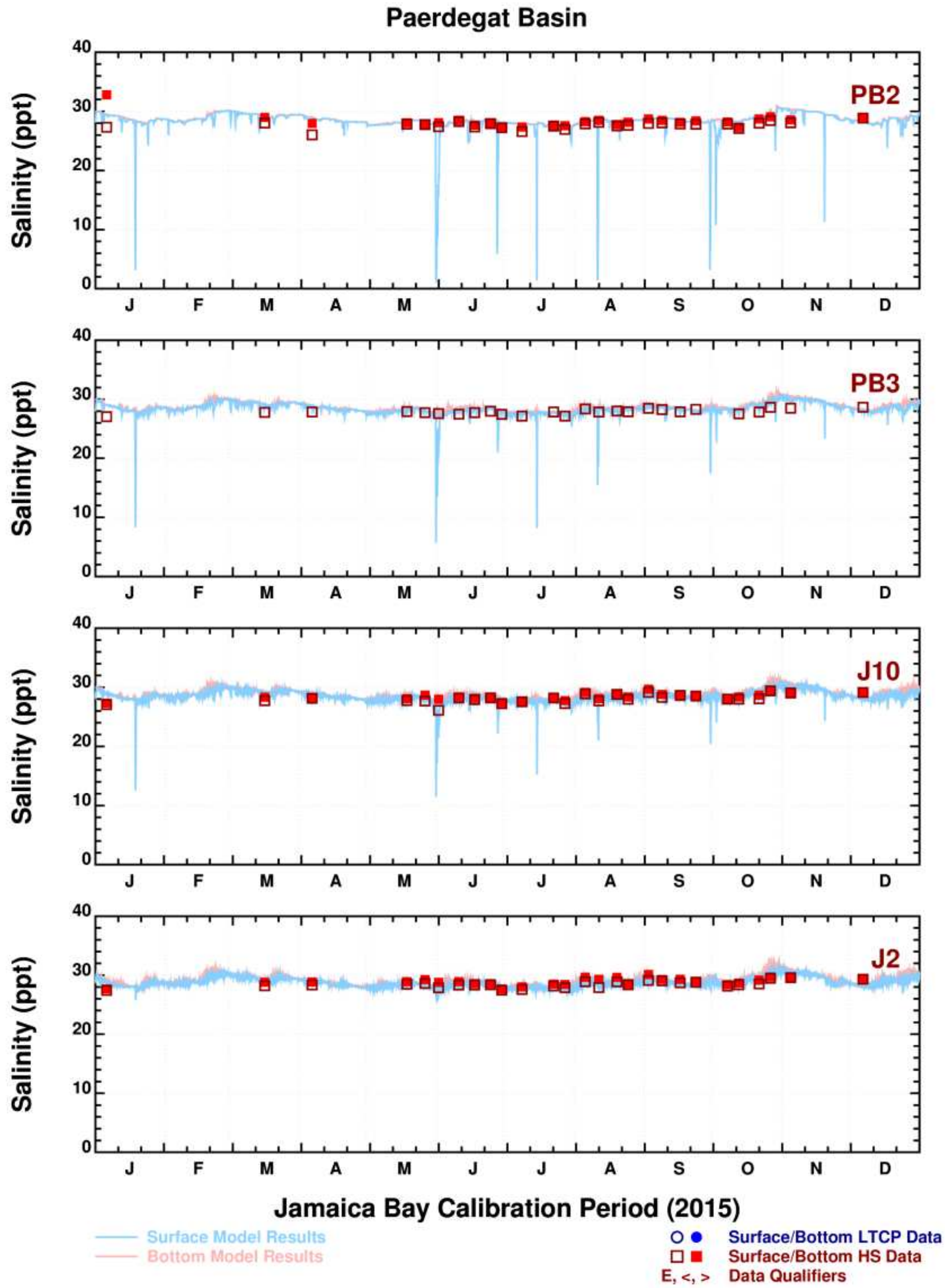

Figure 3-17. 2015 Salinity Calibration in Paerdegat Basin and Nearby Jamaica Bay

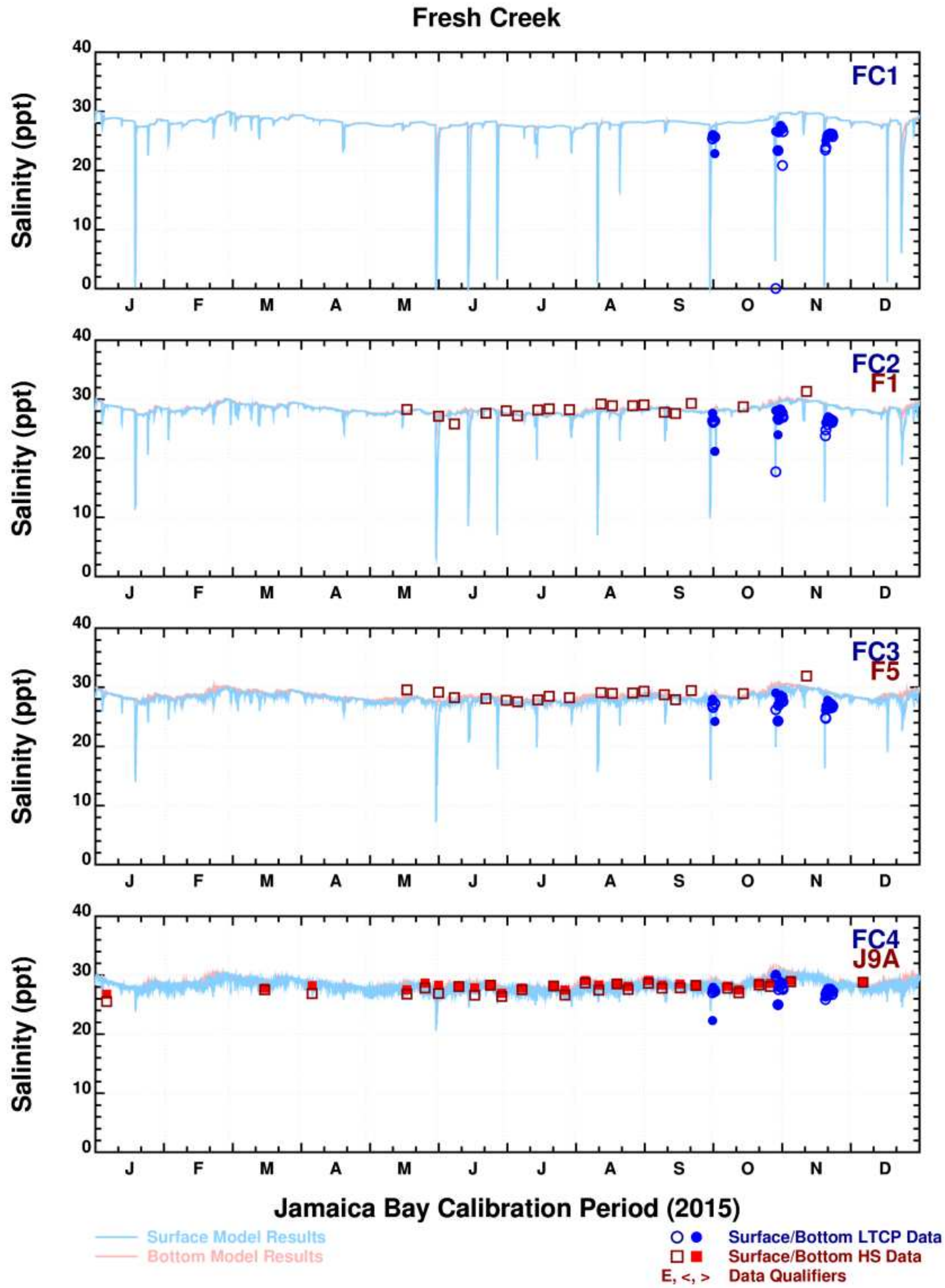

Figure 3-18. 2015 Salinity Calibration Fresh Creek and Nearby Jamaica Bay

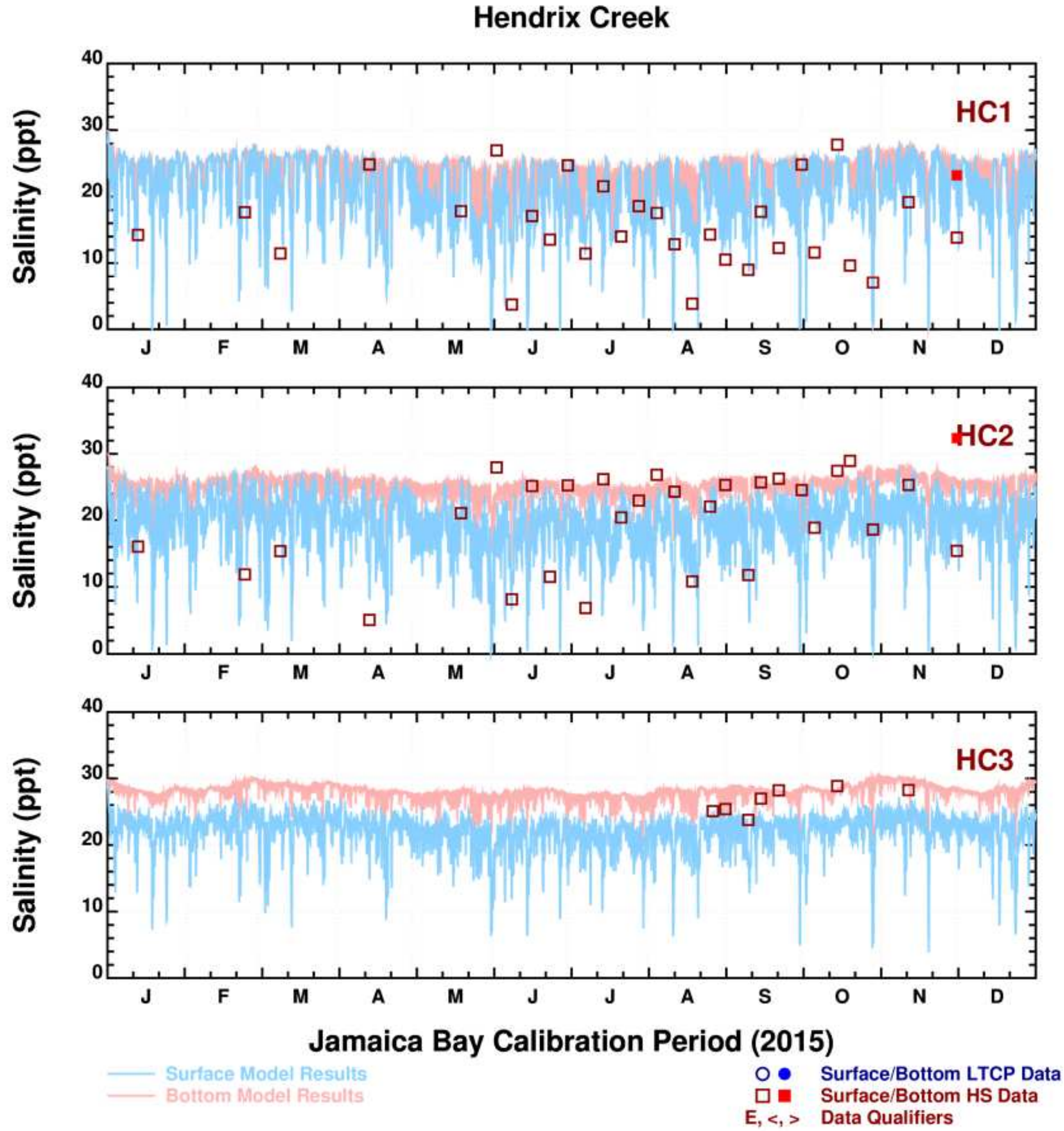

Figure 3-19. 2015 Salinity Calibration in Hendrix Creek

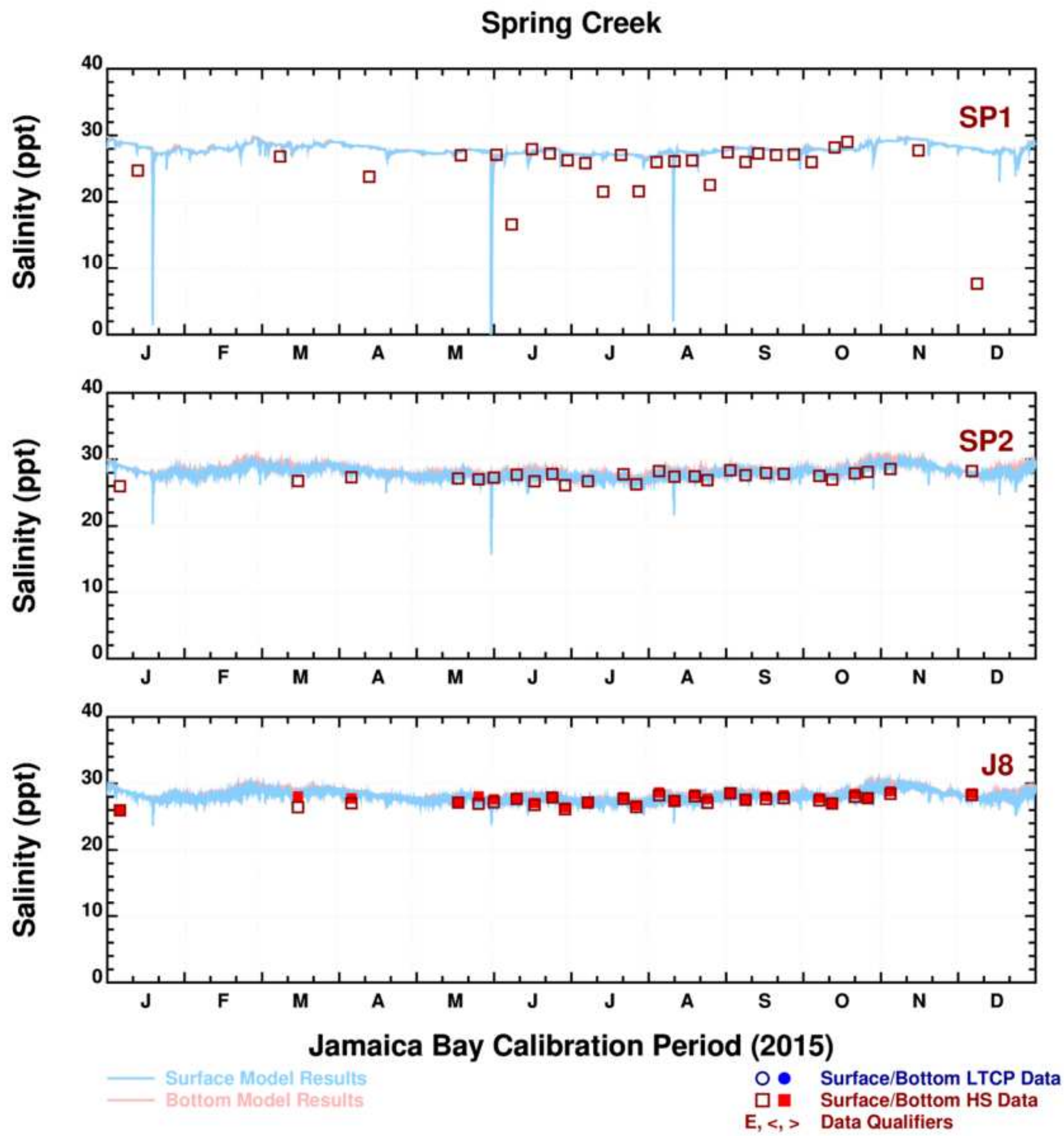

Figure 3-20. 2015 Salinity Calibration in Spring Creek and Nearby Jamaica Bay

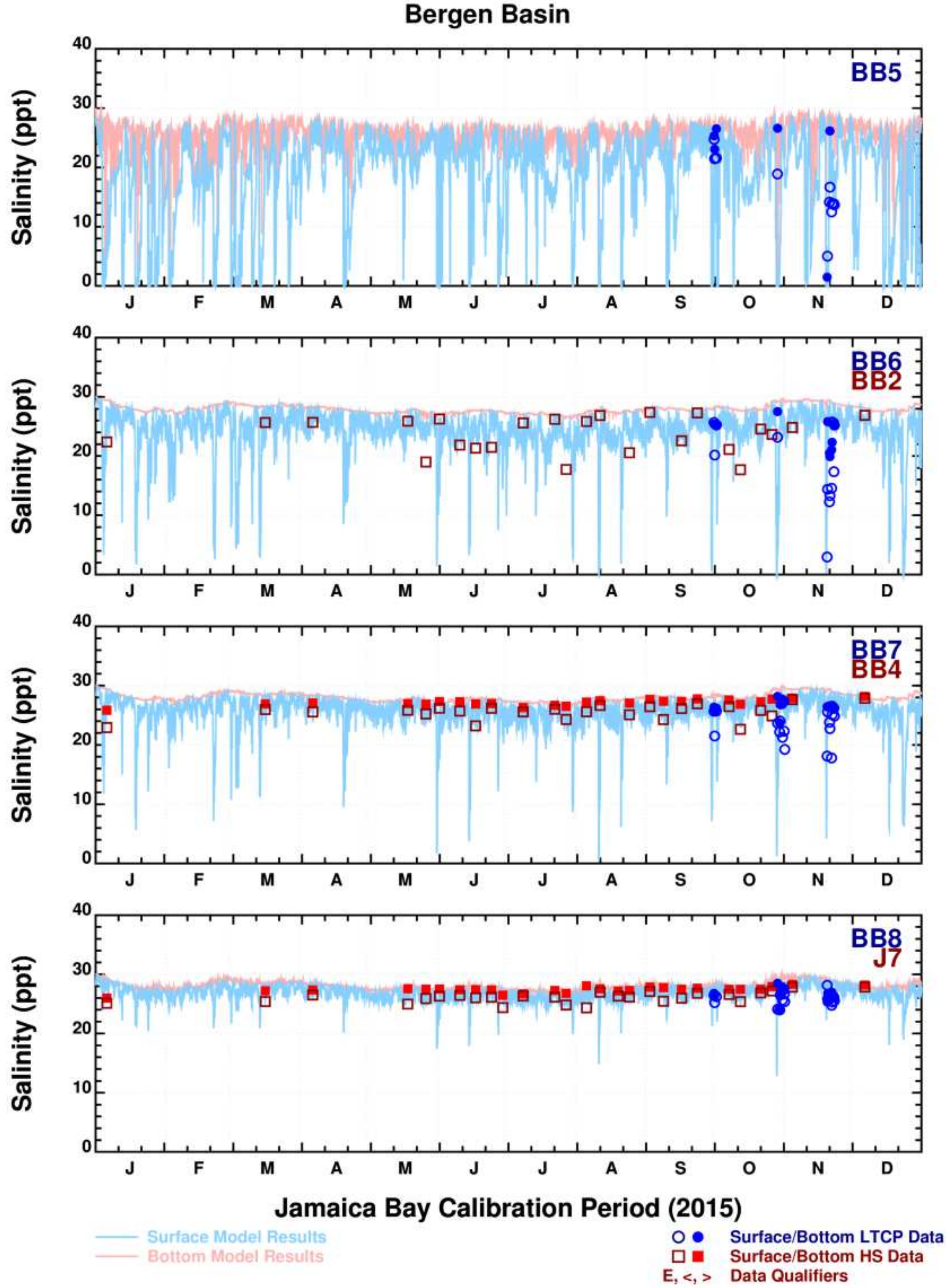

Figure 3-21. 2015 Salinity Calibration in Bergen Basin and Nearby Jamaica Bay

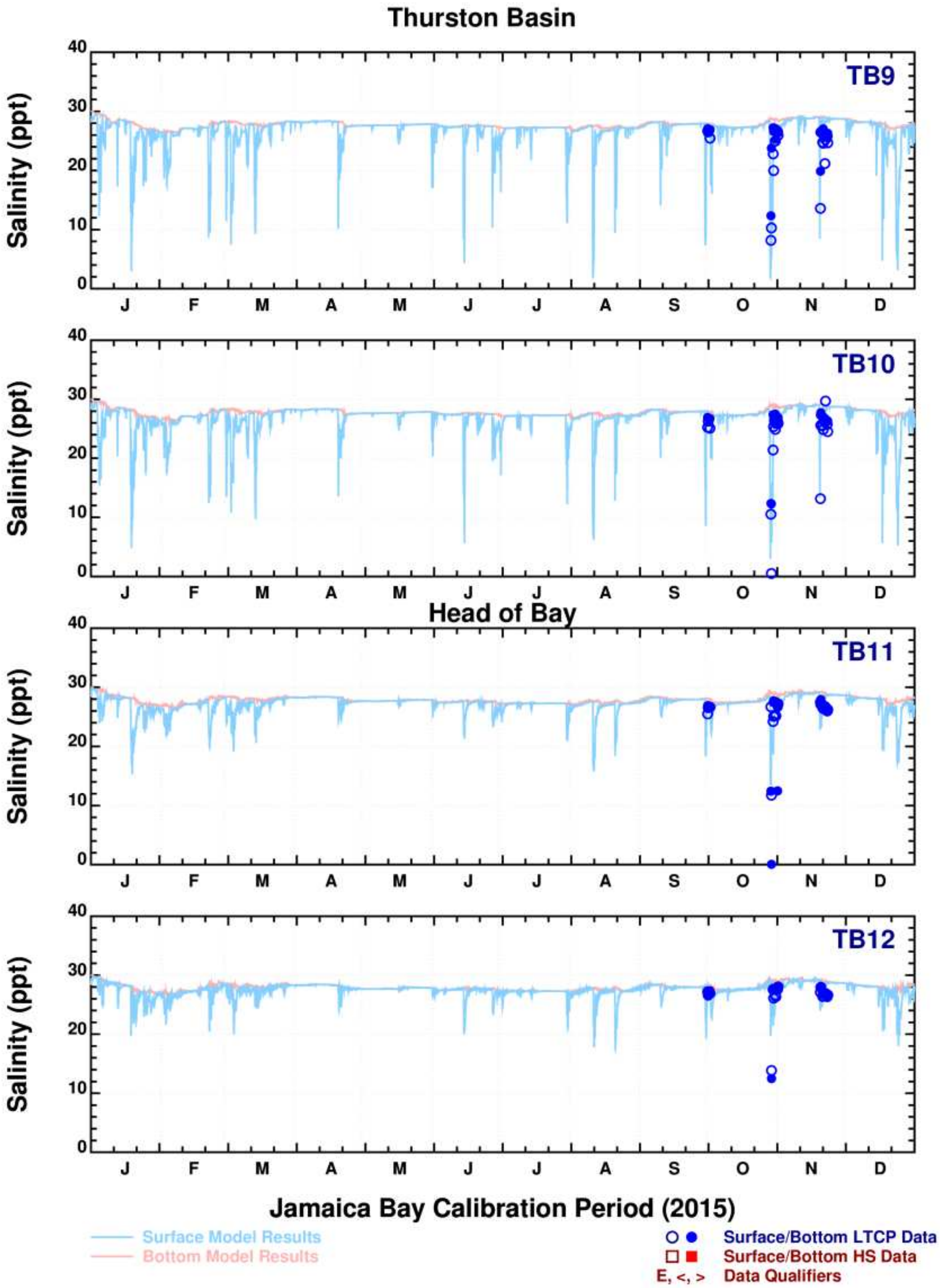

Figure 3-22. 2015 Salinity Calibration in Thurston Basin and Head of Bay

Figure 3-23 presents salinity data versus model results in the eastern, southern and central portions of the open waters of Jamaica Bay. At J12, some of the only observed salinity stratification in the bay is observed, due to the freshwater discharge from the Jamaica WWTP. The model reproduces the data very well. In the southern bay, at Station J5, stratification is generally not observed, and the model reproduces the observed data. In the center of the bay, at Stations J14 and J16, the model under-estimates the data. These salinity data are the highest in the bay, so there may be measurement error, or evaporation is causing higher salinity in the shallower inner portion of the bay.

Figure 3-24 presents salinity data and model comparisons for the western end of the bay. The model reproduces the salinity data very well.

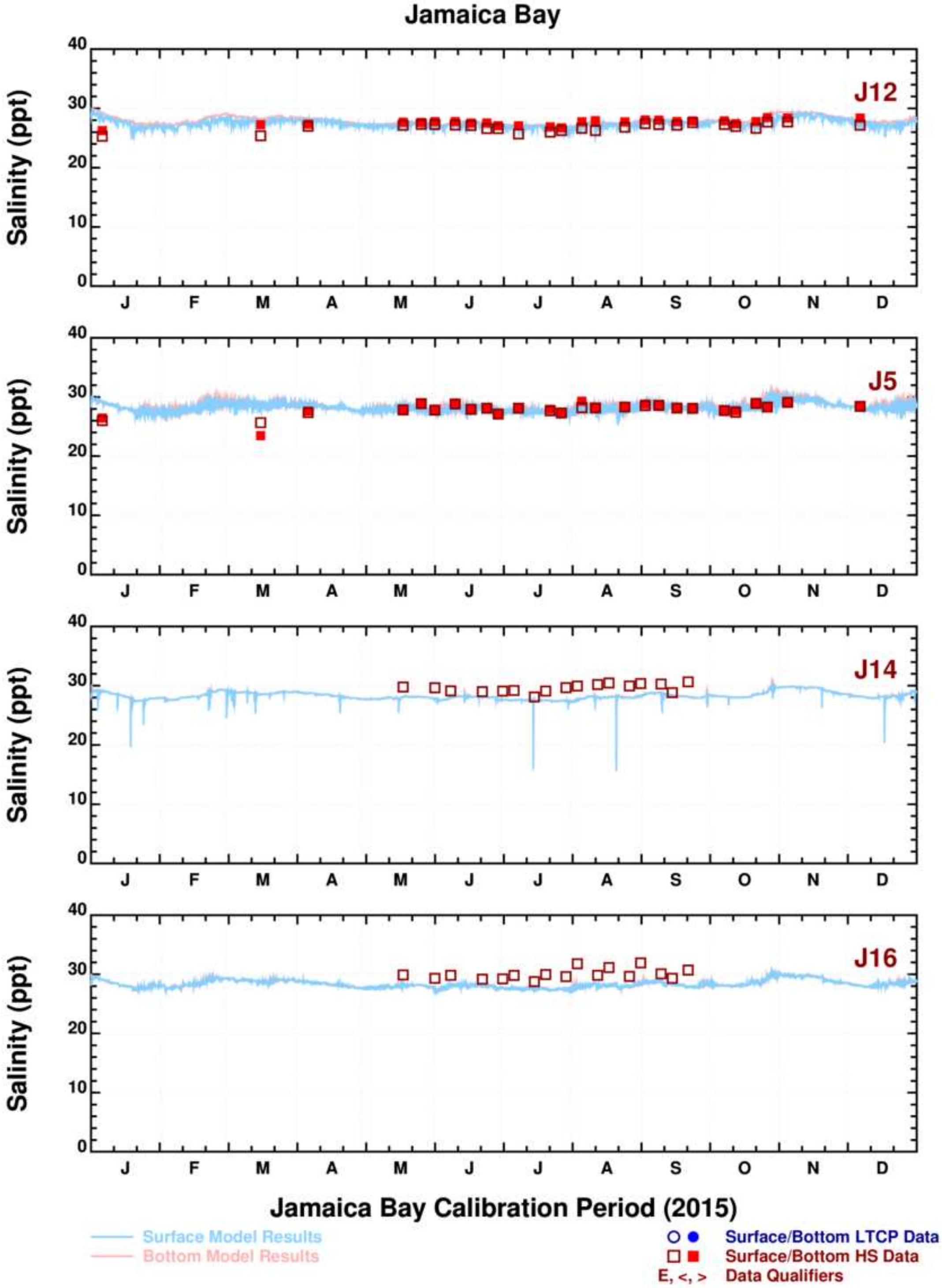

Figure 3-23. 2015 Salinity Calibration in Central and Eastern Jamaica Bay

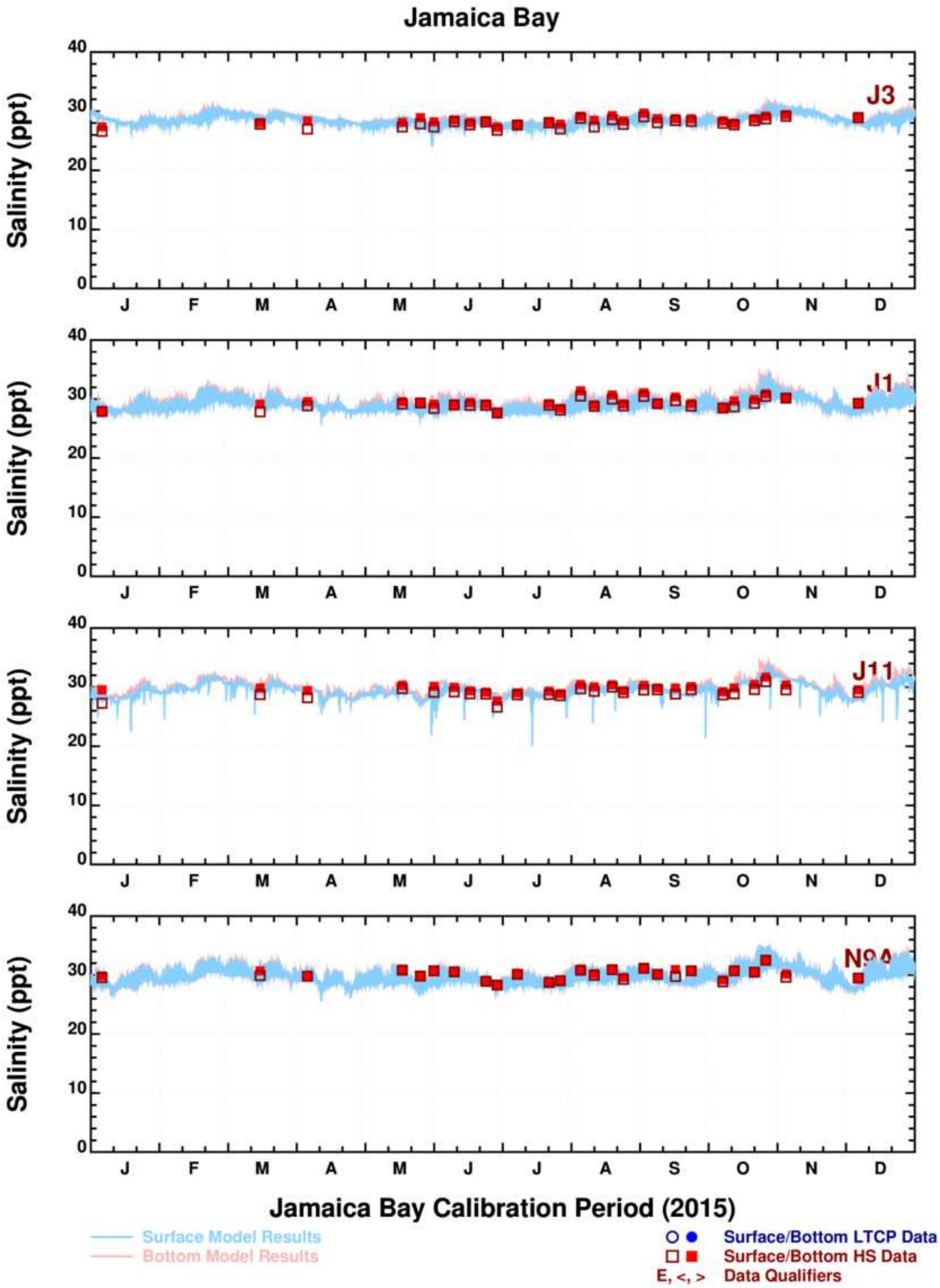

Figure 3-24. 2015 Salinity Calibration in Western Jamaica Bay

3.3 Water Quality Modeling

3.3.a Monitoring Program and Available Data

Data were collected in accordance with the Jamaica Bay FSAP at 12 receiving water sampling locations within Jamaica Bay, representative of wet- and dry-weather conditions. The sampling was conducted during September, October, and November 2015.

Both wet-weather and dry-weather samples were collected for fecal coliform and *Enterococcus* bacteria concentration analysis. Temperature, salinity and dissolved oxygen (DO) were concurrently measured with a multi-parameter water quality probe. Additional information regarding the receiving water sampling can be found in the “Data Collection Memorandum for Jamaica Bay” (AECOM, March 1, 2017).

The Harbor Survey, Sentinel Monitoring, and LTCP data collected during 2015 were used to calibrate the receiving water model.

3.3.b Pathogen Indicator Organism Load Source Sampling and Loading Development

Figure 2-1 presents the locations of existing sources of pollutants to Jamaica Bay including WWTPs, CSOs, stormwater, and direct drainage runoff. Source loads were developed using available and historic data. In addition, sanitary loads were added to the model to improve the model comparison to data during dry periods. These dry-weather loads are subsequently removed for baseline conditions assuming that illicit connections to the stormwater system have been abated.

Wastewater treatment plant effluent data were used to develop the WWTP loads. Fecal coliform bacteria concentrations were available on a daily basis. Very limited *Enterococci* concentration data were available. The sanitary fecal coliform-to-*Enterococci* ratio is estimated to be 4:1, and the disinfection rate of fecal coliform and *Enterococci* using chlorination is assumed to be similar. To be conservative on the higher side of potential concentrations, the *Enterococci* concentrations were assumed to be half of the fecal coliform concentrations.

Stormwater was monitored in several locations in the Jamaica Bay sewershed, but the stormwater results varied considerably in time and by location. To be conservative, most stormwater concentrations were based on previously collected citywide sampling data from the Inner Harbor Facility Planning Study (DEP, 1994) combined with data for the U.S. Environmental Protection Agency Harbor Estuary Program (HydroQual, 2005a). Using a conservative approach, the majority of the stormwater concentrations were based on the high level concentrations, with the exception of the Rockaway sewershed where low level concentrations were applied. An additional exception was Bergen Basin where sufficient data was collected. The IW sewer system model (Section 2) is used to generate the flows from NYC storm sewer outfalls, and concentrations noted in Table 3-1 are applied to the flows to develop pollutant loadings.

Table 3-1. Jamaica Bay Pollutant Source Loadings Characteristics

Source	Fecal Coliform (cfu/100mL)	*Enterococci* (cfu/100mL)	BOD_5 (mg/L)
Urban Stormwater (Bergen Basin)(1)	45,000	55,000	15
Urban Stormwater (Rockaway)(2)	35,000	15,000	15
Urban Stormwater (All Others)(2)	120,000	50,000	15
Sanitary for Mass Balance CSOs(3)	4,000,000	1,000,000	110
CSOs 26W-003, JAM-003, JAM-003A, PB-CSO, CI-004, CI-005 and CI-006(4)	Monte Carlo	Monte Carlo	Mass Balance
All other CSOs	Mass Balance	Mass Balance	Mass Balance
Highway/Airport Runoff (5)	20,000	8,000	15
Direct Drainage(6)	4,000	6,000	15
WWTP Effluent(7)	Monte Carlo	Monte Carlo	Quarterly

Notes:

(1) Stormwater bacteria concentrations based on 2015-2017 Jamaica Bay and Tributaries LTCP measurements. Stormwater BOD_5 based on Jamaica Bay Waterbody/Watershed Report (2011).
(2) Stormwater bacteria concentrations based on HydroQual Memo to DEP, 2005a. Stormwater BOD_5 based on Jamaica Bay Waterbody/Watershed Report (2011).
(3) Sanitary bacteria concentrations from the HydroQual Memo to DEP, 2005a.
(4) MonteCarlo based on 2015 LTCP CSO data.
(5) Highway/Airport runoff concentrations based on airport drainage data used in the Flushing Bay LTCP model estimated from NYS Stormwater Manual, Charles River LTCP, and National Stormwater Data Base.
(6) Direct drainage bacteria concentrations based on NYS Stormwater Manual, Charles River LTCP, and National Stormwater Data Base for commercial and industrial land uses. Direct drainage BOD_5 concentrations specified as stormwater.
(7) WWTP effluent bacteria concentrations based on 2016 DMR measurements: Monte Carlo selection of daily averages for fecal coliform and median of several months for *Enterococci*. BOD concentrations based on quarterly Biowin model results from the FANCJ analysis.

Probability distributions of the calculated and observed data for *Enterococci* and fecal coliform were developed to verify the Monte Carlo distributions. Figure 3-25 shows the calculated and observed distributions at CSO Outfall 26W-003, as well as overflow from the Paerdegat Basin CSO Control Facility. Figure 3-26 shows the calculated and observed distributions at CSO Outfalls JA-003 and JA-003A. Table 3-2 through Table 3-4 compare the characteristics of the observed and Monte Carlo generated distributions. As shown, the Monte Carlo methodology does a very good job of reproducing the observed data and its characteristics.

