Appendix F: Ecology

F-1 Aquatic Sampling Program

Aquatic Sampling Program

AECOM

April 2011

Introduction

In support of the DEIS, this appendix contains aquatic ecological studies by AECOM and their subconstultants. Studies for fish, benthos, oysters and submerged aquatic vegetation were performed for the project from 2006 to 2009. This appendix is organized into the following three sections:

- Section 1 – Study Area Fisheris Resources;
- Section 2 – Benthic Macroinvertebrates; and
- Section 3 – Submerged Aquatic Vegetation

1 Study Area Fisheries Resources

It is important to recognize the configuration of bridge piers and their influence on river conditions in the study area. The placement of the bridge piers is not uniform, which is reflective of the dramatic changes in river bathymetry. Thus, the bridge habitat can be divided into three broad zones, as follows:

- Piers 1 to 168 - The water depths vary between 10 and 18 feet (3.05 and 5.5 m) Mean High Water (MHW). The bridge piers are spaced 50 (15.24 m) feet apart. Except for periods of slack tides, currents are present between the piers. The velocity of the current is increased by the presence of the pier caps and footings and the proximity to the main river channel. Currents are less pronounced at the shoreline.

- Piers 168 to 180 – These piers are spaced 50 to 200+ feet (15.24 to 61+ m) apart. Water depths vary between 20 and 50+ feet. Observations performed during the sampling program determined that the pier's influence on surface water velocity during ebb tides can be considerable.

- Piers 180 to 190 – The piers are spaced approximately 75 feet (22.9 m) apart. The water depths vary between 1 and 20 feet (0.3 and 6 m). Observations performed during the sampling program determined that the pier's influence on water velocity is minor.

1.1 Sampling Program

A year-long fish survey was conducted to document the seasonal variations in fish populations in the study area. Fish sampling was conducted every other month over a two-week period between April 2007 and May 2008. Prior to the start of the sampling program, the sampling plan was provided to the regulatory agencies for their comments. Agencies that reviewed and commented on the plan included the USEPA, NMFS, USFWS, NYSDEC, and the New York State Department of State (NYSDOS). In addition, due to the potential for encountering the endangered shortnose sturgeon, research permits were obtained from NMFS and NYSDEC.

As shown on Figure F-1-1, fish sampling occurred within the current bridge alignment and within the anticipated alignment of the proposed bridge. Fish sampling was accomplished by three methods: acoustic surveys, gill nets, and fish traps. Descriptions of these sampling methods are provided below.

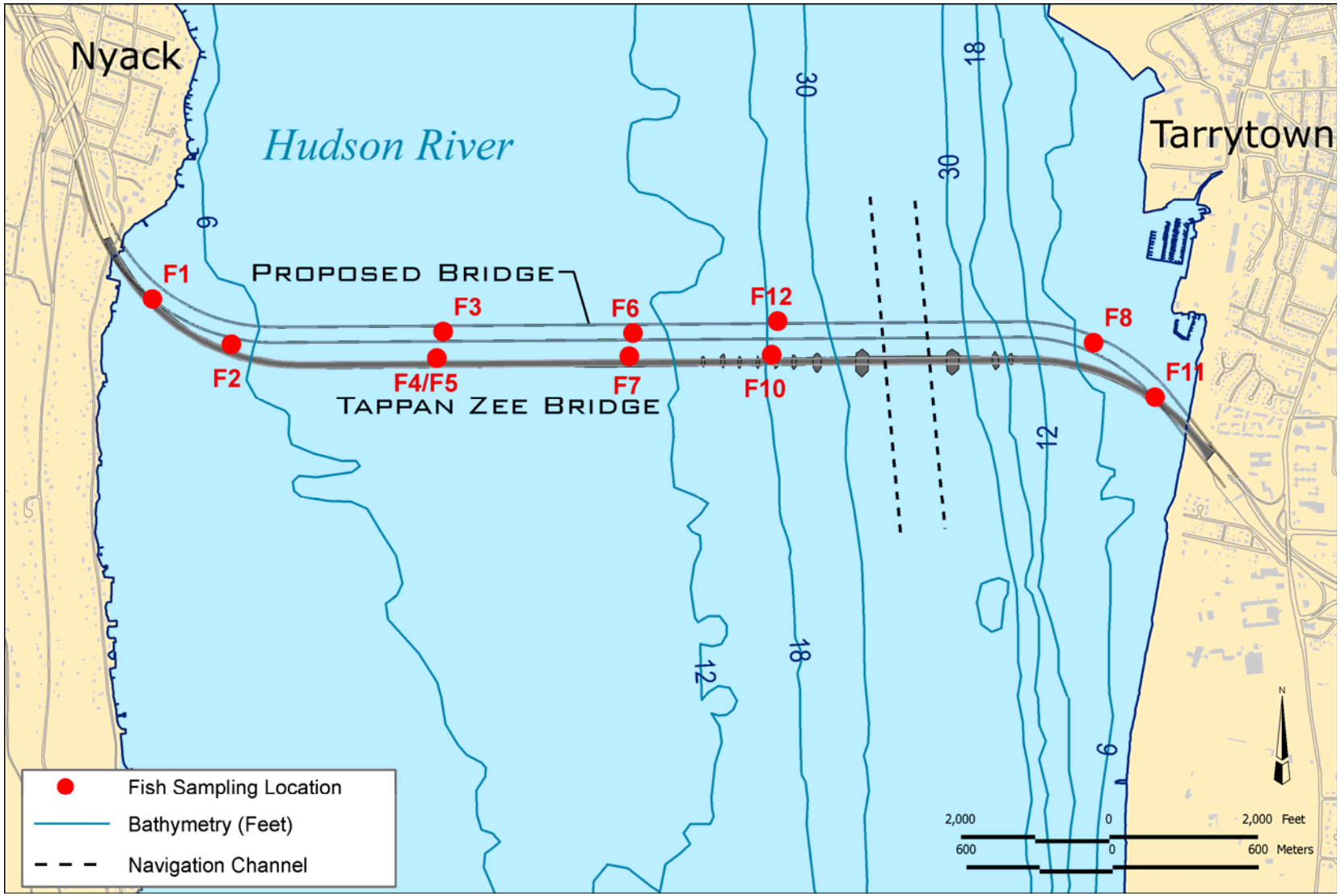

Figure F-1-1 Fish Sampling Locations

Hydroacoustic Survey

A mobile hydroacoustic survey to assess fish populations in the Hudson River was conducted using two 420-kiloHertz (-kHz) split-beam digital transducers (Figure F-1-2). The transducers were mounted on the starboard side of the survey vessel, approximately amidships, one mounted vertically along the side of the vessel and the second mounted horizontally. The transducers were controlled by an echosounder that was connected to a GPS and a data-collection computer. Data-collection parameters were 7 pings per second with a pulse duration of 0.4 milliseconds (ms). The data-collection threshold was set at 90 decibels (dB). Vessel speed was maintained at approximately 4.0 knots during the survey.

A total of 6 systematically located transects were surveyed (Figure F-1-3). Transect locations are labeled as follows:

- Transect 100S – located 100 feet (30.5 m) south of the existing bridge.
- Transect 50S – located 50 feet (15.24 m) south of the existing bridge.
- Transect 50N – located 50 feet (15.24 m) north of the existing bridge.
- Transect 100N – located 100 feet (30.5 m) north of the existing bridge.
- Transect 200N – located 200 feet (61 m) north of the existing bridge.
- Transect 400N – located 400 feet (122 m) north of the existing bridge.

Gill Nets

Experimental gill nets (Photo F-1-1) were deployed to capture and determine which fish species utilize the study area. The gill nets measured 8 feet (2.4 m) high by 125 feet (38.1 m) long and consisted of 5 gill net panels (each 25 feet (7.6 m) long) with mesh sizes ranging between 1 and 5 inches (2.5 and 12.7 cm). In order to keep the nets vertical in the water column, the gill nets are manufactured with a float line on the top of the net and a lead line on the bottom. Additional large surface floats (Photo F-1-2) were added to assist in keeping the net vertical in the water and to act as marker buoys to provide a warning to navigation. The gill nets were set in place using either 10- or 15-pound (4.5- or 6.8-kilogram [kg]) anchors placed at either end of the net. The attached lead line and anchors kept the bottom of the net on the river bottom. Gill nets were generally set perpendicular to the river flow, although some nets were set parallel to the flow when wind and tides did not allow for the net deployment and retrieval parallel to the flow.

To reduce fish mortality, the time each gill net was deployed (soak time) was based on a strict set of temperature criteria. These criteria were as follows:

- For temperatures below 59˚F (15˚C), the net could be deployed for a maximum of 4 hours.
- For water temperatures between 59 and 68˚F (15 and 20˚C), the net could be deployed for a maximum of 2 hours.
- For water temperatures between 68 and 80.6˚F (20 and 27˚C), the net could be deployed for a maximum of 1 hour.
- Nets were not deployed when water temperatures were above 80.6˚F (27˚C).

These soak times are consistent with *A Protocol for Use of Shortnose and Atlantic Sturgeons* (Moser et al. 2000). Upon retrieval of the net, all captured fish were identified by species and their lengths recorded (Photo F-1-3). The fish were then returned to the water.

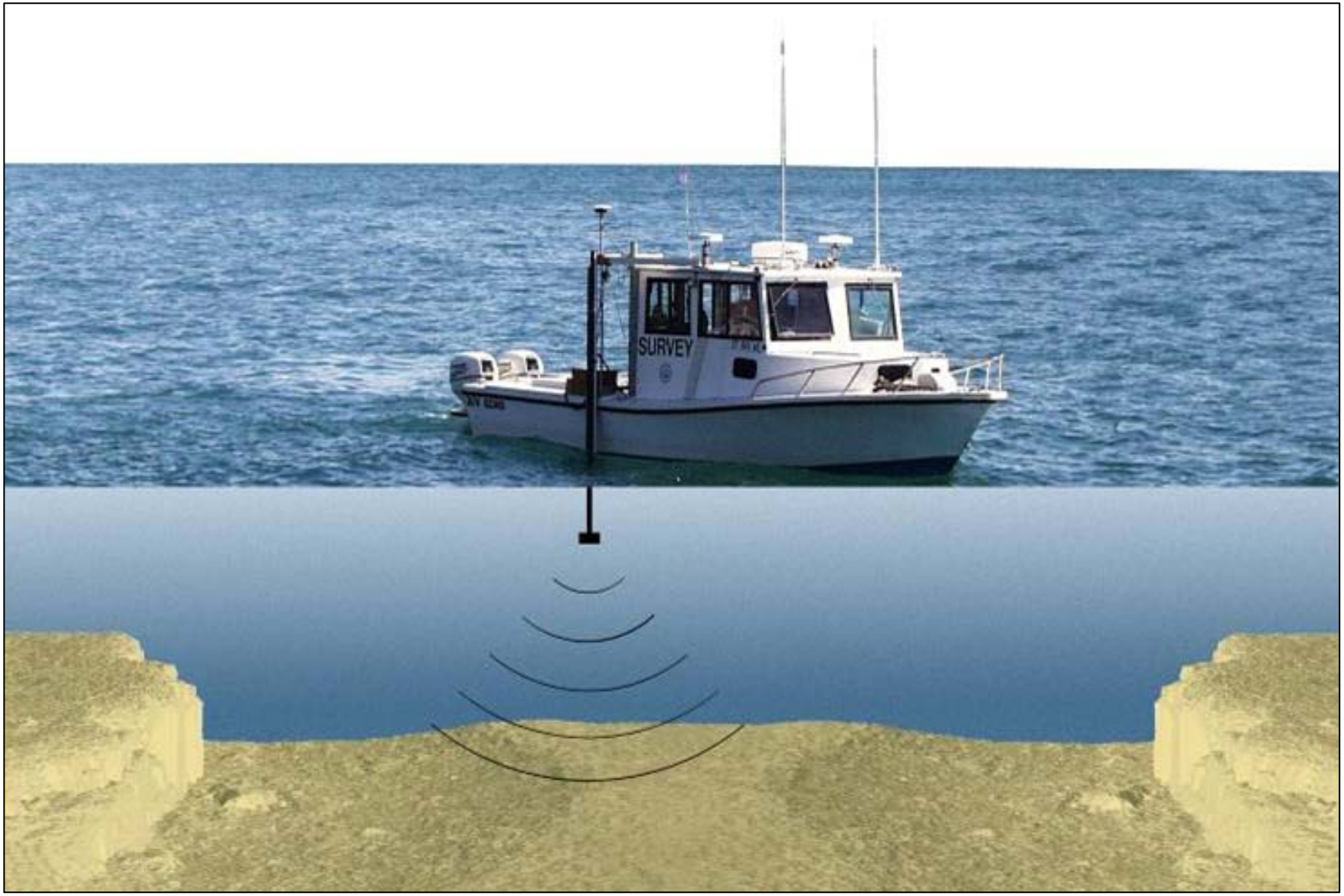

Figure F-1-2 Illustration of the Hydroacoustic Device

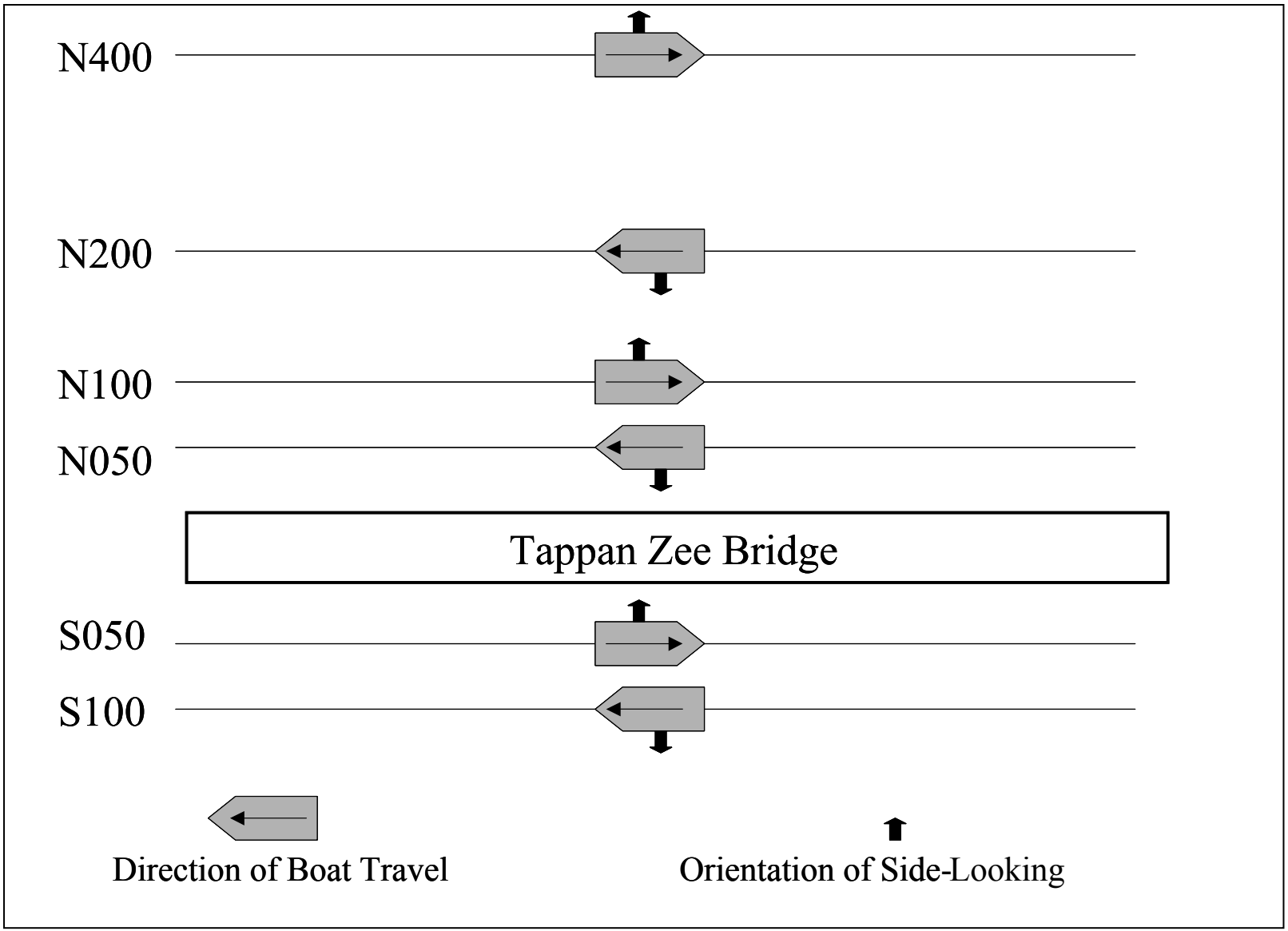

Figure F-1-3 Acoustic Transect Locations

Photo F-1-1 Experimental Gill Net Retrieval

Photo F-1-2 Surface Floats Depicting Gill Net Endpoints

Photo F-1-3 Captured Fish on Measuring Board

All personnel involved in the fish-sampling program were trained by NYSDEC in the proper handling of the endangered shortnose sturgeon and the Atlantic sturgeon. The Atlantic sturgeon is a candidate species for placement on the Threatened and Endangered Species List. Upon capture, the sturgeons were removed from the net and placed in a floating live well (Photo F-1-4) with ambient river water conditions. The floating net pen measured approximately 4 feet by 2 feet by 3 feet (1.2 m by 0.6 m by 0.9 m), with netting on all sides. The pen allowed for the sturgeon to be secured in ambient river conditions, to reduce the stress on the fish. The sturgeons were scanned both visually and electronically for the presence of identification tags. For tagged fish, the information was recorded and provided to the regulatory agencies. The sturgeons were also weighed and measured. The sturgeons were placed in a saline electrolyte bath to reduce stress and restore slime coat. When handling the fish, the scientists donned surgical gloves to further reduce stress on the fish. All sturgeons were handled for less than 15 minutes and returned to the river unharmed. Individuals of all other species of fish were placed within the pen after capture. Each individual was identified to species and measured for length and then returned to the river.

Photo F-1-4 Floating Live Well

Sampling Locations

A total of nine fish-sampling sites were utilized for the gill nets and fish traps. Sampling occurred between the 6-foot (1.8-m) and 35-foot (10.7-m) bathymetric contours. In order to determine the habitat conditions around the existing bridge, six sites were directly adjacent to and/or underneath the bridge. In addition, three sites were selected as reference locations within 500 and 600 feet (152.4 and 182.9 m) north of the bridge. The reference sites were selected to provide locations similar in depth, bathymetry, and sediment characteristics to the bridge pier locations. These locations were also comparable in depth and bottom type to that of the possible replacement bridge locations.

Nets were not deployed in water depths greater than 35 feet (10.7 m), as that would have required the deployment of the nets in an active ship channel. Also, very strong currents are encountered at water depths greater than 30 feet (9.1 m). Descriptions of the nine fish-sampling locations are provided below.

- **Bridge Sampling Sites**

  Site F1, approximately 462 ft (140.8 m) from the western shoreline. The water depths ranged from 7 to 11 feet (2.1 and 3.4 m) and the benthic habitat consisted of soft silt.

  Site F2, located approximately 0.34 mi (0.55 km) from the western shoreline. The water depths ranged between 10 and 14 ft (3.0 and 4.3 m) and the benthic habitat consisted of soft silt.

  Site F4/F5, located approximately 0.86 mi (1.38 km) from the western shoreline. The water depths ranged between 11 and 15 ft (3.4 and 4.6 m) and the benthic habitat consisted of soft silt with some shell material.

Site F7, located approximately 1.35 mi (2.17 km) from the western shoreline. The water depths ranged between 13 and 17 feet (4.0 and 5.2 m) and the benthic habitat consisted of silt with shell material. Oyster shells were periodically encountered in this location.

Site F10, located approximately 1.08 mi (1.74 km) from the eastern shoreline. The water depths ranged between 25 and 34 feet (7.6 and 10.4 m) and the benthic habitat consisted of scoured sediments and oyster reefs.

Site F11, located approximately 481 ft (146.61 m) from the western shoreline. The water depths ranged between 6 and 10 feet (1.8 and 3.0 m) and the benthic habitat consisted of soft silt.

In April and June 2007, two other sampling sites were utilized – Sites F5 and F9. Site F5 was originally located approximately 1.0 mile (1.61 km) from the western shoreline in approximately 12 feet (3.7 m) of water. However, in June 2007, sampling site F5 was removed in order to create the deep-water sampling site F10. Site F9 was moved closer to the east bank of the river and renamed Site F11.

- **Reference Sampling Sites**

Site F3, located approximately 0.86 mi (1.38 km) from the western shoreline and approximately 500 feet (152.4 m) north of the bridge. The water depths ranged from 10 to 14 feet (3.0 and 4.3 m) and the benthic habitat consisted of soft silt.

Site 8, located approximately 0.27 mi (0.43 km) from the eastern shoreline and approximately 500 feet (152.4 m) north of the bridge. The water depths ranged between 9 and 13 feet (2.7 and 4.0 m) and the benthic habitat consisted of soft silt.

Site 12, located approximately 1.09 mi (1.75 km) from the eastern shoreline and approximately 500 feet (152.4 m) north of Site 10. The water depths ranged between 24 and 32 feet (7.3 and 9.8 m) and the benthic habitat consisted of scoured clays with oyster reefs.

In April and June 2007, reference sampling Site F6, located approximately 1.35 mi (2.17 km) from the western shoreline, was utilized. This location was in approximately 14 feet (4.3 m) of water. This location was abandoned to create the deep-water reference sampling site F12.

Fish Traps

Fish traps were deployed to identify the young-of-the-year (YOY) fish resources in the area of the bridge. The traps were designed to have an opening of 1 inch or less, to prevent predation by larger fish or crabs.

In April 2007, two unbaited fish nets sized for small YOY fish were deployed at each location; each net measured 35.9 x 18.1 x 11.8 inches (91 x 46 x 30 centimeters [cm]), with 2-mm mesh stretched over the frame with a single V-shaped 1 x 18.1-inch (2.5 x 46-cm) throat and a 0.12-inch (F-1-mm) nylon mesh cod end. These traps were weighted and marked with buoys for easy retrieval. However, the traps often fouled and ripped due to strong currents and debris around the bridge. Also, on several occasions the weighted traps were swept away by strong currents encountered during winter conditions. Due to the multiple problems encountered with these traps, in June 2007 through May 2008, smaller traps – standard minnow traps (Photo F-1-5) – were placed along the bridge piers and at reference locations at various depths. The traps were baited and secured to the piers so that they would not be dislodged by river currents. Approximately 20 traps were deployed day and night for each two-week sampling period. The traps were deployed at various depths from 2 to 15 feet (0.6 to 4. 6 m) below mean low water (MLW).

Photo F-1-5 Standard Minnow Trap

1.2 Results

Hydroacoustic Survey

A description of each monthly sampling effort is provided below. For each sampling event, the water-quality data did not reveal any water-quality parameters that would significantly limit fish distributions, such as depleted oxygen levels or excessive temperatures.

April 2007

A total of 656 fish were identified during the April 2007 hydroacoustic survey. The greatest abundance of fish occurred south of the existing bridge structure (Figure F-1-4). As can be observed in the figure, approximately 155 fish were observed at Transect 100S. There were progressively fewer fish observed on the northern transects. The survey was conducted between one hour before low tide and four hours after low tide. Transect 100S was conducted at approximately one hour before low tide. Transects 50S and 50N were conducted at slack low water. Transects 100N, 200N, and 400N were conducted on a rising tide, approximately two hours, three hours, and four hours, respectively, after low tide.

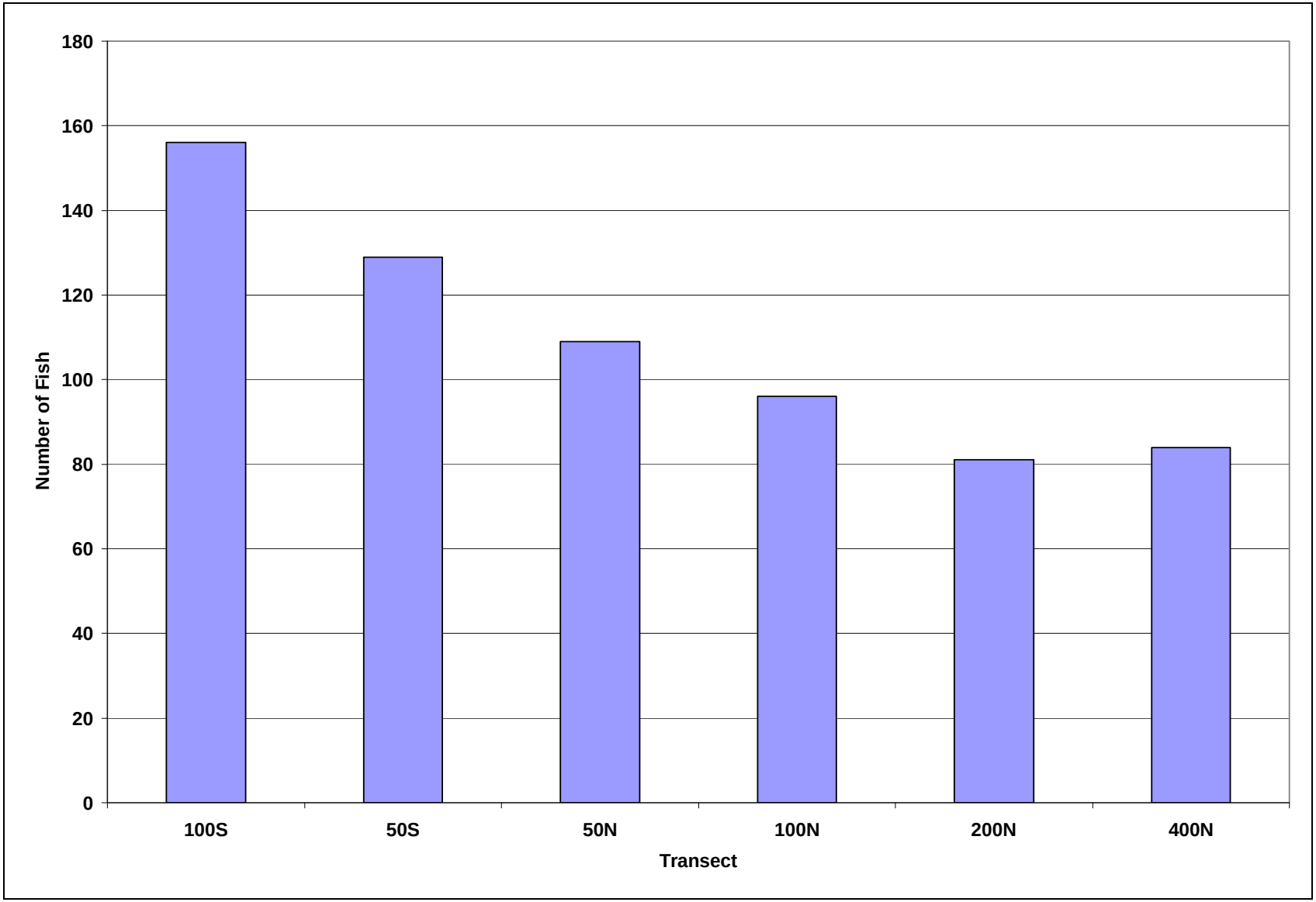

Figure F-1-4 Number of Fish Recorded on Each Acoustic Transect (April 2007)

The horizontal distribution showed that the fish were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline. Figure F-1-5 illustrates the distribution of fish identified across the river at transects 100S and 50S. As can be observed in the figure, the majority of fish are located within the deep channel.

The hydroacoustic and water-quality survey conducted in April 2007 suggested that the main environmental parameter governing fish distribution in the Hudson River is salinity. The greatest number of fish was observed in the main channel at depths below the halocline (approximately 19.7 feet [6 m]).

The hydroacoustic results indicate that the field sampling program may be underestimating the number of smaller fish (<5.9 inches [15 cm] total length) in the area. The hydroacoustic results indicated the presence of a large number of smaller fish that were absent from the April 2007 gill net survey.

June 2007

A total of 122 fish were identified during the June 2007 hydroacoustic survey. The greatest abundance of fish occurred north of the existing bridge structure. Figure F-1-6 illustrates the number of fish identified per transect. As can be observed in the figure, relatively similar numbers of fish were observed at transects 50N, 100N, and 200N, with substantially fewer fish observed at the other three transects. The survey was conducted throughout the tidal cycle. Transect 400N was conducted approximately three hours before high tide. Transects 100S and 50S were conducted at high tide and one hour after high tide, respectively. Transects 200N, 100N, and 50N were conducted on a falling tide, approximately two hours, three hours, and four hours after high tide, respectively.

The horizontal distribution of fish showed that they were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline.

August 2007

A total of 555 fish were identified during the August 2007 hydroacoustic survey. The greatest abundance of fish occurred north of the existing bridge structure. Figure F-1-7 illustrates the number of fish identified per transect. As can be observed in the figure, approximately 195 fish were observed at transect 200N. The survey was conducted throughout the tidal cycle. Transect 50S was conducted at the end of low tide. Transects 100S, 100N, and 50N were conducted at three hours, two hours, and one hour, respectively, before high tide. Transects 200N and 400N were conducted at high tide and one hour after high tide. The horizontal distribution of fish showed that they were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline.

In the absence of any water-column structure (i.e., thermoclines or haloclines) the fish did not appear to exhibit any spatial aggregations vertically. Horizontal distributions were centered on the main channel.

October 2007

A total of 321 fish were identified during the October 2007 hydroacoustic survey. The greatest abundance of fish occurred south of the existing bridge structure. Figure F-1-8 illustrates the number of fish identified per transect. As can be observed in the figure, approximately 115 and 100 fish were observed at transects 100S and 50S, respectively. The survey was conducted throughout the tidal cycle. Transect 50S was conducted at the end of low tide. Transects 100S, 50N, and 100N were conducted at one hour, two hours, and three hours after high tide, respectively. Transects 200N and 400N were conducted at one hour before high tide and at high tide, respectively.

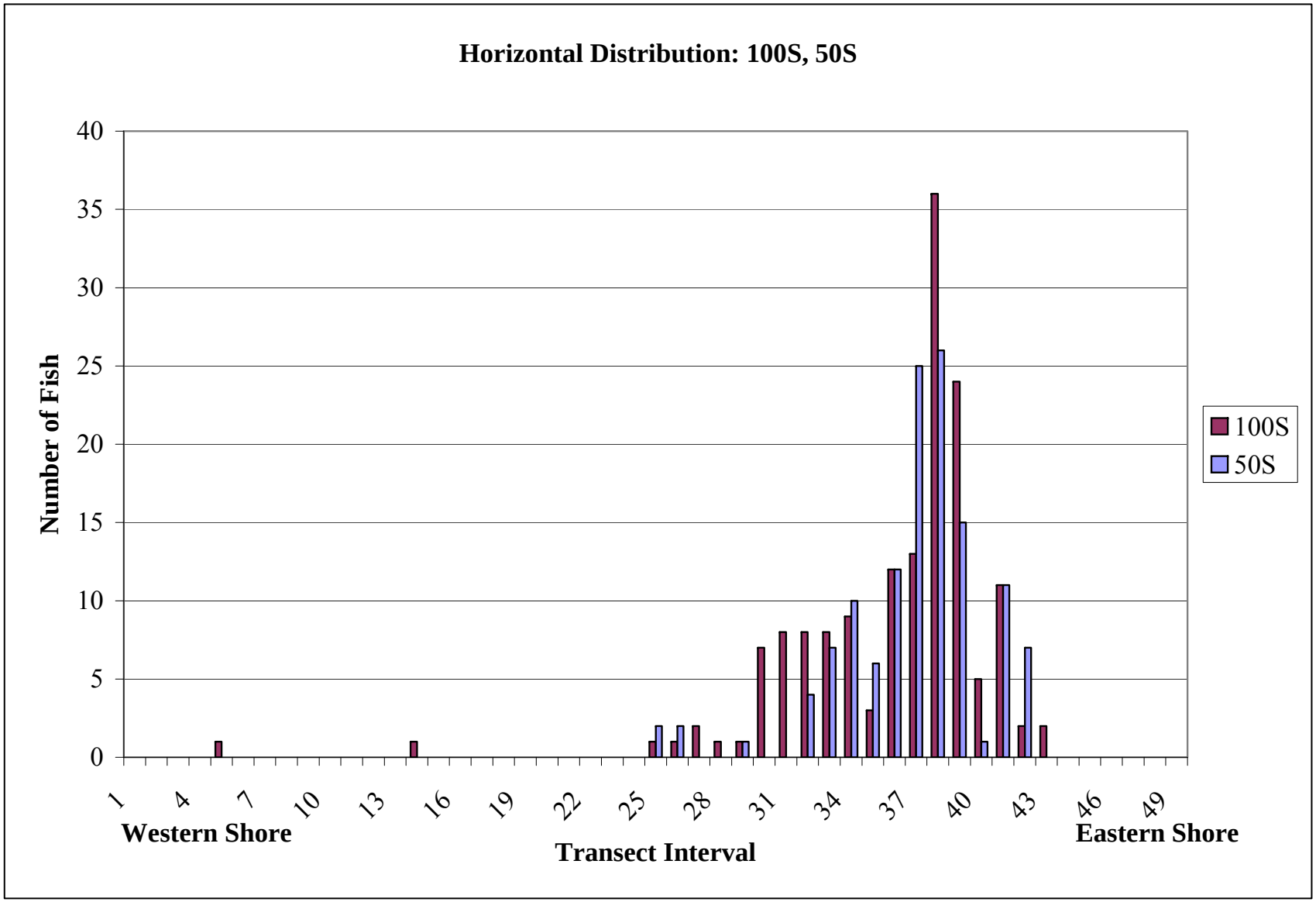

Figure F-1-5 Horizontal Distribution of Fish from West to East across the River (April 2007)

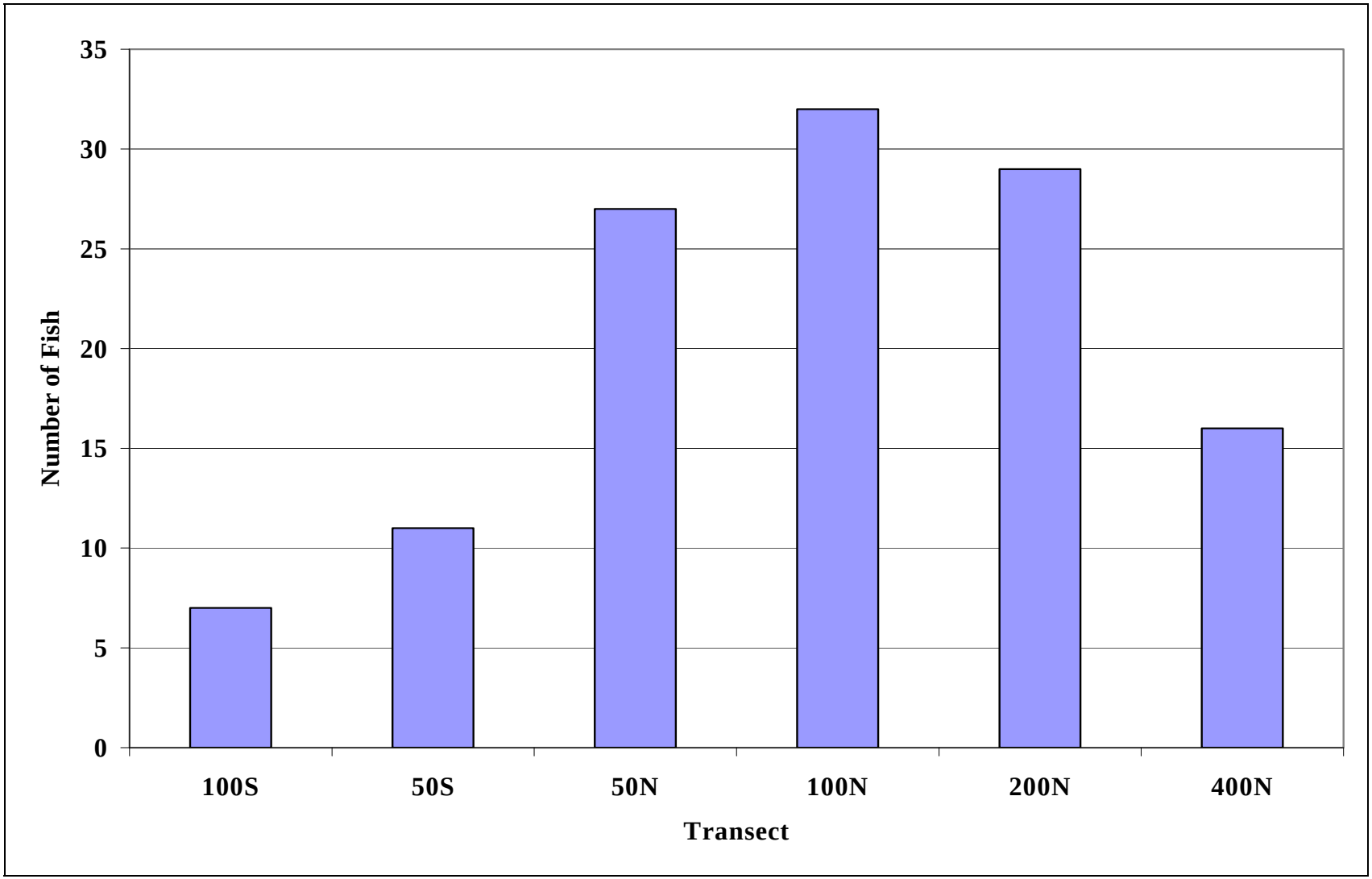

Figure F-1-6 Number of Fish Recorded on Each Acoustic Transect (June 2007)

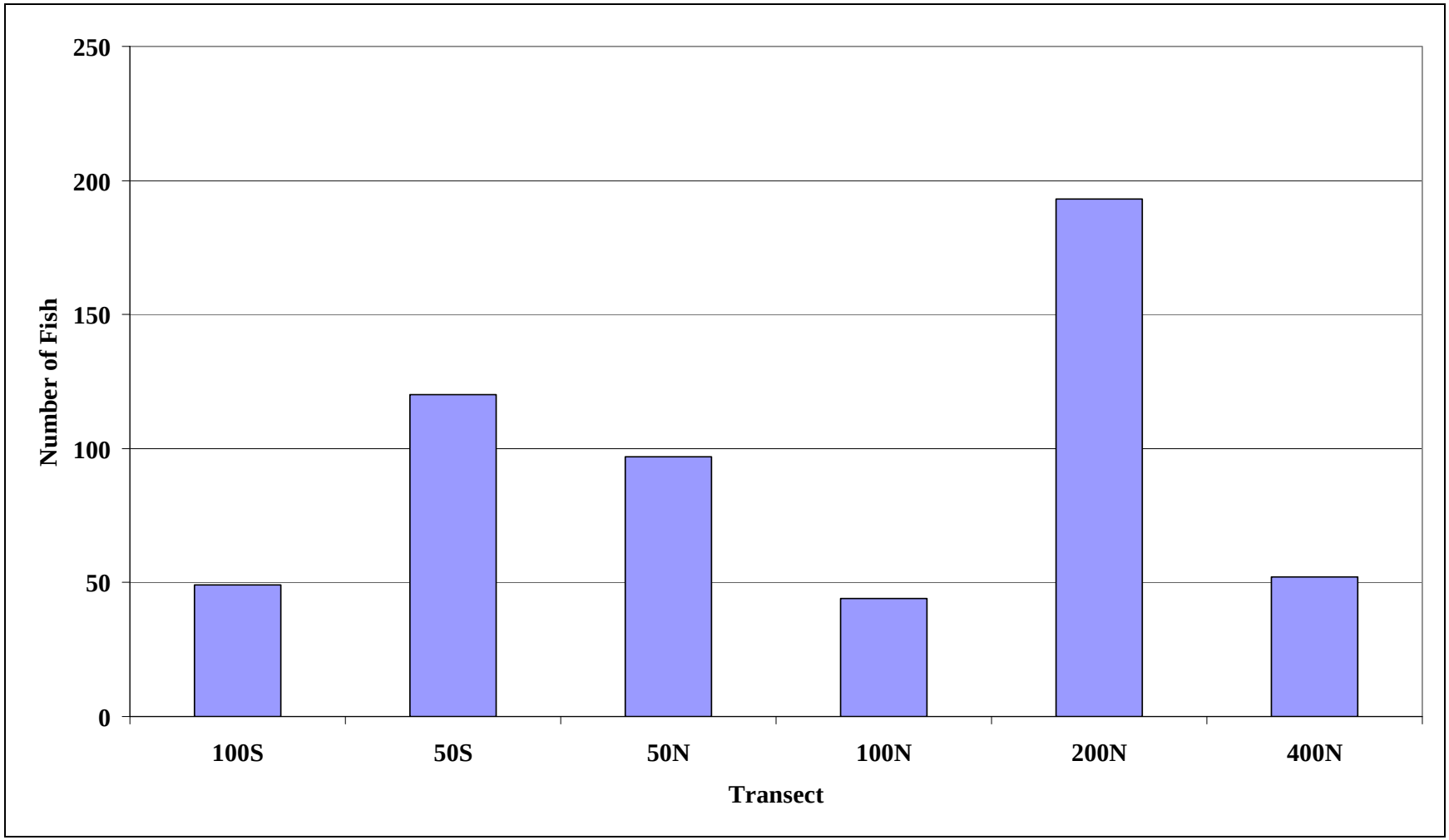

Figure F-1-7 Number of Fish Recorded on Each Acoustic Transect (August 2007)

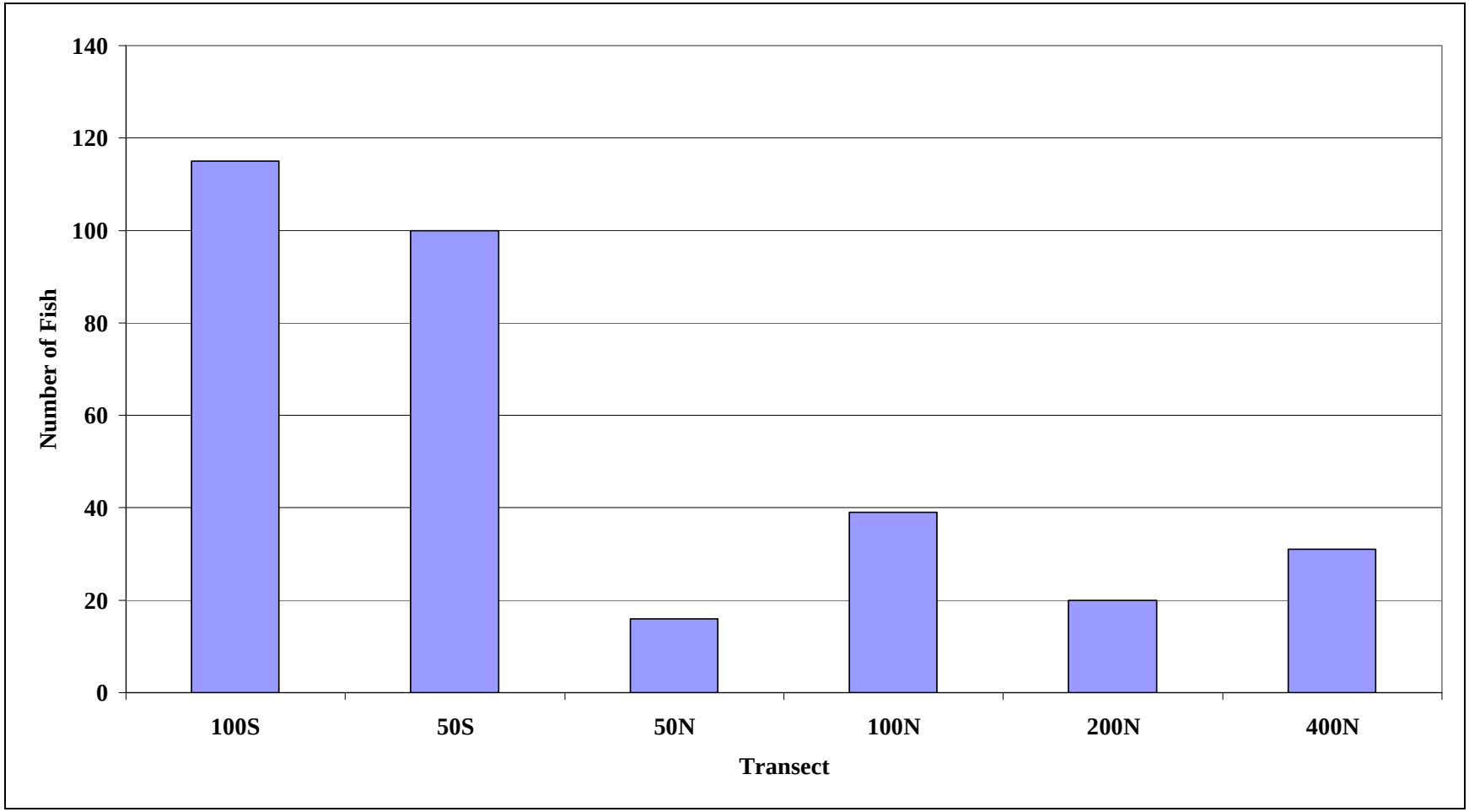

Figure F-1-8 Number of Fish Recorded on Each Acoustic Transect (October 2007)

Figure F-1-9 illustrates the horizontal distribution of fish identified across the river. As can be observed in the figure, the majority of fish are located within the deep channel; although more fish were recorded in shallower locations. The increased number of fish in shallow water is likely the result of warmer more saline waters in shallower locations and utilization of these areas by marine summer residents. Several fish schools were observed during the survey; all were presumed to be schools of bay anchovy.

In the absence of any water-column structure (i.e., thermoclines or haloclines) the fish did not appear to exhibit any spatial aggregations vertically. Horizontal distributions were centered on the main channel.

December 2007

A total of 300 fish were identified during the December 2007 hydroacoustic survey. The greatest abundance of fish occurred away from the existing bridge structure. Figure F-1-10 illustrates the number of fish identified per transect. As can be observed in the figure, a majority of the fish was observed at the 200S and 400N transects. The survey was conducted from three hours before high tide to two hours after high tide. Transects 400N, 100S, and 50S were conducted at three hours, two hours and one hour before high tide, respectively. Transects 50N, 100N, and 200N were conducted at high tide, one hour, and two hours after high tide, respectively. The horizontal distribution of fish showed that they were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline.

In the absence of any water-column structure (i.e., thermoclines or haloclines) the fish did not appear to exhibit any spatial aggregations vertically. Horizontal distributions were centered on the main channel.

February 2008

A total of 520 fish were identified during the February 2008 hydroacoustic survey. The fish were relatively evenly distributed among the transects, with the exception of 400N, where roughly 50 percent fewer fish were observed. Figure F-1-11 illustrates the number of fish identified per transect. The survey was conducted throughout the tidal cycle. Transects 100S and 50S were conducted at high tide and one hour after high tide, respectively. Transects 50N, 100N, 200N, and 400N were conducted at three hours, two hours, one hour before low tide, and at low tide, respectively. The horizontal distribution of fish showed that they were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline. Both water temperatures and salinities were low and constant vertically and horizontally throughout the study area.

In the absence of any water-column structure (i.e., thermoclines or haloclines) the fish did not appear to exhibit any spatial aggregations vertically. Horizontal distributions were centered on the main channel.

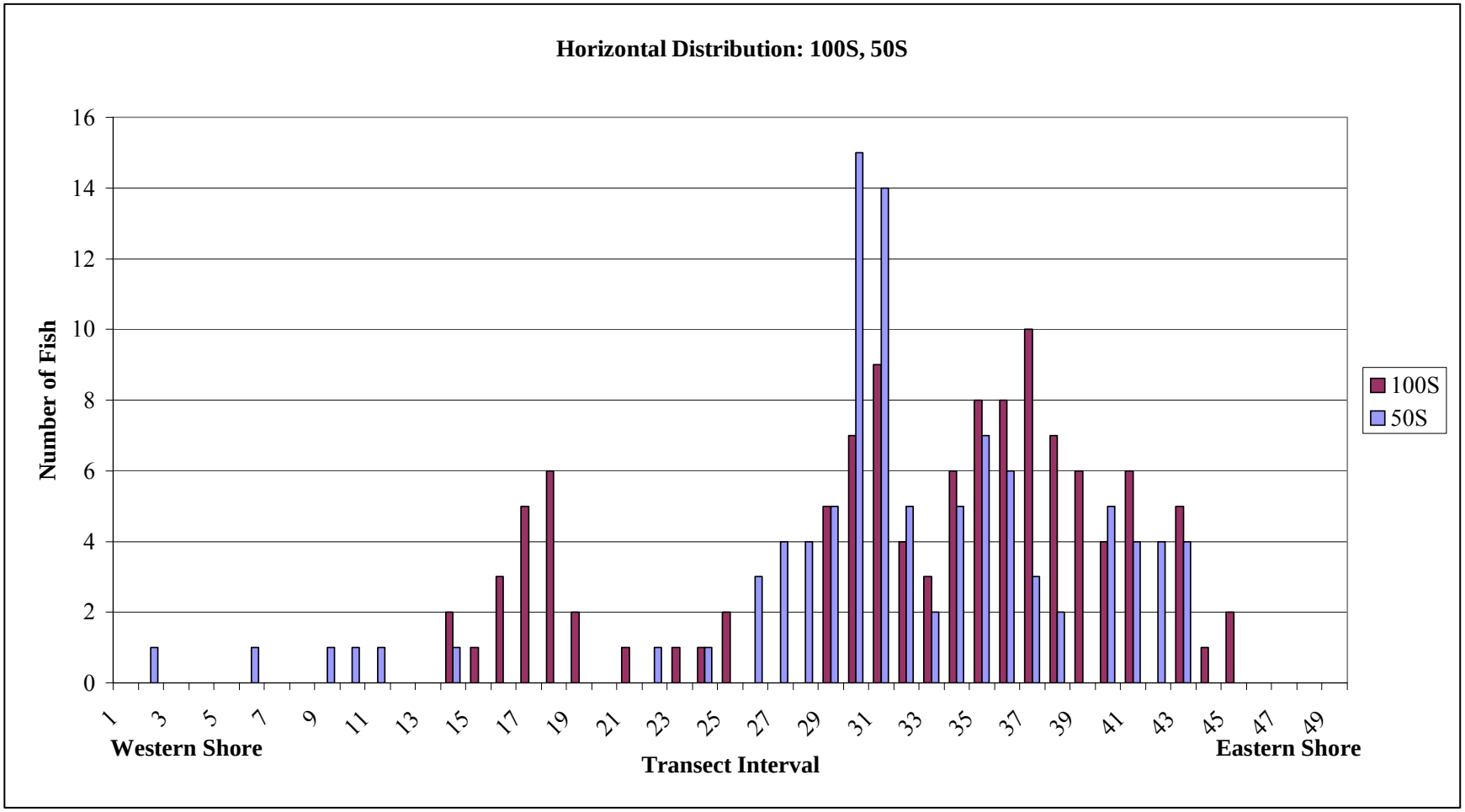

Figure F-1-9 Horizontal Distribution of Fish From West to East (October 2007)

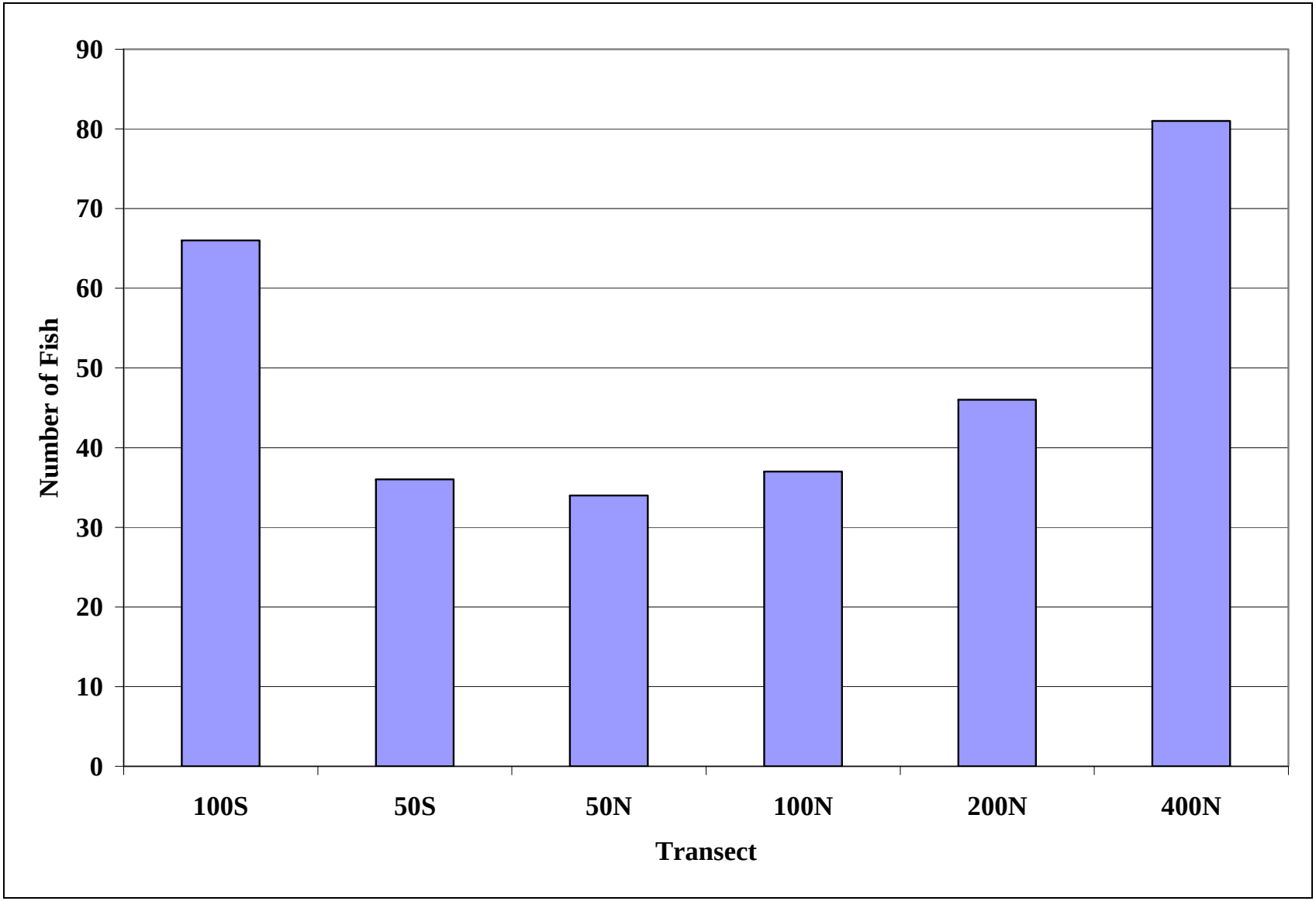

Figure F-1-10 Number of Fish Recorded on Each Acoustic Transect (December 2007)

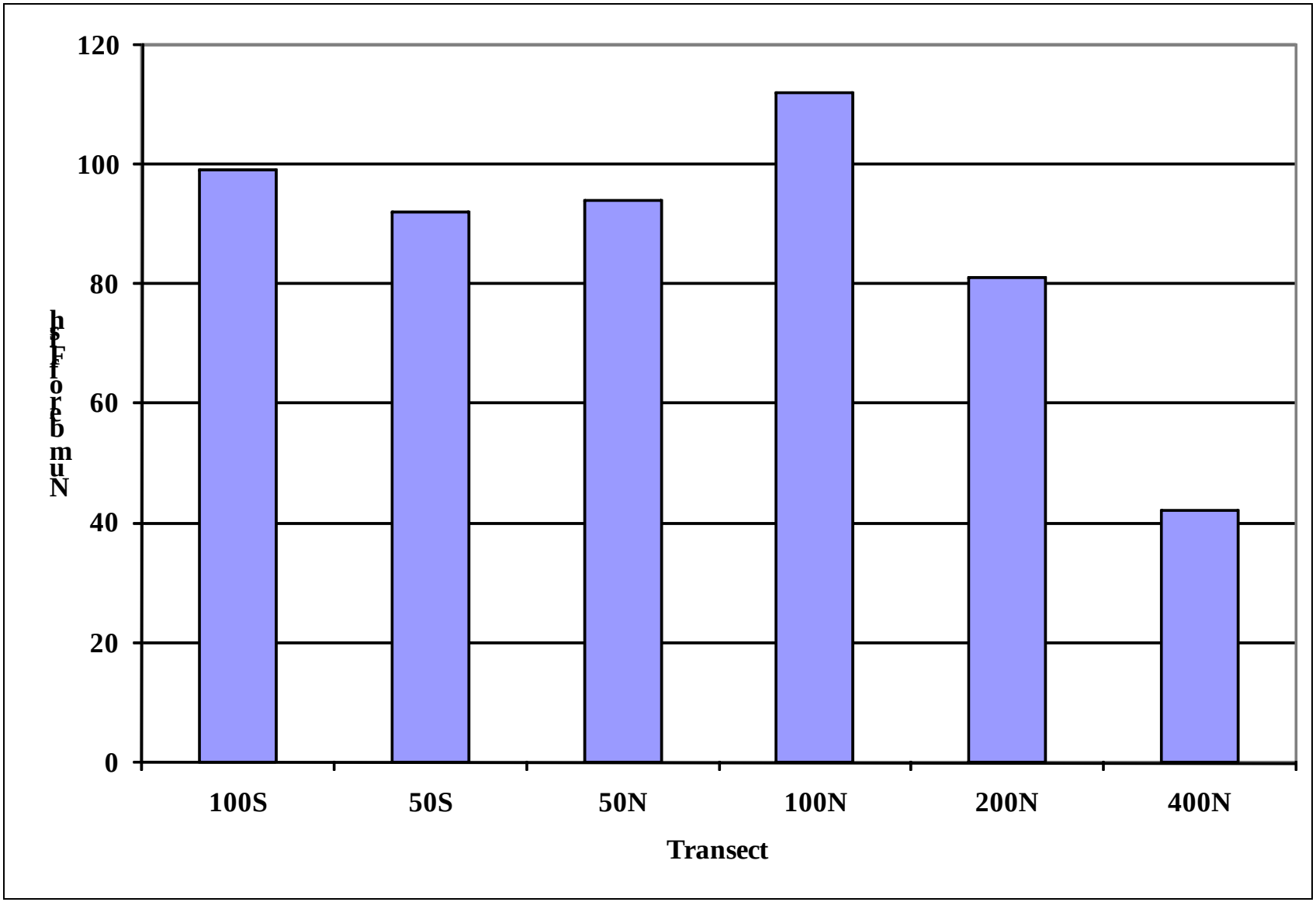

Figure F-1-11 Number of Fish Recorded on Each Acoustic Transect (February 2008)

May 2008

A total of 703 fish were identified during the May 2008 hydroacoustic survey. The greatest abundance of fish occurred on the northern side of the existing bridge structure. Figure F-1-12 illustrates the number of fish identified per transect. The survey was conducted throughout the tidal cycle. Transects 400N, 200N, and 50N were conducted five hours, four hours, and three hours before low tide and at low tide, respectively. Transects 50N, 50S, and 100S were conducted at one hour before low tide, at low tide, and one hour after high tide, respectively. The horizontal distribution of fish showed that they were concentrated in the main channel of the river, with relatively few fish observed in the shallow water that extends from each shoreline. Although fish were distributed throughout the water column, the majority of fish appeared to aggregate below the halocline.

Summary of Hydroacoustic Sampling

The hydroacoustic survey studied the horizontal, vertical, and geographic distribution of fish in the Hudson River. The horizontal distribution of fish in the river showed that they concentrate primarily in the deep water portion of the channel. The study also concluded that salinity is a major factor in determining the vertical distribution of fish. In the late winter and early spring, a distinct halocline is present near a depth of 19.7 feet (6 m). As the water column becomes stratified, with higher salinities at depth, the fish are concentrated in the deeper portions of the channel. As the water temperature warms, the halocline dissipates and fish are more likely to appear in shallow waters. The geographical distribution showed that in the colder months of the year, the fish tend to concentrate south of the bridge. In the warmer portions of the year, greater numbers of fish tend to be concentrated north of the bridge. Presumably these concentrations reflect several factors:

- In the winter, waters with higher salinities occur south of the bridge (towards New York Harbor and the Atlantic Ocean).
- In the warmer months (June through October), the salinity increases throughout the Tappan Zee Reach and the fish utilize the entire reach as a habitat resource.
- For no sampling event did the water-quality data reveal any water-quality parameters that would significantly limit fish distributions, such as depleted oxygen levels or excessive temperatures. Also, no discernible patterns with respect to fish populations could be attributed to the tide stage.

Results (Gill Nets and Traps)

Gill nets were deployed for more than 800 hours during the study. The nets captured 2,004 fish and hundreds of blue crabs. Fish that were captured in the nets were identified to species and measured for length. If a fish fell out of the net during net retrieval, the species was recorded and the length estimated. All captured sturgeons were handled in accordance with NOAA and NYSDEC regulations, measured for length, weighed, and scanned both visually and electronically for identification tags.

Figures F-1-13 through F-1-21 show the deployment locations and directional orientation of each individual net.

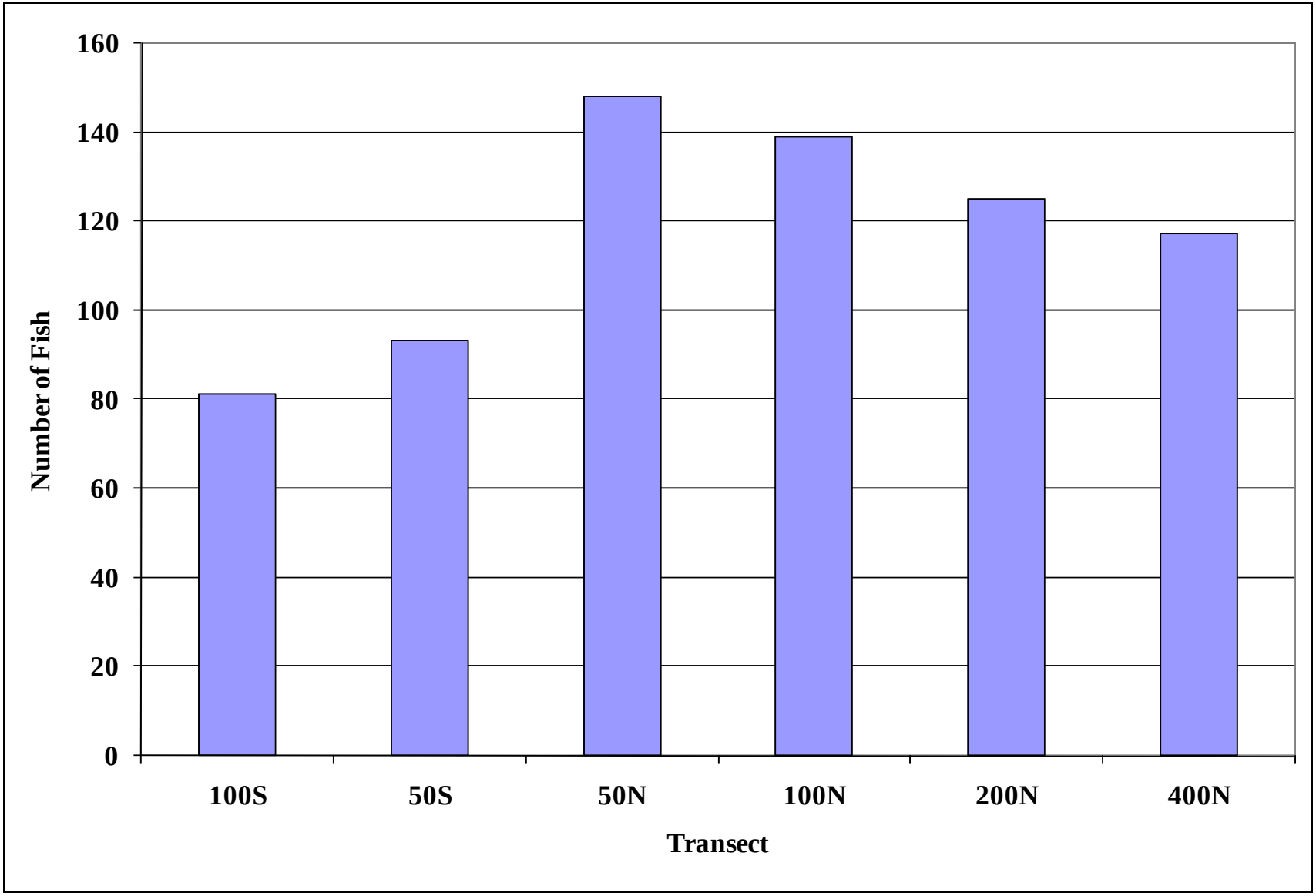

Figure F-1-12 Number of Fish Recorded on Each Acoustic Transect (May 2008)

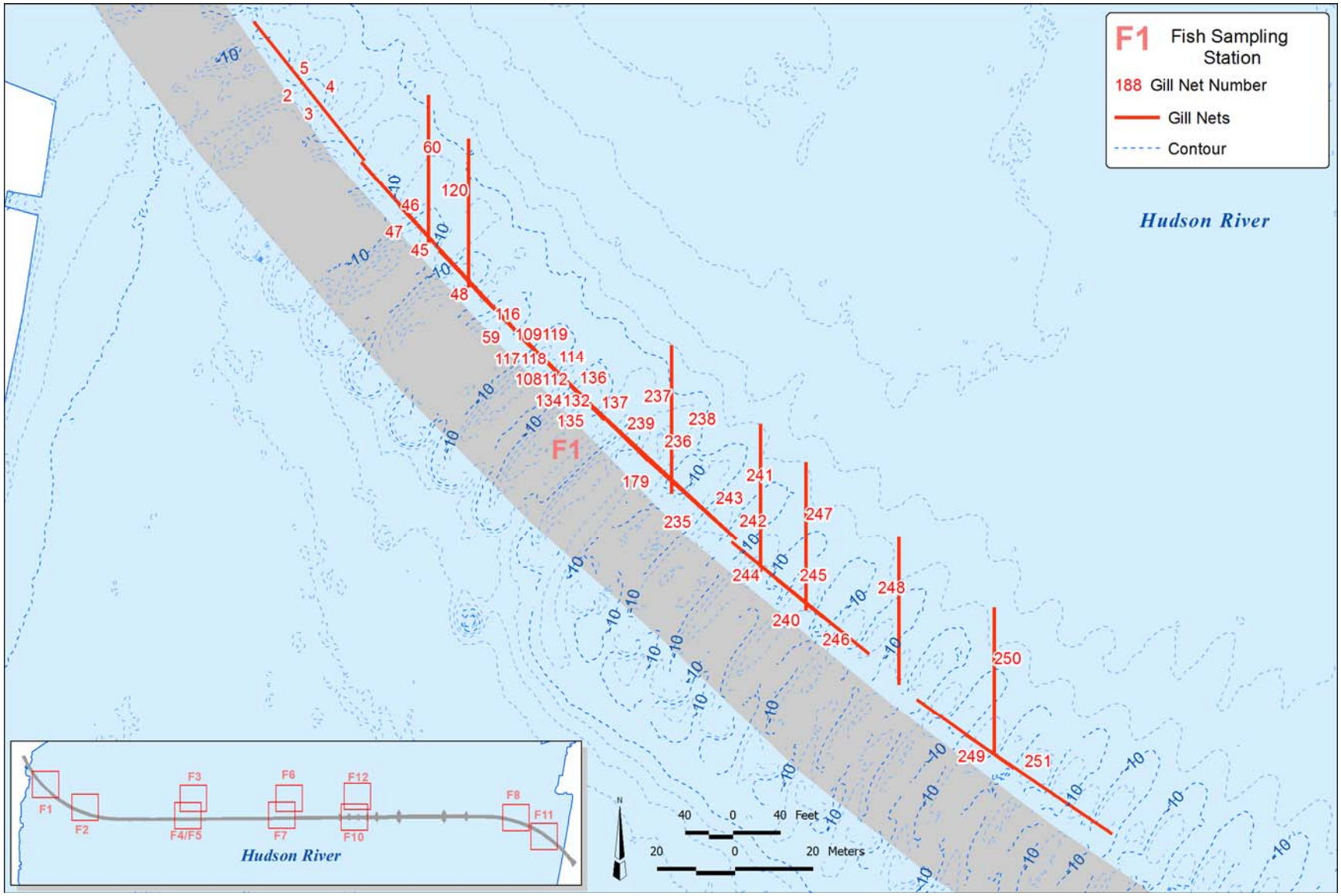

Figure F-1-13 Gill Net Deployment Locations at F1

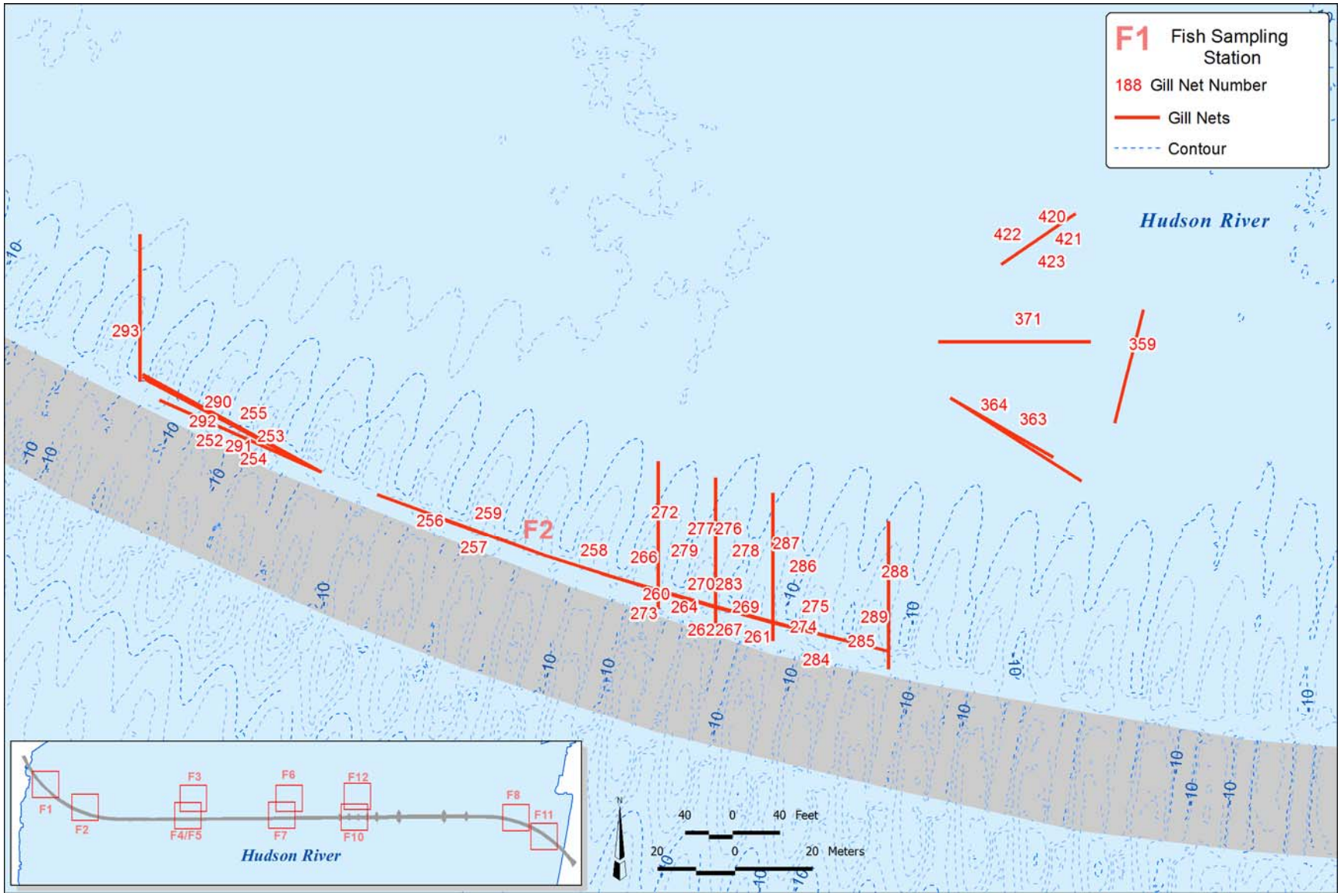

Figure F-1-14 Gill Net Deployment Locations at F2

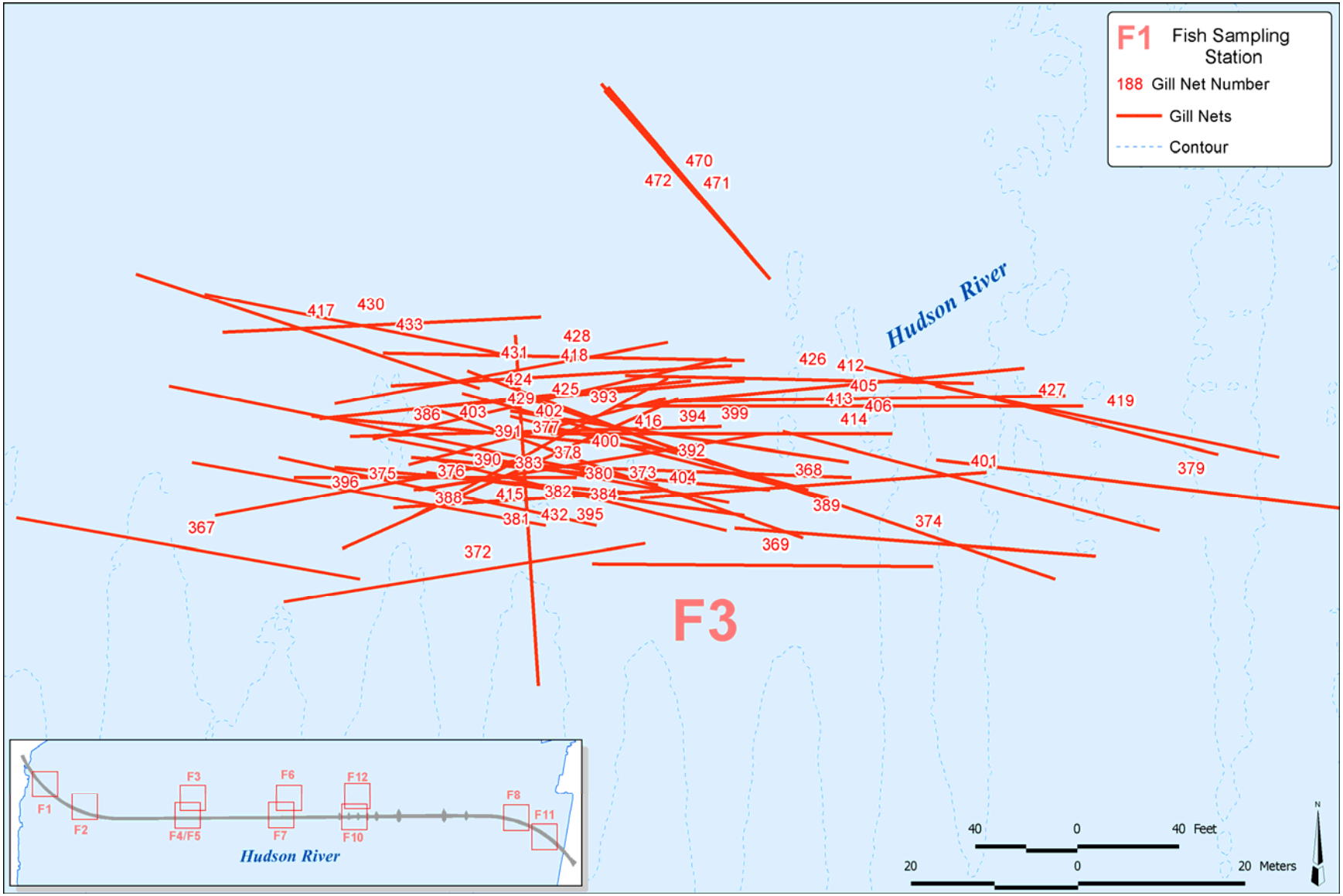

Figure F-1-15 Gill Net Deployment Locations at F3

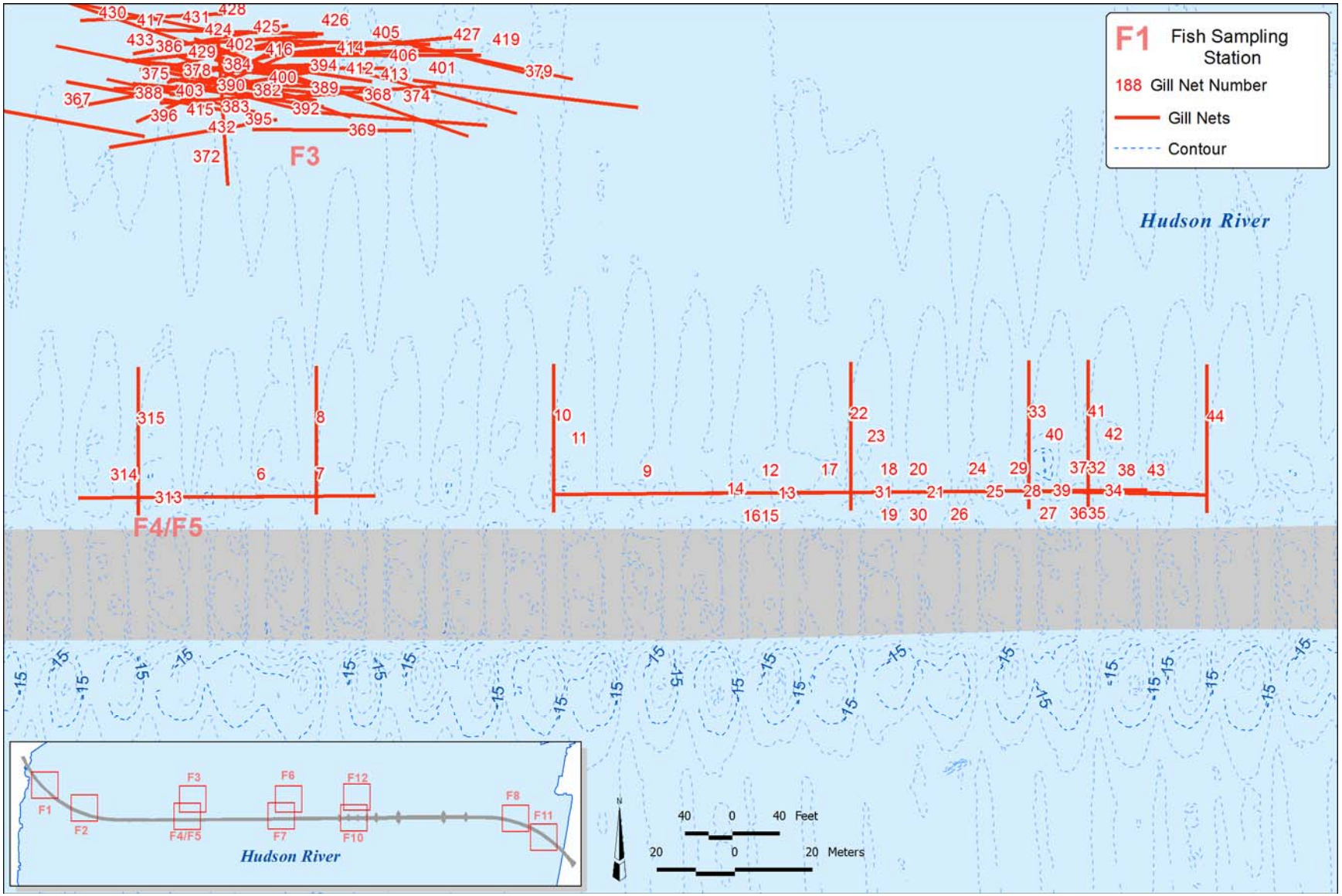

Figure F-1-16 Gill Net Deployment Locations at F4/5

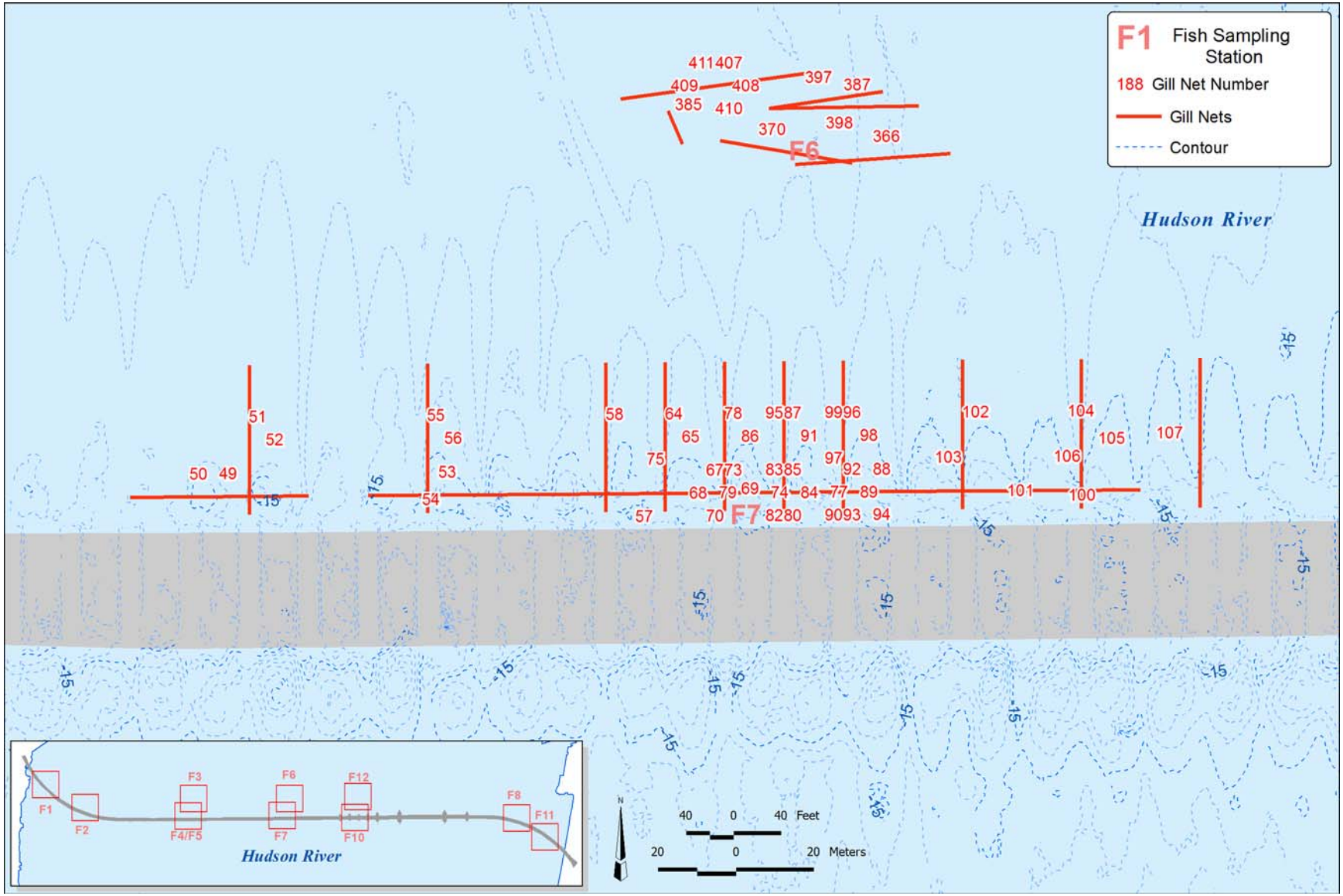

Figure F-1-17 Gill Net Deployment Locations at F6 and F7

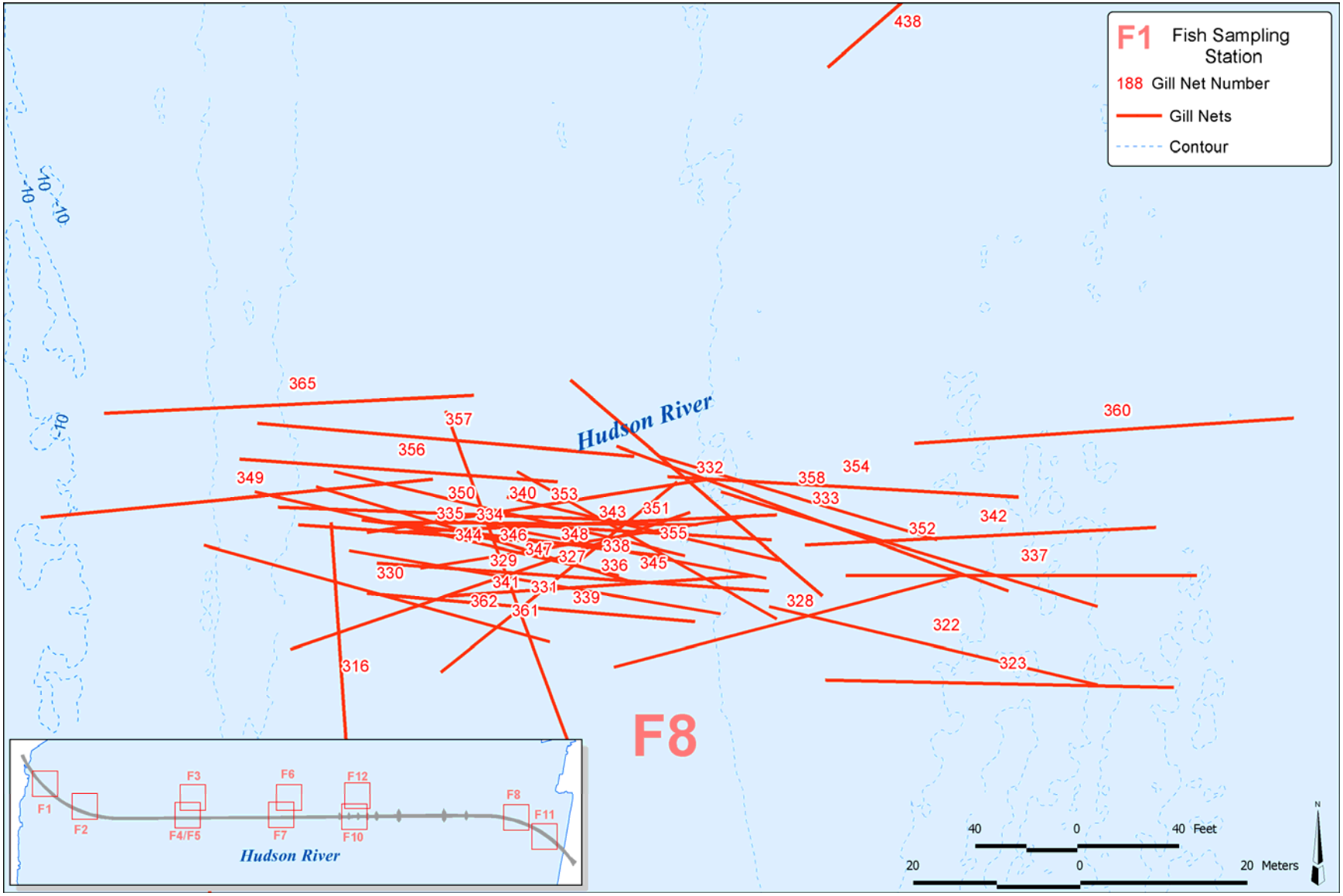

Figure F-1-18 Gill Net Deployment Locations at F8

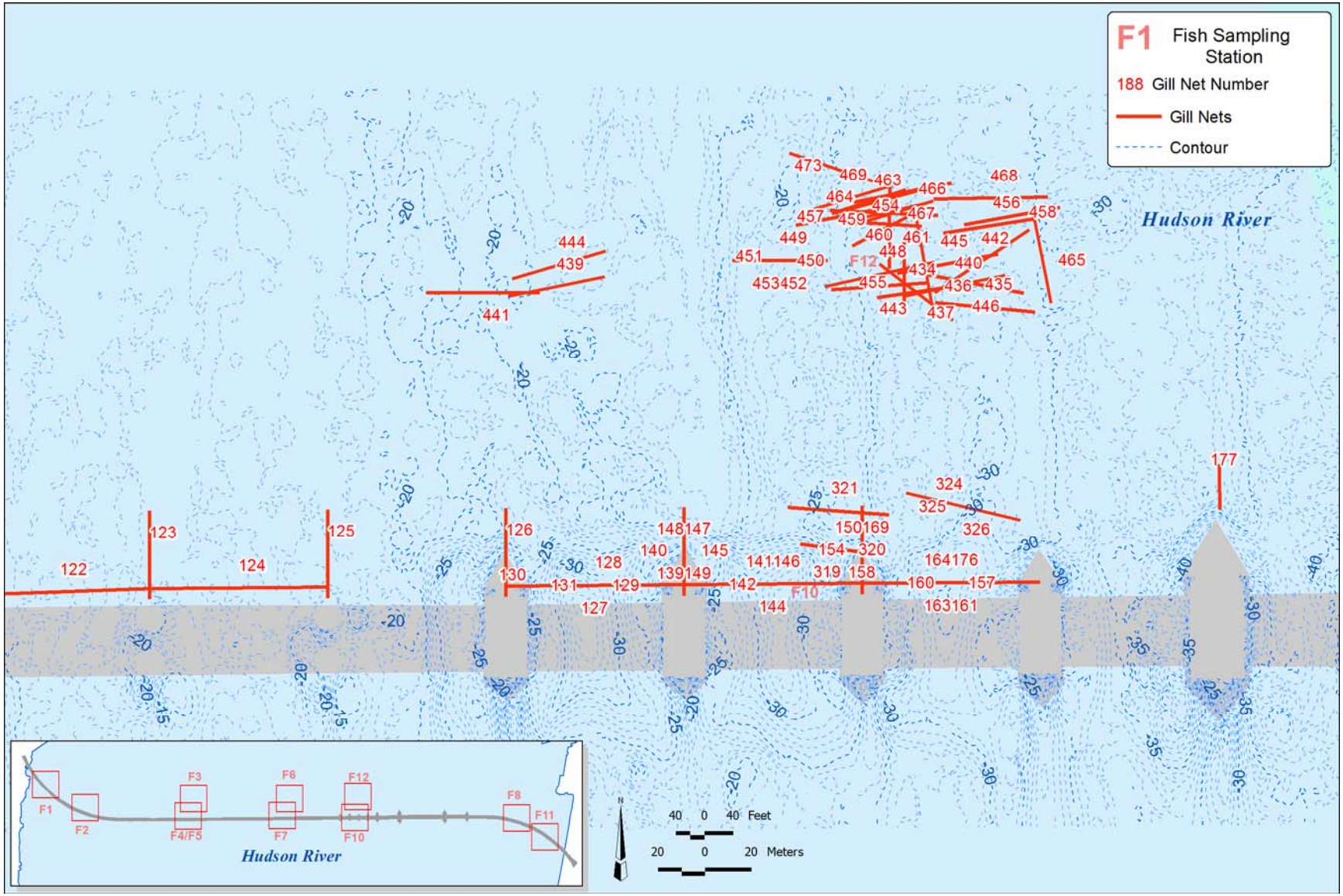

Figure F-1-19 Gill Net Deployment Locations at F10 and F12

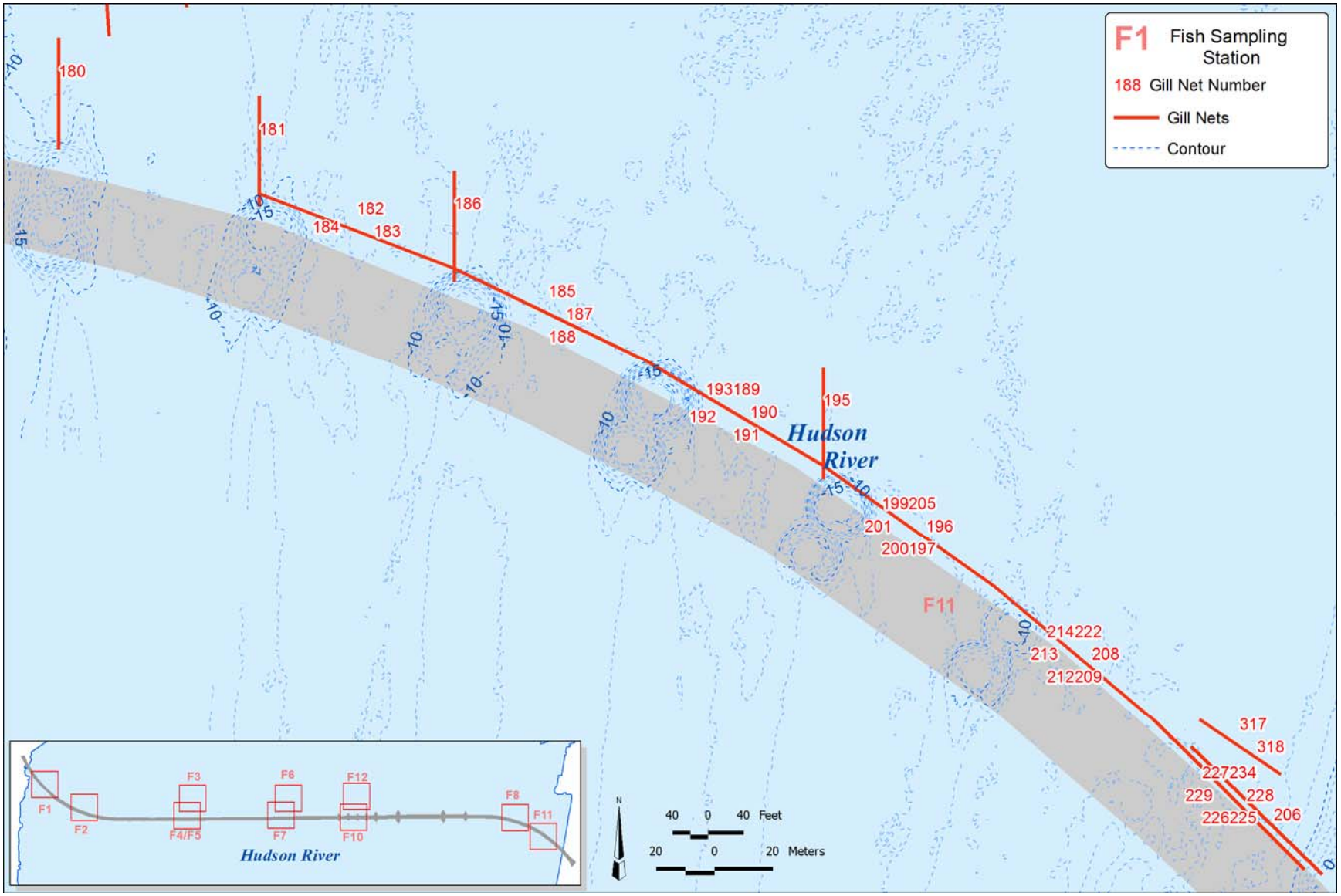

Figure F-1-20 Gill Net Deployment Locations at F11

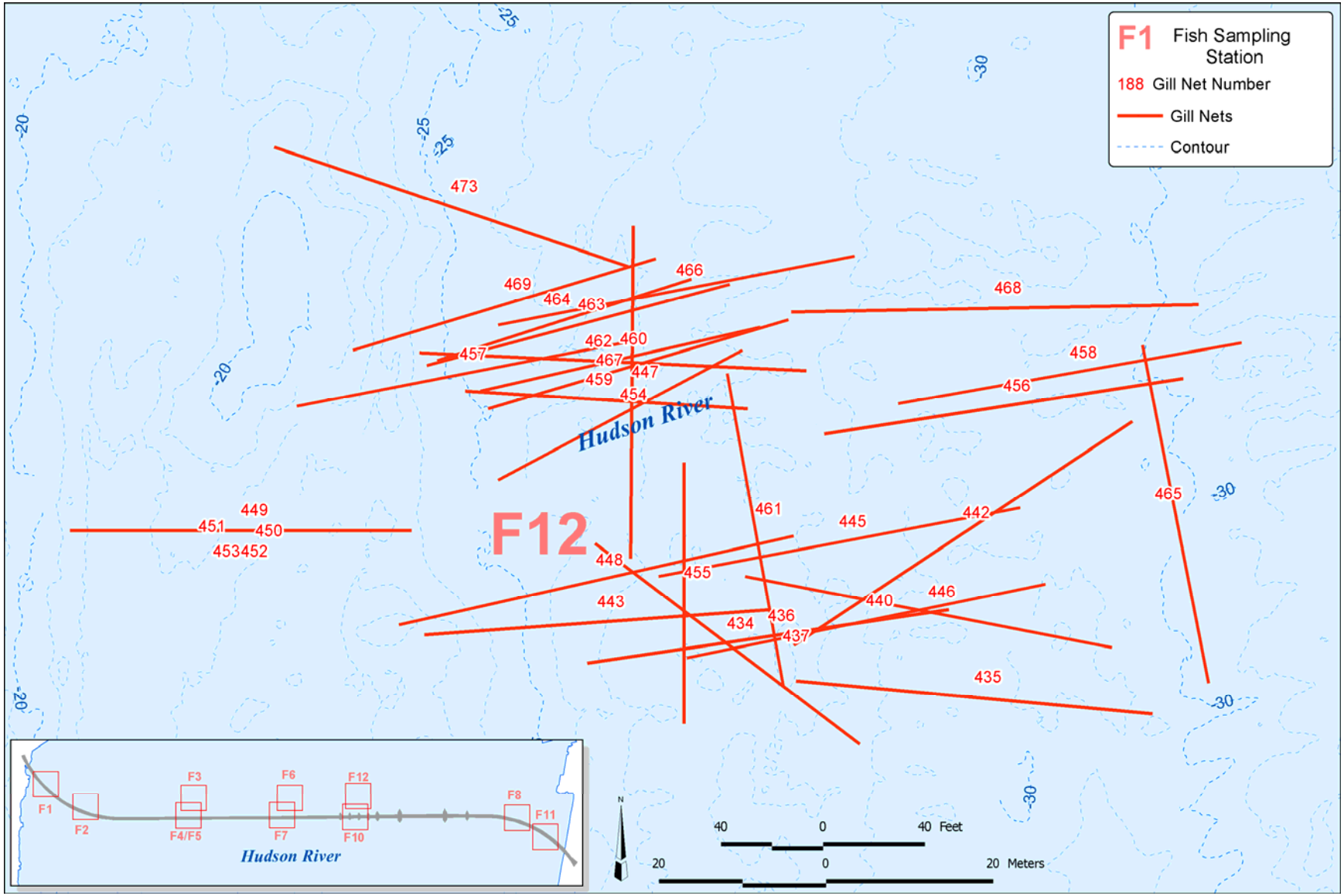

Figure F-1-21 Gill Net Deployment Locations at F12

Sampling Totals and Catch per Unit Effort

Fish Caught by Location

Fish were caught at all sampling locations throughout the year. In the colder months of the year, the total numbers of fish caught at all locations were markedly lower than the numbers of fish caught during the warmer months of the year. Moreover, there were higher numbers of fish caught at the sampling locations with greater water depths. Table F-1-1 provides the number of fish caught per location each month.

Table F-1-1
Monthly Fish Catch Totals by Location April 2007 – May 2008

Sample Location		Monthly Fish Catch Totals							Totals
		2007					2008		
		April	June	Aug	Oct	Dec	Feb	May	
Bridge	F1	5	16	76	107	2	1	31	*238*
	F2	2	6	51	101	1	1	13	*175*
	F4/F5	4	58	123	57	7	1	78	*328*
	F7	15	22	22	77	10	3	36	*185*
	F9	1	4	n/a	n/a	n/a	n/a	n/a	*5*
	F10	n/a	48	74	35	3	19	15	*194*
	F11	n/a	5	84	27	2	1	41	*160*
	Totals	*27*	*159*	*430*	*404*	*25*	*26*	*214*	*1,285*
Reference Area	F3	13	78	97	86	13	6	19	*312*
	F6	29	42	10	n/a	n/a	n/a	n/a	*81*
	F8	1	2	26	15	6	0	45	*95*
	F12	n/a	24	69	38	9	20	15	*175*
	Totals	*43*	*146*	*202*	*139*	*28*	*26*	*79*	*663*
GRAND TOTALS		70	305	632	543	53	52	293	*1,948*
Note: n/a = not applicable (These locations were not sampled within the respective months).									

Sampling Effort

Table F-1-2 shows the number of gill net deployment hours (i.e., soak time) per location, per month. Due to concerns of injuring the shortnose sturgeon, the gill net soak times were limited by water temperatures. For temperatures below 59˚F (15˚C), the maximum soak time was 4 hours; for temperatures between 59 and 68˚F (15 and 20˚C), the soak times were limited to 2 hours. For temperatures between 68 and 80.6˚F (20 and 27˚C), the soak times were limited to 1 hour. No netting was permitted when the water temperatures exceeded 80.6˚F (27˚C).

Table F-1-2
Total Soak Time April 2007 – May 2008

Sample Locations		Hours Per Sampling Location							*Totals*
		April	June	Aug	Oct	Dec	Feb	May	
Bridge	F1	11.25	3	9	8.75	23.4	21.4	17.4	*94.2*
	F2	4	2	6	8.5	18.5	27.75	4.3	*71.05*
	F4	8.5	14	10.75	8.75	20.25	20.4	16.5	*99.15*
	F7	9.6	8	6.25	9.15	24.25	30.45	12	*99.7*
	F10	-	9	10.25	6	12.75	24.25	15	*77.25*
	F11	-	2	13.35	9.25	22.75	34	24.5	*105.85*
	Totals	*33.35*	*38*	*55.6*	*50.4*	*121.9*	*158.25*	*89.7*	*547.2*
Reference Area	F3	12	7	10	6	20.75	37.25	17	*110*
	F8	7.5	1	7	8.15	22.5	25.45	25	*96.6*
	F12	-	5	7.5	7	12.5	23	14.8	*69.8*
	Totals	*19.5*	*13*	*24.5*	*21.15*	*55.75*	*85.7*	*56.8*	*276.4*
GRAND TOTALS	*Totals*	*52.85*	*51*	*80.1*	*71.55*	*177.65*	*243.95*	*146.5*	*823.6*

Generally, in the warmer portions of the year a total of two nets were deployed in the river. The nets were set at 0.5-hour intervals. The scientists would retrieve one net; identify the fish species captured, remove the fish, re-deploy the net, and travel to another location to repeat the process. In the warmer months up to 12 nets were set and deployed each day.

In the winter months (December and February), the colder water temperatures allowed for longer soak times and the placement of additional nets.

CPUE, the metric that identifies the number of fish caught per effort (i.e., gill net deployment), is calculated by the number of fish caught per gill net hour. Thus, if six fish were captured in a gill net that was deployed for three hours, the CPUE would be 2. Table F-1-3 identifies the CPUE for each sample location in the study area.

Review of the data shows that there was minor variation of total CPUE between reference and bridge locations of similar depth and substrate. For the mid-depth locations on the west side of the river, the reference location (Sample Site F3) usually had a slightly higher CPUE than did the bridge locations (Sample Sites F1, F2, F4, and F7); although the difference was substantial for the month of June, when the reference location CPUE was double that of the bridge locations.

Table F-1-3

CPUE for each Sample Location

Sample Location		Apr	Jun	Aug	Oct	Dec	Feb	May
Bridge	F1	0.44	5.33	8.44	12.23	0.09	0.05	1.78
	F2	0.50	3.00	8.50	11.88	0.05	0.04	3.02
	F4	0.47	4.14	11.44	6.51	0.35	0.05	4.73
	F7	1.56	2.75	3.52	8.52	0.41	0.10	3.00
	F10	-	5.33	7.22	5.83	0.24	0.78	1.00
	F11	-	2.50	6.22	2.92	0.09	0.03	1.67
	Totals	*0.78*	*4.08*	*7.72*	*8.04*	*0.21*	*0.16*	*2.39*
Reference Area	F3	0.92	11.14	9.70	14.33	0.63	0.16	6.41
	F8	0.13	2.00	4.00	1.84	0.27	0.00	1.80
	F12	-	4.80	9.20	5.14	0.72	0.87	1.01
	Totals	*1.05*	*17.94*	*22.90*	*21.32*	*1.61*	*1.03*	*9.23*

Identified Fish Populations

A total of 25 fish species were collected during the fish-sampling activities between April 2007 and May 2008. A list of these species is presented in Table F-1-4.

In order to determine the use of the study area by the fish populations, each species identified in Table F-1-4 was assigned to one of the five assemblages (anadromous, catadromous, estuarine, freshwater, marine) based on the species' migratory habits and salinity preferences. As noted earlier, the grouping of species in this manner is a common way to identify the ecology of a specific study area in an estuarine environment. The assemblages are the same as those identified in the utilities' annual Year Class Reports. Table F-1-5 identifies the fish species comprising each assemblage.

Table F-1-6 identifies the numbers of fish captured each month, by assemblage. As can be observed in the table, for each month there is a similar distribution of anadromous, estuarine, and marine fish between the bridge and the reference locations. There is also no perceivable difference between the bridge and the reference area as habitat for freshwater fish. Although no freshwater fish were captured in the reference area, only four fish were captured in the bridge location. This likely reflects the fact that there were twice as many bridge sampling locations as there were reference locations.

Only two catadromous fish were captured (using traps) in the bridge location. It should be noted that fish traps were deployed overnight and for considerably longer periods at the bridge locations. (Traps could not be left overnight at reference locations as they would pose a hazard to navigation.)

Anadromous and estuarine fish were captured in every sampling event. Marine fish were only captured in the warmer months of the year when salinities permitted their presence in the study area.

Table F-1-4
Species Identified During Sampling

Common name	Scientific Name
Alewife	*Alosa pseudoharengus*
American eel*	*Anguilla rostrata*
American shad	*Alosa sapidissima*
Atlantic butterfish	*Peprilus triacanthus*
Atlantic menhaden	*Brevoortia tyrannus*
Atlantic tomcod	*Microgadus tomcod*
Bluefish	*Pomatomus saltatrix*
Blueback herring	*Alosa aestivalis*
Blue runner	*Caranx crysos*
Common carp	*Cyprinus carpio*
Gizzard shad	*Dorosoma cepedianum*
Hickory shad	*Alosa mediocris*
Hogchoker	*Trinectes maculatus*
Naked goby*	*Gobiosoma bosci*
Northern kingfish	*Menticirrhus saxatilis*
Northern sea robin	*Prionotus carolinus*
Oyster toad fish*	*Opsanus tau*
Porgy sp.	Order Perciformes
Shortnose sturgeon	*Acipenser brevirostrum*
Spot	*Leiostomus xanthurus*
Striped bass	*Morone saxitalis*
Summer flounder	*Paralichthys dentatus*
Weakfish	*Cynoscion regalis*
White catfish	*Ameiurus catus*
White perch	*Morone Americana*
Note: * Species only captured in fish traps.	

Table F-1-5

Captured Fish Species by Identified Assemblage

Assemblage	Species
Anadromous	Alewife American shad Atlantic tomcod Blueback herring Hickory shad Striped bass
Catadromous	American eel
Estuarine	Hogchoker Shortnose sturgeon White catfish White perch
Freshwater	Common carp Gizzard shad
Marine	Atlantic butterfish Atlantic menhaden Bluefish Blue runner Naked goby Northern kingfish Northern sea robin Oyster toad fish Porgy Spot sp. Summer flounder Weakfish

Table F-1-6

Numbers of Fish Captured each Month by Assemblage

Location	Assemblage	Apr	Jun	Aug	Oct	Dec	Feb	May	Totals
Bridge	Anadromous	39	8	30	29	4	10	38	158
	Catadromous*	0	0	0	1	0	0	1	2
	Freshwater	1	0	0	1	2	0	0	4
	Estuarine	16	124	202	266	19	16	64	707
	Marine	0	69	207	112	0	0	72	460
	Totals	56	201	439	408	25	26	174	1,331
Reference Area	Anadromous	13	3	29	10	7	8	40	110
	Catadromous	0	0	0	0	0	0	0	0
	Freshwater	0	0	0	0	0	0	0	0
	Estuarine	1	46	85	79	21	18	63	313
	Marine	0	55	77	50	0	0	68	250
	Totals	14	104	191	139	28	26	171	673
GRAND TOTALS		70	104	191	139	28	26	171	2,004

Note: Catadromous fish were only captured in fish traps.

Analysis of Captured Species

The utilities' annual Year Class Reports provide detailed information on 16 key species within the Hudson River. Individuals of 12 of these 16 species were captured during the bi-monthly sampling effort. An analysis of those 12 species is provided below.

Alewife

A total of 39 alewives were captured, with 37 individuals captured in the May event, one in the April event, and one in the October event. Alewives varied in length between 3.5 and 10.4 inches (9 and 26.3 cm). Alewives were only captured at Sample Sites F1, F2, F3, F4 and F8. The capture of alewives in May, April, and October is likely reflective of the anadromous nature of the species. In the spring the species migrates through the Tappan Zee Reach upstream to spawn, and in the fall it migrates through the reach towards the ocean.

American Shad

A total of five American shad were captured during the study. Four shad were captured in April and one in May. They varied in length between 6.3 and 21.7 inches (16 and 55.2 cm). The capture of shad in May and April is likely reflective of the anadromous nature of the species. In the spring the species migrates through the Tappan Zee Reach upstream to spawn, and in the fall it migrates through the reach towards the ocean.

Atlantic Tomcod

A total of 11 tomcod were captured during the survey, all of them in the May sampling event. The tomcod varied in length from 8.6 to 11.6 inches (21.9 to 29.5 cm); all individuals were captured in the deep-water sampling locations (Sample Sites F10 and F12). It is unclear whether the captured tomcod were migrating back towards the ocean in the spring or were part of a resident population of the Hudson River. In December and February, when tomcod are most prevalent in the lower estuary, gill nets were deployed for more than 420 hours and yielded no individuals of this species.

Blueback Herring

One blueback herring was captured during the May sampling event. The fish measured 9.4 inches (24 cm) and was captured at Site F8. The capture of the blueback herring in May is likely reflective of the anadromous nature of the species. In the spring the species migrates through the Tappan Zee Reach upstream to spawn, and in the fall it migrates through the reach towards the ocean.

Gizzard Shad

A total of six gizzard shad were captured during the sampling program. The shad were caught in the months of April, May, October, and December. They were primarily captured at the sampling sites closest to the shoreline (F1 and F11), but one was caught at Site F5. The shad varied in length between 7.1 and 19.7 inches (18 and 50.1 cm). Gizzard shad are a resident estuarine fish, so their capture during all four seasons was not unanticipated.

Hogchoker

A total of 15 hogchokers were captured. Hogchokers were recorded at both shallow and deep-water sampling stations. Hogchokers were captured during the months of June, August, and October, when the salinity in the Tappan Zee Reach was higher.

Sturgeons – Atlantic and Shortnose

A total of 12 shortnose sturgeons (Photo F-1-6) were captured during the bi-monthly fish-sampling effort. The sturgeons were captured in the warmer months of the year – between May and October – at both the bridge and reference locations in water depths between 6 and 30 feet (1.8 and 9.1 m). Table F-1-7 lists the sturgeons caught, giving their length, weight, and location. No Atlantic sturgeons were captured, although in May 2008 the carcass of an Atlantic sturgeon was observed floating approximately 500 feet (152.4 m) north of the bridge.

No discernible trend regarding the presence or absence of shortnose sturgeons can be inferred from the data. Although no individuals were captured during the December, February, and April sampling events, it is possible that the species is present within the Tappan Zee Reach but that the cold waters slowed its movements.

Photo F-1-6 Shortnose Sturgeon Captured at the F1 Sampling Location. Note the bridge in the background.

Table F-1-7

Sturgeons Caught During the Fish Survey

Date	Station	Water Depth in Feet	Water Temperature		Species	Length		Weight	
			C°	F°		M	Feet	Kg	Lbs
06/13/07	F1	10.5	22.41	72.3	Shortnose sturgeon	0.99	3.02	5.2	11.65
06/14/07	F11	6	21	69.8	Shortnose sturgeon	0.86	2.61	3.6	8.07
08/21/07	F8	7.5	23.92	75.1	Shortnose sturgeon	0.88	2.67	4.25	9.52
09/04/07	F4	12	23.53	74.4	Shortnose sturgeon	0.45*	1.37	-	-
09/06/07	F7	15	24.68	76.4	Shortnose sturgeon	0.71	2.16	2.9	6.50
10/02/07	F5	14	21.02	69.8	Shortnose sturgeon	0.77	2.35	4.2	9.41
10/03/07	F10	32	22.12	71.8	Shortnose sturgeon	0.89	2.72	3.9	8.74
10/08/07	F7	15	22.82	73.1	Shortnose sturgeon	0.75	2.29	3	6.72
10/08/07	F7	15	22.82	73.1	Shortnose sturgeon	0.83	2.53	4.1	9.19
10/09/07	F10	30	22.92	73.3	Shortnose sturgeon	0.65*	1.98	-	-
5/7/08	F12	28	14.18	57.5	Shortnose sturgeon	0.69	2.10	3.25	7.28
5/16/08	F8	8	15.58	60.0	Shortnose sturgeon	0.81	2.47	3.3	7.39
5/16/08	F3	12	15	59.0	Atlantic sturgeon**	2.50 **	7.62	-	-

Notes:

* Length estimated. Fish fell out of net during retrieval.

** Carcass was observed floating on the surface. The carcass was scanned both visually and electronically for identification tags, but none were found. Total length was estimated, as the carcass was exhibiting signs of decomposition and disarticulation (its head was missing).

Striped Bass

A total of 185 striped bass were captured during the fish survey. The length of a striped bass is correlated with its age. For purposes of this study, YOY fish are those less than 4.7 inches (12 cm) in length. Fish larger than 17 inches (43 cm) in length are potentially sexually mature males or egg-bearing females. Fish of lengths between these two values are classified as sub adults. Of the 185 individual fish sampled, 48 were YOY, 83 were sub adult, and 54 were capable of bearing young.

The striped bass were captured throughout the river during the year, with their numbers and sizes varying by season and location. Table F-1-8 displays the total number of individual striped bass captured each month and the average length, minimum length, and maximum length of individuals captured at each location each month.

During the colder months (December and February) and the month of June, the number of fish captured was low, and fish were segregated by size and depth. YOY and sub adults were generally located in the shallow shoals, while larger fish were captured in the deeper portion of the river. During the spawning period (April and May), larger fish were captured within the shallow shoals. Also, in the May sampling event, 18 of the 32 individuals captured were YOY fish. In June, August, and October, most of the fish captured were sub adults. The fish were caught throughout the river at different depths, although during these months as well, larger fish were caught at the deeper-water sites.

Weakfish

A total of 19 weakfish were captured during the study. The weakfish varied in length between 3.9 and 15.7 inches (10 and 40 cm). Weakfish were only captured during August and October and the large majority of them (16 of the 19) were captured at the deep-water locations (Sites F10 and F12). Weakfish are marine species and were captured during the portions of the year when salinity in the study area was at its highest.

White Catfish

White catfish were captured during the March, May, June, August, and October sampling periods. A total of 37 were captured, and varied in total length between 5.9 and 17.7 inches (15 and 45 cm). During the June sampling period, white catfish were only captured at the deep-water sampling locations (Sites F10 and F12). In other months of the year, they were captured in both shallow and deep-water locations. White catfish are a resident estuarine fish, so their capture during all four seasons was not unanticipated.

White Perch

Roughly 50 percent (983) of all the fish captured in gill nets during the sampling program were white perch. Sampling events in warmer water temperatures had dramatically higher captures of white perch than months with colder water temperatures. White perch were most abundant during the October sampling (335 individuals captured) and least abundant during the April sampling event (only 17 individuals). The average length of fish captured each month generally was fairly constant, except for the May sampling event, which likely reflects an increase in the number of captured YOY fish. Table F-1-9 shows the number of white perch captured and average lengths each month.

Table F-1-8
Striped Bass Captured During the Sampling Effort

Month	Sample Site	Fish Length in centimeters		
		Average	Minimum	Maximum
All months (N* = 186)	All	30.2	7.6	83.0
February (N = 17)	All sites combined	39	10.0	80.0
	F1	10	10	10
	F3	11.0	10	12
	F10	53.6	42	80
	F11	20	20	20
	F12	41.4	10	56.4
April (N = 46)	All sites combined	45.8	17	76
	F1	57.5	57.5	57.5
	F3	45.65	27	76
	F4	45.4	41.8	47.3
	F6	46.5	33	61
	F7	44.3	17	56
May (N= 33)	All sites combined	22.4	9	83
	F1	11.5	11	12
	F2	22	22	22
	F3	23.8	9	83
	F4	23.4	9	48.1
	F7	42.4	21.2	57
	F8	26	10	11
	F10	61	61	61
	F11	11	10	12
	F12	11.75	11	12
June (N =8)	All sites combined	12.6	7.6	24.4
	F3	15.8	15.6	15.8
	F5	9.2	n/a	n/a
	F6	10.0	n/a	n/a
	F7	12.2	12.2	12.2
	F10	17.3	10.2	24.4
August (N =37)	All sites combined	23.9	8	60
	F1	9.8	9.5	10
	F2	20.0	10	30
	F3	21.2	10	31.5
	F4	19.6	10	26.5
	F7	14.9	10.1	22.5
	F8	14.5	10	19
	F10	36.3	20	60
	F11	21.5	21.5	21.5
	F12	22.2	15	27

Table F-1-8 (con't)

Striped Bass Captured During the Sampling Effort

Month	Sample Site	Fish Length in centimeters		
		Average	Minimum	Maximum
Oct (N =34)	All sites combined	24.1	10	52.5
	F1	21.1	10	38.1
	F2	14.5	11	23
	F3	17.9	11	24.3
	F4	16.8	10	23.5
	F7	21.3	12	27
	F10	39.7	23.5	52.5
	F11	-	-	-
	F12	35.5	25	46
Dec (N =10)	All sites combined	28.0	12.0	59.0
	F1	37.5	37.5	37.5
	F3	35.2	19.8	50.5
	F5	12.0	12.0	12.0
	F7	22.5	21.9	23
	F8	22.3	20.5	24.1
	F12	59.0	59.0	59.0

Notes: "N" refers to the number of individuals.
n/a = not applicable.
A total of 185 striped bass were captured during the survey.

Table F-1-9

Number and Average Length of White Perch Captured by Month

Month	Number Captured	Average Length in centimeters
April	17	18.3
May	146	15.0
June	151	18.9
August	263	19.7
October	335	19.9
December	40	19.8
February	31	19.1
TOTAL	983	18.67

Review of the data shows that there is a slight correlation of average fish length to water depth. Shallow-water sampling sites (F1, F8, and F11) had the smallest average fish lengths and deeper-water sampling sites had greater fish lengths, although there was wide variation in lengths at all sites. Average fish length per sample site is shown in Table F-1-10.

Table F-1-10
Average Length of White Perch Captured by Location

Sample Site	Number	Average Length in centimeters
F1	95	18.4
F2	92	19.1
F3	163	18.3
F4	163	19.1
F6	30	19.4
F7	97	19.7
F8	32	16.8
F10	120	20.0
F11	96	18.2
F12	95	19.0

American Eel, Atlantic Menhaden, Bluefish, and Hickory Shad

The American eel, Atlantic Menhaden, Bluefish, and Hickory Shad are four species that occur seasonally within the Hudson River.

- American eel – This catadromous species utilizes the lower Hudson estuary. Eels are predatory fish, but they also serve as prey species for larger predatory fish. Only two American eels were captured (in the fish traps) during the sampling period. This low number of capture likely underrepresents the eel population, as the sampling program's objective and gear was not designed to capture eels.

- Atlantic Menhaden – This marine species is present within the estuary during the warmer months of the year when salinity levels are at their highest. Menhaden are a prey species for many of the predatory fish, especially striped bass. Both the Atlantic menhaden and bluefish (see below) generally swim in large schools. Between the months of May and October, large schools of both species were observed swimming in the Tappan Zee Reach. During the fish survey, 382 Atlantic Menhaden were captured. Menhaden were captured at all sampling locations.

- Bluefish – This marine species is present in the Tappan Zee Reach during the warmer months when salinity levels are at their highest. Bluefish are voracious predators. During the fish survey, 151 bluefish were captured. Bluefish were captured at all sampling locations.

- Hickory Shad – This anadromous species is in the same family as alewives, American shads and herrings. The hickory shad is one of the species that make up the "shad runs" during the spring. Five hickory shad were captured during the survey, all during the months of June and August at Sites F4 and F5.

Other Species Captured

Nine other marine species of fish were captured during the sampling program, including the Atlantic butterfish, blue runner, naked goby, northern king fish, northern sea robin, oyster toadfish, porgy, spot, and summer flounder. These marine species were either gill netted or trapped during the June, August, and October sampling periods. During the warmer summer months, the increase in river salinity permits the utilization of the Lower Hudson River by typical marine fish or species adapted to live in polyhaline conditions. The number of captured individuals of each species was minimal.

The naked goby and the oyster toad fish are common species within the Hudson River estuary and New York Harbor. Both of these species are cryptic and live on the bottom within dark recesses, under ledges, or on oyster reefs. These two species may use the bridge piers as a habitat resource.

The common carp is a freshwater species. One individual was captured during the May sampling event after a very large rain event. It is likely that the fish was washed out of a nearby stream and does not reside in the study area. The fish was captured at Sample Site F11 along the shoreline.

Essential Fish Habitat Species

Of the 13 EFH species identified, only two – the bluefish and the summer flounder – were captured during the sampling program. These marine species were captured in the warmer months of the year when higher salinities are present within the study area. It should be noted that the winter flounder (*Pleuronectes americanus*), designated as an EFH species by NMFS, was not captured or observed during the sampling program. This is important to note, as winter flounders lay their eggs over softer sediments (silty sand) in shallow waters during the winter months. Soft sediments in shallow waters dominate the western side of the river.

Fish Traps

Despite being deployed for hundreds of hours throughout the year-long survey, the fish traps yielded limited catches. Two American eels and one dozen naked gobies were captured in the traps. The low catch is likely a result of the strong currents present around the bridge piers and the resulting limited numbers of small fish that utilize the piers as habitat. Also, commercial crab traps deployed as part of the benthic invertebrate survey incidentally captured an oyster toadfish and numerous white perch.

Fish Utilization of the Study Area

As stated previously, the Hudson River Estuary is a dynamic environment. The presence of a particular species is often dependent on water temperature, migratory patterns, salinity, and other ecological factors. Table F-1-11 provides a brief synopsis of notable species, their lifestages, and biomass that occur within the Tappan Zee Reach throughout the year.

The combination of hydroacoustic surveys and gill nets and traps identified fish populations and distributions in and around the study area. Except for a few common cryptic species, the surveys determined that fish populations do not solely utilize the bridge as a refuge or foraging area.

Table F-1-11

Seasonal Presence of Biomass and Species in the Tappan Zee Reach

Hudson River Location	Bathymetric Contour (feet)	Biomass Abundance			Notable Species and Life Stages Present in the Study Area		
		Dec - Mar	Apr - May	Jun - Nov	Water Temps Below 5°C	Water Temps Above 5°C	
					Dec -Mar	Apr-May	Jun - Nov
West Side	0-6	Low	Low	Low (although large schools may transit through the shallow waters)	Atlantic Tomcod and its early life stages (e.g., eggs and larvae- more prevalent in March.) Striped Bass (mid-March)	Striped Bass Shad and Herring Early life stages (e.g., eggs and larvae)of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY (e.g., striped bass, shad, tomcod, and white perch).
	6-12	Low	Moderate	Moderate	Atlantic Tomcod and its early life stages (e.g., eggs and larvae - more prevalent in March.) Striped Bass (mid-March)	Striped Bass Shad and Herring Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY (e.g., striped bass, shad, tomcod, and white perch).

Table F-1-11 (con't)

Seasonal Presence of Biomass and Species in the Tappan Zee Reach

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		Dec -Mar	Apr - May	Jun – Nov	Water Temps Below 5°C	Water Temps Above 5°C	
					Dec -Mar	Apr-May	Jun - Nov
West Side (cont'd)	12-18	Low	Moderate	Moderate	Striped Bass (mid-March)	Atlantic Sturgeon Striped Bass Shad and Herring Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY (e.g., striped bass, shad, tomcod, and white perch).
	18-24	Low-Moderate	Moderate	Moderate	Striped Bass (mid-March)	Atlantic Sturgeon Shortnose Sturgeon Striped Bass Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Tomcod Weakfish Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae)

Table F-1-11 (con't)

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Hudson River Location	Bathymetric Contour (feet)	Biomass Abundance			Notable Species and Life Stages Present in the Study Area		
		Dec -Mar	Apr - May	Jun – Nov	Water Temps Below 5°C	Water Temps Above 5°C	
					Dec -Mar	Apr-May	Jun - Nov
Deep Channel	24+	Moderate - High	Moderate - High	High	Shortnose Sturgeon Striped Bass (mid-March)	Atlantic Sturgeon Atlantic Tomcod Shortnose Sturgeon Striped Bass Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Tomcod Weakfish Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae)
East Side	18-24	Low-Moderate	Moderate	Moderate	Striped Bass (mid-March)	Atlantic Sturgeon Shad and Herring Shortnose Sturgeon Striped Bass Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Tomcod Weakfish Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae)

Table F-1-11 (con't)

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East Side (con't)	12-18	Low	Low	Moderate	Striped Bass (mid-March)	Atlantic Sturgeon Shad and Herring Shortnose Sturgeon Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY, especially striped bass and white perch after mid-July through September.
	6-12	Low	Low	Moderate	Atlantic Tomcod and its early life stages (e.g., eggs and larvae- more prevalent in March.)	Shad and Herring Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY, especially striped bass and white perch after mid-July through September.

Table F-1-11 (con't)

Seasonal Presence of Biomass and Species in the Tappan Zee Reach

Hudson River Location	Bathymetric Contour (ft)	Biomass Abundance			Notable Species and Life Stages Present in the Study Area		
					Water Temps Below 5°C	Water Temps Above 5°C	
		Dec -Mar	Apr-May	Jun – Nov	Dec -Mar	Apr-May	Jun - Nov
East Side (con't)	0-6	Low	Low	Low (although large schools may transit through the shallow waters)	Atlantic Tomcod and its early life stages (e.g., eggs and larvae- more prevalent in March.)	Shad and Herring Early life stages (e.g., eggs and larvae) of various species begin to appear in May (striped bass, shad, white perch)	Blue Crabs Shortnose Sturgeon Shad and Herring* Large schools baitfish and summer marine species (e.g., bluefish, menhaden) Early life stages for many species (e.g., eggs and larvae) Numerous YOY, especially striped bass and white perch after mid-July through September.
Notes: * Shad and herring present during the fall migration (September – October).							

The horizontal, vertical, and geographical distribution of fish within the Tappan Zee Reach and the study area is substantially influenced by temperature and salinity. In the colder months of the year (December through April), the fish populations are concentrated in deeper waters with higher salinities. In the late winter and early spring, a distinct halocline was observed at a depth of approximately 19.7 feet (6 m). Fish concentrations increased below this depth. As the water warms in the late spring, the halocline dissipates and there is a notable increase in salinity in the shallower depths. Also observed is a marked increase in fish populations at those depths, although, the greatest numbers of fish continue to occur in the deepest portion of the channel. In the warmer months of the year, early life stages of many species are present within the Tappan Zee Reach.

Within the study area, fish do not appear to utilize the bridge structure in a significant way compared to the reference areas. The hydroacoustic survey determined that there was no clear pattern of habitat preference (bridge vs. reference area) by the fish species. Moreover, review of the CPUE data indicates that slightly higher populations of fish were captured at the reference area in the western portion of the river. This may be a result of three factors:

1) The increased water velocities near the bridge during certain portions of the tidal cycle and shading from the bridge during daylight hours are unattractive habitat characteristics for fish.

2) A large percentage of the individuals that were captured are members of large schooling species. The presence of the bridge piers restricted the potential approach direction to the gill net, resulting in slightly lower catches.

3) Sample Site F3 is the closest sampling location to historical oyster beds north of the bridge and is in close proximity to new oyster beds that were mapped in 2009. Oyster reefs and beds serve as attractive foraging areas for fish. It is likely that due to the presence of these oyster beds, more fish congregate near F3 that at other locations.

The endangered shortnose sturgeon was not determined to utilize the bridge structure in a significant way. The sturgeons were captured in the warmer months of the year at different depths. Only two EFH species, bluefish and the summer flounder, were captured during the fish survey. The winter flounder, another EFH-listed species, whose spawning area preferences match the conditions in the western portion of the study area, was not captured during the fish survey.

2 Benthic Macroinvertebrates

2.1 Area-Wide Macrobenthic Data

In 2000 and 2001, Versar (NYSDEC, 2009) collected 130 benthic community samples between RMs 11 and 40 within the study area. These samples were collected over a surface area of 0.43 sq feet (399.4 square centimeters [sq cm]) to a depth of 3.94 inches (10 cm). The benthic abundance and biomass data are summarized by calculating the total number of species per sample and the total biomass (grams ash free dry weight) per sample, respectively.

The highest numbers of species per sample are generally located in the lower region of the study area (south of the Tappan Zee Bridge), while the lowest numbers of species per sample are located primarily in

the upper region of the river (north of the Tappan Zee Bridge). The highest benthic biomass occurs in the shallow-water regions of the river in Croton Bay and north of the Piermont Pier on the western side of the river.

The densities of benthic species – the number of individuals per sq m – were derived by summing all occurrences throughout the study area, dividing by the sample area (399.4 sq cm), and converting this value to an area in sq m (Table F-1-12). The species with the three highest densities are as follows:

- The species with the greatest density was the oligochaete worm *Tubificoides* spp., at 522/sq m, with the highest-density samples found near Hastings-on-Hudson, on the eastern shore of the river near RM 19.
- The species with the second-highest density was the small clam *Rangia cuneata*, at 401/sq m, with the samples of greatest density occurring near RM 31, Upper Nyack.
- The species having the third-highest density was the amphipod *Leptocheirus plumulosus*, at 263/sq m, with the samples of greatest density occurring near RM 35, near Croton Point.

2.2 Project-Specific Data

Benthic macro-invertebrate sampling locations were linked to the construction and demolition activities that may be evaluated in the EIS. As shown on Figure F-1-22 benthic sampling occurred in locations anticipated to be disturbed from proposed construction and/or rehabilitation.

For purposes of evaluating the potential ecological impacts of the removal of the existing bridge, the benthic community sampling occurred at 11 stations along a transect within 50 feet (15.24 m) of the existing bridge. In addition to the sampling near the bridge, 11 benthic sampling stations were placed along two transects within 150 feet (45.7 m) north of the existing bridge for the replacement bridge, at four locations along the southeast shoreline, and at two locations each on the southeast and southwest sides of the existing bridge for potential temporary causeways. Benthic sample locations were located within both scour and depositional areas near bridge piers and, where possible, based on boat safety restrictions, under the bridge itself. Sampling sites were selected in consultation with NYSDEC Region 3 using results of both the hydrographic surveys (described further below) and geophysical surveys conducted by LDEO.

Sampling was conducted bimonthly over a one-year period concurrent with the fish sampling. Sampling methods included use of a modified Van Veen grab (Photo F-1-7). Three replicates per location were collected. Samples were sieved in the field through a No. 35 mesh (0.5 mm), preserved in 70 percent ethyl alcohol and rose bengal and shipped to a laboratory for identification to the lowest practicable taxon (Photo F-1-8). Species identifications were verified by a third party. *In situ* water-quality measurements – of temperature, dissolved oxygen, and salinity – were collected at each station.

2.2.1 Sampling Locations

A total of 41 benthic invertebrate sediment sampling locations and six benthic invertebrate bridge pier sampling locations were utilized for this project.

Table F-1-12

Benthic Density of Species in the Study Area

Phylum	Species	Total Abundance	Density per sq m
Arthropoda	*Leptocheirus plumulosus*	1,506	263
	Balanus improvisus	1,096	192
	Cyathura polita	497	87
	Coelotanypus spp.	402	70
	Leucon americanus	291	51
	Neanthes succinea	187	33
	Rheotanytarsus spp.	97	17
	Ameroculodes species complex	68	12
	Chironomidae pupae	43	7.5
	Rhithropanopeus harrisii	37	6.5
	Leitoscoloplos spp.	36	6.3
	Edotea triloba	33	5.8
	Polypedilum halterale group	31	5.4
	Apocorophium lacustre	28	4.9
	Parachironomus hirtalatus	24	4.2
	Synidotea laticauda	18	3.1
	Parachironomus monochromus/tenuicadatus grp.	16	2.8
	Ampelisca abdita	10	1.7
	Melita nitida	10	1.7
	Cricotopus spp.	9	1.6
	Dicrotendipes spp.	9	1.6
	Cryptochironomus spp.	9	1.6
	Almyracuma proximoculi	3	0.5
	Procladius spp.	3	0.5
	Thienemannimyia grp.	3	0.5
	Ampelisca spp.	2	0.3
	Gammarus spp.	2	0.3
	Nais communis	2	0.3
	Neomysis Americana	2	0.3
	Crangon septemspinosa	1	0.2
	Harnischia spp.	1	0.2
	Monocorophium spp.	1	0.2
	Orthocladius spp.	1	0.2
Ampharetidae	Ampharetidae	1	0.2

Table F-1-12 (con't)

Benthic Density of Species in the Study Area

Phylum	Species	Total Abundance	Density per sq m
Annelida	*Tubificoides* spp.	2,986	522
	Marenzelleria viridis	1,209	211
	Heteromastus filiformis	1,090	191
	Hobsonia florida	621	109
	Boccardiella ligerica	575	101
	Polydora cornuta	539	94
	Streblospio benedicti	379	66
	Sabellaria vulgaris	237	41
	Immature Tubificid without capiliform chaetae	108	19
	Tubificidae without capiliform chaetae	61	11
	Mediomastus ambiseta	27	4.7
	Eteone heteropoda	24	4.2
	Aulodrilus limnobius	22	3.8
	Aulodrilus limnobius	22	3.8
	Laeonereis culveri	15	2.6
	Manayunkia aestuarina	15	2.6
	Limnodrilus hoffmeisteri	7	1.2
	Pectinaria gouldii	6	1
	Incisocalliope aestuarius	5	0.9
	Spiophanes bombyx	5	0.9
	Asabellides oculata	4	0.7
	Glycera Americana	4	0.7
	Nephtyidae	1	0.2
	Podarke obscura	1	0.2
	Podarkeopsis levifuscina	1	0.2
	Turbellaria	1	0.2
Chordata	*Molgula manhattensis*	131	23
Cnidaria	Anthozoa	38	6.6
Hepatophyta	*Mytilopsis leucophaeata*	12	2.1

Table F-1-12 (con't)

Benthic Density of Species in the Study Area

Phylum	Species	Total Abundance	Density per sq m
Mollusca	*Rangia cuneata*	2,292	401
	Mulinia lateralis	273	48
	Mya arenaria	149	26
	Macoma balthica	148	26
	Littoridinops tenuipes	104	18
	Odostomia engonia	51	8.9
	Crassostrea virginica	39	6.8
	Acteocina canaliculata	21	3.7
	Dreissena polymorpha	10	1.7
	Tellinidae	6	1
	Gastropoda	2	0.3
	Mytilus edulis	1	0.2
	Mytilidae	1	0.2
Nemertea	*Carinoma tremaphoros*	330	58
	Amphiporus bioculatus	3	0.5
	Micrura leidyi	1	0.2
Platyhelminthes	*Stylochus ellipticus*	5	0.9
Source: Densities calculated from data presented by Versar in 2003 *as cited in* NYSDEC, 2009.			

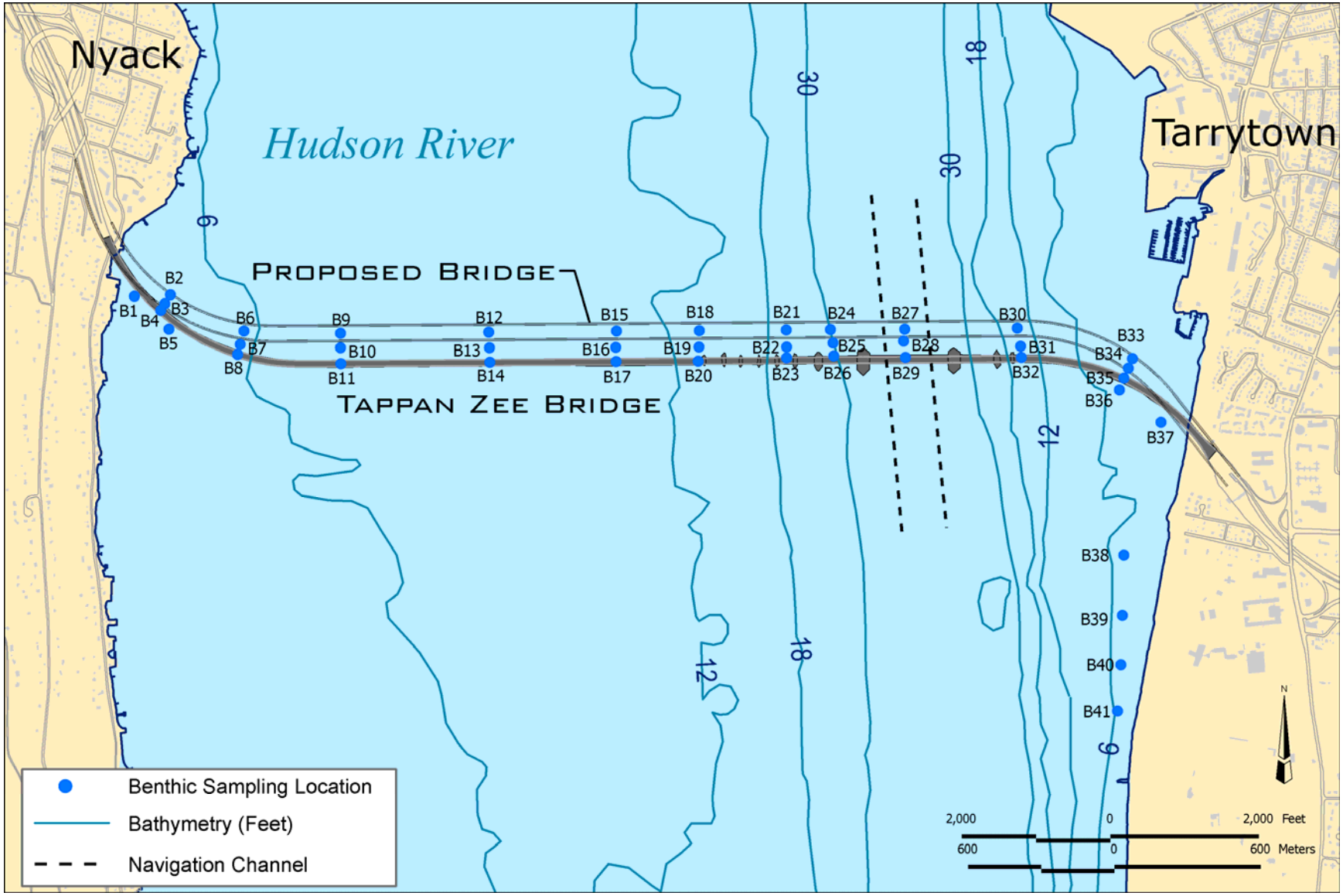


Figure F-1-22 Benthic Invertebrate Sampling Locations

Photo F-1-7 A Van Veen Grab Used for Benthic Sampling. Note glove for scale.

Photo F-1-8 Scientists processing benthic invertebrate samples.

Soft Sediment Sampling Locations

Benthic invertebrate samples were collected in five general geographical areas. Descriptions of these areas are as follows:

- Bridge Span – Sediment sampling sites within this area were located directly beneath the footprint of the current alignment.
- Mid Span – Sediment sampling sites within this area were located 50 feet (15.2 m) north of the current alignment.
- New Span – Sediment sampling sites within this area were located 150 feet (45.7 m) north of the current alignment. This area is presumed to be the alignment of the new bridge.
- South – Sediment sampling sites within this area were located in the areas of the potential alignments of southerly approaches to a new bridge.
- Shoreline – Sediment sampling sites within this area were in four locations south of the bridge along the eastern bank of the river.

In order to accurately describe the distribution of benthic invertebrates in the study area, the benthic habitat has been broken down into five broad categories with respect to the composition of the benthic substrate: fine sediments; sediments with shell hash; oyster shells/reef; scoured; and shoreline. Descriptions of each of these habitats follow:

- Fine Sediment Habitat. This habitat is comprised of thick deposits of soft, fine-grained sediments. Silt environments often occurred in shallow waters near the river banks where the river flow is attenuated by the shallow depth and bridge piers, which permits the buildup of soft sediments. The silt environment had limited shell material within the matrix.
- Sediment with Shell Hash Habitat. This habitat likewise contains very fine-grained sediments, but there is a marked increase in the number of shells and shell fragments (i.e. shell hash) in the matrix.
- Oyster Shells with Sediment. A majority of the matrix consisted of live oysters, oyster shells, and shell fragments. Sediments associated with this habitat were generally comprised of coarser-grained materials.
- Scoured. This habitat is limited to the deeper river channel. The presence of strong currents has affected the sediments, which generally consist of densely-packed, scoured clays with pockets of shells.
- Shoreline Habitat. This habitat was present south of the bridge on the eastern bank of the river. The sediments here are coarse-grained, with some gravel in the matrix. The sediments are influenced by previous Shoreline construction and outwash from small brooks and rivulets that empty into the river. There was often a limited recovery of sediment material in these locations.

Table F-1-13 provides a description of the each sediment sample.

Table F-1-13

Benthic Invertebrate Soft Sediment Sampling Locations

Sample Point	Geographical Area	Depth in feet	Habitat Category	Sediment Description
B-1	South	5	Fine Sediment	Silt
B-2	New Span	6	Fine Sediment	Very fine silt
B-3	Mid	7	Fine Sediment	Very fine silt with organic material
B-4	Bridge	10	Fine Sediment	Very fine silt
B-5	South	11	Fine Sediment	Very fine silt with organic material
B-6	New Span	7	Fine Sediment	Very fine silt with organic material and shells
B-7	Mid	9	Fine Sediment	Very fine silt with organic material and shells
B-8	Bridge	10	Fine Sediment	Silt with high amounts of shell hash
B-9	New Span	12	Sediment with Shell Hash Habitat	Clayey silt with shells
B-10	Mid	12	Sediment with Shell Hash Habitat	Clayey silt with shells
B-11	Bridge	12	Sediment with Shell Hash Habitat	Shells, gravel, and silt
B-12	New Span	11	Sediment with Shell Hash Habitat	Silty Material with shells
B-13	Mid	13	Sediment with Shell Hash Habitat	Oyster shells with clayey-silt
B-14	Bridge	12	Sediment with Shell Hash Habitat	Rocks, shells, and gravels
B-15	New Span	13	Sediment with Shell Hash Habitat	Silt material with organic matter
B-16	Mid	14	Sediment with Shell Hash Habitat	Silt material with shells
B-17	Bridge	14	Sediment with Shell Hash Habitat	Oyster shells with sand and gravel
B-18	New Span	20	Oyster Shells with Sediment	Oyster Shells with Silt
B-19	Mid	20	Oyster Shells with Sediment	Oyster Shells with Silt
B-20	Bridge	21	Oyster Shells with Sediment	Oyster Shells with Silt
B-21	New Span	24	Oyster Shells with Sediment	Oyster Shells with Silt
B-22	Mid	25	Oyster Shells with Sediment	Oyster Shells with Silt
B-23	Bridge	37	Oyster Shells with Sediment	Oyster Shells with Silt
B-24	New Span	37	Oyster Shells with Sediment	Oyster Shells with Silt
B-25	Mid	40	Oyster Shells with Sediment	Oyster Shells with Silt
B-26	Bridge	42	Oyster Shells with Sediment	Oyster Shells with Silt
B-27	New Span	50	Scoured	Rocks, shells, and gravels
B-28	Mid	49	Scoured	Rocks, shells, and dense clays
B-29	Bridge	48	Scoured	Rocks, shells, limited sediment
B-30	New Span	12	Oyster Shells with Sediment	Silty material with organic matter

Table F-1-13 (con't)

Benthic Invertebrate Soft Sediment Sampling Locations

Sample Point	Geographical Area	Depth in feet	Habitat Category	Sediment Description
B-31	Mid	20	Oyster Shells with Sediment	Oyster shells, very low recovery of material
B-32	Bridge	22	Oyster Shells with Sediment	Gravel, pebbles, with shells
B-33	New Span	9	Oyster Shells with Sediment	Oyster Shells
B-34	Mid	10	Oyster Shells with Sediment	Oyster Shells and silt
B-35	Bridge	9	Sediment with Shell Hash Habitat	Silt with Shells
B-36	South	9	Fine Sediment	Very fine silt with shell hash
B-37	South	7	Fine Sediment	Very fine silt with shells
B-38	Shoreline	5	Shoreline Habitat	Sand and Silt
B-39	Shoreline	11	Shoreline Habitat	Sand and Silt
B-40	Shoreline	6	Shoreline Habitat	Sandy material, with shells
B-41	Shoreline	10	Shoreline Habitat	Sandy material

Bridge Pier Sampling Locations

To obtain data regarding the benthic flora and fauna that colonized the bridge pier structures, Self Contained Underwater Breathing Apparatus (SCUBA) divers performed visual observations and collected specimens for analysis. Six piers were selected for the study, conducted in October 2007; their locations are shown in Figure F-1-23.

