ATTACHMENT M

Water Quality Modeling

Transmission
Developers Inc.

Champlain Hudson Power Express Project

Water Quality Modeling Report

Lake Champlain

October 2010

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1. Project Overview

Champlain Hudson Power Express Inc (CHPEI) proposes to develop the Champlain Hudson Power Express Project (Project) to connect renewable sources of power generation to load centers in and around the New York City. The Project will include underwater and underground, high-voltage direct current (HVDC) transmission cables. To the extent possible, CHPEI proposes to install the transmission cables along and within existing waterways to minimize land use and visual impacts typically associated with traditional overhead transmission lines, while simultaneously providing the additional capacity required to meet the increasing clean energy demands of the greater New York City metropolitan area. The Project consists of a 1,000 megawatt (MW) HVDC underwater/underground HVDC transmission system that includes one 1,000 MW bipole (a bipole includes two cables connected as a bipole pair), extending between the Canadian border and New York City, New York. CHPEI has designed the Project to meet the New York City area's need for additional sources of competitively priced electricity from safe and reliable renewable sources of energy

The northern part of the underwater cable route extends through Lake Champlain. The proposed cable route enters Lake Champlain near the U.S/Canadian Border and exits at southern end of the lake for the overland portion of the route. The total length of cable to be installed within Lake Champlain is approximately 111 miles.

For the majority of the proposed transmission cable route, the submarine cables would be buried approximately 4 feet; however, burial depths may vary along the cable route based on bottom conditions or existing infrastructure (e.g. at existing utility crossings). A mathematical model was developed to evaluate the potential impacts of the proposed cable installation via water jetting in Lake Champlain on water quality. This report describes the development and application of a three-dimensional hydrodynamic and time-variable water quality model to assess water quality impacts and compliance with water quality standards. As it is anticipated that the vast majority of the cable will be installed using water jetting, the model inputs are based on the use of this technology.

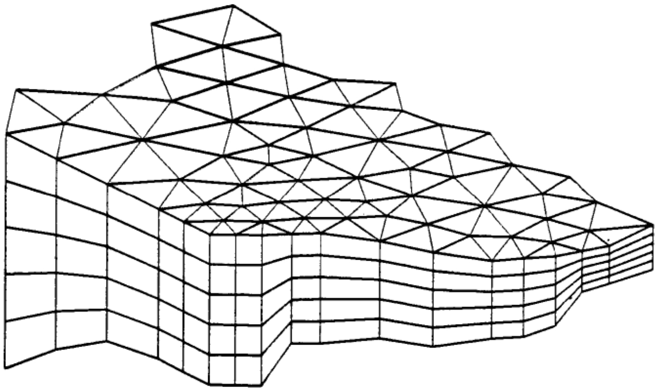
2. Model Description

The model used in this project was the Danish Hydraulic Institute (DHI) three dimensional hydrodynamic and water quality model called MIKE3 FM. The modeling system is based on the numerical solution of the three dimensional incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure (DHI, 2009). The model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulence closure scheme. The density does not depend on pressure but only on temperature and salinity. The free surface is taken into account using a sigma-coordinate transformation approach.

The following effects are accounted for:

- Flooding and drying
- Momentum dispersion
- Bottom shear stress
- Coriolis force
- Wind shear stress
- Precipitation/evaporation
- Heat exchange
- Sources and sinks
- Water quality

The solution technique uses the cell centered finite volume method as shown in Figure 1. The spatial domain is discretized by subdivision of the continuum into non overlapping elements. In the horizontal plane an unstructured mesh is used, while a structured mesh is used in the vertical domain. Elements can be prisms or bricks whose horizontal faces are triangles or quadrilateral elements.



Principle of 3D mesh

Figure 1. Finite Volume Mesh.

2.1 Model Mesh for Lake Champlain

The bathymetry of Lake Champlain is shown in Figure 2 and are relative to the Lake Surface Datum (28.35 m, NGVD), which is also referred to as low lake level (VDEC/NYSDEC 1997). The horizontal mesh for Lake Champlain uses 1520 triangular elements as shown in Figure 3, Figure 4 and Figure 5. The bathymetric data were obtained from the Vermont Center for Geographic Information (www.vcgi.org).

The vertical layering of the model uses two sigma coordinate system upper layers with 13 variable depth fixed layers below them. A schematic of the vertical layers along the lake centerline is shown in Figure 6.

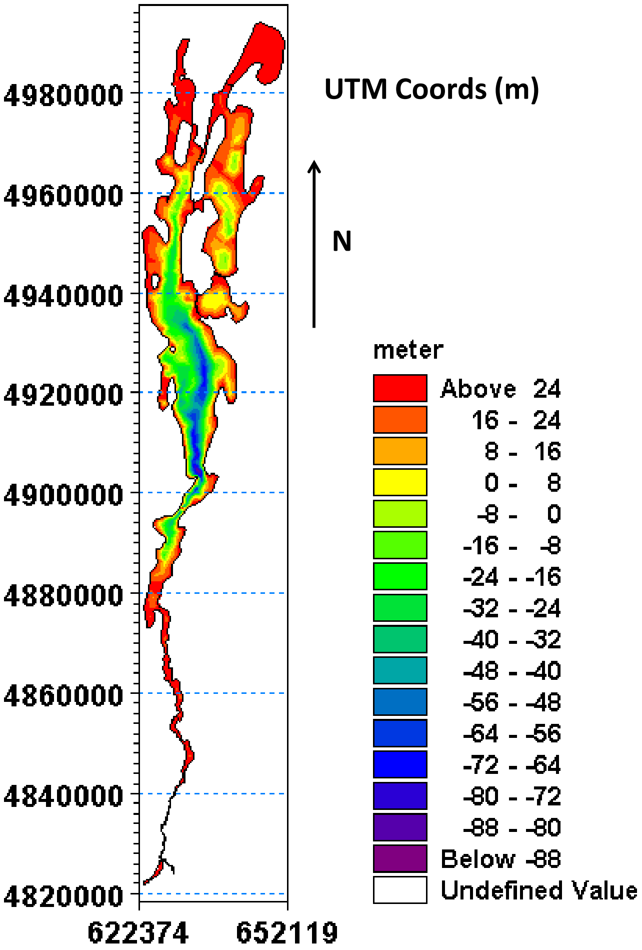


Figure 2. Lake Champlain bathymetry (m).

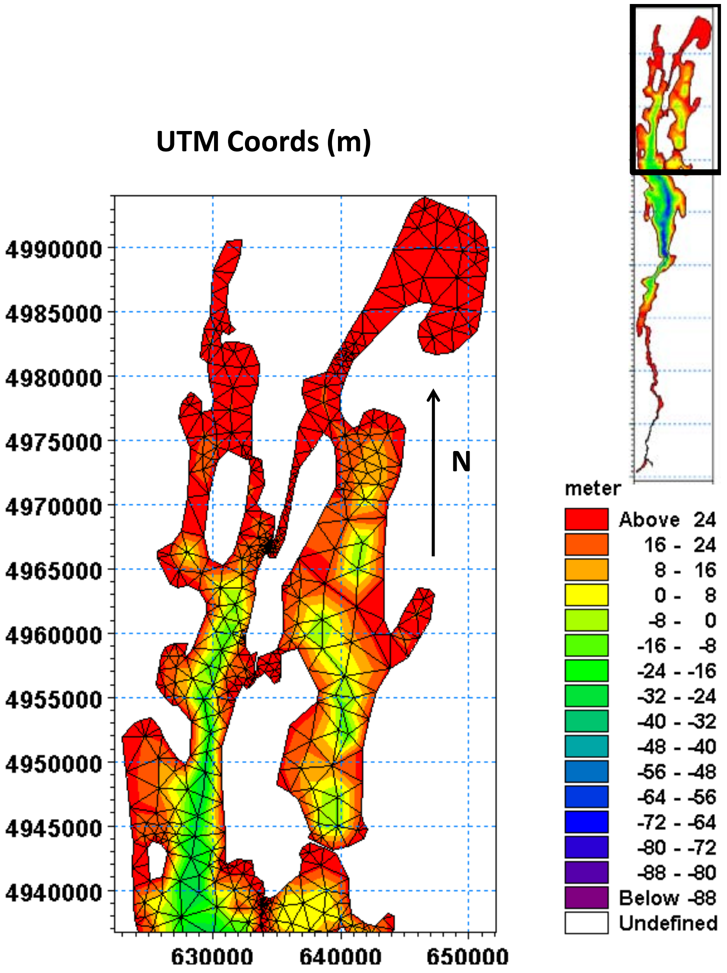


Figure 3. Mesh detail – northern portion of Lake Champlain.

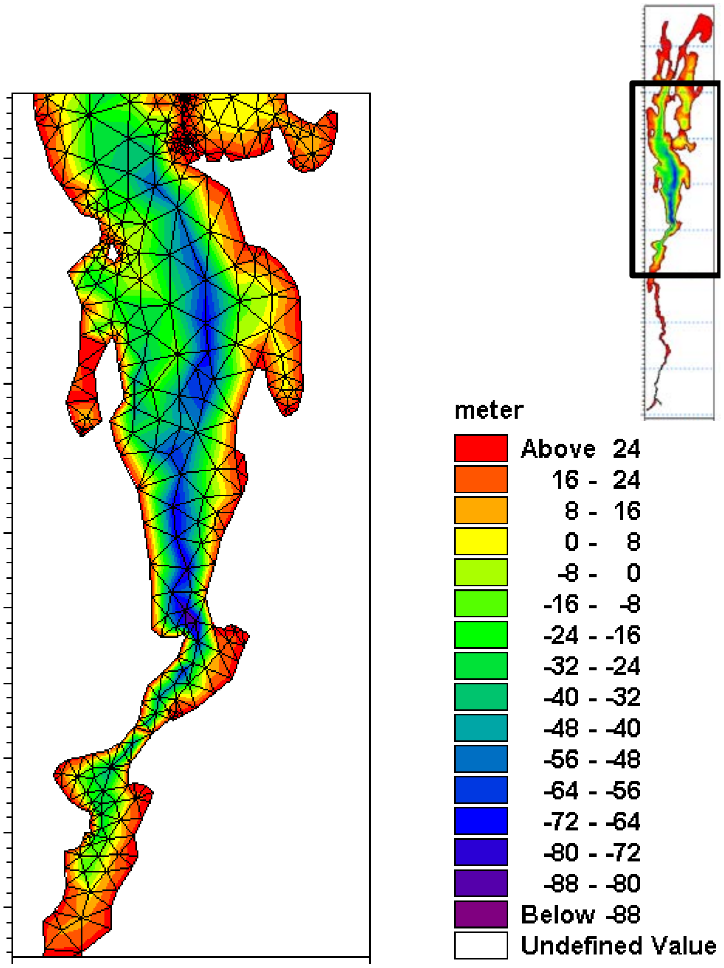


Figure 4. Mesh detail – central portion of Lake Champlain.

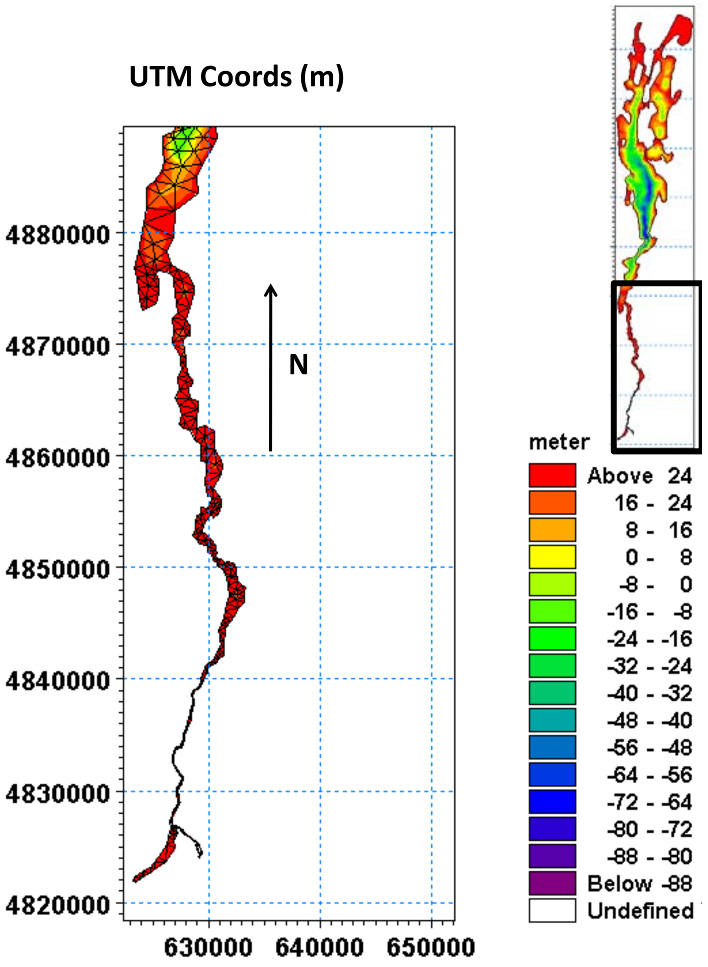


Figure 5. Mesh detail – southern portion of Lake Champlain.

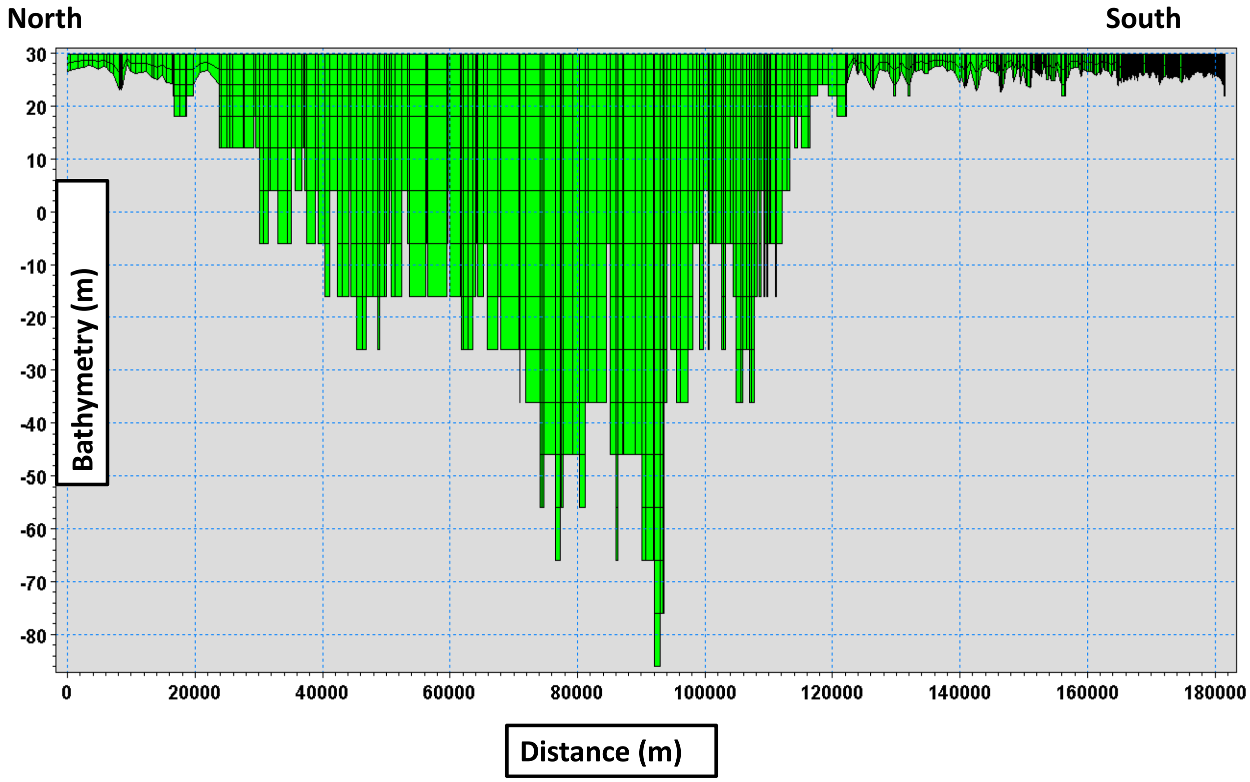


Figure 6. Vertical mesh layering.

2.2 Model Set Up

The model was set up using data for 2009 as described below.

2.2.1 Rivers

The model includes daily flow and temperature data for 30 rivers listed below. Data was obtained from the USGS, Environment Canada or the Quebec Ministry of Sustainable Development, Environment and Parks.

- Missisquoi
- Poultney
- Lamoille
- Bouquet
- Putnam
- Pike
- Little Chazy
- Winooski
- Otter-New Haven
- Lewis
- Little Otter
- LaPlatte
- Rock
- Saranac
- Ausable
- Mettawee
- Great Chazy
- Salmon
- Putnam
- Little Ausable
- East (SouthFork)
- Stevens
- Malletts-Indian
- Stonebridge
- LaChute
- Mt. Hope
- Mill-Pt.Henry
- Highlands Forge
- Mill-Putnam Sta.
- Hoisington

The flows at gaging stations were adjusted to include the entire drainage area at the confluence with Lake Champlain based on linear extrapolation and published drainage areas (VDEC/NYSDEC 1997). The flow exits the lake via the Richelieu River. The flow in the Richelieu was not specified but calculated as the model outflow. This is shown in the calibration section.

2.2.2 Meteorological Data

The following hourly meteorology for 2009 was specified based on data obtained from the Northeast Regional Climate Center:

- Wind speed
- Wind direction
- Precipitation
- Evaporation
- Air temperature
- Humidity
- Cloud cover

3. Model Calibration

The model was calibrated using measured vertical temperature profiles (VT DEC 2010) and measured flow in the Richelieu River (Environment Canada 2010).

The comparison between computed and measured flows in the Richelieu River is shown in Figure 7. The location of the vertical temperature profiles is shown in Figure 8. A sample of the comparison of measured and computed temperatures for July 2009 is shown in Figure 9 and Figure 10.

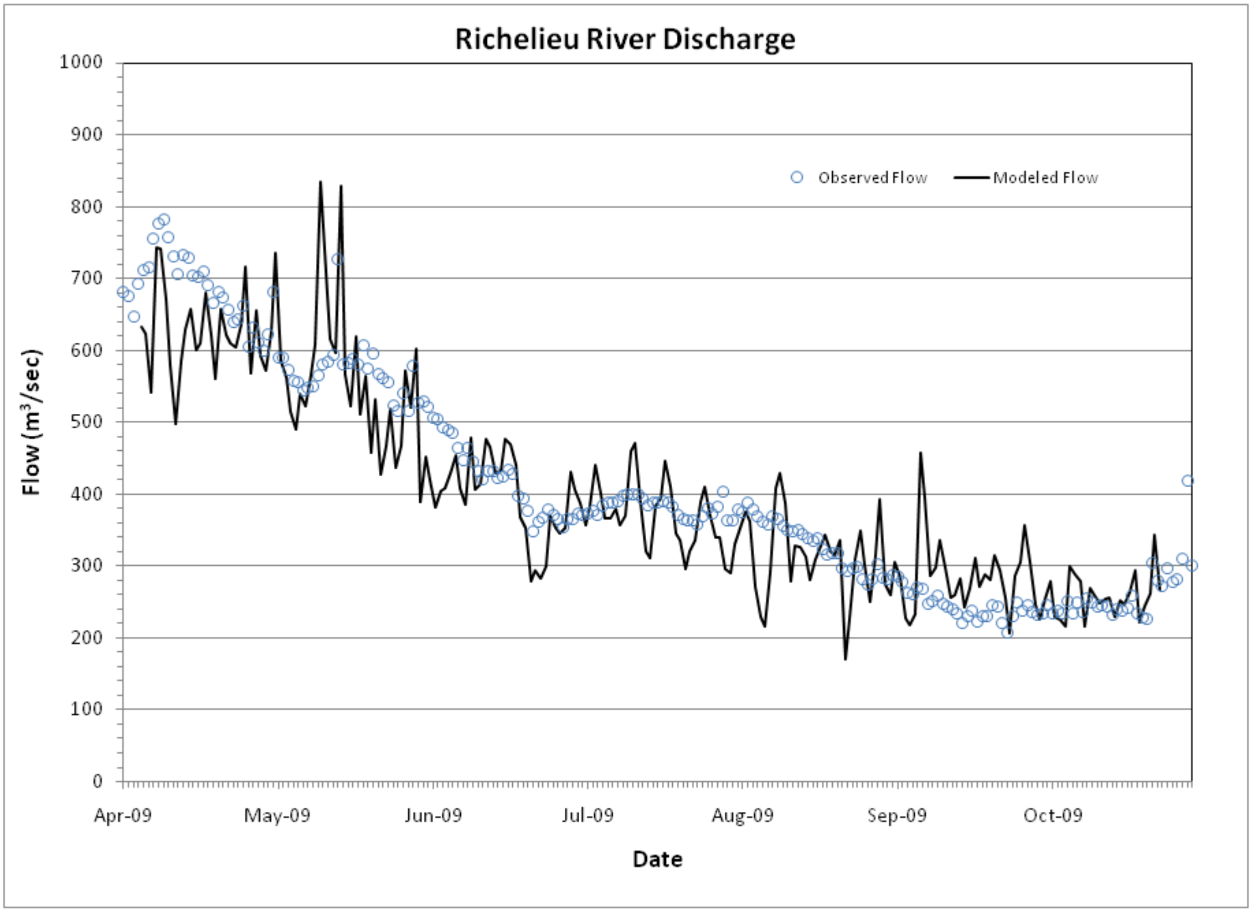


Figure 7. Measured and computed flows in the Richelieu River, 2009.

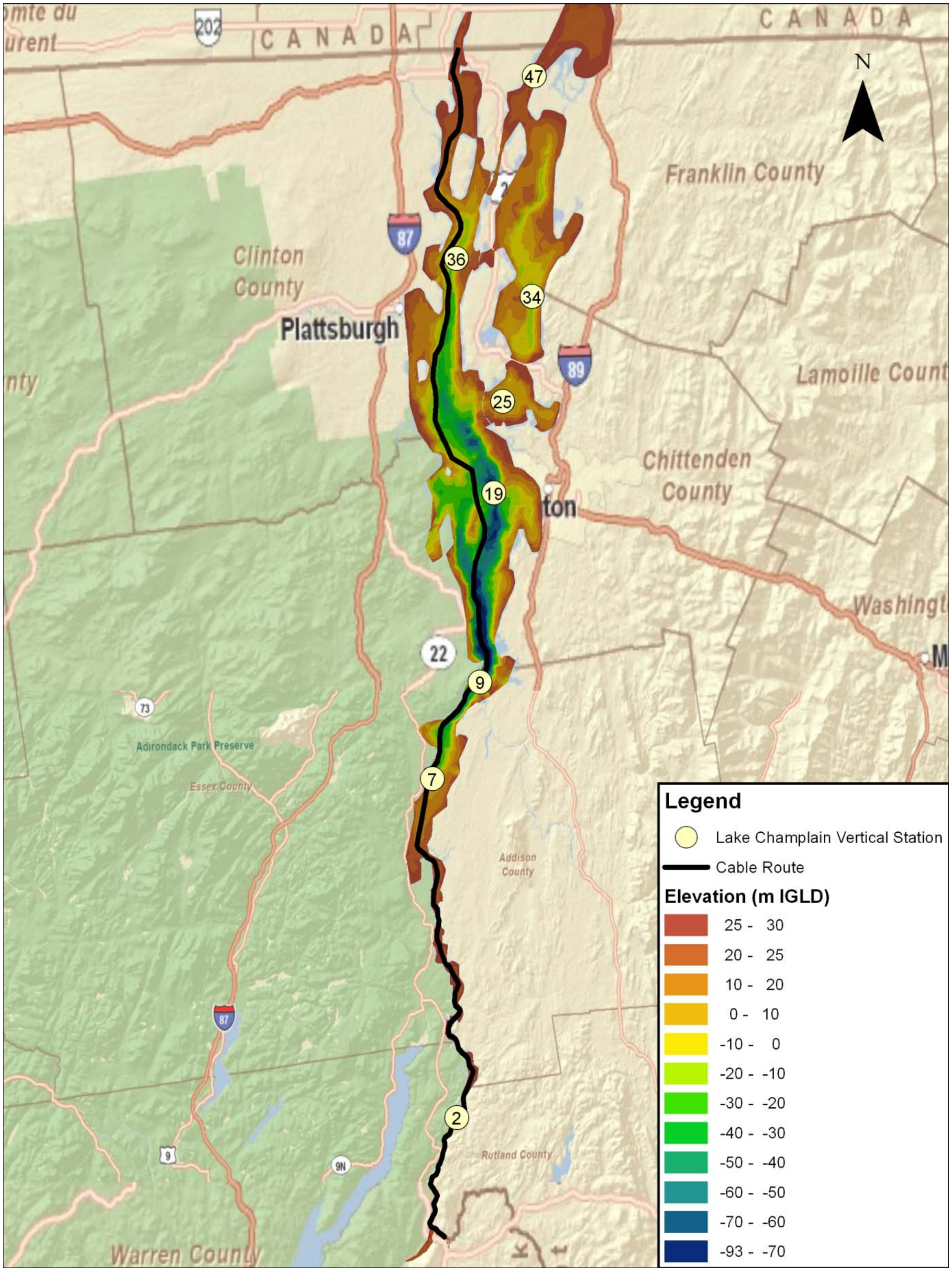


Figure 8. Location of VDEC Vertical Temperature Profile Stations.

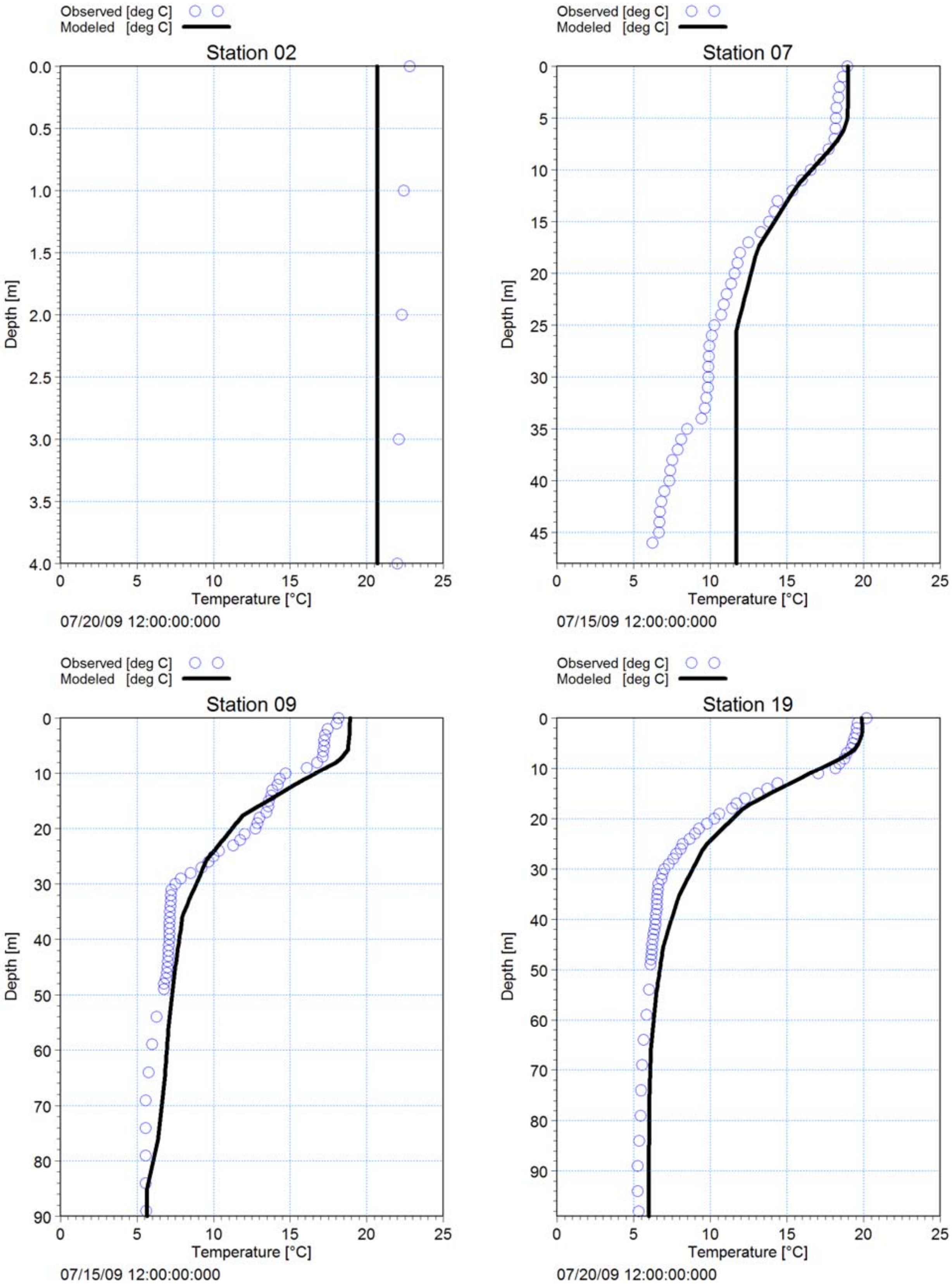


Figure 9. Temperature calibration for July 2009, stations 2,7,9,19.

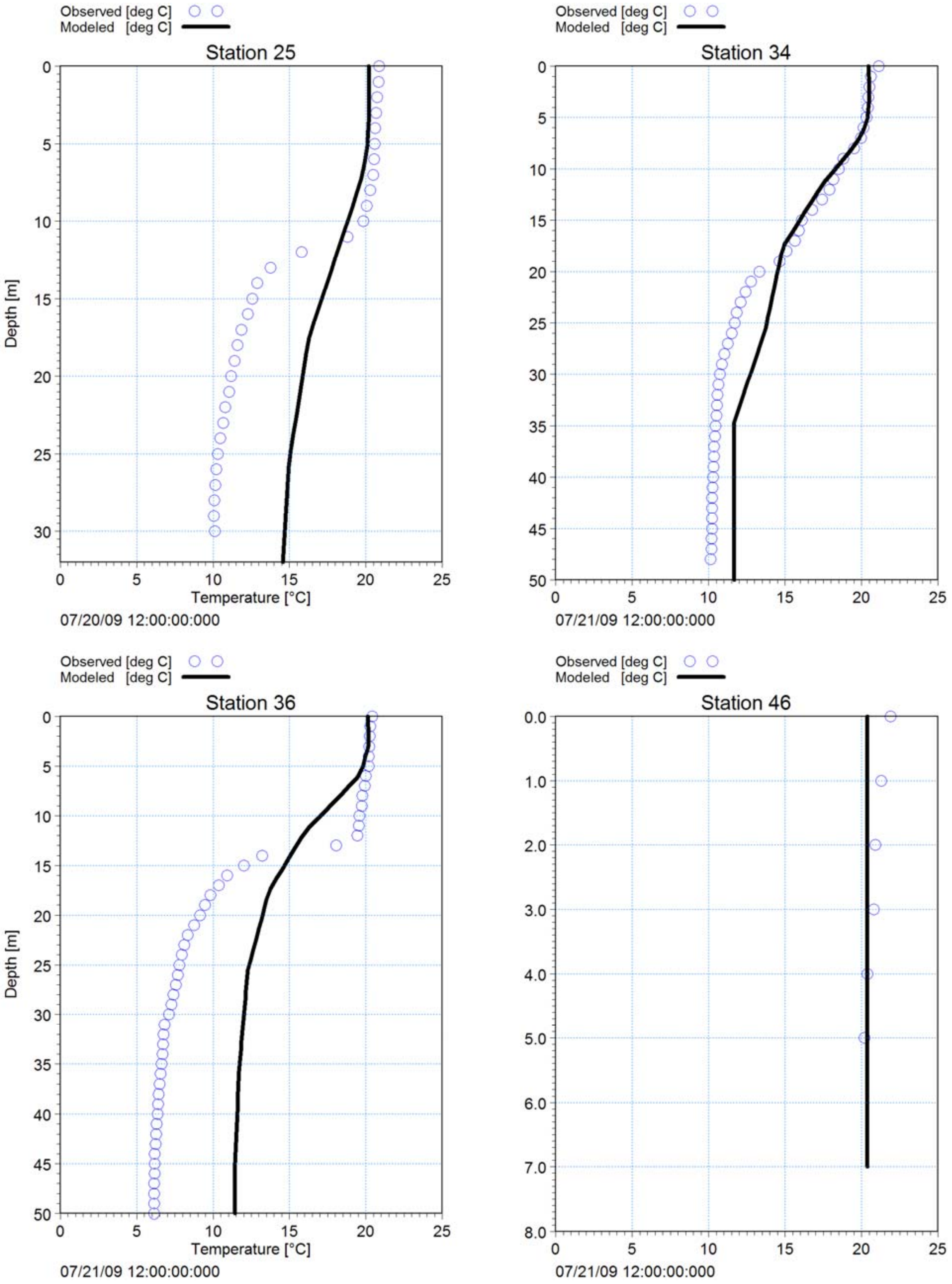


Figure 10. Temperature calibration for July 2009, stations 25,34,36,46.

4. Selected Contaminants and Water Quality Standards

The contaminants to be modeled were based on the potential short-term impact of re-suspended sediment and associated contaminants as a result of the cable installation process. Water quality criteria are set based on protecting human health and aquatic life. Human health criteria address the consumption of water and/or fish over a human's entire life expectancy. Aquatic life criteria address acute toxicity and chronic toxicity. Acute toxicity results from a relatively short exposure duration whereas chronic toxicity takes a longer exposure. Due to the short duration of the cable installation and the transient nature of the sediment re-suspension caused by the proposed cable installation has the greatest potential to affect acute toxicity rather than human health or chronic toxicity.

Sediment samples along the cable route were analyzed for certain organic and inorganic contaminants, including pesticides, PAHs, PCBs and metals. Contaminants that have a water quality standard (criterion) based on acute toxicity were identified for comparison to model results. The lower of the two states' standards is used, if both states have acute toxicity standards.

The maximum concentration of all Lake Champlain sediment samples indicates the potentially highest concentration of that chemical in the overlying water during and after cable installation. The chemical concentration in the water column consists of the particulate and dissolved forms. The sediment released by the cable installation will increase the chemical concentration in the water primarily via the particulate form, because of the chemical's affinity for adsorption onto solids (i.e., partitioning).

Based on the assumption that there is a constant level of re-suspended sediments along the cable installation route, the ratio of sediment chemical concentration to the water quality standard is an indicator of the likelihood that the chemical concentration will be greater than the water quality standard. The concentration of re-suspended sediment will vary in water quality model simulations depending on sediment characteristics; however, the assumption is made at this time to select 10 sediment contaminants for modeling.

The following list is the top 10 contaminants that were used for modeling based on the ratio of maximum chemical concentration to water quality standards:

1. Copper
2. Zinc
3. Lead
4. Cadmium
5. Benz(a)anthracene
6. Nickel

7. Chromium
8. Mercury
9. Arsenic
10. Pyrene

The applicable water quality standards for the ten contaminants modeled are given in Table 1.

Table 1. NY and VT water quality standards for the ten contaminants modeled.

Chemical	**Water Quality Standard**
Pyrene	42 ug/L – New York (based on class AA waters acute aquatic, total) 11,000 ug/L – Vermont (based on Protection of Human Health, consumption of organisms, total)
Benzo(a) anthracene	0.23 ug/L – New York (based on class AA waters acute aquatic, total) 0.031 ug/L – Vermont (based on Protection of Human Health, consumption of organisms, total)
Lead	93.9 ug/L – New York (based on class AA waters acute aquatic,dissolved) – assumes a hardness of 97 mg/L, based on water quality measurements $NY = (1.46203-\ln(97)x0.145712\ ) e^{1.273x\ln(97)-1.052} = 93.9$ ug/L 52.7 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT = e^{1.2763x\ln(97)-1.46)} = 52.7$ ug/L
Mercury	1.4 ug/L – New York (based on class AA waters acute aquatic,dissolved) 2.4 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total)
Nickel	465.3 ug/l – New York (based on AA waters, acute aquatic, dissolved) – assumes hardness of 97 mg/L, based on water quality measurements $NY = 0.998e^{0.846xkn(97)+2.255} = 456.3$ ug/L 823.5 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT= e^{0.846x\ln(97)+3.361} = 823.5$ ug/L
Arsenic	340 ug/L – New York (based on class AA waters acute aquatic, dissolved) 360ug/L – Vermont (based on Protection of Aquatic Biota, acute, total)
Cadmium	3.7 ug/L – New York (based on class AA waters acute aquatic, dissolved) – assumes hardness of 97 mg/L, based on water quality measurements $NY = 0.85\ e^{1.128x\ln(97)-3.6867} = 3.7$ ug/L 2.3 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT = e^{1.128x\ln(97)-3.828} = 2.3$ ug/L
Chromium	555.7 ug/L – New York (based on class AA waters acute aquatic, dissolved) – assumes hardness of 97 mg/L, based on water quality measurements $NY = 0.316\ e^{0.819x\ln(97)+3.7256} = 555.7$ ug/L 868.8 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT = e^{0.819x\ln(97)+3.688} = 868.8$ ug/L
Copper	13.0 ug/L – New York (based on class AA waters acute aquatic, dissolved) – assumes hardness of 97 mg/L, based on water quality measurements $NY = 0.96\ e^{0.9422x\ln(97)-1.7} = 13.0$ ug/L 18.7 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT = e^{0.9422x\ln(97)-1.464} = 18.7$ ug/L
Zinc	114.2 ug/L – New York (based on class AA waters acute aquatic, dissolved) – assumes hardness of 97 mg/L, based on water quality measurements $NY = 0.978\ e^{0.8473\ x\ \ln(97)+0.884} = 114.2$ ug/L 100.0 ug/L – Vermont (based on Protection of Aquatic Biota, acute, total) - assumes a hardness of 97 mg/L, based on water quality measurements $VT = e^{0.8473\ x\ \ln(97)+0.8604} = 100.0$ ug/L

5. Load Calculation

The cable laying operation represents a moving load source that will deliver a load of solid and dissolved components to the water column. In the model the moving source is represented by a series of load points along the cable route. These load points turn on and off sequentially as the cable laying operation progresses. The load is input into the bottom model cell at the location of load source. The load points are chosen to match the location of sediment cores that were taken along the route. There are 46 locations at approximately two mile intervals as shown in Figure 11. The load at each location for each chemical is derived from the sediment core data as described below. The only source of solids and contaminants in the model is the load delivered by the cable installation, which is assumed to be completed via water jetting.

The load is defined by the flow rate and concentration. The flow rate calculation is described as:

$$Q = A * v * R$$

Where,

Q = Flow (m^3/s)
A = Cross sectional Area of trench (m^2)
v = Plow Velocity (m/s)
R = Release Fraction (%)

The release fraction (i.e. the percent of sediment volume disturbed based on cross-section of trench) was set at 30% based on previous submarine cable projects and discussions with a cable installation firm. The plow speed was estimated at 0.028 m/s while the cross sectional area of the trench was assumed to be 2.3 m^2. These assumptions inputted into the above equation produce a flow of 0.019 m^3/s.

For Total Suspended Solids (TSS) the concentration released is calculated as:

$$TSS = (1 - \phi)\rho_s * 1000$$

Where,
TSS = Total Suspended Solids (mg/L)
φ = Porosity (dimensionless)
ρ_s = density of solids (kg/m^3)

The porosity and density are site specific and are based on the sediment core data.

As solids will settle within the water column, the sediment core data and Stokes law were used to calculate the settling rate along the route. The median grain size and dry density of each sediment core were used to calculate the solids settling rate, which is applied to the reach between sediment core samples. The solids settling rate varied between 0.08 and 64,855 m/day, with higher rates in the north (between milepoints 5 and 30) and south (between milepoints 98 and 113) portions than in the middle (between milepoints 30 and 98) portion of the lake. The median settling rate for the entire lake was determined to be 0.48 m/day.

Contaminants are considered as having both a solid and dissolved fraction whose ratio is defined by a partition coefficient. The sediment core data contains the measured solid chemical concentration, C_{SOLID}, measured as mass chemical/mass solids (mg/kg). This is converted to a fraction (mg/mg) and then multiplied by the TSS concentration (mg/L):

C_{SOLID} (mg/mg) = C_{SOLID} (mg/kg) x 1 kg/10^6 mg (conversion to a fraction)

$C_{PARTICULATE} = C_{SOLID}$ x TSS (mg/L)

The dissolved concentration for the metals (non-organic contaminants) is calculated as:

$C_{DISS} = C_{PARTICULATE} / \pi$ (mg/kg) / (L/kg) = mg/L

Where π is the partition coefficient (L/kg).

For organic contaminants the dissolved concentration is calculated as:

$C_{DISS} = C_{PARTICULATE} /(foc \times \pi_{OC})$ (mg/kg) / (L/kg) = mg/L

Where foc is the fraction organic carbon and π_{OC} is the organic carbon partition coefficient (L/kg).

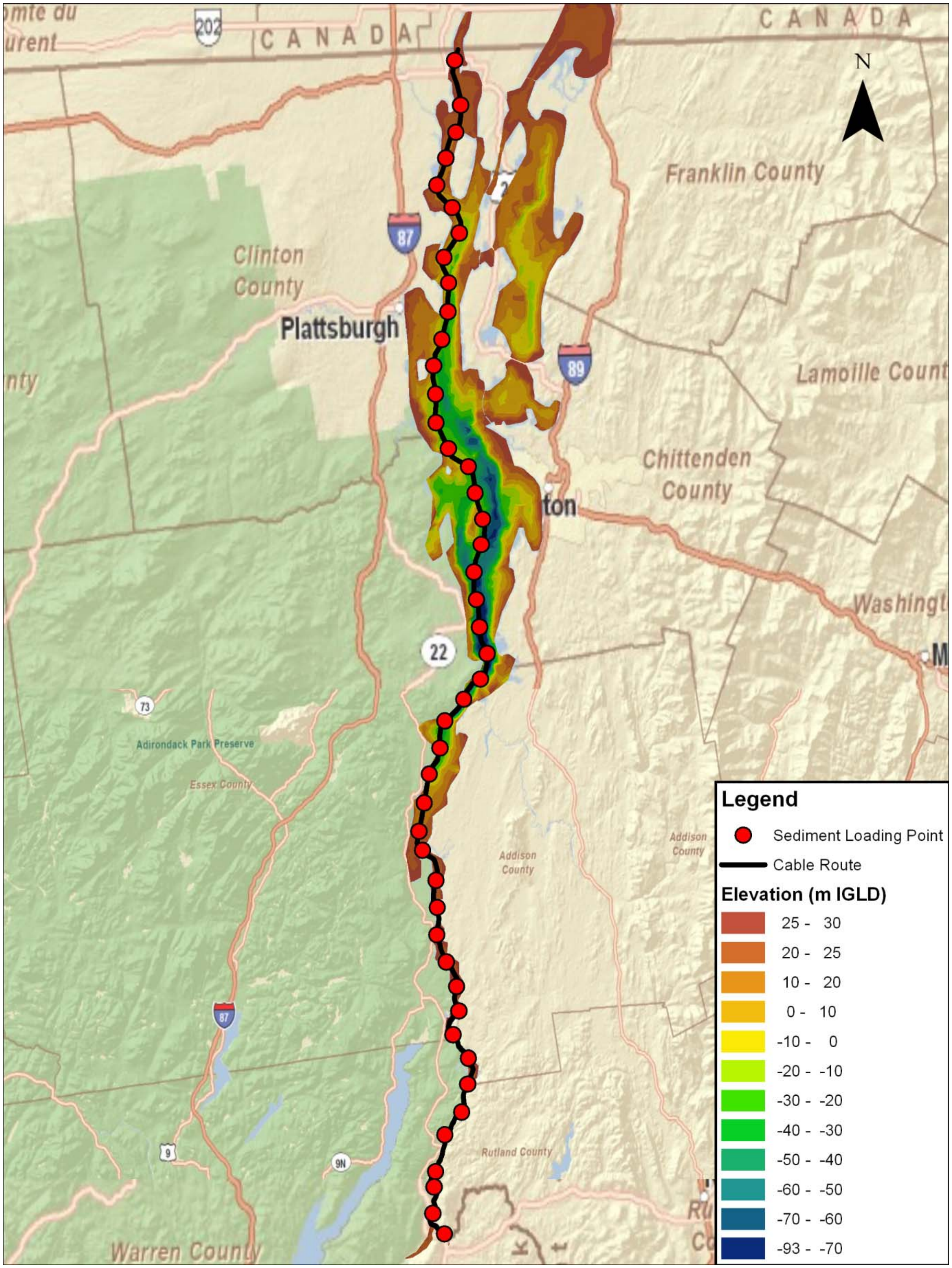


Figure 11. Location of Sediment Loading Points (Sediment Cores).