Table 3-2. Statistical Comparison Between Observed Paerdegat CSO Control Facility Overflow Bacteria Concentrations and Estimated Concentrations from the Monte Carlo Analysis

Statistics	*Enterococci* cfu/100mL		Fecal Coliform cfu/100mL	
	Observed	Estimated	Observed	Estimated
Geometric Mean	515,667	468,787	967,085	1,041,444
Standard Deviation(1)	0.27	0.28	0.30	0.29
Minimum	150,000	104,005	320,000	206,156
Maximum	1,350,000	1,742,642	3,400,000	3,842,722

Note:
(1) Standard deviation of the log of the concentrations.

Table 3-3. Statistical Comparison Between Observed CSO 26W-003 Bacteria Concentrations and Estimated Concentrations from the Monte Carlo Analysis

Statistics	*Enterococci* cfu/100mL		Fecal Coliform cfu/100mL	
	Observed	Estimated	Observed	Estimated
Geometric Mean	154,187	154,983	214,198	210,648
Standard Deviation(1)	0.48	0.49	0.35	0.37
Minimum	17,000	14,315	54,000	39,333
Maximum	1,300,000	4,281,614	790,000	1,714,286

Note:
(1) Standard deviation of the log of the concentrations.

Table 3-4. Statistical Comparison Between Observed CSO JAM-003/003A Bacteria Concentrations and Estimated Concentrations from the Monte Carlo Analysis

Statistics	*Enterococci* cfu/100mL		Fecal Coliform cfu/100mL	
	Observed	Estimated	Observed	Estimated
Geometric Mean	545,248	530,189	668,549	567,173
Standard Deviation(1)	0.39	0.41	0.56	0.57
Minimum	30,000	48,592	60,000	9,804
Maximum	3,000,000	10,919,029	14,700,000	10,697,424

Note:
(1) Standard deviation of the log of the concentrations.

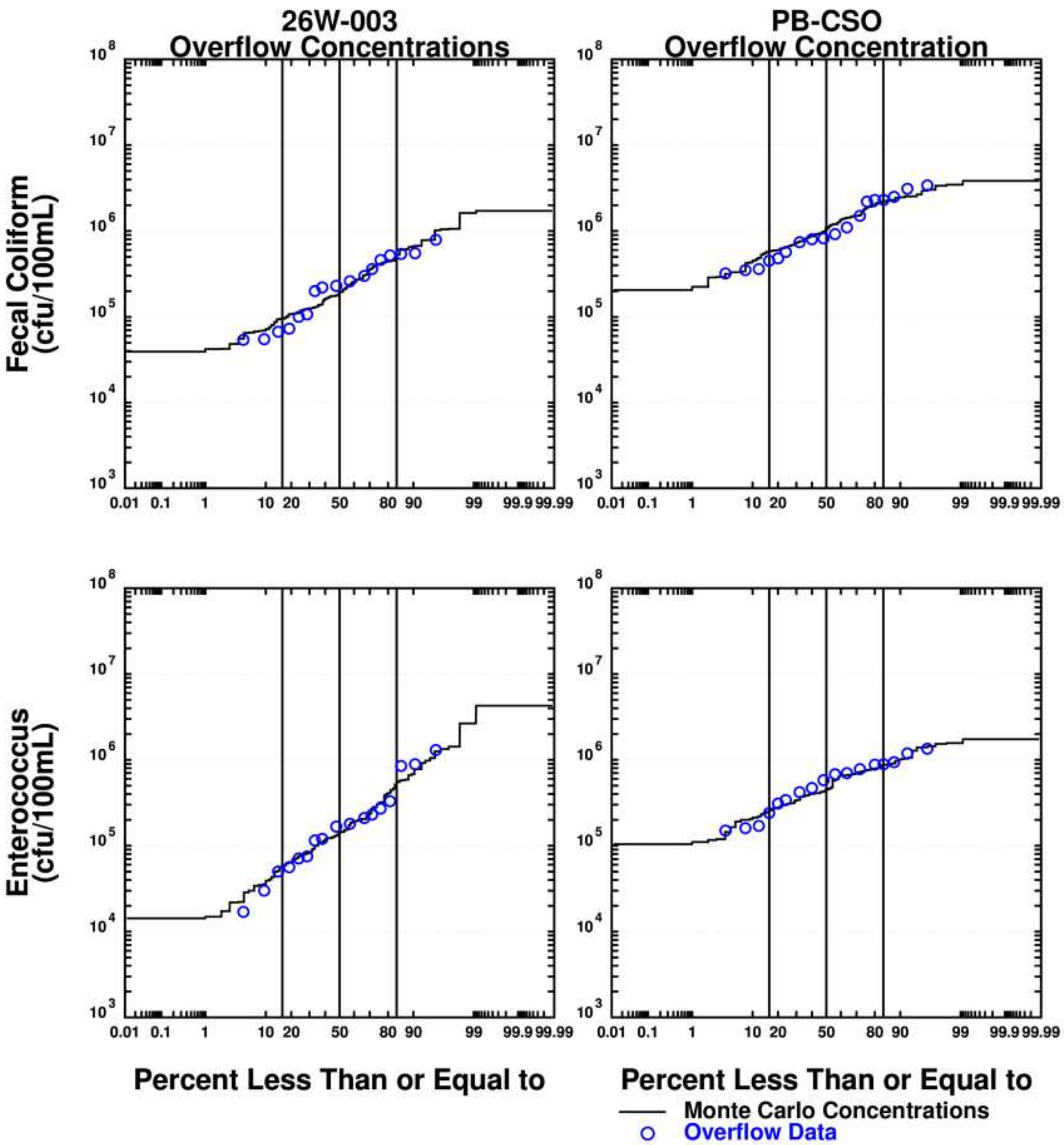

Figure 3-25. Probability Distribution Comparison Between Observed CSO 26W-003 and PB-CSO Bacteria Concentrations and Estimated Concentrations from the Monte Carlo Analysis

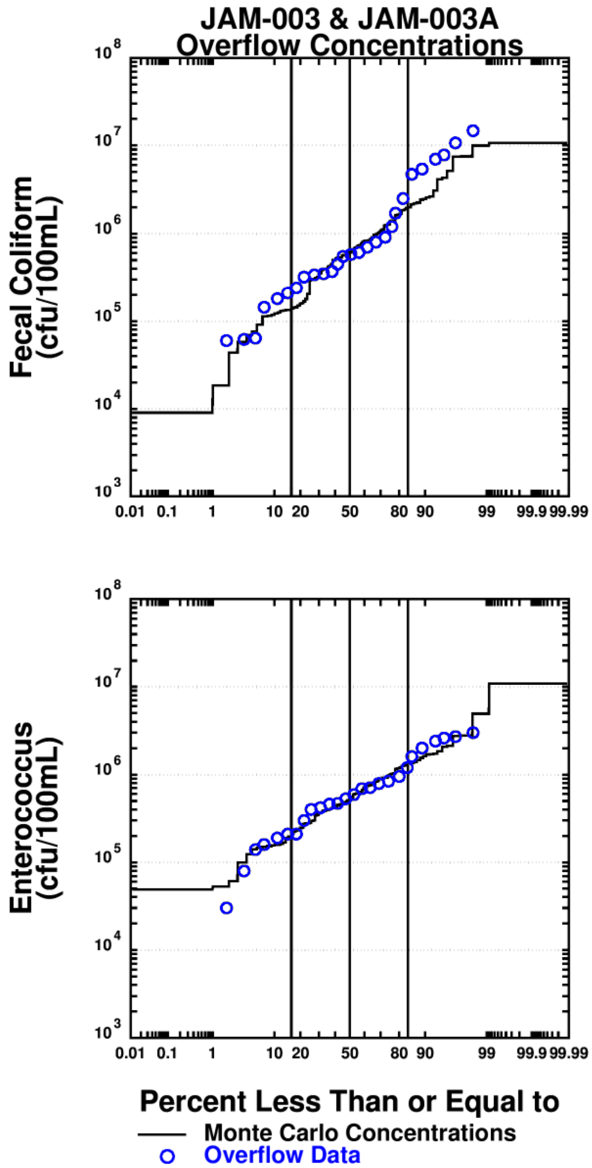

Figure 3-26. Probability Distribution Comparison Between Observed CSO JAM-003 and JAM-003A Bacteria Concentrations and Estimated Concentrations from the Monte Carlo Analysis

3.3.c Bacteria Modeling Skill Assessment

The bacteria loadings described above were incorporated into the receiving water quality model to calculate Jamaica Bay bacteria concentrations. Bacteria modeling results for the calibration were compared against both Harbor Survey and LTCP2 monitoring data to assess whether the model was capable of reproducing receiving water bacteria concentrations and whether the model could be used to assess CSO reduction alternatives.

It was noted during the calibration process that the bacteria concentrations in Jamaica Bay decreased more rapidly after precipitation events than the model predicted using the typical bacteria kinetics used in previously modeled LTCP2 waterbodies. Additionally, there is some variability of the bacteria loss rate from tributary to tributary. While it had been noticed that the bacteria concentrations decreased faster than the model predicted in other waterbodies as well, the difference in other waterbodies between the model and data was not as dramatic. After a review of possible mechanisms that would cause a more rapid decline in bacteria concentrations, such as sunlight or an increased bacteria die-off rate, it was decided that particulate settling was the most likely factor. Additionally, *Enterococci* appeared to decline more rapidly than fecal coliform, which is counter to the expectation that *Enterococci* are more resistant to environmental factors than fecal coliform.

Based on an assessment of Coney Island Creek data, where high fecal coliform to *Enterococci* ratios were observed, it was theorized that under certain conditions fecal coliform can survive in the sediment and return to the water column either through resuspension or some other process. In an effort to reproduce that mechanism, the JEM kinetics were modified to include a net settling rate factor (V_{snet}) to replicate resuspension of fecal coliform into the water column. The net settling rate factor reduces the amount of settleable material that is incorporated into the sediment. It is anticipated that re-suspension would occur due to current speed, as well as wind and wave action, so that shallow areas were more likely to have resuspension than deeper areas. To reproduce this resuspension effect, scale factors shown in Table 3-5 were applied based on the depth of the model segment. The application of this scale factor improved the model fit to the data in some shallow areas, as shown in Figure 3-27. Without the net settling rate factor, the model under-estimates the concentrations at the end of the storm. With the net settling rate factor, the model more favorably reproduces the data.

Table 3-5. Assignment of V_{snet} Based on Depth

Model Depth (m)	V_{snet}
< 2.0	0.2
2.0 – 3.0	0.4
3.0 – 4.0	0.6
4.0 – 5.0	0.8
> 5.0	1.0

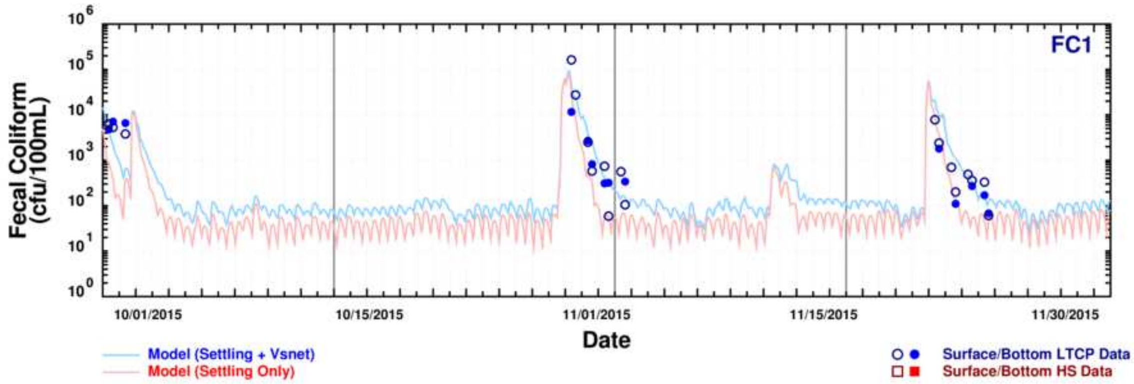

Figure 3-27. Comparison of Fecal Coliform Model Results versus Data for Modeling Scenarios With and Without V_{snet} at Station FC1

The results of the updated calibration are presented in Figure 3-28 through Figure 3-43. Figure 3-28 and Figure 3-29 present the model versus data comparison in Paerdegat Basin for fecal coliform and *Enterococci*, respectively. Like many waterbodies around New York City, there is evidence of an intermittent source of bacteria during dry-weather. To improve the model comparison to data, a small, constant bacteria source, equivalent to a sanitary flow of approximately 6,500 gpd, was applied to the head end of the basin. The model generally matches or exceeds the peak bacteria concentrations measured in the basin. The model is better at reproducing the dry-weather *Enterococci* concentrations than the fecal coliform concentrations, but does reasonably well reproducing both.

Figure 3-30 and Figure 3-31 present model versus data comparisons for fecal coliform and *Enterococci*, respectively, in Fresh Creek. As in Paerdegat Basin, a small constant bacteria load, equivalent to a sanitary flow of approximately 3,200 gpd, was added at the head end of the Creek to reproduce some of the higher bacteria concentrations measured during dry-weather. The model reproduces the high bacteria concentrations very well and also reproduces the lower *Enterococci* concentrations very well. The fecal coliform concentrations remain elevated during dry-weather in Fresh Creek and out into Jamaica Bay, suggesting there are other local sources of fecal coliform.

Model versus data comparisons for fecal coliform and *Enterococci* concentrations in Hendrix Creek are presented in Figure 3-32 and Figure 3-33, respectively. Hendrix Creek bacteria loads include the 26th Ward WWTP, which were based on measured fecal coliform concentrations. *Enterococci* concentrations, which are not measured at the WWTP, were assigned at half of the fecal coliform concentration. Also, a dry, sanitary flow of 320 gpd was assigned to reproduce the dry-weather receiving water concentrations. The model calculates higher peak concentrations than appear in the data, but this may be a function of when samples were collected. The model generally reproduces the bacteria data measured in the Creek.

The Spring Creek model versus data comparisons for fecal coliform and *Enterococci* are presented in Figure 3-34 and Figure 3-35, respectively. A constant dry-weather loading based on 2,600 gpd was added to the head end of the Creek for calibration purposes. The model generally reproduces the measured bacteria data during both dry- and wet-weather; however, toward the mouth of Spring Creek the dry-weather fecal coliform concentrations are sometimes under-estimated. The model accurately reproduces the bacteria concentrations during the larger wet-weather events.

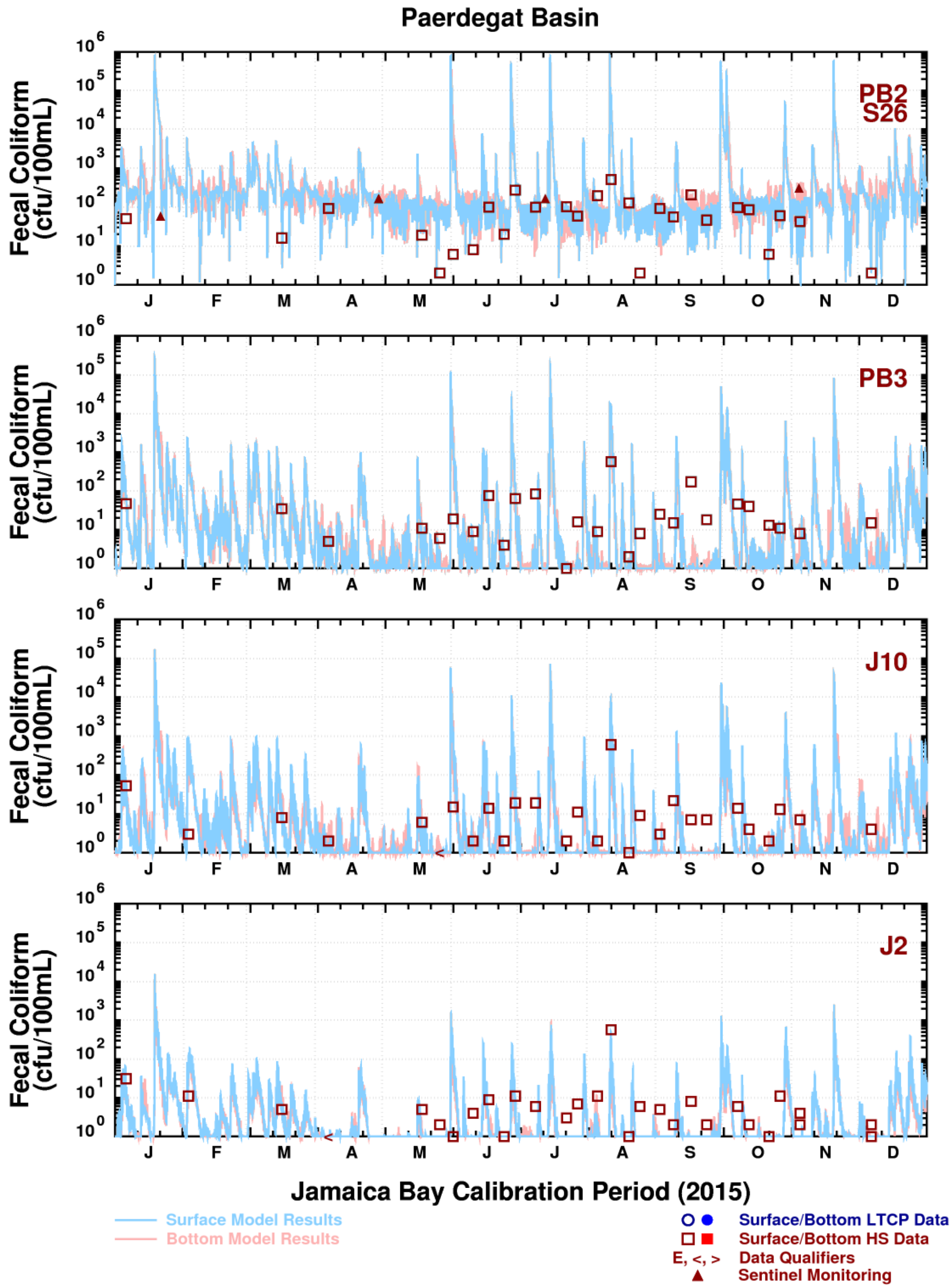

Figure 3-28. 2015 Fecal Coliform Calibration in Paerdegat Basin and Nearby Jamaica Bay Stations

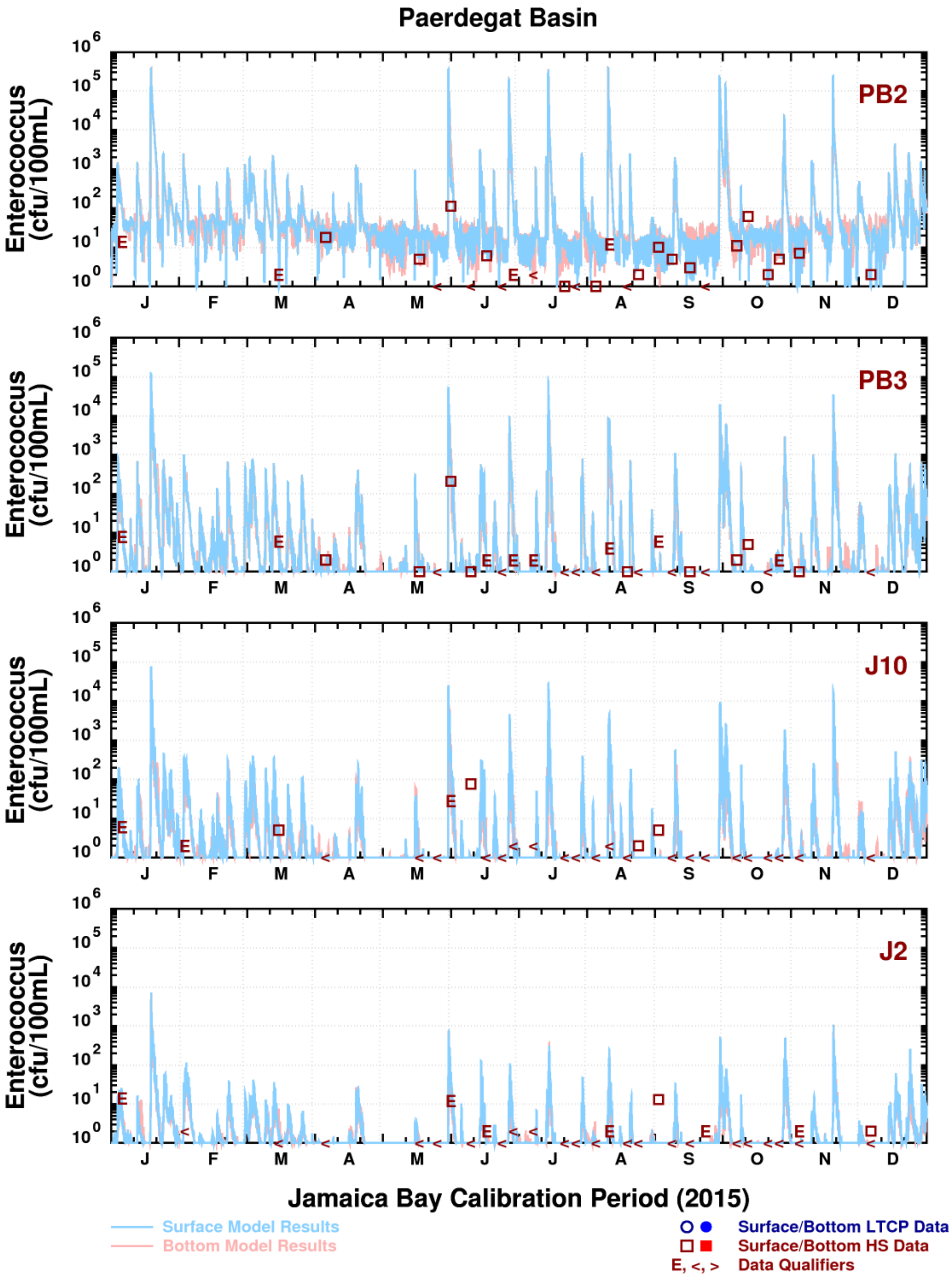

Figure 3-29. 2015 *Enterococci* Calibration in Paerdegat Basin and Nearby Jamaica Bay Stations

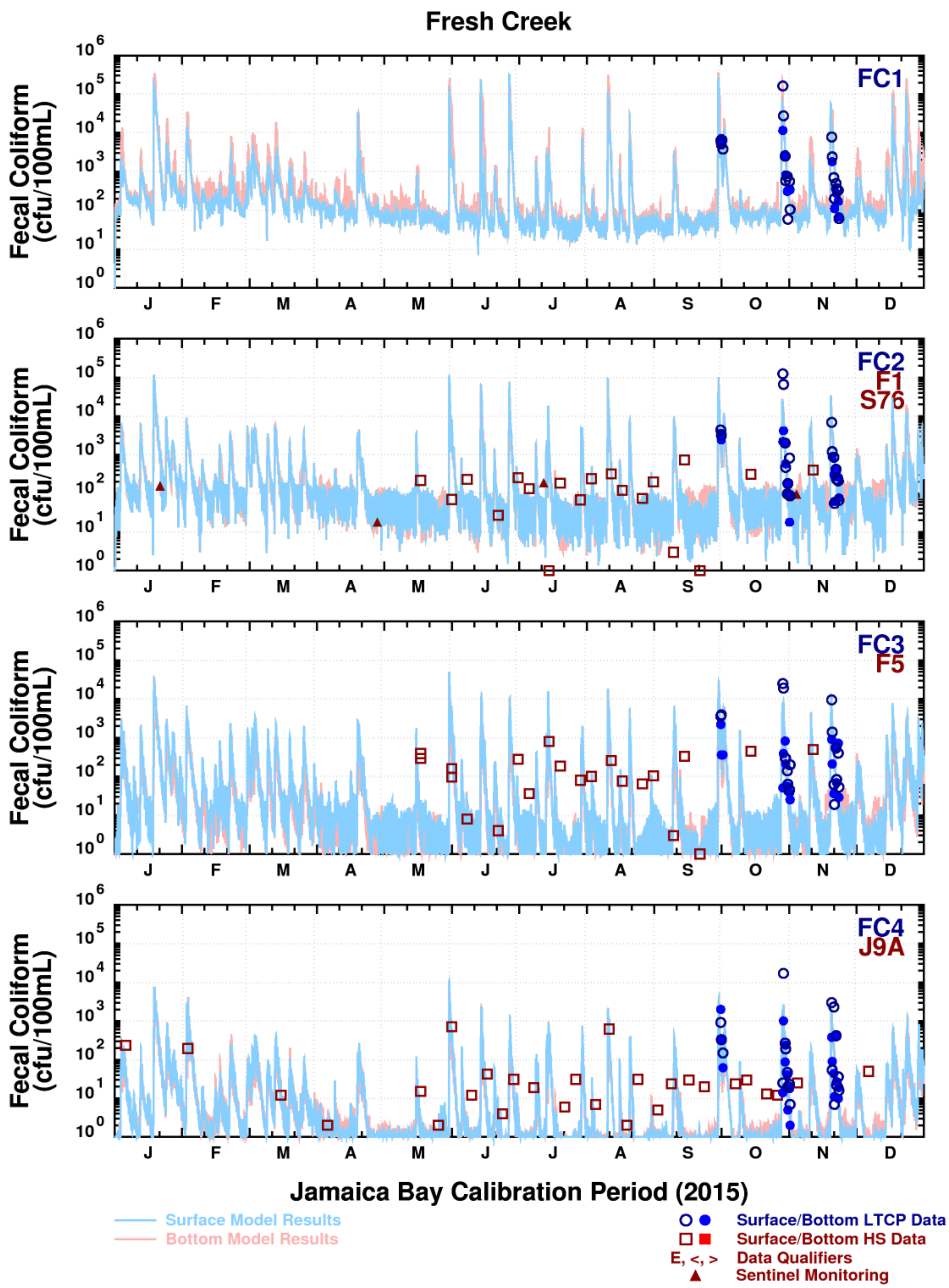

Figure 3-30. 2015 Fecal Coliform Calibration in Fresh Creek and Nearby Jamaica Bay Stations

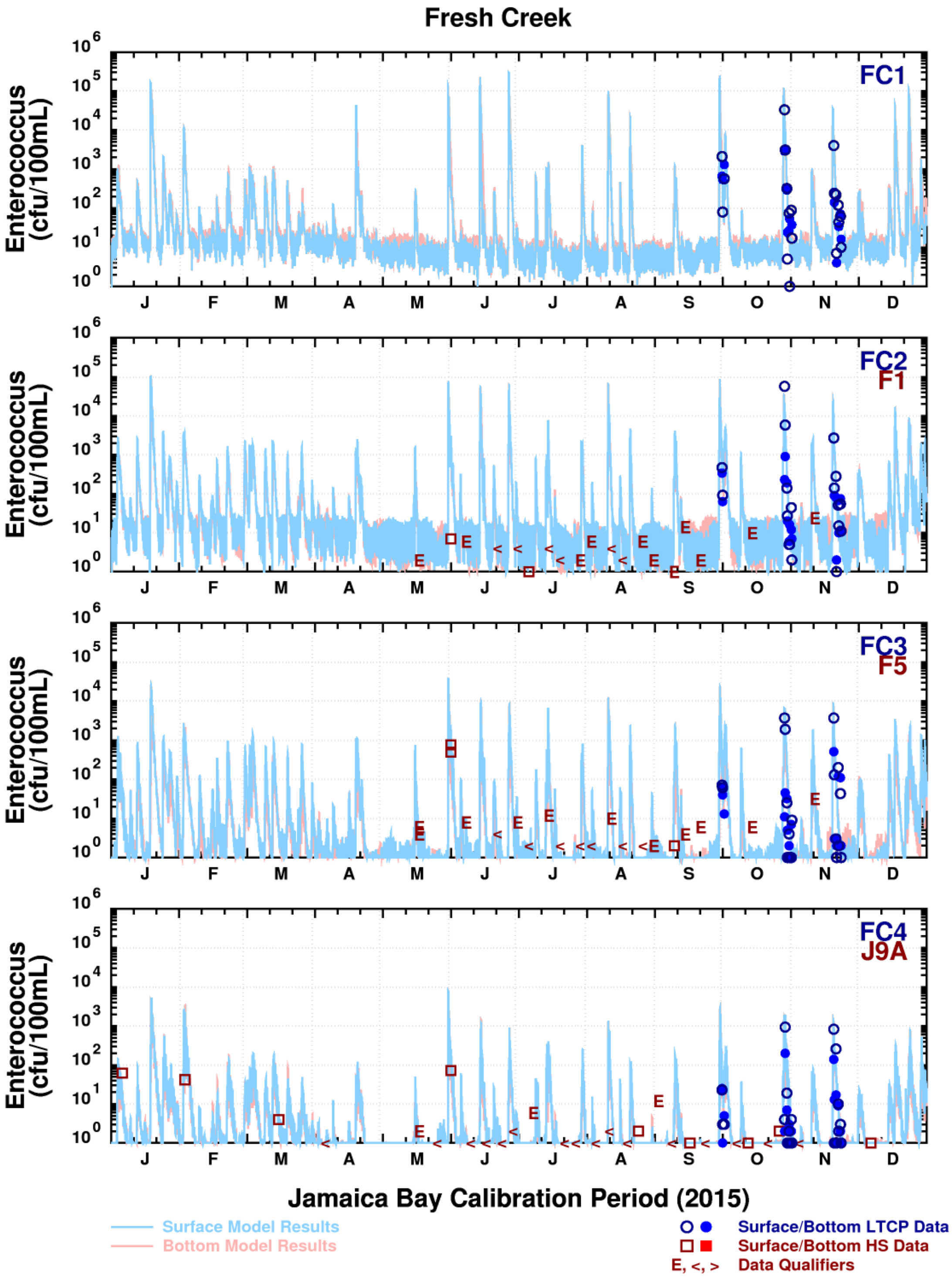

Figure 3-31. 2015 *Enterococci* Calibration in Fresh Creek and Nearby Jamaica Bay Stations

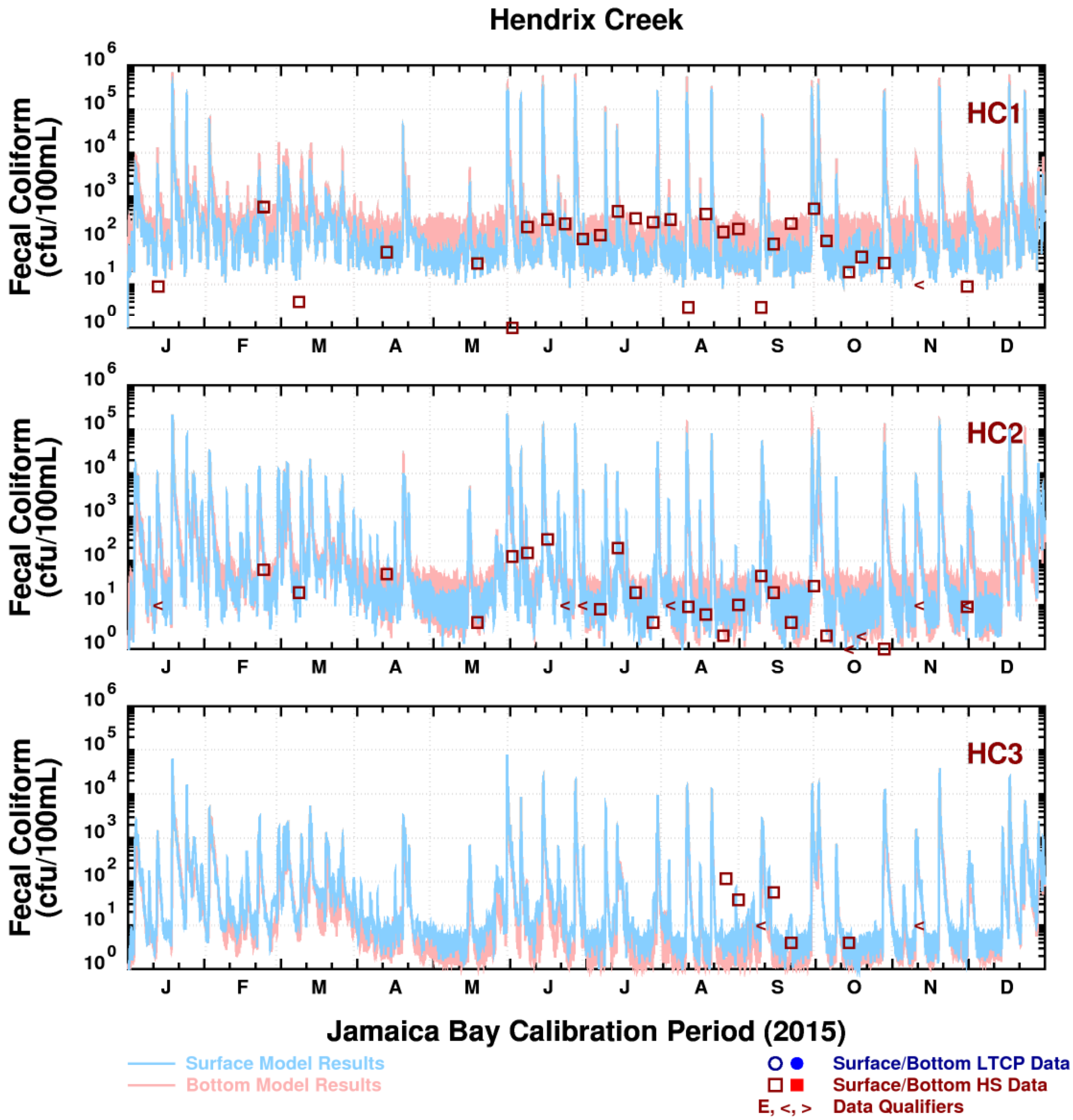

Figure 3-32. 2015 Fecal Coliform Calibration in Hendrix Creek

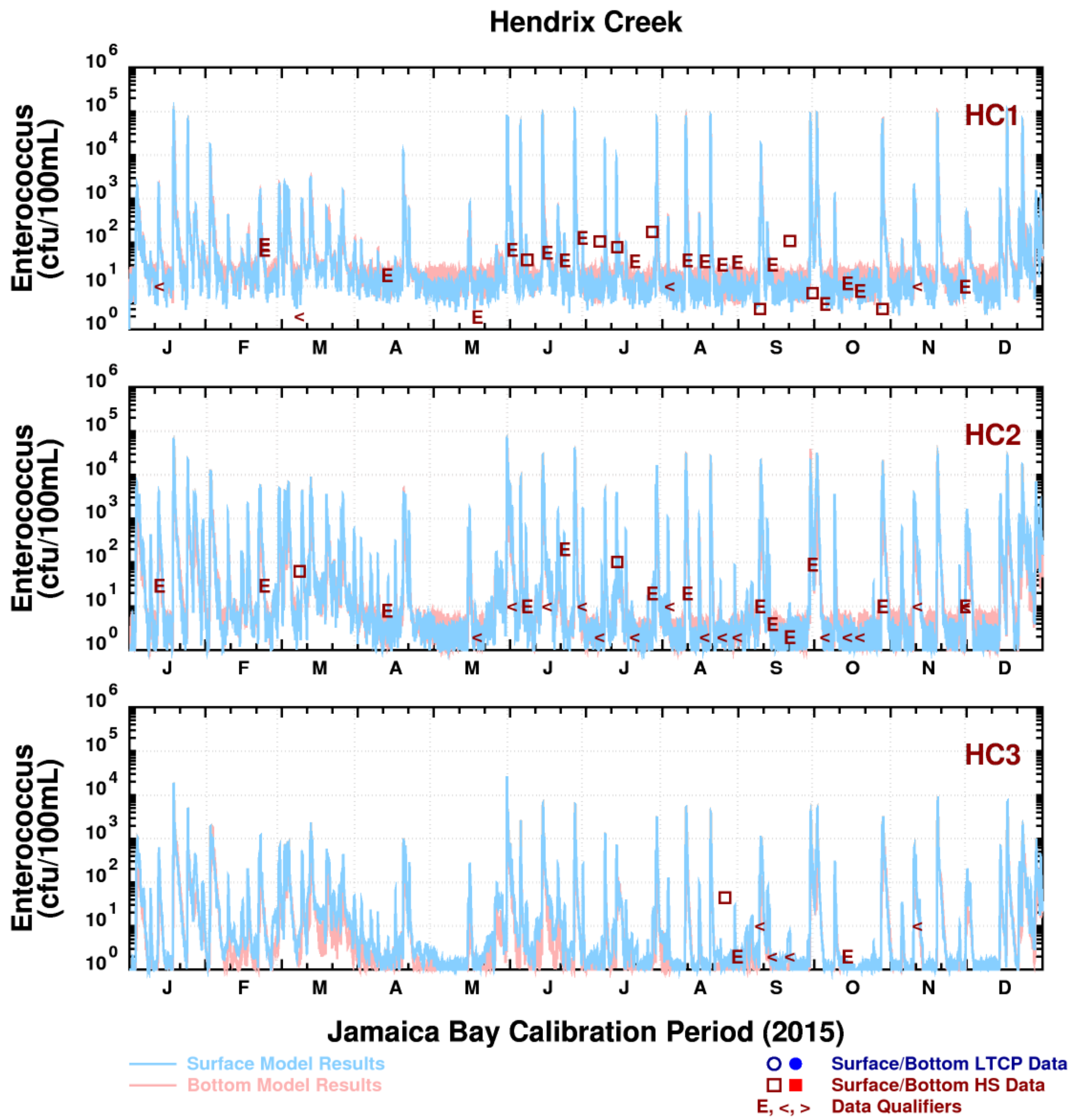

Figure 3-33. 2015 *Enterococci* Calibration in Hendrix Creek

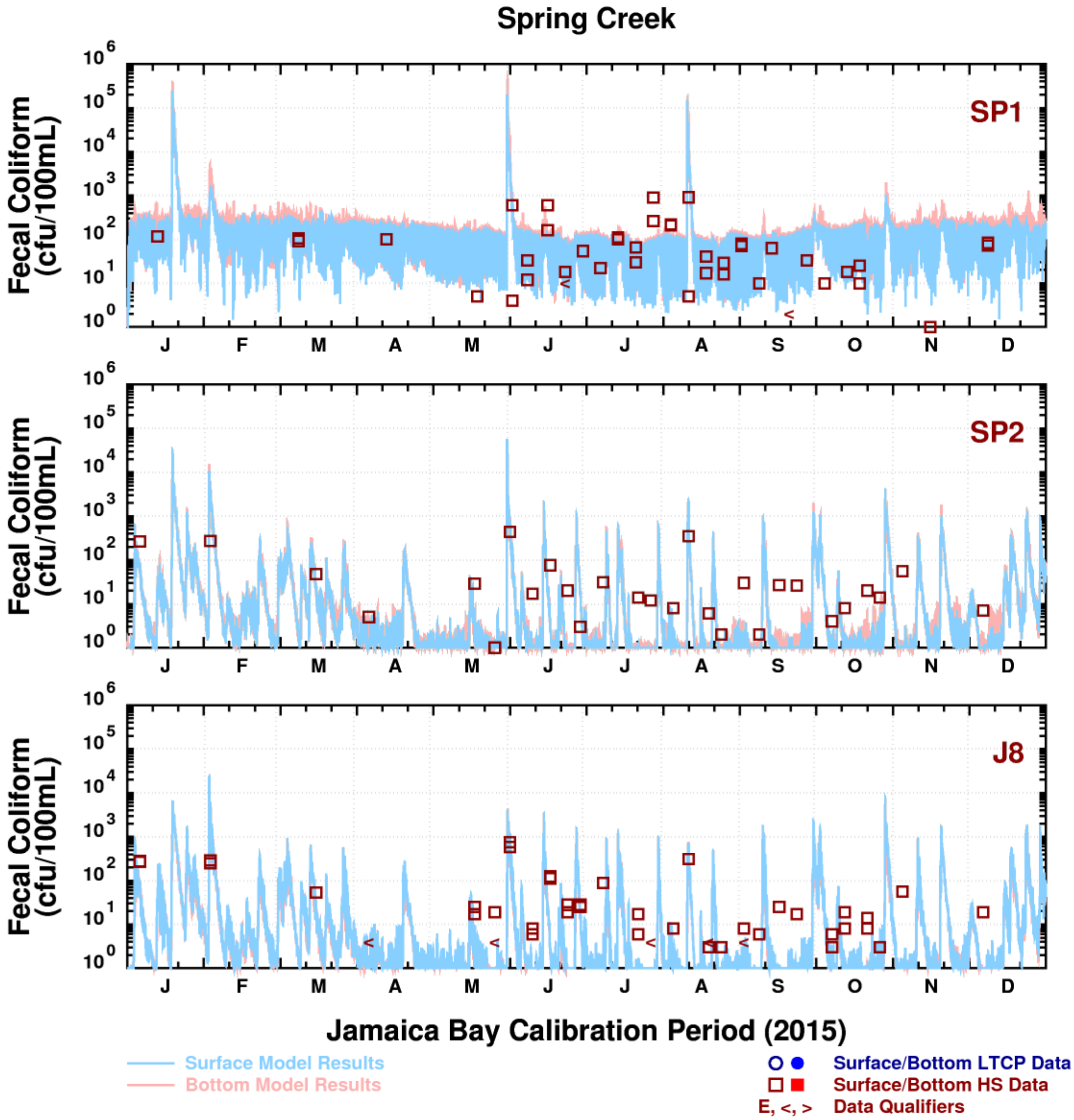

Figure 3-34. 2015 Fecal Coliform Calibration in Spring Creek and Nearby Jamaica Bay Stations