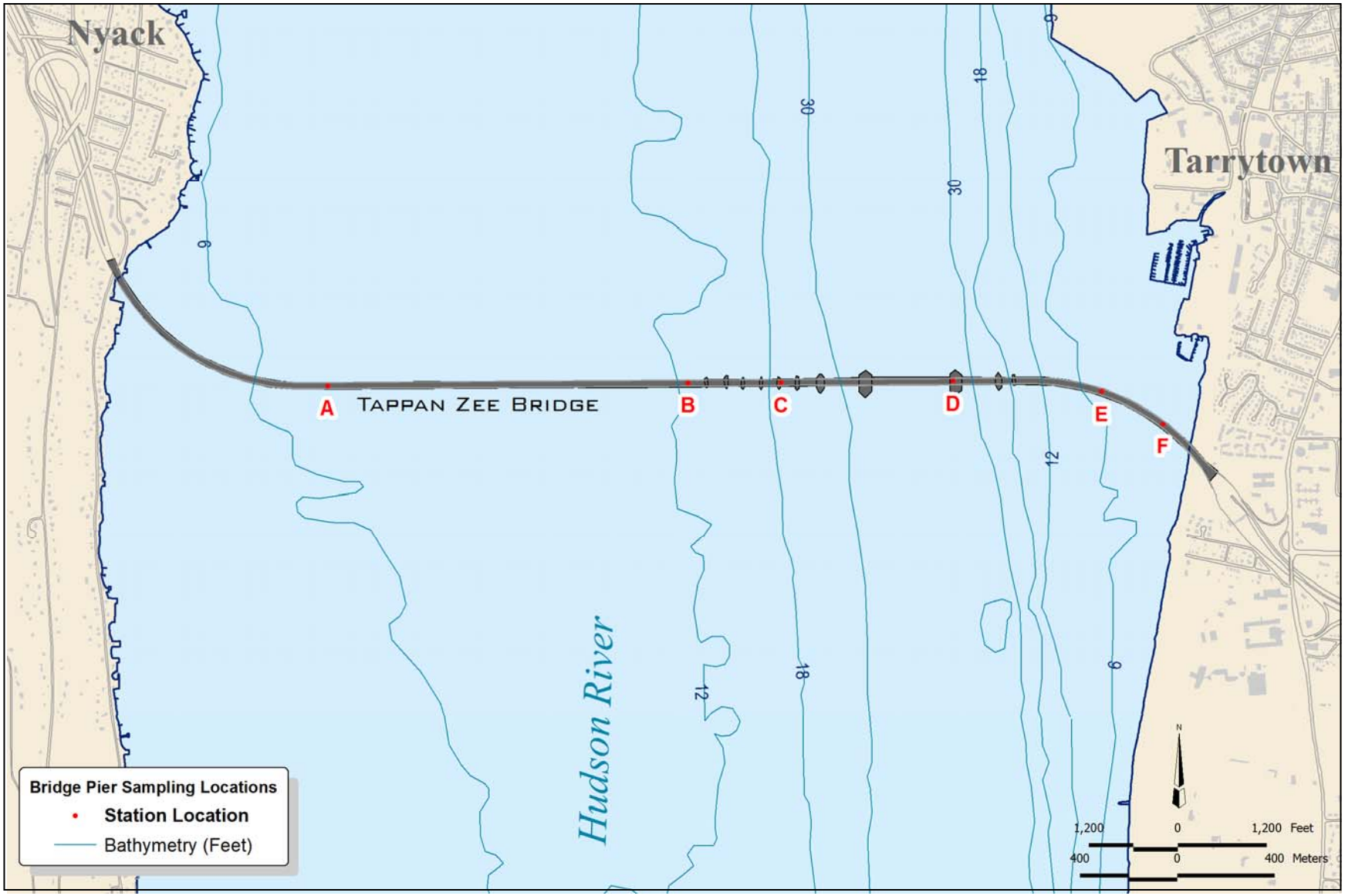


Figure F-1-23 Bridge Pier Sampling Locations

Six locations on different bridge piers were inspected by remote video methods to develop an understanding of the extent to which fish use these structures as habitat. Also, twenty 0.5-meter quadrants were sampled by divers by scraping off any attached organisms into sampling containers. The flora and fauna samples collected by the diver at each pier were combined in a labeled plastic jar containing a 70 percent concentration of isopropyl alcohol (a preservative) with rose bengal (a biological stain). Organisms in the sample jars were identified by Earth Tech staff to the lowest practical taxonomy.

Table F-1-14 provides a brief description of each of the six bridge pier sampling locations; some information on the piers themselves is given immediately below.

- Location A – In a shallow-water area along the west side of the river; water depth 12 feet (3.7 m) below mean sea level (MSL). The substructure of this pier consists of a concrete pile cap supported by numerous timber piles.

- Location B – In a mid-depth area along the western side of the river; water depth 18 feet (5.5 m) MSL. The substructure of this pier consists of a concrete pile cap supported by a concrete-filled steel cofferdam and timber piles (below the mudline).

- Location C – In a slope area near the main channel; water depth 25 feet (7.6 m) MSL. The substructure of this pier consists of a concrete pile cap supported by a steel caisson and timber piles (below the mudline).

- Location D – In the main channel area; water depth 40 feet (12.2 m) MSL. The substructure of this pier consists of a concrete pile cap supported by a steel caisson and timber piles (below the mudline).

- Location E – In shallow water along the eastern side of the river; water depth 12 feet (3.7 m) MSL. The substructure of this pier consists of a concrete pile cap supported by a concrete-filled steel cofferdam and timber piles (below the mudline).

- Location F – In a near-shore area along the eastern side of the river; water depth 10 feet (3 m) MSL. The substructure of this pier consists of a concrete pile cap supported by a concrete-filled steel cofferdam and timber piles (below the mudline).

Table F-1-14

Description of Pier Habitats

Pier Location	Depth of River in feet at Pier Location	Description
A	10	Shallow-water environment near the river's west bank.
B	15	This pier represents the start of the slope from the western shoal to the deep channel.
C	25	This pier is in the lower portion of the slope.
D	50	This pier represents benthic organisms inhabiting the deepest portion of the river.
E	12	Shallow-water environment along the eastern side of the river.
F	6	Shallow-water environment near the river's east bank.

2.2.2 Results of Sediment Sampling and Bridge Pier Sampling Programs

In what follows, the results of the sediment sampling program are discussed first, followed by the results of the bridge pier sampling program. At the end of this chapter, an analysis of the benthic invertebrate community within the study area is provided.

Sediment Sampling Program

A total of 48 species and 213,000 individual organisms were collected during the sediment sampling program. Generally, the species richness and numbers of individuals were lower in the late winter and early spring and higher in the summer and the fall. Species diversity remained relatively constant throughout the year, with slightly higher numbers during the July sampling event. Table F-1-15 shows the numbers of individuals, species richness, and total diversity (calculated using the Shannon-Weiner Index) for each of the six sample months. The Shannon Weiner Index is a measure of uncertainty. The higher the value of H, the greater is the probability or uncertainty that the next individual chosen at random from a collection of species will not belong to the same species as the previous one (Smith, 1990). The index is expressed by the following equation:

$$H = -\sum_{i=1}^{s} (pi)(\log pi)$$

where
H = diversity index
s = number of species
i = species number
pi = proportion of individuals of the total sample belonging to the *i*th species

Source: Smith, 1990

Table F-1-15

Sediment Sampling Program Results

Sampling Month	Abundance (Number of Individuals)	Species Richness	Total Diversity
January	30,182	34	0.505514
March	17,382	32	0.537161
May	23,700	27	0.5209935
July	66,271	38	0.6282055
September	34,840	39	0.514145
November	41,003	38	0.5209843

In Table F-1-15, the total diversity for each month is a relative measure. The data presented in the table show that July is the month with the highest species diversity and that January the month with the lowest diversity.

Species

Review of the entire sample collection shows a variety of benthic organisms that comprises taxonomic groups. A description of the taxonomic groups collected is provided below:

- Phylum Annelida. Commonly referred to as annelids, this is a large phylum of animals comprising the segmented worms, with about 15,000 modern species, including the well-known earthworms, leeches, and marine worms.

  Class Oligochaeta – Oligochaeta means "few bristles," which refers to the small bundles of hair-like bristles that occur on each body segment. These worms have long been recognized as pollution-tolerant because of their ability to thrive in poor water quality conditions.

  Class Polychaeta – Meaning “many hairs,” referring to the many bristles (parapodia) that extend from the side of the species. Polychaetes are a major prey species for a variety of marine organisms. These worms live in a variety of depths and habitats throughout the lower Hudson River and New York Harbor.

- Phylum Arthropoda – Arthropods comprise over three quarters of living creatures. They vary from spiders and scorpions to shrimp and lobsters. Common characteristics of arthropods are an exoskeleton and the necessity to molt. In the marine environment arthropods comprise a major portion of the food chain, and larger arthropods (e.g., blue crabs, shrimp, and lobsters, etc.) are commercially harvested.

  Class Amphipoda – These are small crustaceans that number about 4,000 species. Amphipods have a vertically thin body and one set of legs for jumping or walking and another set for swimming. Examples of amphipods include beach fleas, sand hoppers, and water lice.

  Class Cripedia – The only species of crustaceans whose adults are wholly sessile (e.g., barnacles).

  Class Diptera – Diptera are true flies. Diptera species in the samples were often represented by larvae.

  Class Decapoda – Decapods are ten-legged crustaceans. These species (crabs and lobsters are examples) are familiar species and are commercially harvested.

  Class Isopoda – These are benthic invertebrates that comprise a portion of the diet of many estuarine species.

- Phylum Chordata – This phylum consists of species with a spinal column.

  Class Osteichthyes – This is a class of bony fish. Two species of this class were found in the samples.

- Phylum Mollusca – This phylum consists of shellfish common to northeast estuaries.

  Class Bivalvia – Clams and oysters.

  Class Gastropoda – Gastropod is derived from Greek and means “stomach foot.” Whelks are examples of species in this class.

- Phylum Platyhelminthes

  Class Polycladida – Species in this class are generally referred to as flatworms.

Table F-1-16 provides a listing of species collected during each sampling month and comments about each species within the study area.

Review of the data collected during the bi-monthly sampling shows that two species – *Balanus* spp. and *Leptocheirus plumulosus* – were predominant during each sampling event. Often these two species combined comprised over 50 percent of the total individuals recorded. *Hypaniola grayi*, *Chironomidae* spp. (larvae), *Hydrobia minuta* (juvenile), and *Capitellidae* spp. comprised the third- highest percentage of individuals in the combined monthly samples; however, these percentages were often much smaller that barnacles and *Leptocheirus plumulosus*. Table F-1-17 shows the three species with the highest abundance in each monthly sample. All of the species are common within estuaries of the northeast United States.

In order to determine habitat value and species usage within the benthic communities that occupy the various benthic habitat types – Fine Sediment, Sediment with Shell hash, Oyster Shells with Sediment, Scoured, and Shoreline – sampling locations were grouped by habitat and separated by the four geographical areas – i.e., existing span [bridge], mid span, new span, and southern locations. Sampling locations south of the bridge (i.e., the shoreline) are separated as the benthic substrate is markedly different within that portion of the study area. Tables 1-18, 1-19, and 1-20 show the total numbers of individuals, species richness, and diversity, by month, habitat, and location.

Findings

As can be seen in Table F-1-18, for all alignments, the total numbers of individuals was correlated with seasons. The months of March and May had the lowest numbers of individuals and the month of July had the highest numbers of individuals. Benthic invertebrate communities in estuaries typically have a higher number of individuals in the summer. The higher populations are a result of recruitment and changes to water quality parameters.

In order to determine what, if any, statistically significant difference existed between the benthic communities of the bridge – the new, mid, and proposed bridge alignments and the southern approaches – an analysis of variance (ANOVA) test was applied to the findings. Due to the limited number of sampling locations and markedly different benthic habitat, statistical analysis was not performed on the shoreline samples. In addition, southern locations were only used for comparison with bridge alignment locations whose benthic communities comprised fine sediments.

The results of the fine-sediment habitats for each alignment were compared using a two-way ANOVA for each sampled month. Table F-1-21 displays the statistical data for comparison of benthic communities between alignments (bridge, mid, new span), bottom habitat, and interaction effects between the two. The analysis shows that there is generally no statistically significant difference in benthic communities between the alignments (i.e., existing bridge alignment, mid-span, or new replacement bridge alignment). There was no statistically significant difference among individuals, except for the month of November. There was a statistically significant difference regarding species richness (the number of identifiable taxa) in March, September, November, and January samplings, but not in May and July.

Table F-1-16
Occurrence of Species Collected during the Sediment Sampling Program

PHYLUM / Class	Species	Jan	Mar	May	Jul	Sep	Nov	Comments
ANNELIDA Oligochaeta	*Oligochaete* spp.	✓	✓	✓	✓	✓	✓	Samples collected each month had very low numbers of oligochaete worms.
Polychaeta	*Capitellidae* spp.	✓	✓	✓	✓	✓	✓	A common prey species for fish and marine invertebrates. *Capitellidae* species were observed every month at benthic stations throughout the study area.
	Eteone heteropoda	✓				✓	✓	A common prey species for fish and marine invertebrates. This species was observed in marine samples associated with deep-water habitats. Abundance was low for this species.
	Goniadidae sp.						✓	This species was observed at one location and in very low abundance.
	Hypaniola grayi	✓	✓	✓	✓	✓	✓	A common prey species for fish and marine invertebrates. This species was observed every month at benthic stations throughout the study area.
	Nereis diversicolor	✓	✓	✓	✓	✓	✓	A prey species for fish and marine invertebrates. This species was observed every month, although its distribution and abundance were limited throughout the study area.
	Nereis succinea	✓	✓	✓	✓	✓	✓	A common prey species for fish and marine invertebrates. This species was observed every month at benthic stations throughout the study area.
	Pectinaria gouldii	✓				✓	✓	This species is a tube worm that was observed in only a handful of samples and in very low abundance.
	Polydorids (Boccardia spp. *& Polydora* spp.*)*	✓	✓	✓	✓	✓	✓	Referred to as "oyster worms" these species commonly live among oyster reefs. These species were observed during each bi-monthly sampling event. Their distribution was mostly limited to deeper-water stations where oysters were present. They were recorded in high abundance.
	Sabellaria viridis						✓	Also commonly referred to as "oyster worms" this species also lives among oyster reefs. This species had a limited distribution and abundance in the study area.
	Scolecolepides viridis	✓	✓	✓	✓	✓	✓	This species is a burrowing worm. It was found throughout the study area and in every month, although abundance was low.
	Scoloplos sp.	✓				✓		This species had limited distribution and abundance.
	Streblospio benedicti	✓			✓	✓	✓	This small worm (less than one-half inch long) had a limited distribution and abundance in the study area.
ARTHROPODA Amphipoda	*Ampelisca vadorum*				✓	✓		This amphipod had an extremely limited abundance and distribution in the study area.
	Corophium sp.	✓	✓	✓	✓	✓	✓	This species' abundance and distribution was limited in the study area
	Gammarus daiberi	✓	✓	✓	✓	✓	✓	This species' abundance and distribution was limited in the study area

Table F-1-16 (con't)

Occurrence of Species Collected during the Sediment Sampling Program

PHYLUM / Class	Species	Jan	Mar	May	Jul	Sep	Nov	Comments
ARTHROPODA Amphipoda (con't)	*Leptocheirus plumulosus*	✓	✓	✓	✓	✓	✓	This burrowing amphipod is often found in estuarine and marine communities with strong currents. This species was well-distributed throughout the study area and was in very high abundance.
	Melita nitida	✓	✓	✓	✓	✓	✓	This species had limited distribution and abundance in the study area.
	Monoculodes sp.	✓	✓	✓	✓	✓	✓	This species had limited-to-moderate distribution and abundance in the study area.
	Pleusymtes glaber (variant)				✓	✓	✓	This species had very limited distribution and abundance in the study area.
Cirripedia	*Balanus* spp.	✓	✓	✓	✓	✓	✓	Barnacles are sessile marine organisms that are common throughout the world. The species affixes itself to hard substrates in shallow estuarine and marine waters. Barnacles are prevalent throughout the Lower Hudson river and New York Harbor.
Decapoda	*Callinectes sapidus*						✓	
	Caridea zoea				✓	✓		Larval stage of shrimp that is a prey for many species within the estuary.
	Crangon septemspinosa		✓	✓	✓	✓		This species of shrimp is highly motile and can be difficult to catch with the sampling device that was employed. Many species of fish feed on shrimp.
	Neomysis americana	✓		✓	✓	✓	✓	This species of shrimp is highly motile and can be difficult to catch with the sampling device that was employed. Many species of fish feed on shrimp.
	Palaemonetes vulgaris	✓	✓		✓	✓	✓	This species of shrimp is highly motile and can be difficult to catch with the sampling device that was employed. Many species of fish feed on shrimp.
	Rhithropanopeus harrisii	✓	✓	✓	✓	✓	✓	This species is a small mud crab. The distribution of this species was limited to shallow-water locations. The abundance was limited in the study area.
	Rhithropanopeus harrisii (mega)				✓			This species is a small mud crab. The distribution of this species was limited to deep-water locations. The abundance was very limited in the study area.
	Rhithropanopeus harrisii (zoe)				✓			This species is a small mud crab. The distribution of this species was limited to deep-water locations. The abundance was very limited in the study area.
Diptera	*Chironomidae* spp. *(larvae)*	✓		✓	✓	✓	✓	Larvae of a small fly that is a prey for many species within the estuary.
Isopoda	*Chiridotea* sp.		✓	✓				Isopods are aquatic crustaceans with seven pairs of legs adapted for crawling. Isopods are often preyed upon by various fish and other benthic invertebrates.
	Cyathura polita	✓	✓	✓	✓	✓	✓	
	Edotea triloba	✓	✓	✓	✓	✓	✓	
	Sphaeromatidae sp.		✓				✓	
	Synidotea sp.				✓	✓		
CHORDATA Osteichthyes	*Gobiosoma bosci*	✓	✓		✓	✓	✓	This species is a small fish that is common to estuarine benthic habitats.
	Trinectes maculatus		✓					This species, commonly referred to as a hogchoker, is a small species of flounder that is common in estuarine environments.

Table F-1-16 (con't)

Occurrence of Species Collected during the Sediment Sampling Program

PHYLUM / Class	Species	Jan	Mar	May	Jul	Sep	Nov	Comments
MOLLUSCA Bivalvia	*Congeria leucopheata*	✓	✓	✓	✓	✓	✓	A mussel species that usually inhabits the less-saline waters of an estuary.
	Crassostrea virginica	✓	✓	✓	✓	✓	✓	Oysters were not present in environments with high amounts of silt (sampling sites B1 through B8 and B35 through B39). Oysters were densely concentrated in the sampling sites located in the middle of the river (sites B-12 through B33 and B-40). Juvenile and adult individuals were identified in each sample. The total number of oysters collected ranged from 289 (March) to a high of 789 (November)
	Macoma balthica	✓			✓	✓	✓	A small clam approximately 1.5 inches in size that is usually buried in mud.
	Modiolus demissus	✓	✓	✓	✓	✓	✓	A mussel species that is very common to the New York Harbor area; a filter feeder.
	Mulinia lateralis	✓				✓	✓	Referred to a "surf clam". A small bivalve that is approximately 1 inch in length that inhabits subtidal, muddy bottoms.
	Mya arenaria	✓			✓	✓	✓	A clam approximately 4 inches long that inhabits subtidal benthic sediments.
	Rangia cuneata	✓	✓	✓	✓	✓	✓	A clam approximately 2.5 inches long that is common in estuaries in the northeast US.
	Tellina agillis						✓	A small clam approximately 0.5 inches in length that is usually buried in mud.
	Bivalvia spp. *(juvenile clams)*	✓	✓	✓	✓	✓	✓	Bivalvia are small clams that were not identified to species.
Gastropoda	*Hydrobia minuta (juvenile)*	✓	✓	✓	✓	✓	✓	Commonly referred to as "seaweed snails" this 0.2-inch bivalve inhabits grass beds or muddy bottoms in estuaries.
PLATYHELMINTHES Polycladida	*Stylochus ellipticus*	✓			✓	✓	✓	An aquatic worm that is a major predator of barnacles.

Note: ✓ indicates that individuals of the listed species were collected in the given month.

Table F-1-17

The Three Dominant Species Collected during each Bi-Monthly Sampling Event

Month and Year	Species	Percentage of Total Sample
January 2008	*Balanus* spp.	25.5
	Leptocheirus plumulosus	22
	Hypaniola grayi	7.3
March 2007	*Balanus* spp.	39.9
	Leptocheirus plumulosus	24.8
	Chironomidae spp. (larvae)	6
May 2007	*Balanus* spp.	39.5
	Leptocheirus plumulosus	17.6
	Hydrobia minuta (juvenile)	8.2
July 2007	*Leptocheirus plumulosus*	35.4
	Balanus spp.	32.9
	Hydrobia minuta (juvenile)	15.1
September 2007	*Balanus* spp.	42.5
	Leptocheirus plumulosus	17.2
	Capitellidae spp.	8.5
November 2007	*Balanus* spp.	28.6
	Leptocheirus plumulosus	25.9
	Capitellidae spp.	14.2

Table F-1-18

Total Numbers of Individuals Collected by Benthic Habitat and Proposed Bridge Alignments and Approaches

Month	Benthic Habitats Within Existing and Proposed Bridge Alignments and Approaches													Shore-line*
	Fine Sediments				Sediment with Shell Hash			Oyster Shells/Reefs			Scoured			
	New	Mid	Bridge	South	New	Mid	Bridge	New	Mid	Bridge	New	Mid	Bridge	
Jan	1,038	919	684	970	841	653	639	826	848	715	135	338	600	476
Mar	659	800	247	421	538	397	533	416	478	508	274	196	209	114
May	750	628	402	909	457	316	839	620	689	584	228	391	798	311
Jul	2,497	3,073	1,555	1,933	1,425	1,440	1,407	842	1,094	1,462	1,187	1,462	2,698	2,148
Sep	881	598	942	537	693	672	746	882	1,088	1,177	794	1,019	818	875
Nov	1,434	1,005	805	928	1,057	1,208	916	920	759	900	444	1,681	1,468	1,158

Notes:
*The data for the four locations that represent the shoreline sampling stations are presented as an average.
New refers to the proposed bridge alignment, approximately 150 feet north of the existing bridge alignment.
Mid refers to the alignment that is 50 feet north of the existing bridge.
Bridge refers to the existing alignment.
South refers to several locations south of the existing bridge, near the east and west banks.
Shoreline refers to the locations along the shoreline south of the bridge.

Table F-1-19

Species Richness by Benthic Habitat and Proposed Bridge Alignments and Approaches

Month	Benthic Habitats Within Existing and Proposed Bridge Alignments and Approaches													Shoreline
	Fine Sediments				Sediment with Shell Hash			Oyster Shells/Reefs			Scoured			
	New	Mid	Bridge	South	New	Mid	Bridge	New	Mid	Bridge	New	Mid	Bridge	
Jan	16.0	15.5	14.5	16.3	13.3	16.0	13.3	17.6	17.8	14.4	7.0	21.0	13.0	18
Mar	12.0	15.5	17.5	10.5	18.3	18.3	18.3	16.4	14.0	15.4	10.0	14.0	13.0	15
May	13.0	9.5	13.0	12.8	13.7	16.0	13.3	13.2	16.2	14.6	9.0	13.0	16.0	13
Jul	11.0	15.5	16.0	13.3	16.7	17.7	14.7	18.0	16.0	16.2	18.0	11.0	11.0	15
Sep	15.0	15.5	15.5	17.3	13.7	13.3	13.7	19.4	18.0	14.2	23.0	15.0	20.0	20
Nov	15.5	15.0	14.5	14.8	17.3	17.7	11.3	19.2	19.0	15.4	19.0	21.0	19.0	19

Notes:
*The data for the four locations that represent the shoreline sampling stations are presented as an average.
New refers to the proposed bridge alignment, approximately 150 feet north of the existing bridge alignment.
Mid refers to an alignment that is 50 feet north of the existing bridge.
Bridge refers to the existing alignment.
South refers to several locations south of the existing bridge, near the east and west banks.
Shoreline refers to the locations along the shoreline south of the bridge.

Table F-1-20

Species Diversity by Benthic Habitat and Proposed Bridge Alignments and Approaches

Month	Benthic Habitats Within Existing and Proposed Bridge Alignments and Approaches													
	Fine Sediments				Sediment with Shell Hash			Oyster Shells/Reefs			Scoured			
	New	Mid	Bridge	South	New	Mid	Bridge	New	Mid	Bridge	New	Mid	Bridge	Shoreline*
Jan	0.530	0.578	0.611	0.552	0.497	0.390	0.292	0.491	0.482	0.404	0.477	0.544	0.291	0.494
Mar	0.612	0.596	0.525	0.412	0.555	0.528	0.274	0.399	0.415	0.411	0.446	0.512	0.490	0.534
May	0.595	0.617	0.560	0.574	0.533	0.530	0.388	0.459	0.508	0.565	0.576	0.465	0.450	0.580
Jul	0.659	0.565	0.593	0.623	0.462	0.324	0.437	0.544	0.367	0.542	0.656	0.629	0.610	0.367
Sep	0.546	0.553	0.499	0.533	0.585	0.403	0.282	0.535	0.412	0.376	0.555	0.478	0.438	0.544
Nov	0.485	0.562	0.282	0.564	0.569	0.582	0.192	0.551	0.547	0.482	0.522	0.445	0.522	0.531

Notes:
* The data for the four locations that represent the shoreline sampling stations are presented as an average.
New refers to the proposed bridge alignment, approximately 150 feet north of the existing bridge alignment.
Mid refers to an alignment that is 50 feet north of the existing bridge.
Bridge refers to the existing alignment.
South refers to several locations south of the existing bridge, near the east and west banks.
Shoreline refers to the locations along the shoreline parallel to the south of the bridge.

Table F-1-21
Statistical Comparison of Species Richness and Individuals

Month	Source	Individuals	Richness
March	Alignments	0.767	0.470
	Habitat	0.460	**0.028**
	Alignment X Habitat	0.647	0.526
May	Alignments	0.636	0.244
	Habitat	0.895	0.096
	Alignment X Habitat	0.469	0.161
July	Alignments	0.722	0.696
	Habitat	0.032	0.255
	Alignment X Habitat	0.411	0.341
September	Alignments	0.878	0.216
	Habitat	0.298	**0.008**
	Alignment X Habitat	0.963	0.197
November	Alignments	0.636	**0.022**
	Habitat	0.463	**0.007**
	Alignment X Habitat	0.278	0.420
January	Alignments	0.139	0.178
	Habitat	0.950	**0.016**
	Alignment X Habitat	0.831	0.115
Note: Values <0.05 are statistically significant and are indicated by numbers in boldface.			

To further elucidate the findings, a one-way ANOVA analysis was applied to the data (divided by sampled month and habitat type) to determine the difference, if any, between the existing and proposed spans in diversity, richness, and numbers of individuals (Table F-1-22) for fine sediment, silt with shell hash, and oyster shells. (Due to low sample size, the scoured and shoreline habitats could not be statistically analyzed.) Following every significant (or near-significant) finding, a Tukey HSD post-hoc test is done to examine which alignments are significantly different from each other. The table displays a matrix of pairwise comparison probabilities between alignments, after every significant (or near-significant) statistical result; (any value <0.05 is considered significantly different). Data that were excessively skewed, or showed high kurtosis, were transformed, as was most effective, prior to analysis. If data failed the F-test, a Krustal-Walis Non-Parametric test was used instead. Data analysis was carried out using SYSTAT 9.

There was no statistically significant difference in benthic diversity, total numbers of individuals, or richness between the current and proposed bridge alignments. There was a difference between the current bridge alignment and approaches to the south; however, the habitat south of the bridge is different than both the bridge alignment and proposed locations north of the bridge. Habitats north of the bridge are influenced by marinas and active barge traffic associated with the maintenance yard. There is little development or benthic disturbance south of the bridge. Also, locations south of the bridge normally accumulate thick sediment deposits, which may cause changes to the benthic community structure.

Table F-1-22

Results of Statistical Tests on Benthic Invertebrate Populations

Month	Habitat	Parameter	Alignments	Alignments			
				Bridge	Mid	New Span	Southern
March	Fine Sediments (Silt)	**Diversity p=0.002**	Bridge	1			
			Mid	0.289	1		
			New Span	0.171	0.969	1	
			Approach	**0.039**	**0.004**	**0.003**	1
		Richness p=0.013	Bridge	1			
			Mid	0.673	1		
			New Span	0.70	0.278	1	
			Approach	**0.014**	**0.058**	**0.755**	1
		Individuals p=0.020	Bridge	1			
			Mid	0.289	1		
			New Span	0.171	0.969	1	
			Approach	**0.039**	**0.004**	**0.003**	1
	Sediment With Shell Hash	Diversity	p=0.061*				
		Richness	p=1.000				
		Individuals	p=0.804				
	Oyster Shells With Sediment	Diversity	p=0.984				
		Richness	p=0.387*				
		Individuals	p=0.997*				
May	Fine Sediments (Silt)	**Individuals p=0.045**	Bridge	1			
			Mid	0.519	1		
			New Span	0.218	0.860	1	
			Approach	**0.036**	0.258	0.659	1
	Sediment With Shell Hash	Diversity	p=0.150				
		Richness	p=0.187*				
		Individuals	p=0.180*				
	Oyster Shells With Sediment	Diversity	p=0.512*				
		Richness	p=0.264				
		Individuals	p=0.641				
July	Fine Sediments (Silt)	Diversity	p=0.269*				
		Richness	p=0.343*				
		Individuals	p=0.546				
	Sediment With Shell Hash	Diversity	p=0.725				
		Richness	p=0.422				
		Individuals	p=0.977				
	Oyster Shells With Sediment	Diversity	p=0.066				
		Richness	p=0.485				
		Individuals	p=0.336				
September	Fine Sediments (Silt)	Diversity	p=0.557				
		Richness	p=0.294				
		Individuals	p=0.443				
	Sediment With Shell Hash	Diversity	p=0.148*				
		Richness	p=0.977				
		Individuals	p=0.980				
	Oyster Shells With Sediment	Diversity	p=0.288				
		Richness p=0.057	Bridge	1			
			Mid	0.177	1		
			New Span	0.054	0.765	1	
		Individuals	p=0.546				

Table F-1-22 (con't)

Results of Statistical Tests on Benthic Invertebrate Populations

Month	Habitat	Parameter	Alignments	Alignments			
				Bridge	Mid	New Span	Southern
November	Fine Sediments (Silt)	**Diversity p<0.001**	Bridge	1			
			Mid	0.001	1		
			New Span	0.003	1.86	1	
			Approach	**0.000**	1.00	0.112	1
		Richness	p=0.963				
		Individuals	p=0.154				
	Sediment With Shell Hash	**Diversity p=0.003**	Bridge	1			
			Mid	0.004	1		
			New Span	0.005	0.980	1	
		Richness p=0.055	Bridge	1			
			Mid	0.071	1		
			New Span	0.087	0.986	1	
	Oyster Shells With Sediment	Diversity	p=0.452				
		Richness p=0.018	Bridge	1			
			Mid	0.036	1		
			New Span	0.028	0.986	1	
		Individuals	p=0.932*				
January	Fine Sediments (Silt)	Diversity	p=0.341				
		Richness	p=0.842				
		Individuals	p=0.639				
	Sediment With Shell Hash	Diversity	p=0.367				
		Richness	p=0.089				
		Individuals	p=0.749				
	Oyster Shells With Sediment	Diversity	p=0.478				
		Richness	p=0.188				
		Individuals	p=0.800*				
Note: * p-value calculated via Krustal-Walis Non-Parametric Test							

Oyster Reefs

Oysters (*Crassostrea virginica*) are reef-building organisms found in the intertidal and subtidal zones along the east coast of the US in muddy bays and harbors. The juvenile oysters attach (with a glue-like substance) themselves to adult oysters already attached to rocks, shell or other oysters (NYSDEC, 2011). The number of species found on any given oyster reef varies according to location, temperature, and salinity, but all oyster reefs have a diversity of species on, within, and around them. Because they are filter feeders, oysters (Photo F-1-9) can greatly influence nutrient cycling in estuarine systems, maintain the stability of the ecosystem, and may have significant effects on phytoplankton biomass in an area (NOAA, 2009).

Photo F-1-9 Live Oysters Collected During the Benthic Invertebrate Sampling.

Several historical oyster beds were identified in the area of the study. Figure F-1-24 identifies the presence of historical reefs near the study area. North of the bridge and west of the navigation channel, oyster reefs have been mapped within 1,000 ft (305 m) of the Tappan Zee Bridge. Benthic sampling results showed that oysters comprised a portion of the samples in the deeper portions of the western shoals.

In September and October of 2009, oyster beds were mapped approximately 2 miles (3.2 km) north and south of the bridge. They were accomplished through the use of side scan sonar and physical grab samples to confirm the findings of the sonar.

A Klein Model 3000 dual frequency (100 and 500 KHz) digital side scan sonar was used to image the river bottom to locate potential oyster beds. The system was operated at 500 kHz with a 75m range per channel. The side scan sonar revealed a bottom with varying characteristics, dependent on depth and geology. Along the west bank of the river, mud flats were seen to extend nearly two miles eastward to the main channel of the river. Within the channel, sand and till were present, comprising large, undulating ripples. The eastern bank featured a combination of mud and gravel, with outwash deposits noted at the mouth of tributary streams.

Distributed throughout the survey area at differing depths was a distinct bottom texture somewhat like gravel. This texture was tentatively identified as oyster shells based on its initial appearance in what was noted as an historical oyster bed. Figure F-1-25 identifies the mapped oyster beds.

In the southern block, seven potential oyster beds were identified. The most southern of the seven, denoted as S1, appeared to abut against the edge of an old channel about 9,000 ft south of the bridge

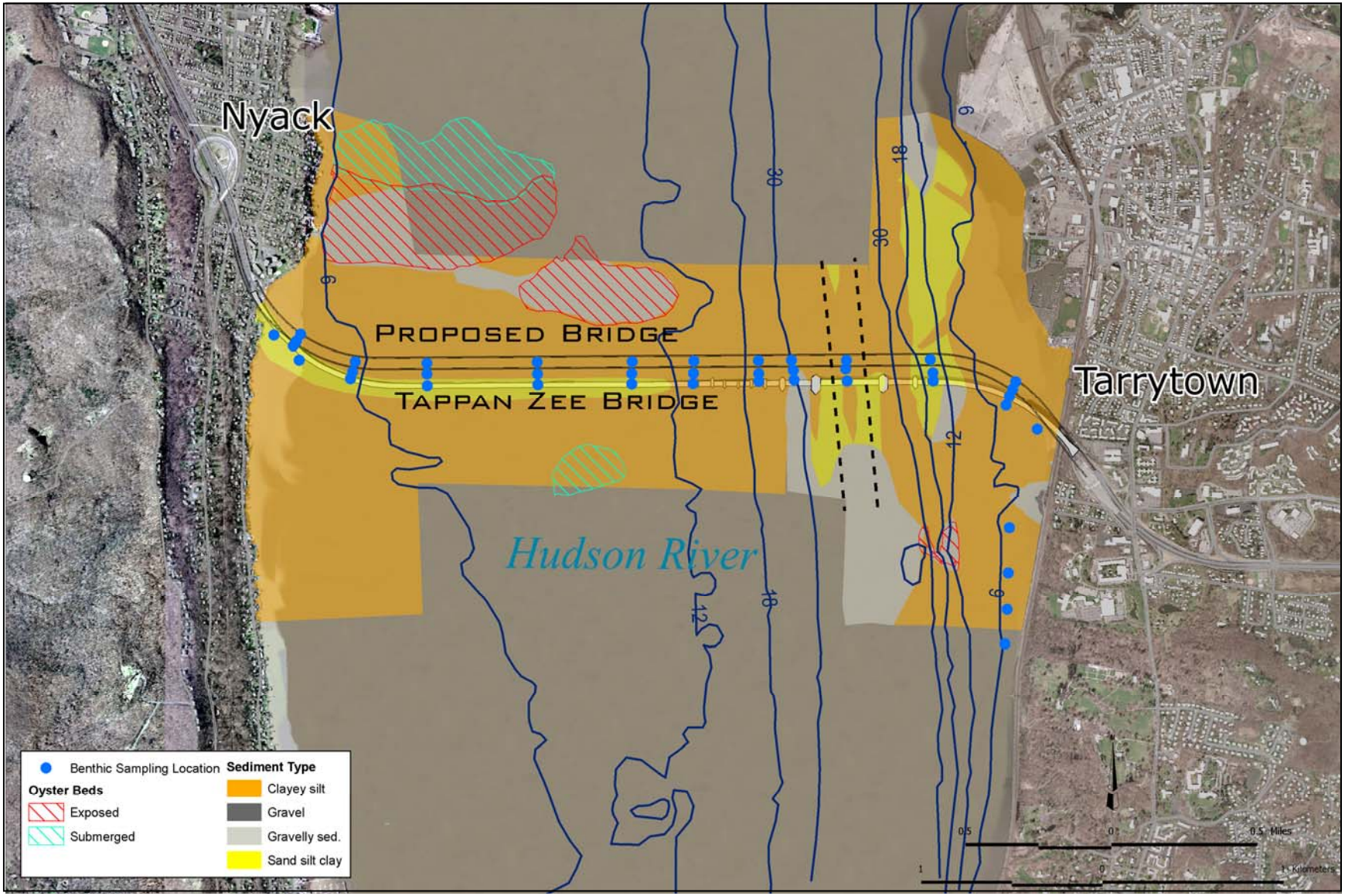


Figure F-1-24 Oyster Reefs and Substrate Types within Proximity of the Benthic Invertebrate Sampling Locations

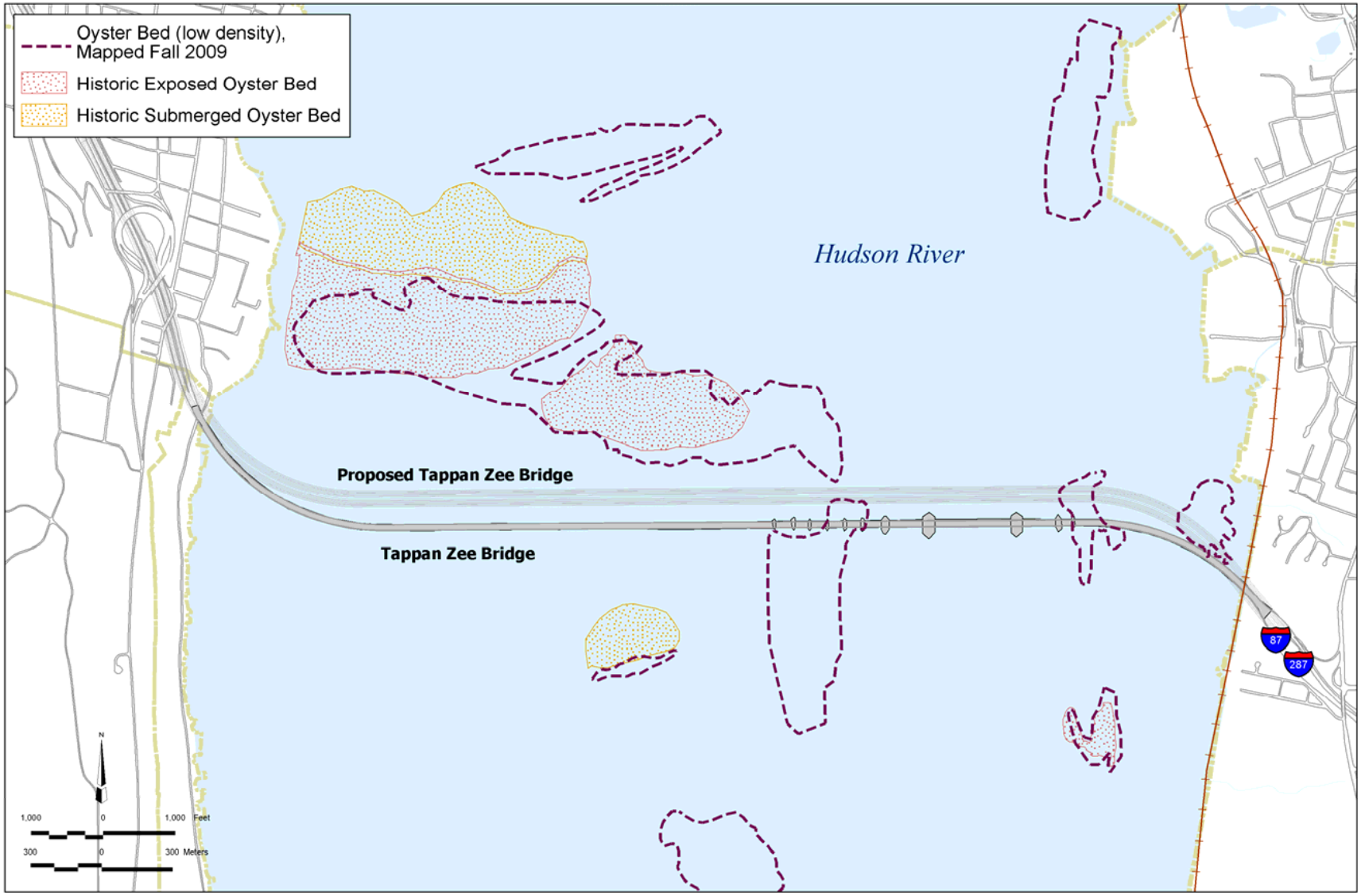


Figure F-1-25 Mapped Oyster Beds - 2009

along the north side of Piermont Pier. The bed seemed somewhat diffuse in terms of density. S2, located northwest of S1 along the channel about 8,500 ft south of the bridge, appeared to be a diffuse, clumpy bed. S3 appeared to be a dense bed located near the middle of the flats 5,000 ft south of the bridge. S4 and S5 were two thin but dense strips located about 2,000 ft south of the Tappan Zee Bridge causeway. S6 appeared diffuse and was positioned along the slope of the channel leading up to and under the western main support columns of the Tappan Zee Bridge's central truss. S7 was located about 2000 ft south of the Tappan Zee's eastern approach, along the edge of the channel. It appeared to be rather dense.

Six potential beds were identified in the north. Adjacent to the bridge, along the eastern side of the channel, was N1. Due east of N1, near the shore, was N2. These beds appeared to have a somewhat diffuse density. Along the shore, 2,500 ft north of N1, was N3. N3 appeared to have some oyster-like texture, but for the most part the area appeared very rocky/gravelly. On the flats west of the channel there were three beds that had been previously delineated. These were N4 (10,000 ft north of bridge), N5 (5,000 ft north of bridge), and N6 (2,000 ft north of bridge). All of these beds appeared to be dense.

The side scan sonar revealed a bottom with varying characteristics, dependent on depth and geology. Along the west bank of the river, mud flats were seen to extend nearly two miles eastward to the main channel of the river. Within the channel, sand and till were present, comprising large, undulating ripples. The eastern bank featured a combination of mud and gravel, with outwash deposits noted at the mouth of tributary streams.

Distributed throughout the survey area at differing depths was a distinct bottom texture somewhat like gravel. What was unique about this texture was that its reflectivity was particularly strong and uniform, sometimes causing the return echo to become chaotic at the edge of the sonar's range. This texture was tentatively identified as oyster shells based on its initial appearance in what was noted as an historical oyster bed.

Photo F-1-10, Side Scan Sonar in Flashlight Mode, shows the side scan sonar image as seen in 'flashlight mode', which makes more acoustically reflective areas appear lighter and more absorptive areas appear darker. The bottom half of the image shows the edge of a confirmed oyster bed, while the top half shows the bed tapering off into mud.

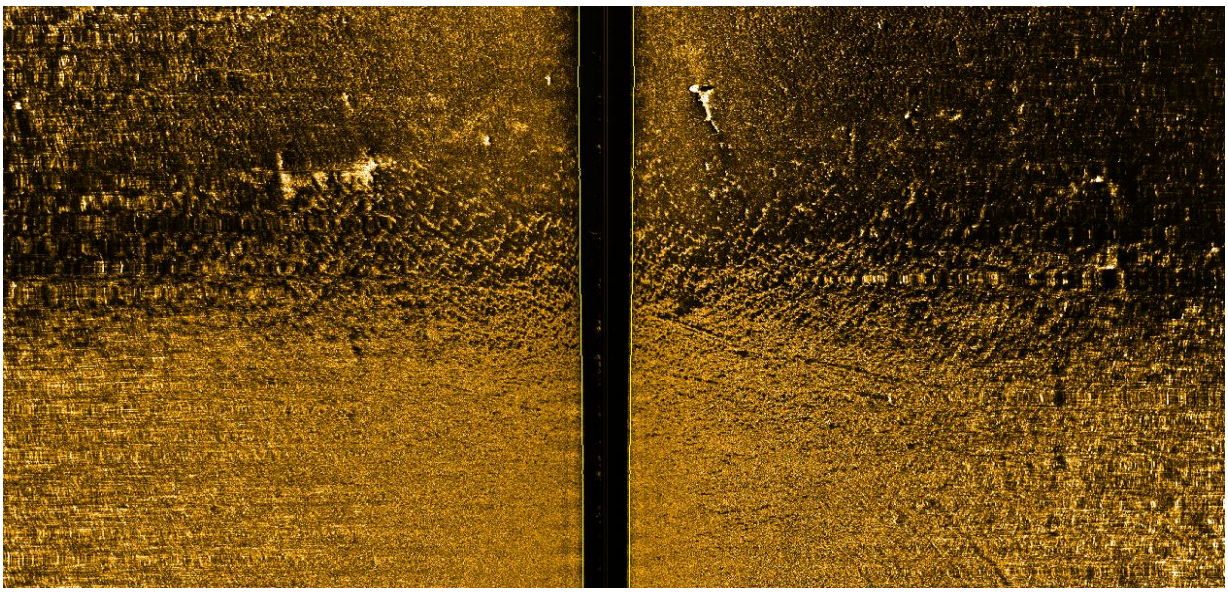


Photo F-1-10 Side Scan Sonar in Flashlight Mode

Photo F-1-11, Typical Oyster Bed of the Eastern Bank, shows a flashlight mode image of mud (in the upper right) adjacent to the bed. In the lower right quadrant of the image, the bed appears clumpy, probably overlying a more gravelly/till-laden terrain.

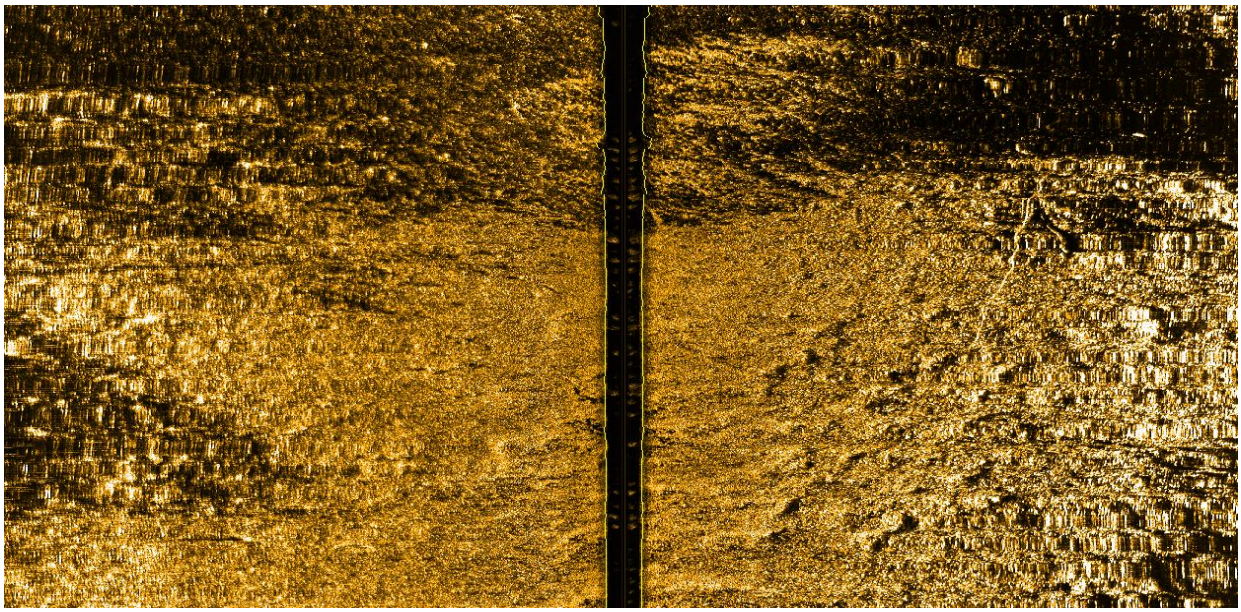


Photo F-1-11 Typical Oyster Bed of the Eastern Bank

In the southern block, seven potential oyster beds were identified. The most southern of the seven, denoted as S1, appeared to abut against the edge of an old channel about 9,000 ft south of the bridge along the north side of Piermont Pier. The bed seemed somewhat diffuse in terms of density. S2, located northwest of S1 along the channel about 8,500 ft south of the bridge, appeared to be a diffuse, clumpy bed. S3 appeared to be a dense bed located near the middle of the flats 5,000 ft south of the bridge. S4 and S5 were two thin but dense strips located about 2,000 ft south of the Tappan Zee Bridge causeway. S6 appeared diffuse and was positioned along the slope of the channel leading up to and under the western main support columns of the Tappan Zee Bridge's central truss. S7 was located about 2000 ft south of the Tappan Zee's eastern approach, along the edge of the channel. It appeared to be rather dense. Six potential beds were identified in the north. Adjacent to the bridge, along the eastern side of the channel, was N1. Due east of N1, near the shore, was N2. These beds appeared to have a somewhat diffuse density. Along the shore, 2500 ft north of N1, was N3. N3 appeared to have some oyster-like texture, but for the most part the area appeared very rocky/gravelly. On the flats west of the channel there were three beds that had been previously delineated. These were N4 (10000 ft north of bridge), N5 (5000 ft north of bridge), and N6 (2,000 ft north of bridge). All of these beds appeared to be dense.

Oyster Bed Grab Sampling Results

Grab sampling on the oyster beds began at site S1, proceeding northward. At S1, the grabs sampler failed to retrieve live oysters, but upon recovering the boat anchor, live oysters were found. The oysters appeared to be clustered around a piece of wooden debris. At S2, oysters were again recovered on the anchor, this time clinging to a large fragment of red sandstone. S3 produced live oysters in the grab, but none on the anchor. At S4, only shell hash was recovered, but at S5 live oysters were recovered both on the anchor and in the grab. Photo F-1-12, Live Oysters Recovered from S2 and S5, shows oyster

encrusted block of sandstone recovered from the anchor at area S2 on the left and a live oyster recovered from the grab at S5 is opened on the right.

Photo F-1-12 Live Oysters Recovered from S2 and S5

Grabs were taken at three separate locations along S6, at the center of the site, and just north and south of the bridge. At the center, live oysters were recovered both in the grab and on the anchor. For the other two grabs adjacent to the bridge, oysters were recovered only on the anchor. The last of the southern sites, S7, produced live oysters from the grab.

The northern sites were sampled starting with N1. Despite a strong current at N1, which made staying in position difficult, oysters were successfully recovered on the anchor in the area north of the bridge. Live oysters were later recovered in the grab in the area of N1 south of the bridge. At N2, live oysters were recovered from the anchor along the southern edge of the bed. Additional live oysters were noted upon anchoring at a more central location within the bounds of N2. N3 produced live oysters on both the anchor and in the grab. It should be noted that the grab on N3 was unique due to the large quantity of gravel also recovered. Taking into consideration the results of the side scan imagery, the bed at this location is likely scattered and diffuse, intermixed heavily with gravel. N4, N5, and N6 produced small to medium-sized live oysters with a large amount of shell hash. These beds, which were apparently previously identified, are likely remnants, containing only a small fraction of the living oysters they once held.

Side scan sonar imagery indicated the presence of potential oyster beds throughout the survey area, including under the Tappan Zee Bridge, in depths ranging from 8 ft to 30 ft. Grab sampling on the beds delineated using the side scan sonar data confirmed the presence of live oysters at all survey locations, except one location south of the bridge, S4.

Oyster beds were delineated north, south, and under the bridge, occupying depths between 8 ft and 30 ft. All identified oyster beds, except for one bed south of the bridge, were confirmed to contain live oysters. Oyster beds were of differing character, being dense, diffuse, or remnant, and sometimes containing gravel or sandstone fragments.

Oyster Bed Findings

Side scan sonar imagery indicated the presence of potential oyster beds throughout the survey area, including under the Tappan Zee Bridge, in depths ranging from 8 ft to 30 ft. Grab sampling on the beds

delineated using the side scan sonar data confirmed the presence of live oysters at all survey locations, except one location south of the bridge, S4.

Oyster beds were delineated north, south, and under the bridge, occupying depths between 8 ft and 30 ft. All identified oyster beds, except for one bed south of the bridge, were confirmed to contain live oysters. Oyster beds were of differing character, being dense, diffuse, or remnant, and sometimes containing gravel or sandstone fragments.

BRIDGE PIER SAMPLING RESULTS

In total, eight species from three phyla of fauna and two species from two phyla of flora were collected by SCUBA divers (Photo F-1-13). The collected species are identified in Table F-1-23. The differences in the organisms collected at the piers as presented in the table is likely due to the manner in which the samples were collected. As an example, barnacles were collected at four of the piers but review of the video footage collected by the SCUBA divers clearly showed barnacles present at the other two piers. It is likely that all of the organisms identified in the table live within the habitat of all of the bridge piers. As indicated in the note to the table, the species of isopod that was collected may be *Synidotea laevidorsalis*, which has been identified as an invasive species.

Photo F-1-13 SCUBA Diver Entering the River to Perform Bridge Pier Analysis

The entire surface of the piers was covered with fauna and flora from the high water line to the bottom of the pier. The surfaces of the pier substructure consist of timber, concrete, and areas of steel sheeting. In general, the fauna and flora equally colonized these three different growth surfaces.

Green algae growth was found on all of the piers between the high-water lines to the low-water line. The mean tidal range of the Hudson River at the Tappan Zee Bridge is 3.2 feet (0.98 m). The growth was observed to generally be denser on the south side of the structures due to increased exposure to sunlight.

Below the low-tide line, barnacles colonize the structure; they reach their highest density about 3 feet (0.9 m) below the low-water line. Below this depth, the barnacles gradually diminish in size and density and are no longer found at depths greater than 15 feet (4.6 m) below the low-water line. Red algae growth starts at about 4 feet (1.2 m) below the low-water line and reaches its greatest density at about 10 feet (3 m) below the low-water line. Oyster shells were found attached to the pier starting at a depth of about 8 feet (2.4 m) below the low-water line and were found to increase in density to the bottom of the pier. Mussels were not common and. when found, were generally limited to cavities beneath the steel sheeting.

- **Location A** – Fauna and flora on the pier were observed to correspond to the general conditions identified above.

- **Location B** – At a depth of 10 feet (3 m) below MLW, oysters were observed at a density of about ten shells per square foot.

- **Location C** – In 2004, the Self Contained Underwater Breathing Apparatus (SCUBA) survey leader was involved in the installation of a polyvinyl chloride (PVC) plastic pipe at Pier 171 to carry electrical cable to pumps associated with the pier caissons. It was observed that the growth of the fauna and flora on the plastic pipe was very similar in variety and density to the organisms on the adjacent concrete and steel surfaces. This observation would indicate that the colonization of new surfaces takes place rapidly (within three years) in this environment.

- **Location D** – Fauna and flora on the pier were observed to correspond to the general conditions identified above.

- **Location E** – All of the underwater surfaces observed were steel sheeting; there was no exposed concrete. The northern side of the pier had less red algae and more oysters than the other sides of the pier.

- **Location F** – There was a much lower density of red algae than at the other piers. It was observed that there was a greater density of mussels than at the other piers.

The survey of the underwater portions of the bridge piers indicated that the pier surfaces were completely covered with various fauna and flora. The fauna consisted of eight species from three phyla; flora consisted of two species from two phyla. The fauna and flora attached to the pier surfaces were found at similar depths on each of the six piers surveyed. The results of the analysis are shown in Table F-1-23.

Table F-1-23

Species Collected on Bridge Piers

Taxonomy	Scientific Name	Common Name	Pier Locations					
			A	B	C	D	E	F
ANNELIDA	Polychaeta *Nereis* spp.	clam worm			✓		✓	✓
ARTHROPODA	*Gammarus* spp.	scuds	✓	✓	✓			
	Cirripedia *Balanus* spp.	barnacles		✓	✓	✓	✓	
	Palaemonetes vulgaris	common shore shrimp		✓		✓		
	Rhithropanopeus spp.	mud crab	✓	✓	✓	✓	✓	✓
	Isopoda *Synidotea* spp.	isopod	✓	✓	✓	✓	✓	✓
MOLLUSCA	*Crassostrea virginica*	oyster	✓	✓		✓	✓	✓
	Modiolus demissus	ribbed mussel	✓	✓	✓	✓	✓	✓
RHODOPHYTA	*Rhodymenia* spp.	red algae	✓	✓	✓	✓	✓	✓
CHLOROPHYTA	*Entromorpha* spp.	green algae	✓	✓	✓	✓	✓	✓
Notes: ✓ indicates presence in sample. *Synidotea* spp. may be *Synidotea laevidorsalis* which is identified as an invasive species.								

The underwater pier structures consisted of three types of surfaces – concrete, steel and timber. At the same water depth, these surfaces were colonized by the same flora and fauna in approximately similar densities. The PVC pipe installed in 2004 at Location C was found to have a similar diversity and density of flora and fauna as the adjacent concrete and steel surfaces.

2.2.3 Summary of Benthic Community in the Study Area

Within the study area there is a robust benthic community. Both the bridge piers and sediments are well colonized by sessile and motile benthic invertebrates. The bridge piers are also well colonized with algal growth. Statistical analysis shows that there is no significant difference in populations between the existing and proposed bridge alignments. Also, benthic populations markedly increase in the warmer months and decrease in the colder months.

3 Submerged Aquatic Vegetation

Submerged Aquatic Vegetation (SAV) beds are subtidal plant communities that occur in water as much as six feet below low tide (Sea Grant, 2011). SAV beds act as nurseries for numerous larval and juvenile fish, such as alewife, banded killifish, and white perch and produce organic matter that is an integral part of the Hudson River food web (Sea Grant, 2011). The SAV beds improve the clarity of the river by filtering suspended sediments (Sea Grant, 2011). A number of diving ducks, such as the canvasback, bufflehead, common goldeneye, merganser and scaup, feed on the SAV and the fish and invertebrates that inhabit SAV beds.

Using NYSDEC mapping as a guide, surveys were conducted in late summer of 2006 to confirm the extent and characteristics of SAV in the study area. These surveys were performed in the bridge study area along both shorelines (Figure F-1-26). The investigations were conducted during late summer, and

included sediment grabs in locations where visibility was poor. The grabs were brought to the surface and inspected for the presence of SAV and the range of species present.

The surveys covered the shoreline to a depth of approximately 8 feet (2.4 m) from 3,000 feet (914 m) south of the existing bridge to 8,000 feet (2,438 m) north of it. Transects were run in a north-south direction with ponar grab collected every 50 to 100 feet (15.2 to 30.5 m). Only two locations north of the existing bridge were found to contain SAV. On the eastern shore, SAV was found within Tarrytown Marina along the shoreline; on the western shore – approximately 1 mile north of the bridge – SAV was encountered within the 2-foot (0.61-m) contour.

Based on these survey results, no significant areas of SAV were found within the area of potential impact from either the construction of the replacement bridge or the demolition of the existing bridge.

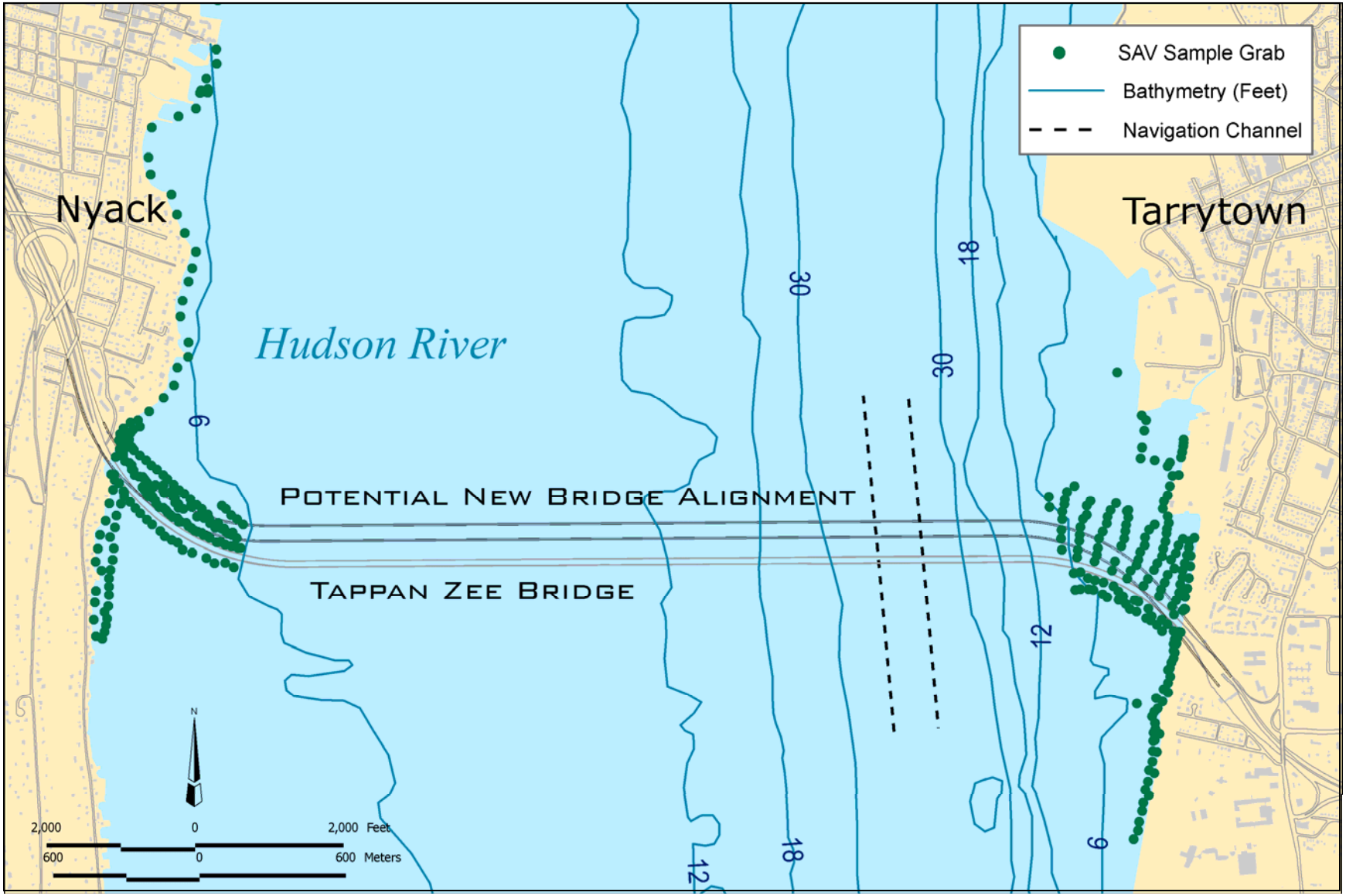


Figure F-1-26 SAV Sampling Locations

In September 2009, previous SAV mapping data were obtained from the NYSDEC. SAV beds are mapped using aerial photo interpretation every five years by the NYSDEC. The mapped polygons are later field confirmed. The available SAV mapping is from years 1997 and 2002. These data are depicted on Figure F-1-27. Results of the 2007 mapping are considered preliminary and are not available for the public; however, preliminary review of the data shows that no new SAV beds near the Tappan Zee Bridge were identified. As part of this project, field studies in Fall 2009 confirmed the presence of the SAV beds depicted on Figure F-1-26.

In September 2009, previous SAV mapping data were obtained from the NYSDEC. SAV beds are mapped, using aerial photo interpretation, every five years by the NYSDEC. The first stage of the investigation involved obtaining the available SAV mapping through the NYSDEC from years 1997 and 2002. These data are depicted on Figure F-1-26. The second part was to ground truth each mapped SAV bed. This involved traversing the Tappan Zee via boat to each location and taking one (1) to three (3) Van Veen grab samples at each location.

If the grab sample confirmed the presence of SAV during the first sample, then the investigators would identify the SAV species, count the number of individual shoots for each species, document the recovery and move to the next location. Otherwise, up to three samples were taken at various locations within the site to confirm the presence or absence of the SAV beds. SAV grab samples were divided into four regions, comprised of the bank north and west of the bridge (WBN), south and west of the bridge (WBS), north and east of the bridge (EBN), and south and east of the bridge (EBS). On the WBN, eleven (11) targets were explored using the Van Veen grab sampling technique. Of those 11 targets, 10 were confirmed to have SAV beds. This confirmation came in the form of grab sampling the general area as shown on Figure F-1-26. The sampling program produced grabs of *Vallisneria* sp. (water celery) shoots that were rooted in the sediment, as shown in Photo F-1-14.

Photo F-1-14 *Vallisneria* sp. sample taken from EBN5.

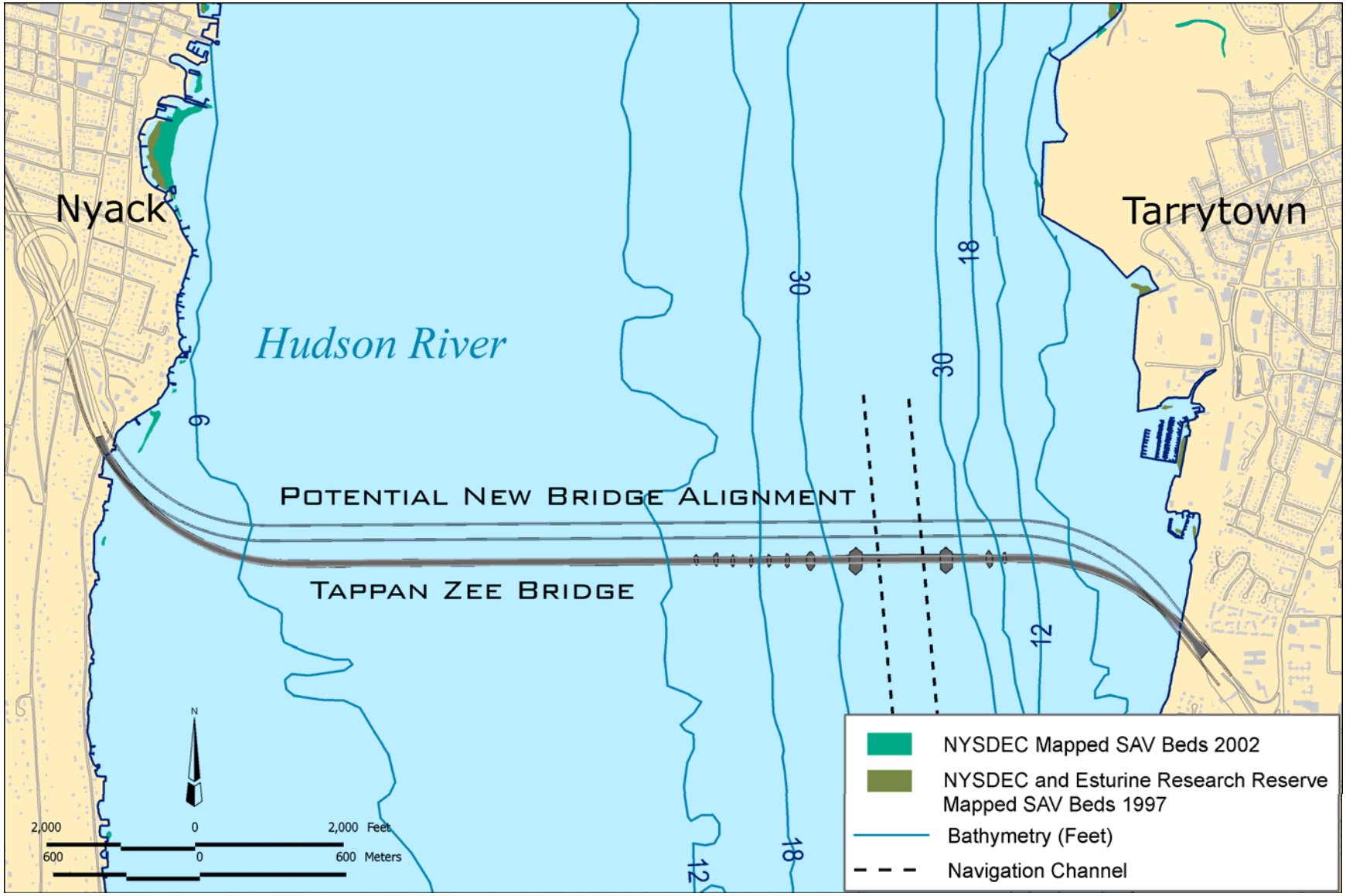
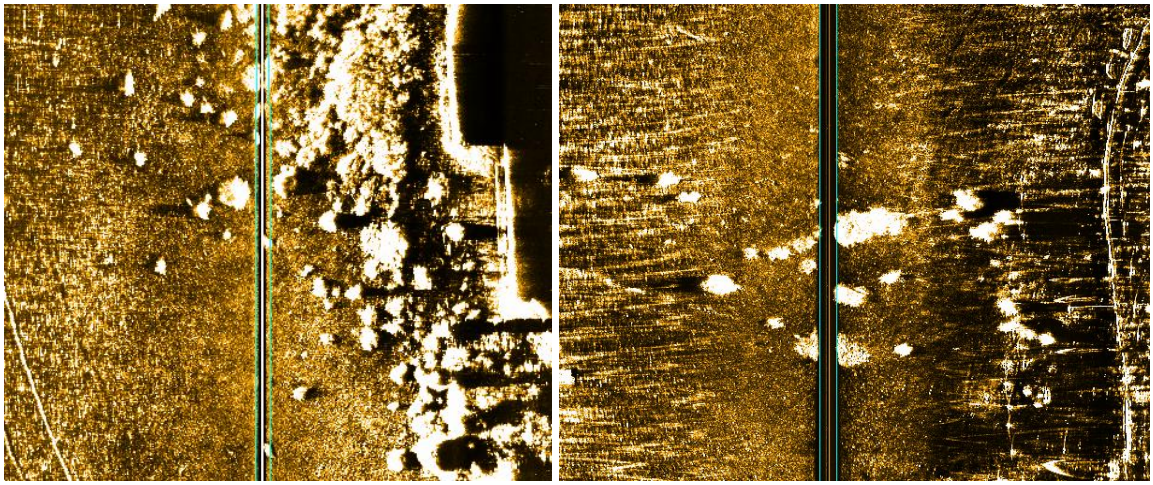


Figure F-1-27 NYSDEC Mapped SAV Beds 1997 and 2002

Visual surveys were also conducted to determine the presence of floating vegetation, specifically *Trapa natans* (water chestnut) *Myriophyllum spicatum* (Eurasian milfoil) and *Potamogeton pectinatus* (Sago pondweed). On the WBS, one (1) target was explored, in which an SAV bed was confirmed and is depicted in Photo F-1-15. Vegetation in this image appears as cloudy, whitish spots, often casting black acoustic shadows. The same cloudy, whitish features noted in the image of WBS-1 can be seen, although the apparent density of possible vegetation is not as great. For scale, the left channel on both images is approximately 55 meters wide.

On the EBN, six (6) targets were explored. The sampling program produced 5 SAV beds. On the EBS, three (3) targets were explored, none of which yielded any confirmed SAV beds.



Note: Left: Confirmed SAV bed imaged at WBS-1. *Right*: Tentative SAV bed imaged by side scan sonar.

Photo F-1-15 WBS-1 Side-scan Sonar Survey SAV Bed

SAV Findings

SAV was found at all previously delineated beds along the west bank. On the east bank, SAV was found only north of the bridge. In addition to the oyster beds that were delineated (see details below), a tentative SAV bed was seen on the side scan sonar in an area not noted in prior studies. The possible vegetation was located in a shallow cove north of the landward section of Piermont Pier in the area around 653474.88 E, 805316.77 N (NAD83 NY State Plane East). Grab sampling in areas previously known to harbor SAV confirmed the presence of vegetation in all sites along the west bank of the study area. Side scan sonar imagery may have also identified an additional area of SAV adjacent to the northern side of Piermont Pier on the west bank. Along the east bank, SAV was only found north of the bridge.

Appendix F: Ecology

F-2 Terrestrial Resources Tables

Table F-2-1
2000-2005 Breeding Bird Atlas Results for Census Blocks

Common name	**Scientific name**
Canada Goose	*Branta canadensis*
Mute Swan	*Cygnus olor*
Mallard	*Anas platyrhynchos*
Ring-necked Pheasant	*Phasianus colchicus*
Wild Turkey	*Meleagris gallopavo*
Double-crested Cormorant	*Phalacrocorax auritus*
Great Blue Heron	*Ardea herodias*
Green Heron	*Butorides virescens*
Black-crowned Night-Heron	*Nycticorax nycticorax*
Osprey*	*Pandion haliaetus*
Turkey Vulture	*Cathartes aura*
Red-tailed Hawk	*Buteo jamaicensis*
Peregrine Falcon*	*Falco peregrinus*
Killdeer	*Charadrius vociferus*
Spotted Sandpiper	*Actitis macularius*
American Woodcock	*Scolopax minor*
Rock Pigeon	*Columba livia*
Mourning Dove	*Zenaida macroura*
Eastern Screech-Owl	*Megascops asio*
Chimney Swift	*Chaetura pelagica*
Belted Kingfisher	*Megaceryle alcyon*
Red-bellied Woodpecker	*Melanerpes carolinus*
Downy Woodpecker	*Picoides pubescens*
Hairy Woodpecker	*Picoides villosus*
Northern Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Eastern Wood-Pewee	*Contopus virens*
Willow Flycatcher	*Empidonax traillii*
Eastern Phoebe	*Sayornis phoebe*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Kingbird	*Tyrannus tyrannus*
White-eyed Vireo	*Vireo griseus*
Yellow-throated Vireo	*Vireo flavifrons*
Warbling Vireo	*Vireo gilvus*
Red-eyed Vireo	*Vireo olivaceus*
Blue Jay	*Cyanocitta cristata*
American Crow	*Corvus brachyrhynchos*
Fish Crow	*Corvus ossifragus*
Tree Swallow	*Tachycineta bicolor*
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
Bank Swallow	*Riparia riparia*
Barn Swallow	*Hirundo rustica*
Black-capped Chickadee	*Poecile atricapillus*
Tufted Titmouse	*Baeolophus bicolor*
White-breasted Nuthatch	*Sitta carolinensis*
Carolina Wren	*Thryothorus ludovicianus*
House Wren	*Troglodytes aedon*

Table F-2-1
2000-2005 Breeding Bird Atlas Results for Census Blocks

Eastern Bluebird	*Sialia sialis*
Veery	*Catharus fuscescens*
Wood Thrush	*Hylocichla mustelina*
American Robin	*Turdus migratorius*
Gray Catbird	*Dumetella carolinensis*
Northern Mockingbird	*Mimus polyglottos*
Brown Thrasher	*Toxostoma rufum*
European Starling	*Sturnus vulgaris*
Cedar Waxwing	*Bombycilla cedrorum*
Blue-winged Warbler	*Vermivora pinus*
Yellow Warbler	*Dendroica petechia*
Black-throated Blue Warbler	*Dendroica caerulescens*
Black-throated Green Warbler	*Dendroica virens*
Pine Warbler	*Dendroica pinus*
Prairie Warbler	*Dendroica discolor*
Black-and-white Warbler	*Mniotilta varia*
American Redstart	*Setophaga ruticilla*
Worm-eating Warbler	*Helmitheros vermivorum*
Ovenbird	*Seiurus aurocapilla*
Northern Waterthrush	*Seiurus noveboracensis*
Louisiana Waterthrush	*Seiurus motacilla*
Kentucky Warbler	*Oporornis formosus*
Common Yellowthroat	*Geothlypis trichas*
Canada Warbler	*Wilsonia canadensis*
Hooded Warbler	*Wilsonia citrina*
Eastern Towhee	*Pipilo erythrophthalmus*
Chipping Sparrow	*Spizella passerina*
Song Sparrow	*Melospiza melodia*
Swamp Sparrow	*Melospiza georgiana*
White-throated Sparrow	*Zonotrichia albicollis*
Dark-eyed Junco	*Junco hyemalis*
Scarlet Tanager	*Piranga olivacea*
Northern Cardinal	*Cardinalis cardinalis*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Indigo Bunting	*Passerina cyanea*
Red-winged Blackbird	*Agelaius phoeniceus*
Common Grackle	*Quiscalus quiscula*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*
Baltimore Oriole	*Icterus galbula*
Purple Finch	*Carpodacus purpureus*
House Finch	*Carpodacus mexicanus*
American Goldfinch	*Spinus tristis*
House Sparrow	*Passer domesticus*
Source: 2000-2005 NYS Breeding Bird Atlas results for Blocks 5854B and 5954A. **Notes:** Boldface indicates the subset of species with potential to nest in the study area based on the habitat present. *NYSDEC-listed species.	

Table F-2-2

Mammals with Potential to Occur in the Study Area

Common name	**Scientific name**
Virginia opossum	*Didelphis virginiana*
Moles	*Scalopus spp.*
Little brown bat	*Myotis lucifugus*
Big brown bat	*Eptesicus fuscus*
Hoary bat	*Lasiurus cenerius*
Silver-haired bat	*Lasionycteris noctivagans*
Eastern red bat	*Lasiurus borealis*
Eastern cottontail	*Sylvilagus floridanus*
Groundhog	*Marmota monax*
Eastern chipmunk	*Tamias striatus*
Gray squirrel	*Sciurus carolinensis*
White-footed mouse	*Peromyscus leucopus*
House mouse	*Mus musculus*
Eastern coyote	*Canis latrans*
Red fox	*Vulpes vulpes*
Raccoon	*Procyon lotor*
Striped skunk	*Mephitis mephitis*
White-tailed deer	*Odocoileus virginianus*

Table F-2-3
Reptile and Amphibian Species Recorded by the NYSDEC Herp Atlas Project near the Study Area

Common name	Scientific name
Marbled salamander[1]	*Ambystoma opacum*
Spotted salamander	*Ambystoma maculatum*
Eastern newt	*Notophthalmus viridescens*
Northern redback salamander	*Plethodon cinereus*
Northern slimy salamander	*Plethodon glutinosus*
Northern two-lined salamander	*Eurycea bislineata*
American toad	*Bufo americanus*
Fowler's toad	*Bufo fowleri*
Gray treefrog	*Hyla versicolor*
Spring peeper	*Pseudacris crucifer*
Bullfrog	*Rana catesbeiana*
Green frog	*Rana clamitans*
Wood frog	*Rana sylvatica*
Southern leopard frog[1]	*Rana sphenocephala*
Northern watersnake	*Nerodia sipedon*
Northern brown snake	*Storeria dekayi*
Common garter snake	*Thamnophis sirtalis*
Ring-neck snake	*Diadophis punctatus*
Black racer	*Coluber constrictor*
Common snapping turtle	*Chelydra serpentina*
Spotted turtle[1]	*Clemmys guttata*
Musk turtle	*Sternotherus odoratum*
Eastern box turtle[1]	*Terrapene carolina*
Northern diamondback terrapin	*Malaclemys terrapin*
Painted turtle	*Chrysemys picta*

[1] NYS Species of Special Concern
Notes: List represents species documented in "White Plains" and "Nyack" USGS quadrants. Boldface indicates the subset of species with the potential to occur in the study area based on the habitat present (Mitchell et al. 2006, Gibbs et al. 2007).

Table F-2-4

Threatened, Endangered, Candidate, and Special Concern Species Known to Occur in Westchester and/or Rockland County, NY

	Scientific name	Status
Plants		
Late flowering boneset	*Eupatorium serotinum*	NY-E
Birds		
Golden eagle[1]	*Aquila chrysaetos*	NY-E
Bald eagle	*Haliaeetus leucocephalus*	NY-T
Peregrine falcon	*Falco peregrinus*	NY-E
Osprey	*Pandion haliaetus*	NY-SC
Sharp-shinned hawk	*Accipiter striatus*	NY-SC
Cooper's hawk	*Accipiter cooperii*	NY-SC
Red-shouldered hawk[1]	*Buteo lineatus*	NY-SC
Northern goshawk[1]	*Accipiter gentilis*	NY-SC
Northern harrier[1]	*Circus cyaneus*	NY-SC
Pied-billed grebe	*Podilymbus podiceps*	NY-SC
Common loon	*Gavia immer*	NY-SC
Mammals		
Indiana bat	*Myotis sodalis*	US-E
New England cottontail	*Sylvilagus transitionalis*	US-C
Reptiles and amphibians		
Bog turtle	*Clemmys* [*Glyptemys*] *muhlenbergii*	US-E
Eastern box turtle	*Terrapene carolina*	NY-SC
Spotted turtle	*Clemmys guttata*	NY-SC
Marbled salamander	*Ambystoma opacum*	NY-SC
Southern leopard frog	*Rana sphenocephala*	NY-SC

Sources: USFWS County Lists; NYNHP Environmental Resource Mapper; NYNHP request letters; Hook Mountain Hawk Watch data; 2000-2005 NYS Breeding Bird Atlas; 2010 Audubon Christmas Bird Count.
Notes: [1]Occurance in study area primarily limited to passage overhead during migration.
E=Endangered; T=Threatened; C=Candidate; SC=Special Concern.

Table F-2-5

Relative Commonness of Bird Species Occurring in the Lower Hudson Valley

Common name	Scientific name	Spring	Summer	Fall	Winter
Snow Goose	*Chen caerulescens*	U		U	O
Brant	*Branta bernicla*	U	R	U	O
Canada Goose	*Branta canadensis*	C	C	C	C
Mute Swan	*Cygnus olor*	C	C	C	C
Wood Duck	*Aix sponsa*	C	C	C	U
Gadwall	*Anas strepera*	U	R	U	U
American Wigeon	*Anas americana*	C	R	C	C
American Black Duck	*Anas rubripes*	C	C	C	C
Mallard	*Anas platyrhynchos*	C	C	C	C
Blue-winged Teal	*Anas discors*	C	U	C	R
Northern Shoveler	*Anas clypeata*	U	R	U	O
Northern Pintail	*Anas acuta*	U		U	O
Green-winged Teal	*Anas crecca*	C	O	C	O
Canvasback	*Aythya valisineria*	C	R	U	C
Redhead	*Aythya americana*	O		U	O
Ring-necked Duck	*Aythya collaris*	U		O	U
Greater Scaup	*Aythya marila*	C	R	C	C
Lesser Scaup	*Aythya affinis*	C	R	C	U
Surf Scoter	*Melanitta perspicillata*	O		O	O
White-winged Scoter	*Melanitta fusca*	U	R	U	O
Black Scoter	*Melanitta americana*	O		O	O
Long-tailed Duck	*Clangula hyemalis*	C	R	U	C
Bufflehead	*Bucephala albeola*	C	R	C	C
Common Goldeneye	*Bucephala clangula*	C	R	U	C
Hooded Merganser	*Lophodytes cucullatus*	C		C	C
Common Merganser	*Mergus merganser*	C	R	C	C
Red-breasted Merganser	*Mergus serrator*	C	R	C	C
Ruddy Duck	*Oxyura jamaicensis*	C	R	C	C
Northern Bobwhite	*Colinus virginianus*	R	R	R	R
Ring-necked Pheasant	*Phasianus colchicus*	R	R	R	R
Ruffed Grouse	*Bonasa umbellus*	U	U	U	U
Wild Turkey	*Meleagris gallopavo*	C	C	C	C
Red-throated Loon	*Gavia stellata*	O		C	U
Common Loon	*Gavia immer*	U	R	C	U
Pied-billed Grebe	*Podilymbus podiceps*	U	R	C	U
Horned Grebe	*Podiceps auritus*	U		U	C
Red-necked Grebe	*Podiceps grisegena*	O		R	O
Double-crested Cormorant	*Phalacrocorax auritus*	C	C	C	O
Great Cormorant	*Phalacrocorax carbo*	C	R	C	C
American Bittern	*Botaurus lentiginosus*	O		O	R
Least Bittern	*Ixobrychus exilis*	O	O	R	
Great Blue Heron	*Ardea herodias*	C	U	C	C
Great Egret	*Ardea alba*	C	C	C	R
Snowy Egret	*Egretta thula*	U	R	U	
Little Blue Heron	*Egretta caerulea*	O	U	O	
Green Heron	*Butorides virescens*	C	C	C	
Black-crowned Night-Heron	*Nycticorax nycticorax*	C	C	C	U
Yellow-crowned Night-Heron	*Nyctanassa violacea*	O	O	O	
Glossy Ibis	*Plegadis falcinellus*	U	U	O	
Black Vulture	*Coragyps atratus*	U	U	U	U
Turkey Vulture	*Cathartes aura*	C	C	C	U

Table F-2-5
Relative Commonness of Bird Species Occurring in the Lower Hudson Valley

Common name	Scientific name	Spring	Summer	Fall	Winter
Osprey	*Pandion haliaetus*	U	U	C	
Bald Eagle	*Haliaeetus leucocephalus*	O	R	U	C
Northern Harrier	*Circus cyaneus*	C	O	C	O
Sharp-shinned Hawk	*Accipiter striatus*	C	O	C	U
Cooper's Hawk	*Accipiter cooperii*	U	O	C	U
Northern Goshawk	*Accipiter gentilis*	O	R	O	O
Red-shouldered Hawk	*Buteo lineatus*	U	R	U	O
Broad-winged Hawk	*Buteo platypterus*	C	O	C	
Red-tailed Hawk	*Buteo jamaicensis*	C	C	C	C
Rough-legged Hawk	*Buteo lagopus*	R		O	O
Golden Eagle	*Aquila chrysaetos*	R		O	R
American Kestrel	*Falco sparverius*	C	U	C	O
Merlin	*Falco columbarius*	O	R	U	R
Peregrine Falcon	*Falco peregrinus*	O	O	U	O
Clapper Rail	*Rallus longirostris*	C	C	C	U
Virginia Rail	*Rallus limicola*	C	U	C	U
Sora	*Porzana carolina*	U	R	U	R
Common Moorhen	*Gallinula chloropus*	O		O	
American Coot	*Fulica americana*	U		C	C
Killdeer	*Charadrius vociferus*	C	U	C	U
Greater Yellowlegs	*Tringa melanoleuca*	R		R	
Lesser Yellowlegs	*Tringa flavipes*	U	C	C	
Solitary Sandpiper	*Tringa solitaria*	R		R	
Spotted Sandpiper	*Actitis macularius*	C	C	C	
Semipalmated Sandpiper	*Calidris pusilla*	R		R	
Least Sandpiper	*Calidris minutilla*	C	R	U	
Purple Sandpiper	*Calidris maritima*	C		U	C
Dunlin	*Calidris alpina*	R			
Wilson's Snipe	*Gallinago delicata*	U	R	U	R
American Woodcock	*Scolopax minor*	C	U	U	O
Bonaparte's Gull	*Chroicocephalus philadelphia*	R	R	R	R
Ring-billed Gull	*Larus delawarensis*	C	C	C	C
Herring Gull	*Larus argentatus*	C	C	C	C
Great Black-backed Gull	*Larus marinus*	C	C	C	C
Rock Pigeon	*Columbia livia*	C	C	C	C
Mourning Dove	*Zenaida macroura*	C	C	C	C
Yellow-billed Cuckoo	*Coccyzus americanus*	U	U	U	
Black-billed Cuckoo	*Coccyzus erythropthalmus*	U	U	U	
Barn Owl	*Tyto alba*	R	R	R	R
Eastern Screech-Owl	*Megascops asio*	C	C	C	C
Great Horned Owl	*Bubo virginianus*	C	C	C	C
Snowy Owl	*Bubo scandiacus*			R	R
Barred Owl	*Strix varia*	U	U	U	U
Long-eared Owl	*Asio otus*	R		R	U
Short-eared Owl	*Asio flammeus*				R
Northern Saw-whet Owl	*Aegolius acadicus*	O		U	U
Common Nighthawk	*Chordeiles minor*	U	U	U	
Eastern Whip-poor-will	*Caprimulgus vociferus*	O	O	O	
Chimney Swift	*Chaetura pelagica*	C	C	U	
Ruby-throated Hummingbird	*Archilochus colubris*	C	C	C	
Belted Kingfisher	*Megaceryle alcyon*	C	C	C	C
Red-headed Woodpecker	*Melanerpes erythrocephalus*	R	R	R	R

Table F-2-5
Relative Commonness of Bird Species Occurring in the Lower Hudson Valley

Common name	Scientific name	Spring	Summer	Fall	Winter
Red-bellied Woodpecker	*Melanerpes carolinus*	C	C	C	C
Yellow-bellied Sapsucker	*Sphyrapicus varius*	U	U	U	U
Downy Woodpecker	*Picoides pubescens*	C	C	C	C
Hairy Woodpecker	*Picoides villosus*	C	C	C	C
Northern Flicker	*Colaptes auratus*	C	C	C	U
Pileated Woodpecker	*Dryocopus pileatus*	U	U	U	U
Olive-sided Flycatcher	*Contopus cooperi*	U		U	
Eastern Wood-Pewee	*Contopus virens*	C	C	C	
Yellow-bellied Flycatcher	*Empidonax flaviventris*	U		U	
Acadian Flycatcher	*Empidonax virescens*	U	U	U	
Alder Flycatcher	*Empidonax alnorum*	U	U		
Willow Flycatcher	*Empidonax traillii*	U	C	U	
Least Flycatcher	*Empidonax minimus*	C	U	R	
Eastern Phoebe	*Sayornis phoebe*	C	C	C	R
Great Crested Flycatcher	*Myiarchus crinitus*	C	C	U	
Eastern Kingbird	*Tyrannus tyrannus*	C	C	C	
Northern Shrike	*Lanius excubitor*			R	R
White-eyed Vireo	*Vireo griseus*	C	C	U	
Yellow-throated Vireo	*Vireo flavifrons*	C	C	U	
Blue-headed Vireo	*Vireo solitarius*	C	C	C	
Warbling Vireo	*Vireo gilvus*	C	C	C	
Philadelphia Vireo	*Vireo philadelphicus*	R		R	
Red-eyed Vireo	*Vireo olivaceus*	C	C	C	
Blue Jay	*Cyanocitta cristata*	C	C	C	C
American Crow	*Corvus brachyrhynchos*	C	C	C	C
Fish Crow	*Corvus ossifragus*	U	U	U	U
Common Raven	*Corvus corax*	U	U	U	U
Horned Lark	*Eremophila alpestris*	O	R	U	C
Purple Martin	*Progne subis*	U	U	U	
Tree Swallow	*Tachycineta bicolor*	C	C	C	
N. Rough-winged Swallow	*Stelgidopteryx serripennis*	U	U	U	
Bank Swallow	*Riparia riparia*	U	U	U	
Cliff Swallow	*Petrochelidon pyrrhonota*	U	U	U	
Barn Swallow	*Hirundo rustica*	C	C	C	
Black-capped Chickadee	*Poecile atricapillus*	C	C	C	C
Tufted Titmouse	*Baeolophus bicolor*	C	C	C	C
Red-breasted Nuthatch	*Sitta canadensis*	U	O	U	U
White-breasted Nuthatch	*Sitta carolinensis*	C	C	C	C
Brown Creeper	*Certhia americana*	C	C	C	C
Carolina Wren	*Thryothorus ludovicianus*	C	C	C	C
House Wren	*Troglodytes aedon*	C	C	C	
Winter Wren	*Troglodytes hiemalis*	U	U	U	R
Marsh Wren	*Cistothorus palustris*	U	O	O	
Blue-gray Gnatcatcher	*Polioptila caerulea*	C	U	U	
Golden-crowned Kinglet	*Regulus satrapa*	C	O	C	U
Ruby-crowned Kinglet	*Regulus calendula*	C		C	O
Eastern Bluebird	*Sialia sialis*	C	C	C	C
Veery	*Catharus fuscescens*	C	C	C	
Gray-cheeked Thrush	*Catharus minimus*	U		U	
Bicknell's Thrush	*Catharus bicknelli*	R		R	
Swainson's Thrush	*Catharus ustulatus*	C		C	
Hermit Thrush	*Catharus guttatus*	C	U	C	U

Table F-2-5
Relative Commonness of Bird Species Occurring in the Lower Hudson Valley

Common name	Scientific name	Spring	Summer	Fall	Winter
Wood Thrush	*Hylocichla mustelina*	C	C	C	
American Robin	*Turdus migratorius*	C	C	C	U
Gray Catbird	*Dumetella carolinensis*	C	C	C	O
Northern Mockingbird	*Mimus polyglottos*	C	C	C	C
Brown Thrasher	*Toxostoma rufum*	C	C	C	O
European Starling	*Sturnus vulgaris*	C	C	C	C
American Pipit	*Anthus rubescens*	R		C	R
Cedar Waxwing	*Bombycilla cedrorum*	C	C	C	C
Snow Bunting	*Plectrophenax nivalis*	R		C	O
Blue-winged Warbler	*Vermivora pinus*	C	C	C	
Golden-winged Warbler	*Vermivora chrysoptera*	O		O	
Tennessee Warbler	*Oreothlypis peregrina*	C		C	
Orange-crowned Warbler	*Oreothlypis celata*	R		R	
Nashville Warbler	*Oreothlypis ruficapilla*	U		U	
Northern Parula	*Parula americana*	C		C	
Yellow Warbler	*Dendroica petechia*	C	C	U	
Chestnut-sided Warbler	*Dendroica pensylvanica*	C	C	C	
Magnolia Warbler	*Dendroica magnolia*	C		C	
Cape May Warbler	*Dendroica tigrina*	U		U	
Black-throated Blue Warbler	*Dendroica caerulescens*	C	O	C	
Yellow-rumped Warbler	*Dendroica coronata*	C	O	C	U
Black-throated Green Warbler	*Dendroica virens*	C	U	C	
Blackburnian Warbler	*Dendroica fusca*	U	U	U	
Pine Warbler	*Dendroica pinus*	U	U	U	
Prairie Warbler	*Dendroica discolor*	C	C	U	
Palm Warbler	*Dendroica palmarum*	U		U	
Bay-breasted Warbler	*Dendroica castanea*	U		R	
Blackpoll Warbler	*Dendroica striata*	C		C	
Cerulean Warbler	*Dendroica cerulea*	O	O		
Black-and-white Warbler	*Mniotilta varia*	C	C	C	
American Redstart	*Setophaga ruticilla*	C	C	C	
Prothonotary Warbler	*Protonotaria citrea*	R			
Worm-eating Warbler	*Helmitheros vermivorum*	U	U	U	
Ovenbird	*Seiurus aurocapilla*	C	C	C	
Northern Waterthrush	*Parkesia noveboracensis*	C	O	U	
Louisiana Waterthrush	*Parkesia motacilla*	C	U	U	
Mourning Warbler	*Oporornis philadelphia*	U		O	
Common Yellowthroat	*Geothlypis trichas*	C	C	C	
Hooded Warbler	*Wilsonia citrina*	U	U	O	
Wilson's Warbler	*Wilsonia pusilla*	R		R	
Canada Warbler	*Wilsonia canadensis*	C	O	O	
Eastern Towhee	*Pipilo erythrophthalmus*	C	C	C	O
American Tree Sparrow	*Spizella arborea*			U	C
Chipping Sparrow	*Spizella passerina*	C	C	C	
Field Sparrow	*Spizella pusilla*	C	C	C	U
Vesper Sparrow	*Pooecetes gramineus*	O	O	U	R
Savannah Sparrow	*Passerculus sandwichensis*	C	U	C	O
Grasshopper Sparrow	*Ammodramus savannarum*	O	O		
Fox Sparrow	*Passerella iliaca*	U		U	O
Song Sparrow	*Melospiza melodia*	C	C	C	C
Lincoln's Sparrow	*Melospizia lincolnii*	O		U	
Swamp Sparrow	*Melospizia georgiana*	C	C	C	U

Table F-2-5
Relative Commonness of Bird Species Occurring in the Lower Hudson Valley

Common name	Scientific name	Spring	Summer	Fall	Winter
White-throated Sparrow	*Zonotrichia albicollis*	C		C	C
White-crowned Sparrow	*Zonotrichia leucophyrs*	O		U	O
Dark-eyed Junco	*Junco hyemalis*	C	U	C	C
Scarlet Tanager	*Piranga olivacea*	C	C	C	
Northern Cardinal	*Cardinalis cardinalis*	C	C	C	C
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	C	C	C	
Indigo Bunting	*Passerina cyanea*	C	C	U	
Bobolink	*Dolichonyx oryzivorus*	C	C	C	
Red-winged Blackbird	*Agelaius phoeniceus*	C	C	C	U
Eastern Meadowlark	*Sturnella magna*	U	U	U	O
Rusty Blackbird	*Euphagus carolinus*	U		U	O
Common Grackle	*Quiscalus quiscula*	C	C	C	U
Brown-headed Cowbird	*Molothrus ater*	C	C	C	U
Orchard Oriole	*Icterus spurius*	U	U		
Baltimore Oriole	*Icterus galbula*	C	C	C	R
Pine Grosbeak	*Pinicola enucleator*			R	R
Purple Finch	*Carpodacus purpureus*	U	U	U	U
House Finch	*Carpodacus mexicanus*	C	C	C	C
White-winged Crossbill	*Loxia leucoptera*	R		R	R
Common Redpoll	*Acanthis flammea*	R		R	R
Pine Siskin	*Spinus pinus*	O		U	U
American Goldfinch	*Spinus tristis*	C	C	C	C
Evening Grosbeak	*Coccothraustes vespertinus*	U		U	R
House Sparrow	*Passer domesticus*	C	C	C	C

Notes:
C=common, U=uncommon, O=occasional, R=rare
(sources: DeOrsey and Butler 2006, Bochnick 2011)

Table F-2-6
Plant Species of the Study Area

Botanical Species	Common Name
Trees and Shrubs	
Acer platanoides	Norway Maple
Acer pseudo-platanus	Sycamore Maple
Acer rubrum	Red Maple
Acer saccharinum	Silver Maple
Aesculus hippocastanum	Horsechestnut
Ailanthus altissima	Tree-of-Heaven
Berberis thunbergii	Japanese Barberry
Celtis occidentalis	Hackberry
Cornus sp.	Dogwood
Crataegus sp.	Hawthorne
Forsythia	Forsythia sp.
Ginkgo biloba	Ginko tree
Hybiscus syriacus	Rose of Sharon
Juniperus virginiana	Eastern Red Cedar
Liquidambar styraciflua	Sweetgum
Liriodendron tulipifera	Tuilptree
Lonicera japonica	Japanese Honeysuckle
Morus alba	White Mulberry
Picea abies	Norway Spruce
Pinus strobus	Eastern White Pine
Platanus x *acerifolia*	Londonplane Tree
Populus deltoides	Common Cottonwood
Populus sp.	Poplar
Prunus avium	Sweet Cherry
Prunus serotina	Black Cherry
Pyrus calleryana	Callery Pear
Quercus palustris	Pin Oak
Quercus rubra	Red Oak
Quercus veluntina	Black Oak
Rhus copallina	Winged Sumac
Rhus typhina	Staghorn Sumac
Robinia pseudoacacia	Black Locust
Rosa multiflora	Multiflora Rose
Salix sp.	Willow
Ulmus rubra	Slippery Elm

Table F-2-6
Plant Species of the Study Area

Woody Vines	
Ampelopsis brevipedunculata	Porcelainberry
Celastrus orbiculatus	Asiatic Bittersweet
Hedera helix	English Ivy
Parthenocissus quinquefolia	Virginia Creeper
Toxicodendron radicans	Poison Ivy
Vitis sp.	Grape
Forbs	
Ageratina altissima	White Snakeroot
Alliaria petiolata	Garlic Mustard
Apocynum cannabinum	Indian Hemp
Arctium minus	Common Burdock
Artemisia biennis	Biennial Wormwood
Artemisia vulgaris	Mugwort
Asclepias syriaca	Milkweed
Calystegia sepium	Hedge Bindweed
Chelidonium majus	Celandine
Cichorium intybus	Chickory
Conyza canadensis	Horseweed
Daucus carota	Queen Anne's Lace
Erigeron annuus	Daisy Fleabane
*Eupatorium serotinum**	Late Boneset
Eurybia divaricata	White-wood Aster
Euthamia sp.	Goldenrod
Galium sp.	Bedstraw
Hieracium vulgatum	Hawkweed
Humulus japonicus	Japanese Hops
Impatiens sp.	Jewelweed
Lepidium campestre	Field Peppergrass
Lotus corniculatus	Birds Foot Trefoil
Lychnis alba	White Campion
Melilotus alba	White Sweet Clover
Oenothera biennis	Common Evening Primrose
Oxalis sp.	Sorrel
Phytolacca americana	Pokeweed
Polygonum cespitosum	Oriental Lady's Thumb
Polygonum lapathifolium	Dock-leaved smartweed

Table F-2-6
Plant Species of the Study Area

Polygonum cuspidatum	Japanese Knotweed
Rubus phoenicolasius	Wine Rasberry
Solanum carolinense	Horse Nettle
Solanum dulcamara	Climbing Nightshade
Solidago rugosa	Wrinkleleaf Goldenrod
Solidago sempervirens	Seaside Goldenrod
Solidago sp.	Goldenrod sp.
Thlaspi arvense	Field pennycress
Trifolium spp.	Clovers
Verbascum thapsus	Common Mullein
Xanthium chinense	Clotbur
Grasses	
Bromus sp.	Field Brome
Dactylis glomerata	Orchard Grass
Festuca sp.	Fescue
Juncus canadensis	Canadian Rush
Panicum clandestinum	Deer-Tongue Grass
Phragmites australis	Common Reed
Setaria faberi	Giant Foxtail
Setaria sp.	*Foxtail* sp.

Notes: (*) denotes a state-listed endangered plant species.
Sources: AKRF October 2011 field reconnaissance

Appendix F: Ecology

F-3 Essential Fish Habitat

Essential Fish Habitat Assessment for the Tappan Zee Hudson River Crossing Project

January 2012

Essential Fish Habitat Assessment
For the Tappan Zee Hudson River Crossing Project

January 2012

Primary Agency and Contact:

Jonathan McDade, New York Division Administrator

Federal Highway Administration

In Coordination with:

New York State Department of Transportation

New York State Thruway Authority

Prepared by:

AKRF, Inc.

AECOM

Arthur Popper, Ph.D.

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Primary Agency and Contact:

Jonathan McDade, New York Division Administrator

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Chapter 1: Introduction and Federal Nexus

Essential fish habitat (EFH) is defined under the Magnuson-Stevens Fishery Conservation Management Act (16 USC §§ 1801 to 1883), as amended by the Sustainable Fisheries Act (SFA) of 1996, as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." "Waters" include aquatic areas and their physical, chemical and biological properties that are used by fish. "Substrate" includes sediment, hard bottom, structures, and associated biological communities that are under the water column. Waters and substrates necessary for fish spawning, breeding, feeding or growth to maturity—covering all stages within the life cycle of a particular species—refers to those habitats required to support a sustainable fishery and a particular species' contribution to a healthy ecosystem (50 Code of Federal Regulations (CFR) 600.10).

Section 303(a)(7) of the Magnuson-Stevens Act requires that the eight Regional Fishery Management Councils (RFMC) describe and identify EFH for each Federally managed species, and minimize adverse impacts from fishing activities on EFH. Section 305(b) (2)-(4) of the Magnuson-Stevens Act outlines the process for providing the National Marine Fisheries Service (NMFS) within the National Oceanic and Atmospheric Administration (NOAA), and the RFMC with the opportunity to comment on activities proposed by Federal agencies that have the potential to adversely impact EFH areas. Federal agencies are required to consult with NMFS (using existing consultation processes for the National Environmental Policy Act (NEPA), the Endangered Species Act, or the Fish and Wildlife Coordination Act) on any action that they authorize, fund or undertake that may adversely impact EFH.

Adverse effects to EFH, as defined in 50 CFR 600.910(A) include any impact that reduces the quality and/or quantity of EFH. Adverse effects may include:

- direct impacts such as physical disruption or the release of contaminants;
- indirect impacts such as the loss of prey, reduction in the fecundity (number of offspring produced) of a managed species; and
- site-specific or habitat wide impacts that may include individual, cumulative or synergetic consequences of a Federal action.

An EFH assessment of a Federal action that may adversely affect EFH must contain:

- a description of the proposed project;
- an analysis of the effects, including cumulative, on EFH, the managed species and associated species such as major prey species, and the life history stages that may be affected;
- the agency's conclusions regarding the effects of the action on EFH; and
- proposed mitigation if applicable (50 CFR 600.920(g)).

This EFH assessment has been prepared to demonstrate that the Tappan Zee Hudson River Crossing Project (the project) would be in compliance with the requirements of 50 CFR §660.920 implementing the Magnuson-Stevens Act, as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267).

The following sections provide:

- An overview of the Tappan Zee Replacement Bridge Alternative of thethe project);
- A description of the aquatic habitat and aquatic biota within the study area for the Replacement Bridge Alternative;
- An assessment of the potential for construction and operation of the Replacement Bridge Alternative to adversely affect aquatic habitat and aquatic biota;
- An assessment of potential adverse impacts to the fish species for which EFH has been identified within the study area for the project;
- An assessment of potential adverse impacts to non-EFH species with the potential to occur in the vicinity of the project as seasonal transients including; striped bass, a Fish and Wildlife Coordination Act (FWCA) species; and four species of federally-listed threatened or endangered marine turtles. Shortnose sturgeon, a federal and state-listed endangered species; and Atlantic sturgeon, a species proposed for listing for federal protection under the Endangered Species Act (http://www.regulations.gov/#!documentDetail;D=NOAA-NMFS-2010-0200-0001) and marine mammals are addressed separately in the Biological Assessment for the Tappan Zee Hudson River Crossing Project (see Appendix F-3 of the Tappan Zee Hudson River Crossing Project Draft Environmental Impact Statement (DEIS) (Federal Highway Administration in coordination with New York State Department of Transportation and New York State Thruway Authority 2012), ;;
- A summary of potential direct, indirect and cumulative effects on EFH and the other species evaluated.

Chapter 2: Project Description

2.1 OVERVIEW

The Replacement Bridge Alternative would replace the existing Tappan Zee Bridge (see Figures 1 and 2) with two new structures to the north of its existing location. The existing bridge would be demolished and removed. The purpose of the project is to maintain a vital link in the regional and national transportation network by providing a Hudson River crossing between Rockland and Westchester Counties, New York, that addresses the limitations and shortcomings of the existing Governor Malcolm Wilson Tappan Zee Bridge. Constructed in 1955, the 3.1-mile-long Tappan Zee Bridge (**Figures 1 and 2**) and its highway connections have been the subject of numerous studies and subsequent transportation improvements. Despite these improvements, congestion has grown steadily over the years and the aging bridge structure has reached the point where major reconstruction and extensive measures are needed to sustain this vital link in the transportation system.

2.2 DESCRIPTION OF THE REPLACEMENT BRIDGE ALTERNATIVE

The Replacement Bridge Alternative (see **Figure 3**) would be located to the north of the existing Tappan Zee Bridge where there is available NY State Thruway Administration (NYSTA) right-of-way available on both sides of the river to accommodate construction of the crossing and bridge landings for construction storage and staging areas and allow for a straight approach to the Westchester toll plaza. It would include two separate spans to provide service redundancy—a 96-foot-wide deck for the superstructure that includes a shared-use path and an 87-foot-wide deck for the superstructure that does not include a shared-use path. The two spans would be an average of 40 feet apart.

The following sections describe the proposed landings, approach spans, main spans, and ancillary facilities of the Replacement Bridge Alternative.

2.2.1 LANDINGS

In Rockland and Westchester Counties, Interstate 87/287 would be shifted northward to meet the new abutments of the Replacement Bridge Alternative (see **Figure 3**). The two approach span options (Short Span and Long Span described below) would result in a different configuration of the Rockland County landing. Where notable differences between the Short Span and Long Span Options would occur at the landings, they are described below. **Figure 3** reflects the Rockland County landing for the Short Span Option.

2.2.2 APPROACH SPANS

There are two options for the approach spans, the sections of the bridge that link the landings with the main spans over the navigable channel. These options—Short Span and Long Span—differ in terms of the type of structure as well as the number of and distance between bridge piers. Both approach span options would not preclude future transit service across the Tappan Zee Hudson River Crossing.

2.2.2.1. Short Span Option

The Short Span Option would consist of two parallel bridge structures that would have a typical highway design with a road deck supported by girders and piers (see **Figures 4 and 5**). The decks of the parallel structures would be separated by a gap of about 70 feet for length of about 2,600 feet at the main span that would diminish closer to the shorelines. The following describes the general characteristics of the Rockland County and Westchester County approach spans for the Short Span Option:

- The Rockland County approach spans would extend 4,125 feet between the abutments and the main spans, and each would consist of 43 sections. The average distance between the piers of Rockland County approach spans would be 230 feet. There would be no gap between the parallel bridges at the abutments. The gap between the highway decks would widen to 70 feet at the main span.
- The Westchester County approach spans would extend 1,800 feet between the main spans and the abutments, and each would consist of 16 sections with an average distance between the piers of approximately 230 feet. The gap between the decks of the parallel bridges would range from 70 feet at the main span to about 40 feet at the abutments.

As the approach spans meet the main span, the road deck would be at an elevation of 175 feet above the Hudson River's mean high tide elevation.

2.2.2.2. Long Span Option

The Long Span Option would also consist of two parallel bridges structures. Each structure would have a truss supported by piers (see **Figures 4 and 6**). The road deck would be located on top of the trusses. As with the Short Span Option, the decks of the parallel structures would be separated by a gap of about 70 feet that would diminish closer to the shorelines. The following describes the general characteristics of the Rockland County and Westchester County approach spans for the Long Span Option:

- The Rockland County approach spans would extend 4,125 feet between the abutments and the main spans, and each would consist of 23 sections. The average distance between the piers of Rockland County approach spans would be about 430 feet. There would be no gap between the parallel bridges at the abutments. The gap between the highway decks would widen to 70 feet at the main spans.
- The Westchester County approach spans would extend 1,800 feet between the main spans and the abutments, and each would consist of 10 sections with an average distance between the piers of 430 feet. The gap between the parallel highway decks would range from 70 feet at the main spans to 40 feet at the abutments.

As the approach spans meet the main span, the road deck would be at an elevation of 195 feet above the Hudson River's mean high water elevation.

2.2.3 MAIN SPANS

The main spans—the portions of the bridge that cross the navigable channel of the Hudson River—would provide adequate vertical and horizontal clearance for marine transport.

- The horizontal clearance affects the width of the Hudson River's navigable channel for water craft and must be clear of bridge piers and other bridge infrastructure. The U.S. Coast Guard requires a minimum horizontal clearance of 600 feet through the Tappan Zee

crossing. However, a clearance of 1,042 feet is preferred to provide a safety buffer for maritime navigation through the channel.

- The vertical clearance affects the height of the bridge as well as the hull-to-mast height of marine vessels that navigate under the bridge. The Replacement Bridge Alternative would provide for a vertical clearance of 139 at mean high water to maintain the existing maximum hull-to-mast height of vessels that travel beneath the Tappan Zee crossing.

The two options considered for the bridge's main spans over the navigable channel—Cable-stayed and Arch—would result in a horizontal clearance of at least 1,000 feet and a vertical clearance of 139 feet over the navigable channel at mean high water. Neither main span options would preclude future transit service across the Tappan Zee Hudson River Crossing.

2.2.4 CONSTRUCTION DURATION

The Replacement Bridge Alternative would be constructed over an approximately 4½- to 5½-year period for the Long Span and Short Span Options respectively. The various stages of construction are described in more detail below.

2.3 PROJECT SETTING

With the exception of the evaluation of the potential hydroacoustic effects resulting from pile driving for the construction of the project, the study area for the evaluation of impacts to surface water quality, aquatic habitat and biota from the project comprises the area extending ½ mile north and south of the Interstate 87/287 right-of-way generally between Interchange 10 (US Route 9W) in Rockland County and Interchange 9 (US Route 9) in Westchester County (see **Figure 7**). This study area incorporates the portions of the bridge, the Rockland and Westchester Bridge Staging Areas on the river, and the bridge landings. The study area for the evaluation of hydroacoustic effects extended to the limit of the SEL_{cum} re $1\mu Pa^2$-s isopleths as described in greater detail below.

The approximately 3-mile-wide portion of the Hudson River within the study area is designated by the New York State Department of Environmental Conservation (NYSDEC) as a Class SB waterbody. Best usages of Class SB saline surface waters are primary and secondary contact recreation and fishing; these waters shall be suitable for fish propagation and survival. Within the study area, the Hudson River is included on the 2010 New York State 303(d) list due to the presence of contaminated sediment containing Polychlorinated Biphenyls (PCBs) (NYSDEC 2010a).

In the vicinity of the Tappan Zee Bridge, the river ranges in depth from less than 12 feet at mean lower low water (MLLW) along the western causeway to greater than 47 feet at MLLW in the shipping channel under the main span (see **Figure 8**). The Hudson River is tidally influenced from the Battery to the Federal Dam at Troy, New York. Tidal currents are generally greatest in the navigational channel. Results of field surveys conducted for the project in April 2007 and November 2008 indicate that peak vertically averaged tidal currents in the navigational channel are about 2.5 feet per second (ft/sec). Peak velocities during the spring freshet—a time of high freshwater inflows resulting from snow and ice melt in rivers—may be greater than 3 ft/sec. Velocities are generally lower in the western mud flats in the vicinity of the bridge, with peak velocities generally on the order of 1 to 2 ft/sec. The tidal excursion at the Tappan Zee Bridge is approximately 4.0 and 6.2 miles for the flood and ebb tide, respectively (DiLorenzo et al. 1999).

2.3.1 SALINITY

The salt front, as defined by the USGS for the Hudson River estuary, is where chloride concentration begins to exceed 100 milligrams per liter (mg/L) (Devries and Weiss, 2001). Seawater has a chloride concentration of about 19,400 mg/L. With the exception of very large freshwater discharge events, there is always a salt front present in the Hudson River estuary, the location of which varies at a given time with tidal forcing and the magnitude of freshwater discharge. In general, the salt front is located between 15 and 75 miles upstream of the Battery. It is located farther upriver during the summer when there are low freshwater inflows, and farther downriver during the spring when freshwater flows are greatest.

The term salt wedge is a more generic term that describes the tendency for saltwater to intrude beneath freshwater without substantial mixing. A salt wedge is marked by a steep salinity gradient, or halocline, in the vertical direction. The presence of a salt wedge does not indicate an immediate horizontal transition from fresh to salt water. In the Hudson River estuary, the transition is often 50 miles long.

Figure 9 shows average salinities in Practical Salinity Units (PSU) over a 16-year period at the USGS gauge at Hastings-on-Hudson (#1376304), which is about 6 miles downstream of the Tappan Zee Bridge. Although salinity concentrations are somewhat lower at the Tappan Zee Bridge, the salinity at Hastings-on-Hudson is indicative of the magnitude and yearly variation of salinity at the bridge. At the Hastings-on-Hudson station, salinity ranged from about 2 to 6 PSU during high freshwater flow periods in the spring to a high of about 8 to 10 PSU during low freshwater flow periods in the summer. Salinities in the winter varied between 4 and 6 PSU. Salinities recorded during the 2006 and 2008 sampling program conducted for the project were similar to those recorded at Hastings-on-Hudson.

2.3.2 TEMPERATURE

Water temperatures are relatively uniform throughout the freshwater reach of the Hudson River estuary, and follow a similar cycle each year. At the mouth of the Hudson River estuary, near the Battery, temperatures are substantially affected by the inflow of water from the New York Bight and tend to exhibit a milder degree of variation throughout the year. **Figure 10** demonstrates the average yearly cycle in water temperature in the upper reach of the Hudson River estuary near Albany, and near its mouth, near the Battery over a period of 2002-2009. The NOAA Gauge at the Battery (#8518750) is 26.5 miles downstream of the bridge. The USGS gauge at Albany (#1359139) is 118 miles upstream of the bridge.

In the lower reaches of the Hudson River estuary and near the Tappan Zee Bridge, ocean water intrudes beneath fresh water to form a salt wedge, often resulting in a large degree of stratification in the water column. In these areas large vertical variations in temperature may be present. Average water temperatures at the Tappan Zee Bridge are generally close to the average of temperatures at the Battery and Albany, NY, ranging from below close to 0º Celsius (C) (32º Fahrenheit (F)) in the winter to about 25º C (77º F) in the summer, with temperatures in the spring ranging between 2º C and 10º C (36º F to 50º F).

2.3.3 SUSPENDED SOLIDS

Generally, suspended solids concentrations (SSC) show a strong correlation with water-column depth, with higher concentrations near the bottom of the river. Significant variation based on a variety of river conditions can also be expected, with the tidal cycle and magnitude of freshwater

discharge being the most dominant factors. During the spring freshet sediment concentrations much higher than normal can be expected.

The USGS operates an Acoustic Doppler Current Profiler (ADCP) at the Hudson River estuary gauge station south of Poughkeepsie, approximately 27 miles north of the bridge. The station uses backscatter information from the ADCP to estimate suspended solids concentration (Wall et al. 2006). Using the SSC data combined with the current data measured by the device, an estimate of total sediment discharge is also calculated. This gauge has been monitoring SSC almost continuously since 2002, and represents the most complete data set of sediment concentration and sediment loading in the Hudson River estuary.

For the purposes of impact evaluation, an understanding of the typical sediment concentrations at the study area, and their variability, is useful. To aid in this understanding, the yearly variation of the depth-averaged SSC concentration at the USGS gauge south of Poughkeepsie is presented in **Figure 11** for the period 2002 through 2009. It is expected that the suspended sediment concentration at the Tappan Zee Bridge will be similarly inherently variable and seasonally dependent, as indicated by the USGS gauge upstream. Depth averaged SSC measurements made during field surveys of the Tappan Zee were similar in magnitude to those recorded at the Poughkeepsie station (see **Figure 11**).

SSC was recorded during water quality sampling conducted from late October through early December 2008 within the study area. Results showed that increases in SSC with depth were more dramatic at deep locations than at shallow water locations. Fluctuations in SSC occurred over each tidal cycle, with the highest SSC observed at max flood and max ebb tides. SSC recorded during this time frame generally ranged from about 10 to 75 mg/L, with maximum concentrations recorded of about 140 mg/L. Depth averaged water-column sediment samples in the vicinity of the Tappan Zee Bridge appear to range from 15 to 50 (mg/L) under normal conditions, and may exceed 100 mg/L during large freshwater events.

2.3.4 SEDIMENT CHARACTERISTICS

Hudson River bottom sediments in the vicinity of the bridge comprise primarily clayey silt (see **Figure 12**). Accumulations of sand, silt and clay material are observed along the causeway section of the existing bridge. Gravelly sediments are also found extensively near the eastern shore of the Hudson River and across a large swath of the mud flats north of the existing causeway section.

Due to releases from industrial activity, sediments deposited on the river bottom during the twentieth century are more likely to exhibit signs of contamination. Examples of industrial contamination include heavy metals, volatile or semivolatile organic compounds (VOCs or SVOCs), pesticides, and PCBs. Industrial-era sediments were identified through a combination of seismic-profiling data and the concentration of lead in sediment samples. The thickness of industrial era sediment deposits in the vicinity of the Tappan Zee Bridge is shown on **Figure 13**. While recently deposited sediments (i.e., from the 20th and 21st centuries) can be found throughout much of the study area. Deposition of recent sediments north of the existing bridge is limited, ranging from no deposition to a depth of about 2 feet, with most of the recent deposits occurring between 0 and about 8 inches. South of the bridge, deposition of recent sediments is limited on the western margin (ranging from 0 to 8 inches) with some areas of deeper deposition further east along the causeway (2 to 4 feet), deposition along the eastern margin appears to be greater (ranging from 0 to at least 6 feet). On the basis of the evaluation of recent sediment deposits, the net rate of deposition within the vicinity of the existing bridge is estimated to range

from 0 inches per year to as high as 1 inch per year in the eastern margin south of the existing bridge.

Results from the 2006/2008 sediment sampling conducted for the project within the study area were compared to results found for historic Hudson River sampling conducted by Llanso et al (2003). These data are summarized in the Tappan Zee Hudson River Crossing Project Draft Environmental Impact Statement (DEIS) and in **Tables 1, 2, and 3**. In general, levels of contaminants such as metals, pesticides, and PCBs in the sediment samples collected within the study area are similar to average levels found elsewhere in the Hudson River as indicated by the Hudson River Benthic Mapping Project. On the basis of the results of the laboratory analysis of 2006 and 2008 sediment cores, the upper few feet of river sediment would be characterized as moderately contaminated following NYSDEC Technical and Operational Guidance Series (TOGS) 5.1.9, (NYSDEC 2004) with the exception of a few locations near the western and eastern Hudson River shorelines and south of the main span bridge piers where higher concentrations appear to have accumulated.

2.3.5 AQUATIC HABITAT

The study area encompasses intertidal and subtidal habitats of varying depths, ranging from shallow intertidal shorelines to shallow subtidal shoals and deeper channel habitats. There are no vegetated tidal wetlands present within the study area. The NYSDEC has mapped areas south of the existing bridge as littoral zone tidal wetlands (i.e., depths of no more than 6 feet at mean low water (MLW)). No NYSDEC tidal wetlands are mapped north of the bridge.

On the west side of the river, the shoreline typically consists of unvegetated intertidal beaches composed of coarse sand with scattered boulders. Immediately north of the bridge the shoreline is bulkheaded.

Shallow water environments occur near the shorelines and along the western and eastern causeways, while deep water habitat occurs within and near the shipping channel and the main bridge span. Shallows attract aquatic organisms that prefer greater sunlight and less water depth for part or all of their life cycles, while deeper water areas attract organisms with deeper water column needs. The region under the existing bridge attracts certain organisms that use the pier structures as habitat, or that seek the organisms that adhere to the structures as food resources.

2.3.6 AQUATIC BIOTA

The tidal action of the Hudson River, currents, and the seasonal variation in the amount of freshwater contributed to it by precipitation and runoff, make it a highly dynamic and unstable system. As a result, the ecosystem is typically dominated by a few well adapted species. The Tappan Zee section of the Hudson River is the major site of river water mixing with ocean water in the Lower Hudson River Estuary. This productive estuary area is a regionally significant nursery and wintering habitat for a number of anadromous, estuarine, and marine fish species, including the striped bass. It is also a migratory and feeding area for birds and fish that feed on the abundant fish and benthic invertebrate resources in this area. In 1992, the Habitat Work Group of the New York-New Jersey Harbor Estuary Program, administered by USEPA, requested that USFWS identifiy significant coastal habitats warranting special protection (USFWS 2011).

Table 1
Sediment Chemistry Summary – Metals

Parameter	Sediment Criteria		Hudson River Average[2]	Number of Samples Analyzed	Detection Rate	Minimum (mg/kg)	Average (mg/kg)	Median (mg/kg)	95th Percentile (mg/kg)	Maximum (mg/kg)
	ERL[1] (mg/kg)	ERM[1] (mg/kg)								
Aluminum	NC	NC	10256.9	313	100%	483	11,714	11,700	17,300	21,700
Antimony	NC	NC	--	156	0%	ND	ND	ND	ND	ND
Arsenic	8.2	70	7.2	313	97%	ND	8.06[A]	7.4[A]	14[B]	26.4[B]
Barium	NC	NC	--	313	92%	ND	43	32.9	91.04	190
Beryllium	NC	NC	--	313	47%	ND	0.79	0.76	1.1	2.61
Cadmium	1.2	9.6	1.0	313	46%	ND	1.9[B]	1.92[B]	3.2[B]	6[B]
Calcium	NC	NC	--	313	98%	ND	4,919	2,620	16,550	64,600
Chromium	81	370	38.1	313	100%	1.17	31	21.9	85.86	116
Cobalt	NC	NC	--	313	96%	ND	10	9.8	13.7	17.3
Copper	34	270	42.4	313	99%	ND	32[A]	12.4[A]	102.55[B]	1,550[C]
Iron	NC	NC	--	313	100%	1380	24,227	24,200	32,600	40,900
Lead	46.7	218	44.6	313	100%	1.42[A]	36[A]	10.9[A]	137.4[B]	604[C]
Magnesium	NC	NC	--	313	100%	252	5,765	5,760	7,476	39,600
Manganese	NC	NC	--	313	100%	21.8	626	587	1,170	1,600
Mercury	0.15	0.71	0.38	313	37%	ND	0.89[B]	0.53[B]	2.46[C]	6.33[C]
Nickel	20.9	51.9	21.5	313	99%	ND	21	20.6	32.6	38.3
Potassium	NC	NC	--	313	97%	ND	2181	2,130	3,257	4,460
Selenium	NC	NC	--	313	43%	ND	4.01	3.945	6.2775	12.6
Silver	1	3.7	1.5	156	17%	ND	2.02	1.9	3.04	3.3
Sodium	NC	NC	--	313	94%	ND	2,229	2,035	3,761.50	5,730
Thallium	NC	NC	--	156	1%	ND	12.4	12.4	12.4	12.4
Vanadium	NC	NC	--	313	99%	ND	24.7	23.7	36.3	54.1
Zinc	150	410	129.2	313	100%	8.74	90	65	221	399

Notes: mg/kg = milligrams per kilogram; NC = no criteria; ND = not detected, -- = not available.

Sources:

[1] NYSDEC 1999

[2] Llanso et al. 2003

[A] Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

[B] Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

[C] Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

Table 2
Sediment Chemistry Summary – SVOCs

Parameter	Sediment Criteria		Hudson River Average[3]	Number of Samples Analyzed	Detection Rate	Minimum (µg/kg)	Average (µg/kg)	Median (µg/kg)	95th Percentile (µg/kg)	Maximum (µg/kg)
	ERL[1] (µg/kg)	ERM[1] (µg/kg)								
Acenaphthene	16	500	289.4	156	8%	ND	36	ND	89	3,270
Acenaphthylene	44	640	139.2	156	16%	ND	13	ND	111	206
Anthracene	85.3	1,100	283.2	156	27%	ND	47	ND	155	2,030
Benzo(a)anthracene	261	1,600	176.4	156	43%	ND	130	ND	418	3,760
Benzo(a)pyrene	430	1,600	174.1	156	51%	ND	133	37	496	3,020
Benzo(b)fluoranthene	NC	NC	184.7	156	42%	ND	110	ND	445	2,460
Benzo(g,h,i)perylene	NC	NC	123.5	156	42%	ND	64	ND	260	1,530
Benzo(k)fluoranthene	NC	NC	163.4	156	42%	ND	91	ND	328	2,370
Chrysene	384	2,800	178.7	156	44%	ND	134	ND	487	3,490
Dibenzo(a,h)anthracene	63.4	260	--	156	15%	ND	14	ND	78	456
Fluoranthene	600	5,100	218.9	156	49%	ND	333	ND	994	13,300
Fluorene	19	540	291.2	156	10%	ND	28	ND	81	2,210
Indeno(1,2,3-c,d)pyrene	NC	NC	104.8	156	33%	ND	53	ND	220	1,510
2-Methylnaphthalene	70	670	--	156	1%	ND	0.96	ND	ND	113
Naphthalene	160	2,100	111.0	156	9%	ND	11	ND	49	504
Phenanthrene	240	1,500	299.1	156	40%	ND	163	ND	539	7,030
Pyrene	665	2,600	265.7	156	48%	ND	288	ND	999	9,570
Total PAHs (sum of above)	4,020	44,792	3,003	156	--	22.8[A]	1,673[A]	113[A]	6,079[B]	48,211[C]
bis(2-Ethylhexyl)phthalate	NC	NC	--	156	33%	ND	82	ND	259	4,240
Butyl benzyl phthalate	NC	NC	--	156	12%	ND	101	ND	289	5,140
Carbazole	NC	NC	--	156	3%	ND	5.25	ND	ND	349
Dibenzofuran	NC	NC	--	156	5%	ND	20	ND	6.6	2,660
Di-n-butyl phthalate	NC	NC	--	156	3%	ND	30	ND	ND	4,360

Notes: µg/kg = micrograms per kilogram; NC = no criteria; ND = not detected; -- = not available.

Sources:

[1] NYSDEC 1999; [2] NYSDEC 1999; [3] Llanso et al. 2003

[A] Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

[B] Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

[C] Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

Table 3
Sediment Chemistry Summary – Pesticides, PCBs, and Dioxins

Parameter	Sediment Criteria					Hudson River Average[2]	Number of Samples Analyzed	Detection Rate	Minimum (µg/kg)	Average (µg/kg)	Median (µg/kg)	95th Percentile (µg/kg)	Maximum (µg/kg)
	ERL[1] (µg/kg)	ERM[1] (µg/kg)	BA- Chronic[1] (µg/gOC)	BA- Acute[1] (µg/gOC)	WA[1] (µg/gOC)								
alpha-Chlordane	NC	NC	NC	NC	0.006	--	156	1%	ND	0.1	ND	ND	16
gamma-Chlordane	NC	NC	NC	NC	0.006	--	156	1%	ND	0.09	ND	ND	15
Chlordane (sum of above)	NC	NC	0.002	0.05		--	156	--	--	0.19[A]	--	--	31[B]
Dieldrin	NC	NC	17.0	NC	NC	--	156	1%	ND	0.03[A]	ND	ND	4.8[A]
4,4'-DDD	NC	NC	-	-	NC	5.7	156	14%	ND	2.07	ND	12	54
4,4'-DDE	2.2	27	-	-	NC	--	156	7%	ND	0.47	ND	3.85	17
4,4'-DDT	1	7	1	130	NC	19.7	156	5%	ND	2.47	ND	0.73	352
Sum of DDT, DDD, and DDE	1.58	46.1	-	-		25.4	156	--	--	5.01[B]	--	16.58[B]	423[C]
Aroclor 1242	NC	NC	NC	NC	NC	--	156	13%	ND	51	ND	280	1,520
Aroclor 1248	NC	NC	NC	NC	NC	--	156	8%	ND	35	ND	239	1,200
Aroclor 1254	NC	NC	NC	NC	NC	--	156	4%	ND	6.13	ND	ND	221
Total PCBs	22.7	180	-	-	NC	726.8	156	--	40[A]	169.95*[B]	64[A]	682.25[B]	1,520*[C]
TCDD TEQ (pptr)	NC	NC	NC	NC	0.0002	--	17	100%	0.069[A]	11.84[C]	0.89[A]	54.2[C]	94.67[C]

Notes: µg/gOC = micrograms per gram of organic carbon; µg/kg = micrograms per kilogram; NC = no criteria; ND = not detected; BA = Benthic Aquatic; WA = Wildlife Accumulation; -- = not available; - ERM/ ERL applies.

Sources:

1 NYSDEC1999

2 Llanso et al. 2003

* The sum of PCBs is multiplied by two to determine the total PCB concentration (NYSDEC 2004).

A Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

B Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

C Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

2.3.6.1. Phytoplankton

Diatoms are generally the most widely represented class of phytoplankton, accounting for 78 percent of the different taxa collected, with green algae (15 percent), blue-green algae (cyanobacteria) (3 percent), golden algae (chrysophyceae) (2.5 percent), dinoflagellates (1 percent), and cryptophyceae (a type of flagellate algae) (0.6 percent) comprising the remainder of the phytoplankton community. High turbidity and rapid mixing of the Hudson River (which lower light availability) limit primary production by phytoplankton (Smith et al. 1998).

2.3.6.2. Submerged Aquatic Vegetation and Benthic Algae

Submerged aquatic vegetation (SAV) are rooted aquatic plants that are often found in shallow areas of estuaries, at water depths of up to six feet at low water (New York's Sea Grant Extension Program undated). These communities exhibit high rates of primary productivity and are known to support abundant and diverse epifaunal and benthic communities. These organisms are important because they provide nursery and refuge habitat for fish. Light penetration, turbidity and nutrient concentrations are all important factors in determining SAV and benthic algae productivity and biomass.

NYSDEC has mapped the distribution of SAV in the Hudson River from Hastings-on-Hudson to Troy using 1997, 2002, and 2007 data. No SAV is mapped in the vicinity of the Replacement Bridge Alternative (see **Figure 14**), although SAV is mapped within the ½-mile study area on either side of the Replacement Bridge Alternative. SAV surveys were conducted as part of the project in 2009 to confirm the locations of SAV identified on the NYSDEC maps. The dominant species of SAV collected as part of the surveys is the native water celery (*Vallisneria americana*); two other species were collected in the vicinity of the project area, including Eurasian water-milfoil (*Myriophyllum spicatum*) and sago palmweed (Potamogeton pectinatus). SAV beds were found along the western bank of the river; on the east bank, SAV was only found north of the bridge.

2.3.6.3. Zooplankton

Zooplankton are an integral component of aquatic food webs—they are primary grazers on phytoplankton and detritus material, and are themselves used by organisms of higher trophic levels as food. Copepods, cladocerans, and rotifers are the primary representatives of zooplankton species in the Hudson River. Zooplankton also include life stages of other organisms such as fish eggs and larvae (i.e., ichthyoplankton) that spend only part of their life cycle as plankton. Analysis of long-term data from the Hudson River Utilities Long River Sampling Monitoring Program indicates larval Atlantic tomcod (*Microgadus tomcod*), bay anchovy (*Anchoa mitchilli*), striped bass, and white perch (*Morone americana*) as the dominant ichthyoplankton species. The higher-level consumers of zooplankton typically include forage fish, such as bay anchovy, as well as commercially and recreationally important species, such as striped bass and white perch during their early life stages.

2.3.6.4. Benthic Invertebrates

Versar (Llanso et al. 2003) collected benthic samples from the lower Hudson River estuary (river miles (RM11 to 40) in 2000 and 2001 which included the vicinity of the study area. In general, they found greatest numbers of species per sample in the lower portions of the study area (south of the Tappan Zee Bridge) and lowest numbers north of the bridge. Greatest benthic biomass occurred in shallow regions of Croton Bay and north of Piermont Pier on the western

side of the river. Taxa which showed the greatest densities included the oligochaete worm Tubificoides spp., the clam *Rangia cuneata*, and the amphipod *Leptocheirus plumulosus*. They also found the barnacle *Balanus improvisus* and the pollution tolerant polychaete worms *Marenzelleria viridis* and *Heteromastus filiformis* to be present in relatively high abundances.

Bimonthly sampling of benthic resources in the study area for the project was conducted between March 2007 and January 2008. Samples were taken in the vicinity of the existing bridge and the footprint of the Replacement Bridge Alternative. A total of 48 species were collected during the benthic sampling program. Generally, the species richness and numbers of individuals were lower in late winter and early spring and higher in the summer and fall. Species diversity, while relatively constant throughout the year, was observed to be highest in July and lowest in January. The barnacle *Balanus* spp. and the amphipod *Leptocheirus plumulosus* were two of the dominant taxa collected in each of the six sampled months.

Benthic invertebrate sampling of the existing bridge piers conducted for the project in 2007 identified a total of 8 taxa and 2 taxa of benthic algae. The polychaete worm *Nereis* spp., amphipods, barnacles, grass shrimp, mud crabs, isopods, oysters, and ribbed mussels were collected from the piers, as well as red and green algae. These organisms were collected in similar densities on three types of pier structure, namely, steel, concrete and timber.

Surveys (side-scan sonar and seismic profiling combined with grab samples) identified seven potential oyster (*Crassostera virginica*) beds south of the bridge and six potential beds to the north. All identified oyster beds except one were confirmed to contain at least some live organisms with beds exhibiting differences in terms of oyster density, amount of shell hash, gravel, or sandstone fragments, etc.

2.3.6.5. Fish

The Hudson River estuary's fish community is species-rich. The estuary's species diversity is enhanced by its mid-latitude location on the Atlantic Coast. Southern tropical marine forms enter the Hudson River during the summer, and a number of northern fishes are near their southern limit. The Hudson River fish community, particularly in the estuarine reach, is a mixture of both temperate and tropical marine forms, freshwater forms, and intentional and accidental introductions (ASA 2006). Despite the large number of species that are occasionally found in the estuary, the majority of the fish represent only a limited number of species. More than 99 percent of the total fish community comprises only 10 to 15 percent of the species. In stable ecosystems, low species diversity may be an indicator of environmental stress. However, in highly dynamic and unstable ecosystems such as the Hudson River estuary, the biological community may be dominated by only a few species that are well adapted to such naturally dynamic conditions (ASA 2006).

Each of the fish species that occurs in the River can be classified by its salinity tolerance. Marine species live in the open Atlantic Ocean and nearshore waters and venture into the estuary during the warmer months of the year when salinity is relatively high. These species typically occupy the lower reaches of the estuary. Estuarine species occupy a large portion of the brackish estuary year-round and may be occasionally found in freshwater and marine reaches. Freshwater species live in the Hudson River and rarely, if ever, venture into low-salinity areas of the estuary such as the region in the vicinity of the Tappan Zee Bridge. Several fish species that occur in the Hudson River migrate from the Atlantic Ocean into freshwater habitats of the River, typically for spawning (anadromous), or leave the river to spawn in the open ocean (catadromous).

The dominant marine species in the Tappan Zee region is the bay anchovy. An analysis of the Fall Shoals data from 1998-2007 indicated that numerically, bay anchovy comprised about 82 percent of the total fish standing stock. Bay anchovy are found in salinities ranging from fresh to seawater and may be the most abundant species in the western north Atlantic. Other marine species which were at times abundant in the Utilities sampling program included weakfish (*Cynoscion regalis*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonius undulatus*), butterfish (*Peprillus triacanthus*) and bluefish (*Pomatomis saltatrix*).

Estuarine species are generally euryhaline (i.e. tolerant of wide salinity ranges), and are year-round residents of the saline portions of the Hudson River. Abundant estuarine species collected by the utilities' monitoring program included white perch, banded killifish (*Fundulus diaphanus*), Atlantic silverside (*Menidia menidia*), and hogchoker (*Trinectes maculatus*).

Anadromous species that use the estuary as spawning and nursery grounds include alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), shortnose sturgeon, Atlantic sturgeon, Atlantic tomcod, blueback herring (*Alosa aestivalis*), and striped bass. Adults typically enter the estuary in the spring and migrate upstream to low-salinity brackish and freshwater areas to spawn. The young fish then use the near-shore shoal areas for food and habitat as they make their way downstream, and generally leave the estuary in the fall. American eel (*Anguilla rostrata*) is the only catadromous species that occur in the Hudson. Although the Utilities data indicate that there are wide variations in the annual totals of collected eels, overall there has been a sharp decline in the number of individuals captured during these surveys since the mid 1980s.- The U.S. Fish and Wildlife Service and NMFS are currently reviewing the status of American eel to determine whether it should be proposed for listing as a protected species.

A year-long fish survey was conducted for the project between April 2007 and May 2008 to further characterize the fish community within the study area and examine seasonal differences in abundance. These surveys combined hydroacoustics, gill nets, and trap nets to characterize the species composition, relative abundances, and distributions of fish populations within the project area.

Results of the hydroacoustic surveys indicate that the horizontal, vertical, and geographical distribution of fishes within the Tappan Zee region and in the project area, in particular, is substantially influenced by temperature and salinity. In the colder months of the year (December through April), the fish populations are concentrated in deeper waters with higher salinities. In the late winter and early spring, a distinct halocline (i.e., salinity gradient) was observed at a depth of approximately 19.7 feet (6 meters), below which fish densities increased. As the water temperature increased during late spring, the halocline dissipated and the salinity in the project area increased in the shallower depths. Also observed was a marked increase in the abundance of fishes at those depths, although the greatest abundances continued to occur in the deepest portion of the channel. In the warmer summer months of the year, early life stages of many species were present within the study area. Presumably these concentrations are salinity driven. A large percentage of the individuals that were captured were members of schooling species.

A total of 25 species (see **Table 4**) and just over 2,000 individual fishes and hundreds of blue crabs were collected during approximately 700 hours of gill-net sampling conducted for the project within the study area between April 2007 and May 2008. Fish were caught throughout the year at all of the sampling locations within the study area. However the total number of fish caught in the colder months was markedly lower than during the warmer months. In the colder months of the year, the total numbers of fish caught at all locations were markedly lower than the numbers of fish caught during the warmer months of the year. Moreover, there were higher numbers of fish caught at the sampling locations with greater water depths. Anadromous and

estuarine fish were captured in every sampling event. Marine fish were only captured in the warmer months of the year.

Table 4
List of Fish Species Occurring within the Project Area
Based on Gill-net Sampling, 2007-2008

Common name	Scientific name	Assemblage
Alewife	*Alosa pseudoharengus*	Anadromous
American eel*	*Anguilla rostrata*	Catadromous
American shad	*Alosa sapidissima*	Anadromous
Atlantic butterfish	***Peprilus triacanthus***	**Marine**
Atlantic menhaden	*Brevoortia tyrannus*	Marine
Atlantic tomcod	*Microgadus tomcod*	Estuarine
Bluefish	***Pomatomus saltatrix***	**Marine**
Blueback herring	*Alosa aestivalis*	Anadromous
Blue runner	*Caranx crysos*	Marine
Common carp	*Cyprinus carpio*	Freshwater
Gizzard shad	*Dorosoma cepedianum*	Freshwater
Hickory shad	*Alosa mediocris*	Marine
Hogchoker	*Trinectes maculatus*	Estuarine
Naked goby*	*Gobiosoma bosci*	Estuarine/Marine
Northern kingfish	*Menticirrhus saxatilis*	Estuarine/Marine
Northern sea robin	*Prionotus carolinus*	Marine
Oyster toad fish*	*Opsanus tau*	Estuarine/Marine
Porgy	Family Sparidae	Marine
Shortnose sturgeon	*Acipenser brevirostrum*	Anadromous
Spot	*Leiostomus xanthurus*	Estuarine/Marine
Striped bass	*Morone saxitalis*	Anadromous
Summer flounder	***Paralichthys dentatus***	**Estuarine/Marine**
Weakfish	*Cynoscion regalis*	Estuarine
White catfish	*Ameiurus catus*	Freshwater
White perch	*Morone americana*	Estuarine

Note:
* Species only captured in fish traps.
Species in Bold are Essential Fish Habitat Designated Species for Hudson River

2.4 DESCRIPTION OF CONSTRUCTION ACTIVITIES

2.4.1 SCHEDULE

As shown in **Figure 15**, construction of the Short Span Option would take approximately 5½ years. The schedule shows both preliminary activities used to support the construction of the project (i.e., dredging and temporary platforms) as well as individual elements of bridge construction (i.e., main span and approaches). Throughout the construction period roadway work would be required at various times. During that time, the approach roadways would be shifted and remain in the new location for an extended period before being shifted again. The dredging would occur in three 3-month phases from August 1 through November 1 over a 4-year period,

and construction of the main span would consist of approximately 3½ years of construction. Completion of the short span approaches would involve approximately 3½ to 4 years of construction. Demolition of the existing Tappan Zee Bridge would be expected to span approximately 1 year.

Construction of the Long Span Option would last approximately 4½ years. The construction sequence and schedule would be similar to that of the Short-Span Option with the exception of the construction of the approaches, which would be expected to take approximately 2½ to 3 years.

2.4.2 BRIDGE ELEMENTS

2.4.2.1. Landings

Landings would employ typical highway construction techniques and would be completed on both the Westchester and Rockland sides of the Hudson River upland from the bridge abutment to the tie in with the existing roadway. Construction of the landings would occur throughout the duration of the construction. The alterations to the landings would consist of changes in roadway grade, elevation, direction, and general configuration.

2.4.2.2. Approaches

Beginning at the abutments, the approaches carry traffic from the land to the main span of the bridge. Construction of the approaches would last for approximately three and a half to four years for the short-span alternative, and two and a half to three years for the long-span alternative. The piles, pile caps, piers, and deck that compose this segment of the bridge would be built sequentially so that as a new pile is being constructed, a completed pile would be undergoing further transformation with, for example, the addition of a pile cap.

2.4.2.3. Main Span

The main span would stretch between the Westchester and Rockland approaches. It is the segment of the bridge that would be defined largely by its superstructure design as an arch or cable stayed bridge. Within its substructure, the piers would be more substantial than those of the approaches. All main span work would be done sequentially and in a similar manner as that of the approaches. The piles, pile caps, pylons, and deck construction would last approximately three and a half years.

2.4.3 CONSTRUCTION OF KEY ELEMENTS

Construction of either option of the Replacement Bridge Alternative would require a wide range of activities on both sides of the river as well as from within the waterway itself. In addition, due to the lack of available land along the waterfront in the vicinity of the bridge, staging areas at some distance from the construction site would be required. Furthermore, it is likely that some bridge components would be pre-fabricated well outside the study area and transported to the site via barge.

