

Cooperating Parties Group

**LOWER PASSAIC RIVER RI/FS
NEWARK, NEW JERSEY**

**APPENDIX L
HYDRODYNAMIC MODEL OF THE
LOWER PASSAIC RIVER**

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1.0 INTRODUCTION

In the Administrative Settlement Agreement and Order on Consent (“Settlement Agreement”) entered into by the United States Environmental Protection Agency (“EPA”) and the Cooperating Parties Group (the “Settling Parties” or “CPG”), it was agreed that the CPG will conduct the Remedial Investigation and Feasibility Study (“RI/FS”) begun by the EPA on the Lower Passaic River Study Area. This RI/FS includes conducting the Modeling Work Plan (“MWP”) for the Lower Passaic River (LPR) and Newark Bay (NB) as defined in (HQI, 2006a; 2006b).

In a letter of June 12, 2008, EPA approved the proposed CPG Modeling Team (“CPG-MT”) of Moffatt & Nichol and Deltares to conduct the MWP, specifically for components Hydrodynamics, Sediment Transport and Contaminant Fate and Transport. Windward Environmental was separately retained by the CPG to conduct the Bioaccumulation Modeling of the MWP. In August 2012, the CPG modified the structure of the Modeling Team incorporating Anchor QEA as the consultant responsible for the Contaminant Fate and Transport component.

The activities of the CPG-MT started in July 2008, with a ‘Modeling Transfer Meeting’ held with the EPA and HydroQual. During this meeting, HQI presented the status of the models to be used for the RI/FS, and an initial transfer of the computer models was made to the CPG-MT.

This report presents the work performed by the CPG to refine and calibrate/validate the hydrodynamic model for the Lower Passaic River. The modeling work for this component is an extension of the work already completed by HydroQual, Inc (HQI, 2008). The model developed and calibrated by HQI was accepted by EPA and the final report was submitted (HydroQual 2008). The CPG modeling team conducted extensive tests on the existing HQI model. In addition, work was done to further the applicability of the model through new developments and to provide information useful to the understanding of the Lower Passaic River and Newark Bay system. The investigations, developments, and analyses described herein represent the application of this model to complete the LPR/NB RI/FS modeling program.

2.0 REVIEW AND SUMMARY OF HYDRODYNAMIC MODEL AND INPUTS FROM HQI/EPA

A series of three submittals were made by HQI to the CPG containing model setups for the completed hydrodynamic modeling effort. In addition, a number of interim transfers of data and input files occurred in order to clarify and resolve issues with the models.

2.1 Calibration Setup

Four model setups corresponding to the four calibration periods were submitted by EPA/HQI to the CPG corresponding to those used and described in the Final Hydrodynamic Modeling Report (HQI, 2008). These model setups were designed to coincide with the four major periods of data collection within the Passaic River and Newark Bay reported in the Final Hydrodynamic Modeling Report (HQI, 2008). HydroQual (2008) presents the model calibration/validation results for these periods. The conclusion is that the model as presented is considered to be calibrated and can be used to proceed with additional simulations of the hydrodynamics and other modeling components.

The hydrodynamic module, ECOM was developed by Blumberg and Mellor (1980, 1987). This model uses a mode splitting technique to separate the vertically integrated equations from the vertical structure of the solution (Simons, 1974 and Madala and Piacesk, 1977). This allows for faster computational time while still maintaining the accuracy in an explicit solution of the momentum equations (external mode). The model is run in a single precision environment which allows for faster computational times. Source code for the ECOM model was submitted with the model setup of the aforementioned four simulated periods used for calibration/validation.

HQI provided time-series output files for the 2004 calibration simulation upon request. This simulation had a duration of 66 days. In addition, time-series output files for the first 30-day period of the Water Year 1995 (WY95) period and map files for the first 10 days of the WY95 period were also provided. These output files were used to determine that HQI results of the calibration periods could be reproduced exactly. Through extensive portability testing, it was found that the only way of exactly reproducing the results of the HQI models was to use the executable provided with the code. Portability issues with ECOM are tied to both the workstation operating system libraries as well as the compiler versions. Differences between the results from the same simulations using executables created using different compiler versions and under different platforms were intermittent and did not increase with the duration of the run. Differences seemed to be more pronounced in specific areas of the grid. HQI reported that portability could be improved with the increase of the smoothing parameter HORCON (horizontal viscosity) in some of these areas. The executable for the calibration runs was compiled using the PGI Fortran compiler version 6.0.8.

For each calibration period, a brief discussion of the input sources and data comparison is included in the following sections. Details of the model setup, sensitivity, and calibration

are not included, as they are discussed at length in the Final Hydrodynamic Modeling Report (HQI 2008).

2.1.1 Model Grid

The LPR model grid is specified in an orthogonal curvilinear coordinate system. The model grid in the vicinity of Newark Bay and the Lower Passaic River is shown in Figure 2-1. The model is made up of elements from $i=1$ to 74 and $j=1$ to 268. The LPR grid was created from the original SWEM and CARP models (HQI, 2008), however the CARP model did not have sufficient resolution in the Passaic River as it was meant for a more regional application. The LPR model has resolution in the lower miles of the Passaic of approximately 60 m by 180 m. A maximum of four grid cells are used to represent the Passaic River laterally (except for a short stretch of about 0.25 miles in the Harrison Reach where up to 6 grid cells are present) with approximately 10 grid cells representing a river mile along the river. The cross-channel resolution decreases up-river. Near Dundee Dam, only two grid cells are defined across the river, and 4 rows of grid cells are used to define a river mile.

In an orthogonal curvilinear system, the less orthogonal the grid cells are, the more error is introduced to the computations. It is therefore advantageous to construct a model with as orthogonal grid cells as possible. In some areas of the LPR model, the deviation from orthogonality is greater than 25%, including some areas in the Passaic River (Figure 2-2). Near the offshore boundary, the orthogonality shows a 15% deviation from orthogonal. Slight degrees of non-orthogonality are generally acceptable in computations. A detailed assessment of the error associated to non-orthogonality of the LPR model grid was not carried out under this study.

2.1.2 Bathymetry

There were three sets of model bathymetry inputs developed by EPA (HQI 2008) for the calibration simulations. The water year (WY) 1995 and WY1996 calibration periods used the TSI bathymetric survey data compiled in 1995 for the first eight miles of the LPR. For the rest of the LPR, the survey from 2004 (USACE) was used. This bathymetry remained unchanged within the model until the 2004 calibration period.

The Hackensack River was defined using the USACE survey data compiled in the mid-1990's. This remained unchanged within the model throughout the calibration periods. Bathymetry within Newark Bay and the Kills was defined for the (pre-1999) WY1995 and WY1996 calibration periods using USACE survey data. This was modified for the 2000-2002 and 2004 calibration periods using survey data from the Harbor Deepening Projects between 1999 and 2004.

The bathymetry used in the model for the Lower Passaic River is shown in Figure 2-3 through Figure 2-5 for each period. Similarly, bathymetry for Newark Bay is shown in Figure 2-6 through Figure 2-8. Especially in the Passaic River, it is noted that the bathymetry shows very strong gradients between neighboring cells in many locations in

the WY1995 model bathymetry. In addition, the former navigation channel within the Passaic River is in some places only defined by one grid cell for the Passaic River bathymetries used from WY1995 through WY2002. This can cause certain issues with the velocities and shear stresses in the model as a narrowly defined channel may cause higher shear stresses on the banks than would be reasonably anticipated. Following discussion with HQI, it was decided that it would be appropriate to change the model to a more smoothly constructed bathymetry which is more representative of the observed WY1995 bathymetry and re-validate the model using these conditions.

One specific requirement for ECOM is that initial depth at every computational cell is set to be greater than zero. Otherwise, the cell is given a mask value and is treated as a permanent dry point. This issue is apparent to a minor extent in the half mile immediately downstream of Dundee Dam where the measured bathymetry is above the vertical datum (MSL) used in the model (Figure 2-9). In order to implement boundary conditions at the Dundee Dam, it was necessary for the bathymetry to be significantly deepened, to a depth of 0.25 MSL (Figure 2-10). This could potentially invalidate the model results in the upper portions of the river, as the model depth is inconsistent with reality, and the water surface slope cannot develop in the way expected. The model has not been calibrated or validated in this stretch due to the lack of suitable data.

2.1.3 Boundary Conditions

Boundary conditions were applied at the offshore boundary of the model located in New York Bight. Surface elevation, temperature, and salinity boundary conditions were applied. Three components of the sea surface elevation were included, the effect of long-term circulation due to the cross-shelf slope, the tidal fluctuations, and sub-tidal meteorological forcing. The sea-surface elevation was specified at hourly time intervals.

The cross-shelf gradient was specified as a constant 13 cm gradient along the Nantucket Shoals boundary and a 11 cm gradient along the Cape May shelf break section of the southern boundary. This was based on the work done by Hopkins and Dieterle (1983) and Blumberg and Galperin (1990). These constants were based on the analysis done for August 1978, a typical summertime period. In both the papers cited, these conditions were applied for a summer average circulation study.

Astronomical tides were implemented with eight primary constituents extracted using the global tidal model, TPXO.2 developed by Oregon State University (Egbert et al., 1994). The tidal synthesis program included with TPXO.2 was used to generate the predicted time-series for each boundary point. This synthesis program uses interpolation of the tidal admittances in the diurnal and semi-diurnal bands to include 9 additional mirror constituents ($2N_2$, MU_2 , NU_2 , I_2 , T_2 , J_1 , NO_1 , OO_1 , RHO_1). It also adds the long-period constituents MF, MM, SSA using the standard equilibrium forms. The time-series generated for the offshore points was generated with a time interval of 1 hour. Figure 2-11 shows that tides generated with a 1 hour time step vs. a 15 minute time step can sometime miss portions of the tidal signal especially near the tidal peaks. However, these missing

portions typically only amount to fractions of an inch in the tidal signal and any artifact in results are therefore expected to be negligible.

Sub-tidal variability is included as a 35-hour low-pass filter of the observed water levels at Cape May, Sandy Hook, and Montauk. It was found that this variability is fairly constant spatially, and is implemented as an addition to the entire model boundary condition.

A modified form of the Sommerfield radiation boundary conditions (Blumberg and Kantha, 1985) is also applied across the Cape May shelf-break function. This allows long waves to propagate and advect through the boundary.

Salinity and temperature boundary conditions are specified monthly. They were obtained from World Ocean Atlas 1998 (WOA98), published by NOAA, which are gridded data at one-degree resolution. They were adjusted to match the monthly mean temperature and salinity in the Long Island Sound, the New York Bay, and the Hudson River. The conditions are identical for each calibration period and only include seasonal variations. It suffices to say that the offshore salinity and temperature boundary conditions are essentially calibrated to conditions inside the model. From the Final Hydrodynamic Modeling Report (HQI, 2008), a value of 2.0 was subtracted from the WOA98 dataset at the boundary in order to obtain appropriate results within the model interior.

2.1.4 Discharge Conditions

The Final Hydrodynamic Modeling Report (HQI, 2008) states that fresh water inflows from 25 rivers and tributaries were implemented in the model. These data were compiled from 24 verified USGS surface water gauges for New York, New Jersey, and Connecticut. For some cases, sources that were located close to each other were implemented within the same computational grid cell for the hydrodynamic model.

HQI (2008) did a detailed analysis of the importance of the discharge temperature. The final calibration used prescriptions of a 3-day moving average of the air temperature at Newark International Airport. All other temperature inputs were based on surface temperature measured at the NOAA Battery station with missing data filled in from the Bergen Point West Reach station.

Wastewater flows from 99 wastewater treatments plants and discharges due to combined sewer outflows, and stormwater runoff at 1297 grid locations were implemented within the model for a total of 1396 inputs. The runoff volumes were computed using RAINMAN (proprietary HQI software) for New York and Northern New Jersey. Rainfall Runoff Modeling Program (RRMP) outputs were used for Connecticut and Southern New Jersey inputs to the model. These models were driven by rainfall records.

All discharge inputs to the model were specified daily. Discharge inputs to the model are specified in the top two sigma layers in the model, 50% in Layer 1 and 50% in Layer 2.

The Final Modeling Report (HQI, 2008) indicates that three major tributaries to the Passaic River, the Second River, the Third River, and McDonald Brook, are ungauged and are described as implemented in the model similar to stormwater runoff using the RAINMAN landside model to develop the inputs.

2.1.5 Meteorological Conditions

Both wind stress and heat flux conditions were implemented in the calibration models. Wind stress is computed from the wind speed and direction. The air temperature, relative humidity, barometric pressure, cloud cover and shortwave radiation are specified for the heat flux computations. All data is specified hourly within the model. The data used to construct the input conditions was obtained from five local airports, and several buoys. Wind conditions were interpolated to the grid and specified as spatially varying hourly data for the duration of the model. The heat flux conditions were specified as a constant value for the entire model domain in a time varying series.

2.1.6 Model-Data Comparisons

As mentioned previously, the hydrodynamic model performance was calibrated by HQI (HydroQual, 2008) using data from a number of different sources, and at various locations and time-periods. These datasets are summarized here to provide an overview of the extensive model calibration and validation undertaken by HQI. The datasets include:

- Quarterly temperature and salinity data collected by the Meadowlands Environmental Research Institute in the Hackensack River from 1993 onwards.
- Data were collected by Tierra Solutions, Inc. (TSI) in the Lower Passaic River during 1995-1996. Data consisted of bottom-mounted moorings measuring temperature, salinity and current meters. Transect survey data were also available. Both moored and transect data were measured at several locations within the lower 8 miles of the LPR (see Figure 4-2 in HydroQual, 2008).
- Data collected by IMCS of Rutgers University between 2000 and 2002 was used to calibrate the model in the Kills and Newark Bay. The data were collected at two locations within Newark Bay, in the Arthur Kill and Kill van Kull near their confluence with Newark Bay, and in the Arthur Kill near its confluence with Raritan Bay (see Figure 4-4 in HydroQual, 2008). These data sets were the same ones used by Pence (2004) to examine the model constructed for the region. These data included bottom mounted ADCP, bottom mounted temperature, conductivity, and pressure sensors. The sensors were rotated throughout the deployment, so there were significant gaps in the data for this time period. Two periods were chosen for calibration and validation of the Newark Bay system.
- Data collected by IMCS of Rutgers University in the Lower Passaic River in 2004. The data were collected at various locations within the lower 8 miles of the LPR (see Figure 4-5 in HydroQual, 2008). These data included measurements from

bottom mounted ADCPs, pressure sensors, and surface and bottom mounted temperature and salinity sensors.

2.1.7 Output

As described, output was provided by HQI for two of the periods. Subsequently, output was provided for the WY1996, and the calibration period in 2000.

2.2 10 Year Simulation

The necessary inputs to carry out a continuous 10-year simulation spanning the period from WY1995 through WY2004 were delivered by HQI to the CPG modeling team in December 2008. This submittal also included sensitivity tests, calibration runs, implementation of sediment heat flux, and tests on the wetting and drying implementation. This section addresses the input setups for the 10-year simulation.

2.2.1 Model Grid

The model setup for the 10-year simulation included a few changes to the grid. The orientation of the computational domain in the Hackensack River was altered north of the Meadowlands. The number of grid cells remained the same, but the orientation of the computational grid was altered. Figure 2-12 shows the changes in terms of computational domain and Figure 2-13 shows the differences in the computational grid for the calibration periods and the 10-year simulation. Changes in the model grid were explained in the Semiannual Modeling Meeting with EPA that took place in March 2009. The original model grid configuration involved a rotation of the Hackensack River in model-space. This was a purely computational heuristic implemented to reduce computation time. The grid used in the 10-year simulation did not retain this rotation of the grid. It should be noted that the model results were unaffected by this change to the model grid.

2.2.2 Model Bathymetry

The model bathymetry used for the 10-year setup is the same as that used in the calibration with the notable exception of the area in the Hackensack River where the grid orientation was altered. The bathymetry within the Lower Passaic River remained constant from WY1995 through WY2002. The bathymetry changed within the Kills and Newark Bay for WY2000 to incorporate the change in bathymetry as a consequence of the deepening of the navigation channel undertaken by the US Army Corps of Engineers during this period. Bathymetric changes associated with the changes in grid orientation in the Hackensack River are shown in Figure 2-14 and Figure 2-15. Changes in the bathymetry in this region were marginal.

2.2.3 Offshore Boundary Conditions

The offshore sea surface elevation conditions for the 10-year simulation were identical to those used for the calibration conditions. They are specified monthly and are the same for each yearly period.

2.2.4 Discharge Conditions

There were 29 river discharges implemented within the 10-year model simulation as opposed to the 26 implemented within the calibration runs. These additional 3 discharges correspond to the Second and Third Rivers and McDonald Brook which were not included in the calibration run. Diffuser inputs (WWTP, CSO, SWO) are changed in two locations, the RAINMAN inputs 75 and 611 located in grid cells I,J = 48,83 and I,J = 52,77. These points are not close to the LPR and NB domain and the changes to the inputs are therefore considered marginal.

2.2.5 Meteorological Conditions

The meteorological inputs for the 10-year simulation are identical to those used for the calibration conditions.

2.3 2005 Verification Period

Model inputs for an additional period corresponding to water year 2005 was prepared by HQI. The model performance during this period was compared by the CPG-MT against data collected by Dr. Chant at Rutgers University (IMCS) during 2005. This included limited data collected during a significant storm event in April 2005. The data included fixed moorings at six mooring locations in the lower 6 miles of the LPR during Fall 2004, Winter 2005, and Summer of 2005. The mooring deployments that are focused on in this analysis were deployments (DOT) 2 and 3 in Winter and Summer of 2005, respectively. These mooring locations are shown in Figure 2-16 and Figure 2-17 and were distributed in the lower 8 miles of the LPR. The types of sensors at each location in the two deployments are shown in Figure 2-18 and Figure 2-19 as provided by IMCS at Rutgers University. Shipboard surveys were also conducted in the LPR and NB. There were a total of 12 cruises conducted from the summer of 2004 through the summer of 2005. No moorings were present during the storm event of 2005, so the only verification for high flow conditions is the data collected during the shipboard surveys.

Using data collected at the mooring locations, time-series of model and data are presented in order to compare model performance. For all comparisons, model velocities were extracted in model space, so that the dominant velocities along the channel are the V velocities in the model. The magnitudes of the velocities were computed and assigned a sign based on the channel direction. The magnitude of the measured data was computed in the same way. Therefore, all velocities shown have positive values during flood and negative values during ebb.

Figure 2-20 shows the discharge conditions during Deployment 2. This period starts with moderately high flow conditions of $\sim 120 \text{ m}^3/\text{s}$ (at Little Falls) declining to relatively average flows towards the end of the deployment. During Deployment 2, ADCP current measurements were taken at Station M2a, and ADP measurements were taken at Station M2b. Station M2a was moored in the channel, while Station M2b was moored near the bank. Figure 2-21 shows the comparison of surface and bottom velocities for Station M2a, which is located within the channel. The model performance metrics in terms of the absolute and relative RMS errors and the coefficient of determination are also shown. The model at this location tends to somewhat over-estimate the surface velocities during flood, and underestimate the ebb velocities during neap. The relative RMS error however, is less than 10%, and the coefficient of determination relatively high at 0.89. At the bottom bin, the model appears to under-predict the flood velocities, while the ebb velocities are relatively comparable to data. Overall, model results for currents compare reasonably well to data at this channel location.

Figure 2-22 shows the comparison of surface and bottom velocities for Station M2b, which is located on the shallows of the river. The model does not perform as well at this location as in the channel. The relative RMS error between model and data at Station M2b is slightly greater than 10% with relatively lower R^2 of 0.63 for both surface and bottom. Model results for the surface layer appears to compare better than the bottom layer which is typically under-predicted, especially the peak ebb velocities. In addition, during the high-flow period at the beginning of the deployment, there is a phase difference in the timing of slack water between the model and the data. These limitations in model performance may be related to artifacts of grid resolution.

In addition to velocity, salinity data were collected at 1 m from the surface and 1 m from the bottom at 6 locations as shown in Figure 2-16. Model salinity was compared to these measurements for available reliable data. Figure 2-23 shows the salinity comparisons at M1. The model appears to match the observed salinity conditions at this location during spring tide reasonably well. However, the salinity conditions during flood tide in neap conditions is significantly under-estimated. The relative RMS error between the model-predictions and observations is nearly 20% at both the surface and the bottom. Figure 2-24 shows salinity comparisons for station M2a. Data near the bottom was unreliable during this time period and is not displayed. The surface layer compares well but does appear to not capture the peaks of the salinity. The relative RMS error is over 15%. Figure 2-25 shows comparisons at Station M3. The surface layer compares well with a relative RMS error of less than 10%, while the model appears to predict less saline conditions in the bottom layer than observed, more so during neap (before December 4th and around December 22nd). During spring (around December 15th), near-bottom salinity calculated by the model is more comparable to the data. Figure 2-26 shows similar comparisons at Station M4. The data in the bottom layer were unreliable, and are not shown. In the surface layer, both the data and the model show primarily fresh conditions in this time period. The model reproduces the change from fresh to more saline conditions around December 18th. Similarly, the salinity conditions at Station M5 are shown Figure 2-27. The model correctly predicts fresh-water conditions during most of this time period, while capturing

the change from fresh to more saline conditions around during the low flow periods around December 24th.

Discharge conditions during Deployment 3 are very low – with maximum discharges of about 30 m³/s as shown in Figure 2-28. Velocities during this deployment were collected at Station M1. From the diagram shown in Figure 2-17 it appears that the mooring of the ADP was located not in the center of the channel but more towards the edge of the channel. Figure 2-29 shows the comparison of surface and bottom velocities for Station M1. The model tends to show greater ebb-dominant currents than noted in the data at the surface, especially during neap; the model tends to under-predict flood velocities and over-predict ebb velocities. However, the overall relative RMS error at the surface is just about 6%. In contrast, the model consistently under-predicts the near-bottom velocities during both flood and ebb, with a relative RMS error of over 9%. These features are indicative of flow patterns expected on the shallows of the LPR rather than in the channel; this may be an artifact of the grid resolution, with the model reproducing features more representative of the shallows. Figure 2-30 shows the comparison of measured and model-calculated surface and bottom velocities for Station M2a within the channel. In general, surface currents appear very well correlated with the data, although the peaks during both flood and ebb seem to be over-estimated resulting in a relative RMS error of over 11%. In the bottom layers, the model appears to capture the flood velocities, while overestimating the ebb currents for an overall relative RMS error of about 10%.

Salinity comparisons during DOT3 are shown in Figure 2-31 through Figure 2-36. CTD sensors were only present in the surface layer at M1 and near the bottom at M6. Some of the data appears unreliable, for example the latter half of the near-bottom time-series at M2a which shows limited intra-tidal variability as well as values lower than surface measurements (Figure 2-32), the flat-lining noted towards the end of the time-series in the near-bottom measurements at M3 and M4 (Figure 2-33 and Figure 2-34). In addition, the near-bottom salinity at M5 (Figure 2-35) does not have the intra-tidal variability seen in other near-bottom stations. Overall, salinity results for these low-flow conditions appear to compare well with measured values. The model reproduces the major features seen in the data – intra- and inter-tidal variability, and the response to the flow event of July 10th.

In addition to comparing model performance to long-term time-series measurements at fixed locations during moderate to below-average flow conditions, the model performance was assessed during an extreme river flow event on April 5, 2005 when the flow at Little Falls peaked at about 12,000 cfs. A series of shipboard measurements of salinity performed by Dr Chant of Rutgers University within LPR and NB provide a snapshot of the salinity distribution within the LPR and NB and information to assess the response of the salt wedge to the elevated river flow. Figure 2-37 shows a comparison of the measured and model-calculated salinity distribution longitudinally within the LPR and NB. The model results were extracted at 15:30 on 5 April 2005, corresponding to the period when the measurements were taken. KM 0 on the x-axis corresponds to the beginning of the survey in the southern part of Newark Bay and not the mouth of the Passaic; according to this frame of reference the mouth of the LPR is at approximately KM 7. This is so as to be able to compare the full results of the shipboard survey. This flow event was preceded by a

period of relatively low flows during which the salt front is expected to have been located well within the LPR. As seen in the data, due to the elevated river flow, the salt front is pushed down to the mouth of the LPR, a trend captured by the model as well. Both the location of the salt front as well as the salinity values in NB are well reproduced by the model.

The qualitative comparison of the model to the 2005 data collection efforts (both moored and shipboard surveys) indicates that the model performs well under varying conditions. Specifically, the comparison of the post-storm salinity contours indicates that the model reproduces the density structure in the system even under storm events with a return period close to 10 years. The comparison to the time-series data also shows that the model is able to capture the gradual process of salinity intrusion up-estuary during the low-flow periods following higher flows.

In addition to the model-data comparisons of velocity and salinity for the individual layers in the water column using the moored deployment data, model performance has also been assessed relative to the vertical gradient in velocity, salinity, and mass flux. This is of relevance because of the depth-dependent residual transport of suspended and dissolved matter. Therefore, it is important to quantify how strong the tidal-residual near-bottom upstream or near-surface downstream residual mass transport of (eroded) sediment is. The stronger this residual mass transport, the more suspended sediment may leave or enter the Passaic river. Figure 2-38 shows the flow at Little Falls (top panel), the comparison of model and data for the surface-bottom along channel velocity gradient (panel A), the surface-bottom salinity gradient (panel B), and the instantaneous salt flux (calculated as product of velocity and salinity) for near surface (panel C) and near-bottom (panel D). From these comparisons, it can be seen that in the surface layer, the model transports similar salt mass during neap tides as noted in the data but more salt mass during spring tides than noted in the data. Near the bottom of the water column, the mass transport appears to be similar over the entire spring-neap cycle. These comparisons suggest that the model performs reasonably well in reproducing the salt flux during most conditions and depth-intervals; the main exception is the surface depth-interval during spring tides where the model tends to over-predict during both ebb and flood.

2.4 Additional water year inputs provided by HQI

In addition to the 10-year setup described previously (from WY1995 through WY2004), and the inputs for WY2005, HQI also developed inputs for additional years. In particular, the following set of inputs were provided for the model:

- WY2006
- WY2007
- WY2008
- WY2009

- WY2010
- WY2011
- WY2012
- WY2013

The model bathymetry provided for WY2008 onwards reflects the post-dredge conditions of the NY-NJ Harbor deepening project within the navigation channels of NY harbor, the Kill van Kull, Arthur Kill, and Newark Bay.

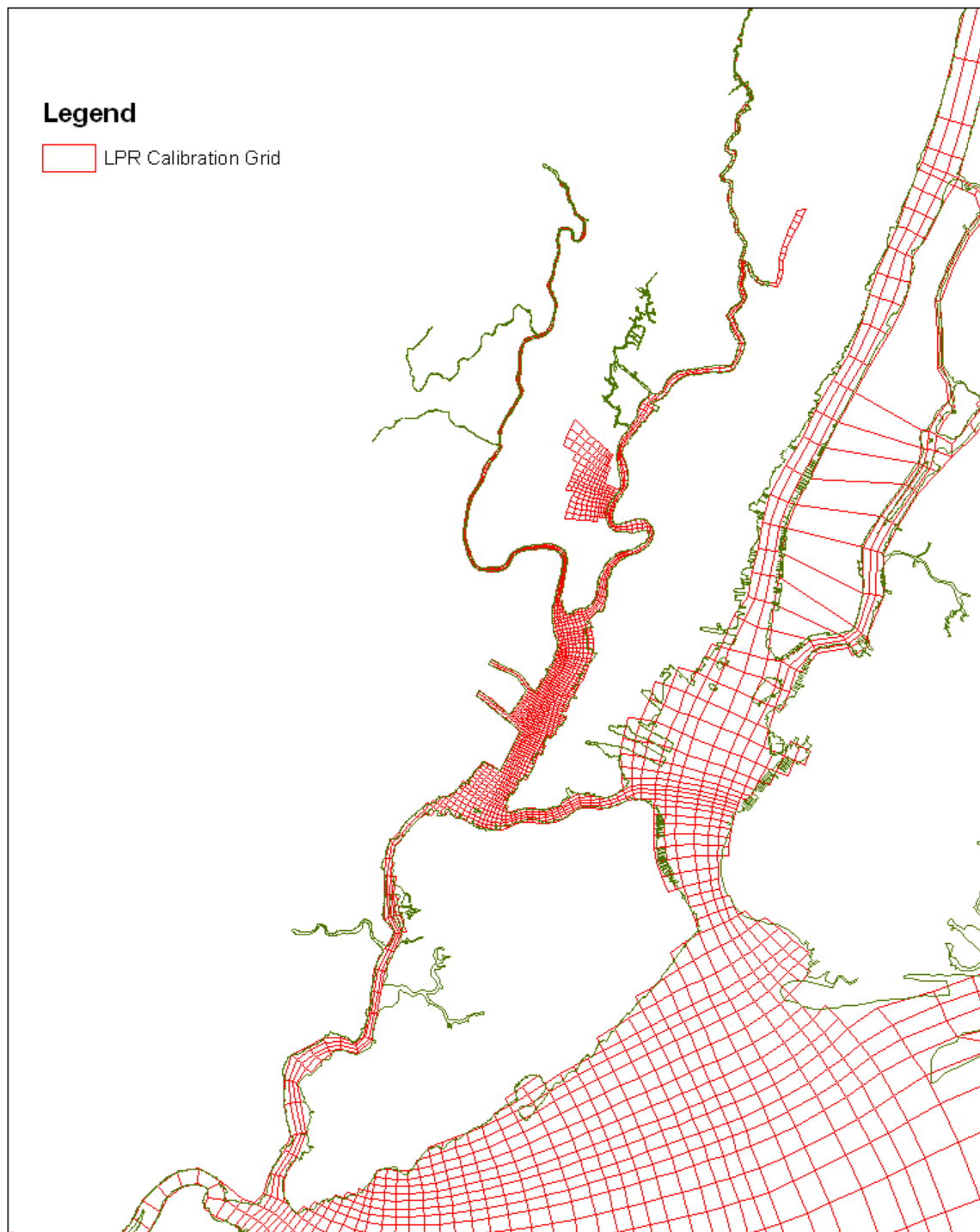


Figure 2-1: Calibration Model Grid

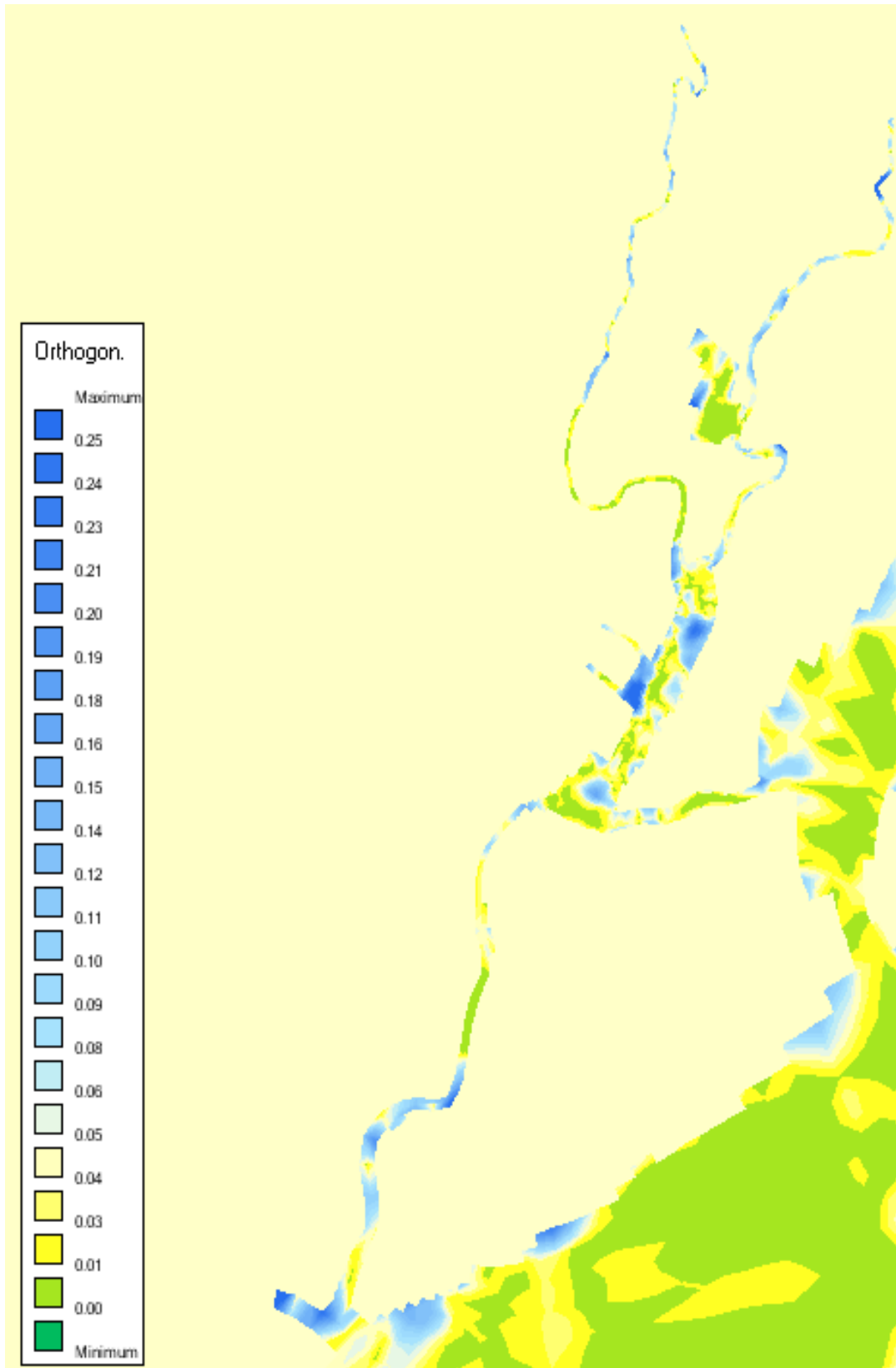


Figure 2-2: Orthogonality in LPR

**Bathymetry, Depth
Below MSL (m)**

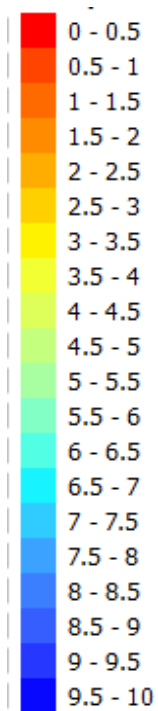


Figure 2-3: Passaic River Bathymetry (1994)

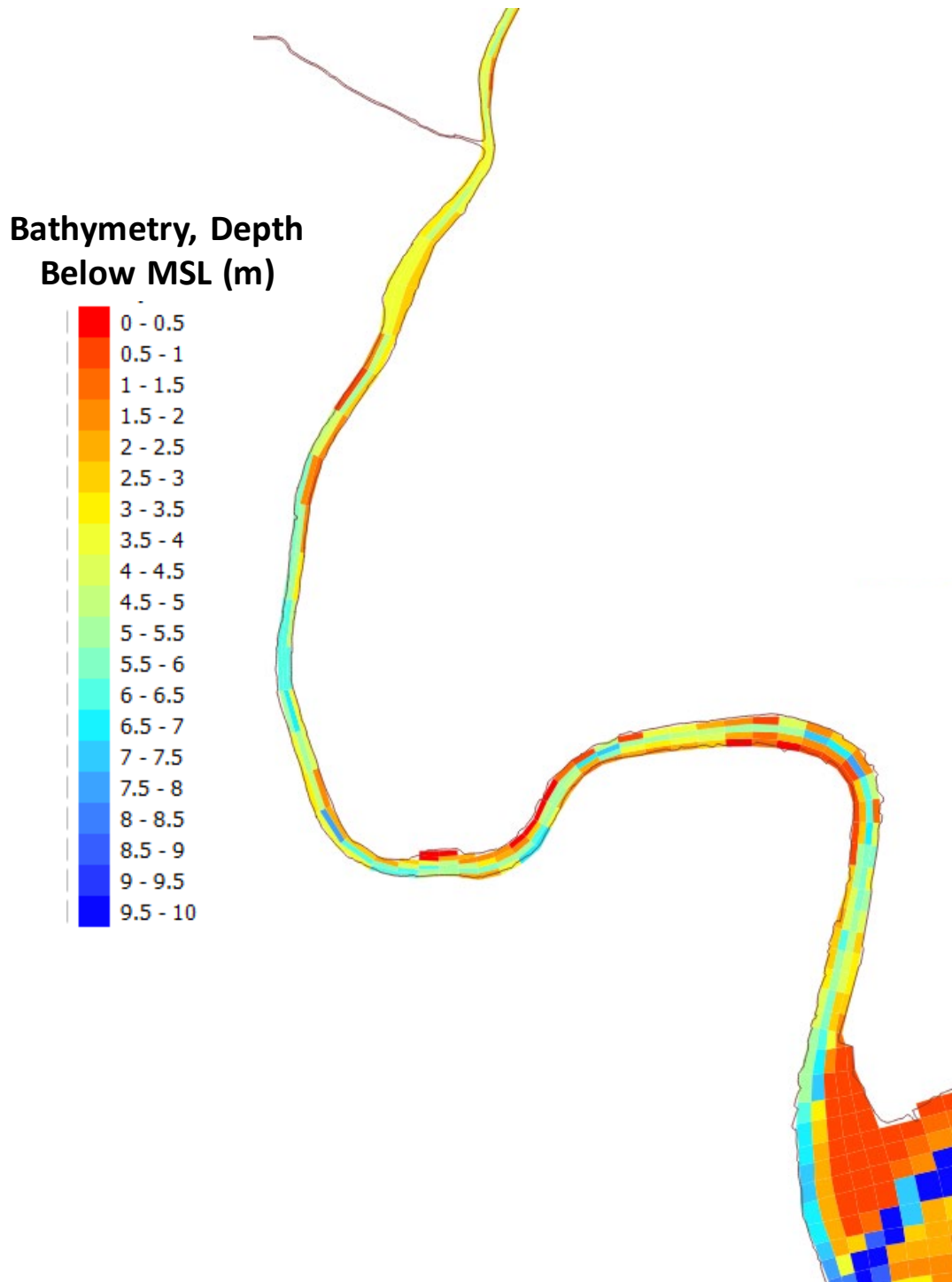


Figure 2-4: Passaic River Bathymetry (2000-2002)