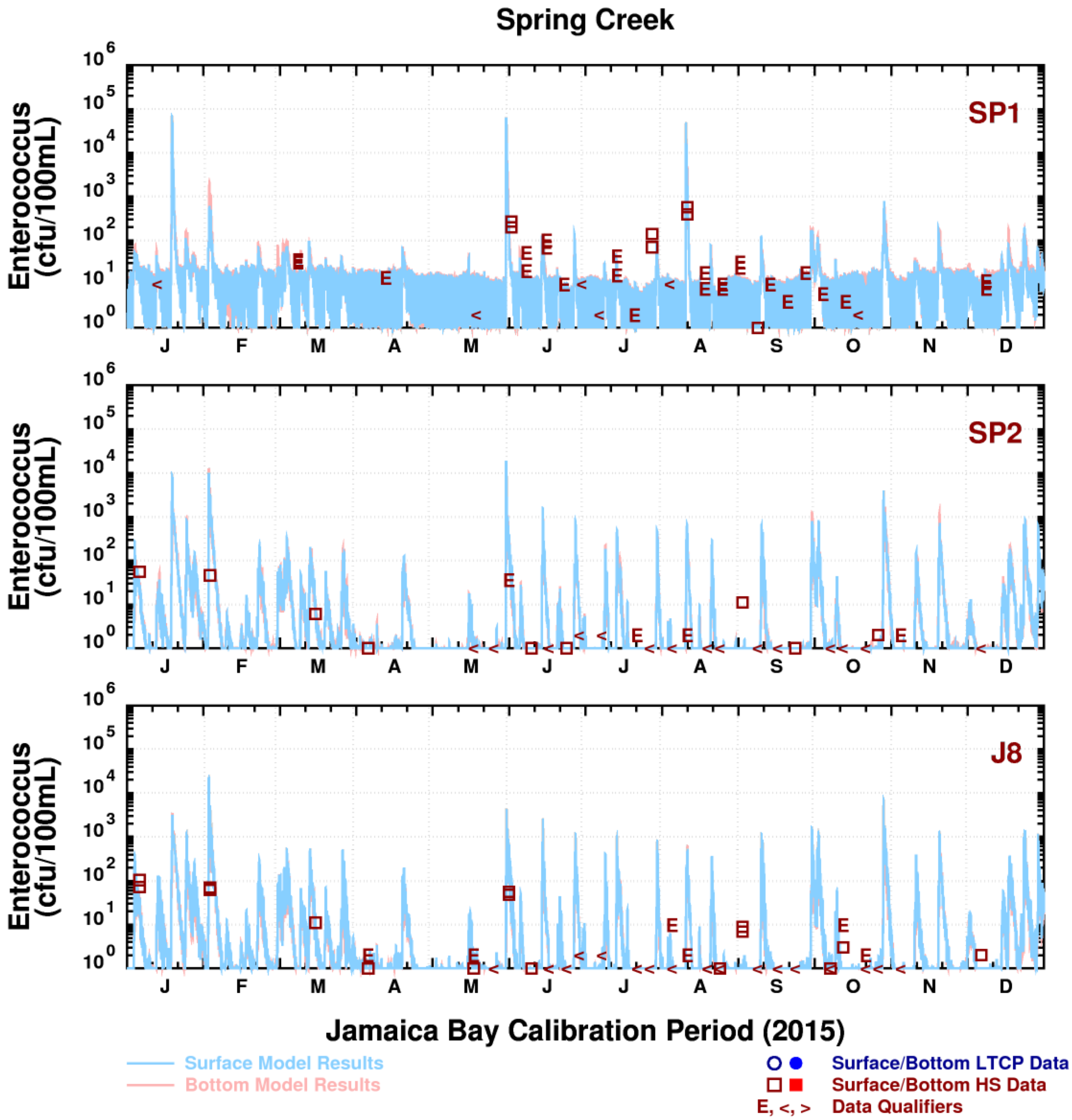

Figure 3-35. 2015 *Enterococci* Calibration in Spring Creek and Nearby Jamaica Bay Stations

The model versus data comparisons for fecal coliform and *Enterococci* in Bergen Basin are presented in Figure 3-36 and Figure 3-37, respectively. Bergen Basin had the largest dry-weather loading assigned to any tributary with a sanitary flow of approximately 32,000 gpd. The model reasonably reproduces the timing and magnitude of the measured wet-weather bacteria concentrations. In general, the measured dry-weather bacteria concentrations fall within the range of concentrations calculated by the model.

The model comparison to fecal coliform and *Enterococci* data collected in Thurston Basin and Head of Bay are presented in Figure 3-38 and Figure 3-39, respectively. Unlike the other tributaries, Harbor Survey does not have stations in Thurston Basin or Head of Bay. Since the typical dry-weather concentrations were unknown, no dry-weather loading was added to the basin. The Sentinel Monitoring Program does have a station at the mouth of Thurston Basin that does suggest elevated fecal coliform concentrations, but since dry-weather loads are removed from baseline conditions, the effort was not made to match the sparse Sentinel Monitoring data. The model generally reproduces the observed wet-weather bacteria concentrations.

Figure 3-40 and Figure 3-41 present the fecal coliform and *Enterococci* model versus data comparisons for eastern and central open waters of Jamaica Bay. Measured fecal coliform and *Enterococci* concentrations are generally low in these regions of the bay, but dry-weather fecal coliform concentrations persist above 1 cfu/100mL whereas dry-weather *Enterococci* data contain many "less–than-detection-limit" values. The model reasonably calculates the peak values observed in the data. The *Enterococci* data are reproduced by the model during wet- and dry-weather. The dry-weather fecal coliform data suggest either a local source such as wildlife or resuspension of sediment or a low level persistent population.

The model versus data comparison for fecal coliform and *Enterococci* are presented in Figure 3-42 and Figure 3-43, respectively, for the western stations in the open water of the bay. The bacteria data in this region of the bay are generally low, with the exception of Station J11 at the mouth of Sheepshead Bay. The fecal coliform data indicate a dry-weather source, but this is less clear in the *Enterococci* data at this station. Since this is not a CSO tributary and dry-weather sources are removed for projection purposes, no effort was made to estimate the size of a potential illicit source. The model reproduces the magnitude of the wet-weather concentrations, but under-estimates some of the dry-weather fecal concentrations. The model reasonably reproduces the *Enterococci* data.

Model versus data probability plots were also created for the fecal coliform and *Enterococci* data, and they are presented in Appendix D.

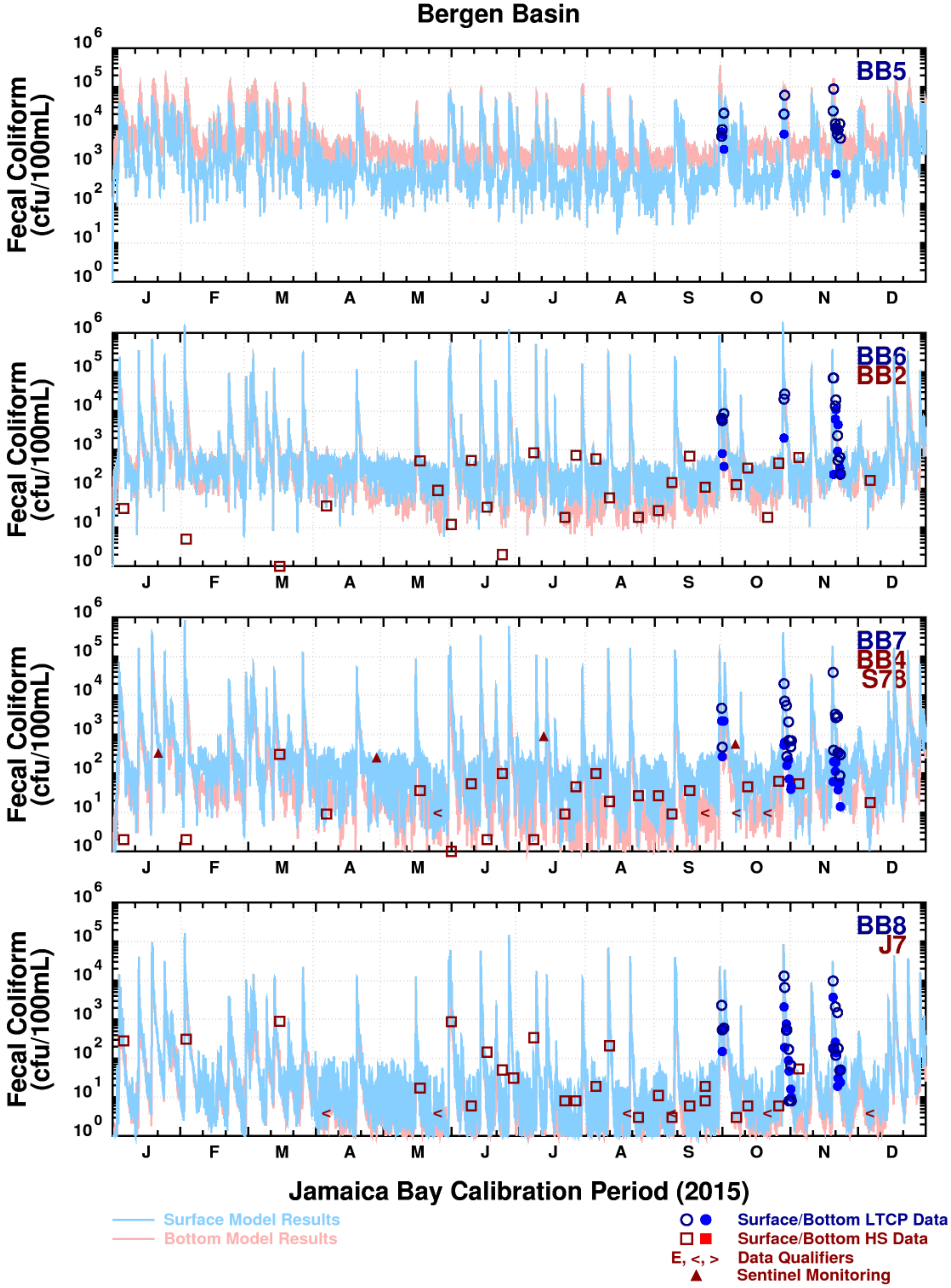

Figure 3-36. 2015 Fecal Coliform Calibration in Bergen Basin and Nearby Jamaica Bay Stations

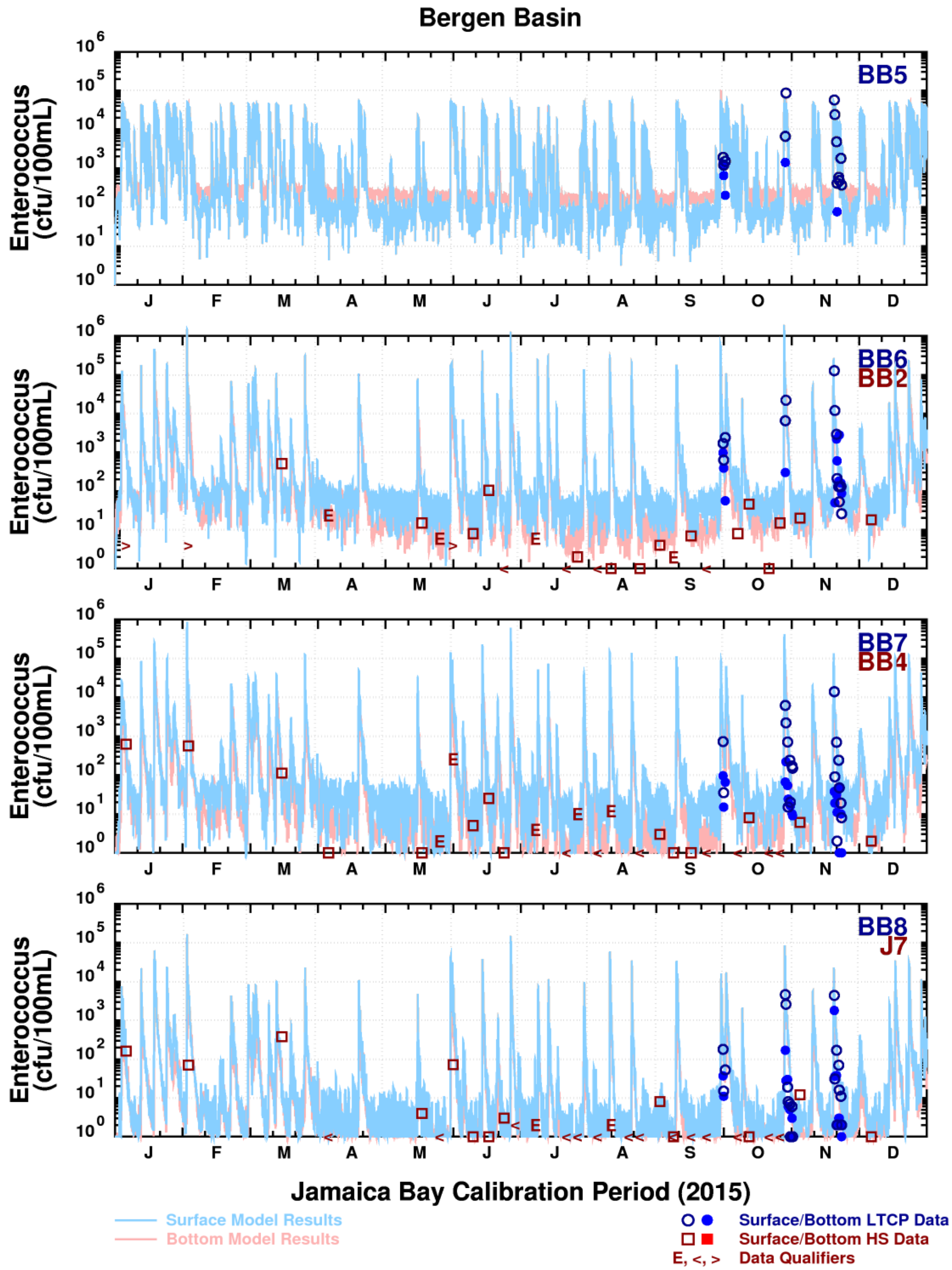

Figure 3-37. 2015 *Enterococci* Calibration in Bergen Basin and Nearby Jamaica Bay Stations

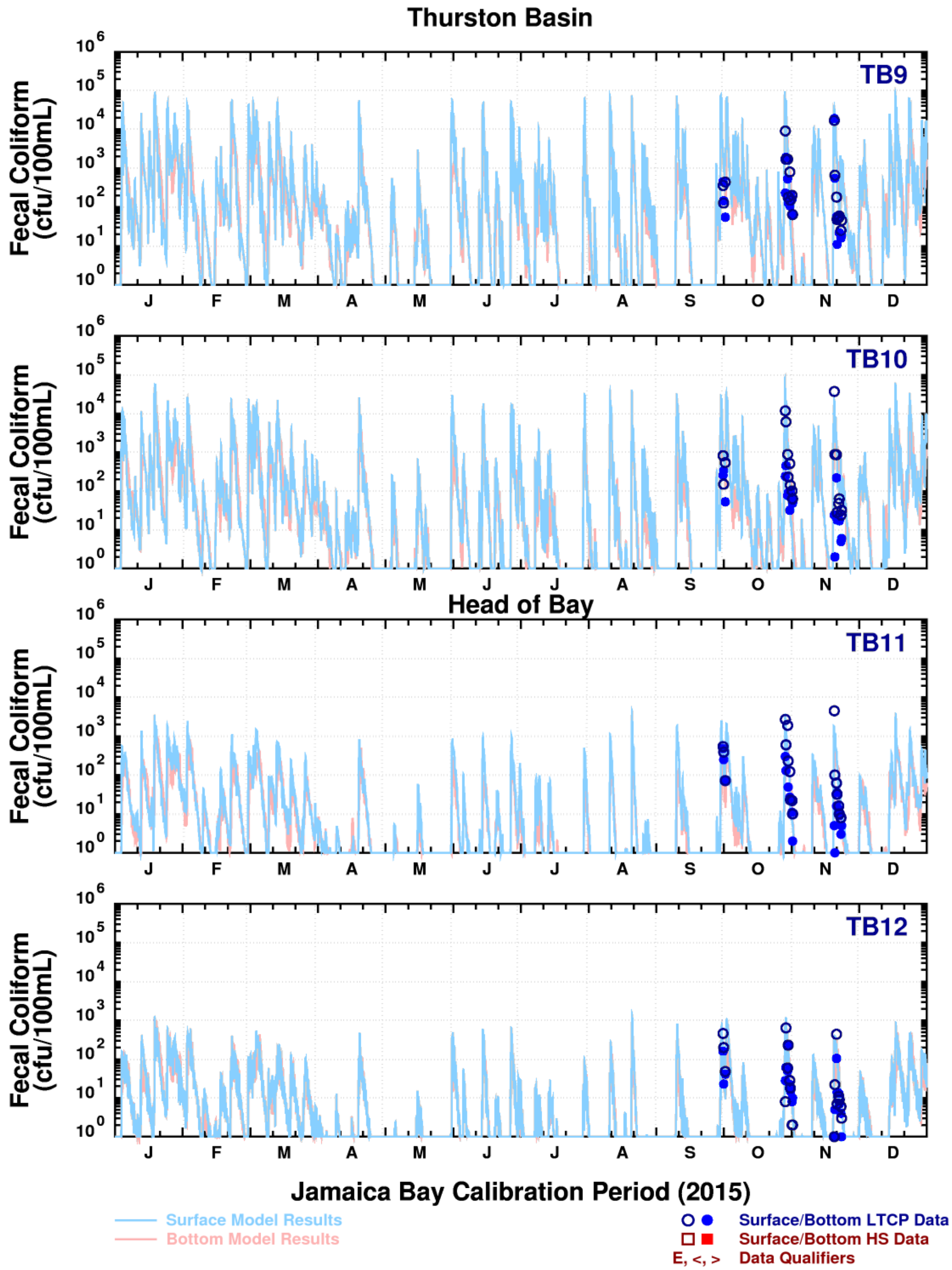

Figure 3-38. 2015 Fecal Coliform Calibration in Thurston Basin and Head of Bay

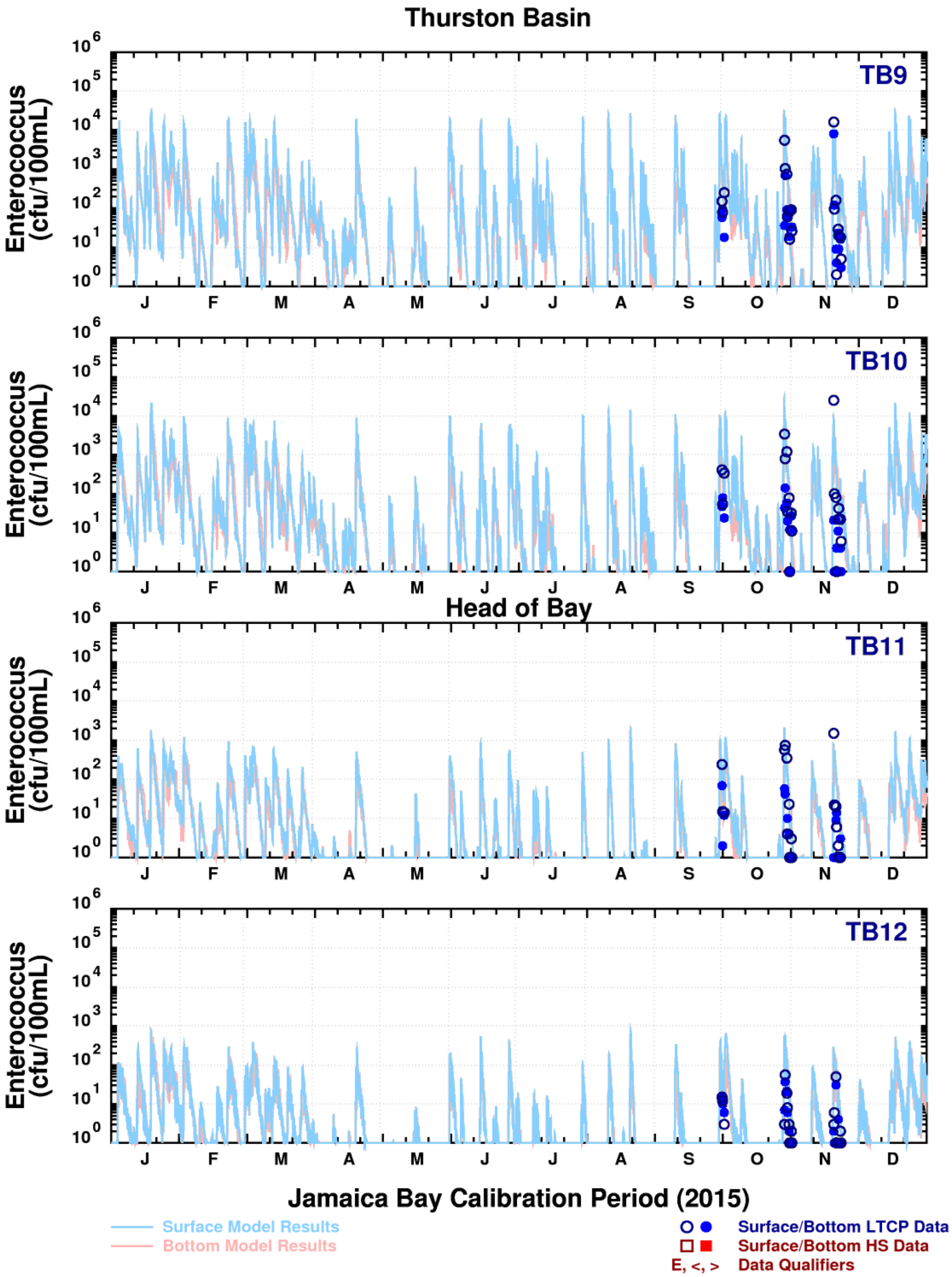

Figure 3-39. 2015 *Enterococci* Calibration in Thurston Basin and Head of Bay

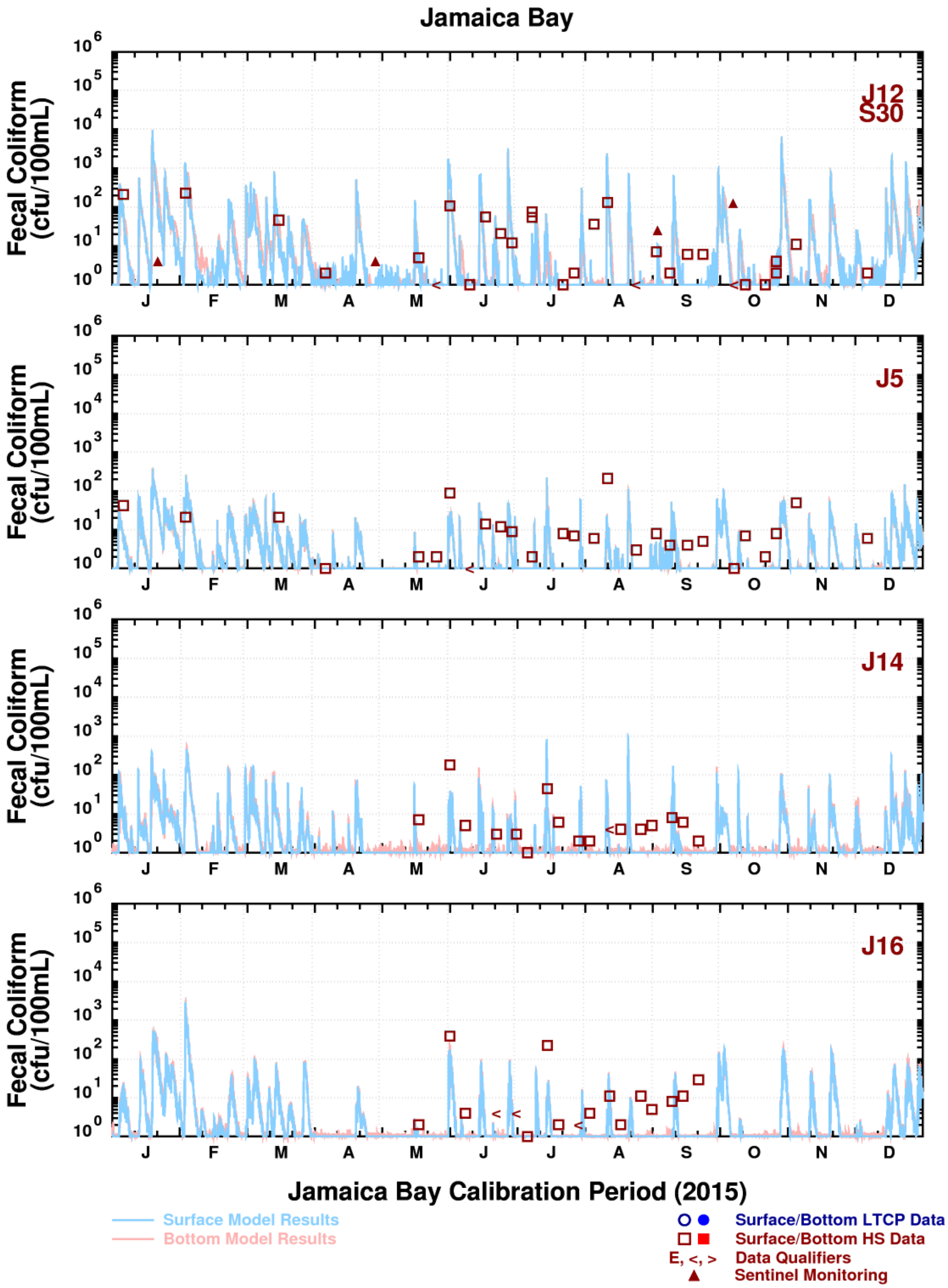

Figure 3-40. 2015 Fecal Coliform Calibration in Central and Eastern Jamaica Bay

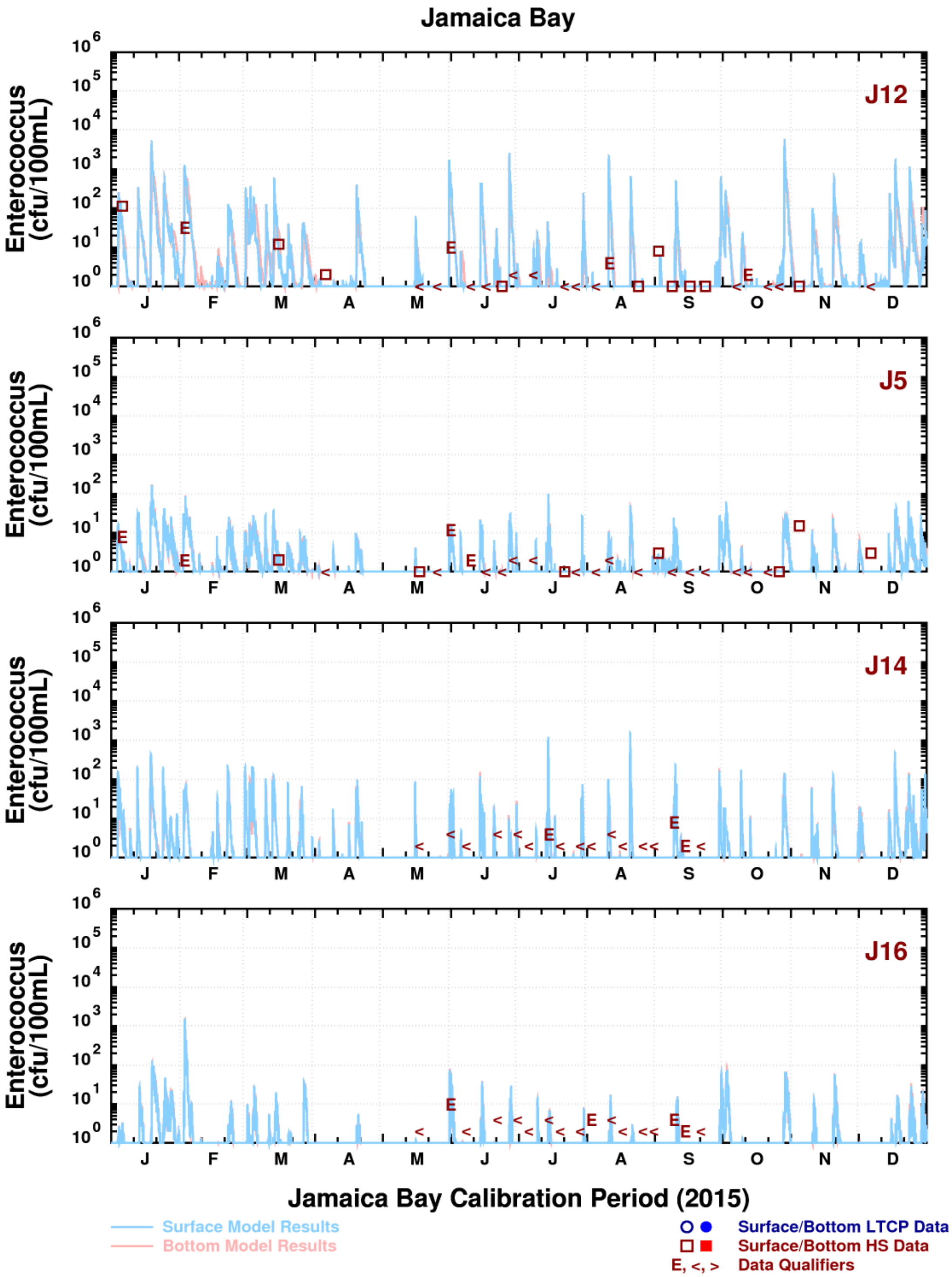

Figure 3-41. 2015 *Enterococci* Calibration in Central and Eastern Jamaica Bay

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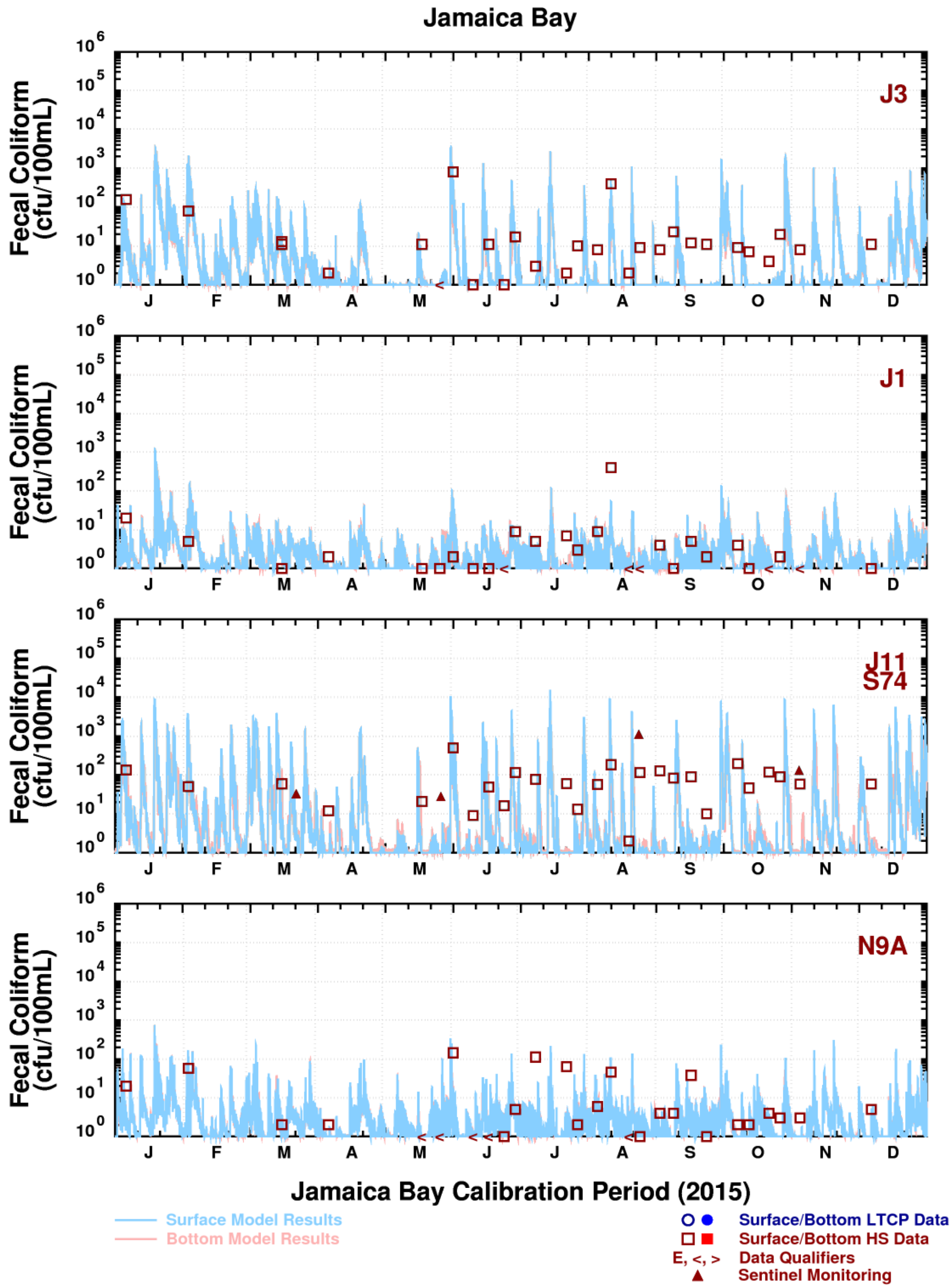