To support construction of the main span and bridge approaches, materials, equipment, and crews would be transported from upland staging areas in Westchester and Rockland counties (see **Figure 16**) to temporary platforms that would be constructed on the shoreline of the river within the Bridge Landing Areas (see **Figures 17 and 18**). Dredged channels (see **Figure 15**) would provide access to the two work areas in the shallow portion of the river crossing: the

Rockland and Westchester approaches. Substructure construction would establish the foundation of the bridge through the processes of pile driving, construction of pile caps, and construction of columns. Superstructure construction would then take place either with a gantry that would move from pier to pier lifting segments from barges below (as in the case of the short-span design option) or a short pier-head truss segment would be lifted atop the next open pier column and secured (as in the case of the long-span option). The following sections describe the construction activities with the potential to affect EFH within the study area.

2.4.3.1. Waterfront Construction Staging

The shoreline areas near the proposed bridge site are limited by adjacent development. In order to provide space for the docking of vessels, the transfer of materials and personnel, and the preparation of construction elements, temporary platforms (approximately 9 acres) would be extended out from the shoreline over the Hudson River (see **Figures 17 and 18**). The 2-–acre permanent portion of the Rockland platform would protect the shoreline and also enable the continued maintenance of the original Tappan Zee Bridge while the replacement bridge is being constructed, as well as provide continued support for the New York State Thruway Authority (NYSTA) Dockside Maintenance facility operation. Steel piles would be driven to support the platforms. These platforms would provide access to the replacement bridge site via temporary trestles. Their main purposes would be to facilitate delivery of heavy duty bridge elements from an offsite fabrication facility, receive deliveries from the concrete batch plant, receive deliveries (i.e., construction equipment and light duty bridge elements) from the staging areas, and allow for barge-mounted cranes to erect heavy duty bridge elements. Upon completion of construction, the temporary platforms and the piles that support them would be removed. The permanent platform within the Rockland Bridge Staging Area would remain.

As the construction of the temporary platforms and access trestles would begin at the shoreline, an access road and work area near the shore would also be constructed. A channel would be dredged specifically to provide barge access to the temporary platforms from in-river work sites.

2.4.3.2. Dredged Access Channel

Since the proposed bridge alignment spans extensive shallows, it would be necessary to dredge an access channel for tugboats and barges to use during construction of the approach spans. These vessels would be used for the installation of cofferdams, pile driving, the construction of pile caps and bridge piers, and the erection of bridge decks and other superstructure components. As noted earlier, temporary, trestle-type access platforms would be constructed near the shoreline to provide access for construction vehicles that would operate on the trestles. With the installation of the temporary platforms, dredging of the near-shoreline area would be avoided.

Two alternate construction methods were evaluated in an effort to avoid the need to dredge an access channel. One method involved the use of overhead gantries for the construction of foundations and the other consisted of the implementation of a full-length temporary trestle for access. Both of these alternatives were found to be impractical: the former because it is not practicable for the heavy-duty pile-driving requirements of the replacement bridge and the latter because the deep soft soils in the shallow waters of the construction zone would require foundations that would be expensive and time-consuming to construct.

As shown in **Figure 15**, dredging would be conducted in three stages over a 4-year period for a duration of three months each year from August 1 to November 1, a dredging period selected to minimize impacts to aquatic resources. The purpose of the first two dredging stages (Years 1 and

2) would be to provide access for bridge construction, while the final dredging stage (Year 4) would provide access for demolition of portions of the existing bridge allowing completion of the remaining portions of the new structure. Each of these three-month spans would occur during the August 1 to November 1 window. All dredging would be done using environmental bucket with no barge overflow.

Based on an analysis of the types, number, size and operation of vessels that would operate in the access channel during construction, it was determined that a clear draft of 14 feet at MLLW would be required within the access channel. To avoid the potential for grounding of vessels, an additional two feet would be added to provide a working channel depth of 16 feet at MLLW.

In addition, to minimize any adverse effects from the re-suspension of the fine sediment material due to movement of vessels, particularly tugboats, within the dredged channel, a layer of sand and gravel (referred to as "armor") would be placed at the bottom of the channel following dredging. The sediments in the vicinity of the area to be dredged are highly susceptible to resuspension into the water column. Without "armoring," prop scour from working tugboats in the channel would result in the generation of suspended sediment at rates several orders of magnitude greater than what would occur from the dredging operation itself. Therefore, it was concluded that this level of sediment resuspension and ultimate transport into the river would pose an unnecessary and potentially substantial adverse effect to the marine environment.

The installation of the sand and gravel would take place as soon as the dredging for that section of the channel was completed, forming a protective layer to keep sediment from further disturbance. Without this protective layer, additional dredging would be required to create a deeper work zone. The stone or gravel materials used for the armoring would be delivered by barges or scows, and would be placed within the channel in a manner that minimizes resuspension of bottom material during placement. The materials would not be removed after the project completion, since they would become fully buried by the gradual deposition of river sediments over time. The dredging depth required assumes that two feet of stone or gravel armor is placed on the bottom. In total, the channel would be dredged to a depth corresponding to 16 feet below MLLW.

Table 5 shows the amount of material to be dredged during each stage for the two bridge design options. For either design option, the channel width would measure approximately 475 to 530 feet, and it would extend approximately 7,000 feet from the Rockland County side into deeper waters and 2,000 feet from the Tarrytown temporary platform into deeper waters. Because the long span alternative would occupy a wider footprint, a slightly larger area must be dredged for that alternative. It is estimated that approximately 1.68 and 1.74 million cubic yards of sediment would be dredged for the short and long span options, respectively.

Environmental Performance Commitments (EPCs) to be implemented during dredging operations include:

- Adherence to a 3-month fall window of August 1 to November 1 when dredging would be allowed;
- Use of an environmental bucket with no barge overflow; and
- Armoring of the channel to prevent re-suspension of sediment during the movement of construction vessels, installation and removal of cofferdams, and pile driving.

Table 5
Dredging Quantities for the Replacement Bridge Alternatives

Construction Stage	Short Span		Long Span	
	Quantity (million CY)	Percent of Total	Quantity (million CY)	Percent of Total
Stage 1	1.08	64%	1.12	64%
Stage 2	0.42	25%	0.43	25%
Stage 3	0.18	11%	0.19	11%
Total	1.68	100%	1.74	100%

Notes:
CY = cubic yards
Dredging for bridge demolition (Stage 3) includes that portion of the bridge which must be removed to complete the Replacement Bridge Alternative tie-in.

2.4.3.3. Transport and Disposal of Dredged Material

During each three-month period when dredging is occurring, dredged materials would be collected from the bottom of the river by barge-mounted cranes with an environmental bucket and placed into hopper scows, which are boats with a capacity of approximately 2,500 cubic yards. To ensure that the scows do not exceed the maximum allowable draft of the river work zone, they would be limited to 80 percent of their maximum load, or 2,000 cubic yards per load.

Each dredging stage would occur during a 90-day period. During that period, it is estimated that dredging would occur up to 75 of the 90 days, with two dredge operations occurring at a time. During the most extensive dredging stage, Stage 1, up to approximately 15,000 cubic yards of materials would be dredged each day. **Table 6** presents the estimated daily volumes of materials removed for each dredging stage for the two replacement bridge alternatives.

Table 6
Daily Materials Removal by Construction Stage

Construction Stage	Short Span Daily Volume (cubic yards/day)	Long Span Daily Volume (cubic yards/day)
Stage 1	14,600	15,000
Stage 2	5,700	5,800
Stage 3	2,400	2,600

After placement in the hopper scows, the next step in the dredge materials handling would depend on the dredge placement option selected. The disposition of the dredged material would be left to the discretion of the contractor. Transport by ocean scow and placement in the Historic Area Remediation Site (HARS) in the New York Bight would offer a number of benefits to the project including cost, schedule, logistics and the avoidance of impacts to the surrounding residential communities on the Rockland and/or Westchester shorelines. Should this option be pursued by the contractor, the dredged materials would be transported to HARS, located about 4 miles east of Sandy Hook, NJ. The HARS is overseen by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA). This site was historically used for ocean disposal of dredged material and a variety of waste products, including some contaminated materials. Today, the site is being remediated through a program to cap those

historic sediments with cleaner sediments dredged from New York Harbor that meet certain criteria established by the Ocean Dumping Act. A permit is required for dredged material to be placed at the HARS from the USACE for that placement. To receive the permit, the materials must be suitable for remediation, in that they meet certain criteria related to contaminants based on sediment toxicity and bioaccumulation tests. In addition, in accordance with 40 CFR §227.16, the USEPA must evaluate alternative disposal options before permitting placement of dredged material at the HARS, and must find that there are no practicable alternative locations and methods of disposal or recycling available. In support of this required finding, and alternatives analysis can be found in Appendix F-4 to the Draft Environmental Impact Statement documenting that there are no practicable alternative locations for the placement of the dredged material at the HARS site.

In recognition of the many benefits offered by the HARS site, the project is proceeding with sampling and analysis of the dredged material in support of a permit under Section 103 of the Marine, Protection, Research, and Sanctuaries Act of 1972 from the USACE. If approved the dredged materials from the project being placed at the HARS would be transferred from the hopper scows to larger capacity (up to 4,500 cubic yards) ocean scows (vessels with a larger draft, typically up to 18 feet, that are too deep for the construction channel) in deeper water. The ocean scows would then travel to the HARS, where materials would be placed at the site in accordance with the permit conditions for that placement. An assessment of potential effects from the placement of dredged material from the project at HARS is presented in Chapter 8 of this EFH.

If the permit application for the use of HARS is denied in whole or part, the contractor would be required to dispose of the dredged material at an approved upland facility in accordance with all applicable laws and regulations. However, due to the estimated number of truck trips that would be required (nearly 800 round trips daily) and the potential for adverse traffic, air quality and noise impacts on the local community the contractor would not be allowed to transport the dredged material by truck from the waterfront staging areas in Rockland or Westchester Counties. The contract documents would specify that alternate means of transport of the dredged material such as barge or barge to rail would be required for disposal.

2.4.3.4. Substructure Construction

Substructure construction would vary as a function of water depth and sediment conditions at each location. Work on the foundations can be categorized into three segments referred to as Zone A, Zone B, and Zone C (see **Figures 5 and 6**). Pile installation would typically be performed one row of piles at a time. The actual pile driving is done one pile at a time. As shown in **Table 7**, a total of 1,326 piles for Piers 1 to 57 would be required for the Short Span Option. **Table 8** includes similar information for the Long Span Option at Piers 1 thru 32. The Long Span Option would require 836 piles. In terms of the largest piles, the number of the 10-foot piles would be the same (50) for either option. The greatest difference between the two options would be the number of smaller 4-foot piles with the Sport Span Option requiring approximately 346 more piles than the Long Span Option. The Long Span Option would also require 104 less 6-foot piles and 40 less 8-foot piles for a total difference of 490 piles. Under either option, the driving of the largest piles (8- and 10-foot) would only occur for a few months in the first year of construction. During April 1 to August 1, driving of 8- or 10-foot diameter piles with an impact hammer would be limited to 5 hours per day within in-water construction Zone C (deeper than 18 feet at MLLW).

Table 7
Pile Driving, Short Span Option

Pier No.	Substructure Zone	Pile Size (diameter ft)	No. of Piles Within each Pier	Total No. of Piles
1-3	A1	6	4	24
4-8	B1	6	6	60
9 - 14	B1	4	20	240
15-32	B1	4	20	720
33-35	B1	8	4	24
36-43	C	8	4	64
44-45	C	10	25	50
46-50	C	6	6	60
51-57	B2	6	6	84
Total				**1,326**

Table 8
Pile Driving, Long Span Option

Pier No.	Substructure Zone	Pile Size (diameter ft)	No. of Piles Within each Pier	Total No. of Piles
1-2	A1	6	4	16
3	A1	6	6	12
4	B1	6	6	12
5-17	B1	4	25	614
18-21	B1	8	4	32
22-23	C	8	4	16
24-25	C	10	25	50
26-28	C	6	6	36
29-30	B2	6	6	24
31-32	A2	6	6	24
Total				**836**

EPCs to be employed during construction of the substructure include:

- Driving the largest (10 and 8 ft) diameter piles within the first few months of the project thereby limiting the period of greatest potential impact from pile driving activities.
- Using cofferdams and silt curtains, where feasible, to minimize discharge of sediment into the river.
- Using a vibratory pile driver to the extent feasible (i.e., all piles would be vibrated at least to depth of 120 feet or to vibration refusal) particularly for the initial pile segment.
- Using bubble curtain, cofferdams, isolation casings, Gunderboom, or other technologies to achieve a reduction of at least 10 dB of noise attenuation.
- Using the results of the Hudson River site specific Pile Installation Demonstration Project (PIDP) to inform the project on the effectiveness of BMP technologies for reducing sound levels, and implementing BMPs to achieve maximum sound reduction.

- Limiting the periods of pile driving to no more than 12-hours/day.
- Limiting driving of 8- and 1-foot diameter piles with an impact hammer within Zone C (water depths greater than 18 feet at MLLW) to 5 hours per day during the period of spawning migration for shortnose, Atlantic sturgeon, and other anadromous fish species (April 1 to August 1).
- Maintaining an acoustic corridor of at least 5000 feet at all times from pile driving with an impact hammer. Corridor shall be continuous to the maximum extent possible but at no point shall any contributing section be smaller than 1500 feet.
- Pile tapping (i.e., a series of minimal energy strikes) for an initial period to frighten fish from the region of the pile being driven.
- Development of a comprehensive monitoring plan. Elements would include:
    1. Monitoring to characterize the hydroacoustic field surrounding pile driving operations, which also includes a nearfield component to evaluate the performance of underwater noise attenuation systems that are integral to the project.
    2. Monitoring water quality parameters such as temperature, salinity, and suspended sediment concentrations in the vicinity of the pile driving.
    3. Monitoring fish mortality and inspection of fish for types of injury.
    4. Monitoring predation levels by gulls and other piscivorous birds.
    5. Developing criteria for re-initiating consultation with NMFS should specific numbers of shortnose or Atlantic sturgeon come to the surface wounded or dead.
    6. Preparing a Standard Operating Procedures Manual outlining the monitoring and reporting methods to be implemented during the program.

Foundation Zone A

The two areas of shallowest water depth extend from the shorelines on the Rockland and Westchester sides of the Hudson. These areas, where the water depth is less than 7 feet, are labeled as Zone A. The area adjacent to the Rockland shoreline is labeled Zone A1; the area adjacent to the Westchester shoreline is Zone A2. Zone A substructure elements would be constructed within cofferdams from adjacent temporary trestle platforms. These cofferdams would be constructed prior to pile driving the bridge foundation piles. The cofferdam would remain flooded during pile installation.

<u>Cofferdams</u>

A cofferdam is a watertight chamber designed to facilitate construction in an area that would otherwise be underwater. In this case, the cofferdams would be composed of interlocking sheet piles extending into the riverbed a distance of up to 20 feet. Upon completion of the cofferdam, foundation piles would be driven into the riverbed prior to dewatering. The remaining work of pile cap and pier construction would follow the dewatering process.

<u>Pile installation</u>

Prior to pile driving, a template to guide piles would be placed within the cofferdam to ensure that the piles are in position and to hold them when pile driving is not taking place. Once all piles are driven, the template and its supports would be removed and transitioned to the next cofferdam. A quick, low-noise, moderate-energy vibratory hammer would be used to install

much of the length of the pile, after which a high efficiency hydraulic impact hammer suspended from cranes operating on the two temporary shoreline access trestles would be used to apply force to the tops of the piles so as to deliver the piles more deeply into the riverbed. It should be noted that the use of vibratory hammers for the entire driving operation is not possible due to the excessive depth to bedrock. Feasibility of using vibratory hammers to drive piles deeper than originally proposed in order to reduce the duration of impact hammering will be tested in the PIDP. It is anticipated that the initial set for these deep piles cannot be overcome after pile sections are spliced. Using the vibratory hammer rather than the impact hammer to accomplish the majority of the pile driving would require the addition of substantially more pilings than originally proposed in order to achieve the desired weight-bearing capacity and settlement of pilings into the substrate. The extent of vibratory piling will be reconsidered after the results from the PIDP are available.

A 300-ton crawler crane would suspend the 150-foot pile sections and support the pile driving hammer during operation. Upon completion of pile installation, the soil within each pile would be excavated and transported to an off-site disposal facility. Finally, a tremie concrete plug, which braces the bottom of the sheet pile cofferdam and provides a seal at the base of the cofferdam to allow for dewatering of the cofferdam, would be poured inside the pile and a steel reinforcing cage would be inserted into the pile. Since the water within the cofferdam would be of the same quality as the water outside the cofferdam, treatment during the dewatering process is not proposed but would be done if required by the NYSDEC.

Pile caps

As previously mentioned, a tremie concrete plug would be poured into the hollowed pile. The pile itself would be dewatered down to the plug. Prior to the installation of the pile cap, pier reinforcement, post tensioning ducts, and pile reinforcement would be secured. A pile cap, which is a reinforced concrete slab constructed atop a cluster of foundations piles, would then be constructed to form a single structural element that would allow for even distribution of the weight that the piles bear, avoiding over stressing any individual component. These slabs would also provide a larger area for the construction of the columns that they will support.

Foundation Zone B

The water depths in Zone B range from 5 to 18 feet, and the zone is characterized by a relatively deep soft-soil profile. Zones B1 (close to the Rockland shoreline) and B2 (close to the Westchester shoreline) are located adjacent to Zones A1 and A2 and are closer to the centerline of the river. The functions performed in Zone B substructure construction would take place in cofferdams, as in Zone A, but the tasks would be completed from barges and support vessels rather than the temporary platforms.

Pile Installation

Piles, which would be transported in two pieces to Zone B by barge, would measure between 250 and 300 feet due to the relatively deep soft-soil profile within the zone. Pile driving would begin immediately upon completion of the cofferdam construction. As in Zone A, a 300 ton crawler crane would lift the pile sections. A pile-driving rig would supply a hammer suspended from the barge mounted crane. The template would be positioned to guide the lower pile section into proper position before the pile would be allowed to delve into the soft stratum under its own weight. The depth achieved in this manner would be considerable, and should the application of further pressure be called for, a vibratory hammer would be used to drive the remainder of the pile into place. Upon the placement of the lower segment of the pile, preparations to begin

welding the two segments together will commence. In order for the two segments to be joined, the upper segment would be hovered over the lower until the automated welding process was complete. Upon the completion and inspection of the welding, the remaining length of the conjoined pile would be driven to required depth or specified penetration resistance with a hydraulic hammer. As in Zone A, the soil within the pile would be excavated and transported to an off-site disposal facility in order to create space for the tremie plug and steel reinforcing cage.

Pile caps

The construction process of pile caps in Zone B would be similar to that of Zone A. One difference would be that a granular fill material would be distributed inside of the cofferdam to enable the tremie seal to be poured to its planned elevation. This granular material would remain after the removal of the cofferdam.

Foundation Zone C

Foundation Zone C lies between Zones B1 and B2, connecting the two sides of the river. This zone is defined by the greatest water depths, which range from 18 to 45 feet. Construction in this zone would encompass the construction of the main span as well as that of both approaches.

The first substructure construction activity in Zone C would be the installation of the foundation piles. In this zone, due to the greater depths than Zones A or B, cofferdam construction would follow the pile installation, thus requiring that the cofferdam be constructed around the installed pile to create a dry environment in which to construct the tremie seal. The cofferdam in Zone C would be constructed using a different method than that utilized in Zones A and B. This alternative method, the "hanging cofferdam method," would begin with the installation of a temporary support structure above the foundation piles on which the cofferdam would be assembled. The cofferdam components would then be pieced together from pulleys secured to the top beams of the support structure. After the placement of the cofferdam, the tremie slab would be poured onto a steel deck acting as the cofferdam floor. Divers would seal the gaps between the piles and the cofferdam deck before the dewatering process. The tremie slab would then be poured, and the unreinforced slab would bond the piles to the cofferdam pending the construction of the reinforced pile cap.

2.4.3.5. Construction of Bridge Superstructure

Completion of the bridge superstructure would include piers, columns, pylons (for a cable-stayed option), bridge deck, roadway finishes, lighting, and the shared use path. Much of the material would be pre-fabricated at various locations and delivered to the project site via barge. At the construction site, these elements would be lifted into place by gantries and cranes operating on barges, the temporary work platforms, or completed portions of the structure.

2.4.3.6. Existing Bridge Demolition

The existing Tappan Zee Bridge contains five segments: causeway, east trestle, east deck truss, west deck truss, and main spans. The demolition of the existing bridge will be performed in two stages. The first stage will include partial demolition to allow for construction of the new bridge, and the second stage will occur after the completion of the new bridge. No blasting of the existing structure would occur.

Causeway and East Trestle Spans

The causeway is a simple span construction composed of 166 spans measuring 50 feet, with the exception of one 100-foot span. The east trestle consists of 6 spans. Within its simple span construction, the causeway contains a stringer and deck superstructure and a substructure of concrete columns and footings on timber piles. Initially, the deck and stringers would be lifted out and placed onto awaiting barges. Then, the protective dolphins would be cut so as to offer unrestricted access for pier removal. Columns and footings would either be cut with diamond wire or broken by pneumatic hammers. Finally, the timber piles forming the causeway foundation would be cut to just below the mud line. All materials would be transported to an appropriate permitted off-site disposal facility, and a turbidity curtain would be utilized to ensure that demolition debris would not be dispersed. Side-scan sonar surveys would be performed in order to verify that all generated debris would be removed from the river.

Deck Truss Spans

The deck truss spans, including 13 east deck, 7 west deck, and all approach truss spans, each contain a deck slab, steel trusses, and concrete piers supported on buoyant foundations or caissons. The deck slabs would be removed and transported off-site by an awaiting barge. A channel would then be dredged in Stage 3 to provide access to the trusses near the Westchester shoreline, and steelwork would either be removed by barge-mounted crane or a crane mounted on an adjacent in-tact span. Caisson-supported piers would be demolished using the same process as in the causeway and east trestle spans, and would then be removed to the mud line using diamond cutting wire devices or pneumatic hammers. Steel H piles would remain below the mud line. Turbidity curtains and netting would also be used in this stage.

Main Span

The main span stretches 2,412 feet and is structurally formed by a through truss above a deck supported by four latticework piers on buoyant foundations, ice deflectors around the two central piers, and pre-stressed concrete beams on 30-inch diameter steel piles. Initially, the main span deck slab would be lifted and removed off-site by barge. Then, the entire suspended span would be lowered onto a barge via a strand jack or winch system. Conventional barge-mounted cranes would then deconstruct the anchor span steelwork piece by piece and the ice-breaker and fender structures protecting the main span piers would be demolished by divers and barge-mounted cranes. The pier steelwork would also be removed piece by piece, and the buoyant caissons would be cut and flooded. Following main span demolition, a barge-mounted crane operated clam shell bucket would clear the river bottom of debris. Side-scan sonar surveys would verify that all debris and concrete were removed from the river.

Chapter 3: EFH Designations

To delineate EFH, coastal littoral and continental shelf waters were first mapped by the regional Fisheries Management Councils (FMCs) and then superimposed within ten minute-by-ten minute (10' by 10') square coordinate grids. Finally, survey data, gray literature, peer-review literature, and reviews by academic and government fisheries experts were used by the FMCs to determine whether these 10' X 10' grids support EFH for federally managed species. The Mie-Atlantic Fishreies Management Council (MAFMC) has designated EFH in the lower portion of the Hudson River. The study area is within a portion of the Hudson River/Raritan/Sandy Hook Bays, New York/New Jersey Estuary. **Table 9** lists the species and life stages of fish identified as having EFH in the portion of the Hudson River near the project site.

Table 9
Essential Fish Habitat Designated Species for the Hudson River

Species	Eggs	Larvae	Juveniles	Adults/ Spawning Adults
Red hake (Urophycis chuss)		M, S	M, S	M, S/
Winter flounder (*Pseudopleuronectes americanus*)	M, S	M, S	M, S	M, S/M, S
Windowpane flounder (*Scophthalmus aquosus*)	M, S	M, S	M, S	M, S/M, S
Atlantic herring (*Clupea harengus*)		M, S	M, S	M, S/
Bluefish (*Pomatomus saltatrix*)			M, S	M, S/
Atlantic butterfish (*Peprilus triacanthus*)		M	M, S	M, S/
Atlantic mackerel (*Scomber scombrus*)			S	S/
Summer flounder (*Paralichthys dentatus*)		F, M, S	M, S	M, S/
Scup (*Stenotomus chrysops*)	S	S	S	S/
Black sea bass (*Centropristis striata*)	n/a		M, S	M, S/
King mackerel (*Scomberomorus cavalla*)	x	x	x	x
Spanish mackerel (*Scomberomorus maculatus*)	x	x	x	x
Cobia (*Rachycentron canadum*)	x	x	x	x

Source: National Marine Fisheries Service. "Summary of Essential Fish Habitat (EFH) Designation" posted on the Internet at http://www.nero.noaa.gov/hcd/ny3.html
M=The EFH designation for this species includes the mixing water/brackish salinity zone of the Hudson River estuary (0.5ppt<salinity<25.0 ppt)
F=The EFH designation for this species includes the tidal freshwater salinity zone of the hudson River estuary (0.0 ppt<or=salinity<or=0.5 ppt)
S=The EFH designation for this species includes the seawater salinity zone of the Hudson River estuary (salinity> or=25.0 ppt)
Blank cells indicate that no EFH designation occurs for the particular life stage.
X= EFH has been designated for this species and lifestage.

Detailed descriptions of the life histories, habitat requirements, and potential project impacts to these species, as well as to marine turtles and mammals and striped bass are provided below following the general discussion of potential aquatic impacts from the proposed project.

Chapter 4: Potential Impacts to EFH

4.1 GENERAL DISCUSSION OF POTENTIAL AQUATIC IMPACTS FROM THE CONSTRUCTION OF THE PROPOSED PROJECT

4.1.1 WATER QUALITY

For the Hudson River, the principal water quality resources issues for the construction of the Replacement Bridge Alternative is the resuspension of river sediments during construction and removal of the existing bridge foundations, and the transport and eventual deposition of this resuspended sediment elsewhere in the Hudson River. While the sand fraction of river sediment settles out relatively quickly after being resuspended, the finer sediment fractions will remain suspended and will be transported away from the construction area and will be deposited elsewhere in the estuary or leave the estuary altogether. Hydrodynamic modeling was used to project the plume of resuspended sediment that would result from sediment disturbing construction activities and the fate and transport of this plume within the Hudson River estuary. Two public domain models were employed in the modeling; the Environmental Fluid Dynamics Code (EFDC) model and Research Management Associates (RMA) model. The EFDC is a state-of-the-art hydrodynamic model that can be used to simulate aquatic systems in one, two, and three dimensions. It is one of the most widely used and technically defensible hydrodynamic models in the world (www. Epa.gov/Athens/wwqtsc/html/efdc.html). The EFDC model and technical support is available from the USEPA and is the most widely used hydrodynamic model. The RMA model is a dynamic two-dimensional depth-averaged finite element hydrodynamic model that was developed for the USACE and is used extensively for bridge scour evaluations in estuaries. It is one component of the US Army Corps of Engineers TABS-MD System (US Geological Service (USGS) Surface Water and Water Quality Models Information Clearinghouse (http://smig.usgs.gov/cgi-bin/SMIC/model_home_pages/model_home?selection=rma2).

As indicated in the construction timeline presented in **Figure 15**, there are periods when sediment disturbing activities evaluated in the hydrodynamic modeling would occur concurrently, with the majority of the potential for sediment resuspension occurring during the first two dredging periods. The hydrodynamic modeling results evaluated in this EFH comprise conservative scenarios that would be expected to result in the greatest sediment resuspension:

- Stage 1 dredging with pile driving for the main span (Zone C) and trestles;
- Pile driving and cofferdam installation and dewatering for Zones C and B, movement of construction vessels, and trestle construction after Stage 1 dredging is complete; and
- Stage 2 dredging combined with pile driving and cofferdam installation and dewatering for Zones C and B, and movement of construction vessels.

4.1.1.1. Sediment Resuspension and Transport

The Long Span Option would have fewer total number of piers (35) than the Short Span Option (62), resulting in a shorter construction duration (4½ years) than the short span option (5½ years). While the number of main span piers is the same between the two options, the long span option has far fewer piers in the approaches.

Sediment disturbing construction activities include dredging, cofferdam construction, and pile driving within Substructure Zones A and B, pile driving within Substructure Zone C (see

Figures 5 and 6 for the location of these zones) and the movement of construction vessels within the construction access channel for the Long and Short Span options. Within Construction Zones A and B (see **Figures 5 and 6**) pile driving would occur within the cofferdams and would not have the potential to re-suspend sediment within the river. Within Zone C, piles would be driven first and then the pile caps installed within hanging cofferdams. Therefore, only the Zone C piles would have the potential to result in additional sediment re-suspension. Hydrodynamic modeling was used to project the plume of resuspended sediment that would result from these concurrent sediment disturbing construction activities and the fate and transport of this plume within the river estuary.

The results of the modeling of the scenarios expected to result in the greatest resuspension of sediment indicated in **Figures 19 through 22** are similar for the Long Span and Short Span Options and indicate that total suspended sediment concentrations in the range of 50 to 100 mg/L above ambient conditions would only occur in the immediate vicinity of the dredges. This level of increase would be expected to occur within the allowable mixing zone for dredging. Other sediment disturbing construction activities would result in a much smaller contribution of suspended sediment (i.e., driving of piles for the cofferdams, pile driving, vessel movement and cofferdam dewatering). On flood and ebb tides, concentrations of 10 mg/L above ambient conditions may extend in a relatively thin band approximately 1,000 to 2,000 feet from the dredges, while concentrations of 5 mg/L may extend a greater distance. Total suspended sediment concentrations recorded during sampling conducted for the project ranged from 13 to 111 mg/L. Additionally, the approximately 8-year record of suspended sediment concentration (SSC) recorded by the USGS at Poughkeepsie (see **Figure 11**) indicates there is considerable variation in the suspended sediment concentration within the Hudson River, as would be expected with an estuarine environment. During periods of higher freshwater flow the differences between low and high SSCs range between approximately 20 to 40 mg/L, during periods of low freshwater inflow the differences between low and high SSCs range from about 5 to 20 mg/L.

Therefore, the projected increases in suspended sediment due to dredging concurrent with other sediment-disturbing construction activities would be well within the natural variation in suspended sediment concentration and would not result in adverse impacts to water quality and would be expected to meet the turbidity standard for Class SB waters at the edge of the mixing zone. Concentrations of total suspended sediment from cofferdam construction (which include the discharge of river water recovered during dewatering) and pile driving would be approximately 5 to 10 mg/L in the immediate vicinity of the activity (within a few hundred feet) which would be much less than that projected to result from dredging and would not result in adverse water quality impacts. Concentrations of total suspended sediment resulting from construction vessel movement are projected to be less than 5 mg/L. Increases of total suspended sediment concentration above ambient would be greatest during slack tide, without tidal action to disperse it (see **Figures 19 and 21**).

Placement of the sand/gravel armoring material within the dredged area, similar to the placement of granular capping material over contaminated sediment, has the potential to result in sediment resuspension when the capping material is deposited upon the sediment, but would not be expected to affect the magnitude of sediment resuspension projected through the hydrodynamic modeling. Results of monitoring conducted during placement of granular capping material on soft sediment indicated that resuspended sediment plumes were due to fines washed of the sand cap material and not due to resuspension of bottom sediment as the capping material was put in place (USACE 2005). Measures would be implemented during placement of the sand layer of

the armoring to minimize resuspension of the newly exposed sediment. These measures are the same type of measures that have been demonstrated to successfully cap contaminated sediment with minimal mixing of the cap with contaminated sediment (Palermo et al. 2011), and for the capping of subaqueous dredged material (Palermo et al. 1998). They include both mechanical (dry sand capping material with bottom-dump barge, side-casting, bucket/clamshell, tremie (gravity-fed downpipe)) and hydraulical (wet/slurry of sand placed from a pipe or tremie, or from a spreader barge) placement of the capping material (USACE 2005 and 2006, USEPA 1994, Palermo et al. 2011). Mechanical methods rely on the gravity settling of the granular capping materials in the water column (Palermo et al. 2011) which can result in less water column dispersion than discharge of hydraulically-handled cap material because it settles faster in the water column (USACE 1991). Hydraulic methods can allow for a more precise placement of the material at the surface or depth but may require use of a dissipation devise to reduce sediment resuspension (Palermo et al. 2011, USACE 1991).

Placing sand capping material in layers has been found to allow gentle spreading, resulting in a more stable sand cap (Ling and Leshchinsky undated), and avoiding displacement of or mixing with the underlying sediment (USEPA 2005). This results in a decrease in the turbidity plume with each successive cap layer. The reduction in sediment resuspension observed by placing granular capping material in lifts or layers may afford the ability to place subsequent layers using an alternative methodology that may allow faster placement (USEPA 2008). Therefore, once the sand layer of the proposed armoring is in place, the placement of the gravel would have limited potential to result in sediment resuspension. With the implementation of these methods of placement of granular capping material that have been proven to reduce sediment resuspension during placement, additional sediment resuspension that would occur during the placement of the armoring material would be minimized and would not be expected to result in adverse water quality impacts.

In summary, the results of the hydrodynamic modeling of changes in suspended sediment resulting from construction activities—dredging, pile driving, cofferdam construction, and vessel movement—indicate that with the exception of the portion of the mixing zone within the immediate vicinity of the dredge, increases in suspended sediment would be minimal for the Long and Short Span Options and within the natural range of variation of suspended sediment concentration within this portion of the river. Sediment resuspension resulting from dredging and other sediment disturbing activities would be expected to meet the Class SB turbidity standard at the edge of the mixing zone. Resuspended sediment would dissipate shortly after the completion of the dredging activities, and would not result in adverse impacts to water quality. During the periods of in-water construction when no dredging is occurring, the limited sediment resuspension during pile driving, cofferdam installation and removal, and vessel movement would be localized, would be expected to dissipate shortly after the completion of in-water construction activity and would not result in adverse water quality impacts. Similarly, with the implementation of measures demonstrated to minimize sediment resuspension during placement of capping or armoring material, the placement of the armoring material within the dredged area would not result in adverse water quality impacts. For all of the reasons presented above the increase in suspended sediment projected to result from dredging and other in-water sediment-disturbing construction activities, even under the worst case scenarios, and the placement of armoring within the dredged channel, would not result in adverse impacts to water quality of the Hudson River.

4.1.1.2. Sediment Quality and Water Quality Impacts Due to Resuspension

As described under *Project Setting*, the moderate levels of contaminants indicated through laboratory analysis of sediment samples collected within the study area in 2006 and 2008 typically apply to only the upper few feet and the concentrations of these contaminants decline to those that would be considered to have no appreciable contamination according to NYSDEC TOGS 5.1.9. within a few feet of the mudline. Resuspension of sediments during dredging can also affect water quality through the release of contaminants dissolved in the sediment pore water (i.e., the water occupying the spaces between sediment particles). Considering the limited plume of increased suspended sediment above ambient concentrations projected to occur during the three-month dredging periods, and the limited area of sediments with low to moderate levels of contamination within the area to be dredged, the release of any contaminants would not result in adverse impacts to water quality.

The other in-water construction activities with the potential to result in sediment resuspension (pile driving, installation of the cofferdam and vessel movement) for the Long and Short Span Options are projected to result in a minimal increase in SSC above ambient concentrations. These projected increases would actually be much lower, because within Zones A and B, the sand/gravel armoring layer installed throughout these two zones to minimize scouring would also minimize any resuspension of sediment resulting from the installation of the cofferdams. River water recovered during dewatering of the cofferdams would be treated (e.g., tanks to settle out any suspended sediments and water filtration system as necessary) and discharged back to the Hudson River in accordance with conditions issued by the NYSDEC under the Section 401 water quality certification for the project and would not result in adverse impacts to water quality of the Hudson River.

4.1.1.3. Existing Bridge Demolition

Bridge demolition would occur in two stages. The first stage includes partial demolition to allow for construction of the replacement bridge in the vicinity of the Westchester shoreline. The second stage includes the remaining demolition after completion of the replacement bridge. Use of turbidity curtains during removal of the columns and footings and cutting of the timber piles would minimize the potential for sediment resuspended during the bridge removal activities to adversely affect water quality. Following removal of the existing bridge, sediment that has been deposited within mounds in the vicinity of the existing bridge piers may erode over time until reaching a new equilibrium elevation. Because the Tappan Zee portion of the Hudson River is considered to be neither a depositional or erosional environment (i.e., in equilibrium) (Nitsche et al. 2007) as indicated by the results of the 20th century sediment mapping presented in **Figure 12**, the erosion of these sediments in the vicinity of the existing bridge would be limited under normal river conditions and would most likely occur during high flow events. While some of these sediment deposits have elevated concentrations of certain contaminants (NYSDEC TOGS 5.1.9 Class B or Class C categories), these elevated concentrations do not extend more than a few feet below the mudline. Therefore, the gradual erosion of some areas of contaminated sediment following the removal of the bridge would not be expected to result in adverse impacts to water quality or result in water quality conditions that fail to meet the Class SB standards.

4.1.2 AQUATIC BIOTA

Construction of the project has the potential to affect benthic macroinvertebrates, fish, and EFH due to loss of habitat from dredging, pier installation (e.g., pile driving, installation of cofferdams and fendering), the temporary change in bottom habitat resulting from dredging and

subsequent placement of armoring, temporary increases in suspended sediment due to dredging and other sediment disturbing construction activities, and hydroacoustic effects on fish and benthic macroinvertebrates, as discussed in detail below.

4.1.2.1. Benthic Macroinvertebrates

Tables 10 and 11 indicate permanent and temporary impacts to benthic macroinvertebrates due to platform coverage, dredging and armoring. Temporary increases in suspended sediment and changes to the hydroacoustic environment have the potential to affect benthic macroinvertebrate resources.

Dredging

The primary impact to benthic macroinvertebrates from dredging is the loss of the habitat and animals associated with the dredged material (Hirsch et al. 1978). Dredging can also cause the conversion of shallow subtidal habitat to deeper subtidal habitat and can result in temporary increases of suspended sediment due to resuspension of bottom sediment. This section addresses the potential impacts to benthic macroinvertebrates from the loss of habitat and individuals. Potential impacts associated with increased suspended sediment are evaluated under *In-water Construction Activities*. The frequency of dredging or disturbance of an area affects the invertebrate community and its ability to recover following each dredging event. Benthic communities found in environments with a great deal of variability such as estuaries have higher rates of recovery from disturbance. Recovery rates of benthic macroinvertebrate communities following dredging range from only a few weeks or months to a few years, depending upon the type of project, the type of bottom material, the physical characteristics of the environment and the timing of disturbance (Hirsch et al. 1978, LaSalle et al. 1991). In a two year study in the lower Hudson River, Bain et al. (2006) reported that within a few months following dredging, the fish and benthic communities at a dredged location were no different from seven nearby sites that had not been dredged. The results of monitoring did not indicate a lasting effect at the dredged site.

Dredging activities for the project have the potential to remove benthic macroinvertebrates, including oyster beds, and the food resources they provide to other aquatic resources. Approximately 165 to 175 acres of bottom habitat—including about 5.3 acres of NYSDEC regulated littoral zone tidal wetland and 160-170 acres of open water benthic habitat—would be dredged during three 3-month phases, from August 1 through November 1, over a four year period (see **Figure 15**). The dredging period of August 1 to November 1 would avoid periods of anadromous fish spawning migrations and peak biological activity. In addition, the trench would be armored following dredging and the benthic habitat within the dredge zone which was primarily soft sediment would be changed to a substrate of sand overlain with gravel. Since armoring would occur up to 20 feet of the side slope, approximately 155 to 165 acres of sand/gravel bottom would be result from the project.

Table 10
Overwater Coverage from Platforms

	Habitat	Acres
Temporary Overwater Coverage		
West Platform-Storage Platform Area	Open Water	4.26
East Platform-Storage Platform Area	Open Water	2.30
East Platform-Docking Platform Area	Open Water	1.84
East Platform-Access Road	Littoral Zone	0.50
TOTAL		**8.9**
Permanent Overwater Coverage		
Permanent Platform	Littoral Zone	0.00
Permanent Platform	Open Water	2.16
TOTAL		**2.16**

Table 11
Potential Loss of River Bottom, Wetlands, and Adjacent Area Habitats due to Project Activities

	Possible Freshwater Wetland Areas (acres)	NYSDEC Littoral Zone Tidal Wetlands (acres)	NYSDEC Tidal Wetland Adjacent Area (acres)	Open Water Benthic Habitat (acres)	Total Short Span (acres)	Total Long Span (acres)
Temporary						
West Platform-Storage Platform Area	-	-	-	0.21	0.21	0.21
East Platform-Storage Platform Area	-	-	-	0.12	0.12	0.12
East Platform-Docking Platform Area	-	-	-	0.09	0.09	0.09
East Platform-Access Road	0.15	0.03	0.4	-	0.58	0.58
Dredging/Armoring	-	5.3	-	160-170/ 155-165	175/165	165/160
West Nyack Staging Area	2.0	-	-	-	2.0	2.0
Tilcon Quarry Staging Area	-	-	-	-	-	0
TOTAL TEMPORARY	**3.5**	**5.3**	**0.4**	**160.4-170.4**	**178**	**168**
Permanent						
Permanent Work Platform-Pile-supported	-	-	-	0.11	0.11	0.11
Permanent Work Platform-Bulkheaded	-	-	-	0.21	0.21	0.21
New Bridge	-	-	-	6.5-8.0	8	6.5
Removal of Existing Structure	-	-	-	(7.1)	(7.1)	(7.1)
TOTAL PERMANENT	0	0	0	(0.28)-1.22	1.22	(0.28)

While the dredging would result in the loss of individual macroinvertebrates, it is not expected to result in adverse impacts of these species at the population level within the Hudson River Estuary System. The majority of the bottom habitat and associated benthic macroinvertebrates within the area impacted is the soft sediment community which dominates the Upper New York Harbor and Hudson River. Calculations suggest that deposition within the dredged channel following completion of construction will occur at a rate of about one foot per year. Recolonization by benthic organisms adapted to softer sediments could be expected to begin within a few months after completion of construction in any given area. Prior to the deposition of sufficient sediment to support a soft substrate benthic invertebrate community, some recolonization of the gravel armor material would be expected occur. Organisms within the nearby gravel substrate located within the main channel (NYSDEC benthic mapper http://www.dec.ny.gov/lands/33596.html, and Nitsche et al. 2007) would serve as a source of organisms to colonize the gravel capping material until the soft sediment is of a sufficient depth to be colonized by soft substrate organisms. Although the area affected by dredging is substantial, the effects to the soft sediment habitat, which is the dominant sediment type in the lower estuary, should be viewed as temporary and not indicative of a long-term adverse impact.

In-Water Construction Activities

In-water construction activities have the potential to result in temporary and permanent habitat loss, habitat modification, and temporary increases in suspended sediment due to resuspension of bottom sediment as described below.

Pier Construction

During construction, a total of approximately 8 acres and 7 acres of open water benthic habitat would be lost within the footprint pilecaps and fendering for the Short Span and Long Span Options, respectively.

Temporary Platforms within Bridge Staging Areas

Impacts to benthic habitat would also occur due to the construction of two temporary work platforms north of the existing bridge within the Bridge Staging Areas. Temporary platforms would be constructed on the east and west sides of the river. Since the work platforms for the two bridge replacement options would be the same, approximately 9 acres of open water benthic habitat would be temporarily affected due to overwater coverage, and about 0.3 acres of open water benthic habitat would be temporarily lost within the footprint of the piles supporting the temporary platforms. After construction, these temporary platforms would be removed and the supporting piles cut at the mudline.

Permanent Platform Within the Rockland Bridge Staging Area

As discussed above, a permanent work platform would also be constructed within the Rockland Bridge Staging Area. In order to support the platform, the existing bulkhead would be extended waterward and about 0.3 acres of open water benthic habitat would be filled. An additional 0.09 acres of open water benthic habitat would be lost within the footprint of the piles supporting the overwater portion of the work platform. The permanent work platform would result in about 2 acres of overwater coverage. The permanent loss of about 0.3 acres of open water benthic habitat and permanent coverage of approximately 2 acres of open water benthic habitat would not result in adverse impacts to benthic macroinvertebrate resources.

Temporary Increases in Suspended Sediment from Construction Activities

Construction activities that are expected to contribute to sediment resuspension include dredging, vessel movements, cofferdam construction, pile driving and demolition of the existing bridge. A wide array of benthic macroinvertebrates occurs near the bridge; they vary from motile to sessile benthic organisms and include mollusks (e.g., oysters and clams), annelids (i.e., worms), and arthropod crustaceans such as mysid shrimp, amphipods, isopods, crabs, and other species. Although estuarine benthos have developed behavioral and physiological mechanisms for dealing with variable concentrations of suspended sediment and are well adapted to changes in sedimentation and resuspension processes, certain organisms could be impacted by high levels of water column TSS interfering with their methods of feeding (e.g., filter feeders) and/or causing possible habitat impairment. With respect to shellfish, negative impacts to oyster egg development have been observed at TSS concentrations of 188 mg/L and impacts to clam egg development at 1,000 mg/L (Clarke and Wilber 2000). NOAA, NMFS has identified 390 mg/L (NMFS 2011a) as a concentration below which adverse impacts to benthos are not anticipated. In studies of the tolerance of crustaceans to suspended sediments that lasted up to two weeks, nearly all mortality was caused by extremely high suspended sediment concentrations (greater than 10,000 mg/L) (Clarke and Wilber 2000), levels which would not occur from the in-water work associated with the proposed project.

Background concentrations of TSS in the bridge vicinity generally vary between 15 mg/L and 50 mg/L throughout the year. The increase in TSS levels predicted to occur as a result sediment-disturbing activities would range from 50-100 mg/L in the immediate vicinity of the dredging to 5 mg/L to 10 mg/L over a relatively limited river area near the replacement bridge construction site. Such increases in water column solids loads would be within the normal variation occurring in the Hudson River and well below levels that would be expected to affect normal life functions of benthic invertebrates. Thus, impacts to benthic invertebrates due to increased water column suspended sediments from construction activities are expected to be minimal and would not result in adverse impacts to benthic communities.

Bridge Demolition

As discussed above, demolition of the bridge could cause turbidity and the potential resuspension of contaminated sediments. Turbidity curtains would be used during removal of the columns and footings and cutting of the timber piles would minimize the potential for sediment that may be resuspended during bridge removal activities to affect benthic macroinvertebrates and other aquatic biota. Since the benthic sampling program for the project indicated similar benthic community structure in bottom sediments at both existing and proposed bridge location, and because the demolition is not expected to substantially alter sediment characteristics, the benthic community recolonizing the restored bottom habitat following bridge demolition would be expected to be similar to that lost as a result of dredging. Demolition of the existing bridge would also remove the benthic invertebrates and algae that are attached to the bridge, which provide forage and structural habitat for fish. However, the new bridge would offset much of these losses by providing similar structural habitat for these species. Impacts to benthic invertebrates due to increased water column suspended sediments from bridge deomolition activities are expected to be minimal and would not result in adverse impacts to benthic communities.

Hydroacoustic Effects

Limited information is available on how benthic invertebrates may use sound (e.g., Popper et al. 2003) and there is little information indicating whether sounds from construction would have any impact on invertebrate behavior. The one available study on effects of seismic exploration on shrimp suggests no behavioral effects at sound levels, with a source level of about 196 dB re 1 μPa rms at 1 meter (Andriguetto-Filho et al. 2005).

There is also no substantive evidence on whether the high sound levels from pile driving or any anthropogenic sound would have physiological effects on benthic invertebrates. The only potentially relevant data are from a study on the effects of seismic exploration on snow crabs on the east coast of Canada (Boudreau et al. 2009). The preponderance of evidence from this study showed no short- or long-term effects of seismic exposure in adult or juvenile animals, or on eggs.

The lack of any internal air bubbles (equivalent to the fish swim bladder) that would be set in motion by high intensity sounds would suggest that there would be little impact on benthic invertebrates. However, like fish, if the benthic invertebrates are very close to the source, the shock wave from the source might have an impact on survival.

Impacts to benthic invertebrates due to increased water column suspended sediments from hydroacoustic effects associated with pile driving activities are expected to be minimal and would not result in adverse impacts to benthic communities.

Summary

In summary, for the reasons presented above, the cumulative permanent loss of benthic habitat due to pier construction, and the construction of the permanent platform for the Rockland Bridge Staging Area of 7 and 8 acres for the Short Span and Long Span Options respectively, the temporary loss of approximately 0.3 acres of benthic habitat within the footprint of the piles for the temporary platforms within the Bridge Staging Areas, and dredging of between 165 and 175 acres of bottom habitat followed by placement of approximately 155 to 165 acres of armoring material would not result in adverse impacts to populations of benthic macroinvertebrates within the lower Hudson River estuary.

4.1.2.2. Submerged Aquatic Vegetation (SAV)

The nearest SAV beds to the replacement bridge construction site are small and located north of the project area (see **Figure 14**). Therefore, dredging and temporary platform construction for the project would not directly impact SAV, but would have the potential to result in indirect impacts due to potential temporary increases in suspended sediment levels and sedimentation rates within these beds. However, dredging operations would occur during the later portion of the SAV growing season, minimizing potential adverse impacts to this resource. Additionally, as discussed above under *Water Quality,* cumulative increases in suspended sediment due to dredging and other in-water construction activities are projected to be within the range of normal variation in SSC within this portion of the Hudson River. Therefore, construction of the project would not result in adverse environmental impacts to SAV within the Hudson River.

4.1.2.3. Fish

Dredging

Where access channels are dredged, there would be a temporary loss of habitat that could impact fish that use the dredged area. These impacts would occur, in part, as a result of a localized reduction in benthic fauna. However, the dredging footprint represents a very small percentage of the Hudson River Estuary. Additionally, dredging would occur from August 1 to November 1, a period that would minimize the potential for impacts to anadromous fish spawning migration and outside the peak period of biological activity within this portion of the Hudson River when there is the greatest potential for EFH species to occur. Thus, the temporary reduction of benthic fauna within the dredged area would not substantially reduce foraging opportunities for the river's fish populations. Once construction is completed, the dredged channels would be restored over time to their original elevations by action of natural sedimentation, and the river's benthic community would recolonize those areas as well.

Temporary and Permanent Platforms Within the Bridge Staging Areas

Approximately 8 acres of temporary platforms would be erected within the Bridge Staging Areas in the Hudson River to facilitate bridge construction. These platforms would be supported by an array of small piles driven into the river substrate. The piles would occupy approximately 0.4 acres of benthic habitat representing a minor reduction of foraging opportunities for fish near the construction site. An approximately 2-acre permanent platform would result in the permanent loss of approximately 0.3 acres of benthic habitat due to bulkhead construction and pile driving. The supporting piles for the platforms would provide a substrate for encrusting organisms which would provide some additional foraging opportunities for fish. Moreover, fish are widely known to seek structures for shelter and the temporary and permanent platforms could represent a favorable diversity in habitat that currently is a large flat, silty bottom. Therefore, the minimal loss of foraging habitat, and the temporary and permanent coverage of aquatic habitat by overwater structures would not result in adverse impacts to fish within the Lower Hudson River estuary.

Temporary Increases in Suspended Sediment from Construction Activities

As described above under Benthic Macroinvertebrates, construction activities expected to contribute to sediment resupsension include dredging, vessel movements, cofferdam construction, pile driving and demolition of the existing bridge.

Resuspension of sediments can have a range of impacts to fish depending on the species and life stages being considered. Lethal levels of TSS vary widely among species; one study found that the tolerance of adult fish for suspended solids ranged from 580 mg/L to 24,500 mg/L (Sherk et al. 1975 as cited in NMFS 2003). Common impacts to fish are the abrasion of gill membranes resulting in an inability to collect oxygen, impairment of feeding, reduction in dissolved oxygen, and fatal impacts to early life stages. Increased TSS can inhibit migratory movements as well. A study conducted by NOAA concluded that TSS concentrations as low as 350 mg/L could block upstream migrations of various species (NOAA 2001). Fish, however, are mobile and generally avoid unsuitable conditions in the field, such as large increases in suspended sediment and noise (Clarke and Wilber 2000). Fish also have the ability to expel materials that may clog their gills when they return to cleaner, less sediment-laden waters.

Burton (1993) indicated that concentrations of suspended solids can reach thousands of milligrams per liter before an acute toxic reaction is reached. Lethal effects were demonstrated

between concentrations of 580 to 700,000 mg/L depending on species, (580 mg/L for sensitive species and 1,000 as more typical). Striped bass did not avoid concentrations of 954 to 1,920 mg/L to reach spawning sites (Summerfelt and Mosier 1976; Burton 1993) which are well above the levels likely to be encountered during dredging operations.

Larval stage fish also have a wide suspended sediment tolerance range. Kiorboe et al. 1981 (as cited in Clarke and Wilber 2000), indicate that hatching of striped bass and white perch can be delayed if daily sediment concentrations reach 100 mg/L. Wilbur and Clarke 2001 (as cited in NMFS 2003), indicate that hatching is delayed for striped bass and white perch at concentrations of 800 mg/L and 100 mg/L, respectively. In a 2003 Biological Opinion, the NMFS indicated that TSS concentrations below 100 mg/L are not likely to affect eggs and larvae—at least over short durations (NMFS 2003).

The TSS projected to occur as a result of the project's construction would be below the physiological impact thresholds of adult and larval fish and also below concentrations that would be expected to impact migration. Furthermore, anadromous fish such as striped bass, American shad, blueback herring, and alewife spawn well upriver and their most vulnerable early life stages such as eggs and yolk-sac larvae would not be expected to occur in the Tappan Zee vicinity. Impacts due to increased water column suspended sediments are expected to be minimal and would not result in adverse impacts to fish within the Lower Hudson River estuary.

Given the tolerance of the EFH species with the potential to occur in the study area to high concentrations of suspended sediments, the turbid nature of the Hudson River under ambient conditions, the limited area over which turbidity would be increased, and the lack of impacts from the release of contaminants due to the resuspension of sediments, the resuspension of bottom sediment that would result from construction of the project would not result in adverse impacts to EFH species.

Hydroacoustic Effects

Sound in water follows the same physical principles as sound in air, however, due to higher density of water, sound in water travels about 4.5 times faster than in air (approximately 4,900 feet per second versus 1,100 feet per second in air), and attenuates much less rapidly over distance from the source than in air. As a result of the greater speed, the wavelength of a particular sound frequency is about 4.5 times longer in water than in air (Rogers and Cox 1988; Bass and Clarke 2003).

The most commonly considered aspects of sound are frequency (i.e., number of cycles per unit of time, with hertz (Hz) as the unit of measurement) and amplitude (loudness, measured in decibels, or dB). The frequencies of primary relevance to humans are those in their hearing range, which is from about 20 Hz to 20,000 Hz in a child and perhaps 20 Hz to 10,000 Hz in an older adult. When considering fish, the hearing range to be considered may extend from as low as 20 Hz to, in most species, perhaps 800 to 1,000 Hz. Most fish in the Hudson River fit into this hearing range, although catfish may hear to about 3 or 4 kHz and some of the herring-like fishes (and specifically the American shad) can hear to over 100 kHz (Popper et al. 2003; Bass and Ladich 2008; Popper and Schilt 2008).

In addition, an acoustic field from any source consists of a propagating pressure wave, generated from particle motions in the medium that causes compression and rarefaction. This sound wave consists of both pressure and particle motion components that propagate from the source. All fishes have sensory systems to detect the particle motion component of a sound field, while fishes with a swim bladder (a chamber of air in the abdominal cavity) may also be able to detect

the pressure component. Pressure detection is primarily found in fishes where the swim bladder (or other air chamber) lies very close to the ear, whereas fishes in which there is no air chamber near the ear primarily detect particle motion (Popper et al. 2003; Popper and Schilt 2009; Popper and Fay 2010).

The level of a sound in water can be expressed in several different ways, but always in terms of dB relative to 1 micro-Pascal (μPa). Decibels, a log scale, is used to "compress" very large differences of sound level (e.g., from a whisper to cracking of thunder) into more manageable numbers. As a consequence, a doubling of sound pressure level (whether in air or water) is seen as a change of just a few dB. Thus, each 10 dB increase is a ten-fold increase in sound pressure. Accordingly, a 10 dB increase is a 10x increase in sound pressure, and a 20 dB increase is a 100x increase in sound pressure.

For the purposes of this EFH, the following measures are defined:

- Peak sound pressure level (SPL) is the maximum sound pressure level in a signal measured in dB re 1 μPa.
- Sound exposure level (SEL) is the integral of the squared sound pressure over the duration of the pulse – in this case a full pile driving strike. Measured in dB re 1μPa^2-s.
- SEL_{cum} is the energy accumulated over multiple strikes. The rapidity with which the SEL_{cum} accumulates depends on the level of the single strike SEL (SEL_{SS}). The actual level of accumulated energy (SEL_{cum}) is the logarithmic sum of the total number of single strike SELs. Thus, SEL_{cum} (dB) = Single-strike SEL + 10log10(N); where N is the number of strikes.

Sound levels are analyzed in several different ways. The most common approach is "root mean square" (rms) pressure level which is the average level of a sound signal over a specific period of time, such as the average level 90 percent of the time of the whole signal. Alternatively, one may measure "Peak" sound level, which is the highest level of sound within a signal. Peak is most often used to give an indication of the maximum level of a sound, but it does not give a good picture of the overall sound energy in a signal.

The frequencies in the impulsive signal that is typical of a single strike from a pile driving operation are primarily below about 500 Hz. In order to attempt to better characterize the full extent of energy in the signal, acousticians developed the concept of Sound Exposure Level (SEL), which is simply the integration over time of the square of the acoustic pressure in the signal. Thus the SEL is an indication of the total acoustic energy received by an organism from a particular source (such as pile strikes).

SEL is generally expressed as the total energy in a signal over one second. There are two ways of looking at SEL that are relevant to the issue of pile driving. First is what is referred to as "single strike" SEL – the amount of energy in one strike of a pile (SEL_{ss}). The second is "cumulative SEL" (or SEL_{cum}), which represents the summed energy in all strikes over some period of time or, perhaps, during the driving of a single pile. SEL_{cum} is particularly useful since it indicates the full energy to which an animal is exposed during any kind of signal (assuming the animal remains in the same place for the duration of the signal – such as for all strikes to embed a single pile), and thus it is possible to use this measure to compare total sound exposure between two signals with waveforms that are very different than one another, such as between a pile driving strike and a burst of sonar.

Physiological Effects

The current interim criteria for onset of physiological effects on fish were agreed to in a Memorandum of Agreement (MOA) by FHWA, USFWS, NMFS, CalkTrans and the Washington Department of Transportation on June 12, 2008. As a result of the MOA a set of interim criteria was established for the acoustic levels at which there could be a potential onset of physiological effects to fish. The criteria are referred to as the interim West Coast criteria (reviewed in Woodbury and Stadler 2008; Stadler and Woodbury 2009). These criteria are intended to reflect the onset of physiological effects (Stadler and Woodbury 2009), and not levels at which fish are mortally damaged. Indeed, the onset of physiological effects may be minimal changes in fish tissues that have no biological consequence (Halvorsen et al. 2011). The interim criteria are:

Peak SPL: 206 decibels relative to 1 micro-Pascal (dB re 1 μPa).

SEL_{cum}: 187 decibels relative to 1 micro-Pascal-squared second (dB re 1μPa^2-s) for fishes above 2 grams (0.07 ounces).

SEL_{cum}: 183 dB re 1μPa^2-s for fishes below 2 grams (0.07 ounces).

Behavioral Effects

For purposes of assessing behavioral effects of pile driving at several West Coast projects, NMFS employs a 150 dB re 1μPa rms SPL criterion, although it is pointed out in Caltrans (2009) that, at least on the West Coast, "…NOAA Fisheries staff informally indicated … that they do not expect exceedance of the 150 dB RMS behavior threshold to trigger any mitigation."

Recent Results Relevant to the Interim Criteria for Onset of Physiological Effects

A recent peer-reviewed study from the Transportation Research Board (TRB) of the National Research Council of the National Academies of Science describes the first carefully controlled experimental study of the effects of pile driving sounds on fish (Halvorsen et al. 2011). This investigation was funded by National Cooperative Highway Research Program (NCHRP) of the TRB, Caltrans, and the Bureau of Ocean Energy Management (BOEM), as well as by the Canadian Department of Fisheries and Oceans (DFO), and was developed and overseen by individuals from highway programs throughout the United States as well as leading experts in underwater acoustics and hearing from the U.S. and abroad. The study was the first to document effects of pile driving sounds (recorded by actual pile driving operations) under simulated free-field acoustic conditions where fish could be exposed to signals that were precisely controlled in terms of number of strikes, strike intensity, and other parameters. The acoustic field simulated one that would take place beyond about 33 ft from a source. Sufficient number of animals exposed to the source, as well as controls (treated identically to experimental other than for their being exposed to sound), were used to provide a strong statistical base. Subsequent to treatment, animals were subject to extensive necropsy (autopsy) to determine the types of physiological effects and the sound exposure levels at which these would show up.

The study was conducted on Chinook salmon (*Oncorhynchus tshawytscha*), an endangered species on the US West Coast. The study considered the onset of a wide variety of potential physiological effects that ranged from small amounts of hemorrhage at the base of fins to severe hemorrhage or rupture of the swim bladder and surrounding body tissues (kidney, liver, spleen, etc.). It was determined that very small effects, such as small hemorrhages at the base of fins are not life threatening nor would they have any short or long-term effect on fish, unlike damage such as swim bladder rupture which would result in mortality. Based on a thorough statistical analysis of results, with extensive controls, it was determined that onset of physiological effects

that have the potential of reduced fitness, and thus a potential effect on survival, started at above 210 dB re 1 $\mu Pa^2 \cdot s$ SEL_{cum}, a level that is about 23 dB above the current West Coast interim onset criteria. The peak level for effects is about the same as the current West Coast level.

Subsequent work, using the identical methodology has demonstrated that there is complete recovery from effects on Chinook salmon exposed to sounds as high as 216 dB 1 μPa2•s SEL_{cum} when fish were kept in the laboratory (higher levels could not be used in that particular study. In addition, other studies have shown that similar results to those reported for Chinook salmon were also found in several other species, including lake sturgeon (*Acipenser fulvescens*). There was small variation in the onset level for physiological effects, but all were well above 200 203 dB 1 μPa2•s SEL_{cum} or levels well above the West Coast interim criteria.

Sound and Effects on Fish

Sound is a critical source of environmental information for most vertebrates (e.g., Fay and Popper 2000). While we most often think in terms of sound for communication (e.g., speech), perhaps the most important use of sound is to learn about one's environment. Indeed, humans and all other vertebrates have auditory systems that listen to the "auditory scene" and can, from this, learn a great deal about the environment, and the things in it (Fay and Popper 2000; Bass and Ladich 2008). Although the "visual scene" is restricted by the field of view of the eyes and light level, the auditory scene provides a three-dimensional, long distance sense that works under most all environmental conditions. It is, therefore, likely that hearing evolved for detection of the auditory scene (Fay and Popper 2000), and that fishes use sound to learn about their general environment, the presence of predators and prey, and, in many species, for acoustic communication. As a consequence, sound is important for fish survival, and anything that impedes the ability of fish to detect a biologically relevant sound could affect individual fish rather than survival of the species.

Richardson et al. (1995) defined different zones around a sound source that could result in different types of effects on fishes. There are a variety of different potential effects from any sound, with a decreasing range of effects at greater distances from the source. Thus, very close to the source, effects may range from mortality to behavioral changes. Somewhat further from the source, mortality is no longer an issue, and the effects range from physiological to behavioral. As one gets even further, the potential effects decline even further. The actual nature of effects, and the distance from the source will vary and depend on a large number of factors, such as fish hearing sensitivity, source level, how the sounds propagate away from the source and the resultant sound level at the fish, whether the fish stays in the vicinity of the source, the motivation level of the fish, etc.

Sound Sources from Which Different Effects Might Occur

There are limited data from other projects to demonstrate the circumstances under which immediate mortality occurs: mortality appears to occur when fish are close [(within a meter to 9 m (a few ft to 30 ft)] to driving of relatively large diameter piles. Studies conducted by California Department of Transportation (Caltrans, 2001) showed some mortality for several different species of wild fish exposed to driving of steel pipe piles 2.4 m (8 ft) in diameter, whereas Ruggerone et al. (2008) found no mortality to caged yearling coho salmon (*Oncorhynchus kisutch*) placed as close as 0.6 m (2 ft) from a 0.45 m (1.5 ft) diameter pile and exposed to over 1,600 strikes. Thus, in the overall range of effects on fish in ecosystems such as the Tappan Zee, only a very small fraction of a fish population likely will be close enough to a pile to be subject to immediate mortality.

Of greater relevance than immediate mortality to aquatic organisms caused by pile driving and other intense sound sources is the potential for physiological effects that could potentially result in delayed mortality. At the same time, many of the physiological effects of exposure to pile driving sound are highly unlikely to have any effect on fish survival. Indeed, the potential physiological effects are highly diverse, and range from very small ruptures of capillaries in fins (which are not likely to have any effect on fitness or survival) to severe hemorrhaging of major organ systems such as the liver, kidney, or brain (Stephenson et al. 2010). Other potential effects include rupture of the swim bladder (the bubble of air in the abdominal cavity of most fish species that is involved in maintenance of buoyancy). (See Halvorsen et al. 2011 for a review of potential injuries from pile driving.)

Effects on body tissues may result from barotrauma or result from rapid oscillations of air bubbles. Barotrauma occurs when there is a rapid change in pressure that directly affects the body gasses. Gas in the swim bladder, blood, and tissue of fish can experience a change in state, expand and contract during rapid pressure changes, which can lead to tissue damage and organ failure (Stephenson et al. 2010).

Related to this are changes that result from very rapid and substantial excursions (oscillations) of the walls of air-filled chambers, such as the swim bladder, striking near-by structures. By way of example, under normal circumstances the walls of the swim bladder do not move very far during changes in depth or when impinged upon by normal sounds. However, very intense sounds, and particularly those with very sharp onsets (also called "rise time"), will cause the swim bladder walls to move greater distances and thereby strike near-by tissues such as the kidney or liver. Rapid and frequent striking (as during one or more sound exposures) can result in bruising, and ultimately in damage, to the nearby tissues.

At the same time, there are data showing that very intense signals may not necessarily have substantial physiological effects and that the extent of effect will vary depending on a number of factors including sound level, rise time of the signal, duration of the signal, signal intensity, etc. For example, investigations on the effects of very high intensity sonar showed no damage whatsoever to ears and other tissues of several different fish species (Kane et al. 2010).

Moreover, studies involving exposure of fish to sounds from seismic air guns, signal sources that have very sharp onset times, as found in pile driving, also did not result in any tissue damage (Popper et al. 2007; Song et al. 2008; although see McCauley et al. 2000, 2003 for an instance of inner ear hair cell damage to seismic air guns). Finally, recent studies of the effects of pile driving sounds on fish showed that there is a clear relationship between onset of physiological effects and single strike and cumulative sound exposure level, and that the initial effects are very small and would not harm an animal (and from which there is rapid and complete recovery), whereas the most intense signals (e.g., >210 dB SEL_{cum}) may result in tissue damage that could have long-term mortal effects (Halvorsen et al. 2011).

Hydroacoustic Modeling

In order to analyze the potential impacts of the project's pile driving on Hudson River aquatic resources, the likely hydroacoustic scale of pile driving was modeled (JASCO 2011) (see **Figures 23 through 27**). The extent of the sound pattern generated by pile driving for the project was determined by application of three different sound propagation modeling approaches (i.e., MONM, VSTACK, and FWRAM). The models account for the frequency composition of the source signal and the physics of acoustic propagation in the Hudson River and underlying geological substrates. This type of modeling differs from generalized and empirical acoustic models, such as "practical spreading loss" models (Caltrans, 2009), that do not take into full

account the source characteristics or the many site-specific factors that could influence the rate of noise transmission such as water depth and substrate transmission characteristics.

Various pile driving scenarios were used to generate the cumulative sound exposure level (SEL_{cum}) for each day over the construction period. Maximum and typical pile driving scenarios were analyzed (see **Figures 23 through 27**). In addition, the application of Best Management Practices (BMPs) that provided a 10 dB reduction in sound was incorporated into the acoustic modeling effort. These practices represent various methods to reduce the extent to which a waterbody would be ensonified by pile driving operations. Various BMPs have been employed on pile driving operations around the country, including air bubble curtains of various forms, isolation casings, Gunderbooms, and dewatered cofferdams. The Project Sponsors have committed to the use of BMPs to attenuate the potential impacts of sound associated with pile driving. The results of the hydroacoustic modeling are depicted in **Figures 23 through 27**, as described below.

Figure 23 presents the peak SPL, with BMPs, for 4-, 6-, 8-, and 10-ft piles being driven at representative locations along the alignment of the replacement bridge. The figure illustrates the transmission loss that would occur as distance from the pile driving site increases. Transmission loss is not uniform across the different size piles since the piles would be driven at locations where water depth and other environmental factors vary. For the 4-ft piles, sound above the interim 206 dB peak threshold encompasses a distance of about 30 ft; for the 10-ft piles the 206 dB peak SPL the distance increases to approximately 300 ft.

The following figures present accumulated energy (SEL_{cum}) for driving a pile over the time for driving the pile and should be understood that way. Thus, the information in these figures does *not* represent the energy from a single strike or the instantaneous level of sound at any one moment in time. (as represented for rms levels in Figure 23). Moreover, the accumulated energy in the following figures represents the received energy for an animal *only* if the animal stays in the same location for the duration of the pile driving activity.

Figure 24 presents the SEL_{cum} metric for installing two 10-ft piles at the replacement bridge main span in one day, which is considered a representative worst case for driving of 10 ft piles, and would be the same for both the Short and Long Span Options. The concentric "circles" (or isopleths) of different colors represent distances from the pile driving activity at which various SEL_{cum} levels would be attained during the driving of the two piles. For example, the 187 dB isopleths extends over a mile in each direction north and south of the point of pile driving and 49 percent of the cross sectional width of the river. This can be contrasted with the 187 dB 1 $\mu Pa^2 \bullet s$ isopleth profile for installing four 4-ft piles at the replacement bridge main span in one day, which does not extend substantial distances in any direction (see **Figure 25**).

Figure 26 indicates the cross sectional area of the river that would be ensonified by the 187 dB re 1μPa^2-s isopleths over the duration of the construction period for the Short Span Option, and assumes a BMP reduction of 10 dB. During the period of driving the 10 foot piles, 49 percent of the river cross sectional width would be occupied within the 187dB re 1μPa^2-s isopleth. This ensonified area would be between 43 and 61 percent during the four-month period when 4, 6, and 8 ft piles are all being driven, sometimes simultaneously. The figure indicates that driving of the 10 and 8 ft piles would take place in the first few months of the first year of construction, limiting the period of time of greatest potential impact, During the remaining years of the construction period, the affected cross section of the river is considerably less, on the order of 14 to 38 percent. Given that the river is approximately 3 miles wide, there would always be a considerable portion of the river that remains below the threshold noise criteria, thereby insuring adequate corridors for migration and movement of fish through the region. **Figure 27** indicates

the cross sectional area of the river that would be ensonified by the 187 dB re 1μPa^2-s isopleths over the duration of the construction period for the Long Span Option.

For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width never reaches the SEL_{cum} criterion established for onset of physiological injury. Furthermore, even within a single day of operations (assuming up to a 12 hour day), there is likely to be no pile driving activity for a substantial amount of time, such as when piles are put in place, being welded, or when the pile driving machinery is relocated. Thus, fish in much of the river will not be exposed to pile driving sounds for significant periods, and the likelihood of accumulating sufficient energy (SEL_{cum}) to result in onset of physiological effects is low. Finally, fish are not likely to remain in an area at which noise (from pile driving or other source) would cause discomfort.

The expression SEL_{cum} represents the total energy at a particular location in the river for a discrete duration (typically the number of strikes) of a particular pile driving operation. Often, this represents the duration for the full driving of a single pile, or even for multiple piles if driven in a single day (if a pile is driven over two days, there is a "resetting" of the SEL_{cum} after 12 hours and accumulation starts again (Carlson et al., 2007; Stadler and Woodbury, 2009). It is important to note that it is highly unlikely that a fish would be exposed to the full SEL_{cum} of a pile driving operation since that could only occur if the fish stays in place and exhibits no swimming behaviors (including behavioral response to the pile driving sounds) for the duration of the pile driving operation. Thus, the scenario with fish receiving a full accumulated exposure to any pile driving is highly unlikely and conservative for most Hudson River species of concern. Moreover, even though fish would accumulate energy over the course of a pile driving operation (assuming the fish does not leave the area), the actual number of strikes to which the fish would be exposed, and the time intervals between the strikes, would be of importance. If the fish is exposed to fewer strikes, the total energy to the fish is lower (assuming that all strikes are generally similar in SEL_{ss}).

Thus, caution must be used when interpreting the model's results that present SEL_{cum} at different locations relative to the pile driving because the model does not take into consideration any behavioral responses of fish that would result in the fish not being exposed to SEL_{cum} levels that would result in onset of physiological effects. Furthermore, data from Halvorsen et al. (2011) document that SEL_{cum} has to be substantially above the minimum level that would result in onset of low levels of physiological effects to be potentially fatal. Thus, for example, Chinook salmon exhibit some minor effects at a SEL_{cum} at about 210 dB re 1μPA^2-s, but it is not until the levels reach 216 – 219 dB re 1μPA^2-s that injuries become potentially fatal (Halvorsen et al. 2011). The study indicated there was recovery from injuries sustained at 210 dB re 1μPA^2-s within several days of exposure, and that none of the injuries observed were of a kind that would lead to a loss of fitness (Casper et al. 2011, in press).

Effects of Sound on Fish Behavior

Results of empirical studies of hearing of fishes, amphibians, birds, and mammals (including humans), in general, show that behavioral responses vary substantially, even with a single species, depending on a wide range of factors such as the motivation of an animal at a particular time, the nature of other activities that the animal is engaged in when it detects a new stimulus, the hearing capabilities of an animal or species, and numerous other factors (Brumm and Slabbekoorn 2005). Thus, it is difficult to assign a single criterion above which behavioral responses to noise would occur.

It is also critical to note that animals (and humans) generally do not respond to sounds that are minimally perceivable (whether there is background sound or not). Sounds generally have to be well above the minimal detectable level in order to elicit behavioral changes (Dooling et al. 2009). At the lowest sound levels the animal may just ignore the sound since it is deemed to be unimportant or too distant to be of immediate relevance. It is only at higher amplitudes where the animal becomes "aware" of the sound and may make a decision whether or not to behaviorally respond to the sound. In some cases, sounds may be "masked" by background noise of the same or similar frequencies (Bee and Swanson 2007). In this case, the masked sound could either be undetectable or less detectable than it would otherwise be under quieter conditions. In a natural setting, it is possible that the sound has to be sufficiently above the masked threshold of detection for the animal to be able to resolve the signal within the surrounding ambient noise and recognize the signal as being of biological relevance.

By way of example, in an experiment on responses of American shad to sounds produced by their predators (dolphins), it was found that if the predator sound is detectable, but not very loud, the shad will not respond (Plachta and Popper 2003). But, if the sound level is raised an additional 8 or 10 dB, the fish will turn and move away from the sound source. Finally, if the sound is made even louder, as if a predator were nearby, the American shad go into a frenzied series of motions that probably helps them avoid being caught. It was speculated by the researchers that the lowest sound levels were those recognized by the American shad as being from very distant predators, and thus, not worth a response. At somewhat higher levels the shad recognized that the predator was closer and then started to swim away. Finally, the loudest sound was thought to resemble a very near-by predator, eliciting maximum response to avoid predation.

At the same time, there is evidence from a recent study in Norway (Doksaeter et al. 2009) that fishes will only respond to sounds that are of biological relevance to them. Doksaeter et al. (2009) showed no responses by free-swimming herring (*Clupea* spp.) when exposed to sonars produced by naval vessels. Similarly, sounds at the same received level that had been produced by major predators of the herring (killer whales) elicited strong flight responses. Significantly, the sound levels at the fishes from the sonar in this experiment was from 197 dB to 209 dB re 1 µPa (rms) at 1,000 to 2,000Hz. The hearing threshold for herring that are most closely related to those used in the Doksaeter et al. (2009) study in this frequency range is about 125 to 135 dB re 1 µPa (also see Mann et al., 2005). This means that the fish showed no reactions to a sound that was up to 84 dB above the fish's hearing threshold (209 dB re 1 µPa sonar vs. 120 dB re 1 µPa threshold) but not biologically relevant to this species.

There is not an extensive body of literature on effects of anthropogenic sounds on fish behavior, and even fewer studies on effects of pile driving, and many of these were conducted under conditions that make the interpretation of the results for this project uncertain. Of the studies available, the most useful in assessing the potential effects on behavior of pile driving on fish are those that use seismic air guns since the air gun sound spectrum is reasonably similar to that of pile driving. The results of the studies summarized below suggest that there is a potential for underwater sound of certain levels and frequencies to affect behavior of fish but that it varies with fish species, the existing hydroacoustic environment, and the behavioral response may change over time as fish individuals habituate. The project will maintain a corridor where ensonification due to pile driving is below the 150 dB µPa rms SPL behavioral guidance level suggested by NMFS (see **Figures 28 through 31**). Therefore, the project would minimize the potential for the driving of piles with an impact hammer project to impede movement of fish in

the Hudson River. Behavioral responses to other noise sources, such as noise associated with vessel traffic, and the results of noise deterrent studies are also summarized below.

Behavioral Studies Using Pile Driving (or Pile Driving-Like) Sounds

There have been very few studies that have examined behavioral effects of pile driving on fish. Most of these studies, as reviewed by Popper and Hastings (2009) were in small cages where behavior is severely constrained and so would not be considered a normal setting. In order for the results of an empirical study to be relevant to an assessment of the potential for pile driving, or other anthropogenic stimuli, to affect fish and other aquatic biota, it be done in free-swimming wild animals. While not done on free-swimming animals, Mueller-Blenke et al. (2010) evaluated response of Atlantic cod (*Gadus morhua*) and Dover sole (*Solea solea*) in large pens to playbacks of sounds recorded during pile driving during construction of wind farms. The investigators reported that a few representatives of both species exhibited some movement response, which they claim to have represented increased swimming speed or freezing to the pile-driving stimulus at peak sound pressure levels ranging from 144 to 156 dB re 1 μPa for sole and 140 to 161 dB re 1 μPa for cod. However, with the methodology used it was impossible to determine fish position more frequently than once every 80 seconds, and so, despite the suggestions of behavioral responses by the investigators, it was scientifically impossible to know if, and how, fish were moving or otherwise responding to the sound. Moreover, even in the few times that the investigators could glean information that suggested that fish moved from one place in the pen to another during sound presentation, this was only for very few fish, and it is not even clear that the authors interpretation of these results were correct since several alternative interpretations are possible from the very limited data. Finally, the statistical analysis of the results was very limited, and could not be used to document any behavioral responses by any animals.

Feist (1991) examined the responses of juvenile pink (*Oncorhyncus gorbuscha*) and chum (*O. keta*) salmon behavior during pile driving operations. Feist had observers watching fish schools in less than 1.5 m water depth and within 2 m of the shore over the course of a pile driving operation. The report (Feist's MS thesis) did not give pile size, other than to say that one was hollow steel and the other solid. While sound measurements were attempted, data were not available for this publication according to the author, thus none of the limited results can be correlated with sound levels from the pile driving operation. Feist did report that there were changes in distribution of schools at up to 300 m from the pile driving operation, but that of the 973 schools observed, only one showed any overt startle or escape reaction to the onset of a pile strike. Moreover, there was no statistical difference in the number of schools in the area on days with and without pile driving, although other behaviors changed somewhat. However, without data on sound levels, it is impossible to use the Feist data to help understand how fish would respond to pile driving and whether such sounds could result in avoidance or other behaviors. Indeed, one interesting observation, though in need of quantification and correlation with sound levels, is that the size of the stocks of salmon never changed, but appeared to be transient, suggesting that normal fish behavior of moving through the study area used was taking place no differently during pile driving operations and in quiet periods. These results, albeit very weak, suggest that at least these species of salmon are not avoiding pile driving operations.

Field Studies of Effects of Seismic Air Guns on Behavior

Aside from the few studies that have examined the effects of pile-driving noise on fishes, a number of additional studies have examined the effects of other anthropogenic impulsive sounds on fish with sound spectrums and rise time similar to those generated by pile driving, such as seismic air guns. The sound produced by seismic air guns is similar to that produced by a pile-

driving strike in terms of the length of time to reach peak amplitude and the component of the sound most likely to elicit a startle response. Because the rise time of the signal for seismic air guns is even sharper for seismic air guns than for pile driving, noise generated by seismic air guns has the potential to be more behaviorally and physiologically disturbing to fish than pile driving.

In an evaluation of the behavior of free-swimming fishes to noise from seismic air guns, fish movement (e.g., swimming direction or speed) was observed in the Mackenzie River (Northwest Territories, Canada) using sonar. Fishes did not exhibit a noticeable response even when sound exposure levels (single discharge) were on the order of 175 dB re 1 μPa2–s and peak levels of over 200 dB re 1 μPa (Jorgenson and Gyselman, 2009).

Wardle et al. (2001) observed very minor behavioral responses to the air gun emissions (most often very brief startle responses) and no permanent changes in the behavior throughout the course of the study in response to peak sound levels of 210 dB re 1 μPa at 16 meters (52.5 feet) and 195 dB re 1 μPa at 109 meters (358 feet) from the source. Moreover, no animals appeared to leave the reef during noise production. Temporary changes in behavior in response to exposure to seismic air guns were reported in Engås et al. (1996), Engås and Løkkeborg (2002), Slotte et al. (2004), and Løkkeborg et al. (2012) although the level of sound received by fish was not reported. In other studies that looked at catch rate, Skalski et al. (1992) showed a 52 percent decrease in rockfish (Sebastes sp.) catch when the area of catch was exposed to a emissions of a seismic air gun at 186-191 dB re 1 μPa (mean peak level). The results also suggested that rockfish would show a startle response to sounds as low as 160 dB (re 1 μPa), but this sound level did not appear to elicit a decline in catch.

McCauley et al. (2000) examined the effects of seismic air guns on caged pink snapper (*Pagrus auratus* Forster). Fish were caged and exposed to hundreds of emissions from an air gun as it approached and moved over and beyond the cage for approximately 1.5 hours. Received SEL exceeded 180 dB re 1 μPa^2-s for several of the shots. Startle responses, when they occurred, were elicited by sound levels greater than 156-161 dB re 1 μPa. In addition to the startle response, some individuals moved from the bottom of the cage, possibly to areas of lower sound levels. Behavior of individuals that did respond to the seismic sounds returned to normal within 14 to 30 minutes of cessation of seismic exposure and those individuals exhibited no long-term physiological or behavioral effects. (McCauley et al. 2003). Fish were also reported to habituate to the seismic air gun (McCauley et al. 2000), which means that after some amount of exposure, fish will no longer pay attention to the sound and the sound will have no further affect on behavior.

In an evaluation of the effects of a seismic survey on wild and caged fish of various species inside of Scotts Reef Lagoon in Western Australia, McCauley et al. (2008) observed some startle responses and small levels of movement in fishes exposed to sound exposure levels (single sound) of about 145-155 dB re 1uPa2-s.

Behavioral Responses to Other Sound Sources

Noise from construction vessels used to conduct the project also have the potential to affect fish behavior. Using divers to observe behavioral responses of bluefin tuna (*Thunnus thynnus*) in large in-ocean cages (approximately 70 meters square opening and 30 meters deep) to passing boats, Sarà et al. (2007) documented changes in the depth, location and swimming patterns of the tuna school in the presence of sounds from approaching ferries and hydrofoils. However, the authors did not provide sound levels received by the fish.

Two recent studies suggest that fish will show behavioral responses to sounds far below 150 dB re 1 μPa (rms). However, both studies were conducted on fish within small tanks with the underwater sound source located close by, an experimental setup which would have exposed the test subjects to both sound pressure and particle motion components of the sound field, although only the sound pressure was measured. Since all of the fish in both studies are very likely to be most responsive to particle motion and not pressure, and since particle motion was not measured, it is impossible to know to which aspect of the signal the fish were responding. Indeed, due to tank acoustics it is very highly likely that there the fish were exposed to very large particle motion signals (Parvulescu, 1967), and any behavioral responses were associated with that component of the sound.

In one study, signals recorded from the operation of wind farms were found to temporarily alter the behavior of roach (*Rutilus rutilus*) and three-spined sticklebacks (*Gasterosteus aculeatus*) (Andersson et al. 2007). The reported sound pressure levels eliciting responses were from 80 to 120 dB re 1 μPa (rms), although, as indicated above, particle motion, the actual stimulus that the fish could detect, was not measured. Similarly, Purser and Radford (2011) also examined the behavioral response (e.g., startle response and foraging behavior) of three-spined sticklebacks to short (10-sec) and long (300-sec) sounds. Fish showed an increased level of startle response and poorer foraging behavior at sound levels of about 150 dB re 1 μPa. Again, however, particle motion, the likely stimulus for both species in this small tank, was not measured or reported.

A nine-month long study by Wysocki et al. (2007) demonstrated that continuous exposure to sounds at 150 dB re 1 μPa produced no behavioral responses in rainbow trout, and no indications whatsoever of effects on stress levels, growth, or feeding. Turnpenny et al. (1994), in an unpublished report, examined the behavior of three species of fish in a pool in response to different sounds and reported avoidance behavior at certain levels of pure-tone test frequencies. However, due to poor experimental design and substantial errors in acoustics, the results of this study are impossible to interpret because of lack of calibration of the sound field at different frequencies and depths of the tanks, and due to other problems with experimental design (see comments on this study by Popper and Hastings 2009).

Studies that examined the effectiveness of underwater sound to deter fish from entering an area (e.g., dam spillways, or irrigation ditches, power plant intakes) suggest that fish will not change movement or show avoidance when sound is used as a potential fish deterrence (reviewed in Van Der Walker 1967; Popper and Carlson 1998). The exception was a study by Maes et al. (2004), who used a sound deterrent system from 20 to 600 Hz to control the movement of some clupeid fishes (*Alosa* spp.) in an attempt to deter fish from the water intake of a nuclear power plant. Fishes without swim bladders, and others that are thought to have poor hearing (e.g., sticklebacks) were not deterred by the sound. In contrast, fish with presumably better hearing capabilities (clupeids) were deterred to some degree by the sound, although there are no data on received sound levels. Moreover, this work has not been replicated. In contrast, Ploskey et al. (2000), in a very well designed study, investigated the responses of a number of schools of different juvenile salmonid species near the Bonneville Dam on the Columbia River to sounds that ramped up and down in intensity from silent to 160 dB re 1 μPa every two seconds. Only one of over 100 schools of fish exhibited a short startle response, but no individuals were deterred from the vicinity of the dam or altered their behaviors in a way that differed from the control fish, thereby indicating no avoidance of the sound.

Hydroacoustic Modeling Results and Fish Behavior

Figures 28 through 31 present the modeled isopleths of areas in which 150 dB re 1 μPa would result from pile driving. These figures indicate that portions of the river would also be below the

150 dB RMS guidance for fish behavioral effect and the likelihood of a behavioral response, such as avoidance or startle, at 150 dB re 1 μPa is very low when one takes into consideration the data presented above regarding known behavioral responses of fish. In all cases, other than in the acoustically flawed studies by Peuser and Radford (2011) and Andersson et al. (2007), fish show no responses to sounds at 150 dB re 1 μPa rms. Other studies show small responses at substantially higher sound levels to which fish either habituate or from which they recover shortly after the end of exposure (e.g., McCauley et al. 2000, 2008; Wardle et al. 2001). In some cases, no response has been observed even at sound levels substantially higher than 150 dB re 1 μPa (e.g., Jorgensen and Gyselman (2009). Additionally, these sounds may not be detectable to fish if there is any masking from other ambient noises, such as those produced by the river, boats, and other non-project related sources (e.g., traffic on the current bridge, the railway along the shore of the Hudson River). As a consequence, even though the 150 dB re 1 μPa isopleth from driving a 10-ft pile (assuming a 10 dB reduction from noise attenuation measures) is considerable in the east-west direction, masking would mean that the sound is not perceived by the fish as being 150 dB re 1 μPa until the actual sound level (without the presence of a masker) is approximately 5-10 dB higher.

While the results of the behavioral studies to date suggest that there is not likely to be any adverse behavioral response from any fish species, at sound levels as low as 150 dB re 1 μPa, implementation of the EPC measures described previously for pile driving would minimize the potential for behavioral effects. Therefore, the project would minimize the potential for the project to impede movement of fish in the Hudson River. Moreover, and perhaps of even greater significance in ensuring a minimal or no behavioral impacts on fish is the fact that the duration of pile driving during bridge construction would be a very small percent of the total project duration. Approximately 93 percent or more of the total duration of bridge construction that there will be no impact hammering sounds in the Hudson River. Combining this with the efforts to ensure a corridor where sounds will be below 150 dB re 1 μPa (rms) during pile driving, construction of the project would not result in adverse impacts to fish due to behavioral effects.

Impacts Associated with Increased Vessel Traffic

Several EFH species are known or documented to occur within the stretches of the river that included the project area; therefore, these species also may be directly impacted by increased vessel traffic in these areas.

Between 2000 and 2008, annual vessel traffic under the Tappan Zee Bridge ranged from 8,000 to 16,000 vessels per year (excluding small recreational boats, for which no data are available). **Table 12** provides a description of some of the larger vessels that travel along the Hudson River shipping channel, as reported by Hudson River Pilots, who operate many of these vessels. These data are based on vessel movements recorded between January 2005 and October 2006.

Materials shipped via the Hudson River vary from construction materials to oil. The majority of imports passing through the Port of Albany (approximately 95 percent) comprise oil. Cargo typically exported from Albany include grain, scrap metal, project cargo (e.g., industrial cargo from General Electric in Schenectady), heavy lift cargo, and cement. Several other marine terminals are located in the Hudson River Valley, including Newburgh, which supports marine terminals that accommodate oil barges; and Yonkers, in which Refined Sugars operates a marine terminal.

Table 12
Ship and Barge Movements on the Hudson River

Displacement (tons)	# of Ships	# of Barges*	Length Min/Max (feet)	Beam Min/Max (feet)	Draft Min/Max (feet)	Air Draft Min/Max (feet)
0-10,000	46		300/400	40/70	15/20	60/150
10,001-20,000	132	20	120/565	64/75	15/27	100/120
20,001-40,000	248	57	500/600	75/90	16/31	111/140
40,001-60,000	233		600/730	76/106	21/33	117/140
60,001-80,000	9		623/811	100/106	21/33	129/140
80,000+	8		735/805	106/137	27/33	129/140

Notes: *This table only reflects the number of vessels operated by Hudson River Pilots. Total barge movements are estimated to be approximately 2,800-3,000 per year.
Sources: Hudson River Pilots, Jan. 2005 – Oct. 2006

Construction of the new bridge and demolition of the existing bridge could affect marine traffic in the Hudson River due to increased use of the navigation channel and restrictions on navigation during construction of the main spans' substructure and superstructure, and demolition of the existing bridge. Delivery and installation of the segments would be coordinated with the U.S. Coast Guard to minimize the effect on shipping. It is anticipated that two hours would be required for the delivery of each section, with time included for the segment to reach the required clearance and be stabilized. For the Arch Option, bridge segments may also be delivered by barge, with a similar number of segments required. However, instead of construction in segments, there is the potential that the contractor may construct the Arch in one large full span lift—a method that would require closing of the main shipping channel for one or two days. To minimize any adverse effects on marine navigation, the NYSDOT and NYSTA would coordinate with the U.S. Coast Guard in conjunction with the Bridge Permit process to develop acceptable navigation windows and limit any channel closures to the minimum time necessary to provide a safe construction process.

Therefore, while the project would have a potential for increased vessel traffic for the delivery of materials, as well as dredge vessel traffic, the construction vessels would not occur within the navigation channel and at times, use of the navigation channel for the project would result in decreased vessel traffic due to restrictions that may be required for delivery and installation of certain bridge elements.

The potential direct effects associated with increases in vessel traffic within the dredged construction channel include potential collision with vessels and disturbance of foraging and migratory adults and juveniles associated with an increase in surface activity and noise. For the fish species for which EFH has been designated in the Hudson River, the effects of vessel strikes is likely a function of fish size and location within the water column; however, impacts to these (smaller) species from increased vessel traffic is more likely to occur in the form of propeller entrainment. While propeller entrainment has not been widely studied, Gutreuter et al. (2003) estimated the mortality rates of adult fish caused by entrainment through the propellers of commercial towboats operating in Mississippi and Illinois River channels. The method combined trawling behind towboats (to recover a fraction of the kills) and the use of a hydrodynamic model of diffusion (to estimate the fraction of the total kills). Estimates of entrainment mortality rates ranged from 0.13 fish/km of towboat travel (80 percent confidence interval, 0.00-0.41 fish/km) for skipjack herring (*Alosa chrysochloris*), 0.53 fish/km (0.00-1.33)

for both shovelnose sturgeon (*Scaphirhynchus platorynchus*) and smallmouth buffalo (*Ictiobus bubalus*), up to 2.52 fish/km (1.00-6.09) for gizzard shad (*Dorosoma cepedianum*). In a related study of the same river reaches, Killgore et al. (2011) detected no effects of towboat operation variables (speed and engine revolutions per minute [RPM]) on entrainment rate (i.e., fish/km); however, the entrainment rate exhibited was closely related to hydraulic and geomorphic characteristics of the channel. Entrainment rate was low (<1 fish/km) in wide sections of the river, deep water, and swift current while entrainment in narrow sections with shallow, slow water was highly variable and reached relatively high levels (>30 fish/km). Although total entrainment rate was not related to engine RPM in this study, the authors reported that the probability of being struck by a propeller increased with fish length and engine RPM, with a presumed increase in mortality.

The increased surface activity and associated noise would have the potential to displace/disrupt adult and juvenile fish within the study area during foraging and migratory activities within the vicinity of in-water activities on a given day, which would minimize the potential for losses due to contact with vessels..

Another potential impact associated with increased vessel traffic is radiated noise. It is of considerable importance that fish transiting the navigable Hudson River will encounter an acoustic environment that is generally highly energetic under "normal" conditions. The sound levels lower in the estuary result from the high volume of commercial shipping traffic within the tidal Hudson and New York Harbor. While noise levels from shipping in the estuary are not known, it is possible to get a first approximation based upon sound levels from other locations. For example, a recent study in Hong Kong harbor, one of the busiest ports in the world, demonstrated that there was a generally high noise level in the area (Würsig et al. 2002). The highest sound levels recorded in that study were associated with ship propellers (probably due to cavitation effects). Sound levels ranged from a high of about 148 dB re 1 µPa2-s to a low of 110 dB. While these recordings were made from within the frequency range of 10 – 20,000 Hz, the bulk of the acoustic energy was below 1,600 Hz. Even from these limited data, it is apparent that the sound from even a single vessel is above hearing thresholds of many fishes found in the Estuary. In other words, the sound level from a single ship could potentially be detectable to a fish within 50 or 100 meters of the propeller.

Other data also demonstrates that ships produce a great deal of noise. For example, a merchant ship traveling at 10-15 knots may produce 163 dB re 1 µPa2-s at 50 Hz and 137 dB re 1 µPa2-s at 300 Hz, while a large tanker (153 - 214 m long) at 15-18 knots may produce 176 dB re 1 µPa2-s at 50 Hz and 149 dB re 1 µPa2-s at 300 Hz (Mazzuca 2001). Although one overall ambient noise level due to marine traffic has been estimated to be around 75 dB re 1 μPa^2-s per Hz at 100 Hz, the source level associated with a large tanker can be as high as 186 dB re 1 µPa2-s per Hz at a distance of 1 meter (Gisiner 1998). Richardson et al. (1995) suggest source levels and dominant frequencies ranging from 152 dB re 1 µPa2-s at 6300 Hz for a five-meter boat with an outboard motor through 162 dB re 1 µPa2-s for a tug and barge traveling at 18 km/hr, to a large tanker with a source level of 177 dB re 1 µPa2-s in the 100 Hz band. Other authors cite shipping traffic at frequencies from 20 to 300 Hz, with smaller vessels producing the higher frequency sound peaking at around 300 Hz and larger cargo vessels producing lower frequency sounds (MMS 2001).

Because these representative values of radiated vessel noise are well below the peak SEL of 206 dB re 1 µPa and the 187 dB re 1 µPa SELcum criteria established for pile driving, and because the Hudson River is subject to substantial commercial and recreational vessel noise under

"normal" conditions, any incremental increase sound associated with vessel traffic related to bridge construction is not expected to affect fish, including EFH species.

Summary

In summary, with the implementation of the EPCs identified previously for dredging and pile driving, neither dredging nor driving piles with an impact hammer would result in adverse impact to fish due to physiological effects. Pile driving and dredging would have minimal effects to anadromous fish migratory activities, as there will always be large portions of the river width that will not be ensonified due to driving piles with an impact hammer and an acoustic corridor of at least 5000 feet at all times free from pile driving with an impact hammer fCorridor shall be continuous to the maximum extent possible but at no point shall any contributing section be smaller than 1500 feet. Driving of 8- or 10-foot diameter piles with an impact hammer in the vicinity of the navigation channel (i.e. Zone C) would be restricted to 5 hours per day from April 1 to August 1, and dredging to be conducted in 3 of the 5 construction years would be limited to three month windows (August 1 to November 1). Dredging of 165 to 175 acres for access channels would create an area of reduced foraging opportunities for fish due to loss of benthic habitat. However, upon completion of in-water activities in a given area, estuarine depositional processes would, over time, allow the benthic habitat to return to its pre-construction state. Additionally, benthic organisms that prefer gravel substrates that would be introduced as a result of armoring would be expected to colonize the dredged construction channel. Gravel substrate is available nearby within and near the navigation channel that would serve as a source of these organisms. The temporary loss of the access channel area would represent a minor fraction of similar habitat in the Tappan Zee portion of the Hudson River. Incidental vessel strikes would be insignificant. Therefore, construction of the Replacement Bridge Alternative would not result in adverse impacts to populations of fish species in the Hudson River, including those designated as having EFH within the study area.

4.2 GENERAL DISCUSSION OF POTENTIAL AQUATIC IMPACTS FROM THE OPERATION OF THE PROPOSED PROJECT

4.2.1 WATER QUALITY

The principal potential impact to water quality of the Hudson River from the operation of the Replacement Bridge Alternative is the discharge of stormwater runoff from the decks of the replacement bridge. NYSDEC General Permit GP-0-010-01 regulates the discharge of stormwater runoff from construction activities associated with soil disturbance, including both water quality and quantity controls. NYSDEC requires treatment of stormwater runoff from areas of soil disturbance to improve water quality, as well as a reduction of peak flows of stormwater runoff providing channel protection, overbank flood protection and flood control. The technical standards and design criteria for stormwater management facilities are presented in NYSDEC's New York State SWMDM (NYSDEC 2010b).

The stormwater quality management goals stated in the SWMDM are to achieve an 80 percent reduction in total suspended solids (TSS) and a 40 percent reduction in total phosphorus (TP). Most water quality treatment practices accomplish this goal by collecting the stormwater runoff and detaining it for some length of time, infiltrating it into the ground or filtering it. These practices, commonly referred to as "standard practices," are assumed to meet the required removal efficiencies if designed according to the requirements presented in the SWMDM. Other treatment systems, or proprietary practices, such as hydrodynamic separators and grit chambers,

can also be employed for water quality treatment. Typically proprietary practices are used when there are certain site specific conditions that prohibit the implementation of "standard practices."

Stormwater runoff discharges from the Replacement Bridge Alternative would be ultimately discharged into the Hudson River, a tidal water body. The Hudson River is not on the State's Section 303(d) list of waterbodies impaired by stormwater runoff or within a watershed improvement strategy area. Therefore, stormwater quantity or the channel protection volume, overbank flood protection or flood control sizing criteria would not be required. However, post-construction stormwater quality treatment practices would be required for runoff discharging to the Hudson River from the bridge landing portions of Interstate 87/287 in both Rockland and Westchester Counties. Stormwater runoff from the approaches and main span of the Replacement Bridge Alternative would be discharged directly to the Hudson River without treatment, as occurs for the existing bridge. With the implementation of post-stormwater quality treatment controls at the bridge landings, the net concentration of pollutants to the Hudson River from the Replacement Bridge Alternative (landings, approach spans, and main spans) would be expected to decrease for TSS and increase by only 3.4 pounds per year for TP. This increase in TP loadings from the Replacement Bridge Alternative would not result in adverse impacts to water quality of the Hudson River, or result in a failure to meet the Class SB water quality standards. When comparing just pollutant loadings within the landings under the existing and Replacement Bridge Alternative, pollutant loadings would decrease for TP and TSS. Given the overall decrease between the existing bridge and the proposed bridge in terms of both TSS and the minimal projected increase in TP, the water quality resulting from the operation of the project would not adversely affect EFH, or striped bass or marine turtles and mammals.

4.2.2 AQUATIC BIOTA

With respect to effects on EFH species potentially present in the project area, or other species of concern, the operation of the replacement bridge is not expected to result in any incremental increase in the effects of the existing bridge (to be removed). As discussed under *Water Quality*, the operation of the project would not result in adverse impacts to water quality of the Hudson River. Given that the Tappan Zee region of the Hudson River is not a migratory pathway for any species for which the Hudson has been designated as EFH, the effects of under-bridge lighting is not expected to result in any impediment to fish migration. Coupled with the generally highly turbid waters of the river, the fact that many species that regularly occur in the project area inhabit the deepest water available, and the presence of other anthropogenic lights along both shorelines of the River and associated with other river crossings, the operation of the project would not result in adverse effects to fish or EFH due to under-bridge lighting.

It has been maintained that shading of estuarine habitats can result in decreased light levels and reduced benthic and water-column primary production, both of which may adversely affect invertebrates and fishes that use these areas, particularly with respect to use as refuge and foraging habitat (Able et al. 1998, and Struck et al. 2004). The amount of area shaded by overwater structures will be affected by the height and width of the structure, construction materials and orientation of the structure relative to the arc of the sun (Burdick and Short 1995, Fresh et al. 1995 and 2000, Olson 1996, 1997 in Nightingale and Simenstad 2001) and piling density. Shading due to bridges has been found to affect plant communities such as tidal marshes and SAV, as well as benthic invertebrate communities within tidal marshes (Struck et al. 2004, and Broome et al., 2005 in CZR 2009). However, adverse effects on marsh vegetation and benthic macroinvertebrates have been found to be minimal when the bridge height-to-width ratio is greater than 0.7 (Struck et al, 2004, Broome et al. 2005 in CZR 2009). Significantly fewer

oligochaete worms, which are common in the Hudson River, were found under bridges with a height-to-width ratio less than 0.7 when compared to marshes not affected by shading (Struck et al. 2004). Struck et al. (2004) found that bridges with height-to-width ratios greater than 1.5 had the lowest light attenuation beneath the bridge.

Because the elevations of the existing Tappan Zee Bridge and the Replacement Bridge Alternative are not consistent over the length of the structure (see **Figure 4**), the height-to-width ratio of the bridge varies along its length. **Table 13** compares the ratio of the existing bridge and the Short and Long Span Options for the Replacement Bridge Alternative at the stations indicated in **Figure 2**. The two spans of the Replacement Bridge Alternative would be separated by a gap of up to 70 feet. While impacts to vegetated wetlands or SAV would not be expected to be affected by the construction of the Replacement Bridge Alternative, the height-to-width ratios presented below provide an indication of the potential for the existing and Replacement Bridge Alternative to result in shading impacts. As indicated below, the height-to-width ratio for the portion of the existing bridge within the causeway (the western approach to the main span comprising Stations 845+00 to approximately 905+00) is low, ranging from 0.2198 to 0.2857). The ratio for these same stations for the Replacement Bridge Alternative, Short and Long Span Options, are much higher, ranging from 0.35 near the shoreline to 1.20, with the ratios for the Long Span Option being slightly greater because the height for this approach option is higher. The portion of the western approach just prior to the main span (Stations 920+00 to 935+00) has a ratio that ranges from 0.54 to 1.05 for the existing bridge. Again, the ratios of these stations for the Replacement Bridge Alternative are much greater, ranging from 1.23 to 1.82. The ratios for the main span of the existing bridge range from 1.51 to 1.52 and for the Replacement Bridge Alternative 1.49 to 1.82, while the ratios for the eastern approach are fairly similar for the existing and Replacement Bridge Alternative, ranging from 0.89 to 1.31 with the Long Span Option for the Replacement Bridge Alternative having the higher ratios.

The ratios in **Table 13** consider the height-to-width ratio separately for the two spans of the Replacement Bridge Alternative, assuming that the separation between the decks of the two spans (i.e., 70 feet at the main span and then decreasing toward the shorelines) allows light to penetrate between the two structures. This represents the best case analysis. Under this case, the Replacement Bridge Alternative would clearly result in a lower potential for shading of aquatic habitat compared to the existing bridge, particularly along the causeway (western approach to the main span). Even under the worst case, which assumes no separation between the spans of the Replacement Bridge Alternative and which would conservatively result in a halving of the height-to-width ratios presented in **Table 13**, the Replacement Bridge Alternative would still result in greater ratios (i.e., less shading) than the existing bridge for the western approach, but may result in more shading than the existing bridge for the eastern approach. Overall, the height-to-width ratios imply that even if the Replacement Bridge Alternative was treated as a single structure, with no separation between the spans, there would be a decrease in the potential for shading impacts to aquatic resources.

The approximately 99,153-square foot permanent platform at the Rockland Bridge Landing would result in additional aquatic habitat affected by shading. Considering the extensive area of aquatic habitat not affected by shading within the study area, the additional shading caused by the temporary platform and by the bridge would not result in adverse impacts to aquatic resources or to EFH.

Table 13
Height-to-Width Ratios for the Existing Bridge and Short and Long Span Options for the Replacement Bridge Alternative at Various Stations Across the Length of the Bridge

	Existing	Short Span		Long Span	
Location	91 ft-wide deck	96ft-wide	87ft-wide	96ft-wide	87ft-wide
845+00	0.29	0.34	0.38	0.44	0.48
860+00	0.22	0.52	0.57	0.60	0.67
875+00	0.22	0.70	0.78	0.78	0.86
890+00	0.22	0.91	1.00	0.96	1.06
905+00	0.22	1.08	1.20	1.13	1.24
920+00	0.54	1.23	1.36	1.24	1.37
935+00	1.05	1.46	1.61	1.46	1.61
950+00	1.52	1.65	1.82	1.65	1.82
965+00	1.51	1.49	1.64	1.49	1.64
980+00	1.01	1.19	1.31	1.19	1.31
995+00	1.07	0.99	1.09	0.89	0.98

4.3 ASSESSMENT OF EFH SPECIES

An analysis of EFH for each fish species and life stage listed in **Table 9**—including the likelihood that the species would occupy the project area—is summarized below. Of the 13 EFH species identified for the Hudson River estuary, the majority were found in highest abundance in the lower reaches of the estuary from the Battery to Yonkers (river miles 0-23). Only three of these species—Atlantic butterfish, bluefish and summer flounder—were captured during the 2007-2008 sampling program for the project. These marine species were captured in the warmer months of the year when higher water temperatures and salinities are present within the project area. Six additional EFH species were collected in the Utilities Long River Monitoring Program between 1998 and 2007, albeit relatively infrequently in the Tappan Zee region (RM 24-33) compared to collections in the lower reaches of the estuary. Among these species were winter flounder (egg, larvae, young of year and yearling or older), bluefish (young of year, yearling and older), Atlantic herring (larvae, young of year, yearling and older), windowpane flounder (eggs, larvae, young of year, yearling and older), summer flounder (larvae, young of year), and Atlantic butterfish (larvae, young of year, yearling and older). The Utilities Fall Shoals Program also collected winter and summer flounder, bluefish and Atlantic butterfish, but in relatively few of the samples taken between 1998 and 2007. Atlantic mackerel, Spanish mackerel and scup were each collected in fewer than 3 of over 1,800 samples taken in the Tappan Zee region (RM 24-33) over the ten year period.

4.3.1 ATLANTIC BUTTERFISH (*PEPRILUS TRIACANTHUS*)

Butterfish occur from Newfoundland to Florida and are most abundant between southern New England and Cape Hatteras. It has been suggested that two populations of butterfish exist. One population appears largely restricted to shoals (less than 20 m [66 ft]) south of Cape Hatteras, and another mainly north of Hatteras that occurs in shoals and possibly some deeper waters

along of the shelf. Throughout its range, butterfish are found over the entire shelf, inshore and offshore. According to Able and Fahay (1998), butterfish move inshore as water temperatures increase during the spring and migrate back offshore as inshore water temperatures decrease in the fall. Butterfish require 10°C (50ºF) for survival. This species spawns from June to August in inshore waters generally less then 30 m (98 ft) deep.

Peak egg production is in late June and early July off Long Island Sound. Very few butterfish eggs have been collected in the Hudson River estuary during utilities-sponsored fish surveys conducted between 1998 and 2007. Those that were collected were found in late June and July in the lower estuary from the Battery to near Yonkers at river mile 23. No butterfish eggs have been reported from the Tappan Zee region during these surveys. Howeve,r the Hudson River is within an area designated as EFH for larval, juvenile, and adult butterfish. Studies performed in the Hudson-Raritan Estuary noted that butterfish comprised less than 1 percent of total catches of fish (USACE 2000).

Newly hatched larvae are between 2 and 16 mm (0.1-0.6 in) in length. Larvae are found at the surface and often in the shelter of the tentacles of large jellyfish. The latter tend to be more nektonic (freely swimming) than planktonic (passively drifting with currents) when between 10 and 15 mm (0.4-0.6 in) long. Larvae are found at temperatures ranging from 7-26°C (45-79°F), although most abundant at 9-19°C (48-66°F), and at depths less than 120 m (394 ft) (Cross et al. 1999).

At 6 mm (0.24 in), larval body depth has increased substantially in proportion to length. At 15 mm (0.6 in), the fins are differentiated and the young fish takes on the general appearance of the adult. Adult butterfish can range from 120 to 305 mm (4.7-12 in) long. Both juveniles and adults have similar habitat characteristics. Both are eurythermal and euryhaline and are common often near the surface in sheltered bays and estuaries during the spring to autumn months. In the Hudson-Raritan trawl survey, juveniles and adults were found at depths from 3-23 m (10-75 ft), salinities from 19-32 parts per thousand (ppt), and dissolved oxygen from 3-10 mg/L. Juvenile and adult butterfish also often prefer sandy and muddy substrates, and temperatures from 3-28°C (37-82°F) (Cross et al. 1999).

Occasional adult and juvenile butterfish have the potential to occur within the study area. Spawning would not occur within the study area. Woodhead (1990) reports butterfish to be a common transient in the New York Harbor in the summer. Atlantic butterfish prefer sandy bottoms, but are not closely associated with the bottom when inshore during the summer. They may stay close to the bottom during the day and move into the water column at night (Smith 1985). They are found in the Hudson-Raritan estuary in greatest abundance during summer and based on the last available decade of Utilities data (1998-2007), butterfish are present in the lower Hudson River from the Battery to West Point (upriver from the study area) from July through October (sampling starts in July). They have not been caught upstream of West Point and are far more abundant in the first 23 river miles (Battery and Yonkers) compared to areas farrther upstream. The highest densities of butterfish are in the channel and to some extent, the deep bottom habitats in waters greater than 20 feet deep. They are infrequently collected in the shallow shoal habitat (i.e., less than 20 feet deep).

Because the Tappan Zee region of the Hudson River is marginal habitat for butterfish in terms of normal salinity ranges and the Hudson River is not a migratory corridor for the species, individuals this species are not likely to occur in the project area in large numbers but would occur during periods of low freshwater flows when the salt front is pushed upriver. The habitat found within the Tappan Zee region of the Hudson River does not represent a significant portion of the EFH for this species. Atlantic butterfish were collected within the study area during the

sampling conducted for the project and were collected during the Utilities Fall Shoals Program from 1998 to 2007, although in relatively few of the samples. The Mid-Atlantic butterfish stock is considered overfished (NOAA 2011).

Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB RMS guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.2 ATLANTIC MACKEREL (*SCOMBER SCOMBRUS*)

Atlantic mackerel is a pelagic marine species that occurs on both sides of the North Atlantic, and in the western North Atlantic from Labrador to North Carolina. It sustains fisheries from the Gulf of St. Lawrence and Nova Scotia to the Cape Hatteras area. There may be two populations: one occurring in the northern Atlantic and associated with the New England and Maritime Canadian coast, and another more southerly population that inhabits the mid-Atlantic coast. Both populations overwinter in the deep waters at the edge of the continental shelf, generally moving inshore (in a northeastern direction) during the spring, and reversing this migration in autumn. The southern population begins its spawning migration by moving inshore between the Delaware Bay and Cape Hatteras and then in a northeastern direction along the coast. The timing of the migration and spawn is driven by warming water temperatures. The peak spawn for the southern population occurs off New Jersey and Long Island Sound in April and May. Most spawning occurs in the shoreward half of the continental shelf and in waters from 7 to 14°C (45-57°F), with the peak being 10 to 12°C (50-54°F) (Studholme et al. 1999). Eggs of the Atlantic mackerel have been collected in low abundance from mid-April to June and primarily in the lower portion of the Hudson River estuary from the Battery up to river mile 23 near Yonkers, based on utilities-sponsored fish survey data. Larval Atlantic mackerel are also collected in low abundances during May and June in the same region. Very few eggs or larvae are collected in the project area near Tappan Zee. Only 1 juvenile Atlantic mackerel was collected during these surveys in the Yonkers region. By June, schools of juveniles can be found off Massachusetts, and they move into the Gulf of Maine by June and July. In the New York Harbor Estuary, juveniles may be present from April to December, but are most common from April through June and October through November. Adults are present from April through June and from September through December, most commonly from April to May and from October to

November (USACE 2000). The Hudson River is within an area designated as EFH for juvenile and adult Atlantic mackerel.

Juvenile metamorphosis includes swimming and schooling behaviors starting at approximately 30-50 mm (1.2-2.0 in), and they closely resemble adults by about 1 year of age. In the New York Harbor Estuary, juveniles are present in the spring and summer months, preferring depths from 4.9-9.8 m (16-32 ft), salinity ranges from 26-28.9 ppt, dissolved oxygen from 7.3-8.0 mg/L and temperatures from 17.6-21.7°C (64-71°F) (Studholme et al. 1999).

Adult Atlantic mackerel can range from 26 cm (10 in) in their second year to about 40 cm (15.8 in) in their sixth year. NEFSC trawl survey data indicate that adults are found in the spring at temperature ranges from 5-13°C (41-55°F) dispersed from 0-380 m (1,250 ft) (most abundant at 160-170 m [525-558 ft]), and in the summer at temperatures ranging from 4-14°C (39-57°F) at depths of 10-180 m (33-591 ft) (abundant at 50-70 m [164-230 ft]). Adults also prefer salinities of 25 ppt or greater (Studholme et al. 1999).

Due to salinity requirements, adults are not likely to be present within the Hudson River, in the study area, where salinity is less than 10 PSU over much of the yearexcept for during periods of low freshwater flows when the salt front is pushed upriver Atlantic mackerel were rarely collected during trawls in the New York Harbor by USACE from October 1998 through November 1999 (USACE 1999). Most individuals were found in the Lower Harbor (Raritan Bay and Sandy Hook Bay) (Woodhead and McEnroe 1991 in USACE 1999).

The habitat found within the Tappan Zee region of the Hudson River does not represent a significant portion of the EFH for juvenile and adult Atlantic mackerel. This species would not be expected to occur within the study area except as rare transient individuals. Therefore, adverse impacts would not occur to the EFH for this species.

4.3.3 ATLANTIC HERRING (*CLUPEA HARENGUS*)

Atlantic herring is a planktivorous marine species that occurs in coastal waters throughout the Northwestern Atlantic waters from Greenland to North Carolina. They are most abundant north of Cape Cod and relatively scarce in waters south of New Jersey (USACE 2000). Adult Atlantic herring routinely move into estuaries, but are largely restricted to well-mixed waters at salinities greater than 24 ppt. Adults rarely move into fresh water (Smith 1985) and appear to limit their distribution based on the transition zone between well-mixed and stratified waters. Juvenile and adult herring undergo complex north-south migrations and inshore-offshore migration for feeding, spawning, and overwintering. They spawn once a year in late August through November in the coastal ocean waters of the Gulf of Maine and Georges Banks. This species never spawns in brackish water and eggs of this species have not been collected in the Hudson River during utilities-sponsored fish surveys between 1998 and 2007. Post-spawn, the adults migrate to the New York Bight to overwinter from December to April and are followed several weeks later by larval herring that are transported to estuaries and tidal rivers where they also overwinter. The autumn migration by adults to overwintering areas is done in tight schools while the spring migration to spawning areas is much more dispersed. The Hudson River is within an area designated as EFH for larval, juvenile, and adult Atlantic herring.

Larval herring are free-floating, and for autumn-spawned fish this stage can last 4 to 8 months until the spring metamorphosis into juveniles. A fraction of those hatched remain at the spawning site, while others may drift in ocean currents, reaching eastern Long Island Sound and entering the Hudson River estuary on flood tides. In the Gulf of Maine, larvae occur at temperatures ranging from 9 to 16°C (48-61°F), and a salinity of 32 ppt. During post-

metamorphosis, which occurs through April and May, juveniles form large schools and move into shallow waters. In the Hudson River, larval Atlantic herring are typically collected during spring and early summer and primarily in the lower reaches of the River from the Battery to river mile 23 near Yonkers. Larval herring are also collected further upstream in the Tappan Zee and Croton-Haverstraw regions, but are sparse upstream of Indian Point and river mile 46. Large schools of juveniles have been collected during spring and early summer (late April through late June) between the Battery and Indian Point and are at peak abundances during May in the Tappan Zee region, based on utilities-sponsored fish survey data collected from 1998-2007. As early juveniles, Atlantic herring are found in brackish waters, but as older juveniles, this species emigrates from the estuary during summer and fall to overwinter in higher salinity bays or near the bottom in offshore areas. Within Long Island Sound, springtime abundances have been reported as being highest at temperatures ranging from 9 to 10°C (48- 50°F), depths ranging from 10 to 30 m (33-98 ft), and salinity ranging from 25 to 28 ppt. Within the New York Harbor Estuary, catches of herring were highest at temperatures ranging from 3 to 6°C (37-43°F) and in the deeper portions of the estuary (USACE 2000). Juveniles in the NOAA Northeast Fisheries Science Center (NEFSC, http://www.nefsc.noaa.gov) bottom trawl surveys of the New York Harbor Estuary were found to prefer temperatures at 2-16°C (36-61°F) and 12-22°C (54-72°F), and were most abundant at 4-6°C (40-43°F) and 15-18°C (59-64°F). Juveniles are commonly found at depths ranging from 30-135 m (98-443 ft) which varied seasonally (depths increasing with the summer months) (Reid et al. 1999).

On average, males and females mature at about 25-27 cm (10-11 in). In the NEFSC bottom trawl surveys, adults collected were most abundant at 3-6°C (37-43°F) at depths ranging from 4.5 to 13.5 m (14 to 44 ft). Preferred salinities for the Atlantic herring are greater than 28 ppt (Reid et al. 1999). Juveniles and adults perform diel and semi-diel vertical migrations in response to daily photoperiods and variations in turbidity. Being sensitive to light intensity, activity is highest after sunrise and just before sunset, when the herring will avoid the surface during daylight to avoid predators (Reid et al. 1999).

In 1999 the NOAA Technical Memo for the species indicated that the U.S. stock complex has fully recovered from the effects of over-exploitation during the 1960s and 1970s (Reid et al. 1999). The Atlantic herring fishery is not overfished and is not approaching an overfished condition (NFMS 2011b). The NMFS has designated the Hudson River mixing and salinity zone as EFH for Atlantic sea herring larvae, juveniles, and adults.

Larvae, young of year, yearling and older Atlantic herring were observed in the Utilities Long River Monitoring Program collections between 1998 and 2007. However, abundances are highest in the lower portion of the estuary downstream of the project area. In the context of this species' habitat requirements, the Tappan Zee region of the Hudson River is marginal habitat for Atlantic herring based on low relative abundances of this species in the vicinity of the project area compared to abundances further downstream. Furthermore, salinities in the project area are near the low end of the species' normal salinity ranges, particularly for older juveniles and adults. Finally, the Hudson River is not a migratory corridor for the species. Because the habitat found within the Tappan Zee region of the Hudson River does not represent a significant portion of the EFH for this species and individuals of this species are not likely to occur in the project area in large numbers. The project is not likely to result in adverse impacts to EFH for this species.

4.3.4 BLACK SEA BASS (*CENTROPRISTIS STRIATA*)

Black sea bass is a marine species that occurs from Cape Cod, Massachusetts to Cape Canaveral, Florida. The fishery is divided into two populations: one major population north of Cape Hatteras, North Carolina, and one in southern waters. The northern population migrates seasonally: shoreward and north in the spring and offshore and south in the autumn. In the autumn, older fish move offshore sooner and overwinter in deeper waters (73 to 163 m [240-535 ft]) than young-of-the-year fish (56 to 110 m [184-361 ft]). Black sea bass can tolerate temperatures as low as 6°C (43°F) but are most abundant in off-shore waters warmer than 9°C (48°F) between 20 to 60 m (66-197 ft) deep (USACE 2000). During the spring migration, adults move to spawning grounds on the nearshore continental shelf and juveniles move inshore and into estuaries. For the northern population, spawning generally takes place in the summer, in water 18 to 45 m deep from the Chesapeake Bay to Montauk Point, New York. The Hudson River is within an area designated as EFH for juvenile and adult black sea bass.

Larvae develop for the most part in continental shelf waters and are most abundant in the southern portion of the Middle Atlantic Bight. Larvae quickly become bottom dwellers and may move into estuaries as late-stage larvae or early juveniles, although eggs and larvae are not typically found in estuaries (Able et al. 1995). While inhabiting the estuary, juvenile black sea bass are strongly structure-oriented and occupy bottom habitats consisting of shells, amphipod tubes and rubble, and have been observed on inshore jetties in late May to early June.

In the Hudson River, young-of-the-year have been captured in both open water and inter-pier areas. Juvenile sea bass occur in the saline portions of estuaries from Massachusetts to Florida starting with the initial spring migration until late autumn and are commonly found around jetties, piers, wrecks, and bottom areas with shells (USACE 2000). They appear to prefer hard bottom (Bigelow and Schroeder 1953).

Juveniles settle in estuaries and the inner continental shelf growing up to 19 cm (7.5 in). Young-of-the-year black sea bass inhabit estuarine areas in the Mid-Atlantic Bight at depths from 1-38 m (3-125 ft) from July to September. They prefer structured bottoms, shell patch substrates and often find shelter around manmade structures. Juveniles can be found in water temperatures ranging from 6-30°C (43-86°F) and salinities ranging from 8-38 ppt (but most preferring >20 ppt). The young-of-the-year are migratory during some portions of the first year. They migrate out of the estuaries and away from inner continental shelf nursery areas during the autumn as water temperatures drop (Steimle et al. 1999b). Adult black sea bass prefer similar habitat conditions as that of the juvenile and perform similar migratory patterns. Adults also tend to seek shelter around manmade structures (Steimle et al. 1999b) and are more common in nearshore coastal and offshore habitats than within estuaries

Black sea bass are bottom feeders, consuming crabs, shrimp, mollusks, small fish, and squid. Woodhead (1990) describes black sea bass as a common summer transient in the New York Harbor. Individuals have been collected in the New York Harbor and the Hackensack River (Smith 1985). Young-of-the-year black sea bass (i.e., juveniles) have been collected in the lower Hudson River off Manhattan from mid-July to September (Able et al. 1995) and are collected during utilities-sponsored fish surveys primarily in August downstream of the project area between the Battery and Yonkers in channel and bottom habitats at depths exceeding 20 feet. Eggs and larvae of this species have not been collected during utilities surveys in the Hudson River. Based on these observations, eggs and larvae are not expected to occur in the study area and there is a low probability that juvenile black sea bass will occur within the study area. For

each of these life stages, it is unlikely that project activities would have an impact on this species.

The black sea bass fishery is not currently overfished or approaching an overfished condition (NOAA 2011). The NMFS has designated the Hudson River mixing and salinity zones as EFH for black sea bass juveniles and adults.

Due to salinity requirements, adults and juveniles are not likely to be present within the Hudson River in the study area except in the lower portion of the estuary downstream of the project area near Tappan Zee or during periods of low freshwater flows when the salt front is pushed upriver. The Hudson River is not a migratory corridor for this species and individuals are not likely to occur within the study area in large numbers as suggested by fish-survey data. The habitat found within the Tappan Zee region of the Hudson River does not represent a significant portion of the EFH for this species (i.e., poly- to euhaline nearshore and offshore structured habitat) and individuals would not be expected to occur within the study area except as rare transient individuals. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.5 BLUEFISH (*POMATOMUS SALTATRIX*)

Bluefish is a carnivorous marine species that occurs in temperate and tropical waters on the continental shelf and in estuarine habitats around the world. In North America, bluefish live along most of the Atlantic coastal waters from Nova Scotia south, around the tip of Florida, and along the Gulf Coast to Mexico. Bluefish migrate between summering and wintering grounds, generally traveling in groups of fish of similar sizes and loosely aggregated with other groups. They generally migrate north in the spring and summer and south in the autumn and winter.

Along the North Atlantic, summering waters are centered in the New York Bight, southern New England and northern sections of the North Carolina coastline. Wintering grounds are found in the southeastern parts of the Florida coast. Juvenile and adult bluefish travel far up estuarine waters (where salinity may be less then 10 ppt), but are more often found at higher salinities in poly- and euhaline waters (>20ppt), while eggs and larvae are largely restricted to marine habitats as a result of the adults preferred spawning locations in nearshore and offshore waters (USACE 2000). The Hudson River is within an area designated as EFH for juvenile and adult bluefish.

There are two spawning stocks along the U.S. Atlantic coast—a south Atlantic spring spawn, and mid-Atlantic summer spawn. The fish spawning in the spring migrate to the Gulf Stream/coastal shelf interface between northern Florida and Cape Hatteras in April and May.

Post-spring spawn, smaller bluefish drift westward while the larger fish slowly migrate north along the shelf and west into mid-Atlantic bays and estuaries including the New York Harbor Estuary where they remain until autumn. Summer-spawning fish migrate to the mid-Atlantic from Cape Cod to Cape Hatteras in June through August. Summer post-spawn fish head towards the mid-Atlantic shores and are particularly abundant in Long Island Sound (USACE 2000, Fahay et al. 1999). Juveniles from the spring spawn drift north in the early summer and enter the important nursery habitats in estuaries and bays along the mid-Atlantic coast in June. Summer-spawned fish enter the estuaries in mid- to late-summer (Buckel et al. 1999). All spent fish and juveniles migrate to the wintering grounds in the autumn (USACE 2000).

Juveniles in the Mid-Atlantic Bight inhabit inshore estuaries from May to October, preferring temperatures between 15 and 30°C (59-86°F), and salinities between 23 and 33 ppt. Although juvenile and adult bluefish are moderately euryhaline, they occasionally will ascend well into

estuaries where salinities may be less than 3 ppt. Juveniles use estuaries as nursery areas, and can be found over sand, mud, silt, or clay substrates.. Bluefish juveniles are sensitive to changes in temperature; thermal boundaries apparently serve as important cues to juvenile migration off shore in the winter season (Fahay et al. 1999) and may impede early migration into the estuary during the spring.

Adult bluefish are pelagic and highly migratory with a seasonal occurrence in Mid-Atlantic estuaries from April to October. They prefer temperatures from 14-16°C (57-61°F) but can tolerate temperatures from 11.8-30.4°C (35-87°F) and salinities greater than 25 ppt. Adult bluefish are not uncommon in bays and larger estuaries, as well as in coastal waters (Bigelow and Schroeder 1953, Olla and Studholme 1971 in Fahay et al. 1999).

Within the Hudson River Estuary, juvenile and adult bluefish may occur in the late spring through autumn. No spawning would occur within the study area and no bluefish eggs or larvae have been collected during utilities-sponsored fish surveys conducted from 1998 through 2007. Juvenile or older bluefish were captured during the 2007-2008 sampling program for the project during the warmer months of the year when higher salinities are present within the study area. Additionally, juvenile bluefish were observed in the Utilities Long River Monitoring and Fall Shoals Program collections (which are targeted to early life stages). Equally high abundances were recorded from the Battery to West Point near river mile 55, including within the project area. Very low abundances were found in the Hyde Park region and no juvenile bluefish were collected upstream of river mile 85. Peak juvenile abundances typically occur in late August and September and dwindle into late October as juveniles migrate offshore for the winter.

Historically, bluefish was categorized as overfished—the stock size was below the minimum threshold set for this species—and a rebuilding program has been implemented. However, recent estimates of fishing mortality suggest that the rebuilding program, state-by-state quota system, and recreational harvest limit have been successful (MAFMC 2002, NMFS 2003, 2004, 2005). The bluefish fishery is not currently overfished, nor considered to be approaching overfishing status (NOAA 2011).

Juvenile and adult bluefish occupy the saline portions of Hudson River estuary during summer and fall, but emigrate from the River in late fall to overwintering grounds on the continental shelf during the rest of the year. The habitat found within the Tappan Zee region of the Hudson River does not represent a significant portion of the EFH for this species. The Hudson River is not a migratory corridor for this species and individuals are not likely to occur within the study area in large numbers as suggested by fish-survey data.

Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep-water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB re 1 μPa rms guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the

river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.6 COBIA (*RACHYCENTRON CANADUM*)

Cobia are large, migratory, coastal pelagic fish of the monotypic family Rachycentridae. In the western Atlantic Ocean, cobia occur from Massachusetts to Argentina, but are most common along the south Atlantic coast of the United States and in the northern Gulf of Mexico. In the eastern Gulf, cobia migrate from wintering grounds off south Florida into northeastern Gulf waters during early spring. They occur off their northwest Florida, Alabama, Mississippi, and southeast Louisiana wintering grounds in the fall. Some cobia overwinter in the northern Gulf at depths of 100 to 125 m (328 to 410 feet). The Hudson River is within an area designated as EFH for eggs, larval, juvenile and adult cobia. However, only one collection of cobia was made during utilities-sponsored fish surveys between 1998 and 2007, which was a juvenile collected in open-water channel habitat in the Yonkers region during late August. Eggs and larval cobia have not been reported from these surveys in the Hudson River.

Information on the life history of cobia from the Gulf and the Atlantic Coast of the United States is limited. Essential fish habitat for coastal migratory pelagic species such as cobia includes sandy shoals of capes and offshore bars, high profile rocky bottom and barrier island ocean-side waters, from the surf to the shelf break zone, but from the Gulf Stream shoreward, including areas inhabited by the brown alga *Sargassum*. For cobia, essential fish habitat also includes high salinity bays, estuaries, and seagrass habitat. The Gulf Stream is an essential fish habitat because it provides a mechanism to disperse coastal migratory pelagic larvae. Preferred temperatures are greater than 20°C and salinities are greater than 25 ppt.

Cobia are likely to occur only as rare transient individuals within thestudy areadue to its coastal migrations, pelagic nature, and salinity requirements. Individuals would have the potential to occur during periods of low freshwater flows when the salt front is pushed upriver. The habitat found within the Tappan Zee Region of the Hudson River does not represent a significant portion of the EFH for this species and individuals would not be expected to occur within the study area except as rare transient individuals..Therefore, the project would not result in adverse impacts to the EFH for this species. The habitat found within the Tappan Zee Region of the Hudson River does not represent a significant portion of the EFH for this species. This species would not be expected to occur near the project site except as rare transient individuals. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.7 KING MACKEREL (*SCOMBEROMORUS CAVALLA*)

King mackerel is a marine species that inhabits Atlantic coastal waters from the Gulf of Maine to Rio de Janeiro, Brazil, including the Gulf of Mexico. There may be two distinct populations of king mackerel. One group migrates from waters near Cape Canaveral, Florida south to the Gulf of Mexico, making it there by spring and continuing along the western Florida continental shelf throughout the summer. A second group migrates to waters off the coast of the Carolinas in the summer, after spending the spring in the waters of southern Florida, and continues on in the autumn to the northern extent of the range. The Hudson River is within an area designated as EFH for eggs, larval, juvenile, and adult king mackerel.

Overall, temperature appears to be the major factor governing the distribution of the species. The northern extent of its common range is near Block Island, Rhode Island, near the 20°C (68°F) isotherm and the 18-meter (59 ft) contour. King mackerel spawn in the northern Gulf of Mexico and southern Atlantic coast. Larvae have been collected from May to October, with a peak in September. In the south Atlantic, larvae have been collected at the surface with salinities ranging from 30 to 37 ppt and temperatures from 22 to 28°C (70-81°F). Adults are normally found in water with salinity ranging from 32 to 36 ppt (USACE 2000).

Due to salinity requirements, king mackerel are not likely to be present within the Hudson River in the study area except during periods of low freshwater flows when the salt front is pushed upriver. This species has not been collected during utilities-sponsored fish monitoring in the Hudson River. The habitat found within the Tappan Zee Region of the Hudson River does not represent a significant portion of the EFH for this species. This species would not be expected to occur near the project site except as rare transient individuals. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.8 RED HAKE (*UROPHYCIS CHUSS*)

Red Hake is a bottom-dwelling fish that lives on sand and mud bottoms along the continental shelf from southern Nova Scotia to North Carolina (concentrated from the southwestern part of the Georges Banks to New Jersey). Spawning adults and eggs are common in marine portions of most coastal bays between Rhode Island and Massachusetts. Spawning occurs from May to June in the New York Bight (Steimle et al 1999a). The Hudson River is within an area designated as EFH for larval, juvenile, and adult red hake.

Larval red hake are free floating and occur in the middle and outer continental shelf. They are most common in water temperatures from 11 to 19°C (52-66°F) and depths from 10 to 200 m (33-660 ft). Recently metamorphosed juveniles remain pelagic (i.e. in the water column) for approximately two months, during which time they achieve growth up to 25-30 mm (1.0-1.2 in) in total length. Shelter/structure is a critical habitat requirement for juvenile red hake. In the autumn, juveniles descend from the water column to the bottom and seek sheltering habitat in depressions in the sea floor. Juvenile settlement usually occurs in October and November. Older juveniles use scallop shells, mussel beds, moon snail egg collars, and other available structure until their second autumn when they move inshore to waters less than 55 m (180 ft) in depth. They typically remain inshore until the temperature reaches 4°C (39°F), at which point they migrate offshore to overwinter (USACE 2000, Steimle et al. 1999a).

Woodhead (1990) describes red hake as a common resident of the New York Harbor system. In the Harbor Estuary, the distribution of red hake is influenced by salinity, water temperature, and dissolved oxygen. Juvenile red hake were collected when salinity was greater than 22 ppt and at depths from 5 to 50 m (16-164 ft) deep. Collections tapered off when salinity reached greater than 28 ppt. Adult red hake prefer temperatures from 2 to 22°C (36-72°F), salinity ranging from 20 to 33 ppt and depths greater than 25 m (82 ft) deep. In Middle Atlantic Bight, red hake occur most often in coastal waters in the spring and autumn, moving offshore to avoid warm summer temperatures. Additionally, red hake have been reported to be sensitive to dissolved oxygen levels and within the Hudson River Estuary they preferred dissolved concentrations of 6 mg/L or more (Steimle et al. 1999a).

Within the study area, juvenile and adult red hake have the potential to occur in the deeper waters of the Hudson River, but may be limited by occasional low DO concentrations and low salinity. The study area represents a small portion of the EFH for this species. Eggs of this

species have been reported at very low densities in early spring (March-April), but were limited primarily to the lower estuary from the Battery to Yonkers at river mile 23 based on utilities-sponsored fish surveys conducted between 1998 and 2007. Several collections of red hake eggs have also been reported from the Cornwall region (river miles 56-61) upstream of the project area, but no red hake eggs have been collected in the Tappan Zee region during these surveys. Larvae of this species have not been reported to occur in the River, however, juvenile red hake have been collected from the Battery in the lower Hudson River estuary in bottom habitat deeper than 20 feet. Juveniles typically occur in this region of the River during spring (April-May) and late fall (November-December), but have not been documented from the project area during these surveys.

In 1999, the NOAA Technical Memo for the species indicated that the red hake are managed as two U.S. stocks: a northern stock, from the Gulf of Maine to northern Georges Bank and a southern stock, from southern Georges Bank into the Middle Atlantic Bight (Steimle 1999a). The southern stock index was relatively stable from the mid-1960s until the 1980s when it declined with a short period of increase about 1990-1991. The southern stock (or overall stock) is not currently considered overfished and no management action is considered required (NMFS 2011b).

Because the Tappan Zee region of the Hudson River is marginal habitat for red hake in terms of normal salinity ranges and the Hudson River is not a migratory corridor for the species, this species is not likely to occur in the project area in large numbers. Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB re 1 μPa rms guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.9 SCUP (*STENOTOMUS CHRYSOPS*)

Scup is a marine fish that occurs primarily on the continental shelf from Cape Cod, Massachusetts to Cape Hatteras, North Carolina. It migrates extensively from inshore summer grounds to offshore winter grounds. Scup arrive in the waters off New Jersey and New York by early May. During the summer months, older fish (four years old or older) tend to stay in the inshore waters of the bays while the younger fish are found the more saline waters of estuaries such as the New York Harbor Estuary. Spawning occurs in May through August with a peak in

June and occurs principally in the estuaries of New York and New Jersey. Juveniles grow quickly and migrate with the rest of the population to offshore wintering grounds starting in late October. They usually are absent from inshore waters by the end of November (USACE 2000). The Hudson River is within an area designated as EFH for eggs, larval, juvenile, and adult scup.

Scup eggs are buoyant and are rather small (0.8 to 1.0 mm [0.03-0.04 in]), hatching in about 2-3 days depending on temperature. Most were collected from May-August at depths less than 50 m (164 ft) and at temperatures ranging from 11-23°C (52-73°F) (Steimle et al. 1999c). Newly hatched larvae are pelagic and approximately 2 mm (0.08 in) long. In approximately three days following hatching, diagnostic characteristics of the species are evident. Shortly thereafter, the larvae abandon the pelagic phase and become bottom dwelling. They occur in water with temperatures ranging from 14-22°C (57-72°F) and occupy more saline (23-33 ppt) portions of estuaries. They are often found within the water column at depths less than 50 m (164 ft) (Steimle et al. 1999c).

Juveniles from 15-30 mm (0.6-1.2 in) and up to 10 cm (4 in) are common during November. By the end of their first year they can reach up to 16 cm (6.3 in). Juveniles inhabit estuarine areas at depths of 5-12 m (16-39 ft), particularly areas with sand and mud substrates or mussel and eelgrass beds. Juveniles prefer temperatures from about 9-27°C (48-81°F) and salinities greater than 15 ppt (Steimle et al. 1999c). Scup males and females reach sexual maturity at age two and reach about 15.5 cm (6 in).

In the New York Harbor Estuary, spawning occurs primarily in the Lower New York Bay and the Eastern Long Island Bay (USACE 2000) and would be unlikely to occur within the vicinity of the study area. However, eggs and larval scup were not collected in the project area or within the Hudson River estuary during utilities-sponsored fish surveys conducted between 1998 and 2007. Juveniles were observed in low abundance, primarily in the lower reaches of the River from the Battery to Yonkers near river mile 23, but were also collected as far upstream as Indian Point above the project area. Juvenile scup were present in the vicinity of the project area in bottom habitats in waters deeper than 20 feet from late July into August. Woodhead (1990) reports that scup is a common summer transient in the New York Harbor. Although overfishing of the scup stock is occurring (NMFS 2004), the rebuilding schedule and management measures implemented in 1996 have resulted in a dramatic increase in scup abundance. The scup fishery is not currently overfished or approaching an overfished condition (NOAA 2011).

Because the Tappan Zee region of the Hudson River is marginal habitat for scup in terms of normal salinity ranges and the Hudson River is not a migratory corridor for the species, this species is not likely to occur in the study area in large numbers. Adults and juveniles would have the potential to occur from July through November with freshwater flows are lower and the salinity is higher. Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB RMS guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment

resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.10 SPANISH MACKEREL (*SCOMBEROMORUS MACULATUS*)

Spanish mackerel is a marine species that can occur in the Atlantic Ocean from the Gulf of Maine to the Yucatan Peninsula. The Hudson River is within an area designated as EFH for eggs, larval, juvenile, and adult Spanish mackerel. This species occurs most commonly between the Chesapeake Bay and the northern Gulf of Mexico from spring through autumn, and then over-winters in the waters of south Florida. Spanish mackerel spawn in the northern extent of their range (along the northern Gulf Coast and along the Atlantic Coast). Spawning begins in mid-June in the Chesapeake Bay and in late September off Long Island, New York. Temperature is an important factor in the timing of spawning and few spawn in temperatures below 26°C (79°F). Spanish mackerel apparently spawn at night. Studies indicate that Spanish mackerel spawn over the Inner Continental Shelf in water 12-34 m (39-112 ft) deep.

Spanish mackerel eggs are pelagic and about 1 mm in diameter. Hatching takes place after about 25 hours at a temperature of 26°C. Most larvae have been collected in coastal waters of the Gulf of Mexico and the east coast of the United States and no eggs or larvae of this species have been collected in the Hudson River during utilities-sponsored fish surveys conducted between 1998 and 2007. Juvenile Spanish mackerel can use low salinity estuaries (~12.8 to 19.7 ppt) as nurseries and also tend to stay close inshore in open beach waters (USACE 2000). Only one juvenile Spanish mackerel was collected in the Hudson River within the Tappan Zee region. This individual was observed in the deep channel habitat during late September.

Overall, temperature and salinity are indicated as the major factors governing the distribution of this species. The northern extent of their common range is near Block Island, Rhode Island, near the 20°C (68°F) isotherm and the 18 meter contour. During warm years, they can be found as far north as Massachusetts. They prefer water from 21 to 27°C (70-81°F) and are rarely found in waters cooler than 18°C (64°F). Adult Spanish mackerel generally avoid freshwater or low salinity (less than 32 ppt) areas such as the mouths of rivers (USACE 2000).

Because this is a marine species that prefers higher salinity waters, Spanish mackerel are not likely to be present within the study area except during periods of low freshwater flows when the salt front is pushed upriver. The habitat found within the Tappan Zee Region of the Hudson River does not represent a significant portion of the EFH for this species. This species would not be expected to occur near the project site except as rare transient individuals. Therefore, the project would not result in adverse impacts to EFH for this species.

4.3.11 SUMMER FLOUNDER (*PARALICHTHYS DENTATUS*)

Summer flounder prefer the estuarine and shelf waters of the Atlantic Ocean and are found between Nova Scotia and southeastern Florida. They are most abundant from Cape Cod, Massachusetts, to Cape Hatteras, North Carolina. Summer flounder usually appear in the inshore waters of the New York Bight in April, continuing inshore in May and June, and reach their peak abundance in July and August. Spawning takes place in the New York Bight in nearshore

waters outside estuarine systems in September to October. Spawning occurs in surface water temperatures of 7-14°C (45-57°F), with peak activity occurring around 10-12°C (50-54°F) (Packer et al. 1999). The Hudson River is within an area designated as EFH for larval, juvenile, and adult summer flounder.

Larvae occur in water from 0 to 22°C (32-72°F) and are transported to estuarine nurseries by currents. Juvenile summer flounder are well adapted to the temperature and salinity ranges present in estuarine habitats. They are distributed throughout the estuary prior to late summer and are more concentrated in sea grass beds (as opposed to tidal marshes) in the late summer and early autumn (USACE 2000). Planktonic larvae (2-13 mm [0.08-0.5 in]) have been found in temperatures ranging from 0-23°C (32-73°F), but are most abundant between 9°C and 17°C (48-63°F). Salinity preference within the New York area for this species was found between 20-30 ppt. In the Mid -Atlantic Bight, larvae were found at depths from 10-70 m (33-230 ft). Greater densities of young fish were found in or near inlets (Packer et al. 1999).

Young summer flounder move into shallow estuaries (i.e. 0.5-5.0 m [1.6-16 ft] in depth) using these areas as nursery habitat in the autumn, summer, and spring months. Juvenile summer flounder are able to withstand a wider range of temperatures (greater than 11°C [52°F]) and salinities from 10-30 ppt than many species, and have evolved this tolerance to exploit estuarine nursery areas. Juveniles can be found on mud and sand substrates in flats, channels, salt marsh creeks, and eelgrass beds (Packer et al. 1999).

Adult summer flounder feed both in the shelf waters and estuaries and are more active in the daylight hours; they generally feed by sight (USACE 2000). Adults are found to grow to lengths ranging from 25-71 cm (10-28 in). They inhabit sand substrates at depths up to 25 m (82 ft), at temperatures ranging from 9-26°C (48-79°F) in the autumn, 4-13°C (39-55°F) in the winter, 2-20°C (36-72°F) in the spring, and 9-27°C (48-81°F) in the summer. Salinity is known to have a minor effect on distribution as compared to substrate preference (Packer et al. 1999).