6. Results

The total concentration, which is the sum of the particulate and dissolved forms, is presented for all of the contaminants modeled in the figures below. Although New York's metals standards for aquatic toxicity apply only to the dissolved form, Vermont's standards effectively apply to the total concentration. As the total concentration is greater than the dissolved concentration, the total concentration is compared to the standard. If the total concentration is lower than the New York State standard, then the dissolved concentration will also be lower than this standard. The maximum concentration of the contaminant at any time in each model cell along the cable route is shown in Figures 12 through 23 and the maximum TSS concentration at any time is shown similarly in Figure 24.

In general the results all show the same trends. In the north and south ends of the lake, which tend to be shallower and narrower, the concentrations are estimated to be higher than in the middle portions of the lake. This is due to there being a smaller volume of water available for dilution of the incoming loads, compared to the deep central portions of the lake. Two contaminants, copper and zinc, are projected to exceed the Vermont water quality standards and in both cases the exceedences are in the southern portion of the lake (Figures 16 and 22). The longitudinal distance where the total copper concentration is estimated to be higher than the Vermont standard of 18.7 ug/l is approximately 1.3 miles. The expected duration of non-compliance with Vermont's copper standard is 16 hours. The calculated dissolved copper concentrations in the lake (as shown in Figure 15) are well below New York's standard of 13.0 ug/l. The longitudinal distance where the total zinc concentration is higher than the Vermont standard of 100.0 ug/l is approximately 0.8 mile, with an expected non-compliance duration of 11 hours. The calculated dissolved zinc concentration in the lake (as shown in Figure 21) are well below New York's standard of 114.2 mg/l.

6.1 Pyrene

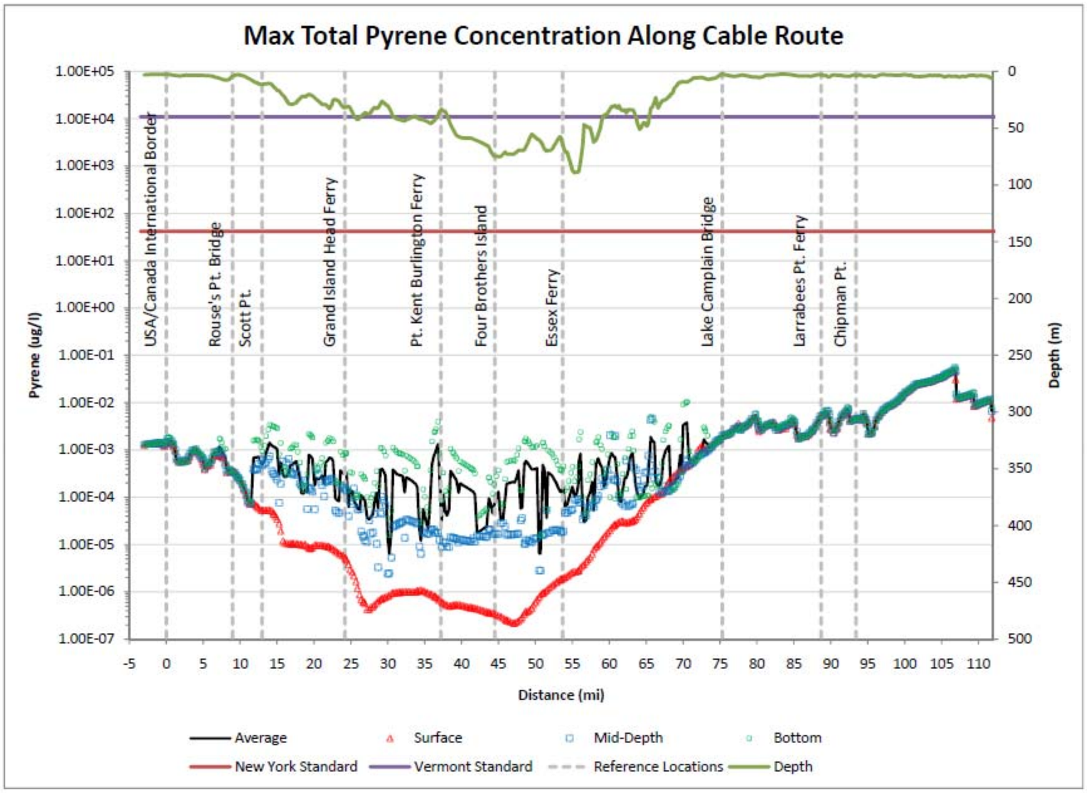


Figure 12. Pyrene concentrations and water quality standards.

6.2 Benzo(a) anthracene

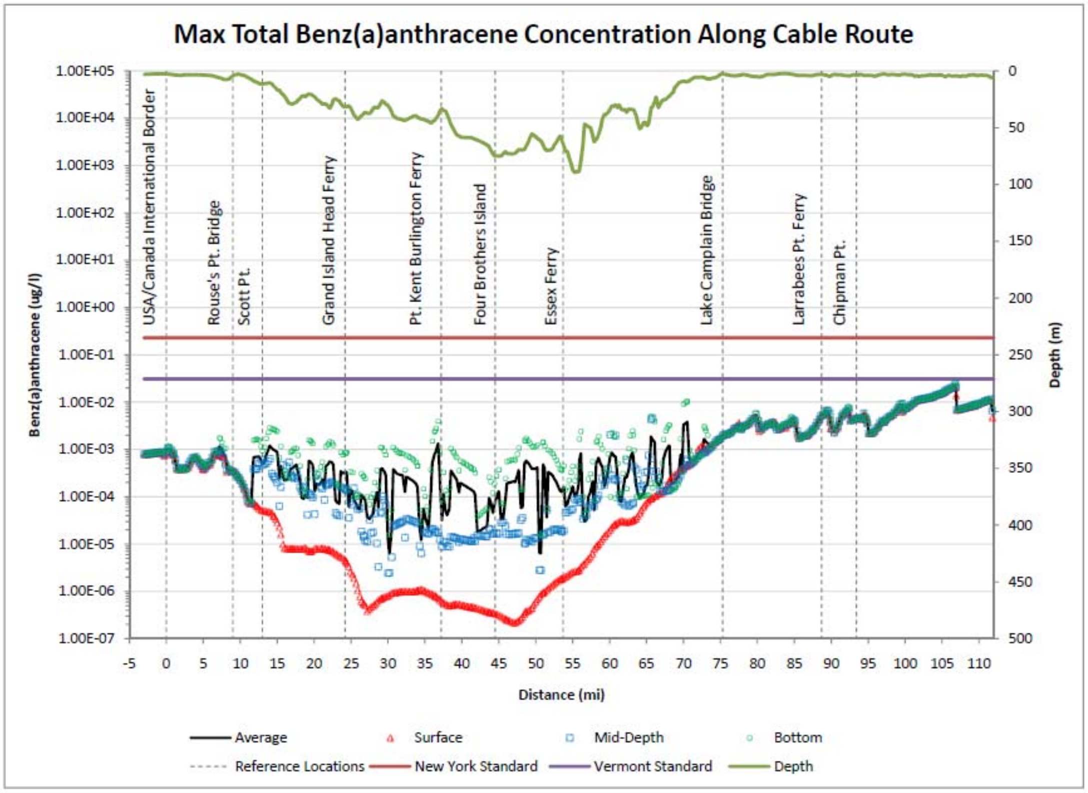


Figure 13. Benzo(a) anthracene concentrations and water quality standards.

6.3 Lead

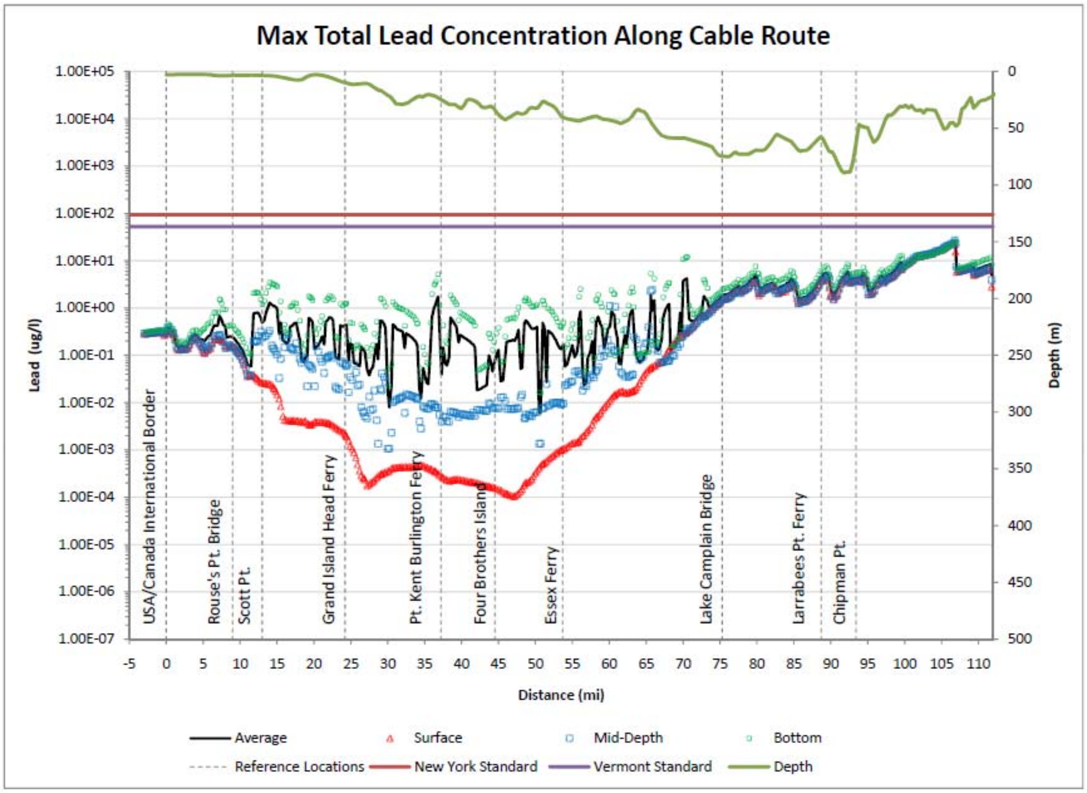


Figure 14. Lead concentrations and water quality standards.

6.4 Copper

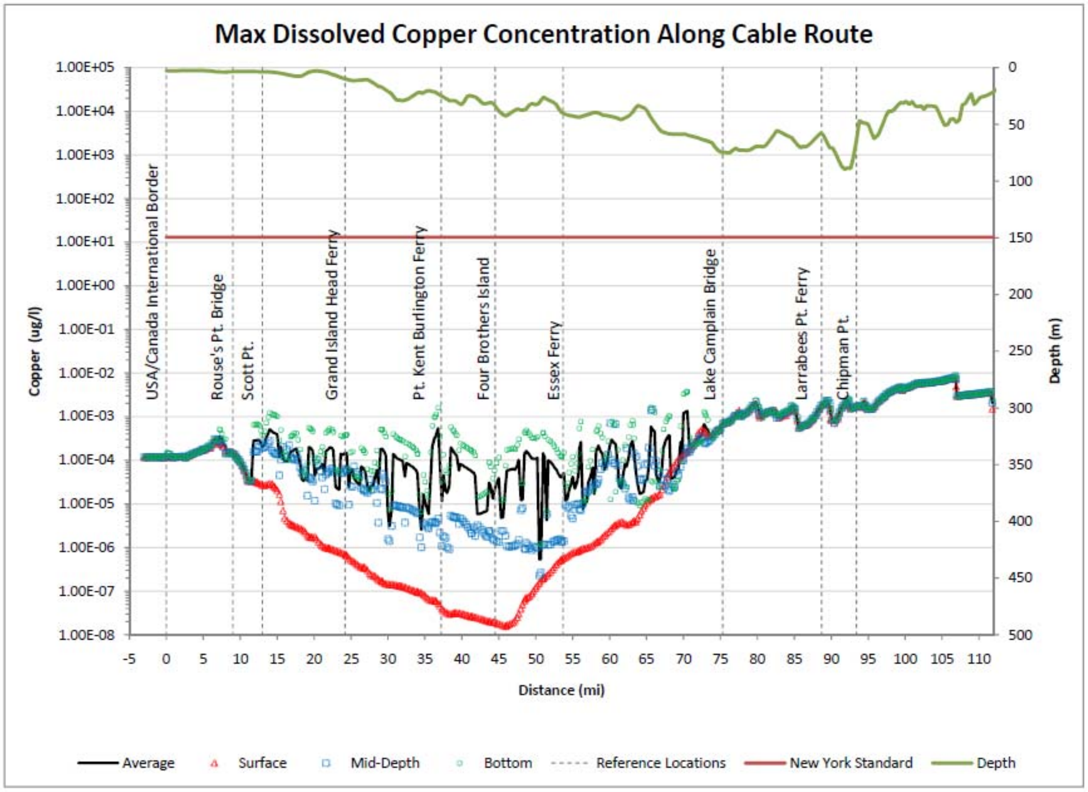


Figure 15. Dissolved copper concentrations and NY water quality standard.

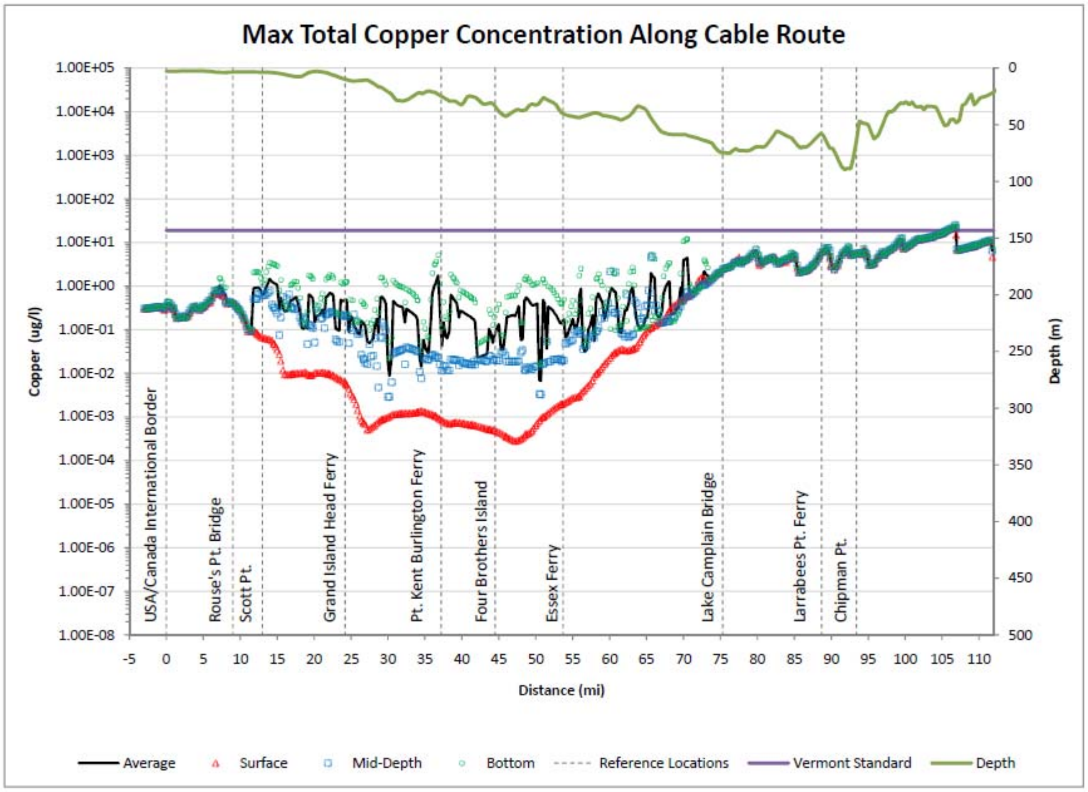


Figure 16. Total copper concentrations and VT water quality standard.

6.5 Chromium

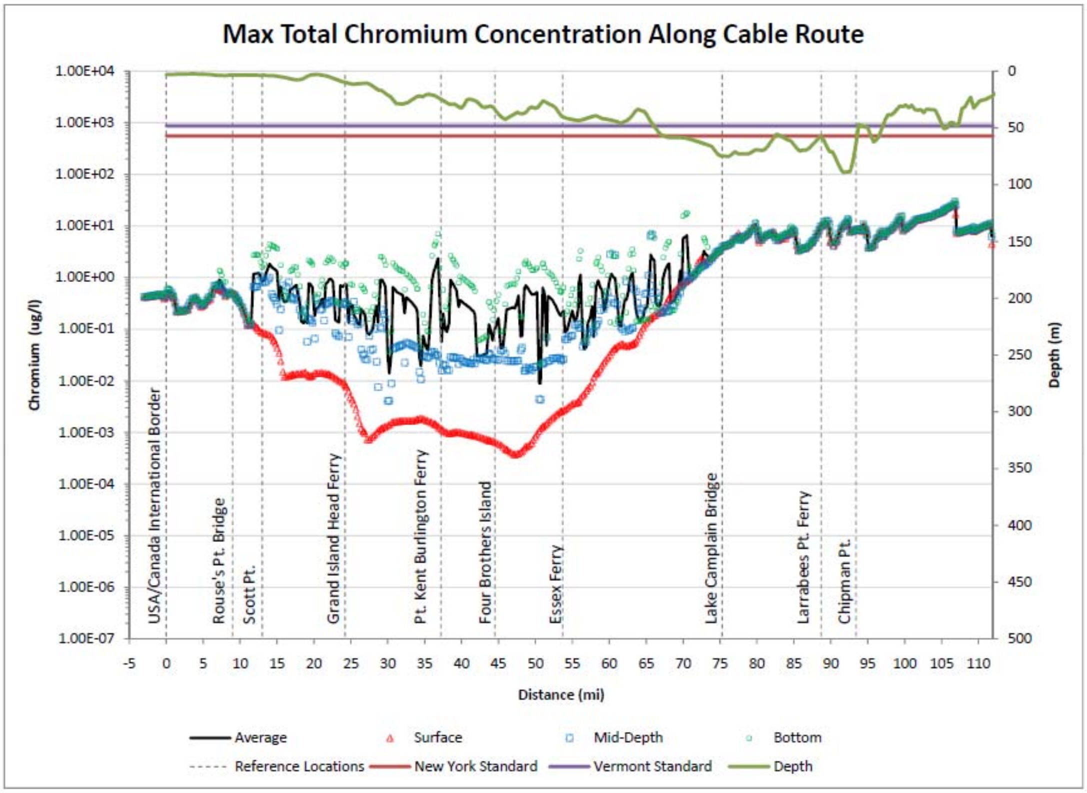


Figure 17. Chromium concentrations and water quality standards.

6.6 Cadmium

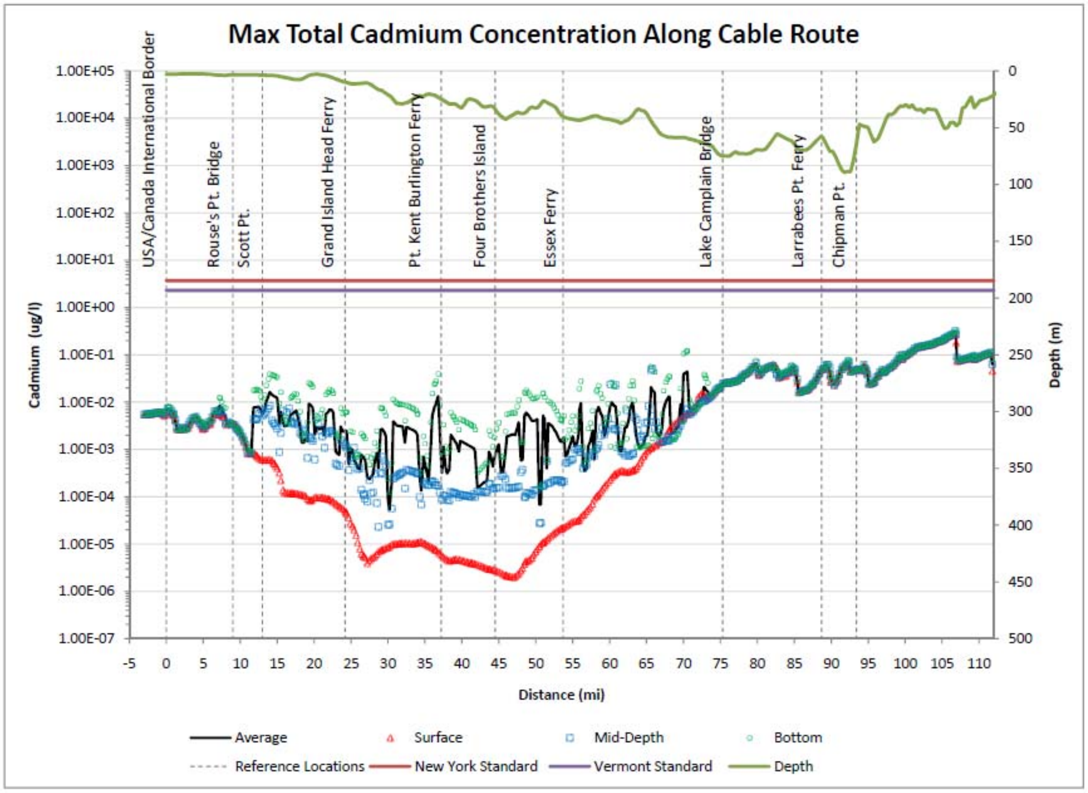


Figure 18. Cadmium concentrations and water quality standards.

6.7 Mercury

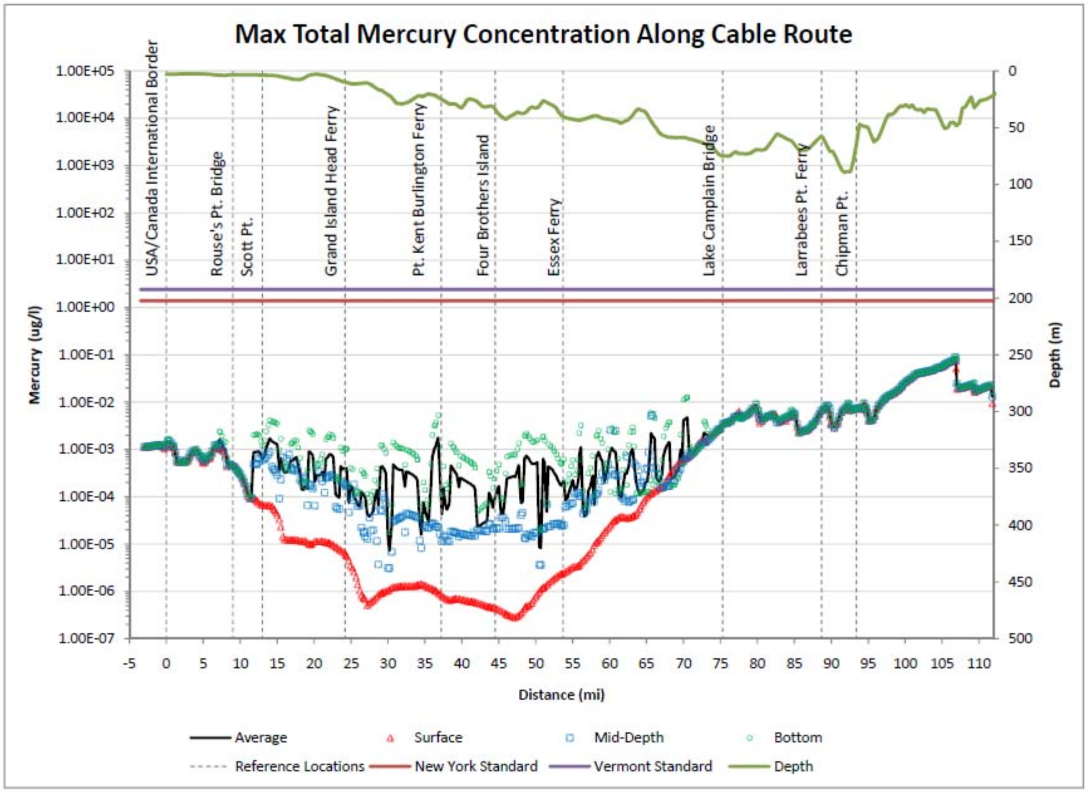


Figure 19. Mercury concentrations and water quality standards.

6.8 Nickel

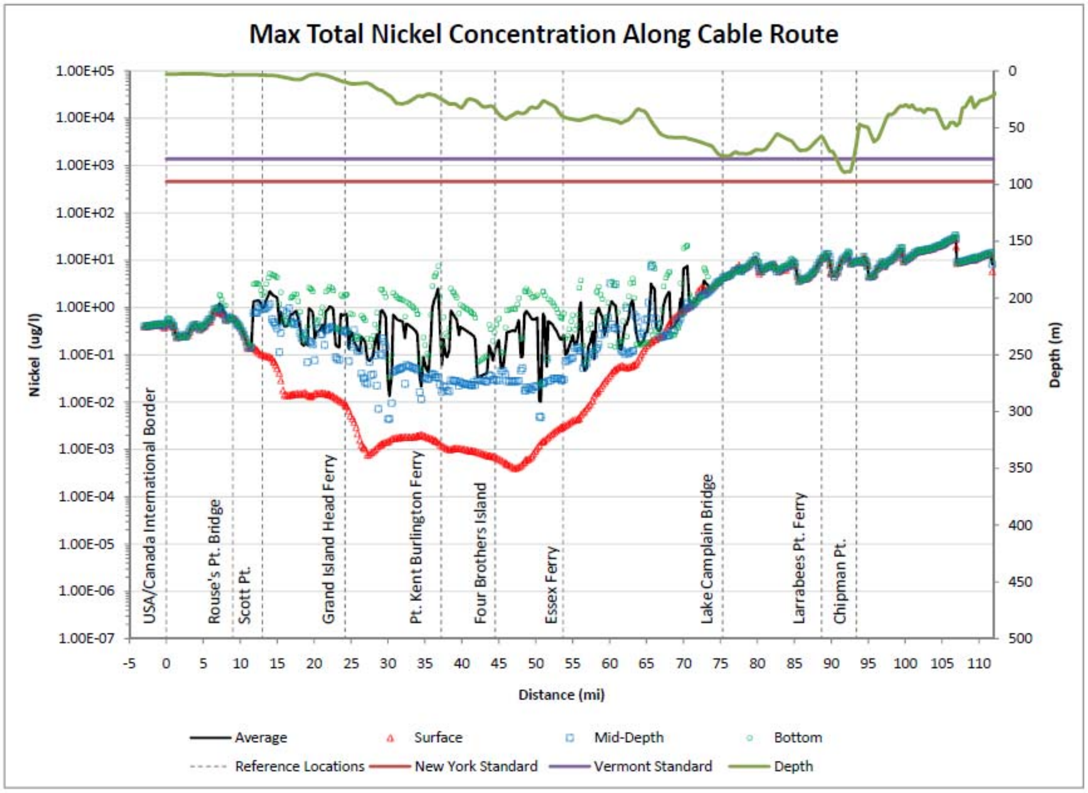


Figure 20. Nickel concentrations and water quality standards.

6.9 Zinc

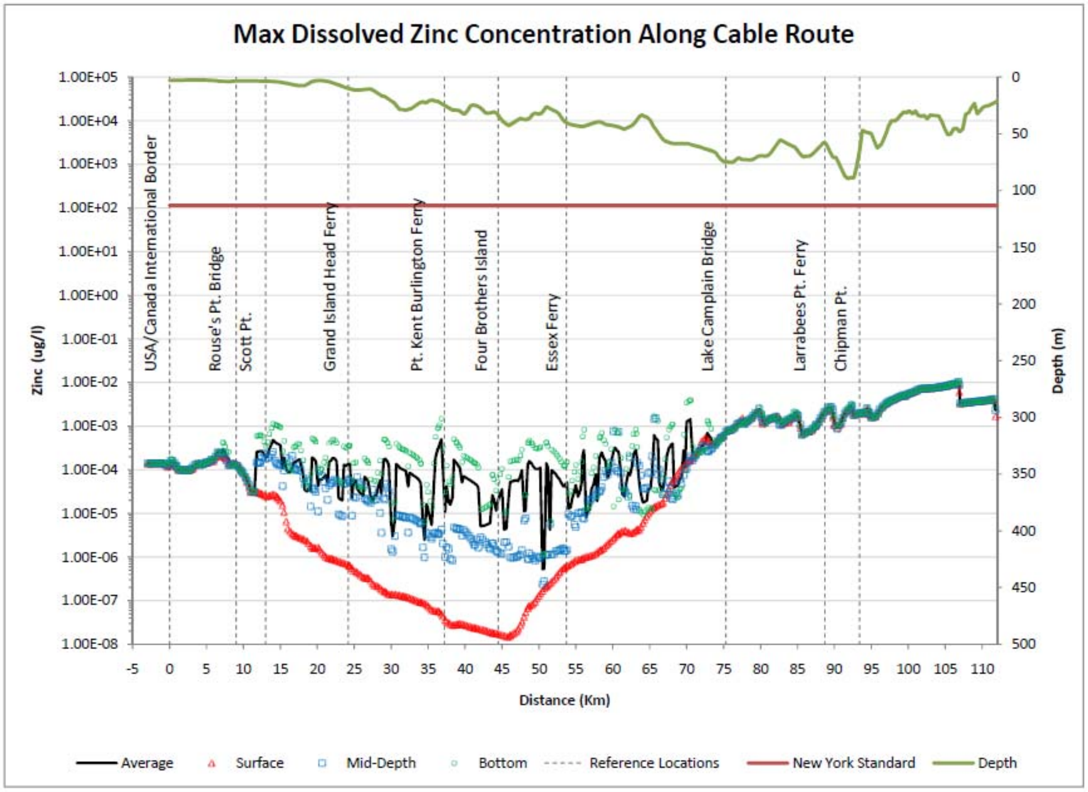


Figure 21. Dissolved zinc concentrations and NY water quality standard.

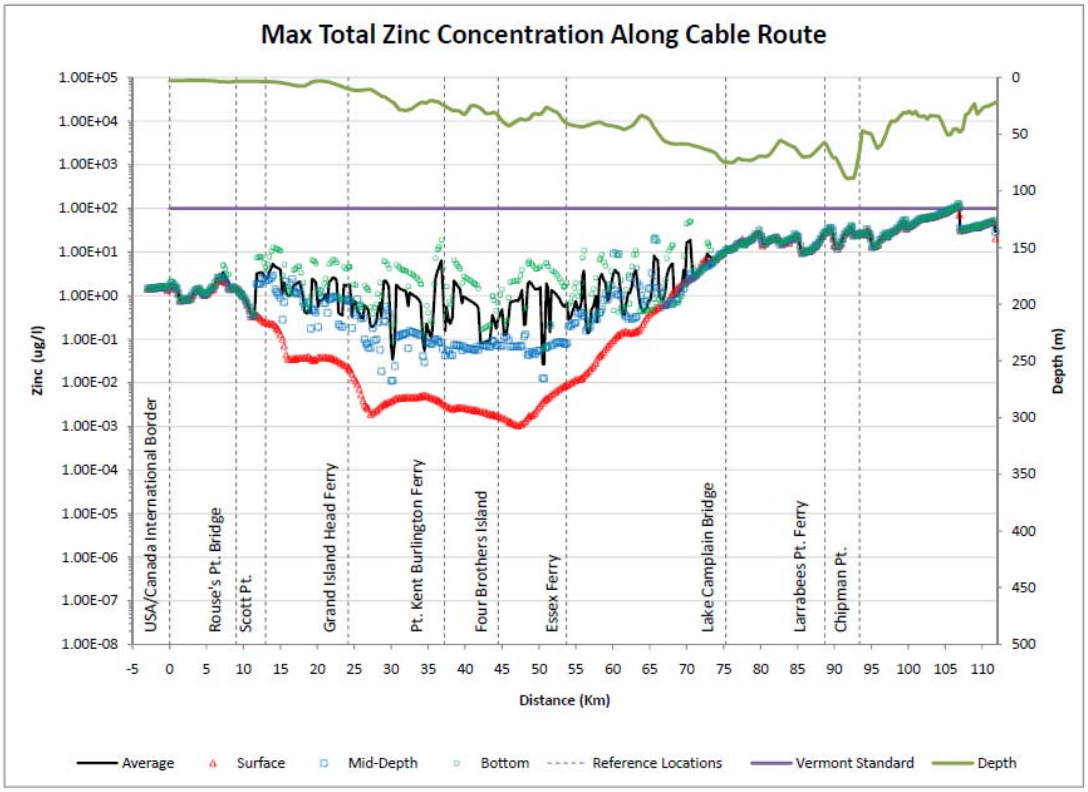


Figure 22. Total zinc concentrations and VT water quality standard.

6.10 Arsenic

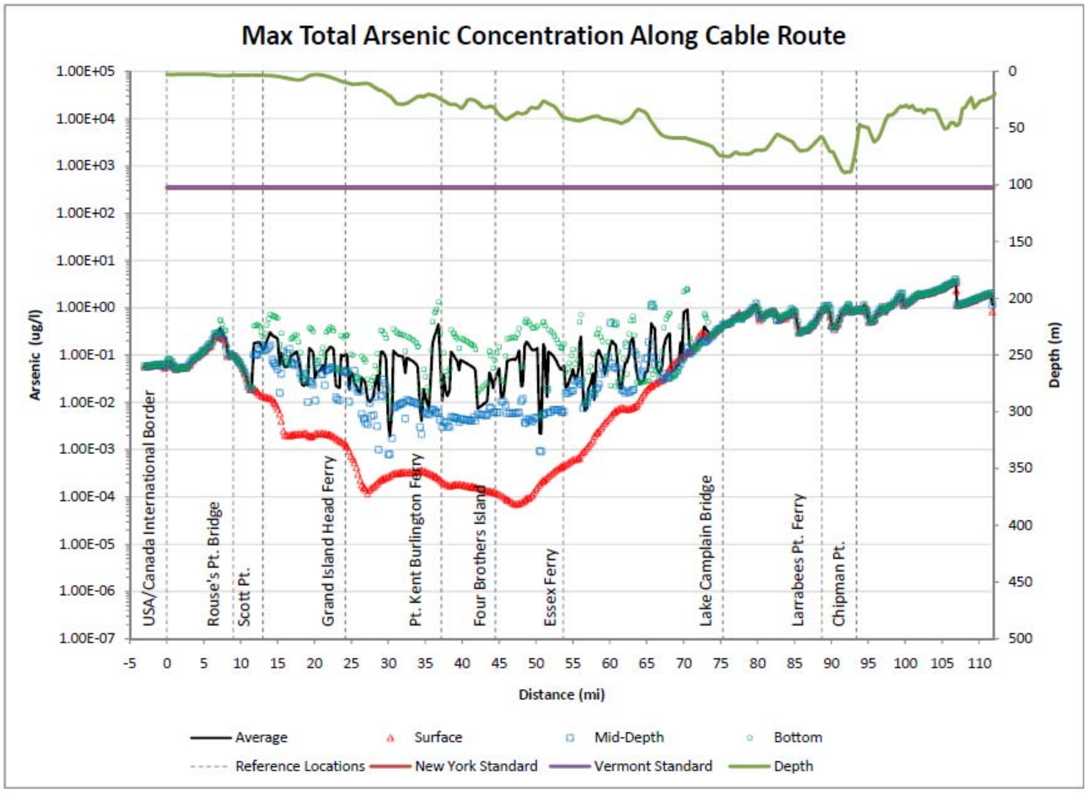


Figure 23. Arsenic concentrations and water quality standards.

6.11 TSS

Along the majority of the route within Lake Champlain, depth-average TSS concentrations associated with cable installation (i.e., no background TSS) are less than 200 mg/l. However, in the southern portion of the route TSS concentrations are greater than 200 mg/l for a total of 21.4 miles (Figure 24) and for an approximate duration of 28 days.

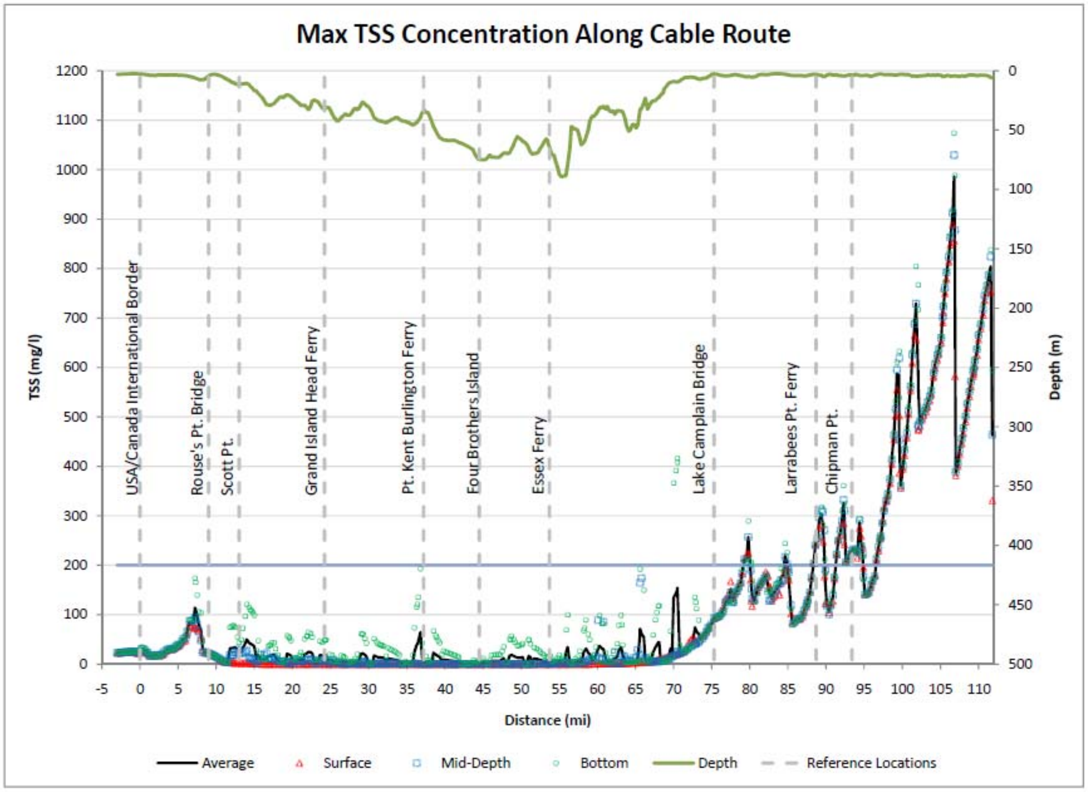


Figure 24. TSS concentrations.

7. Summary

A three dimensional hydrodynamic and water quality model of Lake Champlain was developed using the Danish Hydraulic Institute (DHI) MIKE3 software. The model was calibrated to the flow exiting the lake via the Richelieu River, and to measured vertical temperature profiles throughout the lake.

To simulate the cable laying operation a series of load points at approximately two mile intervals were used. These matched the locations at which sediment cores were taken. At each point the load was sequentially turned on and off to simulate the effect of the continuously moving cable operation. The solids load at each point was computed based on the sediment core data and relevant cable installation data. Both dissolved and solid fractions of contaminants were computed in the model. The model was used to simulate ten contaminants that were present in the sediment cores collected during the Spring 2010 Marine Route Survey.

The maximum model-computed concentrations of contaminants along the cable route were graphically presented and compared to New York and Vermont's water quality standards. The comparisons showed that the effects of the proposed project would comply with NYS/Vermont water quality standards for eight of the ten modeled contaminants. Based on cable installation using the water jetting technique, the projected copper and zinc concentrations in limited extents (approximately 1 mile) and durations (less than 20 hours) of the southern portion of the lake would exceed Vermont's standards, which apply to the total (particulate and dissolved) metal concentration. New York State's standards for copper and zinc apply to the dissolved form; the projected dissolved concentrations of copper and zinc are well below New York State's standards.

In order to reduce the impacts of the project on water quality, it is expect that modifications to the installation program will be necessary in certain areas. Potential best management practices (BMPs) for cable installation may include the following:

- <u>Construction work windows</u>: Construction work windows may vary along the proposed route in order to reduce the potential impacts on sensitive species. These windows should be developed in consultation with regulatory agencies.

- <u>Water jetting operation parameter modifications</u>: In certain areas, the water jetting operations could be modifed so as to reduce the sediment loading rate. These modifications could include a reduction in water jetting pressure and in the rate of installation, which would curtail TSS loading. While it is anticipated that these operational parameters will be set prior to going into the field, it may also be necessary to make modifications in the field based on water quality monitoring results.

- <u>Alternative cable installation techniques</u>: While water jetting is the preferred installation technique for the project, in certain areas alternative technologies should be considered. These could include hand jetting by divers, the use of water jetting to a intermediate depth followed by hand jetting to a final depth, or the use of the plough (assuming soil conditions support the technology.

The results of this modeling strongly indicate that, with certain modifications in certain segments of the route to normal operations, cable installation can occur in Lake Champlain so as to not exceed either Vermont or New York's water quality standards. However, it will be necessary to conduct a water quality monitoring program during cable installation in order to confirm this conclusion.

References

Danish Hydraulic Institute 2009. MIKE21 & MIKE3 Flow Model FM, Hydrodynamic and Flow Transport Model, Scientific Documentation, January 2009.

Environment Canada 2010. Richelieu River preliminary 2009 flow data provided in digital format by Guy Morin, April 2010.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation 1997. A Phosphorus Budget, Model and Load Reduction Strategy for Lake Champlain. Lake Champlain Diagnostic-Feasibility Study Final Report, January 1997.

Vermont Department of Environmental Conservation and New York State Department of Environmental Conservation 2010. Lake Champlain 2009 temperature profile data provided in digital format by Eric Smeltzer, April 2010.