Figure 3-42. 2015 Fecal Coliform Calibration Western Jamaica Bay

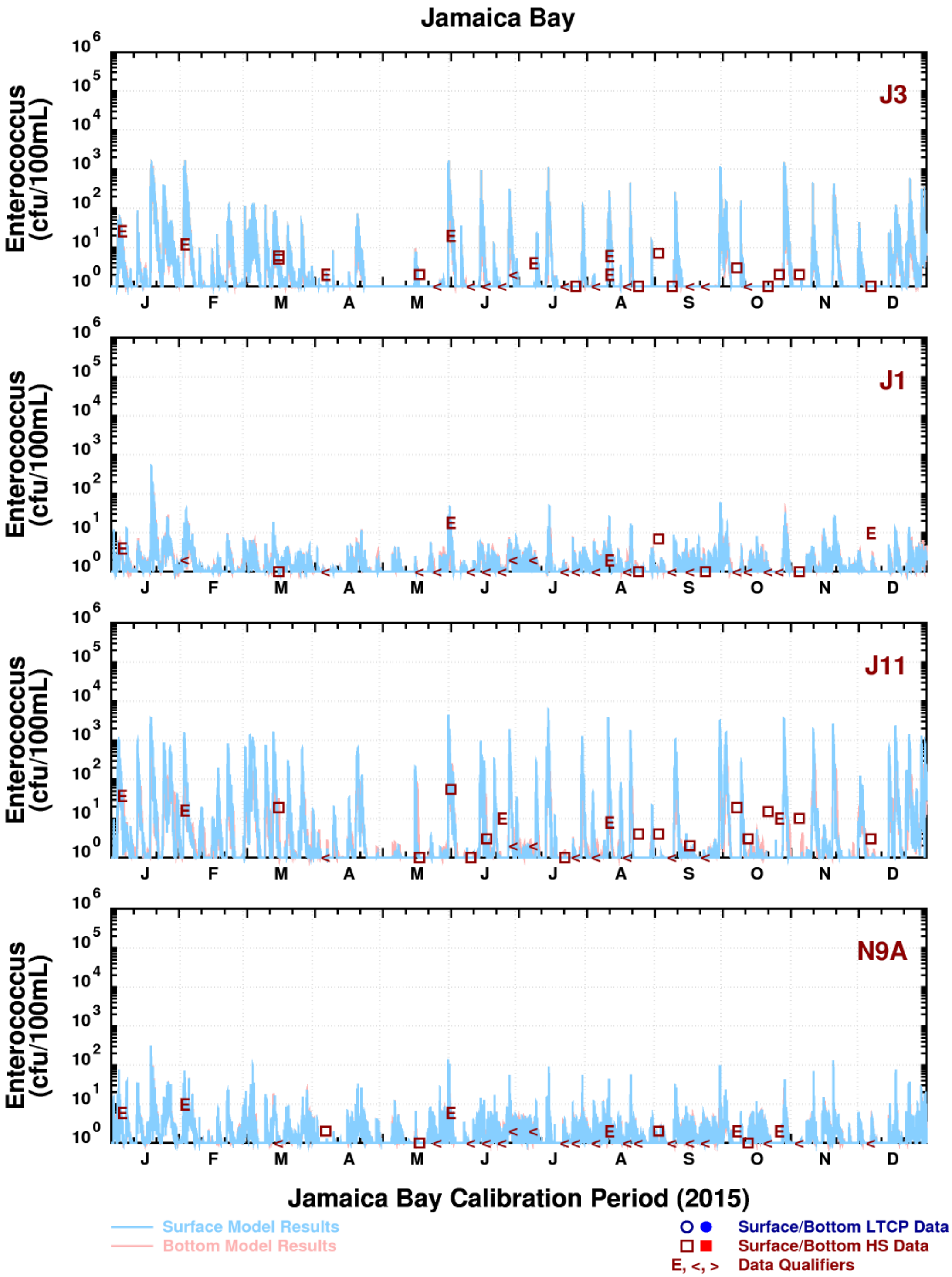

Figure 3-43. 2015 *Enterococci* Calibration in Western Jamaica Bay

3.3.d **Dissolved Oxygen Model Skill Assessment**

The DO validation focused on both the LTCP2 data and the Harbor Survey data. The Harbor Survey sampling is conducted year-round and is more intensive during the summer months. The LTCP2 sampling did not collect data during the critical months for DO. The eutrophication modeling analysis did not involve a model recalibration, so model coefficients were not adjusted from previous modeling efforts. Only model loadings and hydrodynamics were modified for the validation.

The model versus data comparison for DO in Paerdegat Basin and nearby Jamaica Bay is presented in Figure 3-44. In Paerdegat Basin, the model does a better job at reproducing the low DO data than the higher data. There is algal production in the basin that the model does not reproduce. At Station J10, near the mouth of the basin, the model generally reproduces that data, but does not reproduce some of the higher DO concentrations. At Station J2, near the mouth of Mill Basin, the model splits the difference between the surface and bottom data, but does not reproduce the extremes of either.

Figure 3-45 presents the model versus data comparison for DO in Fresh Creek and nearby Jamaica Bay. LTCP2 were collected in Fresh Creek. The model tends to overestimate the lower Harbor Survey DO concentration data. The model does a poor job reproducing the LTCP2 data. However, the majority of the low DO concentrations measured during the wet-weather events appear to be related to eutrophication and algae as the low DO is observed out into North Channel at Station FC4. The wet-weather DO concentrations at Station FC4 are as low as the Station FC1 concentrations near the CSO. This suggests that the low DO is more of a bay-wide phenomenon rather than being caused by CSO discharge.

The comparison between Hendrix Creek model and DO concentration data is presented in Figure 3-46. One of the challenges in modeling the DO concentration in Hendrix Creek is the uncertainty of the DO concentration in the 26th Ward WWTP effluent. At HC1 and HC2, the model generally reproduces the data, but over-estimates some of the lower concentrations. At HC3, the model over-estimates the data.

Figure 3-46 presents the model versus data comparison for Harbor Survey data collected in Spring Creek. The data show very few measurements below the daily average criterion of 4.8 mg/L. There are numerous DO measurements, especially towards the head end of the Creek, indicating supersaturated concentrations associated with an algal bloom. The model generally goes through the middle of the data, not reproducing the extreme highs or lows observed in the data.

The model versus DO data comparison for Bergen Basin is presented in Figure 3-48. The model generally compares favorably to the Harbor Survey data collected along the length of the Creek. The model captures the spatial and temporal variability of the data with the exception of over-estimating the winter concentrations. It is possible that deicing fluid, which has a high BOD load and was not accounted for in the model, could account for some of the differences between the model and sampling data during the colder months. The model also reasonably reproduces the LTCP2 data at Stations BB5 and BB6. However, at stations closer to the mouth of Bergen Basin, the model over-estimates the wet-weather data. As observed in Fresh Creek, this may be a bay-wide event related more to a decrease in algal production than related to CSOs.

Figure 3-49 presents a model versus data comparison for DO concentrations in Thurston Basin and Head of Bay. Thurston Basin and Head of Bay were not sampled by NYCDEP during 2015. The model performs reasonably well against the data from the first two LTCP2 sampling events, but over-predicts the data from the last survey.

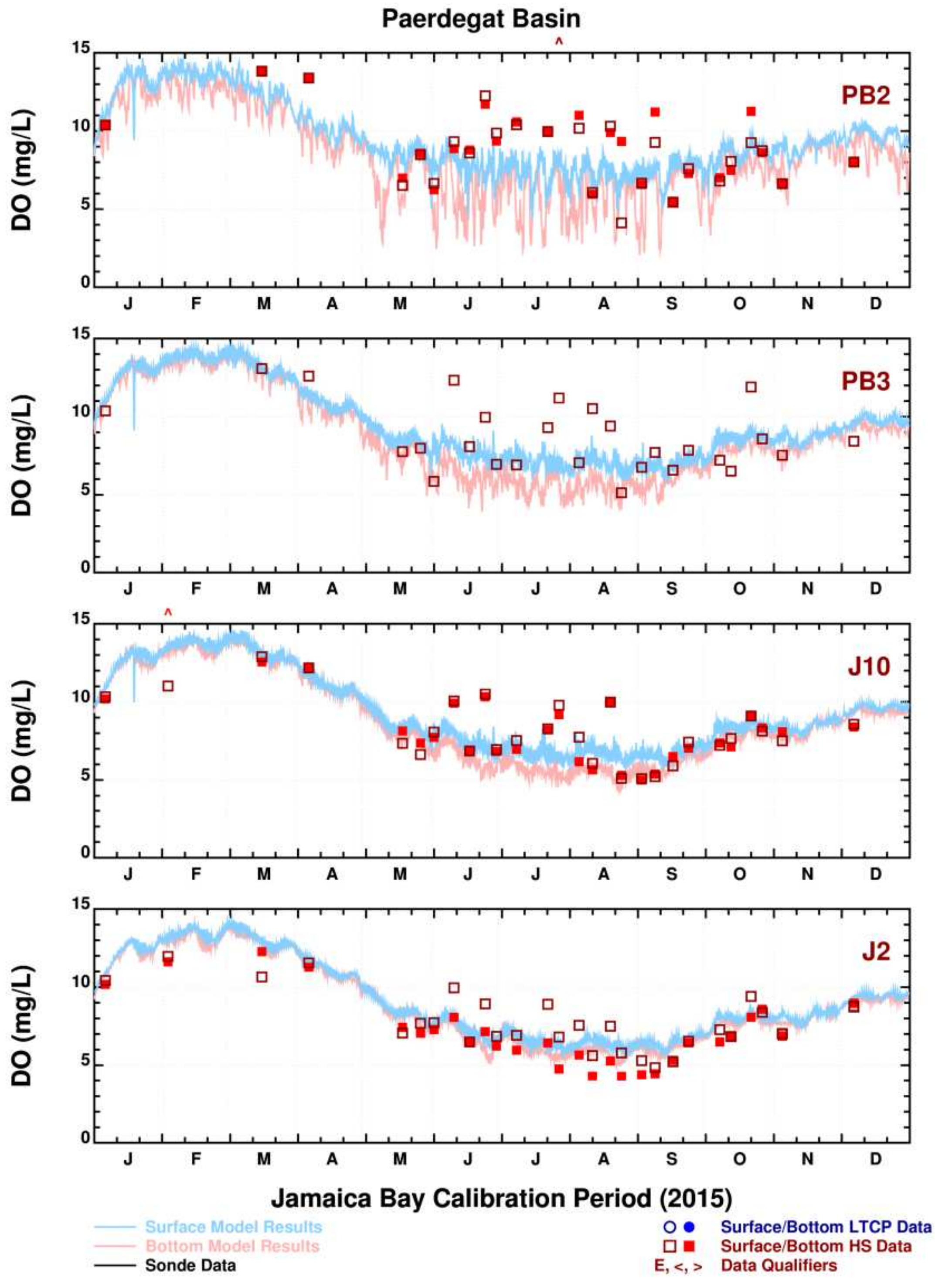

Figure 3-44. 2015 Model Versus Data Comparison for DO in Paerdegat Basin and Nearby Jamaica Bay Stations

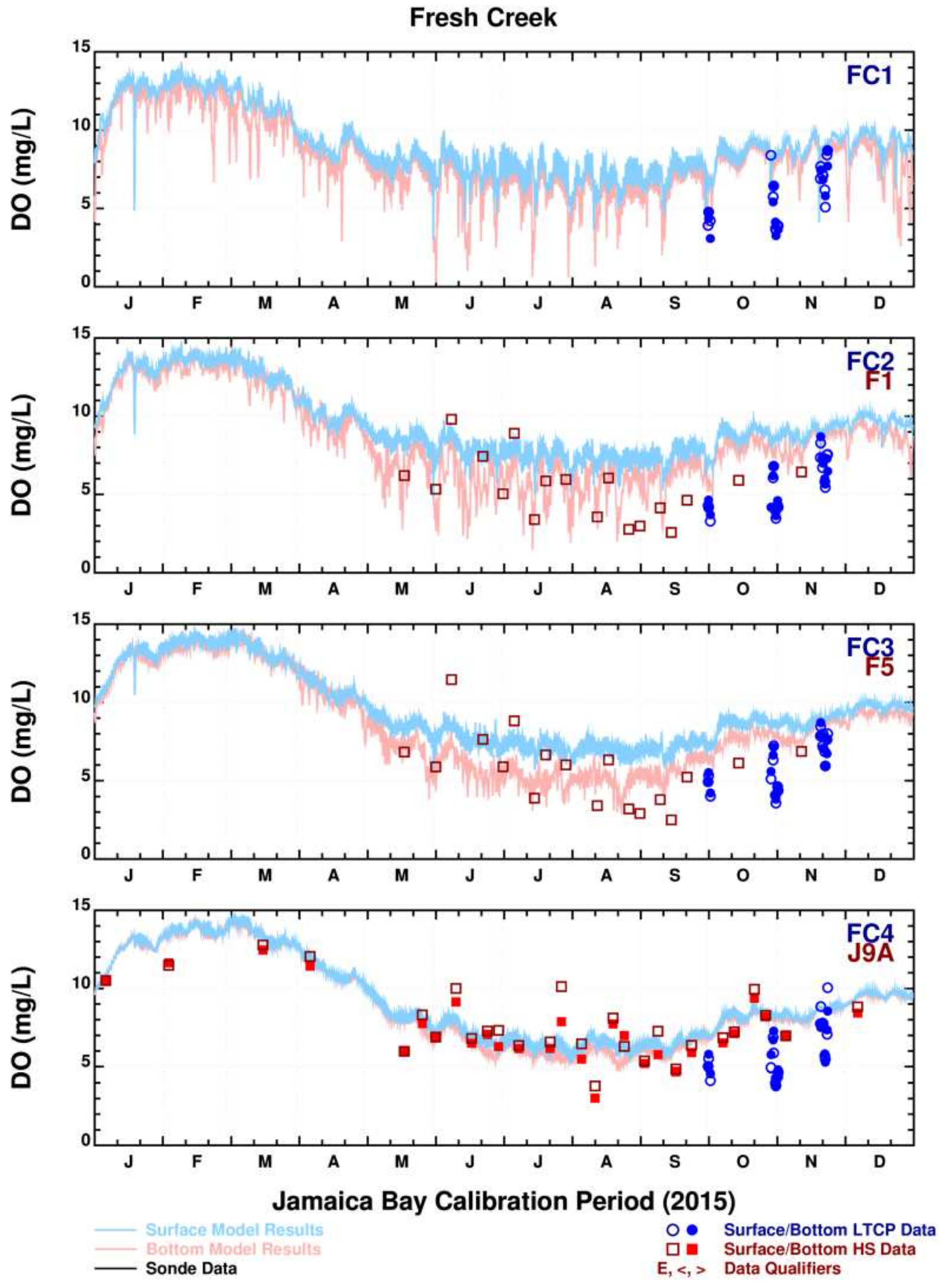

Figure 3-45. 2015 Model Versus Data Comparison for DO in Fresh Creek and Nearby Jamaica Bay Stations

N

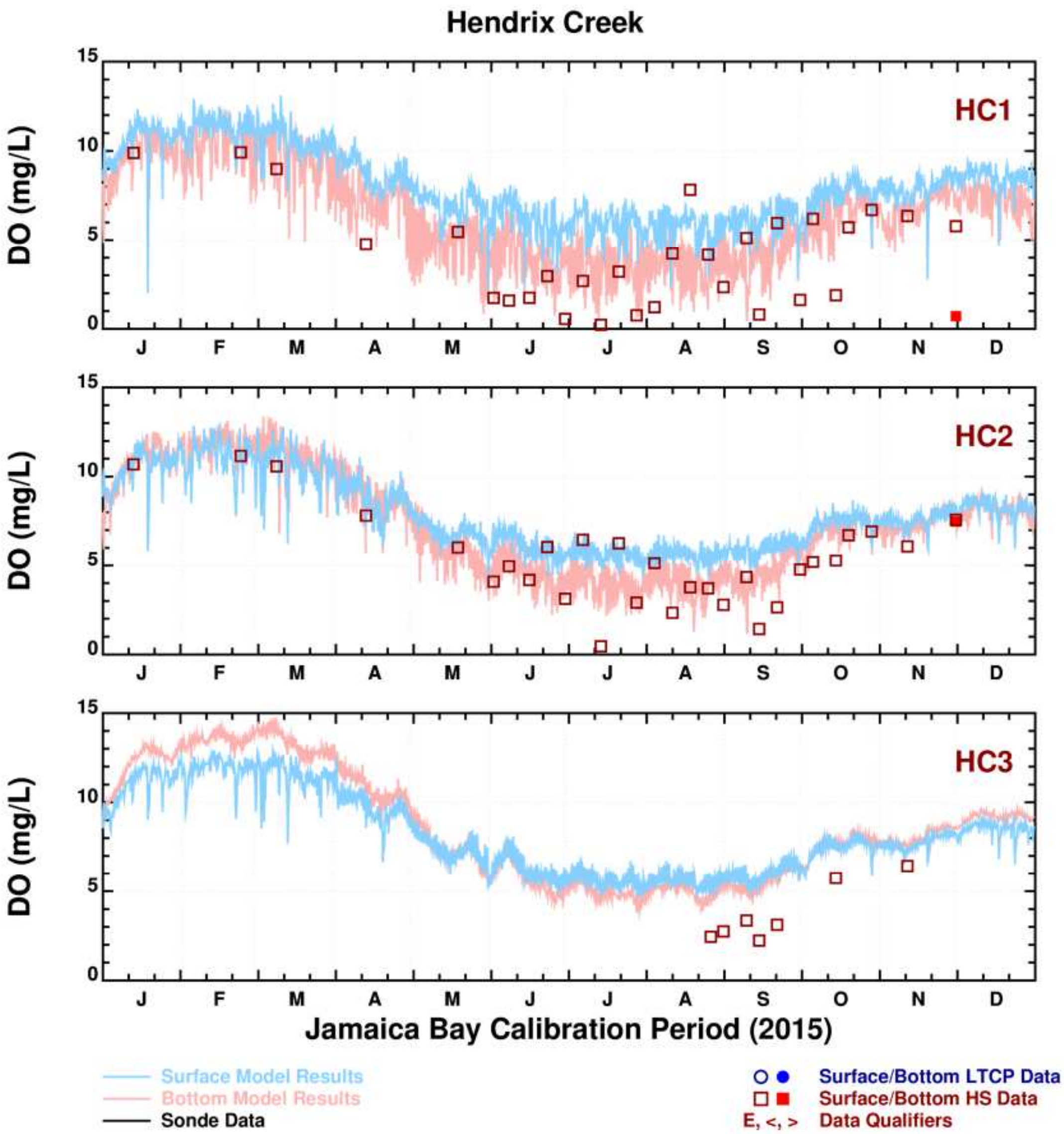

Figure 3-46. 2015 Model Versus Data Comparison for DO in Hendrix Creek

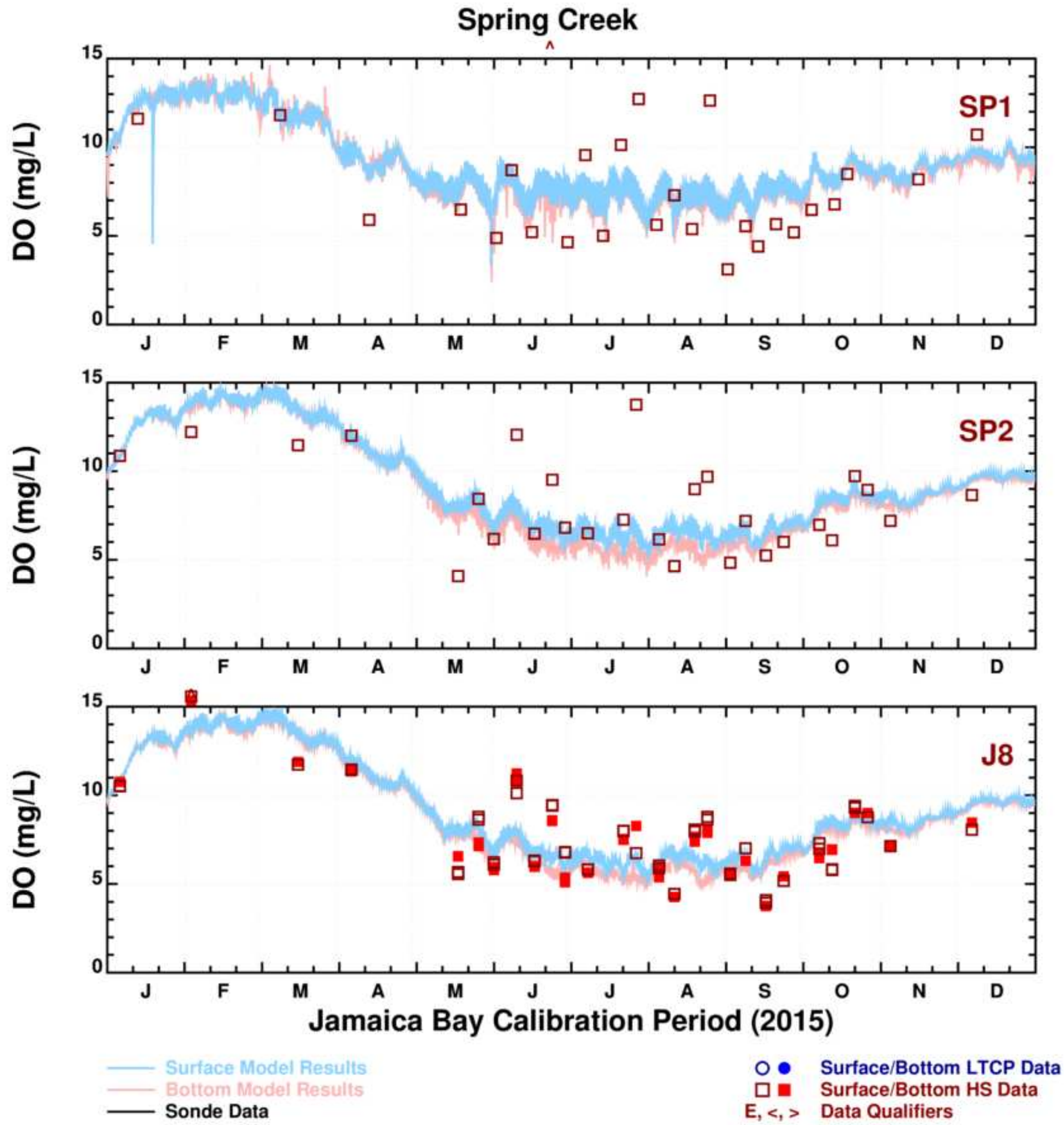

Figure 3-47. 2015 Model Versus Data Comparison for DO in Spring Creek and Nearby Jamaica Bay Stations

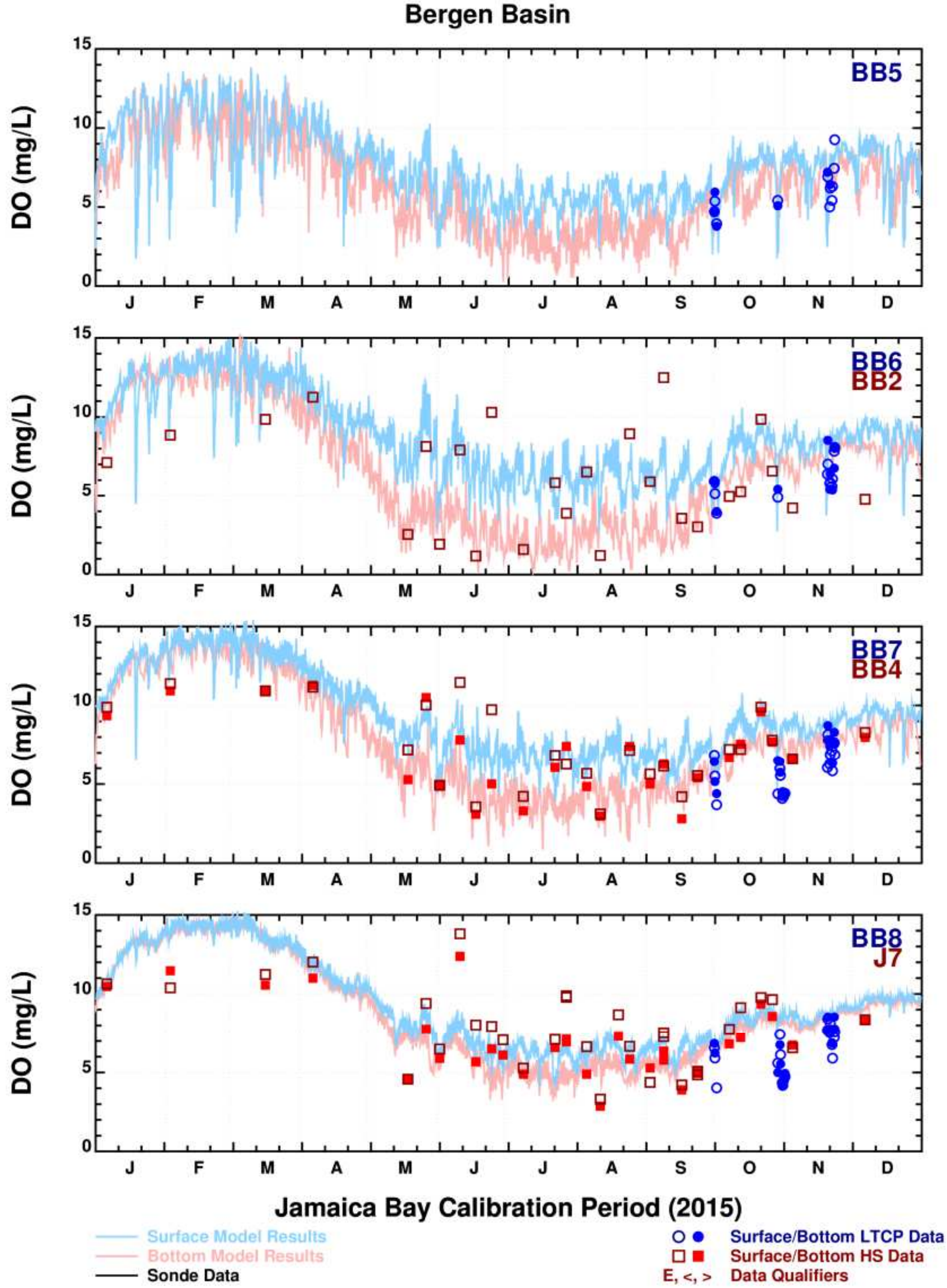

Figure 3-48. 2015 Model Versus Data Comparison for DO in Bergen Basin and Nearby Jamaica Bay Stations

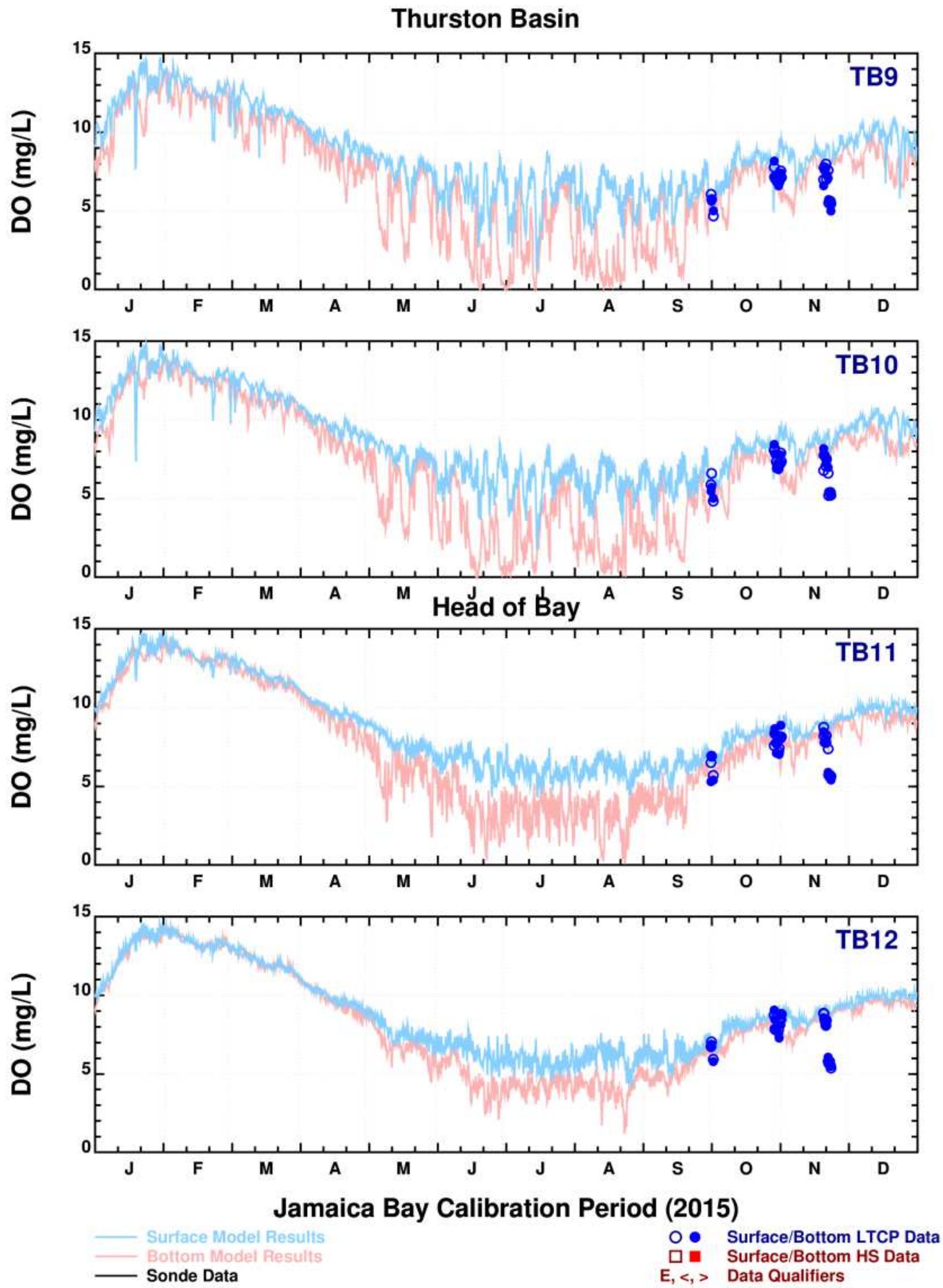

Figure 3-49. 2015 Model Versus Data Comparison for DO in Thurston Basin and Head of Bay

4.0 SUMMARY

The Coney Island, Rockaway, 26th Ward, and Jamaica IW sewer system models, and the JEM hydrodynamic and water quality models, were calibrated extensively as part of the development of the 2011 Waterbody Watershed Plan developed for Jamaica Bay. Since then, recalibration efforts on the Coney Island, Rockaway, 26th Ward, and Jamaica IW models as part of the citywide 2012 recalibration effort have improved the models. Similarly, resizing of the JEM model segmentation and modifying the bacteria kinetics has enhanced the JEM.

The calibration of the JEM to data collected during 2015 shows that the models reasonably reproduce the temperature, salinity, fecal coliform, *Enterococci* and DO observed within Jamaica Bay and its tributaries. The models described herein were used in developing the water quality projections for the baseline and future conditions assessment described in the Jamaica Bay and Tributaries CSO Long Term Control Plan.