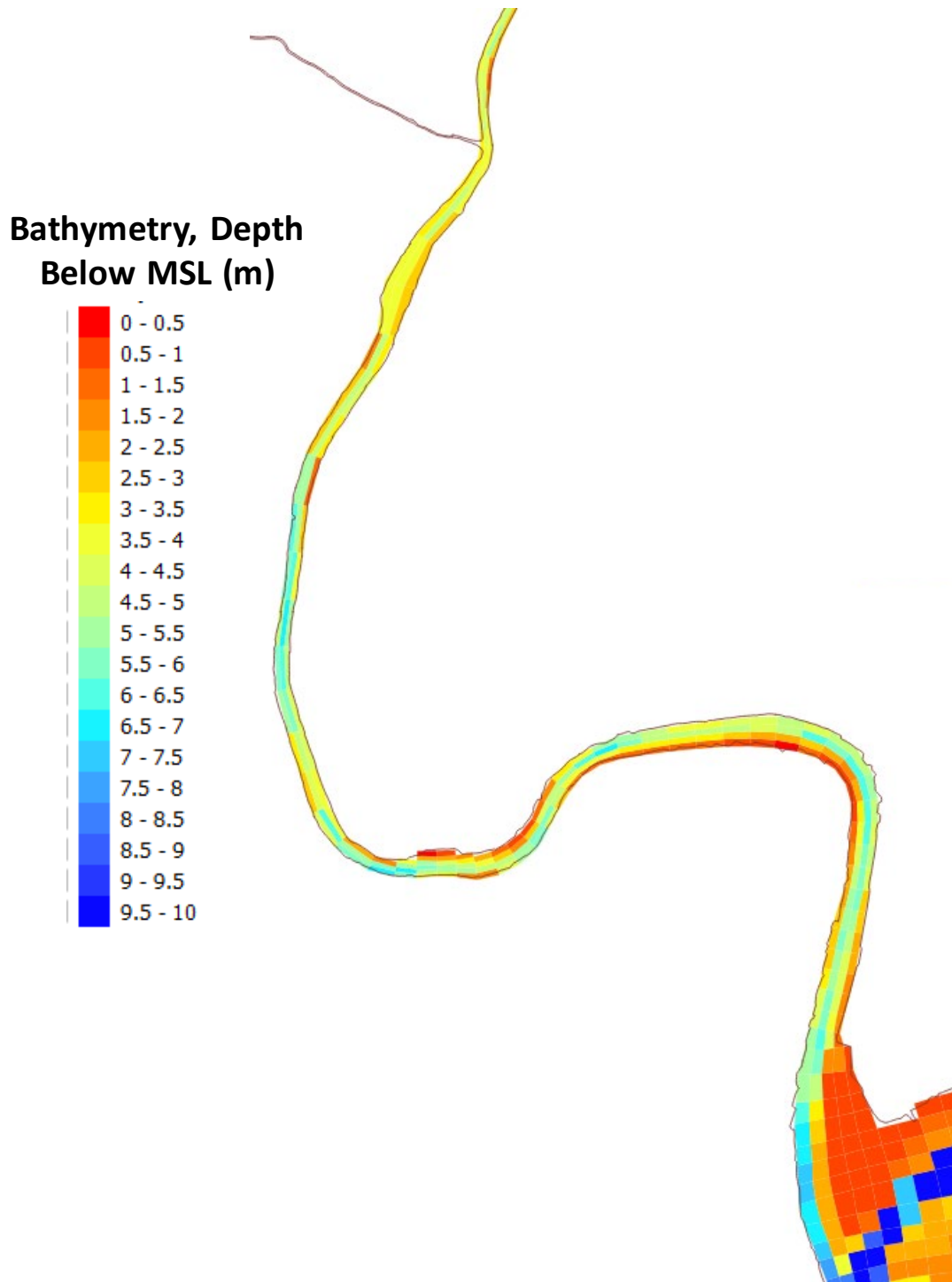


Figure 2-5: Passaic River Bathymetry (2004)

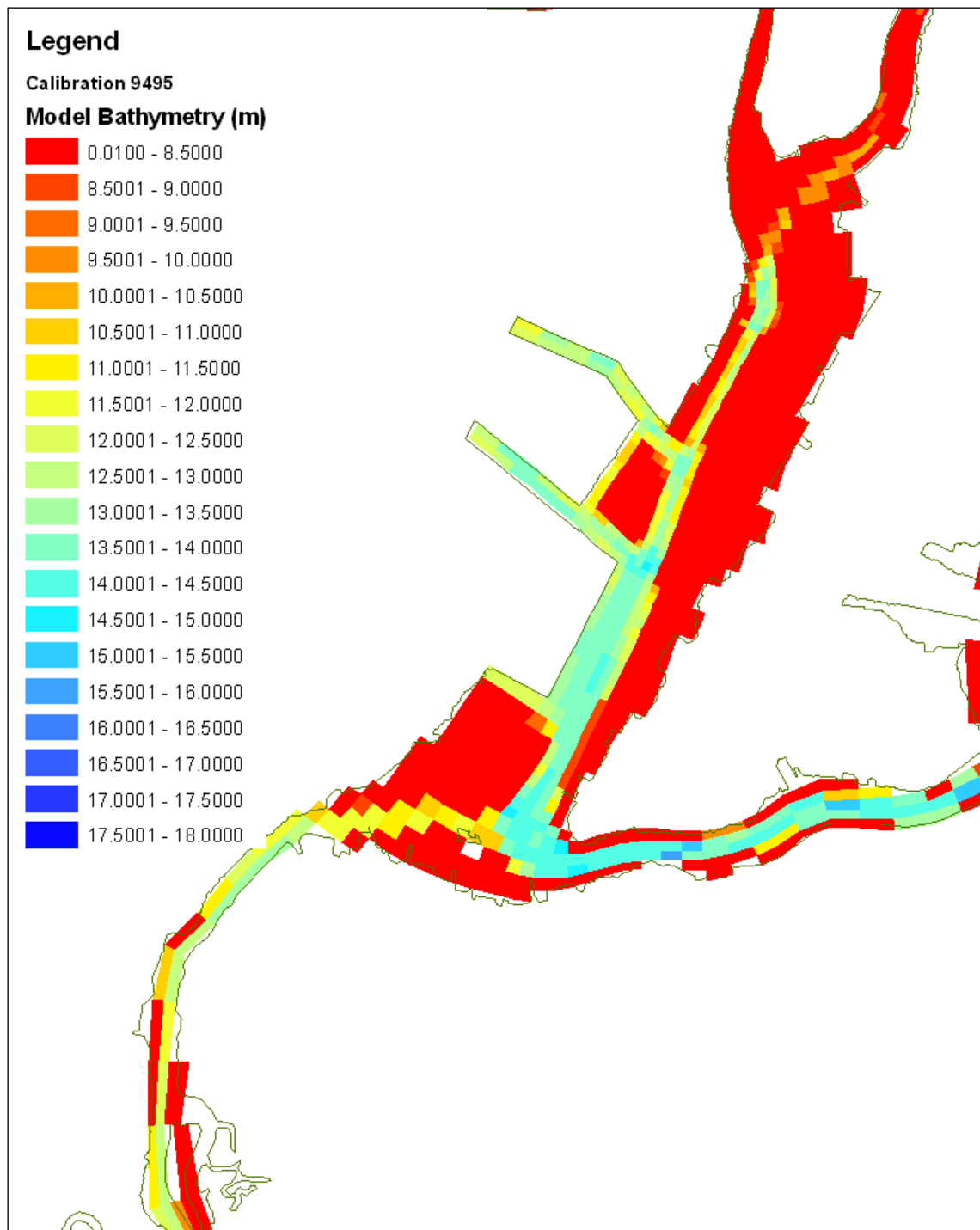


Figure 2-6: Newark Bay Bathymetry (1994)

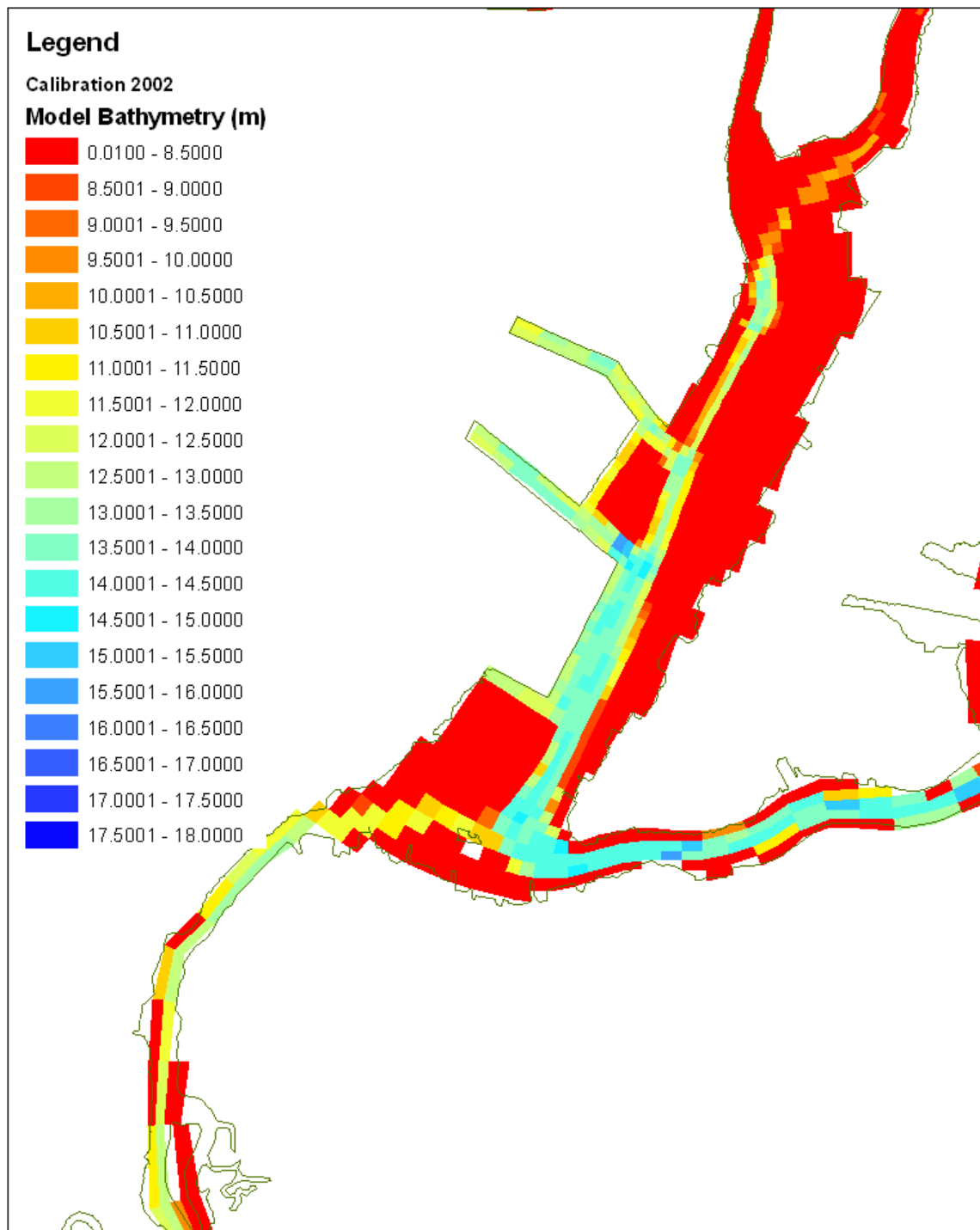


Figure 2-7: Newark Bay Bathymetry (2000-2002)

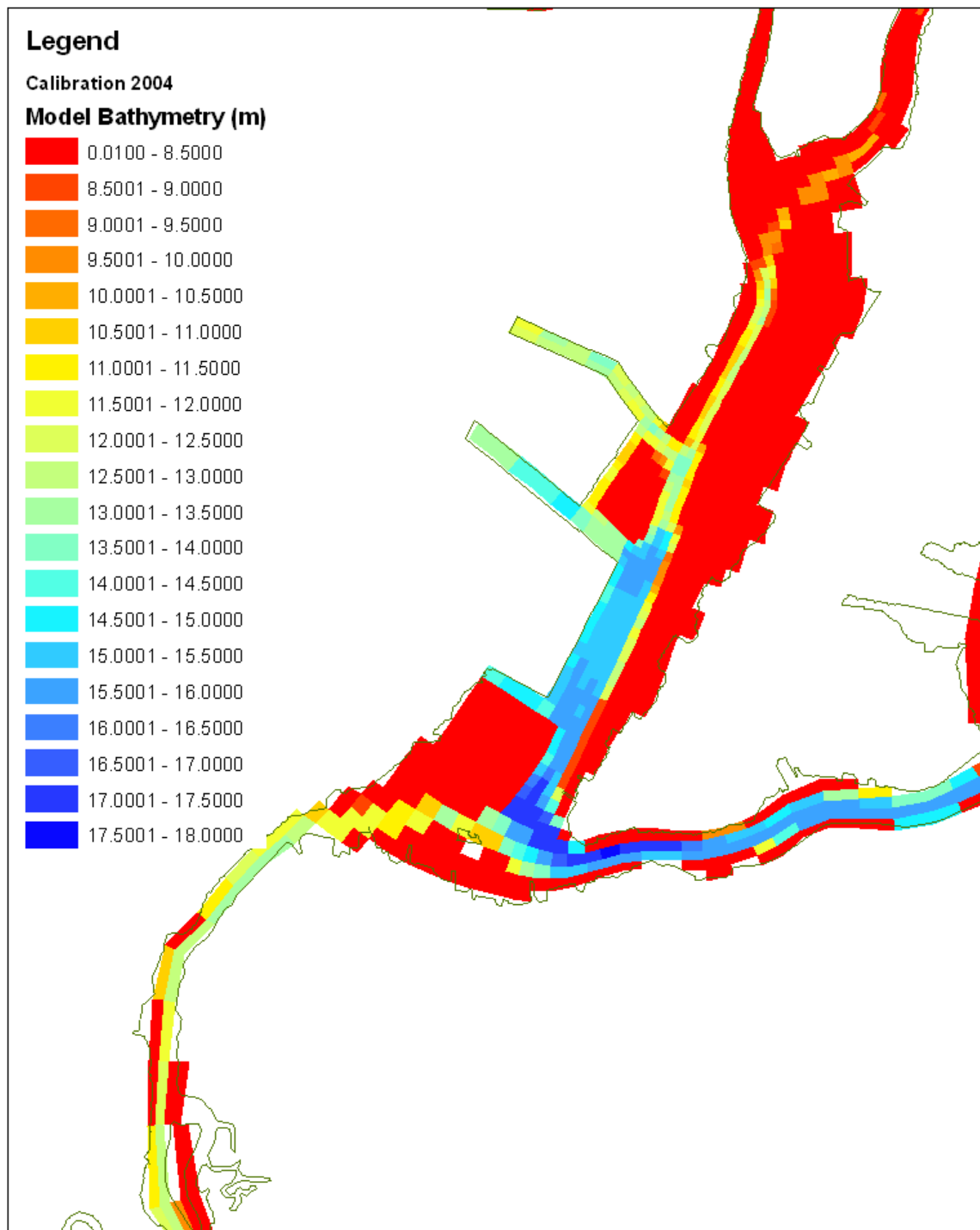


Figure 2-8: Newark Bay Bathymetry (2004)

Legend

**2004 Survey
Bathymetry, m MSL**

- <-1
- -1 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- >4



Figure 2-9: 2004 Bathymetry Upper Passaic

Legend

10yr 2004

Model Bathymetry, m MSL

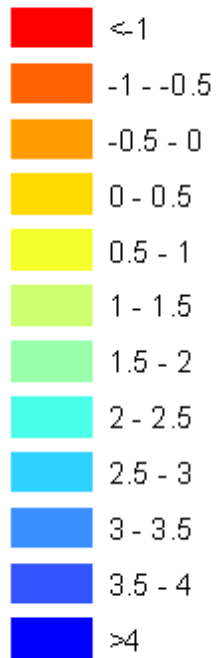


Figure 2-10: Model Bathymetry Upper Passaic

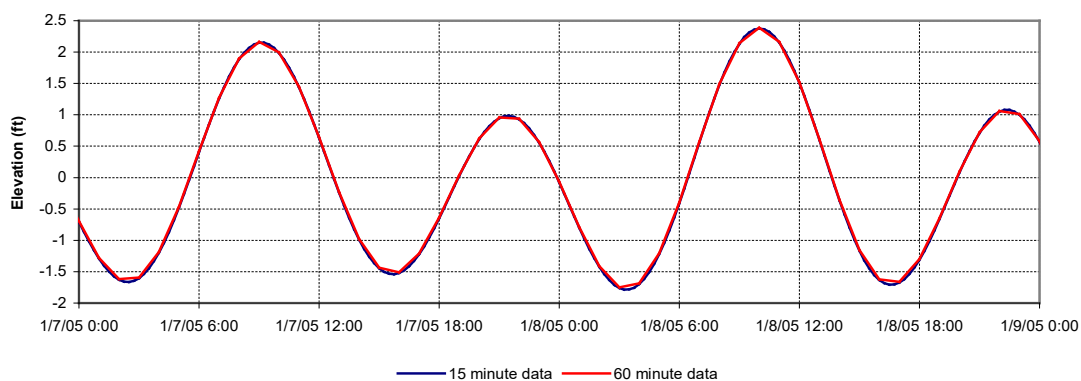


Figure 2-11: Differences in 15 minute and 60 minute elevation data

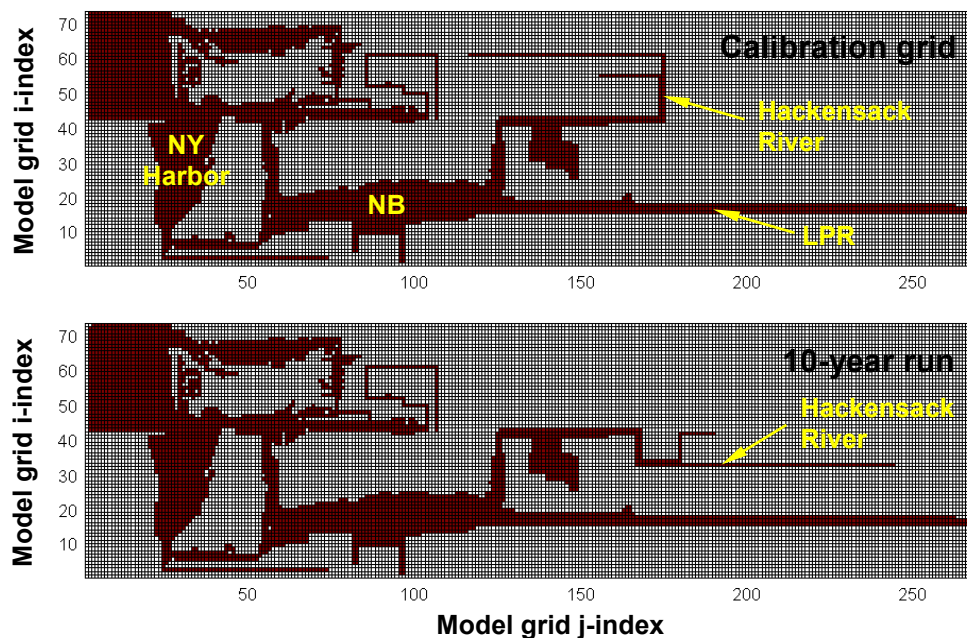


Figure 2-12: Changes in computational domain from calibration to 10 year run. Model domain plotted in IJ index-space. Red cells indicate cells included in computational domain.

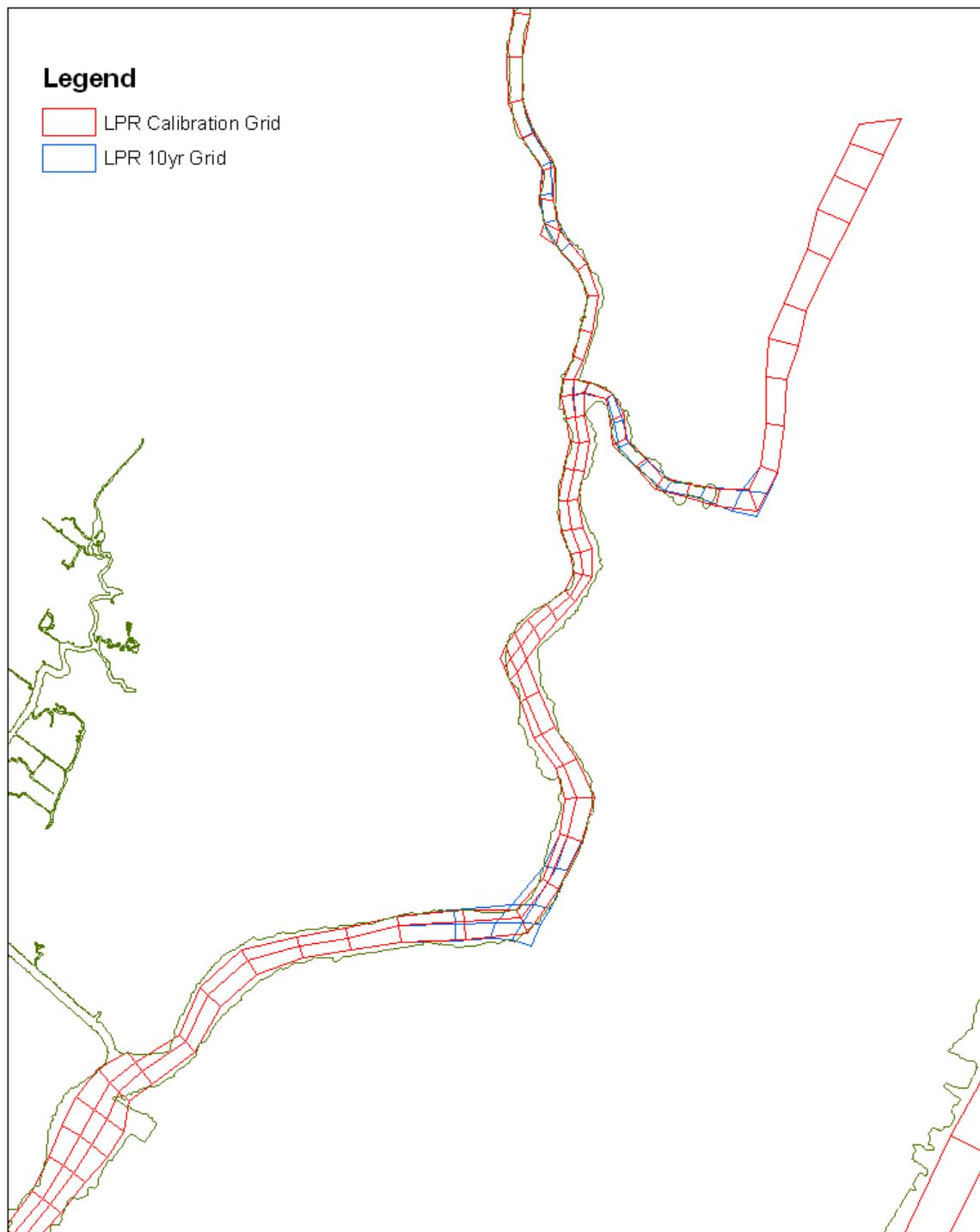


Figure 2-13: Changes in model configuration between calibration and 10 year simulation

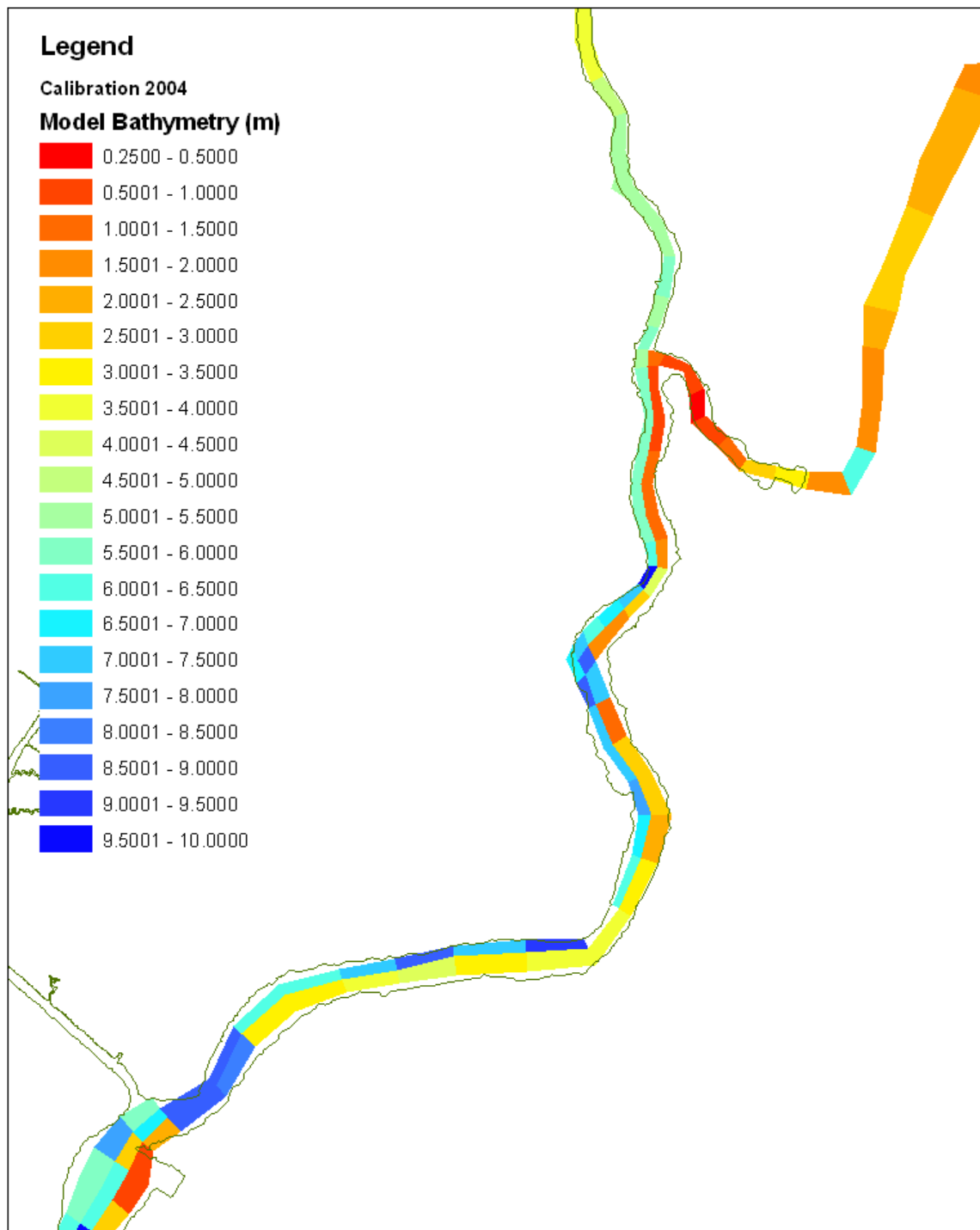


Figure 2-14: Model Bathymetry Calibration

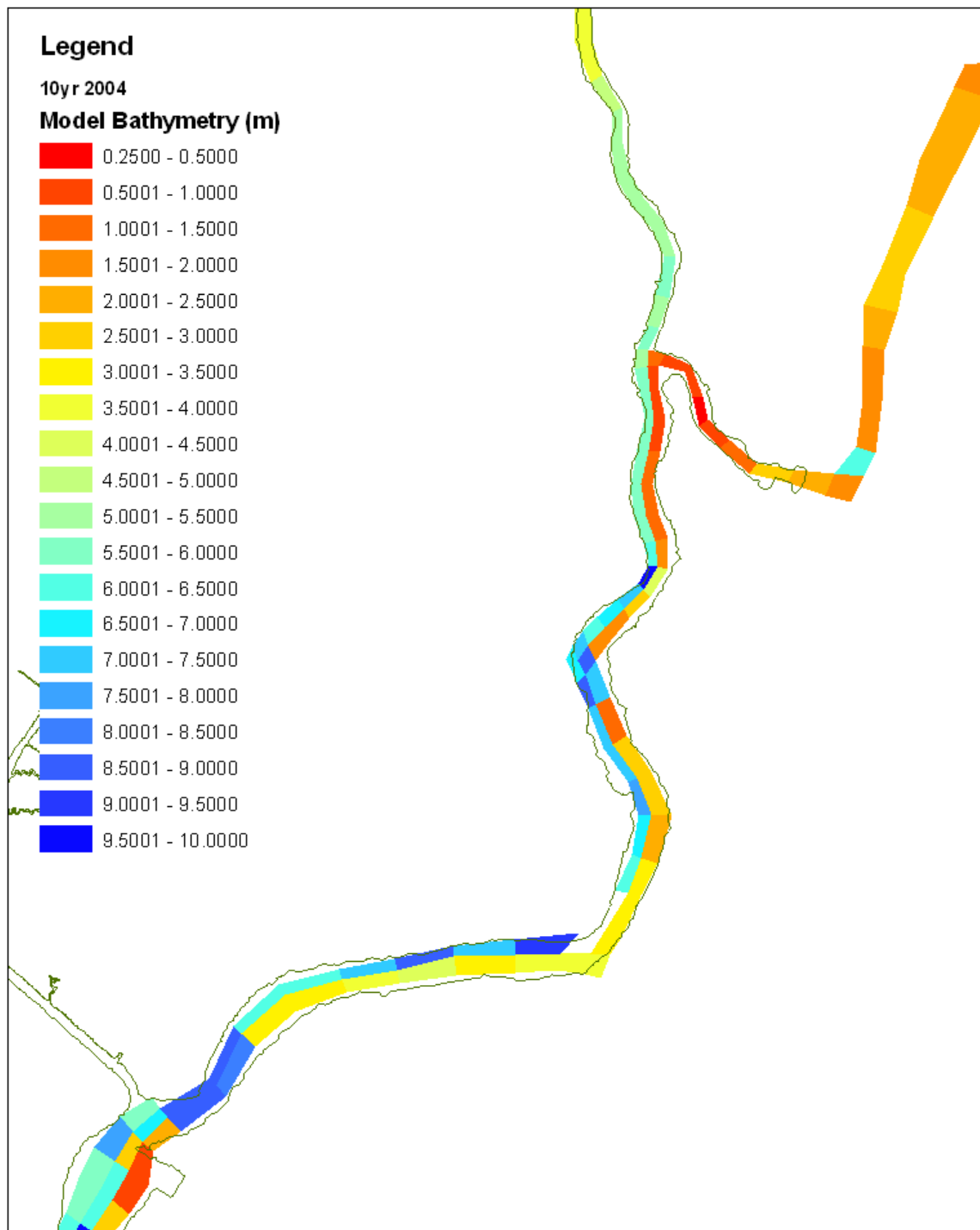


Figure 2-15: Model Bathymetry 10 year simulation

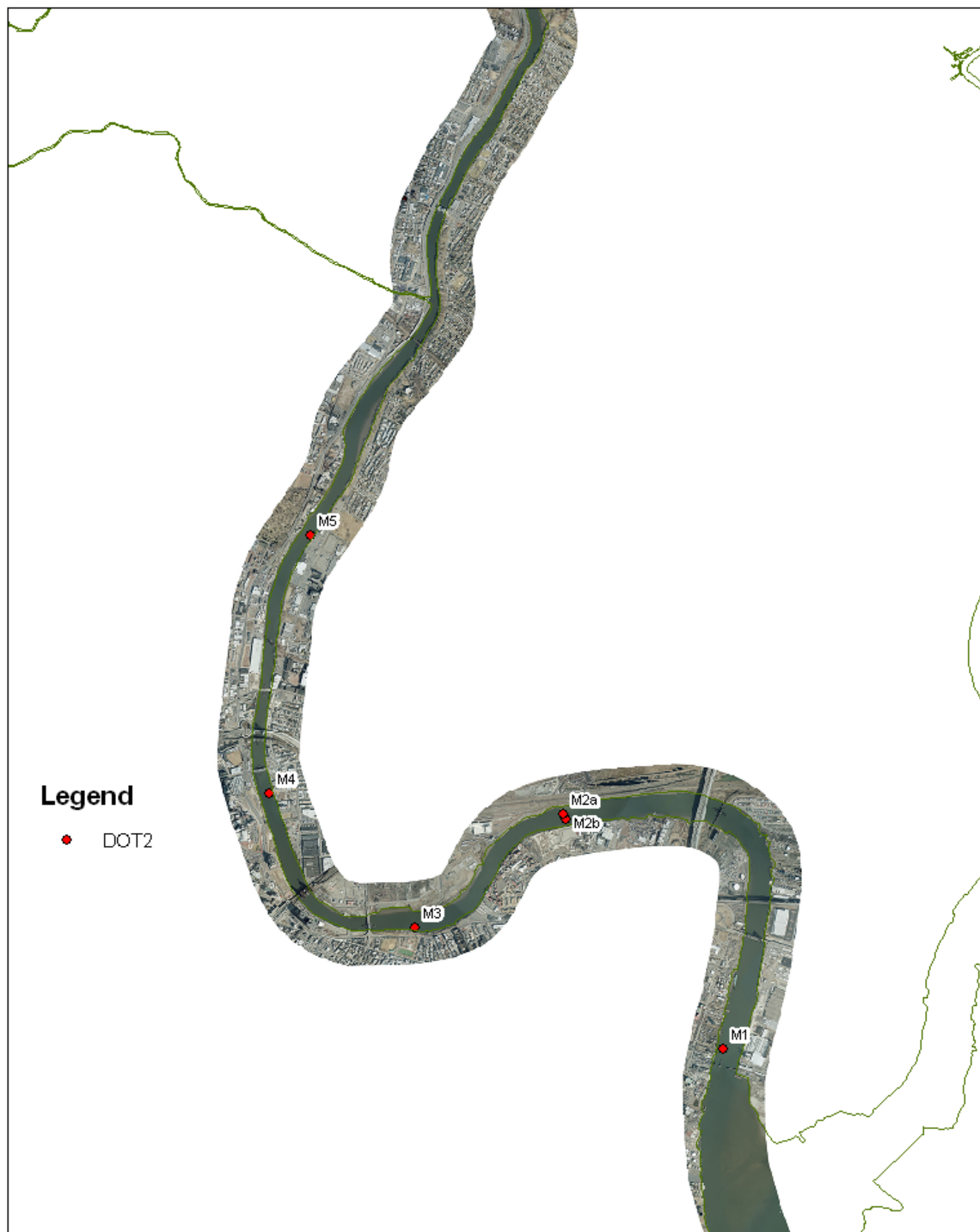


Figure 2-16: Stations used in deployment 2 (DOT2)

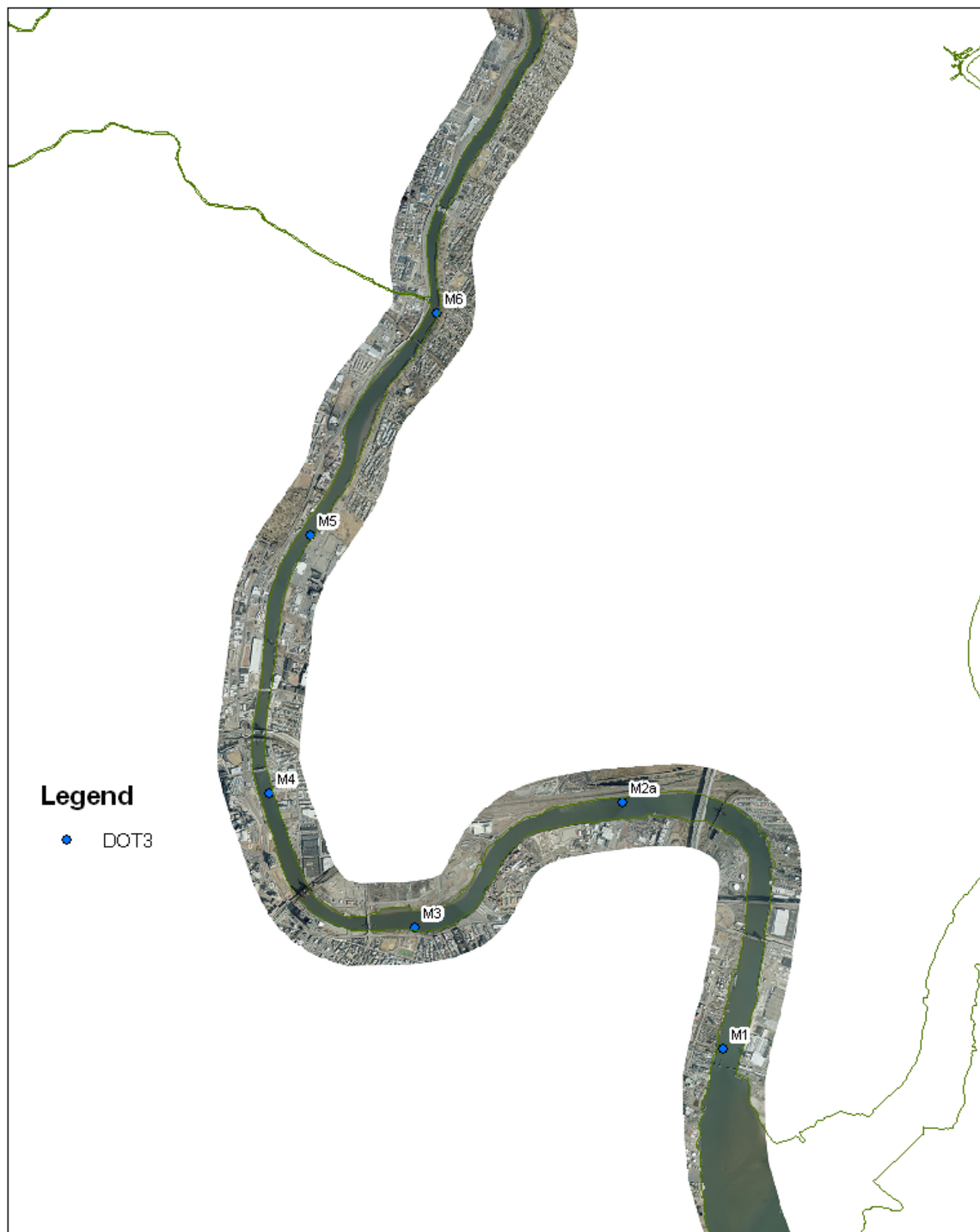


Figure 2-17: Stations used in deployment 3 (DOT3)