Appendix A – Temperature Calibration Plots

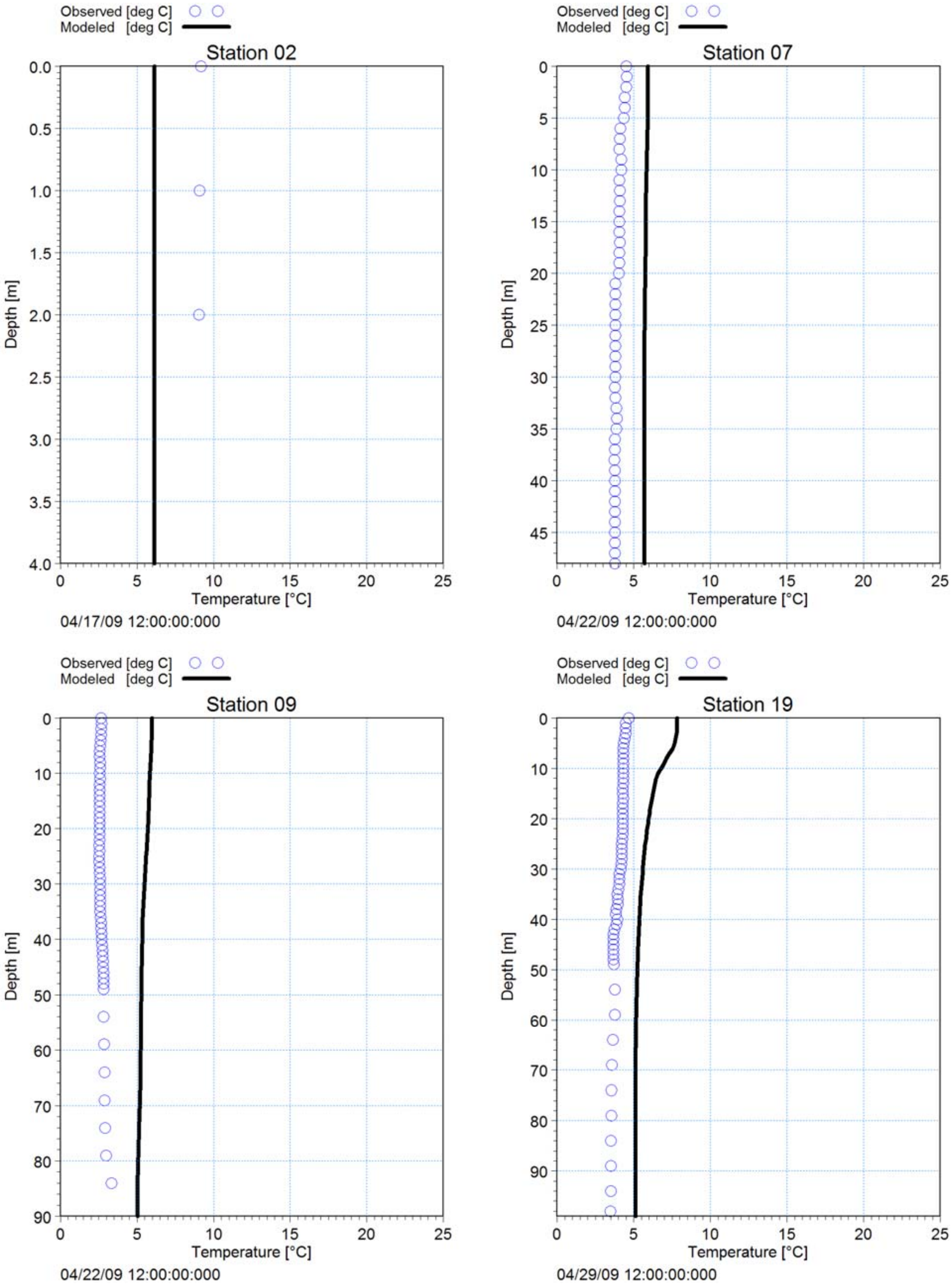


Figure 25. Temperature calibration for April 2009, stations 2,7,9,19.

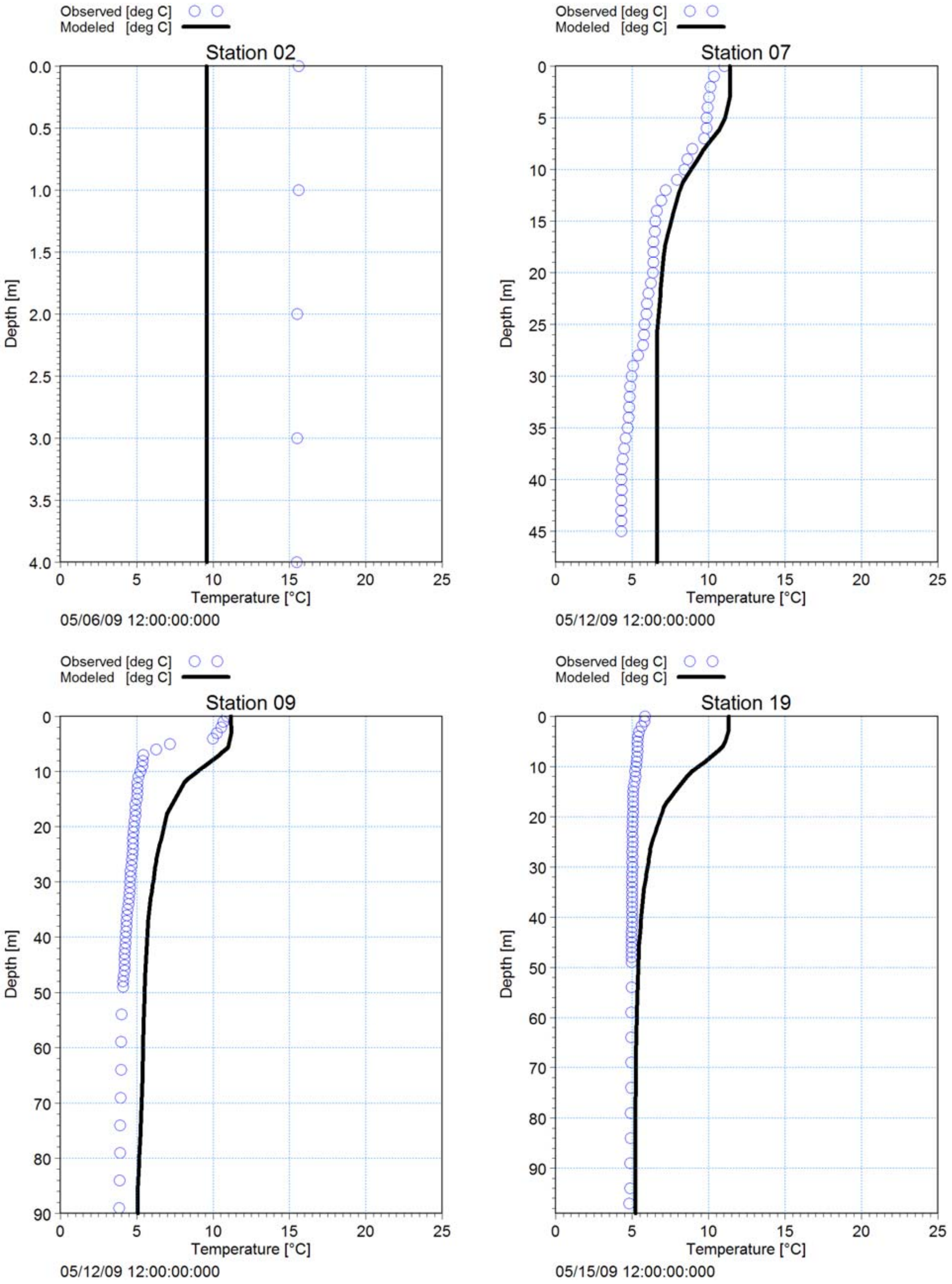


Figure 26. Temperature calibration for May 2009, stations 2,7,9,19.

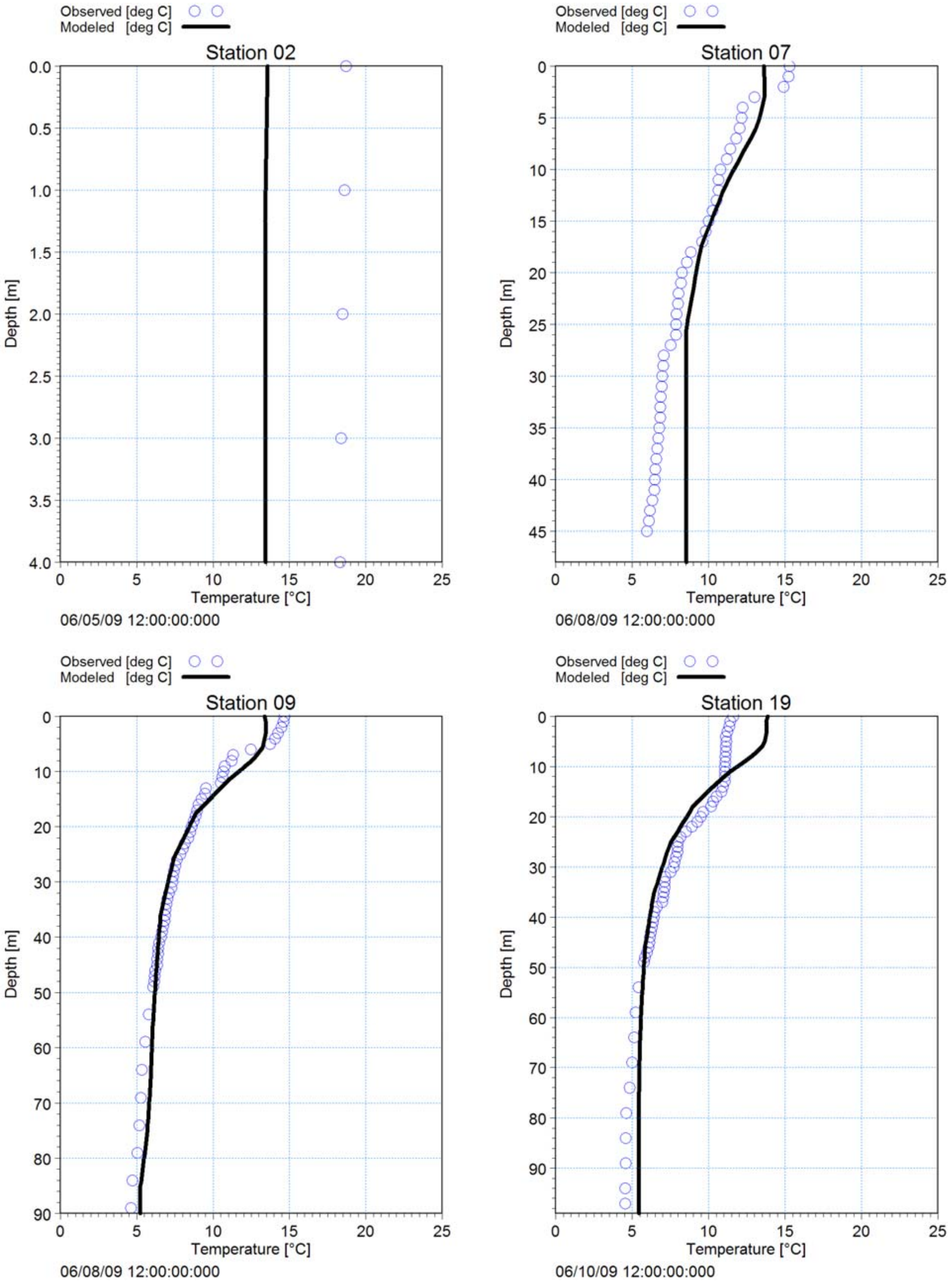


Figure 27. Temperature calibration for June 2009, stations 2,7,9,19.

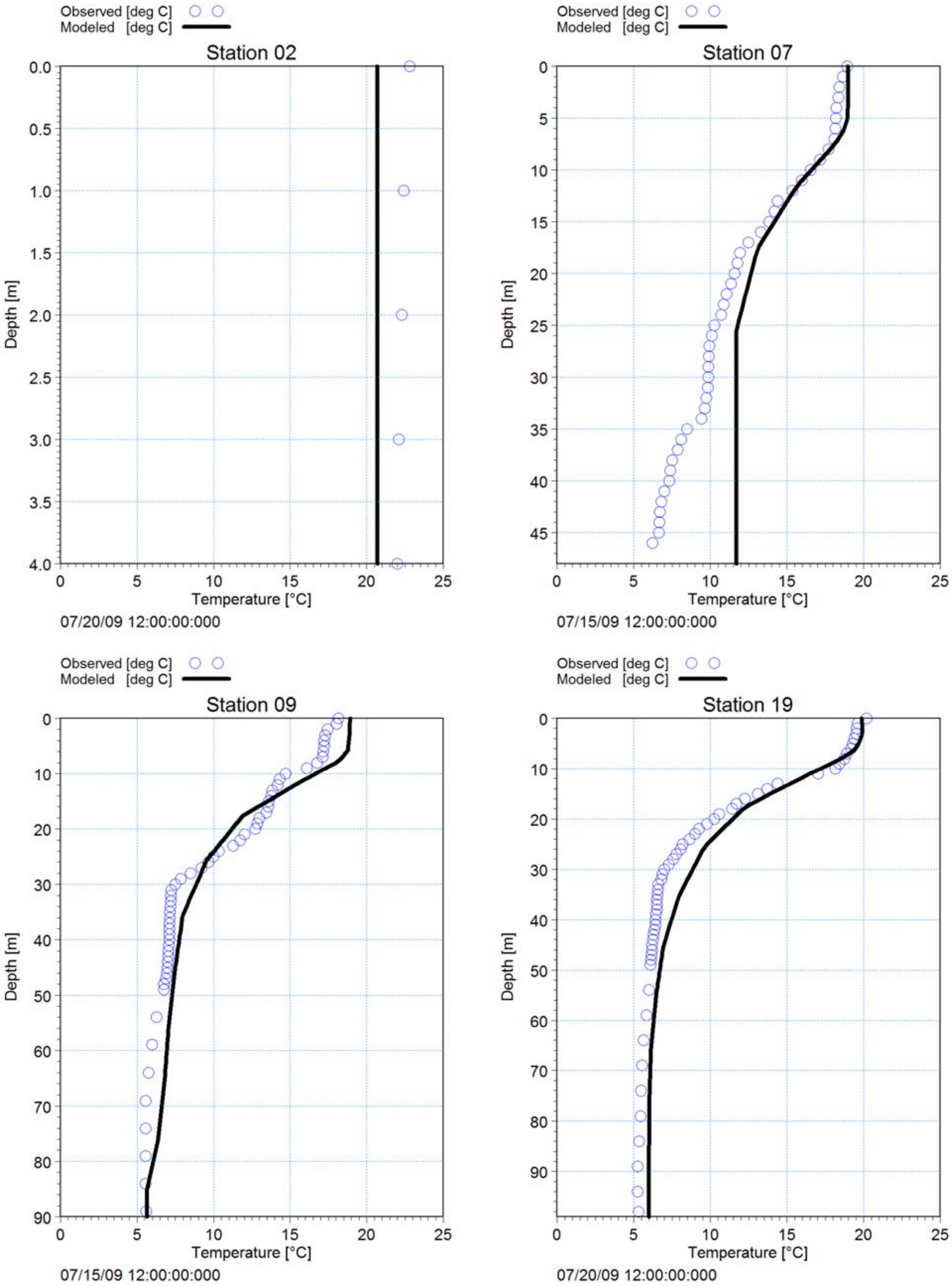


Figure 28. Temperature calibration for July 2009, stations 2,7,9,19.

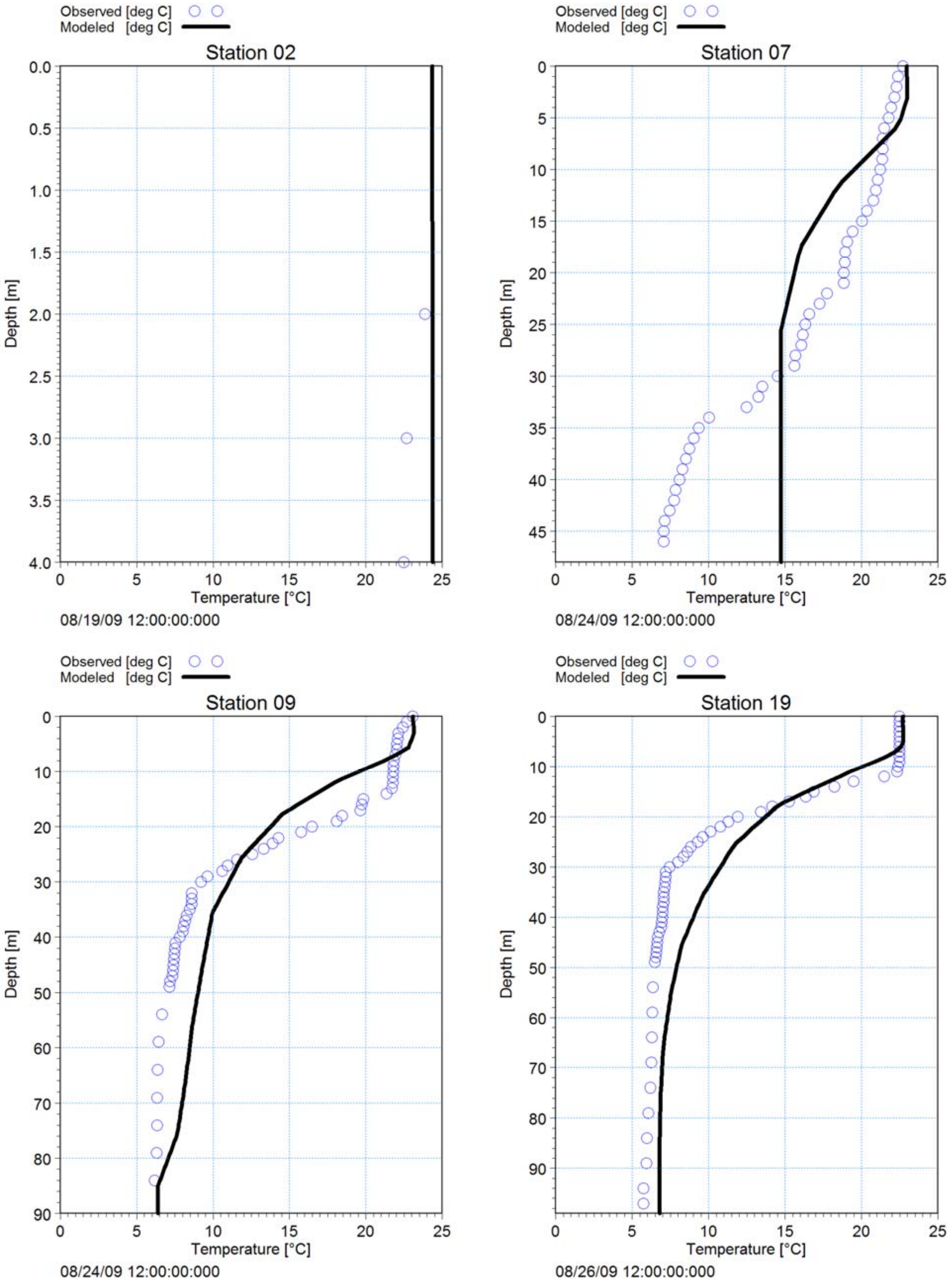


Figure 29. Temperature calibration for August 2009, stations 2,7,9,19.

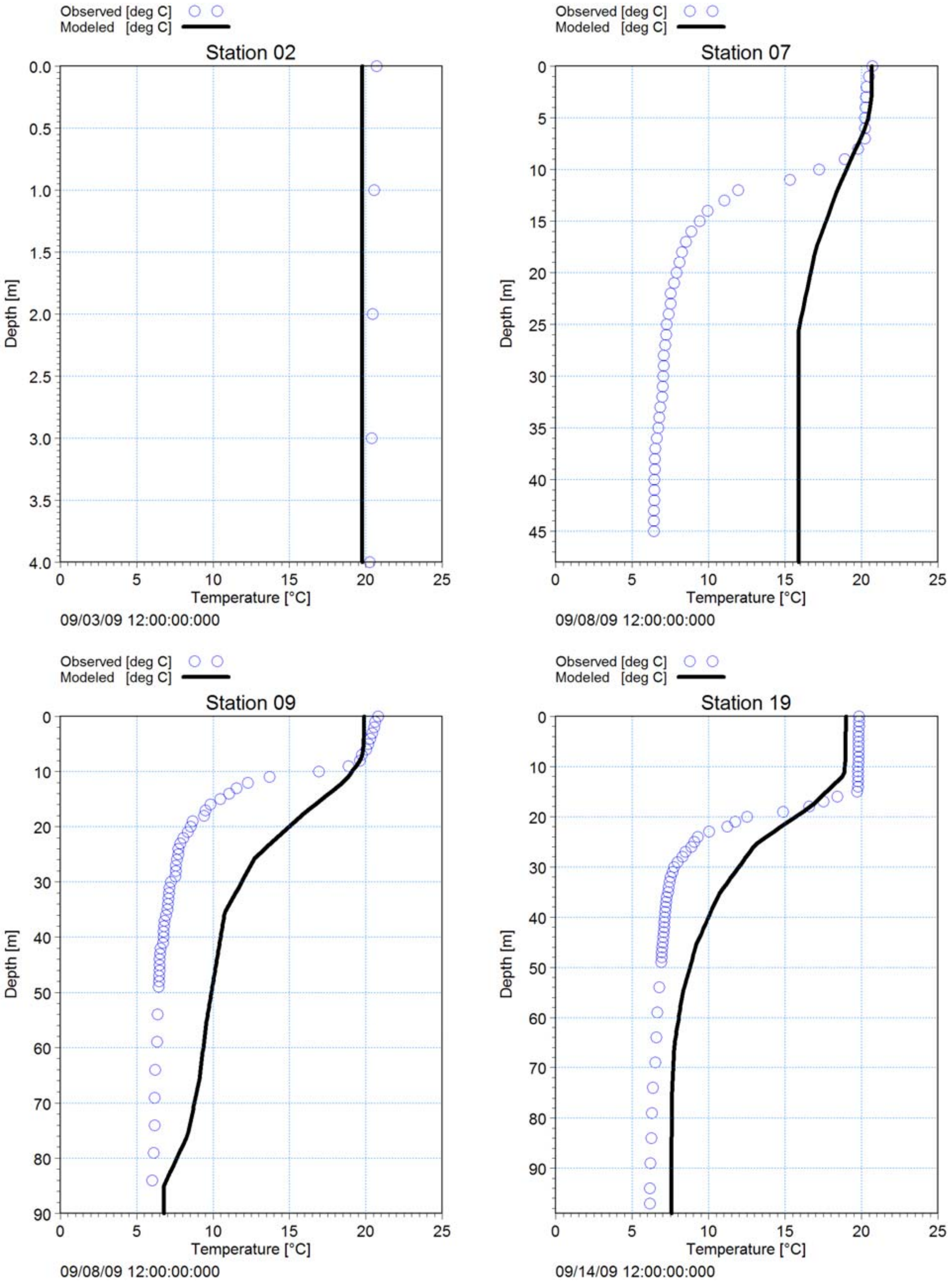


Figure 30. Temperature calibration for September 2009, stations 2,7,9,19.

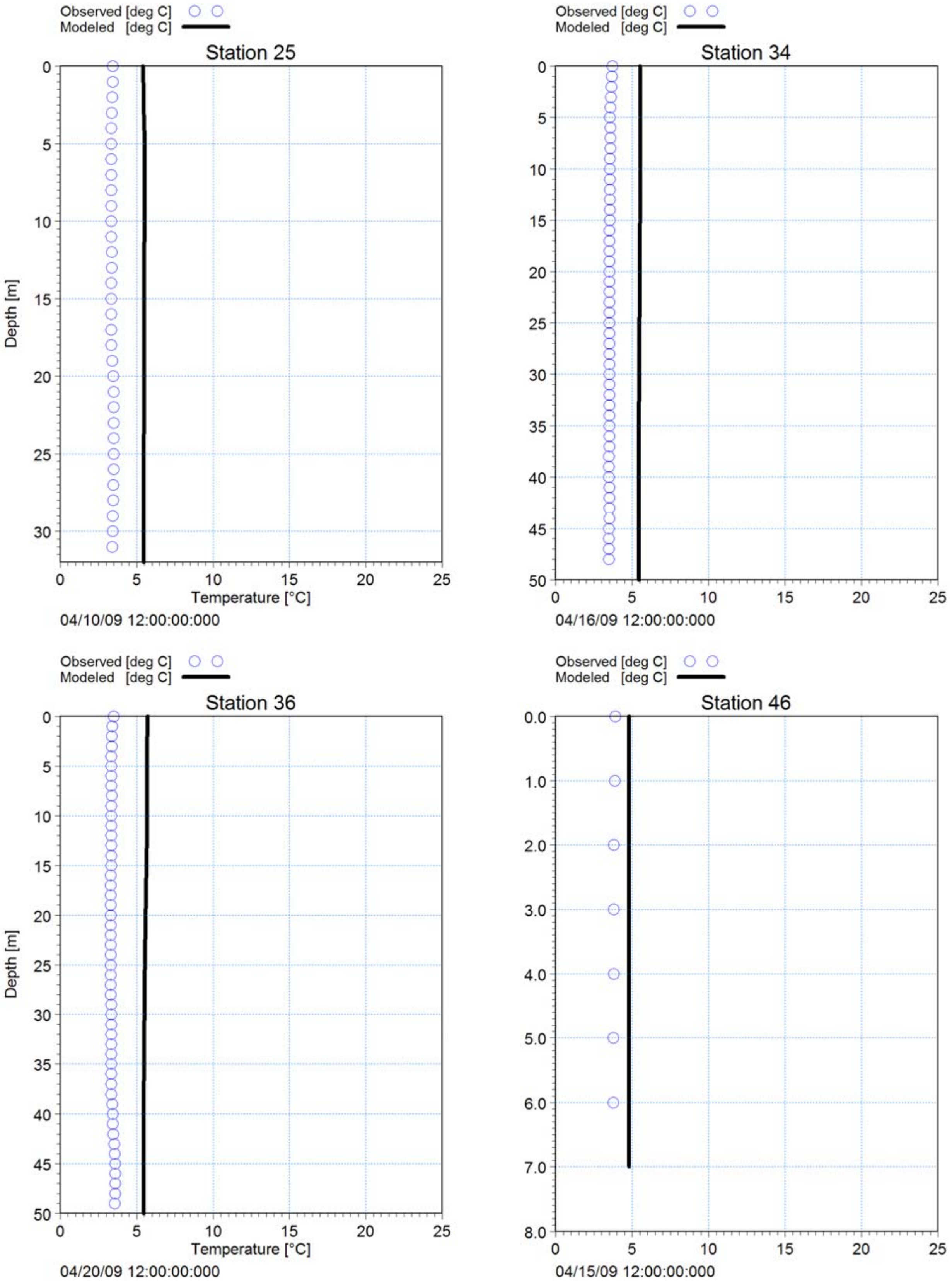


Figure 31. Temperature calibration for April 2009, stations 25,34,36,46.

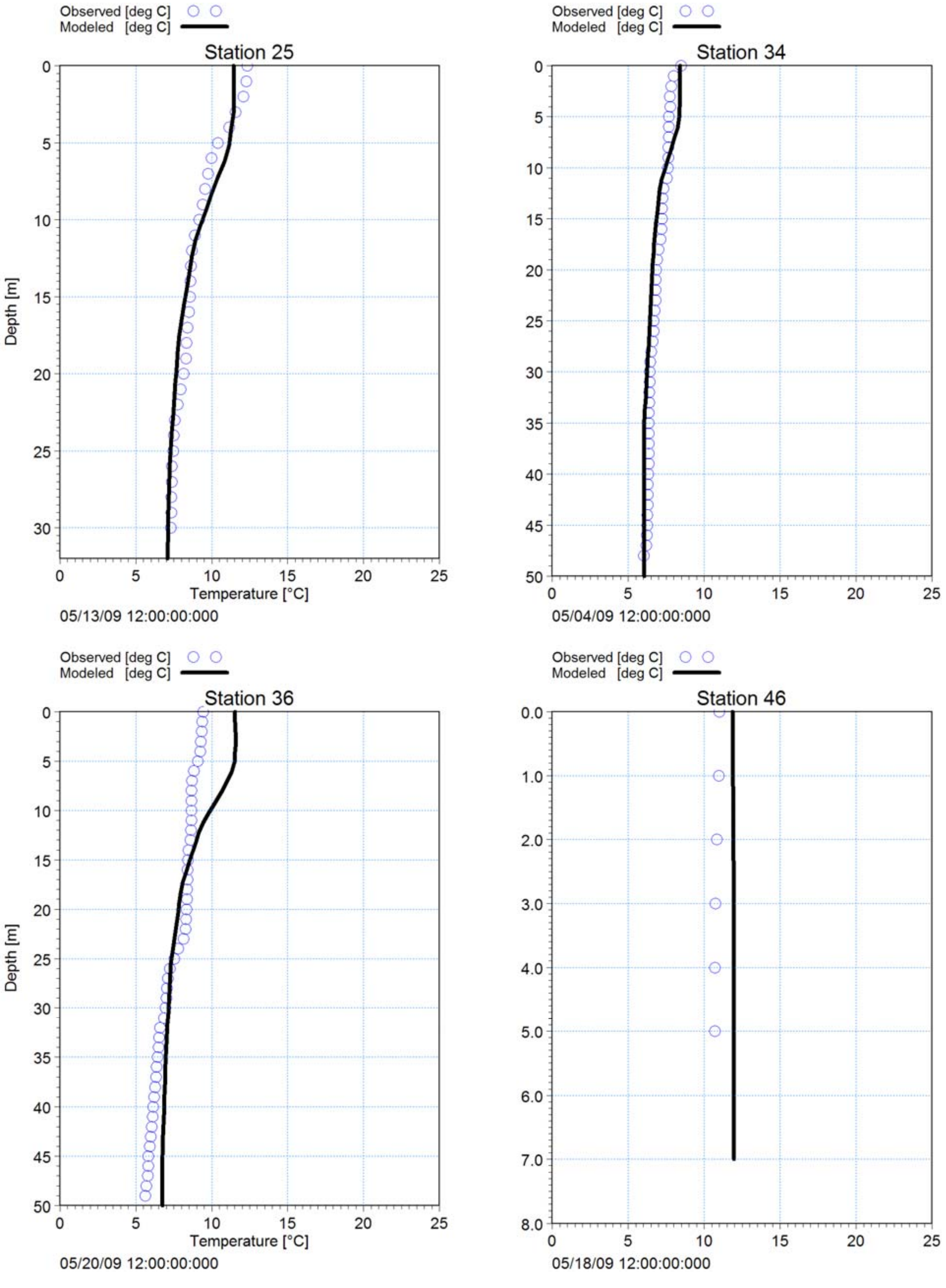


Figure 32. Temperature calibration for May 2009, stations 25,34,36,46.

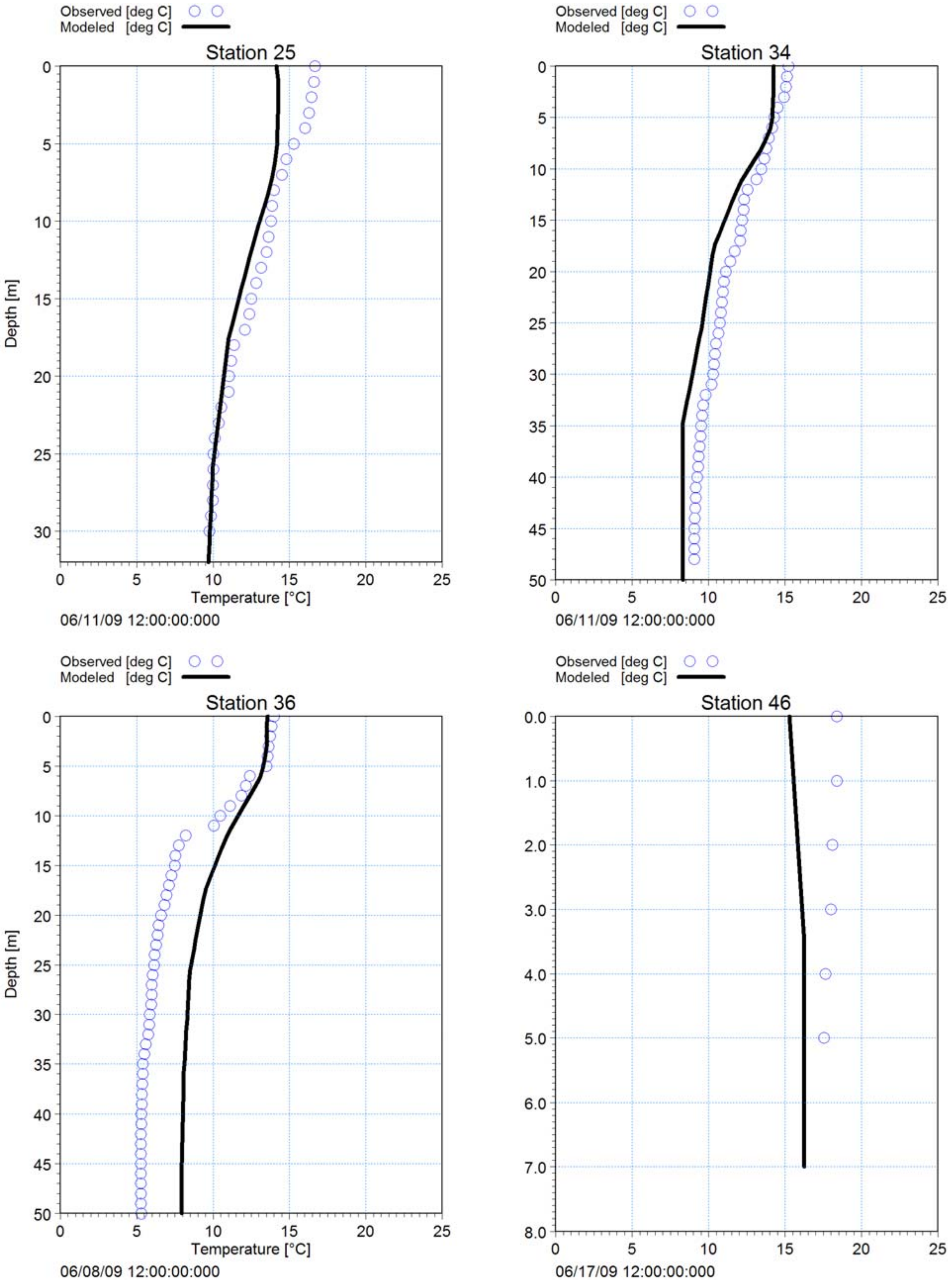


Figure 33. Temperature calibration for June 2009, stations 25,34,36,46.

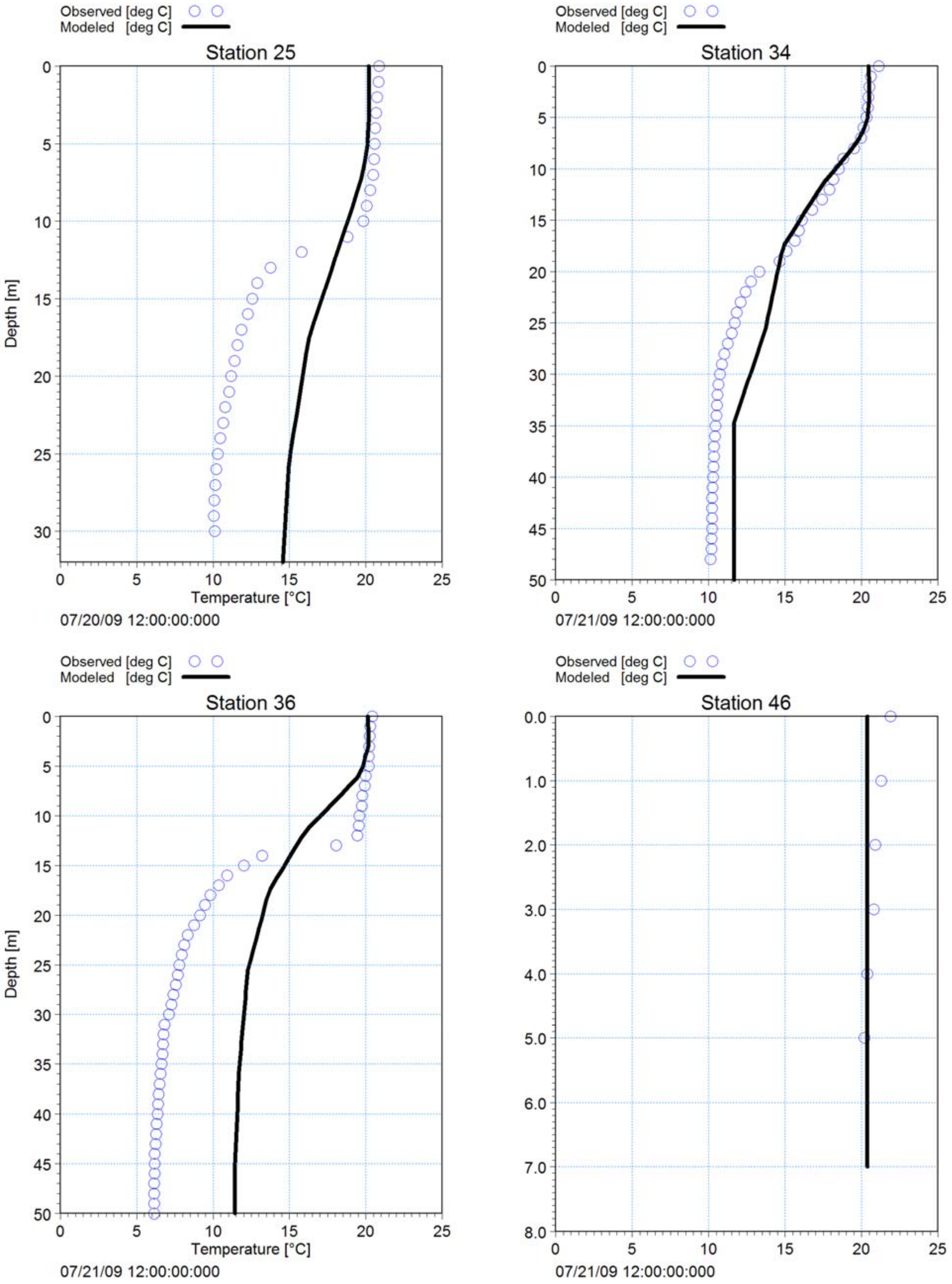


Figure 34. Temperature calibration for July 2009, stations 25,34,36,46.

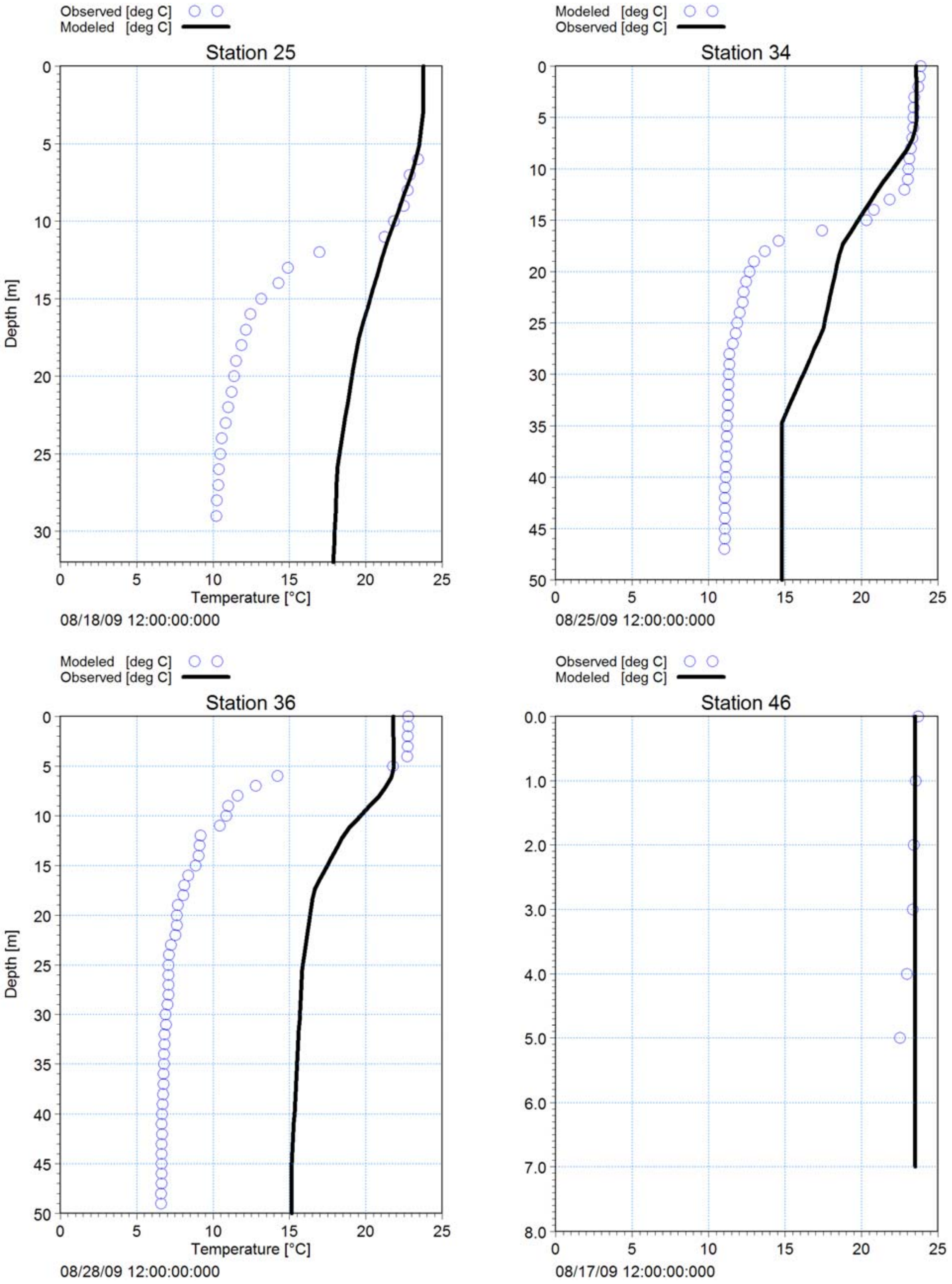


Figure 35. Temperature calibration for August 2009, stations 25,34,36,46.