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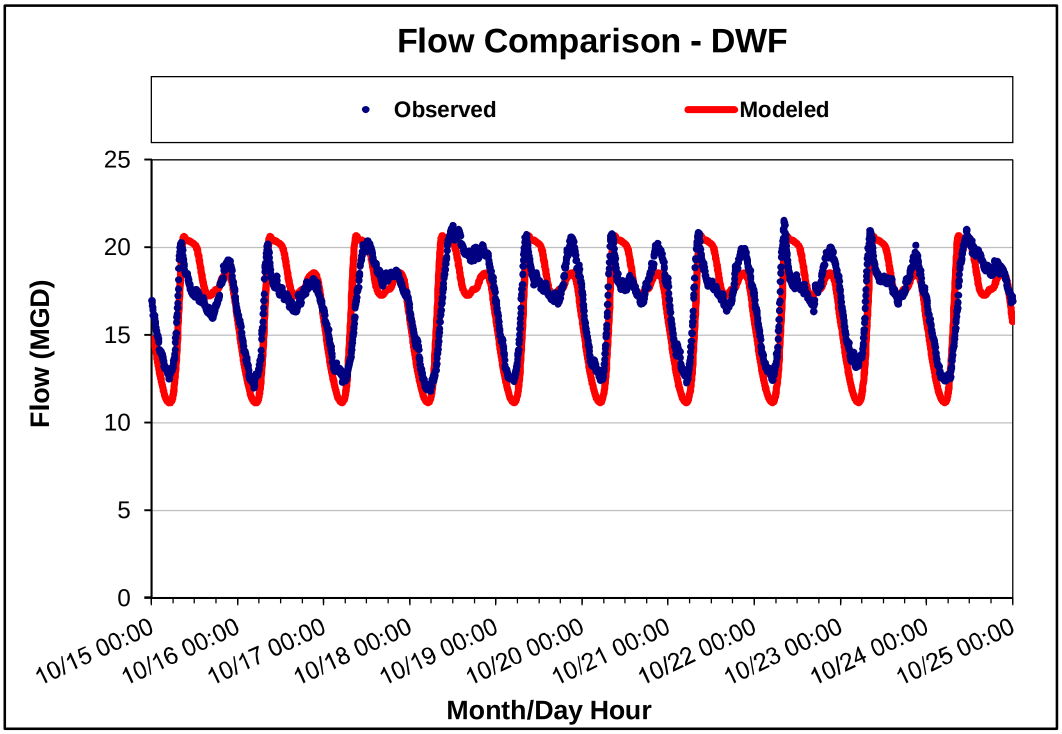
6.0 GLOSSARY

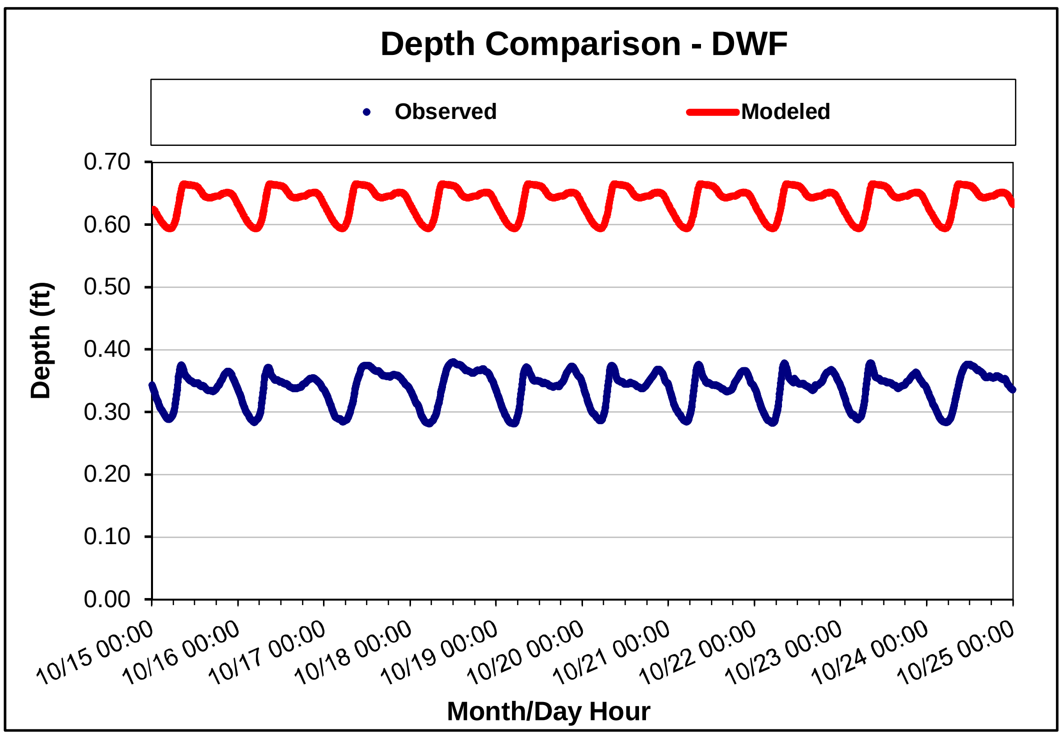
BOD:	Biochemical Oxygen Demand
CPK:	Central Park
CSO:	Combined Sewer Overflow
DCIA:	Directly Connected Impervious Areas
DCP:	New York City Department of City Planning
DEC:	New York State Department of Environmental Conservation
DEP:	New York City Department of Environmental Protection
DO:	Dissolved Oxygen
ET:	Evapotranspiration
EWR:	Newark Liberty International Airport
FSAP:	Field Sampling and Analysis Plan
GIS:	Geographical Information System
in.:	Abbreviation for “Inches”
In/hr	Abbreviation for “Inches per Hour”
IW:	InfoWorks CS™
JFK:	John F. Kennedy International Airport
LGA:	LaGuardia Airport
LTCP:	Long Term Control Plan
NOAA:	National Oceanic and Atmospheric Administration
NRCC	Northeast Regional Climate Center
NYC:	New York City
NYS:	New York State
SWEM:	System-Wide Eutrophication Model
WaPUG:	Wastewater Planning Users Group
WWFP:	Waterbody/Watershed Facility Plan
WWTP:	Wastewater Treatment Plant

APPENDIX A

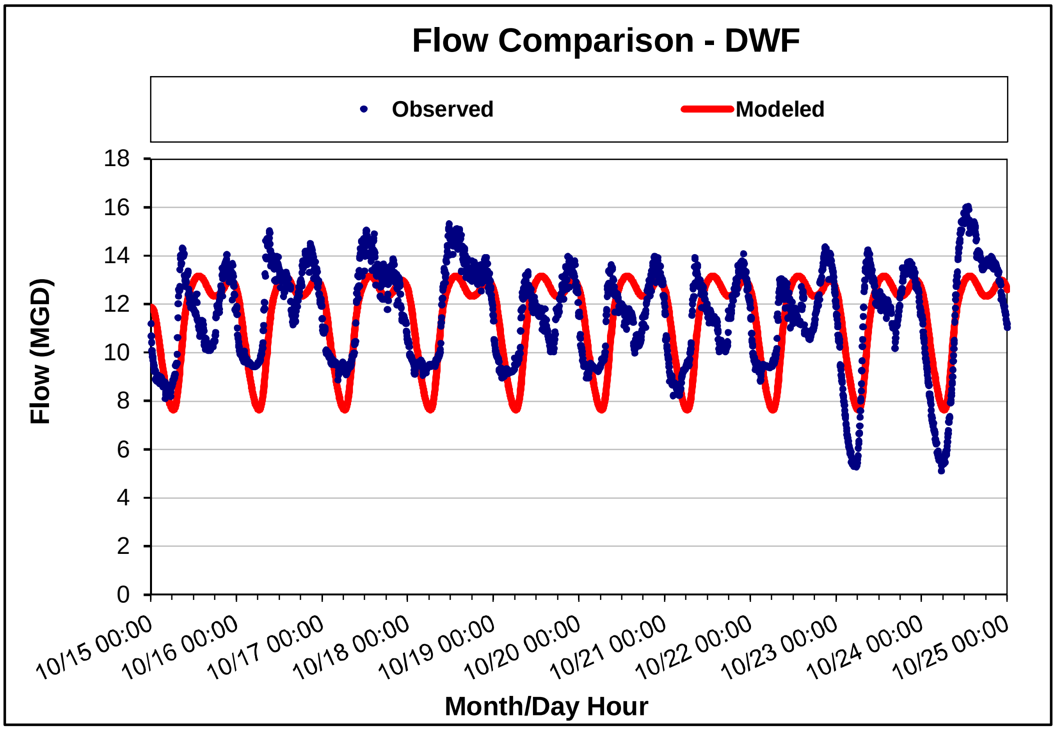
INFOWORKS HYDROGRAPHS AND GOODNESS-OF-FIT FIGURES

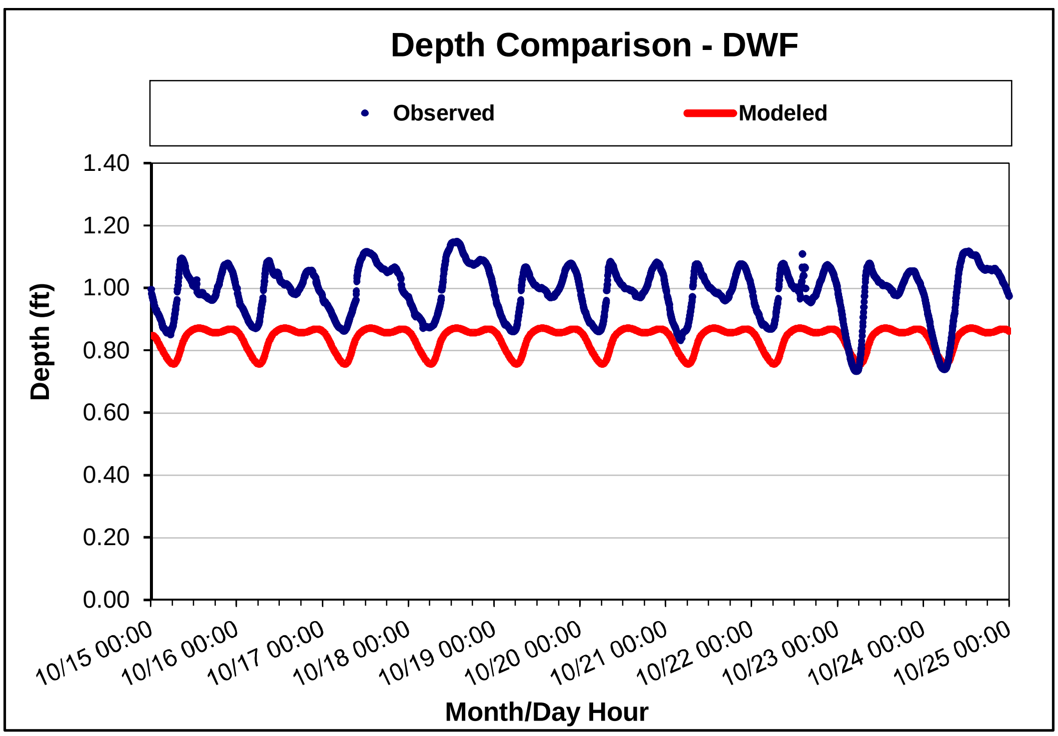
METER 26W-003 M1/M2 INCOMING FLOW





METER JAM-003M1 (REG. JA-03) INCOMING FLOW





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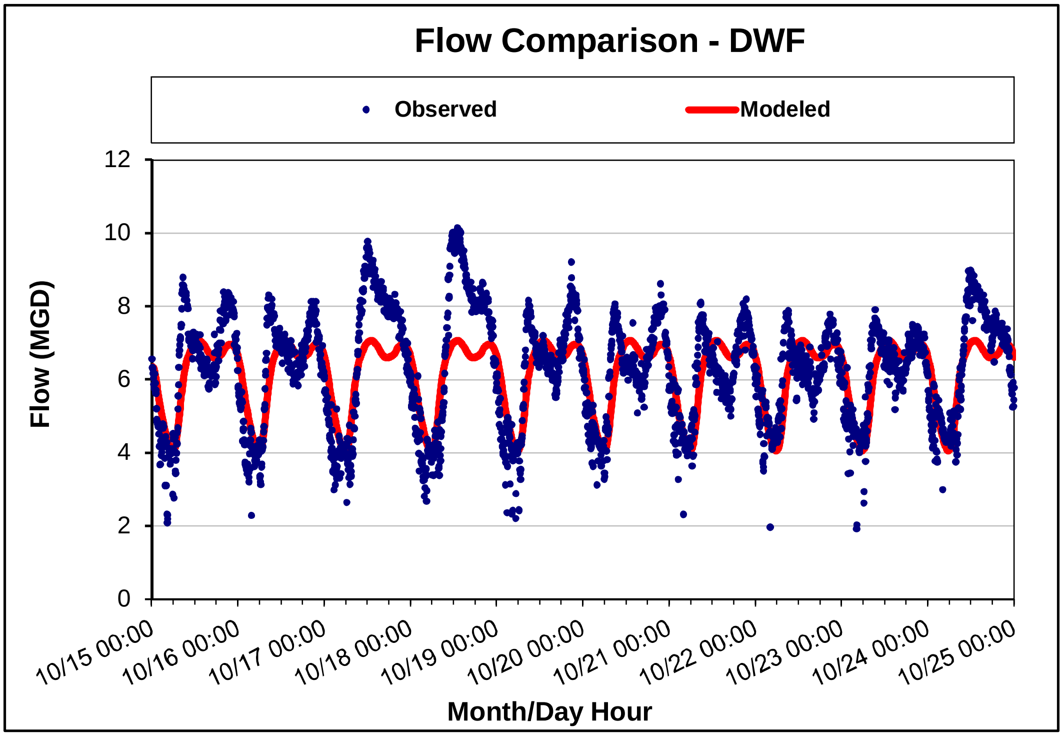
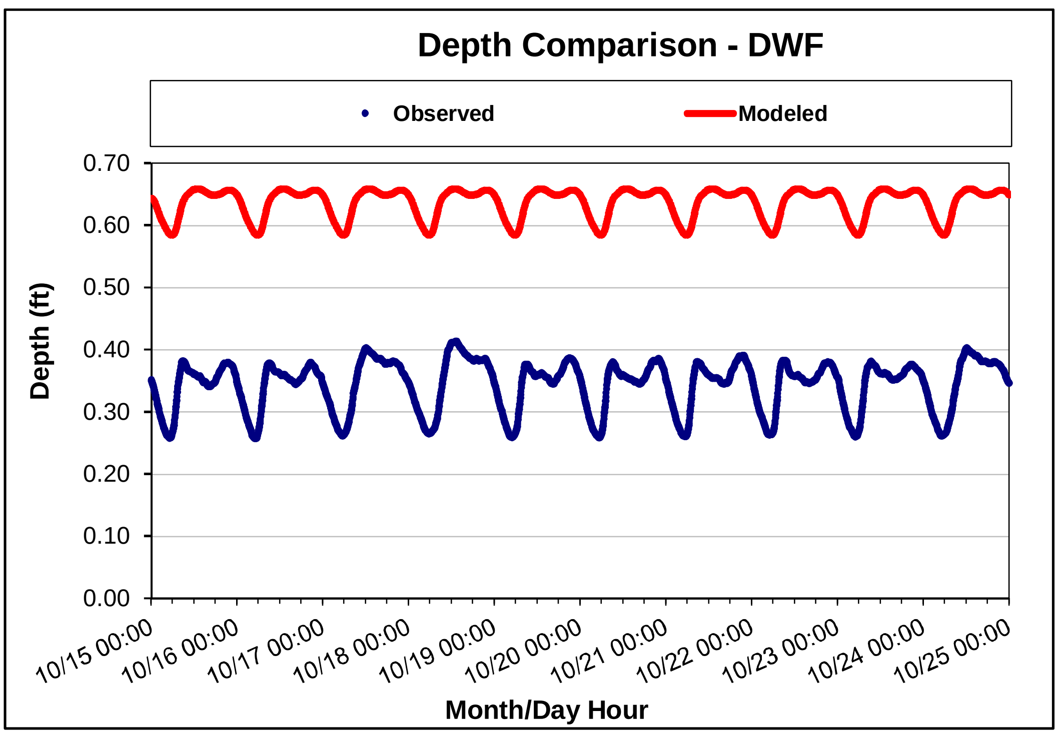
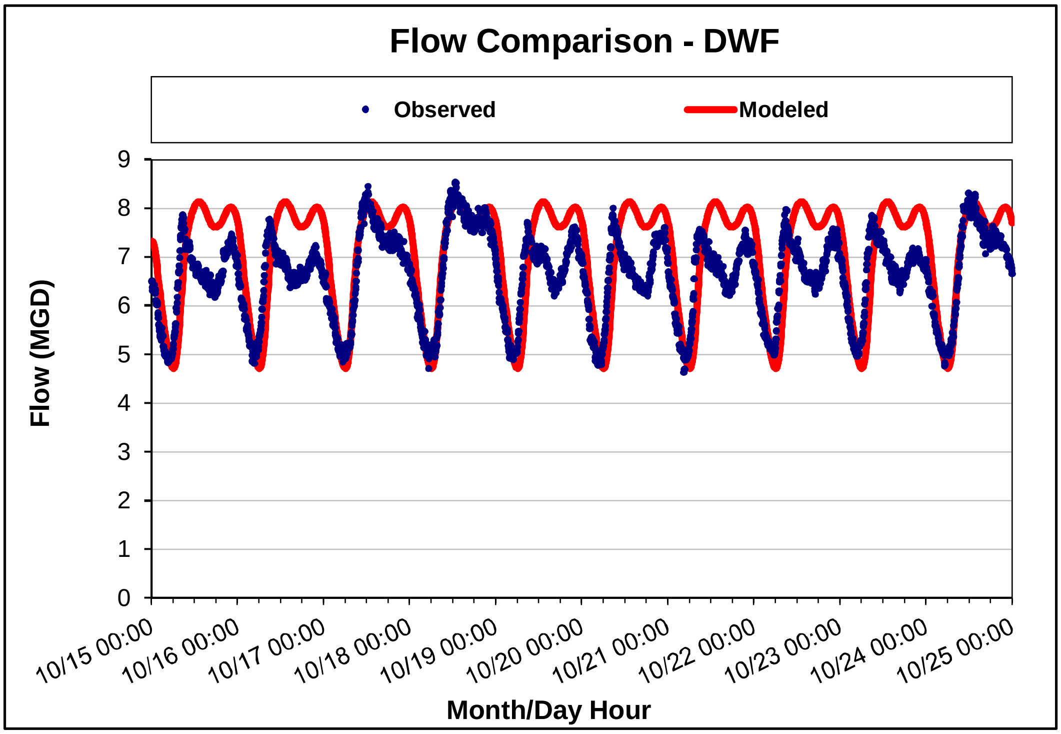
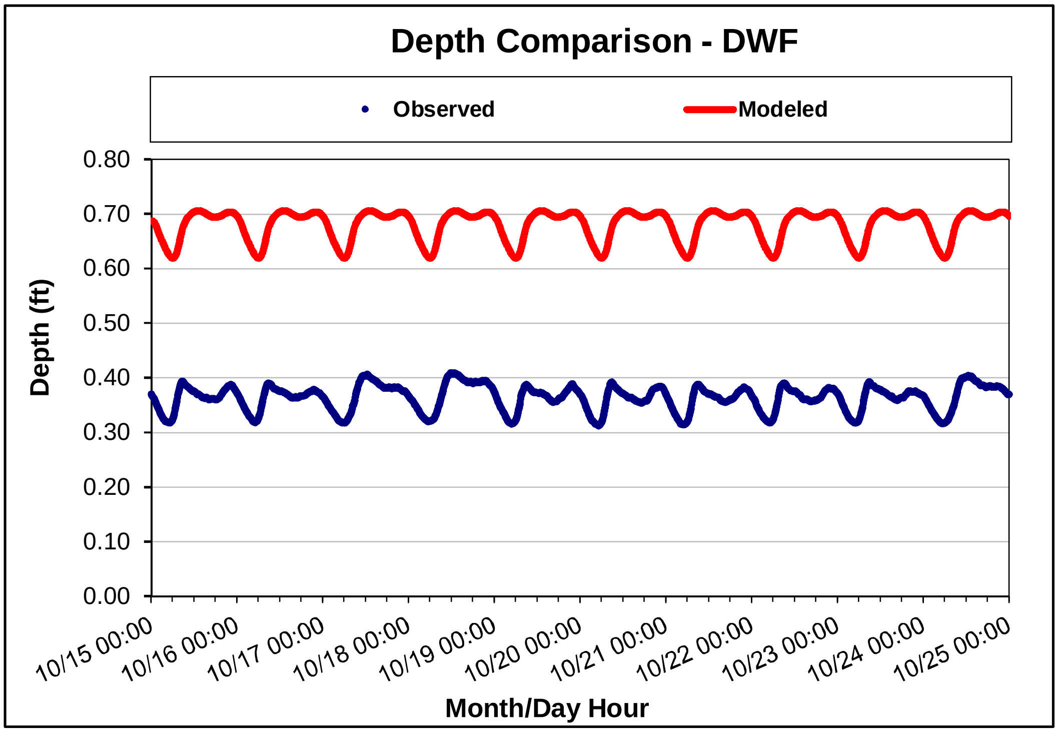




METER JAM-005M1 (REG. JA-06) INCOMING FLOW





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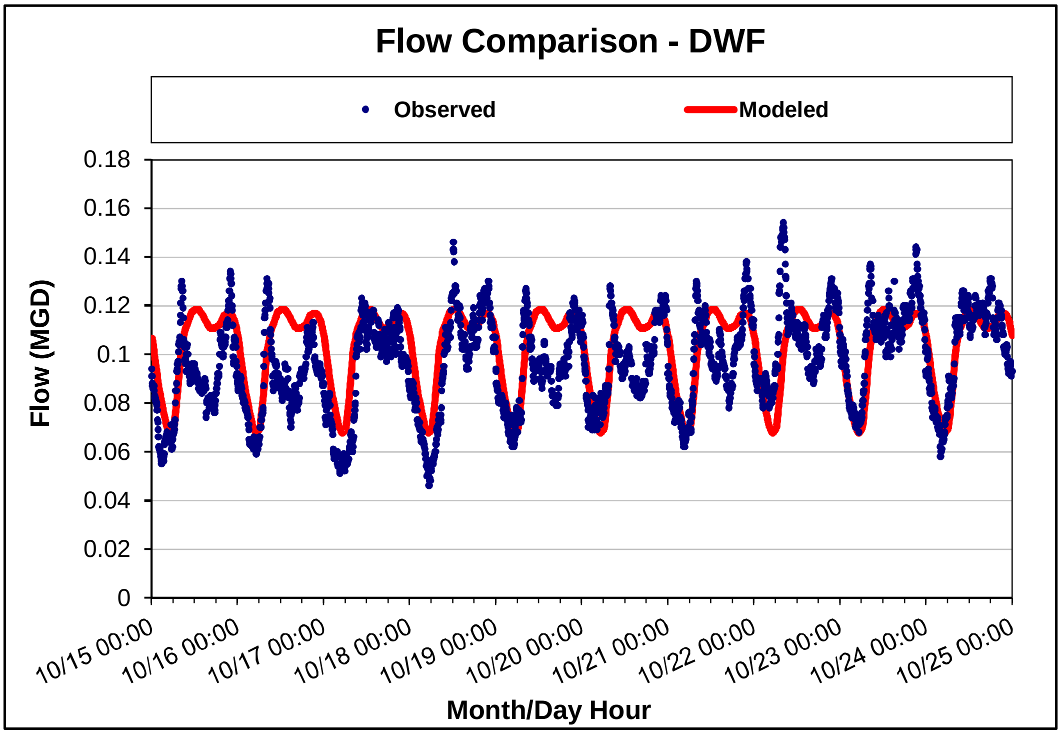
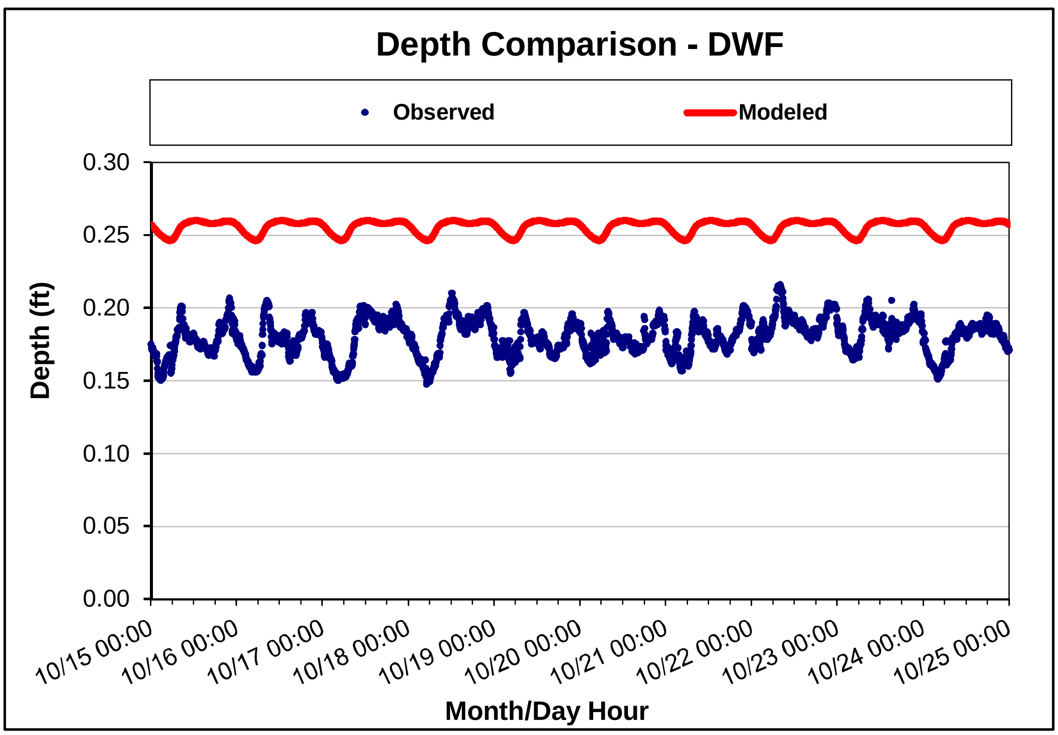
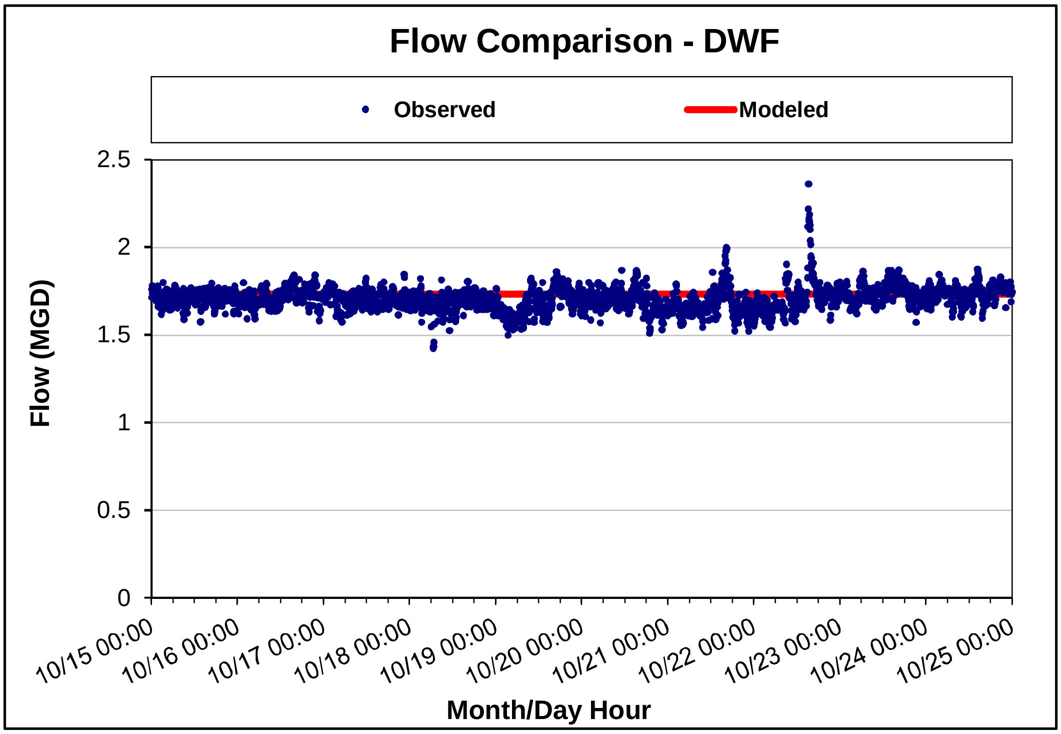
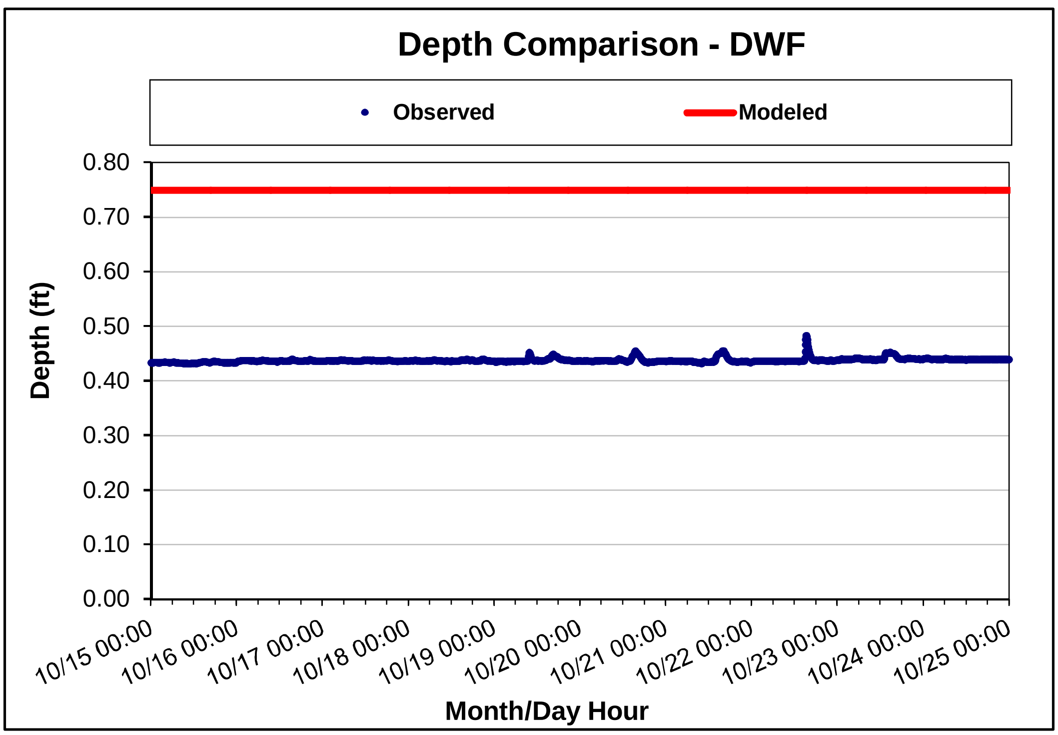




AECOM with Hazen

METER JAM-007M1P1 (REG. JA-07) INCOMING FLOW





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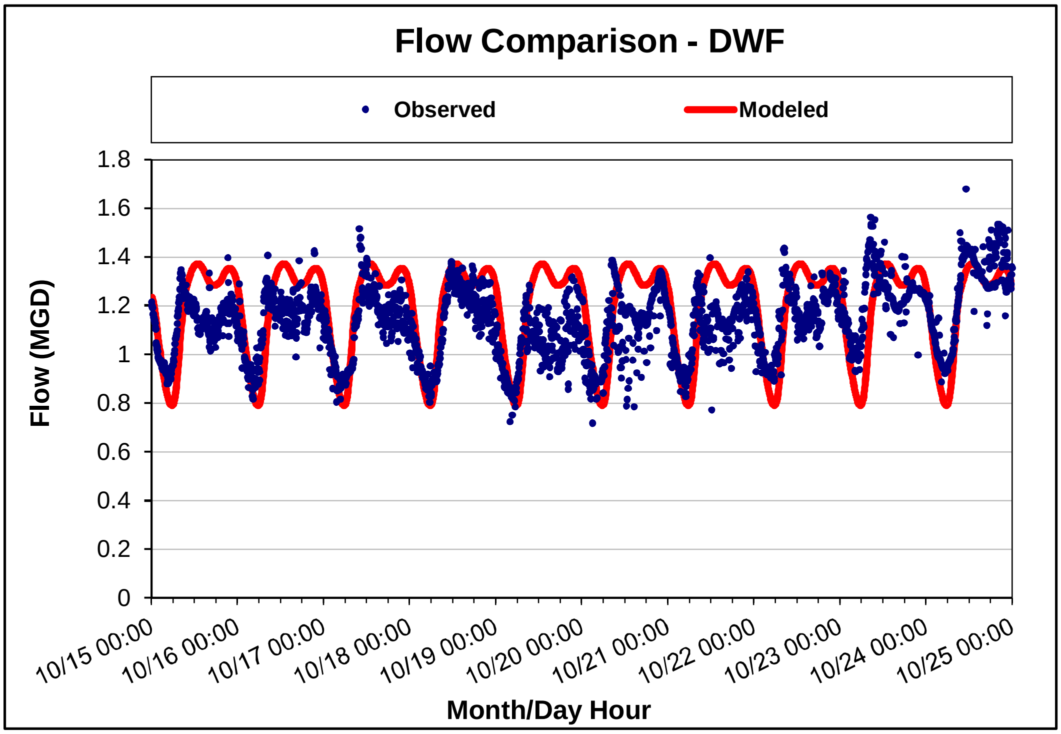
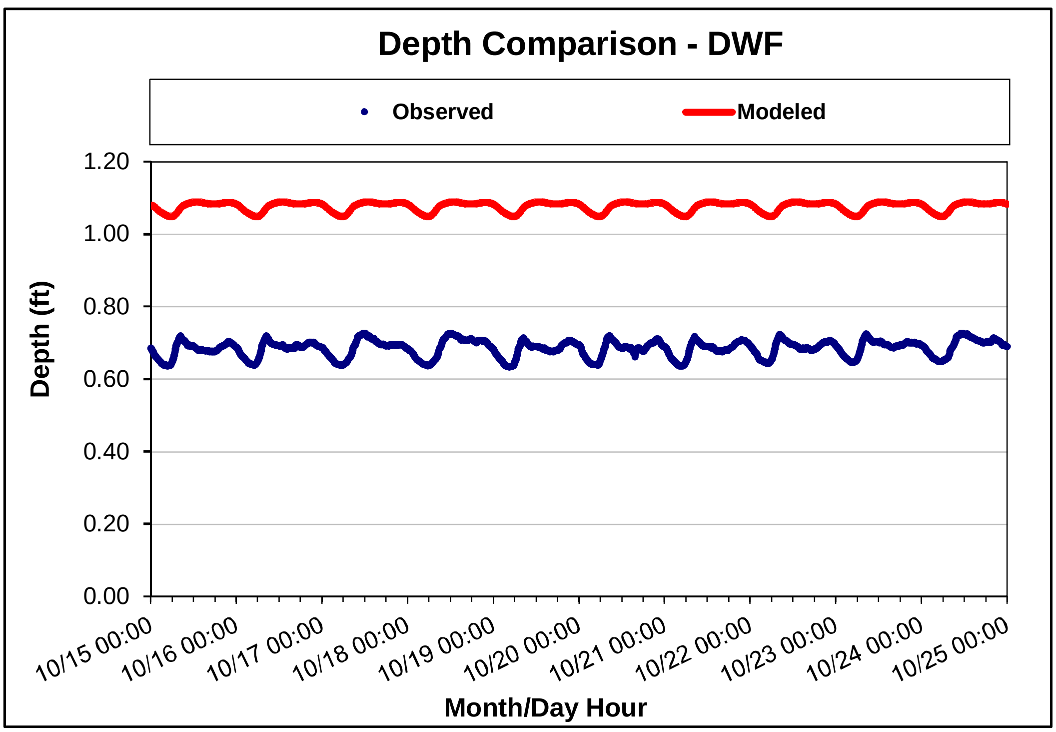
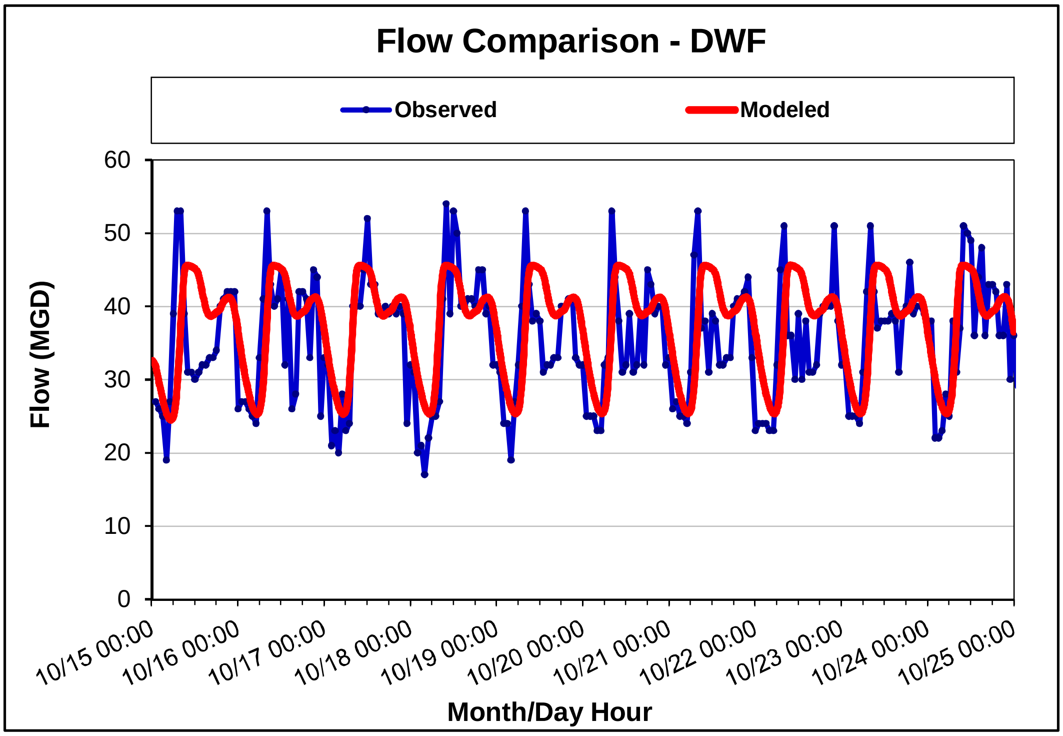