In 2002, the stock was considered overfished and was in the 8th year of a 10-year rebuilding program (NMFS 2003, MAFMC 2002). The latest stock assessment for summer flounder indicates that management measures have been successful. The resource is no longer overfished although overfishing is currently occurring (NMFS 2005). The summer flounder fishery is not overfished and is currently rebuilding (NOAA 2011).

Summer flounder eggs have not been reported from utilities-sponsored fish surveys conducted in the Hudson River from 1998 to 2007. Larval summer flounder, however, are frequently collected during the spring (March-April) in the lower estuary near the Battery (river miles 0-11). Juvenile and adult summer flounder have the potential to occur in the Hudson River within the study area during the warmer months. Juveniles, in particular are often collected in bottom habitats at depths exceeding 20 feet from the Battery to Tappan Zee during the spring (March-April) and again in October. Additionally, summer flounder were captured during the 2007-2008 sampling program for the project during the warmer months of the year when higher salinities are present within the study area.

Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the

maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB re 1 μPa rms guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Furthermore, because summer flounder do not have a swim bladder, the likelihood of physical damage is far lower than for fish species with a swim bladder. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Loss of bottom habitat due to the placement of the piles and other structures (including armoring of the dredged channel) would be minimal and would not be expected to result in significant reductions in fish habitat or prey availability. Furthermore, the loss of these habitats will be fully or nearly fully offset by the removal of the existing bridge and associated piles to below the mud line. The small incremental increase in overwater shading resulting from the proposed project would also be offset by the removal of the existing bridge. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.12 WINTER FLOUNDER (*PSEUDOPLEURONECTES AMERICANUS*)

Winter flounder typically are found from Labrador to North Carolina, but are most common in estuaries from the Gulf of St. Lawrence to the Chesapeake Bay (Bigelow and Schroeder 1953, Heimbuch et al. 1994, USACE 2000). This fairly small, thick flatfish is abundant in the Hudson River Estuary, where it is a resident, but may move upriver into fresh water (Heimbuch et al. 1994). It spawns during the winter and early spring, typically at night in shallow, inshore estuarine waters with sandy bottoms. Woodhead (1990) reports spawning to occur mostly in the Lower New York Bay and the New York Bight. The Hudson River is within an area designated as EFH for eggs, larval, juvenile, adult, and spawning adult winter flounder.

Winter flounder have negatively buoyant eggs that clump together and sink following fertilization (Heimbuch et al. 1994, USACE 2000). Optimal egg hatching occurs at 3°C (37°F) and in salinity ranging from 15 to 25 ppt. Winter flounder larvae develop to juveniles within the estuarine systems. In March, April and May, winter flounder larvae can be found in the Upper New York Bay near the bottom (Heimbuch et al. 1994).

For the first summer, young-of-year winter flounder remain in the shallow waters (0.1-10 m [0.2-33 ft] in depth) of bays and estuaries where temperatures are generally less than 28°C (82°F) and salinities range from 5-33 ppt. Juveniles often occupy areas with sand and/or mud substrates where they feed on a variety of worms and small crustaceans, switching to mostly mollusks as they grow. Juveniles beyond their first year have also been found to overwinter in estuaries at temperatures less than 25°C (77°F), salinities from 10-30 ppt, and depths from 1-5 m (3-16 ft) (Pereira et al. 1999). However, in some studies, wintertime juvenile catches generally increased outside of the estuary while at the same time decreasing within the estuary, suggesting that juveniles migrate out of the estuary in the winter (Pearcy 1962, Warfel and Merriman 1944, and Richards 1963 in Pereira et al. 1999).

Adult winter flounder prefer depths of 20 to 48 m (66-158 ft) and are commonly associated with mud, sand, pebble, or gravel bottoms (USACE 2000), feeding on small invertebrates and fishes. Because they are sight feeders, increased turbidity can interfere with feeding success (USACE

2000).. Adults generally leave the Hudson River Estuary in the summer as water temperatures increase, returning in the autumn (Woodhead 1990). Winter flounder will live close to shore, swimming in shallow water to feed. Adults tend to move to deeper water when water temperatures increase in the summer or decrease in the autumn and winter (Heimbuch et al. 1994). NMFS Northeast Fisheries Science Center (NEFSC) trawls within the New York Harbor Estuary found adult winter flounder at temperatures between 4°C and 12°C (39-54°F) and salinities as low as 15 ppt, although most were found at salinities greater than 22 ppt. The bulk of the adult catch occurred in water depths of 25 m (82 ft) or less in the spring (during and just after spawning) and 25 m or deeper in the autumn (prior to spawning) (Pereira et al. 1999).

All stages of this demersal fish have the potential to occur within the Hudson River in the study area. Winter flounder eggs have been reported in the lower estuary from the Battery to Yonkers near river mile 23 during spring (March and April) , but have not been collected in the Tappan Zee region based on utilities-sponsored fish monitoring data. However, larvae are distributed throughout the River and are commonly observed in most habitats between March and June with peak abundances in the project area during mid-April.

Within the Hudson River, young-of-the-year are most abundant from the mouth of the River at the Battery upriver to Indian Point (river mile 46). Juvenile winter flounder may occur from early April through December, although they are most abundant in the River between April and July, with peak densities in the Tappan Zee region during May and June, based on utilities-sponsored fish surveys conducted from 1998 to 2007. While in the estuary, juvenile winter flounder are most commonly collected in the deeper channel habitats at depths exceeding 20 feet. Catches of winter flounder in the Hudson River Estuary off Manhattan have been reported to be highest from May through June (Woodhead 1990). Older winter flounder have been found in the Harbor Estuary from late May to September (Heimbuch et al. 1994).

While winter flounder are found throughout the Hudson River Estuary, this species is currently experiencing high fishing rates that are in excess of natural production (annual exploitation rates from 55 to 70 percent). The Southern New England/Mid-Atlantic stock unit (which includes the New York population), is subject to overfishing and is considered overfished with reduced harvest currently needed for the fishery to rebuild (NOAA 2011).

Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB re 1 µPa rms guidance for behavioral effect. Furthermore, because winter flounder do not have a swim bladder, the likelihood of physical damage is far lower than for fish species with a swim bladder. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Loss of

bottom habitat due to the placement of the piles and other structures (including armoring of the dredged channel) would be minimal and would not be expected to result in significant reductions in fish habitat or prey availability. Furthermore, the loss of these habitats will be fully or nearly fully offset by the removal of the existing bridge and associated piles to below the mud line. The small incremental increase in overwater shading resulting from the proposed project would also be offset by the removal of the existing bridge. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

4.3.13 WINDOWPANE (*SCOPHTHALMUS AQUOSUS*)

Windowpane, also called sand flounder, is found from the Gulf of St. Lawrence to South Carolina and maximally abundant in the New York Bight. Windowpanes are generally found offshore on sandy bottoms in water between 80 m deep (262 ft) and close inshore in estuaries just below the mean low water mark. They migrate inshore into shallow shoal waters in the summer and early autumn as water temperatures increase, and migrate offshore during the winter and early spring months when temperatures decrease. Windowpanes spawn within the mid-Atlantic Bight from April to December in bottom waters, with temperatures ranging from 8.5 to 13.5°C (47-56°F). Spawning peaks occur in May and then again in the autumn in the southern portion of the Bight (USACE 2000). The Hudson River is within an area designated as EFH for eggs, larval, juvenile, adult, and spawning adult windowpane.

The eggs and larvae are found predominately in the estuaries and coastal shelf water for the spring spawning period and in the coastal shelf waters alone for those eggs spawned in the autumn. Windowpane eggs are buoyant, and can be found in the water column at temperatures of 5-20°C (41-68°F), specifically at 4-16°C (39-61°F) in spring (March through May), 10-16°C (50-61°F) in summer (June through August), and 14-20°C (57-68ºF) in autumn (September through November), and within depths less than 70 m (230 ft) (Chang et al. 1999). Larvae are free swimming, and typically are found in the areas of the estuaries where salinity ranges from 18 to 30 ppt in the spring and on the continental shelf in the autumn. Juvenile windowpanes were found year-round in both the shelf waters and inshore during a recent study of the New York Harbor Estuary (Chang et al. 1999). In this study, juvenile fish were fairly evenly distributed but seemed to prefer the deeper channels in the winter and summer. They were most abundant where bottom water temperatures ranged from 5 to 23°C (41-73°F), depths ranged from 7 to 17 m (23-56 ft), salinities ranged from 22 to 30 ppt, and dissolved oxygen concentrations ranged from 7 to 11 mg/L. Similarly, adults were fairly evenly distributed year-round, preferring deeper channels in the summer months. Adults were collected in bottom waters where temperatures ranged from 0 to 23°C (32-73°F), depths were less then 25 m (82 ft), salinity ranged from 15 to 33 ppt, and dissolved oxygen ranged from 2 to 13 mg/L (USACE 2000).

All life stages of windowpane have the potential to occur within the vicinity of the study area in the Hudson River. Eggs have been reported from the lower estuary from the Battery to Yonkers near river mile 23 during much of the year (March to October), Some windowpane eggs have been collected in the vicinity of the project area near Tappan Zee, primarily in May and June, but abundances there are lower than those observed near the mouth of the River. Larval and juvenile windowpane have been frequently collected during utilities-sponsored fish surveys in the River, where highest abundances were typically reported in the lower estuary near the Battery (river mile 0-11). Relatively high abundances were also observed in the Yonkers and Tappan Zee regions, with less abundances further upstream to West Point near river mile 55.

Larval windowpanes recruit to channel and bottom habitats in the deeper portion of the River (>20 feet deep) during May and June. Juveniles are most abundant in the project area in the Tappan Zee region during June. The southern New England/Middle Atlantic windowpane stock is currently considered to be subject to overfishing but no longer overfished and the Southern New England/Mid-Atlantic stock is rebuilding (NOAA 2011). As with winter flounder, this species is widely distributed throughout the Harbor Estuary.

Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB RMS guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Furthermore, because windowpane do not have a swim bladder, the likelihood of physical damage is far lower than for fish species with a swim bladder. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH for this species and would not be expected to affect movement of this species within the river. Water quality changes, including the resuspension of bottom sediments, during construction of the proposed project would be minimal and temporary, limited to the immediate area of the activity. Loss of bottom habitat due to the placement of the piles and other structures (including armoring of the dredged channel) would be minimal and would not be expected to result in significant reductions in fish habitat or prey availability. Furthermore, the loss of these habitats will be fully or nearly fully offset by the removal of the existing bridge and associated piles to below the mud line. The small incremental increase in overwater shading resulting from the proposed project would also be offset by the removal of the existing bridge. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH for this species.

Chapter 5: Potential Impacts to Marine Turtles

Four species of marine turtles, all state and federally listed, occur in coastal areas around the mouth of the Hudson River. Juvenile Kemp's ridley (*Lepidochelys kempii*) and large loggerhead (*Caretta caretta*) turtles are most common and regularly enter the New York Harbor and bays in the summer and fall. The other two species, green sea turtle (*Chelonia mydas*) and leatherback sea turtle (*Dermochelys coriacea*), are usually restricted to the high salinity areas of New York Harbor (USFWS 1997) and do not routinely move into the Hudson River as far upstream as the Tappan Zee region. These turtle species primarily inhabit Long Island Sound and Peconic and Southern Bays. They neither nest in the Hudson River Estuary, nor do they reside there year-round (Morreale and Standora 1995). It is unlikely that individuals of these four turtle species would occur in the study area (NMFS 2011b). Therefore, the project would not result in adverse impacts to marine turtles.

Chapter 6: Potential Impacts on Striped Bass

Striped bass (*Morone saxatilis*) are anadromous, spending most of their life cycle in the marine environment but returning to fresh water to reproduce. They are native to North America and range along the Atlantic coast from the St. Lawrence River in Canada to the St. Johns River in northern Florida and from western Florida to Louisiana along the coast of the Gulf of Mexico. The Hudson River supports one of several principal spawning populations, which also include Delaware Bay, Chesapeake Bay, the Roanoke and Chowan rivers and Albemarle Sound, North Carolina, the Santee River in South Carolina and the St. Johns River in northern Florida.

Adult striped bass on the Atlantic coast feed in nearshore waters from summer through late winter. Northward migration of Hudson River fish extends as far north as the Bay of Fundy, Nova Scotia, with older fish tending to travel further north (Waldman et al. 1990). Over the winter, adult striped bass (ages 4 and older) aggregate near the mouths of their natal rivers and begin moving upstream to spawn as water temperatures increase in the spring. Spawning begins in the spring when water temperatures reach about 57°F. Peak spawning typically occurs at about 60 to 65°F in freshwater areas of estuaries where currents are moderate to swift (CHGE et al. 1999). In the Hudson River, spawning occurs primarily between mid-May and mid-June in the middle portion of the Hudson River Estuary from Indian Point (RM 42) upstream to Saugerties (RM 106) (CHGE et al. 1999; ASA 2010). Depending on their age and size, females produce up to several million pelagic eggs. Based on utilities fish surveys from 1998 to 2007, striped bass eggs are collected in May and June and primarily upstream of Indian Point at river mile 46, with peak densities near Cornwall (river mile 56-61) and very low densities in the Tappan Zee region. Yolk-sac larvae (YSL) hatch from the eggs in 25 to 109 hrs, depending on temperature. Typically 0.125-inches long at hatching, the YSL initially drift with the current. Older YSL are mobile and exhibit positive phototaxis, or movement toward light (CHGE et al. 1999).

Larval striped bass recruit to the River during summer (May-July) and are abundant throughout the Hudson River but occur in higher numbers from Tappan Zee to Hyde Park than in the lower estuary. The higher numbers of striped bass larvae in the upstream reaches of the Hudson River are a result of spawning in the Croton-Haverstraw reach and further north.

As juveniles, striped bass begin move out of the middle estuary into the broader, shallower nursery habitat of the lower estuary (Tappan Zee through Croton-Haverstraw Bays, RM 24 through RM 38) to feed on copepods and amphipods. Larger juveniles feed on insect larvae, worms, opossum shrimps, crabs and small fish (Gardinier and Hoff 1982). Juvenile abundances are typically highest during late summer (July and August) and upstream Hyde Park in deeper (>20-ft) bottom habitats. In the Tappan Zee region, juvenile striped bass are frequently collected in shallow shoal and deeper bottom habitat, as well.

By the end of their first summer, many juvenile striped bass have moved downstream to the lower estuary and into New York Harbor, western Long Island Sound and along the south shore of Long Island (CHGE et al. 1999; Dunning et al. 2009). Juvenile striped bass overwinter in the lower Hudson River estuary, where they feed primarily on benthic invertebrates, such as gammarid amphipods (Dunning et al. 2009). During their second year, striped bass become largely piscivorous (Walter et al 2003; Dunning et al. 2009) consuming American shad, alewife, blueback herring, white perch, Atlantic tomcod and bay anchovy (Walter et al 2003; Dunning et al 1997; Heimbuch 2008). Juvenile striped bass are also prey for some marine and estuarine predator species.

At Age 2 or 3, striped bass leave Atlantic coast estuaries and begin the typical seasonal coastal migration, northward during the spring and summer and southward during the fall. Dispersal of Age 2+ striped bass out of the Hudson River is density-dependent and possibly to reduce intra-specific competition for food (Dunning et al. 2006). Striped bass in the Hudson River exhibit multiple life history strategies. Some individuals are thought to mature and remain year round in the upper freshwater portion of the estuary, while others adopt an anadromous life style and, once sexually mature, spend most of their time in coastal saltwater habitats but enter freshwater and brackish habitats in the spring to spawn (Zlokovitz et al. 2003).

Adult striped bass are top predators and are prey to few other animals. Adult striped bass in the Lower Hudson-Raritan Estuary prey upon at least 20 different taxa, dominated by a variety of small-bodied and juvenile fishes and crustaceans (Steimle et al. 2000; Dunning et al. 2009). Striped bass predation can impact juvenile abundances of prey species, including alewife and blueback herring, Atlantic tomcod, white perch, and bay anchovy (Heimbuch 2008; Schultz et al. 2006). Intraspecific predation (i.e., cannibalism) may also reduce the survival of striped bass from PYSL to juveniles (Heimbuch 2008). Since striped bass rarely move more than 10 miles offshore, they are available to sport and commercial fishermen throughout their migration route, often resulting in significant sport and commercial harvest (ASMFC 2009). The most recent stock assessment for striped bass found that the coastal stock is healthy, with spawning stock biomass well above the target level specified in the Interstate Fisheries Management Plan (ASMFC 2009) and stocks at historically high levels (NYSDEC 2010c).

The project would not result in adverse impacts to striped bass. Adult striped bass enter the Hudson River to spawn during spring and summer but spend most of their time in coastal waters, not within the study area for the project. Spawning occurs in freshwaters far upstream of the study area and would not be adversely affected by the construction or operation of the Replacement Bridge Alternative. Because striped bass spawning occurs far upriver, the majority of the larval striped bass are also located upstream of the study area. Some larvae would also drift with the prevailing current downstream and into the study area where they are very abundant during the summer. Juvenile striped bass are found in the Tappan Zee region within the study area as well. However, the highest abundances of juvenile striped bass are upstream of the study area, in the Hyde Park region. Because striped bass larvae and juveniles are widely distributed throughout the Hudson River, losses of individuals resulting from the construction of the project would not result in adverse impacts to striped bass populations of the Hudson River.

Chapter 7: Summary of Effects on EFH and Designated Species

7.1 POTENTIAL DIRECT IMPACTS

Direct effects are considered to be any adverse effects arising from project activities that could result in immediate impacts on individual fish. The primary potential direct impact to EFH species from the project is the physical disturbance to adults and juveniles as a result of pile driving, increased vessel traffic, and dredging. In the winter, few, if any, of the EFH species are likely to be in the project area because the salinity of the Hudson River within the study area would be far below the preferred salinity range. However, in the warmer months of the year several EFH species do frequent the Tappan Zee Region. Sounds from pile driving and other in-water construction activities will be temporary, and would not be expected to represent a barrier to movement of individuals within the Hudson River. Potential hydroacoustic impacts to fish using the deep water portions of the Hudson River due to pile driving with an impact hammer would only occur during the initial few months of in-water construction activities, and from April 1 to August 1 would be restricted to 5 hours per day for the 8- or 10-foot diameter piles in the vicinity of the navigation channel (i.e., Zone C— waters18 feet or deeper at MLLW).. Pile driving would not occur at night and would not be continuous during the day (i.e., when piles are being put in place or being welded, or when the pile driver is being relocated). For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width would never reach the SEL_{cum} criterion established for onset of physiological injury, and portions of the river would also be below the 150 dB re 1 μPa rms guidance for behavioral effect. Fish would not be expected to remain in an area at which noise would cause discomfort. Therefore, the hydroacoustic environment resulting from pile driving with an impact hammer would result in a temporary loss of a small area of EFH and would not be expected to affect movement of EFH species within the river. The species identified as having EFH within the study area are common throughout the waters of the Lower Hudson Estuary and it is anticipated that only a small percentage of the fish stock in the region would be potentially exposed to potential impact. None of the EFH species utilize the project area or the Tappan Zee Region as their sole spawning grounds and/or critical habitat. Therefore, pile driving with an impact hammer would not be expected to result in adverse impacts to EFH or the species identified as having EFH within the study area.

The potential direct effects associated with increases in vessel traffic within the dredged construction channel include potential collision with vessels and disturbance of foraging and migratory adults and juveniles associated with an increase in surface activity and noise. For the fish species for which EFH has been designated in the Hudson River, the effects of vessel strikes is likely a function of fish size and location within the water column; however, impacts to these (smaller) species from increased vessel traffic is more likely to occur in the form of propeller entrainment. However, the increased surface activity and associated noise would have the potential to displace/disrupt adults and juveniles during foraging and migratory activities within the vicinity of the in-water activities on a given day, which would minimize the potential for losses due to contact with vessels.

The frequency of dredging or disturbance of an area affects the invertebrate community and its ability to recover following each dredging event. For EFH that feed on benthos dredging would result in a sizable loss of bottom habitat and temporary alteration of this habitat that could affect

foraging opportunities. However, benthic communities found in environments with a great deal of variability such as estuaries generally have high rates of recovery from disturbance, because they are adapted to disturbance. Recovery of the benthic macroinvertebrate community within the dredged and armored areas is expected to start upon cessation of bottom disturbing construction activities in a particular portion of the dredged construction channel. Therefore, while the dredging would result in the loss of individual macroinvertebrates, it is not expected to result in adverse impacts of these species at the population level within the Hudson River Estuary. The majority of the bottom habitat and associated benthic macroinvertebrates within the area impacted is the soft sediment community which dominates the Upper New York Harbor and Hudson River. Deposition of sediment into the dredged channel is projected to occur at a rate of one foot per year. Recolonization by benthic organisms adapted to softer sediments could be expected to begin within a few months after completion of in-water activities in any given area. Prior to the deposition of sufficient sediment to support a soft substrate benthic invertebrate community, some recolonization of the gravel armor material would be expected occur.

7.2 POTENTIAL INDIRECT IMPACTS

Indirect effects are defined as any effects that are caused by or will result from the proposed action later in time that do not directly affect individuals but may affect them by changes in habitat. The primary potential indirect impact to EFH species from the project is the physical disturbance as a result of loss of habitat, changes in interpier water velocities, total suspended solids (TSS), re-deposition of sediments from dredging activities, and operational impacts on water quality. Loss of bottom habitat due to the placement of the piles and other structures (including armoring of the dredged channel) would be minimal and would not be expected to result in significant reductions in fish habitat or prey availability. Furthermore, the loss of these habitats will be fully or nearly fully offset by the removal of the existing bridge and associated piles to below the mud line. Therefore, habitat changes resulting from the project would not adversely affect EFH.

Water quality changes resulting from resuspension of bottom sediment during dredging and other sediment disturbing construction activities would be minimal and temporary, limited to the immediate area of the activity, and within the range of suspended sediment concentration reported for this portion of the Hudson River. Therefore increases in suspended sediment resulting from dredging and other sediment disturbing construction activities would not adversely affect EFH.

Upon completion of construction, the operational impacts of either option would be largely positive. The wider spacing of piers for both options would reduce benthic scour and allow for more sunlight to enter the water column; thereby, reducing the conditions currently experienced along the western cause way of the existing bridge. The Dual Level Design Option would have wider spaced piers which would thereby further reduce interpier velocity and scour approximately 15 less acres of bottom habitat than the Single Level Design Option configuration. The Replacement Bridge Alternative would result in a decrease in the potential for shading impacts to aquatic resources and the overwater shading resulting from the proposed project would also be offset by the removal of the existing bridge. Operation of the project would not result in adverse impacts to water quality of the Hudson River, or adversely affect aquatic habitat due to under-bridge lighting. Therefore, the project would not result in adverse impacts to the EFH.

7.3 POTENTIAL CUMULATIVE IMPACTS

The assessment of cumulative effects addresses the potential impacts from the project and other projects proposed within, or in the vicinity of, the study area that may affect EFH, striped bass, and marine turtles. The proposed Champlain Hudson Power Express Inc. cable project and the American Sugar Refining, Inc. maintenance dredging project are the projects identified for evaluation of cumulative effects with the Tappan Zee Replacement Bridge Alternative because they are reasonably forseeable during construction and may use the same project area. At the present time, US Gypsum, located upriver within Haverstraw Bay, is not expected to dredge its Stony Point facility and is not, therefore, evaluated with respect to cumulative impacts for the Replacement Bridge Alternative.

Champlain Hudson Power Express Inc. filed an application for a Certificate of Environmental Compatibility and Public Need Pursuant to Article VII of the Public Service Law of New York State. The Applicant is proposing to construct and operate a 1,000 MW submarine, underground, high-voltage, direct current, cable transmission system which will transport power from Canada and upstate New York to load centers in the New York City metropolitan area. The proposal calls for burying cables within two separate trenches 6 feet apart along a 118-mile stretch of the Hudson River that includes the study area for the Tappan Zee Replacement Bridge Alternative. Within the study area, the cables would be buried through the use of water jetting, where possible, and by hydroplow or dredging where water jetting is not feasible (i.e., within Haverstraw Bay).

Depending upon the proposed timing of the submarine cable installation, there is a potential for conflict between the competing activities of the cable and Replacement Bridge Alternative that would need to be resolved for the portion of the cable that would be traversing the study area. Water jet embedment as a technique for underwater cable installation, is considered to have temporary and minimal impacts to aquatic resources compared to dredging. This is because the trench (four feet deep and two feet wide) created by the jetting device for each cable and its installation would only result in a temporary disturbance of the river bottom (ESS 2011). The associated increase in suspended sediments would also be expected to be short-term and localized because much of the resuspended sediments would be contained within the limits of the trench wall, with only a minor percentage of the re-suspended sediments leaving the trench. Any re-suspended sediments leaving the trench would be expected to settle out within proximity of the trench depending on sediment grain size, composition, water currents and the hydraulic jetting forces imposed on the sediment column (HDR/DTA, April 2010, *Champlain Hudson Power Express HVDC Transmission Project, Least Environmentally Damaging Practical Alternative Evaluation,* Prepared for Champlain Hudson Power Express, Inc., Toronto, Ontario, http://www.chpexpress.com/docs/regulatory/USACE/CHPE_USACE_Application_Apendices.pdf). Water jetting would potentially result in the loss of some benthic organisms unable to move from within the footprint of the trench, due to direct contact with the water jet or an inability to tolerate burial. The benthic community within the disturbed area would be expected to recover following completion of the trenching process (Ocean Surveys, Inc. 2005 in HDR/DTA 2010). Finfish would be expected to avoid areas of temporarily increased suspended sediment (HDR/DTA 2010).

American Sugar Refining, Inc. received authorization from the NYSDEC and the USACE to conduct maintenance dredging (approximately 80,000 cubic yards) within an approximately 5-acre berth area (approximately 650- to 850-feet long and extending into the river from the shoreline for about 300 feet) located about 14 miles downriver from the study area. The NYSDEC permit expires on October 31, 2016. It restricts dredging to the period of July 1 to

October 31 and requires that anti-sedimentation curtains (floating boom with attached silt curtain with a minimum 3-ft depth) be deployed around the spoil-receiving barge and the mechanical dredge during dredging to minimize dispersal of dredged material. Dredge material was determined to meet the requirements for disposal at the Historic Area Remediation Site (HARS) and would be transported to the HARS in bottom-opening barges.

Maintenance dredging by American Sugar Refining, should it occur concurrently with dredging for the project, would be at least 14 miles down-river. This distance is far beyond the 1,000 to 2,000 feet over which the incremental increase in suspended sediment of 10 mg/L due to the Replacement Bridge Alternative has been projected by the hydrodynamic modeling and beyond the 5 mg/L incremental increase in projected suspended sediment. Furthermore, compliance with the permit conditions would minimize the potential for the maintenance dredging to adversely affect water quality due to increased suspended sediment.

Cumulative adverse impacts to EFH, striped bass, and marine turtles would not be expected to occur as a result of the cable project and maintenance dredging activities with the Replacement Bridge Alternative. Collectively, these projects would not have the potential to affect spawning habitat within the study area for the species evaluated because the majority of the EFH spawn in the coastal and offshore waters of the Atlantic Ocean. No eggs were collected in the Tappan Zee region (RM 24-33) for 11 of the 13 EFH species. Striped bass spawn in the freshwater reaches of the Hudson River well upstream of the Tappan Zee region (RM 24-33) based on peak egg densities in the Cornwall region (RM 56-61). Eggs of Atlantic mackerel have also been reported in the Tappan Zee region, but only rarely and in very low densities, based on utilities fish surveys. The primary spawning habitat for this species is located over the continental shelf within the Mid-Atlantic Bight, with very little evidence for spawning in tidal rivers or estuaries. The primary spawning habitat for windowpane flounder is located in the nearshore coastal waters of the Mid-Atlantic Bight; however, spawning is also known to occur in the saline portions of the lower Hudson River at salinities greater than 25 ppt. Windowpane flounder eggs have been collected in low relative abundance during utilities fish surveys in the Tappan Zee region. The majority of windowpane flounder eggs are reported from the lower 23 miles between the Battery and Yonkers. On the basis of the range of preferred spawning salinities for windowpane flounder and the relatively low abundance of eggs in the Tappan Zee region, it is likely that eggs spawned downstream of the Tappan Zee study area are transported upstream on flood tides, rather than being spawned in the study area. Low densities of striped bass eggs have been reported by the utilities fish surveys from the Tappan Zee region suggesting that some spawning may occur just upstream of, or within, the study area. Based on considerably higher egg densities upstream of the project area, the low densities of striped bass eggs collected in the Tappan Zee region do not represent a significant proportion of the population's reproductive output.

The limited duration and area of disturbance resulting from cable installation within the study area would not be expected to result in changes in water quality (i.e., increases in suspended sediment) or result in long-term changes to aquatic habitat. Furthermore, the cumulative activities of these projects are not expected to adversely affect foraging or migration through the study area for EFH or striped bass. Should dredging be required for the installation of the cable in Haverstraw Bay, the distance between the study area and Haverstraw Bay is greater than 5 miles and outside the projected area of incremental increase in suspended sediment due to the project and would not result in cumulative adverse impacts to water quality within the study area. Therefore, cumulative adverse effects to water quality would not be expected to occur from these three projects.

The area of maintenance dredging for American Sugar Refining extends only 300 feet into the river from the east bank and does not extend into the navigation channel. Therefore, the three projects would not be expected to result in cumulative adverse impacts to migration of EFH or other anadromous fish species.

In summary, no cumulative adverse impacts to EFH, striped bass, and marine turtles would be expected to occur from the Replacement Bridge Alternative.

Chapter 8: EFH Assessment for Placement of Project Dredged Material at HARS

8.1 INTRODUCTION

As discussed in Section 2.4.3.3, "Transport and Disposal of Dredged Material," the disposition of the dredged material would be left to the discretion of the contractor. However, transport by ocean scow and placement in the HARS in the New York Bight would offer a number of benefits to the project including cost, schedule, logistics and the avoidance of impacts to the surrounding residential communities on the Rockland and/or Westchester shorelines. Should this option be pursued by the contractor, the dredged materials would be transported to HARS. This chapter provides:

- an overview of HARS, describing its location, the history of the site and the regulatory agencies responsible for its remediation through the placement of dredged material;
- identifies the permits required for placement of dredged material at HARS and criteria related to contaminants that must be met for placement;
- identifies the environmental reviews and consultations that have been undertaken for remediation of HARS, including the programmatic EFH for Placement of Category I Dredged Material at the Historic Area Remediation Site in the New York Bight Apex;
- summarizes the findings from the "*Programmatic Essential Fish Habitat Assessment for Placement of Category I Dredged Material at the Historic Area Remediation Site in the New York Bight Apex* (USACE 2002), the measures incorporated in the Site Management and Monitoring Plan for the Historic Area Remediation Site (USACE and USEPA 2009) to manage the operational aspects of dredging, HARS remediation activities and HARS monitoring;
- summarizes the existing habitat at the HARS;
- identifies the volume and characteristics of dredged material from the project that would be placed at the HARS as Remediation Material;
- evaluates potential adverse impacts to aquatic biota and EFH from offshore dredged material disposal at the HARS;
- provides profiles for the EFH species currently identified as having EFH in the vicinity of the HARS that were not evaluated in the programmatic EFH for HARS (i.e., clearnose skate, little skate, smooth dogfish, thresher shark and winter skate) and describes the applicability of the Programmatic EFH assessment for HARS to the project; and
- evaluates potential direct, indirect and cumulative impacts to EFH due to placement of dredged material from the project at the HARS.

8.2 BACKGROUND

The HARS is located approximately 4 miles (3.4 nautical miles) east of Highlands, New Jersey and about 9 miles (7.7 nautical miles) south of Rockaway, Long Island (see Figure 32). It comprises about 20 square miles (15.7 square nautical miles) within the apex of the New York

Bight[1] that includes the approximately 3-square-mile (2.2-square nautical mile) Mud Dump Site (MDS). Over the past century, dredged material from the Port of New York and New Jersey was routinely disposed of at the MDS. The USEPA formally designated the MDS as an "interim" ocean dredged material disposal site in 1973, and gave it final designation in 1984. On September 29, 1997, the USEPA under 40 CFR §228, closed MDS and simultaneously re-designated the site and surrounding areas that were used historically as disposal sites for contaminated dredged material as the Historic Area Remediation Site (HARS), and proposed that the site be managed to reduce impacts to acceptable levels (in accordance with 40 CFR §228.1(c)) (62 FR 46142) through remediation with uncontaminated dredged material (Remediation Material)(i.e., dredged material that meets current Category I standards[2] and will not cause significant undesirable effects, including through bioaccumulation)(USACE and USEPA 2009). USEPA published final rule 67 FR 62659 on March 17, 2003, to modify the designation of the HARS to establish a HARS-specific worm tissue polychlorinated biphenyl (PCB) criterion of 113 parts per billion (ppb) for use in determining the suitability of proposed dredged material for use as Remediation Material. This amendment to the HARS designation established a pass/fail criterion for evaluating PCBs in worm tissue from bioaccumulation tests performed on dredged material proposed for use at HARS as Remediation Material (USACE and USEPA 2009).

The HARS comprises three areas (see Figure 33): Priority Remediation Area (PRA), a 12 square-mile (9 square nautical miles) area to be remediated with at least about 3 feet (1 meter) of Remediation Material which is divided into 9 areas; a Buffer Zone, a 0.3-mile-wide (0.27 nautical miles) band around the PRA in which no placement of Remediation Material will be allowed, but may receive Remediation Material that incidentally spreads out of the PRA; and No Discharge Zone, an approximately 1.3-square-mile (1 square nautical mile) area in which no placement or incidental spread of Remediation material is allowed. From 1997 through December 2008, approximately 36 million cubic yards (MCY) of Remediation Material from 61 dredging projects have been placed at HARS as part of the remediation. These remediation projects have included private and Federal maintenance dredging and private and federal deepening projects, with the majority of the Remediation Material (approximately 26 MCY) from Federal Deepening projects. Of the nine PRAs at HARS, only the western PRAS (PRAS 1 through 4) have been remediated. As of 2008, about 13 percent, 17 percent, 64 percent, and 86

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[1] The New York Bight is a region defined as ranging from Cape Cod, MA, to Cape May, NJ, and includes Buzzard's Bay, Long Island Sound, New York Harbor and the New Jersey shore (http://web2.uconn.edu/seagrantnybight/).

[2] USEPA Region 2 and USACE New York District classify dredged material into three categories on the basis of sediment toxicity and bioaccumulation tests:

- Category I: Sediments that meet ocean disposal criteria. Test results indicate no unacceptable toxicity or bioaccumulation. These sediments are acceptable for "unrestricted" ocean disposal. There are no potential short-term (acute) impacts or long-term (chronic) impacts; no special precautionary measures are required during disposal.

-Category II: Sediments that meet ocean disposal criteria. Test results indicate no significant toxicity but a potential for bioaccumulation. To protect from this potential, EPA and the USACE will require appropriate management practices such as capping. This is referred to as "restricted" ocean disposal.

-Category III: Sediments that do not meet ocean disposal criteria. These sediments are those that fail acute toxicity testing or pose a threat of significant bioaccumulation that cannot be addressed through available disposal management practices. These sediments cannot be disposed in the ocean.

percent of the area in PRAs 1, 2, 3, and 4, respectively, and PRAs 5 through 9 are available for Remediation Material.

U.S. Army Corps of Engineers (USACE) New York District and the U.S. Environmental Protection Agency (USEPA) Region 2 jointly manage the HARS in accordance with the *Site Management and Monitoring Plan for the Historic Area Remediation Site* revised May 5, 2009 (SMMP)(USACE and USEPA 2009). The SMMP:

- provides guidelines to document remediation of required areas within the HARS resulting from placement of an approximately 3-foot (1 meter) minimum required cap thickness of Remediation Material;
- specifies the collection of data to ensure that no significant adverse environmental impacts occur from the placement of Remediation Material at the HARS;
- enforces compliance with Marine, Protection, Research and Sanctuaries Act of 1972 (MPRSA) permit conditions;
- provides a baseline assessment of conditions at the HARS;
- provides a program for monitoring the HARS;
- describes special management conditions/practices to be implemented at the HARS;
- specifies the quantity of Remediation Material to be placed at the HARS ant the presence, nature, and bioavailability of the contaminants in Remediation Material;
- specifies the anticipated use of the HARS, including the closure date; and
- provides a schedule for review and revision of the HARS SMMP.

Under MPRSA, the USACE and USEPA share responsibility for permitting and HARS designation and management. Placement of dredged material as Remediation Material at the HARS requires a permit from USACE under Section 103 of the MRPSA, subject to USEPA review and concurrence that the material meets applicable ocean disposal criteria. Placement of non-dredged material as Remediation Material at the HARS requires a permit from the USEPA under Section 102 of the MPRSA. To receive the permit, the materials must be suitable for remediation, in that they meet certain criteria related to contaminants based on sediment toxicity and bioaccumulation tests. In addition, in accordance with 40 CFR §227.16, the USEPA must evaluate alternative disposal options before permitting placement of dredged material at the HARS, and must find that there are no practicable alternative locations and methods of disposal or recycling available. In support of this required finding, and alternatives analysis can be found in Appendix F-4 to the Draft Environmental Impact Statement documenting that there are no practicable alternative locations for the placement of the dredged material at the HARS site.

8.3 AGENCY CONSULTATIONS

8.3.1 NEPA AND SECTION 7 CONSULTATION

Pursuant to the National Environmental Policy Act (NEPA) the USEPA Region 2 prepared a Supplemental to the Environmental Impact Statement (SEIS) on the Dredged Material Disposal Site Designation for the Designation of the HARS (USEPA 1997). Consultations pursuant to Section 7 of the Endangered Species Act (ESA) have taken place for the area of the HARS during preparation of the SEIS. The USEPA prepared a biological assessment that concluded

that the closure of the Mud Dump Site and designation of the HARS would not be likely to adversely affect loggerhead and kemps ridley sea turtles and humpback and fin whales (USEPA 1997). Special conditions are included in USACE Section 103 permits for placement of Remediation Material at HARS that requires the presence of NMFS approved Endangered Species Observer(s) on disposal scows during their trips to the HARS. The role of these observers is to prevent adverse impacts to endangered or threatened species transiting the area between the proposed dredge site and the HARS. With the implementation of these conditions placement of Remediation Material at the HARS would not result in adverse impacts to listed endangered or threatened species.

8.3.2 PROGRAMMATIC EFH FOR PLACEMENT OF CATEGORY I DREDGED MATERIAL AT THE HARS

Disposal of dredged material offshore such as the placement of Remediation Material at the HARS has the potential to result in the following impacts:

- Burial/disturbance of benthic habitat;
- Conversion of substrate/habitat and changes in sediment composition;
- Increased in suspended sediment and turbidity;
- Release of contaminants in the water column;
- Changes in bottom topography, altered hydrological regimes and altered current patterns; and
- Release of nutrients/eutrophication (NMFS 2008).

The USACE prepared a programmatic EFH for placement of Category 1 Dredged material at the HARS (SACE 2002), which was reviewed by NMFS. On the basis of the programmatic EFH and information provided by the USACE and USEPA during the site designation process the NMFS determined that the agency had no conservation recommendations to offer provided that the HARS is operated in accordance with the SMMP and that no further consultation pursuant to Section 305(b) of the Magnuson Stevens Act would be necessary. The Programmatic EFH for the HARS, attached to this EFH as Attachment 1, assessed the potential effects of the placement of Category I dredged material on the managed fish species identified as having EFH within the HARS. Table 14 presented below indicates the managed species currently identified as having EFH in the vicinity of the HARS and identifies those species and or life stages that were not evaluated in the programmatic EFH for the HARS. These species include clearnose skate, little skate, smooth dogfish, thresher shark and winter skate.

Direct impacts evaluated in the programmatic EFH included the burial of the benthic community with Remediation Material and temporary increases in suspended sediment. This loss of prey species for EFH dependent on benthic invertebrates would be minimized spatially and temporally through use of a grid system for the placement of Remediation Material. The USACE determined that direct burial of EFH species is possible yet improbably and, therefore, would have minimal impact on target species of their EFH. Although the placement of Remediation Material would have the potential to result in increased turbidity and contaminant concentrations, these effects are typically short-lived (less than one hour) and would cause no more than minimal impact on EFH. Furthermore, recolonization of a healthier benthic community would occur by those benthic invertebrate individuals able to unbury themselves and recolonization by individuals from nearby similar habitats. The placement of Remediation

Material would result indirect impacts through minor changes in bathymetry that would not be expected to create noticeable changes in the physical oceanography and would not be sufficient to alter the relationship of the benthic community with the photic zone. The cumulative impacts resulting from placement of Remediation Material at the HARS would be beneficial because the "remediation of the HARS will result in an improved benthic community, and ultimately, improvement of the fishing and shellfishing resources of the New York Bight." (USACE 2002).

The programmatic EFH for the HARS states that "The remediation of the HARS with Category I sediments is is the most expeditious means of eliminating the potential risk associated with contaminated sediments of the Priority Remediation Area. Decreased contaminant toxicity and bioavailability to fish and shellfish resources will greatly reduce the risk to biota of the New York Bight. The planned remediation will also prevent dispersion of degraded sediments from the seafloor as a result of resuspension due to high-energy events." Placement of Category I dredged material at the HARS was determined to result in "no more than minimal impact to Essential Fish Habitats" for the species evaluated and that "remediation efforts at the HARS should be conducted without the need for seasonal restrictions or mitigation measures to protect habitat or individual species" (USACE 2002).

8.4 EXISTING HABITAT AT THE HARS

The HARS is located on the shallow continental shelf within the New York Bight. Water depths at the HARS range from 46 to 138 feet. Circulation in the New York Bight is complex with temporal and regional variability. Low frequency meteorological forcing, over 3 to 10 day periods, is responsible for much of the current fluctuations over the shelf. During spring and summer the wind energy is reduced and the water column is tratified. The magnitude of the currents increases with the distance offshore and decreases with depth (Beardsely and Boicourt 1981 in USACE 2002). Circulation in the Bight is dominated by a relatively slow flow to the southwest (0.1 feet per second (fps)) with an occasional clockwise bottom gyre. The southerly flow of the Hudson River plume along the New Jersey shoreline forces an opposing northward flow of more saline waters to the east (USEPA 1982 in USACE and USEPA 2009). Near bottom oscillatory tidal currents at the HARS are relatively weak, with maximum speeds of 0.3 fps. Mean currents are also less than 0.3 fps with directions that are dependent upon location, water depth and bottom topography (SAIC 1994b in USACE and USEPA 2009). Surface waves are generally less than about 7 feet in height except during major storms which are most common in the fall and winter (SAIC 1995c in USACE and USEPA 2009). Wave-induced near-bottom currents are greater than 0.7 fps only when surface wave heights are greater than 10 feet and storm centers are to the east or southeast. These wave conditions would occur less than 3 percent of the time in fall and winter, and less than 1 percent of the time in spring and summer (SAIC 1994a in USACE and USEPA 2009).

Maximum salinities (33 to 34 ppt) occur inshore during the winter (February and March) when sub-freezing conditions reduce river runoff. Surface salinity, particularly near shore decreases with spring thaw and strong vertical gradients may develop. In summer, surface salinities are at the annual minimum (27 to 31 ppt) with bottom salinities of 27 to 29 ppt (USEPA 1982 in USACE and USEPA 2009). Turbidity is low through the water column with a small mid-depth maximum in the central portion of the HARS. The effects of dredged material placement on water quality of the New York Bight have been observed to be minimal, with contaminant concentrations in disposal plumes at the MDS dissipating quickly (less than one hour) to background levels. While plume behavior varies with the grain size of the dredged material, total suspended solids near the center of the dredged material placement plume body have been

observed to reach near background levels in 35 to 45 minutes (Battele 1994 in USACE and USEPA 2009). Dissolved oxygen are consistently above 2.0 milligrams per liter (USACE 2002).

Use of the New York Bight Apex as a disposal area over the past 100 years has influenced sediment characteristics within the HARS (USACE 2009). The HARS is dominated by mounded dredged material that rises up to 40 feet from the historic sea floor in some areas (USEPA 1997 in USACE 2002). Surface sediments are heterogeneous, ranging from areas dominated by muddy (fine-grained) sediments to areas covered with coarse sediments (primarily sand) at the former cellar dirt site (USACE 2002). Toxicity testing of the sediments at HRS using amphipods found a wide range of survival percentage (Battele 1996 a in USACE 2002). Sediments exhibiting significant toxicity were generally located across the middle of the HARS (USACE 2002).

Sampling of benthic invertebrates within the HARS indicated the majority of the species to be annelids (61 percent, including *Prionospio steenstrupi,* a surface deposit feeder, *Polygordius*, and *Pherusa,* a surface deposite feeder) followed by crustaceans (17 percent) and mollusks (11 percent) (USACE and USEPA 2009).

The New York Bight Apex is a transitional region for many species of fish and shellfish. Finfish known to occur in the region include:

- Demersal species—silver hake, red hake, yellowtail flounder, scup, summer flounder, winter flounder, tautog, cod, black sea bass, little skate, windowpane flounder, four spot flounder, ocean pout, cunner, spiny dogfish, spotted hake, northern sea robin, gulf stream flounder, sea raven and longhorn sculpin.
- Pelagic species—butterfish, Atlantic herring, bluefish, and weakfish.
- Pelagic/Anadromous—American shad, alewife and striped bass (USACE and USEPA 2009).

Shellfish include surf clam, sea scallop, American lobster, long-finned squid, rock crab, horshoe crab, short-finned squid, and jonah crab (USACE and USEPA 2009).

8.5 POTENTIAL IMPACTS FROM THE PLACEMENT OF DREDGED MATERIAL AT THE HARS FROM THE PROJECT

Remediation Material has been placed at the HARS since at least 1998. Permit and contract specifications require placement at pre-determined locations within the HARS. Since development and installation of the Automated Disposal Surveillance System (ADISS) monitoring/positioning systems aboard scows and tugs, discrete placement grids have been used for organized placement at the HARS. ADISS allows placement at designated latitude-longitude coordinates. Specific grid coordinates and instructions/requirements are contained in the Department of the Army permits issued by the USACE. Placement of Remediation Material within the nine PRAs (approximately 1 square nautical mile) is managed in priority order, beginning with PRA-1 and ending with Area 9. Use of a particular PRA may be discontinued upon completion of remedial activities and demonstration that at least a 1 meter cap of Remediation Material has been placed over the entire area. Placement is occurring in several phases within each area to allow consolidation of sediments and assessment of coverage. The USACE, using the STFate numerical model, determine the distance from the HARS border where material can be placed such that water quality standards are not exceeded. Most maintenance dredging projects, which are predominantly composed of silt and clay, have been

used to remediate the central and eastern portions of HARS PRAs 1, 2, and 3 and the northern portion of PRA 4. Remediation Material that is mostly sand and dredged rock has been used to remediate areas closer to the outer edges of PRAs 1 through 3 (USACE and USEPA 2009).

The grid area designated for placement is proportional to the estimated volume of material for remediation associated with each project with higher volume projects using larger area grids. Grid cells are typically 250 feet by 500 feet, with cells of 100 to 150 feet by 100 to 200 feet used for coarse material. The goal is to provide 0.5 to 3 feet of coverage within a grid during each dredging project. If an area has been used for placement of maintenance mud, usually the area is not used for additional placement for a year to allow compaction and dewatering of the mud. Grids for concurrent projects are spaced far enough apart, at least 3280 feet if one grid is due north of the other, to avoid vessel interference during placement (USACE and USEPA 2009).

As presented in Table 5 of this EFH, dredging would be conducted in three stages, each stage conducted during a separate dredging season occurring within a three-month period from August 1 to November 1. For the Long Span Option, the option with the higher dredging quantities, approximately 1.12 MCY would be dredged during Stage 1, 0.43 MCY during Stage 2, and 0.19 MCY during Stage 3, for a total of 1.74 MCY. This volume is about 5 percent of the volume of Remediation Material placed at the HARS in PRAs 1 through 4 as of December 2008.

Section 2.3.4, "Sediment Characteristics," provides a detailed discussion of the sediments within the study area that would be dredged as a result of the project. As discussed in that section, Hudson River bottom sediments in the study area comprise primarily clayey silt, similar to much of the sediment within the HARS and already evaluated by the USEPA and the USACE with respect to water quality effects during placement. Additionally, the dredged material from the project would only be placed at HARS as Remediation Material if it is determined to meet the Category I sediment criteria, and therefore, would not cause significant undesirable effects to aquatic biota, including through bioaccumulation. The dredged material would be placed at the location and in accordance with the placement protocols that would be specified in conditions issued by the USACE in the permit for the project. Therefore, increases in suspended sediment and concentrations of contaminants that may be released due to placement of the dredged material from the project within the HARS would be expected to dissipate rapidly and would not result in adverse impacts to water quality or result in adverse effects to fish and other aquatic biota due to changes in water quality. Similarly, the location for placement selected by the USACE, would be determined on the basis of the sediment characteristics developed on the basis of sediment sampling that would be conducted as part of the Section 103 permit application, and would not be expected to adversely affect water quality outside the mixing zone established for the HARS.

As evaluated in the programmatic EFH, direct impacts to fish during placement of the dredged material at the HARS would be expected to be minimal due to the small contact footprint of the fluidized sediments as they leave the barge (typically 50 foot by 100 foot), Remediation Material is placed sequentially in a predetermined grid, resulting in continuous remediation in one zone rather than random placement increasing the chance of escape by fish using the area, and noise from vessels repetitively working in one are would further increase the likelihoods that fish would leave the area receiving placement of material.

Fish species that feed on benthic or pelagic fishes or squid (e.g., bluefish, summer flounder, scup) are present at the HARS. Individuals of these species would be expected to leave the area receiving dredged material during a placement event. Because there would be sufficient similar habitat available nearby with similar benthic invertebrates, adverse impacts due to loss of prey species would not be expected to occur to these species. Fish that feed on pelagic and planktonic

invertebrates and larvae (e.g., Atlantic sea herring, red hake, and Atlantic butterfish) would have minimum disruption to their feeding. It is anticipated that these species would avoid the Remediation Material and plume, and simply relocate to neighboring waters.

Because the characteristics of the sediment from the project would be similar to those in and around the HARS, benthic invertebrates would be expected to quickly recolonize the cells used for the placement of this material.

8.6 EFH SPECIES

Table 14 presents the fish species and life stages identified as having EFH within the HARS. The five species not evaluated in the programmatic EFH, clearnose skate, little skate, smooth dogfish, thresher shark and winter skate, are profiled below.

8.6.1 CLEARNOSE SKATE *(RAJA EGLANTERIA)*

The clearnose skate occurs along the Atlantic coast from the Nova Scotian Shelf to northeastern Florida and in the northern Gulf of Mexico from Texas to Florida. It is considered a southern species that is rare in the northern part of its range (Packer et al. 2003a). The New York Bight is within an area designated as EFH for juvenile and adult clearnose skates. North of Cape Hatteras, clearnose skates move inshore and northward along the continental shelf during the spring and early summer and offshore and southward during autumn and early winter. This species occurs off of New Jersey and New York from late April through May and October through November (Packer et al. 2003a).

In winter, juveniles are concentrated from the Delmarva Peninsula south to Cape Hatteras out to the 200 m contour. In spring they concentrate inshore from the Delmarva south to Cape Hatteras. In summer they occur inshore from the New Jersey coast to around Cape Hatteras with a limited presence off Cape Cod. In Hudson-Raritan Estuary bottom trawls, the largest numbers were found in the summer, particularly in and near channels and south of Coney Island. Small numbers were collected in the spring and autumn, with very few collected in the winter. The distribution of adults in Hudson-Raritan Estuary trawls was similar to that of the juveniles (Packer et al. 2003a).

This skate is found on soft bottoms along the continental shelf but also occur on rocky or gravelly bottoms. It is most abundant at depths less than 364 feet. The Hudson-Raritan trawls found juveniles most abundant at depths of 16 to 23 feet and temperatures 55 to 75°F. Adults were most abundant at depths of 16 to 26 feet and temperatures 48 to 75°F. In this survey, clearnose skates were found at salinities ranging from 22 to 32 ppt (Packer et al. 2003a).

Clearnose skates juveniles and adults would have the potential to occur at the HARS during the period that dredged material from the project would be placed at the HARS, late summer through late fall, although the larger population of this southern species is concentrated around the Delmarva Peninsula and further south. The northeastern stocks of clearnose skate are not overfished and nor is overfishing occurring (NMFS 2011). Because the placement of the Remediation Material from the project would not result in adverse impacts to water quality, sufficient bottom habitat would still be available for foraging for benthic invertebrates within the vicinity of the area receiving placement, and a small percentage of the population for this species would be expected to occur within the HARS, the placement of dredged material from the project at HARS would not result in adverse impacts to EFH for this species.

Table 14
Essential Fish Habitat Designations by Life Stage Within the Historical Area Remediation Site

Species		Life Stage			
Common name	**Scientific name**	**Eggs**	**Larvae/YOY**	**Juvenile**	**Adult**
Atlantic bluefin tuna	*Thunnus thynnus*			X	(1)
Atlantic cod	*Gadus morhua*				X
Atlantic herring	*Clupea harengus*		X	X	X
Atlantic skipjack tuna	*Katsuwonus pelamis*				X
Blue shark	*Prionace glauca*	n/a*	(1)	X (2)	X
Clearnose skate	*Raja eglanteria*		n/a*		X (2)
Dusky shark	*Carcharhinus obscurus*	n/a*	X	X	X (2)
Little skate	*Leucoraja erinacea*		n/a*	X (2)	
Monkfish	*Lophius americanus*	X	X	X	X
Ocean pout	*Macrozoarces americanus*	X	X	X	X
Red hake	*Urophycis chuss*	X	X	X	X
Sand tiger shark	*Carcharias taurus*	n/a*	X		
Sandbar shark	*Carcharhinus plumbeus*	n/a*	(1)	X	X
Shortfin mako shark	*Isurus oxyrinchus*	n/a*	X	X	X (2)
Silver hake (whiting)	*Merluccius bilinearis*	X	X	X	X
Smooth dogfish	*Mustelus canis*	n/a*	X (2)	X (2)	X (2)
Thresher shark	*Alopias vulpinus*	n/a*	X (2)	X (2)	X (2)
Tiger shark	*Galeocerdo cuvier*	n/a*	(1)	X (2)	X (2)
White shark	*Carcharodon carcharias*	n/a*	X (2)	X	X (2)
Windowpane flounder	*Scophthalmus aquosus*	X	X	X	X
Winter flounder	*Pseudopleuronectes americanus*	X	X	X	X
Winter skate	*Leucoraja ocellata*		n/a*	X (2)	
Witch flounder	*Glyptocephalus cynoglossus*	X	X		
Yellowtail flounder	*Limanda ferruginea*	X	X	X	X

Notes:
(1) Species was present in Programmatic EFH for the HARS
(2) Species was not present in Programmatic EFH for the HARS
* Life stage does not exist for this species

Sources:
NOAA's EFH Mapper (http://sharpfin.nmfs.noaa.gov/website/EFH_Mapper/map.aspx)
USACE. Undated. Programmatic Essential Fish Habitat Assessment for Placement of Category I Dredged Material at the Historic Area Remediation Site in the New York Bight Apex.

8.6.2 LITTLE SKATE *(LEUCORAJA ERINACEA)*

Little skates occur from Nova Scotia to Cape Hatteras and are one of the most dominant demersal (bottom-dwelling) species in the northwest Atlantic. The center of abundance is in the northern portion of the Mid-Atlantic Bight and on George's Bank, where it is found year-round. Little skates do not make extensive migrations but do move onshore and offshore with the seasons, generally to shallow waters in the spring and deeper waters in winter (Packer et al. 2003b). The New York Bight is within an area designated as EFH for juvenile and adult little skates.

Little skates are generally found on sandy or gravelly bottoms but can also be found on muddy bottoms. This species are generally found in the Hudson-Raritan Estuary when temperatures are less than about 61 to 64°F. Juvenile little skates are generally absent from the Hudson-Raritan Estuary and the New York Bight apex during summer months and well distributed throughout in the spring, autumn, and winter. Those that were collected in the estuary in the summer during trawl surveys were generally found in the deeper, warmer waters of channels. Juveniles were generally found at depths between 13 to 79 feet and salinities between 17 and 35 ppt (but most at ≥ 25 ppt).

Few adults were collected during the Hudson-Raritan Estuary surveys (conducted 1992-1997), and only two adults were collected during summer surveys. Temperatures where this species was collected ranged from 34 to 63°F, depths from 5 to 16 m (16 to 52 feet), and salinities from 18 to 32 ppt (but most at ≥ 25 ppt). Based on NEFSC trawls, juvenile little skates have the potential to occur in the Hudson-Raritan Estuary and in the New York Bight apex in the autumn through the spring, although the adults would be less common, and would therefore, have the potential to be present during the period when dredged material from the project would be placed at HARS. The northeastern stocks of little skate are not currently overfished nor is overfishing occurring (NMFS 2011). Because the placement of the Remediation Material from the project would not result in adverse impacts to water quality, sufficient bottom habitat would still be available for foraging for benthic invertebrates within the vicinity of the area receiving placement, and a small percentage of the population for this species would be expected to occur within the HARS, the placement of dredged material from the project at HARS would not result in adverse impacts to EFH for this species.

8.6.3 WINTER SKATE *(LEUCORAJA OCCELATA)*

The winter skate occurs from the south coast of Newfoundland and the southern Gulf of St. Lawrence to Cape Hatteras. Its center of abundance is on Georges Bank and in the northern portion of the Mid-Atlantic Bight. It is often second in abundance to the little skate (Leucoraja erinacea) and immature winter skates are often confused with immature little skates (Packer et al. 2003c). The New York Bight is within an area designated as EFH for juvenile and adult winter skates.

This skate is found most often on sandy or gravelly bottoms but can also be found on muddy bottoms. It is most abundant at depths less than 364 feet. During surveys of the Hudson-Raritan Estuary, juvenile winter skates were generally absent during the summer and well distributed in winter, spring, and autumn. This species was most abundant in winter. Those individuals present in the summer were generally found in deeper channel waters. Juveniles are found in warmer waters during the spring and autumn (most at 6 to 9°C and 5 to 17°C, respectively) than winter (mostly in 0 to 7°C), and remain mostly around depths of 16 to 26 feet during those seasons. Salinities ranged from 15 to 34 ppt, but most were found between 23 and 32 ppt. Very few

adults were collected in these surveys (conducted 1992-1997). Too few were found to determine their habitat preferences.

Juvenile and adult winter skates have the potential to occur within the vicinity of the New York Bight and the HARS. The center of distribution for winter skate stocks in the Northeast region is over Georges Bank, north of the HARS, although this species does occur in lesser abundance in the northern Mid-Atlantic Bight and within the New York Bight (Packer et al. 2003c). Seasonally, winter skate juveniles and adults are more common in the vicinity of the HARS during winter and spring and less abundant during the summer and fall months. Therefore, individuals would have the potential to occur at HARS during the late summer to late fall period when dredged material from the project would be placed at the HARS, but in low numbers. In the 2008 Report to Congress, the Southern New Enlgand and Georges Bank stocks were declared overfished (NMFS 2009). However, as of the most recent 2010 Report to Congress, the northeastern stocks of winter skate are not currently overfished, and overfishing is not occurring (NMFS 2011). Because the placement of the Remediation Material from the project would not result in adverse impacts to water quality, sufficient bottom habitat would still be available for foraging for benthic invertebrates within the vicinity of the area receiving placement, and a small percentage of the population for this species would be expected to occur within the HARS, the placement of dredged material from the project at HARS would not result in adverse impacts to EFH for this species.

8.6.4 SMOOTH DOGFISH *(MUSTELUS CANIS)*

This species is not managed in federal waters, but is included in the Atlantic States Marine Fisheries Commission's Interstate Fishery Management Plan. As of 2009, there was no assessment of smooth dogfish stocks on the Atlantic coast (ASMFC 2009).

Smooth dogfish are demersal sharks found along the Atlantic coast as far north as Massachusetts. They occupy continental shelves and inshore waters as deep as 200 meters and primarily feed on large crustaceans (particularly crabs and American lobsters). They also feed on small bony fish, gastropods, bivalves, and marine annelid worms (Compagno 1984). During winter, smooth dogfish are primarily found between southern North Carolina and the Chesapeake Bay. In spring, they migrate along the coast when bottom waters reach 43°F. When temperatures drop again, they migrate offshore to their overwintering areas (Compagno 1984). Smooth dogfish have been collected during sampling programs in the Hudson-Raritan Estuary (USACE 2004; NOAA 2000).

Smooth dogfish would have the potential to occur within the HARS during the period that dredged material from the project would be placed there as Remediation Material. However, because the placement of the Remediation Material from the project would not result in adverse impacts to water quality, sufficient bottom habitat would still be available for foraging for benthic invertebrates within the vicinity of the area receiving placement, and a small percentage of the population for this species would be expected to occur within the HARS, the placement of dredged material from the project at HARS would not result in adverse impacts to EFH for this species.

8.6.5 THRESHER SHARK *(ALOPIAS VULPINUS)*

EFH for the thresher shark has been designated in waters offshore from Long Island, New York in pelagic waters deeper than 164 feet (NMFS 2012). Thresher sharks are large, active, and strong-swimming sharks widely distributed in warm and temperate waters in the Atlantic Ocean.

They are found in both coastal and oceanic waters, but usually occur within 40 to 75 miles of land over continental and insular shelves and slopes (Strasburg 1958, Holts 1988, Litvinov 1990 as cited in Smith et al. 2008). Juveniles tend to remain over the continental shelf in shallow water, while adults are most common in deeper water. Both juveniles and adults are often associated with highly productive water in regions of upwelling or intense mixing.

In the warm season (April to August), the thresher shark undertakes inshore and northerly coastal migrations. They are known to travel in schools segregated by sex and size, and catches of adults are skewed at certain times and locations in the Atlantic. Female-dominated schools move shoreward in spring, presumably towards inshore nursery areas. Near the end of spring, inshore schools are made up of predominantly neonates and pregnant females, to the exclusion of adult males (Moreno et al. 1989; Smith et al. 2008).

The HARS site is located outside the longitude given for thresher shark EFH and is shallower (approximately 46 to 138 feet) than the thresher shark EFH (USACE 2002); therefore, thresher shark EFH is not located within the HARS site and placement of dredged material from the project at HARS would not result in adverse impacts to EFH for this species.

8.7 SUMMARY OF EFFECTS ON EFH FROM PLACEMENT OF DREDGED MATERIAL FROM THE PROJECT AT THE HARS

8.7.1 POTENTIAL DIRECT IMPACTS

As described in the programmatic EFH for the HARS, direct impacts to EFH resulting from the placement of dredged material from the project at the HARS as Remediation Material would be the burial of benthic invertebrates within the cells receiving the material. While the loss of benthic invertebrates within the placement cells would be immediate, there would be sufficient foraging area available outside each approximately 250 foot by 500 foot cell such that fish species that forage on benthic invertebrates would not be adversely affected. Individual EFH would be expected to leave the area of the cells receiving dredged material from the project and would not be directly impacted due to the placement of the material due to burial or contact with the barge. Water quality impacts resulting from placement of the dredged material such as increased turbidity and contaminant concentrations would be expected to be temporary (less than an hour) and would not result in adverse impacts to EFH. Because the dredged material placed at the HARS from the project would be similar to the existing sediment at the HARS recolonization of the cell(s) receiving this material would be expected to occur rapidly.

8.7.2 POTENTIAL INDIRECT IMPACTS

Benthic invertebrates contained in the dredged material from the project would have the potential to provide additional prey for EFH species using the habitats in the vicinity of the cells receiving placement of the Remediation Material. While minor changes to bathymetry may occur as a result in the placement, it would never be more than approximately 3 feet, which would not be expected to adversely affect the suitability of the sediment for benthic invertebrates on the basis of depth or light penetration.

8.7.3 POTENTIAL CUMULATIVE IMPACTS

The primary cumulative impact from the placement of the dredged material from the project at the HARS would be the eventual remediation of the HARS which would result in an improved benthic community and improved habitat for fish and shellfish. The placement of the dredged

material from the project at the HARS in three stages would minimize the area of disturbance within the cells designated for the project by the USACE during each dredging season for the project. Because changes to water quality during placement of Remediation Material would be expected to be limited temporally and spatially, placement of the dredged material with material from other projects would not be expected to result in adverse impacts to water quality or EFH. Given the large area of the HARS yet to be remediated in RPAs 5 through 9, and much of PRA 1 and 2 has been remediated, placement of the dredged material from the project concurrent with placement of material from other projects, sufficient EFH would still be available within the HARS that placement of the dredged material concurrent with placement of Remediation Material from other projects would not be expected to result in adverse impacts to EFH.

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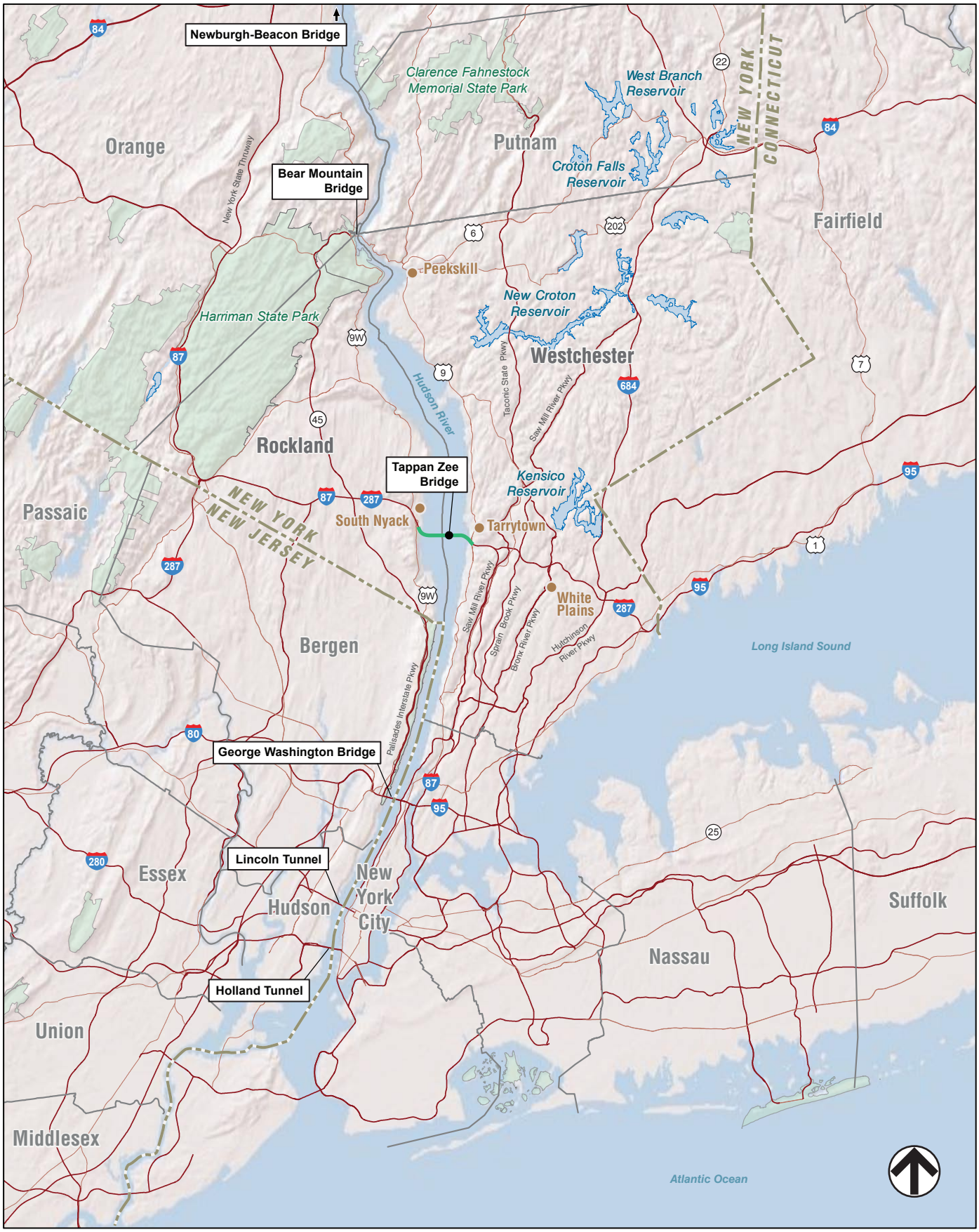
Figures

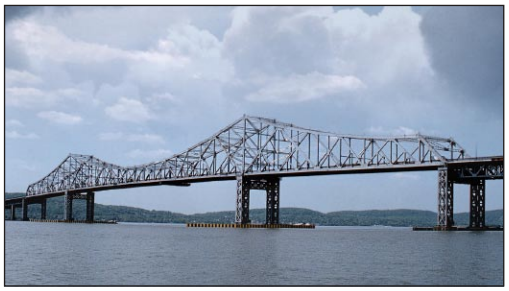
1.4.12

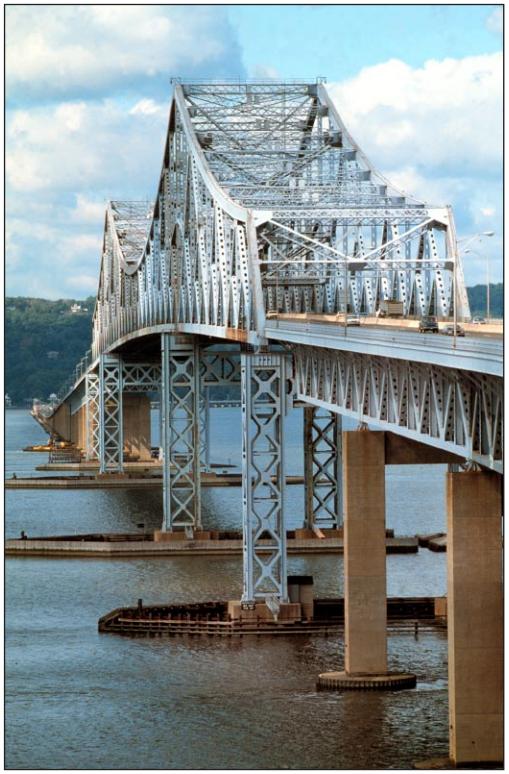


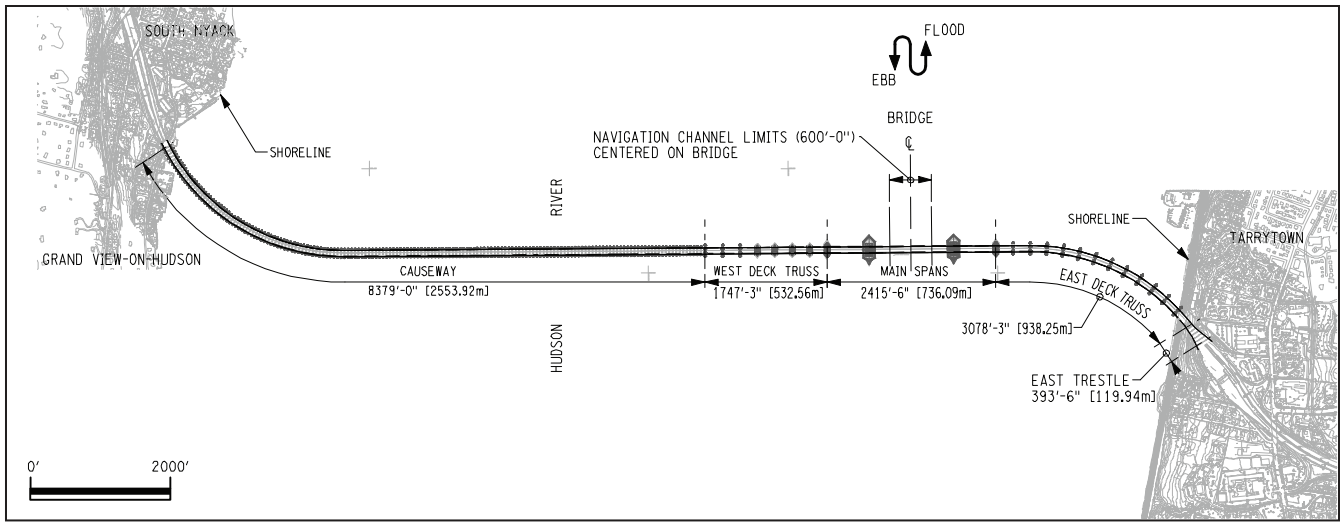
0 10 MILES
SCALE

Figure 1
Project Location and Regional Roadway Network

TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat







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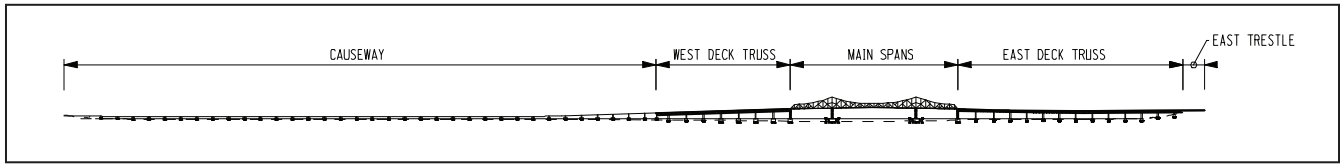
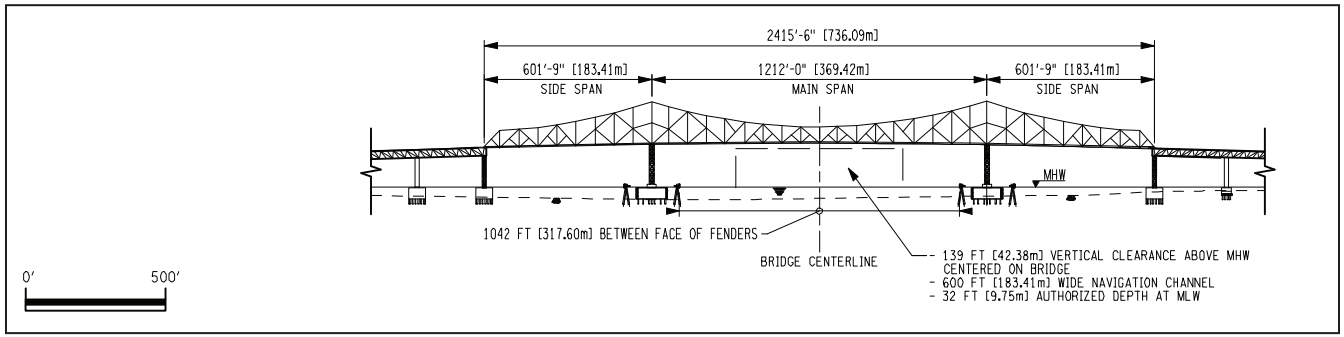


PROFILE

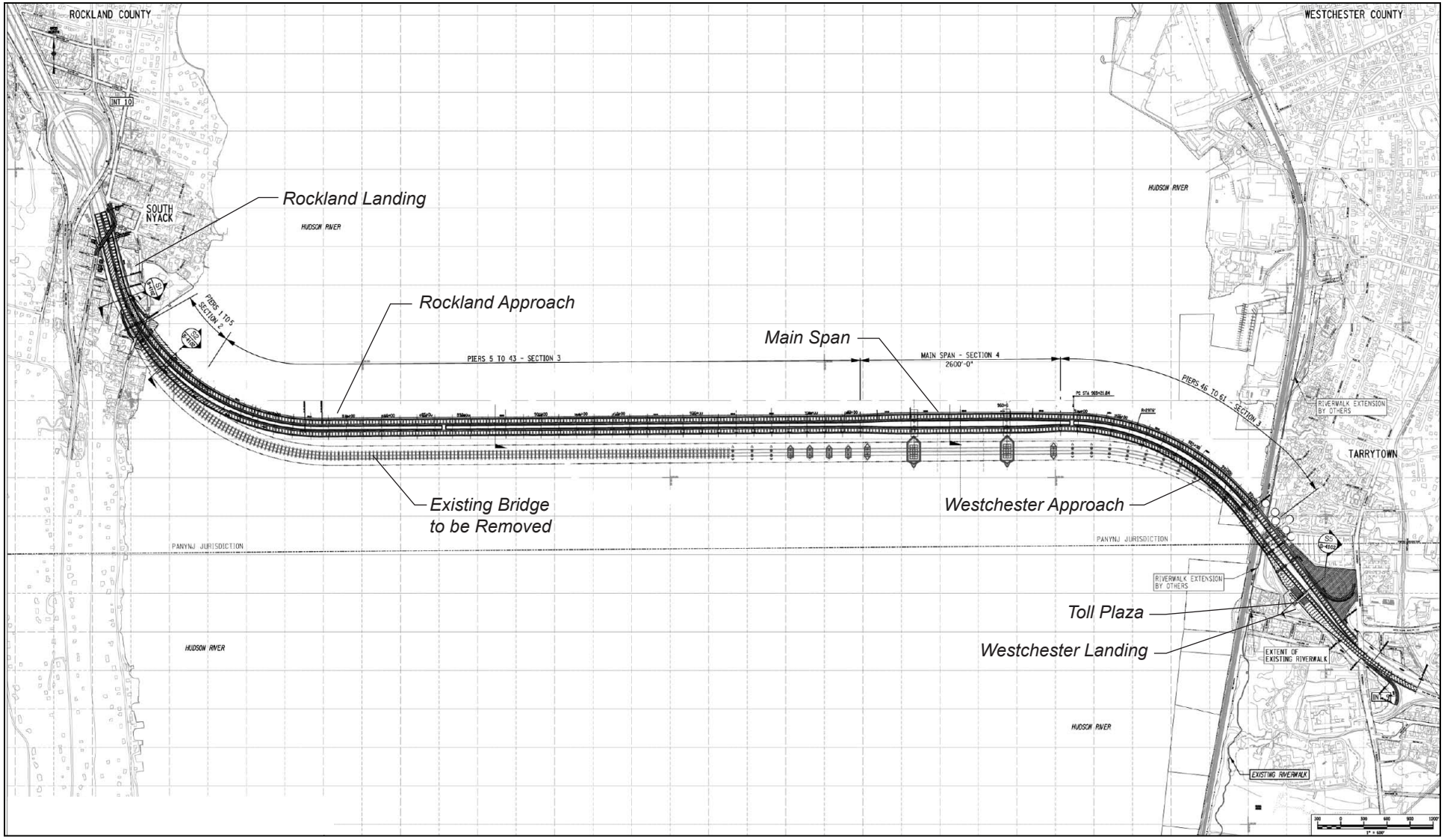


MAIN SPANS

TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 2

Existing Bridge Plan, Profile, and Photographs

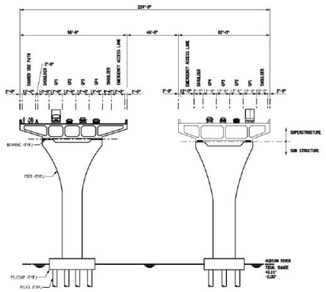


TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

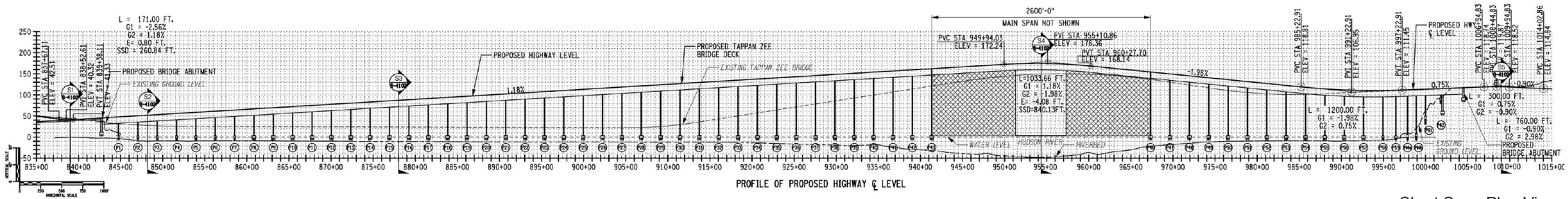
Figure 3
Replacement Bridge Alternative

1.4.12

Short Span Option

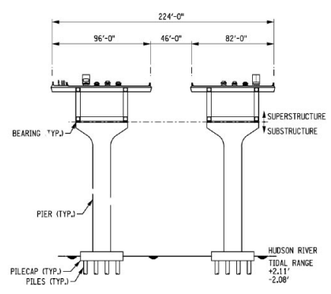


Short Span Cross-Section

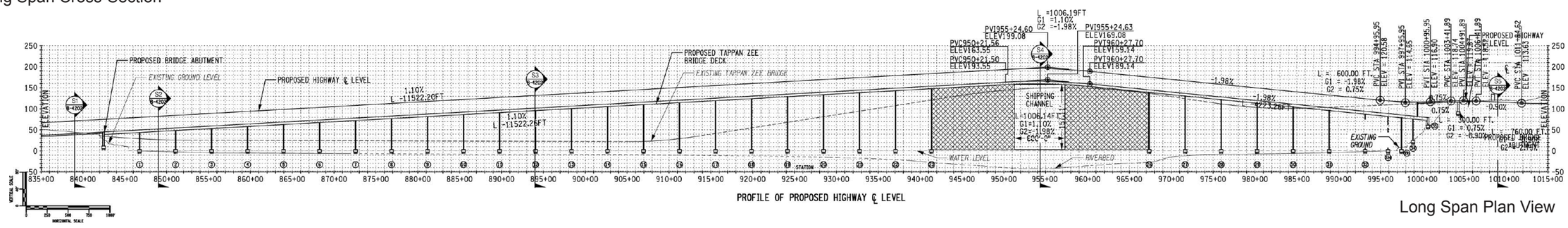


Short Span Plan View

Long Span Option



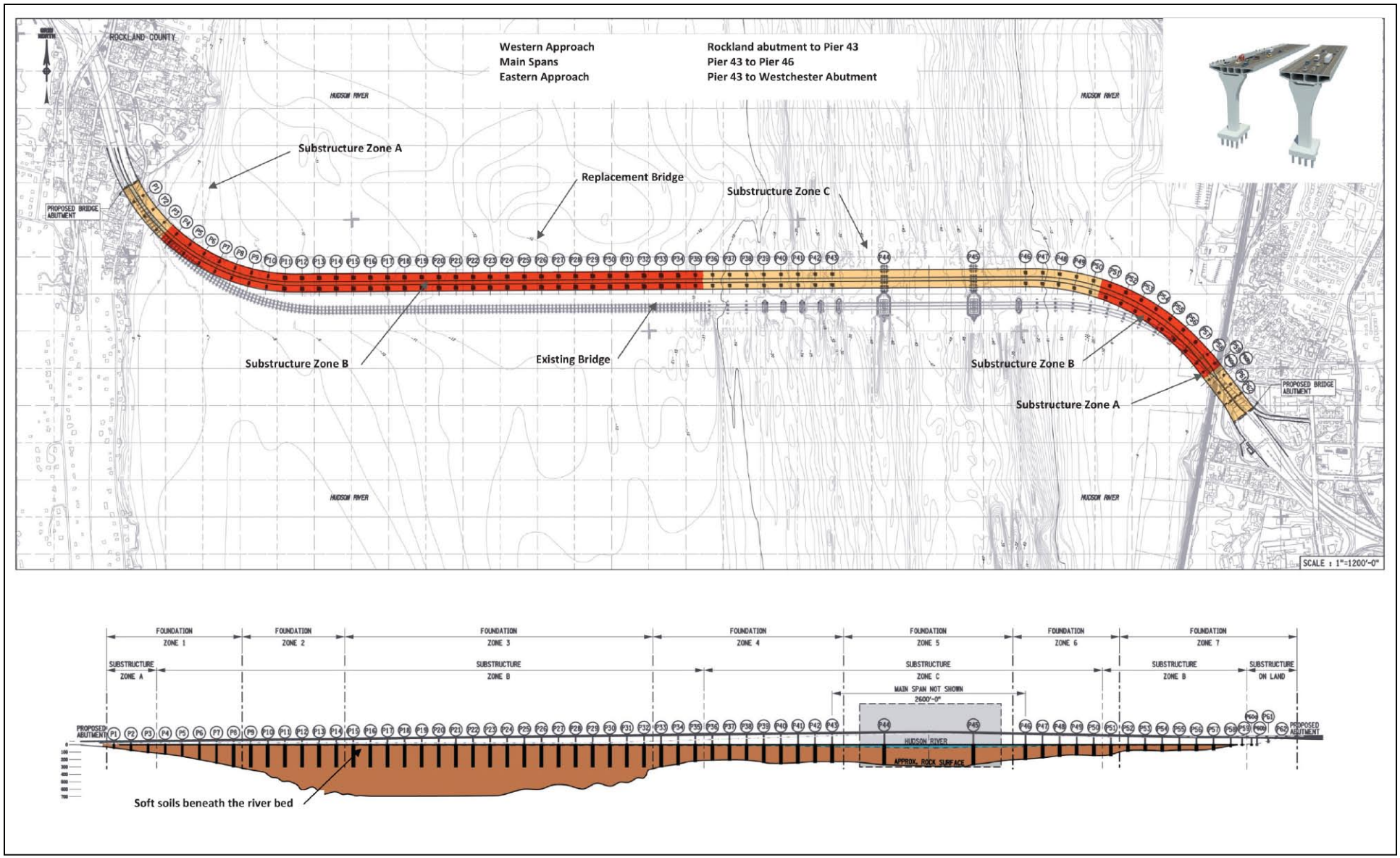
Long Span Cross-Section



Long Span Plan View

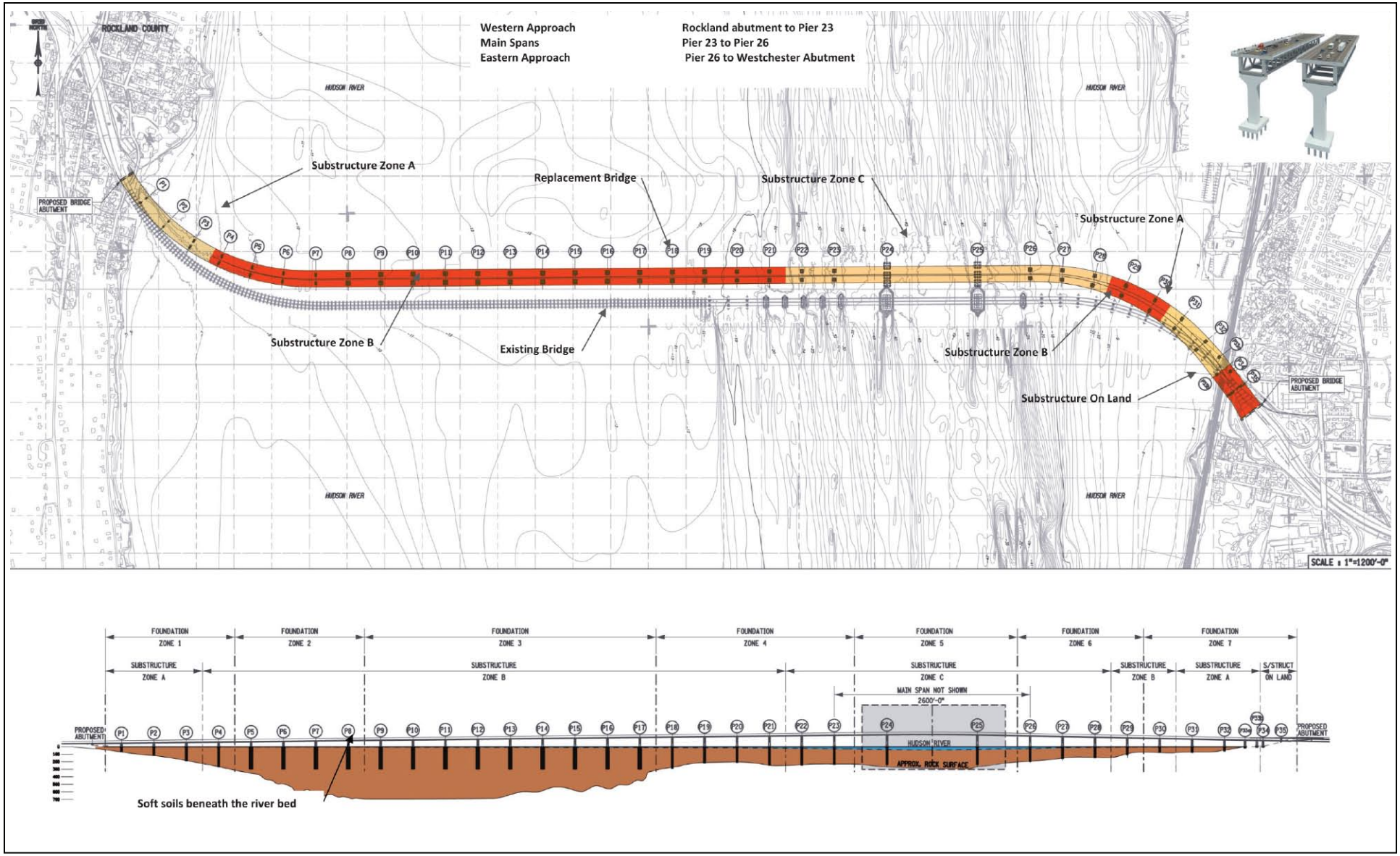
TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 4
Approach Spans Options



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

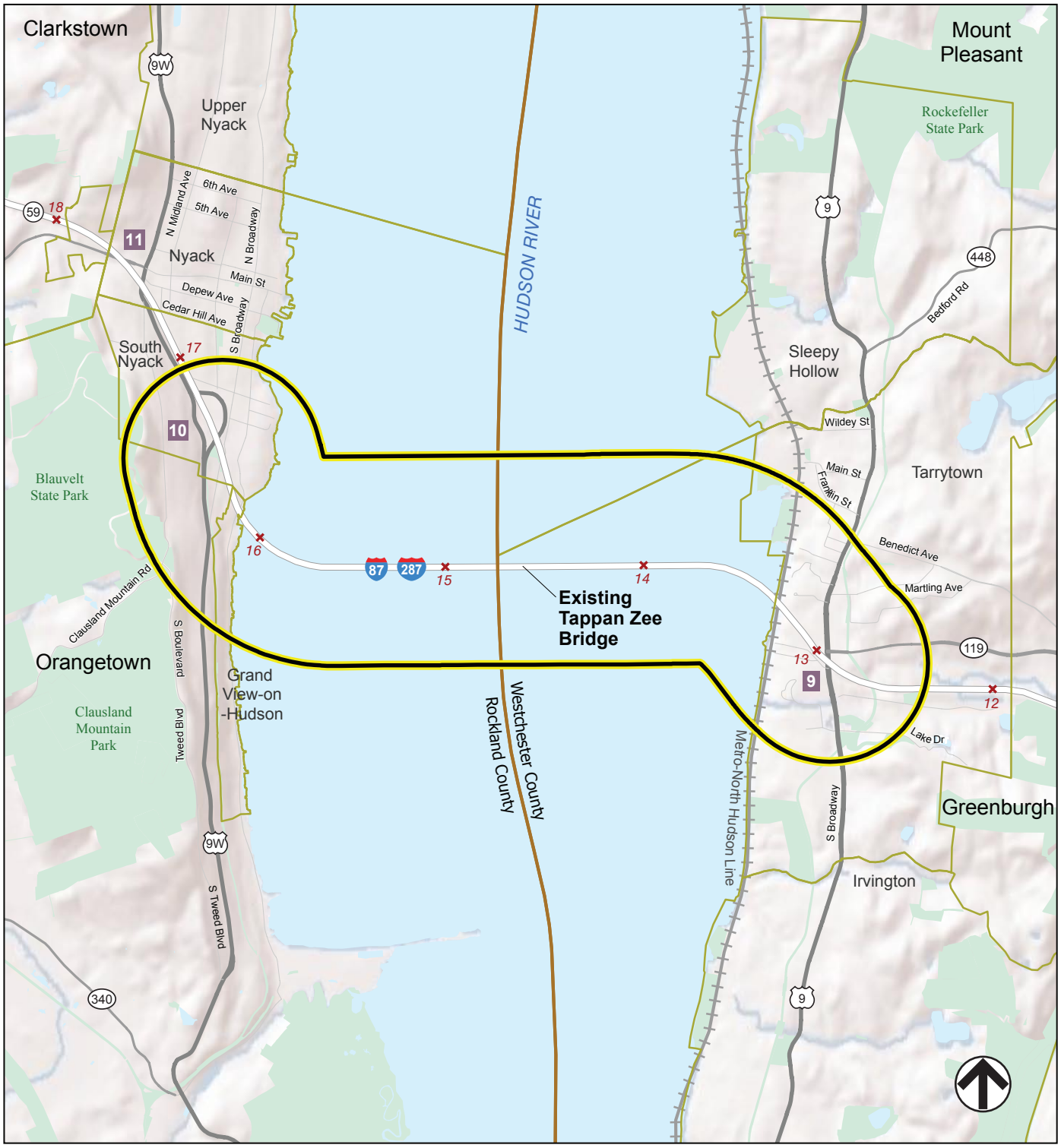
Figure 5
Construction Zones for Short Span Bridge Option



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 6
Construction Zones for Long Span Option

1.4.12



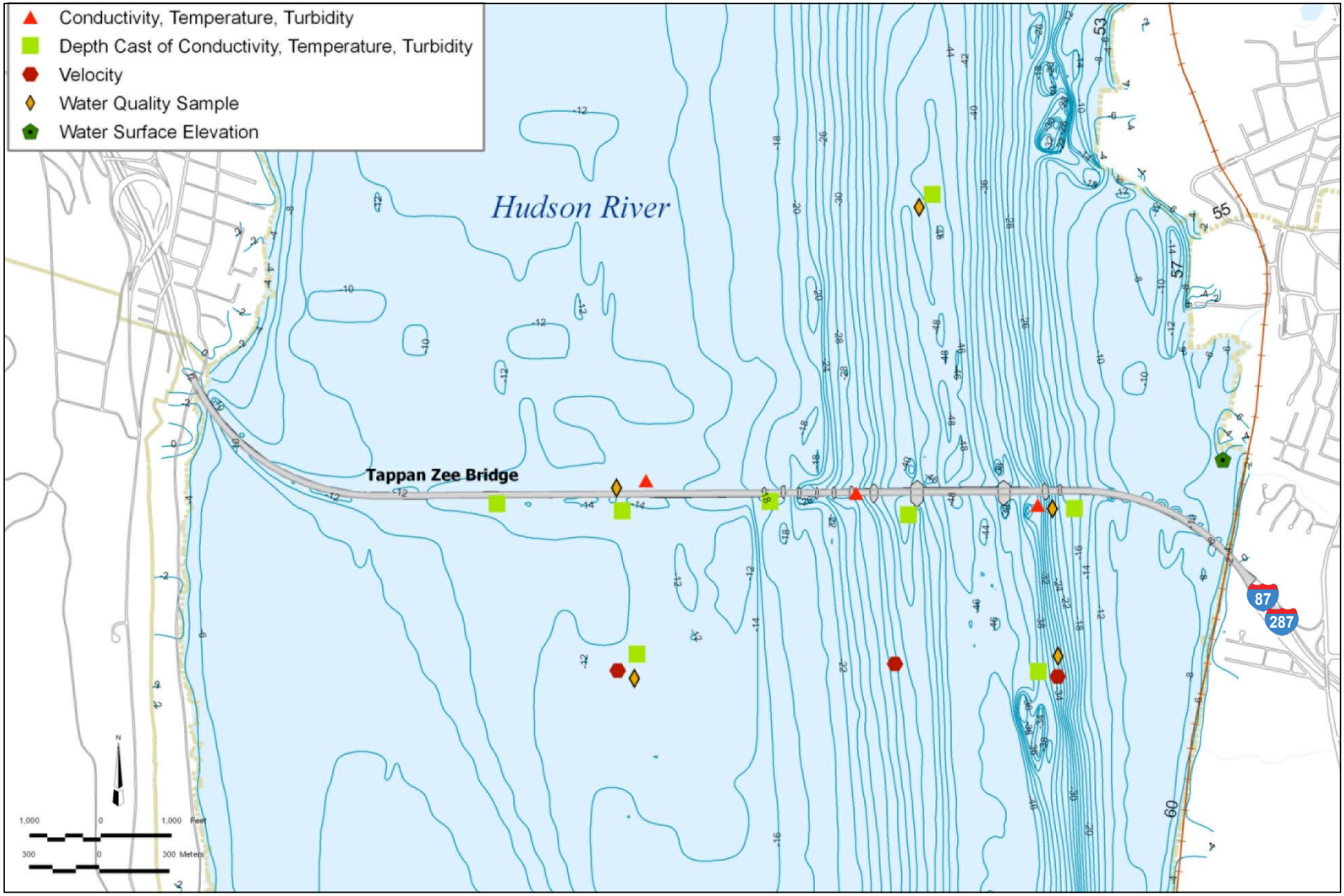
Study Area
15 Mile Post
Municipal Boundary
County Boundary
Railroad
14 Interchange Number
87 Interstate Highway
9W U.S. Highway
59 State Highway
Other Major Road

0 1/2 1 MILE
SCALE

TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 7
Study Area

1.4.12



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 8
Bathymetry

Figure 9
Average Salinity Concentration at Hastings-on-Hudson

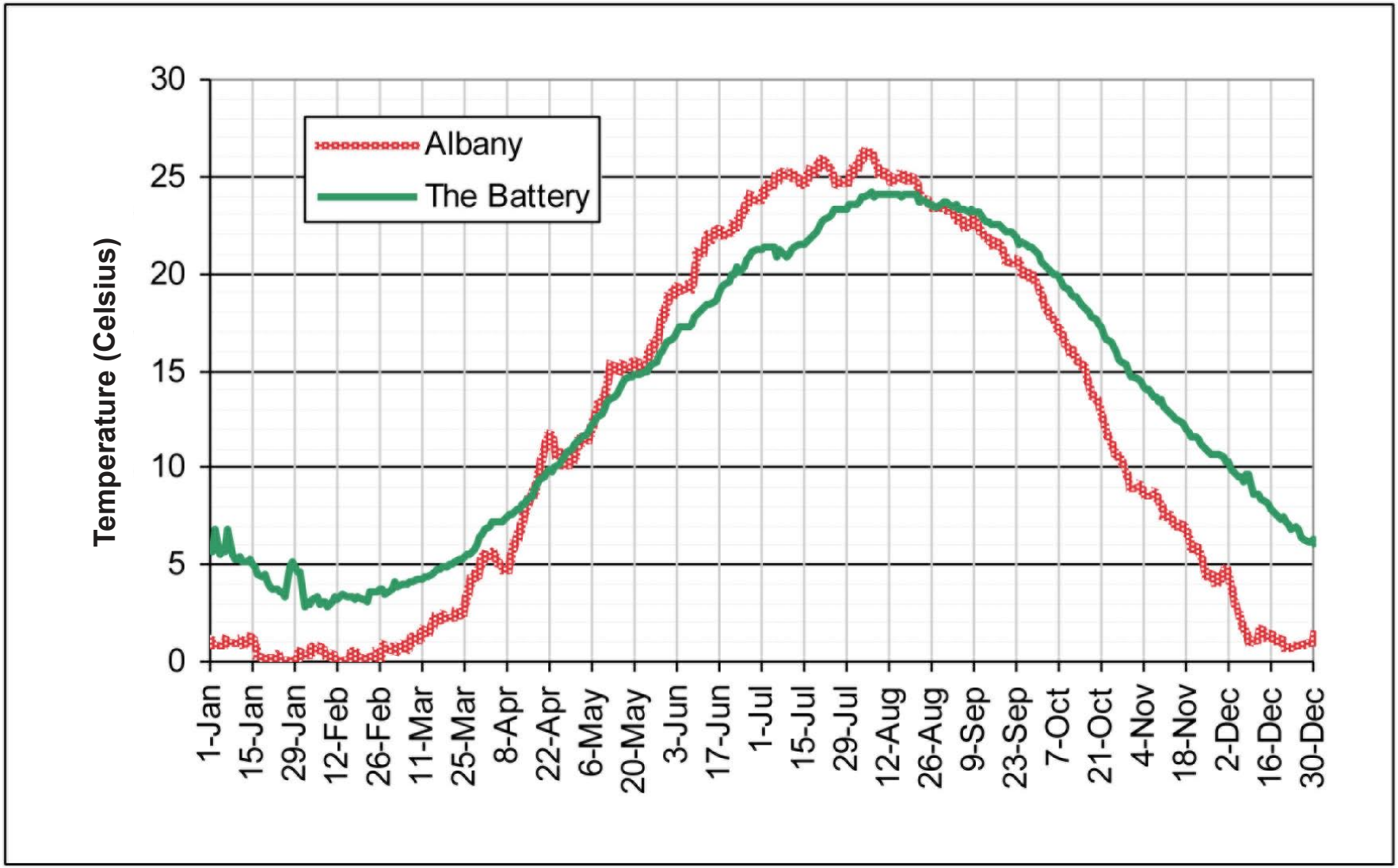
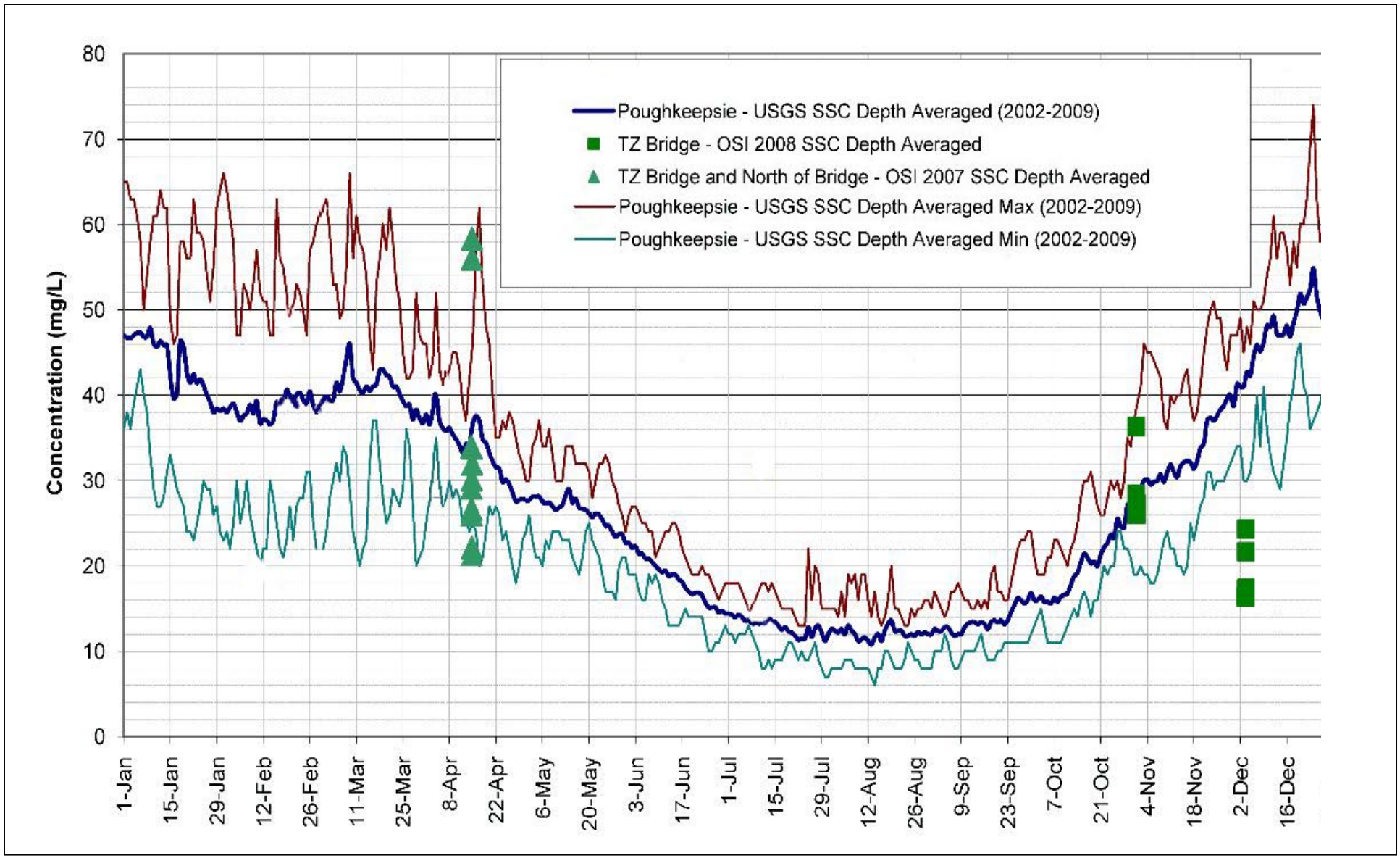


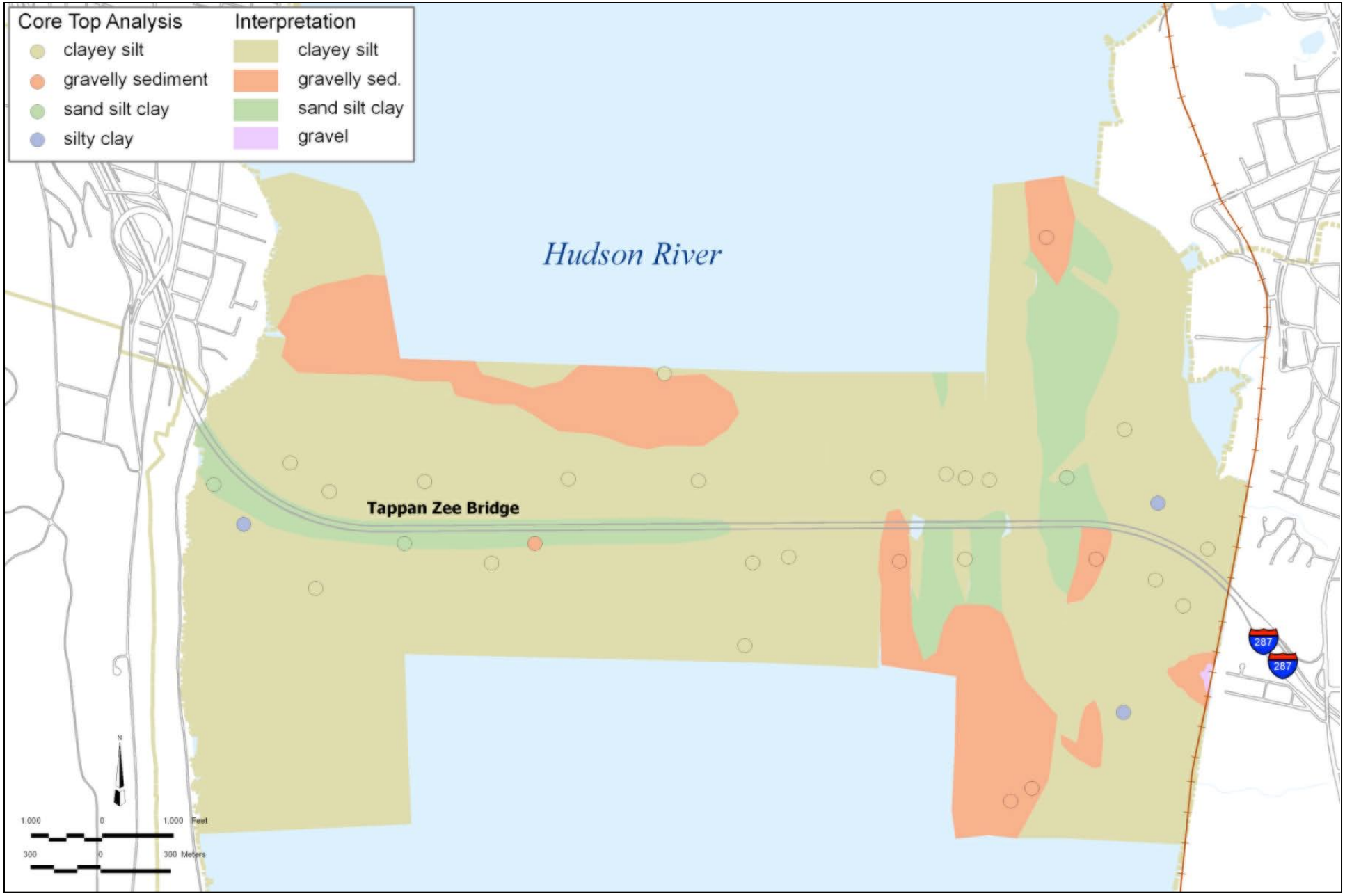
Figure 10
Average Water Temperature at Albany and the Battery



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 11
SSC Data

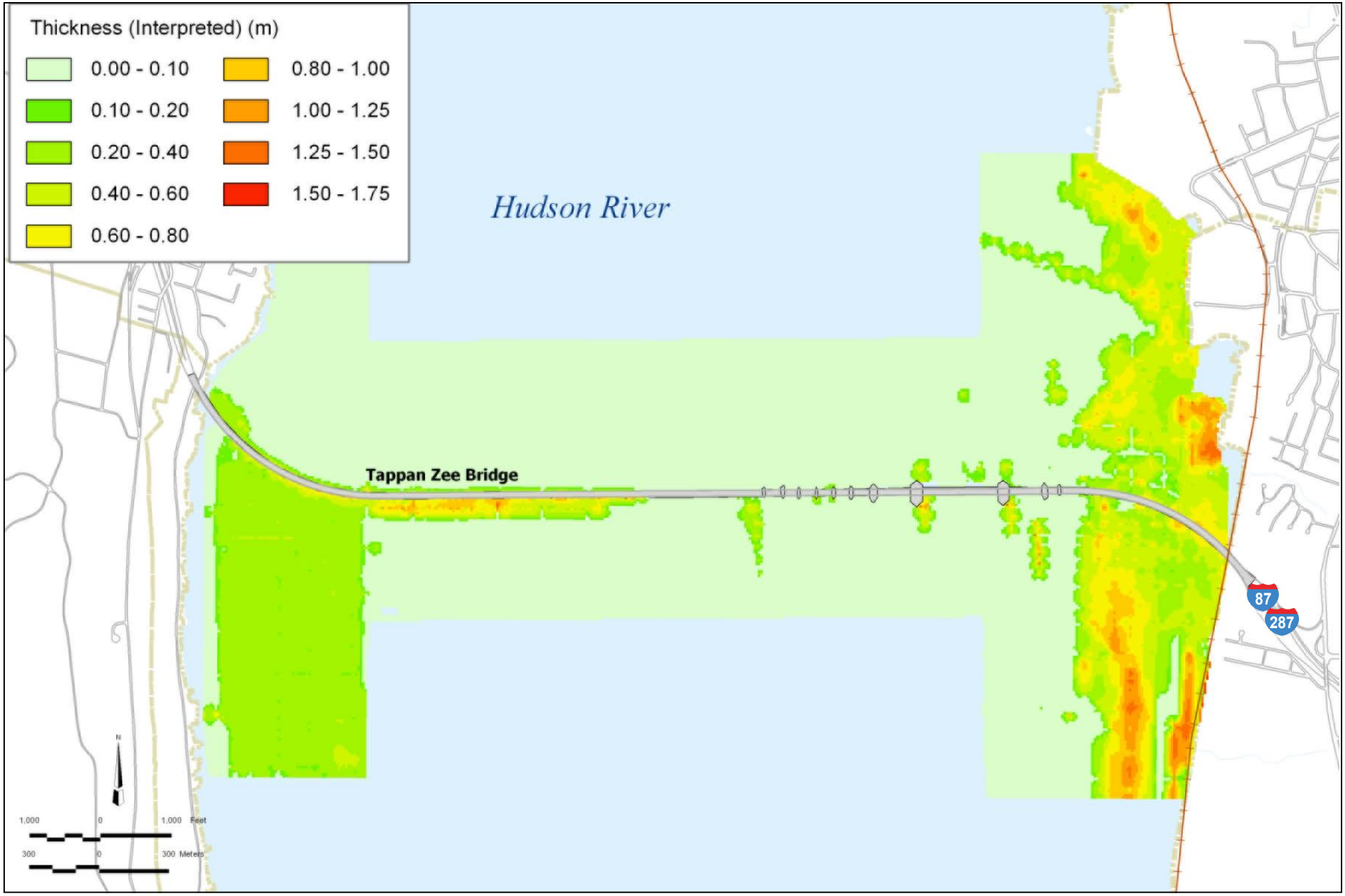
1.4.12



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 12
Sediment Texture

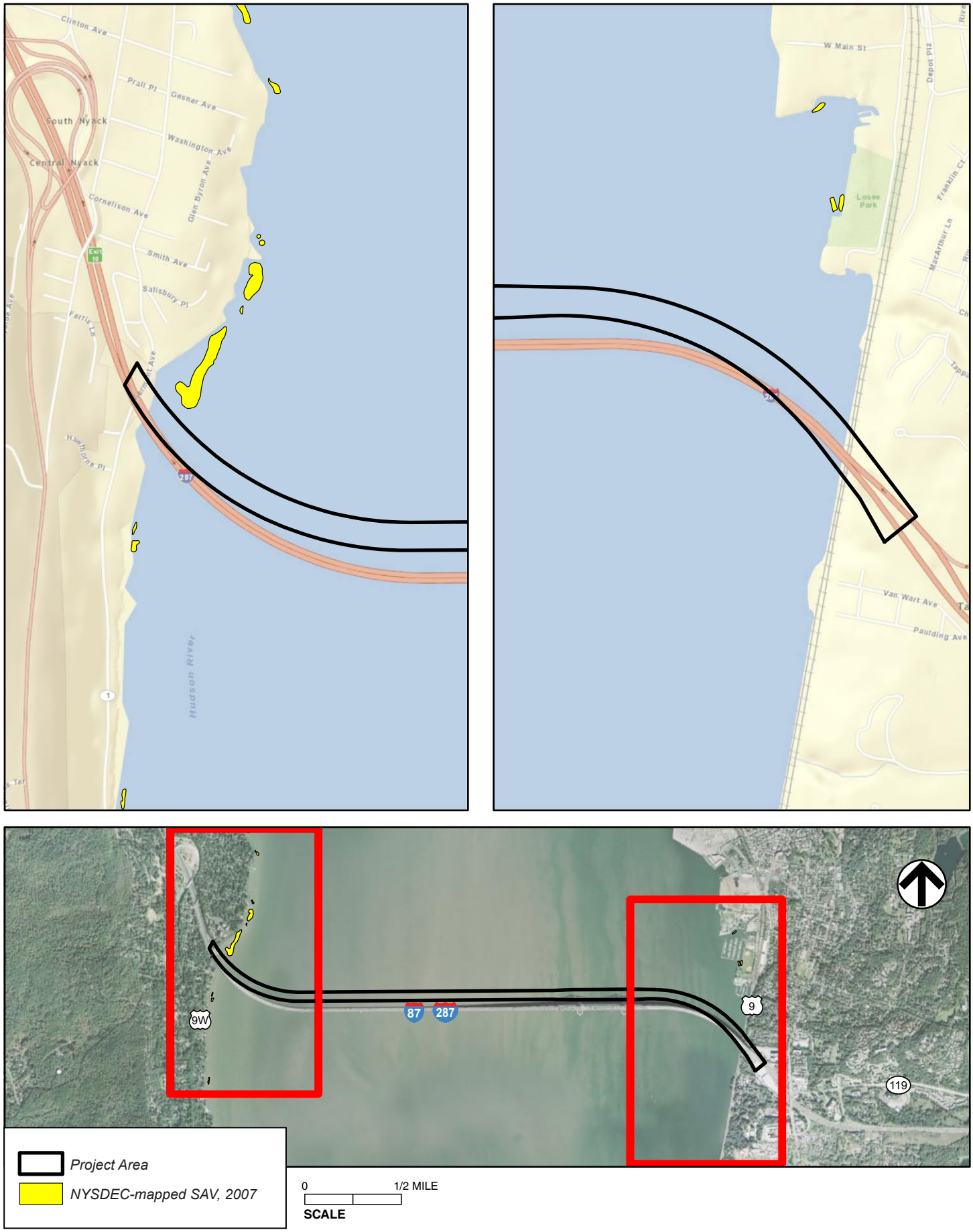
1.4.12



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 13
Recent Sediment Deposit Thickness

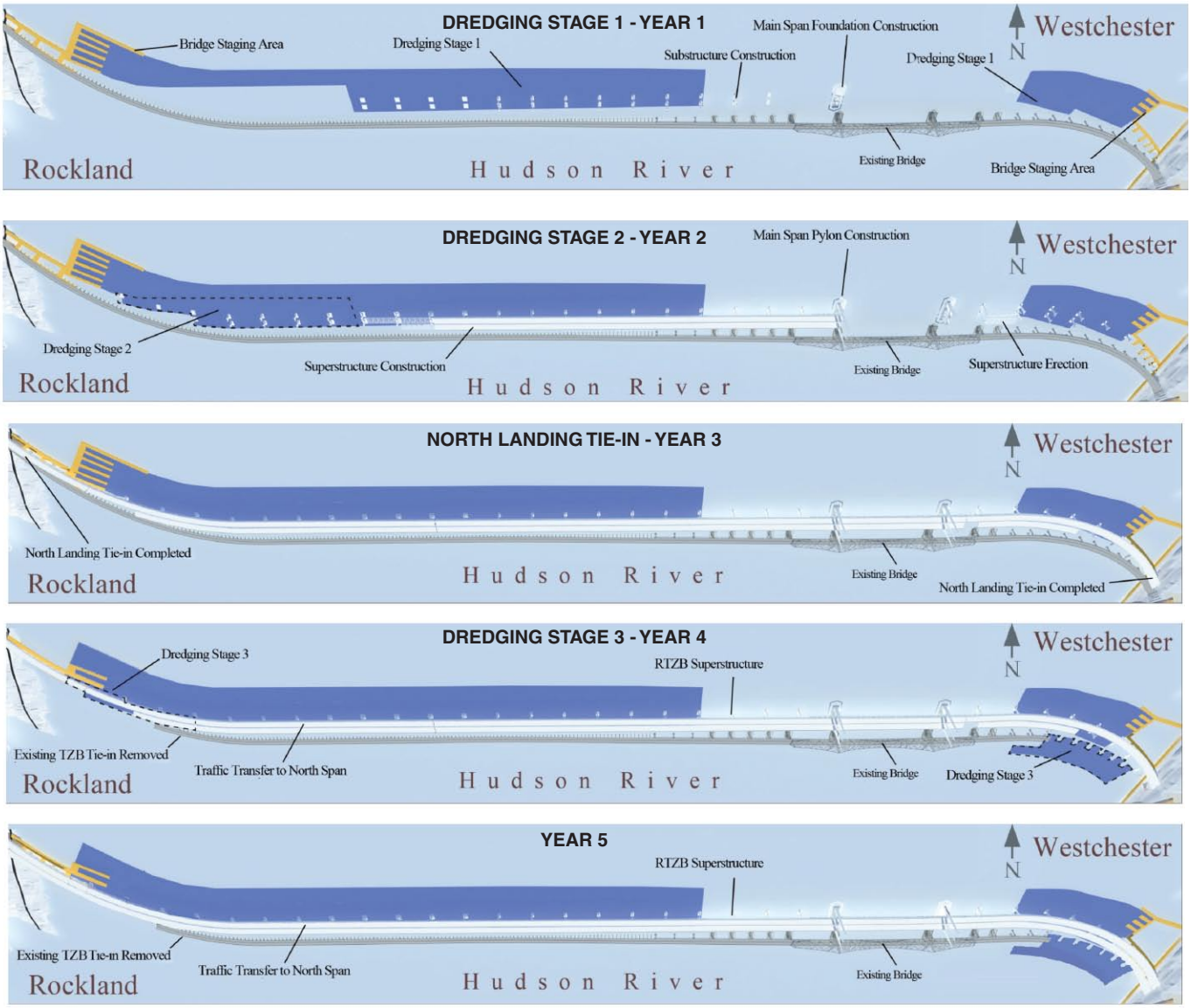
1.4.12



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 14
Submerged Aquatic Vegetation (SAV)

1.4.12



Note: Long Span Option is depicted, Short Span Option will be similar

TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 15
Dredging Sequence, Years 1 to 5

1.4.12

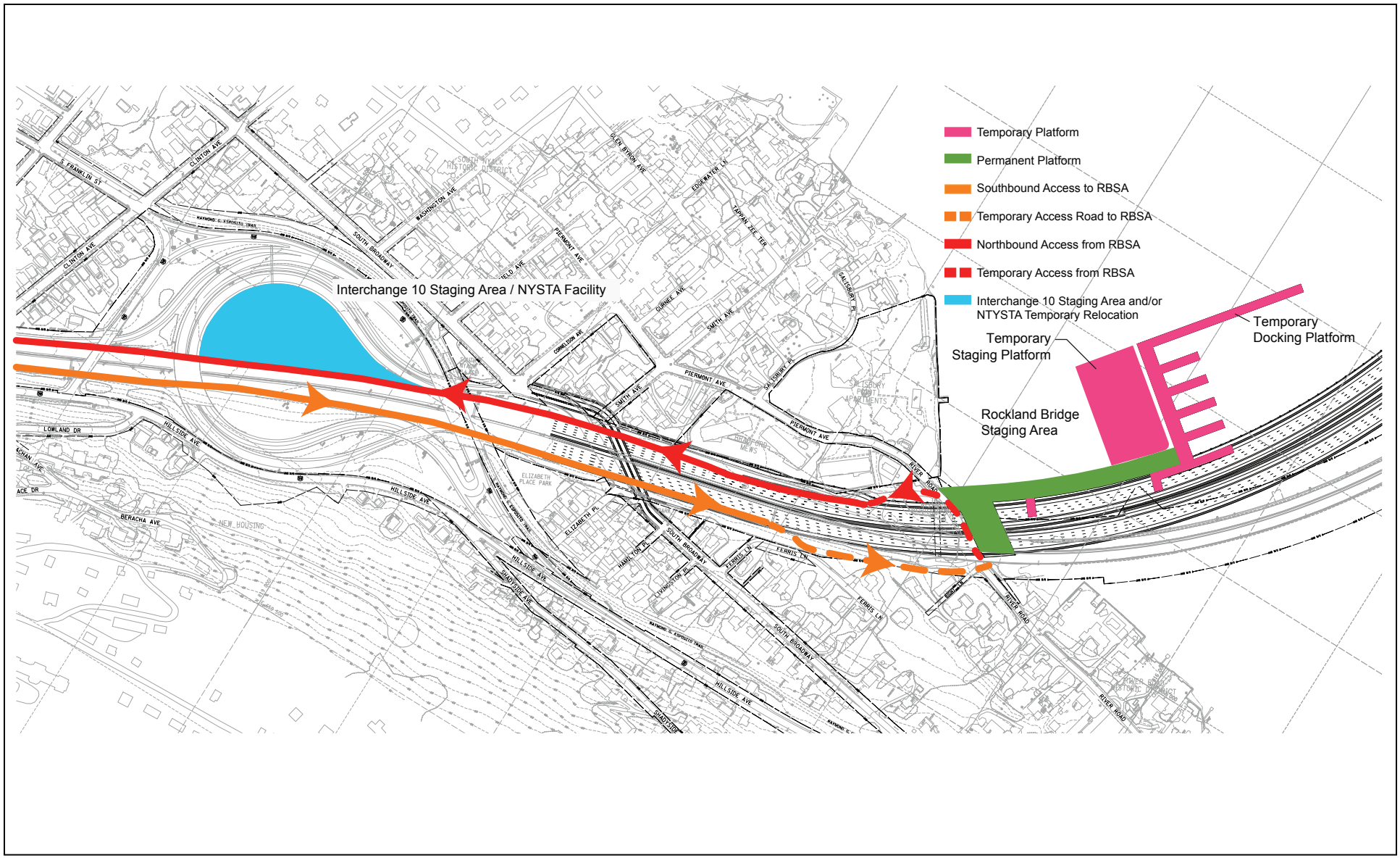
Construction Truck Routes

Potential Temporary Staging Areas

0 1/2 MILE
SCALE

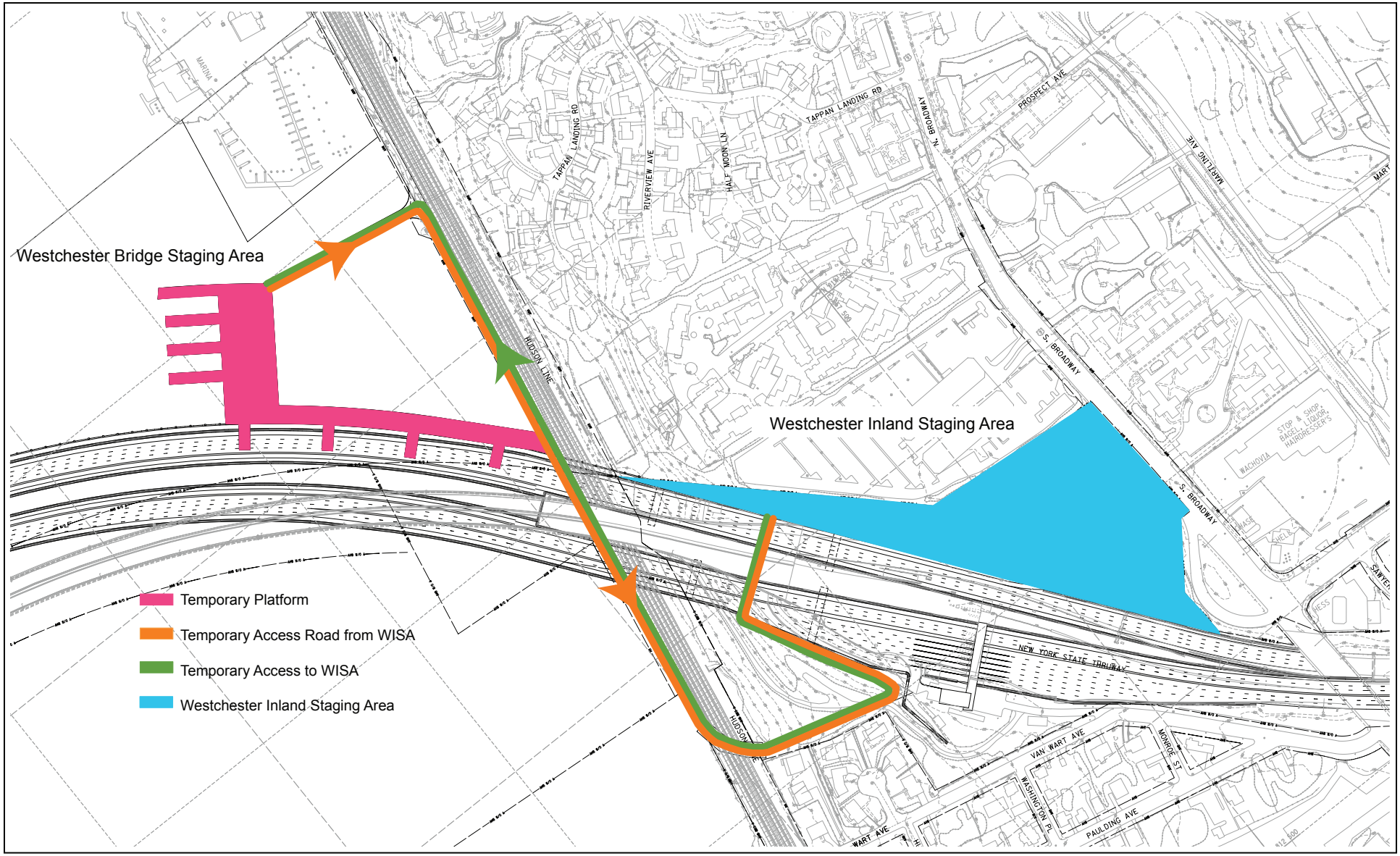
TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 16
Potential Upland Staging Areas



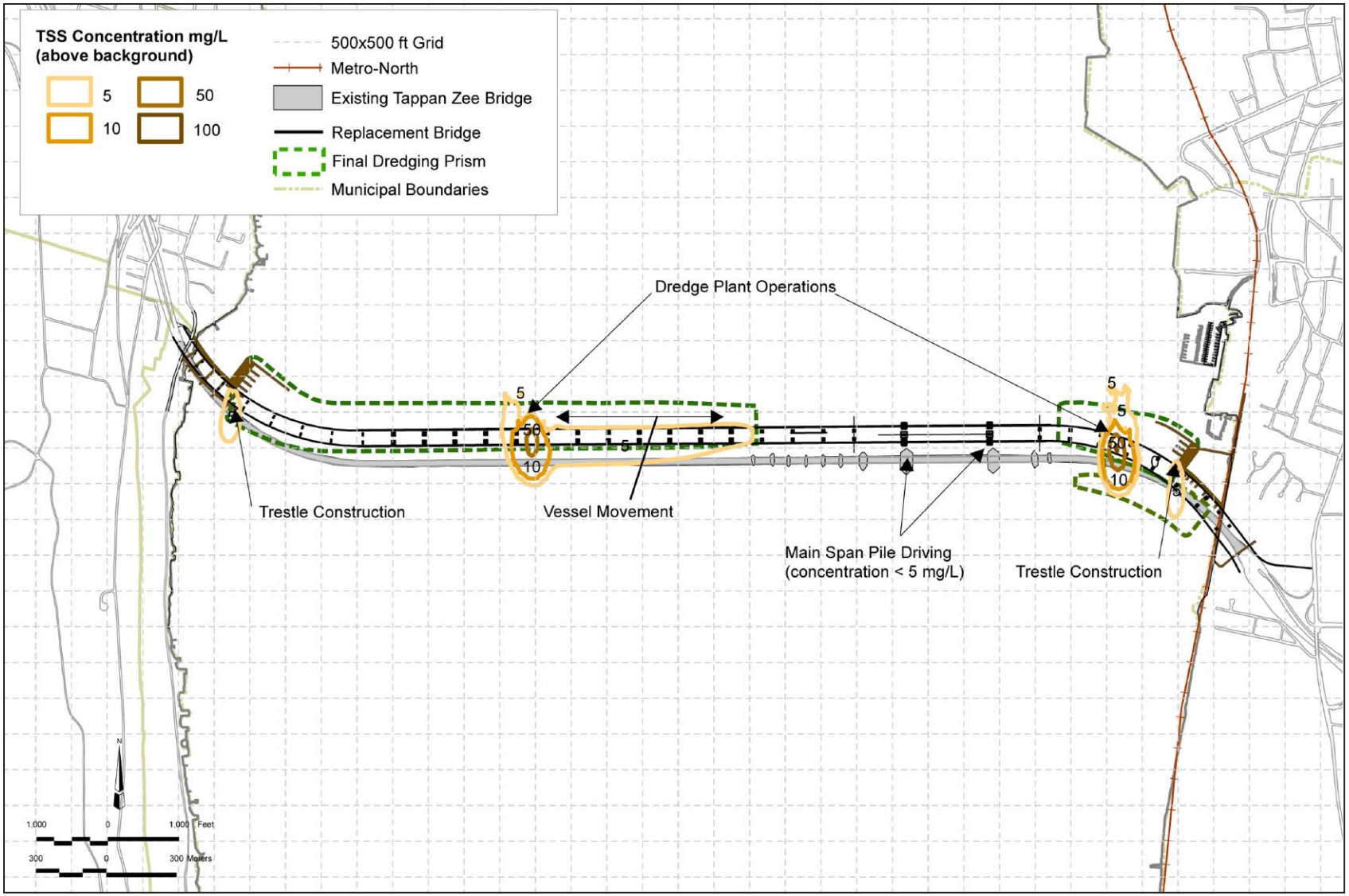
TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 17
Rockland Landing Construction Access



TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 18
Westchester Landing Construction Access

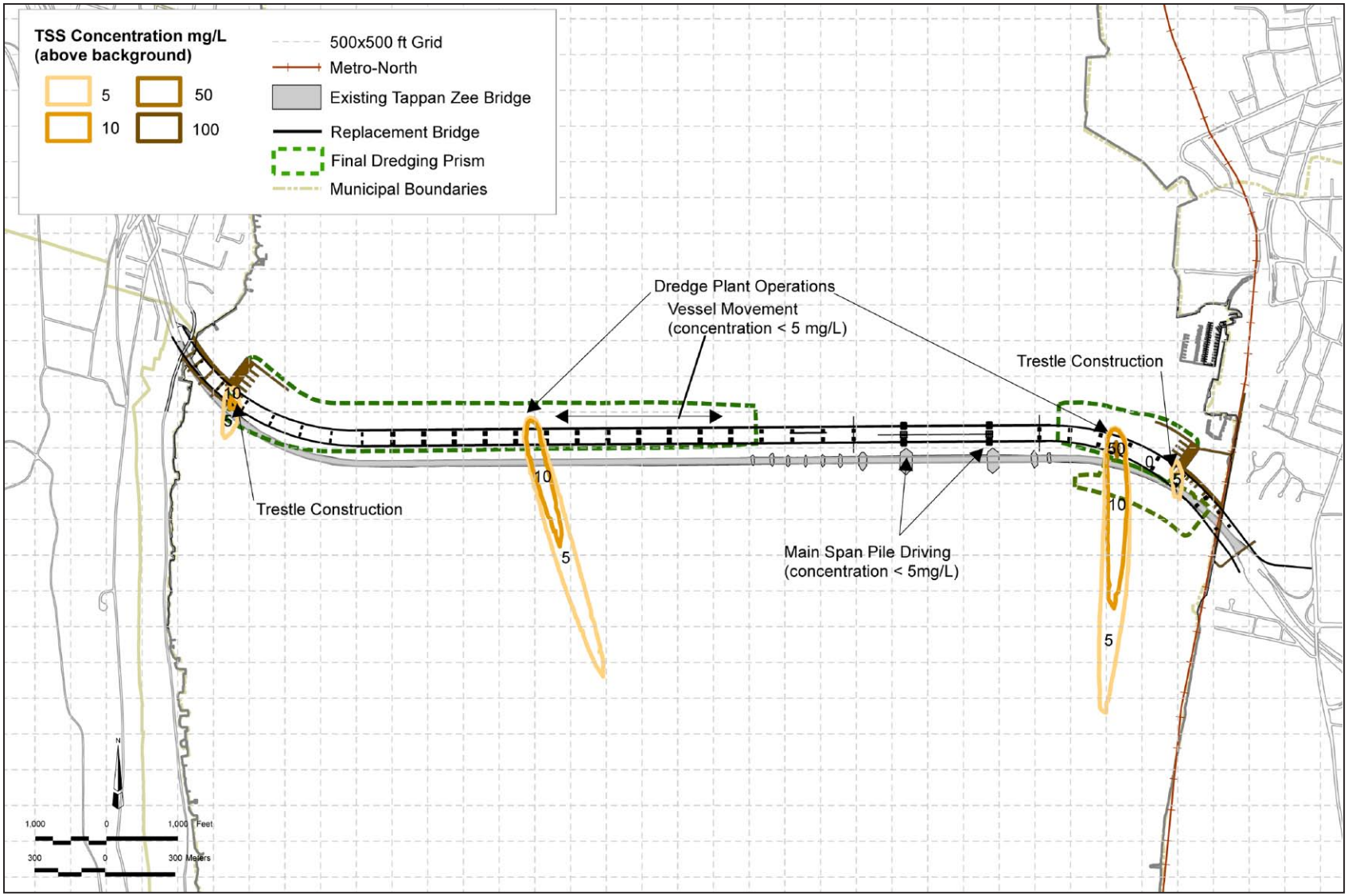


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 1 Dredging-Near Slack Tide

*Note: Short Span Option would be similar

Figure 19

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging – Near Slack Tide

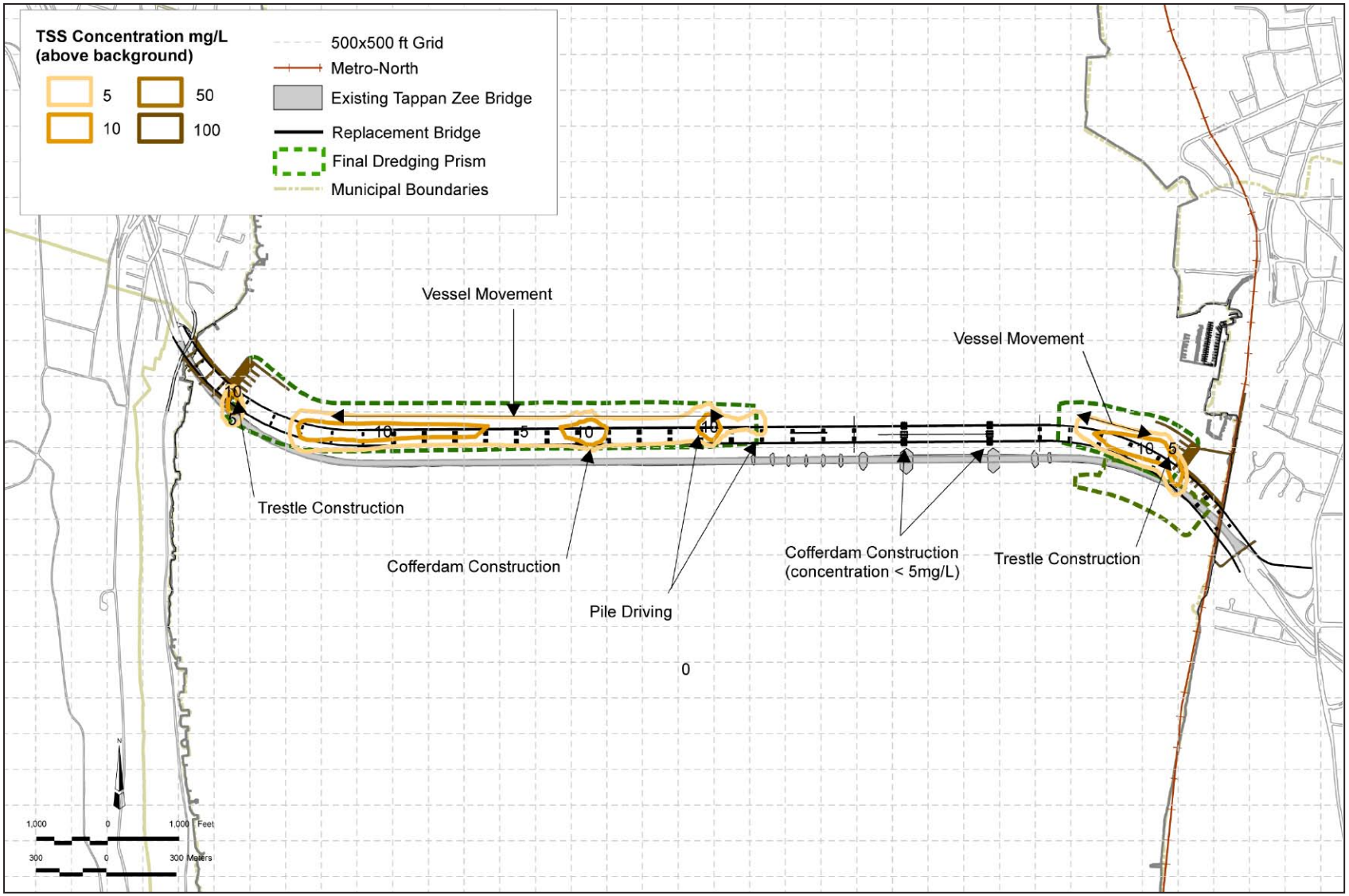


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 1 Dredging-Ebb Tide

*Note: Short Span Option would be similar

Figure 20

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging – Ebb Tide

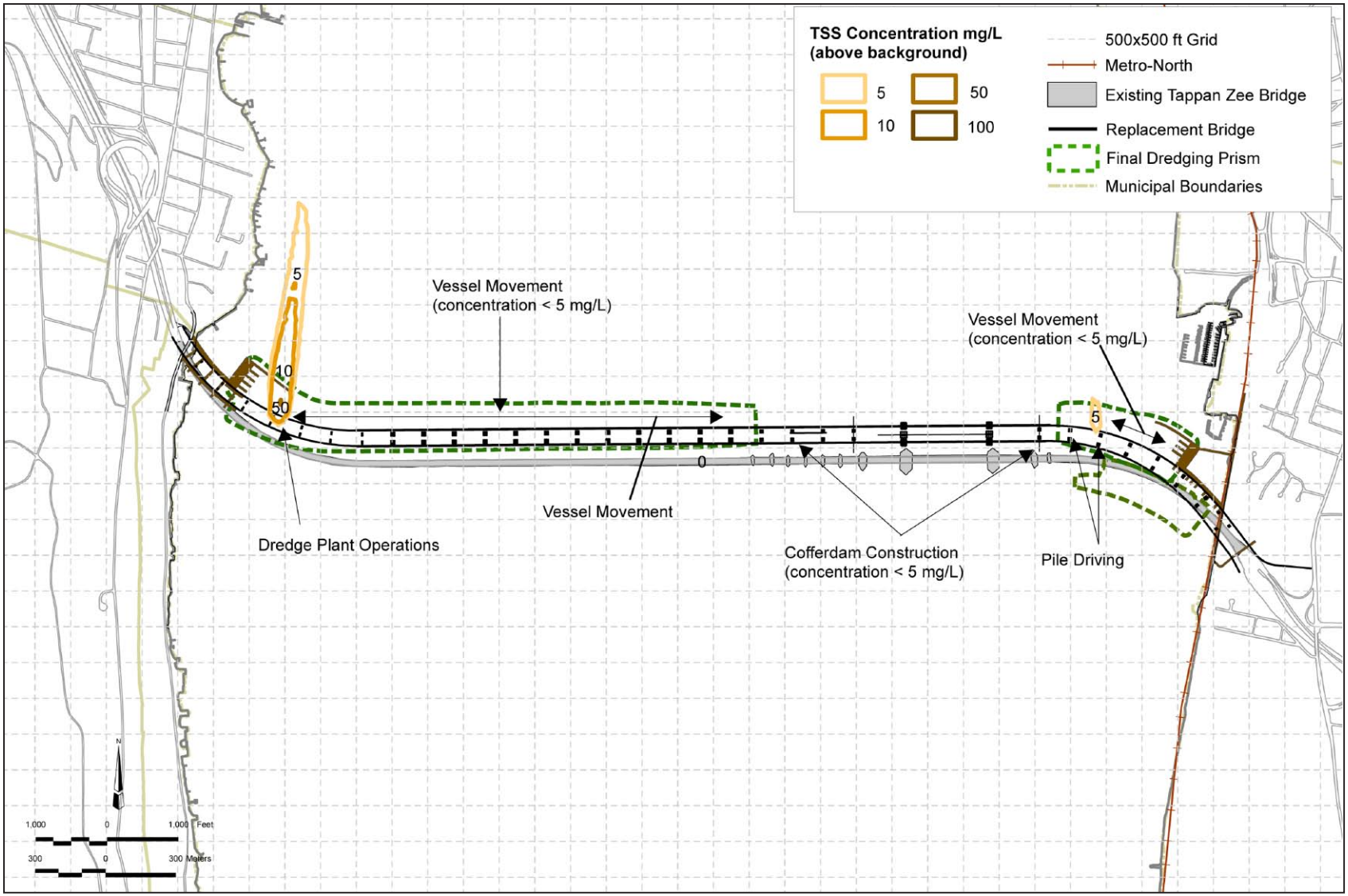


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* Zones C and B Construction After Dredging and Armoring – Near Slack Tide

*Note: Short Span Option would be similar

Figure 21

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring – Near Slack Tide



Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 2 Dredging and Zones C and B Construction– Flood Tide