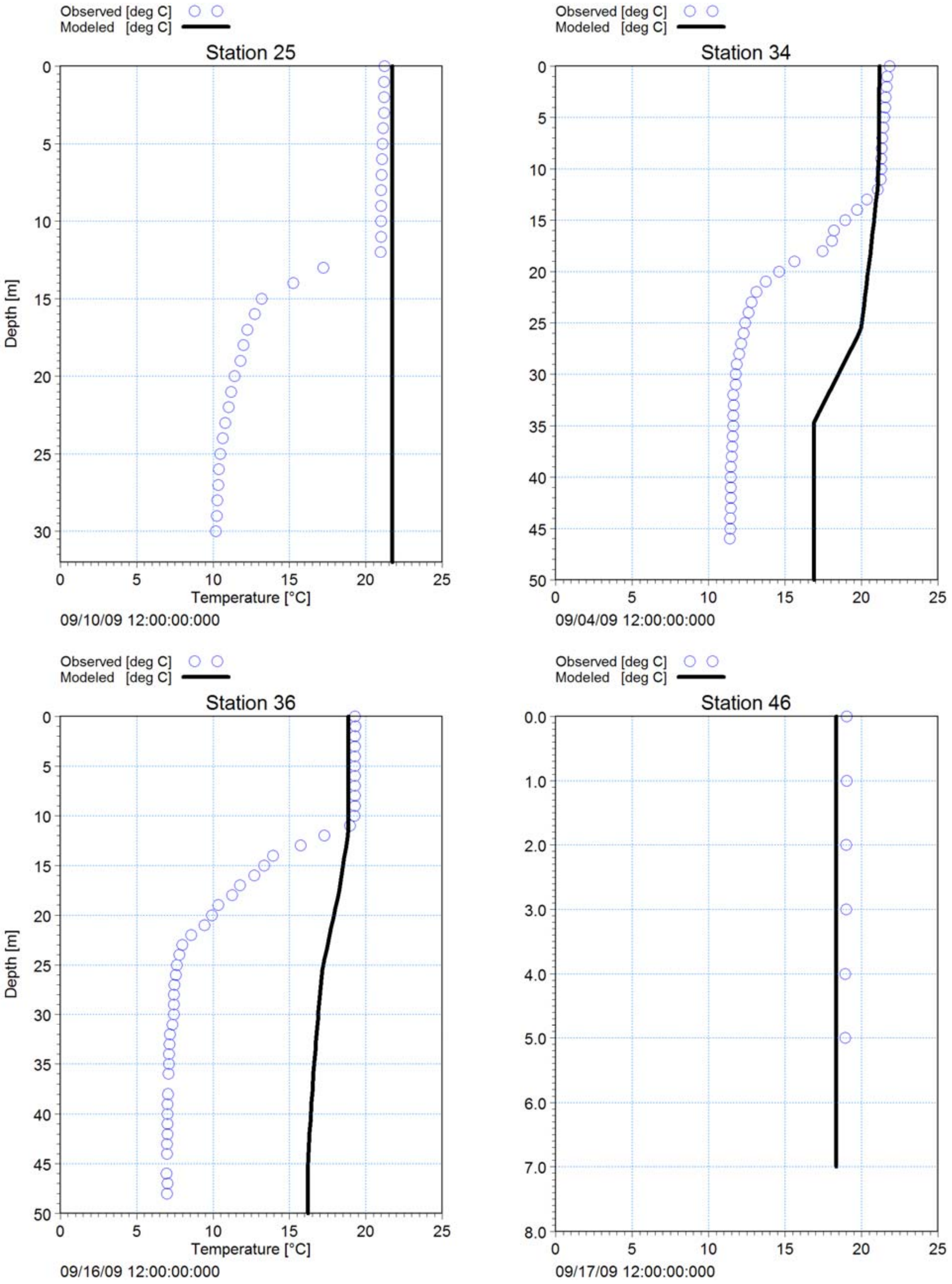


Figure 36. Temperature calibration for September 2009, stations 25,34,36,46.

Transmission
Developers Inc.

Champlain Hudson Power Express Project

Water Quality Modeling Report

Hudson, Harlem and East Rivers

October 2010

Contents

List of Figures

1. Project Overview

Champlain Hudson Power Express Inc (CHPEI) a subsidiary of Transmission Developers Inc (TDI) proposes to develop the Champlain Hudson Power Express Project (Project) to connect renewable sources of power generation to load centers in and around the New York City. The Project will include underwater and underground, high-voltage direct current (HVDC) transmission cables. To the extent possible, CHPEI proposes to install the transmission cables along and within existing waterways to minimize land use and visual impacts typically associated with traditional overhead transmission lines, while simultaneously providing the additional capacity required to meet the increasing clean energy demands of the greater New York City metropolitan area. The Project consists of a 1,000 megawatt (MW) HVDC underwater/underground HVDC transmission system that includes one 1,000 MW bipole (a bipole includes two cables connected as a bipole pair), extending between the Canadian border and New York City, New York. CHPEI has designed the Project to meet the New York City area's need for additional sources of competitively priced electricity from safe and reliable renewable sources of energy.

The northern part of the underwater cable route extends through Lake Champlain with an overland bypass beginning in Whitehall. The cable re-enters the water in the Hudson River near Coeymans, New York. For the majority of the proposed transmission cable route, the submarine cables would be buried approximately 4 feet; however, burial depths may vary along the cable route based on bottom conditions or existing infrastructure (e.g. at existing utility crossings). When the cable route crosses or is in the federally maintained navigation channel the cable will buried 15' below authorized depth.

A mathematical model was developed to evaluate the potential impacts of the proposed cable installation in Lake Champlain, Hudson, Harlem and East Rivers on water quality. A separate report provides the water quality modeling results for the Lake Champlain portion. This report describes the development and application of a three-dimensional hydrodynamic and time-variable water quality model to assess water quality impacts and compliance with water quality standards in the Hudson, Harlem and East Rivers.

For this Water Quality Modeling task, it is assumed that cable installation may be conducted in two stages within the Hudson, Harlem and East Rivers due to construction work windows. The establishment of project specific construction work windows is part of the current permitting process and final work windows have not been established by the regulatory agencies. Based on existing work windows in these water bodies we assumed the following:

- Coeymans, NY to Haverstraw, NY; September 1 – November 11; project miles 202-305.
- Haverstraw, NY to Astoria, NY; May 1- May 21; project miles 305-334.

Two different model runs were made to reflect the two different work windows. In this report the two runs are referred to by the project miles: (202-305) and (305-334). The two runs encompass the entire cable route in the Hudson River to Astoria. As it is anticipated that the vast majority of the cable will be installed using water jetting, the model inputs are based on the use of this technology.

2. Model Description

The model used in this project was the Danish Hydraulic Institute (DHI) three dimensional hydrodynamic and water quality model called MIKE3 FM. The modeling system is based on the numerical solution of the three dimensional incompressible Reynolds averaged Navier-Stokes equations subject to the assumptions of Boussinesq and of hydrostatic pressure (DHI, 2009). The model consists of continuity, momentum, temperature, salinity and density equations and is closed by a turbulence closure scheme. The density does not depend on pressure but only on temperature and salinity. The free surface is taken into account using a sigma-coordinate transformation approach.

The following effects are accounted for:

- Flooding and drying
- Momentum dispersion
- Bottom shear stress
- Coriolis force
- Wind shear stress
- Precipitation/evaporation
- Heat exchange
- Sources and sinks
- Water quality

The solution technique uses the cell centered finite volume method as shown in Figure 1. The spatial domain is discretized by subdivision of the continuum into non overlapping elements. In the horizontal plane an unstructured mesh is used, while a structured mesh is used in the vertical domain. Elements can be prisms or bricks whose horizontal faces are triangles or quadrilateral elements.

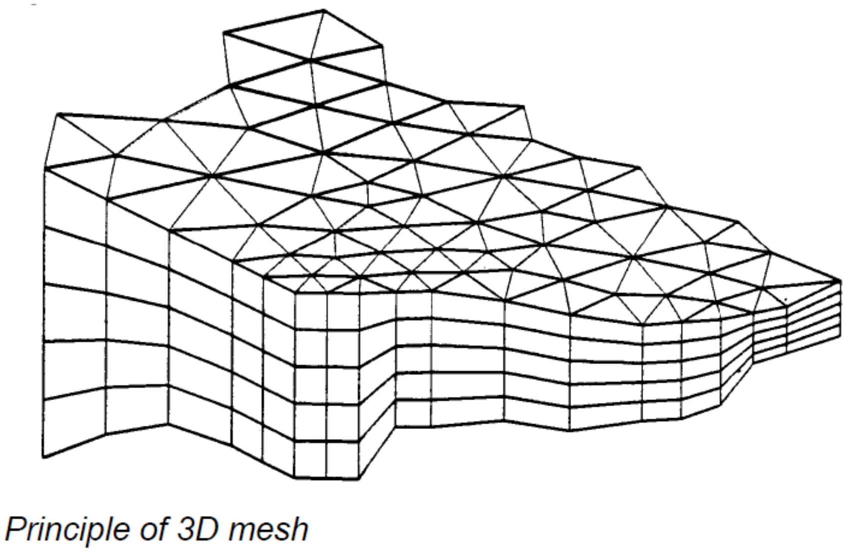


Figure 1. Finite Volume Mesh.

2.1 Model Mesh for Hudson River to Atlantic Ocean

The model domain is shown in Figure 2. The model domain encompasses a much larger area than necessary for this project as this is an existing model developed for previous projects (HDR, 2004). The model extends to the Federal Dam at Troy in the north, Atlantic City in the south, and the end of Long Island Sound in the east. The bathymetry is based on NOAA navigational maps (HDR, 2004).

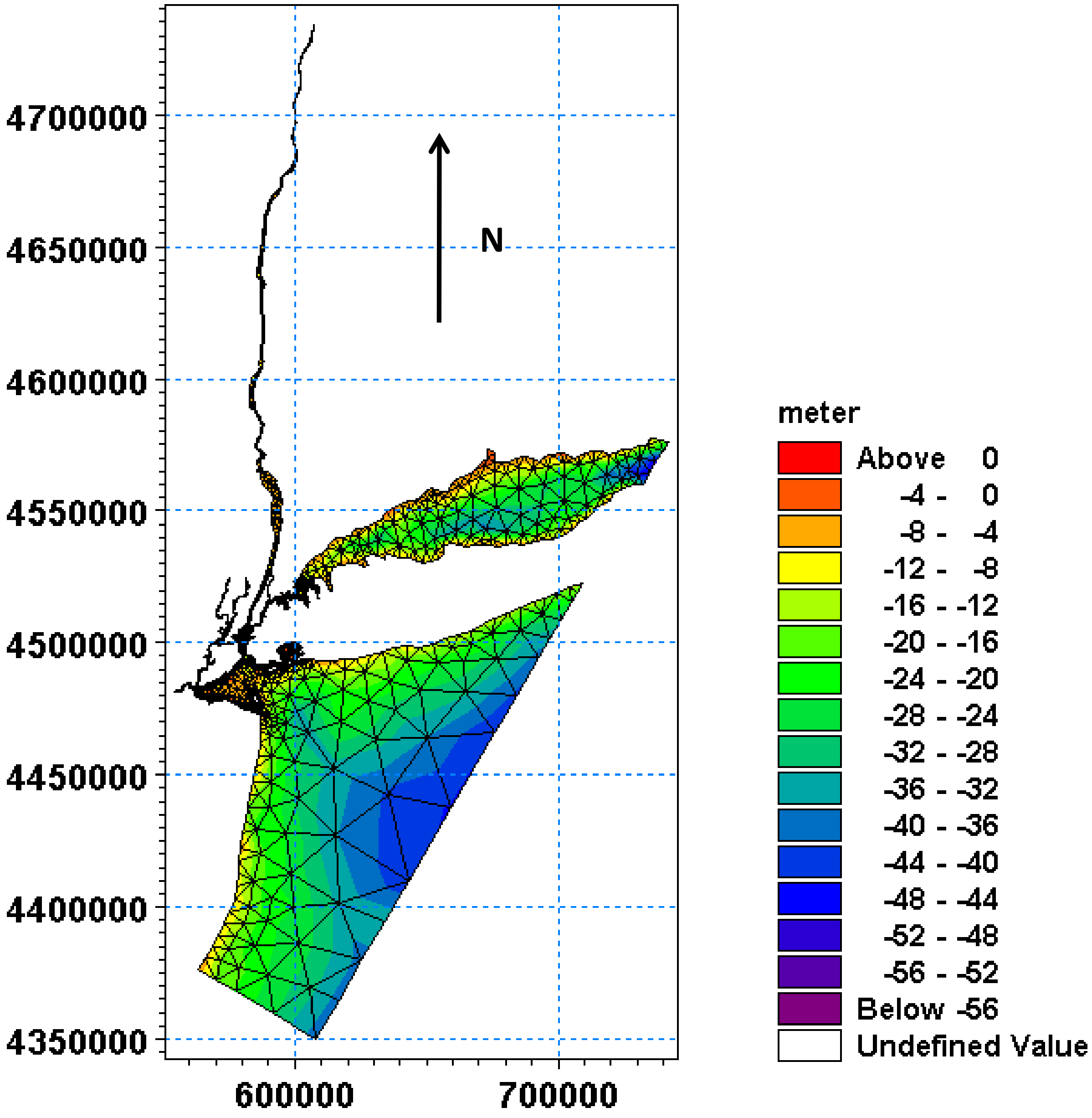


Figure 2. Model domain.

An example of the mesh in the Hudson River Estuary (Albany to north of Kingston) is shown in Figure 3. Details for the Lower Hudson River Estuary, Harlem River and East River are shown in Figure 4.

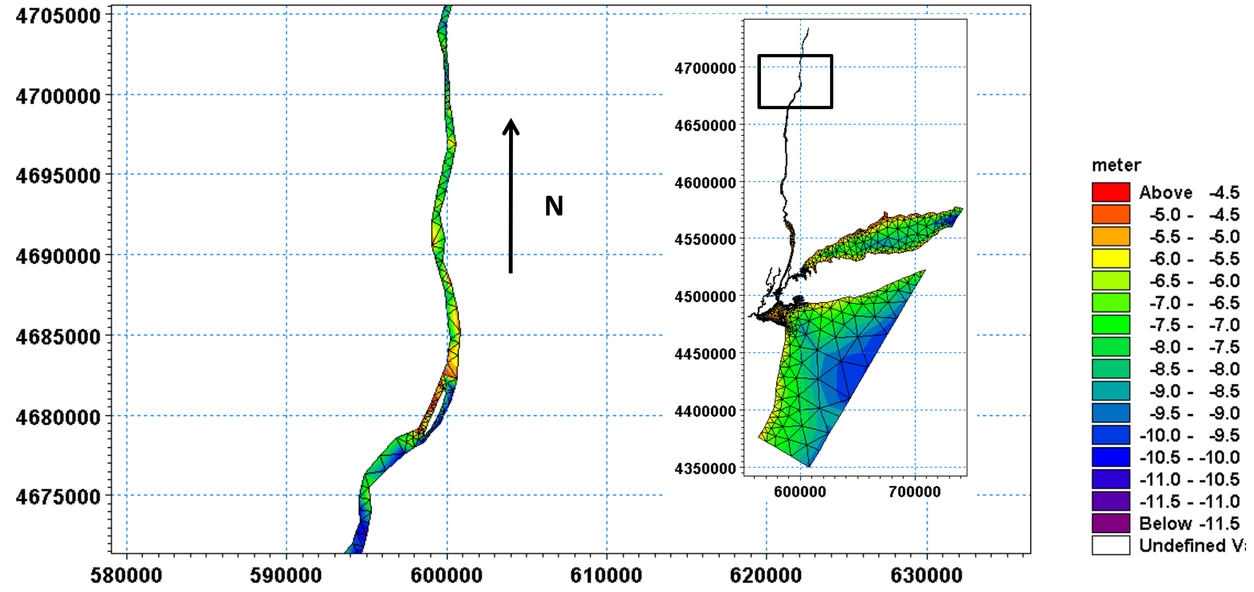


Figure 3. Example Hudson River Estuary mesh detail near Albany.

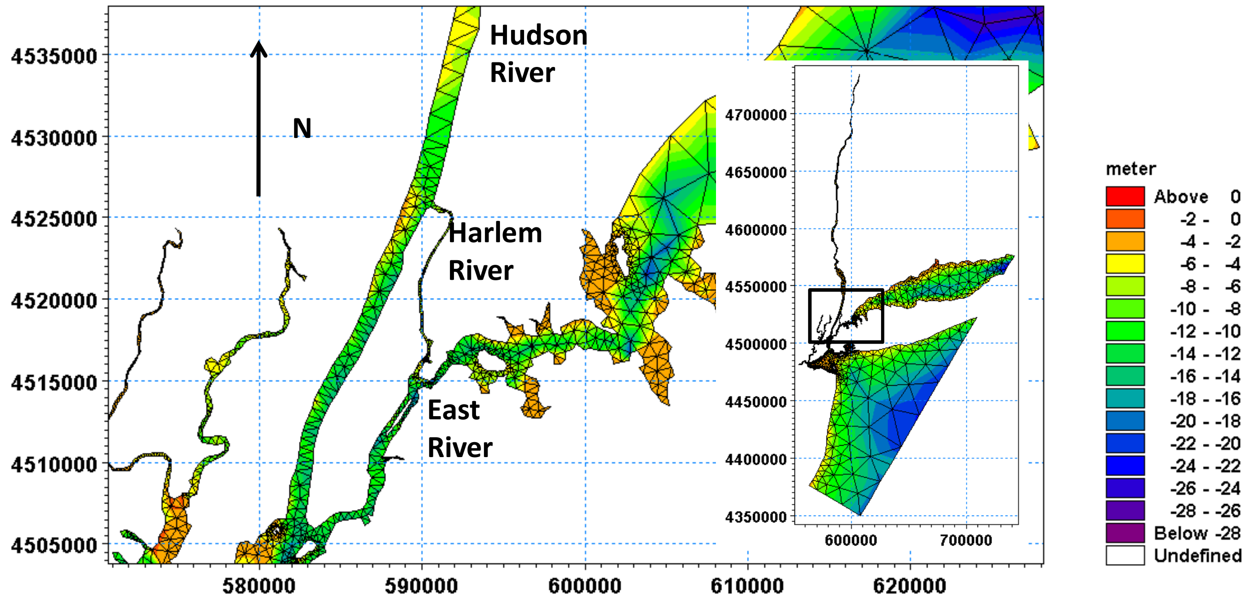


Figure 4. Lower Hudson River Estuary, Harlem River and East River mesh detail.

The vertical layering of the model uses a sigma coordinate system with five layers. Figure 5 shows the mesh detail along the Hudson River from The Battery to the Federal Dam at Troy. In this figure the contours are temperature.

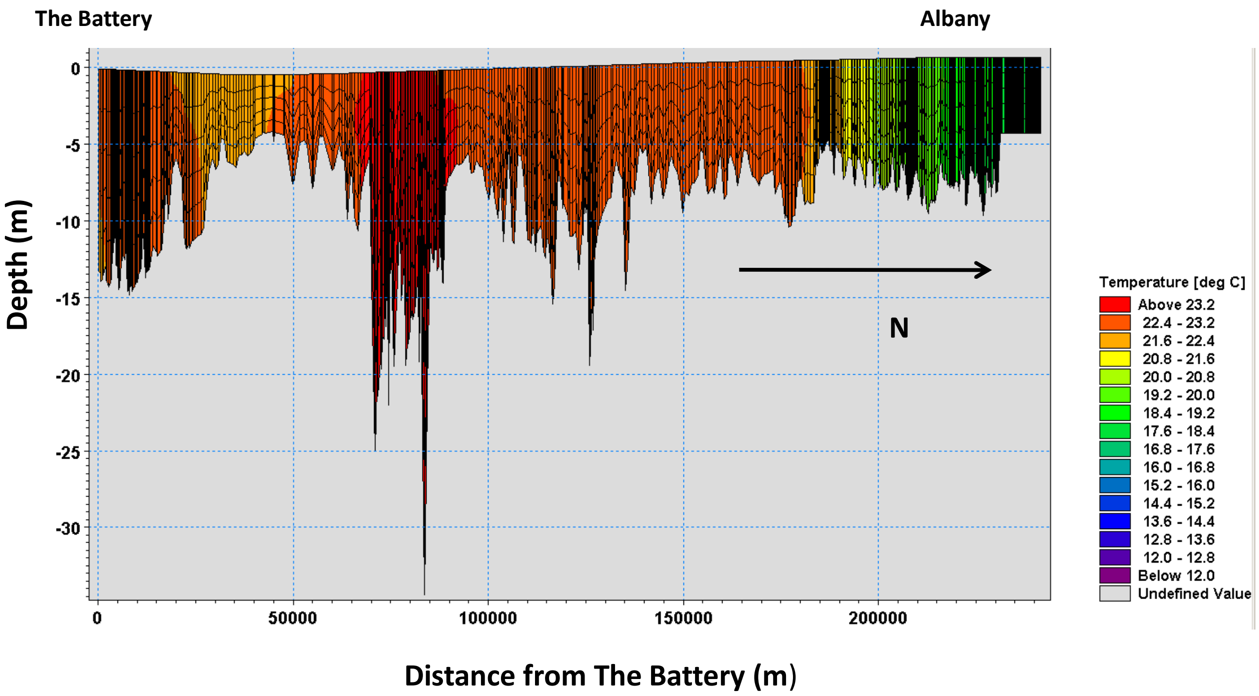


Figure 5. Vertical mesh detail in the Hudson River.

2.2 Model Set Up

The model was originally developed for the US Army Corps of Engineers for use in the Harbor Navigation Study (HDR, 2004). As part of the requirements for the Navigation Study the model was extensively calibrated and verified and approved by both the Corps of Engineers and the EPA, and an independent panel of experts. For this project the model mesh was updated to the Flexible Mesh version of MIKE 3. The model runs are for 1995 conditions as this was the year used in the original model application.

2.2.1 Model Boundary Conditions

The model boundaries at Troy on the Hudson River; the eastern end of Long Island Sound and the southern boundary near Atlantic City are based on NOAA tidal elevation data (NOAA, 2010). The eastern boundary in the Atlantic Ocean is based on tidal elevation output from the US Army Corps ADCIRC hydrodynamic model (Westerink et al. 1993).

2.2.2 Meteorological Data

The following hourly meteorology for 1995 was specified based on data obtained from the Northeast Regional Climate Center:

- Wind speed

- Wind direction
- Precipitation
- Evaporation
- Air temperature
- Humidity
- Cloud cover

2.2.3 Rivers

The flows for the following rivers for 1995 are included in the model (HDR, 2004):

- Hudson River
- Connecticut River
- Hackensack River
- Passaic River
- Norwalk River
- Housatonic River
- Quinnipiac River
- Raritan River
- Saddle River
- Second River
- Third River
- Rahway River

3. Model Calibration

The previous version of this model, which used nested orthogonal grids, was extensively calibrated and verified using observed data (HDR, 2004). The new FM version of the model was recalibrated to NOAA tidal elevation data at several locations, as shown in Figure 6. A comparison between the model and NOAA data for these sites for June, 1995 is shown in Figures 7-13.

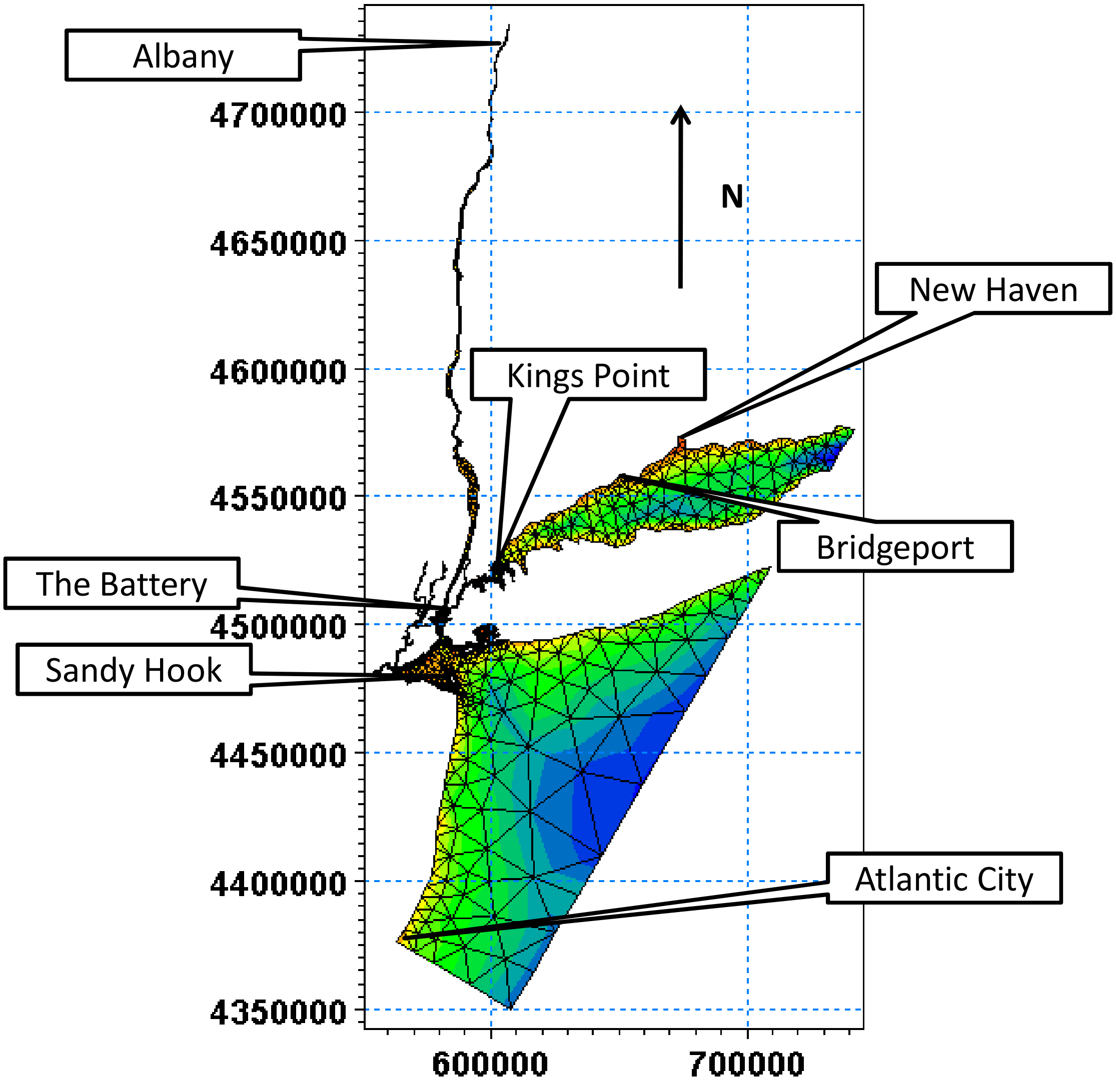


Figure 6. Locations of NOAA Stations

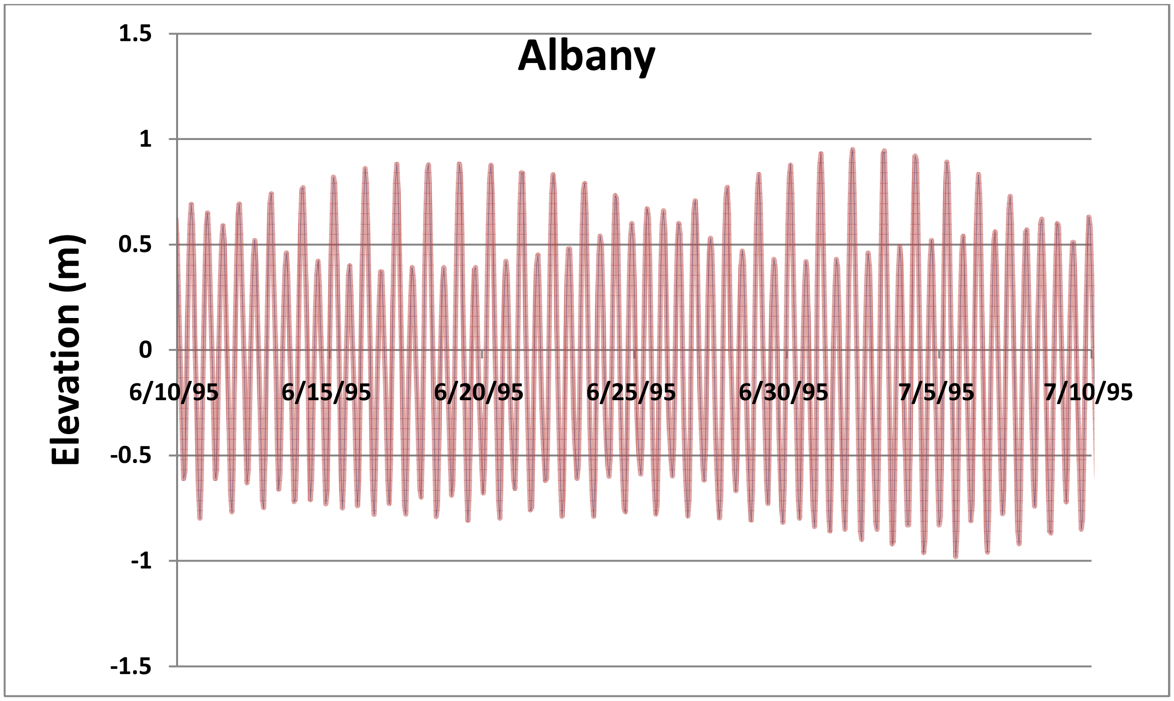


Figure 7. Albany elevation comparison. (Red=Model; Blue=NOAA)

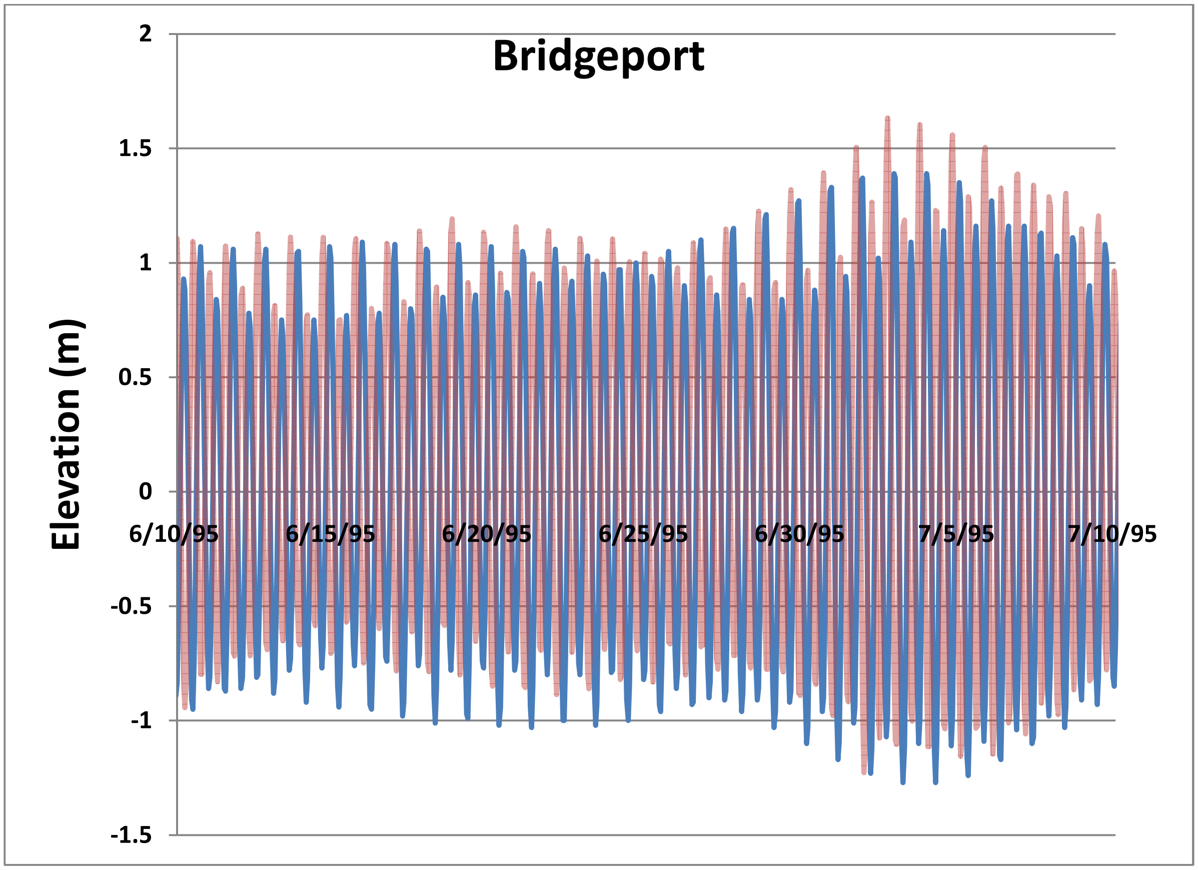


Figure 8. Bridgeport elevation comparison. (Red=Model; Blue=NOAA)

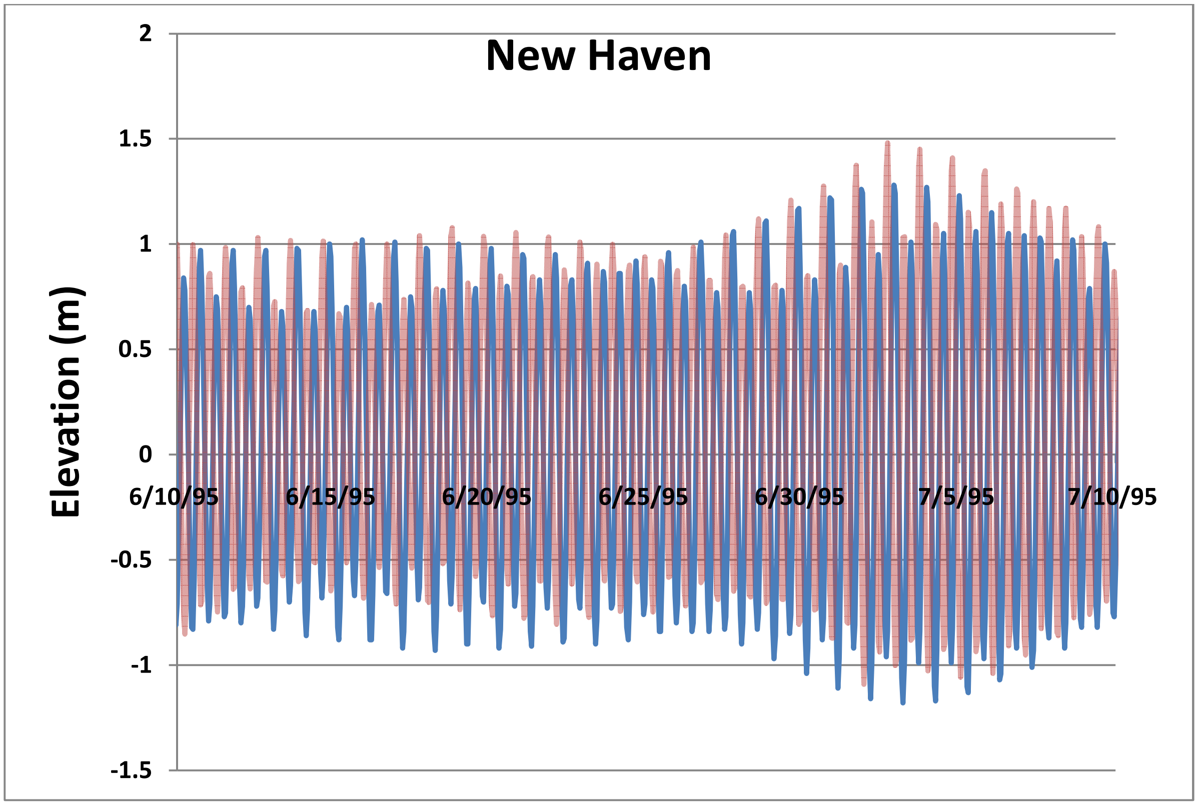


Figure 9. New Haven elevation comparison. (Red=Model; Blue=NOAA)

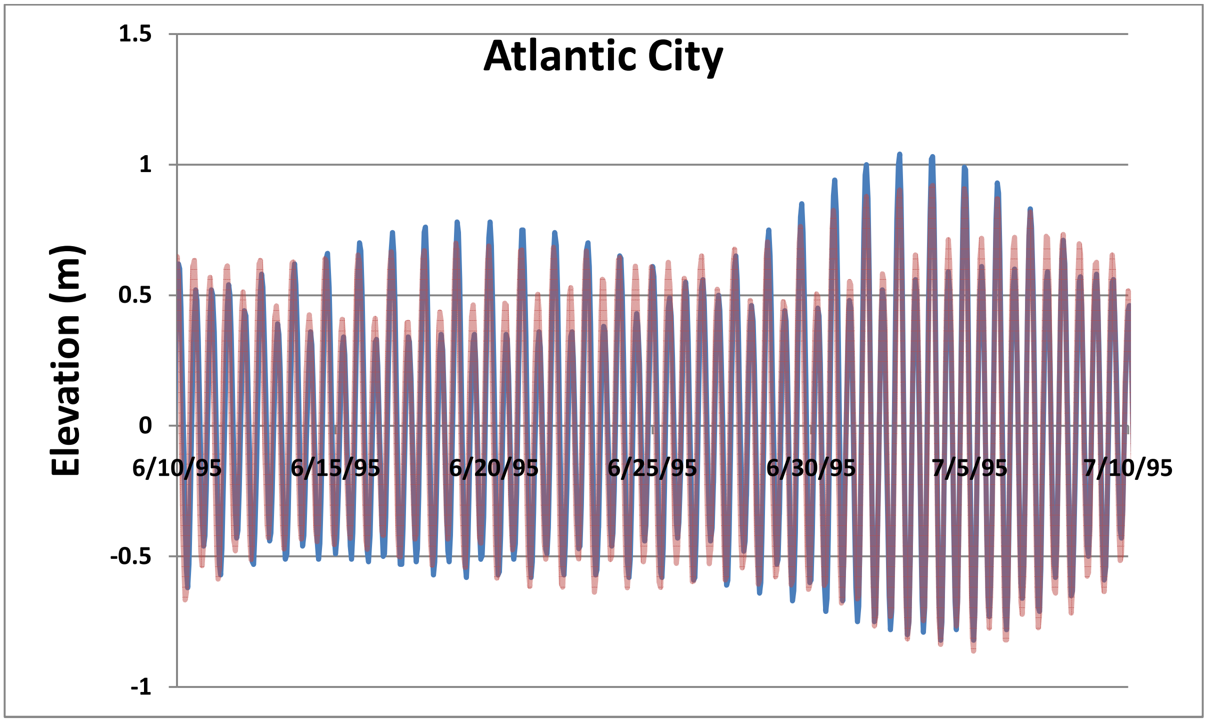


Figure 10. Atlantic City elevation comparison. (Red=Model; Blue=NOAA)

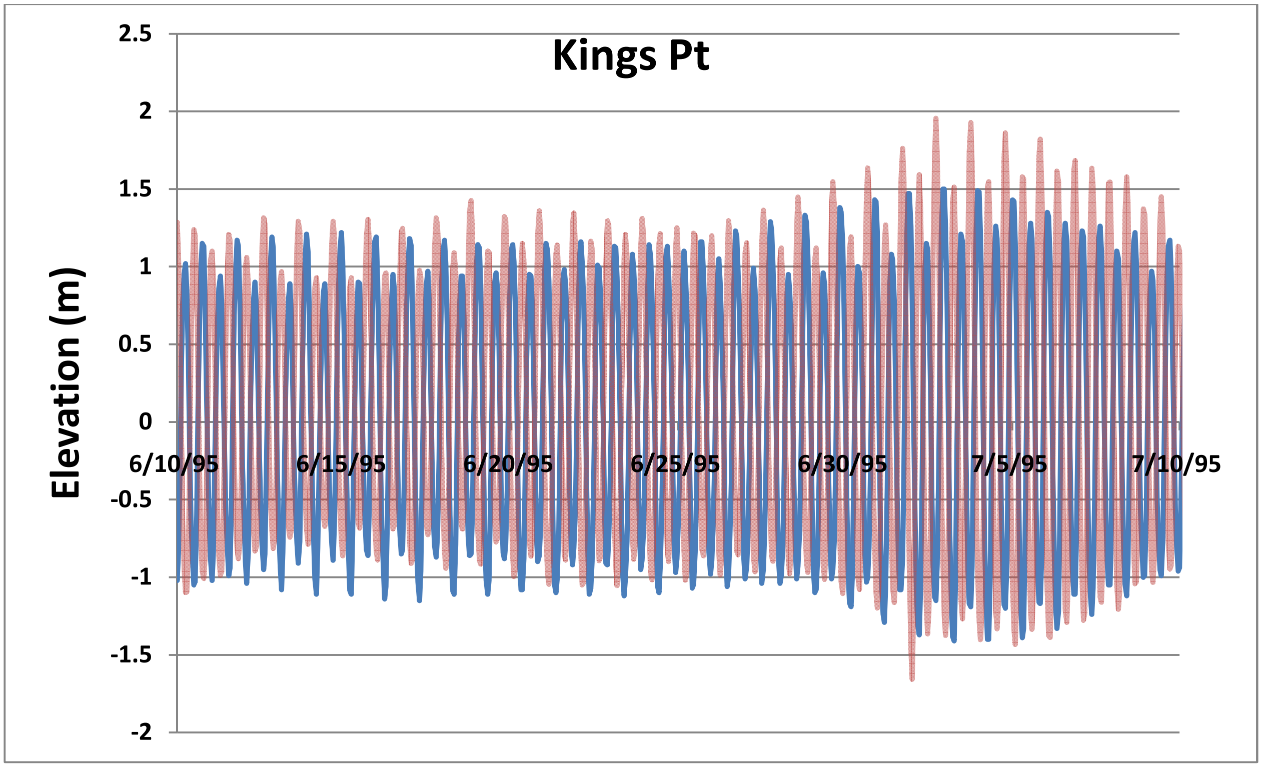


Figure 11. Kings Point elevation comparison. (Red=Model; Blue=NOAA)

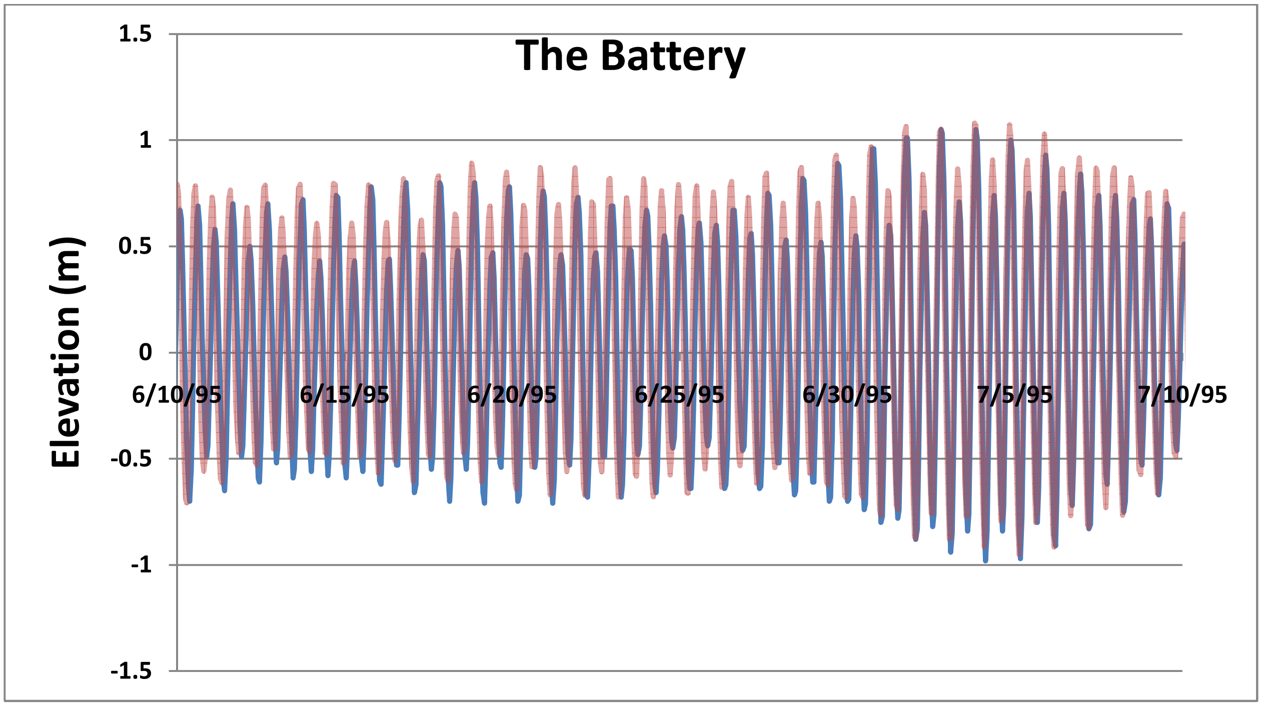


Figure 12. The Battery elevation comparison. (Red=Model; Blue=NOAA)

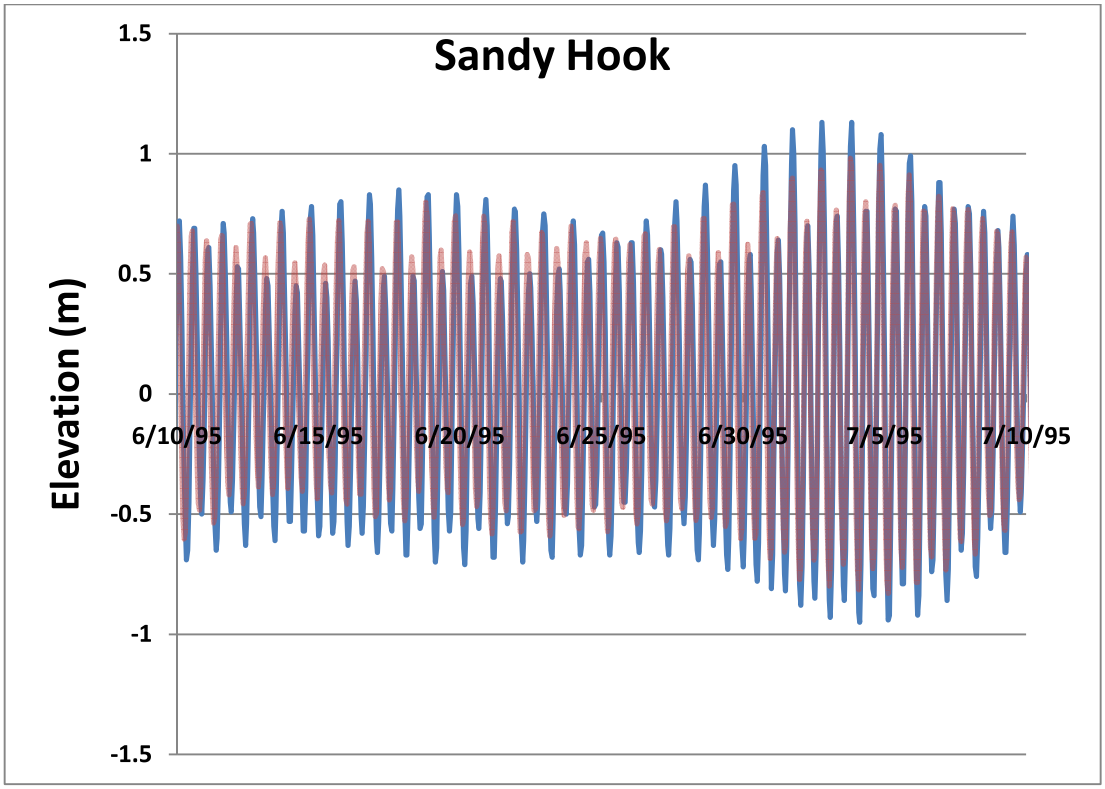


Figure 13. Sandy Hook elevation comparison. (Red=Model; Blue=NOAA)

In addition to tidal elevations, the salinity in the Hudson River was also checked against known ranges at selected locations along the river as summarized in Table 1 (USFWS 2010). These locations are shown in Figure 14. The salinity varies at each site both tidally, seasonally and with freshwater flows. The model comparison for June – September 1995 is shown in Figure 15Figure 15. Computed Hudson River salinity.