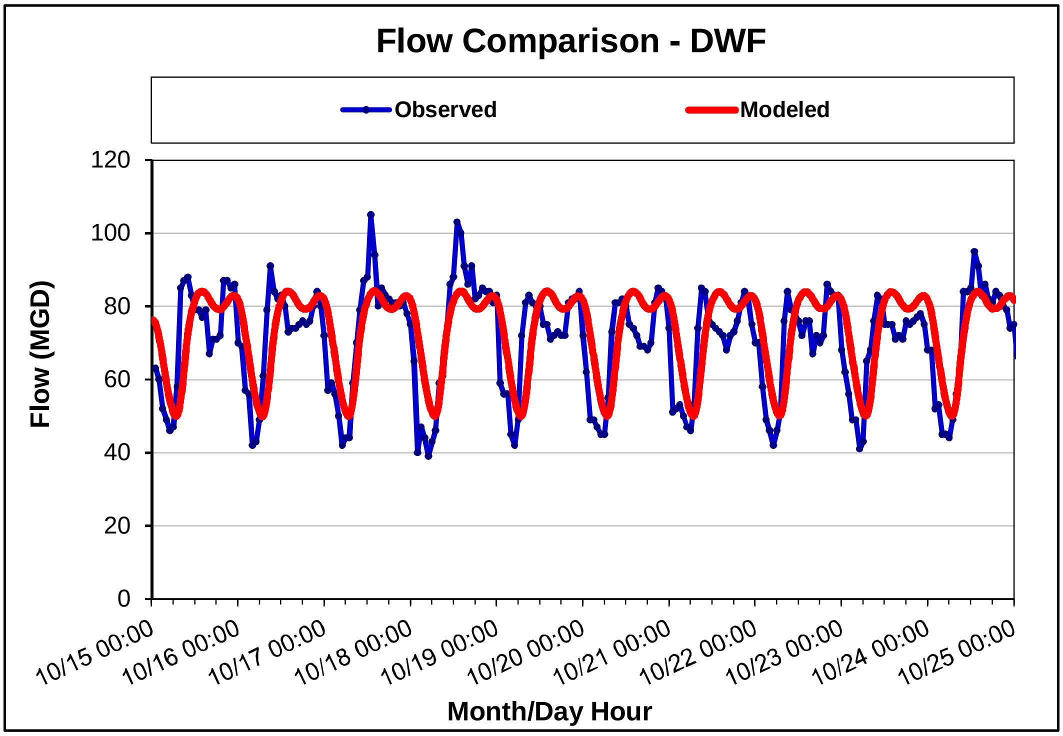


AECOM with Hazen

26TH WARD WWTP FLOW



JAMAICA WWTP FLOW

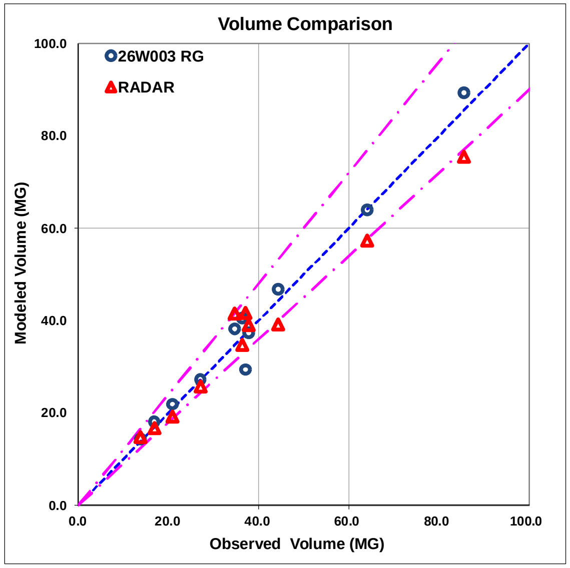


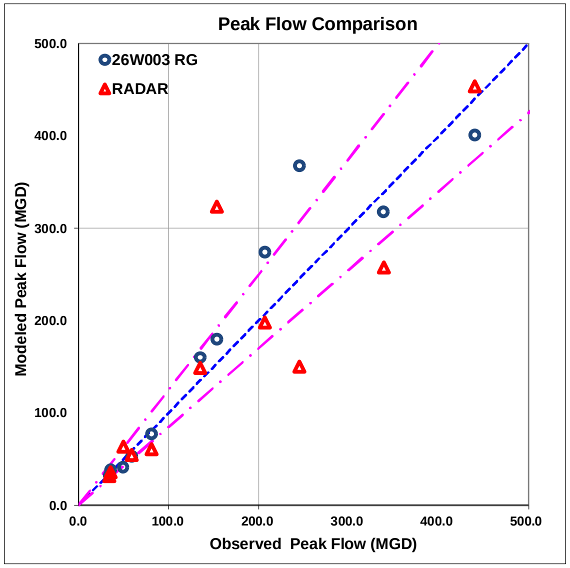
AECOM with Hazen

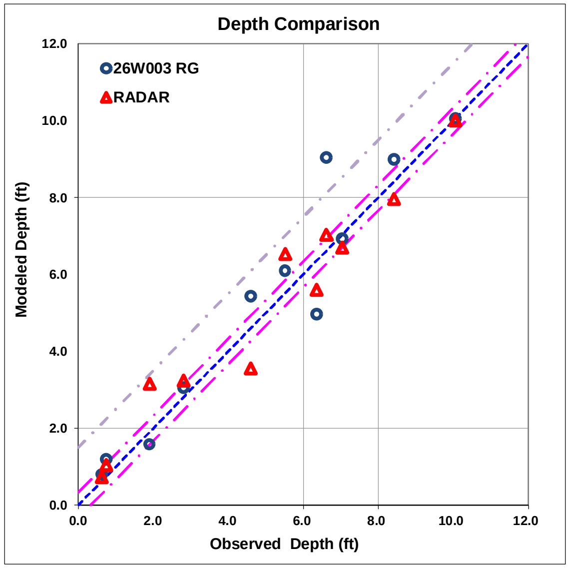
APPENDIX B

WaPUG GOODNESS-OF-FIT FIGURES

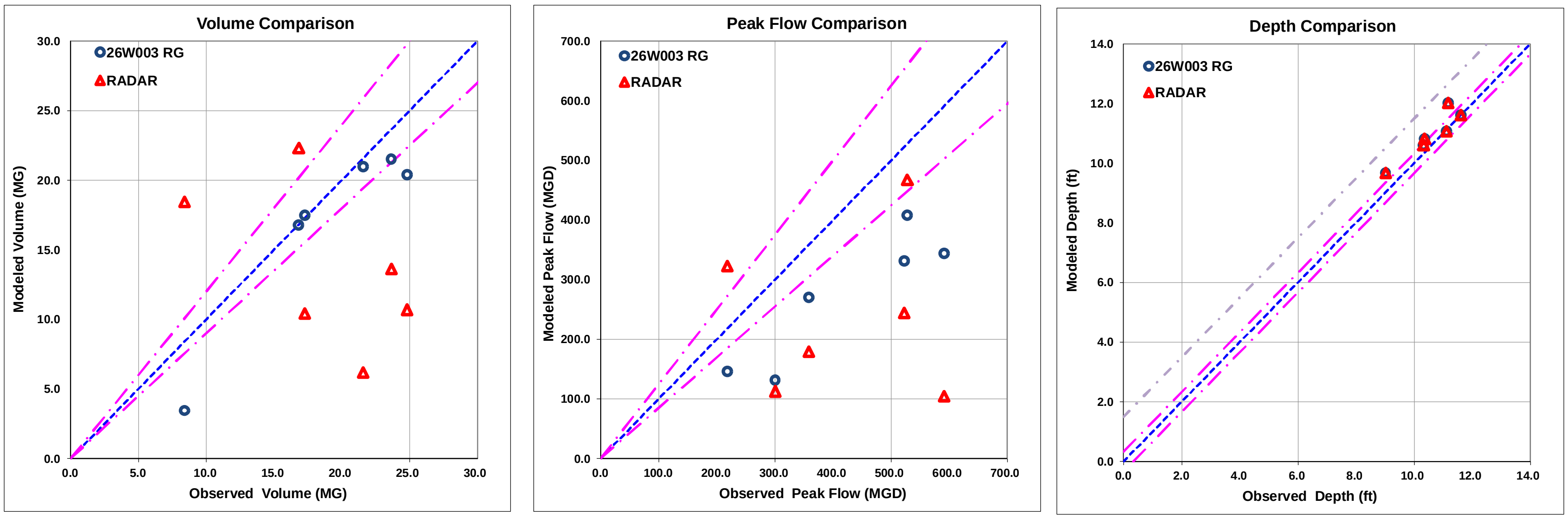
METER 26W-003 M1/M2 INCOMING FLOW



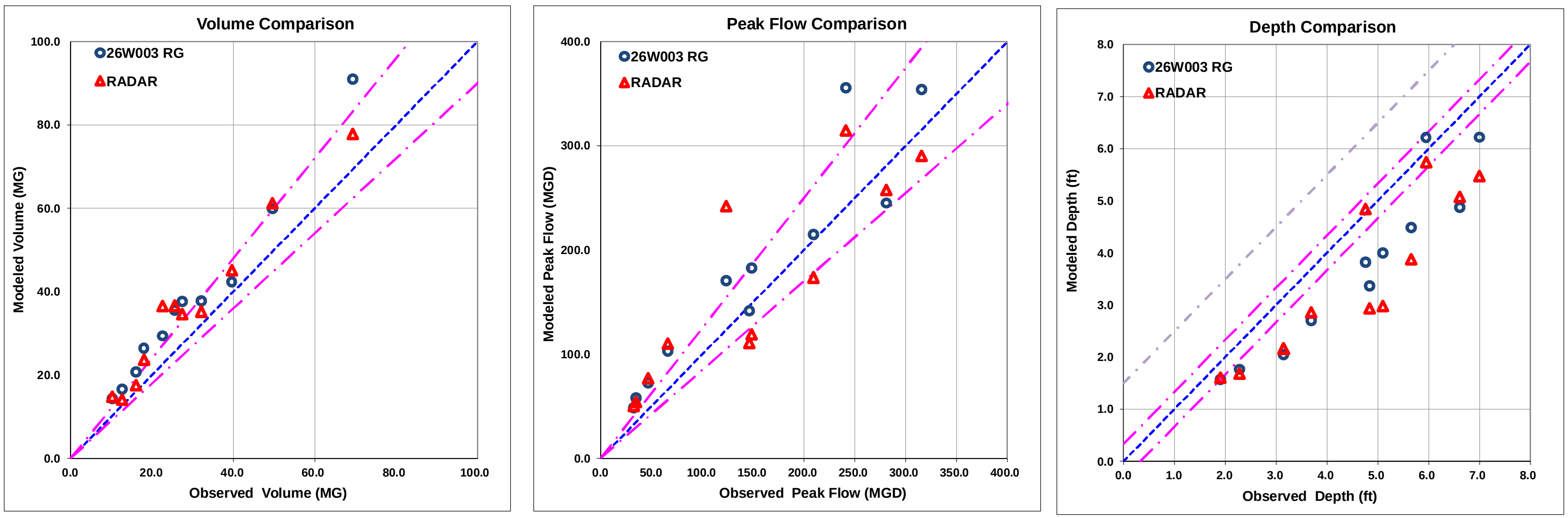




METER 26W-003 M3/M4 OUTGOING FLOW

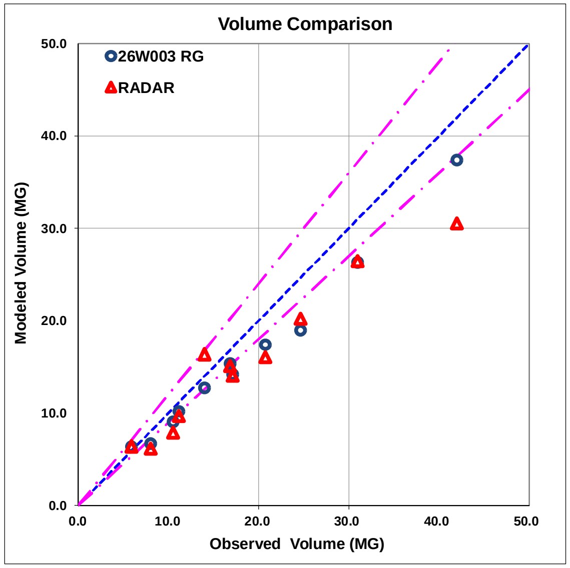


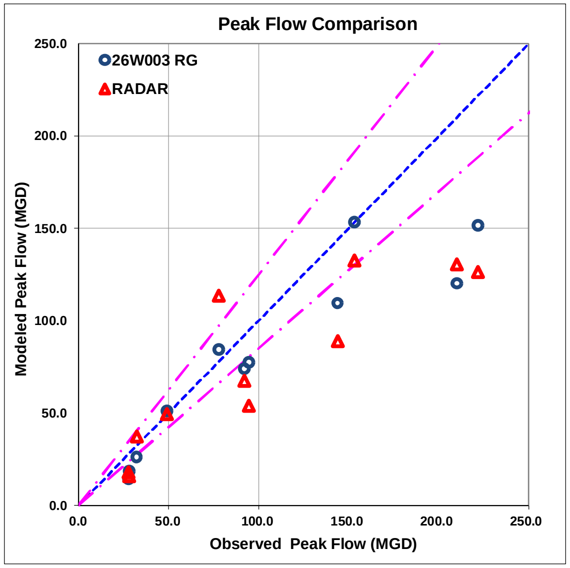
METER JAM-003M1 (REG. JA-03) INCOMING FLOW

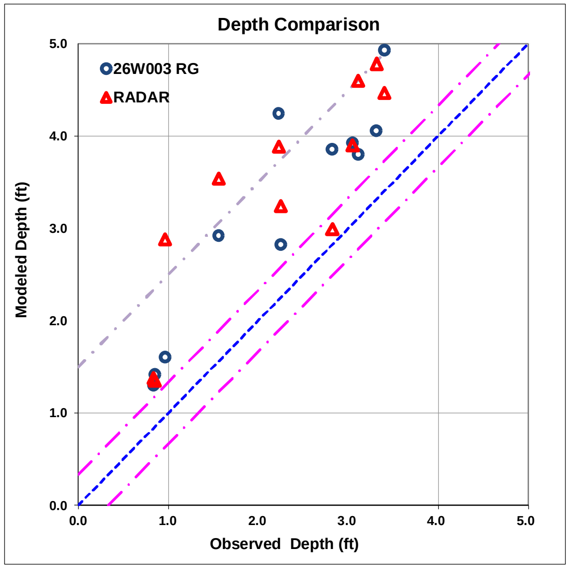


AECOM with Hazen

METER JAM-003A.M1 (REG. JA-14) INCOMING FLOW

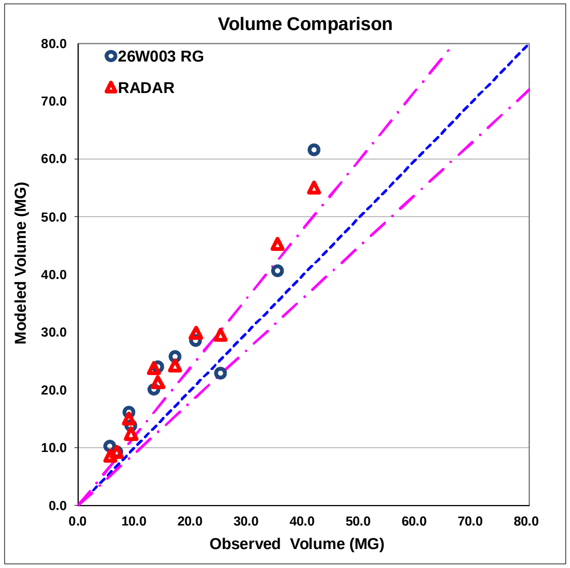


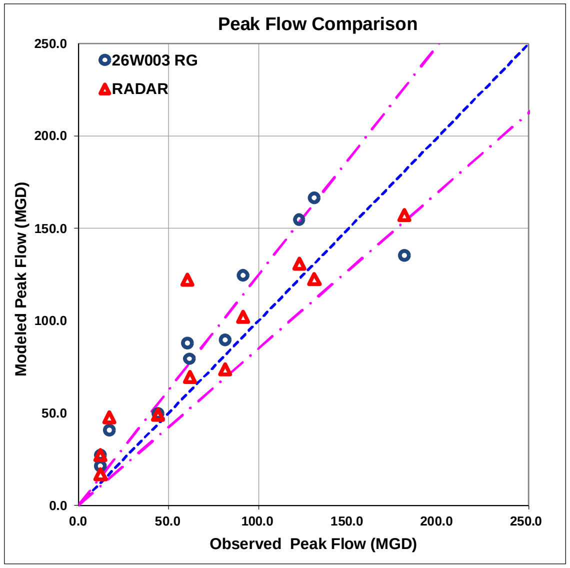


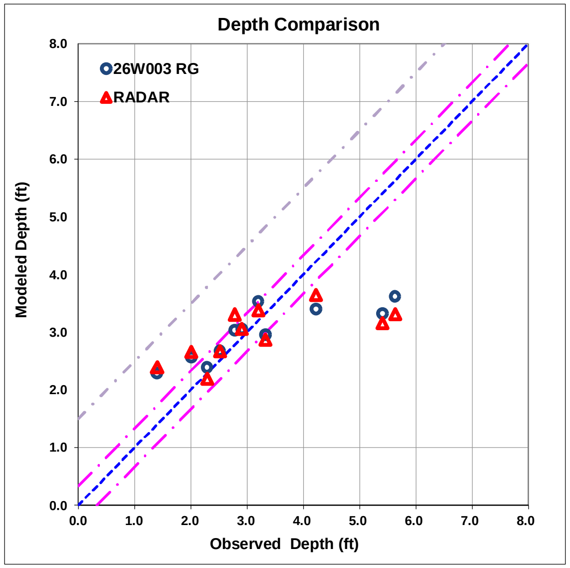


AECOM
with Hazen

METER JAM-005.M1 (REG. JA-06) INCOMING FLOW







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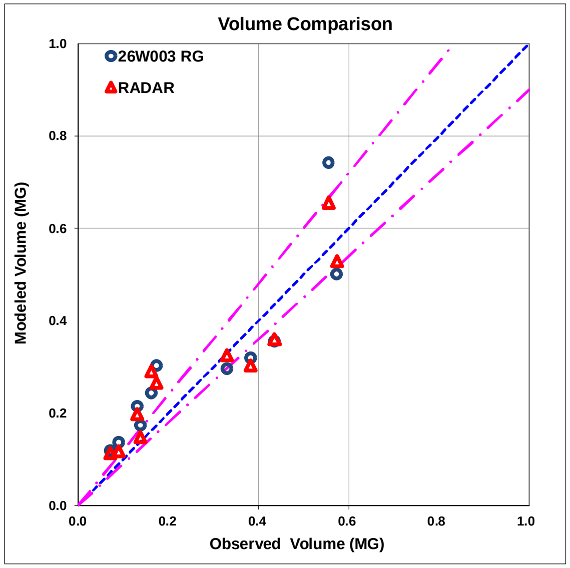
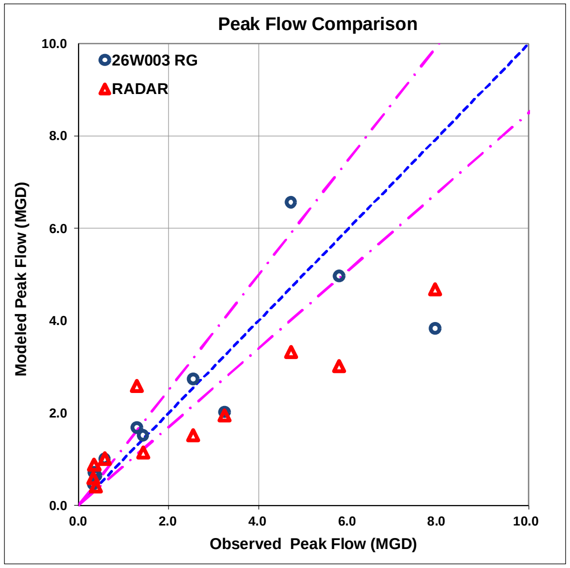
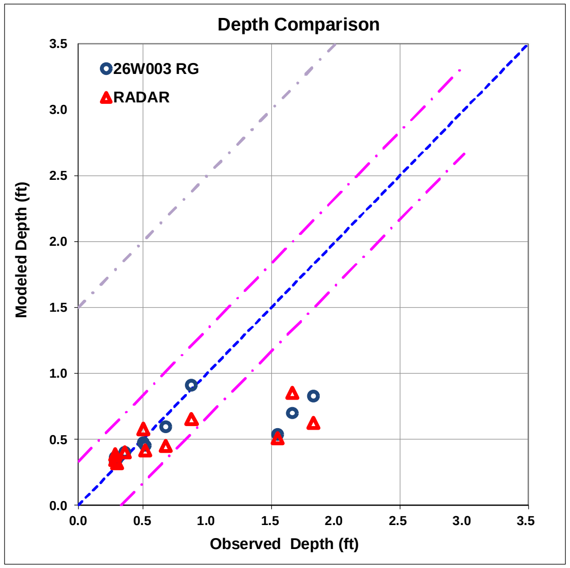
with Hazen

METER JAM-005.M2 (REG. JA-06) INCOMING FLOW

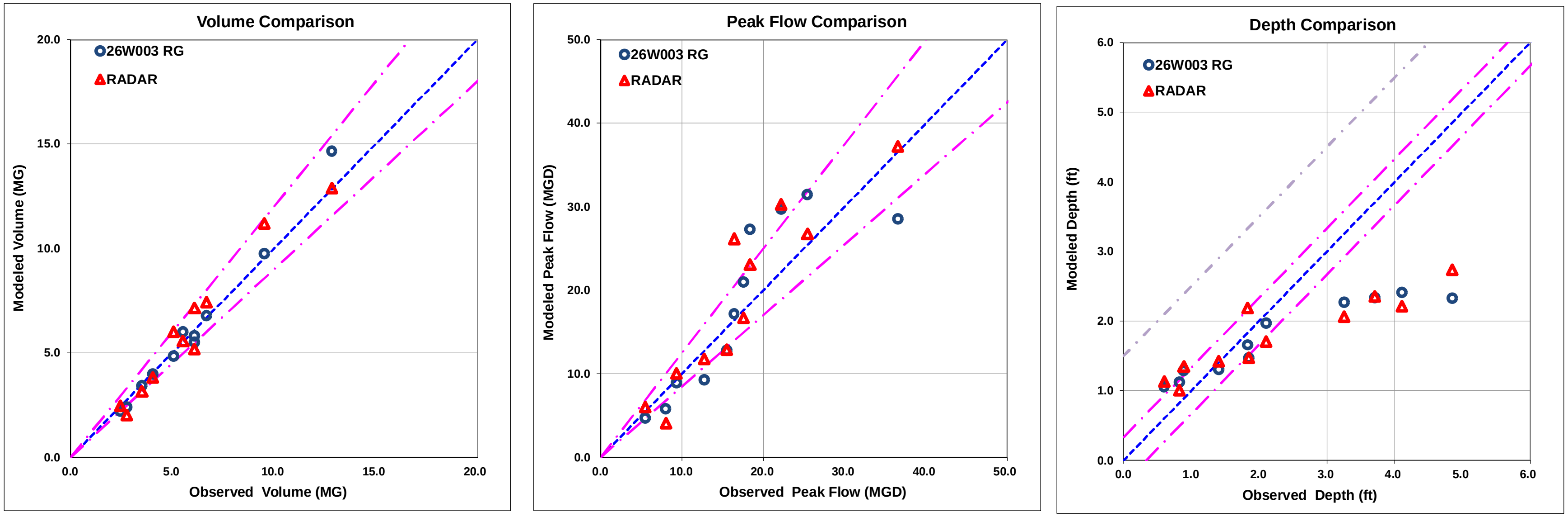






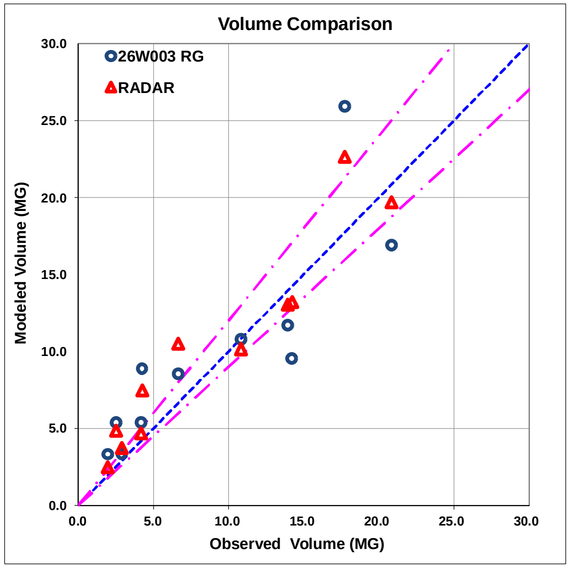
AECOM
with Hazen

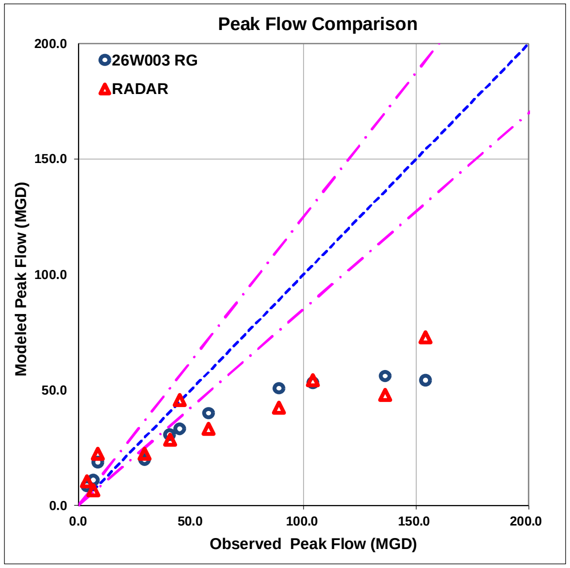
METER JAM-007.M1P1 (REG. JA-07) INCOMING FLOW

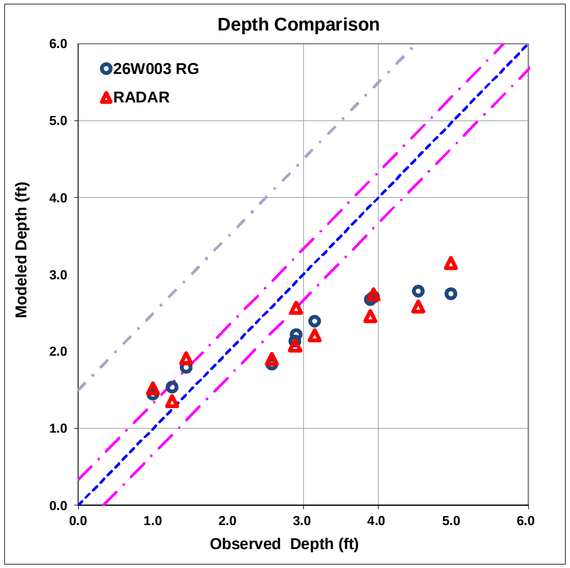


AECOM with Hazen

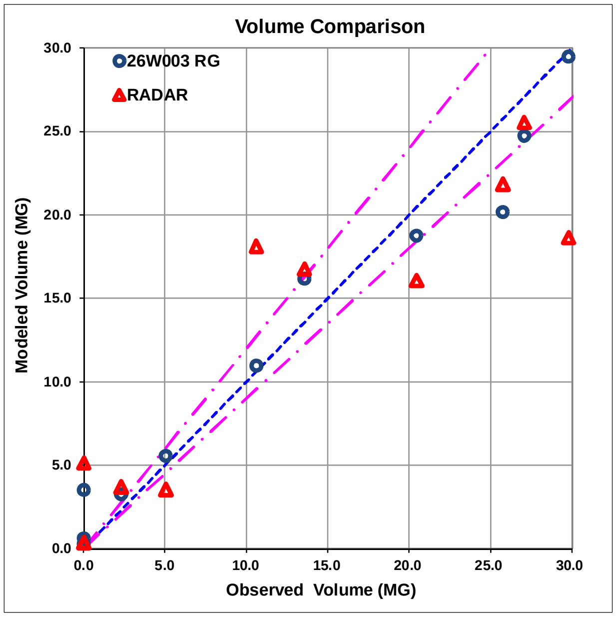
METER JAM-007.M1P2 (REG. JA-07) INCOMING FLOW

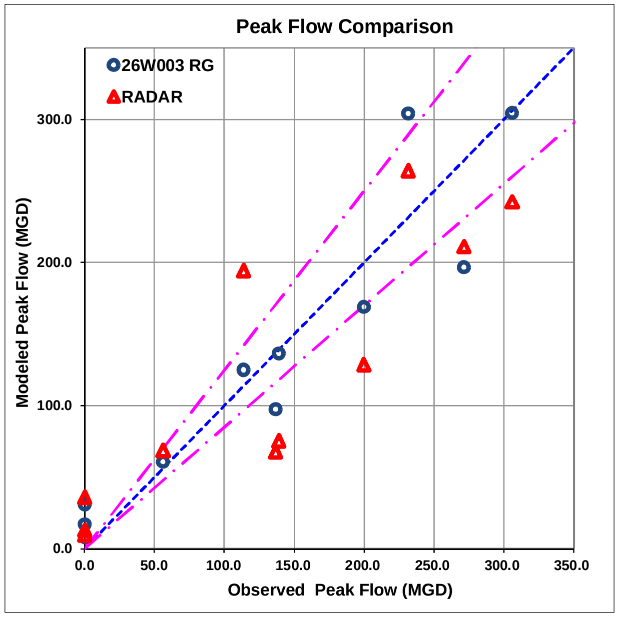




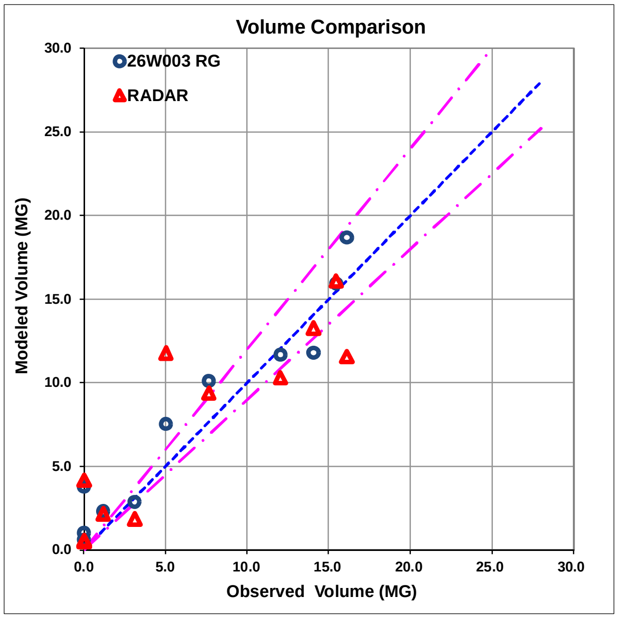


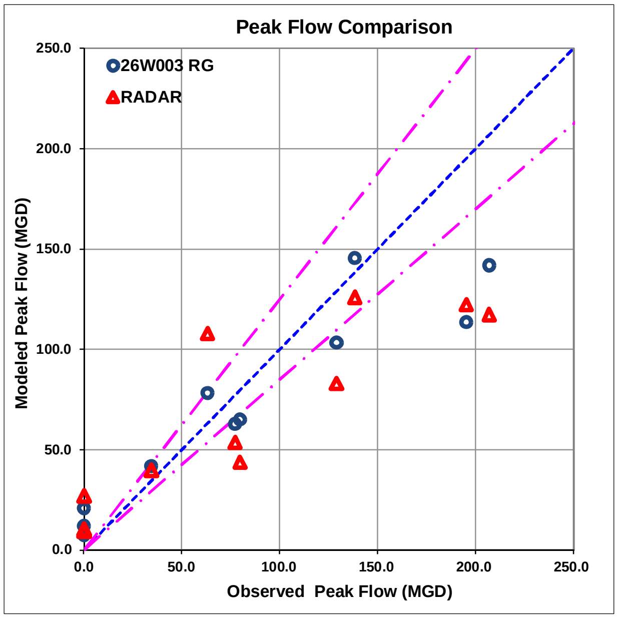
METER JAM-003 (REG. JA-03) CALCULATED CSO





METER JAM-003A (REG. JA-14) CALCULATED CSO





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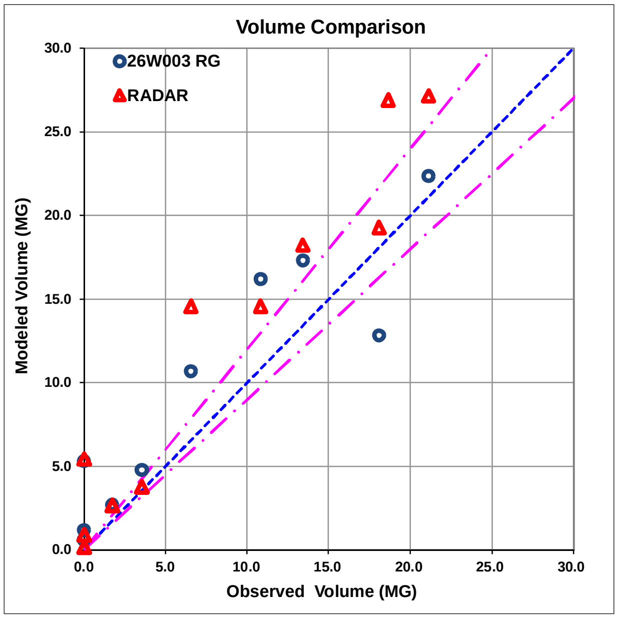
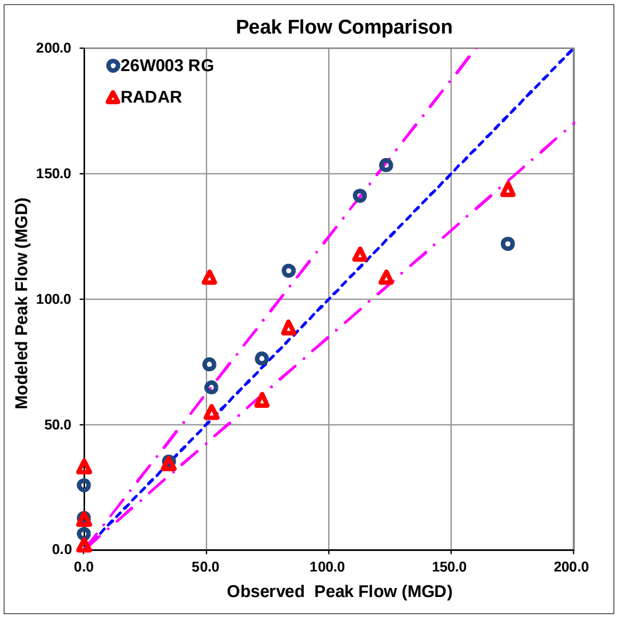