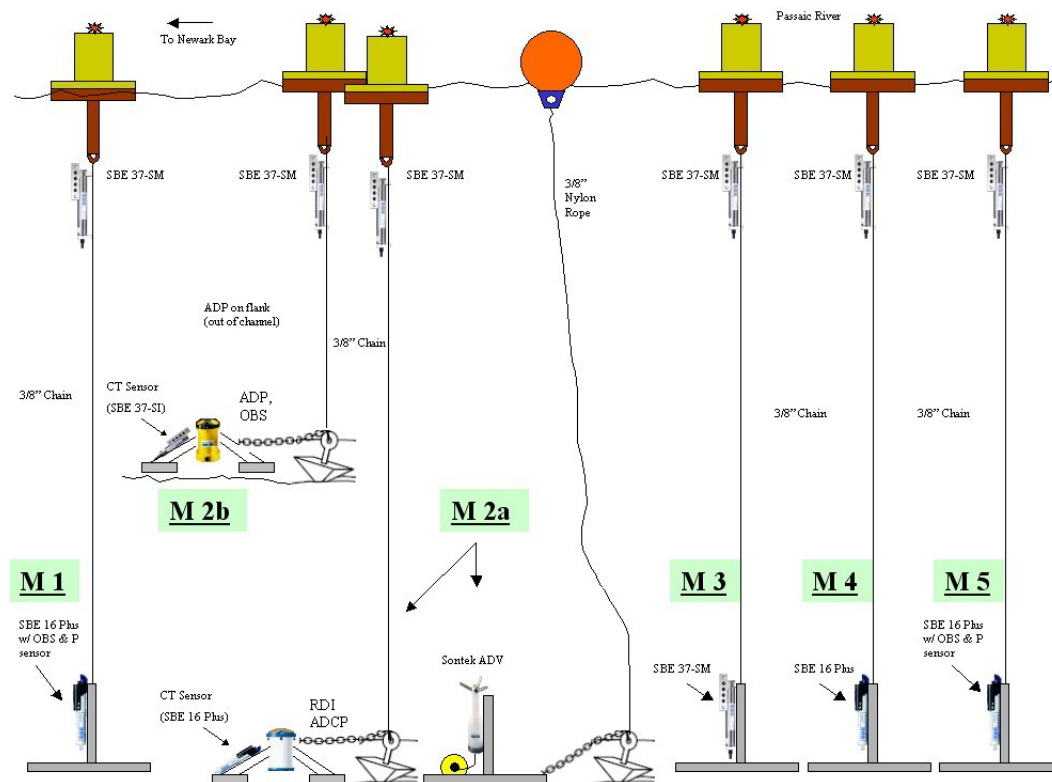


Figure 2-18: Mooring descriptions for deployment 2

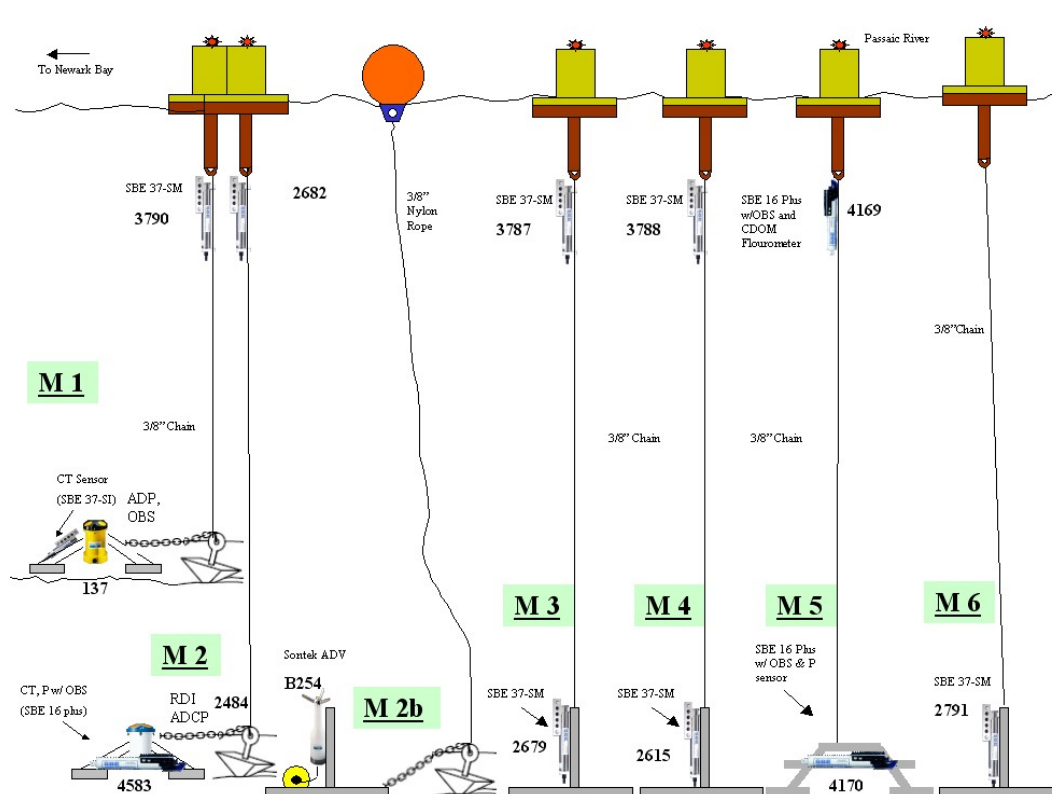


Figure 2-19: Mooring descriptions for deployment 3

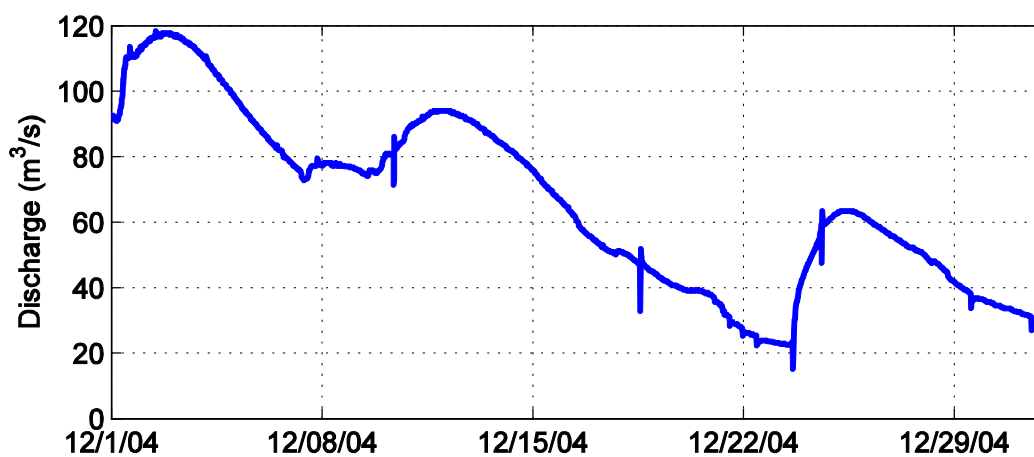


Figure 2-20: 15-minute discharge recorded at the USGS station at Little Falls during DOT2

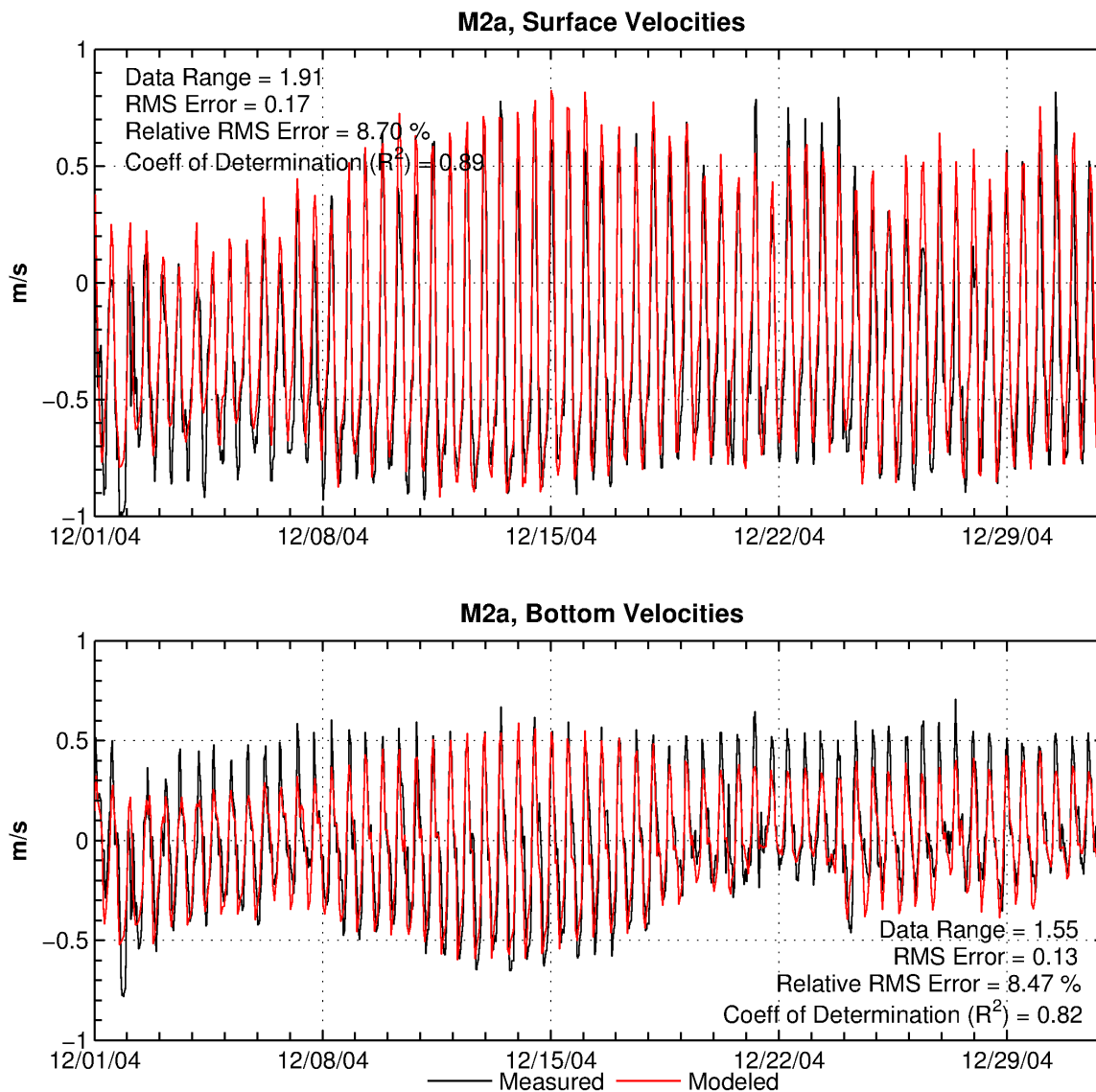


Figure 2-21: Currents near the surface and bottom at station M2a during DOT2

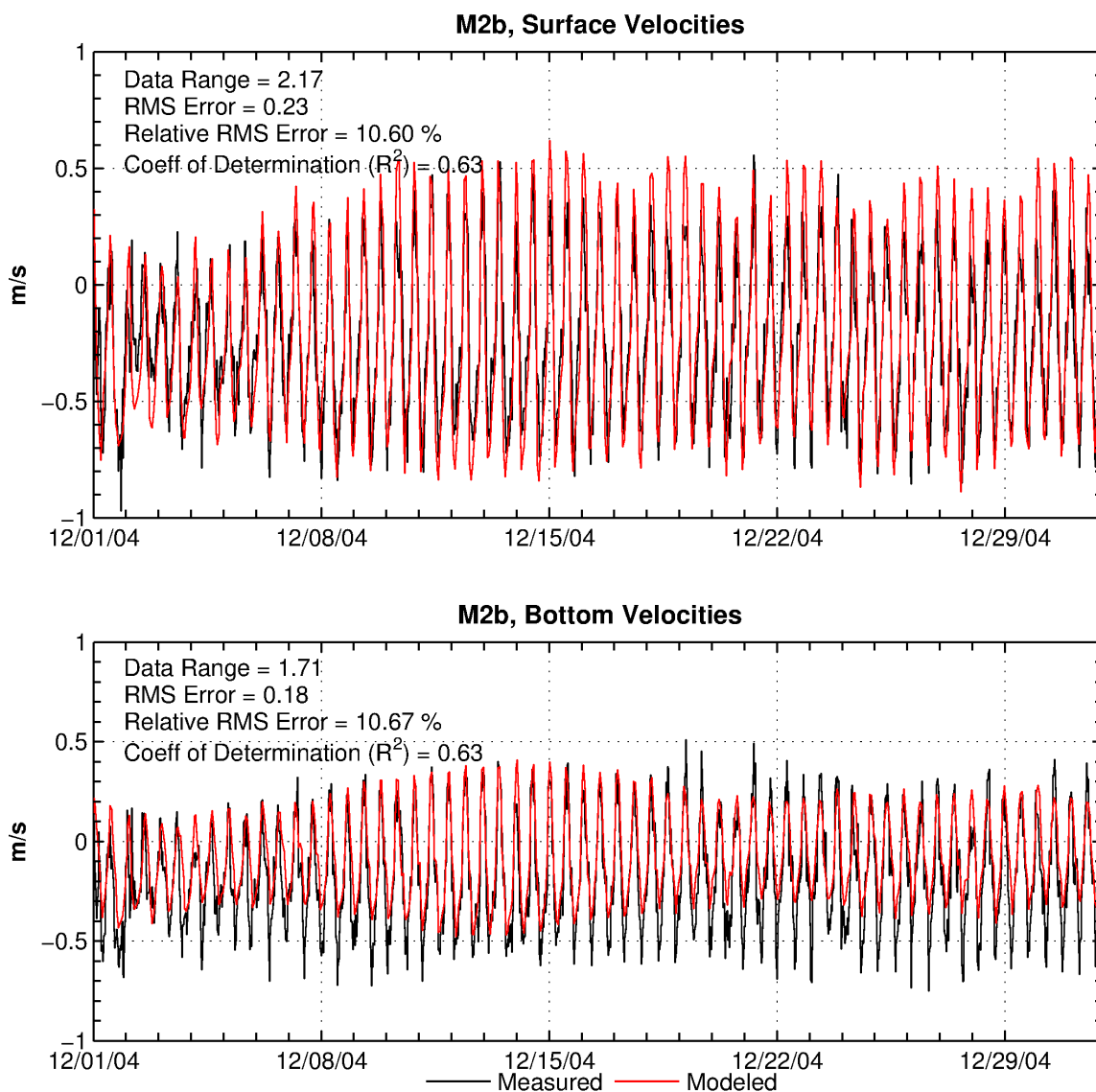


Figure 2-22: Currents near surface and bottom at station M2b during DOT2

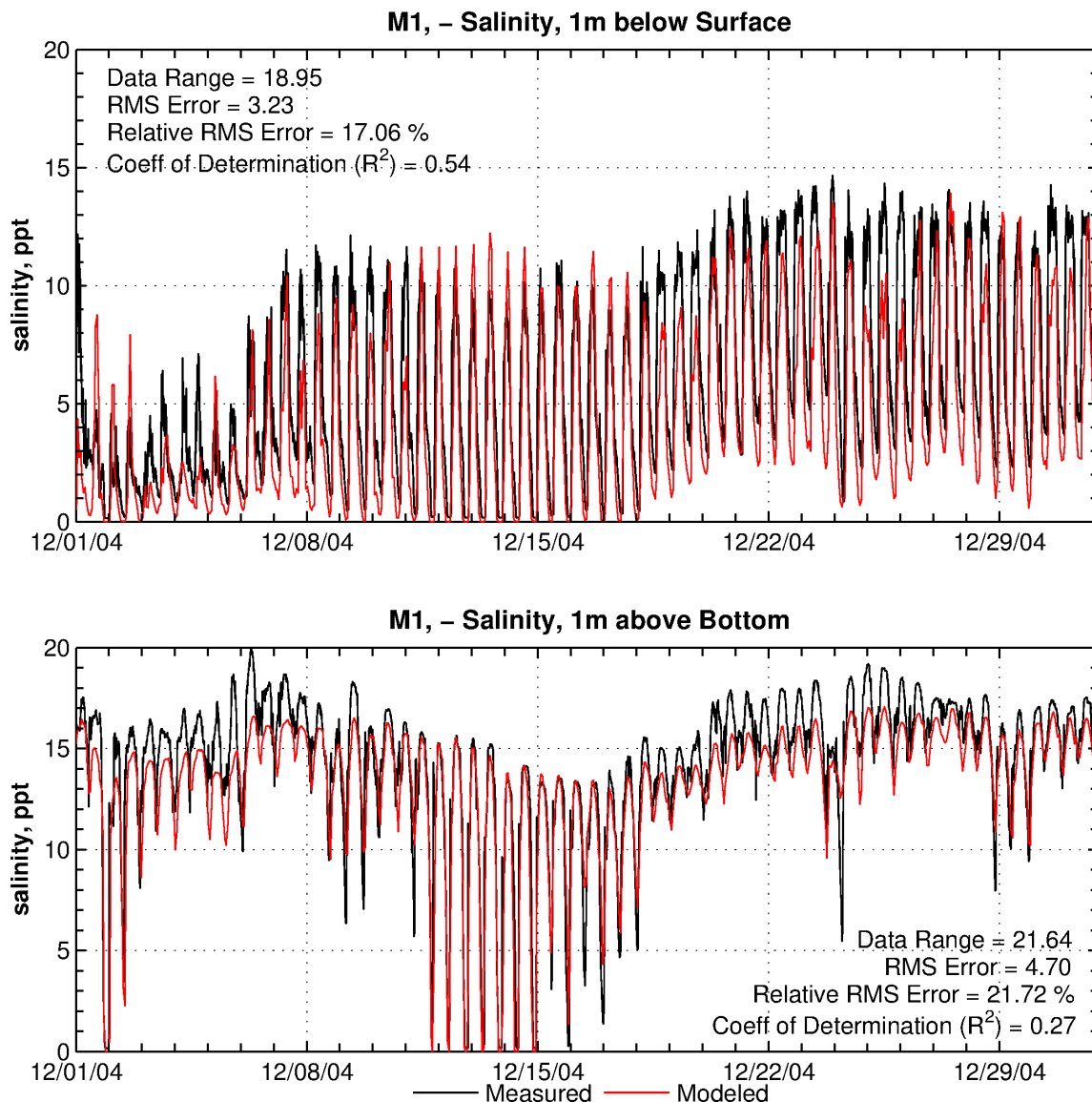


Figure 2-23: Salinity at surface and bottom for M1 during DOT2

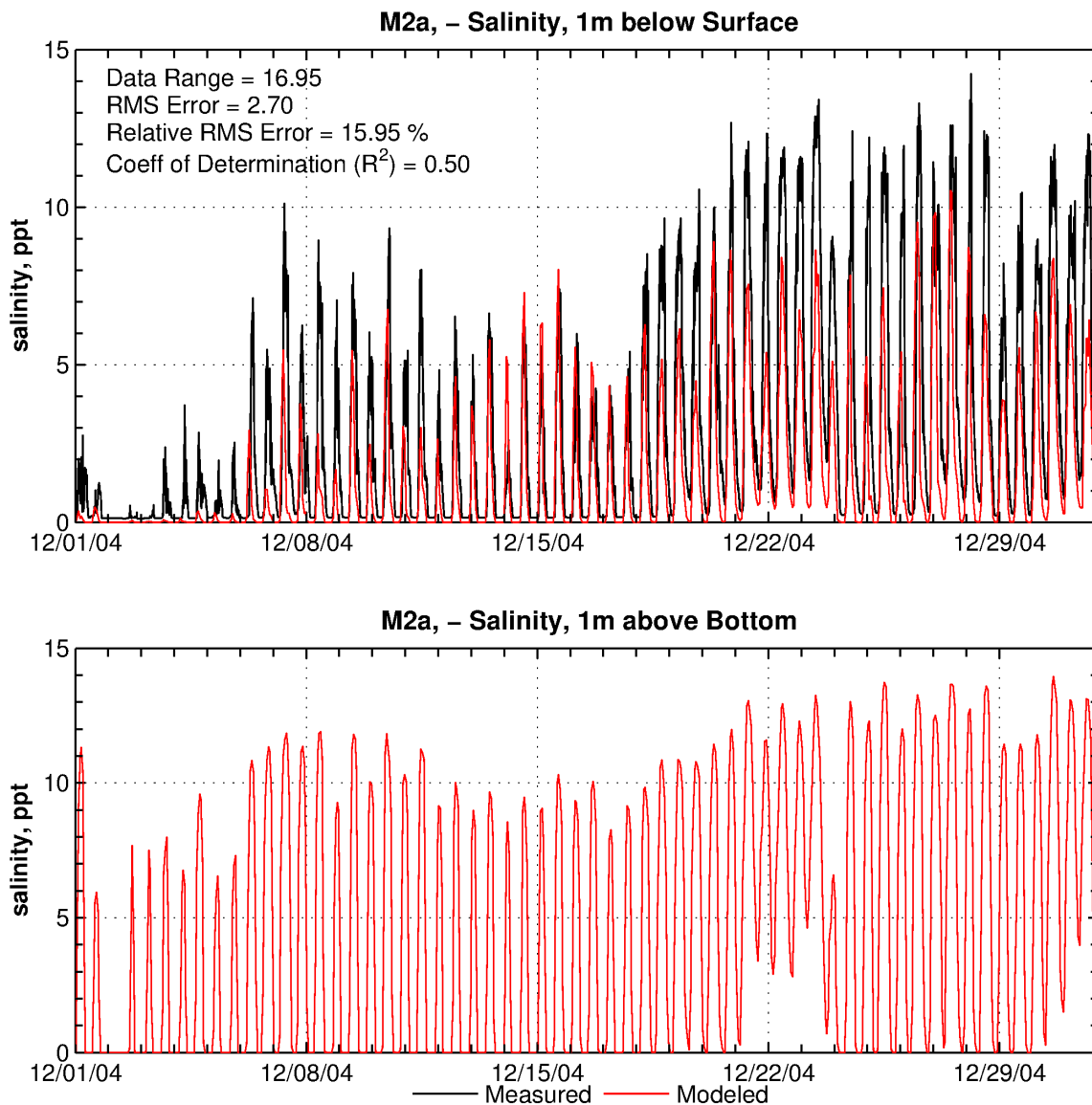


Figure 2-24: Salinity at surface and near-bottom for station M2a during DOT2

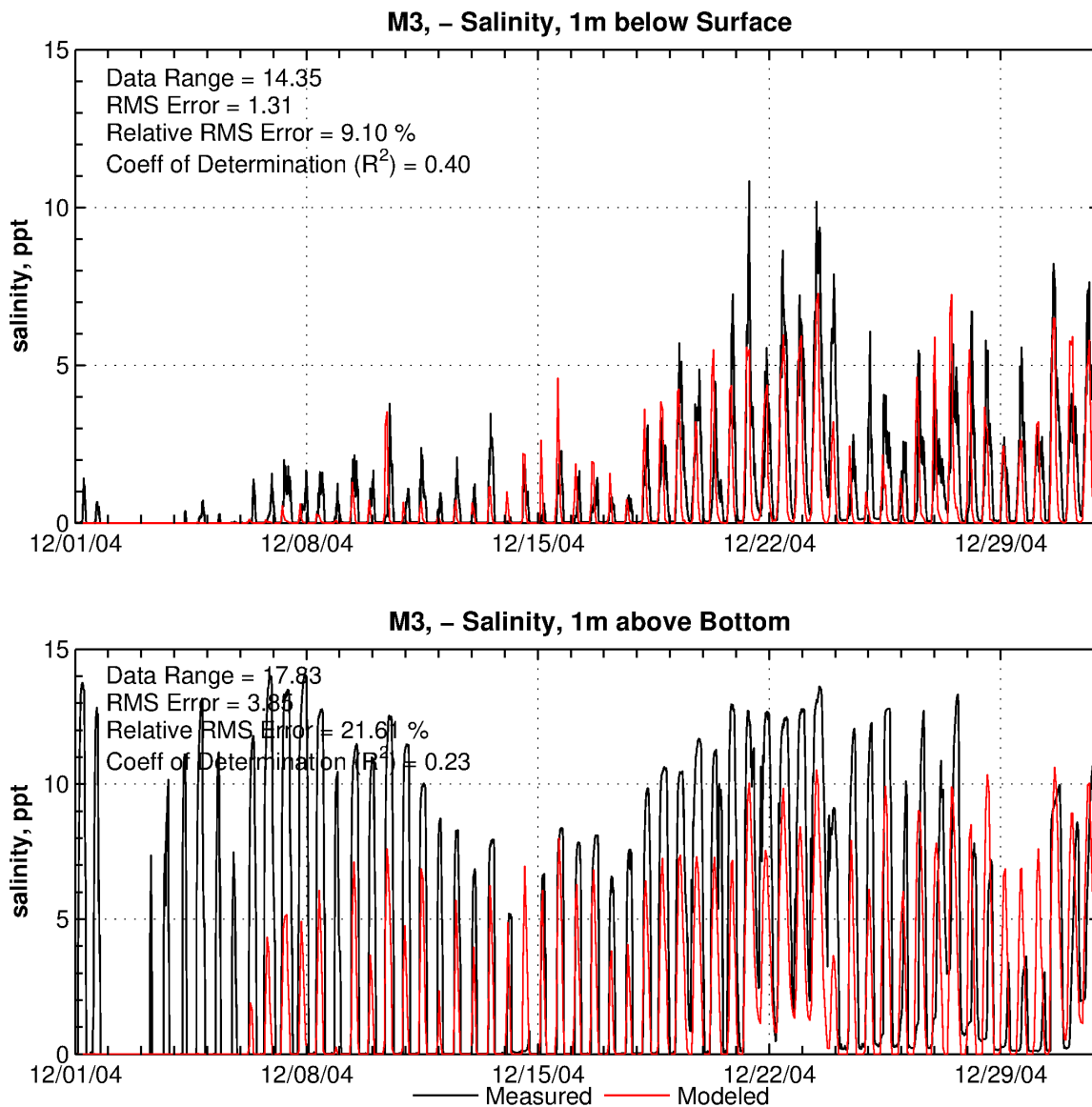


Figure 2-25: Salinity at surface and bottom for Station M3 during DOT2

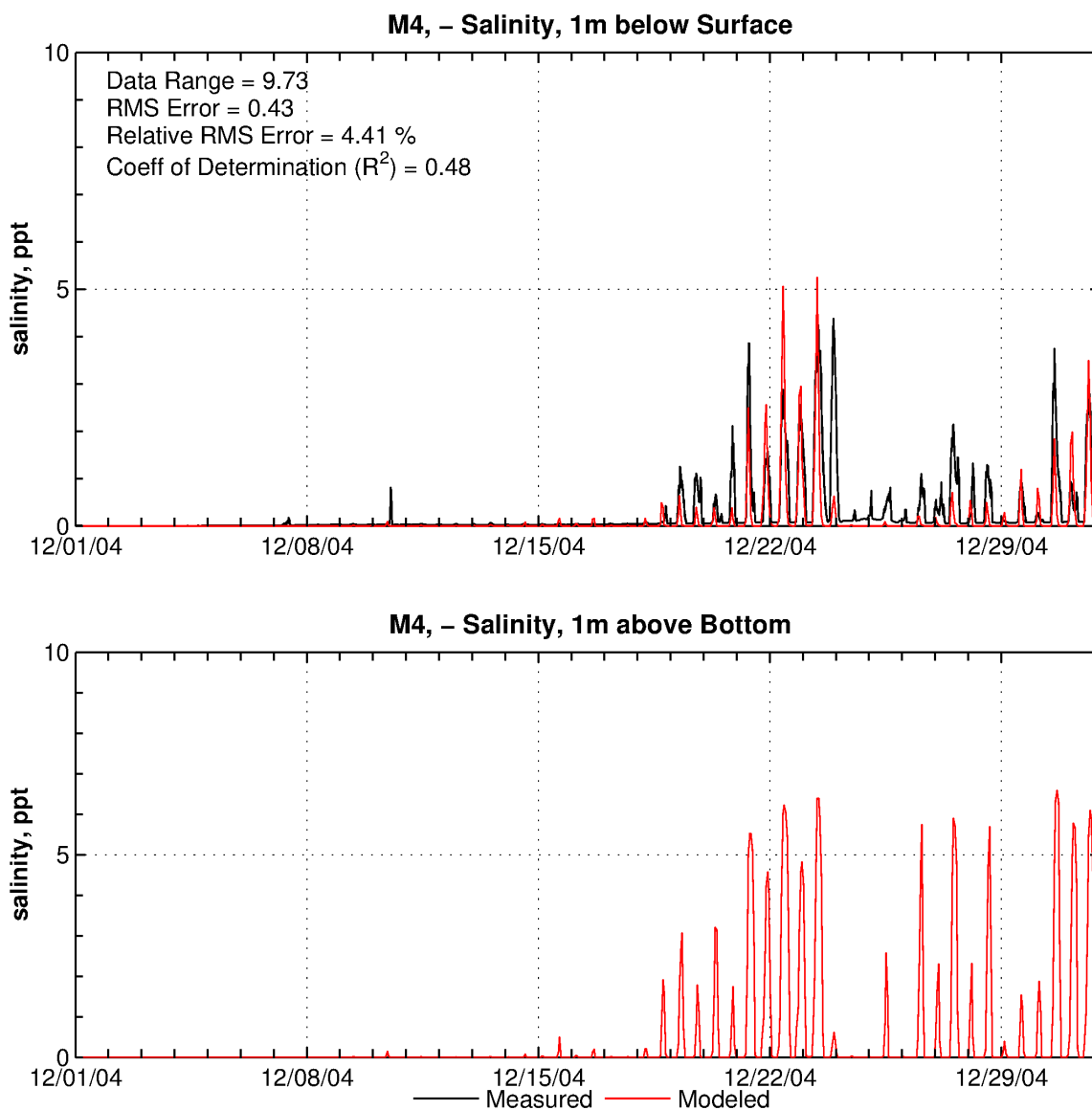


Figure 2-26: Salinity at the surface and bottom for station M4 during DOT2

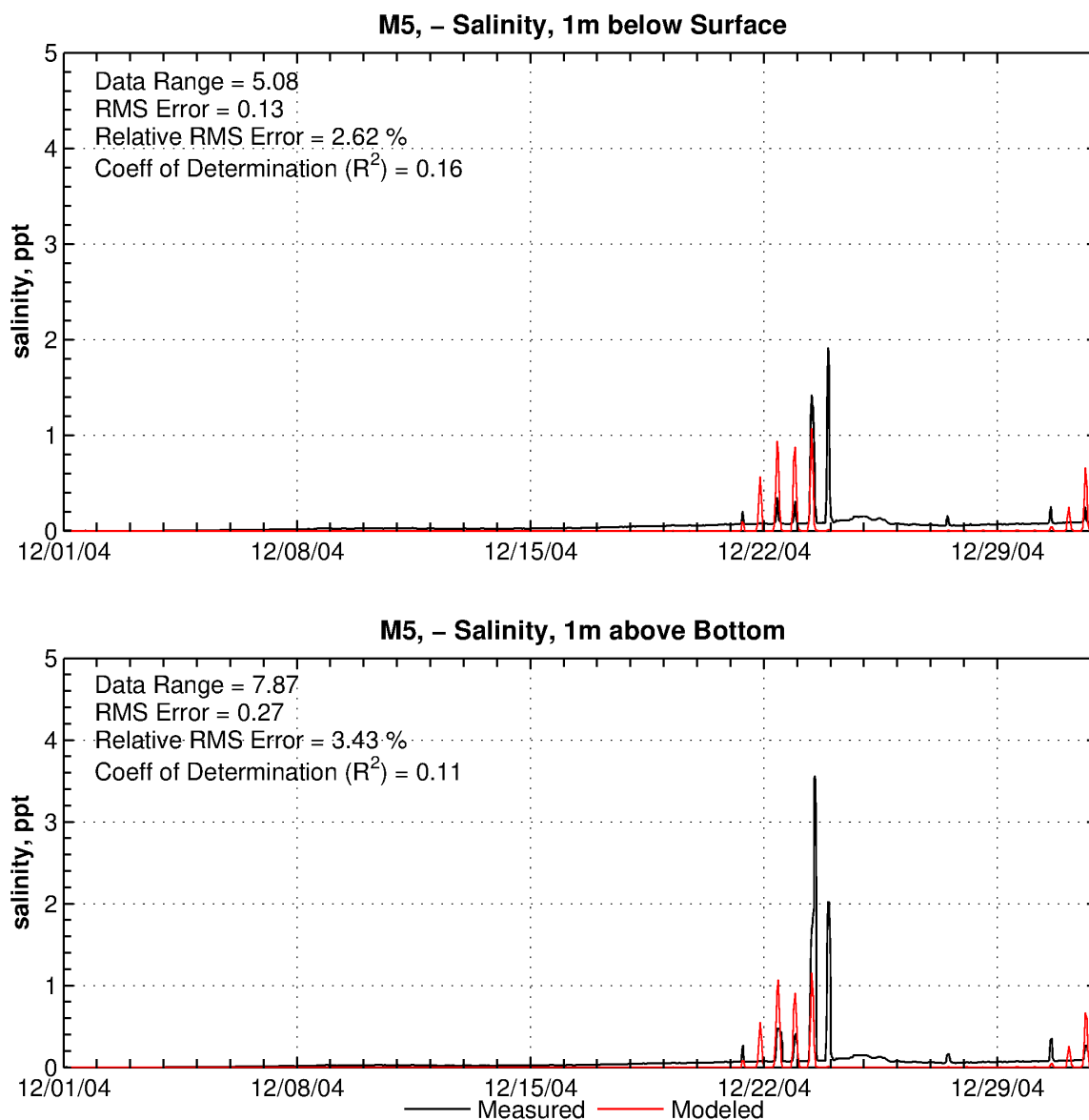


Figure 2-27: Salinity at surface and bottom for station M5 during DOT2

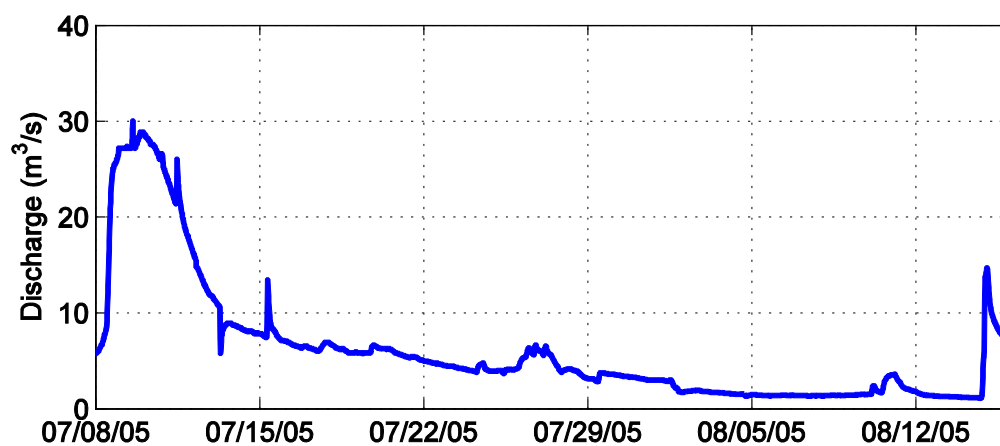


Figure 2-28: 15-minute discharge recorded at the USGS station at Little Falls during DOT3