Table 1. Hudson River Salinity Zones and Ranges

TYPE OF SYSTEM	ZONES	APPROXIMATE GEOGRAPHIC LOCATIONS	SALINITY	RIVER MILE
Riverine	Nontidal Fresh	Hudson and Mohawk Rivers at Troy, and above head of tide tributaries	0 ppt	
Estuarine	Tidal Fresh	Troy dam to about Wappinger Falls and all Hudson tributaries to head	0 - 0.5 ppt	Wappinger Falls RM 68 = 110 km

		of tide		
		SALT FRONT / SALT WEDGE moves seasonally correlated to freshwater inflows		
Estuarine	Oligohaline	Wappinger Falls to Stony Point (RM40=64km)	0.5 - 5.0 ppt	Stony Point RM 40=64 km
Estuarine	Mesohaline	Stony Point to Yonkers (RM20 = 32km)	5.0 - 18.0 ppt	Yonkers RM20 = 32 km
Estuarine	Polyhaline	Yonkers to Manhattan	18.0 - 30.0 ppt	
Marine	Euhaline	Manhattan seaward Harbor Estuary	>30 ppt	

Reference: U. S. Fish and Wildlife Service http://library.fws.gov/pubs5/web_link/text/low_hud.htm

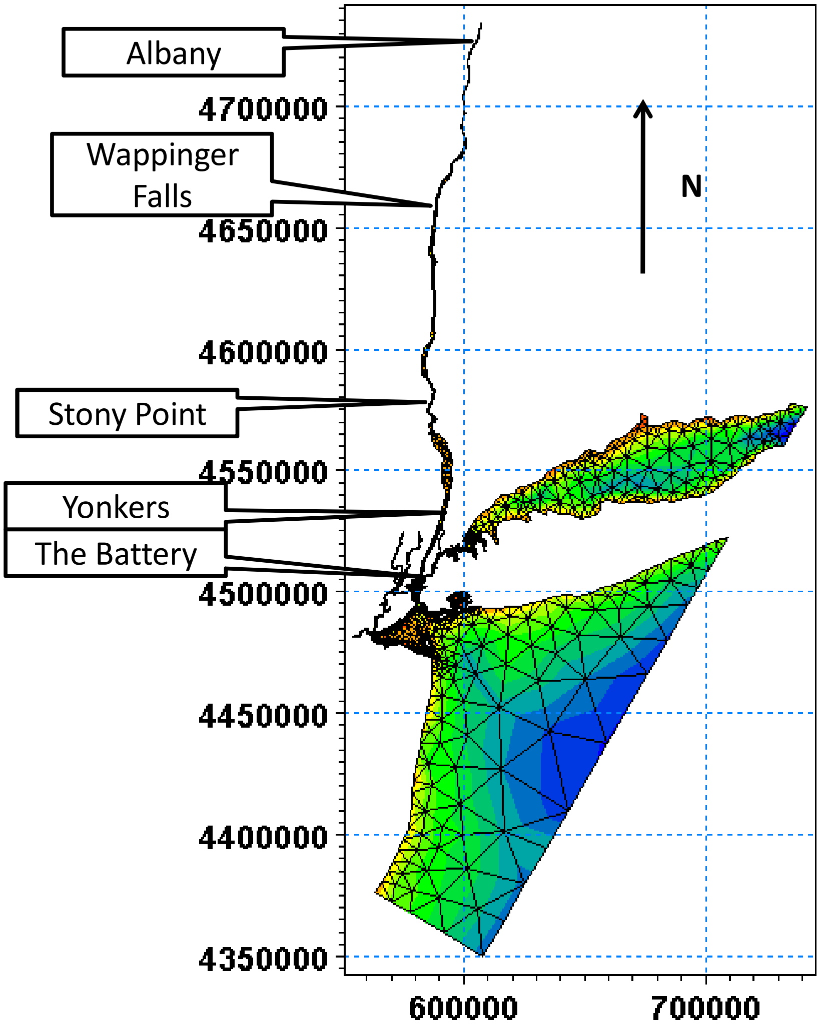


Figure 14. Hudson River salinity comparison sites.

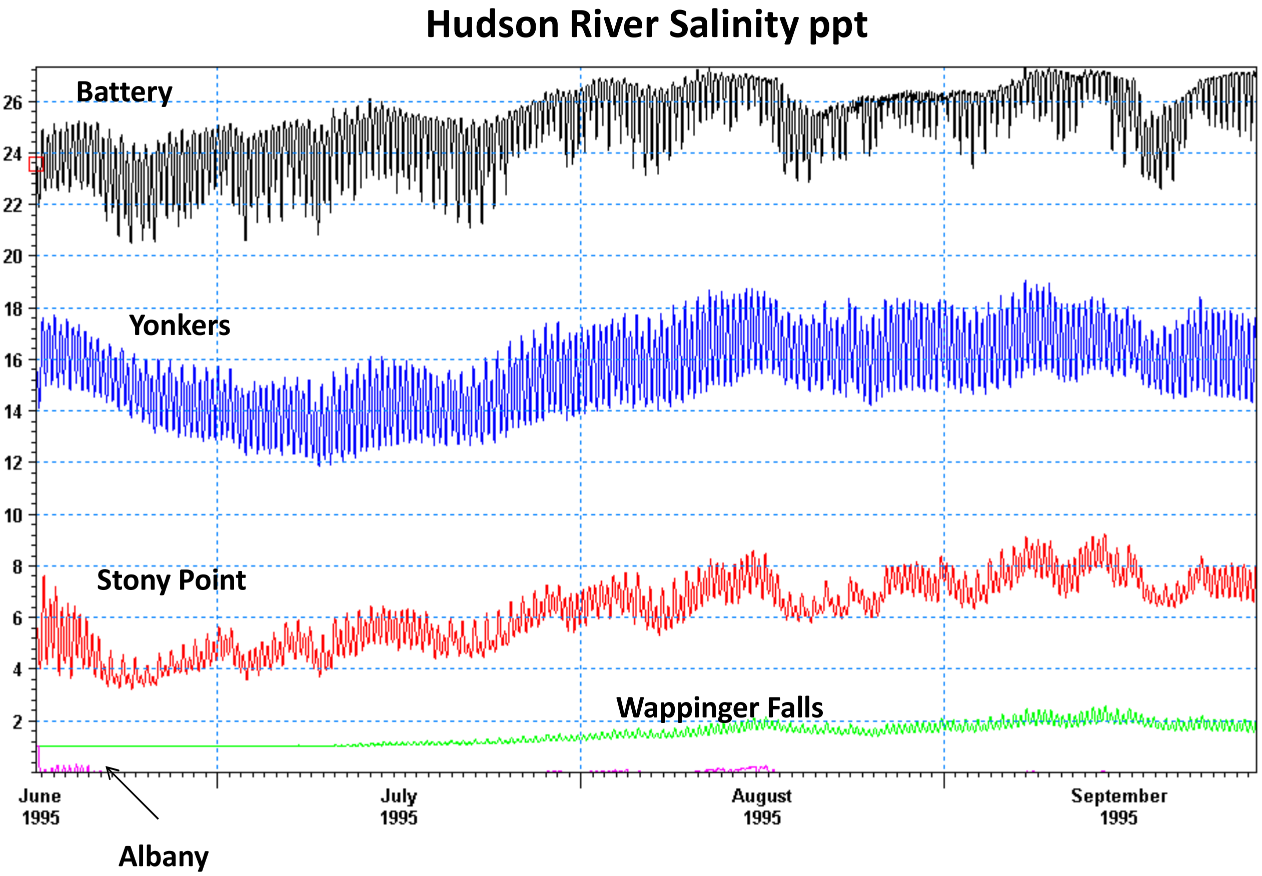


Figure 15. Computed Hudson River salinity.

4. Selected Contaminants and Water Quality Standards

The contaminants to be modeled were based primarily on the potential short-term impact of re-suspended sediment and associated contaminants as a result of the cable installation process. Water quality criteria are based on protecting human health and aquatic life. Human health criteria address the consumption of water and/or fish over a human's entire life expectancy. Aquatic life criteria address acute toxicity and chronic toxicity. Acute toxicity is based on a relatively short exposure duration whereas chronic toxicity is based on a longer exposure. The transient nature of the sediment re-suspension caused by the proposed cable installation has the greatest potential for affecting acute toxicity rather than human health or chronic toxicity.

During the Spring 2010 Marine Route Survey, sediment core samples were collected and were analyzed for organic and inorganic contaminants, including pesticides, PAHs, PCBs and metals along the proposed cable route. For the water quality modeling task, contaminants were selected based on marine route survey data using the following approach.

- Contaminants were selected that exceeded the sediment criteria (NYSDEC's Technical and Operational Guidance Series (TOGS) 5.1.9, In-water and Riparian Management of Sediment and Dredged Material (NYSDEC 2004)) and then compared to water quality standards for NYS water classifications (NYSDEC's Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations (NYSDEC 1998).
- Contaminants without applicable sediment criteria were selected based on ratios associated with water quality standards for NYS water classifications within the project area.

Figure 16 shows the different water quality classifications along the route.

The chemical concentration in the water column consists of the particulate and dissolved forms. The sediment released by the cable installation will increase the chemical concentration in the water primarily via the particulate form, because of the chemical's affinity for adsorption onto solids (i.e., partitioning).

The top ten contaminants for modeling were based on the ratio of maximum chemical concentration in the sediment cores to water quality standard (i.e., acute aquatic criterion) for each portion of the route as well as the sediment criteria in the TOGS. The ten contaminants selected for project miles 202-305 (Coeymans to Haverstraw) modeling were :

1. Arsenic
2. Cadmium
3. Mercury
4. Benz(a)anthracene

5. Pyrene
6. 4,4-DDE
7. Copper
8. Lead
9. Phenanthrene
10. PCB

The ten contaminants selected for project mile markers 305-334 (lower Hudson River, Harlem River and East River) modeling were:

1. 4,4-DDE
2. Copper
3. Lead
4. Phenanthrene
5. PCB
6. Naphthalene
7. Fluorene
8. Nickel
9. Dioxin
10. Acenaphthene

Water quality standards for these contaminants are given in Table 2. Where acute toxicity standards are not available, chronic toxicity standards (i.e., Aquatic - Chronic, Human Health - Fish Consumption, Human Health - Water Source and Wildlife Protection) have been provided as a reference. However, given the non-chronic (i.e., short-term) and incremental nature of the potential exposure to sediment contaminants resulting from the cable installation, comparison of water quality modeling results to acute toxicity standards was considered most appropriate.

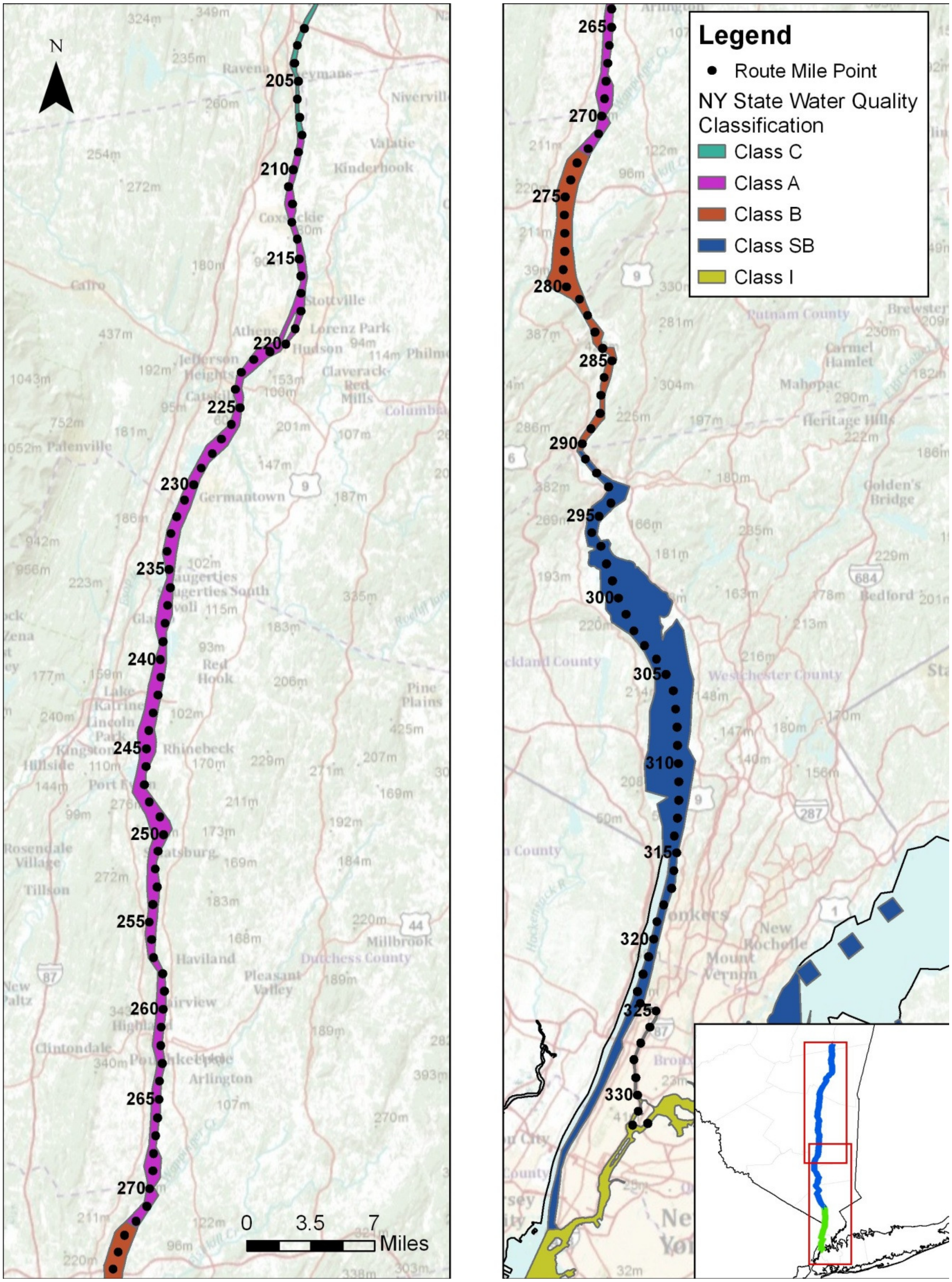


Figure 16. NYS water quality classes along route.

TABLE 2. HUDSON RIVER WATER QUALITY CLASSIFICATION (NY) AND STANDARDS

			Route Mile 201.8 to 207.9		Route Mile 207.9 to 272.3		Route Mile 272.3 to 290.3		Route Mile 290.3 to 324.0		Route Mile 324.1 to 336.0	
	Chemical	**CAS No.**	**Class C (ug/l)**	**Type**	**Class A (ug/l)**	**Type**	**Class B (ug/l)**	**Type**	**Class SB (ug/l)**	**Type**	**Class I (ug/l)**	**Type**
Upper Hudson	Arsenic*	7440-38-2	340	A(A)	340	A(A)	340	A(A)	63	A(C)	36	A(C)-Guidance
	Cadmium*	7440-43-9	2.036	A(A)	2.036	A(A)	2.036	A(A)	7.7	A(C)	7.7	A(C)
	Mercury*	7439-97-6	1.4	A(A)	1.4	A(A)	1.4	A(A)	0.0026	W	0.0026	W
	Benz(a)anthracene	56-55-3	0.23	A(A)	0.23	A(A)	0.23	A(A)	NA		NA	
	Pyrene	129-00-0	42	A(A)	42	A(A)	42	A(A)	NA		NA	
Upper and Lower Hudson	4,4'-DDE	72-55-9	7.00E-08	H(FC)	0.2	H(WS)	7.00E-08	H(FC)	7.00E-08	H(FC)	7.00E-08	H(FC)
	Copper*	7440-50-8	8.69	A(A)	8.69	A(A)	8.69	A(A)	7.9	A(A)	7.9	A(A)
	Lead*	7439-92-1	93.5	A(A)	93.5	A(A)	93.5	A(A)	204	A(A)	204	A(A)
	Phenanthrene	85-01-8	45	A(A)	45	A(A)	45	A(A)	14	A(A)	14	A(A)
	Polychlorinated biphenyls	-	1.00E-06 1.20E-04	H(FC) W	0.09 1.00E-06 1.20E-04	H(WS) H(FC) W	1.00E-06 1.20E-04	H(FC) W	1.00E-06 1.20E-04	H(FC) W	1.00E-06 1.20E-04	H(FC) W
Lower Hudson	Naphthalene	91-20-3	110	A(A)	110	A(A)	110	A(A)	140	A(A)	140	A(A)
	Fluorene	86-73-7	4.8	A(A)	4.8	A(A)	4.8	A(A)	23	A(A)	23	A(A)
	Nickel*	7440-02-0	454.7	A(A)	454.7	A(A)	454.7	A(A)	74	A(A)	74	A(A)
	Dioxins	-	6.00E-10	H(FC)	7.00E-07	H(WS)	6.00E-10	H(FC)	6.00E-10	H(FC)	6.00E-10	H(FC)
	Acenaphthene	88-32-9	48	A(A)	48	A(A)	48	A(A)	60	A(A)	60	A(A)

Notes:
* : Standard based on dissolved fraction
A(A) : Aquatic (Acute), Fish Survival
A(C) : Aquatic (Chronic), Fish Propagation
H(FC) : Human Health (Fish Consumption)
H(WS) : Human Health (Water Source)
W : Wildlife Protection

5. Load Calculation

The cable laying operation represents a moving load source that will deliver a load of solid and dissolved components to the water column. In the model the moving source is represented by a series of load points along the cable route. These load points turn on and off sequentially as the cable laying operation progresses. The load is input into the bottom model cell at the location of load source. The load points are chosen to match the location of sediment cores that were taken along the route.

The cable route was considered in two parts: an Upper Hudson River Estuary portion, and a Lower Hudson River Estuary – Harlem River – East River portion (Figure 17). There are 47 load points in the Upper Hudson River Estuary portion, and 16 load points in the Lower Hudson River Estuary portion of the model (Figure 17). The load points in both portions of the model are approximately two miles apart. The load at each location, for each chemical, is derived from the sediment core data as described below.

The load is defined as a flow and concentration. The flow calculation is described as:

$$Q = A * v * R$$

Where,

Q = Flow (m^3/s)
A = Cross-sectional Area of trench (m^2)
v = Plow Velocity (m/s)
R = Release Fraction (%)

The release fraction (i.e. the percent of sediment volume disturbed based on cross-section of trench) was set at 30% based on conversions with the cable installer. The plow speed is 0.028 m/s based on the installers estimate of averaging 1.5 miles/day of cable installation. The cross sectional area of the trench is 2.3 m^2 based on a burial depth of 6 ft and a trapezoidal section of disturbed sediment Inputting these values into the formula gives a flow of 0.019 m^3/s.

For TSS the concentration released is calculated as:

$$TSS = (1 - \phi)\rho_s * 1000$$

Where,
TSS = Total Suspended Solids (mg/L)
ϕ = Porosity (dimensionless)
ρ_s = density of solids (kg/m^3)

The porosity and density are site specific and and based on the sediment core data. As solids will settle within the water column, the sediment core data and Stokes law were used to calculate the settling rate along the route. The median grain size and dry density of each sediment core were used to calculate the solids settling rate. The median solids settling rate was estimated to be 81.3 m/day for the Upper Hudson River Estuary cable route and 32.4 m/day for the Lower Hudson Estuary cable route. The Upper Hudson River Estuary solids settling rate applies to the model domain for the installation of the Upper Hudson River Estuary cable, and the Lower Hudson River Estuary solids settling rate applies to the model domain for the installation of the Lower Hudson River Estuary cable.

Contaminants are considered as having both a solid and dissolved fraction whose ratio is defined by a partition coefficient. The sediment core data contains the measured solid chemical concentration, C_{SOLID}, measured as mass chemical/mass solids (mg/kg). This is converted to a fraction (mg/mg) and then multiplied by the TSS concentration (mg/L):

C_{SOLID} (mg/mg) = C_{SOLID} (mg/kg) x 1 kg/10^6 mg (conversion to a fraction)

$C_{PARTICULATE} = C_{SOLID}$ x TSS (mg/L)

The dissolved concentration of metals (non-organic contaminants) is calculated as:

$C_{DISS} = C_{PARTICULATE} / \pi$ (mg/kg) / (L/kg) = mg/L

Where π is the partition coefficient (L/kg).

For organic contaminants the dissolved concentration is calculated as:

$C_{DISS} = C_{PARTICULATE} /(foc \times \pi_{OC})$ (mg/kg) / (L/kg) = mg/L

Where foc is the fraction organic carbon and π_{OC} is the organic carbon partition coefficient (L/kg).

The total PCB concentration of each sediment core was calculated as two times the sum of the concentrations of the 22 PCB congeners that were analyzed by the laboratory. This procedure was based on Table 2 in TOGS 5.1.9.

The total chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans (referred to as dioxins) was calculated based on the Toxicity Equivalency Factors in TOGS 1.1.1.

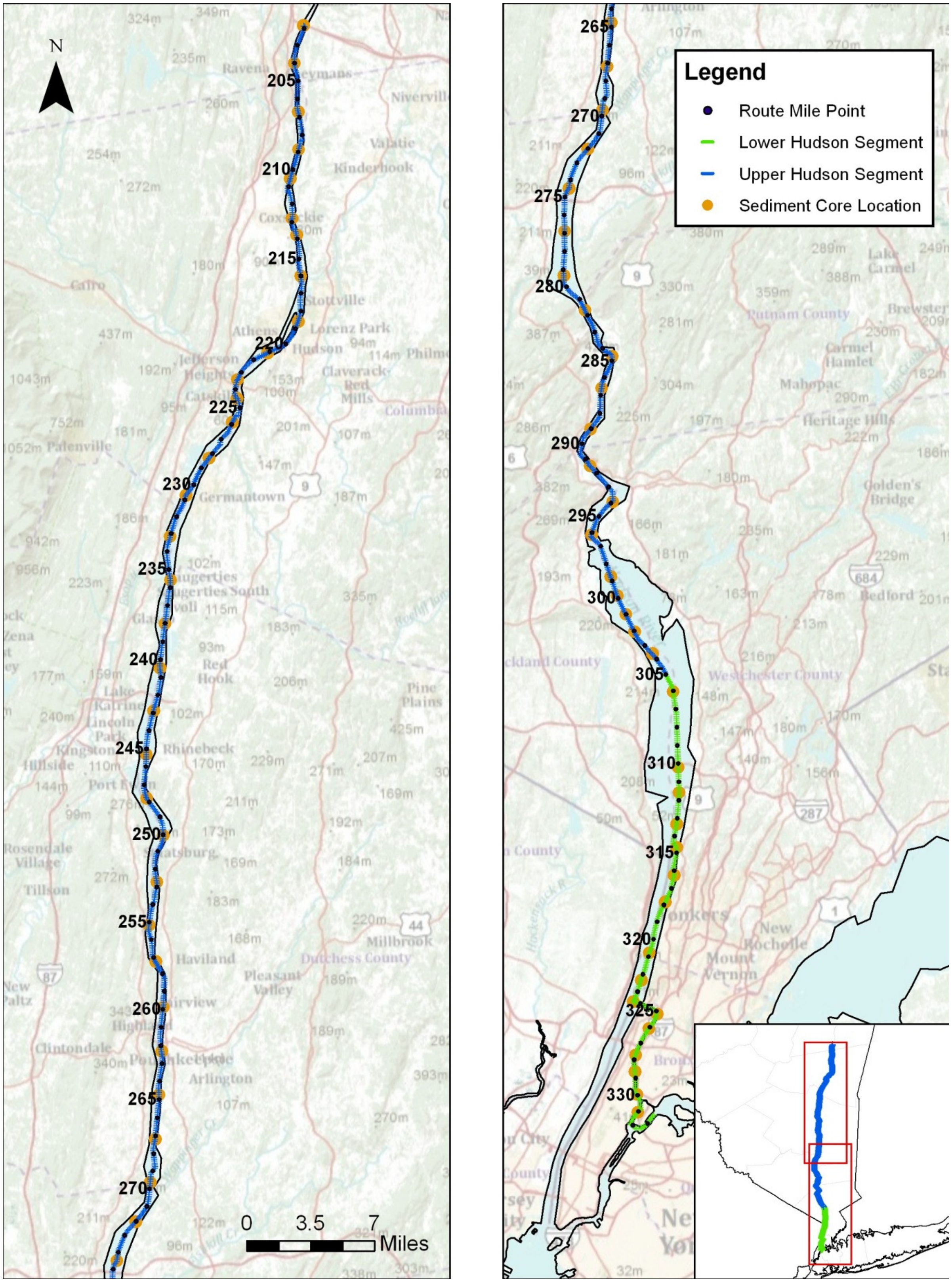


Figure 17. Location of sediment cores.

6. Results

6.1 Project Miles 202-305 (Coeymans to Haverstraw)

The total concentration, which is the sum of the particulate and dissolved forms, is presented for all of the contaminants modeled for the upper Hudson River Estuary portion of the cable route. As the total concentration is greater than the dissolved concentration, the total concentration is compared to the standard. If the total concentration is lower than the New York State standard (when noted as applicable to the dissolved form), then the dissolved concentration will also be lower than this standard. The maximum concentration of the contaminant at any time in each model cell along the cable route is shown in Figures 18 through 27 and the maximum TSS concentration at any time is shown similarly in Figure 28.

Water quality standards that are based on protecting aquatic life from acute toxicity are shown as a solid line in these figures. Human health, wildlife and chronic toxicity values are not appropriate for comparison given the length of exposure duration assumed in developing these criteria is much longer than what is appropriate for the transient effects of the cable installation. The maximum total contaminant concentrations are compared to the water quality standards for Class A, B, C and SB waters, and compliance is summarized in Table 3.

None of the contaminants in the Upper Hudson River Estuary are expected to exceed the water quality standards based on aquatic life protection from acute toxicity. For some contaminants, however, there is no acute standard. PCB concentrations are projected to exceed water quality standards based on human health (fish consumption) and wildlife; however, these criteria were developed by assuming many years (e.g., 70 years for humans) of exposure to PCB. Similarly, 4,4'-DDE concentrations are projected to exceed human health (fish consumption) standards. Projected concentrations of PCB are below the Class A water quality standard for human health as a water supply (0.09 ug/l).

While there are no current NYS or federal acute water quality criteria available for 4,4-DDE, PCBs and dioxins, other states have promulgated values derived from earlier USEPA acute toxicity assessment data or criteria, at 1,050 ug/L for DDE (Nebraska 2009), 2 ug/L for PCBs (Nebraska 2009) and 0.01 ug/L TCDD (Kansas 2004). These values are orders of magnitude higher than human health and wildlife criteria, illustrating the critical impact of the duration of exposure on the derivation of acute vs. non-acute criteria.

The EPA established Engineering Performance Standards for monitoring the Hudson River PCB Superfund Project dredging. The water quality criteria for dredging resuspension was 0.5 ug/l (EPA 2003). If this level is exceeded during dredging, monitoring becomes more intense and other field operations may be altered. Hence, this dredging resuspension water quality criteria is more appropriate than the water quality standards based on human health (fish consumption) and wildlife for the proposed project. The projected maximum total PCB concentration in the Upper Hudson River Estuary is below the water quality criteria for dredging resuspension.

6.1.1 Arsenic

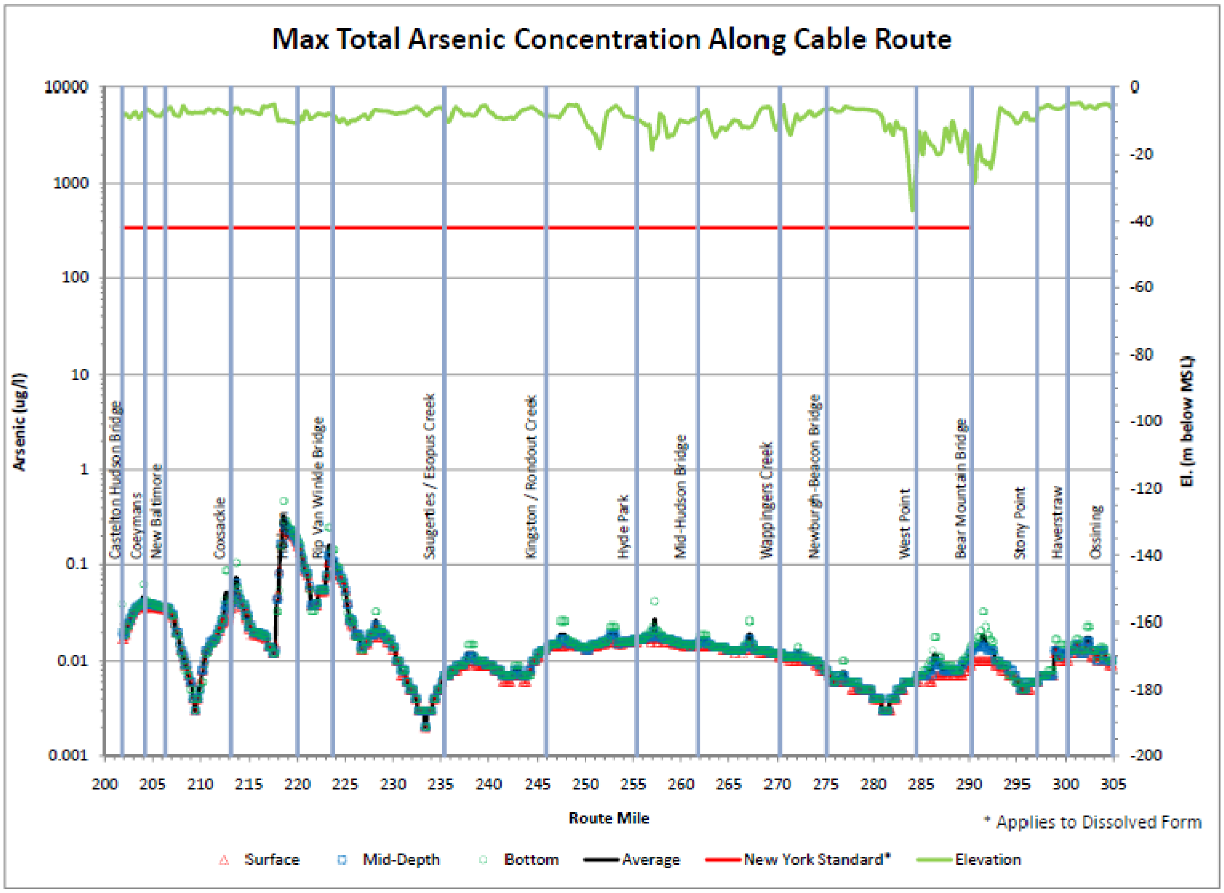


Figure 18. Arsenic concentrations and NY WQ Standards.

6.1.2 Benzo(a) anthracene

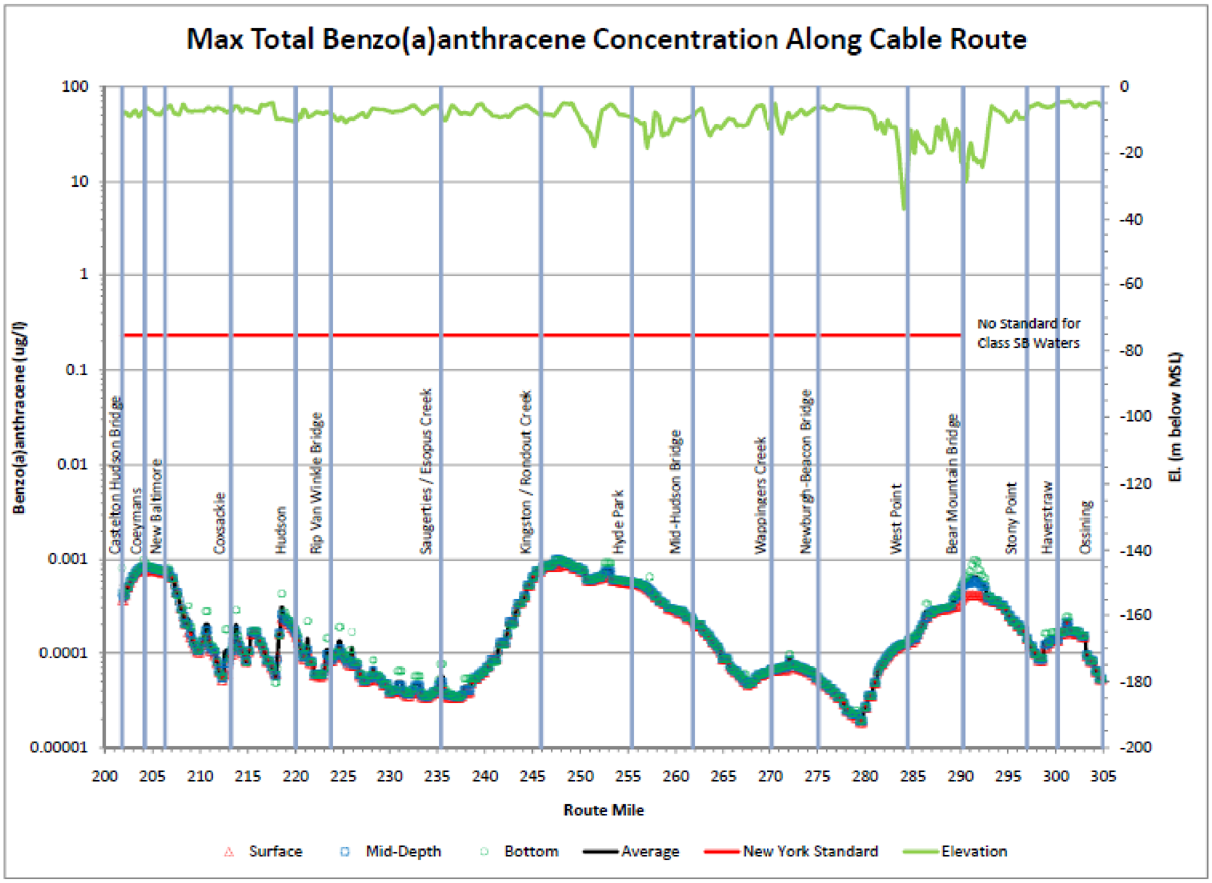


Figure 19. Benzo(a)anthrene concentrations and NY WQ Standards.

6.1.3 Cadmium

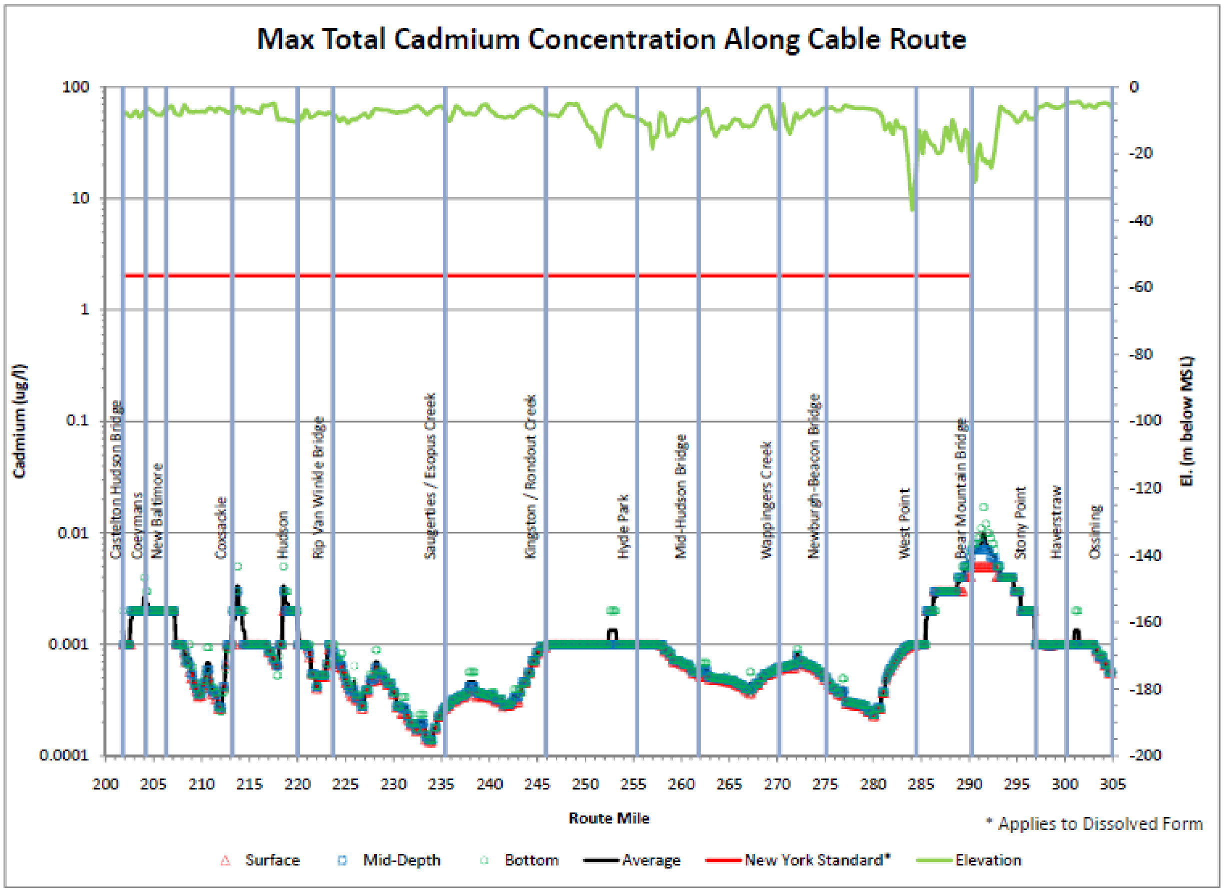


Figure 20. Cadmium concentrations and NY WQ Standards.

6.1.4 Copper

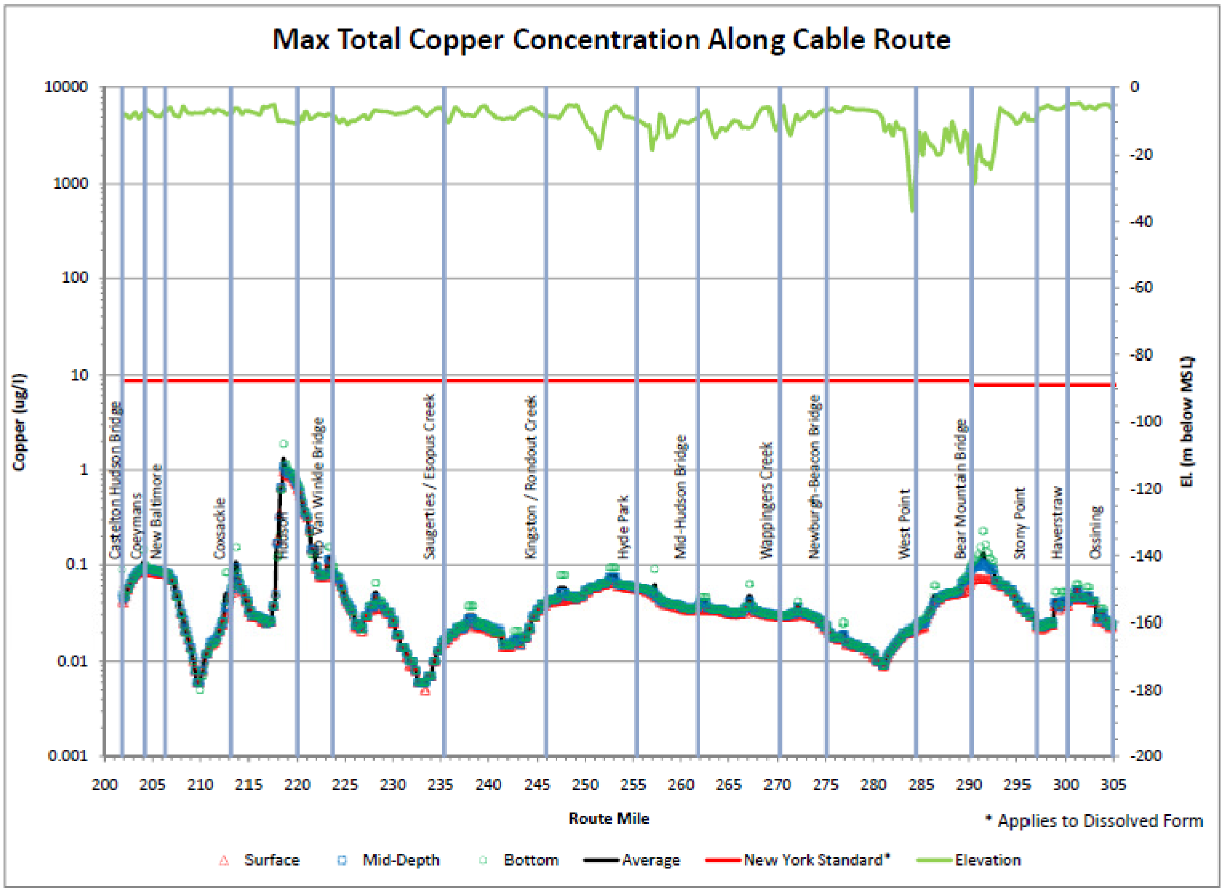


Figure 21. Copper concentrations and NY WQ Standards.