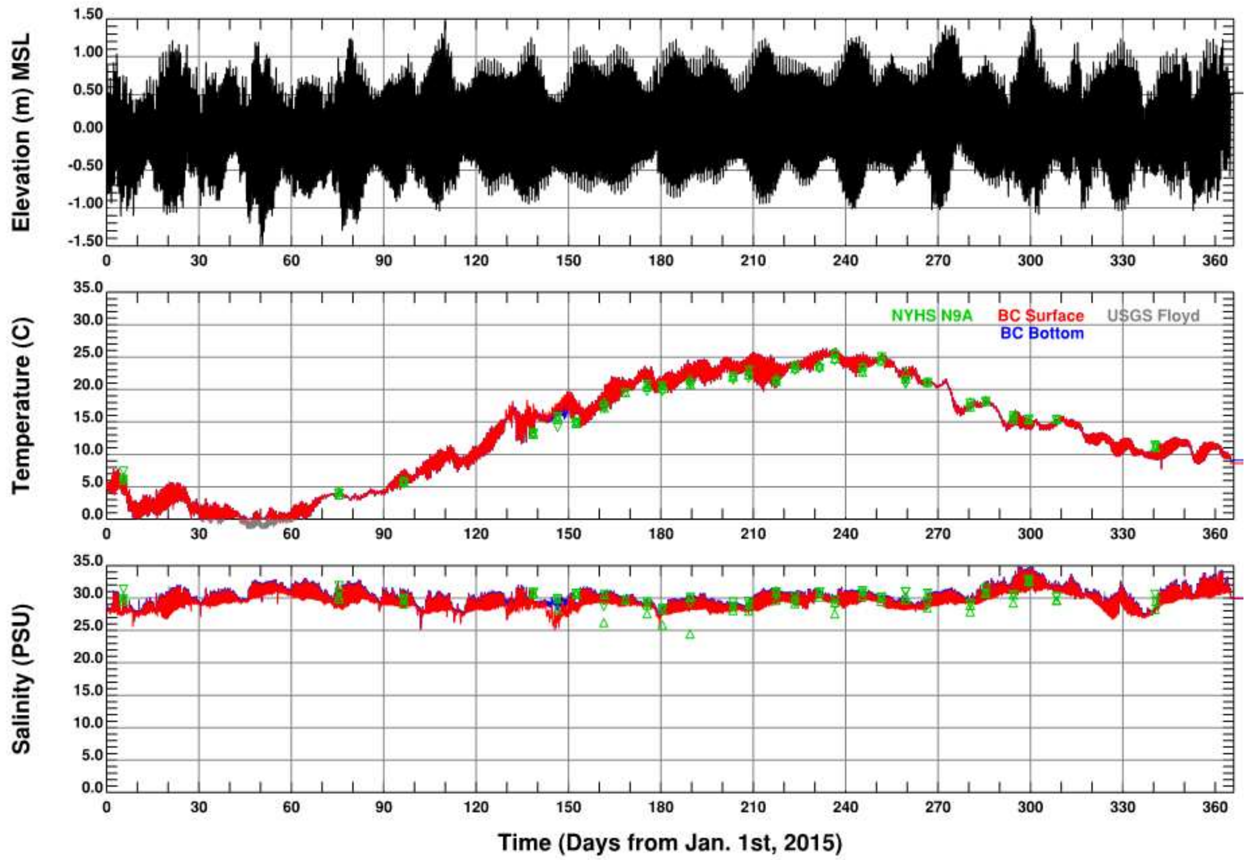


AECOM
with Hazen

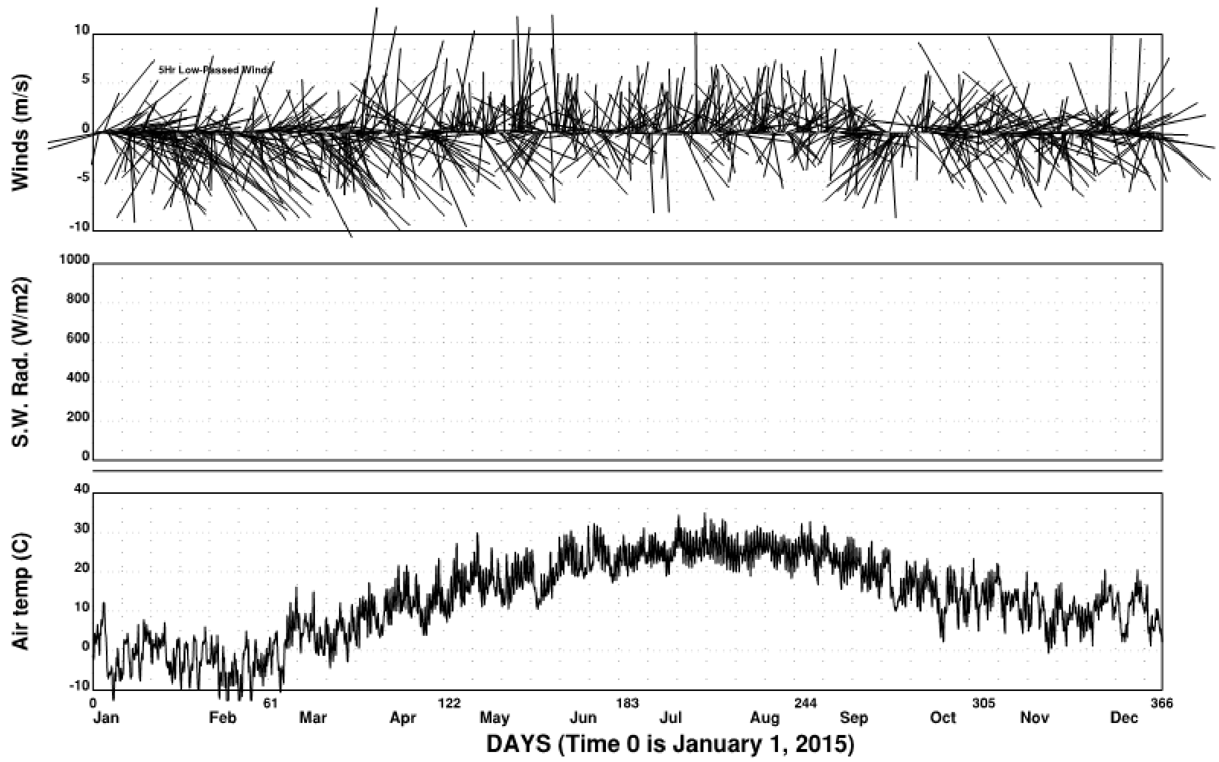
APPENDIX C

ADDITIONAL HYDRODYNAMIC MODEL FIGURES

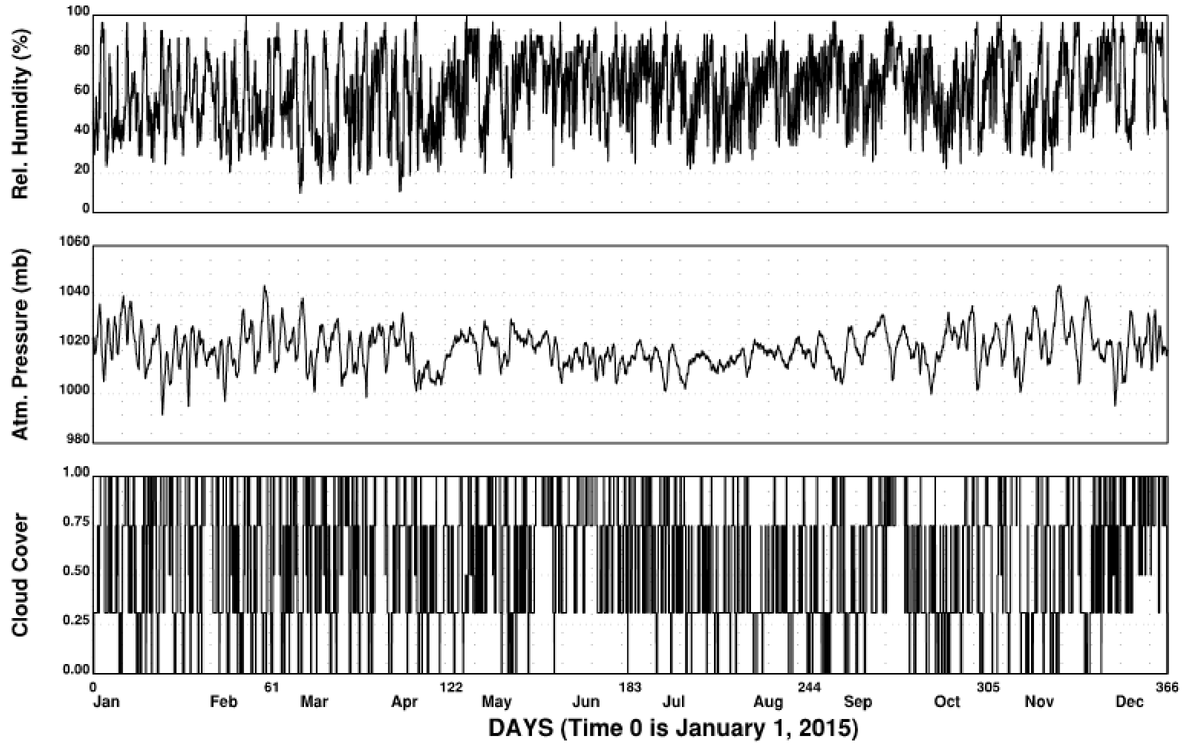
AECOM with Hazen



HYDRODYNAMIC MODEL BOUNDARY CONDITIONS



HYDRODYNAMIC MODEL METEOROLOGICAL INPUTS



HYDRODYNAMIC MODEL METEOROLOGICAL INPUTS

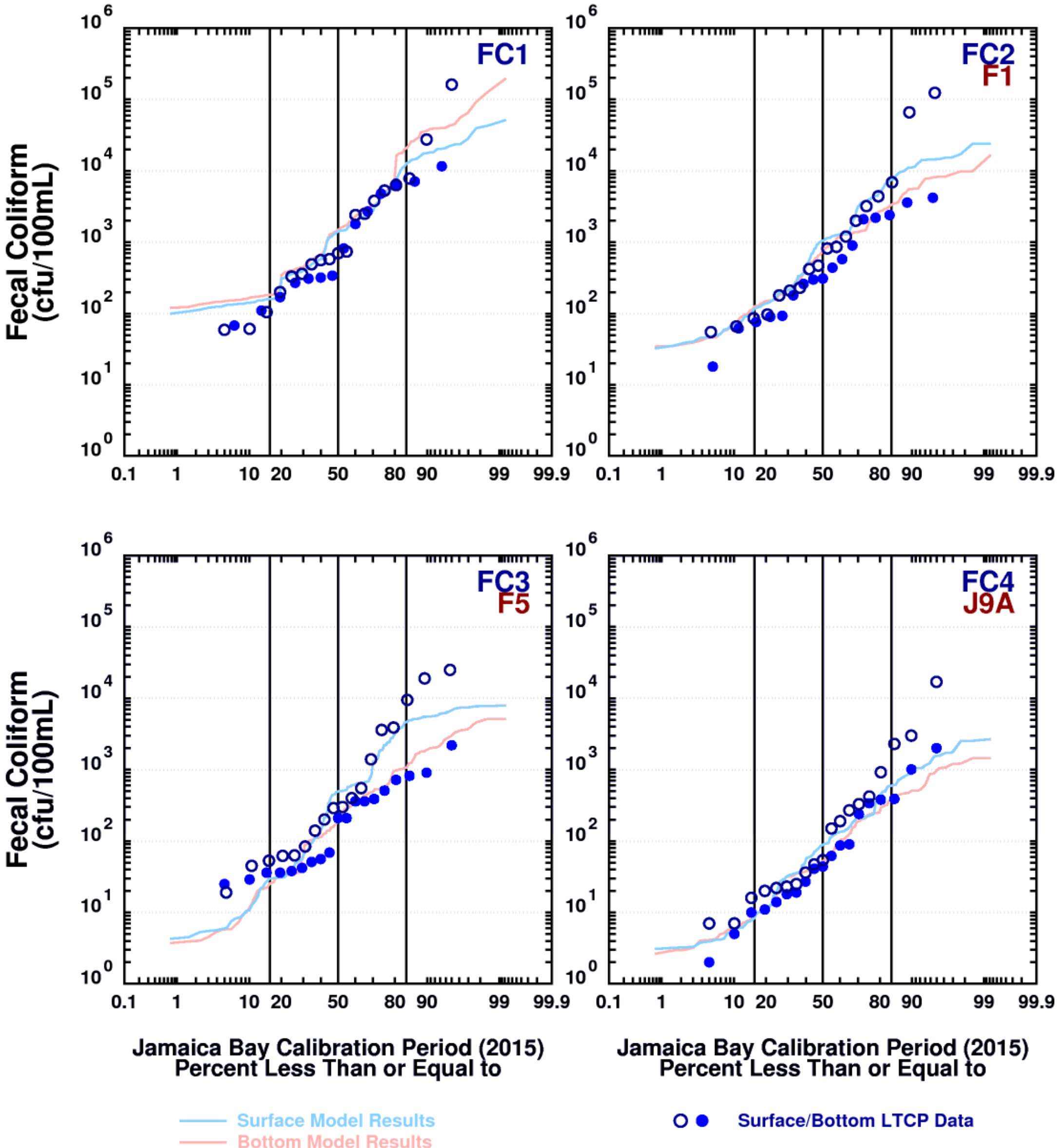
APPENDIX D

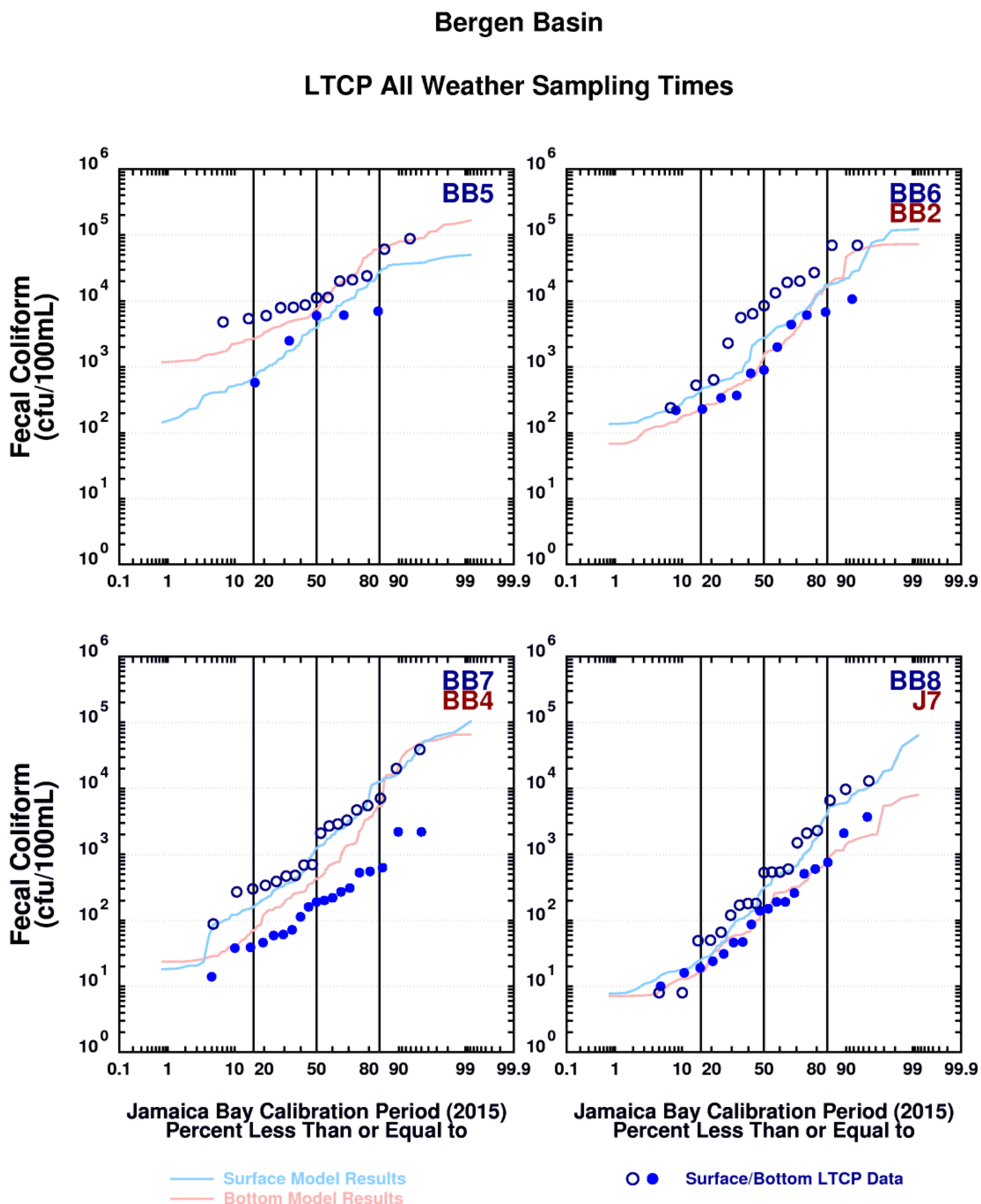
ADDITIONAL PATHOGENS CALIBRATION FIGURES

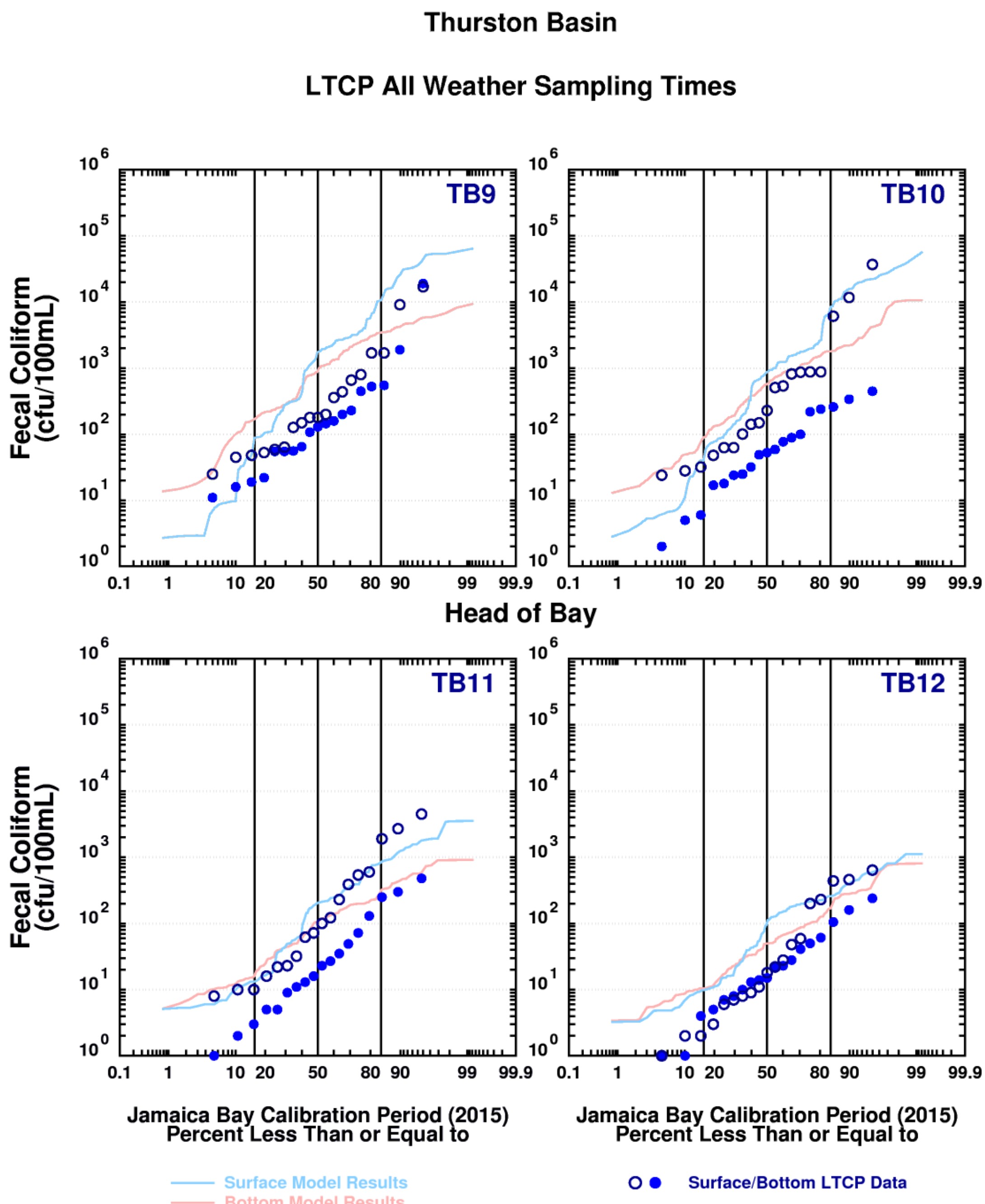
AECOM
with Hazen

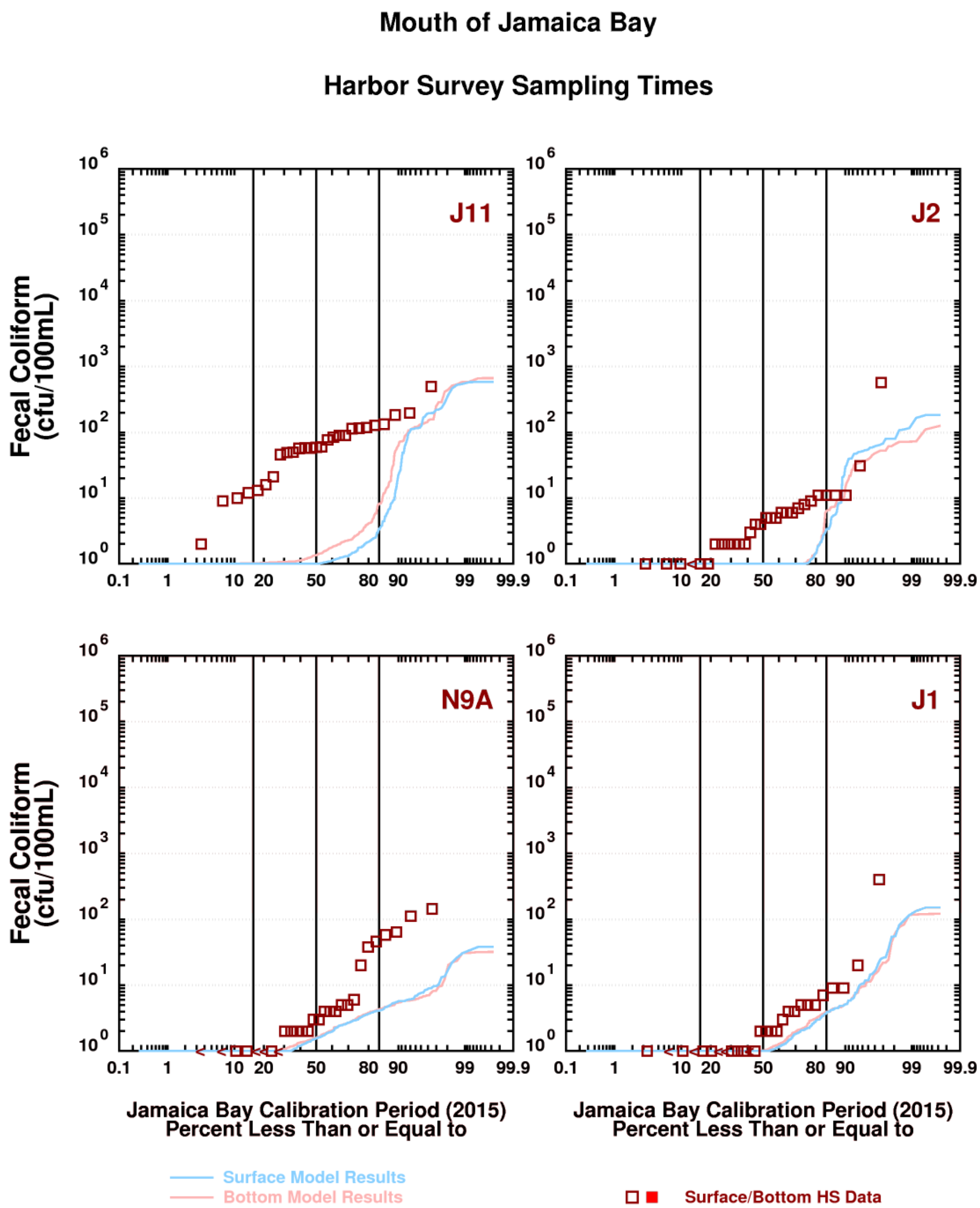
Fresh Creek

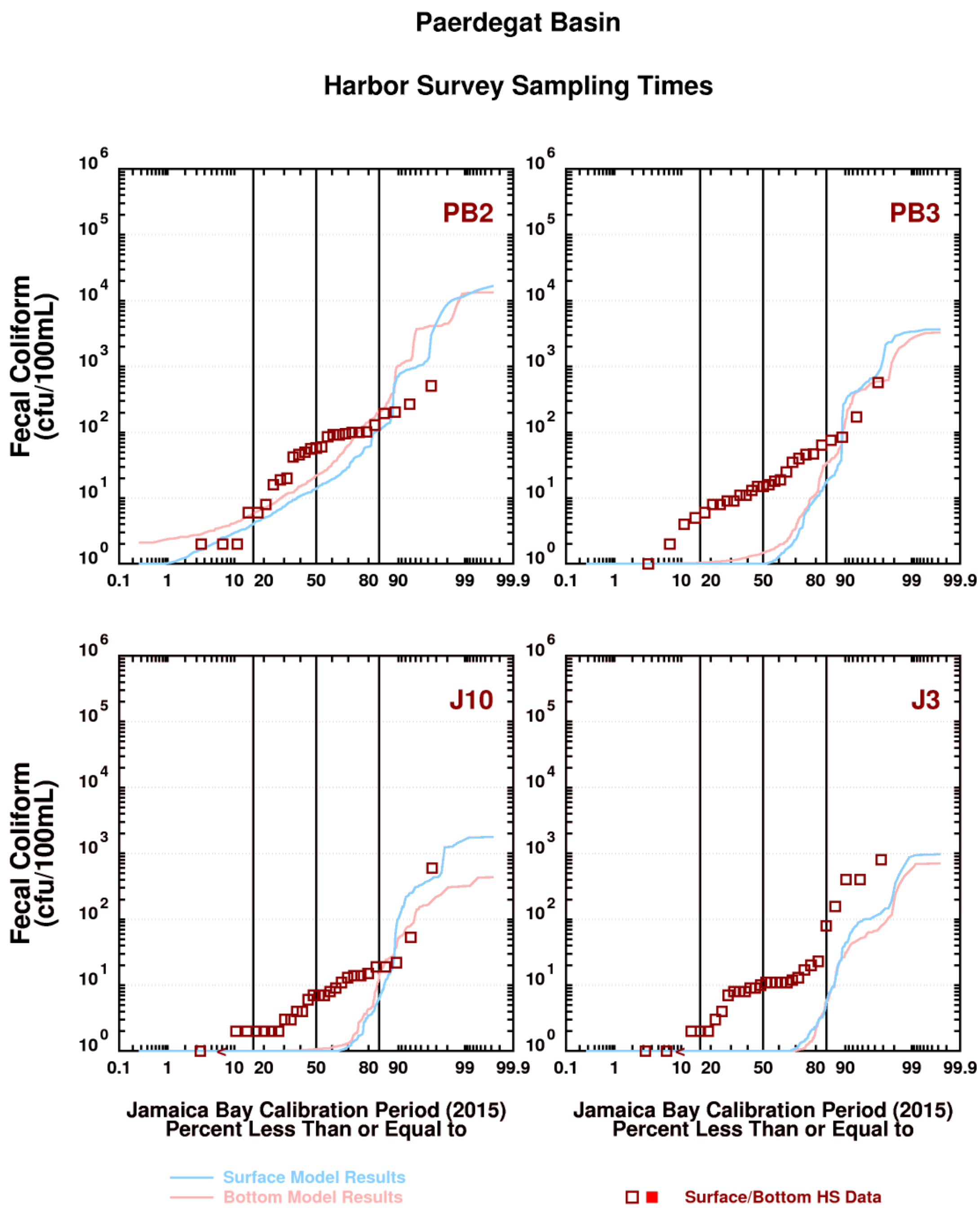
LTCP All Weather Sampling Times

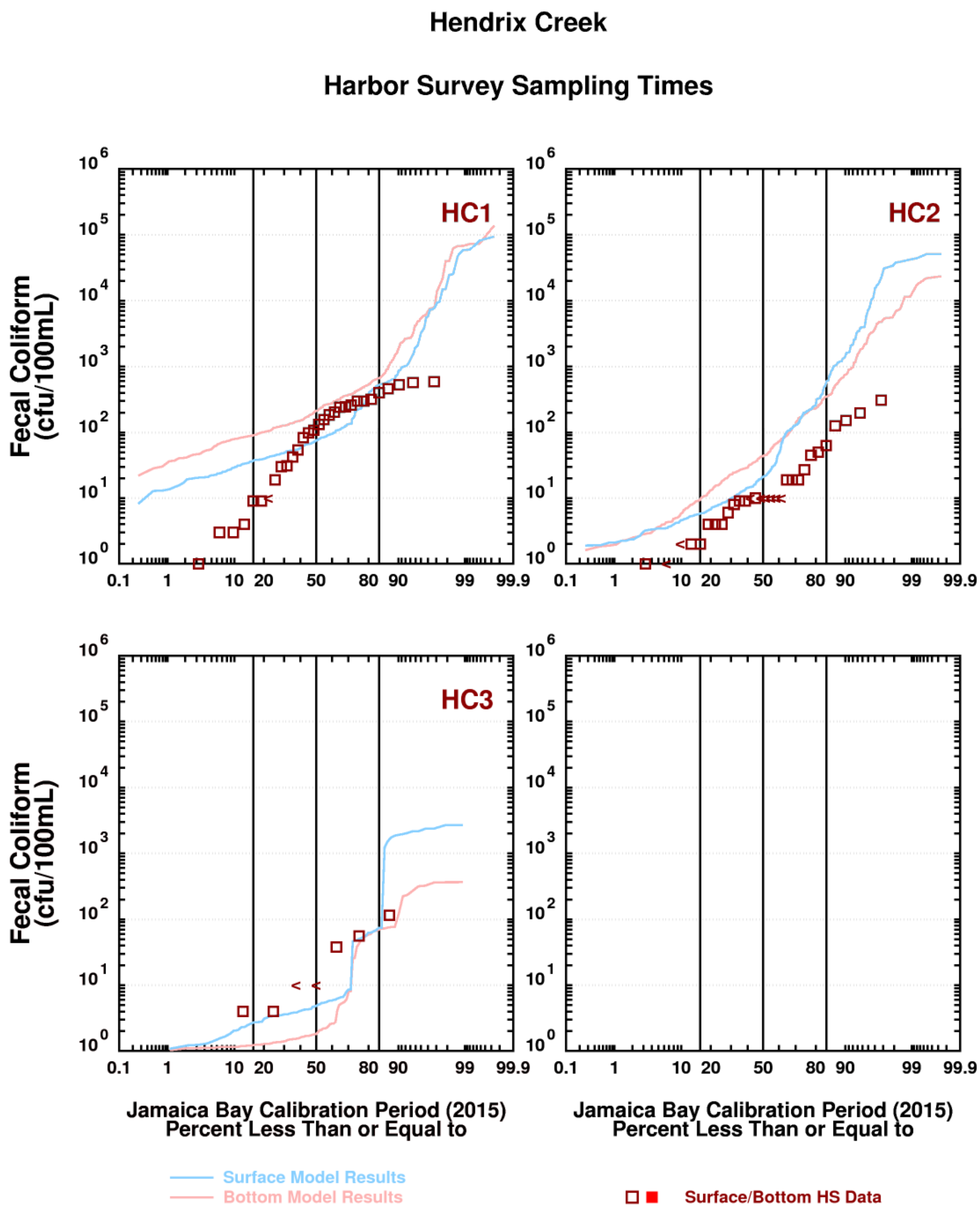



Bergen Basin
LTCP All Weather Sampling Times
BB5
BB6
BB2
BB7
BB4
BB8
J7
Fecal Coliform (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom LTCP Data


Thurston Basin
LTCP All Weather Sampling Times
TB9
TB10
Head of Bay
TB11
TB12
Fecal Coliform (cfu/100mL)
10^0
10^1
10^2
10^3
10^4
10^5
10^6
0.1
1
10
20
50
80
90
99
99.9
Jamaica Bay Calibration Period (2015)
Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom LTCP Data

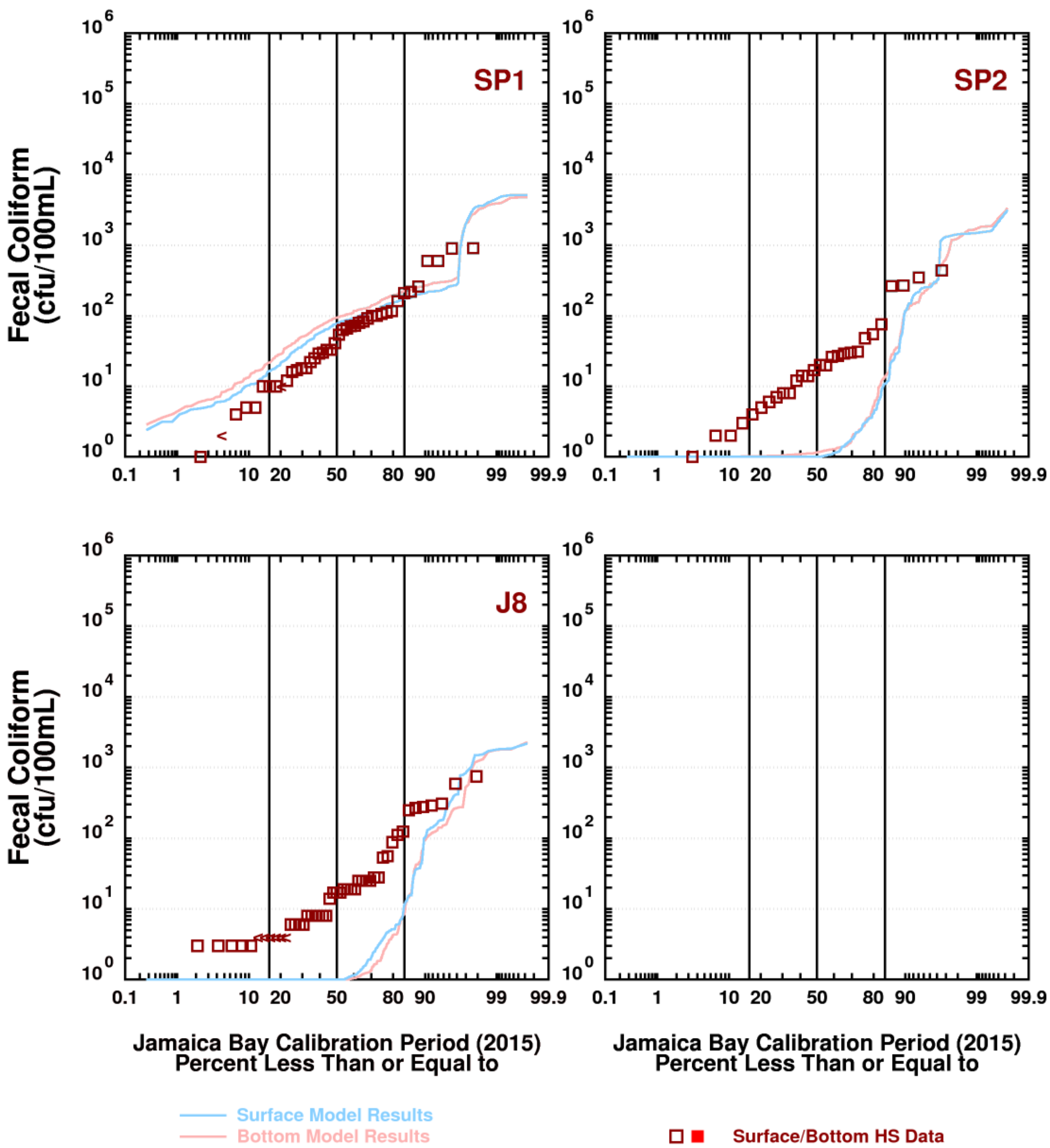

Mouth of Jamaica Bay
Harbor Survey Sampling Times
J11
J2
N9A
J1
Fecal Coliform (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data

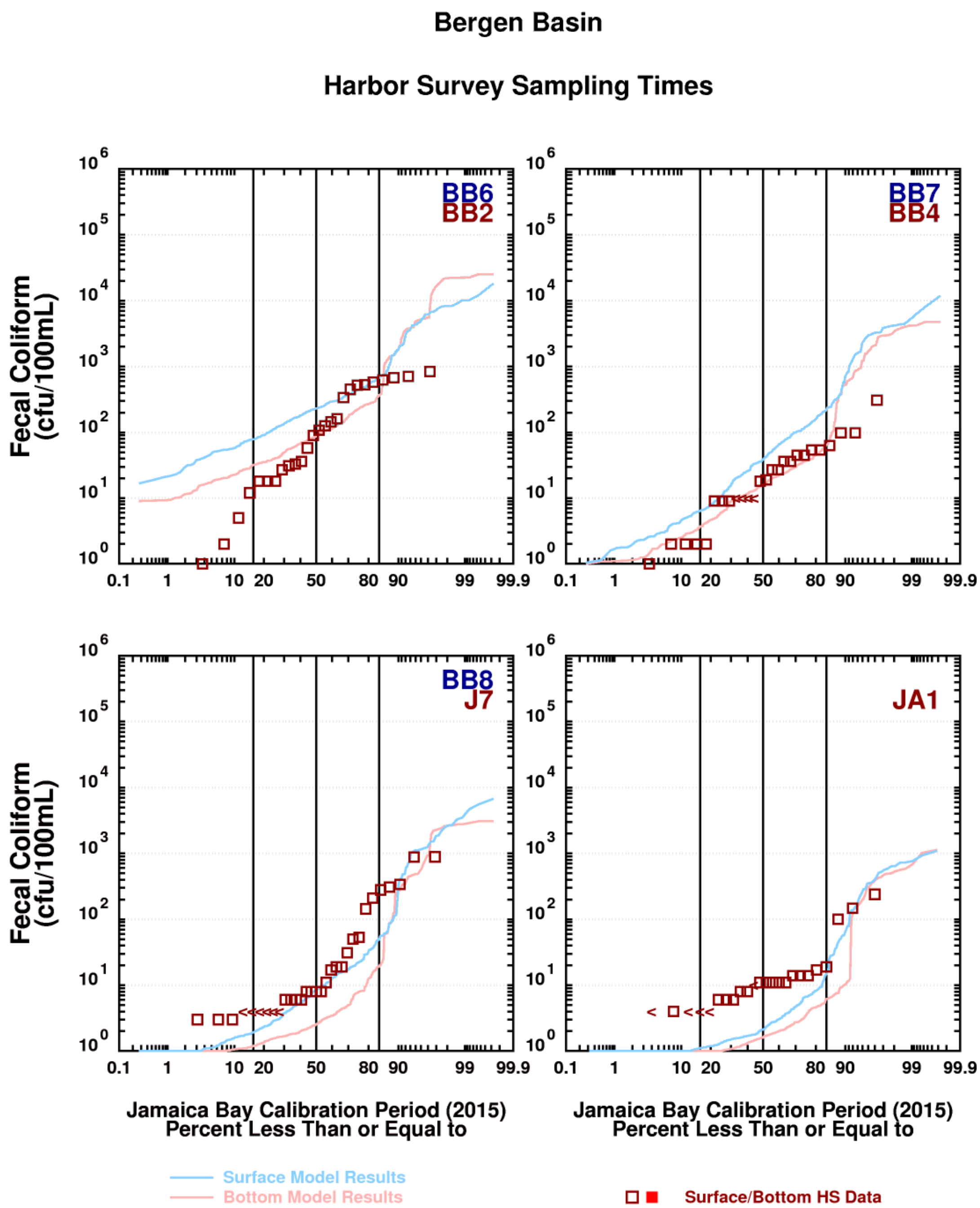

Paerdegat Basin
Harbor Survey Sampling Times
PB2
PB3
J10
J3
Fecal Coliform (cfu/100mL)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0.1
1
10
20
50
80
90
99
99.9
Jamaica Bay Calibration Period (2015)
Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data