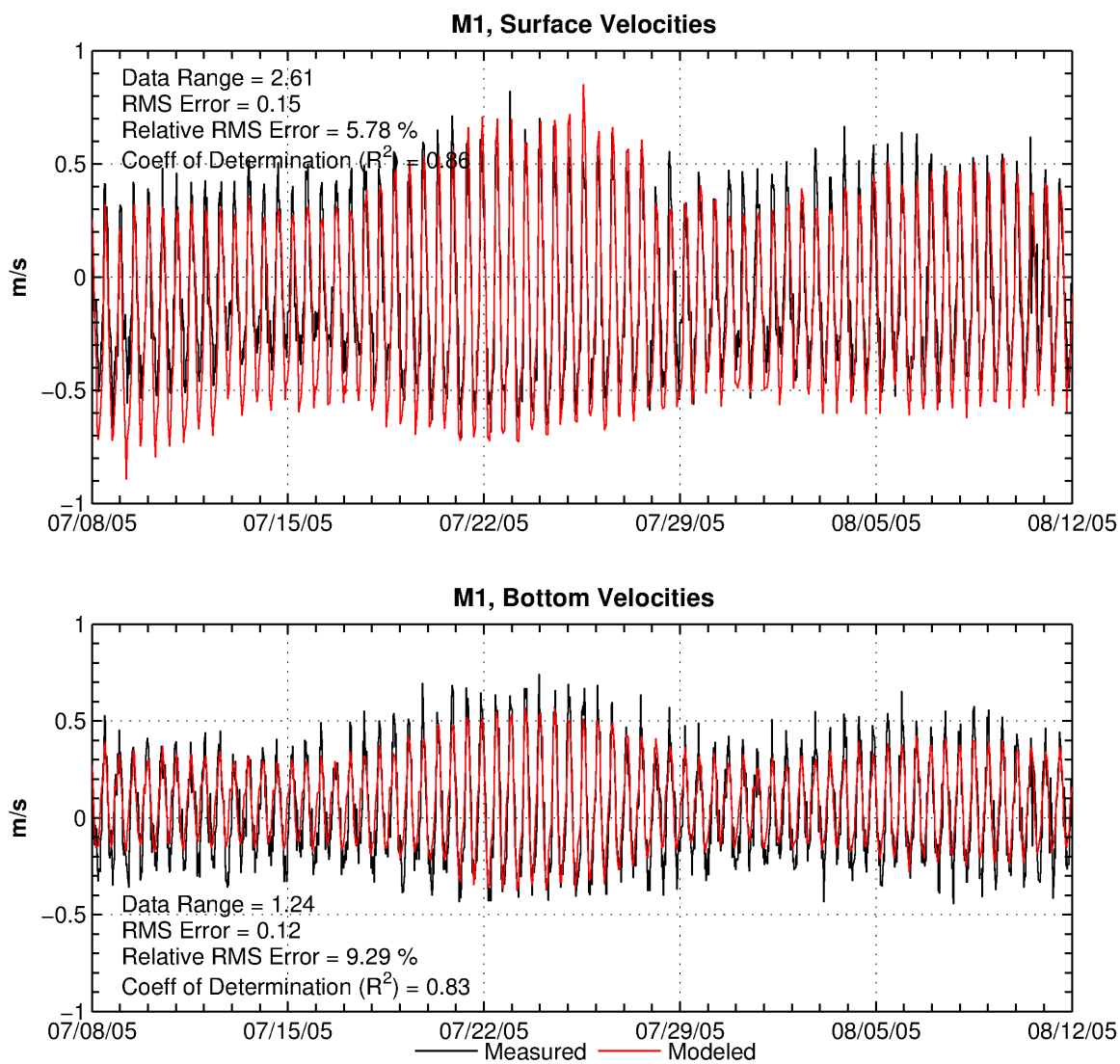


Figure 2-29: Surface and bottom velocities for M1 during DOT3

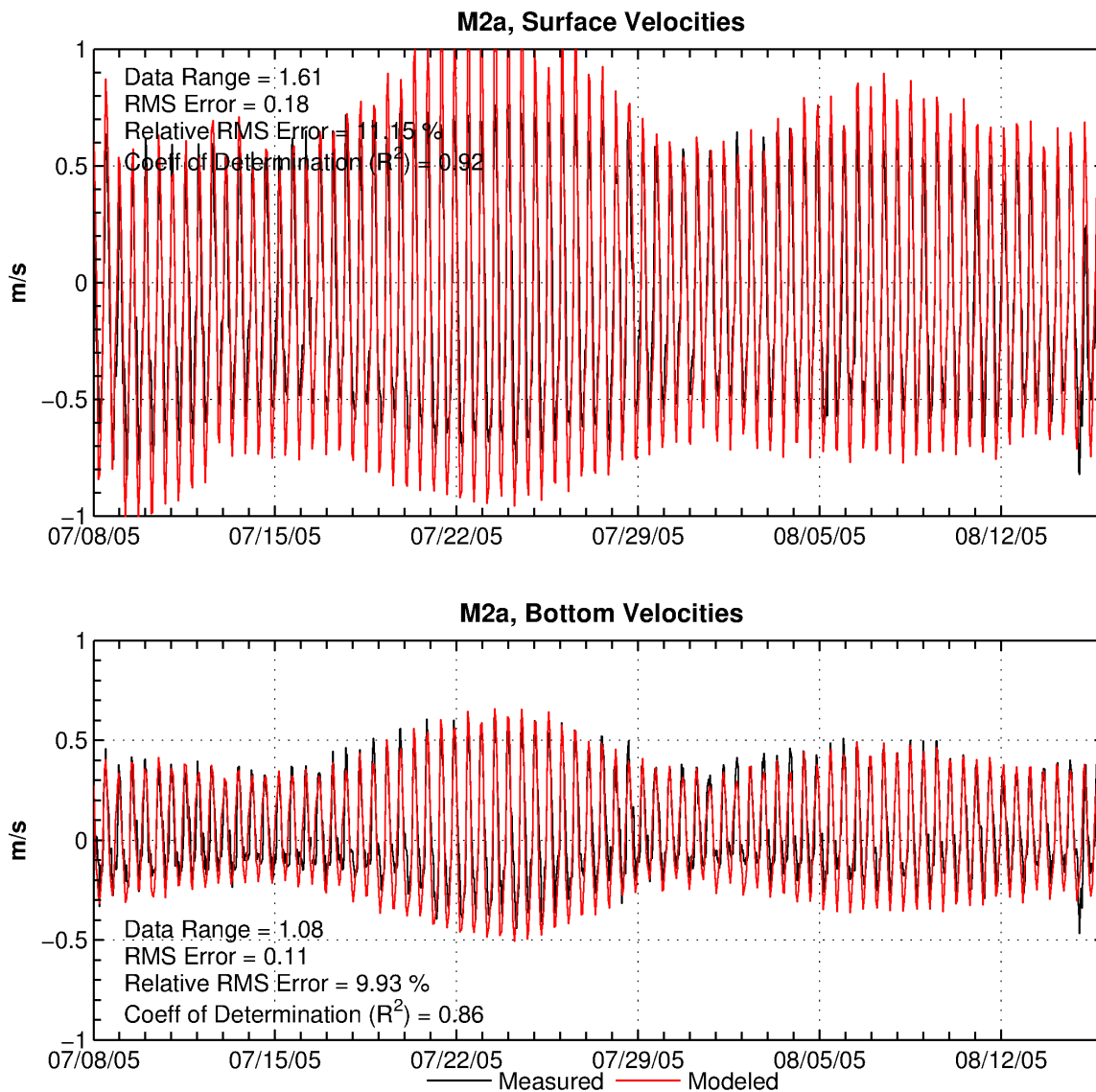


Figure 2-30: Surface and bottom velocities for M2a during DOT3

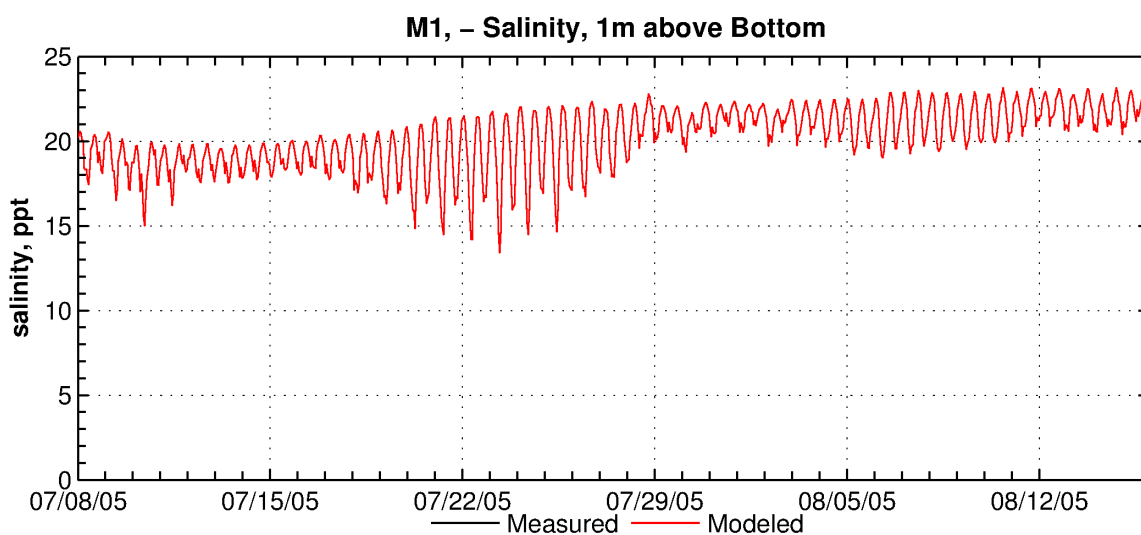
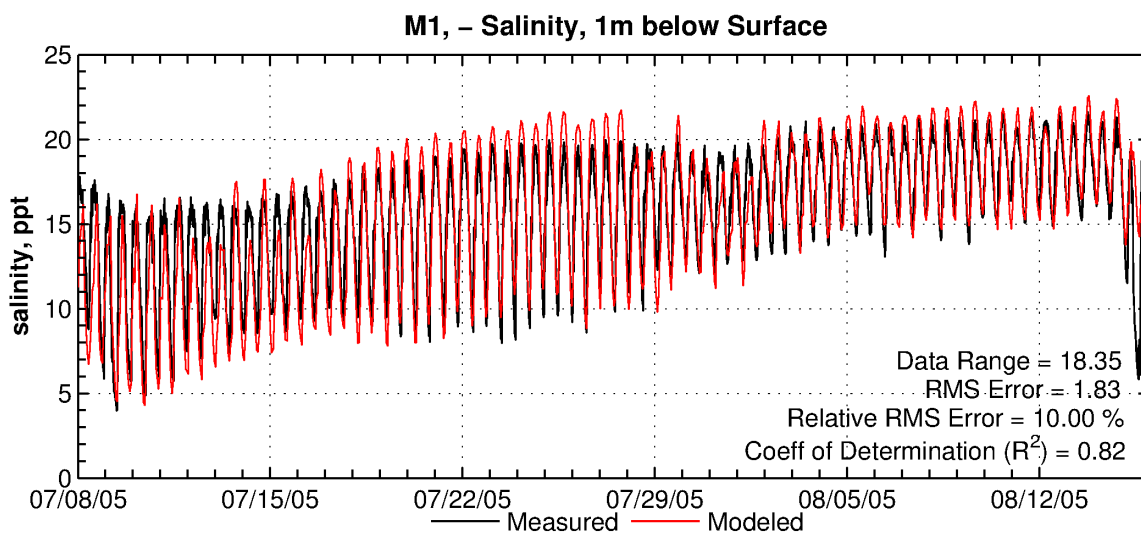


Figure 2-31: Surface salinity at M1 during DOT3

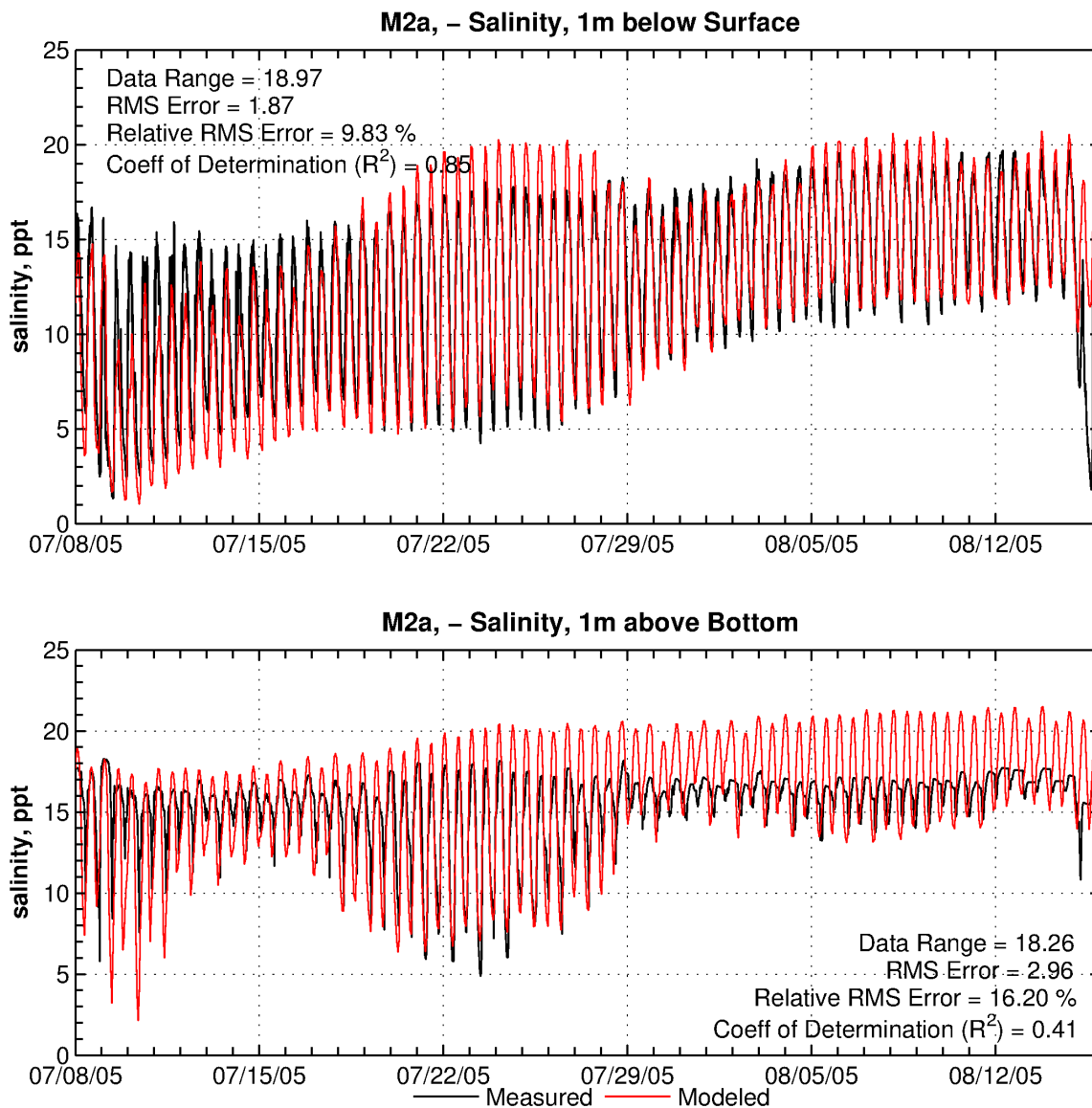


Figure 2-32: Salinity near the surface and bottom for Station M2a during DOT3

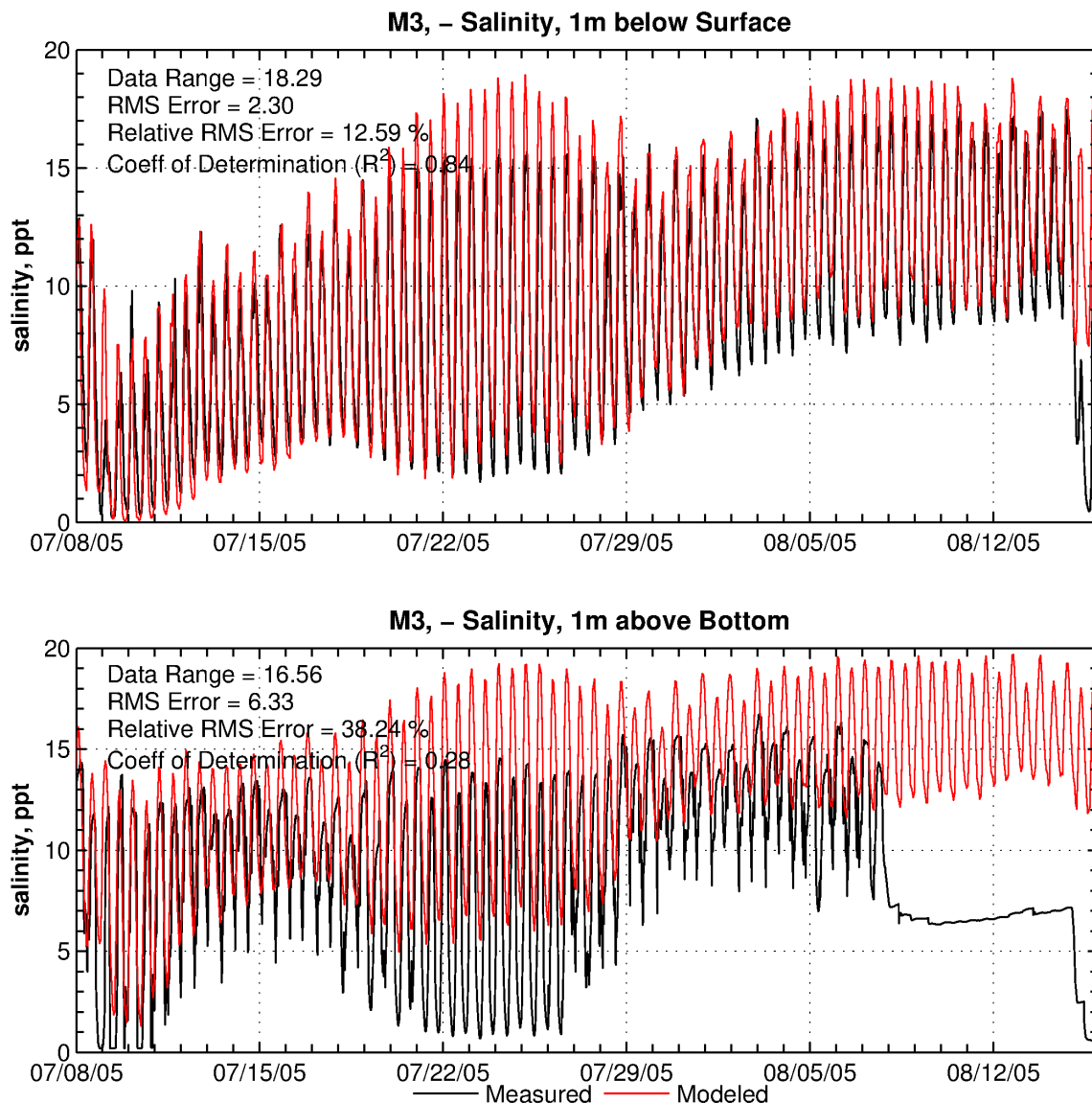


Figure 2-33: Salinity near the surface and bottom for station M3 during DOT3

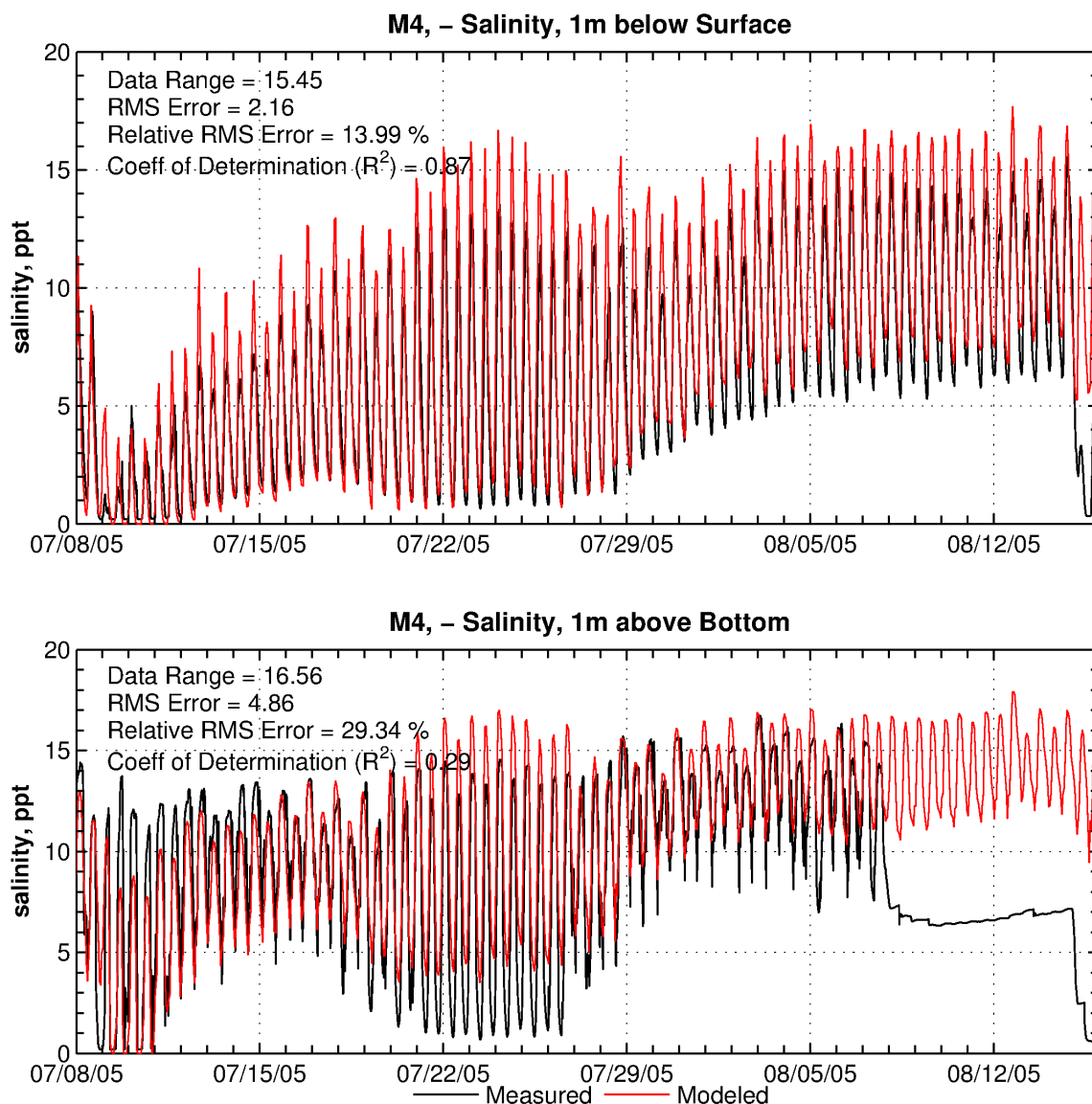


Figure 2-34: Salinity near the surface and the bottom for station M4 during DOT3

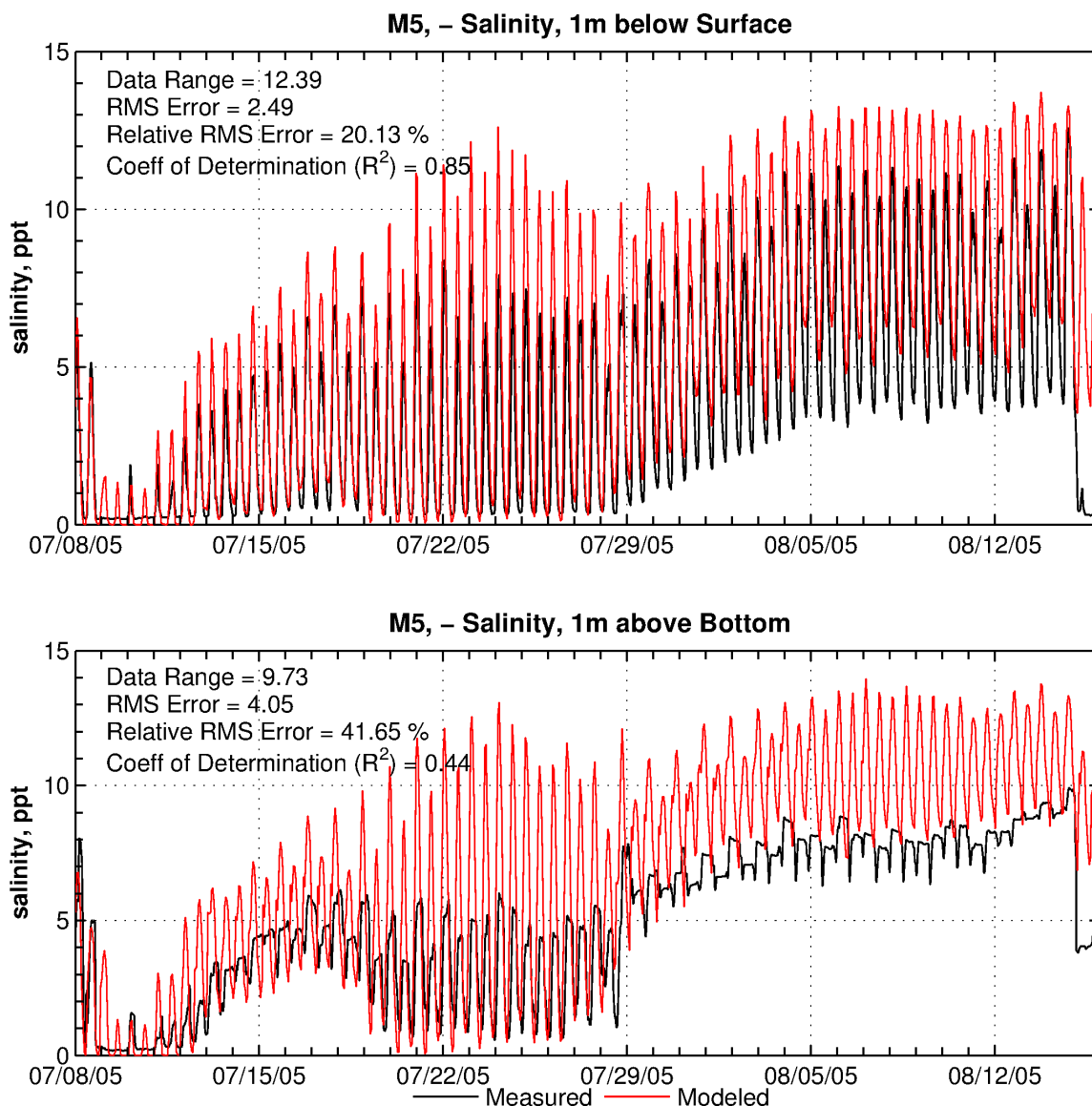


Figure 2-35: Salinity near the surface and bottom for station M5 during DOT3

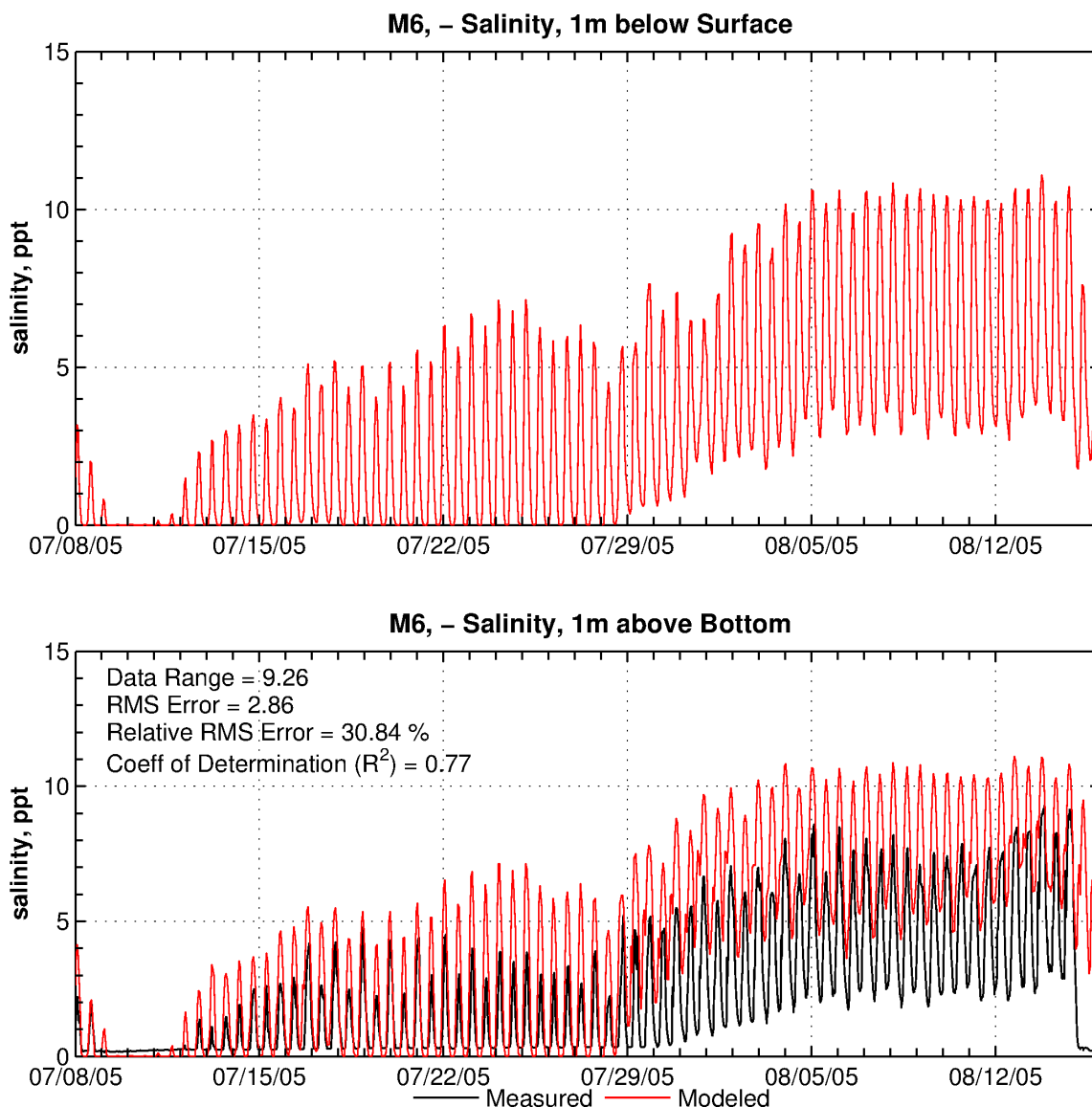


Figure 2-36: Near-bottom salinity for station M6 during DOT3

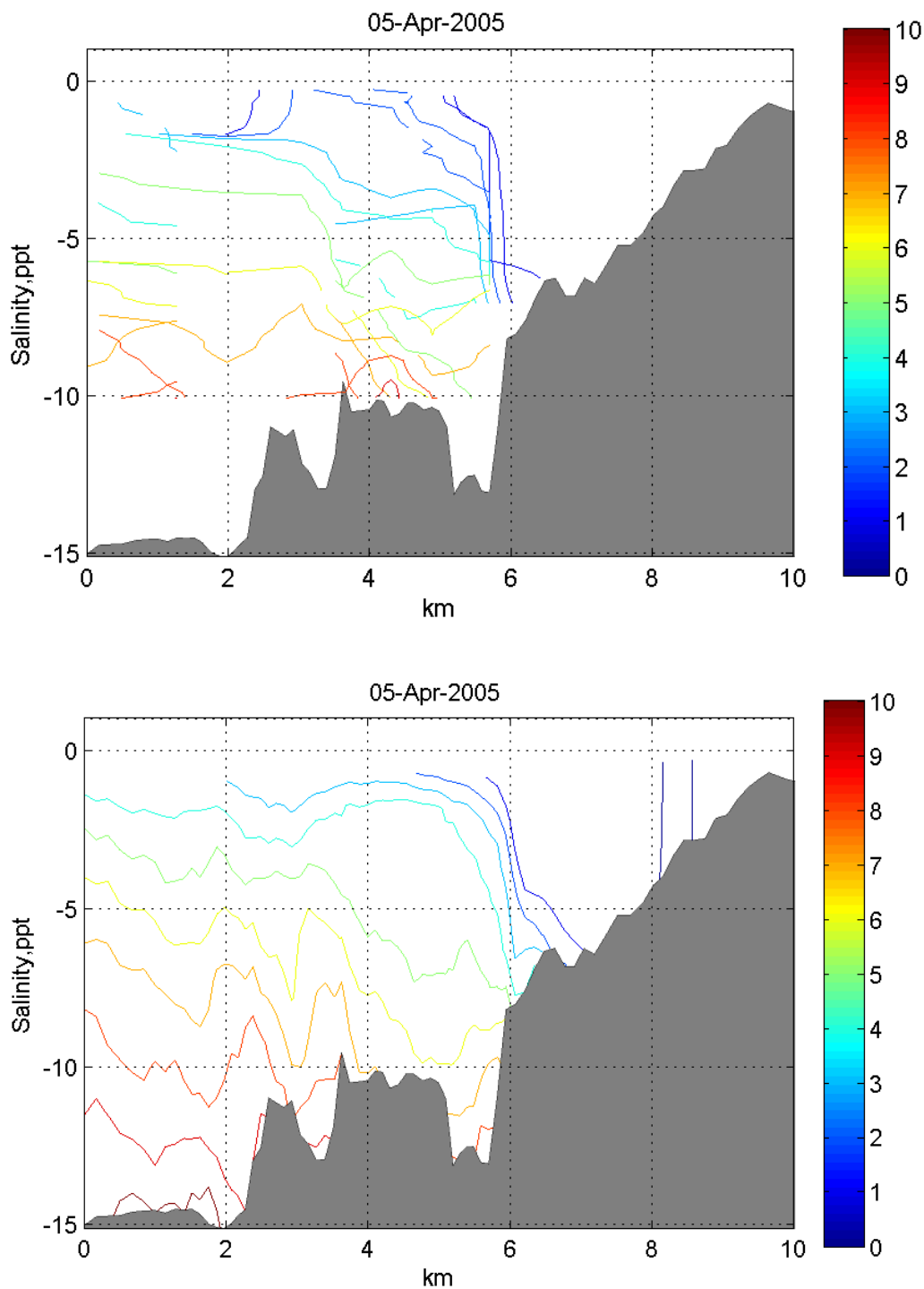


Figure 2-37: Salinity contours measured (top) and modeled (bottom) on 5 April 2005

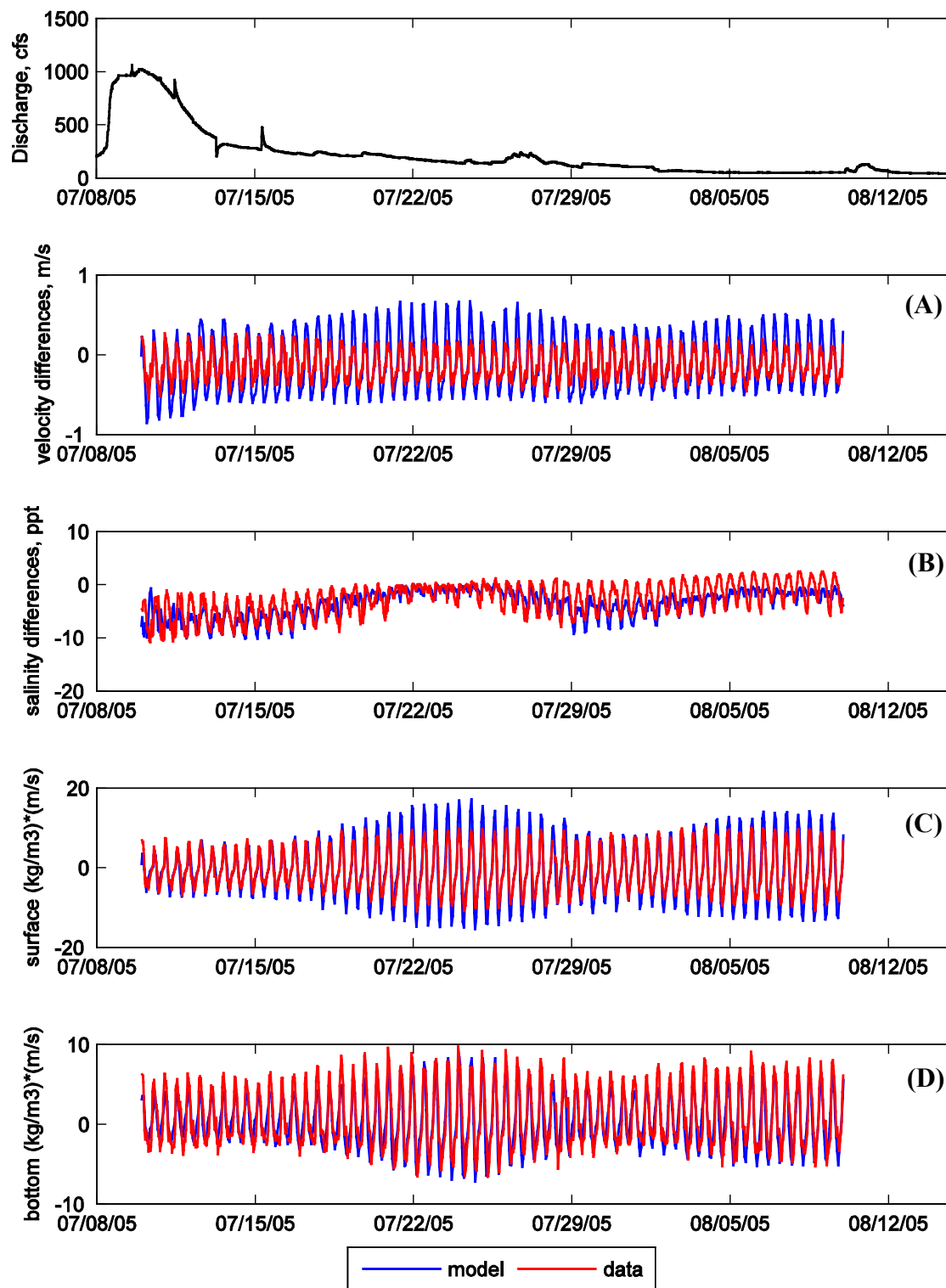


Figure 2-38: Comparison of measured and calculated surface-bottom velocity gradient (A), salinity gradient (B), and the near-surface (C) and near-bottom (D) instantaneous salt flux at M2a during DOT3

3.0 ADDITIONAL MODEL SETUPS: TRUNCATED GRID AND HIGH-RESOLUTION GRID

3.1 Truncated Grid

As described in the previous section, the hydrodynamic model domain included a vast area beyond the extent of the LPR and NB (referred to as the full grid). In order to facilitate model runs with faster run times for simulations including other modules (sediment transport and contaminant fate and transport), the full grid model was used to develop a localized model referred to as the truncated grid model. The truncated grid model setup limits the model domain to a localized area surrounding Newark Bay and the Passaic River.

Previous modeling work in the area (Pence, 2004) involved a model with similar extents but higher resolution than the existing LPR model. In addition, HQI used a model with similar domain for their capping study as part of the Draft Focused Feasibility Study (MPI 2007). A model setup with a similar domain was also developed in parallel by HQI in the interest of computational efficiency for the sediment transport model (Louis Berger Group, 2014).

3.1.1 Extent

The truncated grid model domain includes the 17.4-mile tidal stretch of the LPR extending from Dundee Dam to the mouth at Newark Bay, the Hackensack River (including the Meadowlands wetlands) from Oradell Dam to its mouth at Newark Bay, Newark Bay, and the tidal entrances to Newark Bay, namely the Arthur Kill extending to Raritan Bay and the Kill van Kull extending to upper New York bay. The model grid is shown in Figure 3-1.

3.1.2 Resolution

The resolution of the truncated model was maintained from the full LPR model. No additional resolution was added.

3.1.3 Bathymetric Sources

Bathymetry for the truncated model was maintained from the full LPR model as defined for the 10-year simulation or based on the bathymetry provided by HQI for the water years 2008 onwards, especially for the definition of the deepening project in Newark Bay. Section 5.1 describes additional modifications to the bathymetry that was introduced for the latest version of the model.

3.1.4 Boundary Conditions

Water level boundaries were specified at the southern end of the Arthur Kill and the eastern end of the Kill van Kull. These boundaries were constructed by extracting time-series at

hourly intervals from the full grid model. Similarly, salinity and temperature were extracted from the full grid model, interpolated to a z-grid, as required by ECOM standard boundary definition, and applied at the boundaries. Limitations intrinsic to the code of ECOM do not allow for alternate specifications such as velocity at the open boundaries. In order to obtain a well-posed and unique solution to partial differential equations such as parabolic or hyperbolic sets used within ECOM, a set of initial and boundary conditions for surface elevation and velocity are required. Without a boundary condition implementing a velocity condition, a unique solution to the problem may not be possible. This is especially the case when the boundaries are close to the project area. It was found that by specifying the boundaries in the way described above produces important differences in the discharge in the Arthur Kill, especially during neap tide, when compared to results from the LPR model. These differences dissipate within the model, and discharge through Newark Bay and the Passaic River seem to be unaffected by the specification of the boundaries in the truncated model.

The specification of boundary conditions for the truncated model as described above is similar to the setup and implementation of HQI in their truncated model as well as the implementation of Pence (2004). Using a discharge boundary condition at the end of the Arthur Kill rather than a water level boundary condition may give a better representation of the conditions in the Arthur Kill although this solution will still not contain the momentum component. However, alternate boundary conditions were not implemented with the model due to the limited impact of this artifact on model performance within the LPR.

3.1.5 Discharge conditions

Discharge boundary conditions from rivers and CSOs were kept the same as in the full grid model.

3.1.6 Meteorological forcings

Due to the limited domain of the model, following literature review and discussions with HQI, the meteorological forcings for the truncated grid model were modified from its representation in the full grid model. Due to its limited spatial extent, the spatially-varying wind field that is used in the full grid model is not specified for the truncated grid model. In addition, the construction of the spatially varying wind field in the full grid model was performed using data from Newark (EWR), JFK, Atlantic City, Albany Airport, Bridgeport Airport, and some offshore buoys.

It is worth noting that in Pence (2004), an hourly wind field from Bergen Point NOAA station was used to drive a model with similar extents to the truncated grid model. A comparison of the wind fields at Bergen Point and Newark Airport is found in Figure 3-2. Some short-term deviations mainly in wind speed are apparent between the data at the two locations. However, for purposes of this modeling effort, the use of EWR wind fields is required as the time period of collection is longer than the record at Bergen Point. It is noted however, that since the wind field in Bergen Point is not used, wind stresses in the

model may not be locally as accurate. Accordingly, the wind field in the truncated grid model is specified as a spatially constant but temporally varying input based on the EWR data.

3.2 High-Resolution Model

In addition to the truncated model, a high-resolution hydrodynamic model was developed in order to better quantify the distribution of velocities and shear stresses within the LPR, mainly to support the system understanding analyses for sediment transport. The increased resolution was necessary to resolve features and processes such as secondary flow in river bends, cross-channel variability in flow patterns, and the presence of in-river structures such as bridge abutments. While the spatial extent of the high-resolution hydrodynamic model was maintained the same as the previously described truncated model, the resolution was increased by roughly 4-5 and 2-3 times in the longitudinal and lateral directions, respectively, in the LPR (average high-resolution grid size in the LPR is 18 m wide and 42 m long). The model bathymetry within the LPR was based on the USACE single-beam survey conducted in 2004.