6.1.5 DDE

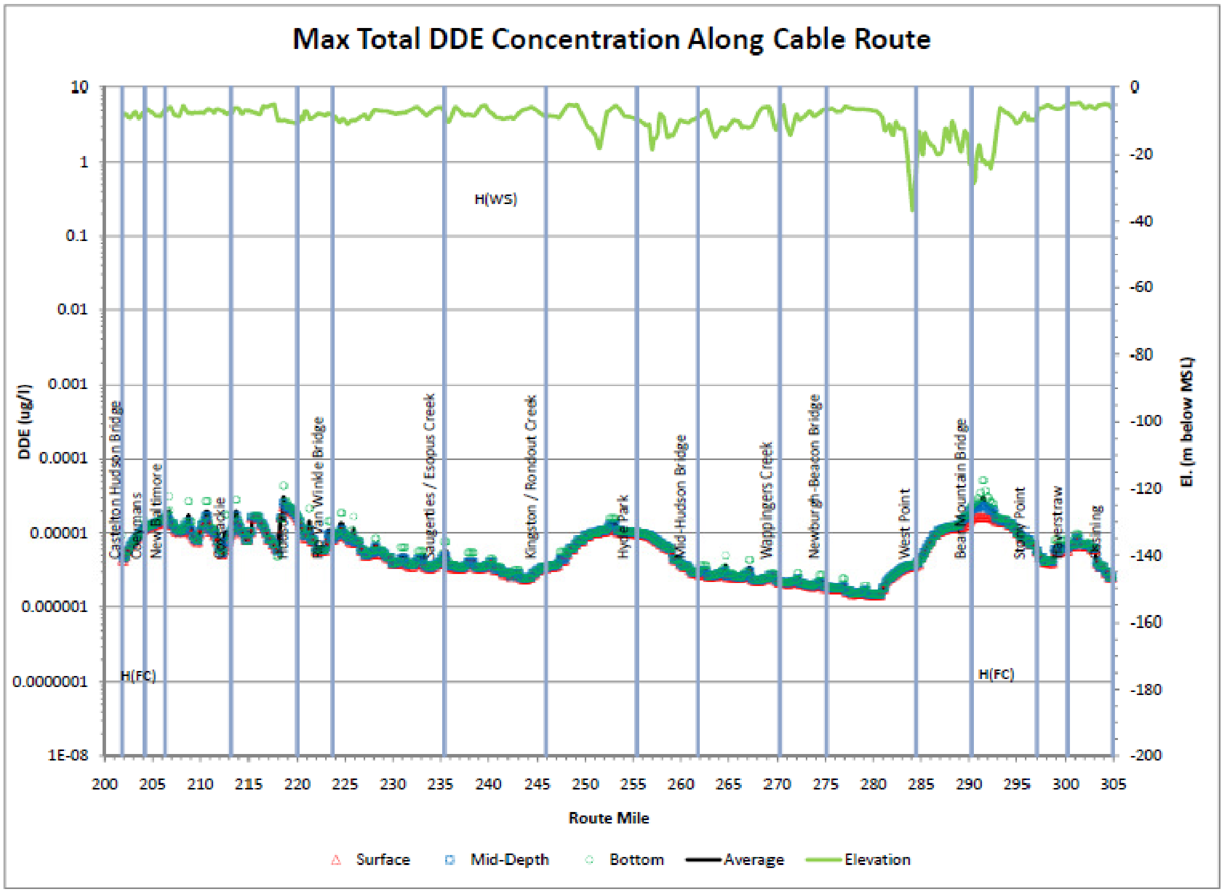


Figure 22. DDE concentrations.

6.1.6 Mercury

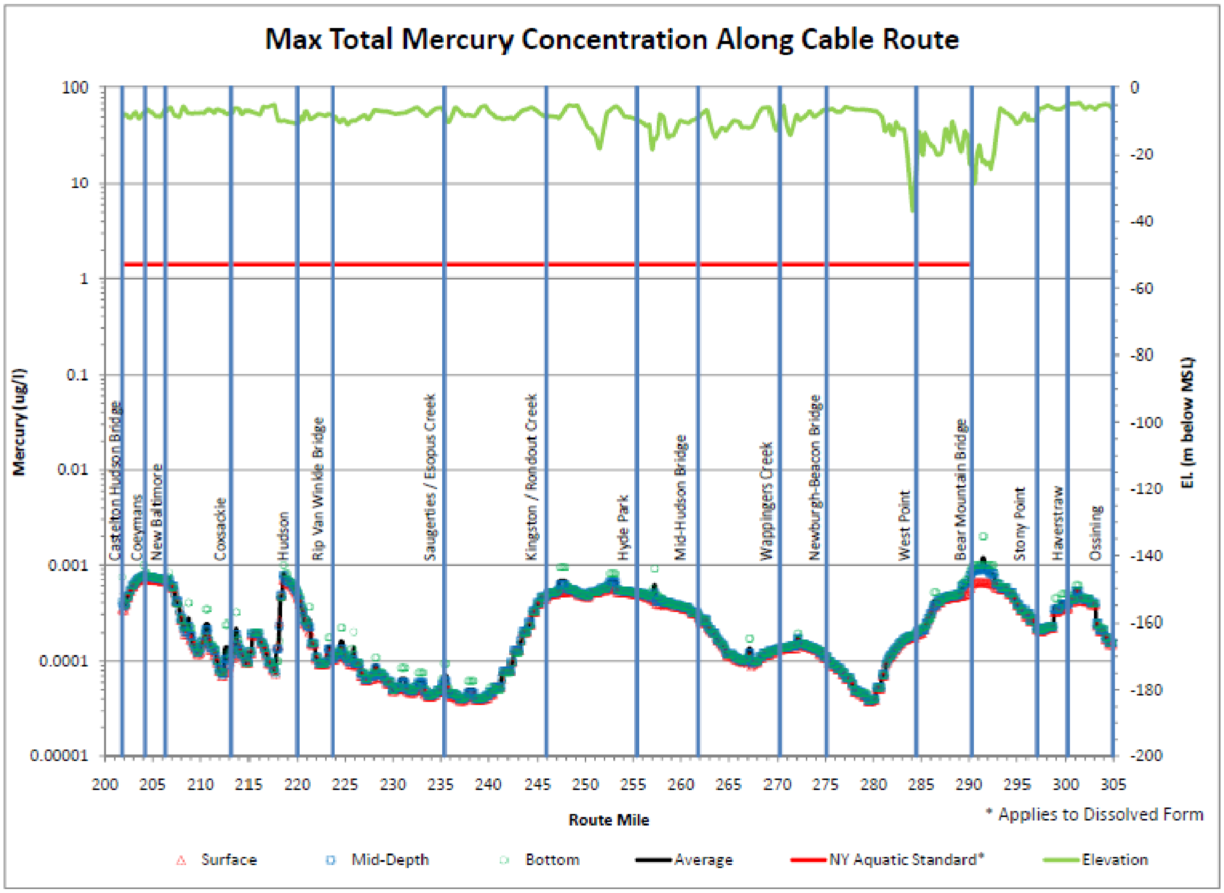


Figure 23. Mercury concentrations and NY WQ Standards.

6.1.7 Lead

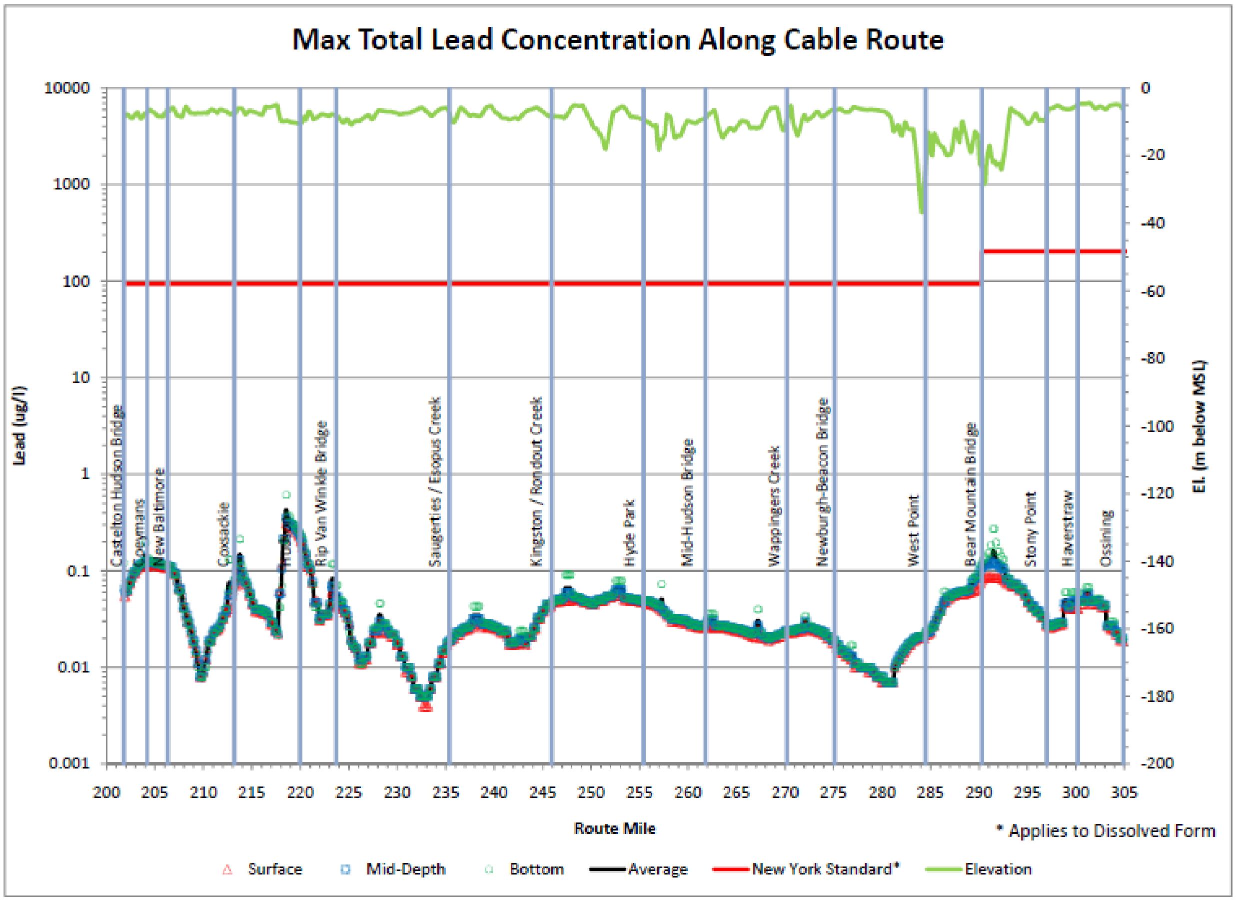


Figure 24. Lead concentrations and NY WQ Standards.

6.1.8 PCB

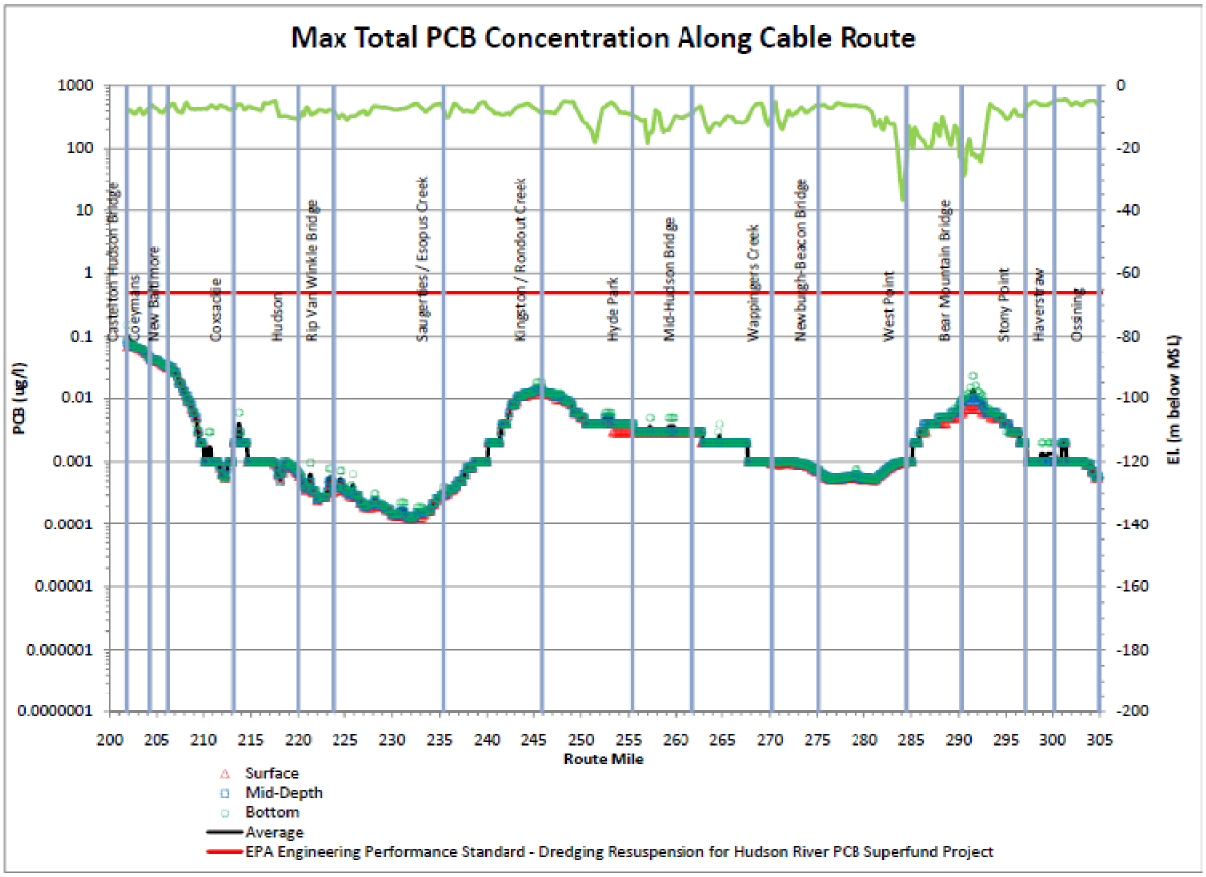


Figure 25. Total PCB concentrations and EPA Engineering Performance Standard for Dredging Resuspension.

6.1.9 Phenanthrene

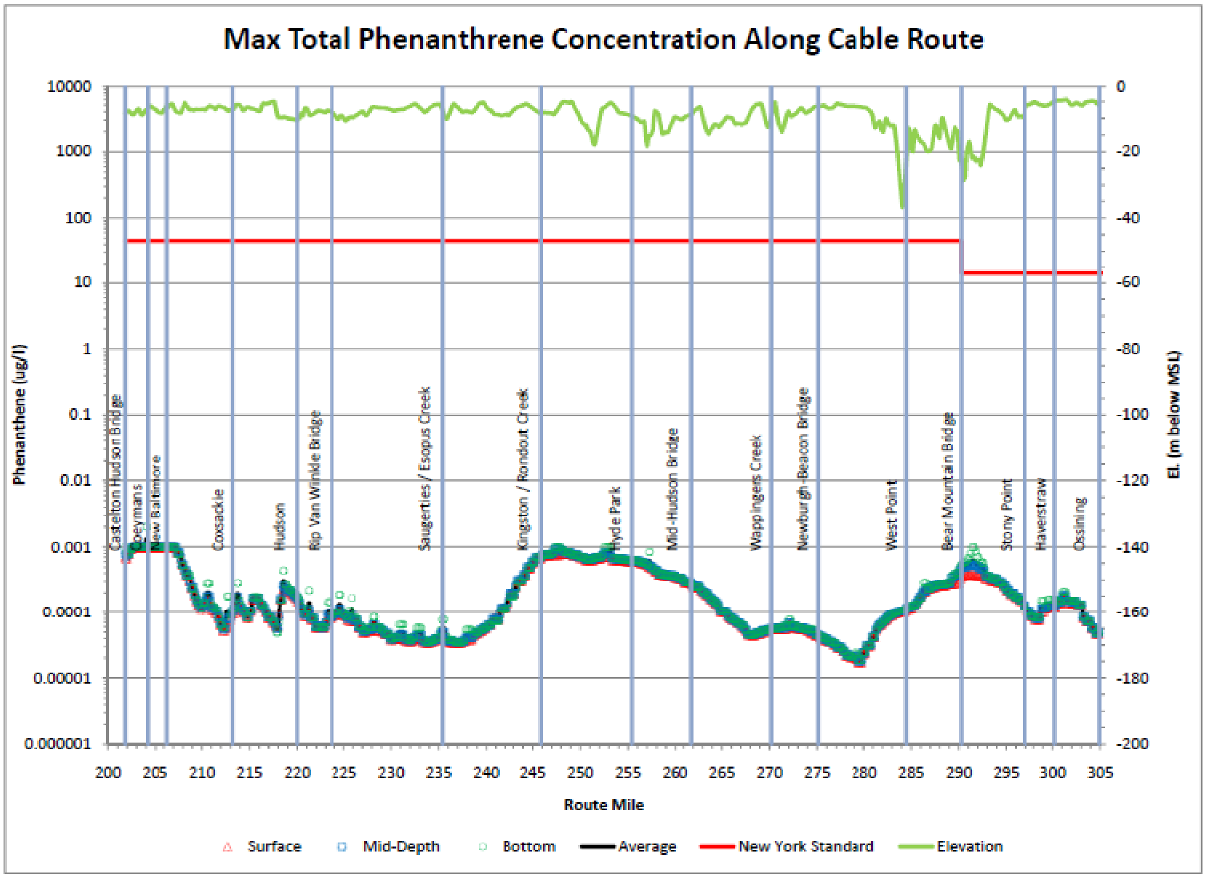


Figure 26. Phenanthrene concentrations and NY WQ Standards.

6.1.10 Pyrene

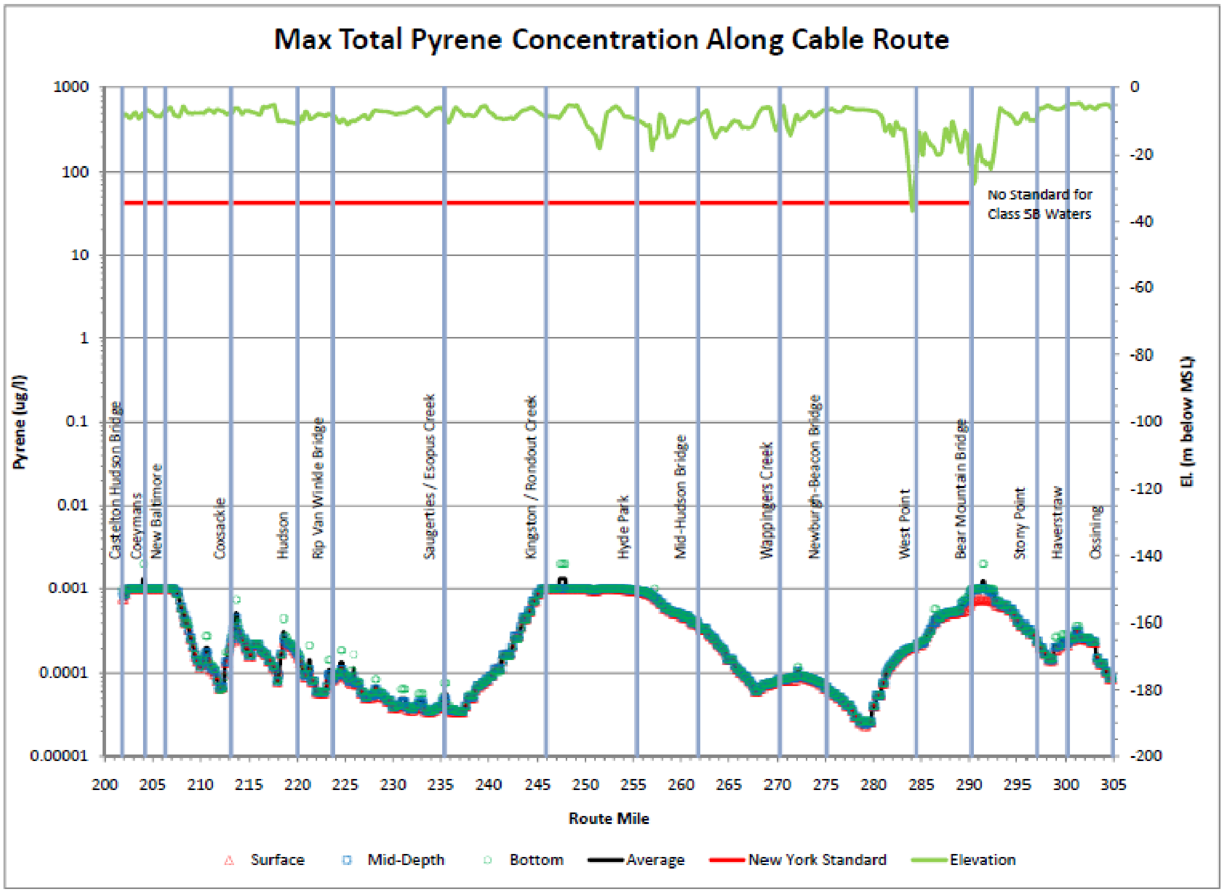


Figure 27. Pyrene concentrations and NY WQ Standards.

6.1.11 TSS

The model-computed depth-average TSS concentration, which is solely due to the project (i.e., no background TSS), is less than an assumed threshold of 200 mg/l as shown in Figure 28.

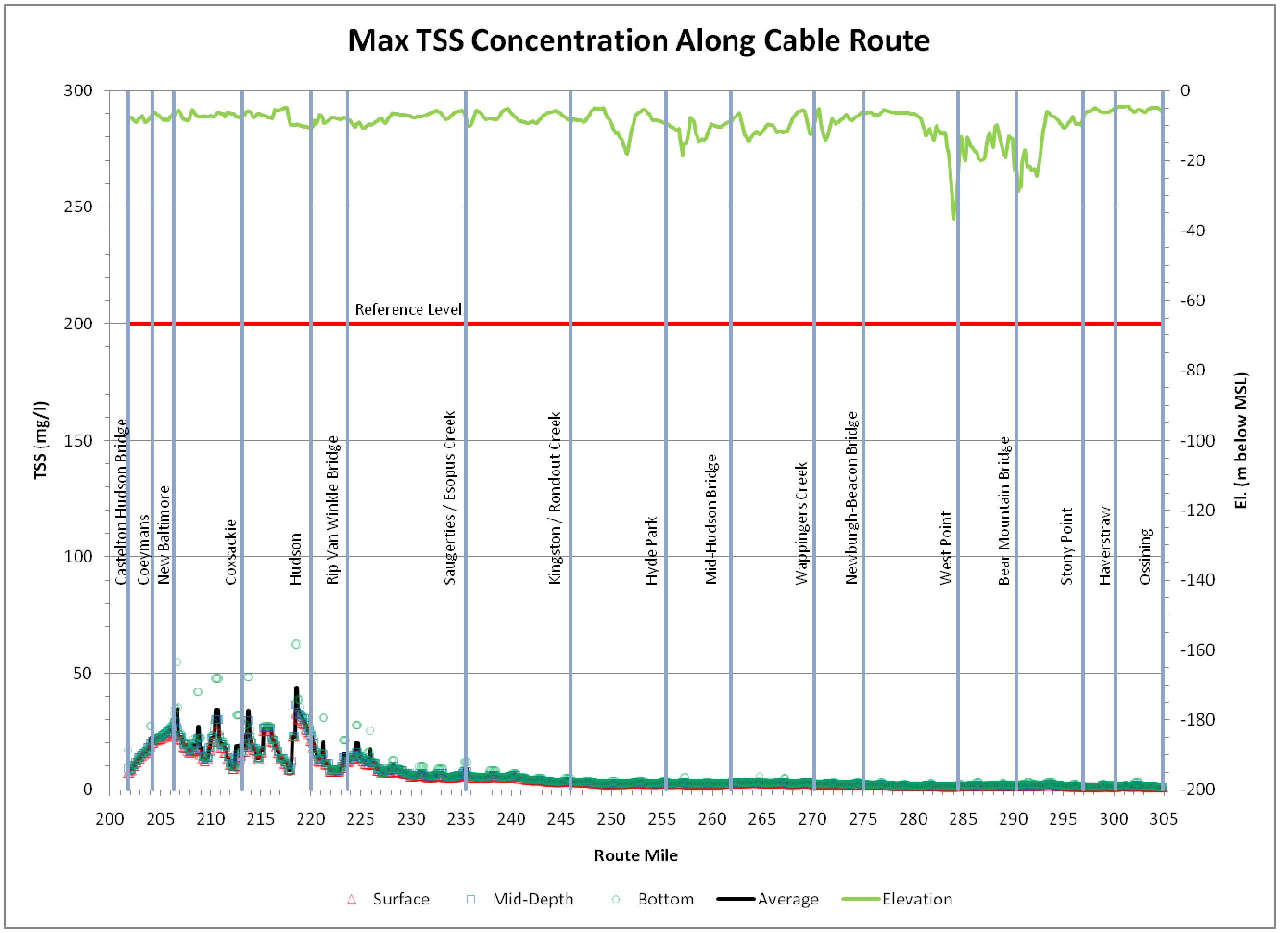


Figure 28. TSS concentrations.

TABLE 3. PROJECTED COMPLIANCE OF ACUTE WATER QUALITY STANDARDS (NY) FOR HUDSON RIVER ESTUARY, HARLEM AND EAST RIVERS

			Route Mile 201.8 to 207.9	**Route Mile 207.9 to 272.3**	**Route Mile 272.3 to 290.3**	**Route Mile 290.3 to 324.0**	**Route Mile 324.1 to 336.0**
	Chemical	**CAS No.**	**Class C**	**Class A**	**Class B**	**Class SB**	**Class I**
Upper Hudson	Arsenic	7440-38-2	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	NA
	Cadmium	7440-43-9	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	NA
	Mercury	7439-97-6	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	NA
	Benz(a)anthracene	56-55-3	Does not exceed standard	Does not exceed standard	Does not exceed standard	No class SB standard	NA
	Pyrene	129-00-0	Does not exceed standard	Does not exceed standard	Does not exceed standard	No class SB standard	NA
Upper and Lower Hudson	4,4'-DDE	72-55-9	acute toxicity standards are not available	acute toxicity standards are not available	acute toxicity standards are not available	acute toxicity standards are not available	acute toxicity standards are not available
	Copper	7440-50-8	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	Standard, which is based on dissolved fraction, was not exceeded
	Lead	7439-92-1	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard
	Phenanthrene	85-01-8	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard	Does not exceed standard
	Polychlorinated biphenyls	-	Does Not exceed EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l	Does Not exceed EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l	Does Not exceed EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l	Does Not exceed EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l	Does Not exceed EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l
Lower Hudson	Naphthalene	91-20-3	NA	NA	NA	Does not exceed standard	Does not exceed standard
	Fluorene	86-73-7	NA	NA	NA	Does not exceed standard	Does not exceed standard
	Nickel	7440-02-0	NA	NA	NA	Does not exceed standard	Does not exceed standard
	Dioxins	-	NA	NA	NA	acute toxicity standards are not available	acute toxicity standards are not available
	Acenaphthene	88-32-9	NA	NA	NA	Does not exceed standard	Does not exceed standard

6.2 Project Miles 305-334 (Haverstraw – Astoria)

Maximum total concentrations of contaminants along the Lower Hudson River Estuary, Harlem River and East River portions of the proposed cable route were projected by the model as shown in Figures 29 through 38 along with water quality standards based on acute toxicity to aquatic life. Maximum TSS concentrations were projected as shown in Figure 39. Compliances and exceedences with water quality standards that apply to the Lower Hudson River Estuary (Class SB) and the Harlem and East Rivers (Class I) were summarized in Table 3.

The total concentrations for all contaminants are below the water quality standards for protecting aquatic life from acute toxicity except for copper. However, the standard for copper is based on the dissolved form and the projected maximum dissolved copper concentration (0.02 ug/l) is well below the standard of 7.9 ug/L. Total PCB concentrations are projected to exceed the water quality standards based on human health, fish consumption and wildlife; however, these criteria were developed for multi-year exposures that are not appropriate for the transient effects of the proposed project. Similarly, 4,4'-DDE and dioxins are projected to exceed the water quality standards based on human health, fish consumption.

While there are no current NYS or federal acute water quality criteria available for 4,4-DDE, PCBs and dioxins, other states have promulgated values derived from earlier USEPA acute toxicity assessment data or criteria, at 1,050 ug/L for DDE (Nebraska 2009), 2 ug/L for PCBs (Nebraska 2009) and 0.01 ug/L TCDD (Kansas 2004). These values are orders of magnitude higher than human health and wildlife criteria, illustrating the critical impact of the duration of exposure on the derivation of acute vs. non-acute criteria.

The EPA established Engineering Performance Standards for monitoring the Hudson River PCB Superfund Project dredging. The water quality criteria for dredging resuspension was 0.5 ug/l (EPA 2003). If this level is exceeded during dredging, monitoring becomes more intense and other field operations may be altered. Hence, this dredging resuspension water quality criteria is more appropriate than the water quality standards based on human health (fish consumption) and wildlife for the proposed project. The projected maximum total PCB concentration (0.1 ug/l) in the Lower Hudson River Estuary, Harlem and East Rivers is below the EPA's Engineering Performance Standard water quality criteria for dredging resuspension, which is a total PCB concentration of 0.5 ug/l (EPA 2003).

6.2.1 Acenaphthene

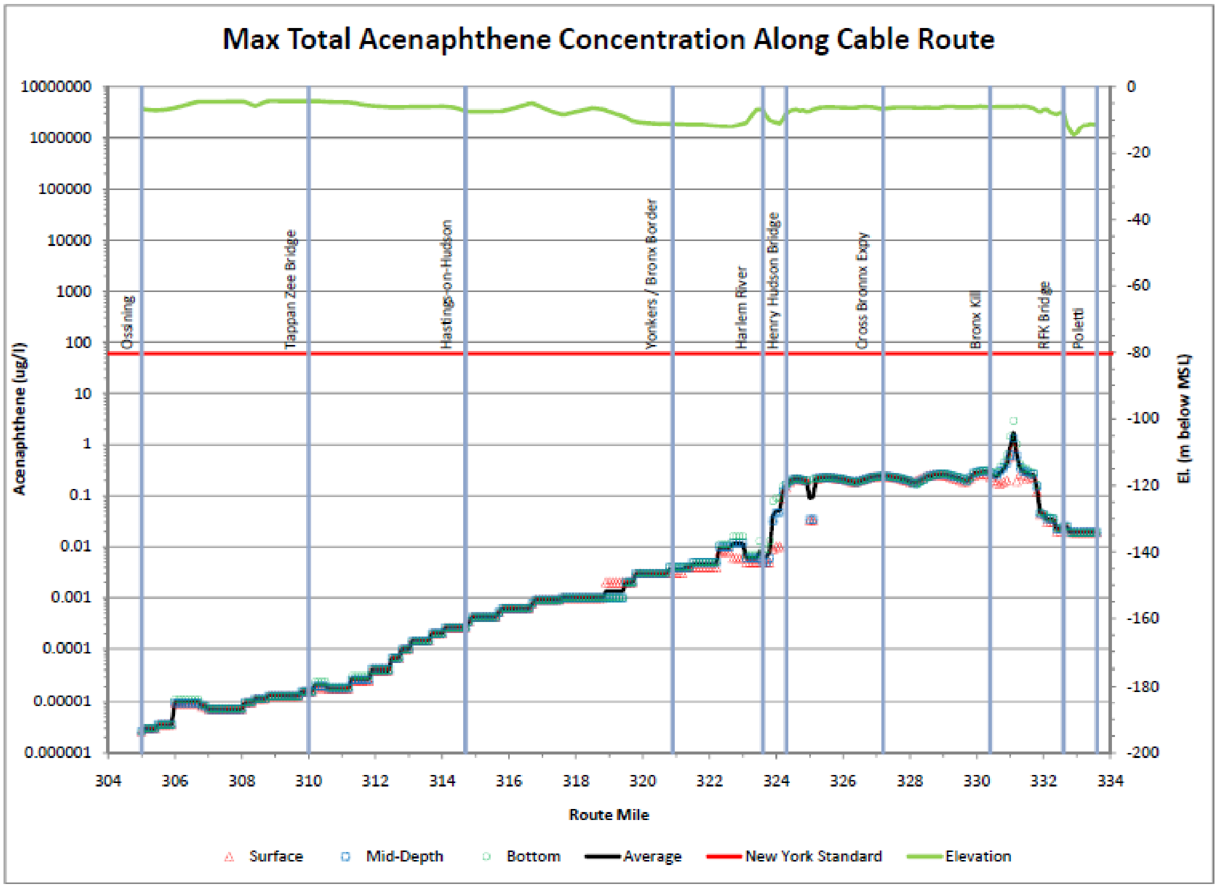


Figure 29. Acenaphthene concentrations and NY WQ Standards.

6.2.2 Copper

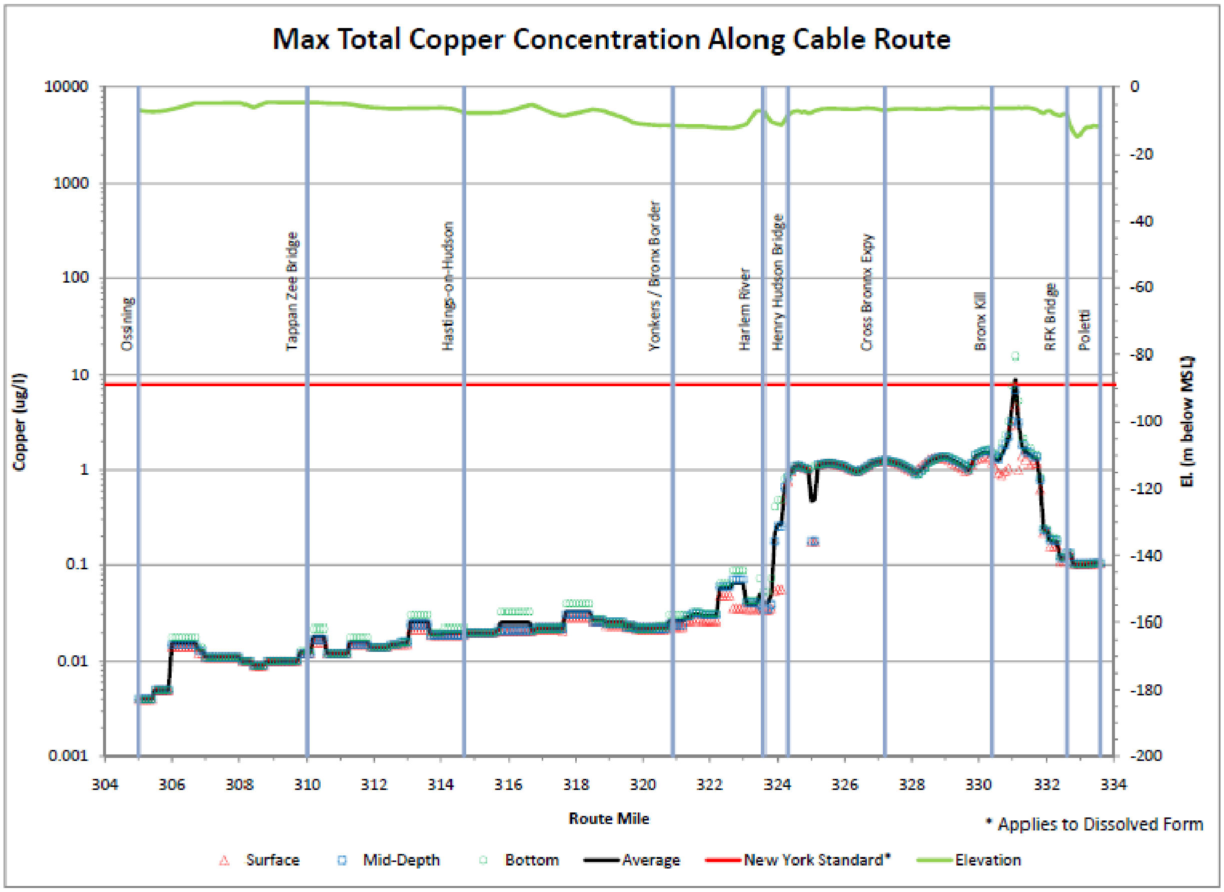


Figure 30. Copper concentrations and NY WQ Standards.

6.2.3 DDE

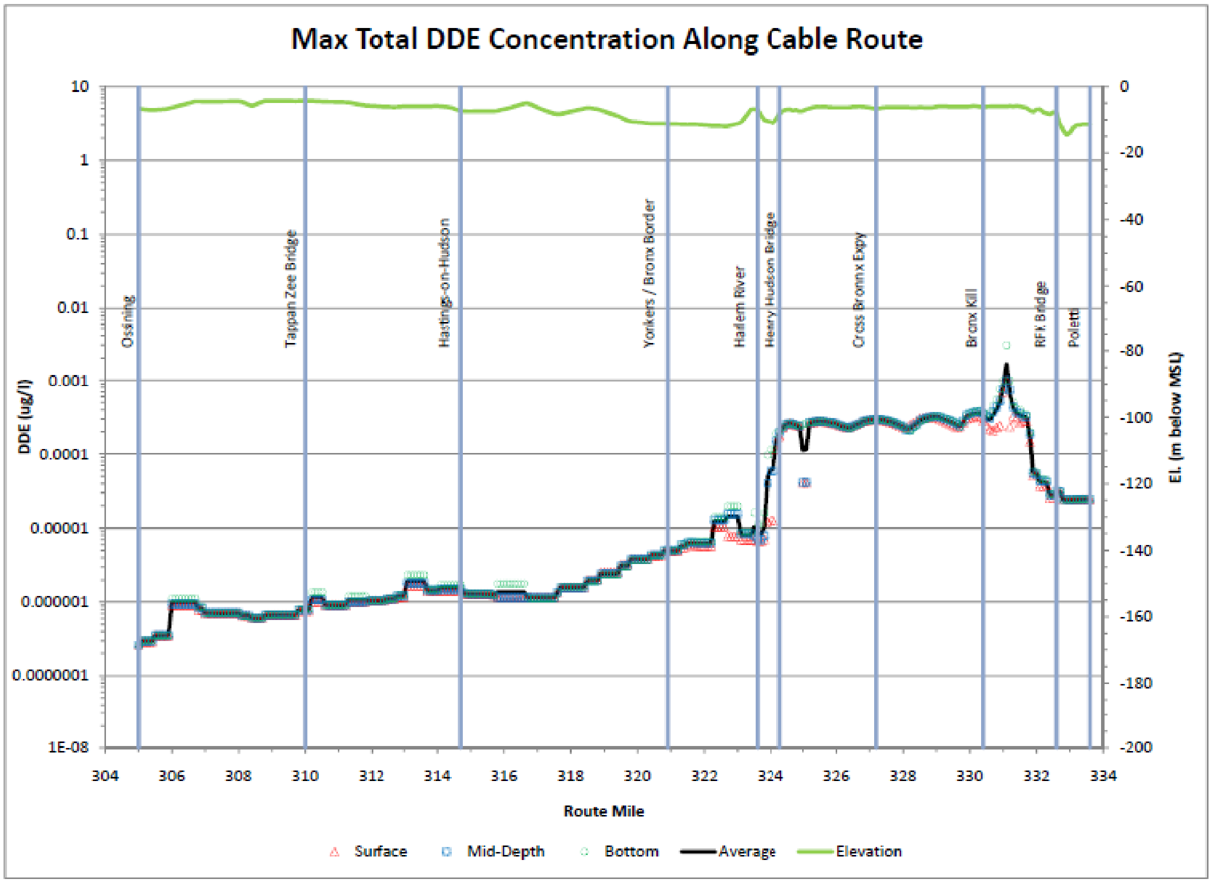


Figure 31. DDE concentrations.

6.2.4 Dioxin

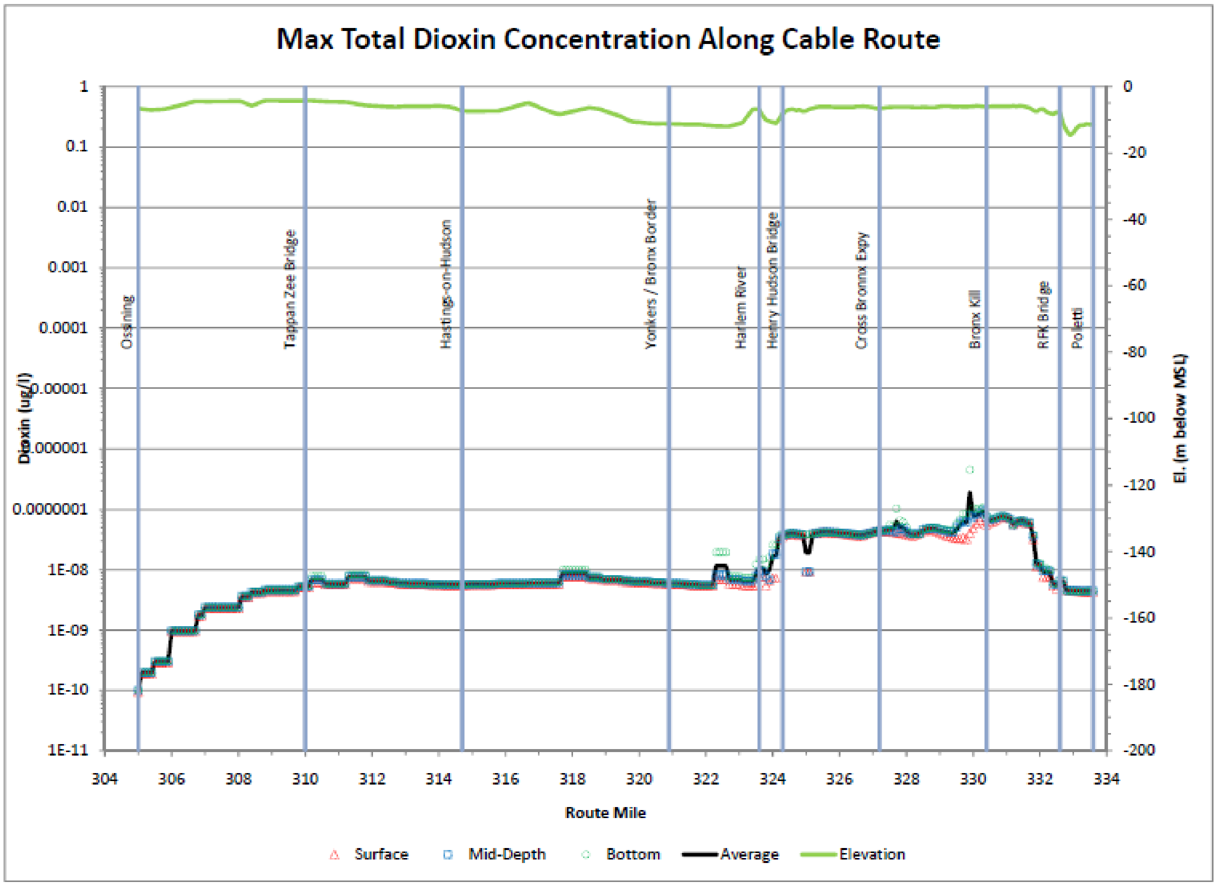


Figure 32. Dioxin concentrations.