*Note: Short Span Option would be similar

Figure 22

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction – Flood Tide

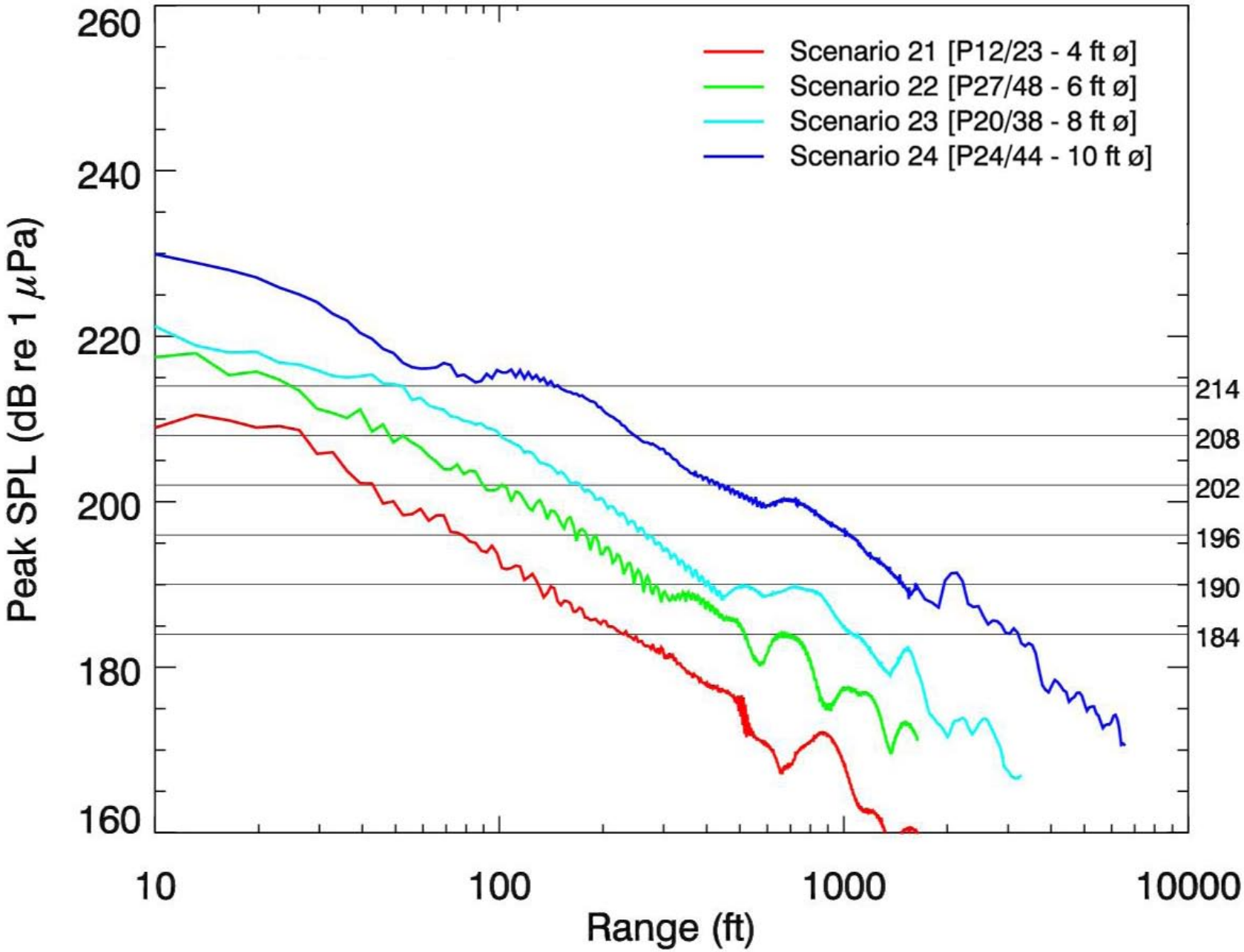


Figure 23

Impact Hammering of 4, 6, 8 and 10 Feet Diameter Piles with BMPs

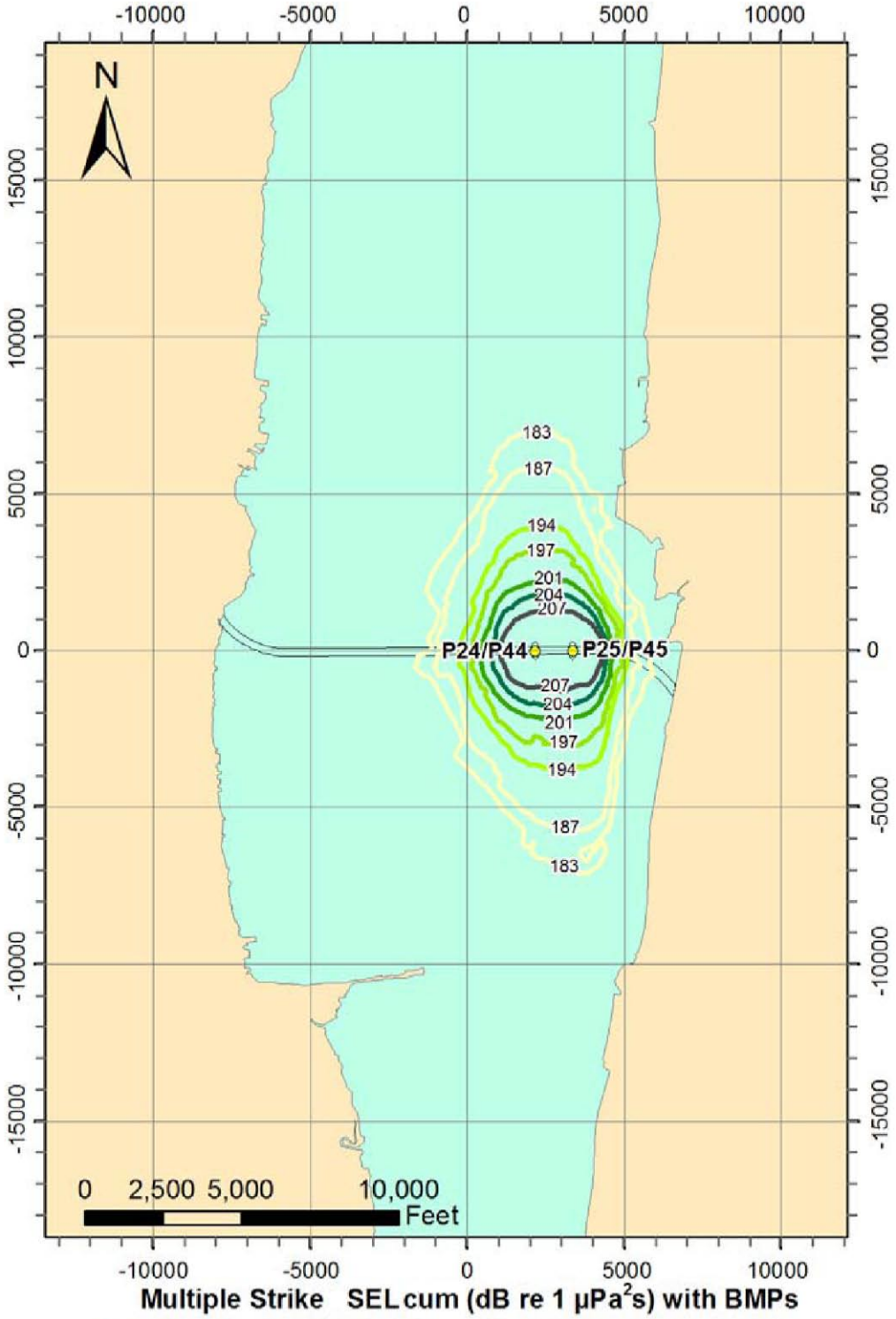


Figure 24

Isopleths for Short and Long Span Options - Driving of Two 10 Foot Piles at Piers 24, 25, 44 & 45

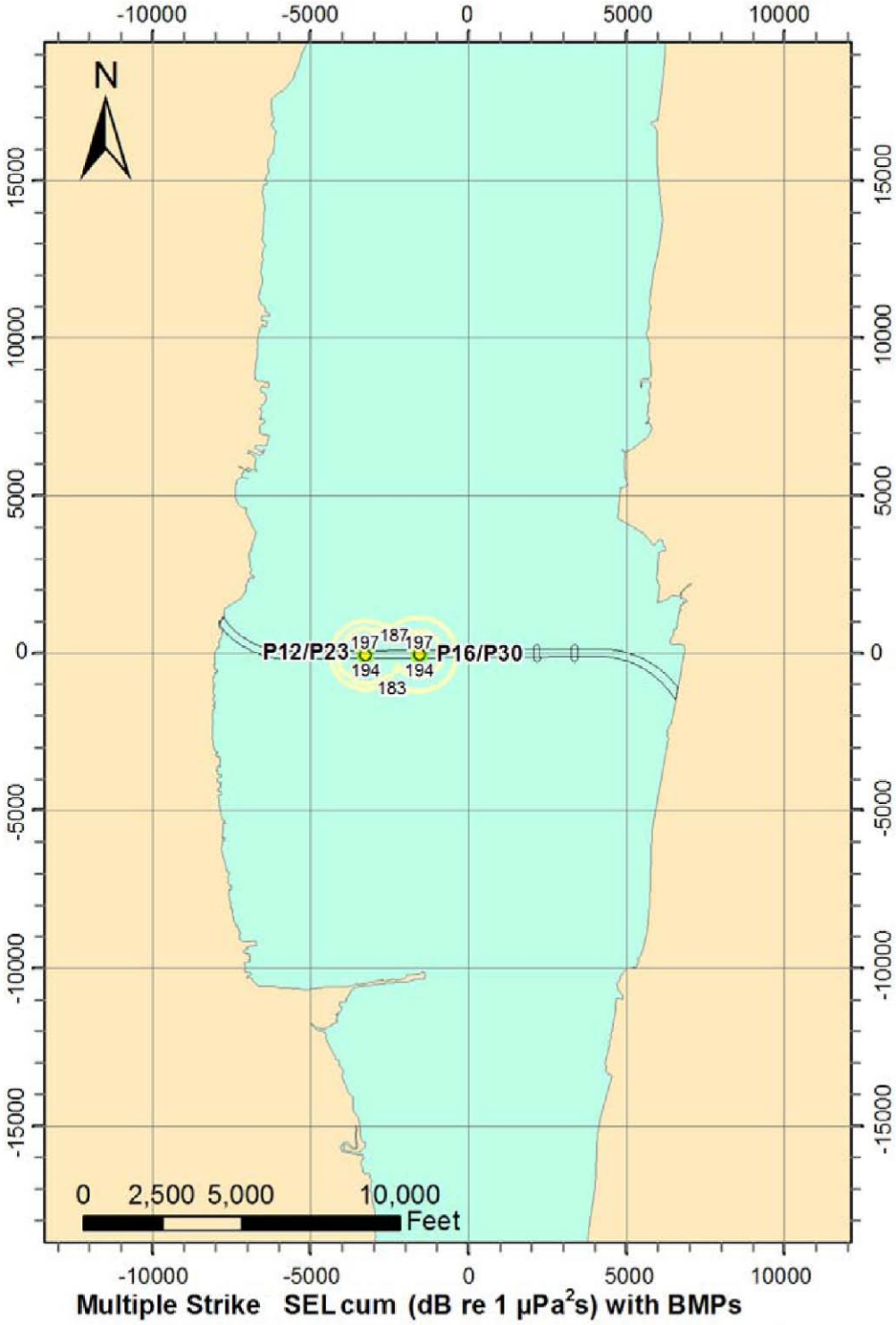


Figure 25

Isopleths for Short and Long Span Options - Driving of Four 4 Foot Piles at Piers 12, 16, 23 & 30

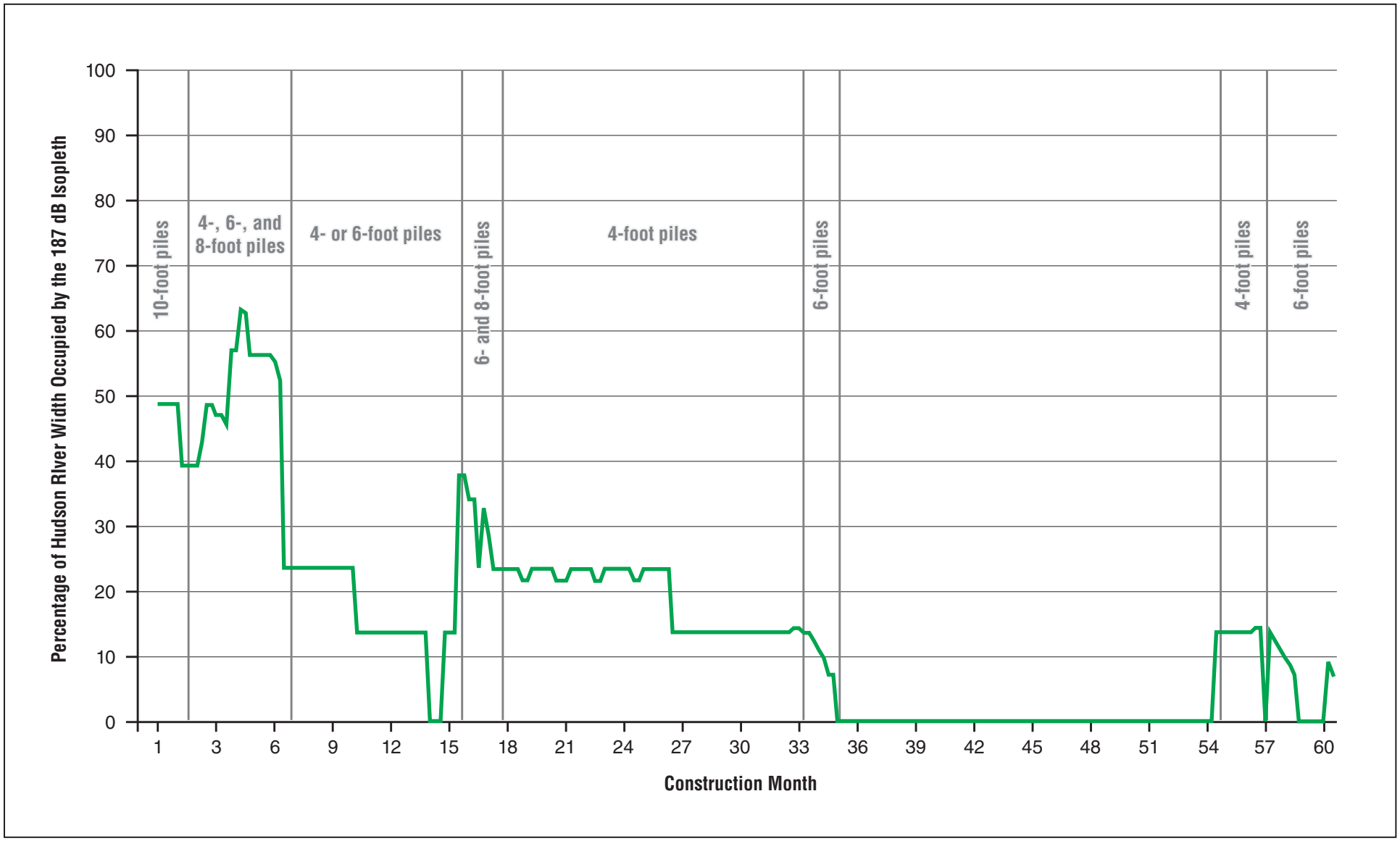


Figure 26

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Short Span Option

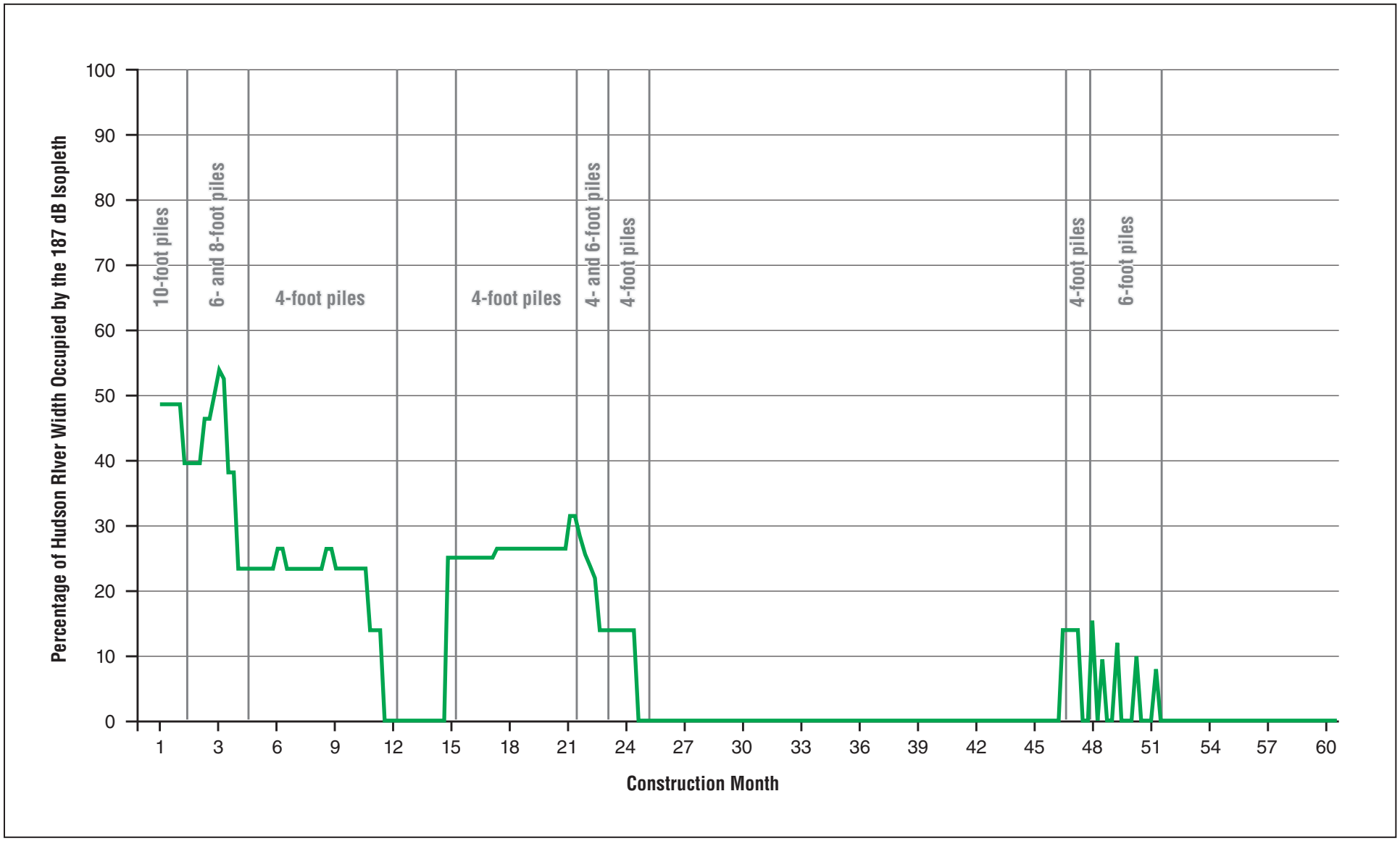


Figure 27

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Long Span Option

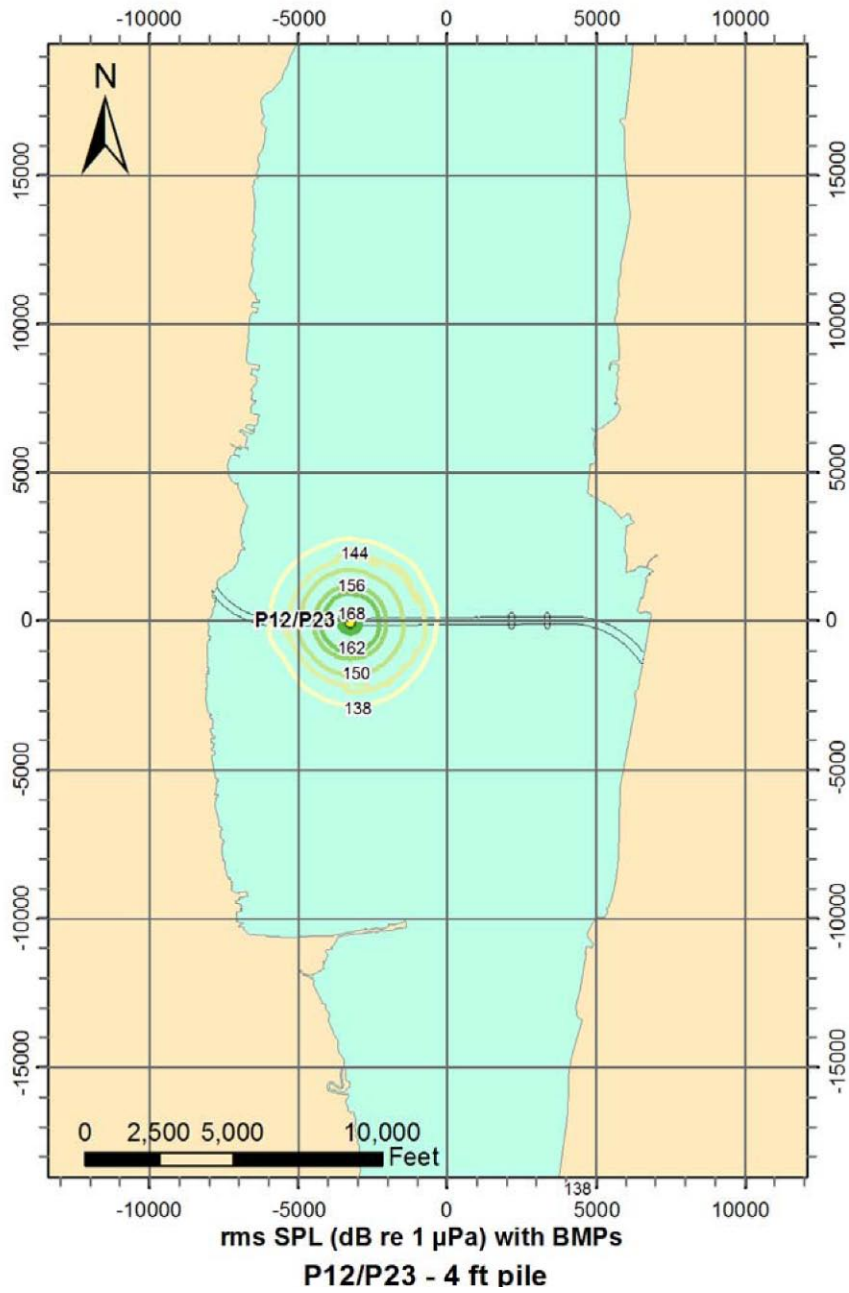


Figure 28

Peak Sound Pressure Levels for Short and Long Span Options, Single 4-foot Diameter Pile BMPs Applied

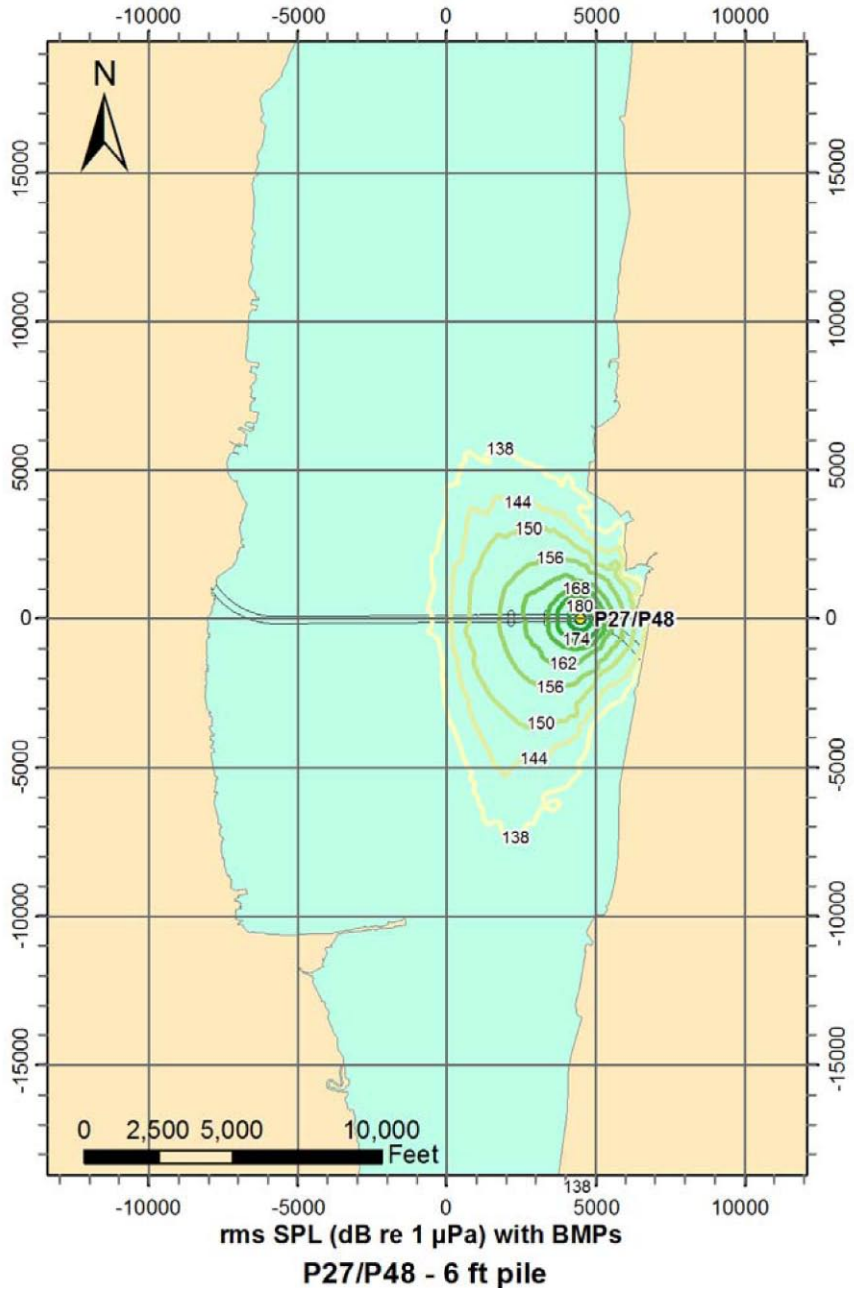


Figure 29

Peak Sound Pressure Levels for Short and Long Span Options, Single 6-foot Diameter Pile BMPs Applied

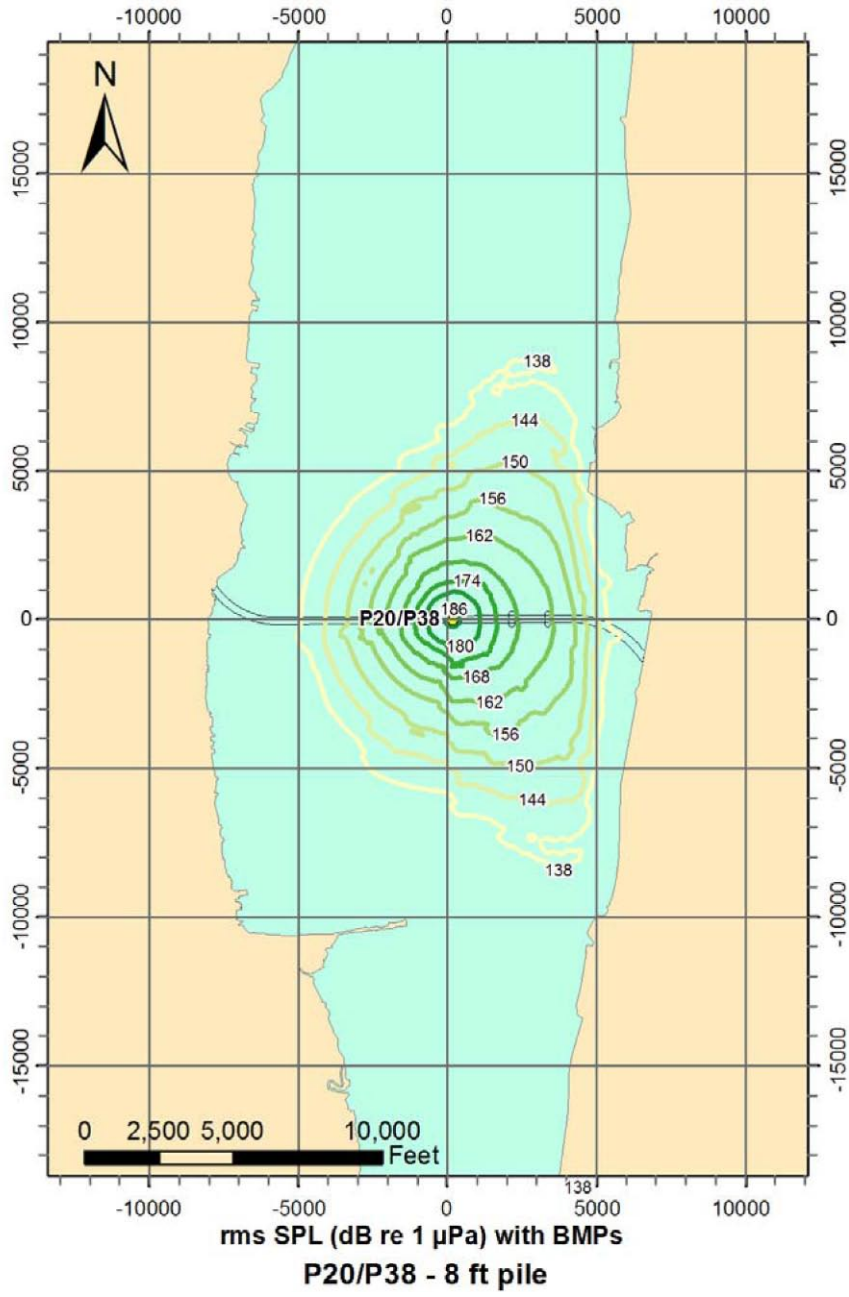


Figure 30

Peak Sound Pressure Levels for Short and Long Span Options, Single 8-foot Diameter Pile BMPs Applied

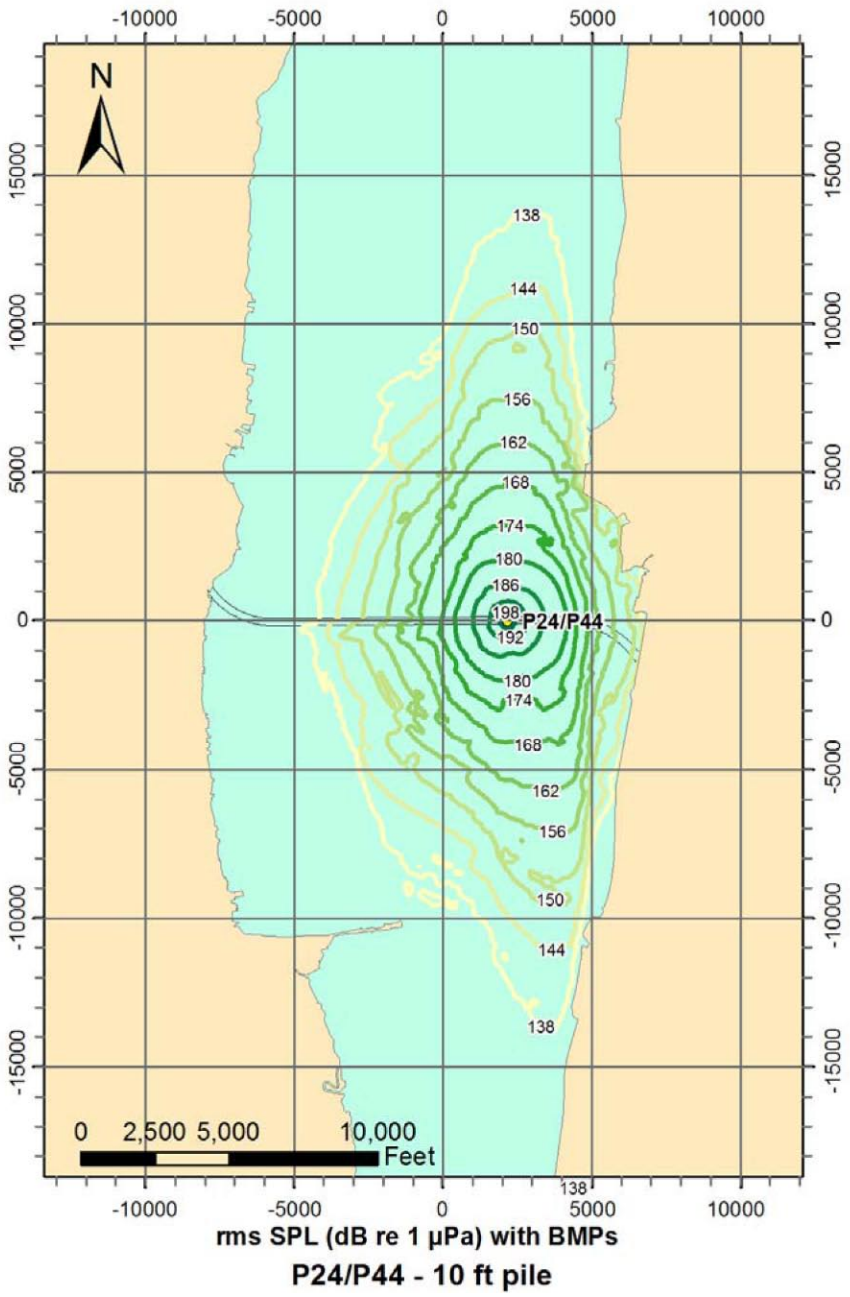
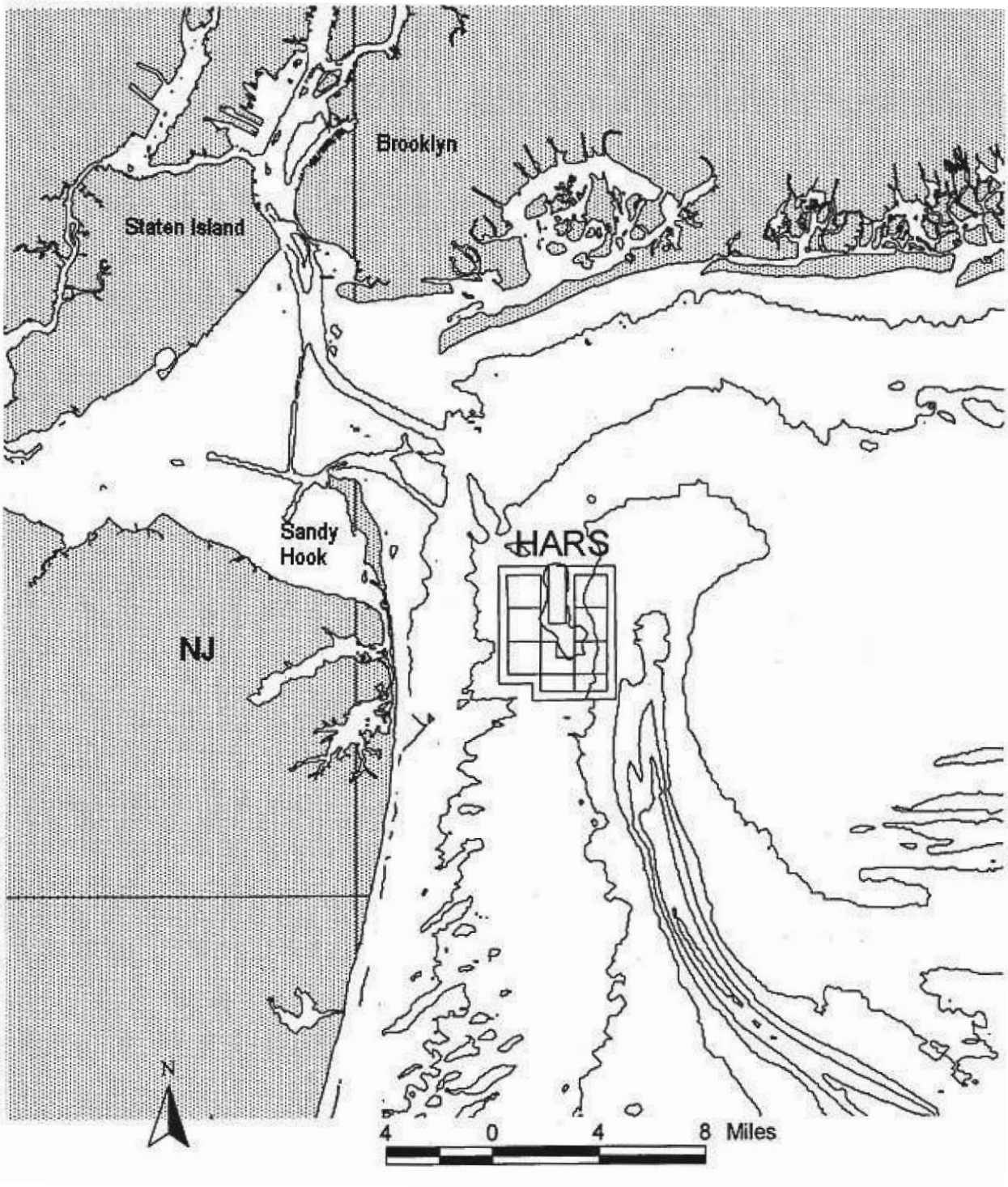


Figure 31

Peak Sound Pressure Levels for Short and Long Span Options, Single 10-foot Diameter Pile BMPs Applied

1.18.12



SOURCE: USACE and USEPA 2009

TAPPAN ZEE HUDSON RIVER CROSSING
Essential Fish Habitat

Figure 32
Location of HARS

1.17.12

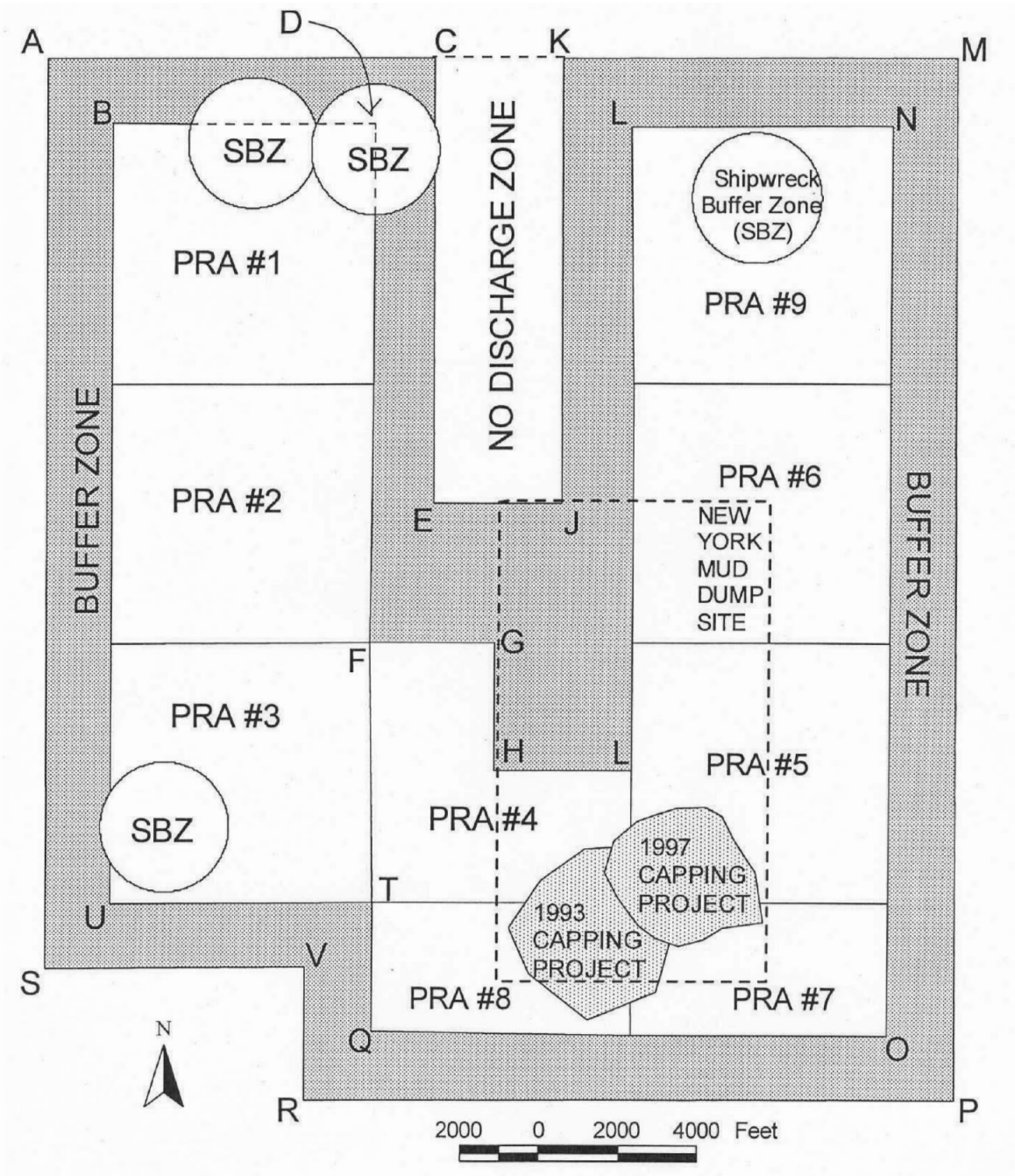
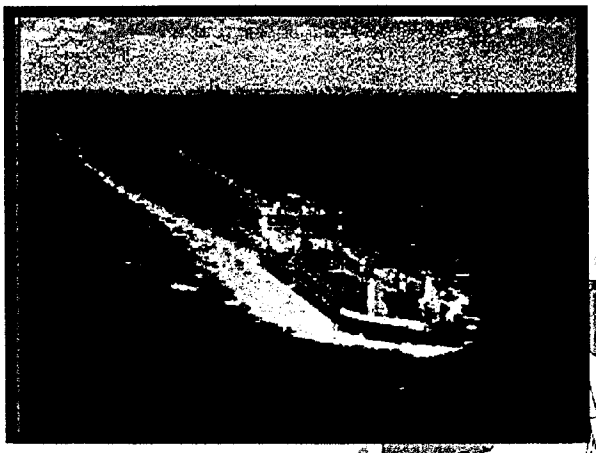


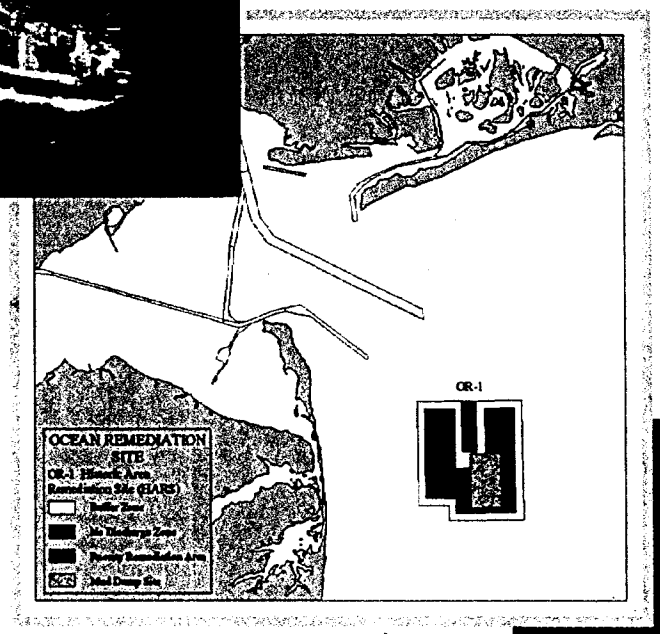
Figure 33

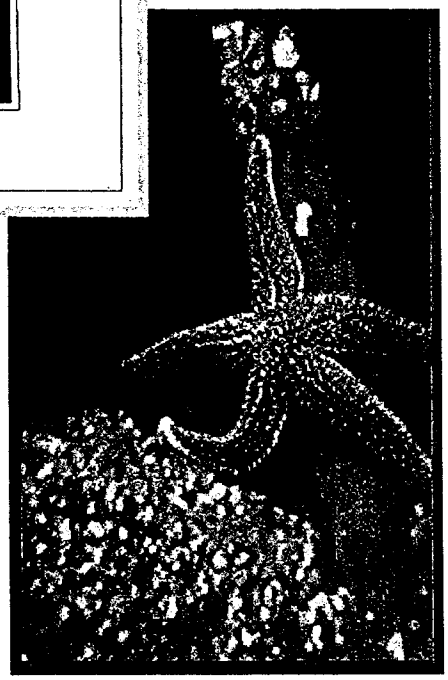
Priority Remediation Areas, Buffer Zone and No Discharge Zone

Attachment 1

PROGRAMMATIC ESSENTIAL FISH HABITAT ASSESSMENT FOR PLACEMENT OF CATEGORY I DREDGED MATERIAL AT THE HISTORIC AREA REMEDIATION SITE IN THE NEW YORK BIGHT APEX







Prepared By: U.S. Army Corps of Engineers
Operations Division
New York District
26 Federal Plaza
New York, NY 1027- 0090

A. INTRODUCTION

In accordance with Section 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (1996 amendments), the U.S. Army Corps of Engineers, New York District (the NYD), is providing this assessment of the potential effects on Essential Fish Habitat (EFH) resulting from the placement of Category I dredged material as Remediation Material at the Historic Area Remediation Site (HARS).

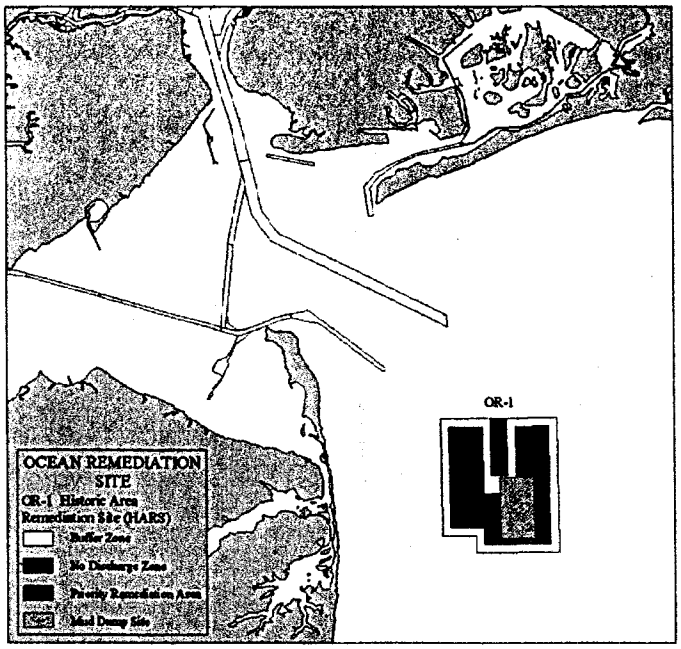
The following assessment addresses habitat characteristics, analyses of the effects (including long-term and cumulative) of dredged material placement on the physical habitats and managed species at the HARS. This evaluation includes a description of the listed managed species, appropriate specific life stages, and general species habitat characteristics.

It should be noted that the HARS was established to remediate habitat that currently has the potential to cause adverse ecological impact. Appropriate remediation material will be used as a cap to bury existing bottom sediments, isolating them from the surrounding biota. Placement of dredged material at this site will result in immediate and long-term environmental benefits to fish habitat; these benefits would greatly outweigh any minimal, short-term adverse effects from sediment placement. Best management practices will be used to minimize potential effects, precluding the need for mitigation or seasonal restrictions on the remediation effort.

B. PROJECT AUTHORIZATION, DESCRIPTION, AND PROPOSED ACTION

1. Authorization

Dredged material from the Port of New York and New Jersey has historically been placed in and around the Mud Dump Site (MDS), located in the open waters of the New York Bight, six nautical miles east of Sandy Hook, New Jersey. Based on concerns about limited site capacity and the environmental effects of past disposal, EPA Administrator Carol Browner, Secretary of Transportation Frederico Peña, and Secretary of the Army Togo West, Jr. issued a "3 Party Letter" in 1996 announcing the closure of the MDS by September 1, 1997. The 3 Party Letter states that simultaneous with the closure of the MDS, the site and surrounding areas which have been historically used for disposal of dredged material having elevated levels of chemical contaminants will be redesignated as the Historic Area Remediation Site. On August 26, 1997, the U.S. Environmental Protection Agency (EPA) finalized the ruling providing for simultaneous closure of the MDS and designation of the HARS (40 CFR Part 280).



2. Description

The HARS is located 3.5 nmi east of Highlands, NJ and 7.7 nmi south of Rockaway, NY. It consists of a 15.7-nmi^2 (54-km^2) area divided into a Priority Remediation Area (PRA) – a 9.0 square nautical mile area to be remediated with at least one meter of Remediation Material; the Buffer Zone (BZ) – an approximately 5.7 square nautical mile area (0.27 nautical mile band around the PRA) in which placement of Remediation Material will not be allowed, but which may receive Remediation Material that incidentally spreads out of the PRA; and the No Discharge Zone (NDZ) – an approximately 1.0 square nautical mile area in which no placement or incidental placement of the Remediation Material may occur. All identified degraded sediments, defined as those exhibiting Category II or Category III characteristics, are within the 9-nmi^2 (31-km^2) U-shaped PRA, and would be capped with at least one meter of Remediation Material. In accordance with the 3-party letter and the EPA final rule, the material for remediation would be "uncontaminated dredged material that meets Category I standards and will not cause significant undesirable effects including through bioaccumulation".

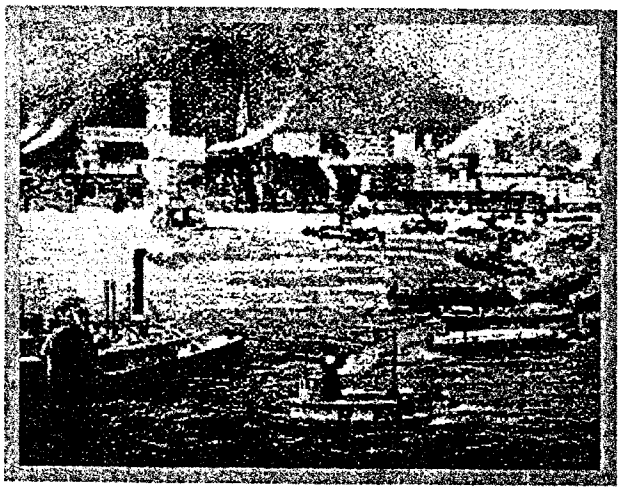
3. Description of Planned Action

At least 40.6 Myd^3 of Remediation Material would be required to cap the nine cells of the PRA with a one-meter thick cap. The placement of additional Remediation Material may be necessary to ensure this thickness after settling and consolidation occur, or to add an extra layer of cap to further isolate degraded sediments. Most of the material used for remediation would be composed of fine-grained silts, clays, and sands. However, other coarser Remediation Material, including coarse sands and gravels may also be used to remediate the HARS.

Since the remediation program for the HARS will permit only appropriate Remediation Material, over time the substrate is expected to improve significantly with regard to its habitat suitability, particularly for benthic and demersal species.

C. DESCRIPTION OF HARS

1. Habitat Characteristics – Historic Area Remediation Site



a. General Site History

New York Harbor, Newark Bay, and the New York Bight have been documented as a repository for waste since the eighteenth century. Raw sewage, garbage, and refuse were regularly disposed in the inner harbor until the early 1900's. Eventually, in response to public complaints, disposal activities moved from the inner harbors to offshore ocean sites. Ultimately these offshore disposal locations were consolidated into a set of specific sites that were designated and managed under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA) and subsequent

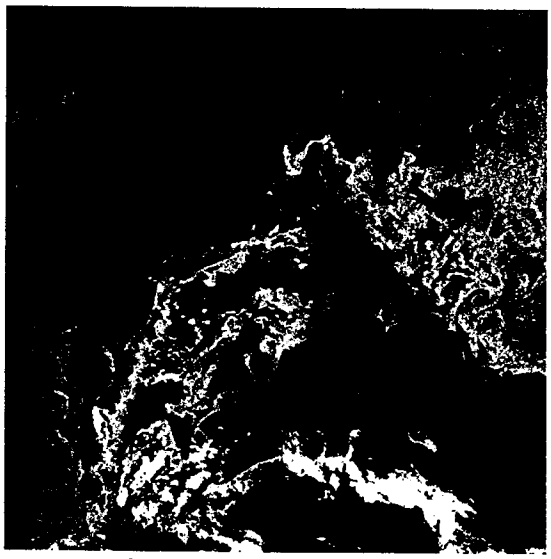
amendments. The MDS was designated as an interim dredged material disposal site with formal designation completed in 1984. Consistent with the July 24, 1996 3-Party letter, the MDS was closed in September, 1997 and simultaneously the HARS was designated for the purpose of remediation.

b. Sediments

The extensive use of the New York Bight Apex as a disposal area over the past 100 years has lead to major anthropogenic changes in its physical character. Consequently, the area contains both naturally occurring sediments and other surface sediments present due to previous dredged material disposal or other disposal practices (i.e., the Former Cellar Dirt Site). The HARS is dominated by mounded dredged material that rises up to 12 meters above the historic sea floor in some places (EPA, 1997). Surface sediments are heterogeneous, ranging from fine-grained materials (hence, the name the Mud Dump) to areas of sandy gravel and artifactual gravel at the former cellar dirt site.

c. Physical Oceanography and Meteorology

Water depths at the site range from 14 to 42 meters. The configuration of circulation in the Middle Atlantic Bight is quite complex with great temporal and regional variability.



Low frequency meteorological forcing (over 3 to 10 day periods) is responsible for much of the current fluctuations over the shelf. During the spring and summer, wind energy is diminished, the water column is stratified and the maximum energy in the water column shifts from being primarily influenced by meteorological conditions to being influenced by inertial and tidal energy (Mayer, 1982). Generally, the magnitude of the currents increases with the distance offshore and decreases with depth (Beardsley and Boicourt, 1981). Near-bottom currents in the remediation area were measured in the summer and winter (SAIC, 1995; 1993a;b). The predominant near-bottom flow was northward (300° - 30°). Mean summer currents were weak (6 to 9 cm/s) with less than 3% of the observed current speeds greater than 20 cm/s. Tidal currents were primarily bi-directional with northwest-southeast orientation and peak ebb and flow values of 6-8 cm/s. National Weather Service data from Ambrose Lighthouse shows the prevailing wave direction in the region follows the prevailing wind directions, from the northwest in the fall and winter and from the south in the spring and summer.

d. Contaminant Distributions

<u>Metals</u> Within the New York Bight Apex, metals (Zn, Cr, Cu, Pb, Ni, Fe, Hg, and Cd) are highly intercorrelated (Krom *et al*, 1985). These metals correlate strongly with the organic matter content of the sediments, and to a lesser degree, with the silt-clay component. Trace metal concentrations in the surface sediments of the HARS can typically be segregated into areas of high and low concentrations. Areas of highest

concentrations are generally correlated with areas containing high amounts of fine-grained sediments and also high organic carbon content.

Organic Contaminants Available data illustrate that background organic sediment concentrations in the New York Bight sediments are generally low (Boehm, 1983) and are strongly associated with the amount of fine-grained sediment in the sample. Sandy sediments from the HARS have organic contaminant concentrations within the range of those found in the New York Bight. A large range in concentrations characterizes both historical and recent organic contamination data of surface sediments.

Sediment Quality The area encompassing the HARS had been subject to anthropogenic influences since colonial times. Environmental impacts to the Bight can be divided into two distinct types – (1) direct impacts resulting from the intentional discharges and disposals of waste in the waters of the Bight and (2) indirect impacts resulting from releases of point and non-point source pollution in the watershed which reaches the Bight via the Hudson River outflow and as atmospheric deposition.

Sediment quality depends on the availability of the contaminants to organisms (Brungs and Mount, 1978; Spacie and Hamelink, 1985; Dickson *et al.*, 1994) and the potential for impact to the larger ecosystem. Contamination concentrations in the HARS region were studied by the EPA using NOAA sediment quality guidelines such as ER-L (Effects Range-Low) and ER-M (Effects Range-Medium)(Long and Morgan, 1991;Long *et al.*, 1995). Additionally, direct methods for estimating potential environmental impact were used, e.g., measurement of a sediment's toxicity to organism through dredged material assays.

Toxicological testing of the sediments in the HARS area using amphipods found a wide range of percentage survival (Battelle, 1996a). For benthic-effects evaluation, the limiting permissible concentration (LPC) of the solid phase of dredged material is applicable and defined as *...that concentration which will not cause unreasonable acute or chronic toxicity or sublethal adverse effects based on bioassay results using...appropriate sensitive benthic marine organisms...* According to the "Green Book (EPA/USACE, 1991), dredged material does not meet the LPC for benthic toxicity when bioassay organism mortality (1) is statistically greater than the reference sediment and (2) exceeds mortality in the reference sediment by at least 10% (or a value that is in accordance with approved testing methods, e.g., 20% for amphipod bioassays. Sediments exhibiting significant toxicity were generally located across the middle of the HARS.

e. Water Quality

Water quality is generally based on the amount of particles in the water (turbidity), dissolved oxygen levels, nutrient and chlorophyll levels, and contaminant concentrations. The Hudson River discharge is a major influence on the water quality of the New York Bight. Concentrations and spatial and temporal distributions of particles, nutrients, and contaminants in the area of the HARS are a function of the outflow of the Hudson River, with a resultant decreasing offshore gradient. Furthermore, seasonal

changes in salinity and density gradients influence spatial and temporal variability in turbidity, dissolved oxygen, nutrient, chlorophyll, and contaminant concentration in the water column.

Temperature Salinity and Density Bight waters reach maximum density during winter (January, February, March) when temperatures are at their lowest and salinity reaches an annual maximum (Bowman and Wunderlich, 1977). There is little river runoff and strong vertical mixing resulting in an unstratified water column. However, bottom temperatures may be slightly warmer than surface temperatures.

Runoff reaches its maximum in April and May. Strong thermal stratification develops in May, resulting in a warm surface layer. A plume of low salinity water is present in the Bight apex at this time, following the New Jersey shoreline and often extending to the HARS. This may result in the trapping of a band of high-salinity water between the New Jersey coast and the river plume.

During the summer (June, July, August) the thermocline intensifies while bottom temperatures remain the same. Surface temperature gradient and the depth of the thermocline reach their maximum in early August. The two-layer water column structure prevents wind energy from reaching surface sediments, decoupling bottom current velocities from surface velocity. This substantially reduces the sediment resuspension and transport potential.

During the fall (September, October) and early winter (November, December) the thermocline breaks down, the isothermal layer deepens and bottom water warms. Eventually shelf waters are almost entirely isothermal with an increase in surface salinity. During this period, the potential for storm-induced sediment resuspension is at its greatest.

Turbidity Turbity survey results showed low turbidity throughout the water column with a small mid-depth maximum in the central portion of the HARS. The feature extends from the north and west into the area of the HARS, but not to the east of it. The data did not reveal elevated turbidity in the vicinity of the MDS that may be attributed to dredged material placement. However, the data did show the Hudson River discharge or coastal currents exerting significant influence on the turbidity in the area of the HARS. Tracking of dredged material plumes demonstrated that turbidity associated with placement events quickly reaches background levels, typically within one hour (Dragos and Lewis, 1993; Dragos and Peven, 1994). Resuspension of sediments during high-energy events may also affect the turbidity of the water column.

Nutrients Most aquatic and marine systems are dominated by the availability of phosphorus and nitrogen, which are taken up as phosphate and nitrate, respectively. The major source of phosphorus to the marine environment is run off. Nitrogen compound input is the result of run off, supplemented by atmospheric flux. In the waters of the New York Bight and the area of the HARS, the major concern is nutrient over-enrichment from terrestrial nitrogen sources, which is the dominant factor affecting nutrients in the area of the HARS (from the Hudson River plume flux). In the past 15 years, nutrient input to the New York Bight has decreased resulting in improved water quality.

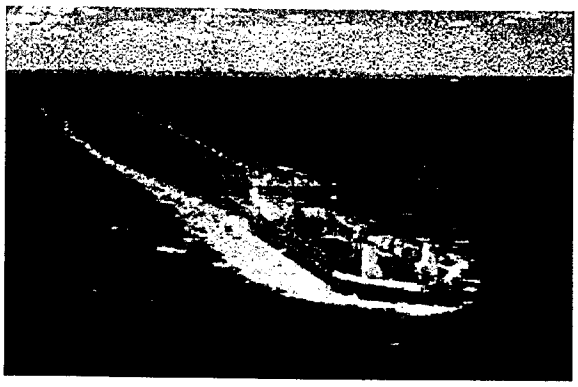
Dissolved Oxygen Dissolved oxygen (DO) levels were measured in the coastal waters off New Jersey and New York to depths of 40 meters (EPA Region 2 STORET database) between May and October (historically a period of low DO). This data shows DO levels consistently above 2.0 mg/l, in contrast to much lower values measured while the 12-Mile Sewage Sludge Disposal Site was in operation. No trends toward lower DO with increased depth were evident in the data set. No correlation between dredged material disposal and decreased DO levels were noted.

Contaminants Contaminant concentrations in the water column in the inner New York Bight are generally low (Hanson and Quinn, 1983). The low total suspended solids (TSS) content in the waters of the region causes most contaminants to be present in the dissolved phase (EPA, 1992; EPA, 1991). Recent data also show the concentration of metals (and by extrapolation organic contaminants) in the water column decrease offshore from the mouth of the Harbor (HydroQual, 1989). This decreasing offshore gradient (EPA, 1991; EPA, 1992; HydroQual, 1989) directly reflects dilution of the contaminant concentrations in the Hudson River plume with marine waters of the Bight region. Repeated sampling of the water column in the vicinity of the former MDS shows that metal concentrations in the area are low and reasonably constant (EPA, 1992; EPA, 1991; Dragos and Lewis, 1993). Consequently, although concentrations of contaminants may vary in the Bight and the area of the HARS, their spatial and temporal distributions have been reasonably consistent.

Dredged Material Effects The effects of dredged material on Bight water quality are minimal. Time series sampling of dredged material plumes at the MDS demonstrated that contaminant concentrations in the disposal plume quickly (less than one hour) return to background levels, well within the initial mixing period allowed under current ocean disposal regulations (Dragos and Lewis, 1993; Dragos and Peven, 1994).

e. Effects on Physical Habitat – Site Remediation

The foremost physical effect of site remediation would be the eventual placement of over forty million cubic yard of Category I sediments within the HARS. These sediments would consist of dredged material from the New Jersey / New York Harbor complex. The former MDS and contiguous environs would be covered with a protective one-meter layer of clean (Category I) sediments. These sediments would generally be placed one barge or scow at a time in pre-designated grids. During the remediation process, the benthic community would be covered with one to two feet of typically comparable sediment. Remediation will improve sediment quality and provide a more suitable environment for benthic fauna habitat.



Water quality in the area would not be compromised by the placement of Remediation Material. If contaminants are present in the plume, concentrations may briefly exceed Federal water quality criteria immediately following deposition. However, contaminant concentrations would typically return to background levels in less than an hour after

placement, well within the initial mixing period allowed under ocean placement regulations (Dragos and Lewis, 1993; Dragos and Peven, 1994). Similarly, turbidity associated with remediation events quickly approaches background levels, generally within an hour after placement (Dragos and Lewis, 1993; Dragos and Peven, 1994). No significant changes in dissolved oxygen or the physical parameters in the water column are predicted.

The Site Management and Monitoring Plan The Site Management and Monitoring Plan for the Historic Area Remediation Site (SMMP) (USACE / EPA, 1997) is a guidance document with the following objectives:

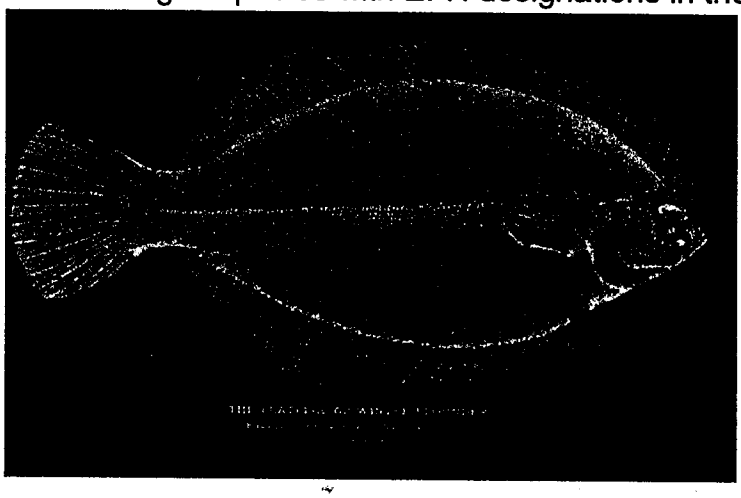
1. To provide remediation of required areas within the HARS.
2. Data collection to ensure that no *significant* adverse environmental impacts occur from the placement of HARS Remediation Material. In order to achieve this, the following factors are considered:
    a. Movement of material into estuaries or marine sanctuaries, or onto oceanfront beaches or sanctuaries;
    b. Movement of material toward productive fishery or shellfishery areas;
    c. Absence from the HARS of pollution-sensitive biota characteristic of the general area;
    d. Progressive, non-seasonal changes in water quality or sediment composition at the HARS, when these changes are attributable to the Remediation Material placed at the HARS;
    e. Progressive, non-seasonal changes in composition or numbers of pelagic, demersal, or benthic biota at or near the HARS, when these changes can be attributed to the effects of Remediation Material placed at the HARS; and,
    f. Accumulation of material constituents in marine biota near the HARS.
3. Recognize and correct any potential unacceptable conditions before they cause any significant adverse impacts to the marine environment or present a navigational hazard to commercial or recreational water-borne vessel traffic.
4. Determine/enforce compliance with permit conditions pursuant to the Marine Protection, Research and Sanctuaries Act.
5. Provide a baseline assessment of conditions at the HARS.
6. Provide a program for monitoring at the HARS.
7. Describe special management conditions/practices to be implemented at the HARS.
8. Specify the quantity of Remediation Material to be placed at the HARS, and the possible presence, nature, and bioavailability of potential contaminants in the Remediation Material.
9. Specify the anticipated use of the HARS.
10. Provide a schedule for review and revision of the HARS SMMP.

The SMMP for the HARS, which will give further details, such as HARS management roles and responsibilities, the monitoring program, and Remediation Material testing requirements, is provided in Appendix A.

f. Effects on Managed Species

EFH Species Listed for the Historic Area Remediation Site

The managed species with EFH designations in the waters within the two designated 10′ latitudinal and 10′ longitudinal grids which contain the project domain are listed in Table 1 by life stages. Among the listed species, 28 species could occur in the remediation site (3 species are potentially present only in the eastern grid) based on the broad distributional boundaries of the EFH grid (NMFS 1999). These species are listed in Table 2, which summarizes their general habitat parameters by life stage.



a. Potential EFH Impacts – Historic Area Remediation Site

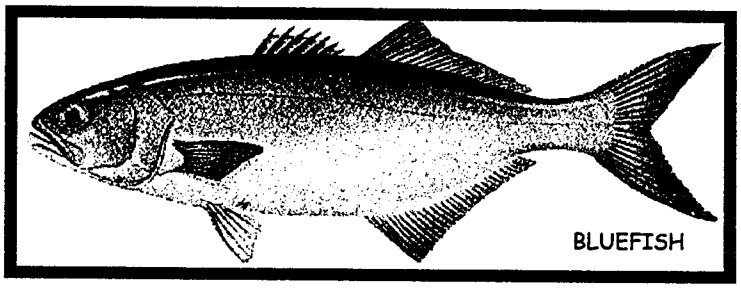
It is essential to note that the purpose of placing material at the HARS is the remediation of the former Mud Dump Site and adjoining environs. Remediation Material would be uncontaminated dredged material that meets Category I standards and will not cause significant undesirable effects, including through bioaccumulation.

For all species, the impacts during site remediation would be minimal and temporary for the following reasons:

- Intermediate temporal changes in turbidity are normally the result of Hudson River discharge or coastal currents. High-energy events may resuspend surface sediments increasing turbidity in the lower water column. Turbidity associated with placement events will typically reach background levels in less than an hour. Hence, placement of Remediation Material at the HARS has an ephemeral impact on water column turbity.
- Other water quality parameters (DO, chlorophyll levels, nutrients, and contaminant concentrations) would have minimal temporal changes at most, and should not adversely affect EFH at the HARS.
- The Corps has used the proposed placement site in the past for placement of dredged material from all sections of the Harbor, including the Newark Bay/New York Harbor/Raritan Complex, with little or no apparent adverse effects to the local biota (NMFS correspondence, 1995). National Marine Fisheries Service has stated that evidence linking contaminants with fish mortality in the New York Bight is insufficient (NMFS correspondence, 1995). In addition, a NMFS finfish tissue study established that recruited species live and thrive in the New York Bight, even near the former Mud Dump Site (NMFS correspondence, 1995).

- Bodily injury to species in the HARS may occur as a result of failure to flee the contact area. However, the likelihood of this scenario occurring is minimized by several factors: 1) The generally fluidized sediments leaving the barge have a relatively small contact footprint, typically a 50 foot by 100 foot area; 2) Remediation sediments are sequentially placed in a predetermined grid, resulting in continuous remediation in one zone, rather than random placement, increasing the chance of escape; and 3) Noise from vessels repetitively working in one area combined with the relatively shallow waters of the HARS (14-42 meters) will further increase the chance of flight from the area. Therefore, given the wide distribution of EFH species at the HARS, the possibility of burial during remediation efforts is minimal.

- The predator/prey cycle at the site may be temporarily disrupted by the placement of Remediation Material. Many species that feed on benthic or pelagic fishes or squid (e.g., bluefish, summer flounder, scup) are present at the HARS. These species will most likely flee a placement event, as will their associated prey. Those species that feed on pelagic and planktonic invertebrates and larvae, such as Atlantic sea herring, red hake, and Atlantic butterfish, will have minimum disruption to their feeding. Only during, and briefly following the placement event (less than one hour) is any water quality impact probable. It is anticipated that these species will avoid the Remediation Material and plume, simply re-locating to neighboring waters. Those species that may feed on benthic invertebrates, including blue fish, scup, black sea bass, and red hake, are most likely to have feeding success impacted as their prey is shrouded in one to two feet of Remediation Material. Some invertebrates, such as certain annelids, crustaceans, and mollusks, may easily pass through overlying Remediation Material, making themselves available as prey within a brief period. Additionally, some invertebrates will be discharged from the Remediation Material upon contact with the seafloor, providing additional food sources. Some demersal fish and epifaunal invertebrates, and the remaining infaunal invertebrates (those lacking greater mobility), may not survive burial. However, recolonization of the benthic community will occur quickly (SAIC, 1995)



- Whenever possible, similar sediment to the substrate of the HARS will be used for remediation to insure a rapid creation of a substrate analogous to pre-remediation conditions.

The following subsections provide a species by species assessment for the species identified in Table 1:

Atlantic Cod EFH is designated within both project area grids for the adult life stage in oceanic waters. Adults and spawning adults are found in bottom habitats in the Middle Atlantic south to Delaware Bay. Spawning adults have a seasonal occurrence from fall

to early spring, however, any eggs or larvae resulting from spawning are not believed suitable for survival in this area (Able and Fahay, 1998). Juveniles, adults, and spawning adults may be present at the HARS during sediment deposition; these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on Atlantic cod or Atlantic cod EFH is associated with this remediation project.

Whiting EFH is designated within the western project grid for all life stages of the whiting and for eggs, larvae, and juveniles in the eastern project grid. Eggs and larvae of this species are typically found in surface waters and would not be affected by the physical release of Remediation Material. Juveniles, adults, and spawning adults are found in bottom waters of the Middle Atlantic south to Cape Hatteras. These life stages may be present at the HARS during sediment deposition and may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial, and the potential for significantly improved sediment quality, no more than minimal impact on whiting or whiting EFH is associated with this remediation project.

Red Hake EFH is designated within the eastern project grid for all life stages of the whiting and for eggs, larvae, and juveniles in the western project grid. Eggs and larvae are typically found in surface waters and would not be affected by the physical release of Remediation Material. Juveniles, adults, and spawning adults are found in bottom waters of the Middle Atlantic south to Cape Hatteras, although spawning adults are typically found in salinities below 25 $^{0}/_{00}$ and would be precluded from the higher salinity waters of the HARS. Juveniles and adults may be present at the HARS during sediment deposition and may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on red hake or red hake EFH is associated with this remediation project.

Witch Flounder EFH is designated within the project grids for eggs (eastern grid only) and larval life stages of the witch flounder. The eggs and larvae of the witch flounder are typically found in surface waters from March to October and March to November, respectively, and would not be affected by the physical release of Remediation Material due to their vertical spatial distribution. Therefore, no more than minimal impact on witch flounder or witch flounder EFH is associated with this remediation project.

Winter Flounder EFH is designated within the project grids for all life stages of the winter flounder. The EFH of eggs and larvae of the winter flounder and spawning adults are typically found at depths of less than six meter in pelagic and bottom waters in a broad range of salinity. Eggs and larvae are seasonally abundant from January to June. Depth preferences generally preclude winter flounder eggs, larvae, and spawning adults from the HARS. EFH for juveniles (year-of-the-young) includes bottom habitats of mud or fine-grained sand substrate in waters ranging from 0.1 to 10 meters in depth, resulting in a potentially small percentage of the population present at the HARS. EFH for juveniles (Age 1+) is found in similar substrates at depths from 1 to 50 meters. EFH for adult winter flounder is bottom habitats with substrates of mud to gravel at depths of 1 to 100 meters.

Since both juveniles and adults may be present at the HARS, these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on winter flounder or winter flounder EFH is associated with this remediation project.

Yellowtail Flounder EFH is designated within the eastern project grid for all life stages of the yellowtail flounder and for only eggs and larvae in the western project grid. EFH for eggs and larvae are typically surface waters from March to July and March to April, respectively, in salinities typically higher than found in surface waters of the HARS, 26.0-28.0 $^0/_{00}$ and 30.0-31.5 $^0/_{00}$ resulting from Hudson River high flow (April) and low flow (August), respectively (Bowman and Wunderlich, 1977). Additionally, they would not be affected by the physical release of Remediation Material due to their vertical distribution. EFH for juveniles, adults, and spawning adults in the eastern grid is bottom habitats of sand to sandy-mud in offshore waters of the Middle Atlantic Bight.

Since both juveniles and adults may be present at the HARS, these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on yellowtail flounder or yellowtail flounder EFH is associated with this project.

Windowpane Flounder EFH is designated within the project area grids for all life stages of windowpane flounder. EFH for eggs and larvae are typically surface waters from February to November in salinities typically lower than those found in surface waters of the HARS during these months – 26.0-28.0 $^0/_{00}$ and 30.0-31.5 $^0/_{00}$, respectively. Additionally, any eggs or larvae present would not be affected by the physical release of Remediation Material due to their vertical distribution. EFH for juveniles, adults, and spawning adults include bottom habitats of mud or fine-grained sand substrate in waters ranging from 1 to 100 meters in depth. No seasonal occurrence is noted except for spawning adults, which are more abundant from February to June, peaking in May. EFH for juveniles and spawning adults typically includes waters of salinities less than 25 $^0/_{00}$ or 20 $^0/_{00}$, respectively. These salinities are lower than those found in bottom waters of the HARS, 32.5-33.0 $^0/_{00}$ and 31.25-31.75 $^0/_{00}$, precluding the HARS as EFH for these life stages. EFH for adult windowpane flounder typically includes bottom habitats with a substrate of mud or fine-grained sand, characteristic of HARS sediments.

Since adults may be present at the HARS, this life stage and its EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on windowpane flounder or windowpane flounder EFH is associated with this project.

Ocean Pout EFH is designated within the eastern project grid only for all life stages of the ocean pout. EFH for ocean pout eggs and spawning adults is typically hard bottom sheltered nest holes or crevices; larvae are found in close proximity to hard bottom nesting areas. EFH for juvenile ocean pout is smooth bottoms near rocks and algae. The habitats for ocean pout eggs, spawning adults, larvae, and juveniles preclude them from the HARS. EFH for adult ocean pout is bottom habitats in salinities

from 32-34‰. EFH is designated for adult ocean pout in the eastern grid of the HARS only where these salinities are typically found in bottom waters during January to March, limiting the presence of the adult ocean pout to these months, and therefore limiting the effect of remediation on the ocean pout.

Since adults may be present at the HARS, this life stage and its EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on ocean pout or ocean pout EFH is associated with this remediation project.

Atlantic Sea Herring EFH is designated within the project area grids for Atlantic sea herring larvae (eastern grid only), juveniles, and adults. EFH for the larvae of this species is typically pelagic waters. They would not be affected by the physical release of Remediation Material due to their vertical distribution. EFH for spawning adults is bottom habitats with salinities of 32-33 ‰ and a substrate of gravel, sand, cobble, and shell fragments, which encompasses parts of the HARS substrate. Atlantic sea herring spawn during the months of July to November; however, salinities at the HARS are below those needed for spawning adults, precluding them from the HARS.

EFH for juvenile and adult Atlantic sea herring is pelagic and bottom habitats, which would include the HARS. Since both juveniles and adults may be present at the HARS, these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on Atlantic sea herring or Atlantic sea herring EFH is associated with this remediation project.

Monkfish EFH is designated within the project area grids for monkfish eggs, larvae, juveniles (eastern grid only), and adults (eastern grid only). EFH for eggs is surface waters. EFH for monkfish larvae is pelagic waters at depths of 25 to 1000 meters. The physical release of Remediation Material would have no more than minimal impact on eggs or larvae due to their vertical distribution. EFH for juvenile, adult, and spawning adult monkfish is bottom substrates of sand-shell mix, algae covered rocks, sand, pebbly gravel, or mud along the outer Continental Shelf at depths of 25-200 meters. Sand and mud substrates are present at the HARS. Therefore, these life stages may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on monkfish or monkfish EFH is associated with this remediation project.

Bluefish EFH is designated within the project area grid for bluefish eggs (easternmost grid only), larvae, juveniles, and adults. EFH for bluefish eggs is generally April through August in mostly pelagic waters over the Continental Shelf at mid-shelf depths at temperatures greater than 18° C and salinities greater than 31‰. The only time when all these criteria are met at the HARS is in surface waters during July and August. This spatial distribution precludes this life stage from more than minimal affects due to the placement of Remediation Material. The EFH for bluefish larvae, juveniles, and adults is pelagic waters over the Continental Shelf. Both juvenile and adult stages are highly migratory (Able and Fahay, 1998). These life stages may be affected, albeit slightly, by the placement of Remediation Material. However, due to the unlikely prospect of burial

and the potential for significantly improved sediment quality, no more than minimal impact on bluefish or bluefish EFH is associated with this remediation project.

Atlantic Butterfish EFH is designated within the project area grids for juvenile Atlantic butterfish. EFH for juvenile butterfish is pelagic waters over the Continental Shelf. This life stage may be affected, albeit slightly, by the remediation project. Therefore, no more than minimal impact on Atlantic butterfish or Atlantic butterfish EFH is associated with this remediation project.

Summer Flounder EFH is designated within the project area grids for summer flounder larvae (westernmost grid only), juveniles and adults. EFH for the larvae of this species is mostly pelagic waters over the Continental Shelf. This life stage should be precluded from impact by the remediation project due to its location within the water column. EFH for juvenile and adult summer flounder is demersal water over the Continental Shelf. Juveniles are found over muddy substrate, but prefer sandy bottoms. Generally adult summer flounder inhabit shallow coastal and estuarine waters during the warmer months and move offshore on the Continental Shelf at depths of 500 ft (152 meters) in colder months. The distribution of adult summer flounder would preclude substantial populations from the HARS for the majority of the year.

Since both juveniles and adults may be present at the HARS, these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on summer flounder or summer flounder EFH is associated with this remediation project.

Scup EFH is designated within the project area grids for scup juveniles and adults. EFH for juveniles of this species is demersal waters over the Continental Shelf, from the coast to the Exclusive Economic Zone (EEZ), but juveniles are generally found in bays and estuaries in association with various sand, mud, mussel, and eelgrass bed substrates during the spring and summer. EFH for adults of this species is demersal waters over the Continental Shelf, from the coast to the EEZ. Generally, wintering adults (November through April) are offshore in water temperatures greater than 7°C. Since both juveniles and adults may be present at the HARS, these life stages and their EFH may be impacted by the placement of Remediation Material. However, due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on scup or scup EFH is associated with this remediation project.

Black Sea Bass EFH is designated within the project area grids for black sea bass larvae (easternmost grid only), juveniles, and adults. EFH for the larvae of this species is initially pelagic waters in estuaries and over the Continental Shelf from the coast to the EEZ. The habitat for transforming larvae is generally near coastal areas and marine zones of estuaries. Once demersal, larvae are found in structured inshore habitats. This spatial distribution precludes this life stage from more than minimal affects due to the placement of Remediation Material.

EFH for the juveniles of this species is predominantly demersal waters over the Continental Shelf from the shore to the EEZ. Juveniles may be found in association with rough bottom, and shellfish and eelgrass beds. Juveniles may overwinter offshore

in sand-shelly areas. Inland, they are found in the estuaries in the summer and spring. EFH for adult black sea bass is demersal waters over the Continental Shelf. Wintering adults (November through April) are generally found offshore. Structured habitats, sand, and shell are the preferred substrates. Inshore, black sea bass are generally found in estuaries in the summer and spring. The preference for substrates generally not analogous to those of the HARS, and the seasonal movement to inshore areas reduce the likelihood of juvenile and adult sea bass being present at the HARS during remediation efforts. Should this life stage be present, its numbers would be minimal.

Due to the unlikely prospect of burial and the potential for significantly improved sediment quality, no more than minimal impact on summer flounder or summer flounder EFH is associated with this remediation project.

Ocean Quahog EFH is designated within the project area grids for adult life stages of the ocean quahog. EFH for this species is throughout the substrate to a depth of three feet. Due to their mobility within sediments, the ocean quahog would be able to burrow to appropriate depths in the sediment after release of the Remediation Material, which should not exceed two feet in depth during a placement event. Furthermore, due to the nature of the Remediation Material, more appropriate substrate for the ocean quahog will be introduced by remediation efforts. Therefore, no more than minimal impact on ocean quahog or ocean quahog EFH is anticipated with the remediation project.

King Mackerel EFH is designated within the project area grids for all life stages of the king mackerel. EFH for this coastal pelagic species is primarily located in the South Atlantic and not customarily encountered in the project area. Due to the regional distribution pattern and dispersal throughout the water column, no more than minimal impact on king mackerel or king mackerel EFH is anticipated with the remediation project.

Spanish Mackerel EFH is designated within the project area grids for all life stages of the Spanish mackerel. EFH for this coastal pelagic species is primarily located in the South Atlantic and not customarily encountered in the project area. Due to the regional distribution pattern and dispersal throughout the water column, no more than minimal impact on Spanish mackerel or Spanish mackerel EFH is anticipated with the remediation project.

Cobia EFH is designated within the project area grids for all life stages of cobia. EFH for this coastal pelagic species is primarily located in the South Atlantic and not customarily encountered in the project area. Due to the regional distribution pattern and dispersal throughout the water column, no more than minimal impact on cobia or cobia EFH is anticipated with the remediation project.

Sand Tiger Shark EFH is designated within the project area grids for sand tiger shark larvae. EFH for neonates/early juveniles (≤ 125-cm total length) is shallow coastal waters from Barnegat Inlet, NJ to Cape Canaveral, FL out to the 25-meter isobath, entirely outside of the project area. Therefore, due to this regional distribution, no more than minimal impact on sand tiger shark EFH is anticipated with the remediation project.

Blue Shark EFH is designated within the easternmost project grid for blue shark larvae and adults. This species is one of the most common and wide-ranging of the sharks. Both life stages may be found in pelagic waters over the Continental Shelf at

typical depths greater than 180 meters. Due to their vertical distribution in the water column and the high mobility of adults, no more than minimal impact on the blue shark or blue shark EFH is anticipated with the remediation project.

White Shark EFH is designated within the easternmost project area grid for white shark juveniles (late juveniles/sub-adults). EFH for this life stage is primarily offshore northern New Jersey and Long Island, NY in pelagic waters from the 25- to 100-meter isobath. The white shark is a scarce apex predator and its presence is usually sporadic throughout its range. Due its limited range and unlikely presence within the HARS, and its high mobility, no more than minimal impact on the white shark or white shark EFH is anticipated with the remediation project.

Tiger Shark EFH is designated within the project area grids for tiger shark larvae. The EFH for tiger shark larvae (neonates/early juveniles) is from shallow coastal areas to 200 m isobath from Cape Canaveral, FL to Montauk, NY. Nursery areas are in coastal waters. The nursery for tiger sharks appears to be offshore areas, but they have yet to be described. Due its high mobility and vertical distribution in the water column, no more than minimal impact on the tiger shark or tiger shark EFH is anticipated with the remediation project.

Dusky Shark EFH is designated within the project area grids for dusky shark larvae and juveniles. EFH for larvae (neonate/early juveniles) of this species is primarily shallow coastal waters, inlets, and estuaries to the 25-meter isobath from Montauk to Cape Lookout, NC, with juveniles (late juveniles/sub-adults) found in coastal and pelagic waters between the 25- and 200-meter isobath. Due to the larvae distribution in the water column and the mobility of later life stages, no more than minimal impact on the dusky shark or dusky shark EFH is anticipated with the remediation project.

Shortfin Mako Shark EFH is designated within the project area grids for shortfin mako shark larvae (neonate/early juvenile) and juveniles (late juvenile/sub-adult) (easternmost grid only). It is an oceanic species at the top of the food chain, feeding on fast-moving fishes such as tuna, swordfish, and other sharks. There is circumstantial evidence that nurseries are in deep tropical waters. EFH for neonates/early juveniles (≤ 95-cm total length) is found between the 25- and 50-meter isobath; for late juvenile/sub-adults of the species, EFH is found between the 25- and 2,000-meter isobath. Generally, both life stages are found with the region of the HARS and may be affected by the remediation project. However, due to high mobility and the geographical and vertical distribution of both life stages, no more than minimal impact on the shortfin mako shark or shortfin mako shark EFH is anticipated with the remediation project.

Sandbar Shark EFH is designated within the project area grids for sandbar shark larvae (neonates/early juveniles), juveniles (late juveniles/sub-adults), and adults. EFH for this species is offshore demersal waters commonly in 20 to 55 meters of water. EFH for larvae (neonates/early juveniles) is nurseries in shallow coastal waters (from the coast to 25-meter isobath) from Cape Canaveral, FL to Great Bay, NJ. This distribution would preclude them from the HARS. EFH for juveniles (late juveniles/early adults) is coastal and pelagic waters north of 40° North and at the shelf break in the mid-Atlantic during winter. EFH for adults are demersal shallow coastal waters from the coast to the 50-meter isobath. These life stages may be affected by the remediation project. However, due to the high mobility of the species, the unlikely prospect of burial and the

potential for significantly improved sediment quality, no more than minimal impact on sandbar sharks or sandbar shark EFH is associated with this remediation project

Atlantic Bluefin Tuna EFH is designated within the project area grids for bluefin tuna juveniles and adults (easternmost grid only). EFH for this species is primarily surface waters, with juvenile EFH found in inshore and pelagic waters between the 25 and 200 meter isobath, and adult EFH found between the 50 meter isobath and the EEZ (precluding this life stage from the HARS). Due to this vertical distribution and the high mobility of the species, no more than minimal impact on bluefin tuna or bluefin tuna EFH is anticipated with the proposed project.

Skipjack Tuna EFH is designated within the project area grids for skipjack tuna adults. EFH for this species is pelagic surface waters. Due to this vertical distribution and the high mobility of the species, no more than minimal impact on bluefin tuna or bluefin tuna EFH is anticipated with the proposed project.

D. EFFECTS ON ENDANGERED SPECIES

Presently, it is not anticipated that any endangered/threatened species will be affected by the remediation project (Battelle, 1997a). However, a USACE Certified Disposal Inspector must accompany all trips for Remediation Material at the HARS and be present during all Remediation Material placement events (See Appendix A). These individuals are also certified Marine Mammal / Sea Turtle Observers. Placement of Remediation Material is prohibited at the HARS if endangered/threatened species are detected. A copy of the NED guidance manual, entitled *Guidance for Inspectors on Open Water Disposal of Dredged Material* is enclosed as Appendix B.

E. IMPACTS

1. Direct Impacts

The most obvious direct impact will be the burial of the benthic community with one meter of Remediation Material. This will have an immediate, albeit temporary, minimal effect on the feeding success of those species dependent upon benthic invertebrates. By utilizing a grid system for the placement of Remedial Material, impact will be minimized spatially and temporally. The Corps has determined that direct burial of EFH species is possible yet improbable and, therefore, will have minimal impact on target species or their EFH. Although increased turbidity and contaminant concentrations may occur in the water column at time of placement, these effects are typically short-lived (less than one hour) and would cause no more than minimal impact on EFH.

Furthermore, recolonization of a healthier benthic community will occur through; 1) benthic infauna that are able to unbury themselves, 2) migration of juvenile and adult infauna from contiguous areas, and 3) larval infauna that settle on the new substrate.

2. Indirect Impacts

The placement of Remediation Material would release biota from the material upon contact with the seafloor. The organisms are typically disoriented and provide a bounty for visual predators such as bluefish, creating a short-term beneficial impact.

Minor changes in bathymetry may occur, but not enough to create noticeable changes in the physical oceanography. Furthermore, the bathymetric changes resulting from remediation should not measurably alter the relationship of the benthic community with the photic zone.

3. Cumulative Impacts

The remediation of the HARS will result in an improved benthic community, and ultimately, improvement of the fishing and shellfishing resources of the New York Bight.

F. CONCLUSIONS

The remediation of the HARS with Category I sediments is the most expeditious means of eliminating the potential risk associated with contaminated sediments of the Priority Remediation Area. Decreased contaminant toxicity and bioavailability to fish and shellfish resources will greatly reduce the risk to biota of the New York Bight. The planned remediation will also prevent dispersion of degraded sediments from the seafloor as a result of resuspension due to high-energy events.

Based on the foregoing, the Corps of Engineers, New York District, concludes that there would be no more than minimal impact to Essential Fish Habitats for the species and life stages listed in Table 2. Remediation efforts at the HARS should be conducted without the need for seasonal restrictions or mitigation measures to protect habitat or individual species.

TABLE 1 Summary of Essential Fish Habitat (EFH) Designation

10' x 10' Square Coordinates:

Boundary	North	East	South	West
Coordinate	40º 30.0' N	73º 50.0' W	40º 20.0' N	74º 00.0' W

Square Description (i.e. habitat, landmarks, coastline markers): The waters within the square both west of and east of the northern majority of Sandy Hook Peninsula. Also affected along with these waters include waters east of Sea Bright, NJ., and north of Monmouth, NJ., and waters within the eastern half of the Shrewsbury River and the very eastern portion of the Navesink River.

Species	Eggs	Larva	Juveniles	Adult	Both
Atlantic cod *(Gadus morhua)*				X	✔
haddock *(Melanogrammus aeglefinus)*					
pollock *(Pollachius virens)*					
whiting *(Merluccius bilinearis)*	X	X	X	X	✔
red hake *(Urophycis chuss)*	X	X	X		✔
redfish *(Sebastes fasciatus)*	n/a (1)				
witch flounder *(Glyptocephalus cynoglossus)*		X			✔
winter flounder *(Pleuronectes americanus)*	X	X	X	X	✔
yellowtail flounder *(Pleuronectes ferruginea)*	X	X			✔
windowpane flounder *(Scopthalmus aquosus)*	X	X	X	X	✔
American plaice *(Hippoglossoides platessoides)*					
ocean pout *(Macrozoarces americanus)*					
Atlantic halibut *(Hippoglossus hippoglossus)*					
Atlantic sea scallop *(Placopecten magellanicus)*					
Atlantic sea herring *(Clupea harengus)*			X	X	✔
monkfish *(Lophius americanus)*	X	X			✔
bluefish *(Pomatomus saltatrix)*	X	X	X	X	✔
long finned squid *(Loligo pealei)*	n/a	n/a			
short finned squid *(Illex illecebrosus)*	n/a	n/a			
Atlantic butterfish *(Peprilus triacanthus)*			X		✔
Atlantic mackerel *(Scomber scombrus)*					
summer flounder *(Paralicthys dentatus)*			X	X	✔
scup *(Stenotomus chrysops)* (2)	n/a	n/a	X	X	✔
black sea bass *(Centropristus striata)* (2)	n/a		X	X	✔
surf clam *(Spisula solidissima)* (3)	n/a	n/a			
ocean quahog *(Artica islandica)* (3)	n/a	n/a		X	✔
spiny dogfish *(Squalus acanthias)* (4)	n/a	n/a			
tilefish *(Lopholatilus chamaeleonticeps)*					
king mackerel *(Scomberomorus cavalla)*	X	X	X	X	✔
Spanish mackerel *(Scomberomorus maculatus)*	X	X	X	X	✔
cobia *(Rachycentron canadum)*	X	X	X	X	✔
sand tiger shark *(Odontaspis taurus)*		X			✔
dusky shark *(Charcharinus obscurus)*		X	X		✔
shortfin mako shark *(Isurus oxyrhyncus)*		X			✔
sandbar shark *(Charcharinus plumbeus)*		X	X	X	✔
Atlantic bluefin tuna *(Thunnus thynnus)*			X		✔
skipjack tuna *(Katsuwonus pelamis)*				X	✔
tiger shark *(Galeocerdo cuvieri)*		X			✔

SHADING INDICATES THAT EFH HAS BEEN DESIGNATED WITHIN THE GRID FOR A GIVEN SPECIES AND LIFE STAGE.

1. Redfish have no eggs – larvae are born live.
2. Long finned squid, short finned squid, surf clams, and ocean quahog are referred to as pre-recruits and recruits, which corresponds with juveniles and adults in the table.
3. There is insufficient data on scup and sea bass for the life stages listed, and no EFH designation has been made as yet.
4. Spiny dogfish have no eggs or larvae – juveniles are born live.

TABLE 1 Summary of Essential Fish Habitat (EFH) Designation (continued)

10' x 10' Square Coordinates:

Boundary Coordinate	North	East	South	West
	40º 30.0' N	73º 40.0' W	40º 20.0' N	73º 50.0' W

Square Description (i.e. habitat, landmarks, coastline markers): The waters within the square within the Atlantic Ocean within the Nantucket/Ambrose shipping traffic lanes one square south of the square affecting the following: Western Long Beach, NY., Hewlett, NY., Woodmere, NY., Cedarhurst, NY., Lawrence, NY., Inwood, NY., Far Rockaway, NY., Springfield, NY., and Rosedale, NY.

Species	Eggs	Larva	Juveniles	Adult	Both
Atlantic cod *(Gadus morhua)*				X	✔
haddock *(Melanogrammus aeglefinus)*					
pollock *(Pollachius virens)*					
whiting *(Merluccius bilinearis)*	X	X	X		✔
red hake *(Urophycis chuss)*	X	X	X	X	✔
witch flounder *(Glyptocephalus cynoglossus)*	X	X			✔
winter flounder *(Pleuronectes americanus)*	X	X	X	X	✔
yellowtail flounder *(Pleuronectes ferruginea)*	X	X	X	X	✔
windowpane flounder *(Scopthalmus aquosus)*	X	X	X	X	✔
American plaice *(Hippoglossoides platessoides)*					
ocean pout *(Macrozoarces americanus)*	X	X	X	X	
Atlantic sea scallop *(Placopecten magellanicus)*					
Atlantic sea herring *(Clupea harengus)*		X	X	X	✔
Monkfish *(Lophius americanus)*	X	X	X	X	✔
bluefish *(Pomatomus saltatrix)*		X	X	X	✔
long finned squid *(Loligo pealei)*	n/a	n/a			
Atlantic butterfish *(Peprilus triacanthus)*			X		✔
Atlantic mackerel *(Scomber scombrus)*					
summer flounder *(Paralicthys dentatus)*		X	X	X	✔
scup *(Stenotomus chrysops)* (2)	n/a	n/a	X	X	✔
black sea bass *(Centropristus striata)* (2)	n/a	X	X	X	✔
surf clam *(Spisula solidissima)* (3)	n/a	n/a			
ocean quahog *(Artica islandica)* (3)	n/a	n/a		X	✔
spiny dogfish *(Squalus acanthias)* (4)	n/a	n/a			
tilefish *(Lopholatilus chamaeleonticeps)*					
king mackerel *(Scomberomorus cavalla)*	X	X	X	X	✔
Spanish mackerel *(Scomberomorus maculatus)*	X	X	X	X	✔
cobia *(Rachycentron canadum)*	X	X	X	X	✔
sand tiger shark *(Odontaspis taurus)*		X			✔
blue shark *(Prionace glauca)*		X		X	
white shark *(Charcharadon carcharias)*			X		
tiger shark *(Galeocerdo cuvieri)*		X			✔
dusky shark *(Charcharinus obscurus)*		X	X		✔
shortfin mako shark *(Isurus oxyrhyncus)*		X	X		✔
sandbar shark *(Charcharinus plumbeus)*		X	X	X	✔
Atlantic bluefin tuna *(Thunnus thynnus)*			X	X	✔
skipjack tuna *(Katsuwonus pelamis)*				X	✔

SHADING INDICATES THAT EFH HAS BEEN DESIGNATED WITHIN THE GRID FOR A GIVEN SPECIES AND LIFE STAGE

1. Redfish have no eggs – larvae are born live.
2. Long finned squid, short finned squid, surf clams, and ocean quahog are referred to as pre-recruits and recruits, which corresponds with juveniles and adults in the table.
3. There is insufficient data on scup and sea bass for the life stages listed, and no EFH designation has been made as yet.
4. Spiny dogfish have no eggs or larvae – juveniles are born live.

SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (‰)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in toto) (Gadus morhua)	Adults	< 10	S (1)	10 – 150		Bottom habitats with a substrate of pebbles, rocks, or gravel from Georges Bank to Delaware Bay
	Spawning Adults	< 10	S (1)	10 – 150	FALL – early SPRING	Bottom habitats with a substrate of smooth sand, pebbles, rocks, or gravel from Georges Bank to Delaware Bay. Eggs and larvae may occur south of Long Island (LI) but are not believed suitable for survival.
Whiting (Merluccius bilinearis)	Eggs	< 20S (2)	S (1)	50iso(3) – 150iso	All year – peak JUN – OCT	Surface waters over the Continental Shelf from Gulf of Maine to Cape Hatteras
	Larvae	< 20S (2)	S (1)	50iso – 130iso	All year – peak JUL –SEP	Surface waters over the Continental Shelf from Gulf of Maine to Cape Hatteras
	Juveniles	< 21	> 20	20 – 270		Bottom habitats of all substrate types on Continental Shelf from Gulf of Maine to Cape Hatteras
	Adults	< 22		30 – 325		
	Spawning Adults	< 13		30 – 325		
Red hake (Urophycis chuss)	Eggs	< 10 (2)	< 25		MAY – NOV Peak JUN – JUL	Surface waters over the Continental Shelf from Gulf of Maine to Cape Hatteras
	Larvae	< 19 (2)	> 0.5	< 200iso		Surface waters over the Continental Shelf from Gulf of Maine to Cape Hatteras
	Juveniles	< 16	31 – 33	< 100		Bottom habitats with a substrate of shell fragments, including areas with an abundance of live scallops over the Continental Shelf from the Gulf of Maine to Cape Hatteras
	Adults	< 10	33 – 34	10 – 130		Bottom habitats in depressions with a substrate of sand and mud over the Continental Shelf to Cape Hatteras
	Spawning Adults	< 10	< 25	< 100	MAY – NOV Peak JUN – JUL	Bottom habitats in depressions with a substrate of sand and mud over the Continental Shelf to Cape Hatteras
Witch flounder (G. cynoglossus)	Eggs	< 13 (2)	(3)	surface	MAR – OCT	Surface waters from Gulf of Maine to Cape Hatteras
	Larvae	< 13 (2)	(3)	surface – 250	MAR – NOV Peak MAY – JUL	Surface waters from Gulf of Maine to Cape Hatteras A&F – trawl data shows Larvae found only in May & June
Winter flounder (Pleuronectes americanus)	Eggs	< 10	10– 30	< 5	FEB – JUN Peak APR	Bottom habitats with substrates of mud to gravel from the Gulf of Maine to Delaware Bay
	Larvae	< 15 (2)	4 – 30	< 6	MAR – JUL Peak APR/MAY	Pelagic and bottom waters of Georges Bank and inshore areas from Gulf of Maine to Delaware Bay
	Juveniles (4)	< 28	5– 33	0.1 – 10		Bottom habitats with a substrate of mud or fine– grained sand; on Georges Bank and inshore areas from Gulf of Maine to Delaware Bay
	Juveniles (5)	< 25	10 – 30	1 – 50		

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SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (°/oo)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in total)	Adults	< 25	15 – 33	1 – 100		Bottom habitats, including estuaries with substrates of mud to gravel on Georges Bank and inshore areas from Gulf of Maine to Delaware Bay
(Pleuronectes americanus) (cont.)	Spawning Adults	< 15	5.5 – 36	< 6	FEB – JUN	
Yellowtail flounder *(Pleuronectes ferruginea)*	Eggs	< 15 (2)	32.4 – 33.5	30iso – 90iso	mid-MAR - JUL peak APR - JUN	Surface waters of Georges Bank and the southern New England Continental Shelf to Delaware Bay.
	Larvae	< 17 (2)	32.4 - 33.5	10iso – 90iso	MAR – APR	
	Juveniles	< 15	32.4 - 33.5	20 - 50		Bottom habitats of sand to sandy-mud on Georges Bank, and from Gulf of Maine along the southern New England shelf
	Adults	< 15	32.4 - 33.5	20 - 50		
	Spawning Adults	< 17	32.4 - 33.5	10 - 125		
Windowpane flounder) *(Scopthalmus aquosus*	Eggs	< 20 (2)		< 70iso	FEB – NOV peak MAY & NOV	Surface coastal waters from Gulf of Maine to Cape Hatteras, from Gulf of Maine to Cape Hatteras including Georges Bank
	Larvae	< 20 (2)		< 70iso	FEB – NOV peak MAY & NOV	Pelagic waters from Gulf of Maine to Cape Hatteras including Georges Bank
	Juveniles	< 25	5.5 - 36	1 - 100		Bottom habitats with a substrate of mud or fine-grained sand from Gulf of Maine to Cape Hatteras including Georges Bank
	Adults	< 28.6	5.5 - 36	1 - 75		Bottom habitats with a substrate of mud or fine-grained sand from Gulf of Maine to VA/NC border including Georges Bank
	Spawning Adults	< 21	5.5 - 36	1 - 75	FEB – DEC peak MAY	Bottom habitats with a substrate of mud or fine-grained sand from Gulf of Maine to VA/NC border including Georges Bank
Ocean pout (6) *(Macrozoarces americanus)*	Eggs	< 10	32-34	< 50	FALL and WINTER	Bottom habitats from Gulf of Maine to Delaware Bay including Georges Bank; low fecundity, gelatinous masses of eggs (<4200) laid on hard bottom, sheltered nests holes, or crevices; development takes 2-3 months (late fall and winter)
	Larvae	< 10 (2)	> 25	< 50	Late FALL - SPRING	Bottom habitats from Gulf of Maine to Delaware Bay including Georges Bank; bottom habitats - remain in close proximity to hard bottom nesting areas
	Juveniles	< 14	> 25	< 80		Bottom habitats, typically smooth bottoms near rocks or algae, from Gulf of Maine to Delaware Bay, including Georges Bank
	Adults	< 15	32-34	< 110		Bottom habitats from Gulf of Maine to Delaware Bay including Georges Bank, EFH for eastern grid only.
	Spawning Adults	<10	32-34	< 50		Bottom habitats with a hard bottom substrate from Gulf of Maine to Delaware Bay including Georges Bank

Attachment 1

SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (‰)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in total) (Clupea harengus)	Larvae	< 16 (2)	~ 32	50 - 90	AUG - APR peaks SEP - NOV	Typically found in pelagic waters in Gulf of Maine, Georges Bank, and southern New England
	Juveniles	< 10	26 – 32	15 -135		Pelagic waters and bottom habitats from the Gulf of Maine to Cape Hatteras including Georges Bank
	Adults	< 10	> 28	20 - 130		Pelagic waters and bottom habitats from the Gulf of Maine to Cape Hatteras including Georges Bank
	Spawning Adults	< 15	32 – 33	20 - 80	JUL - NOV	Bottom habitats with a substrate of gravel, sand, cobble, and shell fragments, or in proximity to aquatic macrophytes in the Gulf of Maine to Delaware Bay including Georges Bank. Eggs are spawned in areas of well-mixed water, with tidal. currents of 1.5 – 3.0 knots
Monkfish (Lophius americanus)	Eggs	< 18 (2)		15 - 1000	MAR - SEP	Egg veils found in surface waters from the Gulf of Maine to Cape Hatteras including Georges Bank
	Larvae	15		25 - 1000	MAR - SEP	Pelagic waters of the Gulf of Maine to Cape Hatteras including Georges Bank
	Juveniles	< 13	29.9 – 36.7	25 - 200		Bottom substrates of sand-shell mix, algae covered rocks, sand, pebbly gravel, or mud along the outer Continental Shelf in the middle Atlantic
	Adults	< 15	29.9 – 36.7	25 - 200		Bottom substrates of sand-shell mix, algae covered rocks, sand, pebbly gravel, or mud along the outer Continental Shelf in the middle Atlantic
	Spawning Adults	< 13	29.9 – 36.7	25 - 200	FEB - AUG	Bottom substrates of sand-shell mix, algae covered rocks, sand, pebbly gravel, or mud along the outer Continental Shelf in the middle Atlantic
Bluefish (Pomatomus saltatrix)	Eggs	> 18	> 31		APR – AUG	Pelagic waters over the Continental Shelf at mid-Shelf depths.
	Larvae	> 18	> 30	< 15	APR – SEP	Pelagic waters over the Continental shelf from the coast to the EEZ (6) at mid-shelf depths from Montauk Point to Cape Hatteras; generally not found in estuaries
	Juveniles	n/a (9)	n/a	n/a	MAY – OCT (7)	Pelagic waters over the Continental Shelf from the coast to the EEZ from Nantucket Island to Cape Hatteras and major estuaries
	Adults		> 25 (9)		APR – OCT (7)	Pelagic waters over the Continental Shelf from the coast to the EEZ from Cape Cod Bay to Cape Hatteras and all major estuaries Blue fish are highly migratory.

Attachment 1

SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (‰)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in toto) (Peprilus triacanthus)	Juveniles	3 - 28	S (1)	10 - 365		Pelagic waters over the Continental Shelf from the coast to the EEZ , from the Gulf of Maine to Cape Hatteras
Summer flounder (Paralicthys dentatus)	Larvae			10 - 70	SEP – FEB	Pelagic waters over the Continental Shelf from the coast to the EEZ from the Gulf of Maine to Cape Hatteras: all estuaries in the mixing (10) and oceanic zones.
	Juveniles	> 3	10 - 30			Demersal waters over Continental Shelf, prefer mostly sandy bottom although may be found in muddy bottoms.
	Adults	--	S	0 (5) - 150		Demersal waters over Continental Shelf, shallow coastal and estuarine waters in warmer months; offshore to depths of 150m in colder months
Scup (Stenotomus chrysops)	Juveniles	> 7	>15		SPRING / SUMMER (8)	Demersal waters over the Continental Shelf; in estuaries found in association with various sand, mud, mussel, and eelgrass bed substrates
	Adults	--	S		NOV-APR (8)	Demersal waters over the Continental Shelf
Black sea bass (Centropristus striata)	Larvae					Initially found in pelagic waters over the Continental Shelf, from the coast to the EEZ; once demersal, larvae are found in association with structured habitats
	Juveniles	> 6	> 18			Demersal waters over the Continental Shelf from Gulf of Maine to Cape Hatteras, from the coast to the EEZ, associated with, rough bottom, sandy – shelly areas winter offshore (including clam beds and shell patches)
	Adults					Demersal waters over the Continental Shelf in association with preferred substrates of structured habitats, sand, and shell.
Ocean quahog (Artica islandica)	Adults	< 18	--	8 – 240 (9)		From E. Georges Bank and Gulf of Maine throughout EEZ to Cape Hatteras
King Mackerel (11) (Scomberomorus cavalla)	Eggs	--	32 – 36	--	MAY-JUN	Coastal pelagic species found from Rio de Janeiro to the Gulf of Maine, predominantly south of VA, EFH includes sandy shoals offshore, high profile rocky bottom, and barrier island ocean-side waters; from the surf zone to the shelf break
	Larvae	22-31	32 – 36	surface	JUL-NOV	
	Juveniles	--	32 – 36	--	APR-OCT	
	Adults	--	32 – 36	--	APR-OCT	
Spanish Mackerel (11) (Scomberomorus maculatus)	Eggs	--	M, S	--	MAY-JUN	Coastal pelagic species found from the Yucatan to the Gulf of Maine, predominantly south of VA, EFH includes sandy shoals offshore, high profile rocky bottom, and barrier island ocean-side waters from the surf zone to the shelf break
	Larvae	--	M, S	--	JUL-NOV	
	Juveniles	--	M, S	--	APR-OCT	
	Adults	--	M, S	--	APR-OCT	
	Spawning Adults		M	12 – 34	late AUG – late SEP	Spawning of relatively small percentage of population occurs during this time off Sandy Hook and Long Island

Attachment 1

SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (‰)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in toto)	Eggs	--	--	--		Coastal pelagic species found from the Yucatan to the Gulf of Maine, predominantly south of VA, EFH includes sandy shoals offshore, high profile rocky bottom, and barrier island ocean-side waters from the surf zone to the shelf break also estuaries and sea grass habitat
Cobia (24) (*Rachycentron canadum*)	Larvae	--	--	--		
	Juveniles	--	M, S	--	MAY-OCT	
	Adults	--	M, S	--	MAY-OCT	
Sand Tiger Shark (*Odontaspis taurus*)	Larvae (12)	--	--	0-25 iso	MAR – APR	EFH for neonates/early juveniles (< 125 cm total length) in shallow coastal waters from Barnegat Inlet, NJ to Cape Canaveral, FL to the 25 m isobath; ~100 cm in length at birth; found in mid-Atlantic bight estuaries and coastal sounds
Blue Shark (*Prionace glauca*)	Larvae (12)	--	--	25-EEZ		Pelagic; one of the most common and abundant sharks, found in tropical, subtropical, and temperate waters; neonates are typically found in higher latitudes; 34 to 48 cm in length at birth; nurseries appear to be in open ocean waters; inhabits, clear, deep blue waters, may be present at eastern fringe of HARS
	Adults	10-20	S	> 180		
White shark (*Charcharadon carcharias*	Juveniles (13)	--	--	25 iso – 100 iso		Pelagic; presence usually sporadic through range, a scarce apex predator; may be present at eastern fringe of HARS (late juveniles/subadults) 175 – 479 cm in length
Tiger shark (*Galeocerdo cuvieri*)	Larvae	--	--	Coastal – 200 iso		Warm waters from shallow coastal to deep oceanic waters from eastern Long island to Cape Lookout, NC; 68-85 cm in length at birth, nurseries appear to be in open ocean waters
Dusky Shark (*Charcharinus obscurus*)	Larvae (12)	--	M, S	0-25 iso	Parturition in summer	Shallow coastal waters, inlets and estuaries to the 25 m isobath from eastern Long island to Cape Lookout, NC
	Juveniles (13)	--	M, S	25 iso-200 iso		From New England to VA/MD border
Shortfin mako shark (*Isurus oxyrhyncus*)	Larvae (12)	--	--	50 iso – 2000 iso		Warm/temperate waters, from NC to Georges Bank nurseries may be in deep tropical water, neonates/early juveniles ≤ 95 cm in length; late juveniles/subadults 96-279 cm in length
	Juveniles (13)	--	--	25 iso – 2,000 iso		
Sandbar shark (*Charcharinus plumbeus*)	Larvae (12)	25-28	22 – 25	0-25 iso		Nurseries believed south of Great Bay NJ to Cape Canaveral, neonates/early juveniles; ≤ 90 cm in length
	Juveniles (13)	> 21	> 22	0-25 iso	SPRING - FALL	All coastal and pelagic waters north of 40° North; in mid-Atlantic Bight at shelf break in winter; 91-179 cm in length
	Adults	--	> 22	0-50 iso		Demersal, shallow coastal areas from the coast to 50 m isobath ≥ 180 cm in length
Atlantic bluefin tuna (*Thunnus thynnus*)	Juveniles/ subadults	> 12 (14)		Surface (15)		Found in inshore and pelagic surface waters from Cape Cod to Cape Hatteras after June migration from FL; < 145 cm in length

Attachment 1

SPECIES	LIFE STAGE	EFH GENERAL HABITAT PARAMETERS				
		Water Temp (°C)	Salinity (‰)	Water Depth (m)	Seasonal Occurrence / Abundance	Comments
(28 in toto) *(Thunnus thynnus) (cont.)*	Adults	(14)		Surface (16)		Found in pelagic waters from Gulf of Maine to Cape Hatteras; > 145 cm in length
Skipjack tuna *(Katsuwonus pelamis)*	Adults	20 – 31 (17)		(17)	MAR – OCT	Circumtropical in western Atlantic, although may be found as far north as Newfoundland in warmest months; > 145 cm in length

(1) 0 – 280 m in depth during day; surface at night
(2) The EFH designation for this species/life stage includes the seawater zone (S) that typically has salinities greater than 25 parts per thousand.
(3) The EFH designation for this species/life stage includes surface waters as designated
(4) The EFH designation for this species/life stage includes surface waters over deep waters of high salinities
(5) The EFH designation for this species/life stage includes only young-of-the-year
(6) The EFH designation for this species/life stage includes only age 1+ juveniles
(7) EEZ = Exclusive Economic Zone
(8) Found in mid-Atlantic estuaries during this period in areas of mixing and seawater zones
(9) Found in areas of mixing and seawater zones
(10) Found 0 – 1 meter below the sediment/seawater interface
(11) Coastal migratory species
(12) Neonate/early juvenile
(13) Late juvenile/subadult
(14) Constrained by the 12° isotherm
(15) 0 – 280 m in depth during day; surface at night
(16) May dive to 6° to 8° to feed
(17) In surface pelagic waters from 20° to 31° in the Mid-Atlantic Bight

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Appendix F: Ecology

F-4 Biological Assessment

Biological Assessment for the
Tappan Zee Hudson River Crossing Project

January 2012

Biological Assessment
For the Tappan Zee Hudson River Crossing Project

January 2012

Primary Agency and Contact:

Jonathan McDade, New York Division Administrator
Federal Highway Administration

In Coordination with:

New York State Department of Transportation
New York State Thruway Authority

Prepared by:

AKRF, Inc.
AECOM
Arthur Popper, Ph.D.

Project Name: *Tappan Zee Hudson River Crossing Project*

Date: *January 2012*

Primary Agency and Contact:
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In Coordination with:
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Executive Summary

The Tappan Zee Bridge opened to traffic in 1955 as part of the New York State Thruway extension between Suffern, New York and Yonkers, New York. Over the years, the bridge and its highway connections have been the subject of numerous studies and transportation improvements. Improvements to the Tappan Zee Bridge included the installation of a movable barrier to allow for operation of a seven-lane cross section with four lanes in the peak direction, electronic toll collection, and variable pricing for commercial vehicles. Despite these improvements, congestion has grown steadily and the aging bridge structure has reached the point where major reconstruction is needed to sustain this vital link in the transportation system.

In April 2000, a Long Term Needs Assessment and Alternatives Analysis was completed by the New York State Governor's I-287 Task Force. The report concluded that while there was no single preferred solution for addressing the transportation needs in Tappan Zee Bridge/I-287 Corridor, both a short-term aggressive Transportation Demand Management (TDM) program and longer-term capital improvements were needed. All of the long-term alternatives evaluated by the Task Force called for replacement of the existing Tappan Zee Bridge. It was concluded that rehabilitation of the existing bridge would be highly disruptive, perhaps as costly, and not as beneficial in mobility enhancement or meaningful congestion relief, compared with a replacement bridge.

Over the next few years, project development continued with increasing involvement by the New York State Department of Transportation (NYSDOT). Alternatives for transit modes along the corridor were identified, as were a set of highway and bridge improvements. In 2011 it was determined that funding for the corridor project (bridge replacement, highway improvements, and new transit service) was not possible due to fiscal constraints. The financing of the crossing alone, however, was considered affordable. Therefore, it was determined that the scope of the project should be limited, and that efforts to replace the Hudson River crossing independent of the transit and highway elements should be advanced. On October 12, 2011, FHWA published an NOI to rescind the Tappan Zee Bridge/I-287 Corridor Project, thereby concluding the environmental review process for the combined study of bridge, highway, and transit elements. On that same date, FHWA published an NOI for the Tappan Zee Hudson River Crossing Project to examine alternatives for an improved Hudson River crossing between Rockland and Westchester Counties. As described in the NOI, FHWA, acting as the federal lead agency, and NYSDOT and NYSTA, acting as the co-sponsoring agencies, are preparing an EIS and other necessary documents to identify alternatives for an improved Hudson River crossing and to document the potential environmental consequences of these alternatives. Two Replacement Bridge Alternative options are being considered and are called the Long Span and Short Span Options. The two options would be constructed using the same general construction sequencing and methods over an approximately 4 ½ to 5 ½ year period, respectively.

Under Section 7 of the Endangered Species Act (ESA), the FHWA is required to consult with the United States Fish and Wildlife Service (USFWS) and National Oceanic and Atmospheric Administration (NOAA) Fisheries to determine whether any federally listed species or species proposed for listing as endangered or threatened, or their designated critical habitats, occur in the vicinity of a proposed project that is subject to United States Environmental Protection Agency

(USEPA) jurisdiction. In the event that a federally listed or proposed endangered or threatened species or its designated critical habitat occurs in the vicinity of a "major construction activity," a Biological Assessment (BA) must be prepared to determine whether the proposed federal action would affect that species. The regulations promulgated pursuant to the ESA require every federal agency to ". . .[e]nsure that any action it authorizes, funds, or carries out, in the United States or upon the high seas, is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat" (50 CFR § 402.01) ."

In compliance with Section 7(c) of the ESA of 1973, as amended, this BA, prepared by FHWA, addresses the proposed action and its potential to impact one listed species – the shortnose sturgeon (*Acipenser brevirostrum*) and one species under consideration for listing – the Atlantic sturgeon (*Acipenser oxyrinchus)*. Section 7 of the ESA requires that, through consultation (or conferencing for proposed species) with the National Marine Fisheries Service (NMFS), federal actions do not jeopardize the continued existence of any threatened, endangered, or proposed species or result in the destruction or adverse modification of critical habitat. This BA evaluates the potential effects of the proposed transportation project on aquatic species that are federally listed or proposed for listing under the ESA. Specific project design elements are identified that avoid or minimize adverse effects of the proposed project on listed species and/or critical habitat.

The limits of the study area considered in this BA are different than from those typically considered in an EIS. The BA study area has been determined by the potential project effects for dredging and resuspension and redeposition of suspended sediment, acoustic impacts from pile driving, and loss of habitat. The potential geographic boundaries of these effects extend across the entire width of the Tappan Zee Reach of the Hudson River, and based on modeled sound isopleths with a 10 dB reduction associated with proposed BMPs, extend a maximum of 2210 meters (m) (7,250 feet) or less in both up and downriver directions. For sediment resuspension, which is a measure for assessing impacts to water quality, project increments 10 mg/L above ambient conditions may extend in a relatively thin band approximately 305-610 m (1,000 to 2,000 ft) from the dredges. Concentrations of 5 mg/L above ambient associated with the project may extend a greater distance in either an upstream or downstream direction, depending upon the tidal stage.

Using the results of a gill-net study conducted in the vicinity of the Replacement Bridge Alternative in 2007-2008, an analysis of the potential effects of pile driving on the shortnose and Atlantic sturgeon was undertaken. Results of this analysis indicated that 482 shortnose sturgeon could potentially be affected by sound at or greater than an SEL_{cum} of 187 dB re 1 μPa^2-s over the project duration for the Short Span Option. Similarly, 365 sturgeon have the potential to be affected by sound at or greater than SEL_{cum} of 187 dB over the project duration for the Long Span Option. The Short Span Option will have the potential to affect 0.80% of the shortnose sturgeon population and the Long Span Option will have the potential to affect 0.61% of the population assuming 60,000 fish as a current standing stock estimate for shortnose sturgeon in the Hudson River, and assuming that this number remains static for the duration of the project. These estimates are considered a conservative maximum number of fish potentially affected because they represent the encounter rate within the isopleths of SEL_{cum} of 187 dB re 1 μPa^2-s over several years of construction, and some fraction of that total number (i.e. the 482 or 365

fish) would likely be encountered more than once without having experienced the necessary sound for the onset of effects.

These findings are also likely to overestimate the number of shortnose sturgeon potentially affected for the following reasons:

- Since the calculations do not take into consideration the normal behaviors of the fish in response to a noxious stimulus, it is reasonable to assume that sturgeon, on hearing the pile driving sound, would either not approach the source or move around it. Since the pile driving sounds are very loud, it is also very likely that many of the fish will hear the sound, and respond behaviorally, well before they reached a point at which the sound levels exceeded even the interim SEL_{cum} criterion of 187 dB 1 μPa2·s. Thus, the likely behavioral response of the fish would be to alter the path through which they were traveling to avoid the sounds that were too loud and then resume their regular path once the highest sound levels were skirted.

- Based on the most recent scientific studies (e.g., Halvorsen et al. 2011), the 187 dB re 1μPa^2-s SEL_{cum} threshold is overly conservative, and far lower than cumulative sound levels that actually result in onset of physiological effects (e.g. greater than SEL_{cum} of 203 dB). If a higher threshold for onset, such as those proposed by Halvorsen et al. (2011), were to be used to evaluate the onset of injury to sturgeon, the size of the ensonified area that could potentially cause onset of physiological effects would be considerably reduced, as would the number of potentially affected fish.

- The analysis was conducted using a 10 dB reduction associated with implementation of BMPs, which may underestimate the level of noise attenuation that can be achieved by bubble curtains or other technologies (i.e., 20 dB; Caltrans 2009)

- Carlson et al. (2007) have provided evidence that as fish get larger there is less of a physiological impact from sounds, and that the threshold for onset to injury to larger fish, such as sturgeon, is substantially higher (i.e. 213 dB re 1 μPa^2-s) for fish above 200 grams, than the West Coast criterion for fish > 2 gm (i.e. 187 dB re 1 μPa^2-s).

Recently, the NMFS identified five Distinct Population Segments (DPS) of Atlantic sturgeon within the western North Atlantic. The Hudson River population is included in the New York Bight DPS. A review of the literature suggests that the likelihood of the project to affect the other four DPS of Atlantic sturgeon in any meaningful way is low. Because Atlantic sturgeon were not collected in the gill net sampling program, no estimate of fish within the ensonified zone was calculated.

A number of Environmental Performance Commitments (EPCs) which would also serve to minimize take will be implemented by the Project These include:

- Driving the largest [3 and 2.4 m (10 and 8 ft)] diameter piles within the first few months of the project thereby limiting the time period of greatest potential impact.

- Using cofferdams and silt curtains, where feasible, to minimize discharge of sediment into the river.

- Using a vibratory pile driver to the extent feasible (i.e., all piles will be vibrated at least to 36.6 m (120ft) depth or to vibration refusal) particularly for the initial pile segment.

- Using bubble curtain, cofferdams, isolation casings, Gunderboom, or other technologies to achieve a reduction of at least 10 dB of noise attenuation.

- Using the results of the Hudson River site specific Pile Installation Demonstration Project (PIDP) which includes the testing of various sound attenuation devices to inform the project on the effectiveness of BMP technologies for reducing sound levels, and implementing BMPs to achieve maximum sound reduction.

- Limiting the periods of pile driving to no more than 12-hours/day.

- Limiting driving of 8 and 10 ft piles with an impact hammer within Zone C [water depths 5.5-13.7 m (18-45 feet)] to 5 hours per day during the period of spawning migration for shortnose and Atlantic sturgeon (April 1 to August 1).

- Maintaining a corridor where the sound level is below the West Coast threshold for onset of behavioral effects to fish totaling at least 5000-ft at all times during impact hammer pile driving. This corridor shall be continuous to the maximum extent possible but at no point shall any contributing section be smaller than 1500 ft.

- Pile tapping (i.e. a series of minimal energy strikes) for an initial period to frighten fish so that they move from the immediate area.

- Development of a comprehensive monitoring plan. Elements would include:

  - Monitoring locations to characterize the hydroacoustic field surrounding pile driving operations to evaluate the performance of underwater noise attenuation systems that are integral to the project.
  - Monitoring water quality parameters such as temperature, salinity, and suspended sediment concentrations in the vicinity of the pile driving.
  - Monitoring fish mortality and inspection of fish for types of injury.
  - Monitoring predation levels by gulls and other piscivorous birds, which would indicate that they are finding an increased number of dead or dying fish at the surface.
  - Developing criteria for re-initiating consultation with NMFS should specific numbers of shortnose or Atlantic sturgeon come to the surface injured or dead.
  - Preparing a Standard Operating Procedures Manual outlining the monitoring and reporting methods to be implemented during the program.

- In addition, dredging using an environmental bucket would only be conducted during a three-month period from August 1 to November 1 for the three years of the construction period in

which dredging would occur, in order to minimize the potential for impacts to sturgeon migration, as well as migration by other fish species.

The results of this BA indicate that:

1. For individual shortnose and Atlantic sturgeon within the immediate vicinity of pile driving and other in-water construction activities, there is a potential for injury.

2. Pile driving and dredging would have minimal effects to sturgeon migratory activities as there will always be large portions of the river width that will not be ensonified, and dredging will be limited to a three-month window between August 1 and November 1 during 3 of the 4 ½ or 5 ½ construction years.

3. There is no designated critical habitat for shortnose sturgeon and none is proposed for Atlantic sturgeon.

4. Dredging of 0.67-0.71 square kilometers (km) (165-175 acres) for access channels will create an area of reduced foraging opportunities for both shortnose and Atlantic sturgeon due to loss of benthic habitat. However, upon completion of in-water activities in a given area, estuarine depositional processes would, over time, allow the benthic habitat to return to its pre-construction condition. The temporary loss of the access channel area would represent a minor fraction of similar habitat in the Tappan Zee portion of the Hudson River.

5. Incidental vessel strikes will be insignificant because sturgeon are generally found within one meter of the bottom in the deepest available water. Based on the types of vessels to be employed and their drafts, there should always be sufficient clearance between vessels and the river bottom.

6. Indirect effects from resuspended sediments are expected to be insignificant.

7. A review of the literature suggests that the likelihood of the project to affect the four other DPS of Atlantic sturgeon in any meaningful way is low.

The BA concludes that while the Replacement Bridge Alternative may injure some individual shortnose and/or Atlantic sturgeon in the immediate vicinity of the pile driving resulting in an incidental take, and while dredging and armoring of the bottom will result in a temporary reduction in foraging opportunities, the project will not jeopardize the continued existence of the shortnose or Atlantic sturgeon populations of the Hudson River.

Based on the fact that marine mammals are rare and transient to the study area, the proposed project will not jeopardize the continued existence of the marine mammal species that have been reported in the Tappan Zee Reach of the Hudson River.

Effect Determination for Critical Habitat

There is no designated critical habitat for the shortnose sturgeon and no critical habitat has been proposed for Atlantic sturgeon at this time.

Overall Effect Determination

Overall project effects are summarized in the table below that lists affected species and major project elements, and the effect determinations associated with each.

Overall Project Effects

Jurisdiction	Federal Status	Common Name	Effect Determination for Pile Driving	Effect Determination for Permanent Loss of Habitat Due to Dredging	Effect Determination for Vessel Traffic	Effect Determination for Sediment Resuspension	Overall Effect Determination for Project
NMFS	Endangered	Shortnose Sturgeon	Likely to adversely affect	No effect	No effect	No effect	Likely to adversely affect
NMFS	Proposed for Listing	Atlantic Sturgeon	Likely to adversely affect	No effect	No effect	No effect	Likely to adversely affect
NMFS	Various	Marine Mammals	No effect	No effect	No effect	No effect	No effect

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Chapter 1 Project Overview

The Tappan Zee Bridge opened to traffic in 1955 as part of the New York State Thruway extension between Suffern, New York and Yonkers, New York. Over the years, the bridge and its highway connections have been the subject of numerous studies and transportation improvements. Improvements to the Tappan Zee Bridge included the installation of a movable barrier to allow for operation of a seven-lane cross section with four lanes in the peak direction, electronic toll collection, and variable pricing for commercial vehicles. Despite these improvements, congestion has grown steadily and the aging bridge structure has reached the point where major reconstruction is needed to sustain this vital link in the transportation system.

In April 2000, a Long Term Needs Assessment and Alternatives Analysis was completed by the New York State Governor's I-287 Task Force. The report concluded that while there was no single preferred solution for addressing the transportation needs in Tappan Zee Bridge/I-287 Corridor, both a short-term aggressive Transportation Demand Management (TDM) program and longer-term capital improvements were needed. All of the long-term alternatives evaluated by the Task Force called for replacement of the existing Tappan Zee Bridge. It was concluded that rehabilitation of the existing bridge would be highly disruptive, perhaps as costly, and not as beneficial in mobility enhancement or meaningful congestion relief as compared with a replacement bridge.

1.1. Federal Nexus

On November 28, 2000, the New York State Thruway Authority (NYSTA) and the Metropolitan Transportation Authority Metro-North Commuter Railroad (MNR) announced that an Environmental Impact Statement (EIS) would be undertaken to identify and evaluate alternatives to address the mobility needs of the I-287 Corridor, as well as the structural and safety needs of the Tappan Zee Bridge. The alternatives contained in the I-287 Task Force report, as well as those suggested by elected officials, transportation and environmental groups, community groups, and the public, were considered and an approach to evaluating and advancing alternatives was established. On December 23, 2002, the Federal Highway Administration (FHWA) published a Notice of Intent (NOI) to prepare an Alternatives Analysis (AA) and EIS for the Tappan Zee Bridge/I-287 Corridor in the Federal Register.

Over the next few years, project development continued with increasing involvement by the New York State Department of Transportation (NYSDOT). Alternatives for transit modes along the corridor were identified, as were a set of highway and bridge improvements. Also, in 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) was enacted, which incorporated changes in the metropolitan planning and environmental review processes for transportation projects. FHWA determined that a revised NOI should be published to update the public and interested agencies on the alternatives development, to identify NYSDOT as the Project Director, and to incorporate the provisions of SAFETEA-LU. The revised NOI was published on February 14, 2008.

In 2011, while advancing financial analysis, it was determined that funding for the corridor project (bridge replacement, highway improvements, and new transit service) was not possible at

that time. The financing of the crossing alone, however, was considered affordable. Therefore, it was determined that the scope of the project should be limited, and efforts to replace the Hudson River crossing independent of the transit and highway elements should be advanced. On October 12, 2011, FHWA published an NOI to rescind the Tappan Zee Bridge/I-287 Corridor Project, thereby concluding the environmental review process for the combined study of bridge, highway, and transit elements.

On that same date, FHWA published an NOI for the Tappan Zee Hudson River Crossing Project to examine alternatives for an improved Hudson River crossing between Rockland and Westchester Counties. As described in the NOI, FHWA, acting as the federal lead agency, and NYSDOT and NYSTA, acting as the co-sponsoring agencies, are preparing an EIS and other necessary documents to identify alternatives for an improved Hudson River crossing and to document the potential environmental consequences of these alternatives.

Under Section 7 of the Endangered Species Act (ESA), the FHWA as the Federal Sponsor is required to consult with the United States Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) to determine whether any federally listed species or species proposed for listing as endangered or threatened species, or their designated critical habitats, occur in the vicinity of a proposed project. While there are no federally listed species under the jurisdiction of the USFWS in the vicinity of the proposed project, the shortnose sturgeon, an endangered aquatic species, occurs throughout the estuarine portion of the Hudson River. In the event that a federally listed or proposed endangered or threatened species or its designated critical habitat occurs in the vicinity of a "major construction activity," a Biological Assessment (BA) must be prepared to determine whether the proposed federal action would affect that species. The regulations promulgated pursuant to the ESA require every federal agency to ". . .[e]nsure that any action it authorizes, funds, or carries out, in the United States or upon the high seas, is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat" (50 CFR § 402.01).

This BA, prepared by FHWA, addresses the proposed action in compliance with Section 7(c) of the ESA of 1973, as amended. Section 7 of the ESA requires that, through consultation (or conferencing for proposed species) with the National Marine Fisheries Service (NMFS), federal actions do not jeopardize the continued existence of any threatened, endangered, or proposed species or result in the destruction or adverse modification of critical habitat. A second BA has been prepared for a Pile Installation Demonstration Project (PIDP), scheduled for spring 2012, which has among its objectives the testing of various sound attenuation technologies.

This BA evaluates the potential effects of the proposed transportation project on species that are federally listed or proposed for listing under the ESA. Specific project design elements are identified that avoid or minimize adverse effects of the proposed project on listed species and/or critical habitat.

The findings of the BA will be discussed in the Record of Decision (ROD), which will include an effects determination that presents conclusions, supported by information presented in the BA, regarding potential effects on the local population of the species discussed. This BA will be submitted to NOAA Fisheries for review and a final determination of effect. The BA will be

completed prior to construction, and the bridge design will reflect appropriate measures to protect these species that result from the consultation process. The BA addresses only the currently proposed construction activities. If NOAA Fisheries determine that the construction activities would adversely affect a federally listed species or a species proposed for listing, then the FHWA must enter into formal consultation and obtain a Biological Opinion concerning the potential for incidental "taking" of such species before conducting the project. "Take" is defined in the ESA as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. Incidental take is understood to occur should the activities associated with implementing the ROD adversely affect the shortnose sturgeon or Atlantic sturgeon habitat and/or mating behavior. If it is determined that the construction activities are not likely to adversely affect the species, NOAA Fisheries will issue written concurrence that the remedial project is not likely to adversely affect the species.

In addition to FHWA's involvement with the project, several other federal agencies will be involved. The USACE and U.S. Environmental Protection Agency (EPA) will require an application for transport and ocean disposal of dredge material under Section 103 of the Marine Protection, Research and Sanctuaries Act, and the United States Coast Guard will be consulted to acquire a bridge permit required under the General Bridge Act of 1946 for construction of bridges over navigable waters of the United States. There is also a possible need for Section 404 and Section 10 permits from the USACE.

1.2. Project Description

The proposed Replacement Bridge Alternative (Project) would result in a new bridge crossing of the Hudson River between Rockland and Westchester Counties. A number of design parameters have been considered to develop the location and general configuration of the Replacement Bridge. However, to provide for flexibility in the final design of the Replacement Bridge, this assessment considers options for certain structural characteristics of the bridge.

The Project would be constructed north of the existing Tappan Zee Bridge. The planning for the Replacement Bridge considered a footprint that would maximize the use of existing NYSTA right-of-way while minimizing effects on existing highway infrastructure in Rockland and Westchester Counties. Replacement bridge alignments both north and south of the existing Tappan Zee Bridge were considered, and it has been determined that an alignment north of the existing bridge is more prudent for the following reasons:

- There is available NYSTA right-of-way to the north of the existing highway on both sides of the Hudson River to accommodate construction of a new crossing. Sufficient right-of-way is not available on the south side of the existing highway at the Rockland landing.

- A north alignment allows for a straight approach to the Westchester toll plaza. A south alignment would result in a conflict between the new crossing's horizontal curvature and the approach to the toll plaza, which would not meet design and safety standards.

- Construction storage and staging areas are available north of the existing bridge on both sides of the Hudson River. Staging for a southern alignment could require temporary or permanent acquisition of property.

Therefore, the Replacement Bridge would be located to the north of the existing Tappan Zee Bridge.

The following sections describe the features of the Project. To conform to highway design standards, including widths and grades, the Replacement Bridge Alternative would result in new bridge and modifications to Interstate 87/287 between approximately Interchange 10 (Route 9W) in Nyack and Interchange 9 (Route 9) in Tarrytown. The following sections describe the proposed salient features relative to this BA, including approach spans, main spans, and ancillary facilities of the Replacement Bridge (see **Figure 1**).

1.2.1. Landings and Approach Spans

In Rockland and Westchester Counties, Interstate 87/287 would be shifted northward to meet the new abutments of the Replacement Bridge. There are two options for the Replacement Bridge's approach spans (Short Span and Long Span Options), which would result in somewhat different configurations of the Rockland County landing.

1.2.1.1. Short Span Option

The Short Span Option would consist of two parallel bridges that would have a typical highway design with a road deck supported by girders and piers (see Figure 2). The parallel bridges would be separated by a gap that would vary in dimension across the approach spans. The following describes the general characteristics of the Rockland County and Westchester County approach spans for the Short Span Option:

- The Rockland County approach spans would extend 1,257 m (4,125 feet) between the abutments and the main spans, and each would consist of 43 sections. The average distance between the piers of Rockland County approach spans would be 70.1 m (230 feet). There would be no gap between the parallel bridges at the abutments. The gap between the highway decks would widen to 70 feet at the main spans.

- The Westchester County approach spans would extend 548.6 m (1,800 feet) between the main spans and the abutments, and each would consist of 16 sections with an average distance between the piers of approximately 70.1 m (230 feet). The gap between the parallel highway decks would range from 70 feet at the main spans to 40 feet at the abutments.

As the approach spans meet the main span, the road deck would be at an elevation of 53.3 m (175 feet) above the Hudson River's mean high-tide elevation.

1.2.1.2. Long Span Option

The Long Span Option would also consist of two parallel bridges. Each bridge would have a truss structure supported by piers (see **Figure 2**). The road deck would be located on top of the trusses. The parallel bridges would be separated by a gap that would vary in dimension across the approach spans. The following describes the general characteristics of the Rockland County and Westchester County approach spans for the Long Span Option:

- The Rockland County approach spans would extend 1,257 m (4,125 feet) between the abutments and the main spans, and each would consist of 23 sections. The average distance between the piers of the Rockland County approach spans would be about 131 m (430 feet). There would be no gap between the parallel bridges at the abutments. The gap between the highway decks would widen to 70 feet at the main spans.

- The Westchester County approach spans would extend 548.6 m (1,800 feet) between the main spans and the abutments, and each would consist of 10 sections with an average distance between the piers of 131 m (430 feet). The gap between the parallel highway decks would range from 70 feet at the main spans to 40 feet at the abutments.

As the approach spans meet the main span, the road deck would be at an elevation of 59.4 m (195 feet) above the Hudson River's mean high-tide level.

1.2.2. Main Span

The main spans, which are the portions of the bridge that cross the navigable channel of the Hudson River, must provide adequate vertical and horizontal clearance for marine transport.

- The horizontal clearance affects the width of the Hudson River's navigable channel for water craft and must be clear of bridge piers and other bridge infrastructure. The U.S. Coast Guard requires a minimum horizontal clearance of 183 m (600 feet) through the Tappan Zee crossing. However, a clearance of 305 m (1,000 feet) is preferred to provide a safety buffer for maritime navigation through the channel.

- The vertical clearance affects the height of the bridge as well as the hull-to-mast height of marine vessels that navigate under the bridge. The Replacement Bridge Alternative would provide for at least 42.4 m (139 feet) of vertical clearance at mean high tide to maintain the existing hull-to-mast height requirements of vessels that travel beneath the Tappan Zee crossing.

This BA considers two options for the bridge's main spans over the navigable channel—Cable-stayed and Arch (see **Figure 3**). Both options would result in a horizontal clearance of at least 305 m (1,000 feet) and a vertical clearance at least 42.4 m (139 feet) over the navigable channel.

1.2.2.1. Cable-stayed Option

The Cable-stayed Span Option would result in two spans supported by cables connected to towers. The four towers (two towers per span) would rise about 122 m (400 feet) above the road deck and would be set approximately 91.4 m (300 feet) outward from the limits of the navigable channel. Cables would extend from each of the towers to various points on the road deck, in effect holding it up from above. The cables would support the entirety of the main spans between the approach structures. The cables would extend both eastward and westward from each tower tying into the road deck as much as 91.4 m (300 feet) away from the towers. The cables would be anchored to the ground through the tower foundations. Each section of the road deck would be connected to the towers by multiple cables, resulting in a highly redundant structure.

1.2.2.2. Arch Option

This option would consist of a steel arch that would extend eastward and westward from the main spans' piers. The main spans' piers would be located about 152.4 m (500 feet) outward from the limits of the navigable channel. The supports would curve upward and support the road deck from below. On either side of the navigable channel, the curved supports would extend above the road deck and meet in the middle forming the arch. The top of the arch would be about 61 m (200 feet) above the road deck. Suspender cables would extend vertically from the arch structure to support the road deck.

1.3. Study Area and Setting

The Hudson River is one of the major rivers on the Atlantic coast, extending from its source at Lake Tear of the Clouds on Mount Marcy in the Adirondacks to the Battery in New York Harbor, a distance of approximately 507 km (315 miles) (Geyer and Chant, 2006). In the study area, the Hudson River is tidally influenced and is commonly referred to as the Hudson River estuary. The estuarine portion of the river begins at the Troy Dam about 247.8 km (154 miles) north of the Battery in southern Manhattan. Tides in the Hudson River estuary are semidiurnal, having two high waters and two low waters each day with an average range of 0.98 m (3.2 feet) (NOAA Tide Tables, 2009). At approximately 4.8 km (3 miles) in width in the study area, the river is designated by New York State Department of Conservation (NYSDEC) as a Class SB (saline) waterbody, intended to be suitable for recreation, and fish survival and propagation. Water quality surveys by the Project Sponsors identified considerably variable concentrations of suspended sediments in the water column near the bridge depending on water depth, season, and weather conditions.

In the vicinity of the bridge, the river ranges in depth from less than 3.7 m (12 feet) along the western causeway to greater than 14.3 m (47 ft) in the shipping channel under the main span. The causeway and bridge piers cause river currents to locally scour the bottom sediments, resulting in depressions in the bottom of the river alongside the bridge.

The Hudson River and its tributaries are tidally influenced. The Hudson River in the vicinity of the TZB is referred to as an estuary due to the blending of freshwater and marine (saline) inputs. Bottom sediments are comprised of clayey silt. The river provides shallow as well as deep water habitat for a wide range of plants and animals, as described in subsequent sections of this chapter. The tidal action of the river, currents, and the seasonal variation in the amount of freshwater contributed by precipitation and runoff, make it a highly dynamic and unstable system. As a result, the ecosystem is generally dominated by a few well adapted species.

Bottom sediments throughout most of the estuary are generally soft and comprised of mud or sandy mud, but other bottom types such as sand or gravelly sand occur as well, and are more common in the upper portions of the estuary (AKRF 2010). The river provides shallow and deep water habitats for a wide range of aquatic and terrestrial plants and animals, as described in subsequent sections of this BA. The tidal action of the river, currents, and the seasonal variation in the amount of freshwater contributed to it by precipitation and runoff make it a highly

dynamic and unstable system. As a result, the ecosystem is typically dominated by a few well adapted species.

In 1992, the Habitat Work Group of the New York-New Jersey Harbor Estuary Program, administered by the United States Environmental Protection Agency (USEPA), requested that USFWS identify significant coastal habitats warranting special protection. The Tappan Zee section of the Hudson River was included in an area described as follows (USFWS 2011):

"The significant habitat complex boundary for the lower Hudson River estuary follows the shores of the Hudson River from the tip of Battery Park, Manhattan, generally referred to as river kilometer 0 (river mile 0), north to the Stony Point area river kilometer 66 (river mile 41). The boundary of the complex includes all riverine and estuarine habitats, including open water and tidal wetlands in this stretch of the river. This section of the river is the major site of river water mixing with ocean water in the Hudson Estuary, and includes the moderate and high salinity zones (mesohaline and polyhaline salinity zones) of the river. This productive estuary area is a regionally significant nursery and wintering habitat for a number of anadromous, estuarine, and marine fish species, including the striped bass (*Morone saxatilis*), and is a migratory and feeding area for birds and fish that feed on the abundant fish and benthic invertebrate resources in this area" (http://library.fws.gov/pubs5/web_link/text/low_hud.htm).

In 1990, the New York State Department of State (NYSDOS) designated several Significant Coastal Fish and Wildlife Habitats (SCFWH) within the stretch of the Hudson River between River Miles 11 and 40. These SCFWWs include Haverstraw Bay and Croton River and Bay (9.7 m, or 6 miles, north of the bridge), the Lower Hudson Reach (6.4 m, or 4 miles, south of the bridge), and Piermont Marsh (3.2 m, or 2 miles, south of the bridge). The NOAA and NYSDEC have designated Piermont Marsh part of the Hudson River National Estuarine Research Reserve. No SCFWHs occur within the study area.

The study area in the immediate vicinity of the replacement bridge encompasses intertidal and subtidal habitats of varying depths, ranging from shallow intertidal shorelines to shallow subtidal shoals and deeper channel habitats. There are no vegetated tidal wetlands present in this area. Areas south of the existing bridge less than 1.8 m (6 feet) deep at mean low water (MLW) are mapped as littoral zone wetlands by the NYSDEC. No NYSDEC tidal wetlands are mapped north of the bridge.

On the west side of the river, the shoreline typically consists of unvegetated intertidal beaches composed of coarse sand with scattered boulders. Immediately north of the bridge the shoreline is bulkheaded. The eastern shoreline adjacent to the railroad tracks consists of riprap armoring in the vicinity of the replacement bridge.

Shallow water environments occur near the shorelines and along the western and eastern causeways, while deep water habitat occurs within and near the shipping channel and the main bridge span. Shallows attract aquatic organisms that prefer greater sunlight and less water depth for part or all of their life cycles, while deeper water areas attract organisms with deeper water

column needs. The region under the existing bridge attracts certain organisms that use the pier structures as habitat, or that seek the organisms that adhere to the structures as food resources.

1.4. Consultation History

Informal consultations have been occurring with NMFS throughout the course of the project. Consultations have occurred with both the Habitat Conservation Division (HCD) in Milford, CT and the Protected Resources Division (PRD) in Gloucester, MA. The objective of the initial informal consultations was to develop and review the Hudson River ecological, hydrodynamic and sediment sampling program (Proposed Ecological Investigations within the Hudson River and along the I-287 Corridor, March 10, 2006), the results of which would support the DEIS and EIS impact analyses. Data were collected from April 2007 through May 2008 with additional sampling of oyster beds and submerged aquatic vegetation (SAV) during 2009. These data were reviewed with NMFS. Furthermore, design option concepts for the replacement bridge were presented to the agency at several meetings beginning in February 2008.