The model was calibrated to the hydrodynamic data (water levels, velocities, and salinity) collected by Rutgers University in 2004 (dataset also used for the calibration of the LPR/NB hydrodynamic model; HydroQual 2008) which covered flows ranging from a few hundred cfs to 3000 cfs (for comparison the long-term average flow at Dundee Dam is estimated as 1200 cfs). The trade-off for higher grid resolution is increased simulation times, and consequently the high-resolution model could not be applied for a long-term simulation. Rather, the calibrated model was applied to a series of constant river discharges covering typical spring-neap tidal cycles to obtain shear stress maps under varying conditions. These maps also formed the basis of a look-up table of predicted shear stresses as a function of tide and discharge, which was used to estimate shear stresses for the high-resolution grid over a 20-year period beginning in 1989. These maps were used for an assessment of the spatial and temporal distribution of shear stresses and to inform the system understanding analyses.

Note that although a constant bathymetry (corresponding to the 2004 time-frame) was used in the high-resolution model, in general, within the LPR, changes in bathymetry are small compared to the overall water depth, even after an extreme event such as Hurricane Irene. Hence, yearly variations in bathymetry will not strongly affect the overall flow patterns, although locally flow velocities and bed shear stresses may be affected.

3.2.1 Extent

The extent of the high-resolution model is similar to the extent of the truncated grid model. The model extends to Dundee Dam in the Passaic River, and Oradell Dam in the Hackensack River. The two offshore boundaries are located at the eastern end of the Kill van Kull and the southern end of the Arthur Kill. The model grid is shown in Figure 3-3.

3.2.2 Resolution

The resolution of the model was increased throughout the model from the resolution of the truncated model grid. Twelve grid cells represent the cross-section of the Passaic River in the lower sections. Three to four grid cells represent each tenth of a mile in the lower sections of the Passaic River. Within Newark Bay, about 20 grid cells represent the model across the northern section of the Bay. In comparison, the truncated grid includes only 12 grid cells to represent this region. The resolution in the upper portions of the Hackensack was kept the same as in the truncated grid model in order to save on computational time and also because this sub-domain is beyond the area of interest for the LPR. Overall, the high-resolution model contains approximately 12,500 grid cells. Because of the increased resolution, the time step of the model also needed to be reduced to 5 seconds in order to maintain numerical stability.

3.2.3 Bathymetric Sources

The high-resolution model bathymetry was currently constructed to simulate 2005 conditions. Within the Passaic River, the 2004 USACE single beam survey was used for the entire length of the Passaic River. Within Newark Bay, model bathymetry was based on a combination of channel surveys conducted by USACE in 2005, and a survey from Tierra Solutions in 2005 (Tierra, 2005). The Arthur Kill and Kill van Kull were constructed from USACE surveys from 2005. Table 3-1 shows the time and sources of the bathymetry sources used in the high-resolution model. Bathymetry for the Lower Passaic River and Newark Bay is found in Figure 3-4 and Figure 3-5.

Table 3-1: Bathymetry Sources

Survey	Source	Date
Channel Survey – Arthur Kill	USACE	Aug 2005
Channel survey - Newark Bay	USACE	Aug - Oct 2005
Channel survey - Kill van Kull	USACE	Oct 2005
Newark Bay – bank to bank	Tierra, 2005	Oct 2005
Hackensack River	HQI model	Surveys from mid-90s
Passaic River	USACE	2004

3.2.4 Boundary Conditions

Water level boundaries were specified at the southern end of the Arthur Kill and the eastern end of the Kill van Kull. These boundaries were constructed by extracting time-series at hourly intervals from the full grid model. Similarly, daily averages of the salinity and temperature were extracted from the LPR model, interpolated to a z-grid, and applied at the boundaries.

3.2.5 Discharges

Discharge inputs and locations were maintained from the full grid model. They were interpolated to the nearest high resolution grid cell.

3.2.6 Meteorological Forcings

Similar to the truncated grid model, the extent of the high-resolution model does not justify the use of spatially varying wind conditions given the amount of wind data available. A spatially constant wind was used varying in time throughout the model.

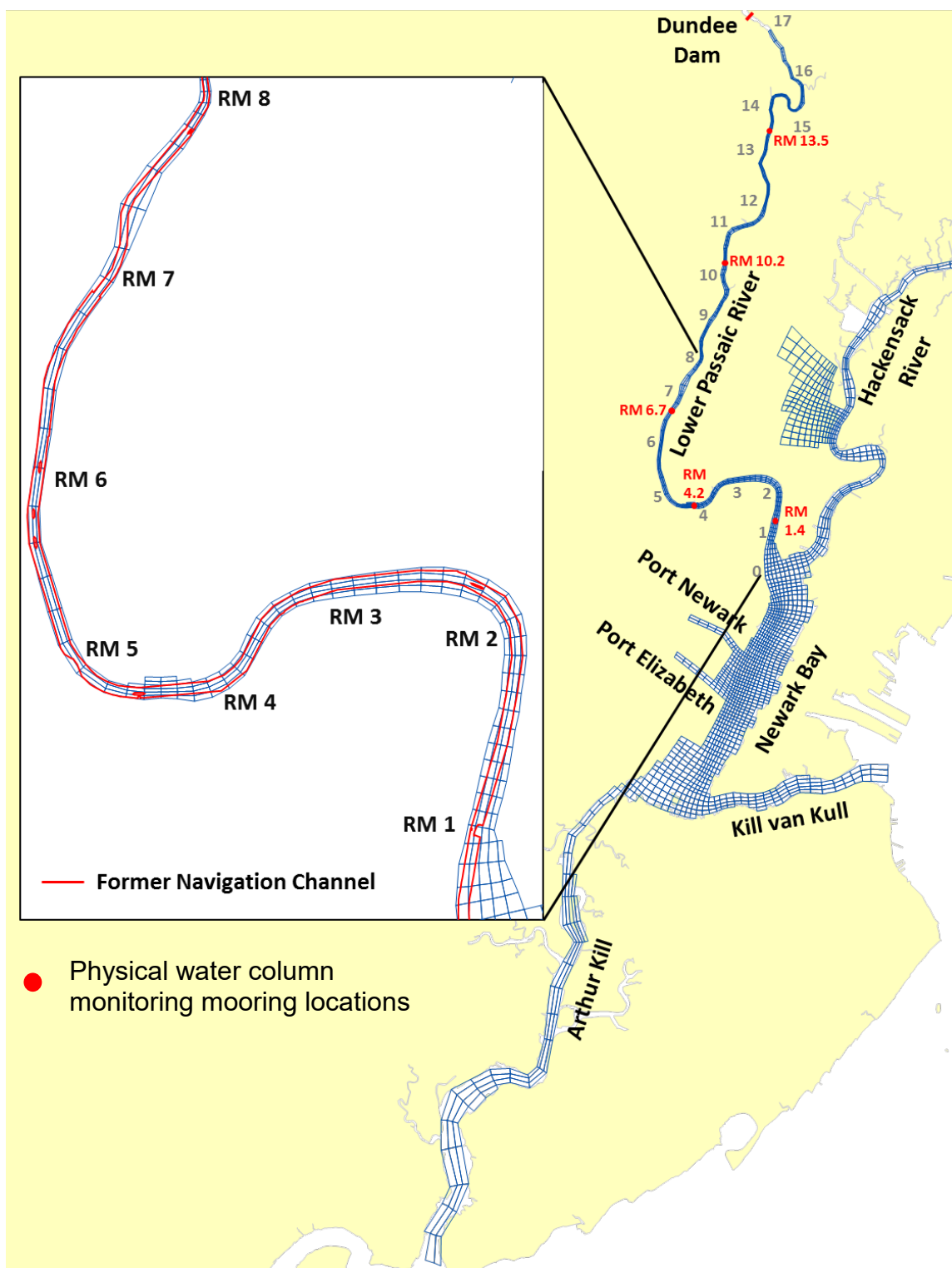


Figure 3-1: The Lower Passaic River and Newark Bay truncated model domain.

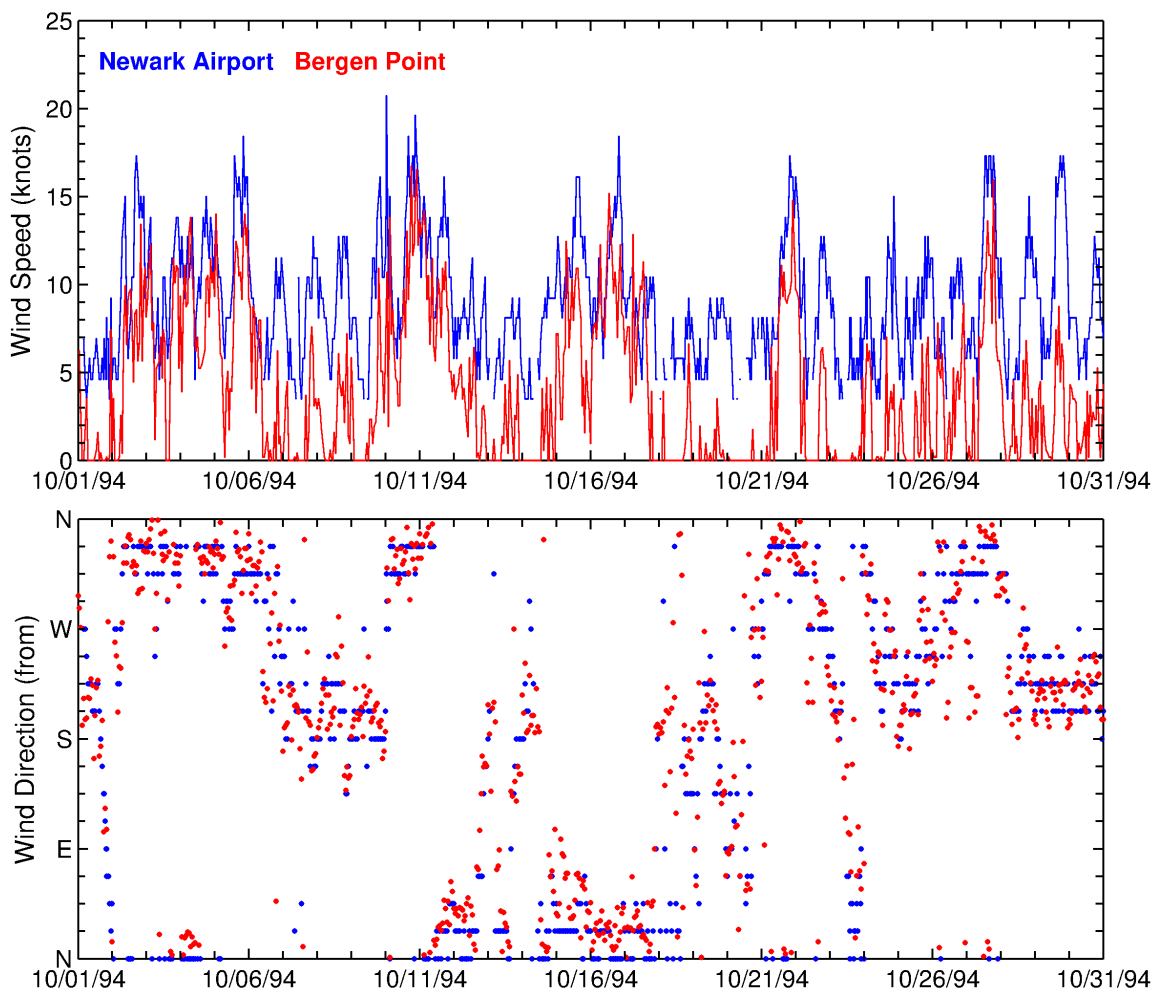


Figure 3-2: Wind Speed (top) and direction (bottom) at Newark Airport and Bergen Point

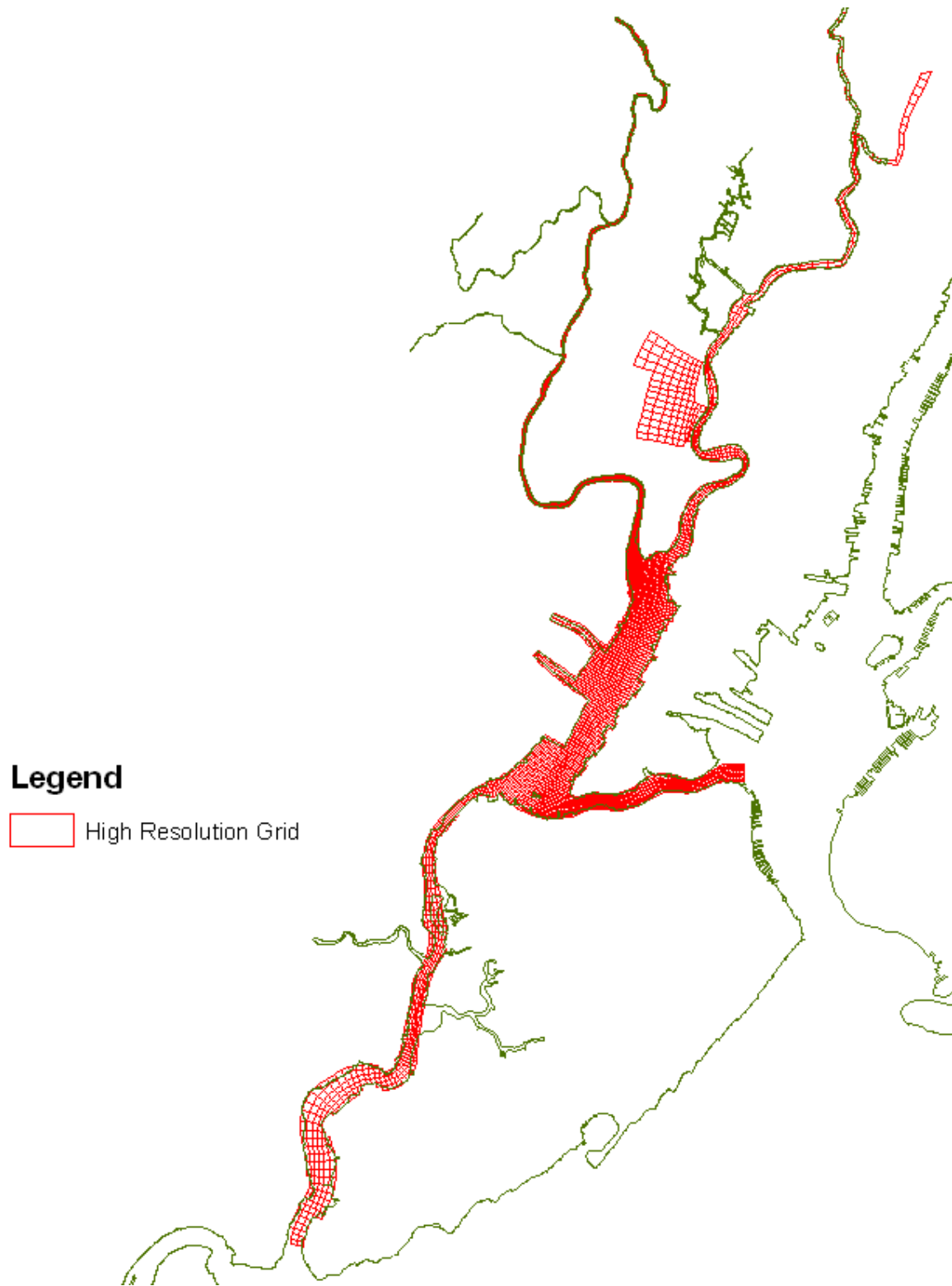


Figure 3-3: High-resolution Model



Figure 3-4: High-resolution Bathymetry in the Passaic

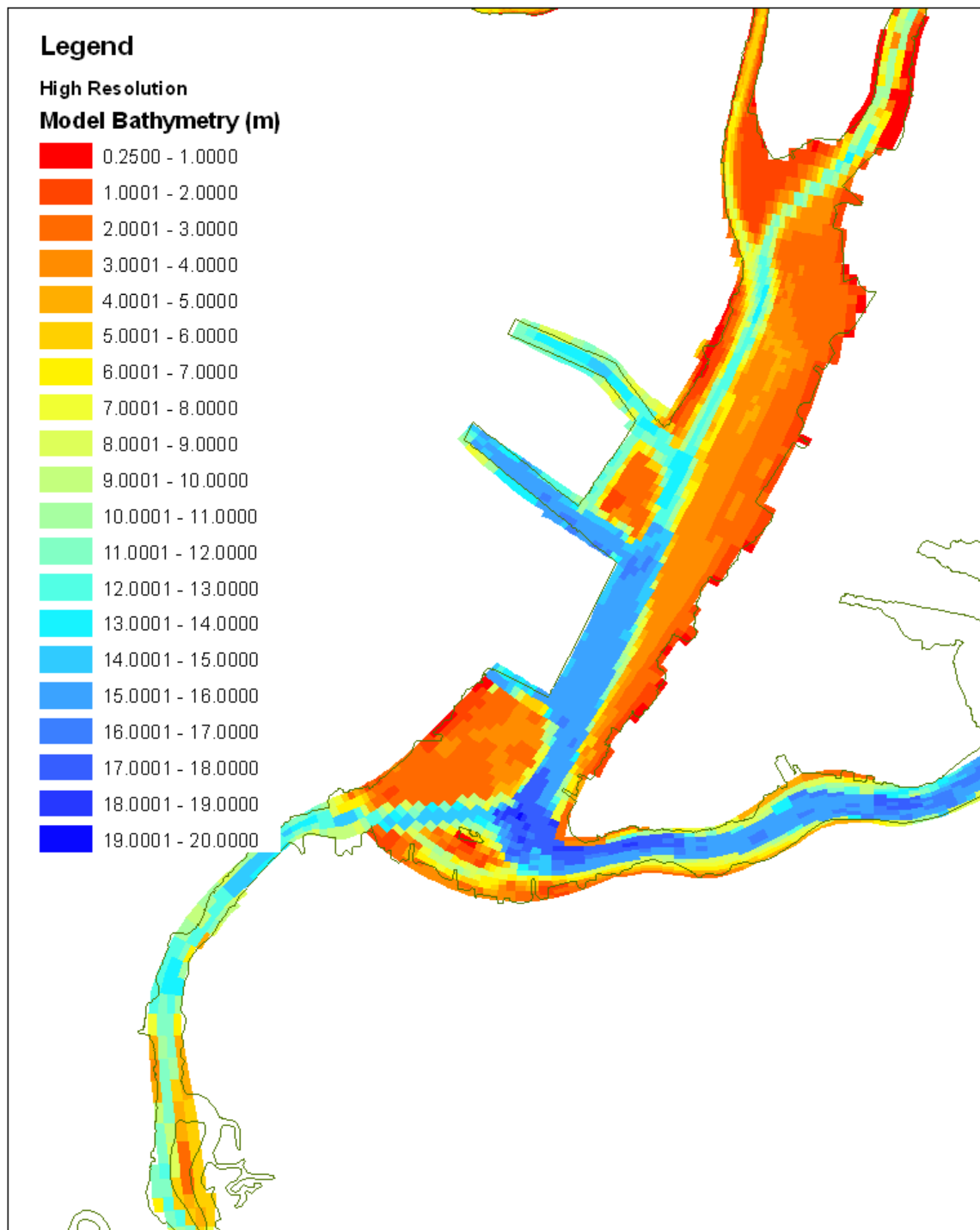


Figure 3-5: High-resolution Bathymetry in Newark Bay

4.0 ANALYSIS OF SALT FRONT DYNAMICS BASED ON 10 YEAR SIMULATIONS OF THE LPR MODEL

The location of the salt front is indicative of a transition of the LPR from a tidal estuarine system to a tidal riverine system. The location of the salt front varies spatially and temporally. The hydrodynamic (HD) model was used for an analysis examining the dynamics of the salt front location. The analysis involved first determining the salt front location time-series using the results from an ECOM model simulation over water years 1995 through 2004. Figure 4-1 shows the river discharges in the LPR during the aforementioned period.

The salt front location in estuaries typically coincides with the estuarine turbidity maximum (ETM; Postma 1967, Geyer et. al. 2004), an area of enhanced suspended sediment concentrations and deposition. At the salt front, the positively buoyant freshwater flow converges with and flows overtop the saltier upstream flow creating a distinctive salt wedge. An example of the salt wedge in the LPR during near average flow conditions (~900 cfs) and high flow conditions (~9,000 cfs) in the LPR is given in Figure 4-2 and Figure 4-3. The salt front is seen to be located in the vicinity of RM 6 during average flow conditions (Figure 4-2), moving down-estuary with increasing discharge to the mouth of the LPR during high-flow conditions (Figure 4-3).

Preferential sediment deposition occurs at the salt front as a result of the convergence of estuarine and fluvial transport processes within the water column (Geyer et. al. 2004). Therefore, the ETM zone and therefore the salt front plays an important role in the fate and transport of sediments in the LPR system. In this analysis, the location of the salt front as well as its variability due to tides, and river discharge was investigated for the model simulation for WY1995 through WY2005. In the remainder of this section the methodology for calculating the salt front location, extent, and excursion is presented, followed by the results from the analysis. For discussion purposes, the salt front is taken to be the location of the 2 ppt isohaline calculated separately at the surface and at the bottom of the water column. During normal tidal and discharge conditions, the salt front is within the LPR, at a location dependent on the freshwater discharge, inter-tidal timing (spring/neap), intra-tidal timing (flood/ebb), and offshore set-up/set-down events. In the following paragraphs and figures although the term ETM has been used interchangeably instead of salt front the analysis presented here does not deal with sediments and therefore is mainly referring to the salt front location.

Model results from the 4 grid cells across the river ($i=16$ to 19) extending from Newark Bay to river mile 16 ($j=110$ to 267) were used exclusively in the salt front analysis. The steps in computing the salt front location in the river are as follows:

- At the surface, the salt front location is selected as the farthest downstream grid cell where the salinity in the top layer is equal to 2 ppt.
- At the bottom, the salt front location is selected as the farthest upstream grid cell where the salinity is equal to 2 ppt.

- The salt front location for the entire river is then computed as the average between the surface and bottom location.

Two additional concepts relevant to the salt front analysis are the salt front excursion (range of salt front location over a tidal cycle) and salt front extent (difference between the surface and bottom 2 ppt salinity isopleth). It is of note that the methodology used here to calculate the salt front is not applicable to determining the salt front in Newark Bay due to the complex circulation patterns within the bay. In cases where the discharge is high enough to push the salt front into Newark Bay (Figure 4-3) it suffices to say that the salt front resides in Newark Bay.

The model results of the 11 year simulation indicate that the location of the salt front ranges from Newark Bay to river mile 13. Histograms of the location of the salt front, shown for three separate simulation periods, WY1995-WY1999, WY2000-WY2002, WY2003-WY2005, where the model bathymetry remained constant during the duration of the simulation, show that the salt front shifts upstream and downstream throughout each time period (Figure 4-4). However, each of the histograms shows a high occurrence rate between river miles 4 and 5. It is apparent from Figure 4-4 that the mean location of the salt front is further upstream during WY2000-20002 than WY2003-2005. It will be shown later that difference in the location of the salt front over these time periods can be related to the discharge, as relatively low-flow conditions persisted during WY2000 to WY2002 allowing the salt wedge to be pushed further upstream than during WY2003 to WY2005.

Over the duration of a tidal cycle (12.42 hours) the location of the salt front shifts upstream and downstream due to tidal motion. During flood, the salt front is pushed upstream by tidal currents and conversely during ebb, the salt front is pushed back downstream due to the tidal currents. The apparent correlation ($r = 0.933$) between the high frequency variability in the location of the salt front and the tidal forcing is shown in Figure 4-5. The magnitude of the tidal excursion is controlled by the tidal range – during spring tides, the salt front excursion reaches 5 miles (Figure 4-6) and conversely during neap tides, the salt front excursion can be as low as 2 miles. The relationship between the tidal range and salt front excursion was found to be linear and is shown in Figure 4-7. It should be noted here that the salt front excursion is also influenced by the discharge rate in the river and high discharges lessen the impact of the tide on the variability of the location of the salt front. This effect will be shown in the model results, where it is easier to isolate the impact of discharge on salt front excursion.

The extent of the salt front (defined as the difference in the salt front location at the surface and bottom of the water column) is influenced by the tides, as the extent generally expands during ebb and contracts during flood. This tidal effect is visible in Figure 4-8, which shows that during ebb the location of the 2 ppt salinity isopleth at the surface of the water column is generally further downstream than the 2 ppt isopleth near the river bed. During flood, the saltier water from Newark Bay pushes the salt wedge further upstream and in general results in steep salt front and a smaller extent as the vertical stratification in salinity is reduced.

The variability of the salt front extent on longer time scales was investigated by comparing the low-passed salt front extent to the tidal range and discharge in the river. The low-pass filtering was implemented using a Fourier analysis of the salt front location time-series. The time-series of the salt front location was parsed through a Fast Fourier Transform (FFT) to decompose the time-series signal into its underlying harmonic constituents. The major constituents returned from this analysis represent dependencies of the salt front location with the semi-diurnal tides, discharge, lunar phase (spring-neap), offshore set-up and set-down events, etc., with each constituent characterized by a unique frequency or period. In order to filter out the effect of the tides from the salt front location, the constituents from the FFT were low-pass filtered to exclude harmonics with frequencies greater than 0.2/day, i.e. with period less than 5 days. The remaining constituents, representing the dependency of the salt front with discharge and other low frequency forcings, were parsed through an inverse FFT to reconstitute the time-series of salt front locations, and plotted against the corresponding daily Dundee Dam discharge in Figure 4-9. It is evident from Figure 4-9 that the salt front extent is larger during high discharge events and neap tides than during low-flow periods and spring tides.

The impact of river discharge on the location of the salt front was briefly discussed earlier. As evident from the histograms from WY2000 to WY2002 and WY2003 to WY2005 (Figure 4-4), during low-flow periods, the salt front moves upstream and during high-flow periods the salt front shifts downstream. This effect can be clearly seen in Figure 4-10 where the river discharge and the low-passed location of the near-bottom salt front are plotted as a time-series for several months in 1996 and 1997. During the large discharge event on October 23, 1996 the salt front exits the LPR and moves into Newark Bay. In contrast during low flow conditions over the month of October in 1997 the salt front reaches as far upstream as river mile 10. The location of the low-passed salt front plotted versus the river discharge in Figure 4-11 shows that as the discharge in the river increases the location of the salt front moves downstream. The relationship between the river discharge and low-passed salt front location is often described by a power law (Geyer et al. 2004). However, in the LPR a logarithmic relationship provided a better fit to the data, especially for high discharge events. Figure 4-11 shows the logarithmic and power curves obtained from regression analysis in addition to the low-passed salt front results. The model results and logarithmic relationship indicate that the low-passed location of the salt front exits the LPR at approximately 9,000 cfs. However, the salt front may exit the LPR during ebb at lower discharges since the tidal excursion of salt front typically ranges from 2 to 5 miles.

4.1 Summary of findings

Following are the main findings from the salt front analysis presented above:

- The salt-front is situated up-estuary of RM 5 when discharge at Dundee Dam is below the annual average of 1,200 cfs (HydroQual 2006a; 1,140 cfs at Little Falls with drainage-area proration to calculate discharge at Dundee Dam).
- The salt-front location is pushed seaward with increasing flow and at 2,000 cfs it is found on average near RM 3. During a 1-year return flow of about 6,000 cfs, the

- salt front is pushed below RM 2, while a 5-year return flow of about 10,000 cfs pushes the salt front below RM 1, where the river widens rapidly.
- The location of the salt front is also a function of the tidal cycle, moving up-estuary during flood and moving down-estuary during ebb, with tidal excursion lengths on the order of 2 to 5 miles from low to high tide.
 - The salt front location is also a function of spring-neap cycle, on average (tidally averaged) further up-estuary on neap than on spring, primarily due to higher vertical mixing and lesser salinity stratification as well as higher tidal prism during spring tides than neap tides.

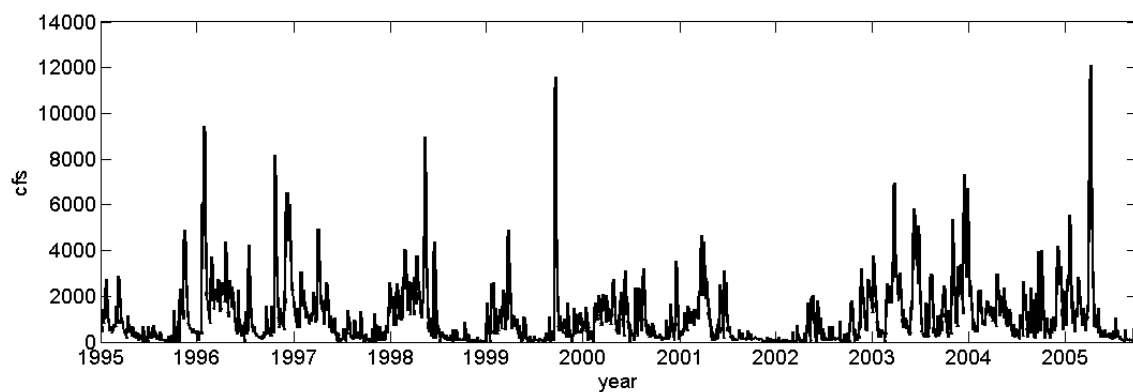


Figure 4-1: LPR discharge as measured by the USGS Little Falls gage station.

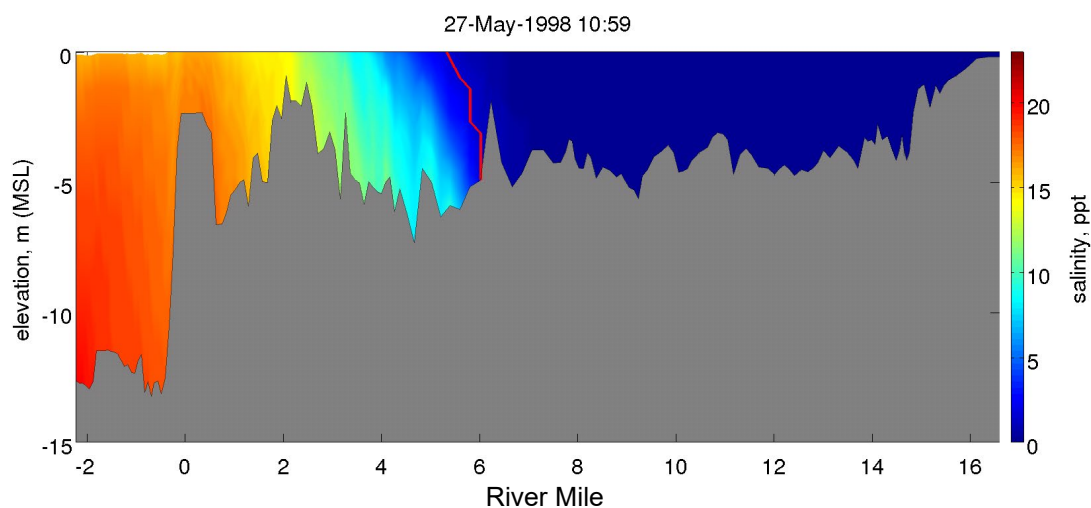


Figure 4-2: Salinity distribution and 2 ppt contour (red line) during typical flow conditions and tidal ebbing.

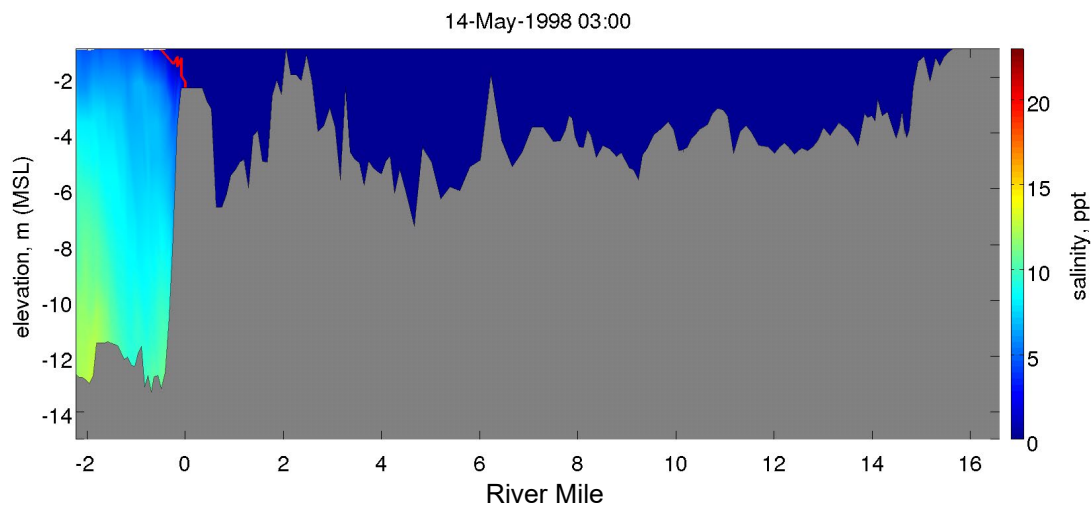


Figure 4-3: Salinity distribution and 2 ppt contour (red line) during a high flow event.

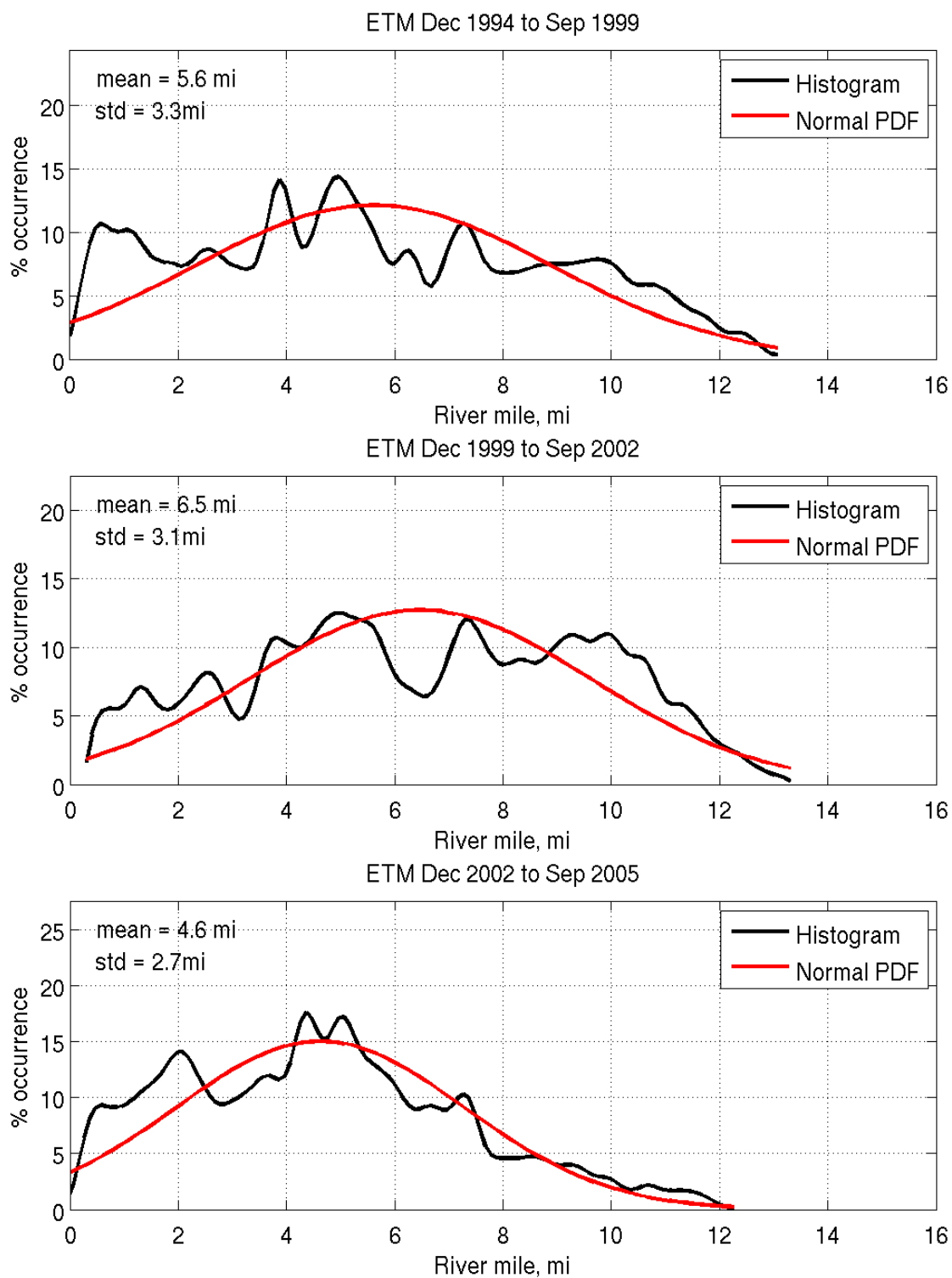


Figure 4-4: Salt-front location during each model period with the same bathymetry.