6.2.5 Fluorene

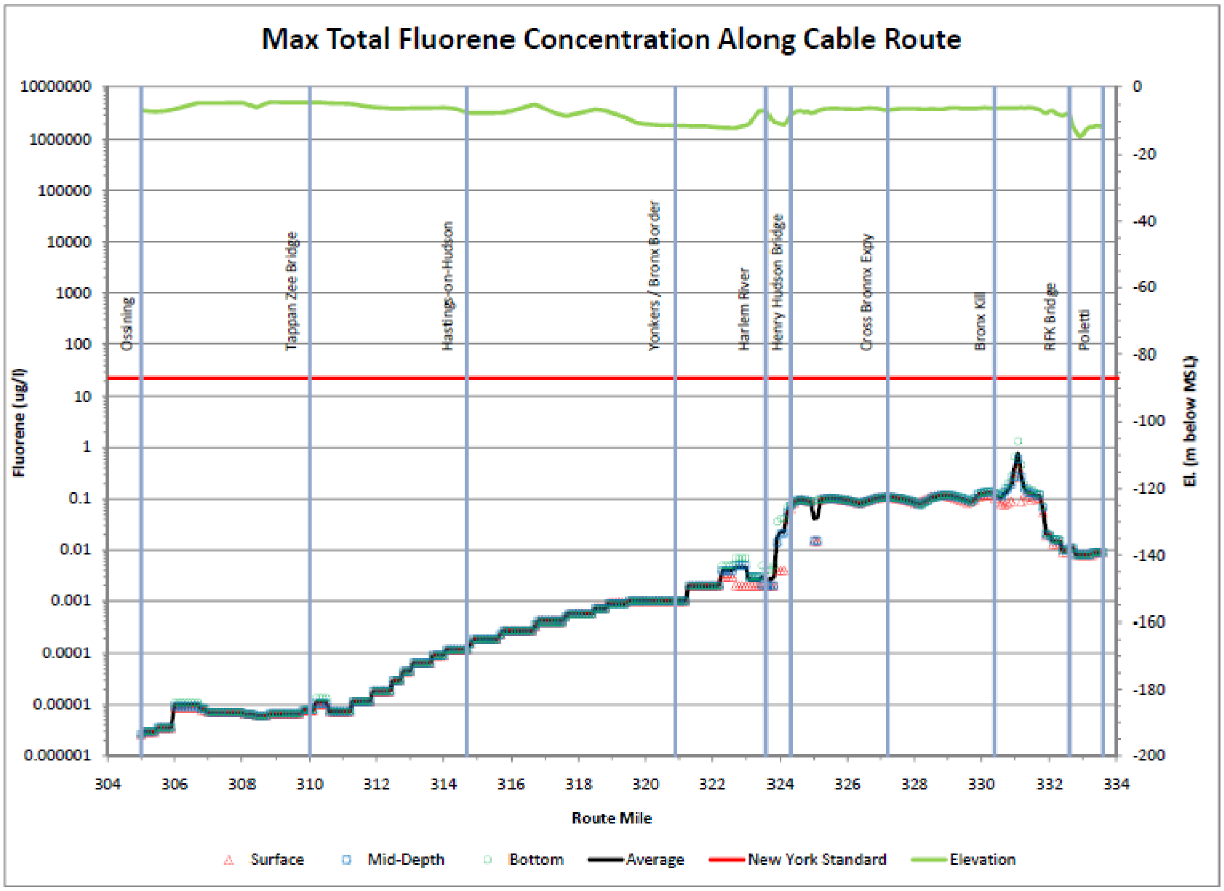


Figure 33. Fluorene concentrations and NY WQ Standards.

6.2.6 Naphthalene

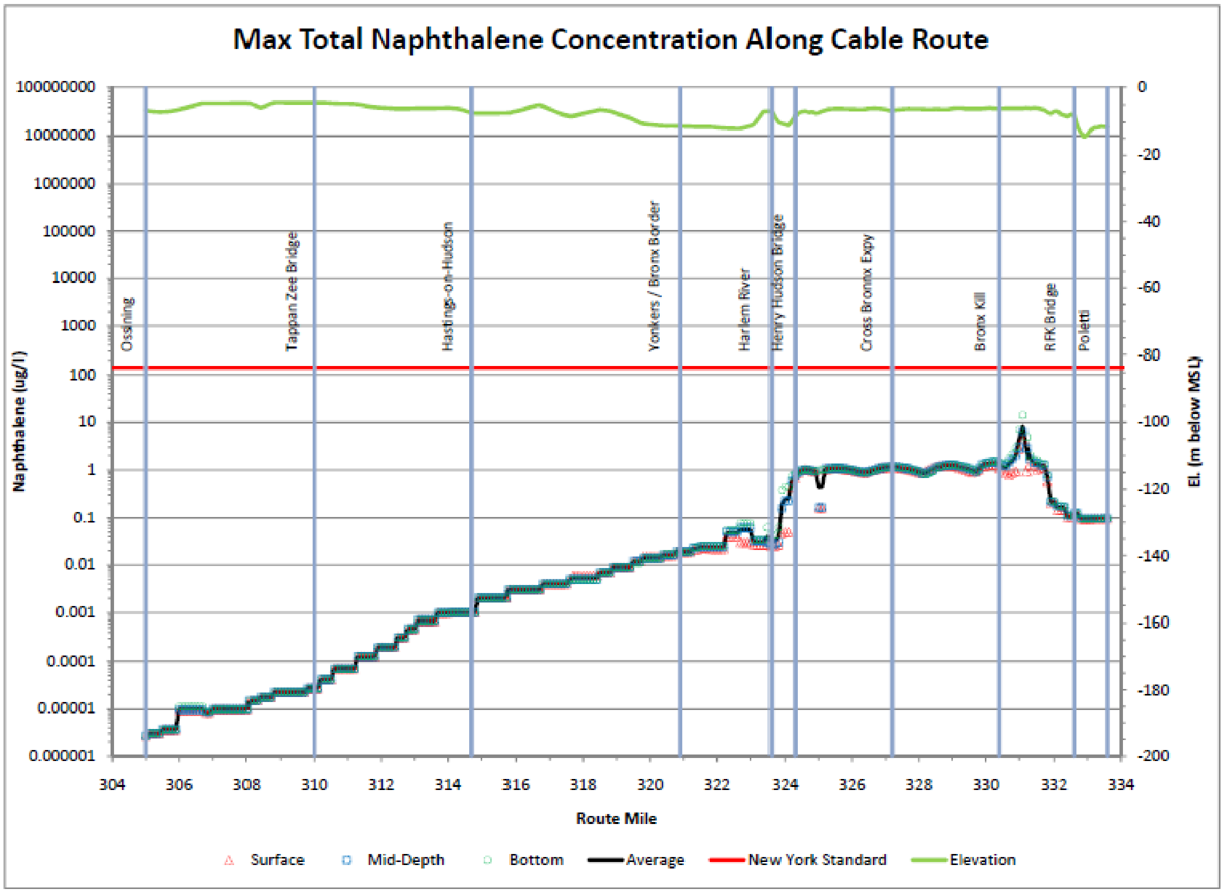


Figure 34. Naphthalene concentrations and NY WQ Standards.

6.2.7 Nickel

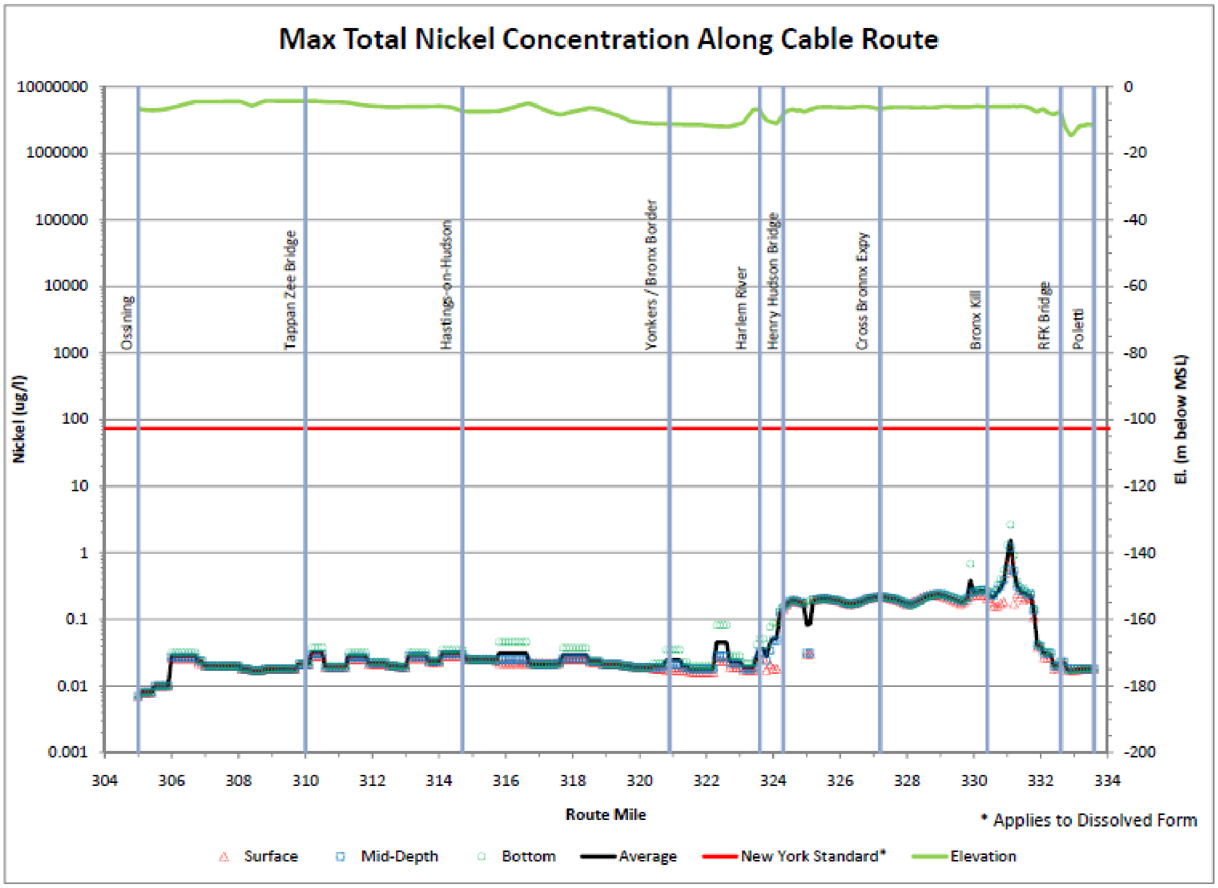


Figure 35. Nickel concentrations and NY WQ Standards.

6.2.8 Lead

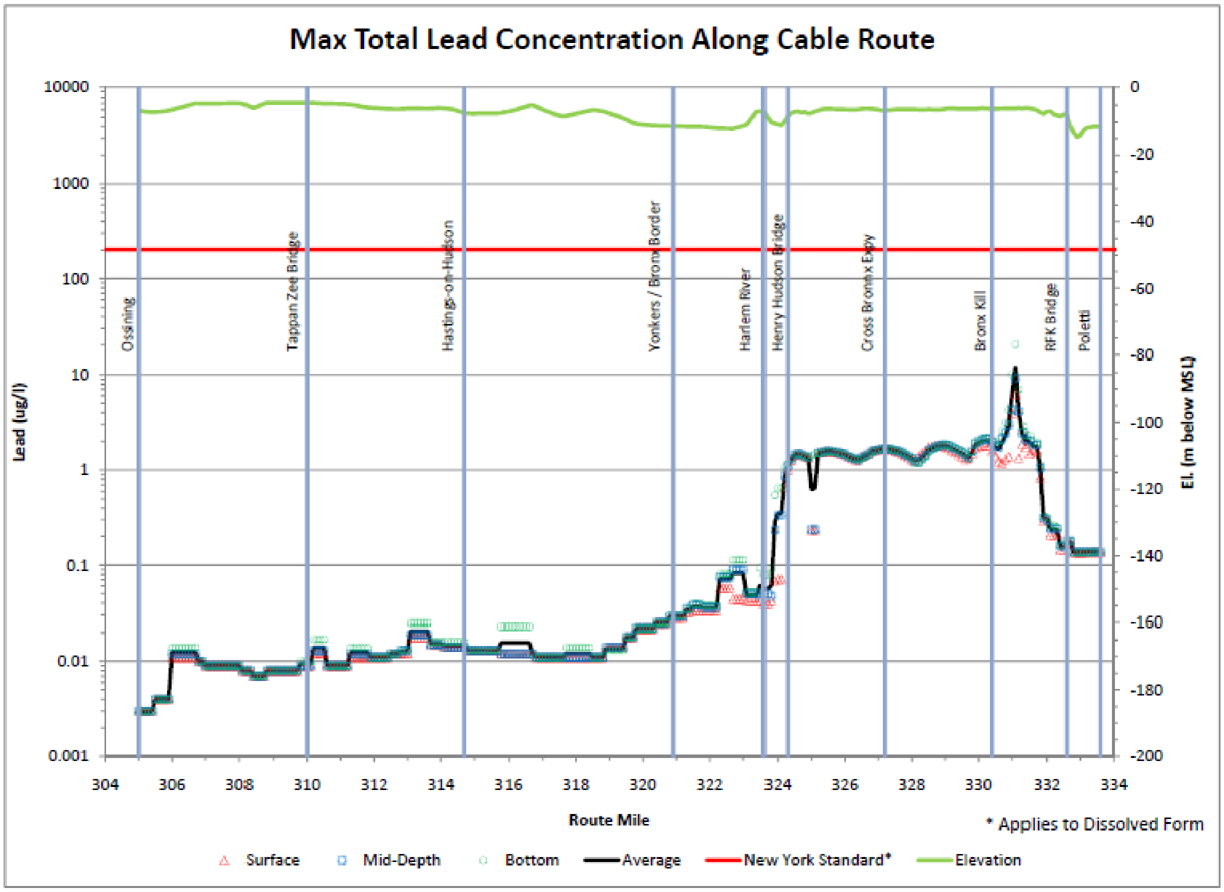


Figure 36. Lead concentrations and NY WQ Standards.

6.2.9 PCB

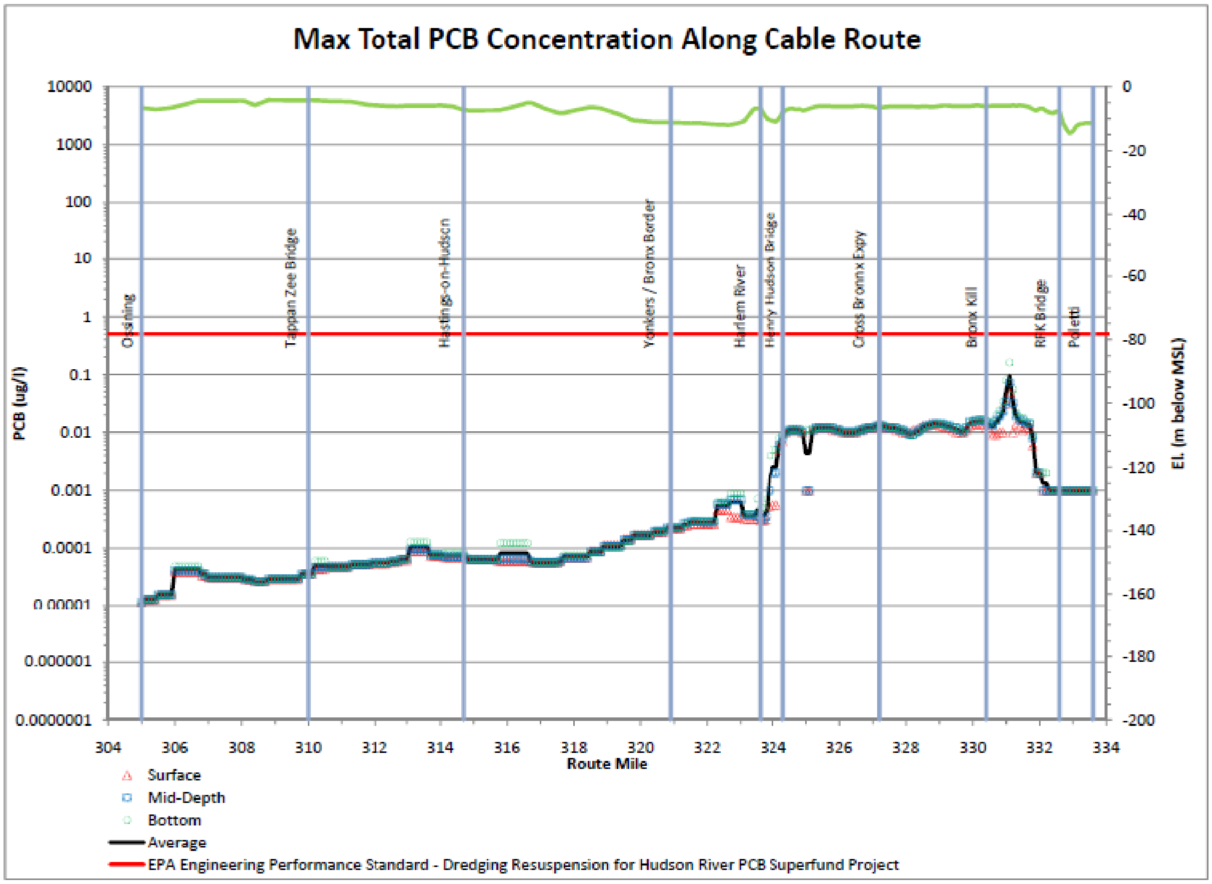


Figure 37. PCB concentrations and EPA Engineering Performance Standard for Dredging Resuspension.

6.2.10 Phenanthrene

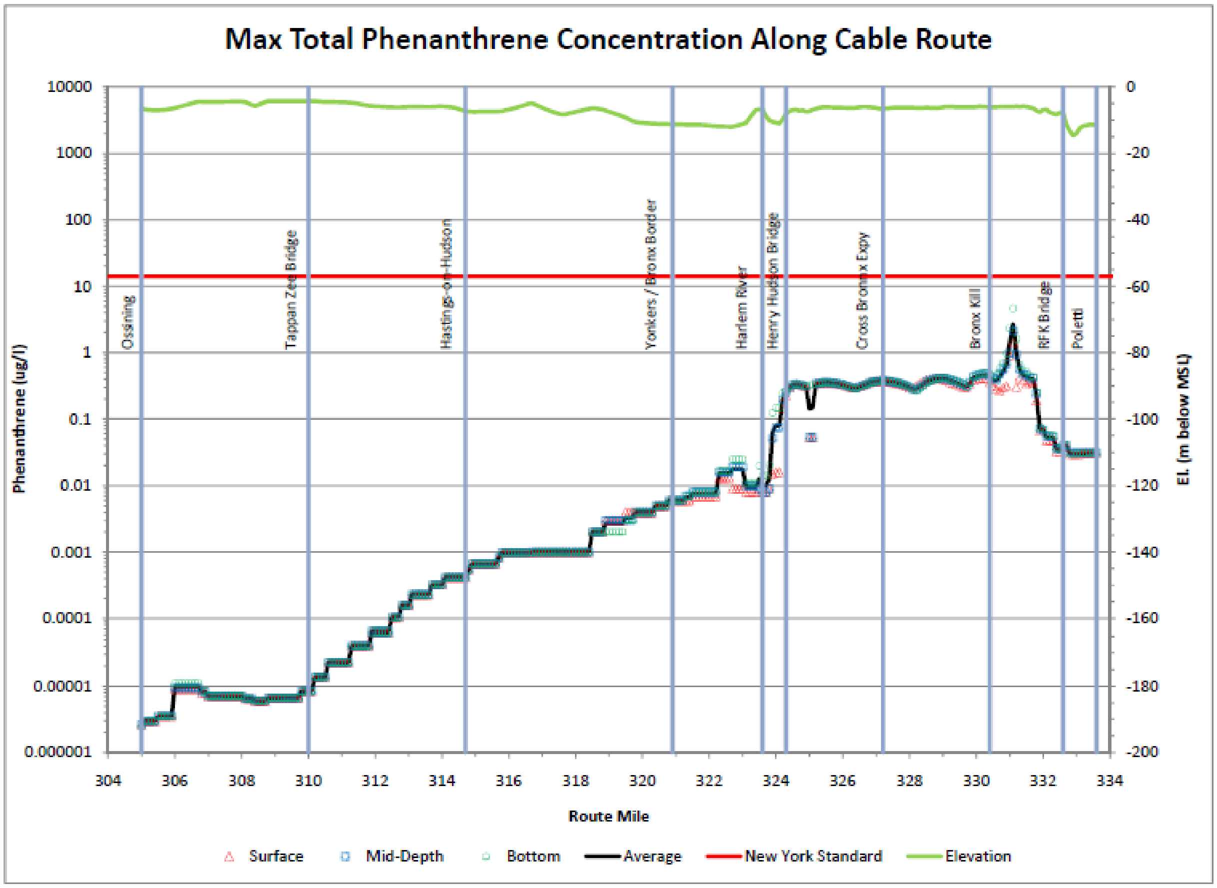


Figure 38. Phenanthrene concentrations and NY WQ Standards.

6.2.11 TSS

Maximum TSS concentrations are projected to be below 100 mg/ throughout the Lower Hudson River Estuary, Harlem and East Rivers, as shown in Figure 39.

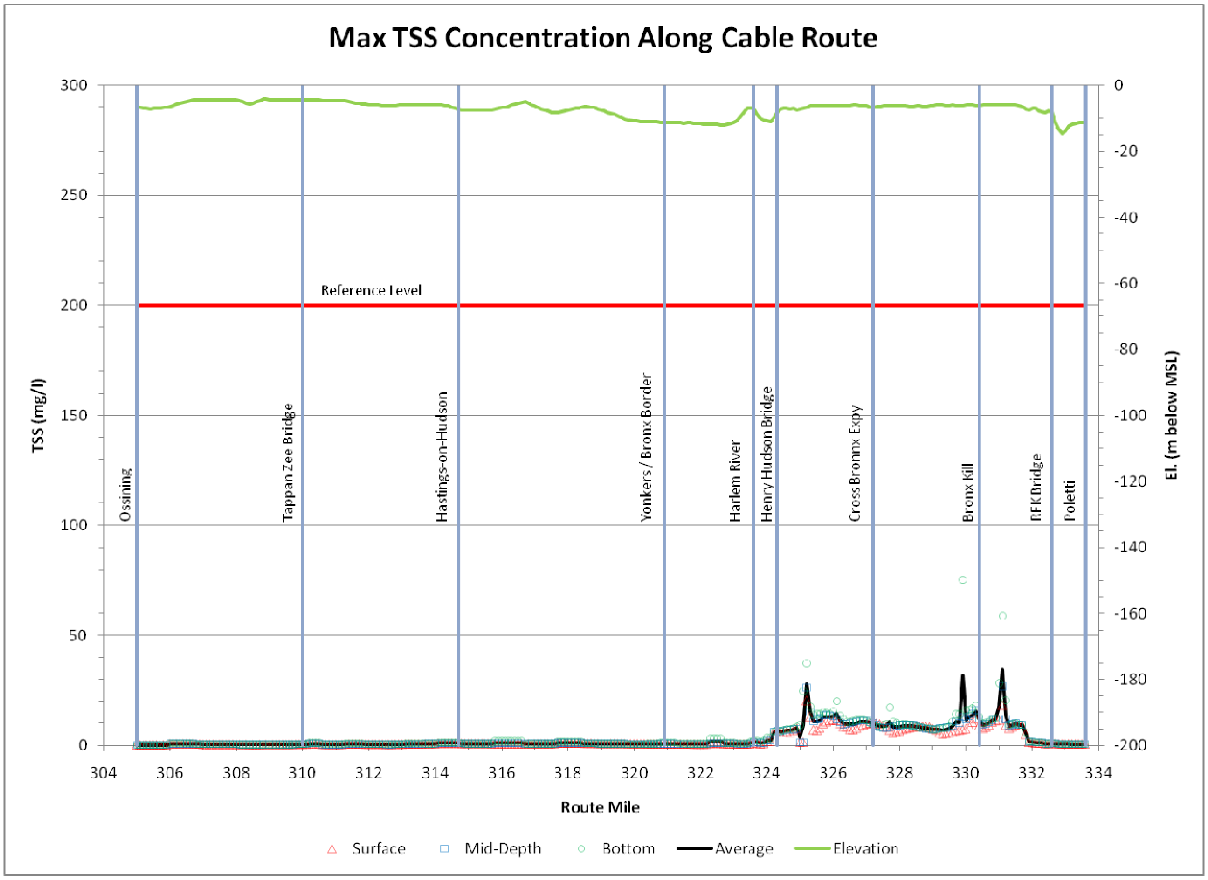


Figure 39. TSS concentrations.

7. Summary

A three dimensional hydrodynamic and water quality model of New York Harbor and the Hudson River Estuary was developed using the Danish Hydraulic Institute (DHI) MIKE3 software. The model was calibrated to tidal elevations observed in New York Harbor and salinity data for the Hudson River Estuary.

To simulate the cable laying operation a series of load points approximated cable installation and sediment disturbance based on the sediment cores collected along the proposed cable route. At each point the sediment load was sequentially turned on and off to simulate the effect of the continuously moving cable operation. Both dissolved and solid fractions were computed in the model. The model was used to simulate ten contaminants that were found in sediment cores collected during the Spring 2010 Marine Route Survey. The maximum model-computed concentrations of contaminants along the cable route were graphically presented and compared to New York State's water quality standards. Where acute toxicity criteria were not available, projected contaminant levels were compared to chronic criteria.

The effects of the proposed cable installation are projected to comply with water quality standards that are based on protecting aquatic life from acute toxicity, which are the most appropriate criteria for the assessment of the proposed project. Given the non-chronic (i.e., short-term) and incremental nature of the potential exposure to sediment contaminants resulting from the cable installation, comparison of water quality modeling results to acute toxicity standards was considered most appropriate.

The projected maximum total PCB concentration is below the EPA's Engineering Performance Standard water quality criteria for dredging resuspension at the Hudson River PCBs Superfund Site (EPA 2003).

In order to reduce the potential impact in sensitive areas, BMPs for cable installation may include the following:

- Construction work windows – Construction work windows may vary along the proposed route. Windows will be coordinated with regulatory agencies.

- Water jetting operation parameter modifications – The primary modifications to the water jetting operation include a reduction in water jetting pressure and a reduction in water jetting rate of installation. Both of these modifications would reduce the sediment loading rate, which would reduce TSS concentrations. In addition, operational modifications may occur in the field based on water quality monitoring results.

- Modified alternative cable installation techniques – Rather than machine jetting, the cable may be installed by diver's hand jetting the cable. Or the cable may be laid on the bottom surface of the lake without jetting through the sediment. In addition, a combination of machine jetting to an intermediate depth followed by hand jetting to the final depth may be done.

In addition, during cable installation, a water quality monitoring program will be conducted and include near field and far field surveys.

8. References

Danish Hydraulic Institute 2009. MIKE21 & MIKE3 Flow Model FM, Hydrodynamic and Flow Transport Model, Scientific Documentation, January 2009.

Environmental Protection Agency 2003. Hudson River PCBs Superfund Site Engineering Standards Dredging Resuspension Fact Sheet

HDR 2004. New York/New Jersey Harbor Navigation Study. Hydrodynamic and Water Quality Modeling. Final Report. Model Calibration, Verification and Application. Submitted to Corps of Engineers, May 2004.

Kansas Department of Health and the Environment. 2004. Kansas Surface Water Quality Standards, Tables of Numeric Criteria , December 2004.

Nebraska Department of Environmental Quality. 2009. Nebraska Administrative Code, Title 117, Chapter 4, Standards for Water Quality , March 2009.

NOAA 2010. http://tidesandcurrents.noaa.gov/

NYSDEC 1998. Division of Water Technical and Operational Guidance Series (1.1.1). Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations.

NYSDEC 2004. Technical and Operational Guidance Series(5.1.9), In-water and Riparian Management of Sediment and Dredged Material.

Westerink, J.J., Luettich, R.A.,Jr., and N.W. Scheffner (1993), "ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries; Report 3, Development of a Tidal Constituent Database for the Western North Atlantic and Gulf of Mexico," TR DRP-92-6, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

U. S. Fish and Wildlife Service 2010. http://library.fws.gov/pubs5/web_link/text/low_hud.htm

Case 10-T-0139
January 31, 2011

Champlain Hudson Power Express: Water Quality Modeling of Shear Plow Cable Installation in Southern Part of Lake Champlain

Introduction

In October 2010, the Applicants for the Champlain Hudson Power Express project ("Project") submitted the Water Quality Modeling – Lake Champlain report to the New York State Department of Public Service (DPS) in response to an interrogatory request (DPS-47) The model's assumptions included that installation of the cable would employ a water jet plow. However, due to concerns over total suspended solids and water quality, as well as engineering considerations, the Applicants have subsequently proposed that an alternative cable installation technology, shear plow, could be utilized in the southern portion of Lake Champlain. The DPS has requested that the model be re-run with the parameters one would reasonably expect for this alternate method.

The suitability of the sheer plow technology for submarine cable installation and burial is limited by both sediment cohesiveness and burial depth. Use of the shear plow is typically limited to sediments that have lower shear strengths and where installation will be at shallower burial depths (less than 5 ft). The sediment shear strength and proposed cable burial depth in Lake Champlain meet the conditions for the installation with the shear plow, so that this equipment could reasonably be considered for cable installation and burial in this area.

The three-dimensional hydrodynamic and water quality model, MIKE3 FM, described in the October 2010 report, was re-run to model the shear plow installation scenario. The model was calibrated to the measured flow exiting the lake via the Richelieu River and to measured vertical temperature profiles throughout the lake. To simulate the cable laying operation, a series of load points at approximately two mile intervals were used, which matched the locations where sediment cores were taken. At each point the load was sequentially turned on and off to simulate the effect of the continuously moving cable operation. The load at each point was computed based on the sediment core data and relevant cable installation data. The only source of solids and contaminants in the model is the resuspension due to the cable installation. Both dissolved and solid fractions of contaminants were computed in the model. The modifications to the model input data, specifically the source loads, are described in this technical memo along with the model projection results of TSS and water quality constituents.

The previous simulation for the installation via water jetting encompassed the entire length of Lake Champlain (referred to as the water jetting model scenario). For this modeling effort, the shear plow installation was assumed to start near the Lake Champlain Bridge at Crowne Point (approximate Mile Point 73) and continue through the remaining extent of the lake to MP 110. Figure 1 shows the load points utilized in the shear plow modeling scenario. The locations of the load points are identical in both modeling scenarios; the loads at the points labeled shear plow are reduced in the shear plow modeling scenario; the loads at the points labeled water jetting are the same in both modeling scenarios.

Load Calculation

The proposed shear plow installation reduces the width of the trench and the release fraction (i.e. the percent of sediment volume disturbed based on cross-section of trench that is suspended into the water column). The following operating assumptions, provided by the cable installer were used for these two parameters:

Trench Width, W = 0.25 m
Release Fraction, R = 2%

All other load parameters from the October 2010 report were unchanged in the shear plow modeling scenario.

The load is defined by the cable installation flow rate and sediment concentration. The flow rate calculation is described as:

$$Q = A * v * R$$

Where,

Q = Flow (m^3/s)
A = Cross sectional Area of trench (m^2)
v = Plow Velocity (m/s)
R = Release Fraction (%)

As the trench depth remained at 2 m, the cross-sectional area of the shear plow trench, which was assumed to be rectangular, was calculated at 0.5 m^2. The plow velocity was the same as previously estimated, 0.028 m/s. These assumed values for the parameters in the above equation produce a flow of 0.00028 m^3/s for the shear plow. This flow is less than 1.5% of the flow for the water jetting installation. The sediment load is also less than 1.5% of the load for the water jetting installation because the total suspended solids concentration of the bottom sediments is the same in both modeling simulations. Similarly, contaminant loads are reduced to less than 1.5% of the contaminant loads in the water jetting installation.

All other model input data for the shear plow scenario were identical to those used in the water jetting scenario.

Results

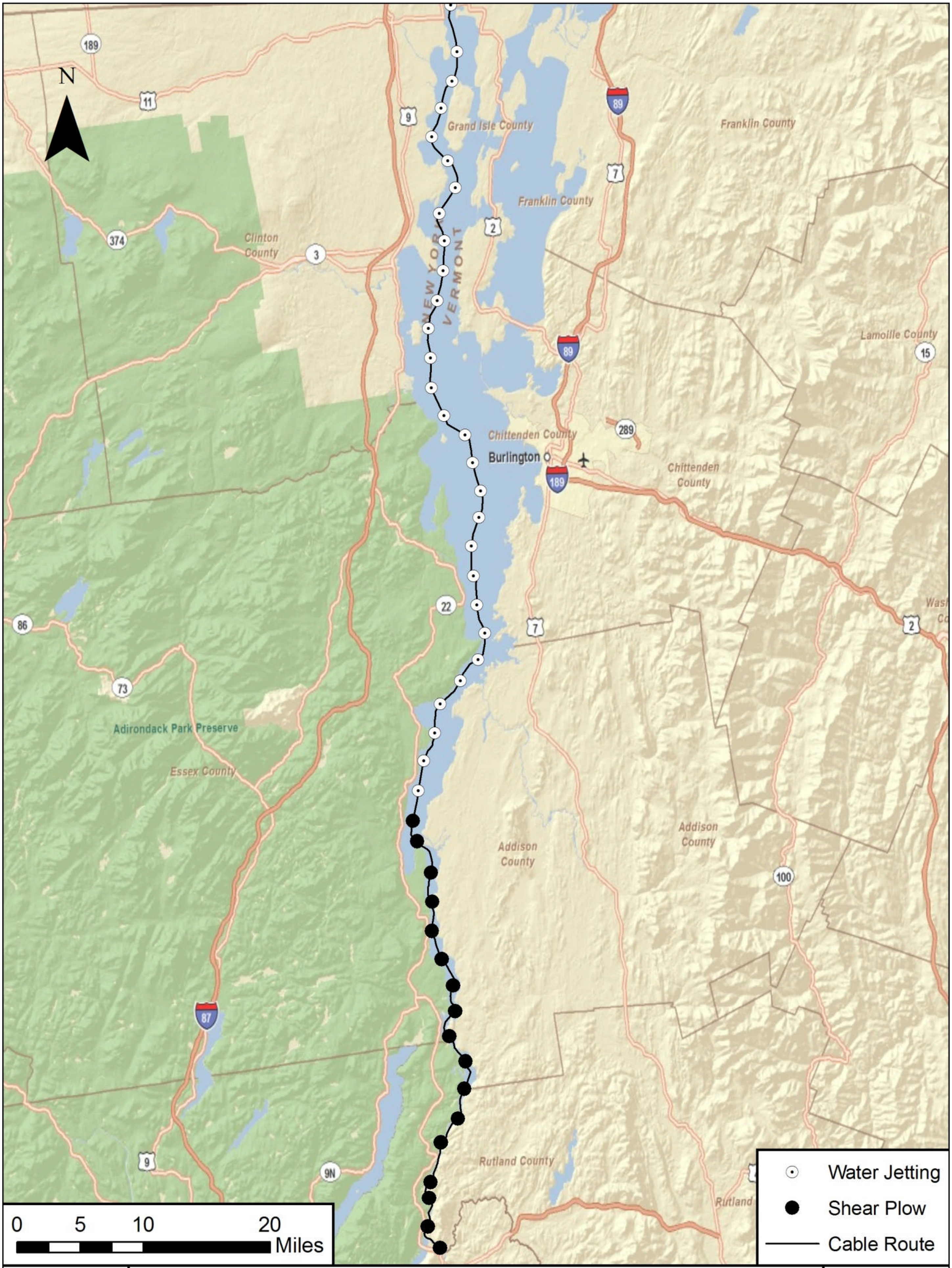
The maximum concentrations of TSS and the ten other modeled water quality constituents (arsenic, benz (a) anthracene, cadmium, chromium, copper, mercury, nickel, lead, Pyrene and zinc) are shown graphically in the attachment to this memo. The TSS concentrations resulting from shear plowing between MP 73 and MP 110 are projected to be substantially lower than those shown when water jetting is the assumed installation technology within South Lake. For example, the maximum TSS concentration which occurs at MP 106.8 in the bottom model layer decreased from 1,080 mg/l in the water jet plow scenario to 15 mg/l under the shear plow scenario. Depth-average TSS concentrations associated with the combined water jetting and shear plow cable installation (i.e., no background TSS) are less than 200 mg/l for the entire lake.

Similar trends of lower concentrations associated with the shear plow technology are shown for the other ten water quality constituents. Of particular interest are copper and zinc, as these two contaminants were projected to exceed the Vermont water quality standards in the southern portion of the lake. While the maximum total copper concentration predicted for the water jet plow model scenario was 22 ug/l at MP 106.8, at this same location the concentration is reduced to 0.4 ug/l under the shear plow model scenario. The maximum total copper concentration in Lake Champlain for the shear plow model scenario (11 ug/l) is projected to be lower than Vermont's acute toxicity-based standard of 18.7 ug/l and the calculated maximum dissolved copper concentration for the lake is below New York's acute toxicity-based water quality standard.

The maximum total zinc concentration in the lake for the water jet plow model scenario was 108 ug/l at MP 106.8 but the concentration at the same location is reduced to 1.6 ug/l in the shear plow model scenario. The maximum total zinc concentration in Lake Champlain for the shear plow model scenario (43 ug/l) is lower than Vermont's standard of 100 mg/l. The maximum dissolved zinc concentration in the lake is below NewYork's acute toxicity-based water quality standard, which applies to the dissolved form, in both cable installation model scenarios. The maximum total concentration of the remaining eight water quality constituents (arsenic, benz (a) anthracene, cadmium, chromium, mercury, nickel, lead and pyrene) are projected to be lower than New York and Vermont's acute toxicity-based water quality standards (Attachment 1).

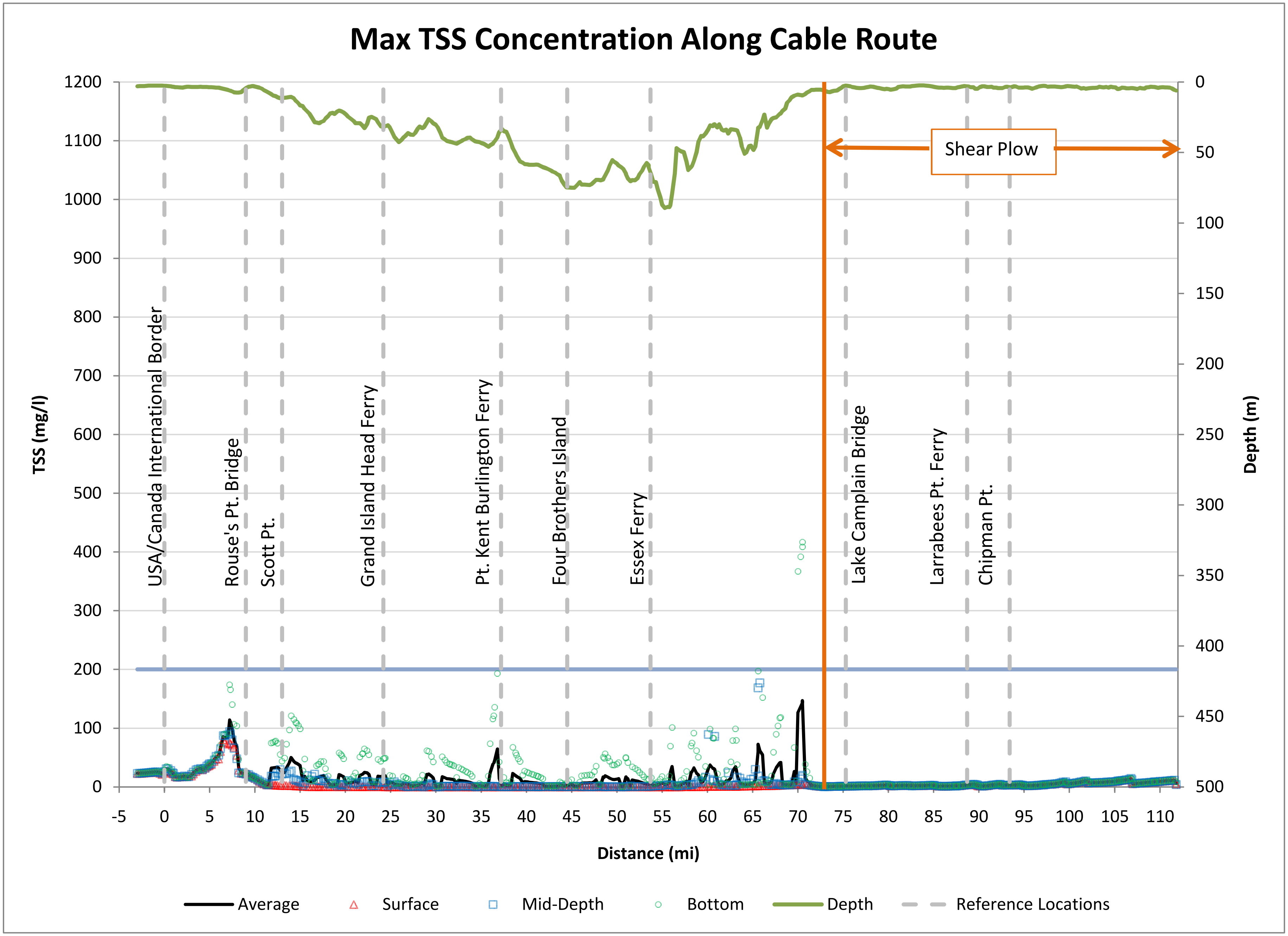
Summary

The proposed shear plow installation of cable in the south portion of Lake Champlain was modeled to assess the effects of an alternative installation technology on water quality. The model projections show that shear plowing under the assumed operating scenario would effectively reduce TSS and contaminant concentrations in the southern part of the lake so that New York and Vermont's acute toxicity-based water quality standards would be attained.