Detailed methodologies have been presented to NMFS related to the approaches that will be employed to assess ecological impacts of resuspended sediment and underwater noise, two of the more complex issues associated with bridge construction. A detailed, explanatory "read-ahead" document was submitted to the agency followed by a presentation in their offices for each of the two methodologies. The presentations were generally organized as follows:

- Discussion of ecological issues
- Relevant construction activities
- Proposed "on set of effects" criteria
- Use of sampling data
- Analytical procedures (i.e., mathematical models).

At each of the methodology meetings, comments were requested from NMFS with regard to the proposed "onset of effects" criteria and the analytical methods that would be employed in the DEIS analysis. General comments on the proposed acoustic "physiological effects" criteria have been received from NMFS-PRD (August 24, 2010; Julie Crocker to Melissa Toni).

A subsequent meeting was held with NMFS in Gloucester, MA on October 14, 2011 with members of the HCD and the PRD. The objective of the initial meeting was to develop and review the planned Pile Installation Demonstration Project (PIDP) for the proposed bridge replacement project. This meeting detailed the PIDP and the methodologies that will be employed to assess direct and indirect ecological effects associated with the PIDP.

Recently, NMFS provided commentary on the Project's scoping document, and provided an extensive list of items to consider during the preparation of the EIS, the BA and Essential Fish Habitat (EFH) evaluation (NOAA 2011a). A second meeting was held in Gloucester, MA on December 14, 2011 to continue the coordination of the PIDP and the Project's Biological

Assessment and Essential Fish Habitat analyses. At this meeting NMFS provided comments on the Draft PIDP BA (NMFS 2011a), but raised issues that are relevant to the Biological Assessment for the Replacement Bridge Alternative as well. Portions of the commentary not addressed herein will be addressed completely though future interactions / meetings with NMFS and subsequent document revisions as the consultation process advances.

Chapter 2 Federally Proposed and Listed Species and Designated Critical Habitat

The USFWS lists of federally threatened, endangered, candidate, and proposed species for Westchester and Rockland Counties include only one endangered fish species, the shortnose sturgeon (*Acipenser brevirostrum*; endangered) occurring within the study area. Shortnose sturgeon are also currently listed for protection by the State of New York as an endangered species. Atlantic sturgeon (*Acipenser oxyrinchus*) are also known to occur in the study area, and although they are not currently federally listed as threatened or endangered, Atlantic sturgeon have been proposed for listing for federal protection under the ESA.

Alewife and blueback herring were designated as candidate species on November 2, 2011. These species are being considered for listing as endangered or threatened under the ESA. Candidate status does not carry any procedural or substantive protections under the ESA.

According to sources cited in the most recent NMFS commentary, a November 15, 2011 letter from Patricia Kurkul to Michael Anderson (NMFS 2011b), seals and dolphins are present occasionally in the Hudson River and may migrate through the study area (DiGiovanni 2011 as cited in NMFS 2011b). Harbor porpoises (*Phocoena phocoena*) occasionally may also be present in the study area (Jackson et al. 2005 as cited in NMFS 2011b). However, the study area does not contain any marine mammal concentration areas or seal haul-out areas (NMFS 2011b). The NMFS letter also indicated that large whales and sea turtles, including those listed under the ESA, are similarly unlikely to occur in the study area.

2.1. Shortnose Sturgeon

The shortnose sturgeon is a member of the family Acipenseridae. The shortnose sturgeon is a long-lived, slow-maturing species. It is the smallest sturgeon species native to North America, achieving maximum lengths of up to 1,070 millimeters ("mm") (42 inches) in the Hudson River (Bain 1997), and maximum lifespans of approximately 50 to 60 years (Kynard 1997).

Within North America, the shortnose sturgeon inhabits large coastal rivers along the Atlantic coast, ranging from New Brunswick, Canada, to the Saint Johns River in Florida. Nineteen distinct sub-stocks, ranging in size from less than 100 adults in the Merrimack River (Massachusetts) to greater than 60,000 adults in the Hudson River, have been recognized (NMFS 1998a). Shortnose sturgeon adults generally remain in their natal rivers or estuaries; there is little evidence of interbreeding or interchange of fish among stocks (Kynard 1997). McCleave et al. (1977) studied daily movements of shortnose sturgeon in a Maine estuary and did not find any conclusive evidence of a distinct or abrupt change in swimming pattern at the time of tidal change.

Hudson River shortnose sturgeon typically inhabit the deepest water available (Hastings et al. 1987; O'Herron et al. 1995) but often move into shallow areas to forage. In tidal reaches of the Hudson River, the deepest water typically is found within or adjacent to the navigation channel, away from river shores. Shortnose sturgeon prefer lower salinity waters, and although they

rarely can be found in pure seawater (approximately 34 parts per thousand ("ppt"), they generally have a maximum salinity tolerance in the range of 30 to 31 ppt (Holland and Yelverton 1973; Dadswell et al. 1984). Their distribution and life history pattern in the Hudson River is summarized in **Figure 4**.

2.1.1. Adults (including spawning adults)

The shortnose sturgeon's age at sexual maturity varies by latitude. In mid-Atlantic estuaries, including the Hudson River, male shortnose sturgeon can reach sexual maturity at three to five years of age, and females at six to ten years (Dadswell et al. 1984). First spawning may follow sexual maturation in males by up to one to two years, whereas in females spawning may be delayed for up to five years (Dadswell 1979). Based on the percentage of sexually developing fish from August through March collections in New Brunswick, Canada, it appears that females spawn once every third year, and males every other year (Dadswell 1979). Other data (e.g., annuli formation in the pectoral rays) suggest a 5 to 11 year interval between individual spawning events (Dadswell 1979). NMFS (2011b) has indicated that, based on limited data, females spawn every three to five years, while males spawn approximately every two years.

Shortnose sturgeon fecundity can be quite variable. Estimates of number of eggs per gravid female range from 27,000 to over 200,000, with a mean of 11,568 eggs/kg body weight (see Dadswell et al. 1984 for review of reported fecundity values). This high fecundity likely evolved in the presence of highly variable environmental conditions of primary spawning grounds, as well as high natural early life stage mortality rates.

Shortnose sturgeons spawn well north of the Tappan Zee Bridge between the Troy dam and RM 131 (Dovel et al 1992). Shortnose sturgeon undertaking the spawning migration in the Hudson River travel upriver in deeper channel areas as far as accessible spawning habitat permits (**Figure 4**, adapted from Bain et al. 1998). Spawning usually occurs when River temperatures increase to about 8.8°C (47°F), and concludes when temperatures reach 12.2°C–15.0°C (54°F–59°F) (Kynard 1997). River channels with rock or gravel substrate and moderate bottom current velocities are the preferred spawning habitat of the shortnose sturgeon (NMFS 1998a).

2.1.2. Eggs

Shortnose sturgeon are broadcast spawners, with fertilization occurring externally (Gilbert 1989). Ripe and fertilized eggs have diameters of 3.0 to 3.2 mm and can be as large as 3.5 mm (0.12 to 0.13 inches and 0.14 inches), respectively (Dadswell et al. 1984; Buckley and Kynard 1981). Shortnose sturgeon eggs are demersal and adhere to objects on the river bottom within 20 minutes of fertilization. Eggs hatch approximately 13 days after fertilization at temperatures between 7.7°C and 12.2°C (46°F and 54°F) (Bain 1997).

Eggs are confined to freshwater reaches above the saline area and would not be expected to occur in Tappan Zee region.

2.1.3. Larvae

Upon hatching, larvae are 7.3 to 11.3 mm (0.29 to 0.44 inches) long (Taubert 1980; Buckley and Kynard 1981). Research on larval behavior indicates that hatchlings exhibit negative phototaxis (i.e. response to light), and seek cover under any available structure immediately after hatching (Richmond and Kynard 1995). Within the first one to two days of hatching, larvae denied access to, or physically dislocated from, cover will exhibit a temporary and short-lived "swim-up and drift" behavior. In the wild, this behavior allows the larvae to move short distances (with the assistance of currents) to locate available cover downstream. Yolk-sac larvae ("YSL") will continue to seek benthic cover for about a week, but after one to two days post-hatch their movements are predominantly parallel to the bottom (Richmond and Kynard 1995). At 9 to 12 days post-hatch, the yolk sac is absorbed and larvae have well-developed, functioning eyes, a mouth with teeth, and fins that enable them to swim normally (Kynard 1997).

In laboratory tests, larvae were nocturnally active, and preferred the deepest water available to them (Richmond and Kynard 1995). Even shortnose sturgeon embryos released near the surface of a test enclosure sought bottom cover. In other hatchery experiments, ten-day-old larvae attempted to remain on the bottom or placed themselves under available cover (Pottle and Dadswell 1979; Washburn and Gillis Associates 1980). After the yolk sac is completely absorbed, post yolk-sac larvae actively feed on zooplankton (Buckley and Kynard 1981; Washburn and Gillis Associates 1980). Snyder (1988) and Parker (2007) considered individuals to become juveniles at around 57 mm TL with the transformation occurring on about day 40 after hatching for fish from the Connecticut River (Parker 2007).

Larvae are predominately confined to freshwater reaches above the saline area and would not be expected to occur in Tappan Zee region.

2.1.4. Juveniles

The juvenile phase can be subdivided into young of the year (YOY) and immature sub-adults. YOY and sub-adult habitat use differs and is believed to be a function of salinity tolerance (NMFS 2011c). Little is known about YOY behavior and habitat use although it is believed that they are found in freshwater habitats above the saltwedge for about one year. Hence, YOY would not be expected to occur in the Tappan Zee study area. Sub-adults would be expected to occupy similar spatio-temporal patterns as adults and occupy a much wider portion of the estuary, including the Tappan Zee study area.

The early growth of shortnose sturgeon is relatively rapid compared to many species, and occurs during the first few months following hatching as YOY gradually migrate to downstream deep, brackish, waters from the spawning grounds. Upon reaching about 14 to 17 mm total length (0.5 to 0.7 inches TL), shortnose sturgeon generally resemble adults and may leave bottom cover briefly to swim in the water column (although they remain strongly bottom-oriented). In the wild, fish of this size probably disperse downstream using currents as conveyance (Richmond and Kynard 1995).

The juveniles (fish ranging from 2 to 8 years old) can be found in brackish areas of the Hudson River. The primary summer habitat for shortnose sturgeon in the middle section of the Hudson River above Newburgh is the deep river channel (13 to 42 m deep, or 43 to 138 feet). The river channel downstream of this middle estuary area is 18 to 48 m deep (59 to 157 feet [Peterson and Bain 2002]).

2.1.5. Hudson River Population

In its 1979 NMFS Biological Opinion for the Indian Point Generating Station, NMFS used an assumption of a shortnose sturgeon population of 6,000 individuals, although other contemporary estimates placed the Hudson River shortnose sturgeon population at approximately 13,000 individual adults (Bain 1997). By the 1990s, the Hudson River adult population was estimated to be as high as approximately 60,000, which represents the largest shortnose sturgeon population in the United States (Bain et al. 1998; 2007). Other researchers have suggested that some populations segments (including the Hudson River) have recovered to historic abundance levels (Wirgin et al. 2005; Woodland and Secor 2007). The increase in the shortnose sturgeon population in the Hudson River has been attributed to both managed population recovery and regional conservation measures, specifically the enactment and enforcement of fishing regulations (Bain et al. 2007).

According to Woodland and Secor (2007), twenty years of sustained annual recruitment has contributed to strong recovery of shortnose sturgeon in the Hudson River. During this period there were several particularly strong year classes that translated into substantial population growth. Size and body condition of the fish caught in these studies indicate the population is primarily healthy, long-lived adults. Hoff et al. (1988, in Bain 1997) reported most captures of adult shortnose sturgeon during river monitoring of fish distributions by the Hudson River electric utilities from 1969 to 1980 occurred between river miles (RM) 24 to 76 (from near the New York/New Jersey border up to near Poughkeepsie).

Dovel et al. (1992) concluded that most of all adults form an overwintering concentration near Kingston. Bain (1997), however, described a second late fall and overwintering area near Haverstraw Bay between km 54 and 61 (RM 33-37).

From 2000-2009, the Fall Shoals Monitoring Program sponsored by a coalition of Hudson River Utilities collected 289 juvenile and adult shortnose sturgeon using a beam trawl. The majority of these fish were collected north of West Point (RM 47) and were adults. Only eight shortnose sturgeon were collected in the Utilities designated Tappan Zee region (RM 24-33). Greater than 90% of all shortnose sturgeon were collected from bottom habitats in waters greater than 6.1 m (20 ft) in depth. A review of commercial catch data provided by NYSDEC (NYSDEC 2011 unpublished data) indicated that from the years 1980-2002 shortnose sturgeon were collected in the Tappan Zee vicinity (RM 25-27) in 14 of 23 years. The Utilities also report the number and size of shortnose sturgeon collected as part of their Striped Bass and Atlantic tomcod sampling program.

A year-long, project-specific fish survey was conducted between April 2007 and May 2008 to further characterize the fish community and examine seasonal differences in abundance near the

Tappan Zee Bridge. These surveys combined hydroacoustics, gill nets, and trap nets to characterize the species composition, relative abundances, and distributions of fish populations within the study area. A total of 25 species and just over 2,000 individual fishes and hundreds of blue crabs were collected during approximately 680 hours of gill-net sampling within the study area between April 2007 and May 2008. A total of 12 shortnose sturgeon were captured in gill nets during the bi-monthly fish-sampling effort within the Tappan Zee study area. The sturgeon were captured in the warmer months of the year—between May and October—at both the bridge and reference locations in water depths between 1.8 and 9.1 m (6 and 30 feet). Although no individuals were captured during the December, February, and April sampling events, it is possible that the species is present within the study area but that the cold waters slowed its movements enough so fish would not be captured by the gill net, a stationary and passive gear type.

The shortnose sturgeon that were collected in the 2007-2008 sampling program ranged in size from an estimated 450 mm (1.5 ft) to 990 mm (3.2 ft) in total length. Eleven of the 12 fish collected were 650 cm (2.1 ft) or larger, and based on their sizes, are presumed to have been adult sturgeon.

2.2. Atlantic Sturgeon

Atlantic sturgeon, proposed for listing as endangered for the New York Bight population by NMFS, is also known to occur in the Hudson River. By contrast with shortnose sturgeon, which spend a great deal of their lives in the Hudson River, Atlantic sturgeon spend most of their lives in marine waters along the Atlantic coast. It is a large anadromous, bottom-feeding species that spawns in the Hudson River and matures in marine waters; females return to spawn at age 15 or older and males return earlier at 12 years o older (Bain 1997, citing other authors). Young et al. (1988) reported that in the Hudson River, maturity of females Atlantic sturgeon begins at age 11 and increases gradually for the next ten years until all females are mature. In the Hudson River, Atlantic sturgeon are found in the deeper portions and do not occur farther upstream than Hudson, New York.

Like shortnose sturgeon, the Atlantic sturgeon is a member of the family Acipenseridae, and ranges from the Hamilton River, Labrador to northeastern Florida (Gruchy and Parker 1980). Atlantic sturgeon is one of the largest fish species in North America with a maximum recorded length of about 4.2 meters (14 feet) (Bain 1997). The oldest recorded Atlantic sturgeon was a 60-year-old individual from the St. Lawrence River (Gilbert 1989). Male Atlantic sturgeon generally do not reach maturity until at least 12 years and females as late as 19 years (Dovel and Berggren 1983). Their interannual spawning period can range from three to five years, and adults usually inhabit marine waters either all year during non-spawning years or seasonally during spawning years (Bain 1997). Atlantic sturgeons are anadromous; they spawn in freshwater, but spend most of their lives in ocean waters often undertaking long distance migrations along the Atlantic Coast (Bain 1997).

Wrege et al. (2011) studied activity patterns of Gulf of Mexico sturgeon, a subspecies of Atlantic sturgeon, in Pensacola Bay. These authors found that Gulf sturgeon were more active at night in

all seasons except summer. Gulf sturgeon migrate out of the estuary to the Gulf of Mexico in fall and up through the bay system to summering habitats in rivers in spring.

Several genetic studies have attempted to characterize the population structure and the homing fidelity of Atlantic sturgeon. DNA studies among different Atlantic sturgeon populations suggest that they are reproductively separate and exhibit high fidelity to natal spawning grounds (Wirgin et al. 2002; Waldman et al. 2002). In 2007, NMFS proposed five distinct population segments (DPS) for the U.S. Atlantic sturgeon based largely on DNA results, while another study estimated at least nine population segments (ASSRT 2007; Grunwald et al. 2008).

2.2.1. Adults (including spawning adults)

In the Hudson River population, spawning and early development occurs in the freshwater portion of the River from late May through mid-July, while adult and large juvenile Atlantic sturgeon occupy marine waters. In recent studies, the primary spawning site for Atlantic sturgeon was identified in Hyde Park, New York at RM 83 (Bain et al. 2000). The spawning habitat is along the west side of the River, and spawning appears to be associated with rock islands, irregular bedrock, and substrate of silt and clay (Bain et al. 2000). The area is freshwater throughout the year, with water depths ranging from 12 to 24 meters (39 to 79 feet). Water temperatures in habitats used for spawning have been documented between 19 to 28°C (66 to 82°F) (Bain et al. 2000).

2.2.2. Eggs and Larvae

Like the eggs of shortnose sturgeon, the eggs of Atlantic sturgeon are adhesive, and after fertilization and hydration are approximately 2.2 mm (0.09 inches) (Hardy and Litvak 2004). After hatching, the larvae remain closely associated with the bottom in deep channel habitats (Bain et al. 2000). Atlantic sturgeon larvae are about 7 mm (0.28 inches) TL upon hatching. The transition from the larval to the juvenile stage is estimated to occur at about 30 mm (1.18 inches) TL, based on Hudson River specimens (Bath et al. 1981). In the Hudson River, the larvae have been recorded from around RM 37 to RM 92 (Dovel and Berggren 1983). This range includes some brackish waters; however, larval Atlantic sturgeon have limited tolerance to salt and the most favorable larval habitat must occur well upstream of the salt front (Van Eenennaam et al. 1996). It is believed that the preferred habitat for larval Atlantic sturgeon is close to the spawning habitat between RM 37 to RM 92, with larvae gradually moving downstream as they grow and develop the salt tolerance that is characteristic of juveniles and adults (Bain et al. 2000). Neither eggs nor larvae would be expected to occur in the vicinity of the project.

2.2.3. Juveniles and Winter Habitat

Juvenile Atlantic sturgeon smaller than about 70 cm TL and 6 years old tend to occupy summer rearing and over-wintering habitats in the freshwater reaches of the Hudson River (Bain et al. 2000). From April through October, early Hudson River juvenile Atlantic sturgeon are primarily found between RM 42 and 66 and at water temperatures between 24 and 28°C (75 and 82°F) (Bain et al. 2000). This region comprises the highland gorge and wide estuarine portion of the Hudson River, where the transition from freshwater to brackish water typically occurs. Juvenile

Atlantic sturgeon are most often found in salinities ranging from 0 to 5 ppt (Bain et al. 2000). Water depths associated with most juvenile captures ranged from 10 to 25 meters (33 to 82 feet), and the substrates were primarily silt and sand (Bain et al. 2000). Later studies have pointed to Haverstraw Bay as the primary habitat for juvenile Atlantic sturgeon (Sweka et al. 2007). These studies suggest that while soft bottoms in deep habitat comprised only 25% of the available habitat in Haverstraw Bay, these habitats yielded the greatest frequency of catches, the highest catch per unit effort ("CPUE"), and lowest variance of CPUE (Sweka et al. 2007).

Hudson River winter habitat of Atlantic sturgeon has been described using data from trawl and gill-net sampling that was conducted between 1975 through 1978 (Dovel and Berggren 1983). When water temperature in the river reaches approximately 9°C (48°F), most juvenile Atlantic sturgeon that have not migrated to the ocean appear to congregate in a deep-water habitat between RM 12 and 46 (Bain et al. 2000). Water temperatures during winter can reach 0°C (32°F) in this segment of the Hudson River, salinity typically ranges from 3 to 18 ppt, and water depths in the channel commonly range from 20 to 40 meters (66 to 131 feet) (Bain et al. 2000). It appears that most juvenile sturgeon habitats prefer clay, sand, and/or silt substrates.

Juvenile Atlantic sturgeon that complete the migration to the ocean generally are older than 6 years and are longer than roughly 70 cm. These fish occupy marine habitats during the winter, and rivers, estuaries, and coastal marine habitats during the summer (Bain et al. 2000). It is thought that adult Atlantic sturgeon undertake the same migrations as the marine migrant juveniles (Bain et al. 2000).

Late juvenile and adult Atlantic sturgeon in the Hudson River also are known to occupy similar habitats in other rivers. Tagged Hudson River Atlantic sturgeon have been recaptured in tributaries of the Chesapeake Bay and in the Delaware River (Dovel and Berggren 1983). There also are accounts of concentrations of late juvenile and adults in coastal marine waters during the summer, including the deep waters of Long Island Sound off the Connecticut coast, with at least one fish collected that was originally tagged in the Hudson River (Bain et al. 2000; Eyler 2006). The Long Island Sound habitat was approximately 30 to 40 meters (98 to 131 feet) deep with mud substrate.

Adult Atlantic sturgeons do not appear to occupy the freshwater reaches of the Hudson River during the winter. Autumn collections of fish leaving the coastal waters and estuaries have been reported by fishermen in Chesapeake Bay, New York, and New Jersey, and some scientific researchers also have documented this out-migration (Bain et al. 2000; Kieffer and Kynard 1993). A study by NYSDEC has indicated that tagged Atlantic sturgeon left the Hudson River by late July (NYSDEC unpublished data).

2.2.4. Hudson River Population and Other Distinct Population Segments (DPS)

No data on abundance of juvenile Atlantic sturgeon in the Hudson River are available prior to the 1970s; however, catch depletion analyses conservatively estimated that 6,000 to 6,800 females comprised the spawning stock during the late 1800s (Secor 2002; Kahnle et al. 2005). Two population estimates of age-1 Atlantic sturgeon have been developed for the Hudson River. In 1977, the 1976 cohort was estimated at 25,647 individuals (95% confidence interval of 13,206–

53,039) (Dovel and Berggren 1983). In 1994, the cohort size was estimated at 4,314 (95% confidence interval of 1,916–10,473) individuals (Peterson et al. 2000). The large confidence intervals from the latter study point to the difficulty in obtaining a precise population estimate for Atlantic sturgeon for a small population in a large river system such as the Hudson River (Sweka et al. 2007). Kahnle et al, (1998) estimated the age-zero Hudson River population in 1994 to be 9,529 based on the capture of 15 captive-hatched and 14 wild origin age-1 Atlantic sturgeon in 1995. Of the total, 4,929 would have been captive-hatched and 4,600 of wild origin. An estimate of 870 spawning adult fish per year, consisting of approximately 600 males and 270 females, was calculated based on fishery dependent data collected from 1985-1995 (Kahnle et al. 1997).

Current abundance trends for Atlantic sturgeon in the Hudson River are also available from a number of ancillary surveys. From July to November during 1982-1990 and 1993, NYSDEC sampled the abundance of juvenile fish in Haverstraw Bay and the Tappan Zee Bay. The CPUE of immature Atlantic sturgeon was 0.269 in 1982 and declined to zero by 1990 (ASSRT 2007). The American shad (*Alosa sapidissima*) gill net fishery in the Hudson River estuary, conducted annually from early April to late May, incidentally captures young Atlantic sturgeon (< 100 cm) and has been monitored by fisheries observers since 1980. The CPUE of Atlantic sturgeon as shad bycatch was greatest in the early 1980s and decreased until the mid 1990s, but has gradually begun to increase slightly since then (ASSRT 2007).

The Utilities' Long River Sampling Program samples ichthyoplankton river-wide from the George Washington Bridge (RM 12) to Troy (RM 153) using a stratified random design (Con Edison 1997; ASSRT 2007). These data, which are collected from May to July, have provided an annual abundance index of juvenile Atlantic sturgeon in the Hudson River estuary since 1974. In addition, data from the Utilities' Fall Shoals Sampling Program, conducted from July through October/November, is used to calculate an annual index of the number of fish captured per haul. Indices from utility surveys conducted from 1974 through 2007 (LRS and FSS) indicate that the annual abundance of juvenile Atlantic sturgeon has been in decline over the monitoring period, with the CPUE peaking at 12.29 in 1986 (the highest of the survey period) and then declining to 0.47 in 1990 (Con Edison 1997; ASSRT 2007). Since 1990, the CPUE has ranged from 0.47-3.17, and has increased somewhat in recent years to 3.85 (in 2003). Taken together, these population estimates and annual abundance indices suggest a generally decreasing population trend for the Hudson River.

Between 2000-2009, the Hudson River Utilities Fall Shoals Sampling Program has collected 241 juvenile and sub-adult Atlantic sturgeon using a beam trawl. The majority of these fish were collected north of West Point (RM 47). Only five Atlantic sturgeon were collected in the Utilities defined Tappan Zee region (RM 24-33). Greater than 95% of all Atlantic sturgeon were collected from bottom habitats in waters greater than 6.1 m (20 ft) in depth. Between 2000-2009, the Utilities' Long River Program also collected 16 yolk and post yolk-sac larvae, all upstream of Cornwall (RM 58). The Utilities also report the number and size of Atlantic sturgeon collected as part of their Striped Bass and Atlantic tomcod sampling program.

No Atlantic sturgeon were captured in project-specific gill nets during the bi-monthly fish-sampling effort within the study area between 2007-2008. However, the carcass of an Atlantic

sturgeon was observed floating approximately 152.4 m (500 feet) north of the bridge in May of 2008.

Commercial catch data provided by NYSDEC from observed fishing trips for the American shad gill net fishery (NYSDEC 2011 unpublished data) indicated that from the years 1980-2002 Atlantic sturgeon were collected in the study area between RM 25 and 27 in 14 of 23 years. However, Atlantic sturgeon were collected in only one year after 1992, which coincided with a marked reduction in commercial fishing effort. A separate adult Atlantic sturgeon tracking program was developed by NYSDEC which began tagging fish in 2007 with digital sonic tags. The study results confirm that the study area serves as a migration corridor for adult Atlantic sturgeon. Most of the fish that were tagged arrived in the Hudson from early April to late June and left the river by late July.

Although not currently listed as either threatened or endangered by the United States Fish and Wildlife Service ("USFWS"), NMFS, or NYSDEC, Atlantic sturgeon (*Acipenser oxyrinchus*) is likely to be listed in the very near future. In 2007, a Status Review Team ("SRT") consisting of biologists from NMFS, the U.S. Geological Survey ("USGS"), and USFWS completed a status review report on Atlantic sturgeon in the United States. The SRT recommended that Atlantic sturgeon in the United States be divided into the following five distinct population segments ("DPS"): Gulf of Maine; New York Bight; Chesapeake Bay; Carolina; and South Atlantic.

The Atlantic Sturgeon Status Review Team identified 15 stressors that appear to be impacting the United States populations of Atlantic sturgeon (ASSRT 2007). Of the stressors evaluated, fishing bycatch mortality, degraded water quality, lack of adequate state and/or Federal regulatory mechanisms, and dredging activities were identified as the most significant threats to the viability of Atlantic sturgeon populations. In addition, some populations were impacted by unique stressors, including habitat impediments (e.g., Cape Fear and Santee-Cooper rivers) and apparent ship/propeller strikes (e.g., Delaware and James Rivers) (ASSRT 2007). NMFS cites locks and dams, overfishing and the more recent impact of bycatch and habitat degradation as causes for the Atlantic sturgeon decline in the Northeast (NMFS, Species of Concern Atlantic sturgeon www.nmfs.noaa.gov/_)

In October 2010, NMFS published two proposed rules to list five distinct population segments (DPS) of Atlantic sturgeon (75 FR 61872; 75 FR 61904). The Hudson River is contained within the New York Bight, which is one of the DPS identified in the proposed rule. Within the northeast region NMFS has determined that for the New York Bight and Chesapeake Bay DPS, an endangered listing is warranted, while a listing of threatened is warranted for the Gulf of Maine DPS.

As part of the ongoing Endangered Species Act listing for Atlantic sturgeon, the National Marine Fisheries Service (NMFS) is considering each of the five Distinct Population Segments (DPS) as an individual species. Because Atlantic sturgeon are thought to range widely along the Atlantic coast and have been shown to move among DPS (Erickson et al. 2011), there is a possibility that individuals from all five DPS could occur in the New York Bight DPS and may potentially pass through the Tappan Zee study area. As a result, Atlantic sturgeon from any of the five DPS could

be affected by project activities associated with construction of the new Tappan Zee Bridge. For this reason, it is necessary to evaluate the potential for project effects on each of the five DPS.

Despite the fact that some individuals may migrate over large distances, their movement, in general, appears to be more localized to the coastal waters of the DPS of their origin (Erickson et al. 2011). For example, movement of Hudson River sturgeon has been shown to be largely limited to coastal waters from Long Island to the Chesapeake Bay, suggesting that the potential impact of bridge construction on Atlantic sturgeon may be greatest for individuals from the New York Bight DPS and possibly individuals from the adjacent Chesapeake DPS and much less for sturgeon from non-contiguous DPS.

The study area is located centrally within the New York Bight DPS, which is bounded to the north by the Gulf of Maine DPS and to the south by the Chesapeake DPS. Further south are the Carolina and South Atlantic DPS. Atlantic sturgeon from each of the DPS are unique in terms of their biological and genetic attributes, which provides the basis for their consideration as separate "species" (ASSRT 2007, Grunwald et al. 2008). While some mixing of individuals between the New York Bight and more southern DPS has been shown to occur in the southern portion of the New York Bight DPS (i.e., Delaware Bay; Waldman et al. 1996), nearly all Atlantic sturgeon (up to 99%) from further north in the New York Bight DPS are considered to be endemic to this DPS based on genetic analyses (Waldman et al. 1996). Fewer than 4% of Atlantic sturgeon in the coastal waters of the New York Bight likely originate from more southern DPS, while very few sturgeon (0% based on genetic analysis by Waldman et al. 1996) from the Gulf of Maine DPS move south into the New York Bight DPS. Earlier tag-recapture studies from the Carolina DPS suggests that Atlantic sturgeon from the two southern DPS have more restricted geographic distributions and move shorter distances than sturgeon from northern DPS, with all the recaptures in those areas coming from the Carolina or South Atlantic DPS (NMFS 1998b). These studies suggest that the majority of Atlantic sturgeon remain in coastal waters within their DPS or in adjacent DPS.

Although Atlantic sturgeon are capable of ranging widely along the Atlantic coast and of movement throughout DPS (Erickson et al. 2011), tagging and genetic studies indicate high site fidelity in natal rivers and very low gene flow among populations (Dovel and Berggren 1983, Savoy and Pacileo 2003, Grunwald et al. 2008). The fact that adult sturgeon return to their natal river to spawn (Collins et al. 2000, Grunwald et al. 2008), reduces the likelihood of impacting individuals from the four other DPS. Furthermore, the infrequency with which Atlantic sturgeon spawn (1-5 years for males and 2-5 years for females) further reduces the potential effects of bridge construction on Atlantic sturgeon from the New York Bight DPS. That is, since only a subset of adult sturgeon migrate to spawning grounds in the Hudson River during a given year, the remainder of the adult sturgeon should be unaffected. Use of the Hudson River by sturgeon from DPS outside of the New York is a possibility (ASSRT 2007), however, the abundance of these individuals in the Hudson River relative to sturgeon from the New York Bight DPS is unknown, but likely to be low.

Based on the best available information, the potential impacts of bridge construction on Atlantic sturgeon are greatest for individuals from the New York Bight DPS and much less likely for individuals from the four other DPS, despite the potential for Atlantic sturgeon to disperse

widely among Atlantic coastal habitats and throughout DPS. Support for this conclusion comes primarily from recent tagging studies demonstrating that the majority of Atlantic sturgeon from the Hudson River remain within the New York Bight and coastal Chesapeake DPS, and from genetic studies that have shown distinct populations among DPS, low gene flow among populations and high site fidelity for natal rivers.

At this time, no critical habitat has been proposed for Atlantic sturgeon.

2.3. Marine Mammals

NMFS indicated that dolphins, harbor porpoises, and seals make occasional use of the Tappan Zee region of the Hudson River (NMFS 2011b). These species are marine, and only occur in the tidal Hudson River as transients. Rigorous scientific surveys of these species within the Hudson River are not known; however, anecdotal sightings of dolphins and other species have been published by the NYSDEC in the Hudson River Almanac. Both alleged and confirmed sightings of bottlenose dolphin (*Tursiops truncatus*) have been mentioned for Tappan Zee, Kingston Point, Tivoli Bay, Rhinecliff, and Peekskill in 1997 and 2008 (NYSDEC 2008). In addition, at least one confirmed death of an observed bottlenose dolphin occurred during the same reporting period. A follow-up necropsy was conducted by the Aquarium of Wildlife Conservation at Coney Island, Brooklyn, New York. The reported cause of death was stress related to an entanglement with monofilament fishing line resulting in septicemia (NYSDEC 2008). The Hudson River Almanac has also reported observation of harbor seals (*Phoca vitulina*), harp seal (*Phoca groenlandica*) in 1996, hooded seal (*Cystophora cristata*) in 1996, gray seal (*Halichoerus grypus*) in 2004, and harbor porpoise (*Phocoena phocoena*) in 1995, 1997, 1999, and 2005. Due to the anecdotal (and often unconfirmed) nature of these reports, it is difficult to determine the frequency of occurrence for any of these species in the Tappan Zee Reach, except to note that the NYSDEC considers the harbor seal “relatively common” in the Hudson River Estuary, although not necessarily in the Tappan Zee Reach.

There is a possibility that the Historic Area Remediation Site (HARS) will be used for the disposal of the project’s dredged material. Consultations pursuant to Section 7 of the Endangered Species Act (ESA) have taken place for the area of the HARS during preparation of the SEIS. The USEPA prepared a biological assessment that concluded that the closure of the Mud Dump Site and designation of the HARS would not be likely to adversely affect loggerhead and kemps ridley sea turtles and humpback and fin whales (USEPA 1997). Special conditions are included in USACE Section 103 permits for placement of Remediation Material at HARS that requires the presence of NMFS approved Endangered Species Observer(s) on disposal scows during their trips to the HARS. The role of these observers is to prevent adverse impacts to endangered or threatened species transiting the area between the proposed dredge site and the HARS. With the implementation of these conditions placement of Remediation Material at the HARS would not result in adverse effects to threatened or endangered species, also including marine mammals.

Chapter 3 Environmental Baseline

The focus of this BA is confined to the habitats and biota that are directly relevant to shortnose and Atlantic sturgeon and marine mammals – namely the aquatic habitats that occur below the mean high tide line. The following narratives describe the physical aquatic habitat and biota within the study area.

3.1. Physical Habitat

The study area encompasses intertidal and subtidal habitats of varying depths, ranging from shallow intertidal shorelines to shallow subtidal shoals and deeper channel habitats. Along the shorelines, coarse woody and rocky debris provide structural refuge and foraging substrates for fishes. Benthic habitat includes submerged aquatic vegetation and oyster beds, as well as unvegetated areas of coarse sandy to fine silty sediments. The navigation channel provides deeper open-water and deep-water benthic habitats.

3.1.1. Water Quality

The water quality classification in the vicinity of the TZB is a driving factor in assessing the effects of the Tappan Zee Replacement Bridge. The Hudson River near the TZB is classified by NYSDEC as a Class SB water. There are no numeric water quality standards for the parameters typically associated with suspended sediments, such as turbidity or total suspended sediment (TSS), colloidal, and settleable solids (6 NYCRR § 703.2). However, the narrative standards state that an action should not increase turbidity sufficiently to result in a substantial visible contrast to natural conditions, or any suspended, colloidal or settleable solids from sewage, industrial or other wastes that would cause deposition or impair the waters for their best use.

The Hudson River is tidally influenced from the Battery to the Federal Dam at Troy, NY. Tides at the Battery have an average range of 1.37 m (4.5 ft), with the mean range decreasing to 0.98 m (3.2 ft) at the TZB and gradually increasing again to 1.43 m (4.7 ft) at the Federal Dam (NOAA Tide Tables, 2009). The majority of freshwater flow enters the Hudson River north of the Federal Dam, with the remaining freshwater flow entering from various tributaries downstream of the dam. The variation between freshwater flows at the mouth of the river and in the vicinity of the TZB is a few percent (DiLorenzo et al. 1999).

The Hudson River estuary is well studied and a large number of other data sources exist. These include permanent monitoring stations, such as the USGS gauge at Hastings on Hudson (8 km, or 5 miles, downstream from the TZB), the Hudson River Environmental Conditions Observing System gauge at Piermont Pier (3.2 km, or 2 miles, downstream), and the US Geological Survey (USGS) gauge at West Point (38.6 km, or 24 miles, upstream). Other monitoring stations include the NOAA gauge at The Battery and the USGS gauge south of Poughkeepsie which continuously monitors SSC.

The USGS gauge south of Poughkeepsie uses backscatter information from an Acoustic Doppler Current Profiler (ADCP) to estimate suspended solids concentration (SSC) (Wall et al. 2006). Using the SSC estimates combined with the current data measured by the device, an estimate of

total sediment discharge is also calculated. This gauge has been operating almost continuously since 2002.

Available guidance and precedent suggest that the suspended solids concentrations (SSC) in the vicinity of the TZB do not need to be rigorously defined, as (1) water quality standards for suspended solids are typically defined in relative rather than absolute terms, and (2) existing background conditions do not materially alter the behavior of sediments resuspended by construction activities.

3.1.2. Sediment Characteristics

The physical properties of river sediments (particularly grain-size distribution, which is an input to dispersion and settling models) and the presence or absence of contamination in the sediment are key parameters in determining potential effects from suspended sediments. The predominant sediment texture in the vicinity of the TZB is clayey silt. As shown in **Figure 5**, accumulations of sand, silt and clay material are observed along the causeway section of the existing bridge. Gravelly sediments are also found extensively in the navigation channel south of the TZB near the eastern shore of the Hudson River and across a large swath roughly 1,000 ft north of the existing causeway section of the TZB.

3.1.3. Sediment Chemistry

Because of anthropogenic influences, sediments deposited during the industrial era are considered more likely to be "contaminated." Mapping of suspected industrial-era sediment deposits in the vicinity of the TZB was developed by Lamont-Doherty Earth Observatory (LDEO) through the integration of acoustic mapping and lead concentration data, as shown in **Figure 6**. This mapping indicates industrial-era sediments in the project study area are generally less than 1 ft in depth. Some thicker deposits are likely to be found south of the existing bridge and near the eastern shore, with depths approaching 1.8 m (6 ft) in certain areas.

In order to identify the sediment chemistry of the study area, sediment samples were collected in 2006 and 2008 using vibracore methods. Up to 1.5 m (5 ft) of sediment was collected at 38 locations; sediment chemistry analyses was conducted for SVOCs-base/neutral (BN) fractions, pesticides, PCBs, and metals. A subset consisting of 17 samples from 10 cores was analyzed for dioxins analysis.

As compared to the 48.3-km (30-mile) segment of the Hudson River centered around the TZB, the results of the 2006 and 2008 sediment sampling programs indicate that sediments in the immediate vicinity of the bridge are not markedly different from the river as a whole in terms of bulk chemistry, as shown by comparison to local river average data in Tables 7 through 9. In the case of metals, for the 10 analytes for which Hudson River average results are available, average concentrations are generally of the same order of magnitude as that found in project-specific samples. While organic contaminants were generally found to be of higher concentrations in the project-specific samples than in the previous samples, this relationship was also generally true when comparing only to the subset of previous Hudson River samples within one mile of the TZB. Comparing only previous samples from within one mile of the bridge to the larger 48.3-km

(30-mile) area, sediment characteristics near the TZB were generally comparable to those further away. Furthermore, in all cases, the data indicated very few exceedances of the benthic aquatic chronic or acute criteria. In that respect, the project-specific and historic Hudson River data are consistent in that they indicate that Hudson River sediments are effected by low-level organic contaminants on a widespread basis.

3.2. Aquatic Biota

3.2.1. Phytoplankton

Phytoplankton are microscopic plants whose movements within the system are largely governed by prevailing tides and currents. Several species can obtain larger sizes as chains or in colonial forms. Light penetration, turbidity and nutrient concentrations are important factors in determining phytoplankton productivity and biomass.

In one 1998 study focusing on the Hudson River, investigators collected 161 phytoplankton species. Diatoms are generally the most widely represented class of phytoplankton, accounting for 78 percent of the different taxa collected, with green algae (15 percent), blue-green algae (cyanobacteria) (3 percent), golden algae (chrysophyceae) (2.5 percent), dinoflagellates (1 percent), and cryptophyceae (a type of flagellate algae) (0.6 percent) comprising the remainder of the phytoplankton community. High turbidity and rapid mixing of the Hudson River (which lower light availability) limit primary production by phytoplankton (Smith et al. 1998).

3.2.2. Submerged Aquatic Vegetation and Benthic Algae

Submerged aquatic vegetation (SAV) are rooted aquatic plants that are often found in shallow areas of estuaries, at water depths of up to six feet at low water (New York's Sea Grant Extension Program undated). These communities exhibit high rates of primary productivity and are known to support abundant and diverse epifaunal and benthic communities. These organisms are important because they provide nursery and refuge habitat for fish. Light penetration, turbidity and nutrient concentrations are all important factors in determining SAV and benthic algae productivity and biomass.

NYSDEC has mapped the distribution of SAV in the Hudson River from Hastings-on-Hudson to Troy using 1997, 2002, and 2007 data. No SAV is mapped in the study area, although SAV is mapped within the ½ mile study area. SAV surveys were conducted as part of the project in 2009 to confirm the locations of SAV identified on the NYSDEC maps. The dominant species of SAV collected as part of the surveys is the native water celery (*Vallisneria americana*); two other species were collected in the vicinity of the study area, including Eurasian water-milfoil (*Myriophyllum spicatum*) and sago palmweed (*Potamogeton pectinatus*). SAV beds were found along the western bank of the river; on the east bank, SAV was only found north of the bridge.

3.2.3. Zooplankton

Zooplankton are an integral component of aquatic food webs—they are primary grazers on phytoplankton and detritus material, and are themselves used by organisms of higher trophic

levels as food. Copepods, cladocerans, and rotifers are the primary representatives of zooplankton species in the Hudson River. Zooplankton also include life stages of other organisms such as fish eggs and larvae (i.e., ichthyoplankton) that spend only part of their life cycle as plankton. Analysis of long-term data from the Hudson River Utilities Long River Sampling Monitoring Program indicates larval Atlantic tomcod (*Microgadus tomcod*), bay anchovy (*Anchoa mitchilli*), striped bass, and white perch (*Morone americana*) as the dominant ichthyoplankton species. The higher-level consumers of zooplankton typically include forage fish, such as bay anchovy, as well as commercially and recreationally important species, such as striped bass and white perch during their early life stages.

3.2.4. Benthic Invertebrates

Invertebrate organisms that inhabit river bottom sediments as well as surfaces of submerged objects (such as bridge piers, riprap, and debris) are commonly referred to as benthic invertebrates. These organisms are important to an ecosystem's energy flow because they convert detrital and suspended organic material into carbon (or living material); moreover, they are also integral components of the diets of ecologically and commercially important fish and waterfowl species.

Some of these animals live on top of the substratum (epifauna) and some within the substratum (infauna). Substrate type (rocks, pilings, sediment grain size, etc.), salinity, and DO levels are the primary factors influencing benthic invertebrate communities; secondary factors include currents, wave action, predation, succession, and disturbance.

Versar (Llanso et al. 2003) collected benthic samples from the lower Hudson River estuary (RM 11 to 40) in 2000 and 2001 which included the vicinity of the study area. In general, they found greatest numbers of species per sample in the lower portions of the study area (south of the Tappan Zee Bridge) and lowest numbers north of the bridge. Greatest benthic biomass occurred in shallow regions of Croton Bay and north of Piermont Pier on the western side of the river. Taxa which showed the greatest densities included the oligochaete worm *Tubificoides* spp., the clam *Rangia cuneata*, and the amphipod *Leptocheirus plumulosus*. They also found the barnacle *Balanus improvisus* and the pollution tolerant polychaete worms *Marenzelleria viridis* and *Heteromastus filiformis* to be present in relatively high abundances.

Bimonthly sampling of benthic resources in the bridge vicinity was conducted between March 2007 and January 2008 on behalf of the Project Sponsors in order to better characterize the fauna in the immediate vicinity of the existing bridge and the Bridge Replacement Alternative. Samples were taken in the vicinity of the footprint of the existing and proposed bridges as well as the locations of the proposed temporary causeways along the southeast and southwest portions of the existing bridge. Forty one bottom benthic locations and six bridge pier locations were sampled for this phase of the project.

A total of 48 species were collected during the bottom sediment sampling program. Total numbers, species richness, and species diversity which consider both number of species and the evenness of distribution were calculated. Greatest diversity was observed in July and lowest in January. The barnacle *Balanus* spp. and the amphipod *Leptocheirus plumulosus* were two of the

dominant taxa collected in each of the six sampled months. A one way analysis of variance (ANOVA) indicated that, for the most part, there was no statistically significant difference in benthic diversity, total numbers of individuals, or species richness between the current and proposed bridge alignment. There was often a statistical difference for the benthic metrics between the approach areas for the causeways and the other locations. These locations, south of the bridge, are thought to accumulate thick sediment deposits which may account for the different benthic community characteristics.

Benthic invertebrate sampling of the existing bridge piers conducted for the project in 2007 identified a total of 8 taxa and two taxa of benthic algae. The polychaete worm *Nereis* spp., amphipods, barnacles, grass shrimp, mud crabs, isopods, oysters, and ribbed mussels were collected from the piers, as well as red and green algae. These organisms were collected in similar densities on three types of pier structure, namely, steel, concrete and timber.

3.2.5. Fish

The Hudson River estuary's fish community is species-rich. The estuary's species diversity is enhanced by its mid-latitude location on the Atlantic Coast. Southern tropical marine species can enter the Hudson River during the summer, and a number of northern fishes are near their southern limit in the New York Harbor Estuary. A report by Smith and Lake (1990) noted that 201 species have been documented in the Hudson River. These species were classified by their probable origin, which demonstrated that the Hudson River fish community, particularly in the estuarine reach, is a mixture of both temperate and tropical marine forms, freshwater forms, and intentional and accidental introductions (ASA 2006). Over the period from 1974 to 2006, the total number of species collected annually in the utilities' monitoring program has varied from 64 to 104. Despite the large number of species that are occasionally found in the estuary, the majority of the fish represent only a limited number of species. More than 99% of the total fish community is comprised of only 10-15% of the species documented to be present in the river. In stable ecosystems, low species diversity may be an indicator of environmental stress. However, in highly dynamic and unstable ecosystems such as the Hudson River estuary, the biological community may be dominated by only a few species that are well adapted to such naturally dynamic conditions (ASA 2006).

Each of the fish species that occurs in the River can be classified by its salinity tolerance. Marine species live in the open Atlantic Ocean and nearshore waters and venture into the estuary during the warmer months of the year when salinity is relatively high. These species typically occupy the lower reaches of the estuary. Estuarine species occupy a large portion of the brackish estuary year-round and may be occasionally found in freshwater and marine reaches. Freshwater species live in the Hudson River and rarely, if ever, venture into low-salinity areas of the estuary such as the region in the vicinity of the Tappan Zee Bridge. Several fish species that occur in the Hudson River migrate from the Atlantic Ocean into freshwater habitats of the River, typically for spawning (anadromous), or leave the river to spawn in the open ocean (catadromous).

The dominant marine species in the Tappan Zee region is the bay anchovy (*Anchoa mitchilli*). An analysis of the Fall Shoals data from 1998-2007 indicated that numerically, bay anchovy comprised about 82% of the total fish standing stock. Bay anchovy are found in salinities ranging

from fresh to seawater and may be the most abundant species in the western north Atlantic. Other marine species which were at times abundant in the Utilities sampling program included weakfish (*Cynoscion regalis*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic croaker (*Micropogonias undulatus*), butterfish (*Peprilus triacanthus*), and bluefish (*Pomatomis saltatrix*).

Estuarine species are generally euryhaline (i.e. tolerant of wide salinity ranges), and are year-round residents of the saline portions of the Hudson River. Abundant estuarine species collected by the utilities' monitoring program included white perch, banded killifish (*Fundulus diaphanus*), Atlantic silverside (*Menidia menidia*), and hogchoker (*Trinectes maculatus*).

Anadromous species that use the estuary as spawning and nursery grounds include alewife (*Alosa pseudoharengus*), American shad (*Alosa sapidissima*), Atlantic sturgeon, Atlantic tomcod, blueback herring (*Alosa aestivalis*), and striped bass. Adults typically enter the estuary in the spring and migrate upstream to low-salinity brackish and freshwater areas to spawn. The young fish then use the near-shore shoal areas for food and habitat as they make their way downstream, and generally leave the estuary in the fall. American eel (*Anguilla rostrata*) is the only catadromous species that occur in the Hudson. Although the Utilities data indicate that there are wide variations in the annual totals of collected eels, overall there has been a sharp decline in the number of individuals captured during these surveys since the mid 1980s. The U.S. Fish and Wildlife Service and NMFS are currently reviewing the status of American eel, blueback herring, and alewife to determine whether any or all of these three species should be proposed for listing as a protected species.

Chapter 4 Project Details

4.1. Construction

As shown in **Figure 7**, construction of the Short Span Option would take approximately 5½ years. The schedule shows both preliminary activities used to support the construction of the project (i.e., dredging and temporary platforms) as well as individual elements of bridge construction (i.e., main span and approaches). Throughout the construction period roadway work would be required at various times. During that time, the approach roadways would be shifted and remain in the new location for an extended period before being shifted again. The dredging would occur in three stages over the 5 ½ year period during a three-month window between August 1 and November 1 and construction of the main span would consist of approximately 3½ years of construction. Completion of the short span approaches would involve approximately 3½ to 4 years of construction. Demolition of the existing Tappan Zee Bridge would be expected to span approximately 1 year.

Construction of the Long Span Option would last approximately 4½ years (see **Figure 7**). The construction sequence and schedule would be similar to that of the Short-Span Option with the exception of the construction of the approaches, which would be expected to take approximately 2½ to 3 years.

4.1.1. Landings

Landings would employ typical highway construction techniques and would be completed on both the Westchester and Rockland sides of the Hudson River upland from the bridge abutment to the tie in with the existing roadway. Construction of the landings would occur throughout the duration of the construction. The construction activity for the landings, however, would be gradual, as the roadways on both sides would be altered and then maintained for lengthy spans of time before being altered again. The alterations to the landings would consist of changes in roadway grade, elevation, direction, and general configuration.

4.1.2. Approaches

Beginning at the abutments, the approaches carry traffic from the land to the main span of the bridge. Construction of the approaches would last for approximately three and a half to four years for the short-span alternative, and two and a half to three years for the long-span alternative. The piles, pile caps, piers, and deck that compose this segment of the bridge would be built sequentially so that as a new pile is being constructed, a completed pile would be undergoing further transformation with, for example, the addition of a pile cap.

4.1.3. Main Span

The main span would stretch between the Westchester and Rockland approaches. It is the segment of the bridge that would be defined largely by its superstructure design as an arch or cable stayed bridge. Within its substructure, the piers would be more substantial than those of the approaches. All main span work would be done sequentially and in a similar manner as that of the approaches. The piles, pile caps, pylons, and deck construction would last approximately three and a half years.

4.2. Construction Of Key Elements

Construction of either option of the Replacement Bridge Alternative would require a wide range of activities on both sides of the river as well as from within the waterway itself. In addition, due to the lack of available land along the waterfront in the vicinity of the bridge, staging areas at some distance from the construction site would be required. Furthermore, it is likely that some bridge components would be pre-fabricated well outside the study area and transported to the site via barge.

To support construction of the main span and bridge approaches, materials, equipment, and crews would be transported from upland staging areas in Westchester and Rockland counties to temporary platforms that would be constructed on the shoreline of the river, as shown in **Figure 8**. Dredged channels would provide access to the two work areas in the shallow portion of the river crossing: the Rockland and Westchester approaches. Substructure construction would establish the foundation of the bridge through the processes of pile driving, construction of pile caps, and construction of columns. Superstructure construction would then take place either with a gantry that would move from pier to pier lifting segments from barges below (as in the case of the short-span design option) or a short pier-head truss segment would be lifted atop the next open pier column and secured (as in the case of the long-span option).

4.2.1. Waterfront Construction Staging

The shoreline areas near the proposed bridge site are limited by adjacent development. In order to provide space for the docking of vessels, the transfer of materials and personnel, and the preparation of construction elements, temporary platforms would be extended out from the shoreline over the Hudson River (see **Figures 9** and **10**). The Rockland platforms would protect the shoreline and also enable the continued maintenance of the original Tappan Zee Bridge as well as providing continued support for the New York State Thruway Authority (NYSTA) Dockside Maintenance facility operation. These platforms would provide access to the replacement bridge site via temporary trestles. Their main purposes would be to facilitate delivery of heavy duty bridge elements from an offsite fabrication facility, receive deliveries from the concrete batch plant, receive deliveries (i.e., construction equipment and light duty bridge elements) from the staging areas, and allow for barge-mounted cranes to erect heavy duty bridge elements. Upon completion of construction, the temporary platforms and the piles that support them would be removed.

As the construction of the temporary platforms and access trestles would begin at the shoreline, an access road and work area near the shore would also be constructed. A channel would be dredged specifically to provide barge access to the temporary platforms from in-river work sites.

4.2.2. Dredged Access Channel

Since the proposed bridge alignment spans extensive shallows, it would be necessary to dredge an access channel for tugboats and barges to utilize during construction of the approach spans. These vessels would be instrumental in the installation of cofferdams, pile driving, the construction of pile caps and bridge piers, and the erection of bridge decks and other superstructure components. As noted earlier, temporary, trestle-type access platforms would be constructed near the shoreline to provide access for construction vehicles that would operate on the trestles. This would avoid the need to dredge the near-shoreline area.

Two alternate construction methods were evaluated in an effort to avoid the need to dredge an access channel. One method involved the use of overhead gantries for the construction of foundations and the other consisted of the implementation of a full-length temporary trestle for access. Both of these alternatives were found to be impractical: the former because it is not practicable for the heavy-duty pile-driving requirements of the replacement bridge and the latter because the deep soft soils in the shallow waters of the construction zone would require foundations that would be expensive and time-consuming to construct.

As shown in **Figure 11**, dredging would be conducted in three stages over a 4-year period for a duration of 3 months in the fall of the year. The purpose of the first two dredging stages (Years 1 and 2) would be to provide access for bridge construction, while the final dredging stage (Year 4) would provide access for demolition of portions of the existing bridge allowing for completion of the remaining portions of the new structure. Each of these three-month spans would occur during the limited fall window (between August 1 and November 1) when dredging is typically allowed in the New York Harbor/Hudson River Estuary area; this is the period when dredging activities would have the minimum effect on aquatic resources.

Based on an analysis of the types, number, size and operation of vessels that would operate in the access channel during construction, it was determined that a clear draft of at least 3.6 m (12 feet) would be required within the access channel. To avoid the potential for grounding of vessels, an additional two feet would be added to provide a working channel depth of 4.3 m (14 feet) at the lowest observed water level, which occurs during the Spring Neap Tide. The lowest observed water level is referred to as Mean Low Low Water (MLLW).

In addition, to minimize any adverse effects from the re-suspension of the fine sediment material due to movement of vessels, particularly tugboats, within the dredged channel, a layer of sand and gravel (referred to as “armor”) would be placed at the bottom of the channel following dredging. As discussed below in Section 18-4-12 (Water Resources) the sediments in the vicinity of the area to be dredged are highly susceptible to resuspension into the water column. Without “armoring,” prop scour from working tugboats in the channel would result in the generation of suspended sediment at rates several orders of magnitude greater than what would occur from the dredging operation itself. Therefore, it was concluded that this level of sediment resuspension and ultimate transport into the river would pose an unnecessary and potentially substantive adverse effect to the environment.

The installation of the sand and gravel would take place as soon as the dredging for that section of the channel was successfully completed, forming a protective layer to keep sediment from further disturbance. Without this protective layer, additional dredging would be required to create a deeper work zone. The sand and gravel materials would be delivered by barges or scows, and would be placed within the channel by barge-mounted cranes. The materials would not be removed after the project completion, since they would become fully buried by the gradual deposition of river sediments over time once construction was completed. The dredging depth required assumes that two feet of sand and gravel armor is placed on the bottom. In total, the channel would be dredged to a depth corresponding to 4.9 m (16 feet) below MLLW.

Table 1 shows the amount of material to be dredged during each stage for the two bridge design options. For either design option, the channel width would measure approximately 145 to 161 m (475 to 530 feet), and it would extend approximately 2,133 m (7,000 feet) from the Rockland County side into deeper waters and 610 m (2,000) feet from the Tarrytown access trestle into deeper waters. Because the long span alternative would occupy a wider footprint, a slightly larger area must be dredged for that

alternative. It is estimated that approximately 1.28 and 1.33 million cubic meters (1.68 and 1.74 million cubic yards) of sediment would be dredged for the short and long span options, respectively.

Table 1
Dredging Quantities for the Replacement Bridge Alternatives

Construction Stage	Short Span		Long Span	
	Quantity (million CY)	Percent of Total	Quantity (million CY)	Percent of Total
Stage 1	1.08	64%	1.12	64%
Stage 2	0.42	25%	0.43	25%
Stage 3	0.18	11%	0.19	11%
Total	1.68	100%	1.74	100%

Notes:
CY = cubic yards
Dredging for bridge demolition (Stage 3) includes that portion of the bridge which must be removed to complete the Replacement Bridge Alternative tie-in.

Environmental Performance Commitments (EPCs) to be used during dredging operations include:

- Adherence to a 3-month fall window when dredging between August 1 and November 1 would be allowed;
- Use of an environmental bucket with no barge overflow; and
- Armoring of the channel to prevent re-suspension of sediment during the movement of construction vessels, installation and removal of cofferdams, and pile driving.

4.2.3. Transport and Disposal of Dredged Material

During each three-month period when dredging is occurring, dredged materials would be collected from the bottom of the river by barge-mounted cranes placed into hopper scows, which are boats with a capacity of approximately 1,911 cubic meters (2,500 cubic yards). To ensure that the scows do not exceed the maximum allowable draft of the river work zone, they would be limited to 80 percent of their maximum load, or 1,529 cubic meters (2,000 cubic yards) per load.

Each dredging stage would occur during a 90-day period. During that period, it is estimated that dredging would occur up to 75 of the 90 days, with two dredge operations occurring at a time. During the busiest dredging stage, Stage 1, up to 11,468 cubic meters (15,000 cubic yards) of materials would be dredged each day. **Table 2** presents the estimated daily volumes of materials removed for each dredging stage for the two replacement bridge alternatives.

Table 2
Daily Materials Removal by Construction Stage

Construction Stage	Short Span Daily Volume (cubic yards)	Long Span Daily Volume (cubic yards)
Stage 1	14,600	15,000
Stage 2	5,700	5,800
Stage 3	2,400	2,600

After placement in the hopper scows, the next step in the dredge materials handling would depend on the dredge placement option selected.

As discussed above in the introduction of this chapter, certain activities related to project construction are left to the discretion of the contractor. One of these specific activities would be the ultimate transport and disposal of dredge spoils from construction of the access channel. Transport by ocean scow and placement in the Historic Area Remediation Site (HARS) in the New York Bight would offer a number of benefits to the project including cost, schedule, logistics and the avoidance of impacts to the surrounding residential communities on the Rockland and/or Westchester shorelines.

In this option, the dredged materials would be transported to HARS, 5.6 km (3.5 miles) east of Sandy Hook, NJ. The HARS is overseen by the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (USEPA). This site was historically used for ocean disposal of dredged material and a variety of waste products, including some contaminated materials. Today, the site is being remediated through a program to cap those historic sediments with cleaner sediments dredged from New York Harbor that meet certain criteria established by the Ocean Dumping Act.

A permit is required for dredged material to be placed at the HARS from the USACE for that placement. To receive the permit, the materials must be suitable for remediation, in that they meet certain criteria related to contaminants based on sediment toxicity and bioaccumulation tests. In addition, in accordance with 40 CFR §227.16, the USEPA must evaluate alternative disposal options before permitting placement of dredged material at the HARS, and must find that there are no practicable alternative locations and methods of disposal or recycling available. In support of this required finding, an alternatives analysis can be found in Appendix H to Draft Environmental Impact Statement documenting that there are no practicable alternatives locations for the placement of the dredged material at the HARS site.

In recognition of the many benefits offered by the HARS site, the project is proceeding with sampling and analysis of the dredged material in support of a permit under Section 103 of the Marine, Protection, Research, and Sanctuaries Act of 1972 from the USACE. If approved, the dredged materials from the Tappan Zee Hudson River Crossing Project placed at the HARS would be transferred from the hopper scows to larger capacity [up to 3,440 cubic meters (4,500 cubic yards)] ocean scows. These vessels have large drafts, typically up to 5.5 m (18 feet), that would be too large to be accommodated in the dredged construction channel. Therefore, materials would be transferred from the hopper scows to the ocean scows in deeper water areas of the Hudson River. The ocean scows would then travel to the HARS, where materials would be placed at the site in accordance with the permit conditions for that placement.

If the permit application for the use of HARS is denied in whole or part, the contractor would be required to dispose of the dredged material at an approved facility in accordance with all applicable laws and regulations. However, due to the estimated number of truck trips that would be required (nearly 800 round trips daily) and the potential for adverse traffic, air quality and noise impacts on the local community the contractor would not be allowed to transport the dredged material by truck from the waterfront staging areas in Rockland or Westchester Counties. The contract documents would specify that alternate means of transport of the dredged material such as barge or barge to rail would be required for disposal.

4.2.4. Substructure Construction

Substructure construction would vary as a function of water depth and sediment conditions at each location. Work on the foundations can be categorized into three segments referred to as Zone A, Zone B, and Zone C (see **Figures 12** and **13**). Pile installation would typically be performed one row of piles at a time. The actual pile driving is done one pile at a time. As shown in **Table 3**, a total of 1,326 piles for Piers 1 to 57 would be required for the Short Span Option. **Table 4** includes similar information for the Long Span Option at Piers 1 thru 32. The Long Span Option would require 836 piles. In terms of the largest piles, the number of the 3-m (10-foot) piles would be the same (50) for either option. The greatest difference between the two options would be the number of smaller 1.2-m (4-foot) piles with the Sport Span Option requiring approximately 346 more piles than the Long Span Option. The Long Span Option would also require 104 less 1.8-m (6-foot) piles and 40 less 2.4-m (8-foot) piles for a total difference of 490 piles. Under either option, the driving of the largest piles [2.4- and 3-m) (8- and 10-foot)] would only occur for a few months in the first year of construction.

Table 3
Pile Driving, Short Span Option

Pier No.	Substructure Zone	Pile Size (diameter ft)	No. of Piles Within each Pier	Total No. of Piles
1-3	A1	6	4	24
4-8	B1	6	6	60
9 - 14	B1	4	20	240
15-32	B1	4	20	720
33-35	B1	8	4	24
36-43	C	8	4	64
44-45	C	10	25	50
46-50	C	6	6	60
51-57	B2	6	6	84
Total				**1,326**

Table 4
Pile Driving, Long Span Option

Pier No.	Substructure Zone	Pile Size (diameter ft)	No. of Piles Within each Pier	Total No. of Piles
1-2	A1	6	4	16
3	A1	6	6	12
4	B1	6	6	12
5-17	B1	4	25	614
18-21	B1	8	4	32
22-23	C	8	4	16
24-25	C	10	25	50
26-28	C	6	6	36
29-30	B2	6	6	24
31-32	A2	6	6	24
Total				**836**

Environmental Performance Commitments (EPCs) to be employed during construction of the substructure include:

- Driving the largest [3 and 2.4 m (10 and 8 ft)] diameter piles within the first few months of the project thereby limiting the time period of greatest potential impact.

- Using cofferdams and silt curtains, where feasible, to minimize discharge of sediment into the river.
- Using a vibratory pile driver to the extent feasible (i.e., all piles will be vibrated at least to 36.6 m (120ft) depth or to vibration refusal) particularly for the initial pile segment.
- Using bubble curtain, cofferdams, isolation casings, Gunderboom, or other technologies to achieve a reduction of at least 10 dB of noise attenuation.
- Using the results of the Hudson River site specific Pile Installation Demonstration Project (PIDP) which includes the testing of various sound attenuation devices to inform the project on the effectiveness of BMP technologies for reducing sound levels, and implementing BMPs to achieve maximum sound reduction.
- Limiting the periods of pile driving to no more than 12-hours/day.
- Limiting driving of 8 and 10 ft piles with an impact hammer within Zone C [water depths 5.5-13.7 m (18-45 feet)] to 5 hours per day during the period of spawning migration for shortnose and Atlantic sturgeon (April 1 to August 1).
- Maintaining a corridor where the sound level is below the West Coast threshold for onset of behavioral effects to fish totaling at least 5000-ft at all times during impact hammer pile driving. This corridor shall be continuous to the maximum extent possible but at no point shall any contributing section be smaller than 1500 ft.
- Pile tapping (i.e. a series of minimal energy strikes) for an initial period to frighten fish so that they move from the immediate area.
- Development of a comprehensive monitoring plan. Elements would include:
  - Monitoring locations to characterize the hydroacoustic field surrounding pile driving operations to evaluate the performance of underwater noise attenuation systems that are integral to the project.
  - Monitoring water quality parameters such as temperature, salinity, and suspended sediment concentrations in the vicinity of the pile driving.
  - Monitoring fish mortality and inspection of fish for types of injury.
  - Monitoring predation levels by gulls and other piscivorous birds, which would indicate that they are finding an increased number of dead or dying fish at the surface.
  - Developing criteria for re-initiating consultation with NMFS should specific numbers of shortnose or Atlantic sturgeon come to the surface injured or dead.
  - Preparing a Standard Operating Procedures Manual outlining the monitoring and reporting methods to be implemented during the program.
- In addition, dredging using an environmental bucket would only be conducted during a three-month period from August 1 to November 1 for the three years of the construction period in which dredging would occur, in order to minimize the potential for impacts to sturgeon migration, as well as migration by other fish species.

4.2.4.1. Foundation Zone A

The two areas of shallowest water depth extend from the shorelines on the Rockland and Westchester sides of the Hudson. These areas, where the water measures less than 2.1 m (7 feet) in depth, are labeled as Zone A. The area adjacent to the Rockland shoreline is labeled Zone A1, while the area adjacent to the Westchester shoreline is Zone A2. Zone A substructure elements would be constructed within cofferdams from adjacent temporary trestle platforms. These cofferdams would be constructed prior to pile driving the bridge foundation piles. The cofferdam would remain flooded during pile installation.

Cofferdams

A cofferdam is a watertight chamber designed to facilitate construction in an area that would otherwise be underwater. In this case, the cofferdams would be composed of interlocking sheet piles extending into the riverbed a distance of up to 6.1 m (20 feet). Upon completion of the cofferdam, foundation piles would be driven into the riverbed.

Pile installation

Prior to pile driving, a template to guide piles would be placed within the cofferdam to ensure that they are in position and to hold them when pile driving is not taking place. A quick, low-noise, moderate-energy vibratory hammer would be used to install much of the length of the pile, after which a high efficiency hydraulic impact hammer suspended from cranes operating on the two temporary shoreline access trestles would be used to apply force to the tops of the piles so as to deliver the piles more deeply into the riverbed. It should be noted that the use of vibratory hammers for the entire driving operation is not possible due to the excessive depths to bedrock. Feasibility of using vibratory hammers to drive piles deeper than originally proposed in order to reduce the duration of impact hammering will be tested in the PIDP. From these tests, it is anticipated that the initial set for these deep piles cannot be overcome after pile sections are spliced. Using the vibratory hammer rather than the impact hammer to accomplish the majority of the pile driving would require the addition of substantially more pilings than originally proposed in order to achieve the desired weight-bearing capacity and settlement of pilings into the substrate. The extent of vibratory piling will be reconsidered after the results from the PIDP are available. Once all piles are driven, the template and its supports would be transitioned to the next cofferdam.

Pile caps

A 300-ton crawler crane would suspend the 45.7-m (150-foot) pile sections and support the pile driving hammer during operation. Upon completion of pile installation, the soil within each pile would be excavated and transported to an off-site disposal facility. Finally, a tremie concrete plug, which braces the bottom of the sheet pile cofferdam and provides a seal at the base of the cofferdam to allow for dewatering of the cofferdam, would be poured inside the pile and a steel reinforcing cage would be inserted into the pile. River water recovered during dewatering of the cofferdams would be treated (e.g., tanks to settle out any suspended sediments and water filtration system as necessary) and discharged back to the Hudson River in accordance with conditions issued by the NYSDEC under the Section 401 water quality certification for the project and would not result in adverse impacts to water quality of the Hudson River.

As previously mentioned, a tremie concrete plug would be poured into the hollowed pile. The pile itself would be dewatered down to the plug. Prior to the installation of the pile cap, pier reinforcement, post tensioning ducts, and pile reinforcement would be secured. A pile cap, which is a reinforced concrete

slab constructed atop a cluster of foundations piles, would then be constructed to form a single structural element that would allow for even distribution of the weight that the piles bear, avoiding over stressing any individual component. These slabs would also provide a larger area for the construction of the columns that they will support.

4.2.4.2. Foundation Zone B

The water depths in Zone B range from 1.5 to 5.5 m (5 to 18 feet), and the zone is characterized by a relatively deep soft-soil profile. Zones B1 (close to the Rockland shoreline) and B2 (close to the Westchester shoreline) are located adjacent to Zones A1 and A2 and are closer to the centerline of the river. The functions performed in Zone B substructure construction would take place in cofferdams, as in Zone A, but the tasks would be completed from barges and support vessels.

Pile Installation

Piles, which would be transported in two pieces to Zone B by barge, would measure between 76.2 and 91.4 m (250 and 300 feet) due to the relatively deep soft-soil profile within the zone. Pile driving would begin immediately upon completion of the cofferdam construction. As in Zone A, a 300 ton crawler crane would lift the pile sections. A pile-driving rig would supply a hammer suspended from the barge mounted crane. The template would be positioned to guide the lower pile section into proper position before the pile would be allowed to delve into the soft stratum under its own weight. The depth achieved in this manner would be considerable, and should the application of further pressure be called for, a vibratory hammer would be used to drive the remainder of the pile into place. Upon the placement of the lower segment of the pile, preparations to begin welding the two segments together will commence. In order for the two segments to be joined, the upper segment would be hovered over the lower until the automated welding process was complete. Upon the completion and inspection of the welding, the remaining length of the conjoined pile would be driven to required depth or specified penetration resistance with a hydraulic hammer. As in Zone A, the soil within the pile would be excavated and transported to an off-site disposal facility in order to create space for the tremie plug and steel reinforcing cage.

Pile caps

The construction process of pile caps in Zone B would be similar to that of Zone A. One difference would be that a granular fill material would be distributed inside of the cofferdam to enable the tremie seal to be poured to its planned elevation. This granular material would remain after the removal of the cofferdam.

4.2.4.3. Foundation Zone C

Foundation Zone C lies between Zones B1 and B2, connecting the two sides of the river. This zone is defined by the greatest water depths, which range from 5.5 to 13.7 m (18 to 45 feet). Construction in this zone would encompass the construction of the main span as well as that of both approaches.

The first substructure construction activity in Zone C would be the installation of the foundation piles. In this zone, due to the greater depths than Zones A or B, cofferdam construction would follow the pile installation, thus requiring that the cofferdam be constructed around the installed pile to create a dry environment in which to construct the tremie seal. The cofferdam in Zone C would be constructed using a different method than that utilized in Zones A and B. This alternative method, the “hanging cofferdam

method", would begin with the installation of a temporary support structure above the foundation piles on which the cofferdam would be assembled. The cofferdam components would then be pieced together from pulleys secured to the top beams of the support structure. After the placement of the cofferdam, the tremie slab would be poured onto a steel deck acting as the cofferdam floor. Divers would seal the gaps between the piles and the cofferdam deck before the dewatering process. The tremie slab would then be poured, and the unreinforced slab would bond the piles to the cofferdam pending the construction of the reinforced pile cap.

4.2.5. Construction of Bridge Superstructure

Completion of the bridge superstructure would include piers, columns, pylons (for a cable-stayed option), bridge deck, roadway finishes, lighting, and the shared use path. Much of the material would be pre-fabricated at various locations and delivered to the project site via barge. At the construction site, these elements would be lifted into place by gantries and cranes operating on barges, the temporary work platforms, or completed portions of the structure.

4.2.6. Existing Bridge Demolition

The existing Tappan Zee Bridge contains five segments: causeway, east trestle, east deck truss, west deck truss, and main spans. The demolition of the existing bridge will be performed in two stages. The first stage will include partial demolition to allow for construction of the new bridge, and the second stage will occur after the completion of the new bridge. No blasting of the existing structure would occur.

4.2.6.1. Causeway and East Trestle Spans

The causeway is a simple span construction composed of 166 spans measuring 15.2 m (50 feet), with the exception of one 30.5-m (100-foot) span. The east trestle is comprised of 6 spans. Within its simple span construction, the causeway contains a stringer and deck superstructure and a substructure of concrete columns and footings on timber piles. Initially, the deck and stringers would be lifted out and placed onto awaiting barges. Then, the protective dolphins would be cut so as to offer unrestricted access for pier removal. Columns and footings would either be cut with diamond wire or broken by pneumatic hammers. Finally, the timber piles forming the causeway foundation would be cut to just below the mud line. All materials would be transported to an appropriate permitted off-site disposal facility, and a turbidity curtain would be utilized to ensure that demolition debris would not be dispersed. Side-scan sonar surveys would be performed in order to verify that all generated debris would be removed from the river.

4.2.6.2. Deck Truss Spans

The deck truss spans, including 13 east deck, 7 west deck, and all approach truss spans, each contain a deck slab, steel trusses, and concrete piers supported on buoyant foundations or caissons. The deck slabs would be removed and transported off-site by an awaiting barge. A channel would then be dredged in Stage 3 to provide access to the trusses near the Westchester shoreline, and steelwork would either be removed by barge-mounted crane or a crane mounted on an adjacent in-tact span. Caisson-supported piers would be demolished using the same process as in the causeway and east trestle spans, and would then be removed to the mud line using diamond cutting wire devices or pneumatic hammers. Steel H piles would remain below the mud line. Turbidity curtains and netting would also be used in this stage.

4.2.6.3. Main Span

The main span stretches 735.2 m (2,412 feet) and is structurally formed by a through truss above a deck supported by four latticework piers on buoyant foundations, ice deflectors around the two central piers, and pre-stressed concrete beams on 76 cm (30-inch) diameter steel piles. Initially, the main span deck slab would be lifted and removed off-site by barge. Then, the entire suspended span would be lowered onto a barge via a strand jack or winch system. Conventional barge-mounted cranes would then deconstruct the anchor span steelwork piece by piece and the ice-breaker and fender structures protecting the main span piers would be demolished by divers and barge-mounted cranes. The pier steelwork would also be removed piece by piece, and the buoyant caissons would be cut and flooded. Following main span demolition, a barge-mounted crane operated clam shell bucket would clear the river bottom of debris. Side-scan sonar surveys would verify that all debris and concrete were removed from the river.

Chapter 5 Project Action Area

5.1. Limits of Action Area

The Hudson River is one of the major rivers on the Atlantic Coast, extending from its source at Lake Tear of the Clouds on Mount Marcy in the Adirondacks to the Battery in New York Harbor, a distance of approximately 507 km (315 miles) (Geyer and Chant, 2006). In the study area, the Hudson River is tidally influenced and commonly referred to as the Hudson River estuary. The estuarine portion of the river begins at the Troy Dam about 248 km (154 miles) north of the Battery in southern Manhattan. Tides in the Hudson River estuary are semidiurnal, having two high waters and two low waters each day with an average range of 0.98 m (3.2 feet) (NOAA Tide Tables, 2009). At approximately 4.8 km (3 miles) in width in the study area, the river is designated by NYSDEC as a Class SB (saline) waterbody, intended to be suitable for recreation, and fish survival and propagation. Water quality surveys by the Project Sponsors identified considerably variable concentrations of suspended sediments in the water column near the bridge depending on water depth, season and weather conditions.

In the vicinity of the bridge, the river ranges in depth from less than 3.6 m (12 feet) along the western causeway to greater than 14.3 m (47 feet) in the shipping channel under the main span. The causeway and bridge piers cause river currents to locally scour the bottom sediments, resulting in depressions in the bottom of the river alongside the bridge.

The study area in the immediate vicinity of the replacement bridge encompasses intertidal and subtidal habitats of varying depths, ranging from shallow intertidal shorelines to shallow subtidal shoals and deeper channel habitats. Areas south of the existing bridge less than 1.8 m (6 feet) deep at mean low water (MLW) are mapped as littoral zone wetlands by the NYSDEC. No NYSDEC tidal wetlands are mapped north of the bridge.

On the west side of the river, the shoreline typically consists of unvegetated intertidal beaches composed of coarse sand with scattered boulders. Immediately north of the bridge the shoreline is bulkheaded. The eastern shoreline adjacent to the railroad tracks consists of riprap armoring in the vicinity of the replacement bridge.

Shallow water environments occur near the shorelines and along the western and eastern causeways, while deep water habitat occurs within and near the shipping channel and the main bridge span. The habitat of the Tappan Zee Reach is dominated by a large shallow western shoal with soft sediments, deep channel in the middle of the river with coarse-grained sediments, and narrow shallow shoal on the east side of the river denominated by soft sediments. Within the Tappan Zee Reach, the benthic habitat also has a patchy distribution of oyster beds. All of the benthic habitats in the reach (e.g., soft and coarse-grained sediments, oyster beds, and bridge piers), provide foraging opportunities for species in the Tappan Zee Reach.

Shallows attract aquatic organisms that prefer greater sunlight and less water depth for part or all of their life cycles, while deeper water areas attract organisms with deeper water column needs. The region under the existing bridge attracts organisms that use the pier structures as habitat, or that seek the organisms that adhere to the structures as food resources.

The entire east bank of the Hudson River within the study area has been developed as rail beds (rip rap), piers, or bulkheads. Several vegetated tidal wetland areas or tidally-influenced areas were observed

along tributaries to the Hudson River, as well as between the rail beds. The rip rap and beach areas may provide food and shelter values for fish, shellfish, and other wildlife.

The limits of the study area considered in this BA have been determined by the potential project effects for dredging and re-deposition of suspended sediment, acoustic impacts from pile driving, and loss of habitat. The potential geographic boundaries extend across the entire width of the Tappan Zee Reach, and based on modeled sound isopleths extend a maximum of 2,210 m (7,250 feet) or less in both up and downriver directions. For sediment resuspension, which is a measure for assessing impacts to water quality, project incremental concentrations above 10 mg/L above ambient conditions may extend in a relatively thin band approximately 305 to 610 m (1,000 to 2,000 ft) from the dredges. Concentrations of 5 mg/L above ambient may extend a greater distance in either an upstream or downstream direction, depending upon the tidal stage.

Chapter 6 Effects Analysis

The assessment of impacts focuses on potential direct and indirect effects on the shortnose and Atlantic sturgeon populations in the study area. The following were determined to be indicators of direct and indirect effects:

- Direct effects. Direct effects are considered to be any adverse effects arising from project activities that could result in immediate impacts on shortnose and Atlantic sturgeon individuals or changes to their habitat. These effects are defined as physical injury or death, disruption of migration or spawning behaviors, and direct alteration of existing habitat. For this BA direct effects were evaluated for pile driving increased vessel traffic, dredging activities, and shading from the new structures.

- Indirect effects. Indirect effects are defined as any effects that are caused by or will result from the proposed action later in time, but which are still reasonably certain to occur (50 CFR § 402.02). These effects are defined as water/sediment quality impairment and indirect alteration of habitat, inclusive of burial of spawning substrates by resuspension of material during vessel movements, dredging or backfill/capping, and associated effects.

6.1. Direct Effects

The primary potential direct effects of the project resulting in an incidental take of shortnose and Atlantic sturgeon from the project are associated with the physical disturbance to adults and juveniles as a result of pile driving and increased vessel traffic. In addition, the dredging required to facilitate construction barge access could also affect the foraging ability of these sturgeon species. Finally, the BA considers the potential for direct effects from shading.

6.1.1. Acoustic Effects from Pile Driving

In order to understand the potential impacts of the sounds produced by pile driving, as well as other anthropogenic sources, on the listed shortnose and candidate Atlantic sturgeon, it is necessary to have a basic understanding of sound, and, in particular, underwater sound. In this BA the potential effects from pile driving are evaluated based on the interim West Coast criteria for onset of physiological effects agreed to in a Memorandum of Agreement (MOA) by FHWA, USFWS, NMFS, CalTrans, and the Washington Department of Transportation on June 12, 2008.

6.1.1.1. Current Interim Criteria for the Onset of Physiological and Behavioral Effects

Physiological effects

As a result of the aforementioned MOA, a set of interim criteria was established for the acoustic levels at which there could be a potential onset of physiological effects to fish. The criteria were established in June 12, 2008 and are referred to as the interim West Coast criteria (reviewed in Woodbury and Stadler 2008; Stadler and Woodbury 2009). These criteria are intended to reflect the onset of physiological effects (Stadler and Woodbury 2009), and not levels at which fish are mortally damaged. Indeed, the onset of physiological effects may be minimal changes in fish tissues that have no biological consequence (Halvorsen et al., 2011). The interim criteria are:

Peak SPL: 206 decibels relative to 1 micro-Pascal (dB re 1 μPa).
SEL_{cum}: 187 decibels relative to 1 micro-Pascal-squared second (dB re 1μPa^2-s) for fishes above 2 grams (0.07 ounces).
SEL_{cum}: 183 dB re 1μPa^2-s for fishes below 2 grams (0.07 ounces).

Behavioral Effects

For purposes of assessing behavioral effects of pile driving at several West Coast projects, NMFS employs a 150 dB re 1μPa rms SPL criterion, although it is pointed out in Caltrans (2009) that, at least on the West Coast, "…NOAA Fisheries staff informally indicated … that they do not expect exceedance of the 150 dB RMS behavior threshold to trigger any mitigation." This BA evaluates the potential for the project to result in onset of temporary behavioral changes to sturgeon.

6.1.1.2. Recent Results Relevant to the Interim Criteria for Onset of Physiological Effects

A recent peer-reviewed study from the Transportation Research Board (TRB) of the National Research Council of the National Academies of Science describes the first carefully controlled experimental study of the effects of pile driving sounds on fish (Halvorsen et al. 2011). This investigation was funded by the National Cooperative Highway Research Program (NCHRP) of the TRB, Caltrans, and the Bureau of Ocean Energy Management (BOEM), as well as by the Canadian Department of Fisheries and Oceans (DFO), and was developed and overseen by individuals from highway programs and federal agencies throughout the United States as well as leading experts in underwater acoustics and hearing from the U.S. and abroad. The study was the first to document effects of pile driving sounds (recorded at actual pile driving operations) under simulated free-field acoustic conditions where fish could be exposed to signals that were precisely controlled in terms of number of strikes, strike intensity, and other parameters. The acoustic field simulated one that would take place beyond about 10 m (33 ft) from a source. Sufficient number of animals exposed to the source, as well as controls (treated identically to experimental other than for their being exposed to sound), were used to provide a strong statistical base. Subsequent to treatment, animals were subject to extensive necropsy (autopsy) to determine the types of physiological effects and the sound exposure levels at which these would show up.

The study was conducted on Chinook salmon (*Oncorhynchus tshawytscha*), an endangered species on the US West Coast. The study considered the onset of a wide variety of potential physiological effects that ranged from small amounts of hemorrhage at the base of fins to severe hemorrhage or rupture of the swim bladder and surrounding body tissues (kidney, liver, spleen, etc.). It was determined that very small effects, such as small hemorrhages at the base of fins, are not life threatening nor would they have any short or long-term effect on fish, unlike damage such as swim bladder rupture which would result in mortality. Based on a thorough statistical analysis of results, with extensive controls, it was determined that onset of physiological effects that have the potential of reduced fitness, and thus a potential effect on survival, started at above 210 dB re 1 μPa^2·s SEL_{cum}, a level that is about 23 dB above the current West Coast interim onset criteria. The peak level for effects is about the same as the current West Coast level.

Subsequent work, using the identical methodology has demonstrated that there is recovery from effects on Chinook salmon exposed to sounds as high as 216 dB 1 μPa^2·s SEL_{cum} when fish were kept in the laboratory (higher levels could not be used in that particular study. In addition, other studies have shown that similar results to those reported for Chinook salmon were also found in several other species, including lake sturgeon (*Acipenser fulvescens*). There was small variation in the onset level for

physiological effects, but all were well above 203 dB 1 $\mu Pa^2 \cdot s$ SEL_{cum} or levels well above the West Coast interim criteria.

Basic Background on Acoustics and Fish Bioacoustics

Sound in water follows the same physical principles as sound in air. The major difference is that due to the density of water, sound in water travels about 4.5 times faster than in air [(approx. 1,493.5 m/s vs. 335.3 m/s (4,900 ft/s vs. 1,100 ft/s)], and attenuates much less rapidly over distance from the source than in air. As a result of the greater speed, the wavelength of a particular sound frequency is about 4.5 times longer in water than in air (Rogers and Cox 1988; Bass and Clarke 2003).

The most commonly considered aspects of sound are frequency (i.e., number of cycles per unit of time, with hertz (Hz) as the unit of measurement) and amplitude (loudness, measured in decibels, or dB). The frequencies of primary relevance to humans are those in their hearing range, which is from about 20 Hz to 20,000 Hz in a child and perhaps 20 Hz to 10,000 Hz in an older adult. In considering fish, the hearing range to be considered may extend from as low as 20 Hz to, in most species, perhaps 800 to 1,000 Hz. Most fish in the Hudson River fit into this hearing range, although catfish may hear to about 3,000 or 4,000 Hz and some of the herring-like fishes (and specifically the American shad) can hear to over 100,000 Hz. (Popper et al. 2003; Bass and Ladich 2008; Popper and Schilt 2008).

In addition, an acoustic field from any source consists of a propagating pressure wave, generated from particle motions in the medium that causes compression and rarefaction. This sound wave consists of both pressure and particle motion components that propagate from the source. All fishes have sensory systems to detect the particle motion component of a sound field, while fishes with a swim bladder (a chamber of air in the abdominal cavity) may also be able to detect the pressure component. Pressure detection is primarily found in fishes where the swim bladder (or other air chamber) lies very close to the ear, whereas fishes in which there is no air chamber near the ear primarily detect particle motion (Popper et al. 2003; Popper and Schilt 2009; Fay and Popper 2000).

Measuring the Energy in a Signal

The level of a sound in water can be expressed in several different ways, but always in terms of dB relative to 1 micro-Pascal (µPa). Decibels, a log scale, is used to "compress" very large differences of sound level (e.g., from a whisper to cracking of thunder) into more manageable numbers. As a consequence, a doubling of sound pressure level (whether in air or water) is seen as a change of just a few dB. Thus, each 10 dB increase is a ten-fold increase in sound pressure. Accordingly, a 10 dB increase is a 10x increase in sound pressure, and a 20 dB increase is a 100x increase in sound pressure.

For the purposes of this report, the following measures are defined:

- Peak sound pressure level (SPL) is the maximum sound pressure level in a signal measured in dB re 1 µPa.

- Sound exposure level (SEL) is the integral of the squared sound pressure over the duration of the pulse – in this case a full pile driving strike. Measured in dB re 1μPa^2-s.

- SEL_{cum} is the energy accumulated over multiple strikes. The rapidity with which the SEL_{cum} accumulates depends on the level of the single strike SEL (SEL_{SS}). The actual level of accumulated

energy (SEL_{cum}) is the logarithmic sum of the total number of single strike SELs. Thus, SEL_{cum} (dB) = Single-strike SEL + $10\log_{10}(N)$; where N is the number of strikes.

Sound levels are analyzed in several different ways. The most common approach is "root mean square" (rms) pressure level, which is the average level of a sound signal over a specific period of time, such as the average level 90% of the time of the whole signal as shown in **Figure 14**. Alternatively, one may measure "Peak" sound level, which is the highest level of sound within a signal (e.g., the highest point in Figure 14). Peak is most often used to give an indication of the maximum level of a sound, but it does not give a good picture of the overall sound energy in a signal.

Figure 14 shows an impulsive signal that is typical of a single strike from a pile driving operation. The frequencies in this sound are primarily below about 500 Hz. In order to attempt to better characterize the full extent of energy in the signal, acousticians developed the concept of Sound Exposure Level (SEL), which is simply the integration over time of the square of the acoustic pressure in the signal. Thus the SEL is an indication of the total acoustic energy received by an organism from a particular source (such as pile strikes).

SEL is generally expressed as the total energy in a signal over one second. There are two ways of looking at SEL that are relevant to the issue of pile driving. First is what is referred to as "single strike" SEL – the amount of energy in one strike of a pile (SEL_{ss}). The second is "cumulative SEL" (or SEL_{cum}), which represents the summed energy in all strikes over some period of time or, perhaps, during the driving of a single pile. SEL_{cum} is particularly useful since it indicates the full energy to which an animal is exposed during any kind of signal (assuming the animal remains in the same place for the duration of the signal – such as for all strikes to embed a single pile), and thus it is possible to use this measure to compare total sound exposure between two signals with waveforms that are very different than one another, such as between a pile driving strike and a burst of sonar.

Sound and Effects on Fish

Sound is a critical source of environmental information for most vertebrates (e.g., Fay and Popper 2000). While we most often think in terms of sound for communication (e.g., speech), perhaps the most important use of sound is to learn about one's environment. Indeed, humans and all other vertebrates have auditory systems that listen to the "auditory scene" and can, from this, learn a great deal about the environment, and the things in it (Fay and Popper 2000; Bass and Ladich 2008). Although the comparable "visual scene" is restricted by the field of view of the eyes and light level, the auditory scene provides a three-dimensional, long distance sense that works under most all environmental conditions. It is, therefore, likely that hearing evolved for detection of the auditory scene (Fay and Popper 2000), and that fishes use sound to learn about their general environment, the presence of predators and prey, and, in many species, for acoustic communication. As a consequence, sound is important for fish survival, and anything that impedes the ability of fish to detect a biologically relevant sound could affect individual fish as well as survival of the population or species.

Potential Effects of Anthropogenic Sound on Fish

Richardson et al. (1995) defined different zones around a sound source that could result in different types of effects on fishes. As shown in **Figure 15**, there are a variety of different potential effects from any sound, with a decreasing range of effects at greater distances from the source. Thus, very close to the source, effects may range from mortality to behavioral changes. Somewhat further from the source, mortality is no longer an issue, and the effects range from physiological to behavioral. As one gets even

further, the potential effects decline. The actual nature of effects, and the distance from the source will vary and depend on a large number of factors, such as fish hearing sensitivity, source level, how the sounds propagate away from the source and the resultant sound level at the fish, whether the fish stays in the vicinity of the source, the motivation level of the fish, etc.

Sound Sources from Which Different Effects Might Occur

There are limited data from other projects to demonstrate the circumstances under which immediate mortality occurs as a result of pile driving: mortality appears to occur when fish are close [(within a meter to 9 m (a few ft to 30 ft)] to driving of relatively large diameter piles. Studies conducted by California Department of Transportation (Caltrans, 2001) showed some mortality for several different species of wild fish exposed to driving of steel pipe piles 2.4 m (8 ft) in diameter, whereas Ruggerone et al. (2008) found no mortality to caged yearling coho salmon (*Oncorhynchus kisutch*) placed as close as 0.6 m (2 ft) from a 0.45 m (1.5 ft) diameter pile and exposed to over 1,600 strikes. Thus, in the overall range of effects on fish in ecosystems such as the Tappan Zee, only a very small fraction of a fish population likely will be close enough to a pile to be subject to immediate mortality.

Of greater relevance than immediate mortality to aquatic organisms caused by pile driving and other intense sound sources is the potential for onset of physiological effects that could potentially result in delayed mortality. At the same time, many of the physiological effects of exposure to pile driving sound are highly unlikely to have any effect on fish survival. Indeed, the potential physiological effects are highly diverse, and range from very small ruptures of capillaries in fins (which are not likely to have any effect on fitness or survival) to severe hemorrhaging of major organ systems such as the liver, kidney, or brain (Stephenson et al. 2010). Other potential effects include rupture of the swim bladder (the bubble of air in the abdominal cavity of most fish species that is involved in maintenance of buoyancy). (See Halvorsen et al. 2011 for a review of potential injuries from pile driving.)

Effects on body tissues may result from barotrauma or result from rapid oscillations of air bubbles. Barotrauma occurs when there is a rapid change in pressure that directly affects the body gasses. Gas in the swim bladder, blood, and tissue of fish can experience a change in state, expand and contract during rapid pressure changes, which can lead to tissue damage and organ failure (Stephenson et al., 2010).

Related to this are changes that result from very rapid and substantial excursions (oscillations) of the walls of air-filled chambers, such as the swim bladder, striking near-by structures. By way of example, under normal circumstances the walls of the swim bladder do not move very far during changes in depth or when impinged upon by normal sounds. However, very intense sounds, and particularly those with very sharp onsets (also called “rise time”), will cause the swim bladder walls to move greater distances and thereby strike near-by tissues such as the kidney or liver. Rapid and frequent striking (as during one or more sound exposures) can result in bruising, and ultimately in damage, to the nearby tissues.

At the same time, there are data showing that very intense signals may not necessarily have substantial physiological effects and that the extent of effect will vary depending on a number of factors including sound level, rise time of the signal, duration of the signal, signal intensity, etc. For example, investigations on the effects of very high intensity sonar showed no damage whatsoever to ears and other tissues of several different fish species (Kane et al. 2010). Moreover, studies involving exposure of fish to sounds from seismic air guns, signal sources that have very sharp onset times, as found in pile driving, also did not result in any tissue damage (Popper et al. 2007; Song et al. 2008; although see McCauley et al. 2000, 2003 for an instance of inner ear hair cell damage to seismic air guns). Finally, recent studies of the effects of pile driving sounds on fish showed that there is a clear relationship

between onset of physiological effects and single strike and cumulative sound exposure level, and that the initial effects are very small and would not harm an animal (and from which there is rapid and complete recovery), whereas the most intense signals (e.g., >210 dB SEL_{cum}) may result in tissue damage that could have long-term mortal effects (Halvorsen et al. 2011).

6.1.1.3. Effects of Sound on Fish Behavior

Currently, NMFS Northwest Regional Office uses a guidance value of 150 dB re 1 µPa rms for the onset of behavioral responses (NMFS 2011). As of this writing, neither NOAA Fisheries nor USFWS has provided any research data or related citations to support this threshold. The following sections provide an analysis based on recent literature.

6.1.1.4. Results of Empirical Studies on Effects of Sound on Behavior

Results of empirical studies of hearing of fishes, amphibians, birds, and mammals (including humans), in general, show that behavioral responses vary substantially, even within a single species, depending on a wide range of factors, such as the motivation of an animal at a particular time, the nature of other activities that the animal is engaged in when it detects a new stimulus, the hearing capabilities of an animal or species, and numerous other factors (Brumm and Slabbekoorn 2005). Thus, it is difficult to assign a single criterion above which behavioral responses to noise would occur.

It is also critical to note that animals (and humans) generally do not respond to sounds that are minimally perceivable (whether there is background sound or not). Sounds generally have to be well above the minimal detectable level in order to elicit behavioral changes (Dooling et al. 2009). At the lowest sound levels, the animal may just ignore the sound since it is deemed to be unimportant or too distant to be of immediate relevance. It is only at larger sound levels where the animal becomes “aware” of the sound and may make a decision whether or not to behaviorally respond to the sound. In some cases, sounds may be “masked” by background noise of the same or similar frequencies (Bee and Swanson 2007). In this case, the masked sound could either be undetectable or less detectable than it would otherwise be under quieter conditions. In a natural setting, it is possible that the sound has to be sufficiently above the masked threshold of detection for the animal to be able to resolve the signal within the surrounding ambient noise and recognize the signal as being of biological relevance.

By way of example, in an experiment on responses of American shad to sounds produced by their predators (dolphins), it was found that if the predator sound is detectable, but not very loud, the shad will not respond (Plachta and Popper 2003). But, if the sound level is raised an additional 8 or 10 dB, the fish will turn and move away from the sound source. Finally, if the sound is made even louder, as if a predator were nearby, the American shad go into a frenzied series of motions that probably helps them avoid being caught. It was speculated by the researchers that the lowest sound levels were those recognized by the American shad as being from very distant predators, and thus, not worth a response. At somewhat higher levels, the shad recognized that the predator was closer and then started to swim away. Finally, the loudest sound was thought to indicate a very near-by predator, eliciting maximum response to avoid predation.

At the same time, there is evidence from a recent study in Norway (Doksaeter et al. 2009) that fishes will only respond to sounds that are of biological relevance to them. Doksaeter et al. (2009) showed no responses by free-swimming herring (*Clupea* spp.) when exposed to sonars produced by naval vessels. Similarly, sounds at the same received level produced by major predators of the herring (killer whales) elicited strong flight responses.

Significantly, the sound levels at the fishes from the sonar in this experiment were from 197 dB to 209 dB re 1 μPa (rms) at 1,000 to 2,000Hz. The hearing threshold for herring that are most closely related to those used in the Doksaeter et al. (2009) study in this frequency range is about 125 to 135 dB re 1 μPa (also see Mann et al. 2005). This means that the fish showed no reactions to a sound that was up to 84 dB above the fish's hearing threshold (209 dB re 1 μPa sonar vs. 120 dB re 1 μPa threshold), but not biologically relevant to this species.

There is not an extensive body of literature on effects of anthropogenic sounds on fish behavior, and even fewer studies on effects of pile driving (see Section 6.1.3.2 below), and many of these were conducted under conditions that make the interpretation of the results for this project uncertain. Of the studies available, the most useful in assessing the potential effects on behavior of pile driving on fish are those that use seismic air guns, since the air gun sound spectrum is reasonably similar to that of pile driving (Section 6.1.3.3). The results of the studies, summarized below, suggest that there is a potential for underwater sound of certain levels and frequencies to affect behavior of fish, but that it varies with fish species and the existing hydroacoustic environment. In addition, behavioral response may change over time as fish individuals habituate. Behavioral responses to other noise sources, such as noise associated with vessel traffic, and the results of noise deterrent studies, are also summarized below.

The vast majority of the (albeit limited) behavioral studies to date, discussed below, suggest that there is not likely to be any adverse behavioral response from sturgeons, or any fish species, at sound levels as low as 150 dB re 1 μPa. However, in order to ensure that there is limited effect at this level, or even at higher sound levels, the project will maintain a corridor where ensonification due to pile driving is below the 150dB rms SPL behavioral guidance level suggested by NMFS. Therefore, the project would minimize the potential for the project to impede movement of fish in the Hudson River. Moreover, and perhaps of even greater significance in ensuring a minimal or no behavioral impacts on sturgeon is the fact that the duration of pile driving during bridge construction will be a very small percent of the total project duration equating to approximately 93% of the total duration of bridge construction during which there will be no impact hammering sounds in the Hudson River. Combining this with the efforts to ensure a corridor where sounds will be below 150 dB re 1 μPa (rms) during pile driving should minimize any chance of behavioral impacts on sturgeons.

6.1.1.5. Behavioral Studies Using Pile Driving (or Pile Driving-Like) Sounds

There have been very few studies that have examined behavioral effects, including avoidance behavior, of pile driving on fish. Most of these studies, as reviewed by Popper and Hastings (2009), were in small cages where behavior is severely constrained and so would not be representative of a natural setting. In order for the results of an empirical study to be relevant to an assessment of the potential for pile driving, or other anthropogenic stimuli, to affect fish and other aquatic biota, such study must examine free-swimming wild animals.

While not done on free-swimming animals, Mueller-Blenke et al. (2010), in an unpublished report that has not been peer reviewed, attempted to evaluate response of Atlantic cod (*Gadus morhua*) and Dover sole (*Solea solea*) in large pens to playbacks of pile driving sounds recorded during construction of Danish wind farms. The investigators reported that a few representatives of both species exhibited some movement response, which they claim to have represented increased swimming speed or freezing to the pile-driving stimulus at peak sound pressure levels ranging from 144 to 156 dB re 1 μPa for sole and 140 to 161 dB re 1 μPa for cod. However, with the methodology used it was impossible to determine fish position more frequently than once every 80 seconds, and so, despite the suggestions of behavioral

responses by the investigators, it was scientifically impossible to know if, and how, fish were moving or otherwise responding to the sound. Moreover, even in the few times that the investigators could glean information that suggested that fish moved from one place in the pen to another during sound presentation, this was only for very few fish, and it is not even clear that the authors interpretation of these results were correct since several alternative interpretations are possible from the very limited data. Finally, the statistical analysis of the results was very limited, and could not be used to document any behavioral responses by any animals.

Feist (1991) examined the responses of juvenile pink (*Oncorhyncus gorbuscha*) and chum (*O. keta*) salmon behavior during pile driving operations. Feist had observers watching fish schools in less than 1.5 m water depth and within 2 m of the shore over the course of a pile driving operation. The report (Feist's MS thesis) did not give pile size, other than to say that one was hollow steel and the other solid. While sound measurements were attempted, data were not available for this publication according to the author, thus none of the limited results can be correlated with sound levels from the pile driving operation. Feist did report that there were changes in distribution of schools at up to 300 m from the pile driving operation, but that of the 973 schools observed, only one showed any overt startle or escape reaction to the onset of a pile strike. Moreover, there was no statistical difference in the number of schools in the area on days with and without pile driving, although other behaviors changed somewhat. However, without data on sound levels, it is impossible to use the Feist data to help understand how fish would respond to pile driving and whether such sounds could result in avoidance or other behaviors. Indeed, one interesting observation, though in need of quantification and correlation with sound levels, is that the size of the stocks of salmon never changed, but appeared to be transient, suggesting that normal fish behavior of moving through the study area used was taking place no differently during pile driving operations and in quiet periods. These results, albeit very weak, suggest that at least these species of salmon are not avoiding pile driving operations.

6.1.1.6. Field Studies of Effects of Seismic Air Guns on Behavior

Aside from the few studies that have examined the effects of pile-driving noise on fishes, a number of additional studies have examined the effects of other anthropogenic impulsive sounds on fish with sound spectrums and rise time similar to those generated by pile driving, such as seismic air guns and have generally shown that there is no onset of behavioral responses, including startle responses until the sounds are well above 150 dB re 1 μPa (rms).

The seismic studies are of some use in helping understand potential effects on fish since the sound produced by seismic air guns is similar to that produced by a pile-driving strike in terms of the length of time to reach peak amplitude and the component of the sound most likely to elicit a startle response. Because the rise time of the signal for seismic air guns is even sharper for seismic air guns than for pile driving, noise generated by seismic air guns has the potential to be more behaviorally and physiologically disturbing to fish than pile driving.

In an evaluation of the behavior of free-swimming fishes to noise from seismic air guns, fish movement (e.g., swimming direction or speed) was observed in the Mackenzie River (Northwest Territories, Canada) using sonar. Fishes did not exhibit a noticeable response even when sound exposure levels (single discharge) were on the order of 175 dB re 1 μPa^2–s and peak levels over 200 dB re 1 μPa (Jorgenson and Gyselman, 2009).

Wardle et al. (2001) observed very minor behavioral responses to the air gun emissions (most often very brief startle responses) and no permanent changes in the behavior throughout the course of the study in

response to peak sound levels of 210 dB re 1 μPa at 16 meters (52.5 ft) and 195 dB re 1 μPa at 109 meters (358 ft) from the source. Moreover, no animals appeared to leave the reef during noise production. Temporary changes in fish catch, and thus presumably in behavior, in response to exposure to seismic air guns were reported in Engås et al. (1996), Engås and Løkkeborg (2002), Slotte et al. (2004), and Løkkeborg et al. (2012) although the level of sound received by fish was not reported. In other studies that looked at catch rate, Skalski et al. (1992) showed a 52 percent decrease in rockfish (*Sebastes* sp.) catch when the area of catch was exposed to a emissions of a seismic air gun at 186-191 dB re 1 μPa (mean peak level). The results also suggested that rockfish would show a startle response to sounds as low as 160 dB (re 1 μPa), but this sound level did not appear to elicit a decline in catch.

McCauley et al. (2000) examined the effects of seismic air guns on caged pink snapper (*Pagrus auratus* Forster). Fish were caged and exposed to hundreds of emissions from an air gun as it approached and moved over and beyond the cage for approximately 1.5 hours. Received SEL exceeded 180 dB re 1 μPa^2-s for several of the shots. Startle responses, when they occurred, were elicited by sound levels greater than 156-161 dB re 1 μPa. In addition to the startle response, some individuals moved from the bottom of the cage, possibly to areas of lower sound levels. Behavior of individuals that did respond to the seismic sounds returned to normal within 14 to 30 minutes of cessation of seismic exposure and those individuals exhibited no long-term physiological or behavioral effects. (McCauley et al. 2003). Fish were also reported to habituate to the seismic air gun (McCauley et al. 2000), which means that after some amount of exposure, fish will no longer pay attention to the sound and the sound will have no further affect on behavior.

In an evaluation of the effects of a seismic survey on wild and caged fish of various species inside of Scotts Reef Lagoon in Western Australia, McCauley et al. (2008) observed some startle responses and small levels of movement in fishes exposed to sound exposure levels (single sound) of about 145-155 dB re $1uPa^2$-s.

6.1.1.7. Behavioral Responses to Other Sound Sources

Noise from construction vessels also has the potential to affect fish behavior. Using divers to observe behavioral responses of bluefin tuna (*Thunnus thynnus*) in large in-ocean cages (approximately 70 meters square opening and 30 meters deep) to passing boats, Sarà et al. (2007) documented changes in the depth, location and swimming patterns of the tuna school in the presence of sounds from approaching ferries and hydrofoils. However, the authors did not provide sound levels received by the fish.

Two recent studies suggest that fish will show behavioral responses to sounds far below 150 dB re 1 μPa (rms). However, both studies were conducted on fish within small tanks with the underwater sound source located close by, an experimental setup which would have exposed the test subjects to both sound pressure and particle motion components of the sound field, although only the sound pressure was measured. Since all of the fish in both studies are very likely to be most responsive to particle motion and not pressure, and since particle motion was not measured, it is impossible to know to which aspect of the signal the fish were responding. Indeed, due to tank acoustics it is very highly likely that there the fish were exposed to very large particle motion signals (Parvulescu, 1967), and any behavioral responses were associated with that component of the sound.

In one study, signals recorded from the operation of wind farms were found to temporarily alter the behavior of roach (*Rutilus rutilus*) and three-spined sticklebacks (*Gasterosteus aculeatus*) (Andersson et al. 2007). The reported sound pressure levels eliciting responses were from 80 to 120 dB re 1 μPa (rms),

although, as indicated above, particle motion, the actual stimulus that the fish could detect, was not measured. Similarly, Purser and Radford (2011) also examined the behavioral response (e.g., startle response and foraging behavior) of three-spined sticklebacks to short (10-sec) and long (300-sec) sounds. Fish showed an increased level of startle response and poorer foraging behavior at sound levels of about 150 dB re 1 μPa. Again, however, particle motion, the likely stimulus for both species in this small tank, was not measured or reported.

A nine-month long study by Wysocki et al. (2007) demonstrated that continuous exposure to sounds at 150 dB re 1 μPa produced no behavioral responses in rainbow trout, and no indications whatsoever of effects on stress levels, growth, or feeding. Turnpenny et al. (1994), in an unpublished report, examined the behavior of three species of fish in a pool in response to different sounds and reported avoidance behavior at certain levels of pure-tone test frequencies. However, due to poor experimental design and substantial errors in acoustics, the results of this study are impossible to interpret because of lack of calibration of the sound field at different frequencies and depths of the tanks, and due to other problems with experimental design (see comments on this study by Popper and Hastings 2009).

Studies that examined the effectiveness of underwater sound to deter fish from entering an area (e.g., dam spillways, or irrigation ditches, power plant intakes) suggest that fish will not change movement or show avoidance when sound is used as a potential fish deterrence (reviewed in Van Der Walker 1967; Popper and Carlson 1998). The exception was a study by Maes et al. (2004), who used a sound deterrent system from 20 to 600 Hz to control the movement of some clupeid fishes (*Alosa* spp.) in an attempt to deter fish from the water intake of a nuclear power plant. Fishes without swim bladders, and others that are thought to have poor hearing (e.g., sticklebacks) were not deterred by the sound. In contrast, fish with presumably better hearing capabilities (clupeids) were deterred to some degree by the sound, although there are no data on received sound levels. Moreover, this work has not been replicated. In contrast, Ploskey et al. (2000), in a very well designed study, investigated the responses of a number of schools of different juvenile salmonid species near the Bonneville Dam on the Columbia River to sounds that ramped up and down in intensity from silent to 160 dB re 1 μPa every two seconds. Only one of over 100 schools of fish exhibited a short startle response, but no individuals were deterred from the vicinity of the dam or altered their behaviors in a way that differed from the control fish, thereby indicating no avoidance of the sound.

6.1.1.8. Behavioral Responses of Sturgeon to Pile Driving

The question remains as to how sturgeon will respond behaviorally to pile driving sounds generated during bridge construction. It has been demonstrated that sturgeons have small swim bladders (Beregi et al. 2001). This finding, along with studies of hearing in sturgeon, suggests the idea that these fish are likely to primarily detect particle motion (see Lovell et al. 2005; Meyer et al. 2010, 2012, discussed below). Accordingly, the low particle motion component of signals likely to arise from pile driving suggest that these species, like flatfish and other fishes with swim bladders far removed from the ear, are less likely to hear such sounds unless they are very close to the sound source.

While there are no data for hearing by either species of sturgeon in the Hudson River, there are data for the closely related lake sturgeon (*Acipenser fulvescens*), both in terms of hearing sensitivity and structure of the auditory system (Lovell et al. 2005; Meyer et al. 2010, 2012). The data suggest that lake sturgeon can hear sounds from below 100 Hz to about 500 Hz (Lovell et al. 2005); while Meyer et al. (2010) reported evidence to suggest that the same species may hear up to 800 Hz. These data also demonstrate that sturgeon are not sensitive to sound pressure, but, instead, that they primarily detect the particle motion component of a sound field (Lovell et al. 2005; Meyer et al. 2010).

Based on the known hearing capabilities of sturgeon and the findings that they are primarily detectors of particle motion and little or no pressure, it is difficult to use pressure as a measure for potential behavioral impacts on sturgeon (e.g., 150 dB re 1 μPa rms). Indeed, as pointed out by Lovell et al. (2005), since sturgeon are primarily (and perhaps only) sensitive to particle motion, it will take a much higher level of signal (with much higher sound pressures) to elicit behavioral responses from sturgeon than from fish that are primarily pressure sensitive.

Sturgeon Behavior at 150 dB re 1 μPa rms

There are no data to indicate how sturgeon will behave in response to sound pressure at the NMFS criterion level. However, even if one makes the assumption that sturgeon do detect pressure signals, the likelihood of a behavioral response, such as avoidance or startle, at 150 dB re 1 μPa is very low when one takes into consideration the data presented above regarding known behavioral responses of fish. In all cases, other than in the acoustically flawed studies by Purser and Radford (2011) and Andersson et al. (2007) (discussed above), fish show no responses to sounds at 150 dB re 1 μPa rms. Other studies show small responses at substantially higher sound levels to which fish either habituate or from which they recover shortly after the end of exposure (e.g., McCauley et al. 2000, 2008; Wardle et al. 2001). In some cases, no response has been observed even at sound levels substantially higher than 150 dB re 1 μPa (e.g., Jorgensen and Gyselman (2009)).

It is also worth noting that, in using the modeled isopleths of areas in which 150 dB re 1 μPa would result from pile driving (see **Figures 16-19**), these sounds may not be detectable to fish if there is any masking from other ambient noises, such as those produced by the river, boats, and other non-project related sources (e.g., traffic on the current bridge, the railway along the shore of the Hudson River). As a consequence, even though the 150 dB re 1 μPa isopleth from driving a 3-m (10-ft) pile (assuming a 10 dB reduction from noise attenuation measures) is considerable in the east-west direction, masking would mean that the sound is not perceived by the fish as being 150 dB re 1 μPa until the actual sound level (without the presence of a masker) is approximately 5-10 dB higher.

The conclusion from the available data is that if/when sturgeon encounter sound levels of 150 dB re 1 μPa, and even sounds of higher levels, they are either not likely to detect the sound nor are they likely show any behavioral responses, such as startle or avoidance, to the sound since it is just at the level of detection. Moreover, even if sounds at higher levels elicit a behavioral response, the most likely reaction will be an initial startle response, similar to that even humans show when they encounter a loud and unexpected signal, but then the fish (as humans) will continue doing what they had been doing. (Indeed, this has been documented many times during attempts to use sound to cause avoidance reactions by fish at hydropower dams and irrigation channels, as discussed above.) In addition the, albeit limited, data suggest that even if fish show an initial behavioral response to the sound, they are likely to quickly habituate to its presence and then “ignore” the sound and continue with their normal behaviors.

It is likely that sturgeon will not show any adverse behavioral response to sounds at 150 dB re 1 μPa, which enlarges the potential migration corridors available to them during the construction. It is conceivable that higher sound levels well above the 150 dB re 1 μPa could potentially cause sturgeons to change behaviors, ranging from just halting movement to their turning away from the source. In many cases the changes in movement are likely to result in sturgeon quickly moving to a region of lower sound levels in the river, at which time they will continue with their original migratory movement through the corridor. In other cases, it is possible that the sturgeon will stop migratory movements, as if the sounds were a physical barrier and then resume movement once the sound stops.

While it is possible that any acoustic barrier could delay migratory and other important behaviors of sturgeon, there is no pile-driving from impact hammering for approximately 93% of the project duration. Thus, few fish would ever encounter an acoustic "barrier" and, even then, they would only be "delayed" for the very small amount of time that the sound is present. Once the sound is ceases, the fish will continue in their normal pathway since the "drive" to reach spawning or feeding grounds is generally very high in animals. (e.g., salmon and American shad are very well known to overcome massive barriers to get to spawning sites, and it is likely that the same applies for other species that have natal homes).

Affected Area and Potential Physiological Effects based on Modeled Pile Driving

In order to analyze the potential impacts of the project's pile driving on Hudson River aquatic resources, the likely hydroacoustic scale of pile driving was modeled (JASCO 2011a). The extent of the sound pattern generated by pile driving for the Project was determined by application of three different sound propagation modeling approaches (i.e., MONM, VSTACK, and FWRAM). The models account for the frequency composition of the source signal and the physics of acoustic propagation in the Hudson River and underlying geological substrate. This type of modeling differs from generalized and empirical acoustic models, such as "practical spreading loss" models (Caltrans, 2009), that do not take into full account the source characteristics or the many site-specific factors that could influence the rate of noise transmission such as water depth and substrate transmission characteristics.

Various pile driving scenarios were used to generate the cumulative sound exposure level (SEL_{cum}) for each day over the construction period. Maximum and typical pile driving scenarios were analyzed. In addition, the application of Best Management Practices (BMPs) that provided a 10 dB reduction in sound was incorporated into the acoustic modeling effort. These practices represent various methods to reduce the extent to which a waterbody would be ensonified by pile driving operations. Various BMPs have been employed on pile driving operations around the country, including air bubble curtains of various forms, isolation casings, Gunderbooms, and dewatered cofferdams. The Project Sponsors have committed to the use of BMPs to attenuate the potential impacts of sound associated with pile driving.

Figure 20 presents the peak SPL, with BMPs, for 4-, 6-, 8-, and 10-ft piles being driven at representative locations along the alignment of the replacement bridge. The figure illustrates the transmission loss that would occur as distance from the pile driving site increases. Transmission loss is not uniform across the different size piles since the piles would be driven at locations where water depth and other environmental factors vary. For the 4-ft piles, sound above the interim 206 dB peak threshold encompasses a distance of about 30 ft; for the 10-ft piles the 206 dB peak SPL the distance increases to approximately 300 ft.

The following figures present accumulated energy (SEL_{cum}) for driving a pile over the time for driving the pile and should be understood that way. Thus, the information in these figures does *not* represent the energy from a single strike or the instantaneous level of sound at any one moment in time. (as represented for rms levels in Figure 20). Moreover, the accumulated energy in the following figures represents the received energy for an animal *only* if the animal stays in the same location for the duration of the pile driving activity.

Figure 21 presents the SEL_{cum} metric for installing two pairs of 10-ft piles at the replacement bridge main span over the number of strikes that are predicted to be needed to fully seat the piles. The concurrent placement of two pairs of 10-ft piles is considered a representative worst case for driving of

10 ft piles, and would be the same for both the Short and Long Span Options. The concentric "circles" (or isopleths) of different colors represent distances from the pile driving activity at which various accumulated sound energy levels (SEL_{cum}) would be reached over the duration of driving of the two piles. For example, the 187 dB isopleths extends over a mile in each direction north and south of the point of pile driving and 49% of the cross sectional width of the river. This can be contrasted with the 187 dB 1 $\mu Pa^2 \cdot s$ isopleth profile for installing four 4-ft piles at the replacement bridge main span in one day, which does not extend substantial distances in any direction (see **Figure 22**).

Figure 23 indicates the cross sectional area of the river that would be reach an accumulated sound level of 187 dB re 1μPa^2-s over the duration of the construction period for the Short Span Option, and assumes a BMP reduction of 10 dB. During the period of driving the 10 foot piles, 49% of the river cross sectional width would be within the 187dB re 1μPa^2-s isopleth. Similarly, the ensonified area would be between 43 and 61% during the four-month period when 4, 6, and 8 ft piles are all being driven, sometimes simultaneously. The figure indicates that driving of the 10 and 8 ft piles would take place in the first few months of the first year of construction, limiting the period of time of greatest potential effects, During the remaining years of the construction period, the affected cross section of the river is considerably less, on the order of 14 to 38%. Given that the river is approximately 3 miles wide, there would always be a considerable portion of the river that remains below the threshold noise criteria, thereby insuring adequate corridors for migration and movement of sturgeon and other fish species through the region. **Figure 24** indicates the cross sectional area of the river that would be ensonified to the 187 dB re 1μPa^2-s isopleths over the duration of the construction period for the Long Span Option.

For most of the pile driving scenarios modeled, including those in which the maximum number of simultaneous piles are being driven and/or for the largest piles, a substantial portion of the Hudson River's width never reaches the SEL_{cum} criterion established for onset of physiological injury. Furthermore, even within a single day of operations (assuming up to a 12 hour day), there is likely to be no pile driving activity for a substantial amount of time, such as when piles are put in place, being welded, or when the pile driving machinery is relocated. Thus, fish in much of the river will not be exposed to pile driving sounds for significant periods, and the likelihood of accumulating sufficient energy (SEL_{cum}) to result in onset of physiological effects is low. Finally, fish are not likely to remain in an area at which noise (from pile driving or other source) would cause discomfort.

The expression SEL_{cum} represents the total energy at a particular location in the river for a discrete duration (typically the number of strikes) of a particular pile driving operation. Often, this represents the duration for the full driving of a single pile, or even for multiple piles if driven in a single day (if a pile is driven over two days, there is a "resetting" of the SEL_{cum} after 12 hours and accumulation starts again (Carlson et al., 2007; Stadler and Woodbury, 2009). It is important to note that it is highly unlikely that a fish would be exposed to the full SEL_{cum} of a pile driving operation since that could only occur if the fish stays in place and exhibits no swimming behaviors (including behavioral response to the pile driving sounds) for the duration of the pile driving operation. Thus, the scenario with fish receiving a full accumulated exposure to any pile driving is highly unlikely and conservative for most Hudson River species of concern. Moreover, even though fish would accumulate energy over the course of a pile driving operation (assuming the fish does not leave the area), the actual number of strikes to which the fish would be exposed, and the time intervals between the strikes, would be of importance. If the fish is exposed to fewer strikes, the total energy to the fish is lower (assuming that all strikes are generally similar in SEL_{ss}).

Thus, caution must be used when interpreting the model's results that present SEL_{cum} at different locations relative to the pile driving because the model does not take into consideration any behavioral

responses of fish that would result in the fish not being exposed to SEL_{cum} levels that would result in onset of physiological effects. Furthermore, data from Halvorsen et al. (2011) document that SEL_{cum} has to be substantially above the minimum level that would result in onset of low levels of physiological effects to be potentially fatal. Thus, for example, Chinook salmon exhibit some minor effects at a SEL_{cum} at about 210 dB re 1μPA^2-s, but it is not until the levels reach 216 – 219 dB re 1μPA^2-s that injuries become potentially fatal (Halvorsen et al. 2011). The study indicated there was recovery from injuries sustained at 210 dB re 1μPA^2-s within several days of exposure, and that none of the injuries observed were of a kind that would lead to a loss of fitness (Casper et al. 2011, in press).

Measures for Minimizing Potential Effects of Pile Driving and Estimating Numbers of Shortnose Sturgeon Potentially Affected

Adult shortnose sturgeon are likely to be present in the Tappan Zee Reach throughout the construction period. If an individual fish remains within an area(s) ensonified over Peak 206 dB re 1 μPa^2-s for a single strike or 187 dB re 1 μPa^2-s for accumulated energy ($SEL_{cum,}$) there is the potential for the onset of physiological effects. While the areas to be ensonified by the pile driving do not represent spawning grounds for any either sturgeon species, they are used for foraging and transit during migrations up and down the river.

Fish that may be close to the piles during a pile driving operation are going to be exposed to single strike sound levels that are above the interim criteria defined above (e.g., 206 dB re 1 μPa peak), and there is the likelihood of mortality to these individual animals. However, methods have been tested that suggest, albeit with minimal data, that it is possible to get fish to move from the vicinity of pile driving prior to the onset of maximum strikes. For example, during the construction of the Woodrow Wilson Bridge over the Potomac River, there is evidence that tapping the pile with lower energy for the first few strikes may “frighten” fish away from the piles before full operations begin (FHWA 2003). Reports from the Woodrow Wilson Bridge construction suggest that this kind of ramp-up procedure substantially decreased mortality; however, it is appropriate to acknowledge that these findings were anecdotal and were not part of scientifically controlled studies.

Pile driving in the warmer months of the year could expose a considerable number of sturgeon to potential effects as they use the project vicinity as a foraging area, but sturgeon would likely leave an area ensonified above the above Peak 206 dB or 187 dB SEL_{cum} from pile driving operations if such sounds caused discomfort. On days when pile driving occurs during migration periods, a substantial portion of the cross section of the Hudson River would not be ensonified with sound energy of greater than 187 dB (**Figures 23** and **24**). Importantly, for a period of 12 hours or more each day there would be no pile driving activities and pile driving is anticipated to occur for no more than five days a week. Thus, the majority of time each week the river would experience no sound energy above normal ambient, and pile driving activities would not represent a barrier to upriver or downriver movement of sturgeon, or to foraging.

Moreover, a number of Environmental Protection commitments (EPCs) are being implemented by the Project to reduce the potential for pile driving associated injury to sturgeon and other aquatic species. These measures were enumerated in Section 4.2.5 Substructure Construction:

Methods for Estimating the Potential Number of Shortnose Sturgeon Affected by the Pile Driving

Using fish abundance estimates from a 1-year comprehensive gill-net sampling study, the encounter rate of shortnose sturgeon in the study area was estimated as the number of shortnose sturgeon collected per

gill net per hour. From June 2007 – May 2008, 476 gill nets were deployed just upstream of the existing Tappan Zee Bridge (and within the study area) for a total sampling time of 679 hours. During this time, 12 shortnose sturgeon were collected: 7 in September and October, 4 in May and June and 1 in August. Based on the observed number of sturgeon collected over 679 gill-net hours, the encounter rate for shortnose sturgeon in the proposed bridge replacement area is 0.02 sturgeon encountered per hour of sampling.

To estimate the potential number of shortnose sturgeon affected by pile driving activities, it was necessary to scale gill-net encounter rates from a single gill-net sample (the gill net is 125 ft in length) to the area encompassed by the isopleth bounding the SEL_{cum} of 187 dB re 1μPa^2-s (**Figures 21** to **22**; JASCO 2011a). The SEL_{cum} of 187 dB re 1μPa^2-s, which is the NMFS interim threshold measure for onset of physical injury to fish was used to determine the number of shortnose sturgeon that would have been collected if multiple gill nets were deployed side-by-side across the width of the 187 dB re 1μPa^2-s isopleth. For the Short Span Option the width of the 187 dB isopleth for the pile sizes ranges from 310.9 m to 2,841.9 m (1,020 ft to 9,324 ft), depending on the size of the pile, or combination of pile sizes being driven (see **Table 5**). However, for about 80% of the weeks that construction will be ongoing, the width of the isopleths will be 1,066.8 m (3,500 ft) or less. For the Long Span Option the width of the 187 dB isopleth for the pile sizes ranges from 359 m to 2,427.7 m (1,178 ft to 7,965 ft), depending on the size of the pile, or combination of pile sizes being driven (see **Table 6**). For 80% of the weeks that construction will be ongoing for the Long Span Option, the width of the isopleths will be 1,191.8 m (3,910 ft) or less.

Movement by shortnose sturgeon has been shown to be strongly oriented into or with river currents (McCleave et al. 1977; Richmond and Kynard 1995). This is supported by data collected during the 2007-2008 gill net study, in which shortnose sturgeon were collected with greater frequency in gill nets deployed across the river current vs. with the current. Based on these results, it can be assumed that sturgeon move in an upstream or downstream direction through the study area and at a constant rate and would thus be intercepted by gill nets spanning the width of the noise isopleth. It was also assumed that catch rates are proportional to shortnose sturgeon abundance, which is a central assumption of most fish-sampling gears, and that sturgeon were uniformly distributed throughout the Tappan Zee region. Under these assumptions, each gill net would encounter shortnose sturgeon at the same rate allowing the estimates of sturgeon number to be scaled to the width of the isopleth.

Estimated Number of Shortnose Sturgeon Potentially Affected by the Replacement Bridge Alternative

Tables 5 and 6 provide a summary of the number of shortnose sturgeon potentially exposed to the pile driving at various locations with BMPs providing a reduction of 10 dB. Based on this approach, 482 shortnose sturgeon have the potential to be exposed to an SEL_{cum} of 187 dB re 1 μPa^2-s over the project duration for the Short Span Option (see **Table 5**). Similarly, 365 sturgeon have the potential to be exposed to an SEL_{cum} of187 dB over the project duration for the Long Span Option (Table 6). Assuming 60,000 as a valid, current standing stock estimate for shortnose sturgeon in the Hudson River and assuming that this number remains static for the duration of the pile-driving activities, the Short Span Option has the potential to expose 0.80% of the population and the Long Span Option has the potential to expose 0.61% of the shortnose surgeon population. These estimates can be viewed as a conservative maximum because they represent the encounter rate within the isopleths over several years, and one should assume that some fraction of that total number would be encountered more than once without having experienced the necessary sound for the onset of injury.

Table 5

Number of Shortnose Sturgeon Potentially Affected by Pile Driving – Short Span Bridge Option

								With 10 dB BMPs			
Year	Week	Pile Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	Width of isopleth for 187-db SEL_{cum} (ft)	Number of gill nets (125-ft) to span width of isopleth	Sturgeon encounter rate per gill net (fish/hr)	Number of shortnose sturgeon potentially exposed to pile driving
	40-44	10	50	4	1.55	2	38.75	7186	57	0.02	44.55
	45-48	6,8	20	7	1.11	2	11.1	5807	46	0.02	10.32
	49	6,8	8	7	1.11	2	4.44	6336	51	0.02	4.50
	50-51	4,8	20	6	1.14	2	11.4	7170	57	0.02	13.08
1	52	4,8	10	6	1.14	2	5.7	6952	56	0.02	6.34
	1	4,8	10	6	1.14	2	5.7	6952	56	0.02	6.34
	2	4,8	10	6	1.14	2	5.7	6735	54	0.02	6.14
	3-4	4,6,8	30	10	1.14	3	11.4	8418	67	0.02	15.36
	5	4,6,8	15	10	1.14	3	5.7	9324	75	0.02	8.50
	6	4,6,8	15	10	1.14	3	5.7	9253	74	0.02	8.44
	7	4,6,8	15	10	1.14	3	5.7	8312	66	0.02	7.58
	8-12	4,6,8	75	10	1.14	3	28.5	7732	62	0.02	35.25
	13	6,8	12	7	1.14	2	6.84	7732	62	0.02	8.46
	14-28	4,4	160	6	1.14	2	91.2	3490	28	0.02	50.9
	29-49	4	95	3	1.14	1	108.3	2024	16	0.02	35.15
	50-51	4,4,6	30	10	1.14	3	11.4	5581	45	0.02	10.18
2	52	4,4,6	15	10	1.14	3	5.7	5036	40	0.02	4.59
	1	4,4,6	15	10	1.14	3	5.7	5036	40	0.02	4.59
	2	4,4	10	6	1.14	2	5.7	3490	28	0.02	3.18
	3	4,4,6	15	10	1.14	3	5.7	4836	39	0.02	4.41
	4	4,4,6	16	10	1.14	3	6.08	4217	34	0.02	4.10
	5-10	4,4	65	6	1.14	2	37.05	3461	28	0.02	20.51
	11-12	4,4	22	6	1.14	2	12.54	3197	26	0.02	6.42
	13-17	4,4	53	6	1.14	2	30.21	3461	28	0.02	16.73
	18-20	4,4	30	6	1.14	2	17.1	3197	26	0.02	8.76
	21-25	4,4	55	6	1.14	2	31.35	3461	28	0.02	17.35
	26-27	4,4	20	6	1.14	2	11.4	3197	26	0.02	5.84
	28-33	4,4	60	6	1.14	2	34.2	3461	28	0.02	18.96
	34-35	4,4	20	6	1.14	2	11.4	3197	26	0.02	5.84
	36-41	4,4	60	6	1.14	2	34.2	3461	28	0.02	18.96
3	42-52	4	60	3	1.14	1	68.4	2024	16	0.02	22.2
	1-14	4	70	3	1.14	1	79.8	2024	16	0.02	25.9
4	15-16	6	12	4	0.33	1	3.96	2120	17	0.02	1.34

Table 5

Number of Shortnose Sturgeon Potentially Affected by Pile Driving – Short Span Bridge Option

Year	Week	Pile Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	With 10 dB BMPs			
								Width of isopleth for 187-db SEL_{cum} (ft)	Number of gill nets (125-ft) to span width of isopleth	Sturgeon encounter rate per gill net (fish/hr)	Number of shortnose sturgeon potentially exposed to pile driving
	17-18	6	6	4	0.33	1	1.98	2019	16	0.02	0.64
	19	6	6	4	0.33	1	1.98	1821	15	0.02	0.58
	20	6	6	4	0.33	1	1.98	1624	13	0.02	0.51
	21	6	4	4	0.33	1	1.32	1440	12	0.02	0.30
	22-23	6	8	4	0.33	1	1.64	1060	8	0.02	0.44
5	50-52	4	15	3	1.14	1	17.1	2024	16	0.02	5.55
	1-5	4	25	3	1.14	1	28.5	2024	16	0.02	1.85
	6-7	6	12	4	0.33	1	3.96	2120	17	0.02	1.34
	9	6	6	4	0.33	1	1.98	2019	16	0.02	0.64
	10	6	6	4	0.33	1	1.98	1821	15	0.02	0.58
	11	6	6	4	0.33	1	1.98	1624	13	0.02	0.51
	12	6	4	4	0.33	1	1.32	1440	12	0.02	0.30
	13	6	4	4	0.33	1	1.32	1280	10	0.02	0.27
	14	6	4	4	0.33	1	1.32	1060	8	0.02	0.22
	21	6	6	4	0.33	1	1.98	1346	11	0.02	0.43
6	22	6	6	4	0.33	1	1.98	1020	8	0.02	0.32
Potential number of sturgeon affected											
Shortnose sturgeon affected											**482**
Percentage of shortnose sturgeon standing crop (60,000 fish)											**0.80**

Table 6

Number of Shortnose Sturgeon Potentially Affected by Pile Driving – Long Span Bridge Option

Year	Week	Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	With 10 dB BMPs			
								Width of isopleth for 187-db SEL_{cum} (ft)	Number of gill nets to span width of isopleth	Sturgeon encounter rate (fish/hr)	Number of shortnose sturgeon potentially affected by pile driving
	40-44	10	50	4	1.55	2	38.75	7186	57	0.02	44.55
	45-48	6,8	20	7	1.11	2	11.1	5866	47	0.02	10.42
	49-50	6,8	16	7	1.11	2	8.88	6862	55	0.02	9.75
	51	6,8	12	7	1.11	2	6.66	7387	59	0.02	7.87
1	52	6,8	14	7	1.11	2	7.77	7965	64	0.02	9.90
	1	6,8	10	7	1.11	2	5.55	7767	62	0.02	6.90
	2-3	8	12	3	1.11	1	13.32	5648	45	0.02	12.04
	4-11	4,4	88	6	1.14	2	50.16	3458	28	0.02	27.76
	12-13	4,4	20	6	1.14	2	11.4	3910	31	0.02	7.14
	14-21	4,4	80	6	1.14	2	45.6	3458	28	0.02	25.2
	22-23	4,4	22	6	1.14	2	12.54	3910	31	0.02	7.84
	24-30	4,4	73	6	1.14	2	41.61	3458	28	0.02	23.01
	31-33	4	45	3	1.14	1	51.3	2064	17	0.02	16.95
2	47-52	4,4	60	6	1.14	2	34.2	3712	30	0.02	20.34
	1-4	4,4	40	6	1.14	2	22.8	3712	30	0.02	13.56
	5-18	4,4	160	6	1.14	2	91.2	3910	31	0.02	57.1
	19	4,4,6	21	10	1.14	3	7.98	3910	31	0.02	4.99
	20-21	4,6	34	7	1.14	2	19.38	4653	37	0.02	14.43
	22	4,6	22	7	1.14	2	12.54	4200	34	0.02	8.43
	23	4,6	16	7	1.14	2	9.12	3784	30	0.02	5.52
	24	4,6	11	7	1.14	2	6.27	3512	28	0.02	3.52
	25	4,6	11	7	1.14	2	6.27	3240	26	0.02	3.25
3	26-33	4	40	3	1.14	1	45.6	2064	17	0.02	15.04
	17-20	4	20	3	1.14	1	22.8	2064	17	0.02	7.52
	23	6	6	4	0.33	1	1.98	2282	18	0.02	0.72
	25	6	4	4	0.33	1	1.32	1395	11	0.02	0.29
	28	6	6	4	0.33	1	1.98	1759	14	0.02	0.56
	32	6	6	4	0.33	1	1.98	1469	12	0.02	0.47
5	36	6	6	4	0.33	1	1.98	1178	9	0.02	0.37
Potential number of sturgeon affected											
Shortnose sturgeon affected											**365**
Percentage of shortnose sturgeon standing crop (60,000 fish)											**0.61**

These findings are also likely to overestimate the number of shortnose sturgeon potentially affected for the following reasons:

- Since the calculations do not take into consideration the normal behaviors of the fish in response to a noxious stimulus, it is reasonable to assume that sturgeon, on hearing the pile driving sound, would either not approach the source or move around it. Since the pile driving sounds are very loud, it is also very likely that many of the fish will hear the sound, and respond behaviorally, well before they reached a point at which the sound levels exceeded the behavioral criterion of 150 dB re 1 μPa or the interim SEL_{cum} criterion of 187 dB 1 $\mu Pa^2 \cdot s$. The likely behavioral response would be to alter the path through which the fish were traveling to avoid the sounds that were too loud and then resume their regular path once the highest sound levels were skirted.

- Based on the most recent scientific studies (e.g., Halvorsen et al. 2011), the 187 dB re 1μPa^2-s SEL_{cum} threshold is overly conservative, and far lower than cumulative sound levels that actually result in onset of physiological effects in rigorous experimental studies. If a higher threshold for onset, such as those proposed by Halvorsen et al. (2011) (e.g. SEL_{cum} of 203 dB or greater) were to be used to evaluate the onset of injury to sturgeon, the size of the ensonified area that could potentially cause onset of physiological effects would be considerably reduced, as would the number of potentially affected fish.

- The analysis was conducted using a 10 dB reduction associated with implementation of BMPs, which may underestimate the level of noise attenuation that can be achieved by bubble curtains or other technologies (i.e., 20 dB; Caltrans 2009)

- Carlson et al. (2007) have provided evidence that as fish get larger there is less of an impact on them from sounds, and that the threshold for onset to injury to larger fish, such as sturgeon, is substantially higher (i.e. 213 dB re 1 μPa^2-s) for fish above 200 grams, than the West Coast criterion for fish > 2 gm (i.e. 187 dB re 1 μPa^2-s).

Because Atlantic sturgeon were not collected in the gill net sampling program no estimate of the number of fish within the ensonifed zone was calculated. However, because the Hudson River population size is considerably less than that for the shortnose, the number would be expected to be substantially less than the 482 and 365 shortnose sturgeon for the Short Span and Long Span, respectively.

While pile driving can potentially result in onset of injury to sturgeon in the immediate vicinity of the pile driving activity, it will not jeopardize the continued existence of shortnose or Atlantic sturgeon in the Hudson River. Their relatively small swim bladder and large size would suggest that the physiological impacts of pile driving on sturgeon may not be as great as for other species with larger swim bladders. Furthermore, NMFS has commented (FHWA 2003) that fish like shad and alewife are more susceptible to pressure waves due to their laterally compressed body shape, in comparison to the shortnose sturgeon's fusiform shape. There is no critical habitat for shortnose or Atlantic sturgeon in the Hudson River.

While pile driving impacts resulting from constructing either Short or Long Span options may impact some individuals of these two species either behaviorally or physiologically, the activity would not jeopardize either population.

6.1.1.9. Effects to Marine Mammals from Pile Driving

Marine mammals rely on the use of underwater sounds to communicate, navigate, and/or obtain information about their environment (the afore-mentioned "auditory scene") (Richardson et al. 1995; Southall et al. 2007). The ability of marine mammals to hear and respond to underwater sounds depends on auditory capability and thus whether the sound is within the hearing range of the animal. All marine mammals potentially found within the Hudson will be able to hear sounds from pile driving since the frequencies are well within the hearing range of the animal (Southall et al. 2007). Moreover, the hearing sensitivity of all of these species is sufficiently acute that they are likely to be able to hear, and behaviorally respond to, the sounds at very substantial distance from the pile driving. Indeed, they are likely to hear the sounds at far greater distances than any fish and move away from the sound well before they get to a location where the pile driving levels would be sufficient to cause potential injury.

Dolphins, harbor porpoises and seals make occasional use the Hudson River and may occur in the vicinity of the project. These species are marine, and only occur in the tidal Hudson River as transients. Given the scarcity of marine mammals in the study area, it is not possible to reliably estimate the number of animals that may even get close enough to hear pile driving sounds (or noises associated with other construction activities). Based on the few anecdotal observations cited above, the presence of these species in the vicinity of the project is rare and is likely attributable to either previously stressed / injured animals or healthy, but transient, individuals. In the case of the former, the pile driving sounds could exacerbate existing stressors and result in either sub-lethal or lethal effects, while in the case of the latter, healthy animals would be expected to retreat from the source of any sounds that produce discomfort. Nevertheless, because this portion of the Hudson River doesn't provide areas for spawning, nursery, or overwintering, or migratory pathway for these species, any anthropogenic sound in the river is not expected to result in adverse effects to the movement, reproduction, feeding, or sustained population of these species.

6.1.2. Effects from Increased Vessel Traffic

The shortnose and Atlantic sturgeon are known to occur within the stretches of the river that include the project area; therefore, sturgeon also may be directly impacted by increased vessel traffic in these areas. Increased vessel traffic will occur during all phases of the work including mobilization and site preparation activities, dredging for channel access, substructure construction, superstructure construction, and bridge demolition. These activities may result in a substantial increase in commercial vessel traffic in the Tappan Zee Reach. The potential direct effects associated with increases in vessel traffic include potential disturbance of foraging and migratory adults and juveniles associated with an increase in surface activity, vessel-impact mortality and noise.

The increased surface activity and associated noise may be considered to have the potential to displace/disrupt adults and juveniles during foraging and migratory activities, if the sounds are loud enough to be heard by sturgeon, which generally have poor hearing sensitivity (Lovell et al. 2005; Meyer et al. 2010, 2011). The increase in the Hudson River shortnose sturgeon population over the past several decades however, demonstrates the ability of the sturgeon to coexist in areas where commercial and industrial vessel traffic overlap.

Vessel traffic has been reported as a source of mortality for Atlantic sturgeon as a result of direct collisions with the hull or propeller. Vessel-strike mortalities have the potential to impact Atlantic sturgeon populations in the Delaware River and New York Bight by reducing the egg-per-recruit ratio and thus, by reducing the overall reproductive potential of the population (Brown and Murphy 2010).

The majority of vessel related sturgeon mortality are likely caused by large transoceanic vessels, with fewer caused by smaller vessels. Large vessels have been implicated because of their deep draft [up to 12.2-13.7 m (40-45 feet)] relative to smaller vessels [<4.5 m (15 feet)], which increases the probability of vessel collision with demersal fishes like sturgeon, even in deep water (Brown and Murphy 2010). Smaller vessels and those with relatively shallow drafts provide more clearance with the river bottom and reduce the probability of vessel-strikes. Because the construction vessels (tug boats, barge crane, hopper scow) have relatively shallow drafts, the chances of vessel-related mortalities are expected to be low. The depth of the construction channel will be 4.3 m (14ft), which is considerably shallower than the typical depths [>6.1-9.1 m (20-30ft)] in which Atlantic sturgeon are found (Hatin et al. 2002). The maximum allowable draft of any of the construction vessels will be 3.2 to 3.6 m (10.5 to 12ft), however, under typical operating conditions, vessels will draft 2.1 to 2.4 m (7 to 8 ft), providing 1.8-2.4 m (6-7 ft) of clearance with the bottom at all times. Maximum allowable drafts will only occur under full load and while turning. Under working conditions, stationary tug boats will maintain 1.8 m (6 ft) clearance between the prop and the bottom and will only infrequently approach 1.1 m (3.5 ft) clearance. The large grain size of the gravel substrate used to armor the bottom of the construction channel is not the desired foraging substrate for sturgeon or their benthic invertebrate prey, which are typically found in fine-grained silt-clay sediments (Hatin et al. 2002, Hatin et al. 2007).

The increased vessel traffic associated with the Tappan Zee Bridge replacement is not expected to result in direct interactions with sturgeon, because the life stages present in this reach of the river tend to occupy the bottom meter of the water column over fine-grained substrates in the deepest water areas and would be below the draft of the vessels involved. Furthermore, if it is assumed that sturgeon will avoid areas of increased noise caused by vessel traffic and other construction-related activities, then the probability of vessel-related impacts is even less likely. This conclusion is consistent with previous NMFS consultations with regional construction projects (e.g., the opinion issued for the Van Houten Holding Corporation's berthing facility upgrades in Upper Nyack, New York, NMFS 2011, NAN-2010-00832-ESP).

Another potential impact associated with increased vessel traffic is radiated noise. It is of considerable importance that fish transiting the navigable Hudson River will encounter an acoustic environment that is generally highly energetic under "normal" conditions. The sound levels lower in the estuary result from the high volume of commercial shipping traffic within the tidal Hudson and New York Harbor, and these do not appear to affect the behavior or migration of sturgeon that bypass this very noisy region each year. While noise levels from shipping in the estuary are not known, it is possible to get a first approximation based upon results of other studies which suggest that sound levels due to radiated vessel noise would be below thresholds for the onset of injury to fish (Wursig et al. 2002). Furthermore, because of the comparatively poor hearing ability of sturgeon (Lovell et al. 2005; Meyer et al. 2010, 2011), it is possible that many of the sounds which are audible to most species, are not audible to sturgeon.

Because these representative values of radiated vessel noise are well below the peak SEL of 206 dB re 1 μPa criterion established for pile driving, and because the Hudson River is subject to substantial commercial and recreational vessel noise under "normal" conditions, any incremental increase sound associated with vessel traffic related to bridge construction is not expected to affect sturgeon.

6.1.3. Effects of Dredging

The frequency of dredging or disturbance of an area affects the invertebrate community and its ability to recover following each dredging event. Since sturgeon feed on benthos, a sizable loss of habitat due to

dredging and temporary alteration of habitat could affect foraging opportunities. However, benthic communities found in environments with a great deal of variability such as estuaries generally have high rates of recovery from disturbance, because they are adapted to disturbance. Recovery rates of benthic macroinvertebrate communities following dredging range from only a few weeks or months to a few years, depending upon the type of project, the type of bottom material, the physical characteristics of the environment and the timing of disturbance (Hirsch et al. 1978, LaSalle et al. 1991). In a two year study in the lower Hudson River, Bain et al. (2006) reported that within a few months following dredging, the fish and benthic communities at a dredged location were no different from seven nearby sites that had not been dredged. The results of monitoring did not indicate a lasting effect at the dredged site.