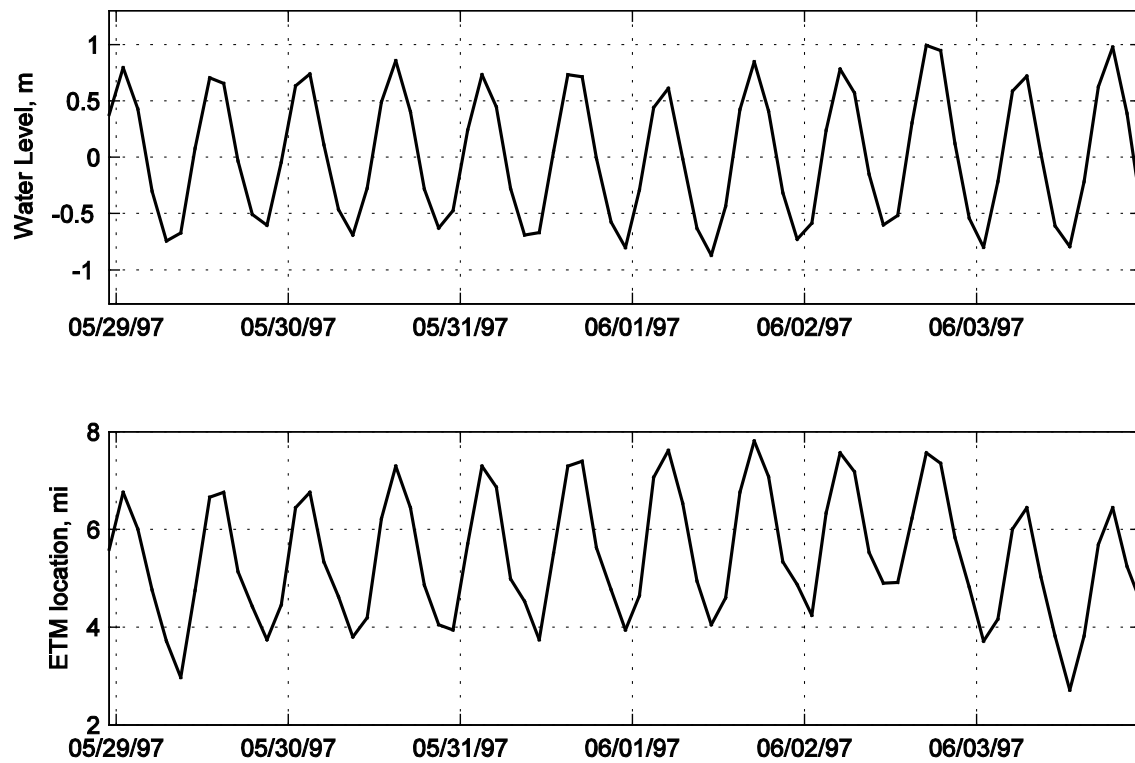


Figure 4-5: High frequency salt-front variability

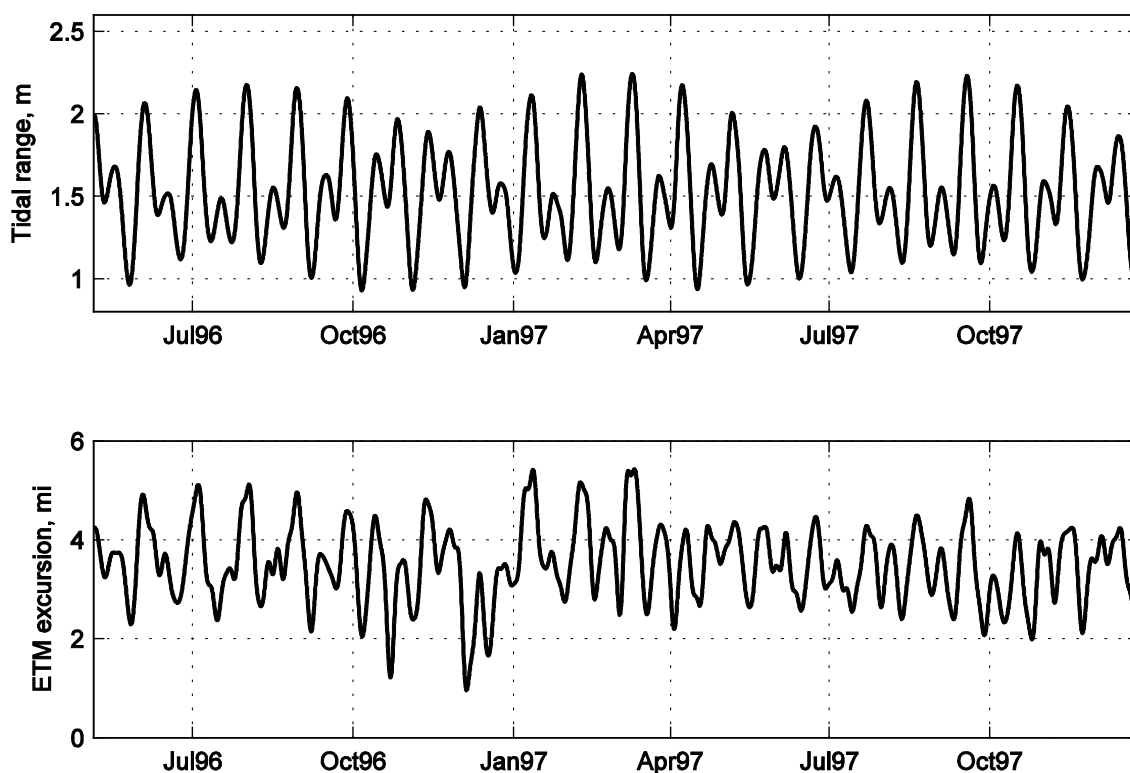


Figure 4-6: Salt-front excursion and tidal range

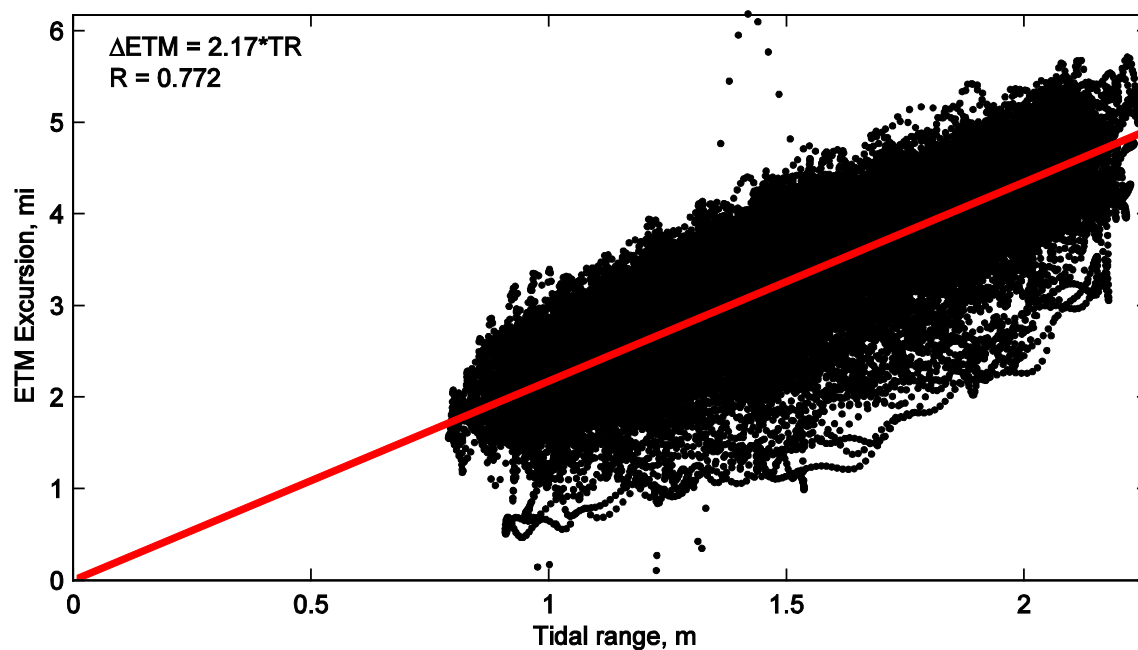


Figure 4-7: Correlation between salt-front excursion and tidal range

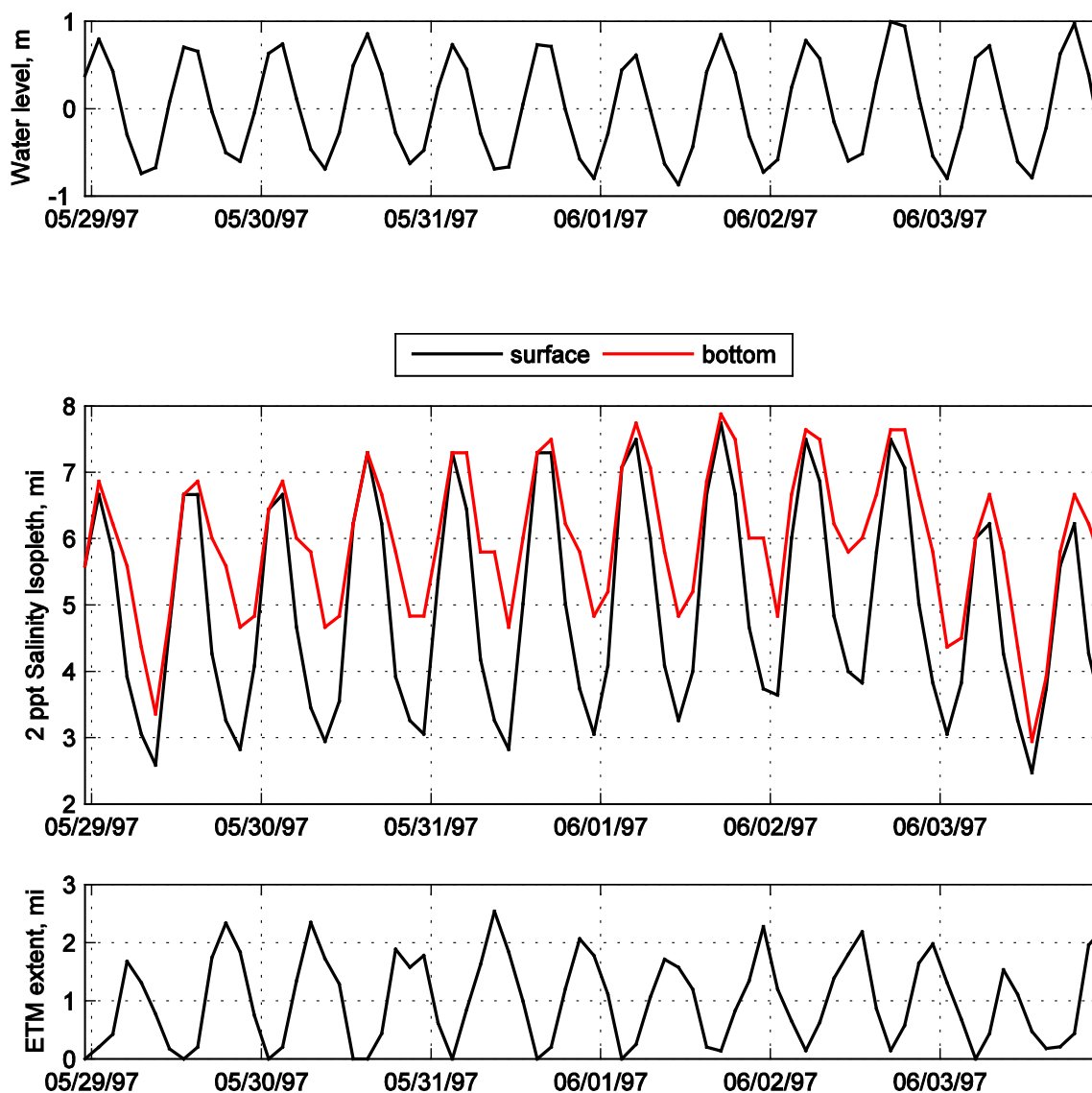


Figure 4-8: High frequency variability of salt-front extent

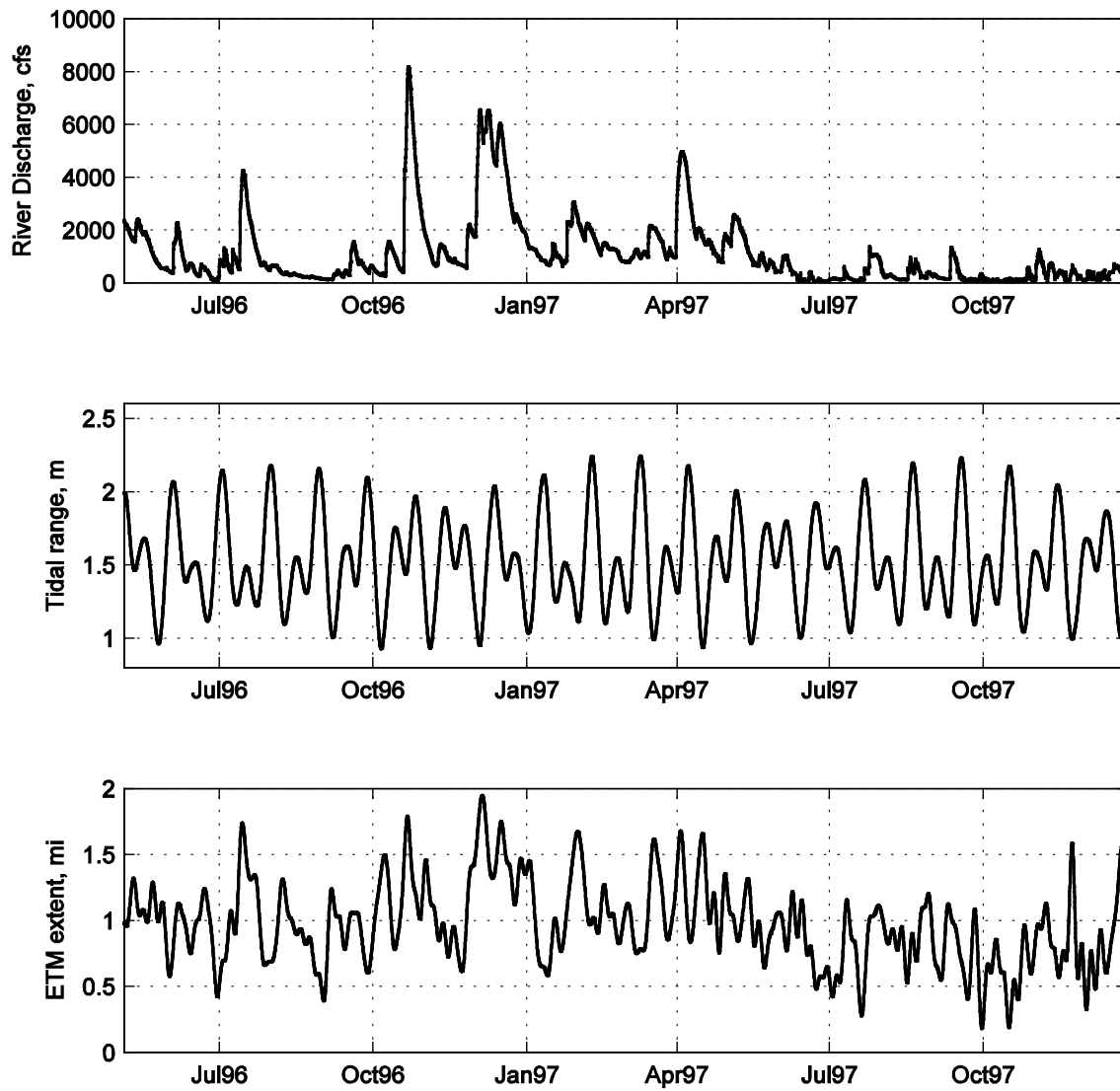


Figure 4-9: Low frequency variability in the salt-front extent

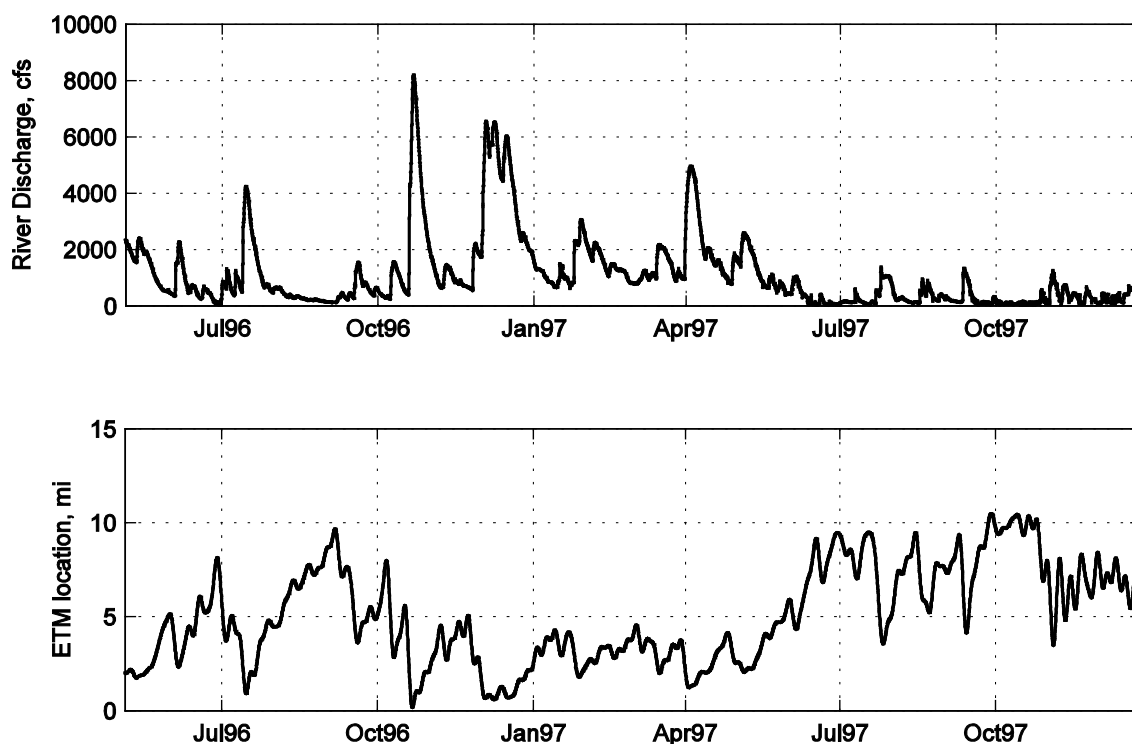


Figure 4-10: Low frequency variations in the salt-front location

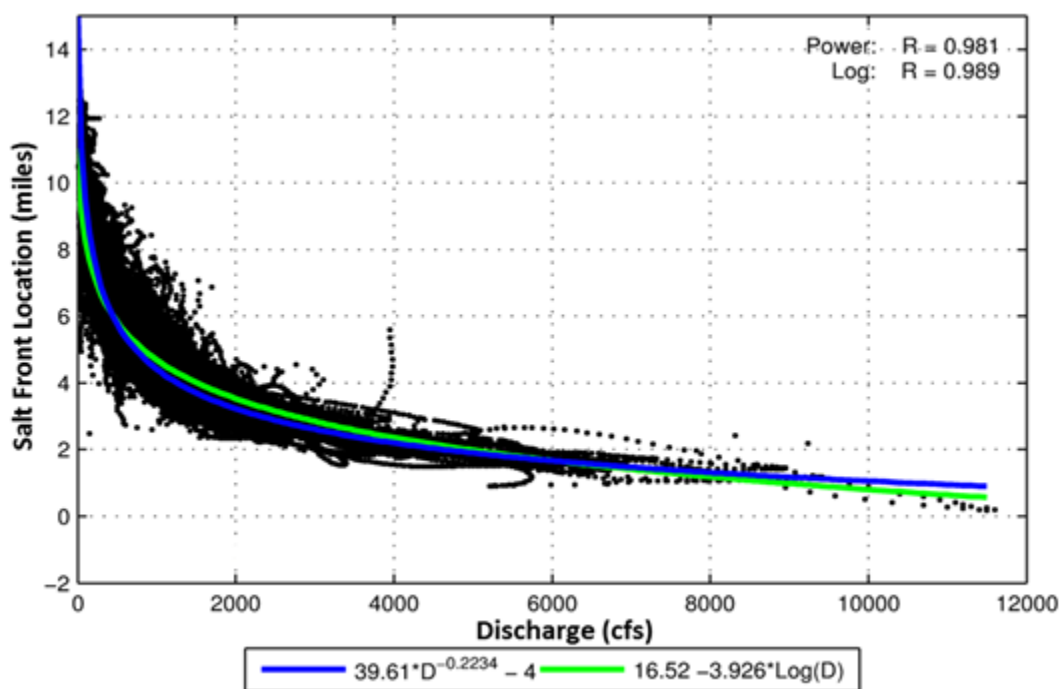


Figure 4-11: Correlation between low-passed salt-front location and discharge.
Power and log curves were fitted to the low-passed salt-front location

5.0 CHANGES TO MODEL INPUTS

Section 2.0 described the model inputs developed by EPA/HQI as part of the model application and calibration. These inputs were maintained as developed by HQI with the exception of the model bathymetry. Changes to the model bathymetry are described in the following section.

5.1 Bathymetry

The Passaic River bathymetry used in the hydrodynamic model was originally developed using the USACE 2004 single-beam bathymetry dataset by Region 2 as part of the FFS model. Although the sediment transport (ST) and contaminant model results using this bathymetry were generally consistent with data on various calibration metrics, some inconsistencies were observed in certain localized cases, such as the morphological behavior in the vicinity of the shoal at RM 7.5. In the ST model, the entire cross-section at RM 7.5 including channel and shoal showed mostly depositional behavior during low-flow as well as some high-flow years, whereas the data, especially the recent multi-beam surveys showed erosional trends during the high-flow years. This depositional trend also translated into a burial and recovery of surficial contaminant concentrations within the contaminant fate and transport model. Especially on the shoal at RM 7.5, this was inconsistent with the recent sediment coring data which showed high surficial sediment concentrations with no sign of recovery. Review of the initial model bathymetry indicated the possibility of an improvement in model performance in this regard.

Figure 5-1 shows two cross-sections looking upstream at RM 7.5 of several bathymetry datasets along with the model bathymetry across the corresponding rows of model cells. The bathymetry data show the deepest part of the channel located along the western edge of the river, with shallower depths along the shoal on the eastern edge of the river. However, the model bathymetry shows a relatively uniform depth across the cross-section which is too deep compared to the data at the shoal, and also over-estimates the cross-sectional area of the river compared to the data. The bias in cross-sectional area between the model and the data would result in lower flow velocities in the model and therefore provides a likely explanation of the depositional tendency noted in the initial ST model application. Therefore, the USACE 2004 single-beam bathymetry dataset was analyzed and used to develop the model bathymetry within the LPRSA.

To develop a more representative model bathymetry, the 2004 data was converted from the NGVD29 to Mean High Water (MHW) datum, and merged together with the coastline data which represent zero elevation with respect to MHW. These data were interpolated to a raster surface, and the raster points overlaying each model grid-cell were averaged to obtain the representative bathymetry for that cell. The resultant model bathymetry, which was finally converted back to the model MSL datum, was found to match the river-volume calculated from data much more closely than the earlier version of the model bathymetry.

The revised model bathymetry which is also shown in Figure 5-1 can be seen to better represent survey data, especially on the shoal. It must be noted that despite the revisions,

artifacts associated with the spatial resolution of the model grid are apparent in the model bathymetry. For instance, as seen in Figure 5-1, the 0.5 mile stretch of the LPR at RM 7.5 where the former navigation channel meanders from the center of the cross-section to the western edge and then back to the center is represented by only 2 rows of cells. As such, the bathymetry developed for a model cell in the center of the cross-section (for instance the middle cell in the row of cells with J=155 in Figure 5-1) represents the higher depths in former navigation channel at the southern end of the cell as well as the shallower depths at the northern end of the cell since the channel migrates to the western edge of the cross-section. The resulting average model bathymetry while good at preserving the total cross-sectional volume over the length-scale of a row of model cells, is still a poor approximation of the river bathymetry over smaller length scales.

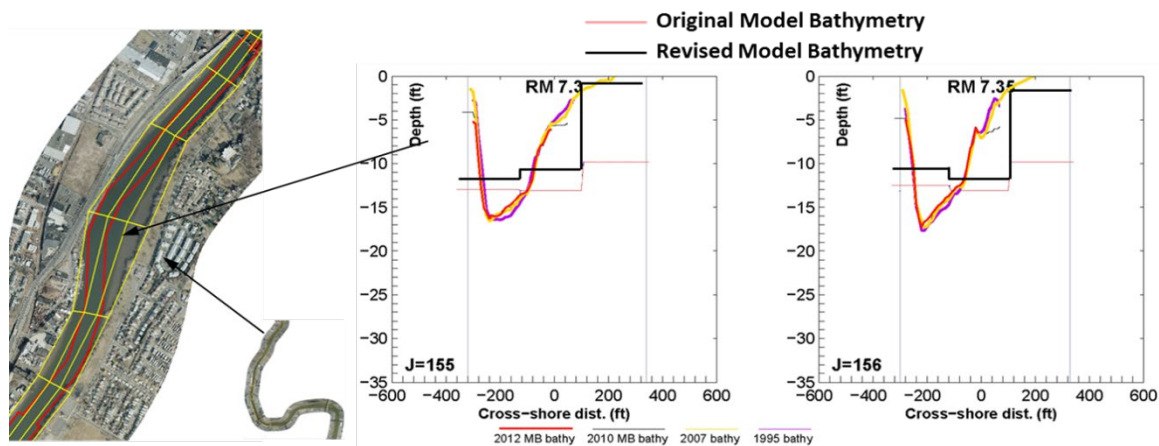


Figure 5-1: Comparison of bathymetric data with the model input bathymetry at RM 7.5

6.0 MODEL VALIDATION

The hydrodynamic model performance with the revised bathymetry was assessed by comparing the model results to the following datasets that included measurements of salinity and velocity:

- Physical Water-Column Monitoring (PWCM) dataset from Fall 2009
- PWCM dataset from Spring 2010
- High-flow event salinity transect collected on March 16, 2010
- Chemical Water-Column Monitoring (CWCM) data from 2012

Note that these comparisons are based on the truncated grid model application.

6.1 Fall 2009 PWCM data

Hydrodynamic data at five different locations within the Lower Passaic River was collected as part of CPG's Fall-2009 PWCM program. Bottom-mounted moored ADCP's at RM 1.4, 4.2, 6.7, 10.2 and 13.5 (see Figure 3-1 for the mooring locations) were used to record current velocities throughout the water-column over 0.5 meter vertical bins. Salinity, temperature, and water depth data were also collected using CTD sensors at the water column surface and bottom at these locations.

6.1.1 Water Levels

A tidal constituent analysis was performed on the water-level predictions and observations, and a comparison of the amplitudes and phases of the major constituents (M2, N2, S2, and K1) between the two is presented in Table 6-1 through Table 6-4 respectively. The amplitudes as well as the phases of the all of the major constituents appear to be in very close agreement at all five stations within the LPR. This indicates that the model is able to reproduce the tidal variability in water-levels within the LPR.

Table 6-1: Comparison of Harmonic Constants for Water Level – M2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.69	214	0.67	212
RM 4.2	0.69	220	0.71	219
RM 6.7	0.78	259	0.76	254
RM 10.2	0.64	201	0.64	194
RM 13.5	0.74	237	0.75	229

Table 6-2: Comparison of Harmonic Constants for Water Level – N2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.11	208	0.11	200
RM 4.2	0.12	217	0.12	212
RM 6.7	0.12	267	0.11	259
RM 10.2	0.12	199	0.12	182
RM 13.5	0.13	240	0.13	224

Table 6-3: Comparison of Harmonic Constants for Water Level – S2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.11	227	0.11	236
RM 4.2	0.11	228	0.12	240
RM 6.7	0.14	270	0.13	275
RM 10.2	0.12	227	0.12	227
RM 13.5	0.13	253	0.13	252

Table 6-4: Comparison of Harmonic Constants for Water Level – K1 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.11	86	0.09	70
RM 4.2	0.11	89	0.09	73
RM 6.7	0.11	109	0.1	93
RM 10.2	0.11	77	0.09	59
RM 13.5	0.11	97	0.09	78

6.1.2 Currents and Salinities

Harmonic Constituent Analysis

A harmonic constituent analysis was also performed on the computed and observed current velocities at the five stations within the LPR. The amplitudes and phases of the four tidal constituents – M2, N2, S2, and K1, are presented in Table 6-5 through Table 6-8 respectively. The harmonic constituents were extracted from the time-series of measured and predicted currents at the bottom ADCP bin, the surface ADCP bin, and at mid-depth separately. The model is found to somewhat overestimate the amplitude of the dominant M2 component, by about 10-20% at the surface to about 20-40% at the bottom. The predicted current phases at all the stations within the LPR however appear consistent with data. The comparison of the N2, S2, and K1 components shows that predicted amplitudes of the smaller constituents are mostly consistent with observations, although there appears to be a small phase lag in the model predictions at these lesser harmonics.

Table 6-5: Comparison of Harmonic Constants for Velocity – M2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.51	156	0.57	157
	Mid-Depth	0.44	157	0.53	158
	Bottom	0.33	151	0.42	153
RM 4.2	Surface	0.42	176	0.56	153
	Mid-Depth	0.34	176	0.54	161
	Bottom	0.26	178	0.46	168
RM 6.7	Surface	0.4	167	0.5	157
	Mid-Depth	0.4	170	0.47	158
	Bottom	0.35	173	0.43	159
RM 10.2	Surface	0.33	171	0.4	163
	Mid-Depth	0.31	171	0.38	163
	Bottom	0.29	172	0.35	163
RM 13.5	Surface	0.15	180	0.2	171
	Mid-Depth	0.14	180	0.22	176
	Bottom	0.13	180	0.18	172

Table 6-6: Comparison of Harmonic Constants for Velocity – N2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.12	163	0.1	148
	Mid-Depth	0.11	162	0.09	148
	Bottom	0.09	160	0.09	151
RM 4.2	Surface	0.1	160	0.13	149
	Mid-Depth	0.08	172	0.12	155
	Bottom	0.07	184	0.08	165
RM 6.7	Surface	0.08	168	0.09	155
	Mid-Depth	0.08	172	0.09	156
	Bottom	0.07	172	0.08	159
RM 10.2	Surface	0.06	173	0.07	160
	Mid-Depth	0.06	174	0.07	161
	Bottom	0.06	176	0.06	162
RM 13.5	Surface	0.03	188	0.03	172
	Mid-Depth	0.03	186	0.06	149
	Bottom	0.02	186	0.03	175

Table 6-7: Comparison of Harmonic Constants for Velocity – S2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.12	177	0.1	175
	Mid-Depth	0.1	176	0.09	176
	Bottom	0.08	175	0.08	177
RM 4.2	Surface	0.12	187	0.13	175
	Mid-Depth	0.09	189	0.12	182
	Bottom	0.07	198	0.09	190
RM 6.7	Surface	0.08	177	0.1	173
	Mid-Depth	0.08	181	0.09	176
	Bottom	0.07	186	0.09	179
RM 10.2	Surface	0.07	185	0.08	180
	Mid-Depth	0.06	185	0.08	181
	Bottom	0.06	186	0.07	181
RM 13.5	Surface	0.03	190	0.04	181
	Mid-Depth	0.03	189	0.04	194
	Bottom	0.03	190	0.04	185

Table 6-8: Comparison of Harmonic Constants for Velocity – K1 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.05	13	0.02	344
	Mid-Depth	0.04	11	0.04	7
	Bottom	0.03	8	0.03	9
RM 4.2	Surface	0.03	35	0.04	352
	Mid-Depth	0.03	32	0.03	1
	Bottom	0.02	28	0.03	13
RM 6.7	Surface	0.03	35	0.03	354
	Mid-Depth	0.03	35	0.03	2
	Bottom	0.02	49	0.03	9
RM 10.2	Surface	0.02	29	0.02	5
	Mid-Depth	0.02	31	0.02	6
	Bottom	0.02	31	0.02	7
RM 13.5	Surface	0.01	42	0.01	16
	Mid-Depth	0.01	41	0.01	30
	Bottom	0.01	42	0.01	24

Time-Series Comparisons

The time-series of surface and bottom velocities and salinities at the five Fall PWCM locations based on model results and the corresponding data from the nearest measured bin are shown in Figure 6-1 through Figure 6-5. The model is found to reasonably capture the movement of the salt front into the river as both the bottom salinity as well as the surface salinity show good agreement with data as far upstream as RM 10.2. The model performance metrics in terms of the RMSE, relative RMSE, and the coefficient of determination of the model predictions are also shown in these figures.

In the comparison of the velocity time-series, the upstream currents at flood tides are considered positive, and the downstream currents during ebb flow are considered negative. The model appears to over-predict the currents more significantly at RM1.4 and RM4.2 especially at the surface, with a relative RMS error between model and data of almost 20%.

The model performance improves further upstream, with the increased dominance of fresh-water flow, and there is much better agreement in surface and bottom current velocities between model and data with a relative RMS error of only about 5%.

6.2 Spring 2010 PWCM data

Hydrodynamic data is also available from ADCP and CTD deployments as part of the Spring PWCM in 2010 at River Miles 1.4, 4.2, 6.7, 10.2, and 13.5 within the LPR. The harmonic constituents of water-level measurements and model predictions at these locations were computed, and are presented in Table 6-9 through Table 6-12.

6.2.1 Water Levels

The results of a harmonic constituent analysis of the predicted and observed water-levels during the Spring 2010 PWCM is shown in Table 6-9 through Table 6-12 for tidal constituents M2, N2, S2, and K1 respectively. For the M2 constituent, the model-predictions and observations generally appear to be in very good agreement, although the model appears to under-estimate the amplitudes of the M2 component by about 5% at RM 1.4 and RM 4.2. Similarly, the model is also able to reproduce very well the observed amplitudes of the N2, S2, and K1 components, although there is appears to be a small phase lag in the model especially at RM 10.2 and RM 13.5.

Table 6-9: Comparison of Harmonic Constants for Water Level – M2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.65	297	0.61	296
RM 4.2	0.78	241	0.74	240
RM 6.7	0.79	246	0.76	243
RM 10.2	0.66	316	0.67	308
RM 13.5	0.67	316	0.69	308

Table 6-10: Comparison of Harmonic Constants for Water Level – N2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.09	290	0.09	282
RM 4.2	0.16	231	0.16	228
RM 6.7	0.16	240	0.16	231
RM 10.2	0.11	325	0.1	306
RM 13.5	0.13	328	0.11	311

Table 6-11: Comparison of Harmonic Constants for Water Level – S2 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.09	310	0.1	320
RM 4.2	0.13	267	0.14	272
RM 6.7	0.12	274	0.14	275
RM 10.2	0.08	336	0.09	334
RM 13.5	0.07	338	0.09	334

Table 6-12: Comparison of Harmonic Constants for Water Level – K1 Component

Location	Observed		Predicted	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	0.11	130	0.08	117
RM 4.2	0.12	99	0.09	85
RM 6.7	0.12	102	0.09	86
RM 10.2	0.1	142	0.09	122
RM 13.5	0.1	143	0.09	121

6.2.2 Currents and Salinities

Harmonic Constituent Analysis

A harmonic analysis was performed on the computed and observed current velocities at the Spring 2010 PWCM locations within the LPR. The amplitudes and phases of the four tidal constituents – M2, N2, S2, and K1, are presented in Table 6-13 through Table 6-16 respectively. The amplitudes of these major components are in general found to be in good agreement with data at all the locations, although the model tends to slightly over-predict the M2 amplitudes in the near-bottom layers. The predicted phase of the M2, N2, and S2 components also compare reasonably well with the observations.

Table 6-13: Comparison of Harmonic Constants for Velocity – M2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.53	160	0.55	158
	Mid-Depth	0.4	159	0.46	154
	Bottom	0.26	151	0.33	148
RM 4.2	Surface	0.43	162	0.55	152
	Mid-Depth	0.35	167	0.48	159
	Bottom	0.27	172	0.39	164
RM 6.7	Surface	0.41	166	0.46	159
	Mid-Depth	0.39	169	0.43	160
	Bottom	0.34	172	0.38	162
RM 10.2	Surface	0.31	171	0.37	165
	Mid-Depth	0.29	172	0.35	165
	Bottom	0.26	173	0.31	165
RM 13.5	Surface	0.16	180	0.19	178
	Mid-Depth	0.13	180	0.17	177
	Bottom	0.11	180	0.16	174

Table 6-14: Comparison of Harmonic Constants for Velocity – N2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.1	156	0.11	148
	Mid-Depth	0.1	151	0.1	142
	Bottom	0.08	150	0.09	140
RM 4.2	Surface	0.1	162	0.13	144
	Mid-Depth	0.08	168	0.11	154
	Bottom	0.07	167	0.08	161
RM 6.7	Surface	0.09	166	0.1	155
	Mid-Depth	0.09	168	0.1	157
	Bottom	0.08	170	0.09	156
RM 10.2	Surface	0.07	174	0.09	164
	Mid-Depth	0.07	174	0.08	164
	Bottom	0.06	174	0.07	165
RM 13.5	Surface	0.04	188	0.06	179
	Mid-Depth	0.03	179	0.06	179
	Bottom	0.03	182	0.04	175

Table 6-15: Comparison of Harmonic Constants for Velocity – S2 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.08	191	0.1	191
	Mid-Depth	0.07	196	0.09	191
	Bottom	0.05	195	0.07	192
RM 4.2	Surface	0.06	187	0.1	186
	Mid-Depth	0.06	200	0.09	193
	Bottom	0.05	208	0.07	198
RM 6.7	Surface	0.06	197	0.08	194
	Mid-Depth	0.06	200	0.08	198
	Bottom	0.06	204	0.07	199
RM 10.2	Surface	0.05	203	0.07	200
	Mid-Depth	0.04	202	0.06	201
	Bottom	0.04	204	0.06	201
RM 13.5	Surface	0.02	223	0.03	221
	Mid-Depth	0.02	209	0.03	224
	Bottom	0.02	212	0.03	214

Table 6-16: Comparison of Harmonic Constants for Velocity – K1 Component

Location		Observed		Predicted	
		Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
RM 1.4	Surface	0.03	23	0.04	357
	Mid-Depth	0.04	15	0.03	355
	Bottom	0.03	6	0.02	340
RM 4.2	Surface	0.03	14	0.03	354
	Mid-Depth	0.03	24	0.03	3
	Bottom	0.02	29	0.03	12
RM 6.7	Surface	0.03	15	0.03	6
	Mid-Depth	0.03	25	0.03	9
	Bottom	0.03	39	0.02	8
RM 10.2	Surface	0.03	30	0.02	13
	Mid-Depth	0.02	30	0.02	11
	Bottom	0.02	33	0.02	10
RM 13.5	Surface	0.01	54	0.02	48
	Mid-Depth	0.01	59	0.01	52
	Bottom	0.01	55	0.01	43

Time-Series Comparisons

Figure 6-6 through Figure 6-15 show the time-series comparison of velocities and salinities between model and data at the five measurement locations within the LPR. For each location, the 4-month long deployment is plotted over two pages to better illustrate the intra-tidal variability. While the salinity data at RM 1.4 appears to be unreliable towards the latter half of the deployment with abrupt changes in reported values and inexplicable trends in bottom and surface salinities, the model results in general seem to compare reasonably well with data. The model reasonably captures the onset of salt-water flow at all the locations towards the end of the high river-flow period.

The model-predicted currents also coincide greatly with the data at both the bottom and surface at most locations, with a relative RMS error averaging around 5%. The most significant exception is at RM 4.2, where the model appears to over-predict the ebb

velocities at the surface as well as bottom resulting in a higher relative RMS error of about 10%.

6.3 March 2010 high-flow transects

On March 16, 2010, the flow over Dundee Dam peaked at 16,300 cfs, which is the equivalent of a 1 in 25-year event in the LPR, providing an opportunity to measure the response of the river under such extreme high flow conditions. Dr. Robert Chant of the Institute of Marine and Coastal Science, Rutgers University conducted a series of longitudinal transects along the thalweg in the LPR and within the navigation channel in NB during the peak of the storm event. The data consists of CTD and OBS casts measuring the water depth, temperature, salinity and SS concentration (OBS measured, converted to SS concentration by means of an OBS-SS concentration relationship) over depth in the water column. A total of three such longitudinal transects were collected over half a tidal cycle, with the first transect collected at the beginning of the ebb tide, the second transect collected around the middle of the ebb tide, and the third transect collected around the following low-water slack.

The model application and comparison to the salinity measured in this event are a measure of the model's capability to capture the response of the river to such extreme high-flow events and represents the model calibration to salinity conditions in the LPR under high-flow conditions. The model results for salinity over the period corresponding to the collection of the three transects have also been plotted along the longitudinal axis of the LPR and NB and compared to the data as shown in Figure 6-16 through Figure 6-18. The model reproduces the salt front location approximately at the same location as seen in the data with some minor discrepancies. The model-calculated salt front is about quarter mile down-estuary in case of transect #1, and about half-mile up-estuary in case of transects #2 and #3 when compared to the salt front location seen in the data.