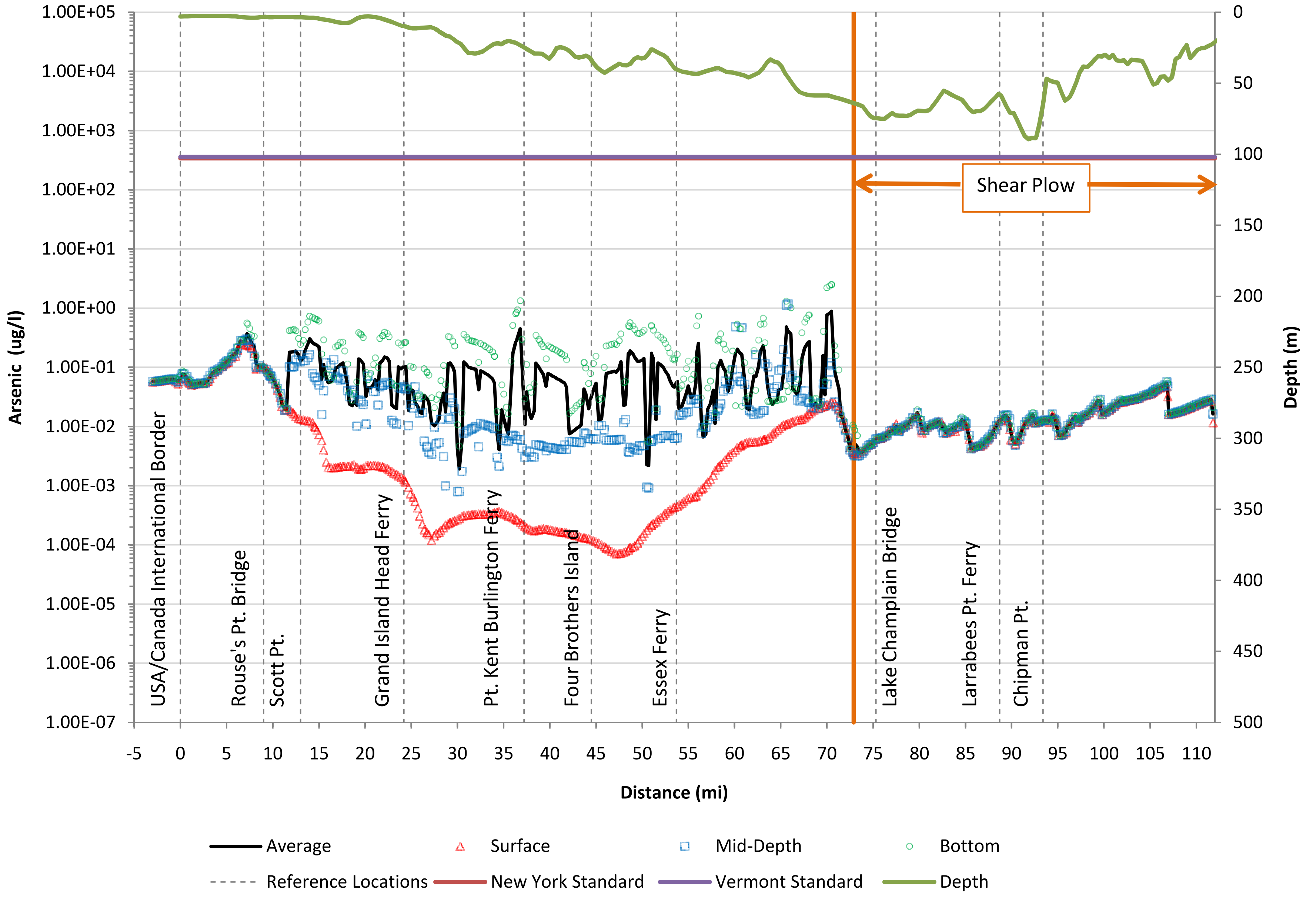


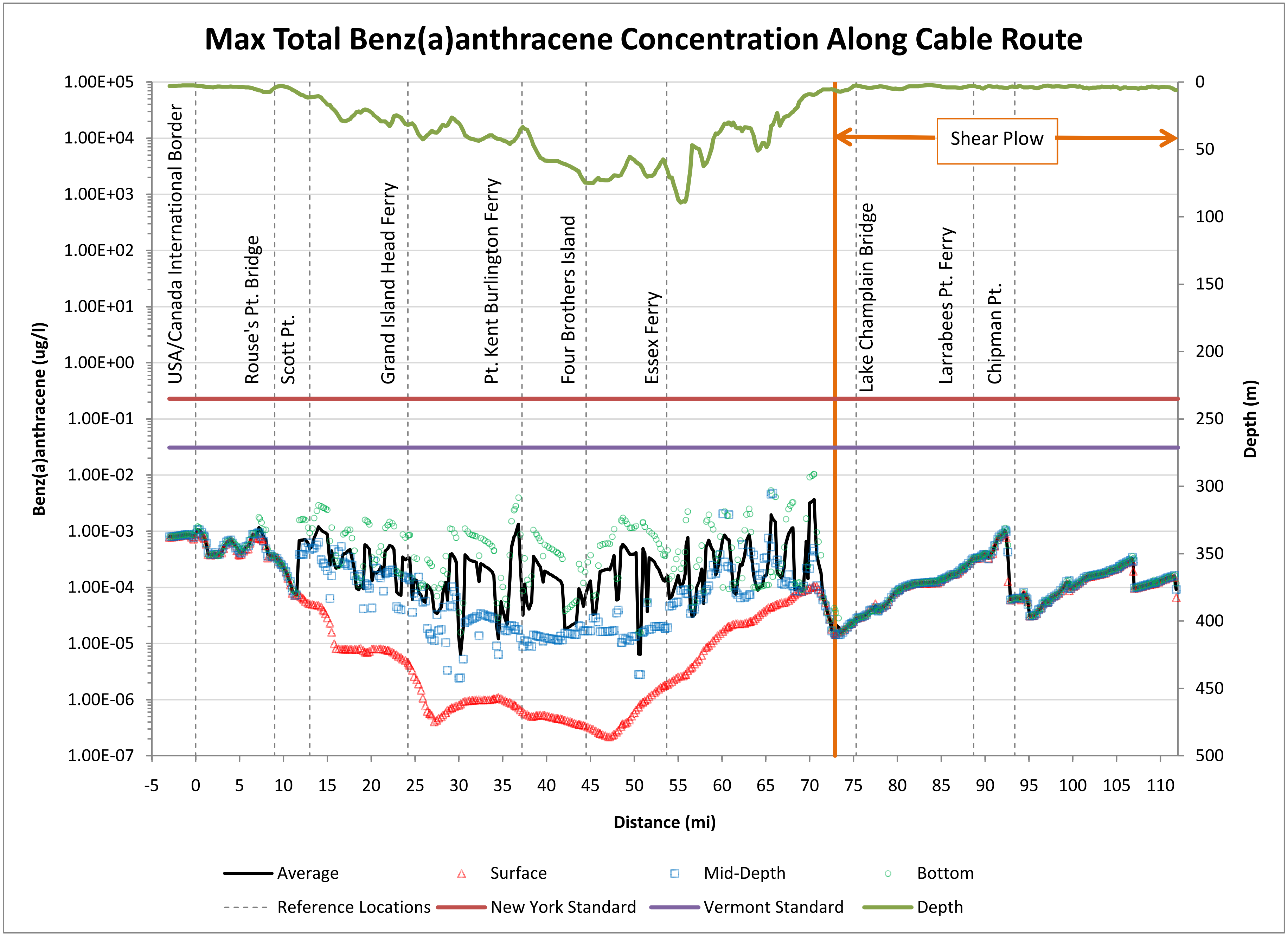
Source Load Points for
Shear Plow Installation Model Scenario

FIGURE
1

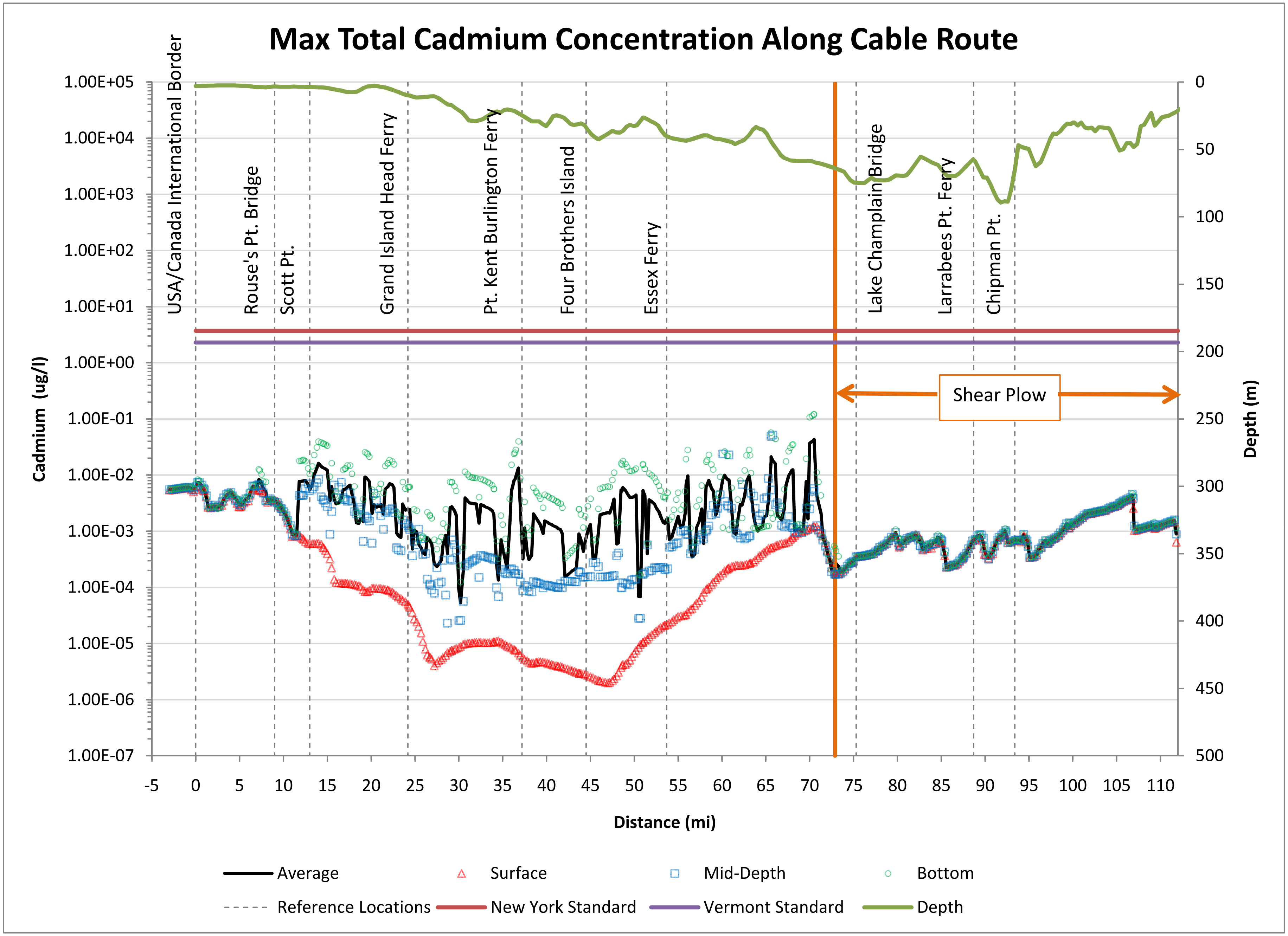

Max TSS Concentration Along Cable Route
TSS (mg/l)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
USA/Canada International Border
Rouse's Pt. Bridge
Scott Pt.
Grand Island Head Ferry
Pt. Kent Burlington Ferry
Four Brothers Island
Essex Ferry
Lake Camplain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Shear Plow
Average
Surface
Mid-Depth
Bottom
Depth
Reference Locations

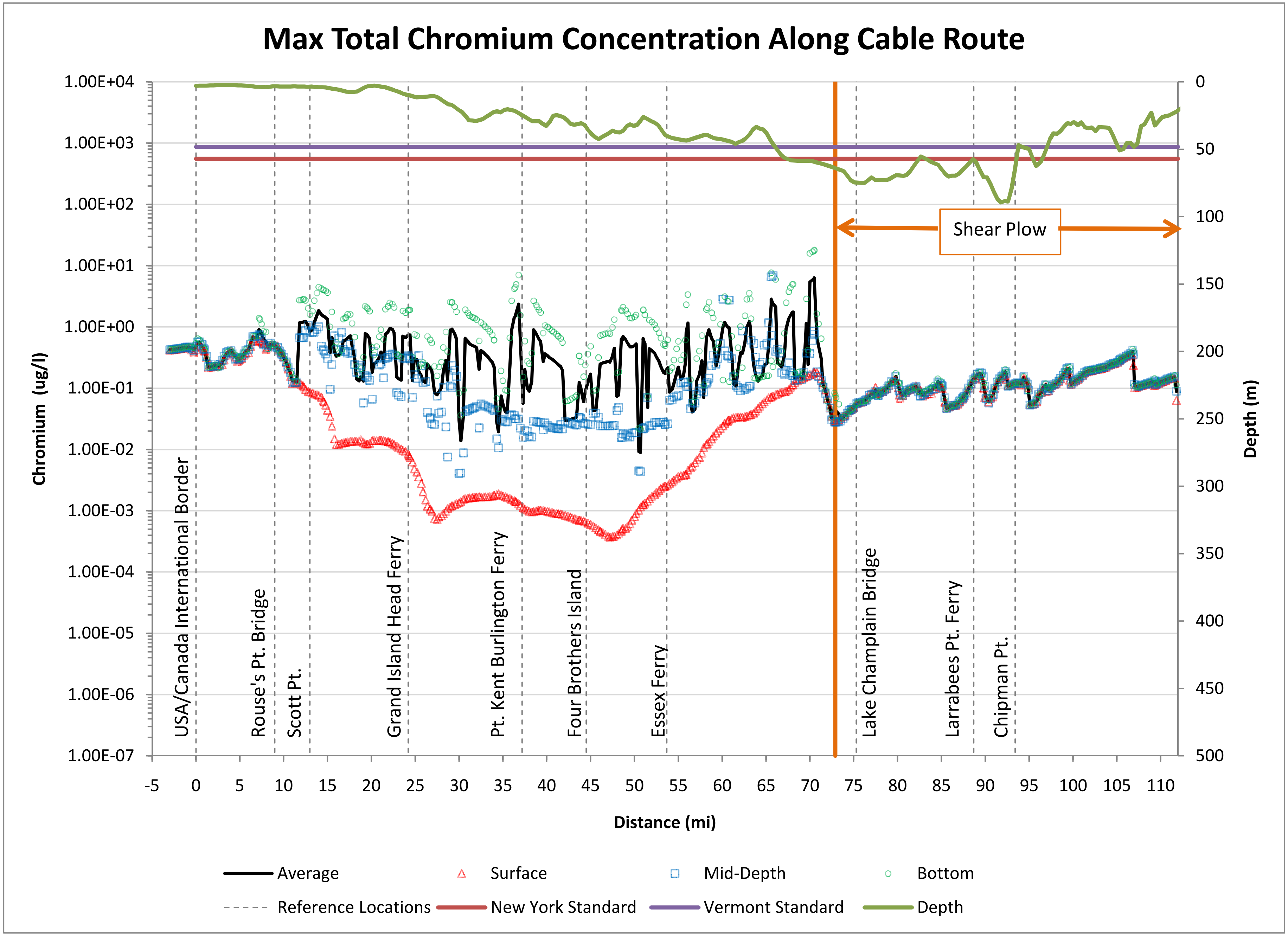
Max Total Arsenic Concentration Along Cable Route

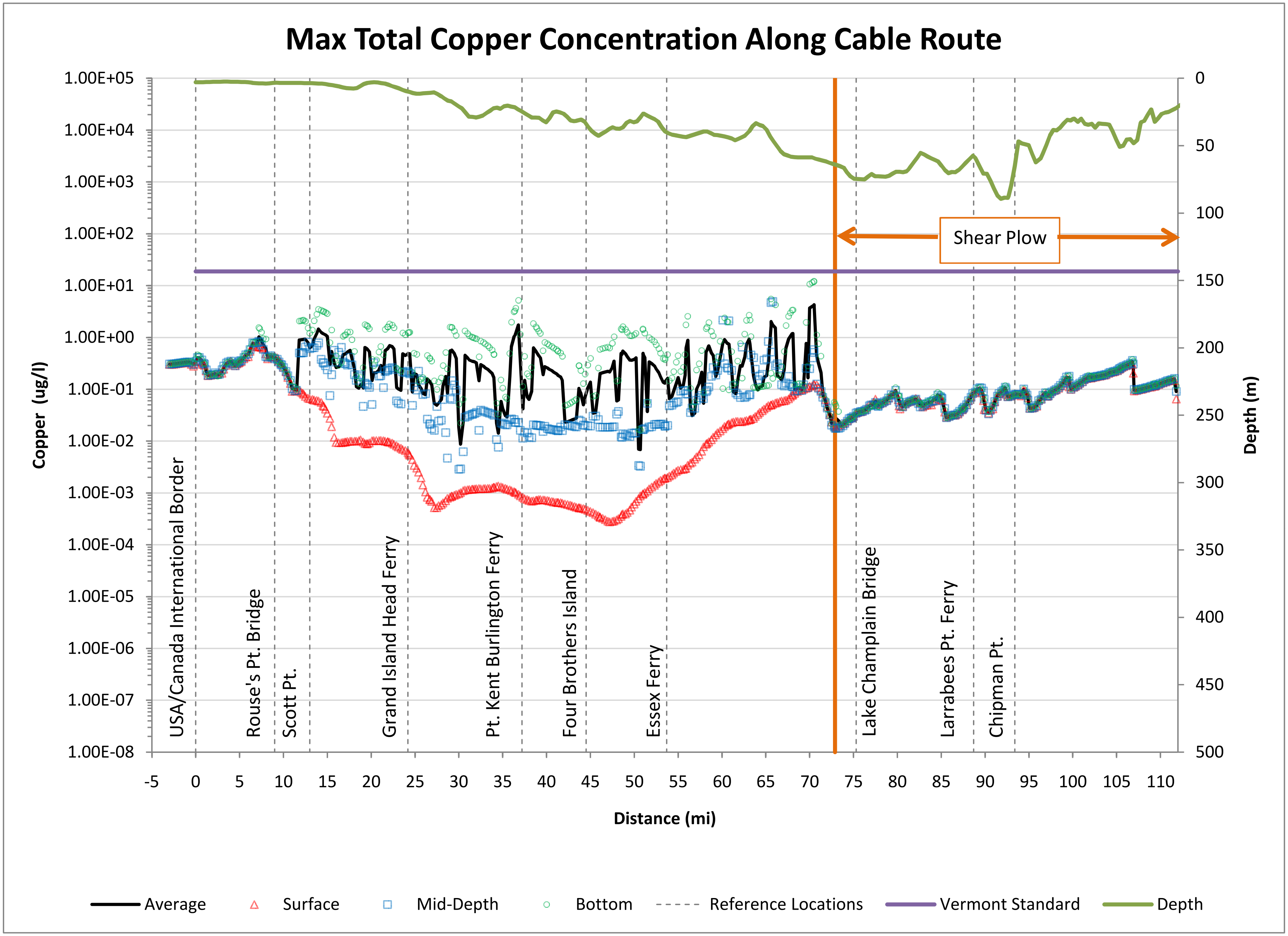




Max Total Benz(a)anthracene Concentration Along Cable Route


Max Total Cadmium Concentration Along Cable Route
Cadmium (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
USA/Canada International Border
Rouse's Pt. Bridge
Scott Pt.
Grand Island Head Ferry
Pt. Kent Burlington Ferry
Four Brothers Island
Essex Ferry
Lake Champlain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Shear Plow
Average
Surface
Mid-Depth
Bottom
Reference Locations
New York Standard
Vermont Standard
Depth


Max Total Chromium Concentration Along Cable Route


Max Total Copper Concentration Along Cable Route
Copper (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
USA/Canada International Border
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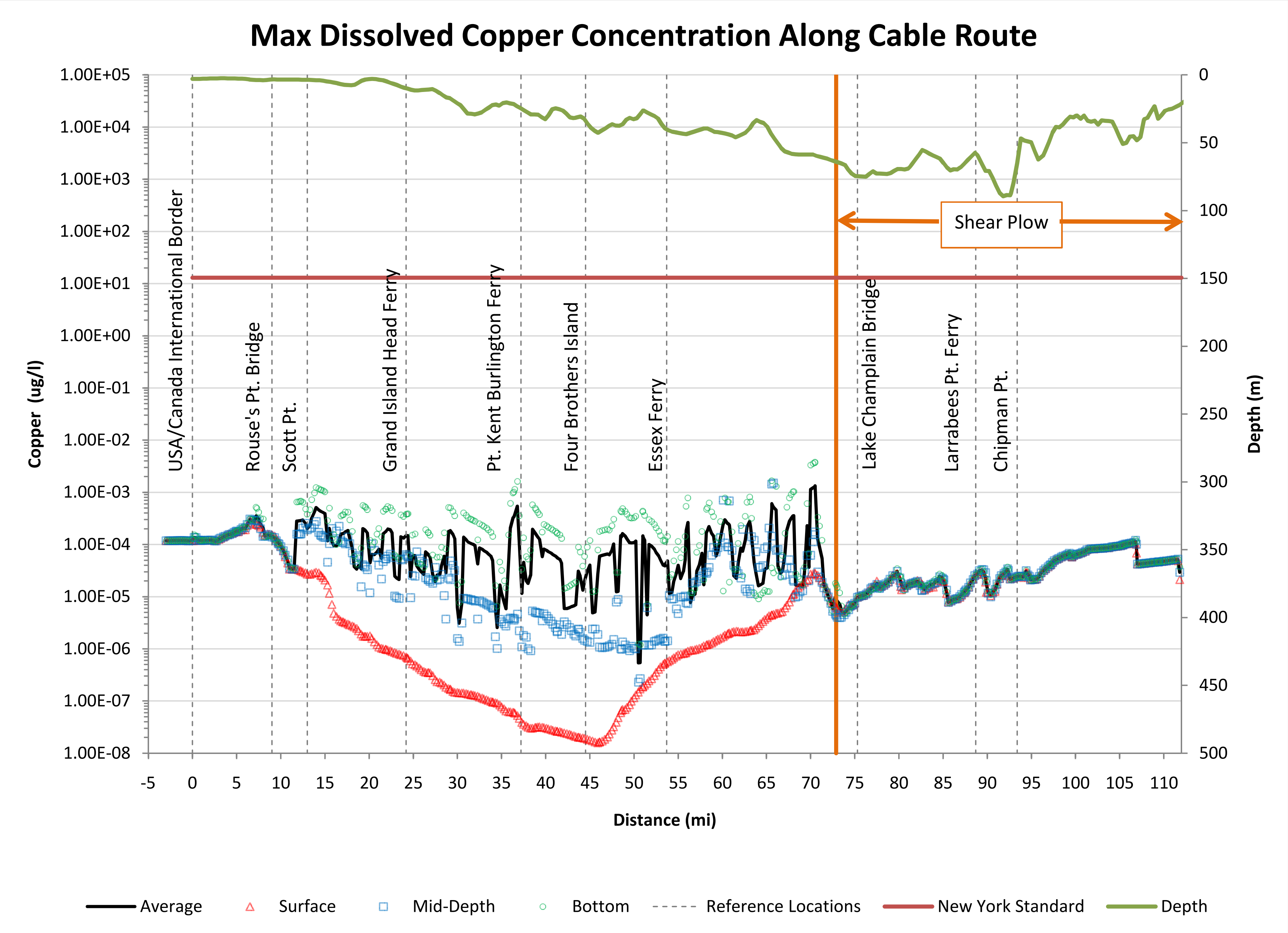
Essex Ferry
Lake Champlain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Shear Plow
Average
Surface
Mid-Depth
Bottom
Reference Locations
Vermont Standard
Depth


Max Dissolved Copper Concentration Along Cable Route
Copper (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
USA/Canada International Border
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Grand Island Head Ferry
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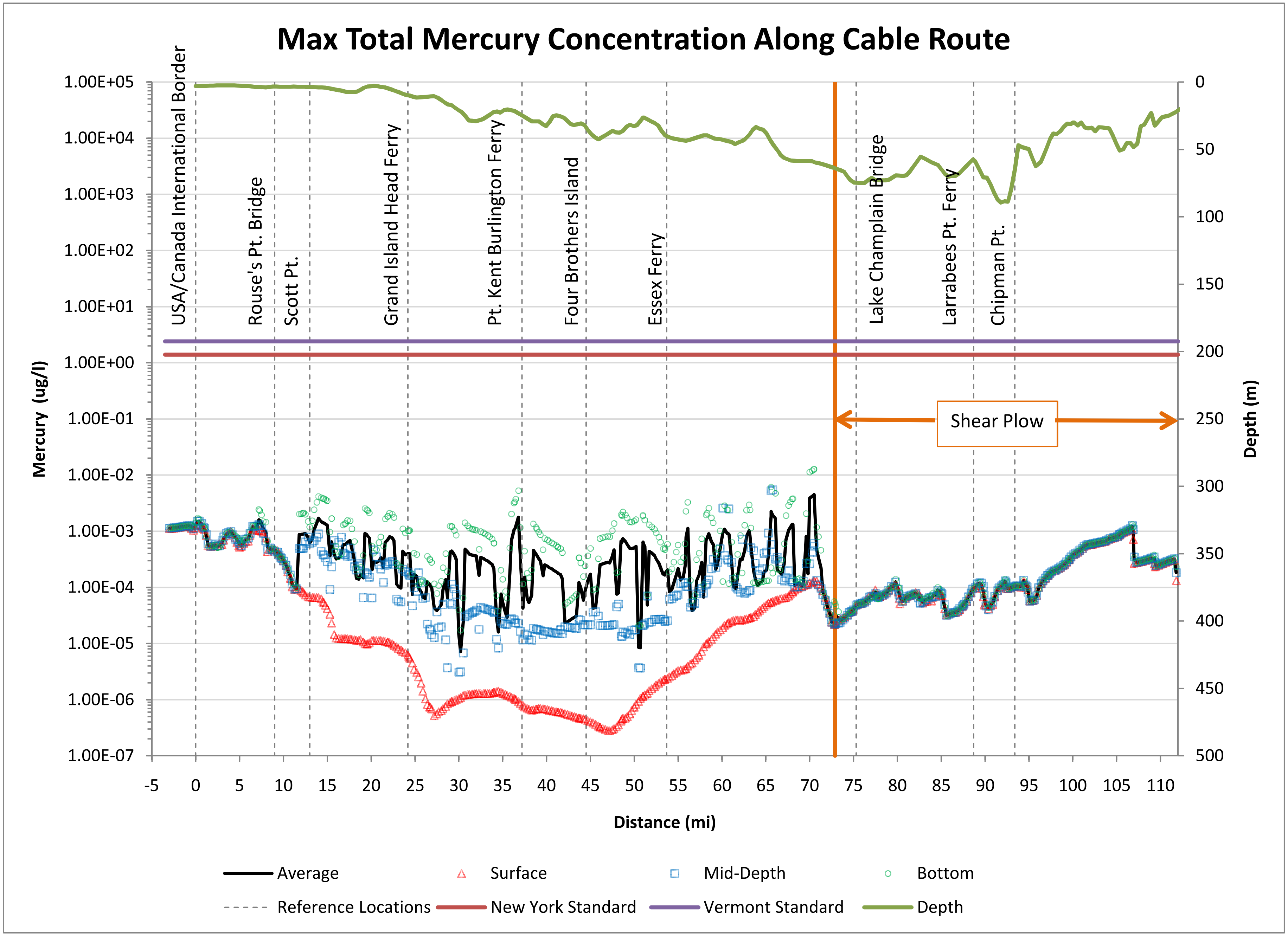
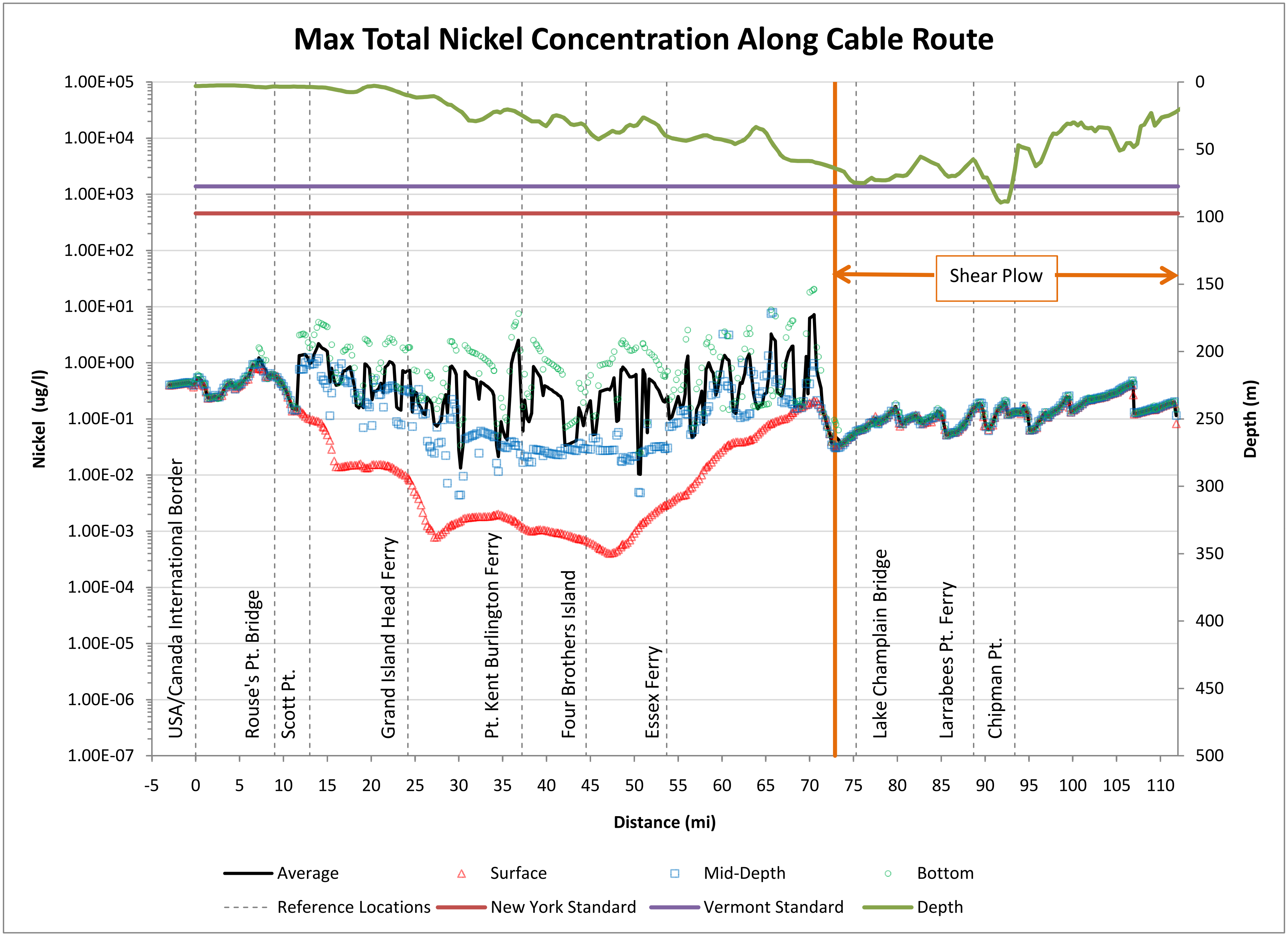
Four Brothers Island
Essex Ferry
Lake Champlain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Shear Plow
Average
Surface
Mid-Depth
Bottom
Reference Locations
New York Standard
Depth


Max Total Mercury Concentration Along Cable Route
Mercury (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
USA/Canada International Border
Rouse's Pt. Bridge
Scott Pt.
Grand Island Head Ferry
Pt. Kent Burlington Ferry
Four Brothers Island
Essex Ferry
Lake Champlain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Shear Plow
Average
Surface
Mid-Depth
Bottom
Reference Locations
New York Standard
Vermont Standard
Depth


Max Total Nickel Concentration Along Cable Route
Nickel (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
Shear Plow
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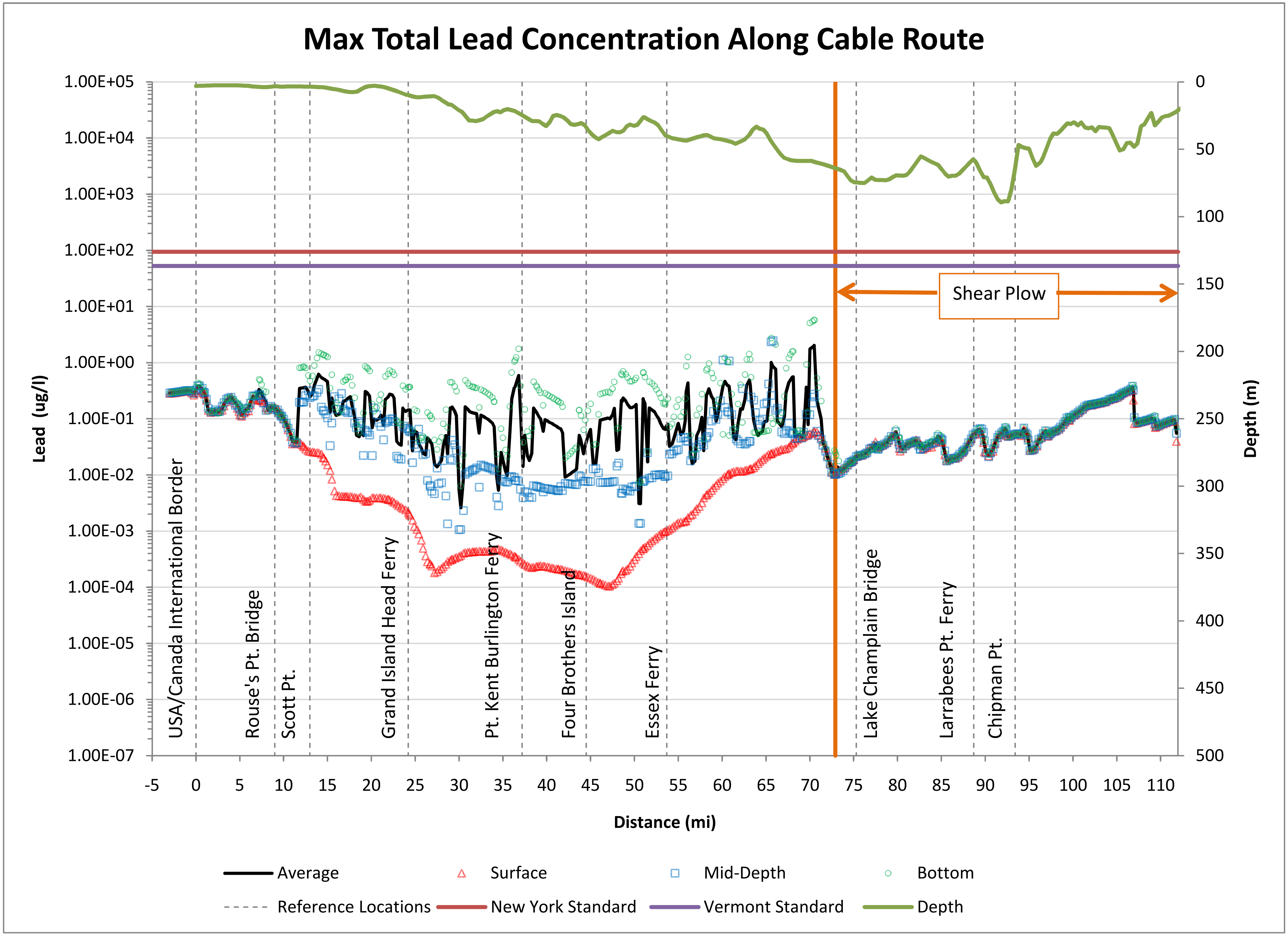
Lake Champlain Bridge
Larrabees Pt. Ferry
Chipman Pt.
Average
Surface
Mid-Depth
Bottom
Reference Locations
New York Standard
Vermont Standard
Depth


Max Total Lead Concentration Along Cable Route
Lead (ug/l)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
Depth (m)
0
50
100
150
200
250
300
350
400
450
500
Distance (mi)
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
Shear Plow
USA/Canada International Border
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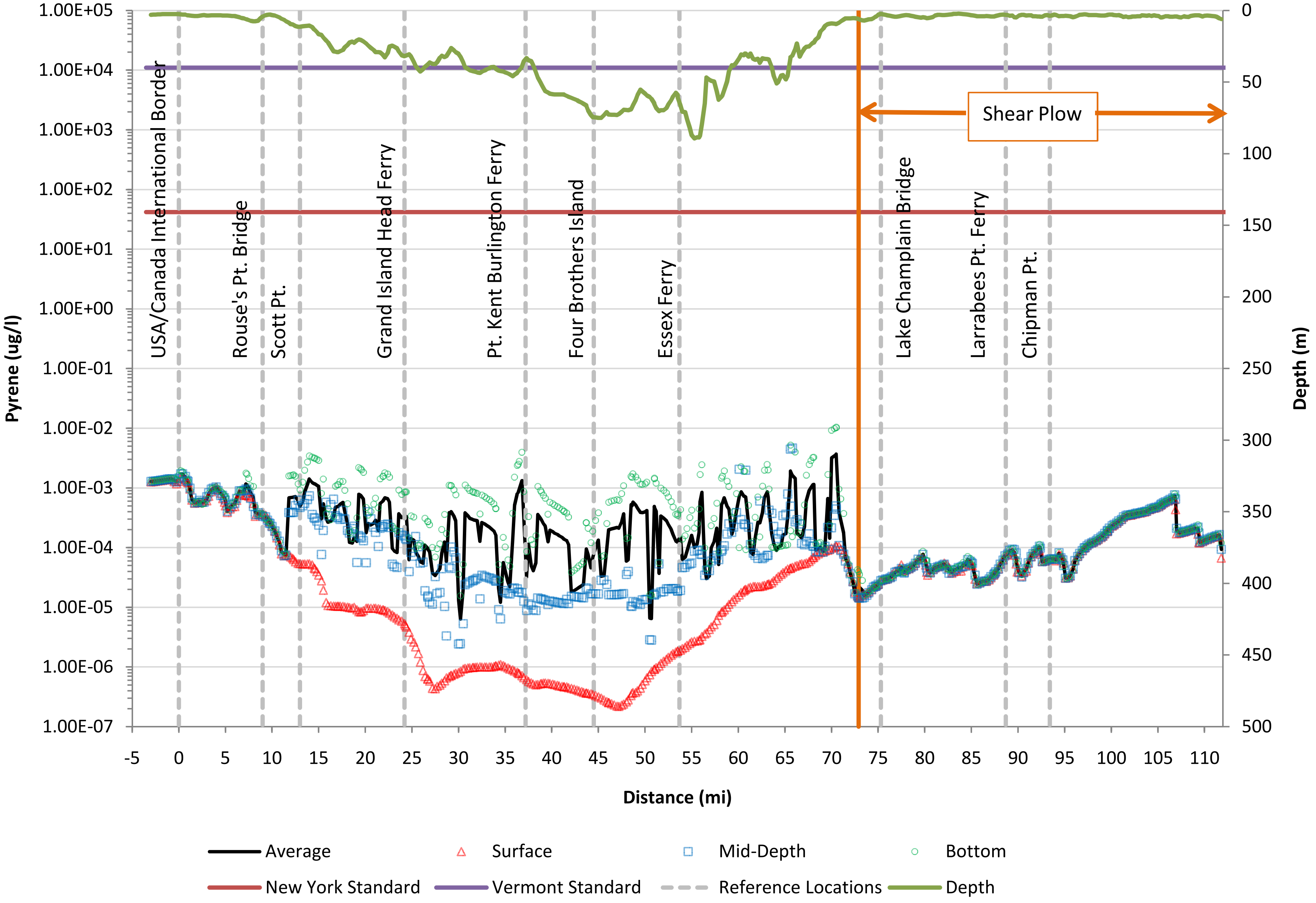
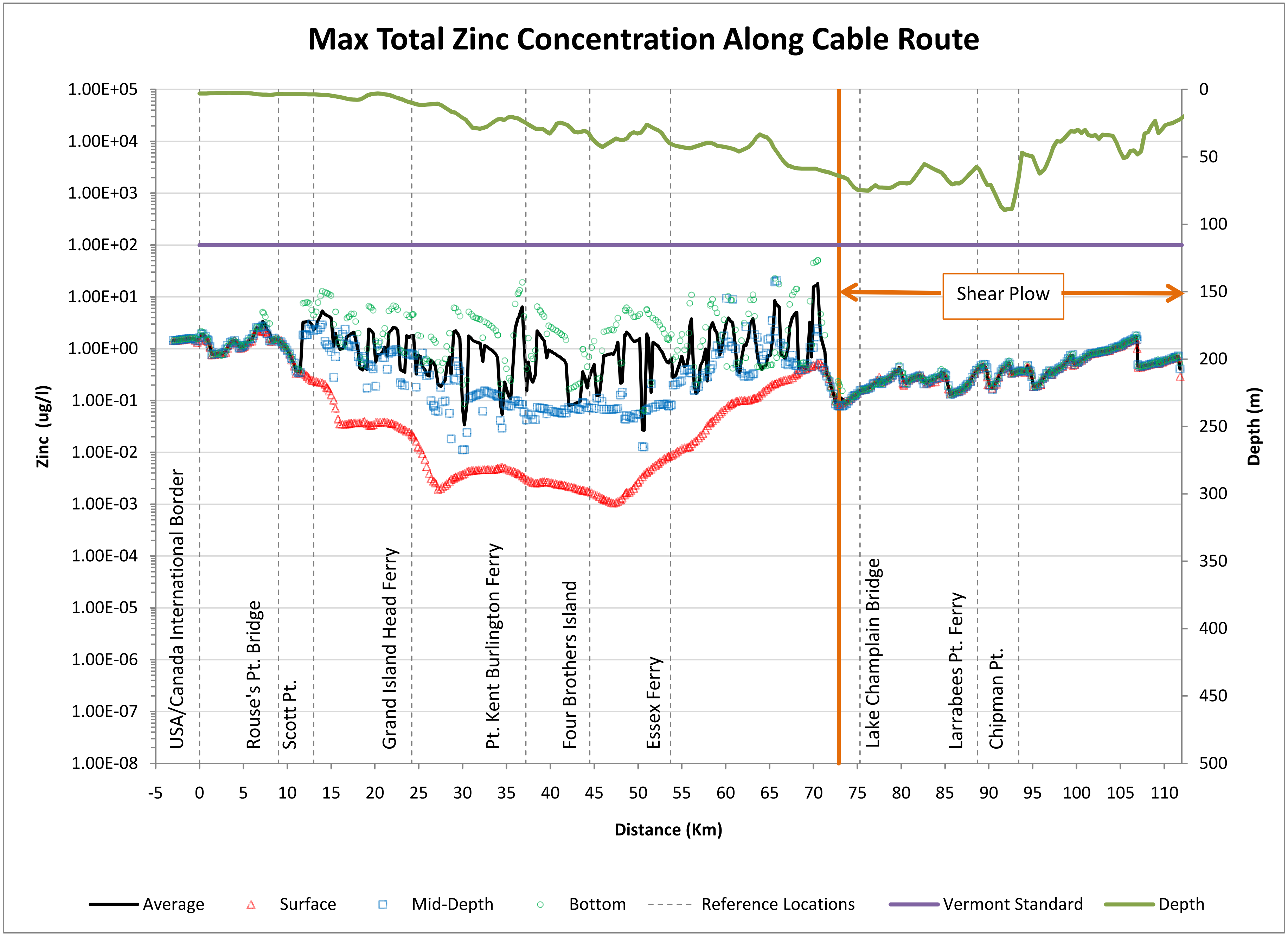
Larrabees Pt. Ferry
Chipman Pt.
Average
Surface
Mid-Depth
Bottom
Reference Locations
New York Standard
Vermont Standard
Depth

Max Total Pyrene Concentration Along Cable Route





Max Dissolved Zinc Concentration Along Cable Route