Dredging activities for the project have the potential to remove benthic macroinvertebrates, including oyster beds, and the food resources they provide to other aquatic resources. Approximately 0.67 to 0.71 km^2 (165 to 175 acres) of bottom habitat—including about 0.02 km^2 (5.3 acres) of NYSDEC littoral zone tidal wetland and 0.65-0.69 km^2 (160-170 acres) of open water benthic habitat—would be dredged during three stages over a four year period for a duration of three months between August 1 and November 1 (see **Figure 11**). Dredging would be initiated during this window to avoid periods of anadromous fish spawning migrations. In addition, the trench would be armored following dredging and the benthic habitat within the dredge zone which was primarily soft sediment would be changed to a substrate of sand and gravel. Since armoring would occur up to 6.1 m (20 feet) of the side slope, total acreage of hard bottom would be approximately 0.63 to 0.67 km^2 (155 to 165 acres). The materials would not be removed after the project completion, since they would become fully buried by the gradual deposition of river sediments over time once construction was completed. The rate of this transformation would begin at approximately 1 foot per year, likely decreasing as the bed nears it natural pre-dredged elevation.

While the dredging would result in the loss of individual macroinvertebrates, it is not expected to result in adverse impacts of these species at the population level within the Hudson River Estuary. The temporary loss of the access channel area would represent a minor fraction of similar available habitat throughout the Tappan Zee region (1.2%) as defined by the Hudson River Utilities (RM 24-33), and an even smaller percentage of the riverwide benthic area (0.2%). The majority of the bottom habitat and associated benthic macroinvertebrates within the area impacted is the soft sediment community which dominates the Upper New York Harbor and Hudson River. Calculations suggest that deposition within the dredged channel will occur at a rate of about one foot per year (see Appendix E of DEIS for deposition rate calculations). Recolonization by benthic organisms adapted to softer sediments could be expected to begin within a few months after completion of in-water activities in any given area. Prior to the deposition of sufficient sediment to support a soft substrate benthic invertebrate community, some recolonization of the gravel armor material would be expected occur. Organisms within the nearby gravel substrate located within the main channel (NYSDEC benthic mapper http://www.dec.ny.gov/lands/33596.html, and Nitsche et al. 2007) would serve as a source of organisms to colonize the gravel capping material until the soft sediment is of a sufficient depth to be colonized by soft substrate organisms. Although the area affected by dredging is substantial, the effects to the soft sediment habitat, which is the dominant sediment type in the lower estuary, should be viewed as temporary and not indicative of a long-term adverse effect. Once in-water activities are completed, the dredged channels would be restored over time to their original elevations by action of natural sedimentation, and the river's benthic community would recolonize those areas as well.

6.1.3.1. Oyster beds

Oyster beds were mapped using side scan sonar imagery approximately two miles north and south of the existing bridge from depths of 2.4 to 9.1 m (8 to 30 feet). Seven potential oyster beds were identified south of the bridge and six potential beds to the north (see Appendix E-3 of the DEIS for a description of each of the beds). During the subsequent grab sample program all identified oyster beds except one were confirmed to contain at least some live organisms with beds exhibiting differences in terms of oyster density, amount of shell hash, gravel, or sandstone fragments, etc. Dredging would remove about 0.05 km^2 (13 acres) of oyster beds, some or all of which may be permanently lost due to dredging and armoring of the bottom. A permanent loss of these oyster beds would result in an unavoidable adverse impact. Potential for implementation of oyster enhancement, relocation, or restoration projects will be explored and other mitigation strategies will be developed through consultation with the USACE, NMFS, USFWS, and NYSDEC. However, because of its sediment composition, oyster habitat is not considered optimal for sturgeon foraging.

In summary, with the exception of oyster beds that may be permanently lost, where access channels are dredged, there would be a temporary loss of habitat that could affect sturgeon that use the dredged area for foraging. These effects would occur as a result of a localized reduction in benthic fauna. However, the dredging footprint represents a very small percentage of the Hudson River Estuary and its soft bottom habitat. Thus, the temporary reduction of benthic fauna within the dredged area would not substantially reduce foraging opportunities for the river's sturgeon populations, because sturgeon are highly mobile and anadromous, moving up and down the estuary. As noted above, once in-water activities are completed, the dredged channels would be restored over time to their original elevations and the river's benthic community would recolonize those areas.

6.1.4. Effects of Shading

It has been maintained that shading of estuarine habitats can result in decreased light levels and reduced benthic and water-column primary production, both of which may adversely affect invertebrates and fishes that use these areas, particularly with respect to use as refuge and foraging habitat (Able et al. 1998, and Struck et al. 2004). The amount of area shaded by overwater structures will be affected by the height and width of the structure, construction materials and orientation of the structure relative to the arc of the sun (Burdick and Short 1995, Fresh et al. 1995 and 2000, Olson 1996, 1997 in Nightingale and Simenstad 2001) and piling density. Shading due to bridges has been found to affect plant communities such as tidal marshes and SAV, as well as benthic invertebrate communities within tidal marshes (Struck et al. 2004, and Broome et al., 2005 in CZR 2009). However, adverse effects on marsh vegetation and benthic macroinvertebrates have been found to be minimal when the bridge height-to-width ratio is greater than 0.7 (Struck et al, 2004, Broome et al. 2005 in CZR 2009). Significantly fewer oligochaete worms, which are common in the Hudson River, were found under bridges with a height-to-width ratio less than 0.7 when compared to marshes not affected by shading (Struck et al. 2004). Struck et al. (2004) found that bridges with height-to-width ratios greater than 1.5 had the lowest light attenuation beneath the bridge.

Because the elevations of the existing Tappan Zee Bridge and the Replacement Bridge Alternative are not consistent over the length of the structure (see **Figure 2**), the height-to-width ratio of the bridge varies along its length. **Table 7** compares the ratio of the existing bridge and the Short and Long Span Options for the Replacement Bridge Alternative at the stations indicated in **Figure 2**. The two spans of the Replacement Bridge Alternative would be separated by a gap up to 70 feet. While there are no vegetated wetlands or SAV that could be affected by the construction of the Replacement Bridge

Alternative, the height-to-width ratios presented below provide an indication of the potential for the existing and Replacement Bridge Alternative to result in shading impacts. As indicated below, the height-to-width ratio for the portion of the existing bridge within the causeway (the western approach to the main span comprising Stations 845+00 to approximately 905+00) is low, ranging from 0.22 to 0.29). The ratio for these same stations for the Replacement Bridge Alternative, Short and Long Span Options, are much higher, ranging from 0.348 near the shoreline to 1.20, with the ratios for the Long Span Option being slightly greater because the height for this approach option is higher. The portion of the western approach just prior to the main span (Stations 920+00 to 935+00) has a ratio that ranges from 0.54 to 1.05 for the existing bridge. Again, the ratios of these stations for the Replacement Bridge Alternative are much greater, ranging from 1.23to 1.82. The ratios for the main span of the existing bridge range from 1.51 to 1.52 and for the Replacement Bridge Alternative 1.4896 to 1.8161, while the ratios for the eastern approach are fairly similar for the existing and Replacement Bridge Alternative, ranging from 0.89 to 1.31 with the Long Span Option for the Replacement Bridge Alternative having the higher ratios.

The ratios in **Table 7** consider the height-to-width ratio separately for the two spans of the Replacement Bridge Alternative, assuming that the separation between the decks of the two spans (i.e., 70 feet at the main span and then decreasing toward the shorelines) allows light to penetrate between the two structures. This represents the best case analysis. Under this case, the Replacement Bridge Alternative would clearly result in a lower potential for shading of aquatic habitat compared to the existing bridge, particularly along the causeway (western approach to the main span). Even under the worst case, which assumes no separation between the spans of the Replacement Bridge Alternative and which would conservatively result in a halving of the height-to-width ratios presented in **Table 7**, the Replacement Bridge Alternative would still result in greater ratios (i.e., less shading) than the existing bridge for the western approach, but may result in more shading than the existing bridge for the eastern approach. Overall, the height-to-width ratios indicate that even if the Replacement Bridge Alternative was treated as a single structure, with no separation between the spans, there would be a decrease in the potential for shading impacts to aquatic resources.

Table 7
Height-to-Width Ratios for the Existing Bridge and Short and Long Span Options for the Replacement Bridge Alternative at Various Stations Across the Length of the Bridge

Location	Existing	Short Span		Long Span	
	91 ft-wide deck	96ft-wide	87ft-wide	96ft-wide	87ft-wide
845+00	0.29	0.34	0.38	0.44	0.48
860+00	0.22	0.52	0.57	0.60	0.67
875+00	0.22	0.70	0.78	0.78	0.86
890+00	0.22	0.91	1.00	0.96	1.06
905+00	0.22	1.08	1.20	1.13	1.24
920+00	0.54	1.23	1.36	1.24	1.37
935+00	1.05	1.46	1.61	1.46	1.61
950+00	1.52	1.65	1.82	1.65	1.82
965+00	1.51	1.49	1.64	1.49	1.64
980+00	1.01	1.19	1.31	1.19	1.31
995+00	1.07	0.99	1.09	0.89	0.98

The approximately 99,153-square foot permanent platform at the Rockland Bridge Landing would result in additional aquatic habitat affected by shading. Considering the extensive area of aquatic habitat not

affected by shading within the study area, the additional shading caused by the permanent platform and by the bridge would not result in direct effects to to sturgeon.

6.2. Indirect Effects

6.2.1. Impacts Associated with Resuspended Sediment

Dredging, pile driving, and construction vessel prop wash have the potential to re-suspend bottom sediments in the vicinity of the activity. Resuspension of sediments can have a range of impacts to fish depending on the species and life stages being considered. Lethal levels of TSS vary widely among species; one study, which included a variety of fish species common to the proposed construction site and representative of tolerant and sensitive species (white perch (*Morone americana*), spot (*Leiostomus xanthurus*), silversides (Atherinidae), bay anchovies (*Anchoa mitchilli*) and menhaden (*Brevoortia* spp.)) found that the tolerance of adult fish for suspended solids ranged from 580 mg/L to 24,500 mg/L (Sherk et al. 1975 as cited in NMFS 2003). Common impacts to fishes can be classified as biological/physiological or behavioral. Among the biological/physiological impacts are: abrasion of gill membranes resulting in a reduction in the ability to absorb oxygen, decrease in dissolved oxygen concentrations in the surrounding waters and effects on growth rate. Behavioral responses by fishes to increased suspended sediment concentrations include impairment of feeding, impaired ability to locate predators and reduced breeding activity. Increased TSS can inhibit migratory movements as well. A study conducted by NOAA concluded that TSS concentrations as low as 350 mg/L could interfere with upstream migrations of various species (NOAA 2001). At high suspended sediment concentrations, mortality has also been documented. Fish, however, are mobile and generally avoid unsuitable conditions in the field, such as large increases in suspended sediment and noise (Clarke and Wilber 2000). The effects of habitat avoidance are not expected to have widespread consequences for the ecology of the fish community based on their ability to move from the impacted area and because the spatial distribution of the community is considerably greater than the predicted extent of increased suspended sediment concentrations and the dredge footprint.

Lethal and sublethal effects of suspended sediments on fish species common to the study area have been observed at concentrations above those expected during project construction. In terms of sublethal effects, a stress response (e.g., elevated corticosterol levels) was reported for striped bass (1,500 mg/L), white perch (650 mg/L) and hogchoker (1,240 mg/L) well above expected concentrations (Wilber and Clarke 2001). Striped bass did not avoid concentrations of 954 to 1,920 mg/L to reach spawning sites (Summerfelt and Mosier 1976; Burton 1993) which are well above the levels likely to be encountered during dredging operations. Burton (1993) indicated that concentrations of suspended solids can reach thousands of milligrams per liter before an acute reaction is observed. Lethal effects were demonstrated between concentrations of 580 mg/L for sensitive species and 700,000 mg/L for more tolerant species. Lethal effects were not observed until suspended sediment concentrations exceeded 750 mg/L, at which point 100% mortality was observed for bluefish, Atlantic menhaden and white perch. More tolerant species exhibited 50% mortality at concentrations above 2,500 mg/L, including silversides (2,500 mg/L), spot (20,340 mg/L), cunner (28,000 mg/L) and mummichog (39,000 mg/L).

Sublethal effects on fish eggs and larvae have been reported in terms of slowed development, delayed hatching or reduced hatching success. Wilbur and Clarke (2001) in a literature summary of available data indicated that hatching is delayed for striped bass and white perch at concentrations of 800 mg/L and 100 mg/L, respectively, however, reduced hatching success (i.e., egg mortality) was not observed until concentrations reached 800-1,000 mg/L for these species. For eggs of Atlantic herring, there were no sublethal effects observed at suspended sediment concentrations of 300-500 mg/L (Wilber and

Clarke 2001), while eggs of blueback herring and Atlantic menhaden exhibited no change in hatching or development at a concentration of 1,000 mg/L (Wilber and Clarke 2001).

Modeling results indicated that on flood and ebb tides, concentrations of 10 mg/L above ambient conditions may extend in a relatively thin band approximately 1,000 to 2,000 feet from the dredges, while concentrations of 5 mg/L may extend a greater distance. These changes are considered well within natural variation that has been observed within the Hudson River. For example, during the sampling conducted for the project TSS concentrations ranged from 13 to 111 mg/L. Data recorded at Poughkeepsie indicated that during higher freshwater flow periods the difference between suspended sediment concentrations can vary by 20 to 40 mg/L. Therefore, the TSS projected to occur as a result of the project's construction would be expected to be below the physiological impact thresholds of adult and larval fish and also below concentrations that would be expected to impact migration. Furthermore, anadromous fish such as American shad, blueback herring, and alewife spawn well upriver and their most vulnerable early life stages such as eggs and yolk-sac larvae would not be expected to occur in the Tappan Zee vicinity. Impacts due to increased water column suspended sediments are expected to be minimal and would not result in adverse impacts to fish within the Lower Hudson River estuary.

While there are no studies on the effects of resuspended sediments on either the shortnose or Atlantic sturgeon they are routinely encountered in turbid waters (Dadswell et al. 1984) and as such are thought to be highly tolerant of suspended sediment at the levels that are generated by marine construction activities (NMFS 2011b). In fact, sturgeon feed on invertebrates that occur both on and within the bottom substrate, and as a consequence have evolved to tolerate high concentrations of suspended sediment. The action of feeding sturgeon itself may lead to substantial resuspension of sediments. In a study of Atlantic sturgeon feeding patterns in the Bay of Fundy, sturgeon feeding activity has been linked significant quantities of clay and silt becoming redistributed (Pearson et al. 2007). Within the area studied, these researchers estimated as much as 1,220 m^3 of sediment being resuspended during the six weeks during which peak sturgeon feeding activity occurred. NMFS concluded that the effect of suspended sediment concentrations in the range of 10-350 mg/L from dredging, pile driving and other construction activities for a marina project in the Haverstraw Bay region would be insignificant to shortnose sturgeon (NMFS 2011d). Citing the literature, NMFS indicated that the concentrations of TSS that would be expected to show adverse impacts to fish would be 580.0 mg/L for the most sensitive species, with 1,000 mg/L being more typical.

Hydrodynamic modeling has been used to project the path and extent of the plume of resuspended sediment that would result from sediment disturbing construction activities such as dredging and pile driving, and to anticipate the fate and transport of this plume within the Hudson River estuary.

Inputs to the hydrodynamic models included the following:

- Results of SedFlume[1] analysis of sediments within the vicinity of the area to be dredged conducted by Dr. Donald Hayes, that indicated sediments within the study area are highly susceptible to resuspension. Dr. Hayes is the director of the Institute for Coastal Ecology and Engineering at the

1 High Shear Stress flume (SEDflume http://www.erdc.usace.army.mil) is designed for estimating gross erosion rates of fine-grained and mixed fine/coarse-grained sediments and the variation of the erosion rate with depth below the sediment-water interface. The erosion data are used to predict stability for contaminated sediments, capping material, native sediment, or dredged material and are often incorporated into numerical sediment transport models. The flume is designed to erode sediment cores layer by layer. Each core layer is eroded by regulating flow over the core surface. The flume is operator-controlled, so the operator selects the range of shear stresses (starting at a low value and proceeding through higher values) for measuring erosion rate.

Universtiy of Louisiana at Lafayette Department of Civil Engineering and a recognized expert in the areas of dredging, sediment management, beneficial uses and contaminated sediment (Louisiana Sea Grant program (http://www.laseagrant.org/comm/experts/hayes.htm).

- Existing information to characterize the Hudson River Estuary within the study area, examples of which include bathymetry from the National Oceanic and Atmospheric Administration (NOAA) navigational charts, tidal data from US Geological Survey (USGS) and NOAA tide stations, USGS freshwater discharge, salinity and suspended sediment concentration data, and USGS suspended sediment concentration data.

- Results of numeric models developed by Dr. Hayes to estimate suspended sediment loadings that would result from dredging; pile driving, coffer dam installation, dewatering, and removal; and vessel movement as described below. Inputs to these models are presented below.

  - Suspended sediment generated by dredging—dredging area (up to approximately 173 acres (about 0.52 km^2, or 0.2 square miles) and volume (up to 1.37 million cubic meters, or 1.8 million cubic yards), rate of dredging [about 5,734 cubic meters (7,500 cubic yards) per dredge per 24 hour period with two dredges operating concurrently], use of environmental/closed bucket with no barge overflow and a conservative sediment loss rate of about 1 percent. This conservative loss rate, combined with the projected dredging rate and the sediment characteristics results in an average sediment resuspension rate for each dredge of 39 kilograms per minute (kg/min), and a maximum rate of 94 kg/min.
  - Suspended sediment generated by cofferdam construction and dewatering—In the absence of existing information on sediment resuspension rates associated with cofferdam construction, resuspension of sediment during installation of sheet pile for cofferdams was developed on the basis of results of suspended sediment monitoring conducted for the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project during dredging and in-water construction activities. (http://biomitigation.org/bio_overview/subjects_overview.asp#water). Results of monitoring for that project indicated that installation of sheet pile for cofferdam construction resulted in average resuspension of bottom material that was about 30 percent of the average resuspension during dredging.
  - Suspended sediment generated by pile driving and dewatering—Existing information on sediment resuspension from pile driving and dewatering was similarly absent and was estimated to be approximately 40 percent of that observed during dredging on the basis of the suspended sediment monitoring for the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project.
  - Suspended sediment generated by vessel movement and prop scour—As discussed previously a layer of gravel and sand would be placed at the bottom of the dredged channel to minimize sediment re-suspension. However, this layer would not prevent the resuspension of sediment that would be naturally deposited each day. Using an estimated depositional rate of sediment within the dredged channel of 104 kilograms per meter per day developed on the basis of van Rijn (1986) and total suspended sediment concentrations measured during studies conducted for the Replacement Bridge Alternative, the hourly scour rate of sediment as the vessels move along the channel was estimated as 8.7 kg per meter per hour (kg/m/hr).

As indicated in the construction timeline presented in **Figure 7**, there are periods when sediment disturbing activities evaluated in the hydrodynamic modeling would occur concurrently, with the majority of the potential for sediment resuspension occurring during the first two dredging periods. The

hydrodynamic modeling results comprise conservative scenarios that would be expected to result in the greatest sediment resuspension:

- Stage 1 dredging with pile driving for the main span (Zone C) and trestles;
- Pile driving and cofferdam installation and dewatering for Zones C and B, movement of construction vessels, and trestle construction after Stage 1 dredging is complete; and
- Stage 2 dredging combined with pile driving and cofferdam installation and dewatering for Zones C and B, and movement of construction vessels.

6.2.1.1. Sediment Resuspension and Transport

The Long Span Option would have fewer total number of piers than the Short Span Option (see **Figures 12** and **13**), resulting in a shorter construction duration (4½ years) than the Short Span Option (5½ years). While the number of main span piers is the same between the two options, the long span option has far fewer piers in the approaches.

Sediment disturbing construction activities include dredging, cofferdam construction, and pile driving within Substructure Zones A and B, pile driving within Substructure Zone C (see **Figures 12** and **13** for the location of these zones) and the movement of construction vessels within the construction access channel for the Long and Short Span options. Within Construction Zones A and B (see **Figures 12** and **13**) pile driving would occur within the cofferdams and would not have the potential to re-suspend sediment within the river. Within Zone C, piles would be driven first and then the pile caps installed within hanging cofferdams. Therefore, only the Zone C piles would have the potential to result in additional sediment re-suspension. Hydrodynamic modeling was used to project the plume of resuspended sediment that would result from these concurrent sediment disturbing construction activities and the fate and transport of this plume within the river estuary.

The results of the modeling of the scenarios expected to result in the greatest resuspension of sediment indicated in **Figures 25** through **28** are similar for the Long Span and Short Span Options and indicate that total suspended sediment concentrations in the range of 50 to 100 mg/L above ambient conditions would only occur in the immediate vicinity of the dredges. This level of increase would be expected to occur within the allowable mixing zone[2] for dredging. Other sediment disturbing construction activities would result in a much smaller contribution of suspended sediment (i.e., driving of piles for the cofferdams, pile driving, vessel movement and cofferdam dewatering). On flood and ebb tides, concentrations of 10 mg/L above ambient conditions may extend in a relatively thin band approximately 305 to 610 m (1,000 to 2,000 feet) from the dredges, while concentrations of 5 mg/L may extend a greater distance. Total suspended sediment concentrations recorded during sampling conducted for the project ranged from 13 to 111 mg/L. Additionally, the approximately 8-year record of suspended sediment concentration (SSC) recorded by the USGS at Poughkeepsie indicates there is considerable variation in the suspended sediment concentration within the Hudson River, as would be expected with an estuarine environment. During periods of higher freshwater flow the differences between low and high SSCs range between approximately 20 to 40 mg/L, during periods of low freshwater inflow the differences between low and high SSCs range from about 5 to 20 mg/L. Therefore, the projected

2 A mixing zone is an area in a water body within which the NYSDEC will accept temporary exceedances of water quality standards resulting from short-term disruptions to the water body caused by dredging or the management of dredged material. A mixing zone can be assigned at the site of dredging (NYSDEC 2004).

increases in suspended sediment due to dredging concurrent with other sediment-disturbing construction activities would be well within the natural variation in suspended sediment concentration and would not result in adverse impacts to water quality and would be expected to meet the turbidity standard[3] for Class SB waters at the edge of the mixing zone. Concentrations of total suspended sediment from cofferdam construction (which include the discharge of river water recovered during dewatering) and pile driving would be approximately 5 to 10 mg/L in the immediate vicinity of the activity (within a few hundred feet) which would be much less than that projected to result from dredging and would not result in adverse water quality impacts. Concentrations of total suspended sediment resulting from construction vessel movement are projected to be less than 5 mg/L. Increases of total suspended sediment concentration above ambient would be greatest during slack tide, without tidal action to disperse it (see **Figures 25** and **27**).

Placement of the sand/gravel armoring material within the dredged area, similar to the placement of granular capping material over contaminated sediment, has the potential to result in sediment resuspension when the capping material is deposited upon the sediment, but would not be expected to affect the magnitude of sediment resuspension projected through the hydrodynamic modeling. Results of monitoring conducted during placement of granular capping material on soft sediment indicated that resuspended sediment plumes were due to fines washed of the sand cap material and not due to resuspension of bottom sediment as the capping material was put in place (USACE 2005). Measures would be implemented during placement of the sand layer of the armoring to minimize resuspension of the newly exposed sediment. These measures are the same type of measures that have been demonstrated to successfully cap contaminated sediment with minimal mixing of the cap with contaminated sediment (Palermo et al. 2011), and for the capping of subaqueous dredged material (Palermo et al. 1998). They include both mechanical (dry sand capping material with bottom-dump barge, side-casting, bucket/clamshell, tremie (gravity-fed downpipe)) and hydraulical (wet/slurry of sand placed from a pipe or tremie, or from a spreader barge) placement of the capping material (USACE 2005 and 2006, USEPA 1994, Palermo et al. 2011). Mechanical methods rely on the gravity settling of the granular capping materials in the water column (Palermo et al. 2011) which can result in less water column dispersion than discharge of hydraulically-handled cap material because it settles faster in the water column (USACE 1991). Hydraulic methods can allow for a more precise placement of the material at the surface or depth but may require use of a dissipation devise to reduce sediment resuspension (Palermo et al. 2011, USACE 1991).

Placing sand capping material in layers has been found to allow gentle spreading, resulting in a more stable sand cap (Ling and Leshchinsky undated), and avoiding displacement of or mixing with the underlying sediment (USEPA 2005). This results in a decrease in the turbidity plume with each successive cap layer. The reduction in sediment resuspension observed by placing granular capping material in lifts or layers may afford the ability to place subsequent layers using an alternative methodology that may allow faster placement (USEPA 2008). Therefore, once the sand layer of the proposed armoring is in place, the placement of the gravel would have limited potential to result in sediment resuspension. With the implementation of these methods of placement of granular capping material that have been proven to reduce sediment resuspension during placement, additional sediment resuspension that would occur during the placement of the armoring material would be minimized and would not be expected to result in adverse water quality impacts.

3 The turbidity standard for Class SB waters is "No increase that will cause a substantial visible contrast to natural conditions."

In summary, the results of the hydrodynamic modeling of changes in suspended sediment resulting from construction activities—dredging, pile driving, cofferdam construction, and vessel movement—indicate that with the exception of the portion of the mixing zone within the immediate vicinity of the dredge, increases in suspended sediment would be minimal for the Long and Short Span Options and within the natural range of variation of suspended sediment concentration within this portion of the river. Sediment resuspension resulting from dredging and other sediment disturbing activities would be expected to meet the Class SB turbidity standard at the edge of the mixing zone. Resuspended sediment would dissipate shortly after the completion of the dredging activities, and would not result in adverse impacts to water quality. During the periods of in-water construction when no dredging is occurring, the limited sediment resuspension during pile driving, cofferdam installation and removal, and vessel movement would be localized, would be expected to dissipate shortly after the completion of in-water construction activity and would not result in adverse water quality impacts. Similarly, with the implementation of measures demonstrated to minimize sediment resuspension during placement of capping or armoring material, the placement of the armoring material within the dredged area would not result in adverse water quality impacts.

For all of the reasons presented above, the modest increase in suspended sediment projected to result from dredging and other in-water sediment-disturbing construction activities, even under the worst case scenarios, and the placement of armoring within the dredged channel, would not be expected to result in any adverse effect to shortnose or Atlantic sturgeon in the Hudson River, which are extremely tolerant of elevated levels of suspended solids.

6.2.1.2. Sediment Quality

The results of sediment quality analyses are summarized in Tables 8, 9 and 10, and identify the samples classified as Class B (moderate contamination) or Class C (high contamination) for metals (see **Table 8**), SVOCs (see **Table 9**), and pesticides, PCBs, and dioxins (see **Table 10**) in accordance with NYSDEC's In-Water and Riparian Management of Sediment and Dredged Material (NYSDEC 2004). Contaminants observed that were classified as Class B or Class C included Total PCBs, Total PAH, mercury, dioxin/furan TEQ, Total DDT, DDD and DDE, arsenic, copper, and cadmium.While there are some locations for which certain contaminants fall under the Class B or Class C category, these concentrations typically apply to only the upper few feet and the concentrations of these contaminants decline to those meeting Class A (no appreciable contamination) category within a few feet of the mudline. Resuspension of sediments during dredging can also affect water quality through the release of contaminants dissolved in the sediment pore water (i.e., the water occupying the spaces between sediment particles). Considering the limited plume of increased suspended sediment above ambient concentrations projected to occur during the three-month dredging periods between August 1 and November 1, and the limited area of sediments with low to moderate levels of contamination within the area to be dredged, the release of any contaminants would not result in adverse effects to sturgeon that may come into contact with the plume.

The other in-water construction activities with the potential to result in sediment resuspension (pile driving, installation of the cofferdam and vessel movement) for the Long and Short Span Options are projected to result in a minimal increase in SSC above ambient concentrations. These projected increases would actually be much lower, because within Zones A and B, the sand/gravel armoring layer installed throughout these two zones to minimize scouring would also minimize any resuspension of sediment resulting from the installation of the cofferdams.

Table 8
Results of Sediment Quality Analysis – Metals

Parameter	Sediment Criteria		Hudson River Average[2]	Number of Samples Analyzed	Detection Rate	Minimum (mg/kg)	Average (mg/kg)	Median (mg/kg)	95th Percentile (mg/kg)	Maximum (mg/kg)
	ERL[1] (mg/kg)	ERM[1] (mg/kg)								
Aluminum	NC	NC	10256.9	313	100%	483	11,714	11,700	17,300	21,700
Antimony	NC	NC	--	156	0%	ND	ND	ND	ND	ND
Arsenic	8.2	70	7.2	313	97%	ND	8.06[A]	7.4[A]	14[B]	26.4[B]
Barium	NC	NC	--	313	92%	ND	43	32.9	91.04	190
Beryllium	NC	NC	--	313	47%	ND	0.79	0.76	1.1	2.61
Cadmium	1.2	9.6	1.0	313	46%	ND	1.9[B]	1.92[B]	3.2[B]	6[B]
Calcium	NC	NC	--	313	98%	ND	4,919	2,620	16,550	64,600
Chromium	81	370	38.1	313	100%	1.17	31	21.9	85.86	116
Cobalt	NC	NC	--	313	96%	ND	10	9.8	13.7	17.3
Copper	34	270	42.4	313	99%	ND	32[A]	12.4[A]	102.55[B]	1,550[C]
Iron	NC	NC	--	313	100%	1380	24,227	24,200	32,600	40,900
Lead	46.7	218	44.6	313	100%	1.42[A]	36[A]	10.9[A]	137.4[B]	604[C]
Magnesium	NC	NC	--	313	100%	252	5,765	5,760	7,476	39,600
Manganese	NC	NC	--	313	100%	21.8	626	587	1,170	1,600
Mercury	0.15	0.71	0.38	313	37%	ND	0.89[B]	0.53[B]	2.46[C]	6.33[C]
Nickel	20.9	51.9	21.5	313	99%	ND	21	20.6	32.6	38.3
Potassium	NC	NC	--	313	97%	ND	2181	2,130	3,257	4,460
Selenium	NC	NC	--	313	43%	ND	4.01	3.945	6.2775	12.6
Silver	1	3.7	1.5	156	17%	ND	2.02	1.9	3.04	3.3
Sodium	NC	NC	--	313	94%	ND	2,229	2,035	3,761.50	5,730
Thallium	NC	NC	--	156	1%	ND	12.4	12.4	12.4	12.4
Vanadium	NC	NC	--	313	99%	ND	24.7	23.7	36.3	54.1
Zinc	150	410	129.2	313	100%	8.74	90	65	221	399

Notes: mg/kg = milligrams per kilogram; NC = no criteria; ND = not detected, -- = not available.

Sources:

[1] NYSDEC 1999

[2] Llanso et al. 2003

[A] Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

[B] Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

[C] Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

Table 9
Results of Sediment Quality Analysis – SVOCs

Parameter	Sediment Criteria		Hudson River Average[3]	Number of Samples Analyzed	Detection Rate	Minimum (µg/kg)	Average (µg/kg)	Median (µg/kg)	95th Percentile (µg/kg)	Maximum (µg/kg)
	ERL[1] (µg/kg)	ERM[1] (µg/kg)								
Acenaphthene	16	500	289.4	156	8%	ND	36	ND	89	3,270
Acenaphthylene	44	640	139.2	156	16%	ND	13	ND	111	206
Anthracene	85.3	1,100	283.2	156	27%	ND	47	ND	155	2,030
Benzo(a)anthracene	261	1,600	176.4	156	43%	ND	130	ND	418	3,760
Benzo(a)pyrene	430	1,600	174.1	156	51%	ND	133	37	496	3,020
Benzo(b)fluoranthene	NC	NC	184.7	156	42%	ND	110	ND	445	2,460
Benzo(g,h,i)perylene	NC	NC	123.5	156	42%	ND	64	ND	260	1,530
Benzo(k)fluoranthene	NC	NC	163.4	156	42%	ND	91	ND	328	2,370
Chrysene	384	2,800	178.7	156	44%	ND	134	ND	487	3,490
Dibenzo(a,h)anthracene	63.4	260	--	156	15%	ND	14	ND	78	456
Fluoranthene	600	5,100	218.9	156	49%	ND	333	ND	994	13,300
Fluorene	19	540	291.2	156	10%	ND	28	ND	81	2,210
Indeno(1,2,3-c,d)pyrene	NC	NC	104.8	156	33%	ND	53	ND	220	1,510
2-Methylnaphthalene	70	670	--	156	1%	ND	0.96	ND	ND	113
Naphthalene	160	2,100	111.0	156	9%	ND	11	ND	49	504
Phenanthrene	240	1,500	299.1	156	40%	ND	163	ND	539	7,030
Pyrene	665	2,600	265.7	156	48%	ND	288	ND	999	9,570
Total PAHs (sum of above)	4,020	44,792	3,003	156	--	22.8[A]	1,673[A]	113[A]	6,079[B]	48,211[C]
bis(2-Ethylhexyl)phthalate	NC	NC	--	156	33%	ND	82	ND	259	4,240
Butyl benzyl phthalate	NC	NC	--	156	12%	ND	101	ND	289	5,140
Carbazole	NC	NC	--	156	3%	ND	5.25	ND	ND	349
Dibenzofuran	NC	NC	--	156	5%	ND	20	ND	6.6	2,660
Di-n-butyl phthalate	NC	NC	--	156	3%	ND	30	ND	ND	4,360

Notes: µg/kg = micrograms per kilogram; NC = no criteria; ND = not detected; -- = not available.

Sources:

[1] NYSDEC 1999; [2] NYSDEC 1999; [3] Llanso et al. 2003

[A] Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

[B] Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

[C] Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

Table 10
Results of Sediment Quality Analysis – Pesticides, PCBs, and Dioxins

Parameter	Sediment Criteria					Hudson River Average[2]	Number of Samples Analyzed	Detection Rate	Minimum (µg/kg)	Average (µg/kg)	Median (µg/kg)	95th Percentile (µg/kg)	Maximum (µg/kg)
	ERL[1] (µg/kg)	ERM[1] (µg/kg)	BA- Chronic[1] (µg/gOC)	BA- Acute[1] (µg/gOC)	WA[1] (µg/gOC)								
alpha-Chlordane	NC	NC	NC	NC	0.006	--	156	1%	ND	0.1	ND	ND	16
gamma-Chlordane	NC	NC	NC	NC	0.006	--	156	1%	ND	0.09	ND	ND	15
Chlordane (sum of above)	NC	NC	0.002	0.05		--	156	--	--	0.19[A]	--	--	31[B]
Dieldrin	NC	NC	17.0	NC	NC	--	156	1%	ND	0.03[A]	ND	ND	4.8[A]
4,4'-DDD	NC	NC	-	-	NC	5.7	156	14%	ND	2.07	ND	12	54
4,4'-DDE	2.2	27	-	-	NC	--	156	7%	ND	0.47	ND	3.85	17
4,4'-DDT	1	7	1	130	NC	19.7	156	5%	ND	2.47	ND	0.73	352
Sum of DDT, DDD, and DDE	1.58	46.1	-	-		25.4	156	--	--	5.01[B]	--	16.58[B]	423[C]
Aroclor 1242	NC	NC	NC	NC	NC	--	156	13%	ND	51	ND	280	1,520
Aroclor 1248	NC	NC	NC	NC	NC	--	156	8%	ND	35	ND	239	1,200
Aroclor 1254	NC	NC	NC	NC	NC	--	156	4%	ND	6.13	ND	ND	221
Total PCBs	22.7	180	-	-	NC	726.8	156	--	40[A]	169.95*[B]	64[A]	682.25[B]	1,520*[C]
TCDD TEQ (pptr)	NC	NC	NC	NC	0.0002	--	17	100%	0.069[A]	11.84[C]	0.89[A]	54.2[C]	94.67[C]

Notes: µg/gOC = micrograms per gram of organic carbon; µg/kg = micrograms per kilogram; NC = no criteria; ND = not detected; BA = Benthic Aquatic; WA = Wildlife Accumulation; -- = not available; - ERM/ ERL applies.

Sources:

[1] NYSDEC1999

[2] Llanso et al. 2003

* The sum of PCBs is multiplied by two to determine the total PCB concentration (NYSDEC 2004).

[A] Concentration falls within Class A - no appreciable contamination/no toxicity to aquatic life (NYSDEC 2004).

[B] Concentration falls within Class B - moderate contamination/chronic toxicity to aquatic life (NYSDEC 2004).

[C] Concentration falls within Class C - high contamination/acute toxicity to aquatic life (NYSDEC 2004).

6.2.2. Effects of Existing Bridge Demolition

Bridge demolition would occur in two stages. The first stage includes partial demolition to allow for construction of the replacement bridge in the vicinity of the Westchester shoreline. The second stage includes the remaining demolition after completion of the replacement bridge. Use of turbidity curtains during removal of the columns and footings and cutting of the timber piles would minimize the potential for sediment resuspended during the bridge removal activities to adversely affect water quality. Following removal of the existing bridge, sediment that has been deposited within mounds in the vicinity of the existing bridge piers may erode over time until reaching a new equilibrium elevation. Because the Tappan Zee portion of the Hudson River is considered to be neither a depositional or erosional environment (i.e., in equilibrium) (Nitsche et al. 2007), the erosion of these sediments in the vicinity of the existing bridge would be limited under normal river conditions and would most likely occur during high flow events. While some of these sediment deposits have elevated concentrations of certain contaminants (Class B or Class C categories), these elevated concentrations do not extend more than a few feet below the mudline. Therefore, the gradual erosion of some areas of contaminated sediment following the removal of the bridge would not be expected to result in adverse impacts to water quality or result in water quality conditions that fail to meet the Class SB standards.

Turbidity curtains would be used during removal of the columns and footings and cutting of the timber piles would minimize the potential for sediment that may be resuspended during bridge removal activities to affect benthic macroinvertebrates and other aquatic biota. Since the benthic sampling program for the project indicated similar benthic community structure in bottom sediments at both existing and proposed bridge location, and because the demolition is not expected to substantially alter sediment characteristics, the benthic community recolonizing the restored bottom habitat following bridge demolition would be expected to be similar to that lost as a result of dredging. Demolition of the existing bridge would also remove the benthic invertebrates and algae that are attached to the bridge, which provide forage and structural habitat for fish. However, the new bridge would offset much of these losses by providing similar structural habitat for these species. Any effects to shortnose sturgeon due to increased water column suspended sediments from bridge demolition activities are expected to be minimal and would not be expected to materially affect shortnose sturgeon feeding opportunities or migrations.

6.2.3. Altered Predator-Prey Relationships

Shortnose and Atlantic sturgeon are benthic predators that forage in the substrate and consume primarily crustaceans, insects, mollusks and polychaete worms (Scott and Crossman 1973, Dadswell 1979, Pottle and Dadswell 1982, Dadswell et al. 1984, Bain 1994, Bain 1997, Bain 2001). Foraging habitat for both sturgeon species in the Hudson River is characterized by deep water and fine, silty sediments (Haley et al. 1996, Bain et al. 2000, Bain 2001) although shortnose sturgeon also feed in shallow areas and along river banks in water 1-5 meters deep, but concentrate in deeper water during late summer (Dovel 1978, Dadswell et al. 1984) where they remain during the winter months (Bain 1997). Within the study area, fine clayey silt substrates are common (**Figure 5**), but deep-water habitat is limited to the channel along the eastern shoreline. Despite the prevalence of fine sediment in the study area though, the primary sturgeon foraging habitat is located well upstream of the Tappan Zee region (Haley et al. 1996, Bain et al. 2000, Bain 2001). For sturgeon that forage within the study area, the most likely potential impacts of the Project are related to dredging of benthic feeding areas and habitat exclusion caused by pile-driving noise.

The dredging and armoring of the 165 to 175 acre (0.67 to 0.71 km2) access channel will create an area of reduced foraging opportunities for shortnose and Atlantic sturgeon during the construction period. However, the dredged area represents a comparatively small percentage of the available benthic area within the Tappan Zee region (1.2%) as defined by the Hudson River Utilities (RM 24-33), and an even smaller percentage of river-wide benthic area (0.2%). Because both sturgeon species typically forage at depths exceeding those in the proposed dredged location, this relatively shallow area is not likely to be preferred foraging habitat prior to dredging. Following dredging, water depths would still be relatively shallow at 4.3 m (14 feet) and the coarse gravel substrate used to armor the channel bottom would not likely support the preferred prey items of sturgeon. Benthic habitat outside of the dredged area would not be expected to change in terms of sediment grain size or forage opportunities for sturgeon.

Temporary habitat exclusion caused by pile driving noise is expected to create an ensonified zone that could be unavailable for foraging during certain periods of the day; however these periods would be limited to less than 12 hours daily during most pile driving, and less than 5 hours a day during the the time period when large piles are driven. Although noise levels in these areas may restrict diurnal foraging opportunities during pile driving, both species of sturgeon are known to forage nocturnally and would still be able to use the ensonified area during the night. There would also be considerable foraging habitat available within the study area and outside of the dredged channel and the ensonified area. Shortnose sturgeon, in particular, are known to travel up to 13.5 km (8.4 miles) within a day (McCleave et al. 1977), which means that construction activities would not prevent foraging as sturgeon could move through the study area to unimpacted foraging areas. The preferred foraging habitat in deep waters, specifically in the navigation channel, would remain available for foraging throughout the large majority of bridge construction based on the location and extent of modeled noise isopleths.

Atlantic sturgeon are less likely than shortnose sturgeon to be affected by potential loss of foraging habitat because their use the Hudson River is more intermittent. Adult females migrate directly to spawning grounds, which are deep, channel or off-channel habitats (Dovel and Berggren 1983) in the freshwater portions of the River, upstream of the study area (K. Hattala, pers. comm.). During the upstream spawning migration, females are thought to fast (Dadswell 1979, Smith 1985). Post-spawn Atlantic sturgeon remain in fresh water habitats upstream of the study area until emigration to coastal marine waters (Smith 1985). Furthermore, Atlantic sturgeon typically remain in water deeper than 7.5 meters (Bain et al. 2000). Therefore, use of the Tappan Zee region for foraging by Atlantic sturgeon adults is likely minimal and loss of benthic habitat due to dredging of the construction channel or from pile-driving noise is not likely to impact adult Atlantic sturgeon. Juvenile Atlantic sturgeon remain in the Hudson River for several years and are found primarily upstream of the study area between river kilometers 68 and 107 (RM 42 to 67) and in water depths from 10-25 meters (Bain et al. 2000), except from November through March when they occupy deep, channel habitats between km 19 to 74 (RM 12 to 45), which includes the study area (Dovel and Berggren 1983).

Several project-related factors reduce the likelihood of impacting sturgeon foraging in the study area, including the restricted schedule for pile driving and the relatively small area of unavailable foraging habitat within the 187 dB SEL_{cum} noise isopleths as well as the shallow depth and small spatial extent of the dredged access channel. These factors, coupled with the spatial distribution of juvenile and adult sturgeon and their primary foraging habitats within the Hudson River relative to the study area (i.e. primarily deep water and upstream) as well as the intermittent occupancy of the Hudson River by adult Atlantic sturgeon make it unlikely that any long-term indirect effects on sturgeon foraging would be realized as a result of the project's construction.

6.2.4. Long-Term Habitat Alteration

The area where the Replacement Bridge Alternative will be constructed is neither shortnose nor Atlantic sturgeon spawning habitat. Both these species spawn well north of the Tappan Zee Bridge with the principal spawning area for the shortnose being as far north as Albany. However, dredging of the access channel will result in a temporary modification of benthic habitat. Over time deposition processes would allow much of the benthic habitat to return to its pre-construction state. The rate of this transformation would begin at approximately 1 foot per year, likely decreasing as the bed nears it natural pre-dredged elevation. The temporary loss of the access channel area would represent a minor fraction of similar habitat available to sturgeon throughout the Tappan Zee Reach. Except for the permanent loss of up to 0.05 km^2 (13 acres) of oyster habitat, which would not be considered optimal shortnose sturgeon foraging habitat, a long-term habitat alteration would not occur.

6.3. Cumulative Effects

The assessment of cumulative effects addresses the potential impacts from the project and other projects proposed within, or in the vicinity of, the study area that may affect shortnose and Atlantic sturgeon. The proposed Champlain Hudson Power Express Inc. cable project and the American Sugar Refining, Inc. maintenance dredging project are the projects identified for evaluation of cumulative effects with the Tappan Zee Replacement Bridge Alternative. At the present time, US Gypsum, located upriver within Haverstraw Bay, is not expected to dredge its Stony Point facility and is not, therefore, evaluated with respect to cumulative impacts for the Replacement Bridge Alternative.

Champlain Hudson Power Express Inc. filed an application for a Certificate of Environmental Compatibility and Public Need Pursuant to Article VII of the Public Service Law of New York State. The Applicant is proposing to construct and operate a 1,000 MW submarine, underground, high-voltage, direct current, cable transmission system which will transport power from Canada and upstate New York to load centers in the New York City metropolitan area. The proposal calls for burying cables within two separate trenches 6 feet apart along a 118-mile stretch of the Hudson River that includes the study area for the Tappan Zee Replacement Bridge Alternative. Within the study area, the cables would be buried through the use of water jetting, where possible, and by hydroplow or dredging where water jetting is not feasible (i.e., within Haverstraw Bay).

Depending upon the proposed timing of the submarine cable installation, there is a potential for conflict between the competing activities of the cable and Replacement Bridge Alternative that would need to be resolved for the portion of the cable that would be traversing the study area. Water jet embedment as a technique for underwater cable installation is considered to have temporary and minimal impacts to aquatic resources compared to dredging. This is because the trench (four feet deep and two feet wide) created by the jetting device for each cable and its installation would only result in a temporary disturbance of the river bottom (ESS 2011). The associated increase in suspended sediments would also be expected to be short-term and localized because much of the resuspended sediments would be contained within the limits of the trench wall, with only a minor percentage of the re-suspended sediments leaving the trench. Any re-suspended sediments leaving the trench would be expected to settle out within proximity of the trench depending on sediment grain size, composition, water currents and the hydraulic jetting forces imposed on the sediment column (HDR/DTA, April 2010, *Champlain Hudson Power Express HVDC Transmission Project, Least Environmentally Damaging Practical Alternative Evaluation,* Prepared for Champlain Hudson Power Express, Inc., Toronto, Ontario, http://www.chpexpress.com/docs/regulatory/USACE/CHPE_USACE_Application_Apendices.pdf).

Water jetting would potentially result in the loss of some benthic organisms unable to move from within the footprint of the trench, due to direct contact with the water jet or an inability to tolerate burial. The benthic community within the disturbed area would be expected to recover following completion of the trenching process (Ocean Surveys, Inc. 2005 in HDR/DTA 2010). Finfish would be expected to avoid areas of temporarily increased suspended sediment (HDR/DTA 2010). Within the study area, the proposed cable project would not have the potential to affect shortnose or Atlantic sturgeon spawning habitat.

Cumulative adverse impacts to shortnose and Atlantic sturgeon are not expected as a result of the cable project and maintenance dredging activities with the Replacement Bridge Alternative although project details would need to be forthcoming and potential impacts more rigorously evaluated by regulatory agencies. Collectively, these projects would not have the potential to affect spawning habitat within the study area. The limited duration and area of disturbance resulting from cable installation within the study area would not be expected to result in changes in water quality (i.e., increases in suspended sediment) or result in long-term changes to aquatic habitat. Furthermore, the cumulative activities of these projects are not expected to adversely affect shortnose sturgeon foraging or migration through the study area for either sturgeon species. Should dredging be required for the installation of the cable in Haverstraw Bay, the distance between the study area and Haverstraw Bay is greater than 5 miles and outside the projected area of incremental increase in suspended sediment due to the project and would not result in cumulative adverse impacts to water quality within the study area. Therefore, cumulative adverse effects to water quality would not be expected to occur from construction of the cable project and the Tappan Zee Hudson River Crossing Project.

American Sugar Refining, Inc. received authorization from the NYSDEC and the USACE to conduct maintenance dredging (approximately 80,000 cubic yards) within an approximately 5-acre berth area (approximately 650- to 850-feet long and extending into the river from the shoreline for about 300 feet) located about 14 miles downriver from the study area. The NYSDEC permit expires on October 31, 2016. It restricts dredging to the period of July 1 to October 31 and requires that anti-sedimentation curtains (floating boom with attached silt curtain with a minimum 3-ft depth) be deployed around the spoil-receiving barge and the mechanical dredge during dredging to minimize dispersal of dredged material. Dredge material was determined to meet the requirements for disposal at the Historic Area Remediation Site (HARS) and would be transported to the HARS in bottom-opening barges.

Maintenance dredging by American Sugar Refining, should it occur concurrently with dredging for the project, would be at least 14 miles down-river. This distance is far beyond the 1,000 to 2,000 feet over which the incremental increase in suspended sediment of 10 mg/L due to the Replacement Bridge Alternative has been projected by the hydrodynamic modeling and beyond the 5 mg/L incremental increase in projected suspended sediment.

The area of maintenance dredging for American Sugar Refining extends only 300 feet into the river from the east bank and does not extend into the navigation channel. Therefore, the three projects would not be expected to result in cumulative adverse impacts to migration of shortnose sturgeon, Atlantic sturgeon, or other anadromous fish species.

Chapter 7 Effect Determinations

7.1. Effect Determination for Listed and Proposed Species

The results of this BA indicate that:

1. For individual shortnose and Atlantic sturgeon within the immediate vicinity of pile driving and other in-water construction activities, there is a potential for injury.

2. Pile driving and dredging would have minimal effects to sturgeon migratory activities as there will always be large portions of the river width that will not be ensonified, and dredging will be limited to three month windows that will take place between August 1 and November 1 during three of the 4 ½ or 5 ½ construction years.

3. There is no designated critical habitat for shortnose sturgeon and none is proposed for Atlantic sturgeon.

4. Dredging of 0.67-0.71 km^2 (165-175 acres) for access channels will create an area of reduced foraging opportunities for both shortnose and Atlantic sturgeon due to loss of habitat. However, upon completion of in-water activities in a given area, estuarine depositional processes would, over time, allow the benthic habitat to return to its pre-construction condition. The temporary loss of the access channel area would represent a minor fraction of similar habitat in the Tappan Zee portion of the Hudson River.

5. Incidental vessel strikes will be insignificant because sturgeon are generally found within one meter of the bottom in the deepest available water. Based on the types of vessels to be employed and their drafts, there should always be sufficient clearance between vessels and the river bottom.

6. Indirect effects from resuspended sediments are expected to be insignificant.

7. A review of the literature suggests that the likelihood of the project to affect the four other DPS of Atlantic sturgeon in any meaningful way is low.

The BA concludes that while the Replacement Bridge Alternative may potentially injure individual shortnose and/or Atlantic sturgeon in the immediate vicinity of the pile driving resulting in an incidental take, and dredging and armoring of the bottom will result in a temporary reduction in foraging opportunities, the project will not jeopardize the continued existence of the shortnose or Atlantic sturgeon populations of the Hudson River.

Based on the fact that marine mammals are rare, transients to the study area, the proposed project will not jeopardize the continued existence of the marine mammal species that have been reported in the Tappan Zee reach of the Hudson River.

There is a possibility that the Historic Area Remediation Site (HARS) will be used for the disposal of the project's dredged material. Consultations pursuant to Section 7 of the Endangered Species Act (ESA) have taken place for the area of the HARS during preparation of the SEIS. The USEPA prepared a biological assessment that concluded that the closure of the Mud Dump Site and designation of the

HARS would not be likely to adversely affect loggerhead and kemps ridley sea turtles and humpback and fin whales (USEPA 1997). Special conditions are included in USACE Section 103 permits for placement of Remediation Material at HARS that requires the presence of NMFS approved Endangered Species Observer(s) on disposal scows during their trips to the HARS. The role of these observers is to prevent adverse impacts to endangered or threatened species transiting the area between the proposed dredge site and the HARS. With the implementation of these conditions placement of Remediation Material at the HARS would not result in adverse effects threatened or endangered species, also including marine mammals.

7.2. Effect Determination for Critical Habitat

There is no designated critical habitat for the shortnose sturgeon and no critical habitat has been proposed for Atlantic sturgeon at this time. As a consequence, there will be no effect on critical habitat.

7.3. Overall Effect Determination

Overall project effects are summarized bekiw. **Table 11** that lists affected species and major project elements, and the effect determinations associated with each.

Table 11
Overall Project Effects

Jurisdiction	Federal Status	Common Name	Effect Determination for Pile Driving	Effect Determination for Permanent Loss of Habitat Due to Dredging	Effect Determination for Vessel Traffic	Effect Determination for Sediment Resuspension	Overall Effect Determination for Project
NMFS	Endangered	Shortnose Sturgeon	Likely to adversely affect	No effect	No effect	No effect	Likely to adversely affect
NMFS	Proposed for Listing	Atlantic Sturgeon	Likely to adversely affect	No effect	No effect	No effect	Likely to adversely affect
NMFS	Various	Marine Mammals	No effect	No effect	No effect	No effect	No effect

7.3.1 Reasonable and Prudent Measures to Minimize Take

As outlined previously, every effort will be made to ensure that the potential for incidental take of Atlantic and shortnose sturgeon is minimized by observing a number of environmental commitments and assurances. Briefly, these include: 1) pilot testing of various noise abatement and sediment containment measures during the PIDP, 2) reduction of noise impacts through the implementation of BMPs and by limiting the duration of pile-driving activities with impact hammers, particularly during biologically significant time periods (e.g., spawning migrations), 3) use of vibratory hammers to the fullest extent possible, 4) maintenance of a minimum 5,000-ft corridor of passage outside of the ensonified area to allow fish migration through the study area, 4) minimization of suspended sediments using cofferdams and silt curtains, 5) monitoring of water quality, noise and sturgeon during pile-driving to ensure re-consultation with NMFS if an incidental take is observed and, 6) limiting dredging to a three-month period from August 1 to November 1 for the three years of the construction period in which dredging would occur,

Chapter 8 References

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Letter from Julie Crocker to Melissa Toni August 24, 2010

Figures

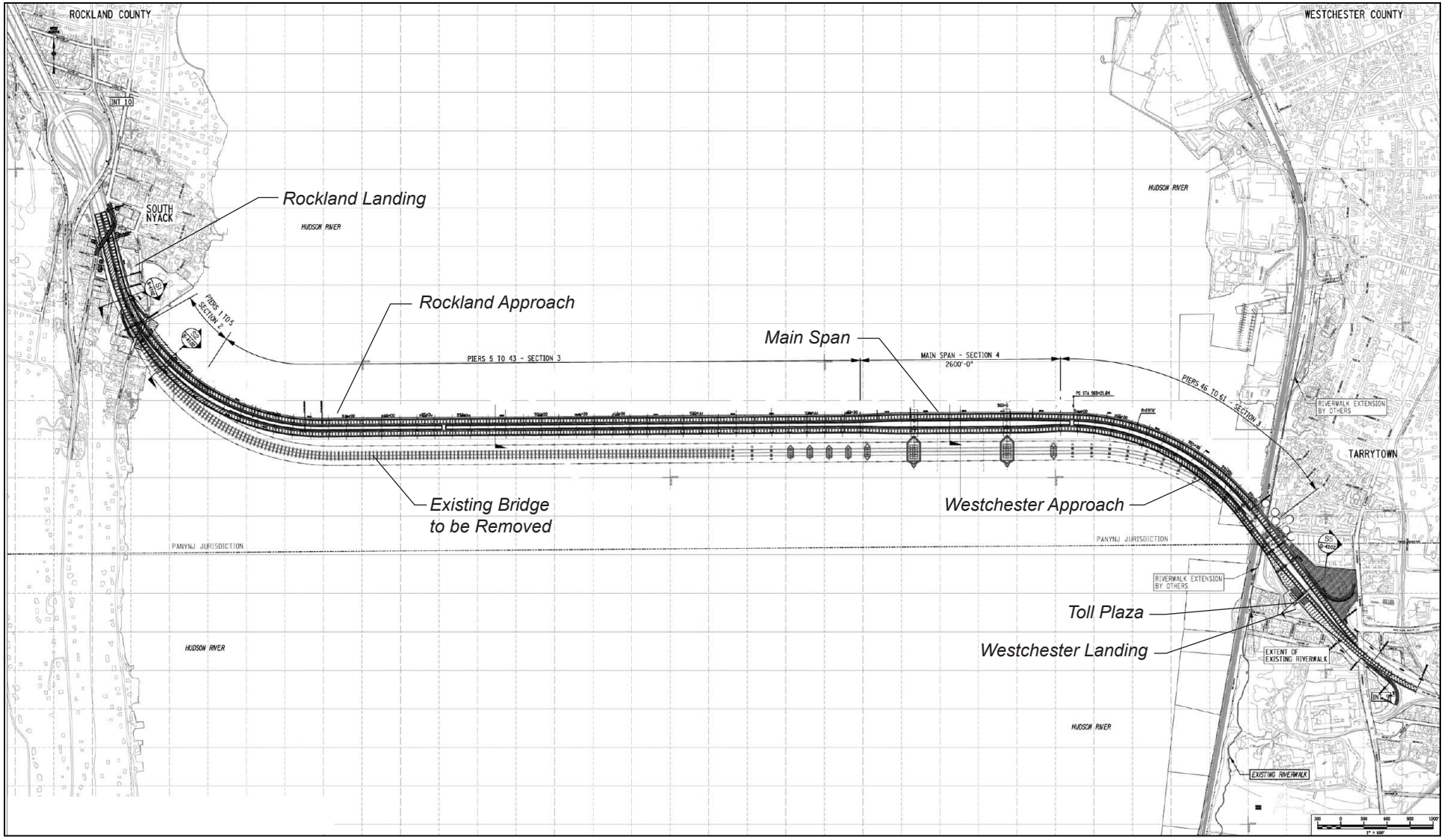
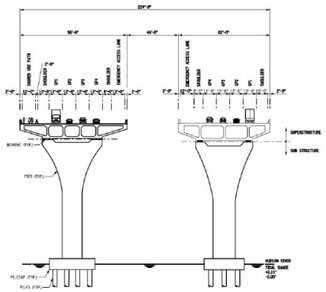


Figure 1

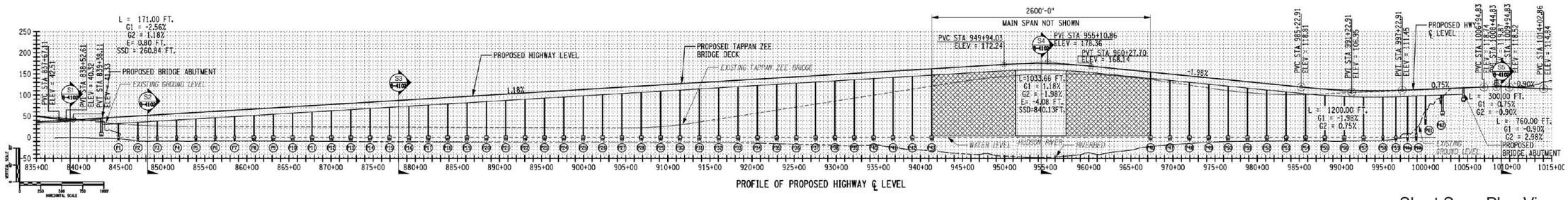
Approach Spans, Main Span, and Ancillary Facilities of the Replacement Bridge Alternative

1.4.12

Short Span Option

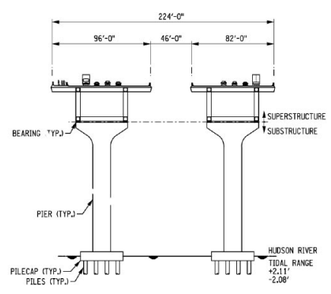


Short Span Cross-Section

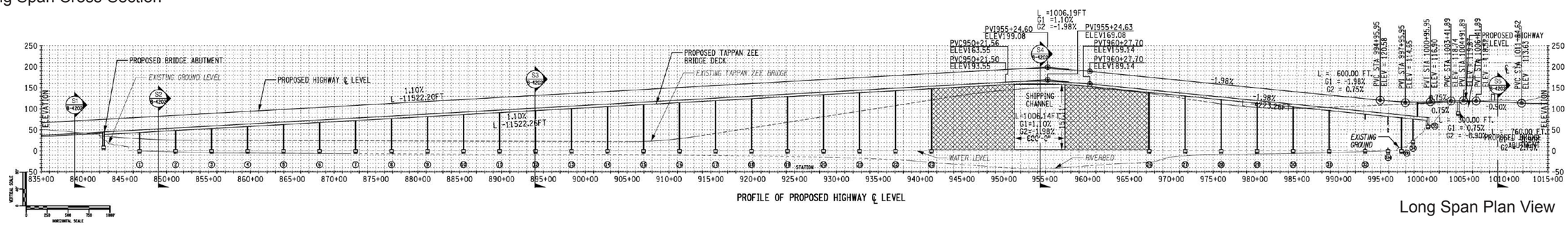


Short Span Plan View

Long Span Option



Long Span Cross-Section

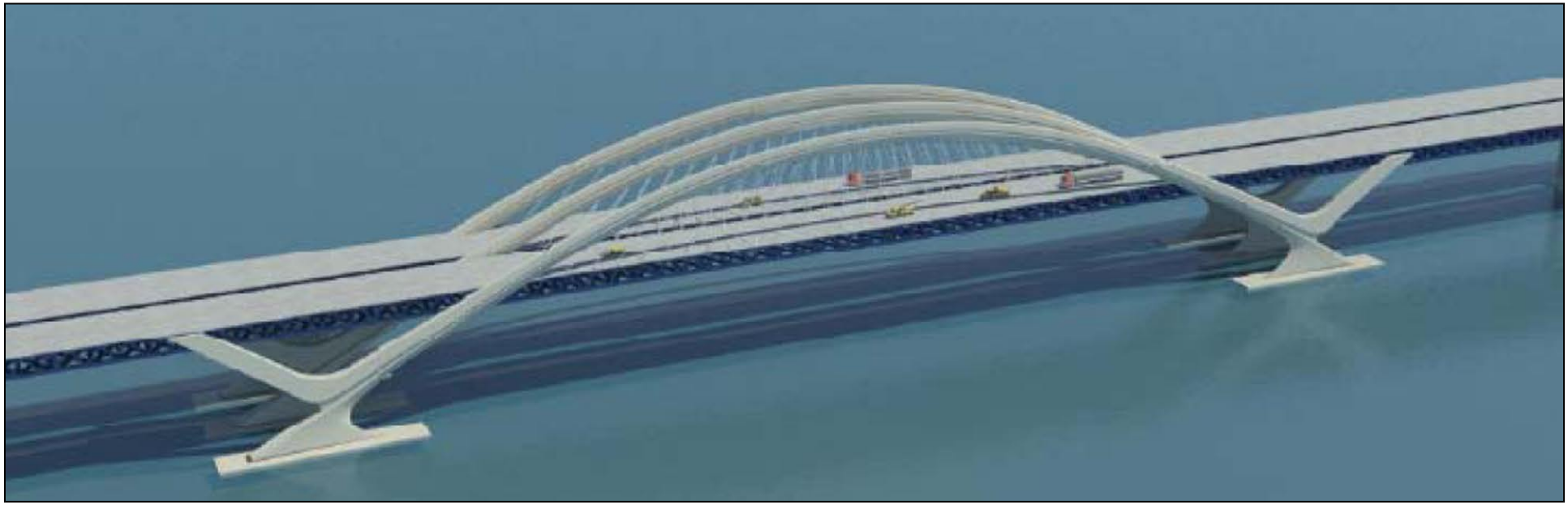


Long Span Plan View

TAPPAN ZEE HUDSON RIVER CROSSING
Biological Assessment

Figure 2
Plan View of Short Span and Long Span Options

Example of Cable-Stayed Option (Oresund Bridge, Denmark/Sweden)



Example of Arch Option (Rendering)

Figure 3

Examples of Cable-Stayed and Arch Bridge Designs

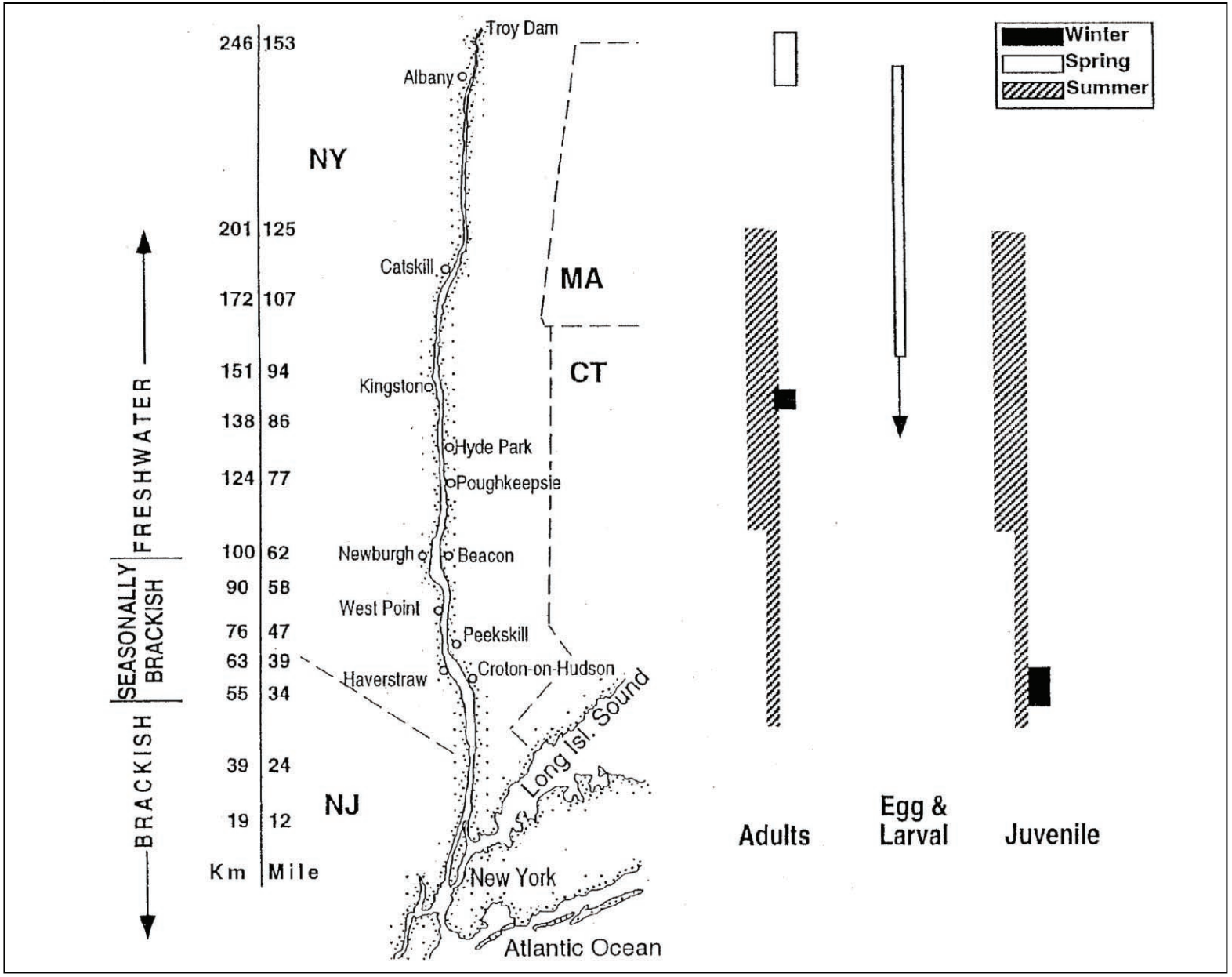


Figure 4

Distribution and Life History Pattern of Shortnose Sturgeon in the Hudson River Estuary by Major Life Stage and Season

Figure 5
Sediment Texture

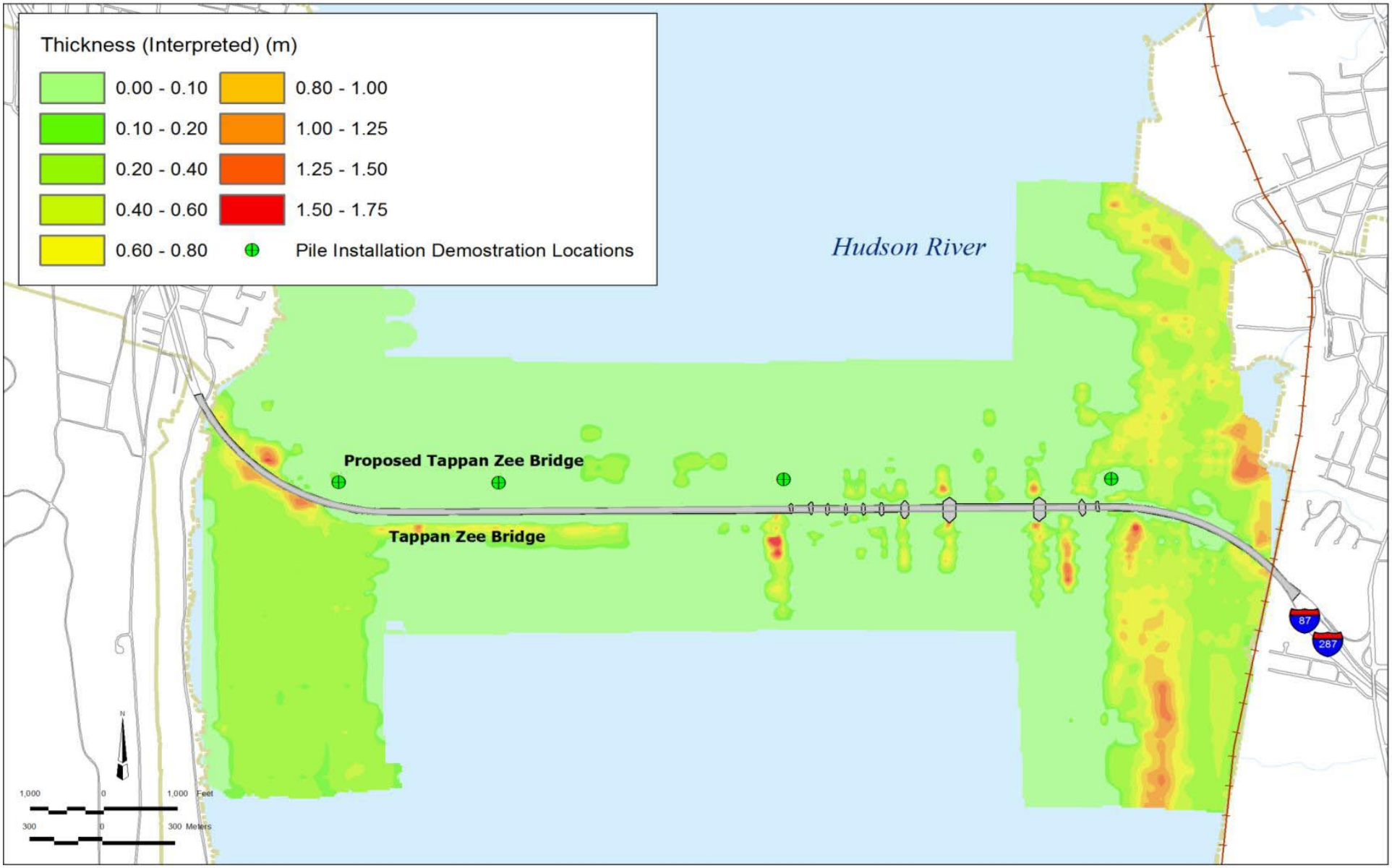
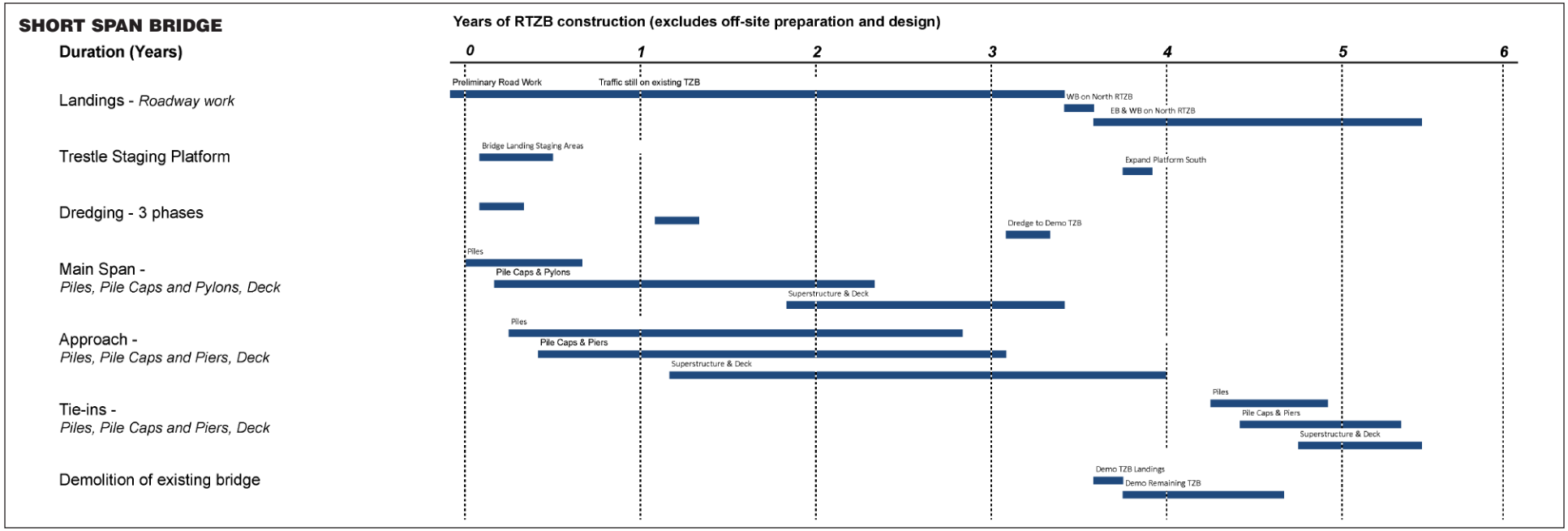


Figure 6
Recent Sediment Deposit Thickness



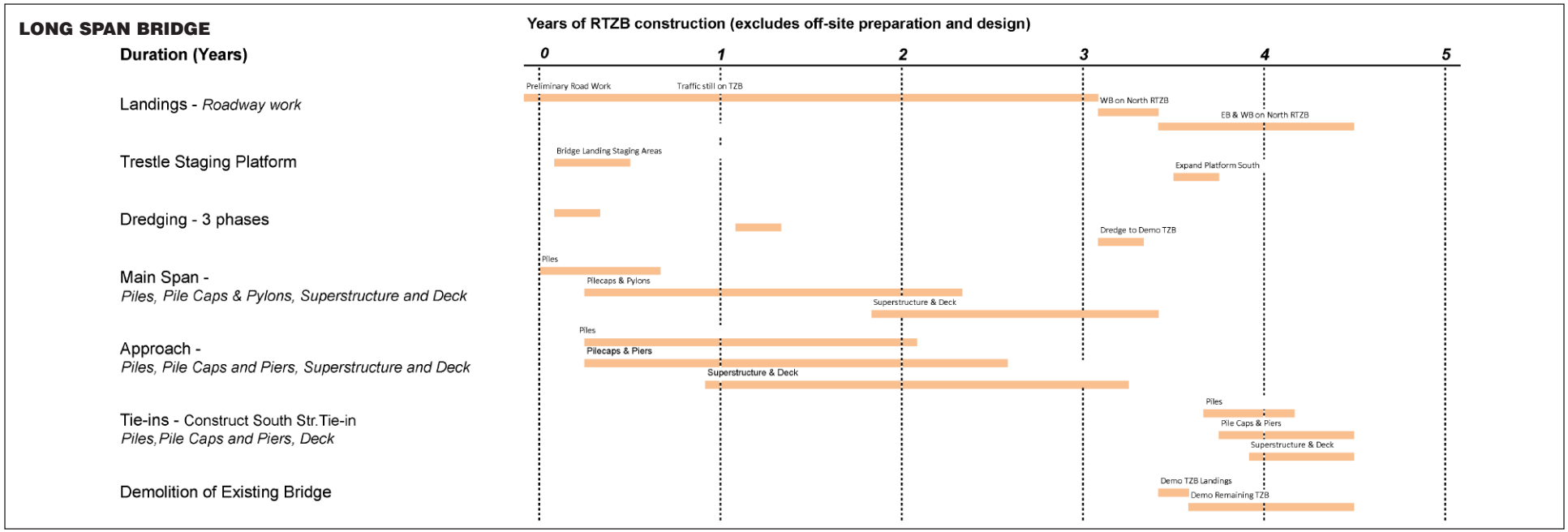
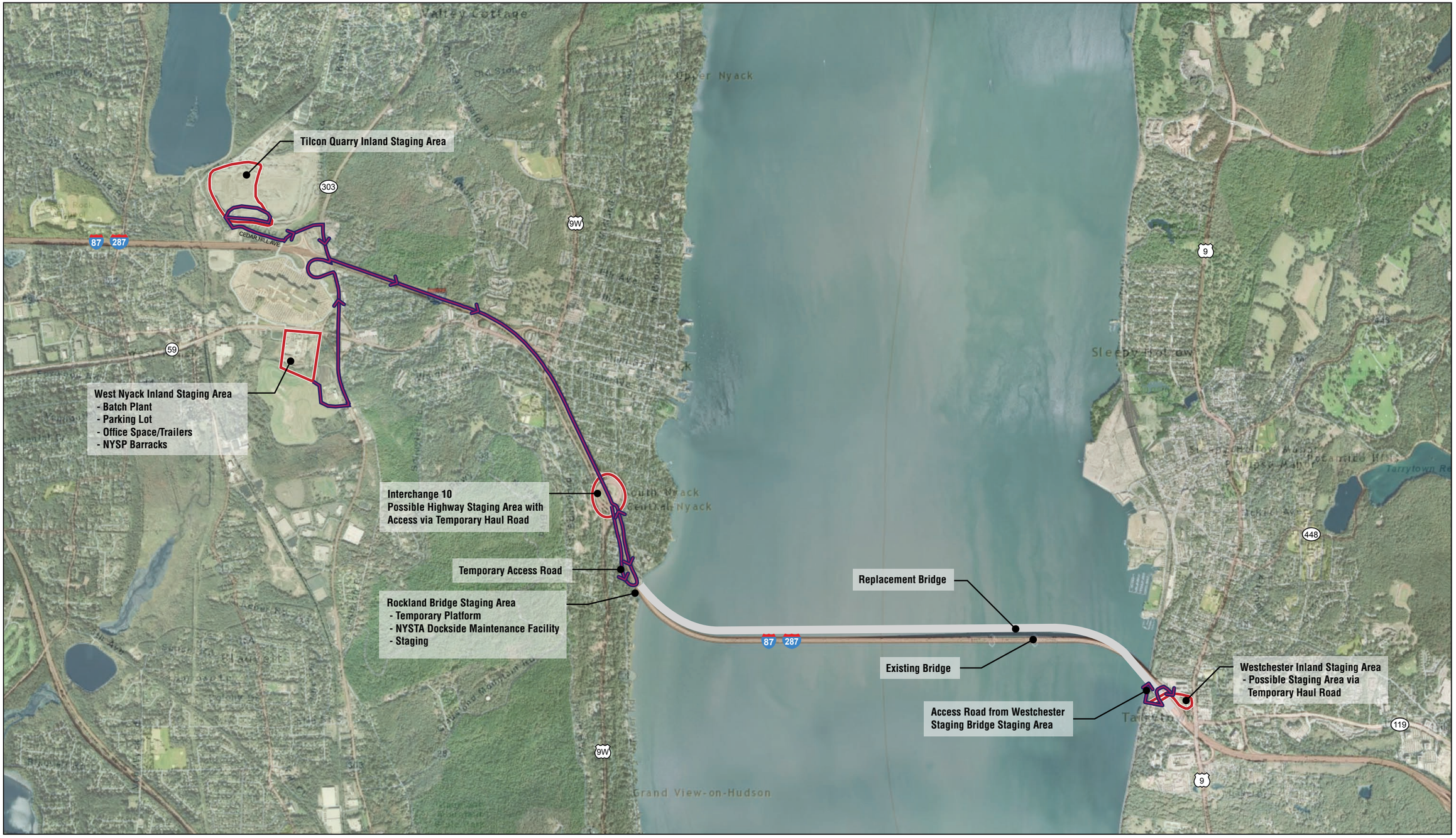


Figure 7

TAPPAN ZEE HUDSON RIVER CROSSING
Biological Assessment

Construction Schedules for Short Span and Long Span Option

1.4.12



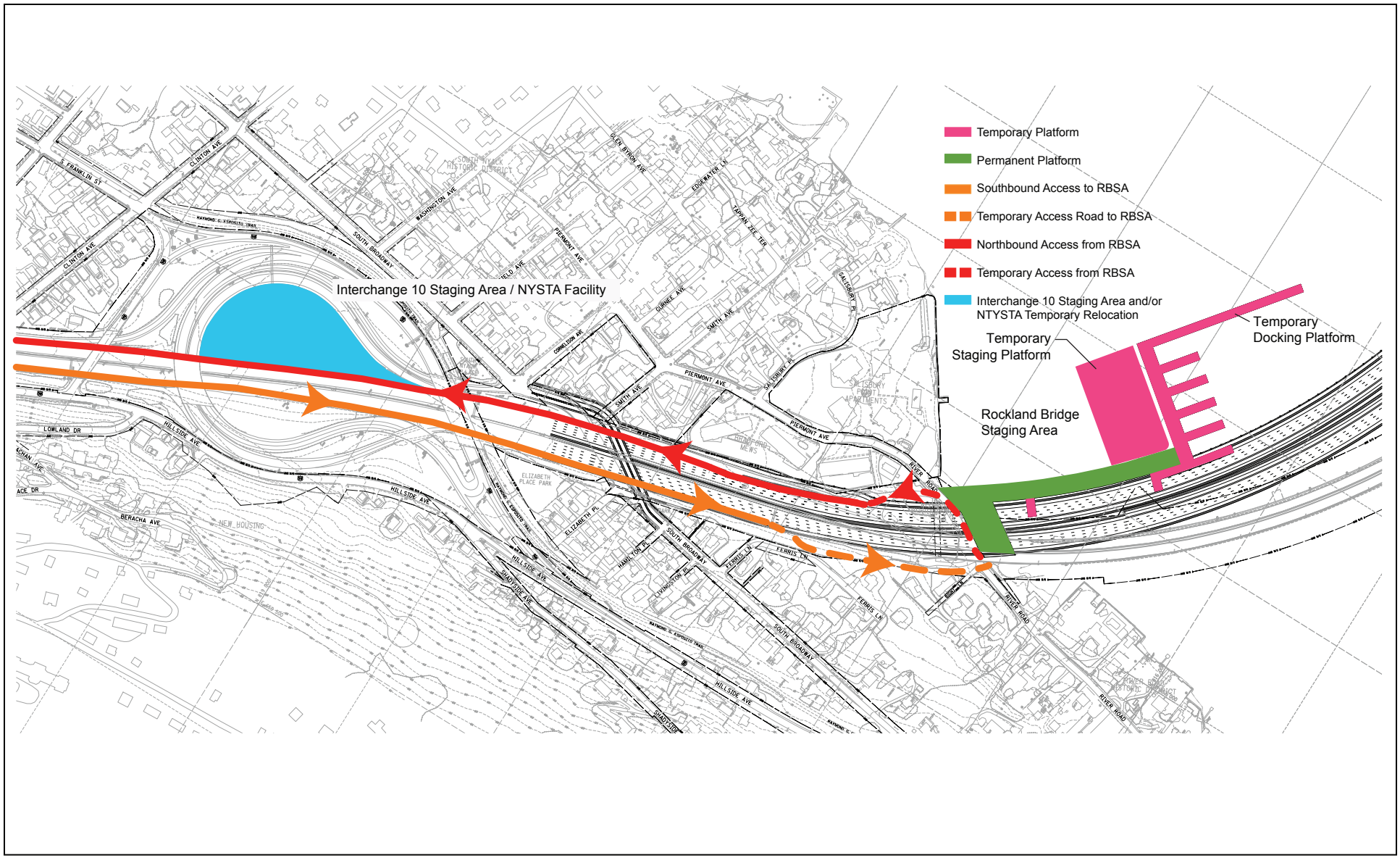
Construction Truck Routes

Potential Temporary Staging Areas

0 1/2 MILE
SCALE

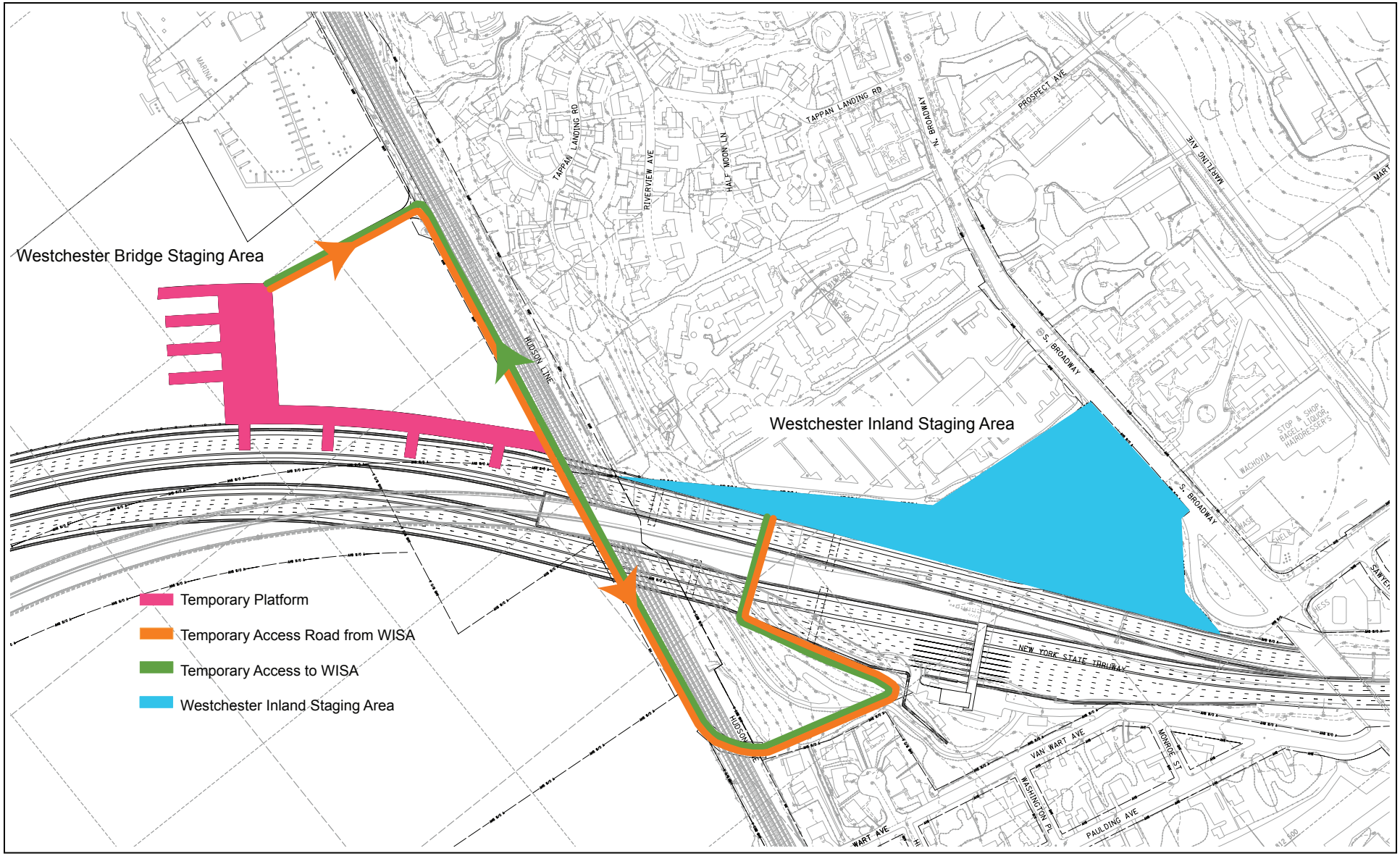
TAPPAN ZEE HUDSON RIVER CROSSING
Biological Assessment

Figure 8
Potential Upland Staging Areas



TAPPAN ZEE HUDSON RIVER CROSSING
Biological Assessment

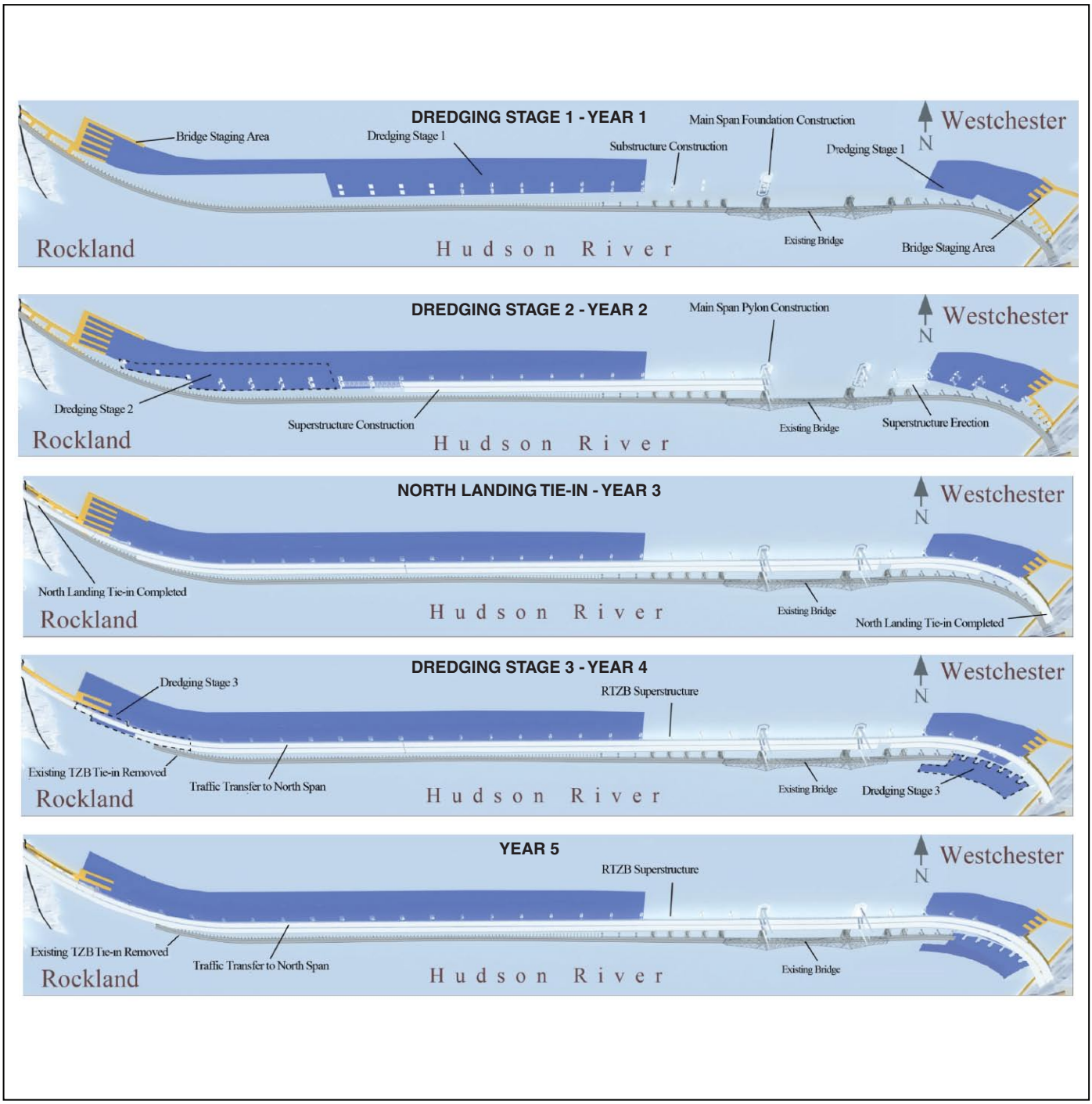
Figure 9
Rockland Landing Construction Access



TAPPAN ZEE HUDSON RIVER CROSSING
Biological Assessment

Figure 10
Westchester Landing Construction Access

1.4.12



Note: Long Span Option is depicted, Short Span Option will be similar

Figure 11
Dredging Sequence, Years 1 to 5

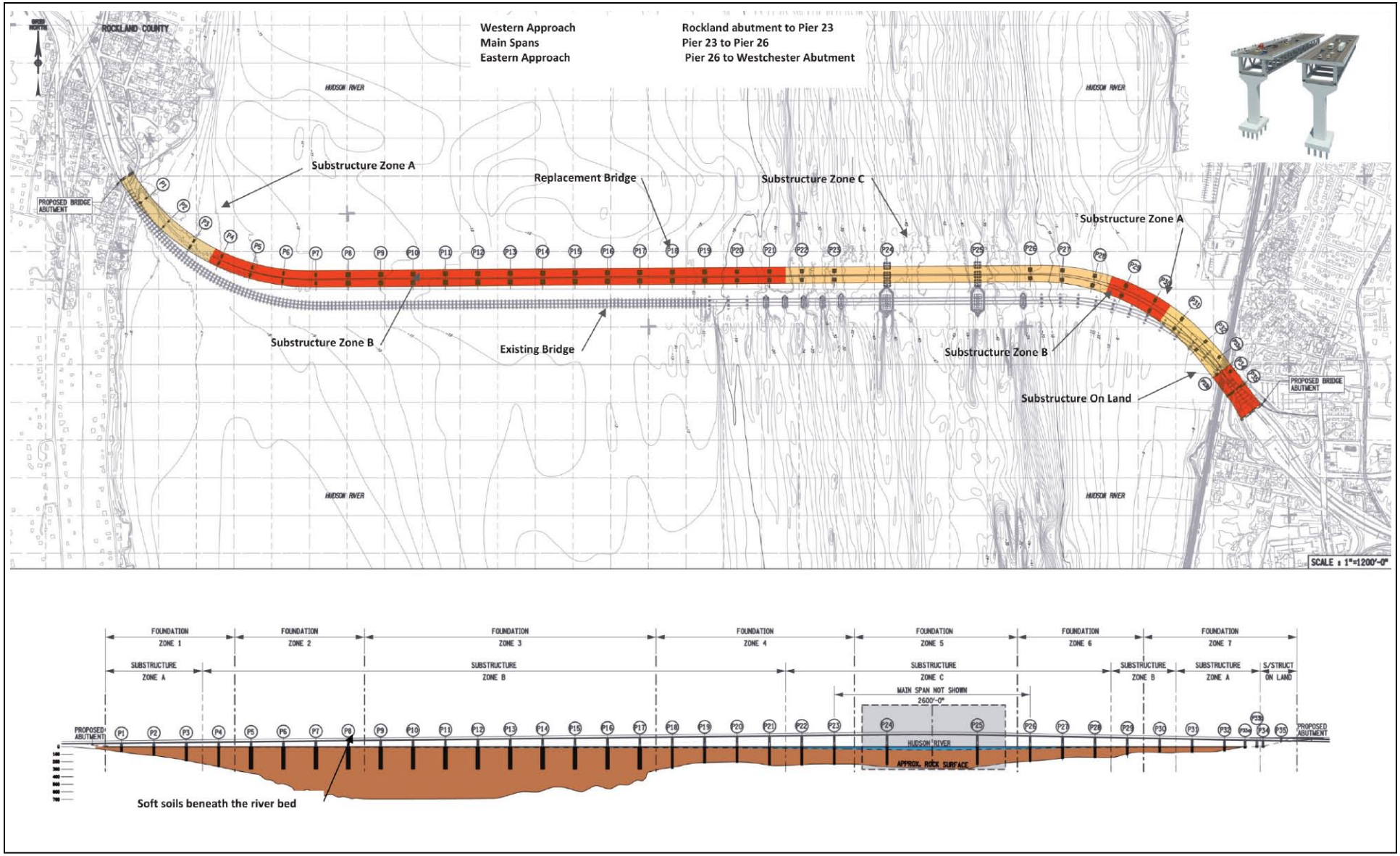
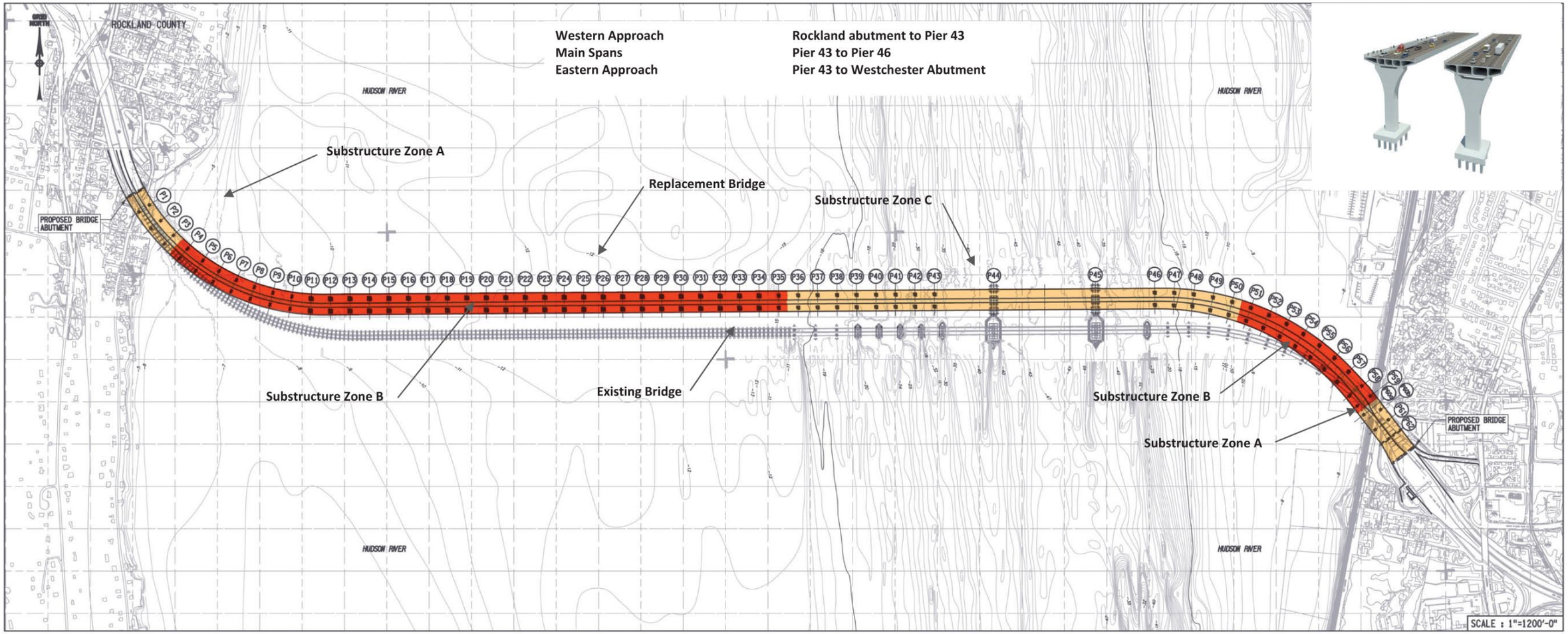
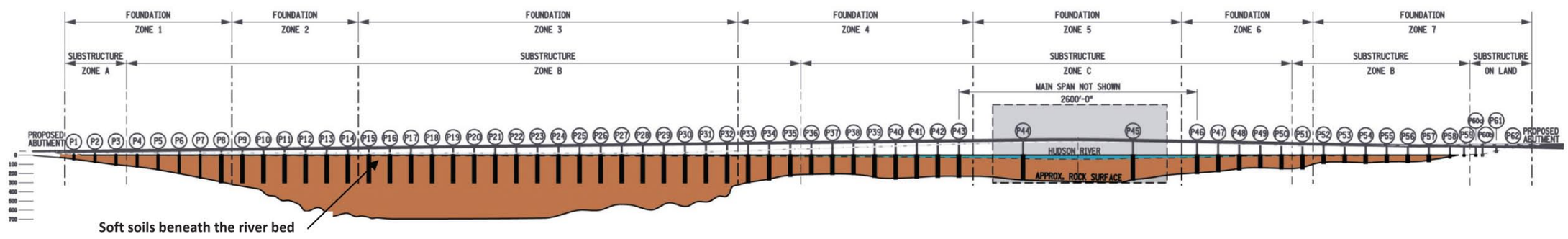


Figure 12

Construction Zones for Long Span Option





TAPPAN ZEE HUDSON RIVER CROSSING
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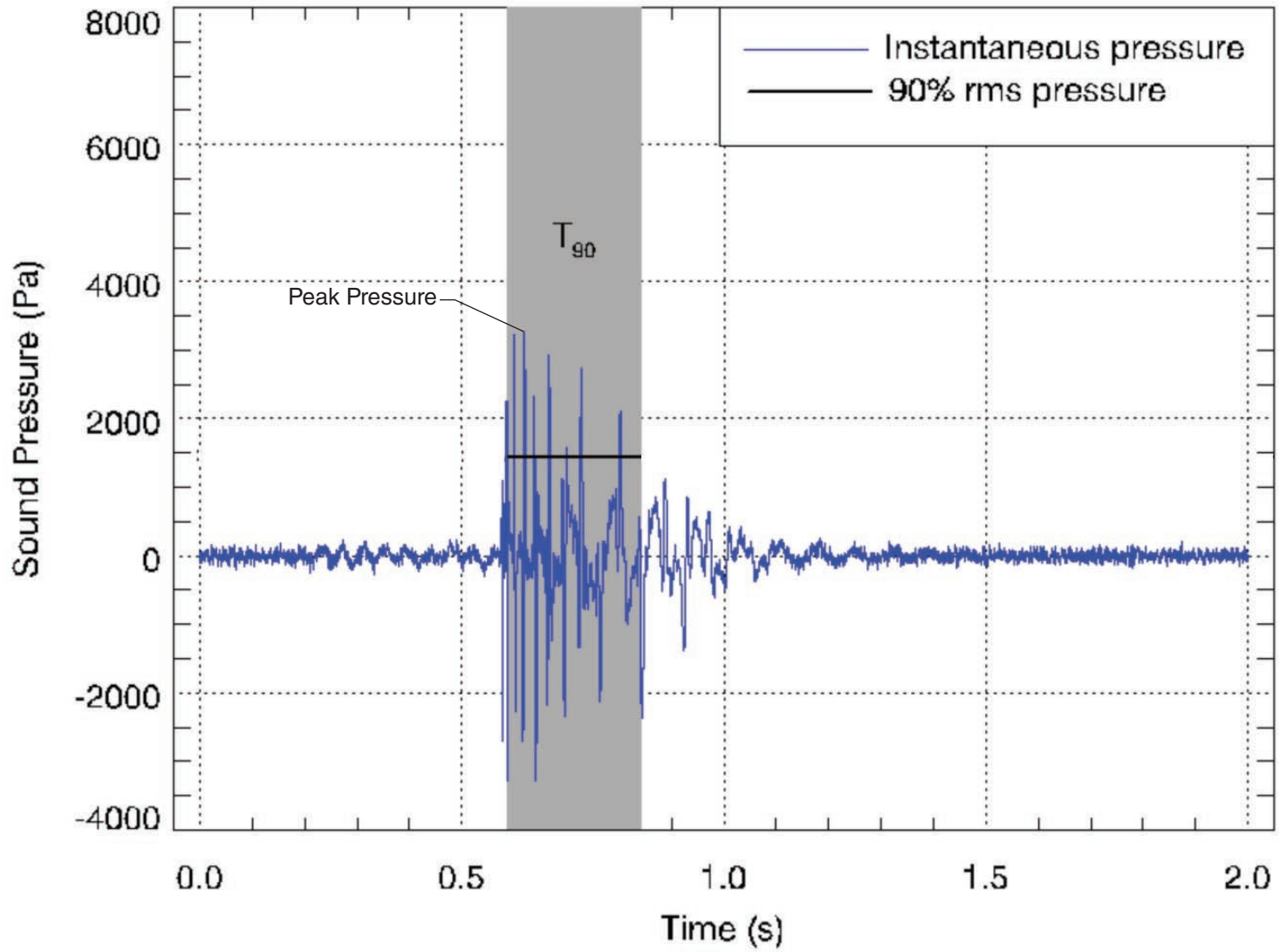
Figure 13
Construction Zones for Short Span Option



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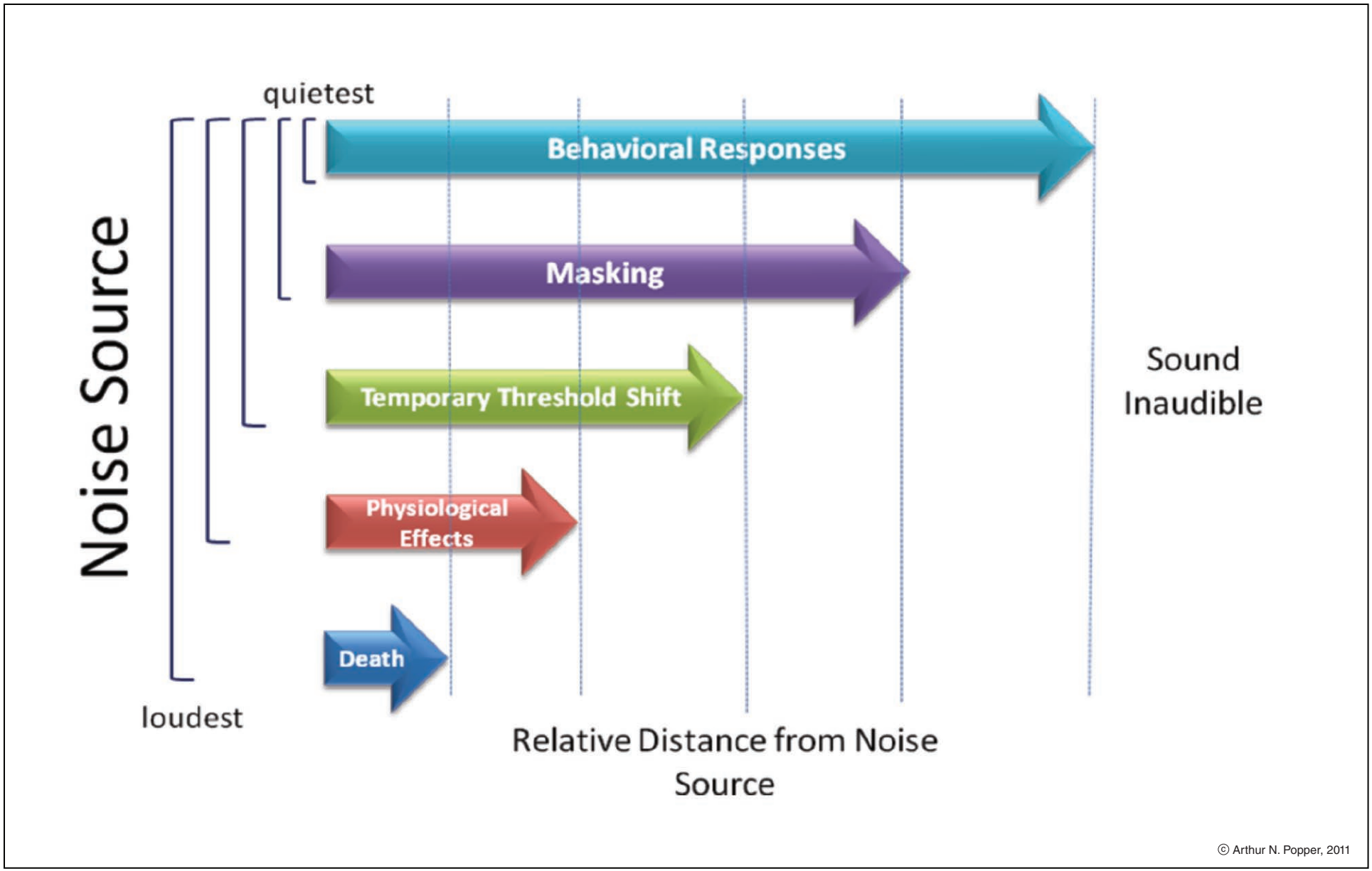

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Relationship Between Noise Levels, Distance, and Potential Effects

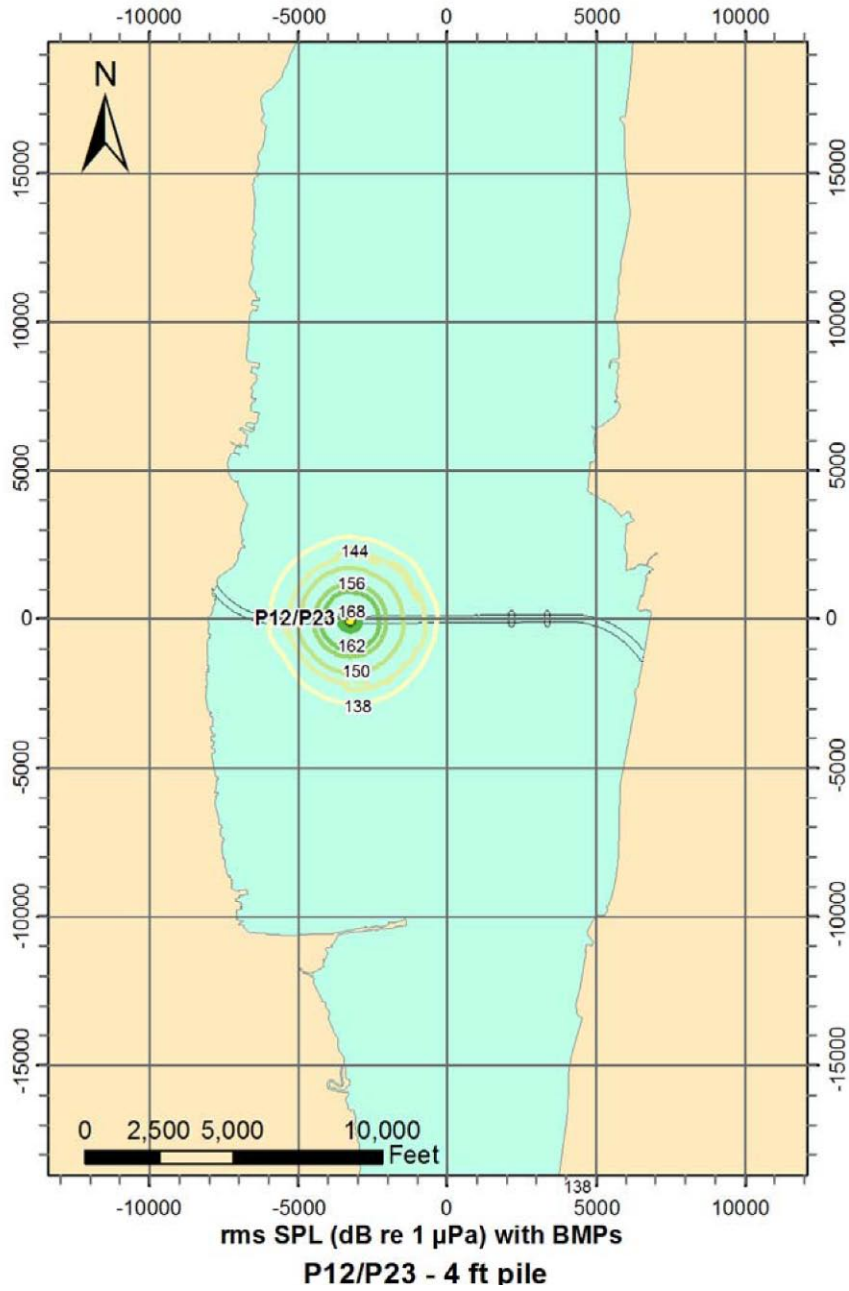


Figure 16

Isopleths for Root Mean Square (rms) Sound Pressure Level from Pile Driving for 4-foot Diameter Piles (with 10dB Reduction from BMPs)

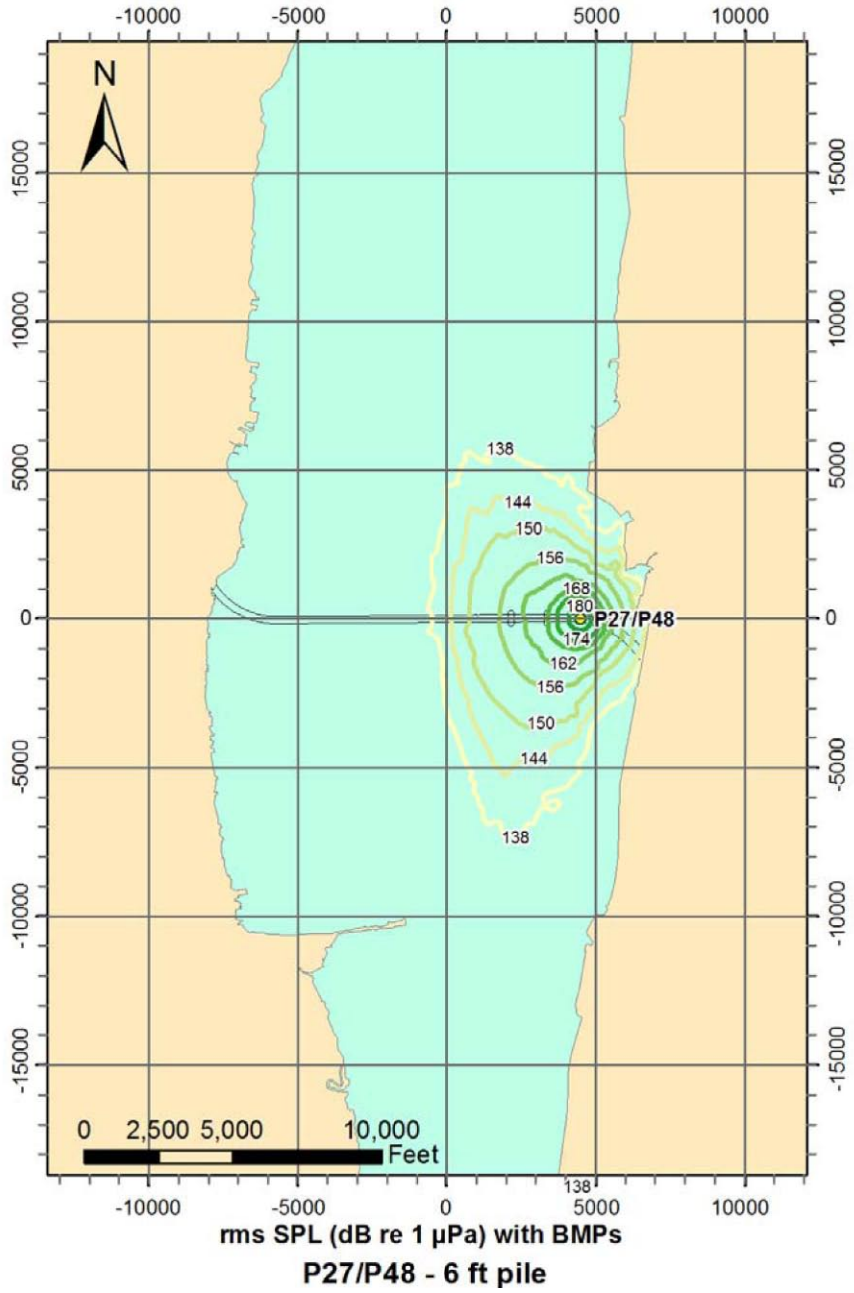


Figure 17

Isopleths for Root Mean Square (rms) Sound Pressure Level from Pile Driving for 6-foot Diameter Piles (with 10dB Reduction from BMPs)

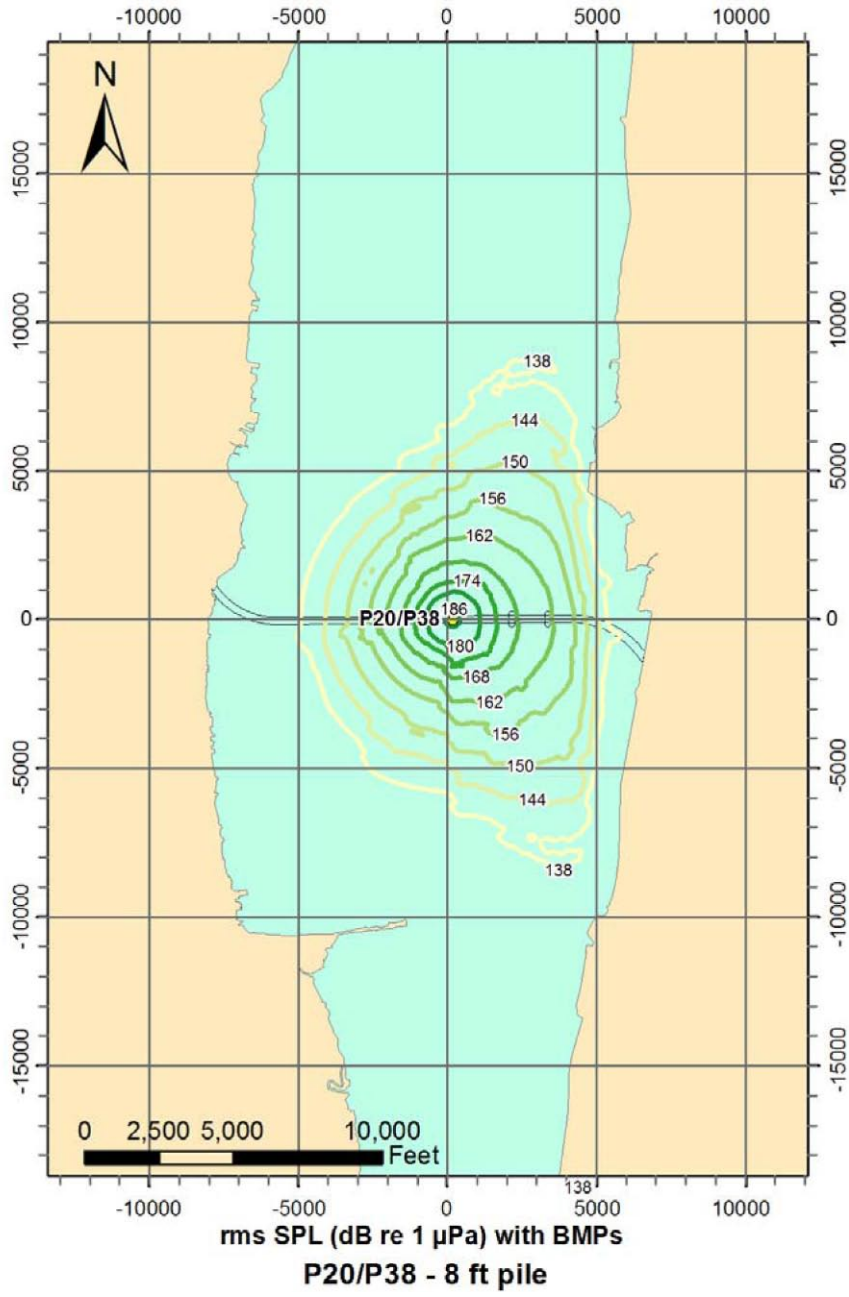


Figure 18

Isopleths for Root Mean Square (rms) Sound Pressure Level from Pile Driving for 8-foot Diameter Piles (with 10dB Reduction from BMPs)

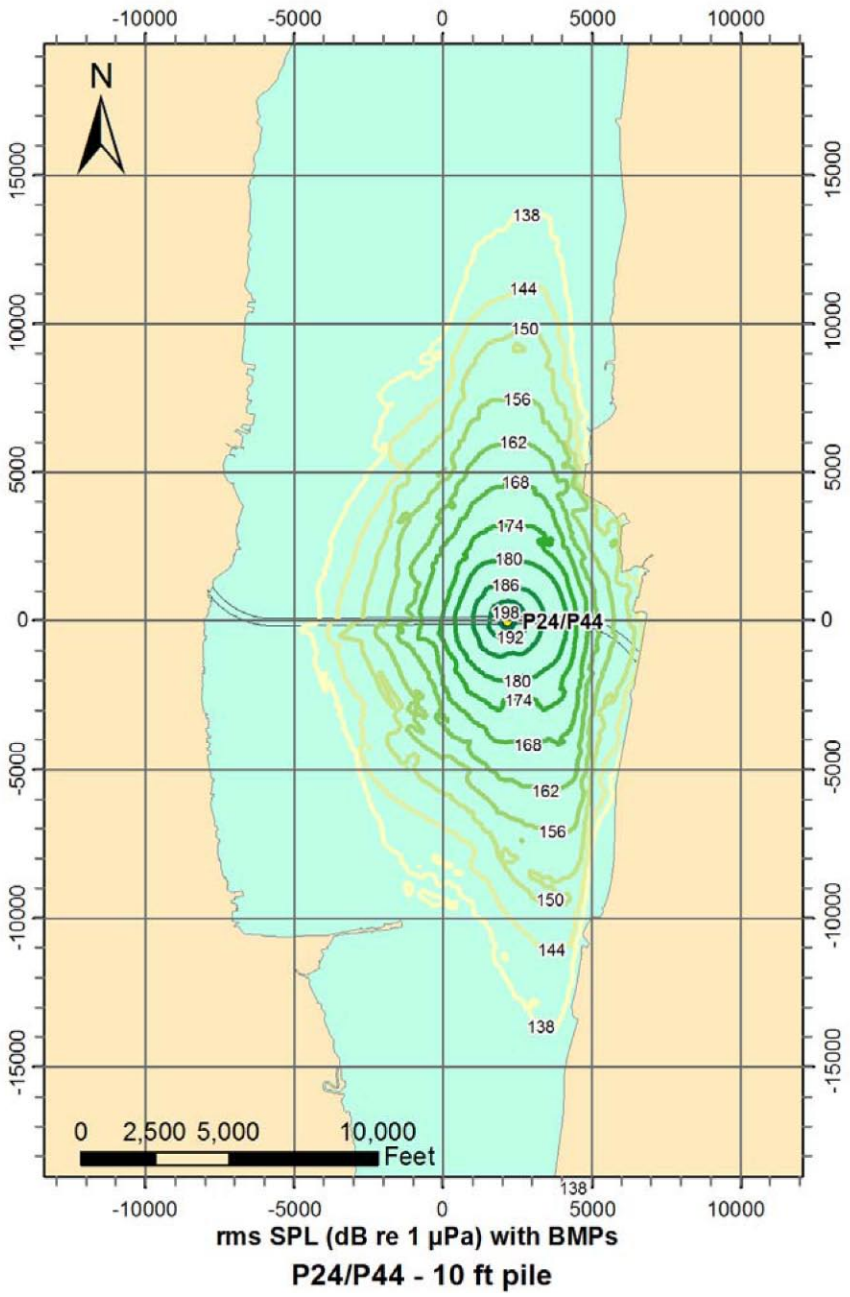


Figure 19

Isopleths for Root Mean Square (rms) Sound Pressure Level from Pile Driving for 10-foot Diameter Piles (with 10dB Reduction from BMPs)

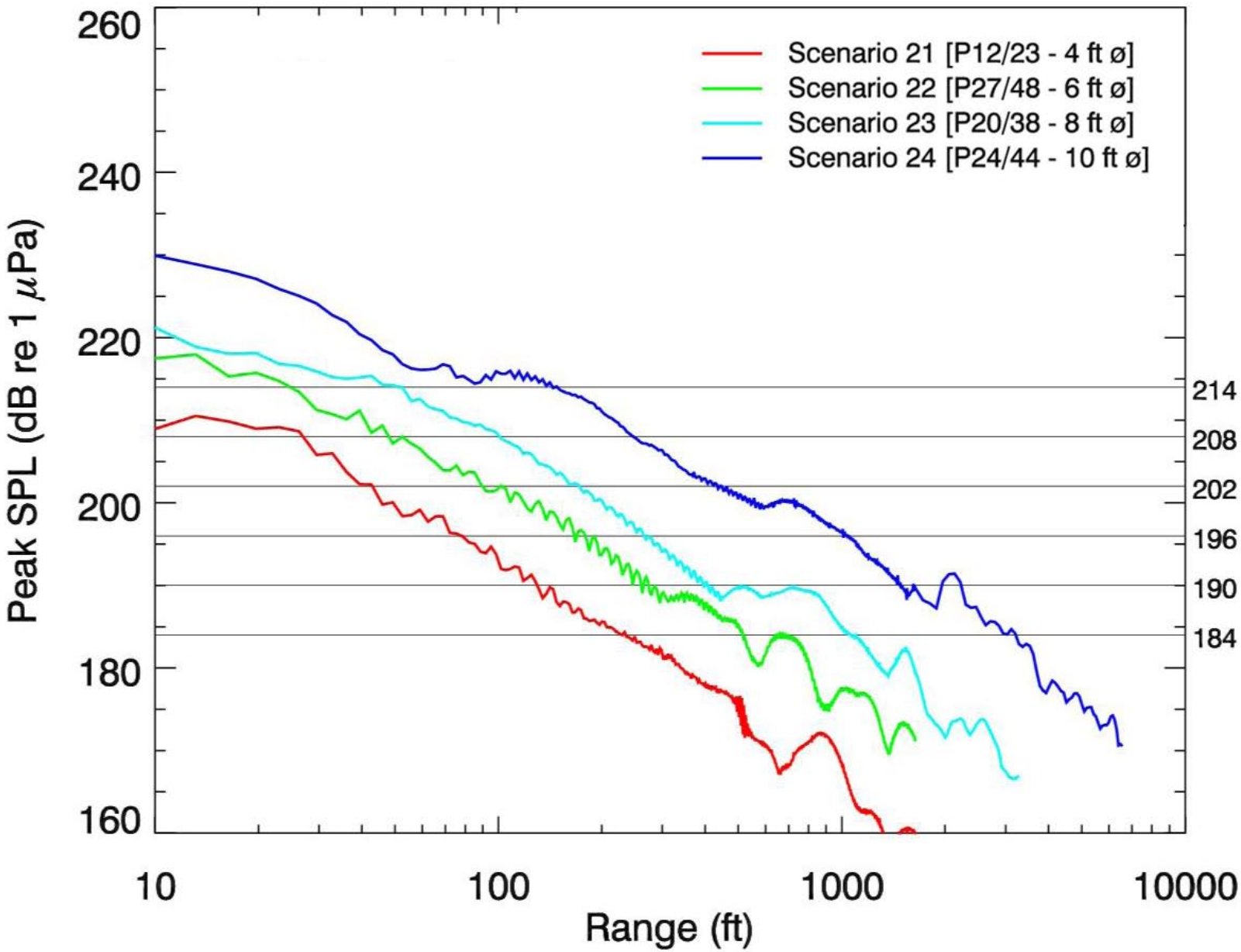


Figure 20

Attenuation of Peak Sound Pressure Level with 10dB Reduction from BMPs as a Function of Distance from Pile Driving for 4-, 6-, 8-, and 10-foot Diameter Piles

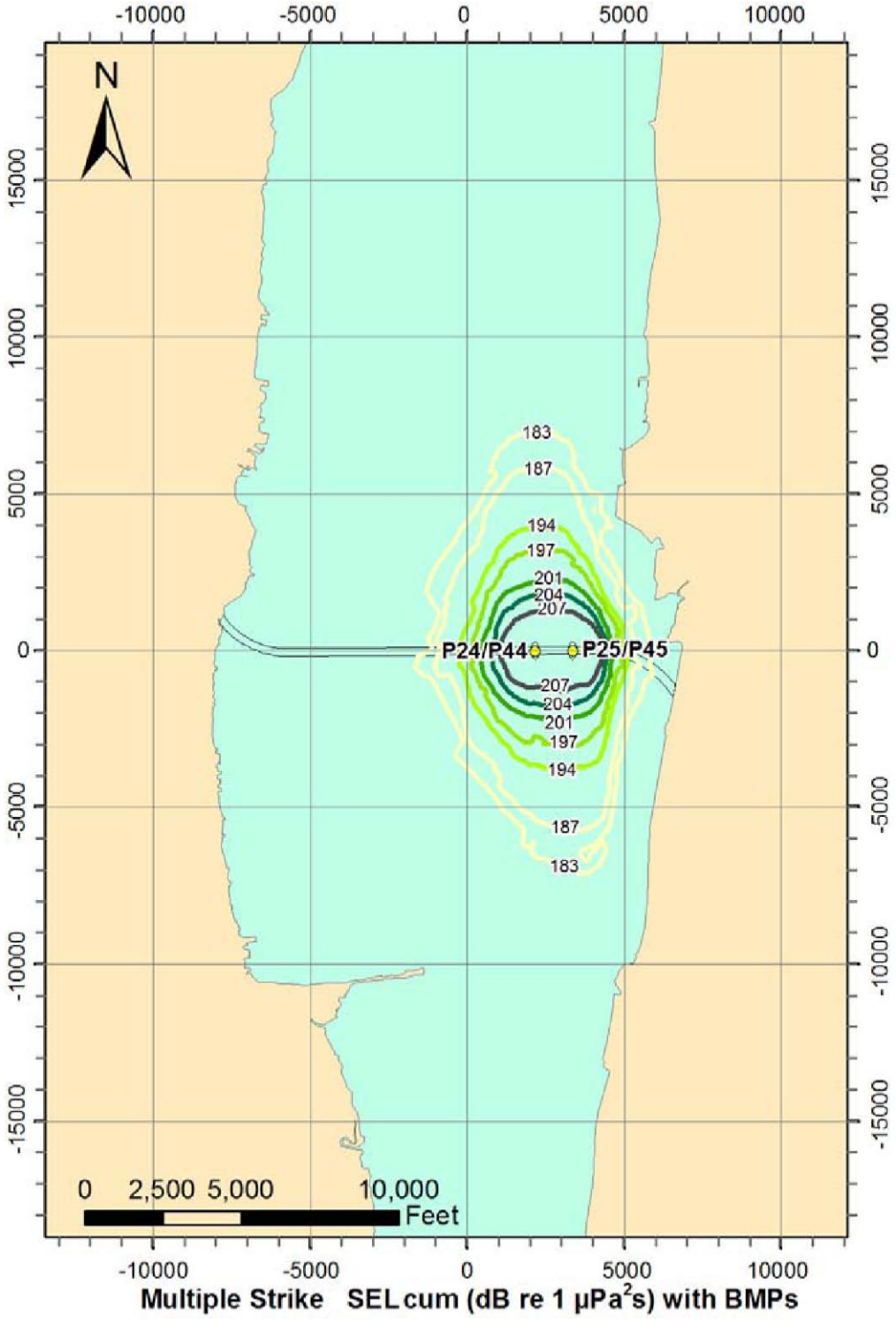


Figure 21

Isopleths for Short and Long Span Options - Driving of Two 10 Foot Piles at Piers 24, 25, 44 & 45

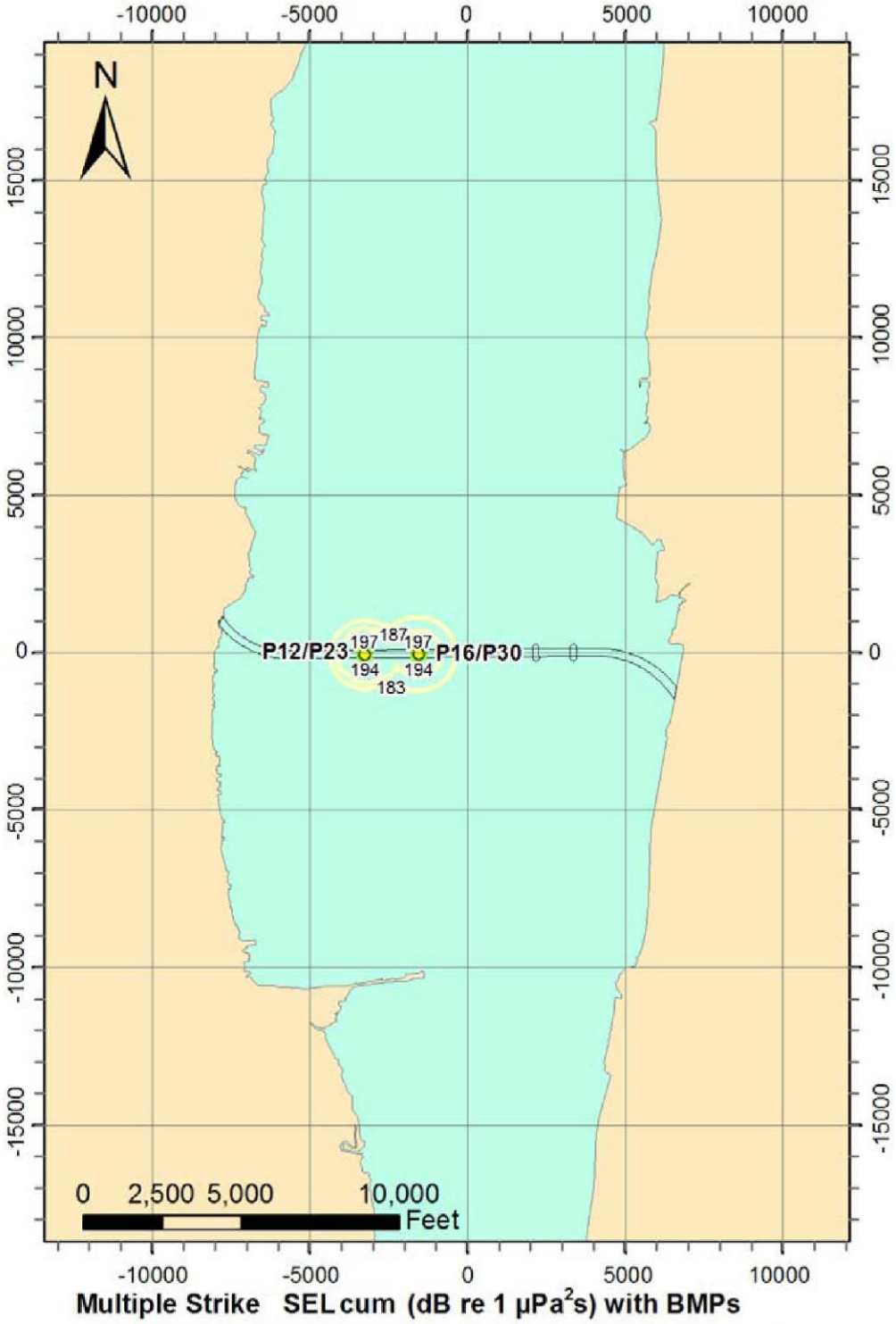


Figure 22

Isopleths for Short and Long Span Options - Driving of Four 4 Foot Piles at Piers 12, 16, 23 & 30

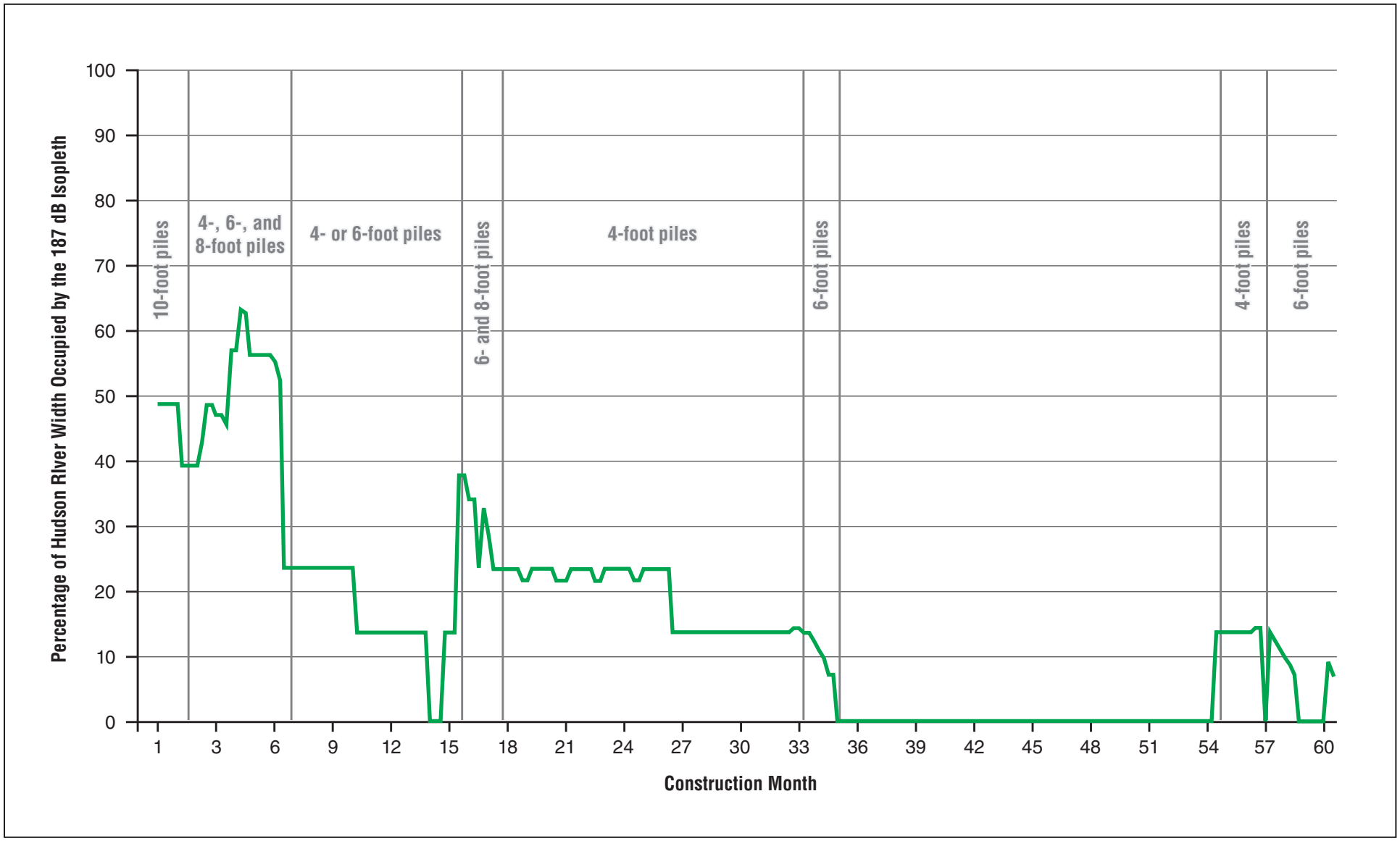


Figure 23

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Short Span Option

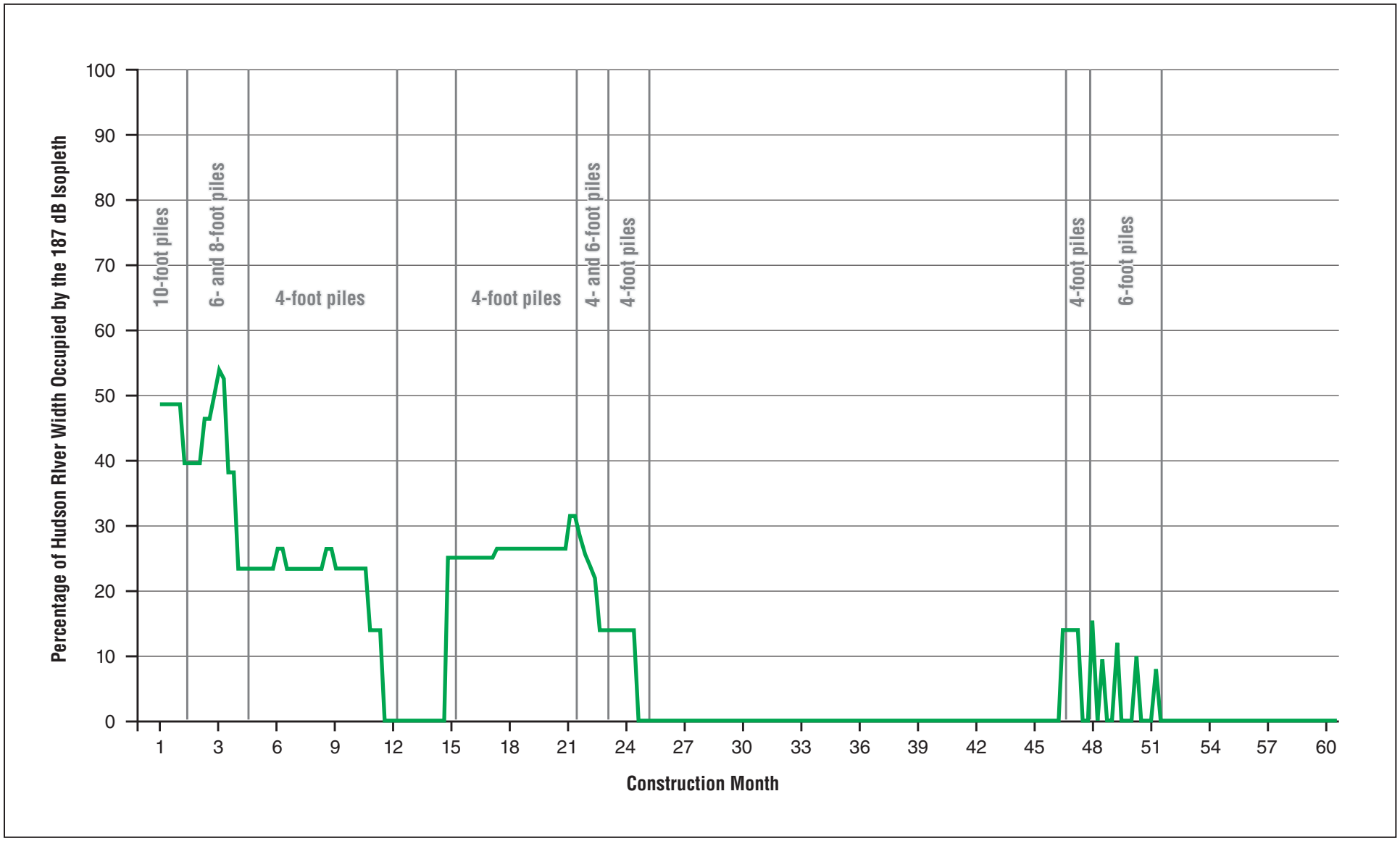
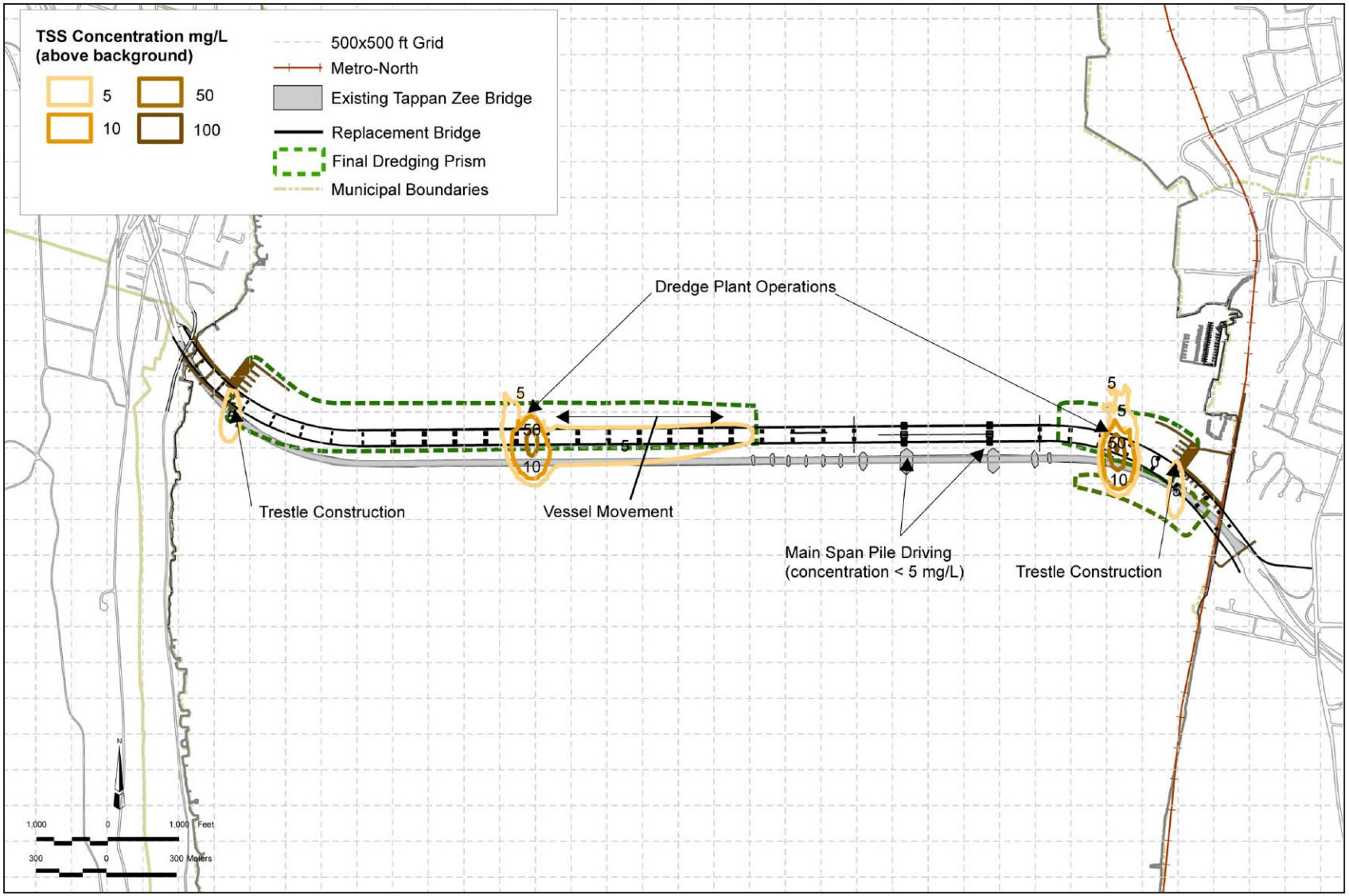


Figure 24

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Long Span Option

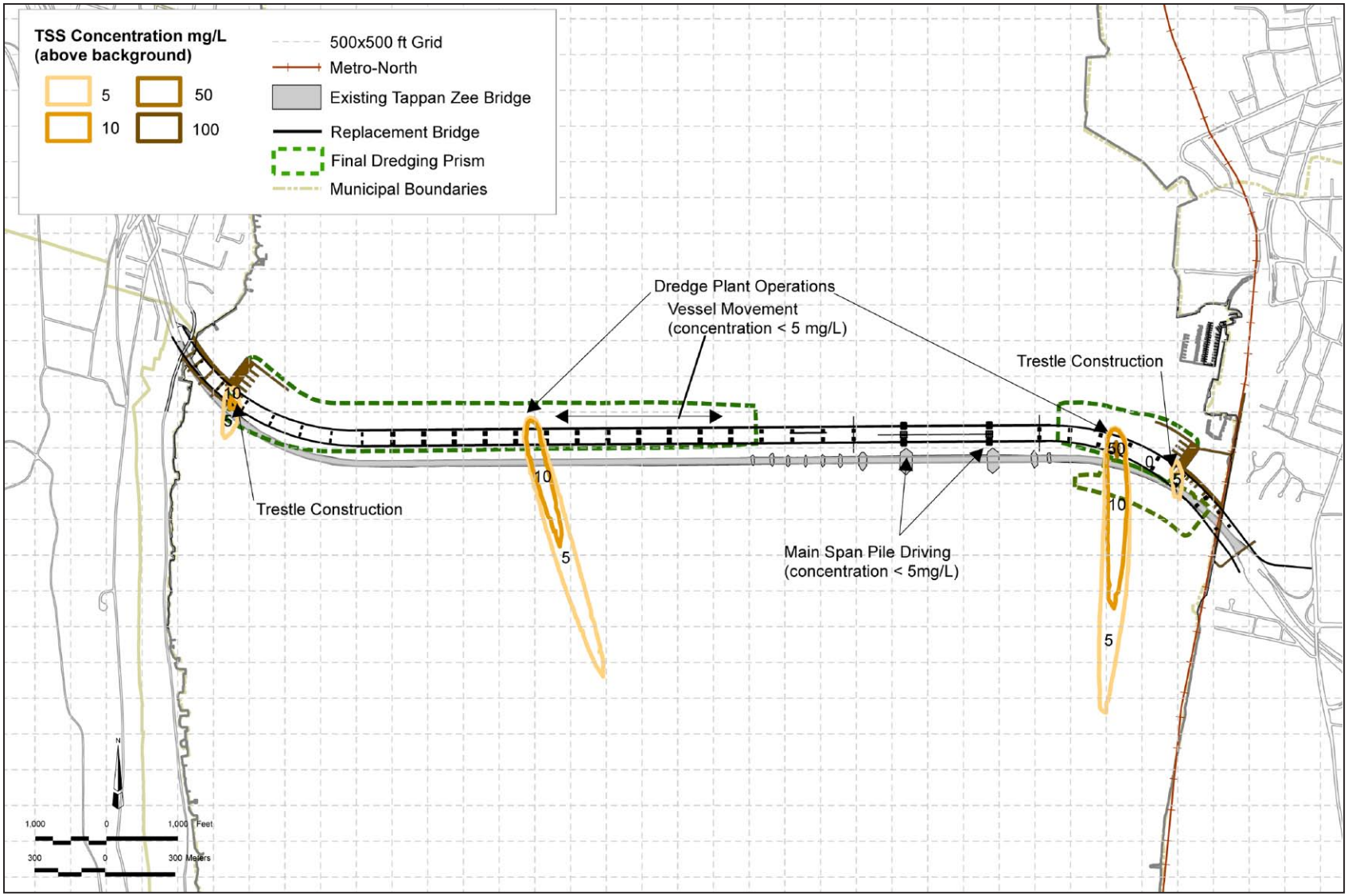


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 1 Dredging-Near Slack Tide

*Note: Short Span Option would be similar

Figure 25

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging – Near Slack Tide

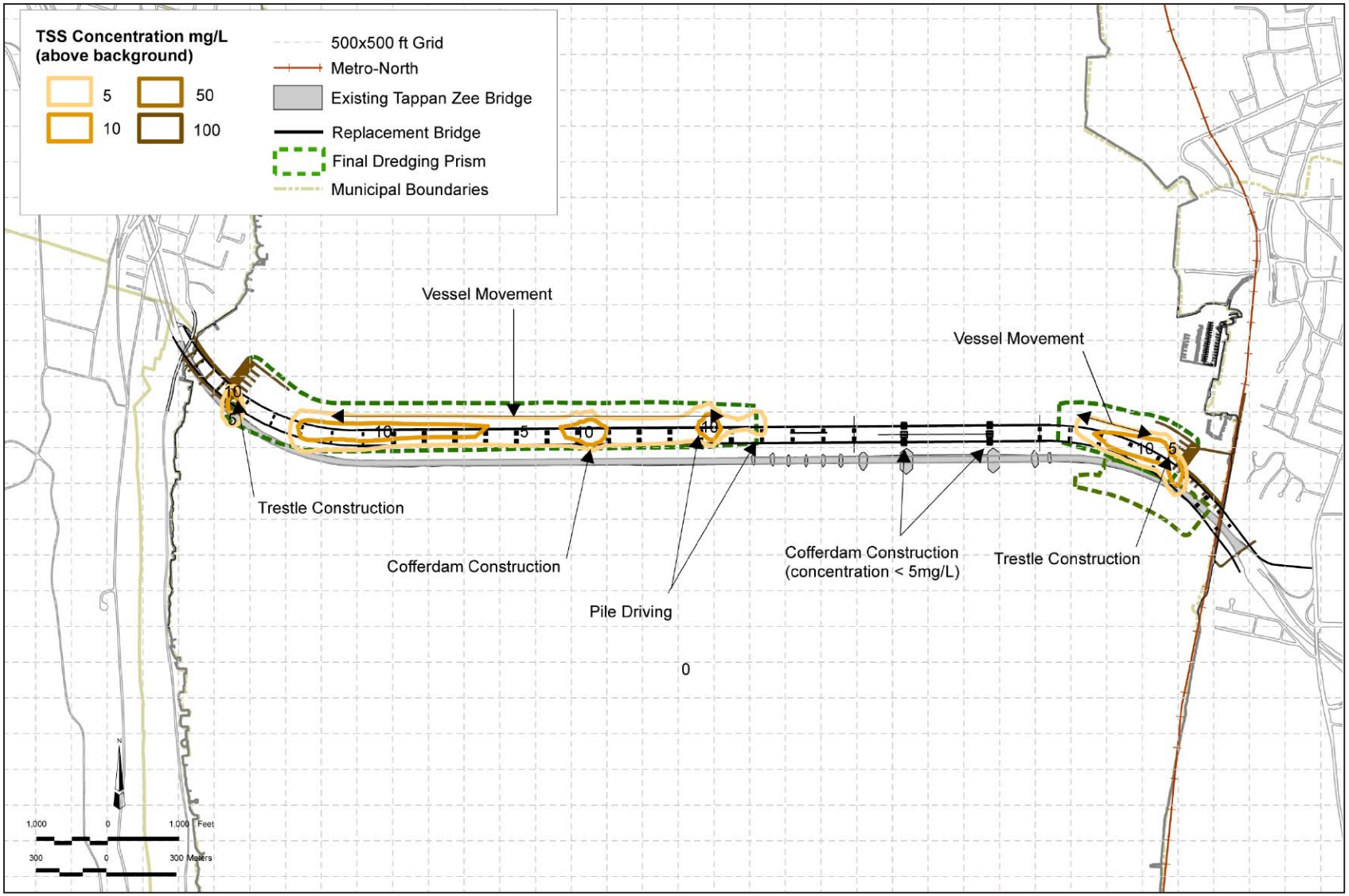


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 1 Dredging-Ebb Tide

*Note: Short Span Option would be similar

Figure 26

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging – Ebb Tide

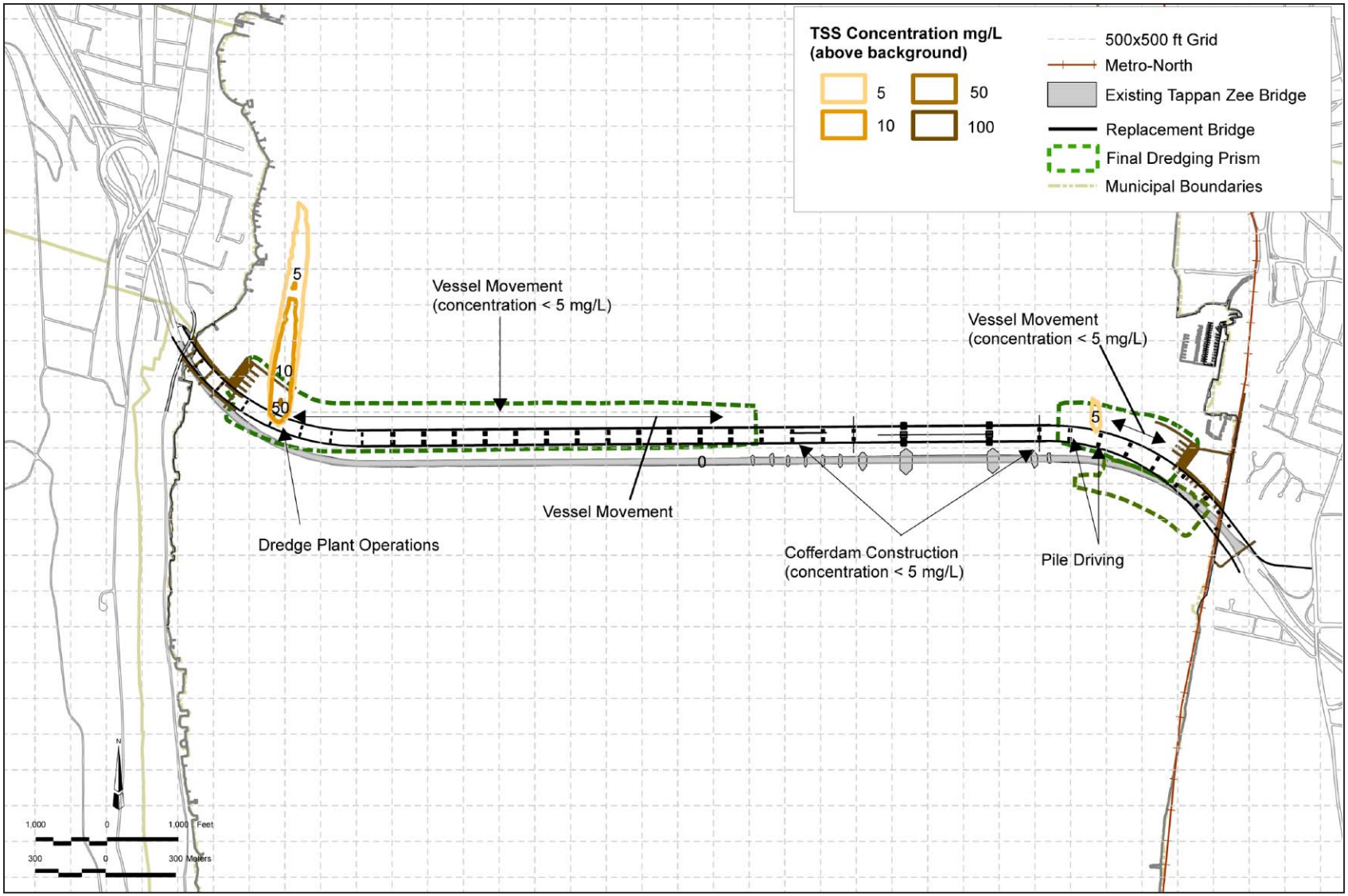


Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* Zones C and B Construction After Dredging and Armoring – Near Slack Tide

*Note: Short Span Option would be similar

Figure 27

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring – Near Slack Tide



Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option* During Stage 2 Dredging and Zones C and B Construction– Flood Tide

*Note: Short Span Option would be similar

Figure 28

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction – Flood Tide

Appendix F: Ecology

F-5A Underwater Ambient Sound Level in the Hudson River near the Tappan Zee Bridge: Short and Long Span Ambient Noise Modeling (Jasco, July 2011)

Tappan Zee Bridge Construction Hydroacoustic Noise Modeling

Final report

Submitted to:
AECOM
One World Financial Center
200 Liberty St, 25th Floor
New York, NY 10281

Authors:
Alexander MacGillivray
Graham Warner
Roberto Racca
Caitlin O'Neill

JASCO Applied Sciences
Suite 2101, 4464 Markham St.
Victoria, BC, V8Z 7X8, Canada
Phone: +1.250.483.3300
Fax: +1.250.483.3301
www.jasco.com

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1. Introduction

This report presents results of a hydroacoustic modeling study of construction noise from the proposed Tappan Zee Bridge/I-287 Corridor Project (the Project). This modeling study has been carried out by JASCO Applied Sciences (JASCO) in support of the Project's Environmental Impact Statement (EIS), to estimate the underwater range-of-influence of noise from pile driving activities. The sound level estimates from this modeling study are expressed, in terms of metrics, locations, environment and presentation, so as to be most readily amenable to assessments of potential biological impacts primarily on fish populations. Interpretation of such impacts is outside the scope of the present work.