6.4 Chemical Water-Column Monitoring (CWCW) data

The water samples collected as part of the CWCW program were characterized for salinity in addition to contaminant concentrations. Since the water samples were collected over a range of discharge (ranging from ~200 cfs to 4000 cfs) and tidal conditions (with measurements over the tidal cycle as well as spring-neap cycle), and with several measurements at several locations within the LPR, these measurements have also been used to provide an additional dataset to judge the performance of the HD model with respect to reproducing the salinity in the LPR.

The comparison of the measured salinity versus the model-calculated salinity for the various events and locations is presented in Figure 6-19. As observed from the figure the model performs well in reproducing the salinity measurements in most events and locations. Only during Routine Event 1 and High-Flow Event 1 does the model show an apparent bias relative to the measured salinity, tending to over-predict during routine event 1 and under-predicting during High-Flow Event 1. Both these discrepancies may be a consequence of minor temporal differences between the model and data which are

exacerbated during episodic events with elevated river flows such as during High-Flow Event 1, but also during Routine Event 1 which occurred during a flow event when river flow at Dundee Dam reached ~3000 cfs and which was preceded by about a month with flows less than 1000 cfs.

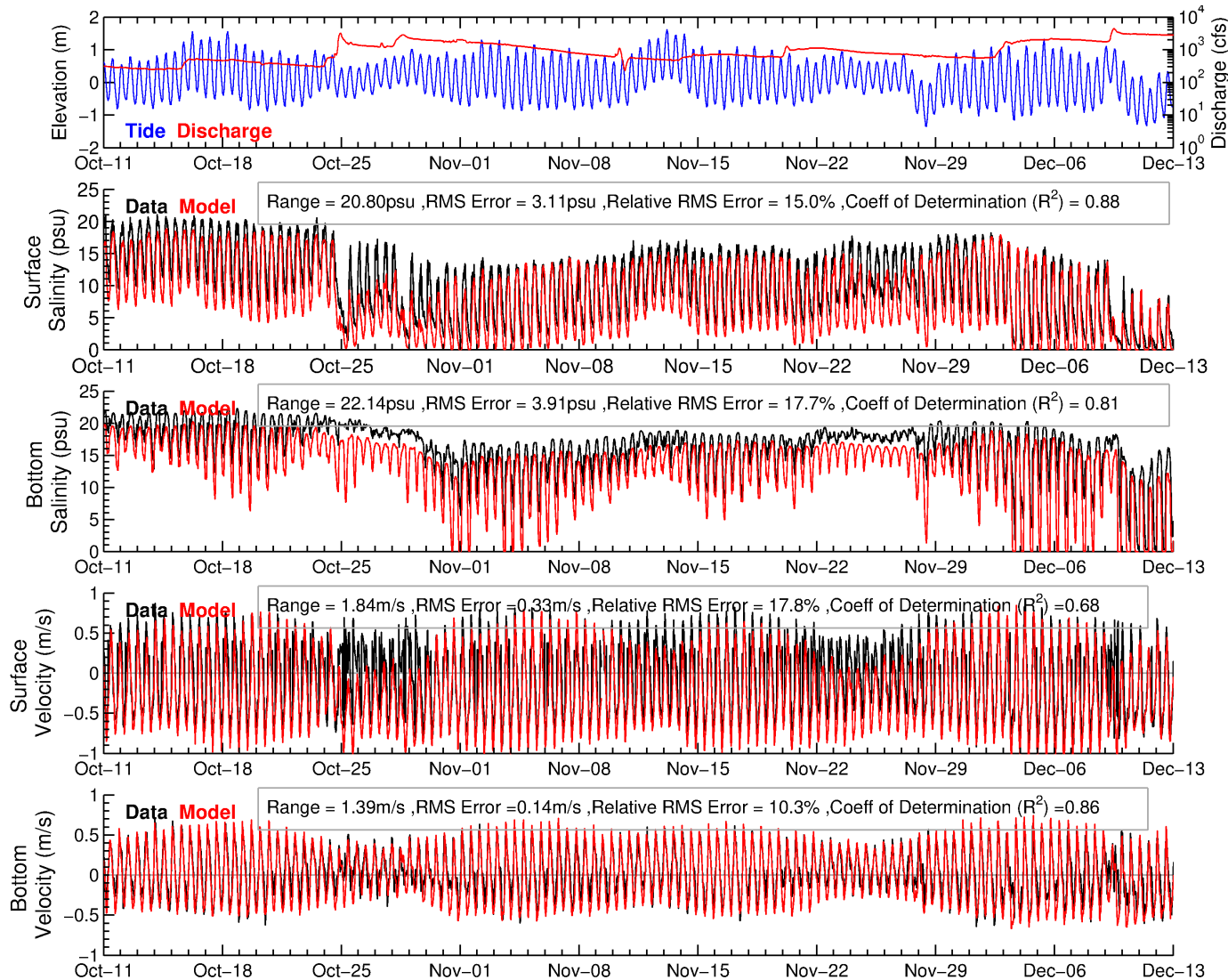


Figure 6-1: Comparison of model and data velocities and salinities at RM 1.4 for the Fall 2009 PWCM period.

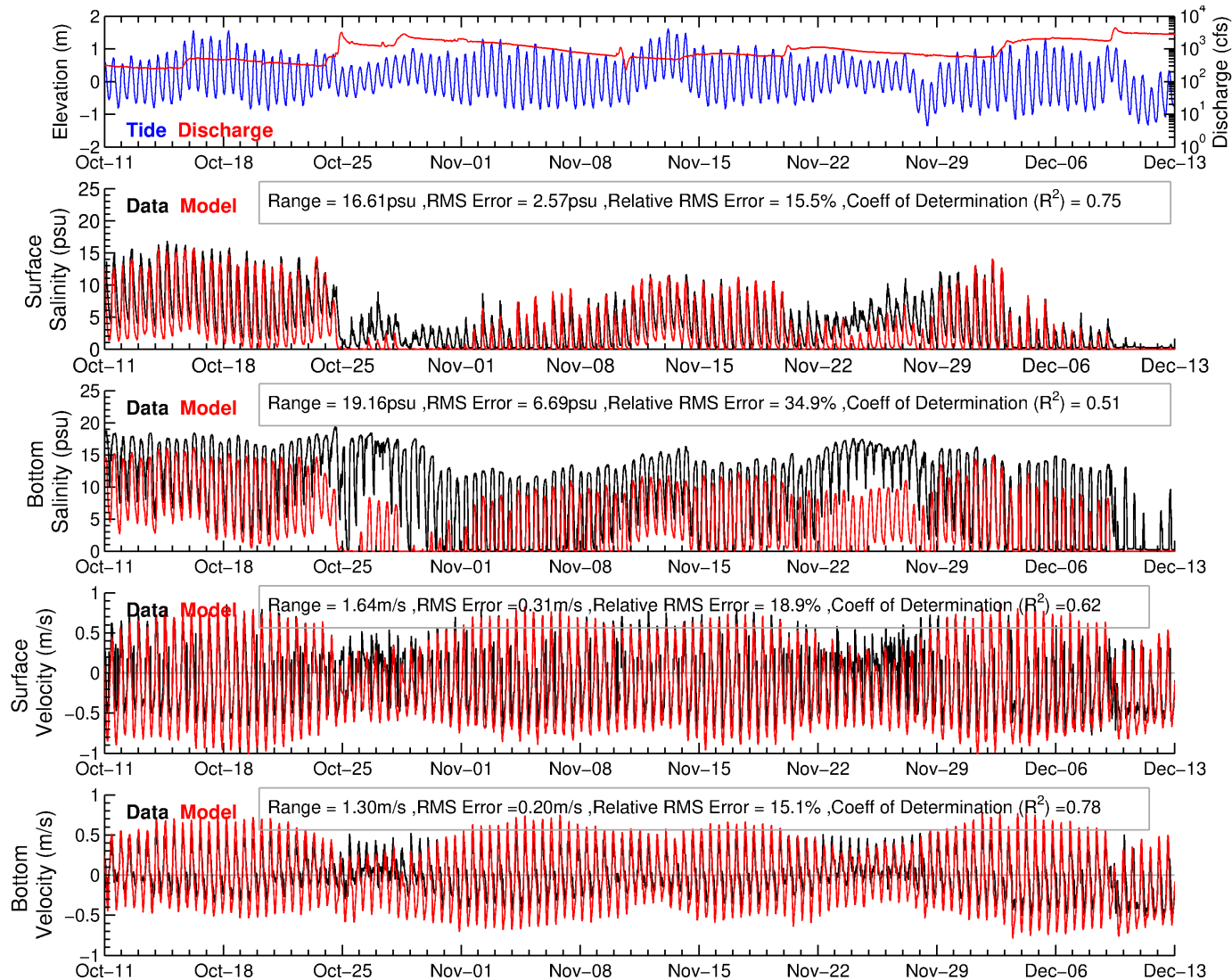


Figure 6-2: Comparison of model and data velocities and salinities at RM 4.2 for the Fall 2009 PWCM period.

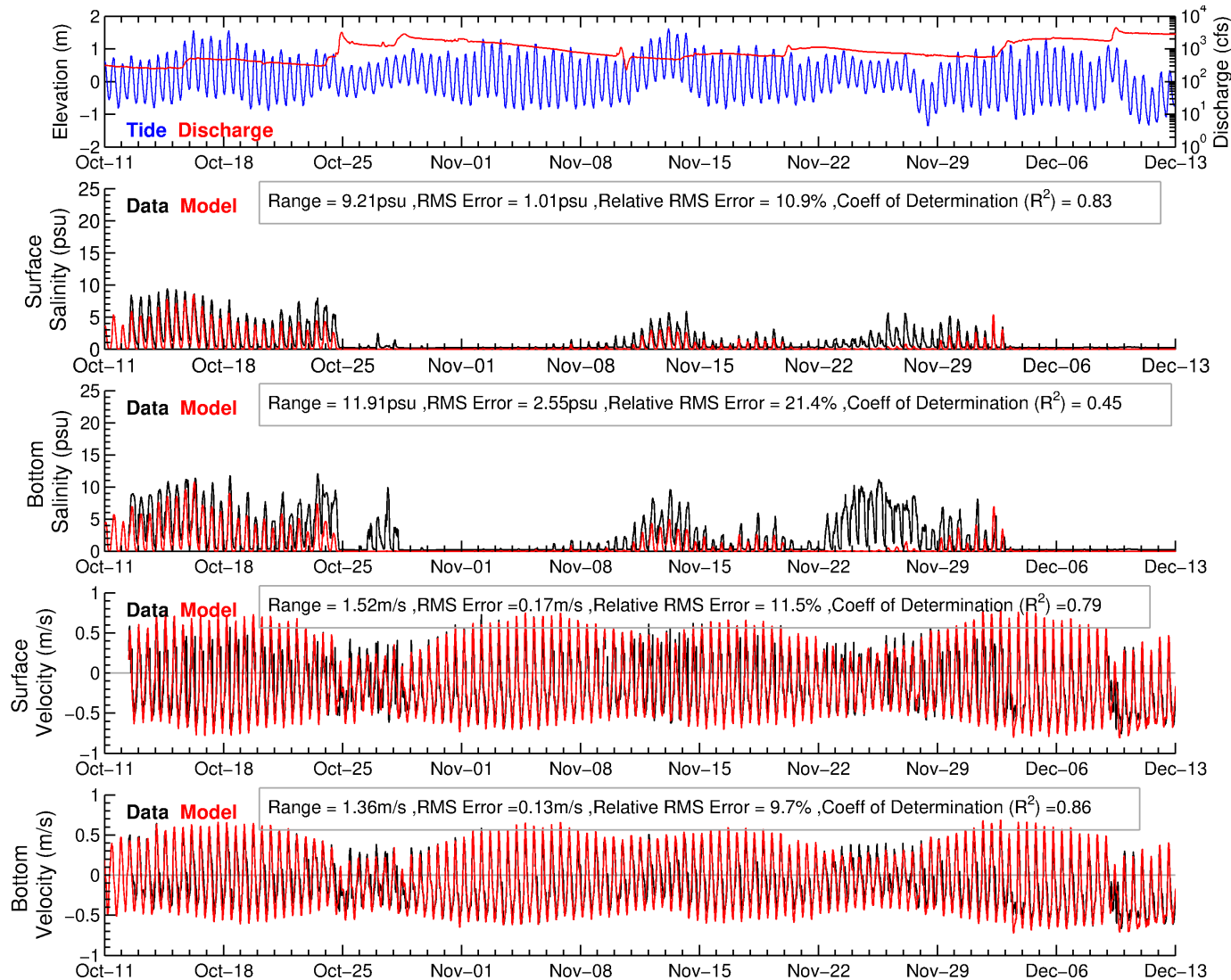


Figure 6-3: Comparison of model and data velocities and salinities at RM 6.7 for the Fall 2009 PWCM period.

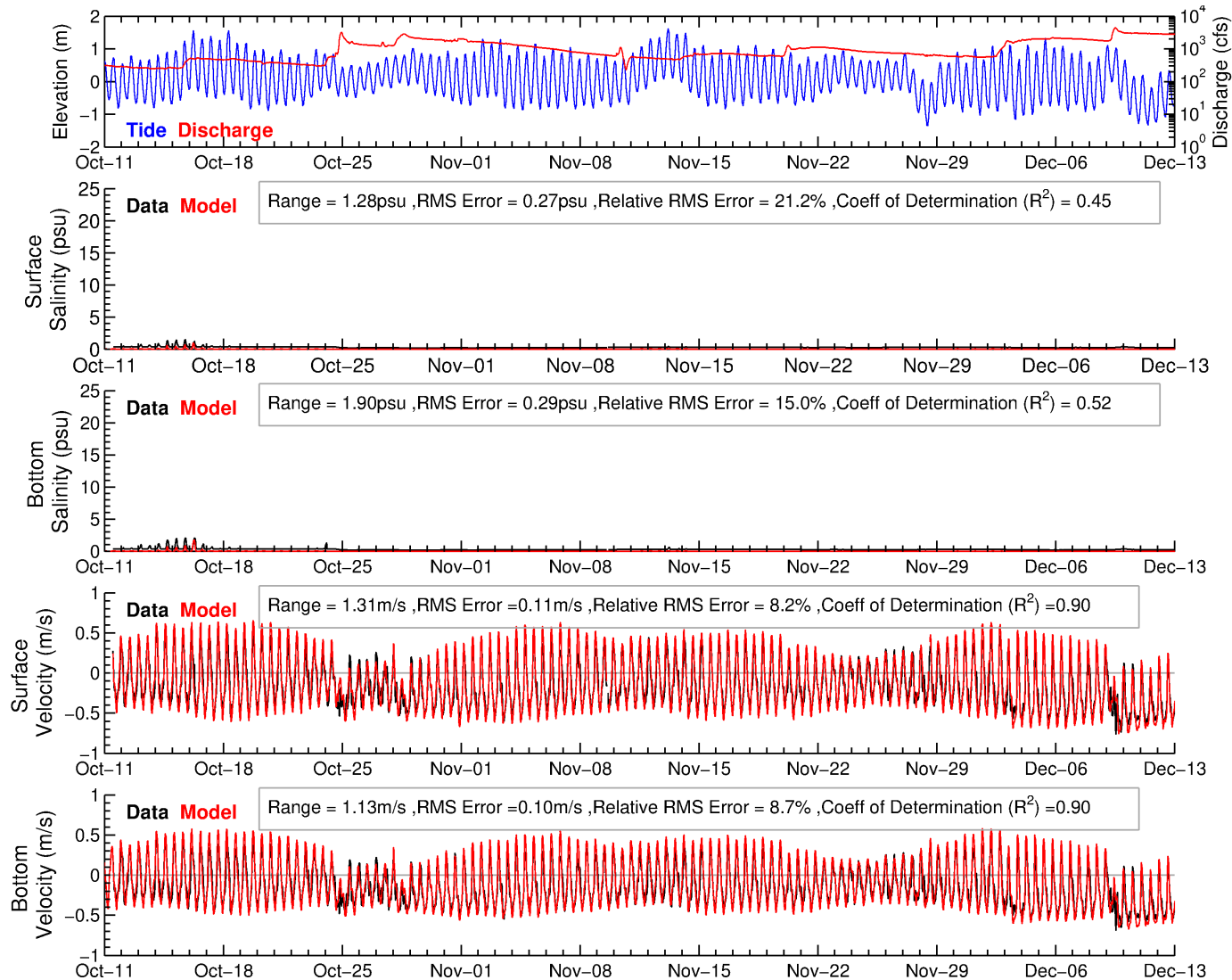


Figure 6-4: Comparison of model and data velocities and salinities at RM 10.2 for the Fall 2009 PWCM period.

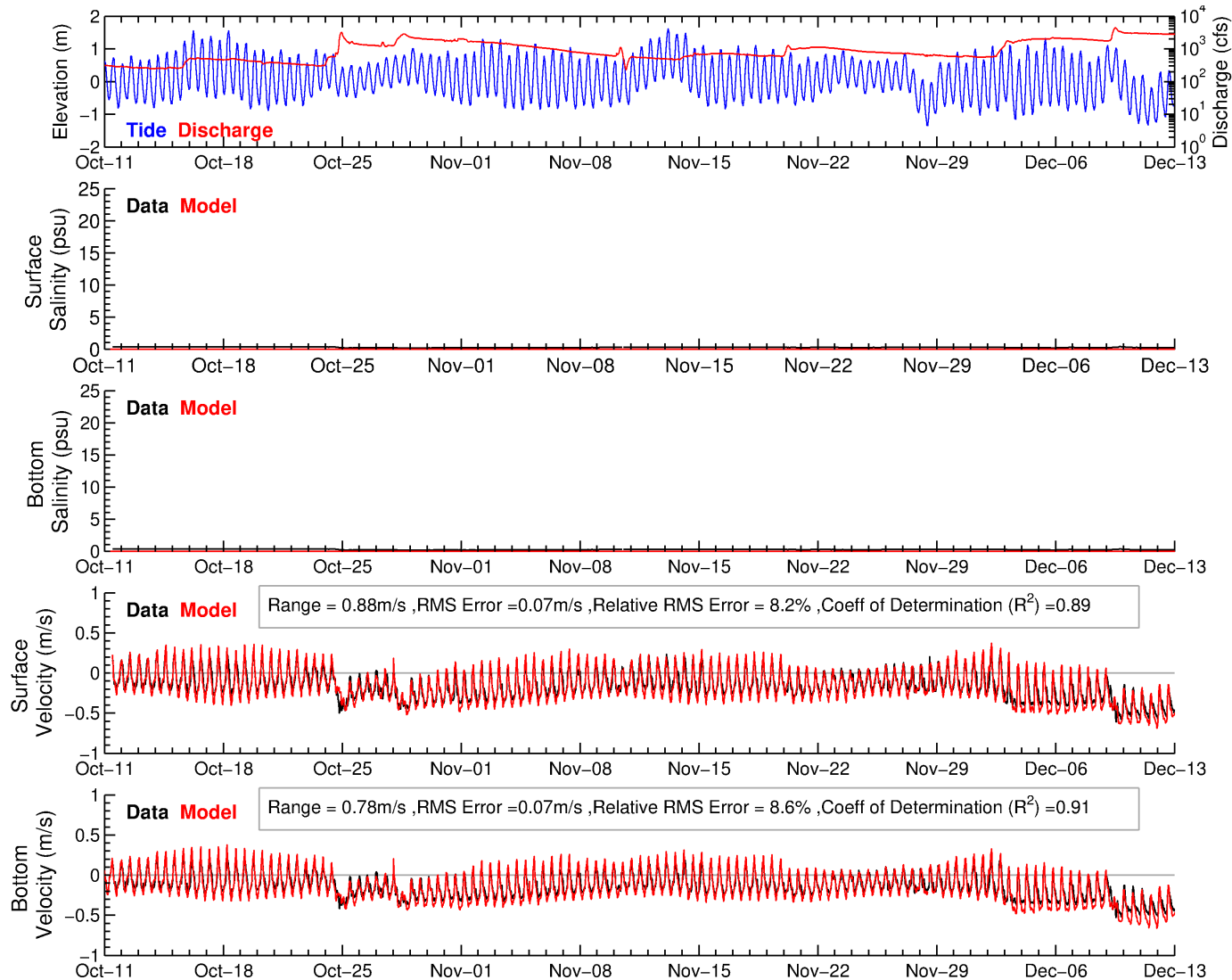


Figure 6-5: Comparison of model and data velocities and salinities at RM 13.5 for the Fall 2009 PWCM period.

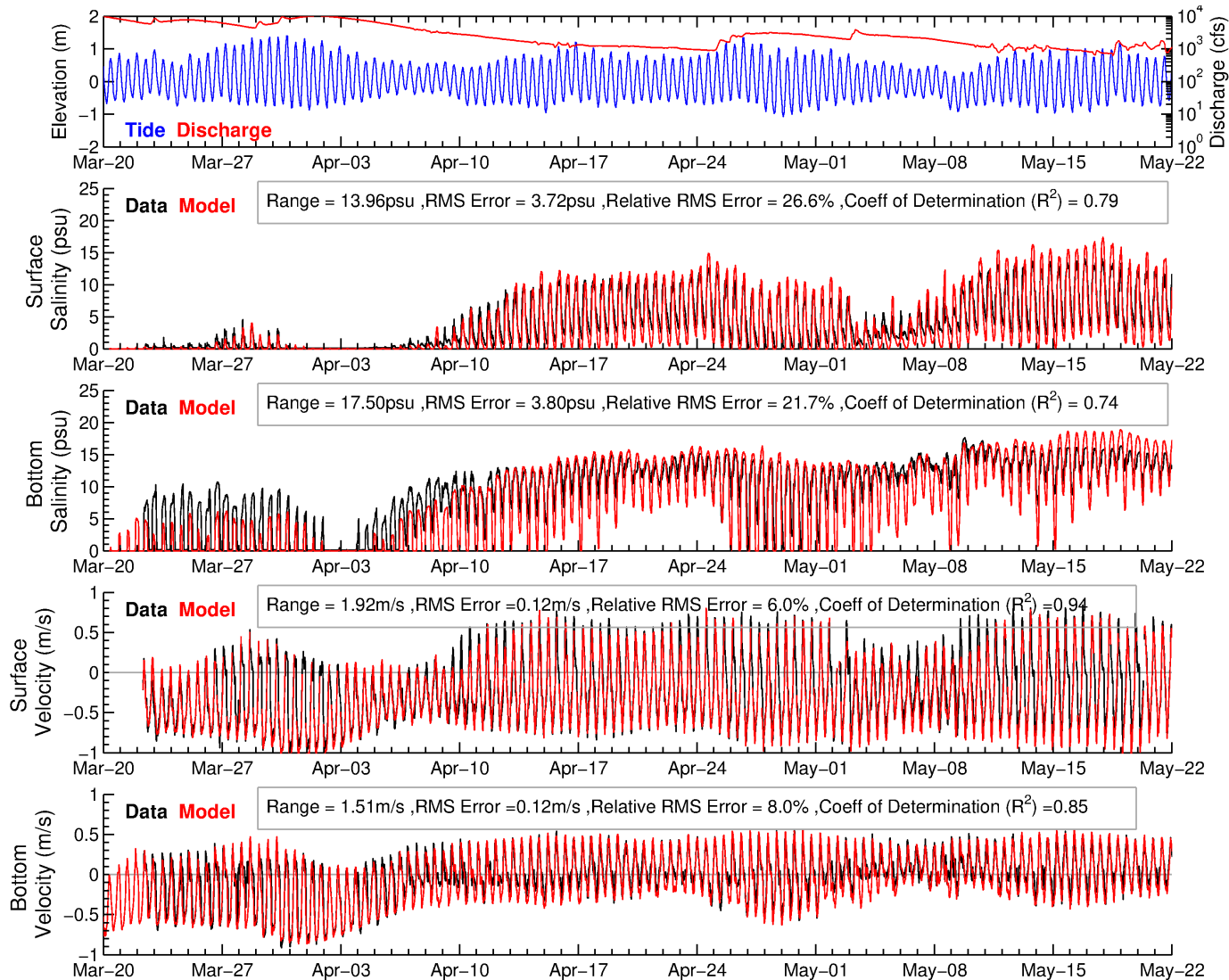


Figure 6-6: Comparison of model and data velocities and salinities at RM 1.4 for the Spring 2010 PWCM period.

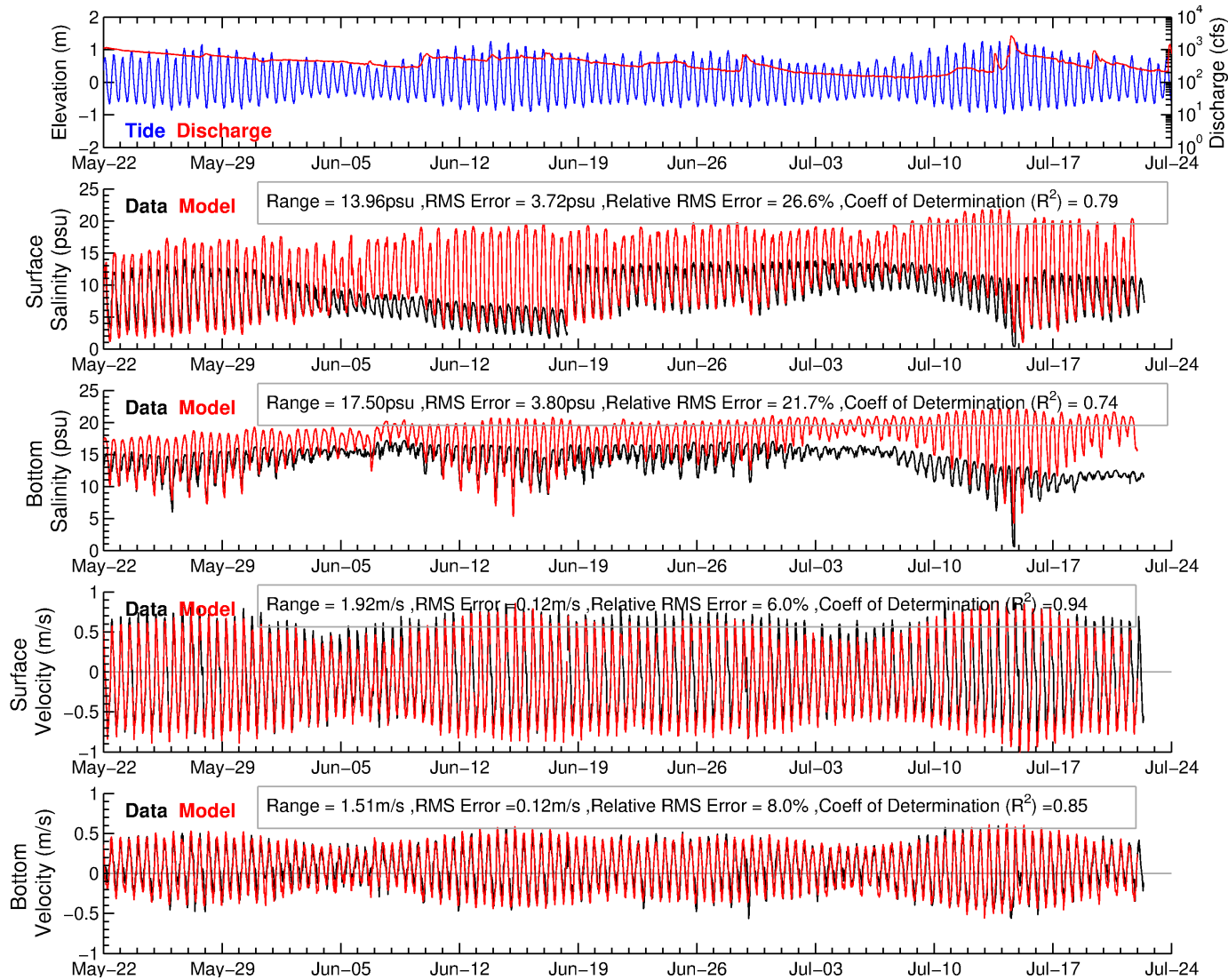


Figure 6-7: Comparison of model and data velocities and salinities at RM 1.4 for the Spring 2010 PWCM period (Contd.).

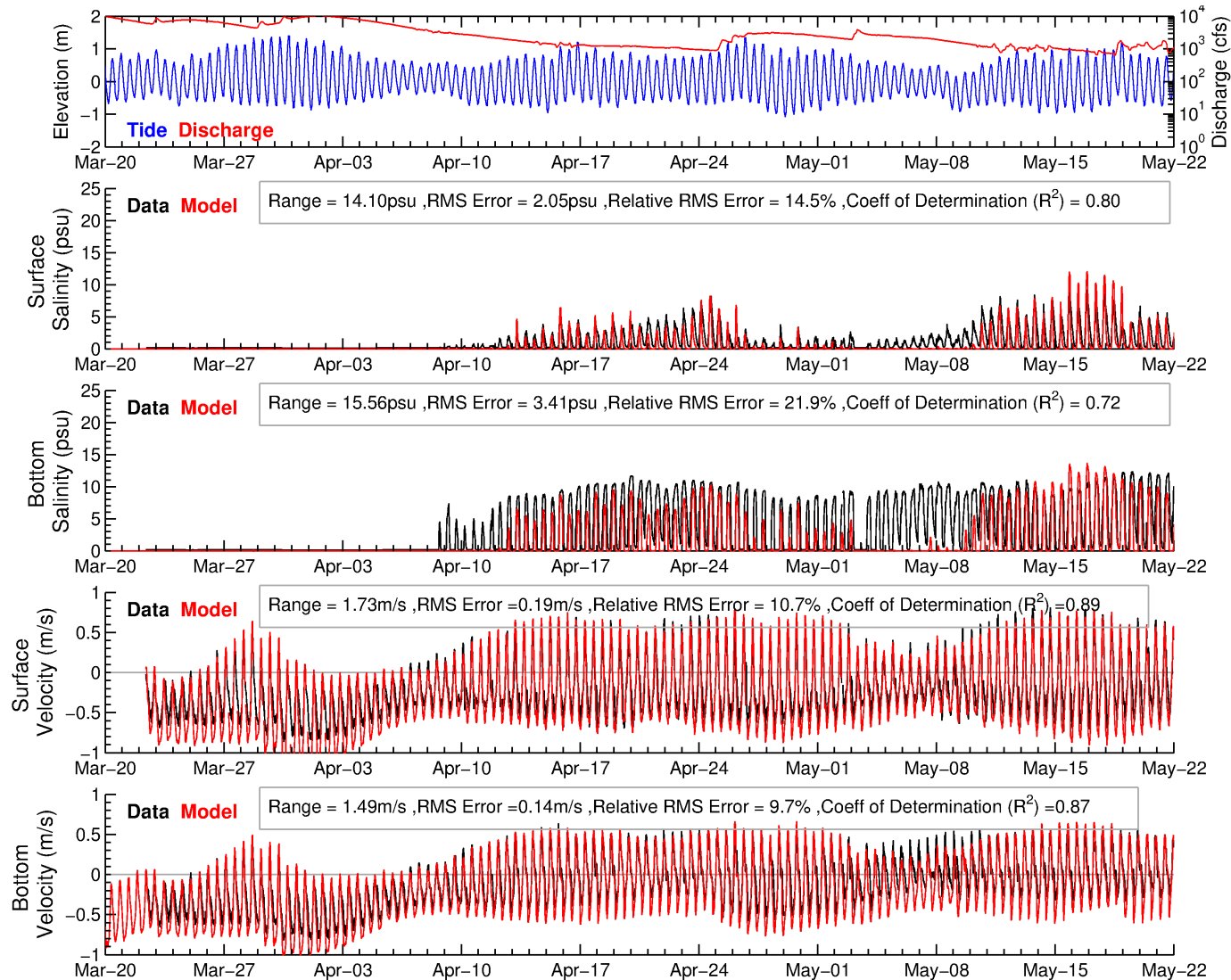


Figure 6-8: Comparison of model and data velocities and salinities at RM 4.2 for the Spring 2010 PWCM period.

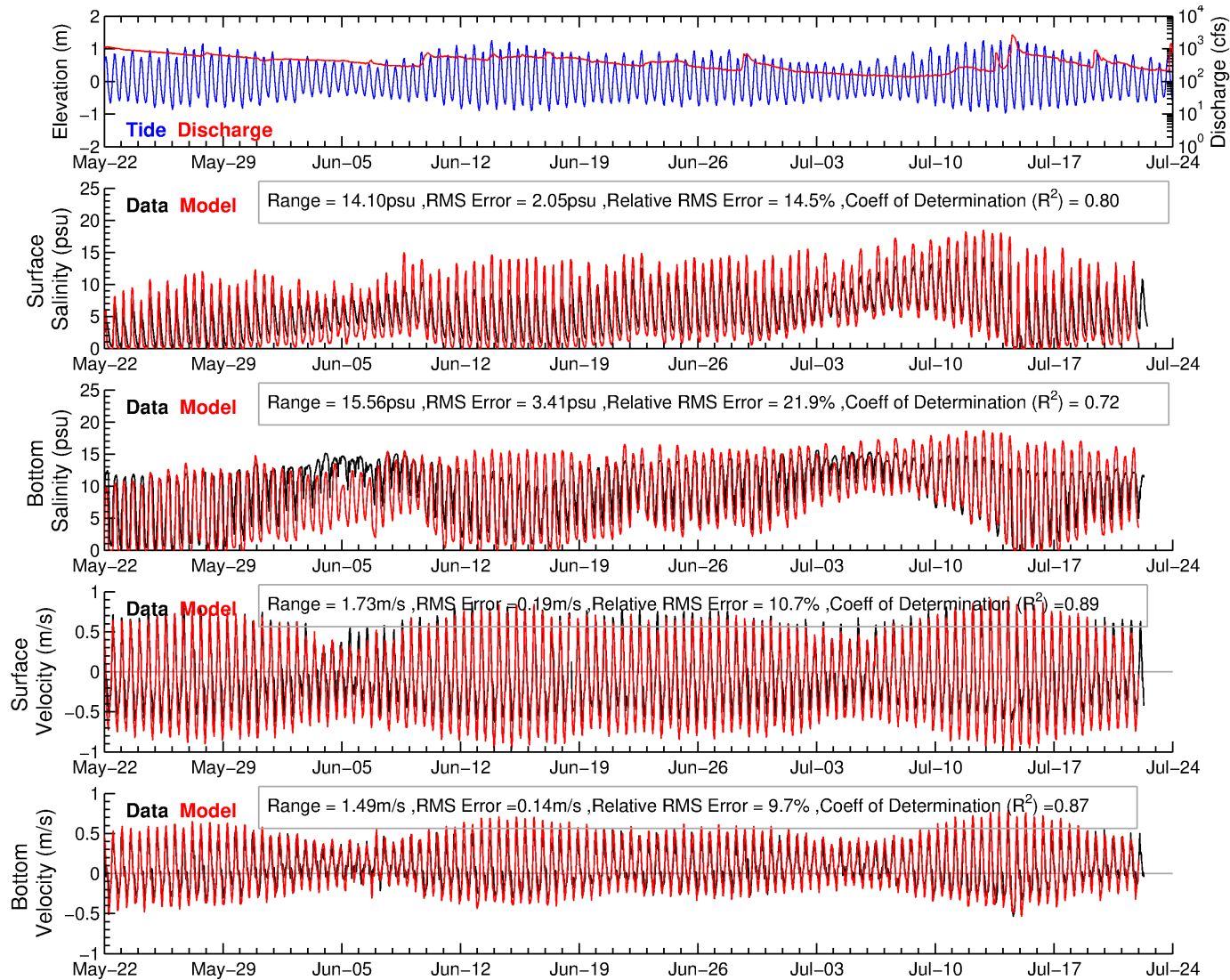


Figure 6-9: Comparison of model and data velocities and salinities at RM 4.2 for the Spring 2010 PWCM period (Contd.).

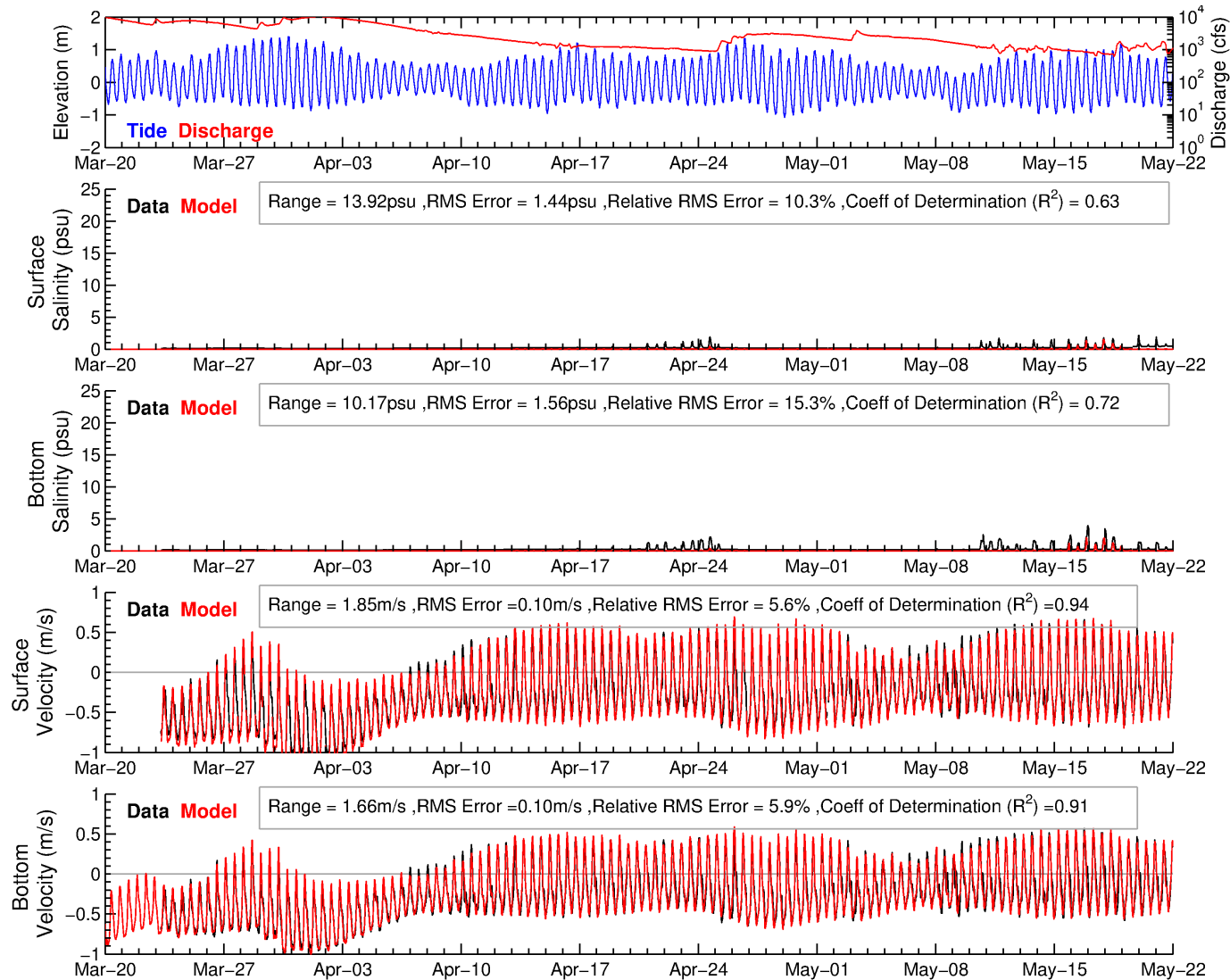


Figure 6-10: Comparison of model and data velocities and salinities at RM 6.7 for the Spring 2010 PWCM period.