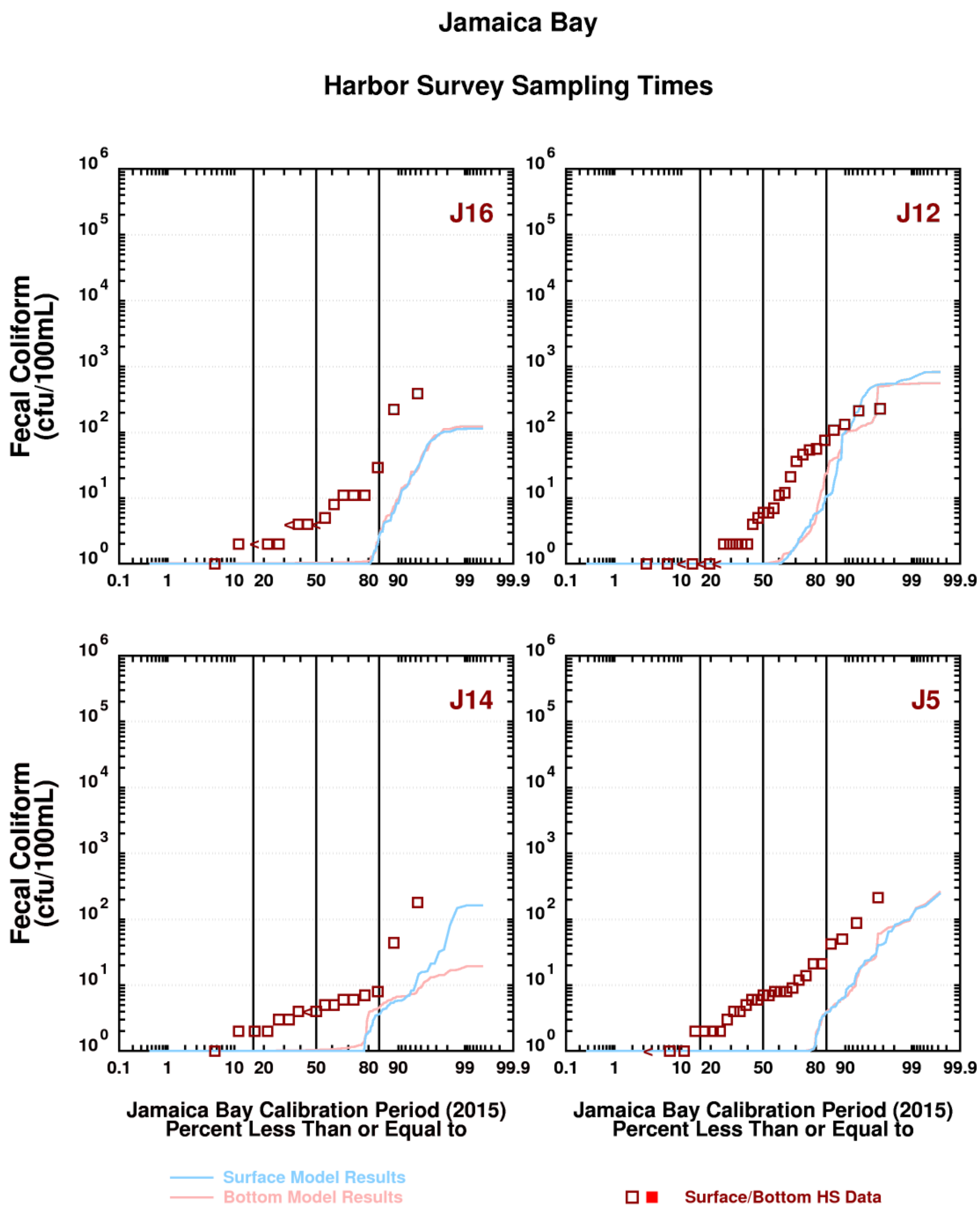

Hendrix Creek
Harbor Survey Sampling Times
HC1
HC2
HC3
Fecal Coliform (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data

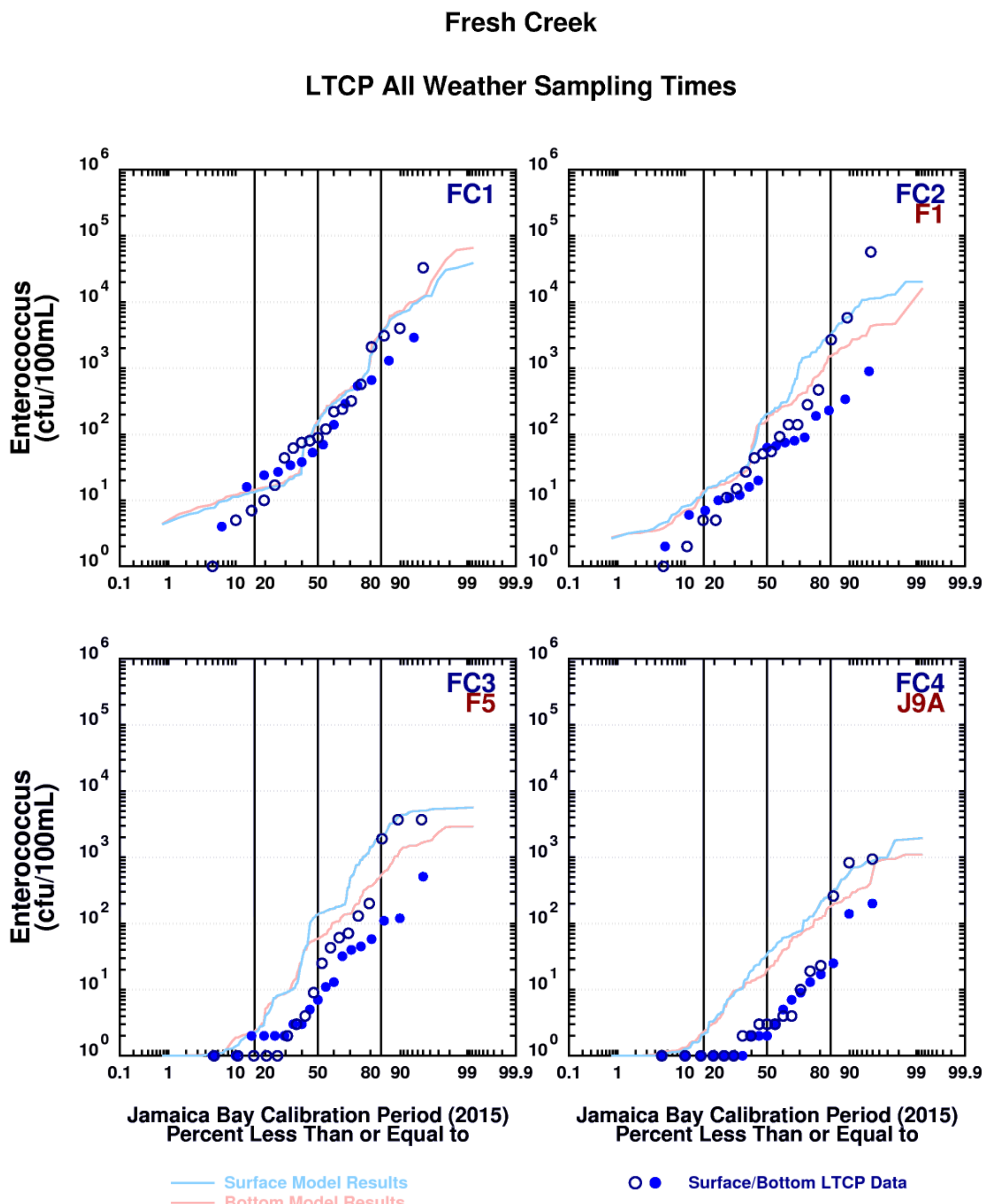
Spring Creek

Harbor Survey Sampling Times

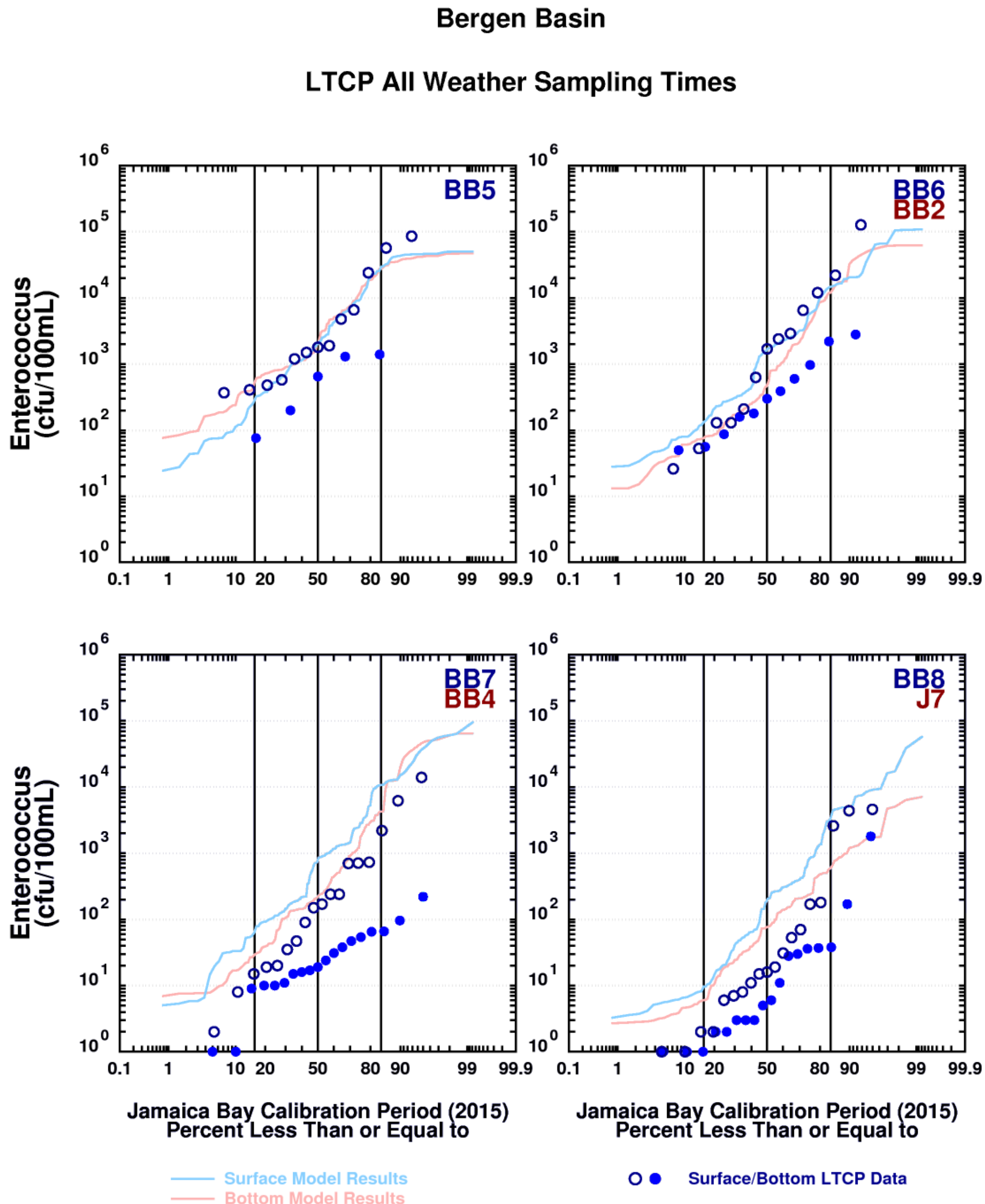


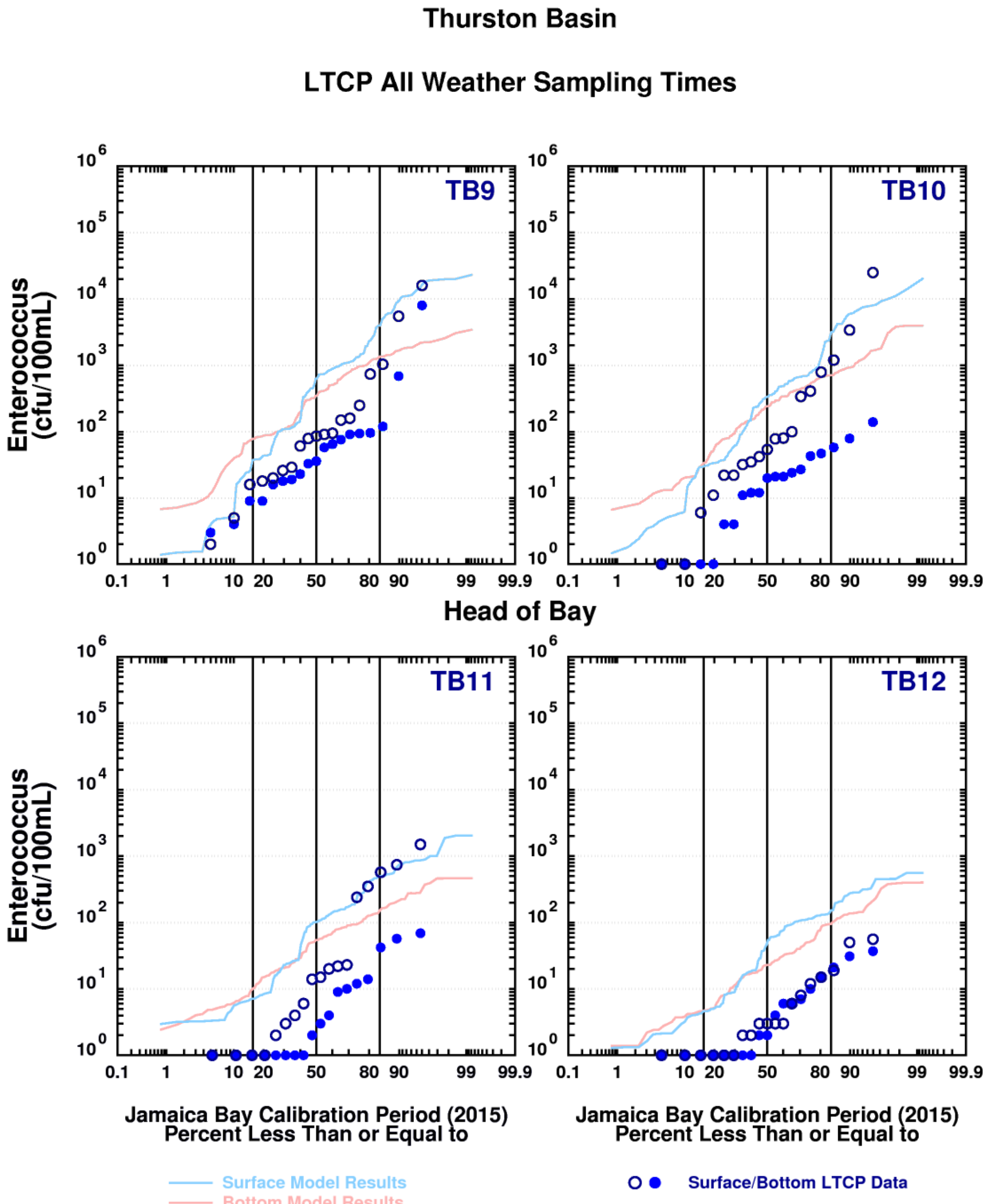

Bergen Basin
Harbor Survey Sampling Times
BB6
BB2
BB7
BB4
BB8
J7
JA1
Fecal Coliform (cfu/100mL)
10^0 10^1 10^2 10^3 10^4 10^5 10^6
0.1 1 10 20 50 80 90 99 99.9
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data

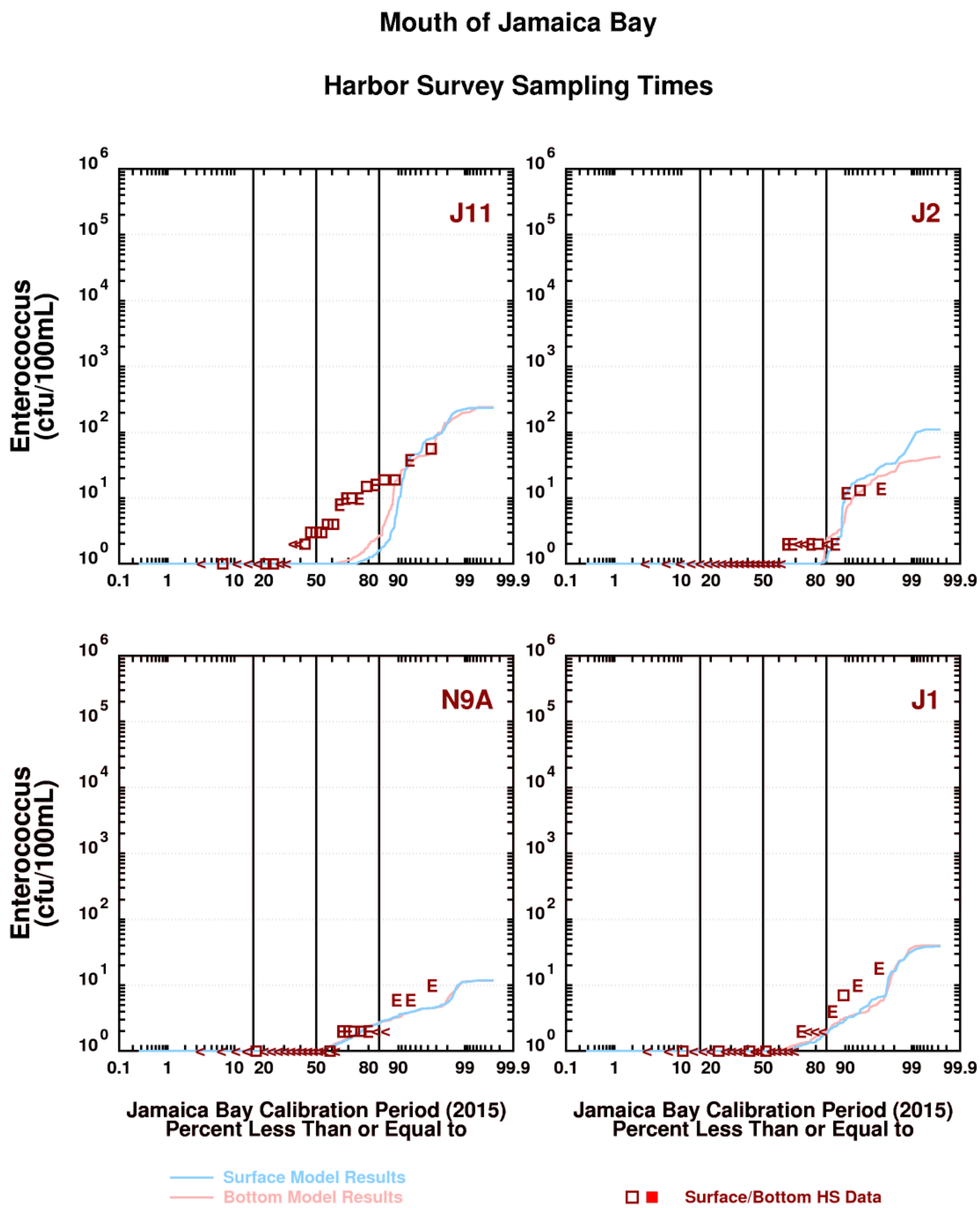

Jamaica Bay
Harbor Survey Sampling Times
J16
J12
J14
J5
Fecal Coliform (cfu/100mL)
10^0
10^1
10^2
10^3
10^4
10^5
10^6
0.1 1 10 20 50 80 90 99 99.9
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data

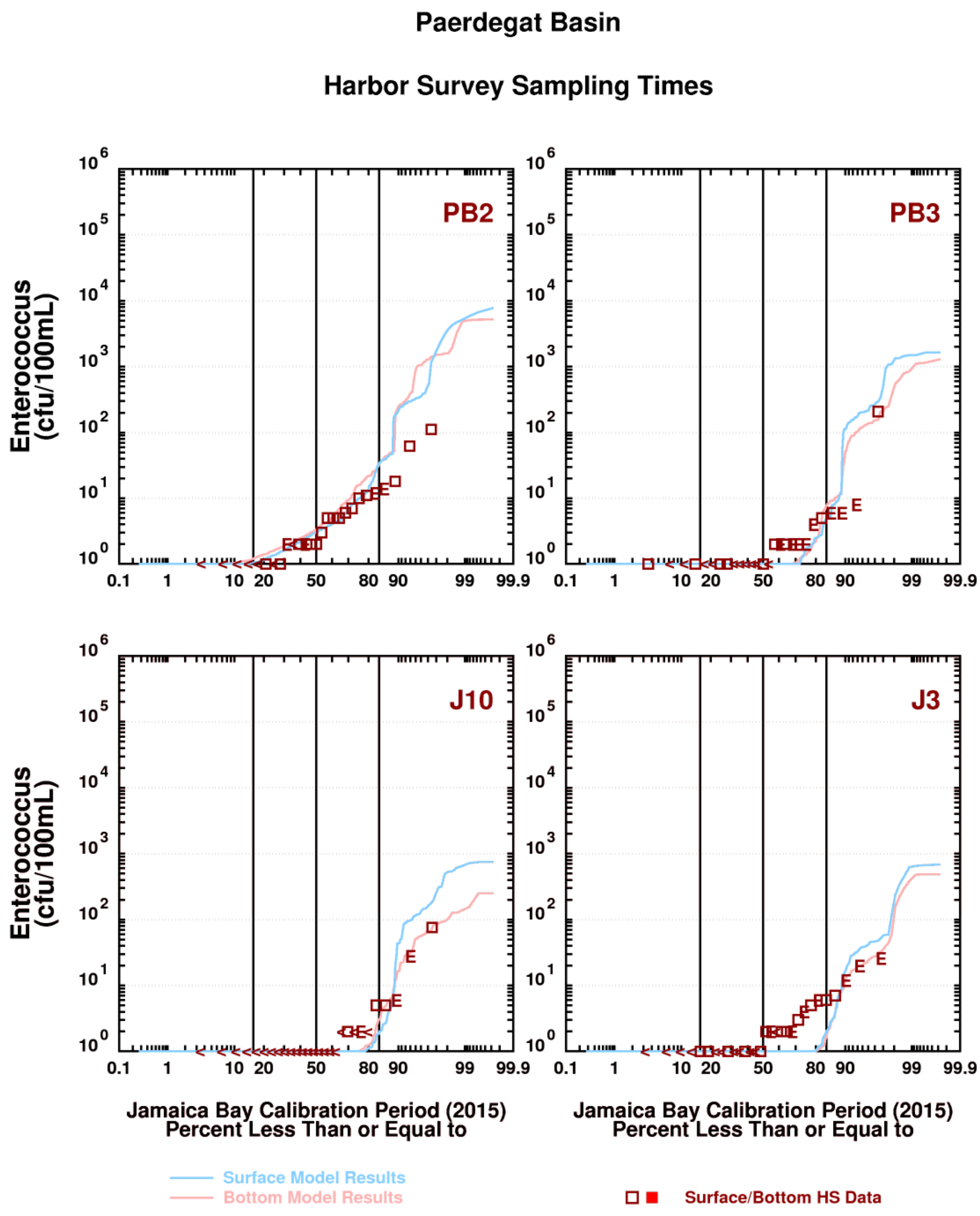


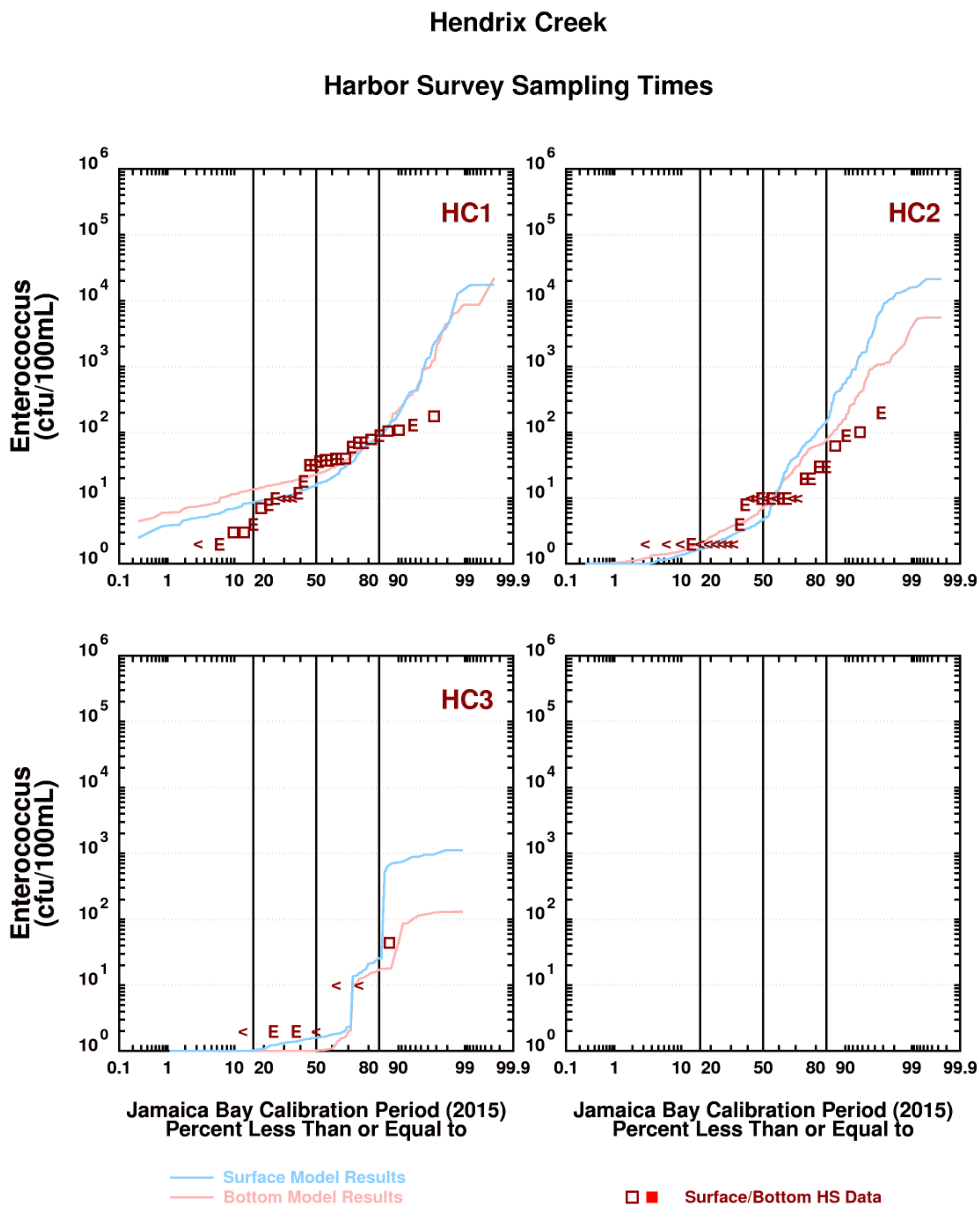
AECOM with Hazen

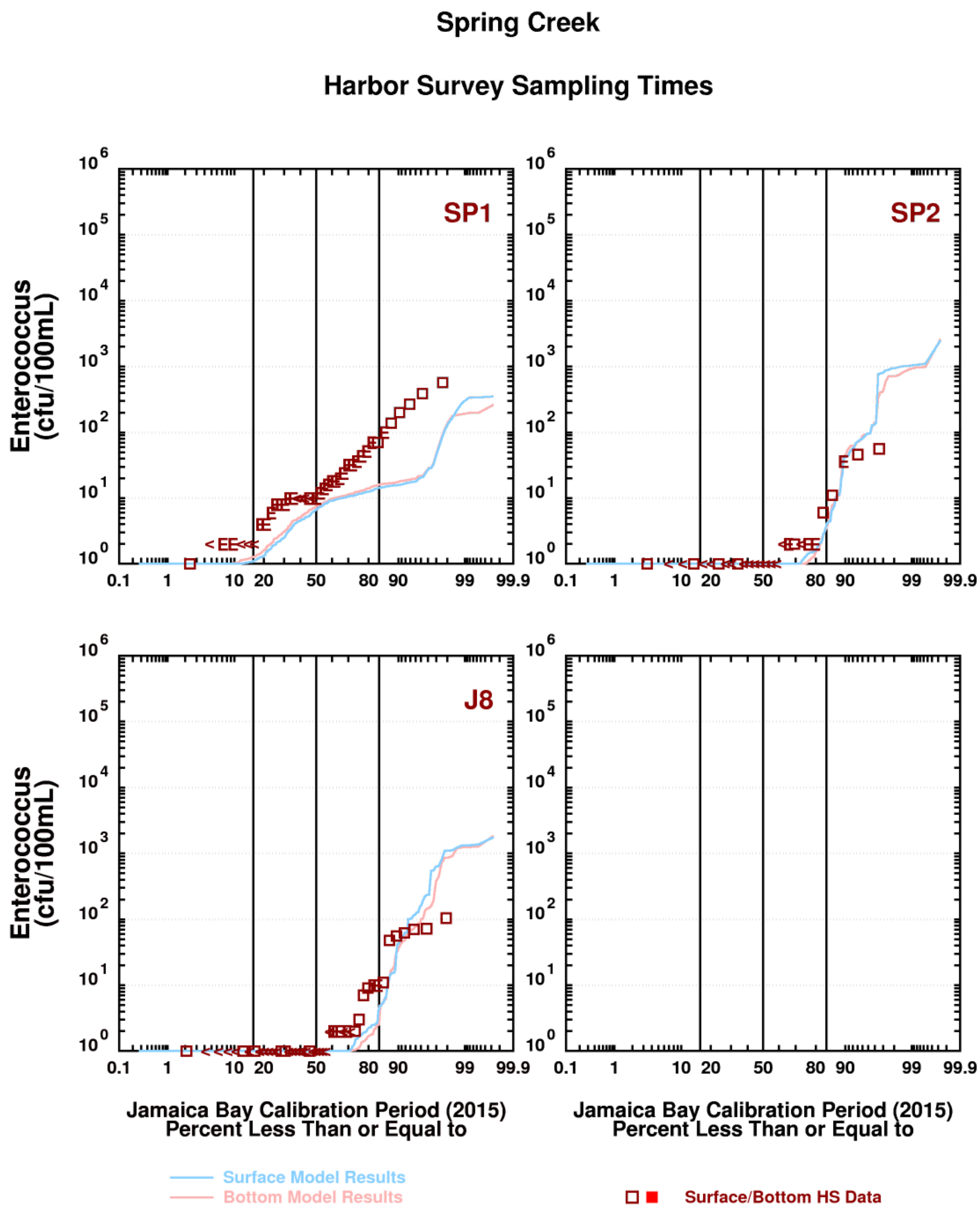

Bergen Basin
LTCP All Weather Sampling Times
BB5
BB6
BB2
BB7
BB4
BB8
J7
Enterococcus (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom LTCP Data

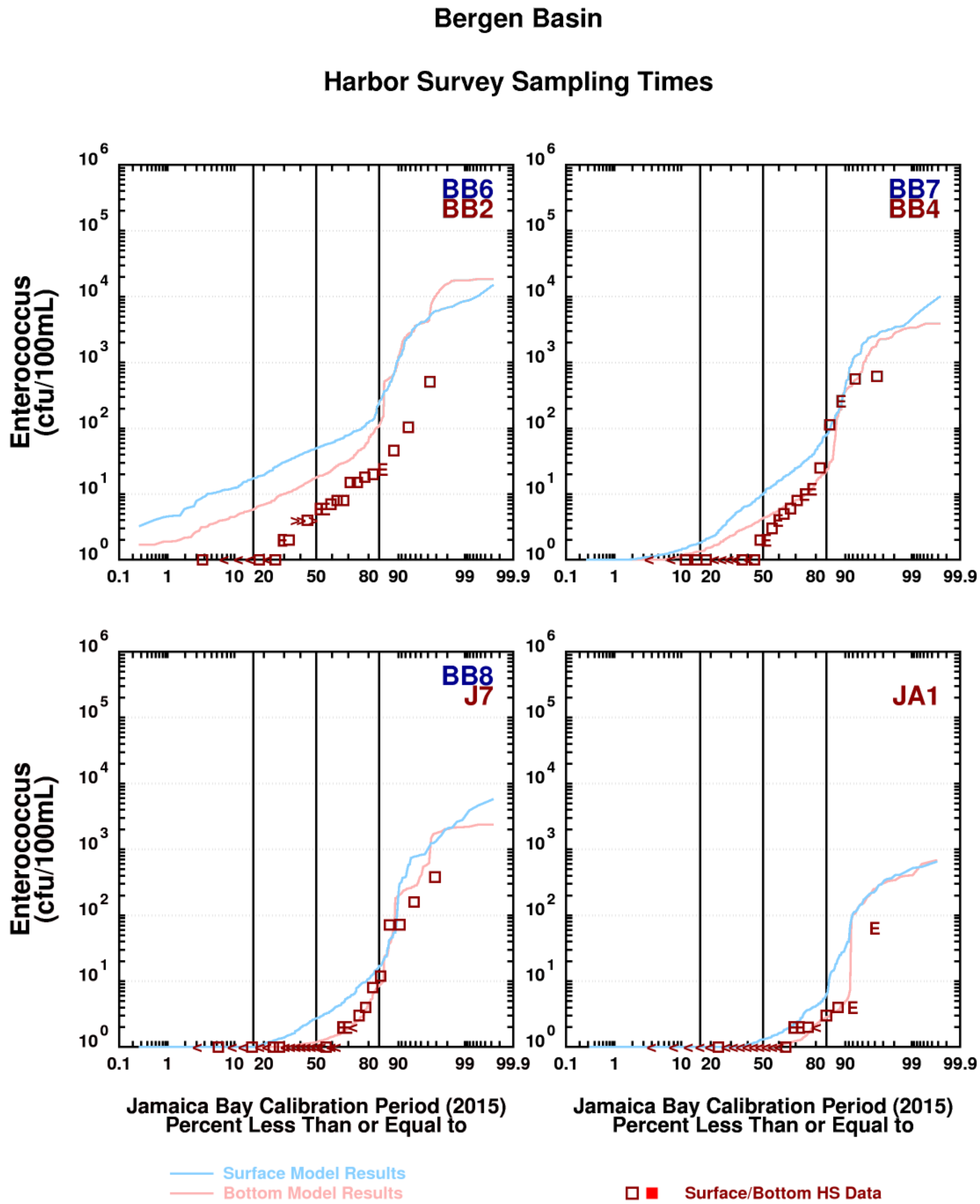

Thurston Basin
LTCP All Weather Sampling Times
TB9
TB10
TB11
TB12
Head of Bay
Enterococcus (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom LTCP Data


Mouth of Jamaica Bay
Harbor Survey Sampling Times
J11
J2
N9A
J1
Enterococcus (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data


Paerdegat Basin
Harbor Survey Sampling Times
PB2
PB3
J10
J3
Enterococcus (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data


Hendrix Creek
Harbor Survey Sampling Times
HC1
HC2
HC3
Enterococcus (cfu/100mL)
10^0
10^1
10^2
10^3
10^4
10^5
10^6
0.1
1
10
20
50
80
90
99
99.9
Jamaica Bay Calibration Period (2015)
Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data


Spring Creek
Harbor Survey Sampling Times
SP1
SP2
J8
Enterococcus (cfu/100mL)
Jamaica Bay Calibration Period (2015) Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data


Bergen Basin
Harbor Survey Sampling Times
Enterococcus (cfu/100mL)
BB6
BB2
BB7
BB4
BB8
J7
JA1
Jamaica Bay Calibration Period (2015)
Percent Less Than or Equal to
Surface Model Results
Bottom Model Results
Surface/Bottom HS Data