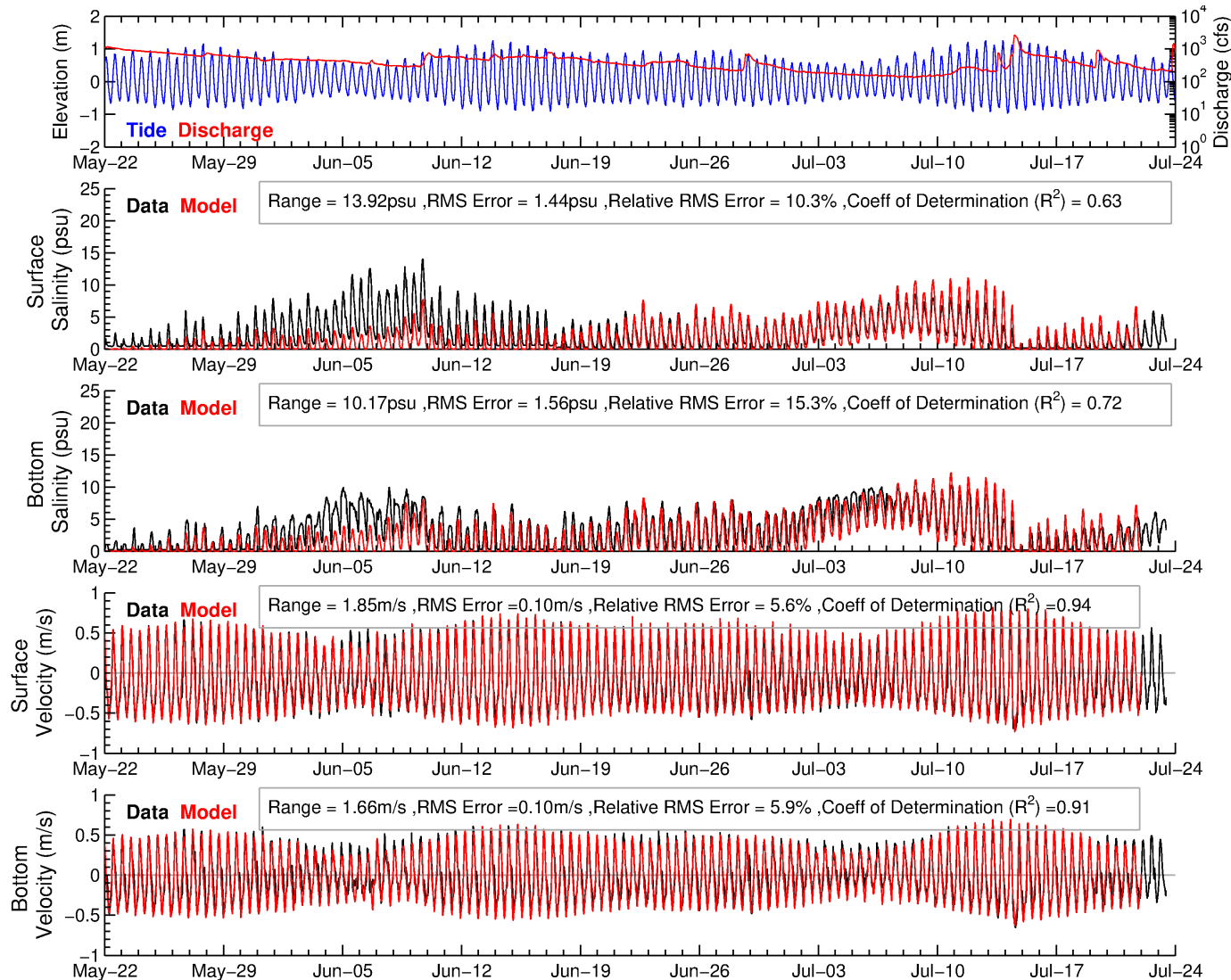


Figure 6-11: Comparison of model and data velocities and salinities at RM 6.7 for the Spring 2010 PWCM period (Contd.).

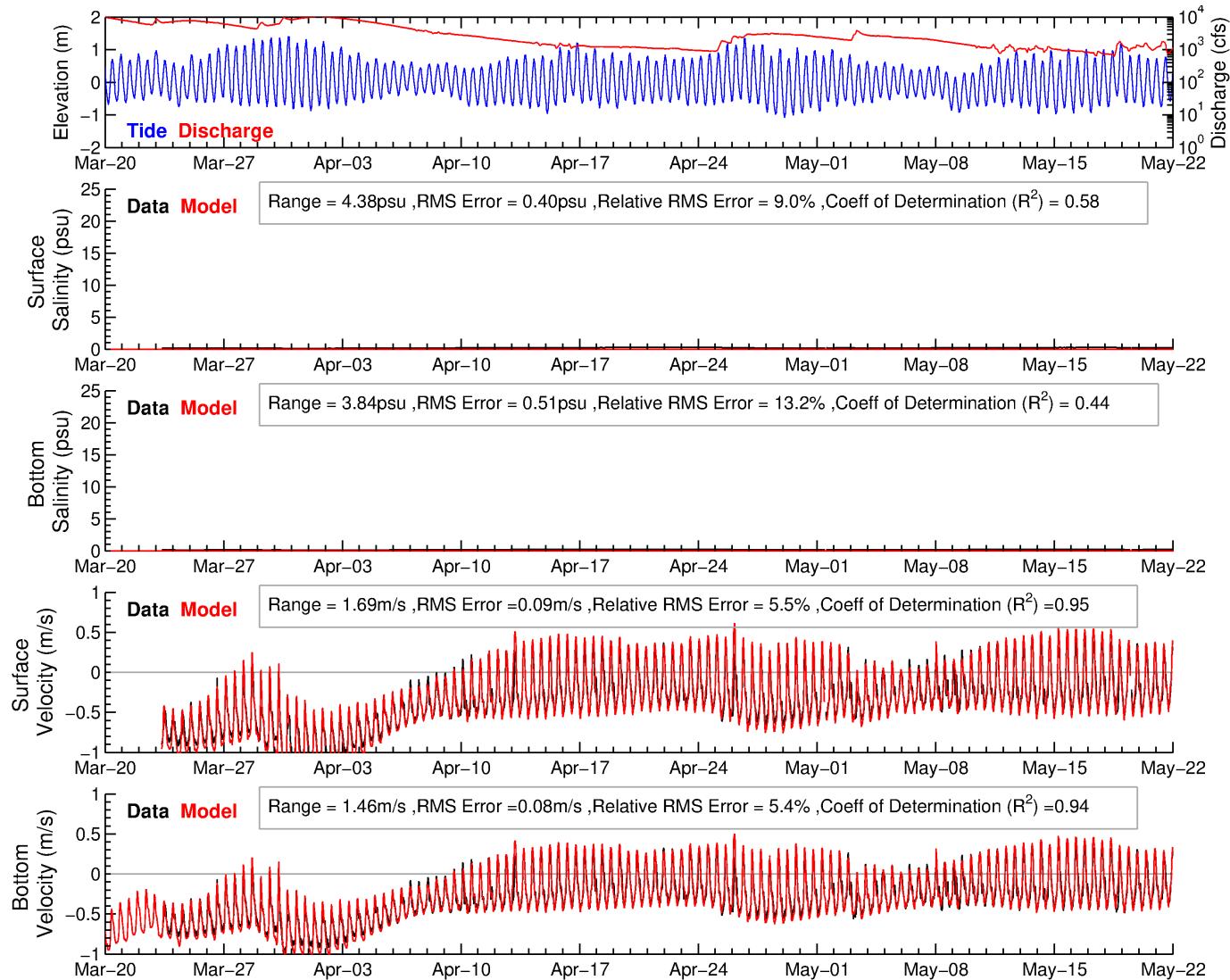


Figure 6-12: Comparison of model and data velocities and salinities at RM 10.2 for the Spring 2010 PWCM period.

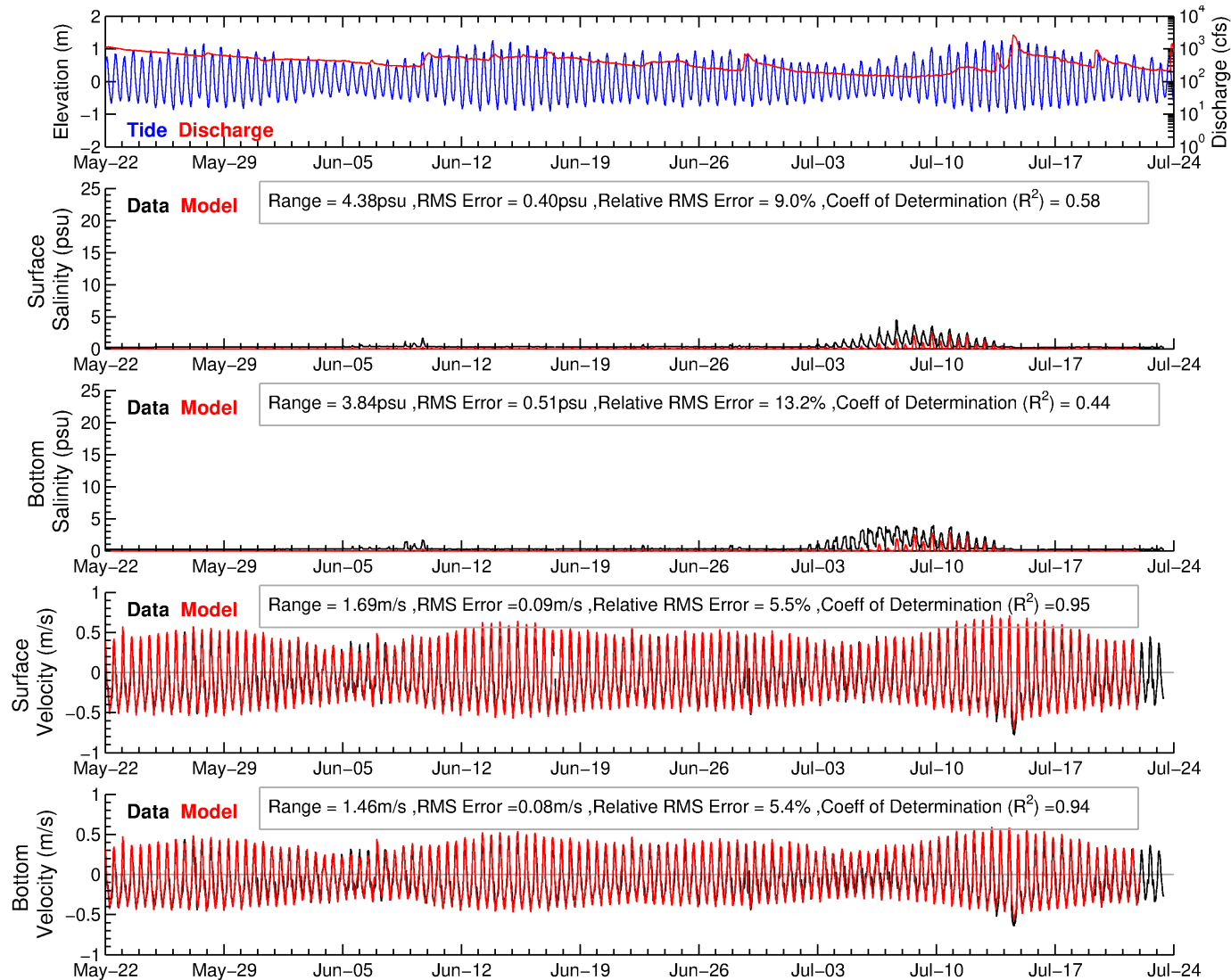


Figure 6-13: Comparison of model and data velocities and salinities at RM 10.2 for the Spring 2010 PWCM period (Contd.).

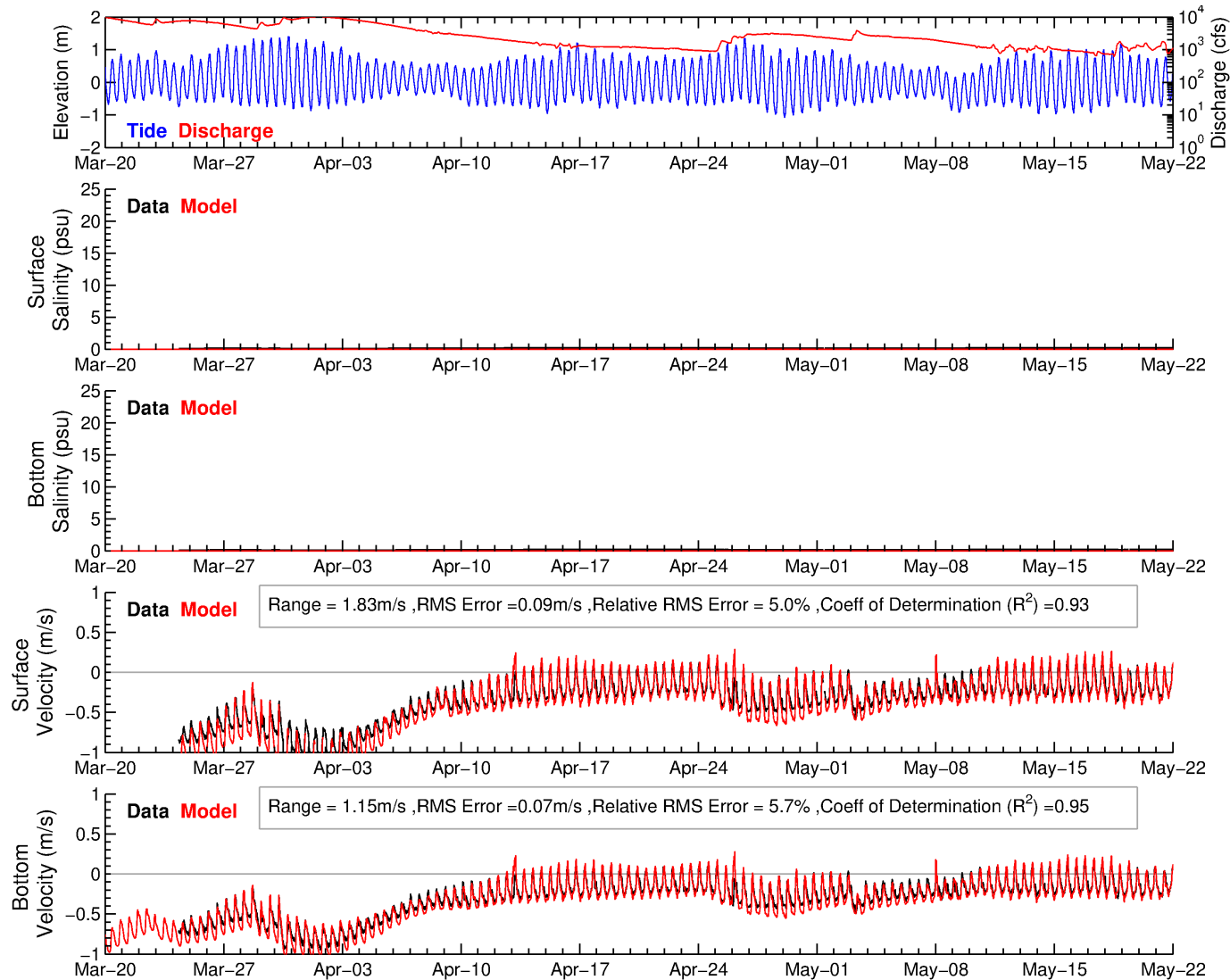


Figure 6-14: Comparison of model and data velocities and salinities at RM 13.5 for the Spring 2010 PWCM period.

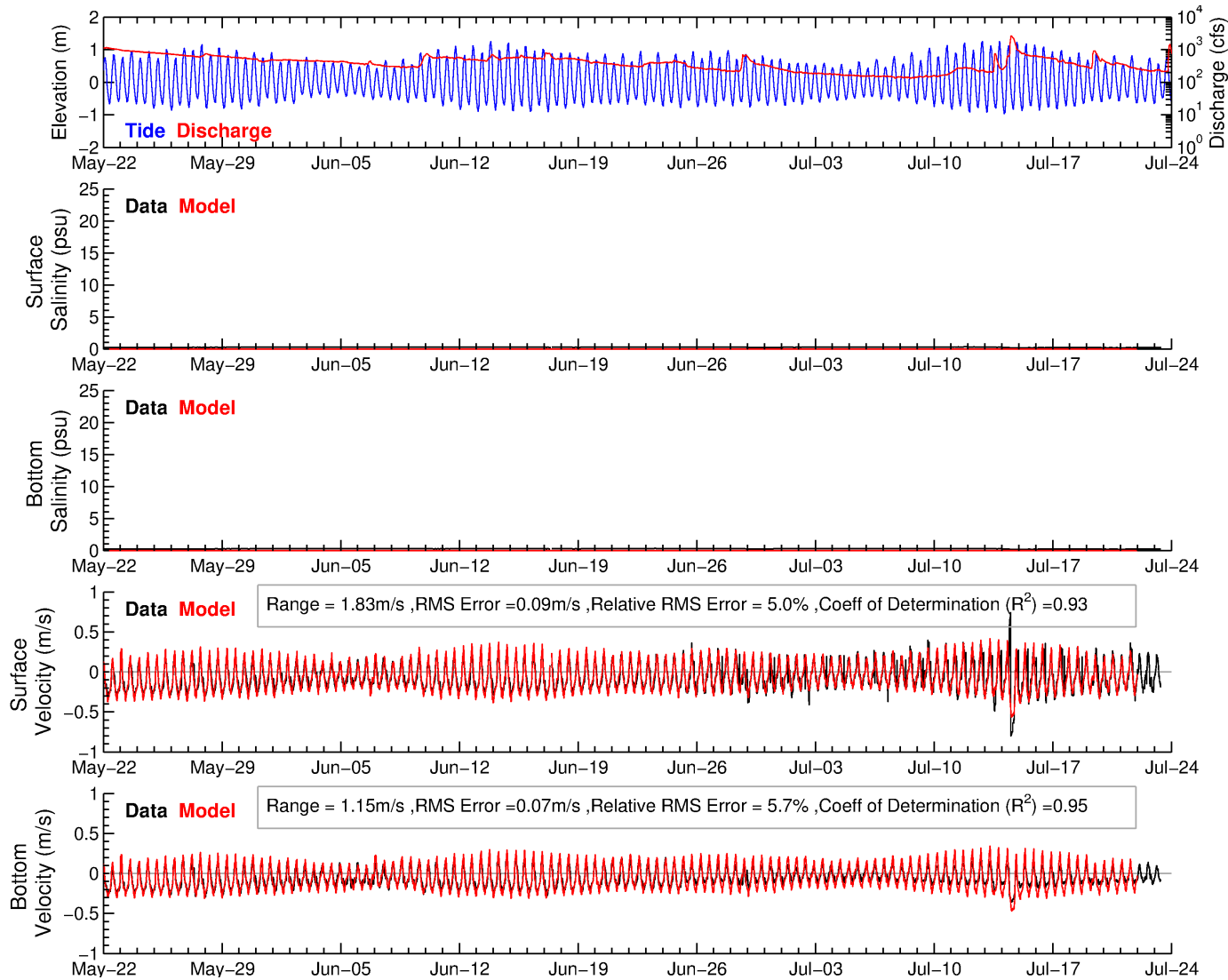


Figure 6-15: Comparison of model and data velocities and salinities at RM 13.5 for the Spring 2010 PWCM period (Contd.)

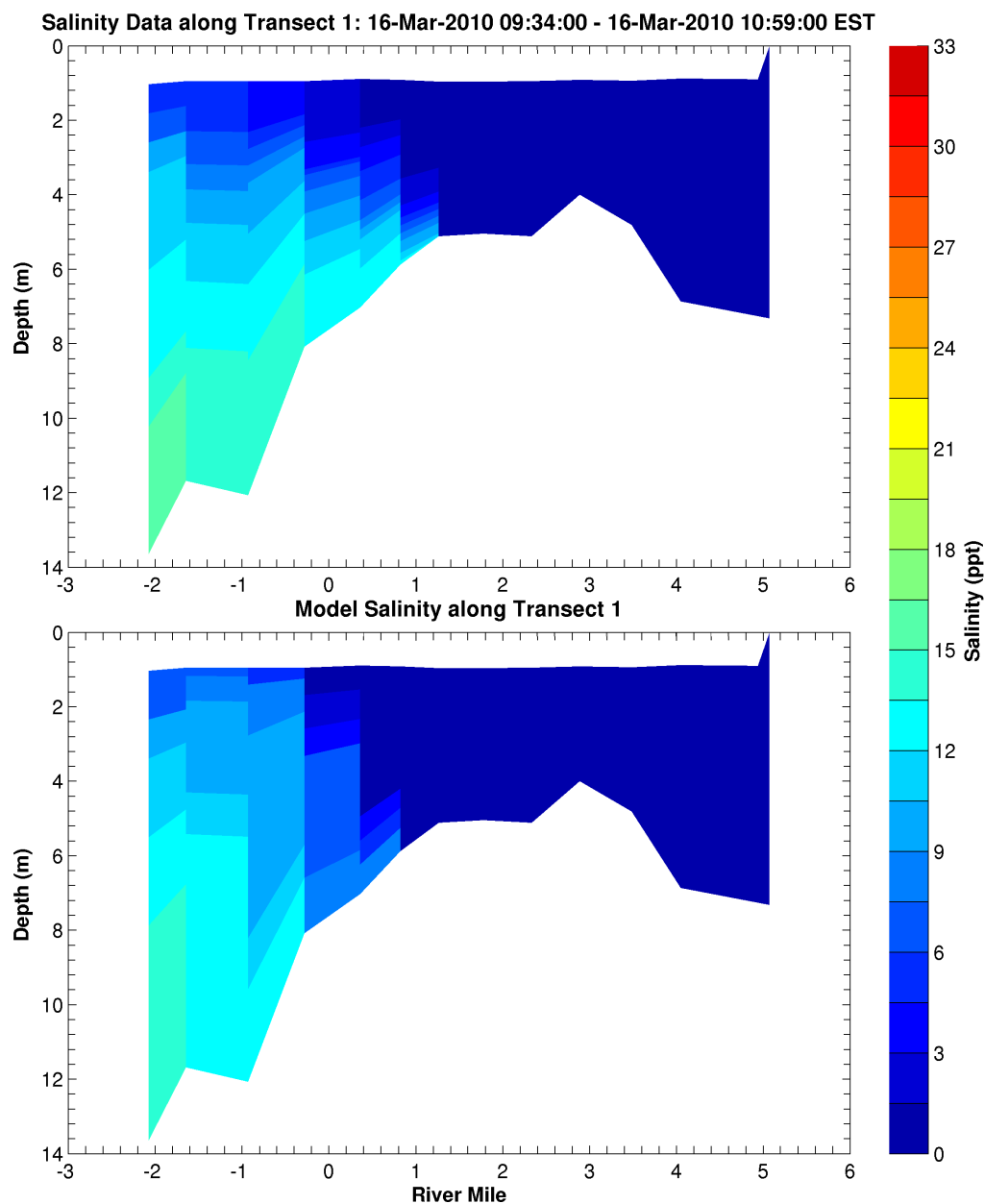


Figure 6-16: Transects of salinity along the longitudinal axis of the LPR and NB on March 16, 2010 (Transect #1); Data (upper panel) and model (lower panel).

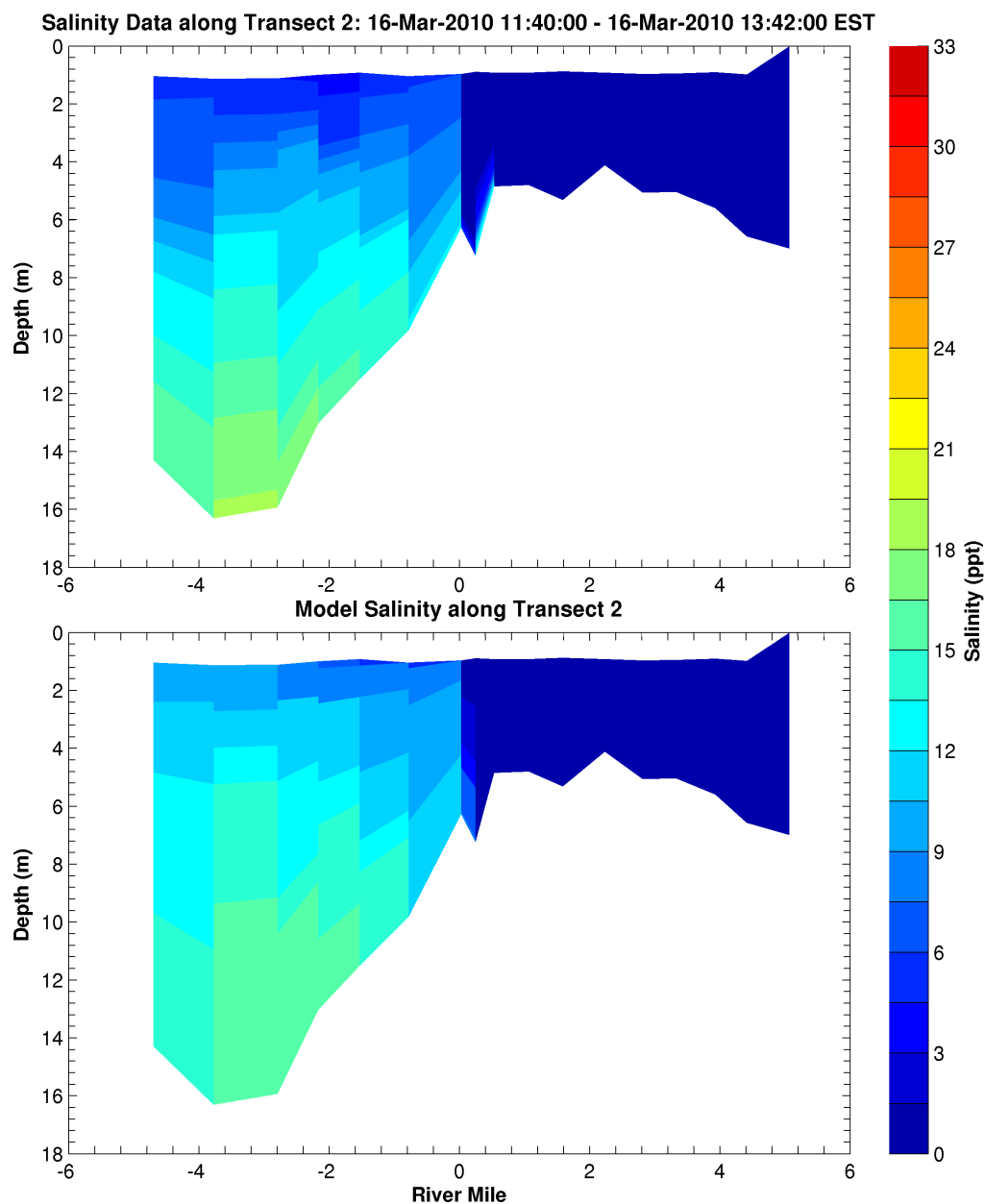


Figure 6-17: Transects of salinity along the longitudinal axis of the LPR and NB on March 16, 2010 (Transect #2); Data (upper panel) and model (lower panel).

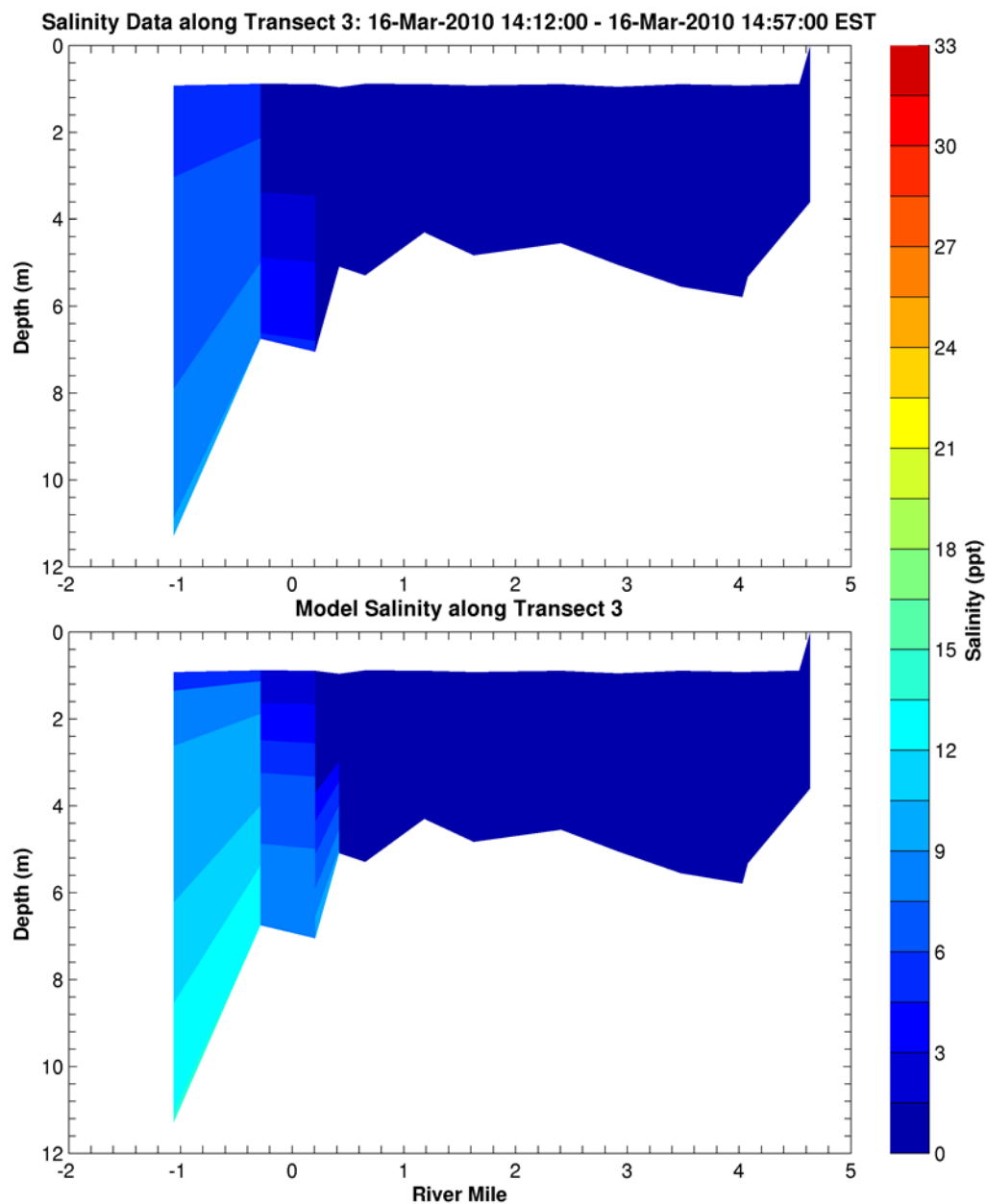


Figure 6-18: Transects of salinity along the longitudinal axis of the LPR and NB on March 16, 2010 (Transect #3); Data (upper panel) and model (lower panel).

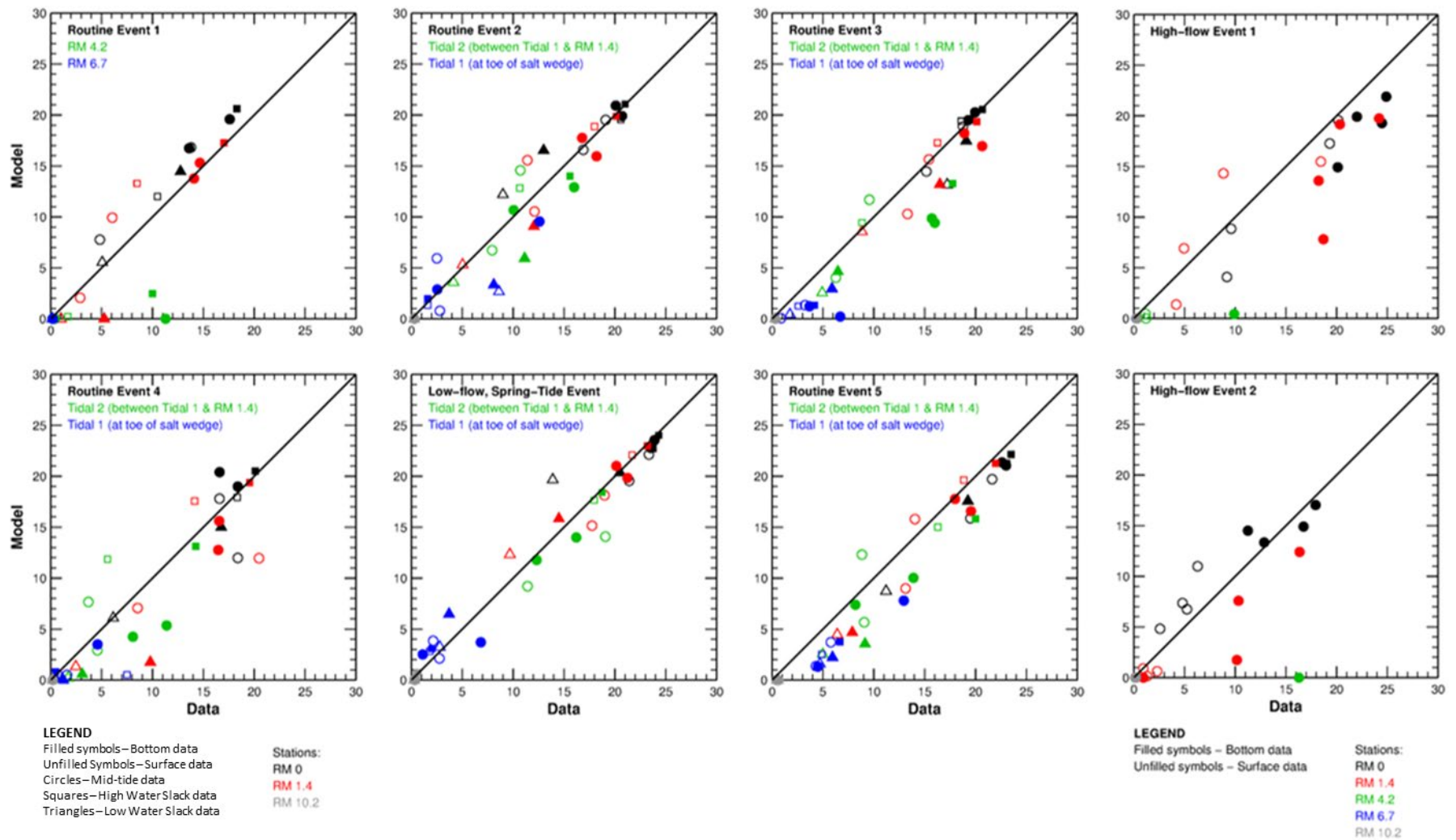


Figure 6-19: Comparison of measured and simulated salinities during the CWCM program.

7.0 SUMMARY

The hydrodynamic model application to the Lower Passaic River and Newark Bay was originally developed by HydroQual (2008). The model source code, inputs, and setup was transferred to the CPG-MT for adoption for the RI/FS of the LPR. The model setup and inputs were reviewed and evaluated for an assessment of the model's ability to reproduce various fate and transport processes in the LPR. As part of the extension of the model application to the RI/FS of the LPR, the model has subsequently been refined by the CPG with respect to its bathymetry inputs within the LPR. The model was also applied to additional periods beyond its original application documented in HydroQual (2008) in order to evaluate its performance against various metrics.

Model performance was assessed against several metrics such as currents, salinity, and water levels using data from various monitoring efforts in the LPR. The monitoring datasets include the Fall 2009 PWCM and Spring 2010 PWCM, and the CWCM program implemented as part of the RI/FS of the LPR, as well as ancillary datasets from other parties such as Rutgers University. The model performance was evaluated against data at various locations in the LPR, and over a wide range of flow conditions ranging from a 1 in 25-year event (16,000 cfs) to extremely low flow conditions ranging over a few hundred cfs. Model performance was also evaluated over various temporal scales ranging from tidal time-scales, to spring-neap cycles, and including episodic high-flow events. Model performance against measured metrics was also assessed quantitatively. The model performance evaluation did not involve any further calibration or parameter adjustment beyond that established during the model calibration documented in HydroQual (2008). Therefore, the model performance documented in this appendix represents a validation of model performance. In general, the model was able to reasonably reproduce various metrics and processes apparent in the data.

The model was also used for further analyses such as an assessment of salt front dynamics, and a high-resolution model developed for an assessment of the shear stress regime in the LPR under various tidal and river flow conditions. The results of these analyses have been used to inform the system understanding of hydrodynamics and sediment transport in the LPR, and to support the conceptual site model of the LPR. The calibrated and validated hydrodynamic model has been subsequently used to model sediment transport (described in Appendix M), organic carbon transport (described in Appendix N), and contaminant fate and transport (described in Appendix O) of this report.

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ATTACHMENT A: FREQUENCY ANALYSIS OF FLOWS AT LITTLE FALLS

An analysis of flow return period was carried out using the flow records from the USGS Little Falls gage station spanning from 1896 to 2012. The historical record included a 34,000 cfs event in 1903 that was reported by USGS as having been affected by dam failure. Expected discharge values corresponding to different return periods were calculated excluding this event, based on a best fit of the discharge peaks to a Fisher Tippet Type II ($k=10$) distribution. To quantify the possible effect of the uncertainty in the magnitude of the 1903 event, a separate analysis including the discharge peak in 1903 was performed. The results of the analyses are presented in Table A-1. There are some apparent differences between the two estimates arising from the shape of the best fit distribution curves. Significantly, the estimated 100-year (1% Annual Exceedance Probability) flow increases from about 22,000 cfs to approximately 25,000 cfs with the inclusion of the 1903 event in the extreme value analysis.

Table A-1: Estimated flow for different return periods at Little Falls.

Return Period (years)	Expected Discharge Value (cfs)	Expected Discharge Value (cfs) including 1903 event
2	7,156	6,978
5	10,485	10,397
10	12,906	13,129
25	16,237	17,225
50	18,920	20,807
100	21,777	24,898
200	24,829	29,584
500	29,194	36,852