The spatial distribution of noise has been analyzed for 24 construction scenarios, encompassing seven unique pile driving locations, four different piles sizes, and five different acoustic metrics including acoustic particle velocity. In addition, noise mitigation resulting from the application of best management practices (BMPs) has been modeled. The modeling has considered two distinct time scales: noise exposure over the brief duration of a single pile driving hammer strike and the cumulative exposure over a full day of construction activity. Model scenarios have been developed to cover two possible bridge designs (single level and dual level). The model scenarios have been developed in cooperation with the Project engineering team to ensure an accurate representation of the activities that will be carried out during construction of the proposed bridge.

Underwater noise levels have been modeled using three different sound propagation modeling codes (MONM, VSTACK, and FWRAM), all of which have been developed by JASCO. These three codes apply different numerical algorithms for modeling underwater sound propagation (parabolic equation, wavenumber integration, Fourier synthesis), and each has a different domain of validity. They have been used in combination to generate the various acoustic metrics that are required for assessing noise impacts on aquatic resources in the Hudson River. All of the models employed in the current study fully account for the frequency composition of the source signal and the physics of acoustic propagation in the water and underlying geological substrates.

The seven modeling locations considered (Figure 1) span the entire bridge crossing and are representative of the distinctive sound propagation regimes among the pile driving scenarios in the overall construction plan. The pile size modeled at each location is appropriate to that particular segment of the bridge span. Site-specific representations of the geoacoustic properties of the underlying substrates have been modeled at each of the seven modeling locations. Acoustic footprints resulting from simultaneous pile driving at multiple locations have been modeled for both proposed bridge designs, and individual footprints have been modeled for four of the seven locations. Lastly, the effect of applying Best Management Practices to reduce acoustic emissions has been estimated at all seven pile driving locations. Modeling results are presented in a variety of complementary formats including planar maps of the sound level maximized over the full depth of the water column, plots of sound level versus range along single transects, and graphs of the frequency content of the sound at a set of sample locations.

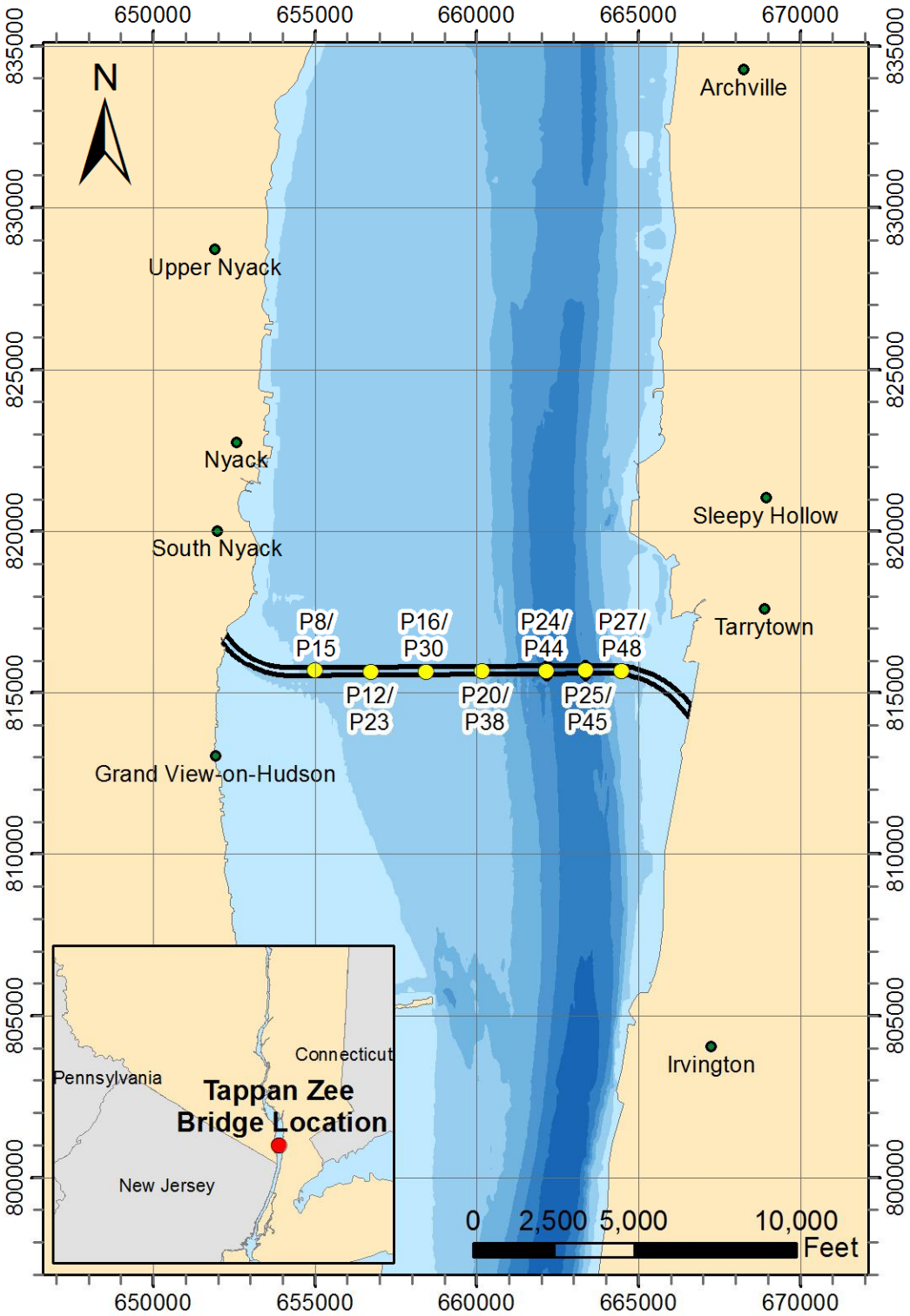

Figure 1. Location of proposed Tappan Zee Bridge and pile driving modeling locations (yellow dots). Annotations indicate construction pier numbers (dual level/single level) corresponding to each modeling location. Map coordinates are New York State Plane East (feet). Inset shows the location of the proposed bridge project.

2. Acoustics Background

2.1. Acoustics Terminology

Sound is the result of mechanical vibration waves traveling through a fluid medium such as air or water. These vibration waves generate a time-varying pressure disturbance that oscillates above and below the ambient pressure. Sound waves may be perceived by the auditory system of an animal, or they may be measured using an acoustic sensor (a microphone or hydrophone). Water conducts sound four times faster than air due to its lower compressibility; the speed of sound travelling in water is approximately 4900 ft/s. Sound is used extensively by marine organisms for communication and for learning about their environment. Humans may use sound purposely to probe the marine environment through technologies like sonar; more often, human activities such as marine construction generate underwater noise as an unintended side-effect.

Sources of underwater sound may be mechanical (e.g., a ship), biological (e.g., a whale) or environmental (e.g., rain). Noise, in general parlance, refers to unwanted sound that may affect humans or animals. Noise at relatively low levels can form a background that interferes with the detection of other sounds; at higher levels noise can also be disruptive or harmful. Common sources of naturally occurring underwater environmental noise include wind, rain, waves, seismic disturbances and vocalizations of marine fauna. Anthropogenic (i.e., man-made) sources of underwater noise include marine transportation, construction, geophysical surveys and sonar. Underwater noise usually exhibits both spatial and temporal variation.

2.2. Properties of Sound

The fundamental properties of sound waves are frequency, amplitude, wavelength, and intensity. Frequency, f, is the rate of pressure oscillation, per unit time, of a sound wave. Amplitude, A, is the maximum absolute pressure deviation of a sound wave. If c is the speed of sound in a medium, then the pressure disturbance due to a plane harmonic sound wave (Figure 2), at time t and location x, may described by the following expression:

$$P(x,t) = A\cos\left(2\pi f\,(x/c - t)\right) \tag{1}$$

The wavelength, λ, is the distance travelled by a sound wave over one complete cycle of oscillation. For plane harmonic sound waves, wavelength is equal to the frequency divided by the speed of sound:

$$\lambda = f/c \tag{2}$$

Harmonic waves are of fundamental importance in acoustics due to a well known mathematical law (Fourier's theorem) which states that any arbitrary waveform can be represented by the superposition of harmonic waves.

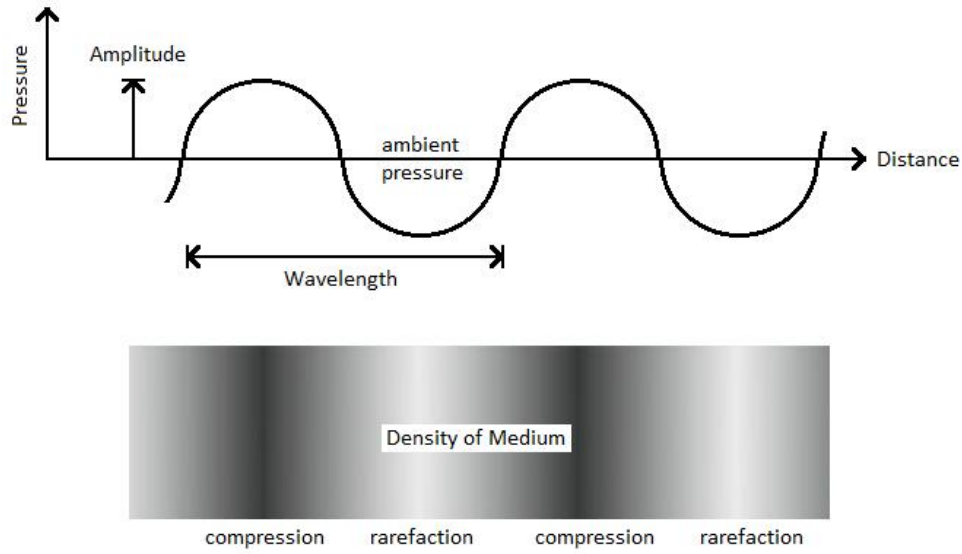

Figure 2: A snapshot of the pressure disturbance due to a plane harmonic sound wave.

Intensity is the acoustic power, per unit area, carried by a travelling sound wave. In general, intensity is related to the amplitude of a sound wave, but it also depends on the compressibility and density of the acoustic medium. The loudness of a sound is related to its intensity; however, loudness is a subjective term that refers to the perception of sound intensity, rather than the actual intensity itself. For humans and other animals, loudness also depends on the frequency and duration of sound.

2.3. Acoustic Metrics

Sound pressure and intensity are most commonly measured on the decibel (dB) scale. The dB scale is a logarithmic scale that expresses a quantity relative to a predefined reference level. Sound pressure, in dB, is expressed in terms of the sound pressure level (SPL), symbolized L_P:

$$L_P = 20\log_{10}(P / P_{ref}) \tag{3}$$

In this formula, P is the pressure amplitude and P_{ref} is the reference sound pressure. For underwater sound, the reference pressure is generally taken to be 1 μPa (10^{-6} Pa or 10^{-11} bar). In most cases, the sound intensity is directly proportional to the mean square of the sound pressure (i.e., $I \propto \langle P^2 \rangle$). Therefore, the sound pressure level (SPL) is usually taken to be synonymous with sound intensity level.

The decibel scale used for measuring hydroacoustic sound is not equivalent to the one used for measuring airborne sound. Airborne decibels are based on a standard reference pressure of 20 μPa, which is 20 times greater than the hydroacoustic reference pressure. Furthermore, due to differences in compressibility and density between the two media, the impedance relationship between sound pressure and sound intensity is not the same in air as it is in water. Taking into account differences in reference pressure and acoustic impedance, the hydroacoustic decibel

value (i.e., dB re 1 μPa in water) is approximately 63 dB greater than the standard airborne decibel value (i.e., dB re 20 μPa in air) for a sound wave with the same intensity in both media.

Since sound is a mechanical wave, it can also be measured in terms of the vibratory motion of fluid particles. Particle motion can be measured in terms of three different (but related) quantities: displacement, velocity, or acceleration. Acoustic particle velocity is the time derivative of particle displacement, and likewise acceleration is the time derivative of velocity. For the present study, acoustic particle motion has been reported in terms of velocity. Unlike sound pressure, particle motion is a vector quantity, meaning that is has both magnitude and direction: at any given point in space, acoustic particle motion has three different time-varying components (x, y, and z). Given the particle velocity in the x, y, and z, directions, v_x, v_y, and v_z, the particle velocity magnitude $|v|$ is computed according to the Pythagorean equation:

$$|v| = \sqrt{v_x + v_y + v_z} \tag{4}$$

The magnitude of the particle velocity can also be expressed in decibels, relative to a predefined reference level, v_{ref}:

$$L_v = 20\log_{10}(|v| / v_{ref}) \tag{5}$$

For the current study, the standard reference velocity, v_{ref}, is taken to be 1 nm/s and particle velocity levels are quoted in units of dB re 1 nm/s.

Sounds that are composed of single frequencies are called “tones”. Most sounds are generally composed of a broad range of frequencies (“broadband” sound) rather than pure tones. Sounds with very short durations (less than a few seconds) are referred to as “impulsive”. Such sounds typically have a rapid onset and decay. Steady sounds that vary only slowly with time, or that do not vary at all, are referred to as “continuous”.

2.3.1. Continuous Noise

Continuous noise is characterized by gradual intensity variations over time. Propeller noise from a transiting ship is an example. The intensity of continuous noise is generally given in terms of the root-mean-square (*rms*) sound pressure. Given a measurement of the time varying sound pressure, $p(t)$, from a given noise source, the *rms* SPL (symbol L_P) is computed according to the following formula:

$$L_P = 10\log_{10}\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}{}^2 \tag{6}$$

In this formula, T is the length of the time period over which the measurement was obtained. Figure 3 shows an example of a continuous noise pressure waveform and the corresponding *rms* sound pressure.

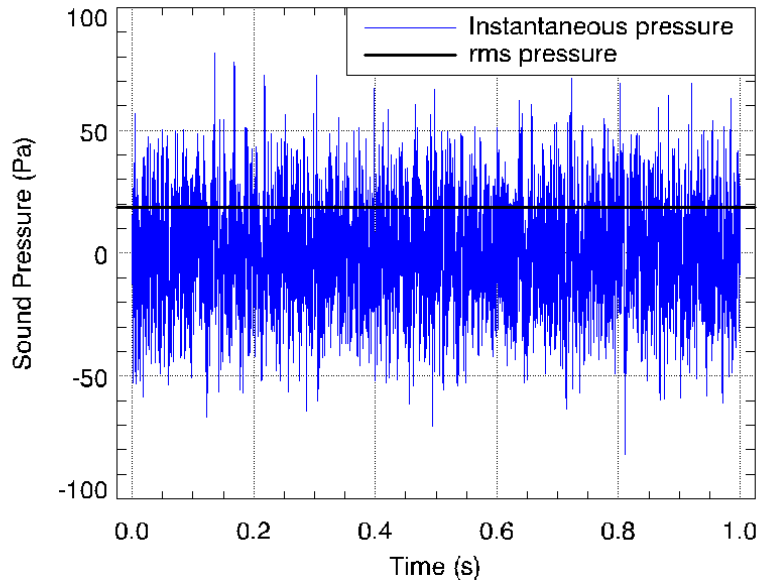

Figure 3. Example waveform showing a continuous noise measurement and the corresponding *rms* sound pressure.

2.3.2. Impulsive Noise

Impulsive or transient noise is characterized by brief, intermittent acoustic events with rapid onset and decay back to pre-existing levels (within a few seconds). Noise from impact driving of piles is an example. Impulse sound levels are commonly characterized using three different acoustic metrics: peak pressure, *rms* pressure, and sound exposure. The peak SPL (symbol L_{Pk}) is the maximum instantaneous sound pressure level measured over the impulse duration:

$$L_{Pk} = 20\log_{10}\left(\max\left|p(t)\right| / P_{ref}\right) \tag{7}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time, measured over the impulse duration $0 \le t \le T$. This metric is very commonly quoted for impulsive sounds but does not take into account the duration or bandwidth of the noise.

The *rms* sound pressure level may be measured over the impulse duration according to the following equation:

$$L_P = 10\log_{10}\left(\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}^2\right) \tag{8}$$

Some ambiguity remains in how the duration T is defined, because in practice the beginning and end of an impulse can difficult to identify precisely. In studies of impulsive noise, T is often taken to be the interval over which the cumulative energy curve rises from 5% to 95% of the total energy. This interval contains 90% of the total energy (T_{90}), and the SPL computed over this interval is commonly referred to as the 90% *rms* SPL (L_{P90}). The relative energy, $E(t)$, of the impulse is computed from the time integral of the square pressure:

$$E(t) = \int_0^t p(\tau)^2\,d\tau / P_{ref}^2 \tag{9}$$

According to this definition, if the time corresponding to n% of the total relative energy of the impulse is denoted t_n, then the 90% energy window is defined such that $T_{90} = t_{95} - t_5$. Figure 4 shows an example of an impulsive noise pressure waveform, with the corresponding peak pressure, *rms* pressure, and 90% energy time interval.

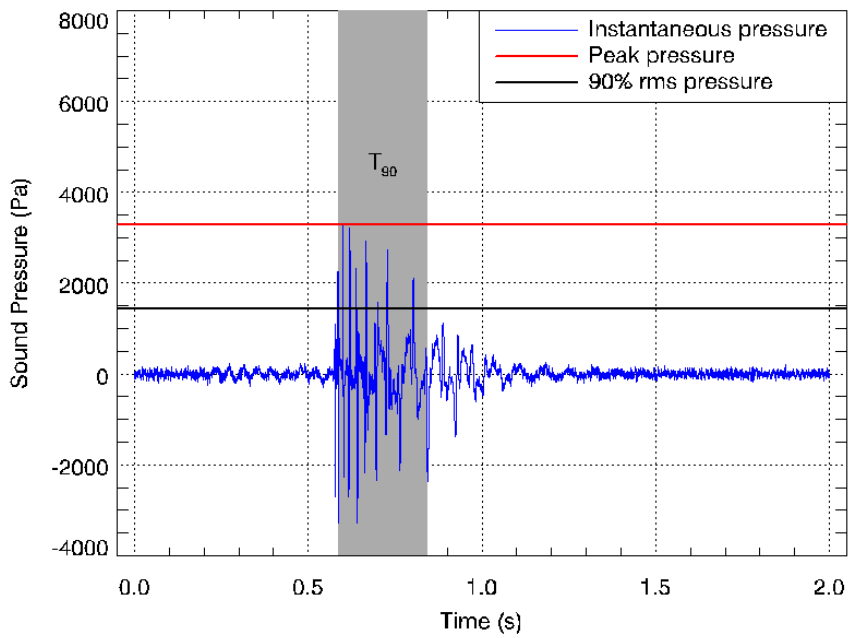

Figure 4. Example waveform showing an impulsive noise measurement. Horizontal lines indicate the peak pressure and 90% *rms* pressure for this impulse. The gray area indicates the 90% energy time interval (T_{90}) over which the *rms* pressure is computed.

The sound exposure level or SEL (symbol L_E) is a measure of the total sound energy contained in one or more impulses. The SEL for a single impulse is computed from the time-integral of the squared pressure over the impulse duration:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2\,dt / P_{ref}^2\right) = 10\log_{10}\left(E(t_{100})\right) \tag{10}$$

Unlike SPL, the SEL is generally applied as a dosage metric, meaning that its value increases with the number of exposure events. The cumulative SEL (cSEL) for multiple impulses (symbol $L_E^{(\Sigma)}$) is computed from the linear sum of the SEL values:

$$L_E^{(\Sigma)} = 10\log_{10}\left(\sum_{n=1}^{N} 10^{L_E^{(n)}/10}\right) \tag{11}$$

In this formula, N is the total number of impulses, and $L_E^{(n)}$ is the SEL of the nth impulse event. Alternatively, given the mean (or expected) SEL for single impulse events, $\langle L_E \rangle$, the cumulative SEL from N impulses may be computed according the following formula:

$$L_E^{(\Sigma)} = \langle L_E \rangle + 10\log_{10}(N) \tag{12}$$

Sound exposure levels for impulsive noise sources (i.e., impact hammer pile driving) presented in this report refer to single pulse SELs as well as cumulative SELs (cSELs) where appropriate. Because the 90% *rms* SPL and SEL for a single impulse are both computed from the integral of square pressure, these metrics are related by a simple expression that depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{P90} + 10\log_{10}(T_{90}) + 0.458 \tag{13}$$

In this formula, the 0.458 dB factor accounts for the remaining 10% of the impulse energy that is excluded from the 90% time window.

2.3.3. Source Level and Transmission Loss

Sources of underwater noise, such as ships' propellers or marine mammals' calls, generate radiating sound waves whose intensity generally decays with distance from the source. The dB reduction in sound level that results from propagation of sound away from an acoustic source is called propagation loss or transmission loss (TL). The loudness or intensity of a noise source is quantified in terms of the source level (SL), which is the sound level referenced to some fixed distance from a noise source. The standard reference distance for underwater sound is 1 m. By convention, transmission loss is quoted in units of dB re 1 m and underwater acoustic source levels are specified in units of dB re 1 μPa at 1 m. In the source-path-receiver model of sound propagation, the sound level L at some receiver position $\mathbf{r}$ is equal to the source level minus the transmission loss along the propagation path between the source and the receiver:

$$L(\mathbf{r}) = SL - TL(\mathbf{r}) \tag{14}$$

2.3.4. Spectral Density and 1/3-octave Band Analysis

The discussion of noise measurement presented so far has not addressed the issue of frequency dependence. The sound power per unit frequency of an acoustic signal is described by the power spectral density (PSD) function. The PSD for an acoustic signal is normally computed via the Discrete Fourier Transform (DFT) of time-sampled pressure data. The units of power spectral density are $\mu Pa^2/Hz$ or dB re 1 $\mu Pa^2/Hz$. For practical quantitative spectral analysis a coarser representation of the sound power distribution is often better suited. In 1/3-octave band analysis, an acoustic signal is filtered into multiple, non-overlapping pass-bands before computing the SPL. 1/3-octave bands are defined so that three adjacent bands span approximately one octave (i.e., a doubling) of frequency. Figure 5 shows an example of power spectral density levels and corresponding 1/3-octave band pressure levels for an ambient noise recording.

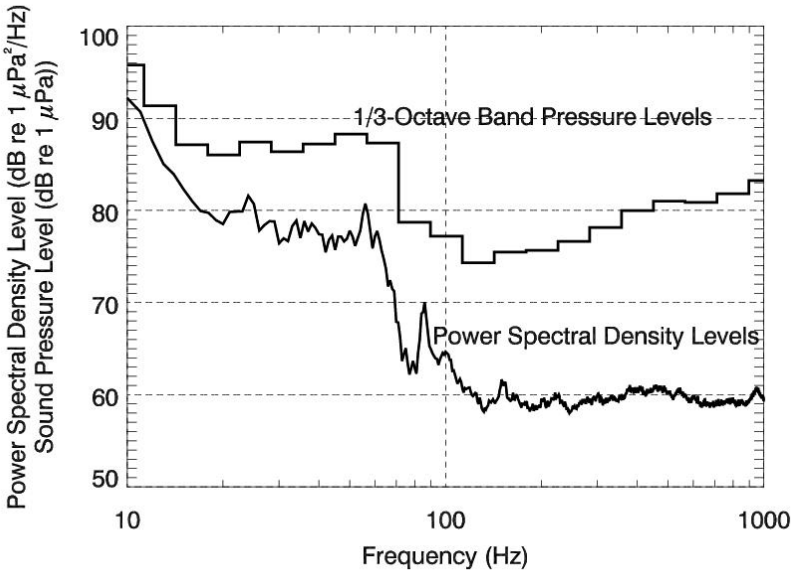

Figure 5. Plot of an ambient noise power spectrum and corresponding 1/3-octave band levels. Frequency is plotted on a log scale so 1/3-octave bands are wider at higher frequencies.

Standard center frequencies for 1/3-octave pass bands are given by the following formula:

$$f_c(n) = 10^{n/10} \quad n = 1, 2, 3... \tag{15}$$

Nominal 1/3-octave band center frequencies, according to ISO standards, for the range relevant to this study are listed in Table 1. The SPL inside a 1/3-octave band, $L_{pb}(f_c)$, is related to the average PSD level inside that frequency band, $L_{ps}^{(avg)}(f_c)$, by the bandwidth, Δf:

$$L_{ps}^{(avg)}(f_c) = L_{pb}(f_c) - 10\log_{10}(\Delta f) \tag{16}$$

The bandwidth of a 1/3-octave band is equal to 23.1% of the band center frequency (i.e., $\Delta f = 0.231 f_c$). Spectrum density levels and band levels are not limited to measurements of sound pressure: they may also, with appropriate selection of reference units, be given for SEL and particle velocity measurements.

Table 1: Nominal 1/3-octave band center frequencies from 10 Hz to 8 kHz.

Band Number	*Center Frequency (Hz)*	*Band Number*	*Center Frequency (Hz)*	*Band Number*	*Center Frequency (Hz)*
10	10	20	100	30	1000
11	12.5	21	125	31	1250
12	16	22	160	32	1600
13	20	23	200	33	2000
14	25	24	250	34	2500
15	31.5	25	315	35	3150
16	40	26	400	36	4000
17	50	27	500	37	5000
18	63	28	630	38	6300
19	80	29	800	39	8000

2.4. Effects Thresholds

The potential impact of anthropogenic (man-made) noise on a marine animal depends on the level of noise exposure. At moderate exposure levels, underwater noise may cause an overt change in the behavior of a subject. At high exposure levels, underwater noise can induce a temporary or permanent reduction in hearing sensitivity. At extreme exposure levels, pressure waves from some noise sources can cause traumatic injury and death. The impact of noise exposure generally depends on a number of factors related to the physical properties of the sound (e.g., the intensity, peak pressure, frequency, duration, duty cycle), and to the animal under consideration (e.g., hearing sensitivity, age, gender, behavioral status, prior exposures). The manner and severity of the impact can also depend on whether the overall noise consists of impulsive or continuous sounds or a combination. Common behavioral responses to noise exposure include startle or avoidance. Physiological effects usually consist of a lessening of the subject's hearing sensitivity. This reduction can be characterized as a temporary threshold shift (TTS) or permanent threshold shift (PTS), depending on whether hearing sensitivity recovers after the exposure. At extreme intensity levels, exposure to certain kinds of noise can cause physical trauma or death. Effect threshold criteria (sound levels deemed to induce onset of certain effects in a given species or category of animals) are generally used to establish zones of impact around marine noise sources for assessment or mitigation purposes.

Of the various construction activities associated with the Project, impact hammer pile driving is expected to generate the highest underwater sound levels. Based on a review of the available scientific data, an interim set of effects thresholds for fishes exposed to pile driving noise has been proposed for the Project's EIS. The proposed criteria for onset of physiological effects are as follows:

Peak SPL	208 dB re 1 µPa
Single strike SEL	187 dB re 1 $\mu Pa^2 \cdot s$
cSEL	197 dB re 1 $\mu Pa^2 \cdot s$

These criteria address physiological effects only, and are considered conservative for Hudson River fish species based on the available literature.

3. Methods

3.1. Sound Propagation Models

3.1.1. Marine Operations Noise Model

Acoustic footprints for marine construction activities in Tappan Zee Reach were modeled using JASCO Applied Sciences' proprietary Marine Operations Noise Model (MONM). MONM generates accurate estimates of the ensonfication of an underwater environment surrounding construction activities using a sophisticated numerical acoustic propagation algorithm. This algorithm fully accounts for the spectral distribution of the source and the physics of sound propagation in the water column and the underlying geological substrates. This type of modeling

differs significantly from generalized and empirical acoustic models, such as “practical spreading loss” models (see CALTRANS 2009, 4-16) that do not take into full account the source characteristics or the many site-specific factors that influence the rate of noise attenuation.

The propagation modeling algorithm in MONM is based on the U.S. Naval Research Laboratory’s split-step Padé parabolic equation (PE) range-dependent acoustic model (RAM). RAM has been extensively benchmarked for accuracy and is widely employed in the underwater acoustics community (Collins, 1993). The split-step Padé solution is not only valid for very wide vertical propagation angles (> 60 degrees in most cases) but it also fully accounts for the geoacoustic properties of the sub-bottom and the discontinuity of these properties at the interface (Jensen et al., 2000, Ch. 6). Furthermore, JASCO has augmented RAM to account for losses due to the elastic (that is, shear-wave) properties of the sub-bottom using the complex density equivalent fluid approximation (Zhang and Tindle, 1995). The combination of the wide-angled PE and the accurate handling of the sub-bottom geoacoustic properties mean that JASCO's approach is completely applicable in shallow water environments.

MONM computes acoustic fields in 3-D by modeling transmission loss along evenly distributed radial traverses covering a 360 º swath from the source (so-called N×2-D modeling). The model makes use of several parameters of the propagation environment including bathymetry, sound speed profiles in water and geoacoustic profiles. Underwater sound propagation is strongly influenced by the geoacoustic properties of the riverbed, which include the material density, seismic compressional-wave (P-wave) and shear-wave (S-wave) speeds, and the seismic wave-attenuation of seabed materials. MONM takes each of these into account when calculating propagation loss. Frequency dependence of the sound propagation is treated by computing acoustic transmission loss in 1/3-octave bands up to several kHz. Sound pressure levels in each band are computed by applying frequency-dependent transmission losses to the corresponding 1/3-octave band source levels. Broadband results are then obtained by summing the levels across all bands. Results from multiple model runs for concurrently operating sources may be meshed into multi-source scenario results. This approach has been validated against benchmarks and experimental data and has proven to be highly accurate for predicting noise levels in the vicinity of industrial operations associated with marine construction and geophysical survey activities (Hannay and Racca, 2005).

The parabolic-equation (PE) based algorithm at the core of MONM, represents the best available method for modeling underwater sound propagation in complex-bathymetry environments like Tappan Zee Reach. While the PE algorithm assumes that sound originates from a single source in the water column (i.e., the "far-field" approximation) rather than a distributed source along the struck pile, the method of effective source level estimation by back-propagation (to be discussed in Section 3.2) ensures that modeled acoustic levels are calibrated against actual pile driving measurements. Back-propagated source levels necessarily account for sound energy from all different propagation paths that contributed to the original measurement, originating both in the water column and below the mudline. Averaging over an ensemble of measurements further ensures the generality of the derived source levels. MONM applies the propagation loss, based on the dominant water-borne path, to the back-propagated source levels to determine the attenuation of sound energy with distance from the pile. Sound levels computed by this method, which is commonly used in the field of hydroacoustics, are expected to be conservative in the near-field and accurate in the far-field.

3.1.2. VSTACK Near-field Wavenumber Integration Model

Near-field peak pressure and particle velocity from marine pile driving were modeled using JASCO's VSTACK wavenumber integration model. VSTACK computes synthetic pressure waveforms versus depth and range for arbitrarily layered acoustic environments using the wavenumber integration approach to solving the exact (range-independent) acoustic wave equation. This model is valid over the full angular range of the wave equation and can fully account for the elasto-acoustic properties of the sub-bottom. Wavenumber integration methods are extensively used in the field of underwater acoustics and seismology where they are often referred to as reflectivity methods or discrete wavenumber methods (Jensen et al., 2000). VSTACK computes sound propagation in arbitrarily stratified water and seabed layers by decomposing the outgoing field into a continuum of outward-propagating plane cylindrical waves. Seabed reflectivity in VSTACK is dependent on the seabed layer properties: compressional and shear wave speeds, attenuation coefficients, and layer densities. VSTACK fully accounts for vibration of the seabed interface excited by the pile and its coupling to the water column. Fundamental to the modeling is the physical constraint that the instantaneous displacements of the seabed and the water are equivalent at the interface between the two media.

VSTACK computes pressure waveforms via Fourier synthesis of the acoustic transfer function in closely spaced (< 1 Hz) frequency bands. In addition, VSTACK includes the ability to model distributed monopole sound sources in the water column and in the sub-bottom. A vertically-distributed array of sources is used to calculate both pressure and particle velocity in the near-field region of a pile. VSTACK assumes range-invariant bathymetry with a horizontally stratified medium (i.e., a range-independent environment) which is azimuthally symmetric about the source. VSTACK is thus best suited to modelling the sound field in close proximity to the pile. Note that, while the range-independent model assumes that the layering of the environment is invariant with range, it does not assume that the vibration field is invariant with range. Even in the range-independent case, the vibration field exhibits very complex variations with distance from the source. This is due to interference between the multiple acoustic paths corresponding to reflection and transmission of vibration from the different layers in the model, which VSTACK accounts for in its calculation.

3.1.3. FWRAM Far-field Waveform Synthesis Model

For computing *rms* SPLs from marine pile driving, far-field pressure waveforms were modeled along single-range depth transects using JASCO's FWRAM time-domain PE model. FWRAM computes synthetic pressure waveforms versus range and depth for range-varying marine acoustic environments using the parabolic equation approach to solving the acoustic wave equation. This software uses the same underlying algorithmic engine as MONM for computing acoustic propagation along 2-D range-depth transects, and takes the same environmental inputs (bathymetry, water sound speed profiles, and seabed geoacoustics). FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands. Like MONM, FWRAM accounts for range-varying properties of the acoustic environment and is therefore capable of computing *rms* SPL at long ranges, outside the near-field zone of the pile driving. FWRAM, being a time-domain model, is well suited to computing time-averaged *rms* SPL values for impulsive sources.

3.2. Acoustic Source Levels

Source levels for impact hammer pile driving scenarios were estimated based on a review and analysis of published sound level measurements from the available literature. Documentation provided by the Project's engineers specified that 4 ft, 6 ft, 8 ft, and 10 ft diameter steel piles would be driven at the proposed bridge site using two different types of hydraulic impact hammers: IHC model S-750 rated to 550.8 kips-ft and IHC model S-600 rated to 443.5 kips-ft. Direct measurements of underwater sound levels for these specific hammer-pile combinations were unavailable; source levels were therefore estimated from analysis of published pile driving measurements (Table 2). These studies presented received levels in spectra or 1/3-octave bands for a variety of pile-hammer configurations, measured in different acoustic environments. Table 2 specifies the pile size, hammer energy, measurement range, measured broadband SEL and frequency range for the measurements that were used to derive acoustic source levels. Source levels for the current study were extrapolated from these data based on hammer energy and pile dimensions, which are the primary factors that determine sound emissions from impact pile driving (Nehls et al, 2007, §2.1.3).

Table 2: Specifications of pile driving measurements from published literature.

Project	Pile Diameter (ft)	Hammer Type	Rated Hammer Energy (kips·ft)	Measurement Range (ft)	SEL at Measurement Range (dB re 1 μPa^2·s)	Reported Frequency Range (Hz)
Eagle Harbor 2005 [(a)]	3.0	Diesel	138	33	179	10-16000
NaiKun 2007 [(b)]	3.0	Drop	236	33	192	10-16000
Alameda 2006 [(c)]	3.3	Diesel	221	33	180	10-5000
ITAP 2006 [(d)]	7.2	Hydraulic	145	98	174	12.5-20000
PIDP 2001 [(e)]	7.9	Hydraulic	738	328	178	50-20000
Richmond 2003 [(f)]	5.5	Diesel	266	98	173	10-5000
Amrumbank 2005 [(g)]	11.5	Unknown	406	2789	174	30-20000
FINO2 2006 [(g)]	10.8	Hydraulic	221	1739	173	16-20000
Utgrunden 2000 [(h)]	9.8	Hydraulic	299*	1050	173	16-12000

Citations: (a) MacGillivray et al. 2005, (b) Racca et al., 2007, (c) Illingworth and Rodkin Inc., 2006, (d) Schultz et al., 2006, (e) Caltrans, 2001, (f) Reyff, 2003, (g) Nehls et al., 2007, (h), McKenzie-Maxon, 2000.
*The hammer energy was not specified for the Utgrunden project. The energy estimate used for the source level calculations, 299 kips-ft, was set lower than both hammer energies proposed in an attempt to derive conservative source levels.

To calculate 1/3-octave band source levels, the measured spectra were first converted to 1/3-octave band received levels by summing the energy in each band. Each measurement was back-propagated to 1 m (3.28 ft) from the source assuming spherical spreading – i.e. by adding $20\log_{10}r$ to the received levels, where r is the measured distance to the pile in meters. At closer distances to the pile, where source levels measurements are preferentially obtained, spherical spreading is expected to accurately represent the mean propagation loss. This is particularly the case when averaging over several different measurements, as has been done here. Spherical spreading may underestimate source levels at some lower frequencies, where bottom loss has greater influence; however, these frequencies are rapidly attenuated with range and do not make a dominant contribution to the far-field sound levels.

The resulting 1/3-octave band source levels were then scaled to a common reference hammer energy assuming that the underwater acoustic energy was directly proportional to the hammer energy – i.e. by adding $10\log_{10}(E_{ref}/E_{ham})$ to the source levels, where E_{ref} is a reference energy

and E_{ham} is the maximum rated energy of the hammer used during the particular measurement. The energy-corrected broadband source level for each measurement was plotted against pile diameter, and linear regression was used to derive the trend of the data (see Figure 6).

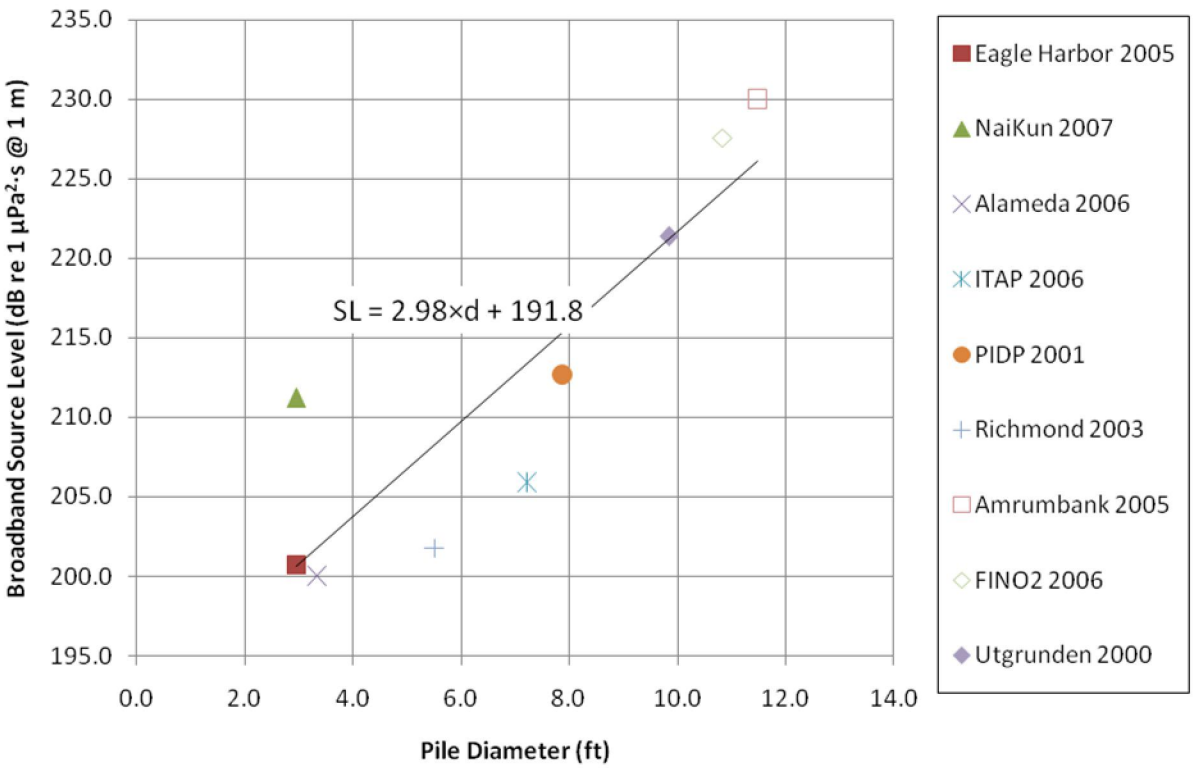

Figure 6. Energy-corrected broadband source level for pile driving as a function of pile diameter. The equation of the regression fit is annotated on the plot, where *d* is in ft and *SL* is in dB re 1 µPa^2·s @ 1 m. Refer to Table 2 for citations.

The resulting energy-corrected 1/3-octave band source levels showed two trends that were dependent on pile size. Levels for small diameter piles (4-6 ft) were highest at frequencies between approximately 200 and 1260 Hz; levels for large diameter piles (8-10 ft) were highest at frequencies between approximately 100 and 630 Hz. Source levels in each 1/3-octave band were averaged for all measurements, in their pile size range, to characterize the frequency distribution for small and large piles. Figure 7 shows the resulting averaged 1/3-octave band source levels for small and large piles.

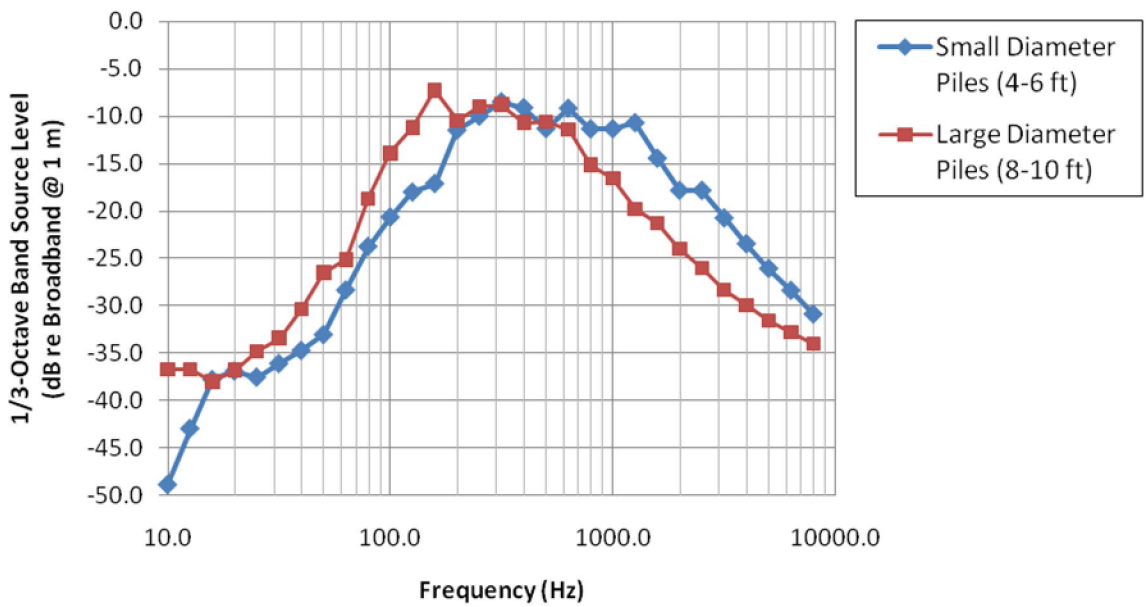

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Figure 7. Normalized 1/3-octave band source levels, corrected for hammer energy, for small (4-6 ft) and large (8-10 ft) diameter piles.

To calculate the 1/3-octave band source levels for each proposed pile-hammer configuration, the appropriate frequency distribution (small or large diameter) was adjusted so that the broadband level matched the level predicted by the regression equation in Figure 6 for the pile size in question. The source levels were then adjusted from the reference hammer energy to the rated hammer energy for the proposed hammer by adding $10\log_{10}(E_{ham}/E_{ref})$ to the estimates. Figure 8 shows the 1/3-octave band source levels for the four pile-hammer configurations used in this modeling study.

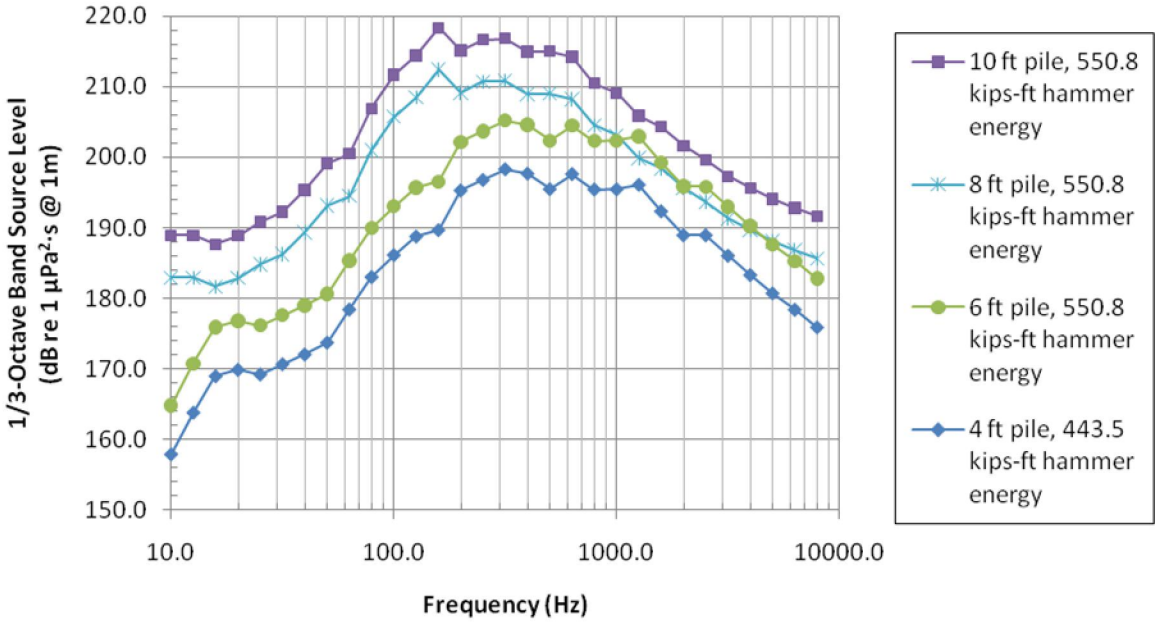


Figure 8. Estimated 1/3-octave band source levels for impact driven steel piles with specified diameter and pile energy.

Estimates of peak SPLs and *rms* SPLs require time-domain representations of source impulses generated in the water by the impact hammer pile driving. Direct-path measurements of source waveforms from pile driving are generally difficult to extract from recorded data because pile driving tends to take place in shallow water where, even at very close range, direct-path source waveforms are contaminated by interference from multiple bottom and surface reflections. For the current study, source wavelets for the piling were instead derived mathematically from the 1/3-octave band source levels via spectral factorization (Claerbout, 1976). The spectral factorization algorithm derives a unique time-domain waveform from a given power spectrum by compressing the maximum amount of signal energy into the shortest causal time period (known as the minimum-phase condition). Far-field source waveforms derived via spectral factorization (Figure 9) are expect to provide a realistic but conservative estimate of peak pressures generated during impact hammer pile driving.

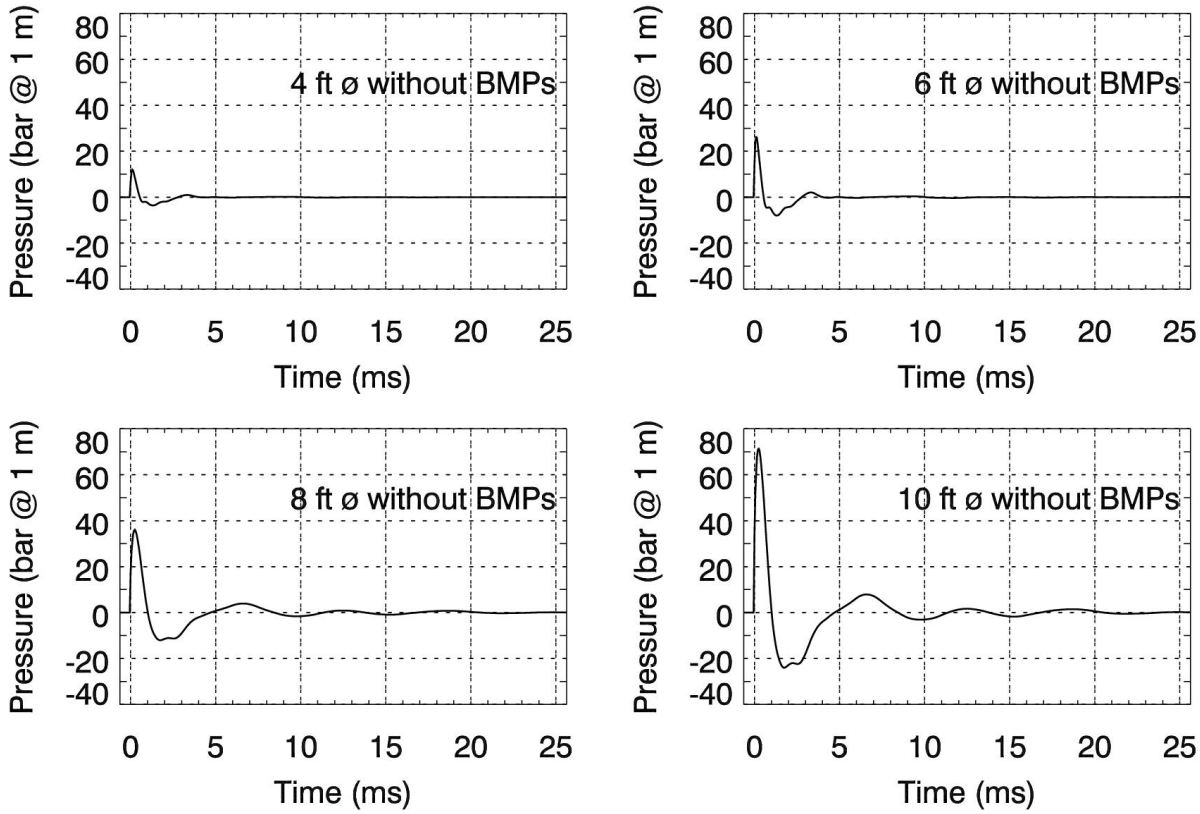


Figure 9. Far-field source waveforms for impact pile driving, referenced to 1 m range, as derived from spectral factorization of 1/3-octave band source levels.

3.3. Best Management Practices (BMPs)

Best Management Practices (BMPs) consist of strategies that may be applied to reduce impacts of construction activities on the surrounding environment. For aquatic pile driving, BMPs are focused primarily on methods for reducing sound levels of waterborne pressure waves. Examples of BMPs for aquatic pile driving include the following:

1. Air bubble curtains (confined and unconfined)
2. Pile sleeves and other physical barriers
3. Working in dewatered cofferdams
4. Vibratory driving instead of impact driving
5. Pile driving cushions

For locations with notable current velocity, like the Tappan Zee Reach, experience has shown that confined air bubble curtains, which consist of one or more bubble rings enclosed in a sleeve surrounding the pile, represent a practical BMP strategy. The application of air bubble curtains for reducing underwater sound levels from pile driving has been studied extensively, particularly for large diameter piles (Vagle, 2003, Nehls et al., 2007, CALTRANS, 2009). The operating principle of this mitigation method is based on the fact that a cloud of air bubbles generated

around the pile changes the acoustic properties of the medium in such a way as to reduce transmission of pressure waves from pile driving into the surrounding water. The reported effectiveness of bubble curtains is highly variable and depends on many factors, including the thickness of the bubble layer, the total volume of injected air, the size of the bubbles relative to the sound wavelength, and whether the curtain is completely closed. Use of a confined air bubble curtain ensures that the submerged section of a pile is shielded from water currents and remains completely enshrouded in bubbles at all times. On the basis of these considerations, confined air bubble curtains were identified as the best probable BMP strategy for the Project.

A review of the available literature yielded a number of measurements of sound attenuation for confined air bubble curtain systems. Of the available data, the relatively few measurements that showed per-frequency comparisons of attenuated and non-attenuated impact piling sound levels were compiled to determine an average attenuation trend for confined air bubble curtain systems (Table 3 and Figure 10). Averaging of 1/3-octave band attenuation levels was limited to the frequency range for which all literature sources reported data (63 Hz to 6300 Hz). While the mean broadband attenuation was found to be approximately 20 dB, the published measurements showed substantial variability in the effectiveness of confined air bubble curtain systems with quoted broadband sound level reductions ranging from 5 dB to 36 dB.

Based on published assessment guidelines (CALTRANS, 2009, 2-25, and WSDOT, 2010b, 7.41) it was determined on precautionary grounds that 10 dB mean attenuation was a more realistically achievable target for BMP performance. The average attenuation trend from the literature review analysis was therefore adjusted downwards for the modeling so that the mean 1/3-octave band attenuation in the range 63 Hz to 6300 Hz was equal to 10 dB (Figure 11). This adjustment resulted in extrapolated attenuation values of approximately 0 dB (no mitigation effect) below 63 Hz, which is consistent with the typically poor low-frequency performance of bubble curtain systems apparent in Figure 10. The confined air bubble curtain attenuation values thus derived were applied to source levels for those modeling scenarios that included BMPs. The same BMP attenuation values were also applied, as appropriate, to the time-domain source waveforms for peak SPL and *rms* SPL modeling scenarios.

Table 3: Specifications of confined air bubble curtain systems from published literature sources for impact driving of steel shell piles.

Project	BMP Description	Air Curtain Specifications*	Pile Diameter (ft)	Meas. Distance (ft)	Quoted Reduction (broadband)
WSDOT SR-520 [(a)]	Steel isolation casing with single bubble ring	680-700 CFM 105-115 PSI	2.5	33	35 dB
Benicia-Martinez Bridge [(b)]	Steel isolation casing 12.1 ft diameter with bubble ring	unkown	7.9	177	21 dB
East Span PIDP [(c)]	Fabric mantle 13.1 ft diameter with bubble ring	1500 CFM	8.5	330	5-10 dB
WSF Eagle Harbor [(d)]	PVC isolation casing 4 ft diameter with single bubble ring	300-350 CFM	2.0	33	9 dB

Citations: (a) WSDOT, 2010a, (b) CALTRANS, 2009, (c) Illingworth and Rodkin, 2001, (d) MacGillivray and Racca, 2005.
* CFM = cubic feet per minute (airflow rate), PSI = pounds per square inch (air pressure).

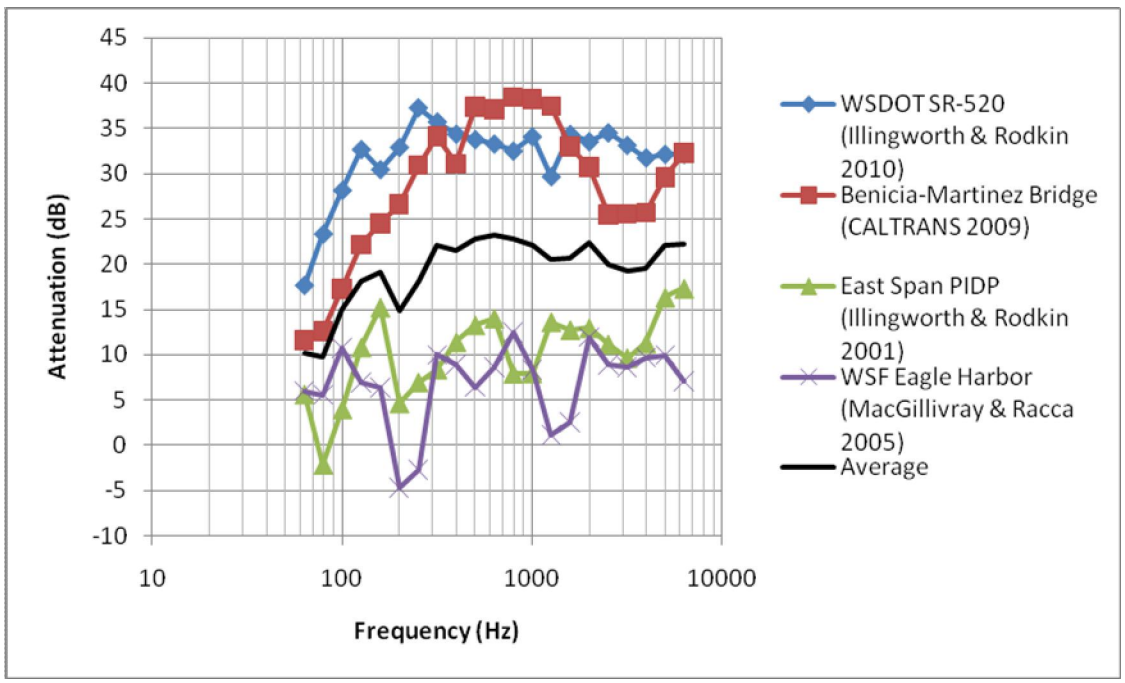


Figure 10. Published measurements of acoustic attenuation for confined air bubble curtain systems in 1/3-octave bands. Black line indicates average attenuation in each frequency band.

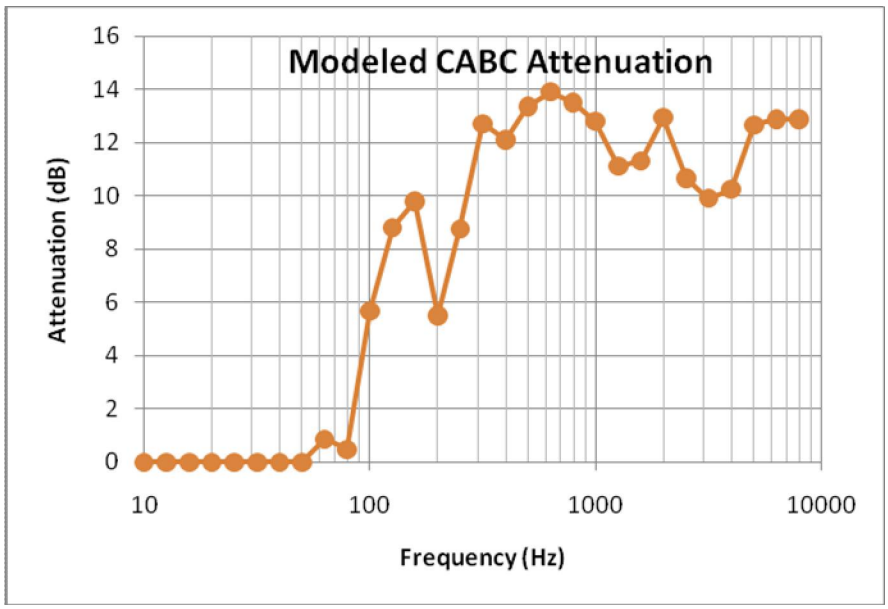


Figure 11: Modeled acoustic attenuation for a confined air bubble curtain system in 1/3-octave frequency bands.

3.4. Acoustic Environment

3.4.1. Bathymetry

JASCO's acoustic models utilize high-resolution grids of bathymetry data to define water depths inside a region of interest. For the current study, high-resolution bathymetric survey data from Ocean Surveys, Inc. (OSI) were combined by AECOM with bathymetric data from publicly available sources (such as NYSDEC and NOAA) to produce the gridded bathymetric dataset used in the acoustic propagation model. The spatial resolution of the gridded dataset was 67 ft (20 m). Water depths were corrected to Mean Sea Level (MSL) (0.08 ft above NAVD88) before being input to the model. The gridded bathymetry dataset (Figure 12) extended approximately 65,000 ft upriver and 65,000 ft downriver from the location of the proposed bridge crossing.

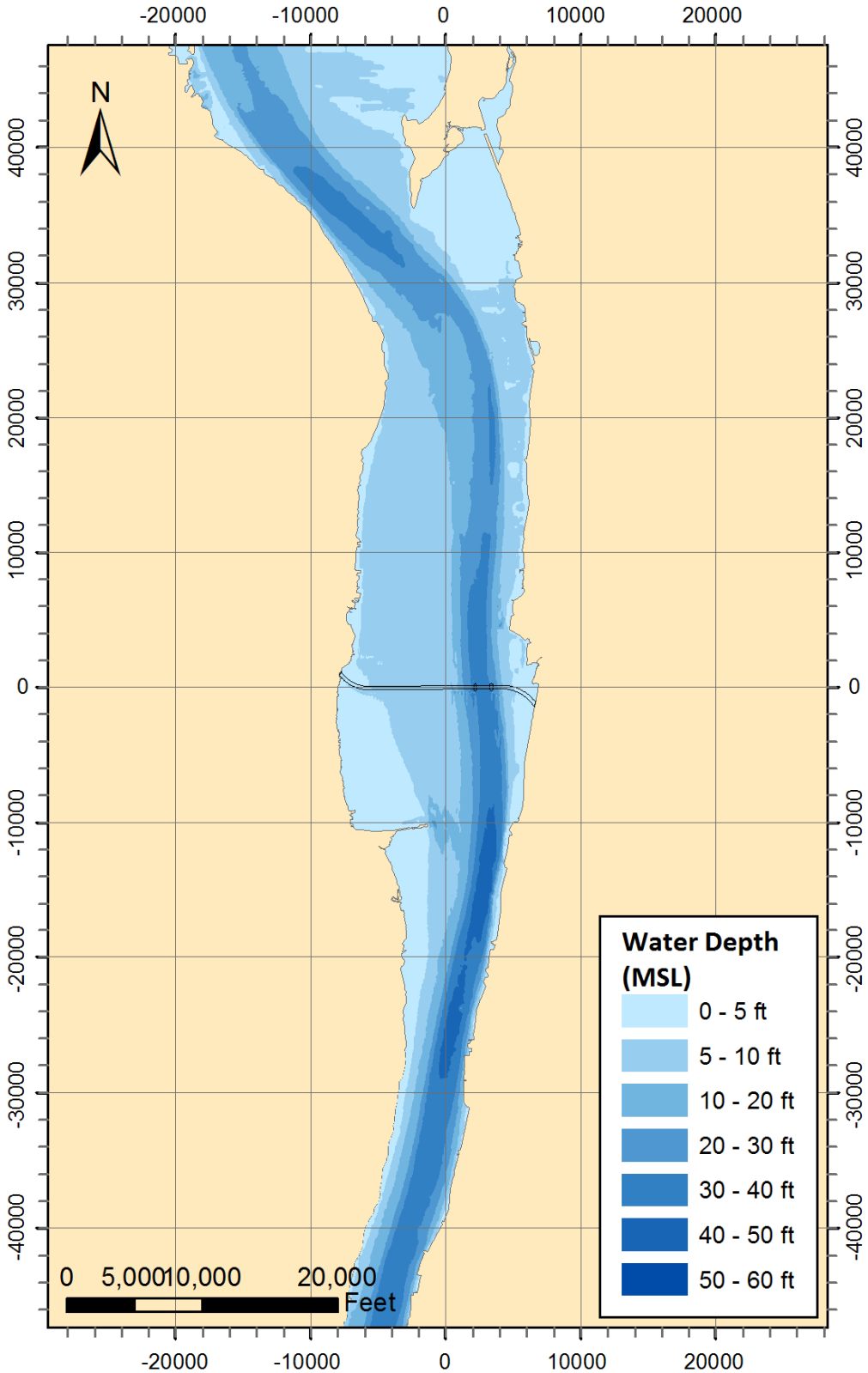


Figure 12: Contour map of Hudson River bathymetry data used in the acoustic modeling. Map grid shows coordinates, in feet, relative to the bridge center.

3.4.2. Underwater sound speed

Temperature and salinity are the most important factors that determine the speed of sound in water. For the current study, river sound speed profiles were derived from conductivity-temperature-depth (CTD) survey data collected at Tappan Zee Reach by OSI in April 2007, October 2008, and December 2008 (OSI, 2009). Profiles from the CTD survey showed that temperature was fairly uniform with depth for all survey periods (typically < 2°F variation), with April temperatures colder at the bottom and December temperatures colder at the surface. Salinity stratification was more variable than temperature stratification: both the April and December profiles showed a strong halocline (~8 PSU), whereas the October data did not.

The weak stratification of the October profiles corresponded to a nearly uniform distribution of sound speed with depth. Given the observed temporal variability, a uniform sound velocity profile was considered to best reflect the mean conditions in Tappan Zee Reach; the October conditions were thus selected as representative for the modeling. Seven CTD records collected on 31 October 2008 within 2500 ft of the existing Tappan Zee Bridge were combined to derive a uniform underwater sound speed profile representative of conditions near the bridge (Figure 13), which was used as input to the acoustic models. The sound speed profiles shown were computed directly from temperature and salinity values using standard formulae (Coppens, 1981).

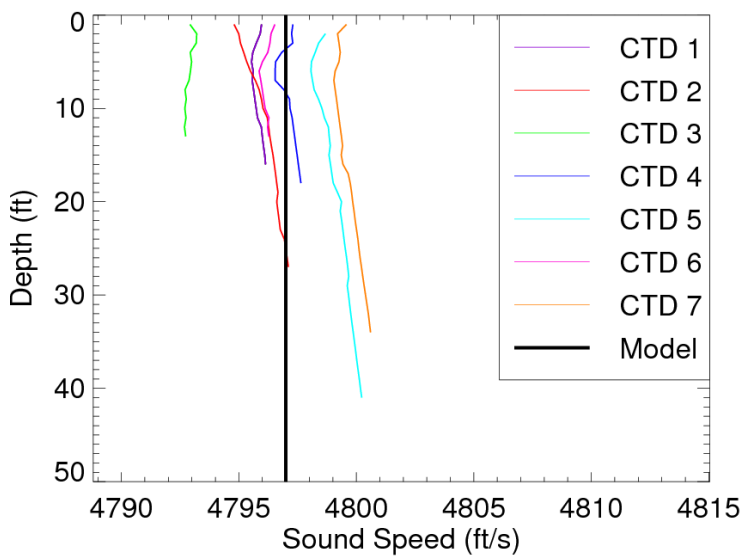


Figure 13: Model sound speed profile as derived from temperature and salinity measurements obtained during October 2008 in Tappan Zee Reach.

3.4.3. Riverbed geoacoustics

Geoacoustic profiles, describing the elasto-acoustic properties of the riverbed sediments, were estimated from geological stratigraphy data for the bridge span documented by NYSDOT (Arup, 2010, Lacey, 2008). A cross-section of the riverbed stratigraphy at the Tappan Zee Bridge site showed that it is composed primarily of five layered units: organic silty clay, organic silty clay with sand, sand, glacial varved silt and clay, and bedrock. The thicknesses and depths of these

layers vary across the span of the river. Descriptions of soil composition for these layers were used to estimate geoacoustic properties using the methods described by Hamilton (1980).

In order to account for variations in the layering of the riverbed sediments, unique site-specific geoacoustic profiles were created for each of the source locations used in the modeling (Table 4); these profiles were used for modeling sound propagation at ranges up to 820 ft from the piles. At longer distances from the piles, the range-dependent models (MONM, FWRAM) transitioned to a common geoacoustic profile, also shown in Table 4, intended to represent mean sediment properties over the span of the river. Riverbed properties near the pile are more influential than those at long ranges, since bottom loss at the source determines the total amount of sound energy that remains trapped in the water column. Geoacoustic properties were defined up to a maximum depth of 340 ft below the riverbed, which was the maximum depth of the available geological data.

The five geoacoustic properties used by MONM for modeling sound propagation in sub-bottom sediments are as follows:

1. Relative density: The density of the bottom materials relative to the density of water.
2. Compressional-wave sound speed: The phase speed of longitudinal body waves (P-waves) in the bottom materials (units of ft/s).
3. Compressional attenation: The rate of attenuation (units of dB per wavelength) of longitudinal body waves in the bottom materials.
4. Shear-wave sound speed: The phase speed of transverse body waves (S-waves) in the bottom materials (units of ft/s).
5. Shear attenuation: The rate of attenuation (units of dB per wavelength) of transverse body waves in the bottom materials.

In MONM, profiles of density, compressional-wave speed, and compressional attenuation may be defined to arbitrary depth in the sub-bottom. The complex-density fluid approximation used by MONM accounts for bottom loss due to shear-wave conversion at the seabed interface. In this approximation, shear-wave properties of the sediments are only modelled at the water-riverbed interface. Shear-wave properties of the deeper layers do not significantly influence sound propagation in the water column and are not incorporated into the complex-density approximation.

Table 4. Site-specific geoacoustic profiles for each of the seven pile modeling locations (identified by dual/single construction pier number). The last profile in the table is the average river geoacoustic profile that was common to all model scenarios at distances > 820 ft from the source.

Depth (ft below riverbed)	Soil Description	Relative Density (water=1)	Compressional Sound Speed (ft/s)	Compressional Attenuation (dB/λ)	Shear Sound Speed (ft/s)	Shear Attenuation (dB/λ)
P8/P15						
0	Organic silty	1.42	4768	0.11	361	1.9
80	clay	1.45	4848	0.12	–	–
80	Organic silty	1.63	5035	0.32	–	–
160	clay with sand	1.65	5115	0.46	–	–
160	Sand	2.00	5796	0.87	–	–
175		2.01	5812	0.87	–	–
175	Glacial varved	1.55	5039	0.17	–	–
340	silt and clay	1.61	5204	0.27	–	–
P12/P23						
0	Organic silty	1.42	4768	0.11	361	1.9
80	clay	1.45	4848	0.12	–	–
80	Organic silty	1.63	5035	0.32	–	–
115	clay with sand	1.64	5070	0.38	–	–
115	Sand	2.00	5751	0.86	–	–
175		2.02	5812	0.86	–	–
175	Glacial varved	1.55	5039	0.17	–	–
340	silt and clay	1.61	5204	0.27	–	–
P16/30						
0	Organic silty	1.42	4768	0.11	361	1.9
100	clay	1.46	4868	0.13	–	–
100	Organic silty	1.63	5055	0.36	–	–
140	clay with sand	1.65	5095	0.43	–	–
140	Sand	2.00	5776	0.87	–	–
165		2.01	5801	0.87	–	–
165	Glacial varved	1.55	5029	0.16	–	–
340	silt and clay	1.61	5204	0.27	–	–
P20/38						
0	Organic silty	1.42	4768	0.11	361	1.9
85	clay	1.45	4853	0.12	–	–
85	Organic silty	1.63	5040	0.33	–	–
105	clay with sand	1.63	5060	0.36	–	–
105	Sand	2.00	5741	0.86	–	–
135		2.01	5771	0.86	–	–
135	Glacial varved	1.54	4999	0.16	–	–
190	silt and clay	1.56	5054	0.17	–	–
190	Rock	2.20	7216	0.10	–	–

Depth (ft below riverbed)	Soil Description	Relative Density (water=1)	Compressional Sound Speed (ft/s)	Compressional Attenuation (dB/λ)	Shear Sound Speed (ft/s)	Shear Attenuation (dB/λ)
P24/44						
0	Organic silty	1.42	4768	0.11	361	1.9
70	clay	1.45	4838	0.12	–	–
70	Organic silty	1.62	5025	0.31	–	–
75	clay with sand	1.62	5030	0.32	–	–
75	Sand	2.00	5711	0.86	–	–
95		2.01	5731	0.86	–	–
95	Glacial varved	1.52	4959	0.15	–	–
230	silt and clay	1.57	5094	0.18	–	–
230	Rock	2.20	7216	0.10	–	–
P25/45						
0	Organic silty	1.42	4768	0.11	361	1.9
75	clay	1.45	4843	0.12	–	–
75	Organic silty	1.62	5030	0.32	–	–
85	clay with sand	1.63	5040	0.33	–	–
85	Sand	2.00	5721	0.86	–	–
100		2.01	5736	0.86	–	–
100	Glacial varved	1.52	4964	0.15	–	–
230	silt and clay	1.57	5094	0.18	–	–
230	Rock	2.20	7216	0.10	–	–
P27/48						
0	Organic silty	1.42	4768	0.11	361	1.9
25	clay	1.43	4793	0.12	–	–
25	Organic silty	1.61	4980	0.23	–	–
80	clay with sand	1.63	5035	0.32	–	–
80	Sand	2.00	5716	0.86	–	–
100		2.01	5736	0.86	–	–
100	Glacial varved	1.52	4964	0.15	–	–
145	silt and clay	1.54	5009	0.16	–	–
145	Rock	2.20	7216	0.1	–	–
Average						
0	Organic silty	1.42	4768	0.11	361	1.9
80	clay	1.45	4848	0.12	–	–
80	Organic silty	1.63	5035	0.32	–	–
110	clay with sand	1.64	5065	0.37	–	–
110	Sand	2.00	5747	0.86	–	–
140		2.01	5776	0.86	–	–
140	Glacial varved	1.54	5004	0.16	–	–
400	silt and clay	1.63	5264	0.38	–	–
400	Rock	2.20	7216	0.10	–	–

3.5. SEL and cSEL Modeling

MONM was used to directly compute single-strike SEL and cumulative SEL produced by marine pile driving activities at Tappan Zee Reach. Acoustic fields were computed on a three-dimensional spatial grid, resolved into 1/3-octave frequency bands. For subsequent presentation and interpretation, sound levels from MONM were rendered as two-dimensional contour maps that showed the acoustic footprint maximized over the depth dimension. Two different kinds of impact pile driving scenarios were modeled for the current study: single-pile, single-strike SEL scenarios, and multi-pile, multi-strike cSEL scenarios. The single-pile, single-strike scenarios considered the SEL field produced by a single hammer blow at a single location. The multi-pile, multi-strike scenarios considered the total cSEL field produced by driving of multiple piles at several different locations over the course of a 12-hour work day.

The modeling procedure for the single-pile, single-strike SEL scenarios was as follows:

1. MONM was used to compute three-dimensional fields (range, azimuth, depth) of transmission loss for each pile driving source location in 1/3-octave frequency bands.
2. Single-strike SEL fields, in 1/3-octave bands, were computed by combining pile driving source levels (Section 3.2) with transmission loss.
3. The 1/3-octave band SEL fields for each pile were resampled onto a 10 m cartesian grid (easting, northing). A 100 m radial-smoothing kernel was applied to the SEL fields prior to gridding.
4. The 1/3-octave band SEL grids were summed over frequency and maximized over depth to generate a two-dimensional plane of received levels.
5. A contouring algorithm was used to extract SEL contours from the received level data.
6. SEL contours were converted to GIS layers and rendered on thematic maps.

The modeling procedure for the multi-pile, multi-strike cSEL scenarios was as follows:

1. Aligned grids of single-strike SEL values were computed for the individual source locations, according to steps 1-3 above.
2. For each individual source location, multi-strike cSEL was computed from the single-strike SEL according to the total number of pile driving hammer blows (i.e., by adding $10\log_{10}(N)$).
3. The cSEL results from all sources were summed at the aligned grid points to compute the multi-source cSEL.
4. The cSEL grids were converted to maximum-over-depth cSEL contours according to steps 4-6 above.

Acoustic propagation estimates generated by MONM are suitable for computing SEL and cSEL from aquatic pile driving operations in the acoustic far-field of the pile. The far-field region is where the distributed nature of the pile can be safely neglected for the purpose of computing propagation loss, treating the sound as radiating from a single point. The choice of this point is nonetheless important for generating propagation loss estimates. For modeling aquatic pile driving with MONM, the point of radiation was placed midway between the surface and the mudline as this provides the maximum acoustic excitation of the water column by the pile.

Estimates of pile driving sound levels in the acoustic near-field were addressed separately using a specially designed near-field model based on the wavenumber integration acoustic modeling method (Section 3.7).

3.6. Far-field rms SPL Modeling

For impulsive sound sources like impact pile driving, MONM does not directly model *rms* SPL. Nonetheless, as discussed in Section 2.3.2, SEL and *rms* SPL for impulses are related by a simple formula that depends only on the 90% energy duration of the impulses. Knowing the length of an impulse, therefore, it is possible to compute the *rms* SPL from the modeled SEL. For the current study, FWRAM was used to estimate the 90% energy length for pile driving impulses in Tappan Zee Reach by modelling synthetic pressure waveforms along a limited number of representatives transects. Range-dependent impulse-response functions were modeled at frequencies from 10 Hz to 2048 Hz in 1 Hz steps and convolved with the appropriate far-field source signatures for pile driving operations (Section 3.2) to generate synthetic pressure waveforms along each transect. These waveforms were then analyzed to determine the 90% energy length as a function of range from the pile. Three different representative transects extending to 50,000 ft (15 km) distance from the bridge were modeled using FWRAM: one transect extending upriver from pier P16/P25, one transect extending upriver from pier P25/P45, and another extending downriver from pier P25/P45.

The FWRAM pulse length predictions were used to derive a range-dependent conversion function between SEL and *rms* SPL. A smoothed function representing the mean difference between *rms* SPL and SEL was fit to the FWRAM model predictions for the three transects (Figure 14). The maximum effective pulse length was constrained on precautionary grounds to be 500 ms (corresponding to a difference of 3 dB between *rms* SPL and SEL) so that the *rms* amplitudes could not be underestimated by excessively long averaging times. The resulting range-dependent conversion factor was applied to the single-strike SEL modeling grids from MONM in order to compute *rms* SPLs from the piles. As with the SEL scenarios, *rms* SPL values were maximized over depth and rendered as two-dimensional contours on thematic maps. In addition, *rms* SPL values were decomposed into power spectral density levels (in 1/3-octave bands) at selected receiver stations and presented as plots of spectrum level versus frequency.

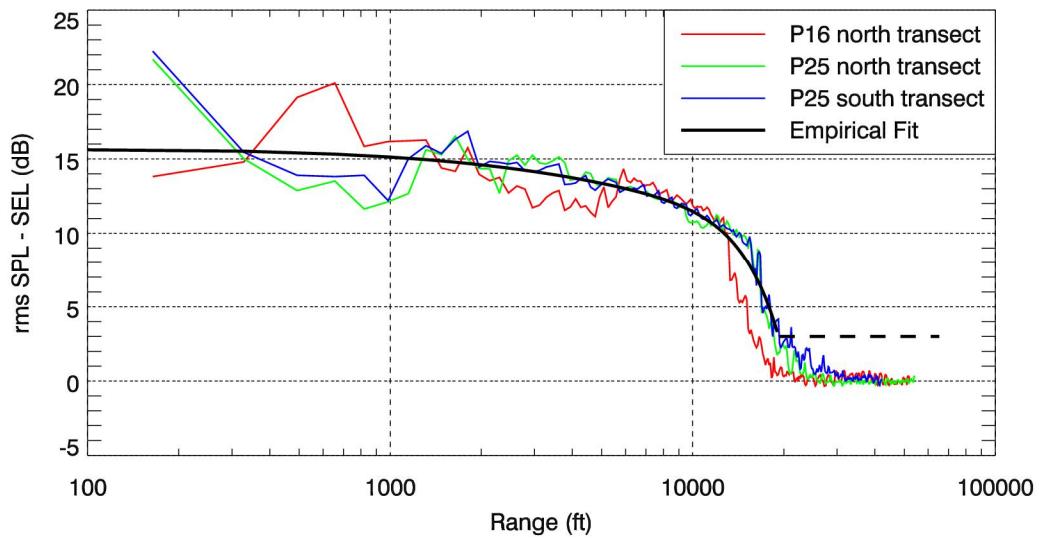


Figure 14: Conversion between SEL and *rms* SPL for pile driving in Tappan Zee Reach, as derived from three full-waveform modeling transects. The precautionary limiting value of 3 dB (corresponding 500 ms pulse length) is indicated by the dashed line.

3.7. Near-field Peak SPL Modeling

The VSTACK wavenumber integration model was used for predicting peak SPLs generated by impact pile driving. Because the wavenumber integration technique is accurate in the near-field, in VSTACK the pile was treated as a vertically distributed source extending into the sub-bottom (Figure 15). This ensured that peak SPL predictions were accurate in the near-field zone, where physical injury due to pile driving noise is most likely to occur. For the peak SPL scenarios the pile was modelled as an array of monopole elements with 3.28 ft (1 m) vertical separation. The elements representing the pile extended from 1.64 ft (0.5 m) below the water surface to the lower tip of the pile 160-300 ft (50-90 m) below the mudline. The substrate was modeled as a set of horizontally stratified acousto-elastic layers according to the site-specific geoacoustic profiles for each site (Table 4). The frequency range included in the VSTACK calculation was from 10 Hz to 2048 Hz.

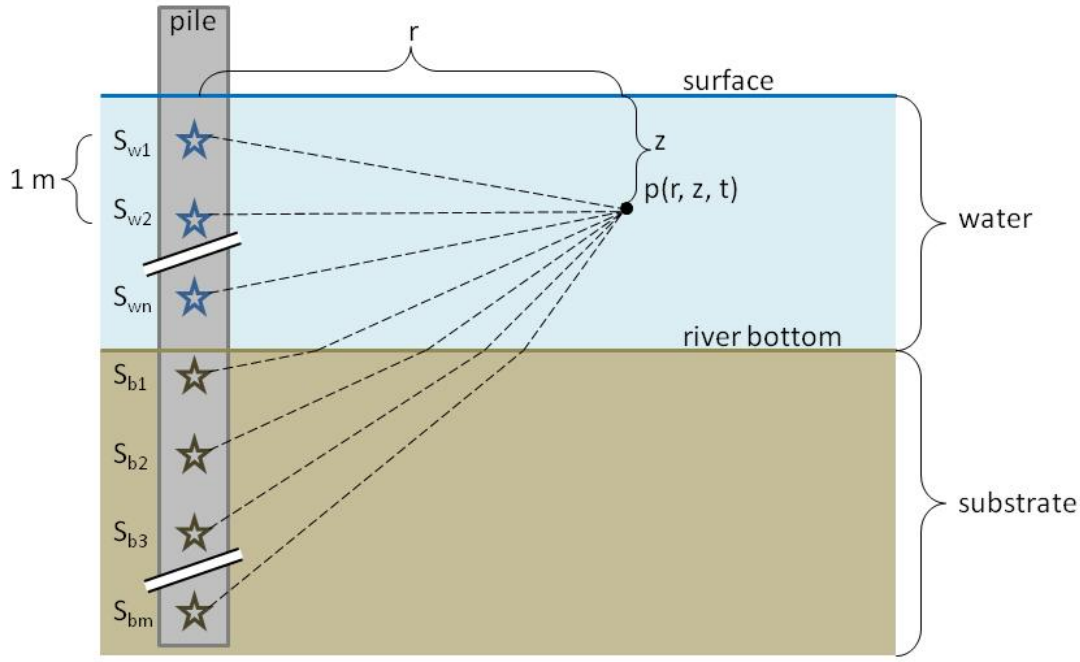


Figure 15: Diagram of VSTACK computation geometry for estimating near-field acoustic waveforms from pile driving (only direct-path rays are illustrated). Stars indicate the placement of the source elements. The vertical separation of the source elements is 1 m.

Each source element used an identical source wavelet, with time delay specified according to the vertical location of the element along the pile. Source wavelets were derived from spectral factorization of 1/3-octave band source levels for a particular pile hammer configuration (Section 3.2). The pressure wave in the water is generated by a stress wave propagating down the length of the pile with a phase speed of approximately 16,400 ft/s (5 km/s). The onset of the source wavelet for each pile element was therefore delayed according to the distance of each element along the pile divided by the phase speed of the stress wave (60 µs/ft or 200 µs/m).

In modeling sources below the mudline, the radial displacement of the pile wall was assumed to be approximately the same in the water and in the riverbed sediments. The pressure amplitude of pile elements below the mudline was therefore multiplied by the relative acoustic impedance of the sediment materials in accordance with the impedance relationship for acoustic waves (Jensen et al., 2000, §2.1). As VSTACK's handling of sub-bottom sources is limited to computing the upward-propagating acoustic wave component originating inside a uniform sediment layer, the properties of the top-most layer were used when accounting for the contribution of pile elements below the mudline. This was the most conservative assumption as it maximizes transfer of sound energy from the substrate to the water. Note that this approximation was only necessary for computing the transmission coefficient from the riverbed into the water: the full complexity of the sub-bottom layering was taken into account when considering acoustic energy from water-borne propagation paths coupling into the riverbed.

For the BMP scenarios, use of a confined bubble curtain is only expected to reduce sound emissions from the in-water segment of the pile. The frequency-dependent bubble curtain attenuation (Section 3.3) was therefore only applied to in-water pile elements. In all VSTACK based modeling the amplitudes of the bottom 10 elements of the pile were tapered to zero as a

computational requirement to prevent a sharp pressure discontinuity at the pile tip and consequent spatial "ringing". It was also necessary to scale the individual amplitudes of the source elements so that in aggregate they matched the far-field source strength of the pile. This was done by matching the received SEL predicted using VSTACK with the equivalent far-field model predictions at 1640 ft (500 m) range.

The contributions of all the pile elements were summed to generate a 250 ms long pressure-versus-time trace for each receiver point in the VSTACK output (Figure 16). Peak SPLs for each receiver were extracted directly from the modeled synthetic pressure traces. Peak SPLs were modeled at three different receiver depths (¼ water depth, ½ water depth, and ¾ water depth) to a maximum distance of 10,000 ft (3 km) from the pile. The maximum peak SPL over the three receiver depths was extracted at each range and plotted versus distance from the pile. Ranges corresponding to specific peak SPL thresholds of interest were extracted from the level versus distance plots. The ability to model finely resolved pressure spatial gradients was also the basis for particle velocity computation as discussed in the next section.

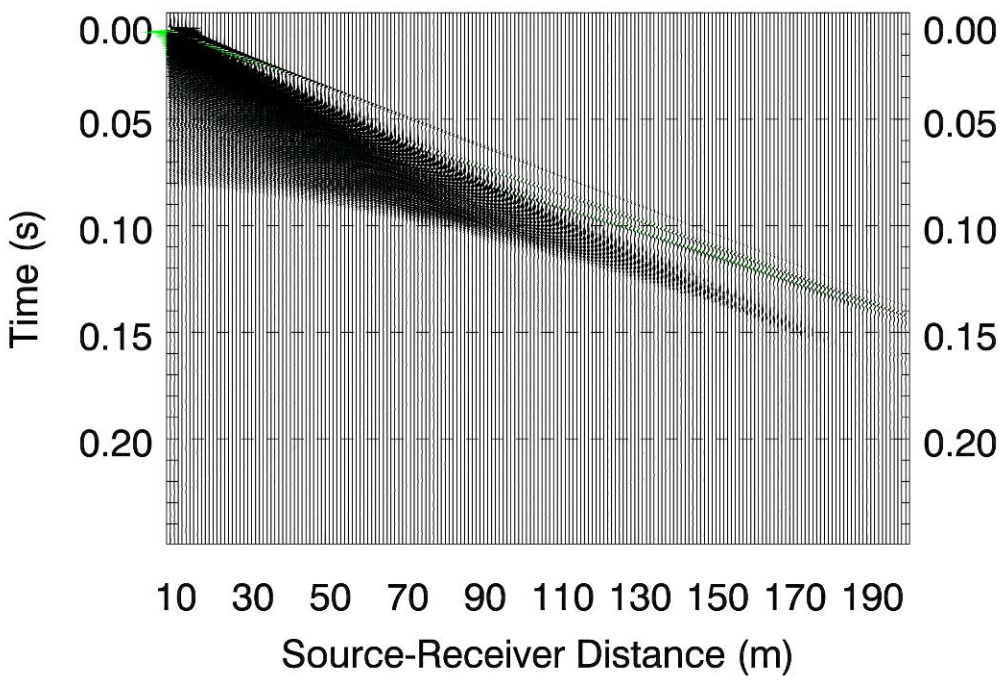


Figure 16: Time-offset plot of synthetic pressure waveforms computed using VSTACK. Black areas indicate positive acoustic pressures and green areas indicate negative acoustic pressures.

3.8. Near-field Particle Motion Modeling

VSTACK was also used to compute estimates of particle velocity for the impact pile driving scenarios. As with the peak SPL modeling, particle motion estimates were computed in the time-domain from synthetic waveform calculations. As VSTACK does not compute particle motion directly, particle velocity was derived mathematically from the numerical gradient of the

acoustic pressure. Mathematically, Euler's linearized momentum equation can be used to show that acoustic particle velocity is related to the time integral of the acoustic pressure gradient (Fahy, 1977):

$$\mathbf{v}(r,z,t) = -\int \nabla p(r,z,t)/\rho_0 dt$$

In this equation, **v** is the vector particle velocity, ρ_0 is the fluid density and p is the acoustic pressure. Numerically, the pressure gradient along a particular axis may be computed from the differential pressure between two closely spaced receivers. In the range-depth coordinate system employed by VSTACK, the numerical gradient is computed as follows:

$$\nabla p(r,z,t) \cong \frac{p(r+\Delta/2,z,t) - p(r-\Delta/2,z,t)}{\Delta}\hat{r} + \frac{p(r,z+\Delta/2,t) - p(r,z-\Delta/2,t)}{\Delta}\hat{z}$$

In this equation, r is the radial coordinate, z is the depth coordinate (the hat notation indicates the vector component along each axis), and Δ is the spatial separation between receivers. The difference approximation depends on the condition that the receiver separation, Δ, is small relative to the acoustic wavelength. The vector components of the particle velocity **v** are obtained by time-integration of the differential pressure traces, after dividing by the water density.

The VSTACK model setup for the particle velocity scenarios was identical to that for the peak SPL scenarios (Section 3.7) in terms of source treatment, frequency range and environmental model. The important difference was that the configuration for the particle velocity scenarios used a modified receiver geometry for computing the differential pressure at each range from the pile (Figure 17). The receiver separation Δ for the gradient calculation was chosen to be 0.33 ft (0.1 m). Vector particle velocity traces were computed to a maximum distance of 1,600 ft (500 m) from the pile. The particle velocity estimates were based on the amplitude of the model predicted velocity vector and were presented as plots of peak value versus range.

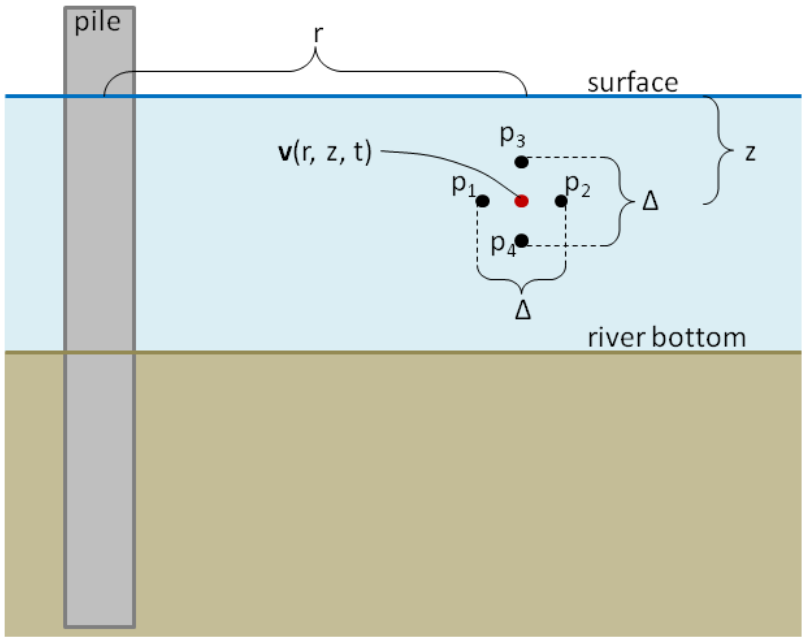


Figure 17: Diagram of VSTACK particle velocity calculation method (not to scale). The four black circles indicate the stencil points (p_1, p_2, p_3, p_4) used for computing the numerical gradient. The red circle indicates the actual computation point for the particle velocity vector.

4. Model Scenarios and Results

4.1. Overview of Model Scenarios

Model scenarios were developed with guidance from the Project's engineering team so as to represent, as accurately as possible, construction activities associated with the proposed bridge. The Project, if carried out, is expected to take 3-5 years to complete and would involve driving of approximately 1,000 steel support piles in the Hudson River. Pile driving would take place across the entire width of the river, so for the purpose of this study the bridge the span was divided into seven different foundation zones common to both proposed bridge options (dual level and single level). Piles would be driven at multiple pier locations within each foundation zone. The proposed pile diameter and hammer type are consistent inside each foundation zone, although the quantity and arrangement of the support piers would depend on the particular bridge option selected.

Seven unique source locations, distributed across the proposed bridge span, formed the basis of the impact pile driving model scenarios (Figure 18). Each source location comprised a unique set of pile driving attributes, taken from the engineering design documents: pile diameter, pile depth, hammer characteristics, and expected number of hammer strikes per pile (Table 5). Two models of hydraulic pile driving hammers are planned for use on the Project: IHC S-600 (444 kips·ft rated energy) and IHC S-750 (551 kips·ft rated energy). A unique set of geoacoustic profiles were also associated with each source location, as discussed in Section 3.4.3. It should be noted that the coordinates for each source represent an average piling location, since for each

support pier multiple piles would be installed in clusters; the small differences in source location, however, would cause only negligible changes in acoustic propagation.

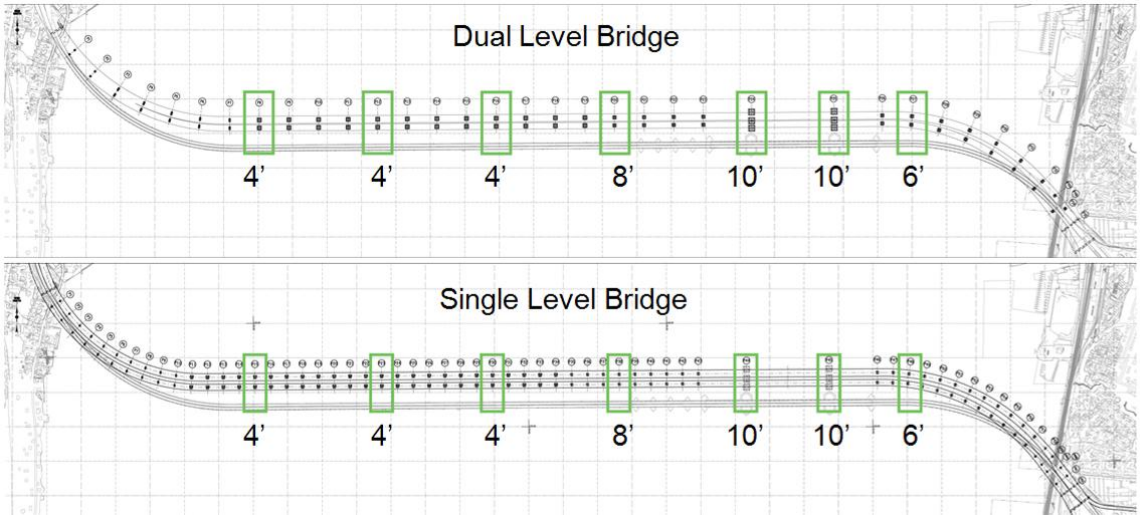


Figure 18: Impact pile driving modeling locations for dual level and single level bridge options. The annotation indicates the pile diameter at each source location.

Table 5. Modeling source locations for impact pile driving, and pile driving characteristics.

Pile ø	Pier Number Dual	Pier Number Single	Pile Depth Dual	Pile Depth Single	Found-ation Zone	Hammer Model and Energy	Strike Count	*Coordinates (NY State Plane East)* Easting (feet)	Northing (feet)
4'	P8	P15	300'	300'	2	IHC S-600, 444 kips·ft,	3800	655,012	815,695
4'	P12	P23	300'	300'	3	IHC S-600, 444 kips·ft,	3800	656,733	815,643
4'	P16	P30	300'	300'	3	IHC S-600, 444 kips·ft,	3800	658,453	815,662
8'	P20	P38	210'	210'	4	IHC S-750 551 kips·ft	2100	660,174	815,672
10'	P24	P44	280'	240'	5	IHC S-750, 551 kips·ft	2900	662,163	815,685
10'	P25	P45	280'	240'	5	IHC S-750, 551 kips·ft	2900	663,367	815,695
6'	P27	P48	160'	160'	6	IHC S-750, 551 kips·ft	1000	664,490	815,687

Two different kinds of pile driving scenarios were modeled for the current study:

1. Cumulative scenarios that considered cumulative sound exposure (cSEL) from a full day of construction activities. Estimates from cumulative scenarios are intended for evaluating physiological impacts on fishes due to pile driving activities.

2. Single-strike scenarios that considered the acoustic footprint of a single impulse from a pile driving hammer. Estimates from single-strike scenarios are intended for evaluating both physiological and behavioral impacts on fishes due to pile driving activities.

Representative combinations of piling activities for the cumulative scenarios were devised through consultations between the EIS team and the Project engineering team. Construction schedules for both proposed bridge options involve hundreds of days of pile placement. On a single day, different sizes and quantities of piles may be driven at multiple locations. A set of daily piling combinations was selected from the proposed schedules based on a specific set of requirements:

1. To translate the schedules into a limited number of locations and modeling runs,
2. To include ecologically important scenarios,
3. To focus on the main span, which encompasses the river's migratory channel.

The pile driving acoustic footprint is likely to be largest when: (1) large diameter piles are being driven and (2) multiple piles are driven during the same day. The Project's engineering team developed a series of daily maximum pile driving combinations to be considered in establishing the proposed hydroacoustic modeling framework. From these pile driving combinations, three maximum case scenarios were selected for each bridge option that reflected conditions of greatest ecological interest (Table 6). Three additional pile driving scenarios were selected for each bridge options so as to generate acoustic modeling results for typical daily pile driving events, as opposed to the maximum events. Each of the maximum and typical cases was modeled with and without BMPs, for a total of 24 cumulative modeling cases. Eight of the model scenarios, however, were common to the single level and dual level bridge options. Thus, a total of 16 unique cumulative model scenarios were considered. Outputs from the corresponding model runs were expressed in terms of cumulative sound exposure level (cSEL).

Table 6. Quantities, sizes, and locations of impact pile driving for cumulative (cSEL) modeling scenarios. All scenarios listed in the table were modeled with and without BMPs.

Pile Size	4'	4'	4'	8'	10'	10'	6'
Pier Number Dual	*P8*	*P12*	*P16*	*P20*	*P24*	*P25*	*P27*
Max Case 1					2	2	
Max Case 2A		3		3			4
Max Case 3	3						4
Pier Number Single	*P15*	*P23*	*P30*	*P38*	*P44*	*P45*	*P48*
Max Case 1					2	2	
Max Case 2B		3		3			4
Max Case 3	3						4
Pier Number Dual	*P8*	*P12*	*P16*	*P20*	*P24*	*P25*	*P27*
Typical Case 1					1	1	
Typical Case 2A				2			2
Typical Case 3		2	2				
Pier Number Single	*P15*	*P23*	*P30*	*P38*	*P44*	*P45*	*P48*
Typical Case 1					1	1	
Typical Case 2B		2		2			2
Typical Case 3		2	2				

Single-strike pile driving events were modeled at four different locations across the bridge span (Figure 19). Locations and pile driving characteristics for the single-strike cases were common to both bridge options. The cases were modeled both with and without BMPs, for a total of eight single-strike scenarios. These scenarios were modeled by means of three different hydroacoustic models (Section 3.1), yielding results in multiple acoustic metrics. The following metrics relevant to physiological and behavioral impact assessment were computed: peak SPL (physiological and behavioral), single-strike SEL (physiological), *rms* SPL (behavioral), SPL power spectral density (behavioral), and particle velocity (behavioral). SPL power spectral density levels for the single-strike scenarios were computed in 1/3-octave bands at 14 fixed locations (virtual receiver stations) in Tappan Zee Reach (Figure 19). Receiver stations were grouped according to their position relative to the river channel: WS (west shallows), WC (west channel), SC (south channel), and CC (central channel).

In total, 24 distinct pile driving scenarios were modeled by multiple methods to obtain acoustic data for assessing the physiological and behavioral impacts of pile driving on Hudson River aquatic resources (Table 7). The following report sections provide an overview and samples of results for the various model scenarios and outputs. Detailed results for all 24 scenarios are provided in an appendix to this report. Results from the cumulative scenarios (1-16) are presented in Section 4.2 and Appendix A. Results from the single-strike scenarios (17-24) are presented in Sections 4.3-4.6 and Appendices B-D.

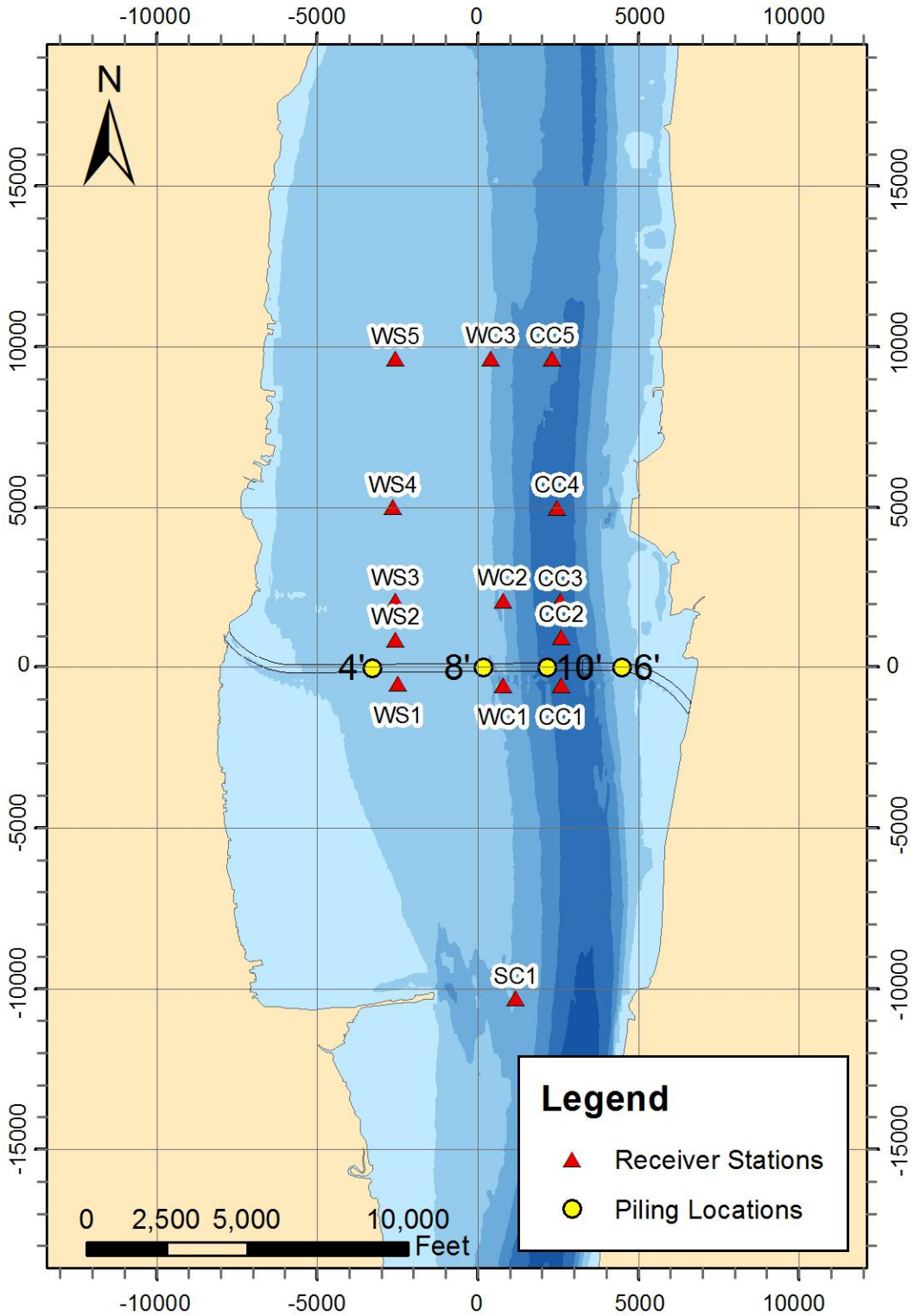


Figure 19: Impact pile driving locations for single-strike model scenarios (yellow circles) and receiver stations for reporting of PSD levels from impact pile driving (red triangles). Map grid shows coordinates in feet, relative to the bridge center.

Table 7. List of all impact pile driving model scenarios. "X"s indicate the metrics that were modeled for each scenario.

Scenario				Metric				
Number	Bridge Type	BMPs	Description	*Cumulative Physiological* cSEL (§4.2, App. A)	*Single Strike Physiological* SEL (§4.3, App. B)	*Single Strike Physiol./Behav.* Peak SPL (§4.4, App. C)	*Single Strike Behavioral rms* SPL (§4.5, App. D)	*Single Strike Behavioral* Particle Velocity (§4.6)
1	Dual/Single	No	Max Case 1	X				
2	Dual	No	Max Case 2A	X				
3	Dual/Single	No	Max Case 3	X				
4	Single	No	Max Case 2B	X				
5	Dual/Single	Yes	Max Case 1	X				
6	Dual	Yes	Max Case 2A	X				
7	Dual/Single	Yes	Max Case 3	X				
8	Single	Yes	Max Case 2B	X				
9	Dual/Single	No	Typical Case 1	X				
10	Dual	No	Typical Case 2A	X				
11	Dual/Single	No	Typical Case 3	X				
12	Single	No	Typical Case 2B	X				
13	Dual/Single	Yes	Typical Case 1	X				
14	Dual	Yes	Typical Case 2A	X				
15	Dual/Single	Yes	Typical Case 3	X				
16	Single	Yes	Typical Case 2B	X				
17	Dual/Single	No	Single Strike 4'		X	X	X	X
18	Dual/Single	No	Single Strike 6'		X	X	X	X
19	Dual/Single	No	Single Strike 8'		X	X	X	
20	Dual/Single	No	Single Strike 10'		X	X	X	X
21	Dual/Single	Yes	Single Strike 4'		X	X	X	
22	Dual/Single	Yes	Single Strike 6'		X	X	X	
23	Dual/Single	Yes	Single Strike 8'		X	X	X	
24	Dual/Single	Yes	Single Strike 10'		X	X	X	

4.2. Cumulative SEL Metric

4.2.1. cSEL contour areas

For the cumulative scenarios (1-16), three-dimensional spatial grids of cSEL were computed using MONM according to the methodology described in Section 3.5. The cSEL model results were then converted to maximum-over-depth contours and rendered on thematic maps (Appendix A). Contours were rendered at the following seven cSEL threshold levels:

- 207 dB re 1 $\mu Pa^2 s$
- 204 dB re 1 $\mu Pa^2 s$
- 201 dB re 1 $\mu Pa^2 s$
- 197 dB re 1 $\mu Pa^2 s$
- 194 dB re 1 $\mu Pa^2 s$
- 187 dB re 1 $\mu Pa^2 s$
- 183 dB re 1 $\mu Pa^2 s$

The total surface area ensonified at levels above each cSEL threshold was computed from the model output for each scenario and reported (in units of 1,000 ft^2) in Table 8. It should be stressed here that cSEL contours must not be interpreted as representing a static picture of the sound field in Tappan Zee Reach. The contours in fact grow steadily around the piling activity as multiple piles are driven at each pier over the course of a day, and the cSEL contours and surface areas presented in the maps and tables represent the maximum extent of a dosage metric at the end of a complete working day.

The following subsections present example cSEL contour maps for four selected scenarios (2, 4, 6, and 8). Sound level contour maps for all 16 cumulative SEL scenarios are presented in the appendix.

Table 8. Area ensonified above the specified cSEL threshold levels (units of 1,000 ft^2) for the cumulative model scenarios.

Scenario						Area of cSEL contour (1,000 ft^2)						
Number	Description	Bridge Type	Activity	BMPs	Map Reference	207 dB re 1 μPa^{2}s	204 dB re 1 μPa^{2}s	201 dB re 1 μPa^{2}s	197 dB re 1 μPa^{2}s	194 dB re 1 μPa^{2}s	187 dB re 1 μPa^{2}s	183 dB re 1 μPa^{2}s
1	Max Case 1	Dual/ Single	2×10 ft ø piles @ P24/P44 2×10 ft ø piles @ P25/P45	No	A1.1	25,331	31,776	40,000	52,773	64,843	98,347	123,380
2	Max Case 2A	Dual	3×8 ft ø piles @ P20 4×6 ft ø piles @ P27	No	A3.2	6,359	9,942	13,057	23,083	29,503	50,897	65,529
3	Max Case 3	Dual/ Single	3×4 ft ø piles @ P8/P15 4×6 ft ø piles @ P27/P48	No	A1.3	1,541	2,192	2,932	5,860	8,561	20,425	29,970
4	Max Case 2B	Single	3×4 ft ø piles @ P23 3×8 ft ø piles @ P38 4×6 ft ø piles @ P48	No	A1.2	6,491	10,134	14,153	26,550	33,901	57,379	72,259
5	Max Case 1	Dual/ Single	2×10 ft ø piles @ P24/P44 2×10 ft ø piles @ P25/P45	Yes	A2.1	10,528	14,777	19,111	30,008	37,338	60,361	77,708
6	Max Case 2A	Dual	3×8 ft ø piles @ P20 4×6 ft ø piles @ P27	Yes	A4.2	1,495	2,394	3,735	7,200	10,808	26,333	36,608
7	Max Case 3	Dual/ Single	3×4 ft ø piles @ P8/P15 4×6 ft ø piles @ P27/P48	Yes	A2.3	90	141	427	1,306	1,980	5,151	10,164
8	Max Case 2B	Single	3×4 ft ø piles @ P23 3×8 ft ø piles @ P38 4×6 ft ø piles @ P48	Yes	A2.2	1,526	2,443	3,803	7,316	10,972	29,856	40,846
9	Typical Case 1	Dual/ Single	1×10 ft ø piles @ P24/P44 1×10 ft ø piles @ P25/P45	No	A1.4	17,704	25,315	31,752	42,330	52,731	82,355	102,870
10	Typical Case 2A	Dual	2×8 ft ø piles @ P20 2×6 ft ø piles @ P27	No	A3.5	4,651	7,582	10,860	16,350	25,258	44,073	57,345
11	Typical Case 3	Dual/ Single	2×4 ft ø piles @ P12/P23 2×4 ft ø piles @ P16/P30	No	A1.6	217	297	545	4,106	6,843	11,842	17,399
12	Typical Case 2B	Single	2×4 ft ø piles @ P23 2×8 ft ø piles @ P38 2×6 ft ø piles @ P48	No	A1.5	4,760	7,729	11,168	18,886	29,190	50,174	64,833
13	Typical Case 1	Dual/ Single	1×10 ft ø piles @ P24/P44 1×10 ft ø piles @ P25/P45	Yes	A2.4	6,782	10,516	14,764	22,195	29,976	50,060	65,710
14	Typical Case 2A	Dual	2×8 ft ø piles @ P20 2×6 ft ø piles @ P27	Yes	A4.5	213	1,945	2,785	5,174	8,583	20,968	31,475
15	Typical Case 3	Dual/ Single	2×4 ft ø piles @ P12/P23 2×4 ft ø piles @ P16/P30	Yes	A2.6	53	79	111	181	255	4,291	7,542
16	Typical Case 2B	Single	2×4 ft ø piles @ P23 2×8 ft ø piles @ P38 2×6 ft ø piles @ P48	Yes	A2.5	241	1,982	2,838	5,266	8,717	23,570	35,587

4.2.2. Single Level Bridge: No BMPs applied

Figure 20 shows cSEL contours for Scenario 4: Max Case 2B without BMPs. Refer to Appendix A.1 for the complete set of cSEL maps for the single level bridge without BMPs.

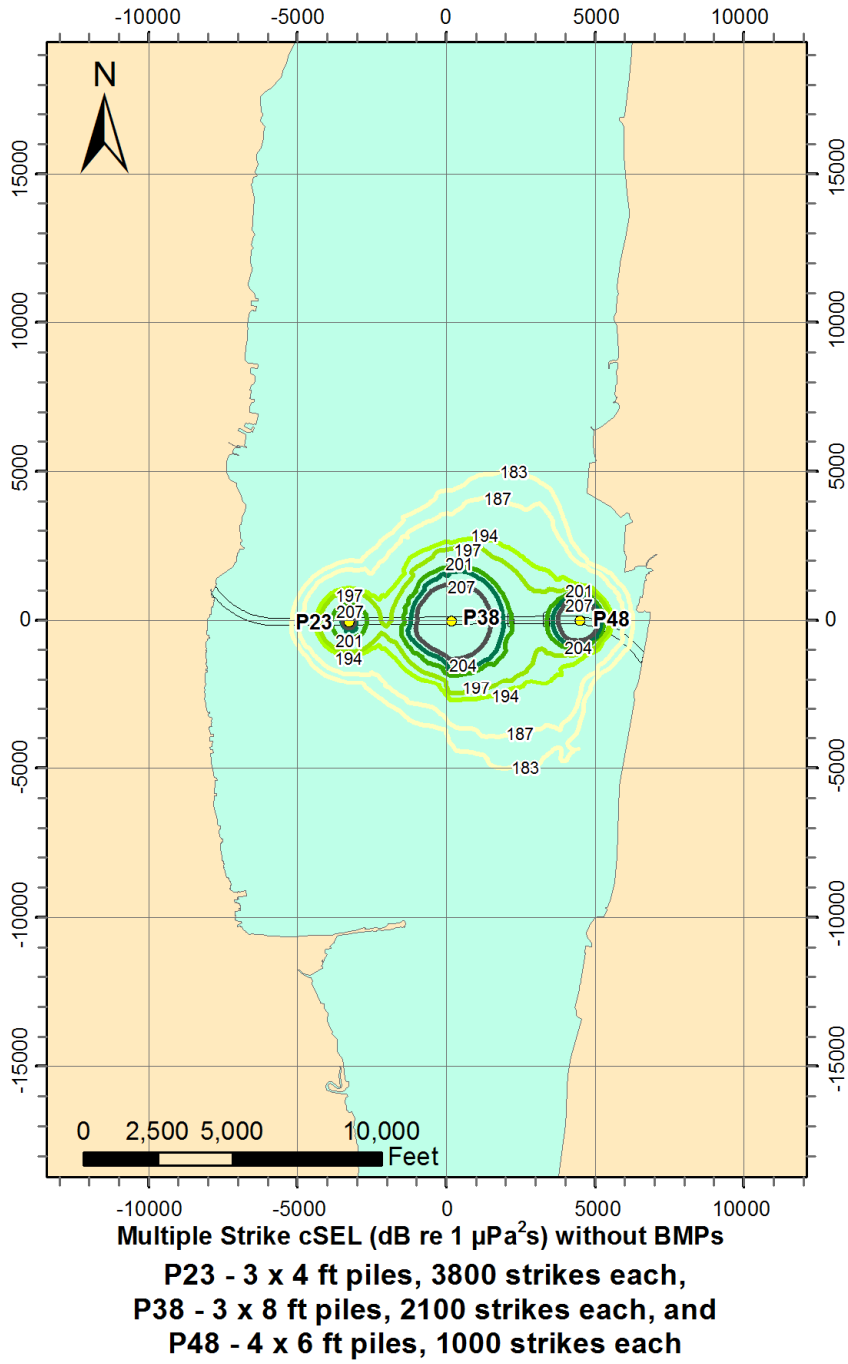


Figure 20: cSEL contour map for Scenario 4: Max Case 2B without BMPs.

4.2.3. Single Level Bridge: BMPs applied

Figure 21 shows cSEL contours for Scenario 8: Max Case 2B with BMPs. Refer to Appendix A.2 for the complete set of cSEL maps for the single level bridge with BMPs.

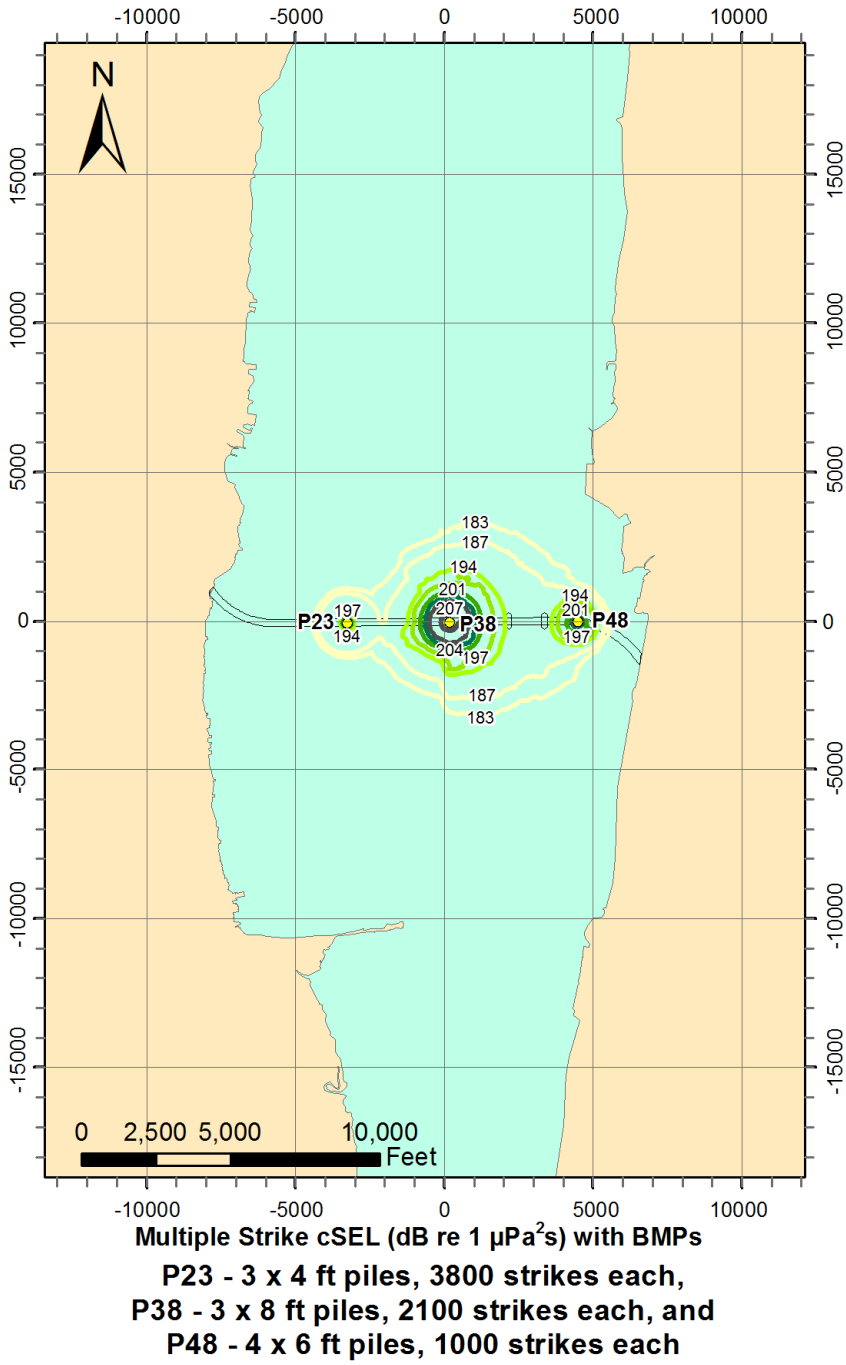
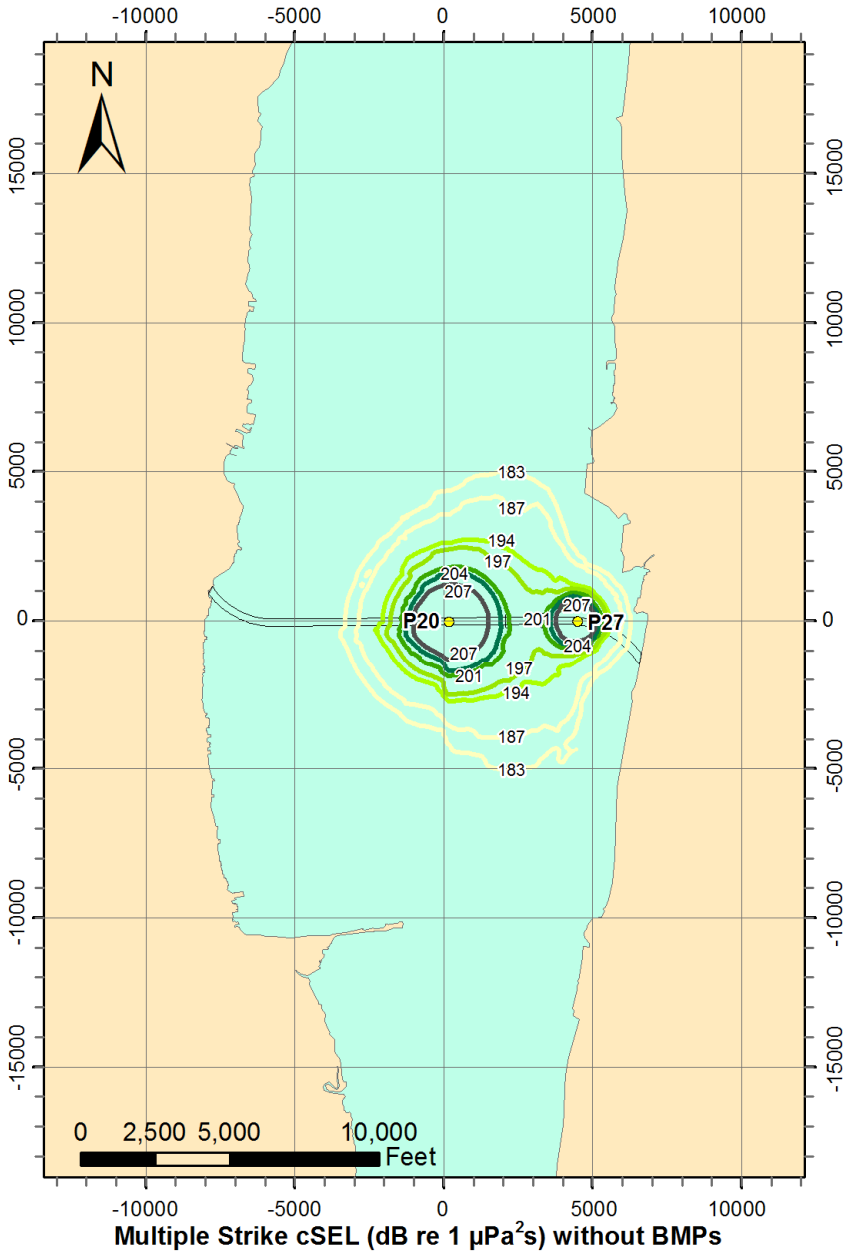


Figure 21: cSEL contour map for Scenario 8: Max Case 2B with BMPs.

4.2.4. Dual Level Bridge: No BMPs applied

Figure 22 shows cSEL contours for Scenario 2: Max Case 2A without BMPs. Refer to Appendix A.3 for the complete set of cSEL maps for the dual level bridge without BMPs.



Multiple Strike cSEL (dB re 1 μPa^{2}s) without BMPs

P20 - 3 x 8 ft piles, 2100 strikes each and
P27 - 4 x 6 ft piles, 1000 strikes each

Figure 22: cSEL contour map for scenario 2: Max Case 2A without BMPs.

4.2.5. Dual Level Bridge: BMPs applied

Figure 23 shows cSEL contours for Scenario 6: Max Case 2A with BMPs. See Appendix A.4 for the complete set of cSEL maps for the dual level bridge without BMPs.

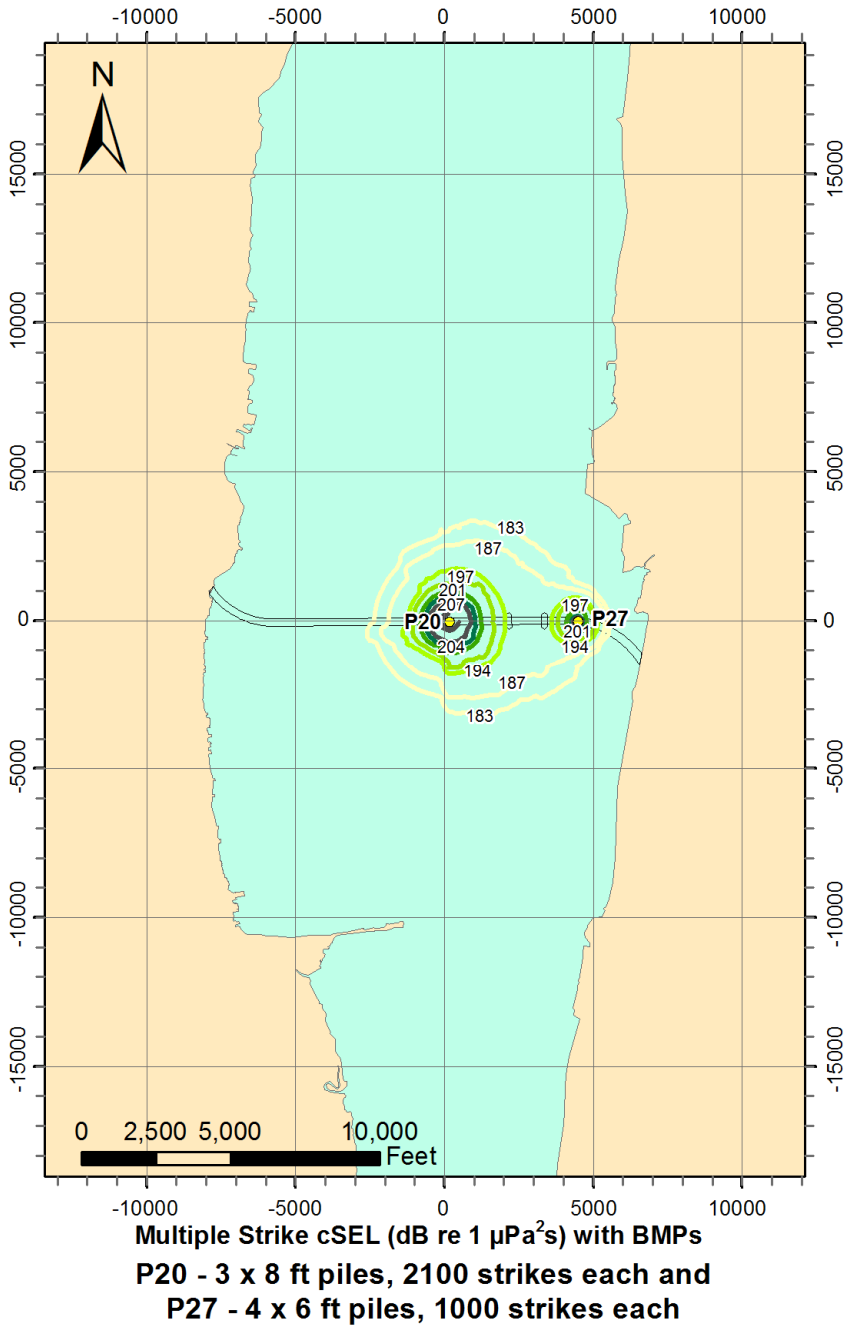


Figure 23: cSEL contour map for Scenario 6: Max Case 2B with BMPs.

4.3. Single Strike SEL Metric

For the single strike scenarios (17-24), three-dimensional spatial grids of single-impulse SEL were computed using MONM according to the methodology described in Section 3.5. The SEL model results were then converted to maximum-over-depth contours and rendered on thematic maps (Appendix B). Contours were rendered at the following six SEL threshold levels:

- 193dB re 1 $\mu Pa^2 s$
- 187 dB re 1 $\mu Pa^2 s$
- 181 dB re 1 $\mu Pa^2 s$
- 175 dB re 1 $\mu Pa^2 s$
- 169 dB re 1 $\mu Pa^2 s$
- 163 dB re 1 $\mu Pa^2 s$

Unlike the cSEL results, the SEL contours represent a snapshot of the acoustic energy footprint temporarily introduced into the river during a single blow of the pile driving hammer acting at one pier location. The SEL contours are intended to present average per-strike sound levels for the specified pile driving activity. The intensity of sound emitted during impact pile driving fluctuates over time, to some degree, as varying soil resistance conditions are encountered (Robinson et al., 2007).

The following subsections present examples of single strike SEL contour maps for two selected scenarios (18 and 22). Sound level contour maps for all eight single-strike SEL scenarios are presented in the appendix.

4.3.1. Single and Dual Level Bridge: No BMPs Applied

Figure 24 shows single strike SEL contours for Scenario 18: 6 ft diameter pile at P27/P48 without BMPs. Refer to Appendix B.1 for the complete set of single strike SEL maps without BMPs.

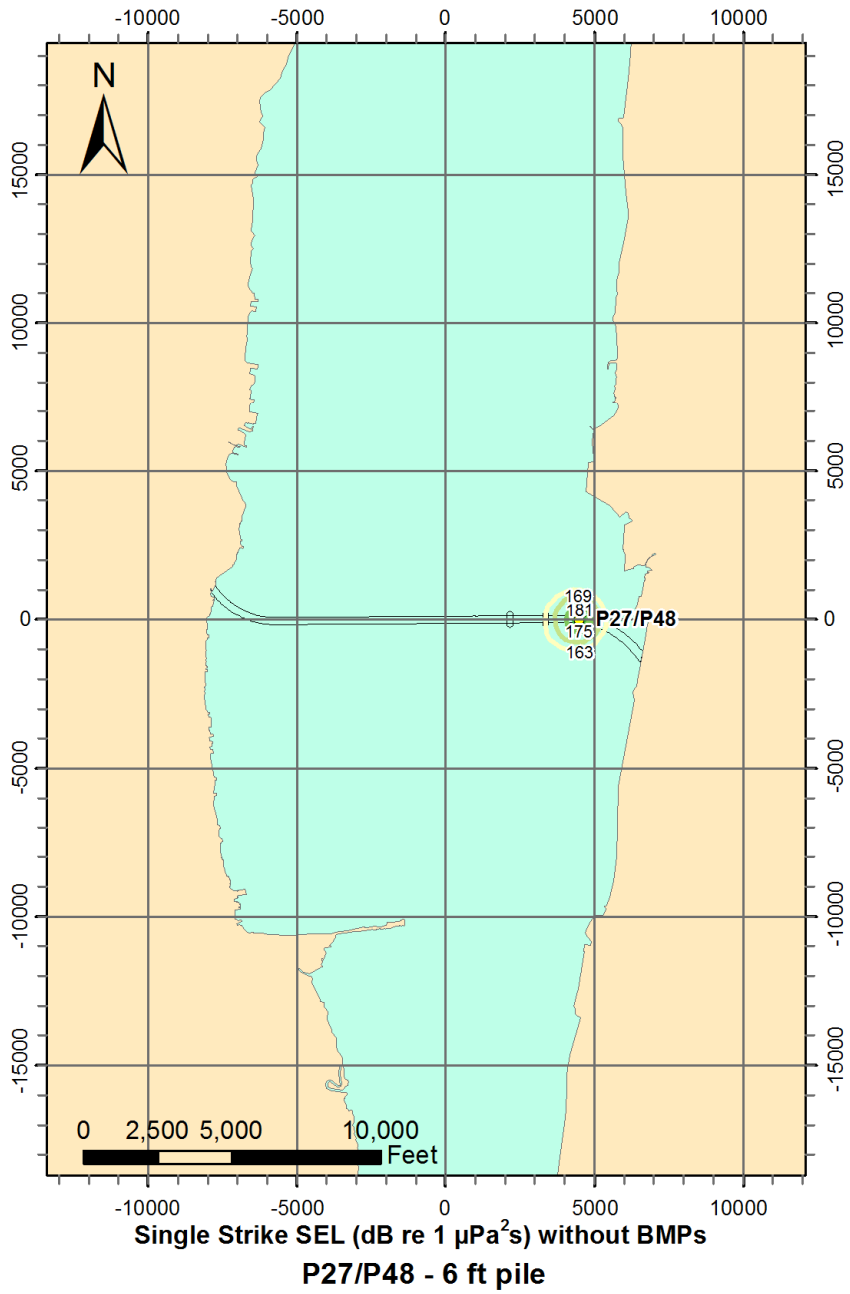


Figure 24: Single strike SEL contour map for Scenario 18: 6 ft pile at P27/P48 without BMPs.

4.3.2. Single and Dual Level Bridge: BMPs Applied

Figure 25 shows single strike SEL contours for Scenario 22: 6 ft diameter pile at P27/P48 with BMPs. Refer to Appendix B.2 for the complete set of single strike SEL maps with BMPs.

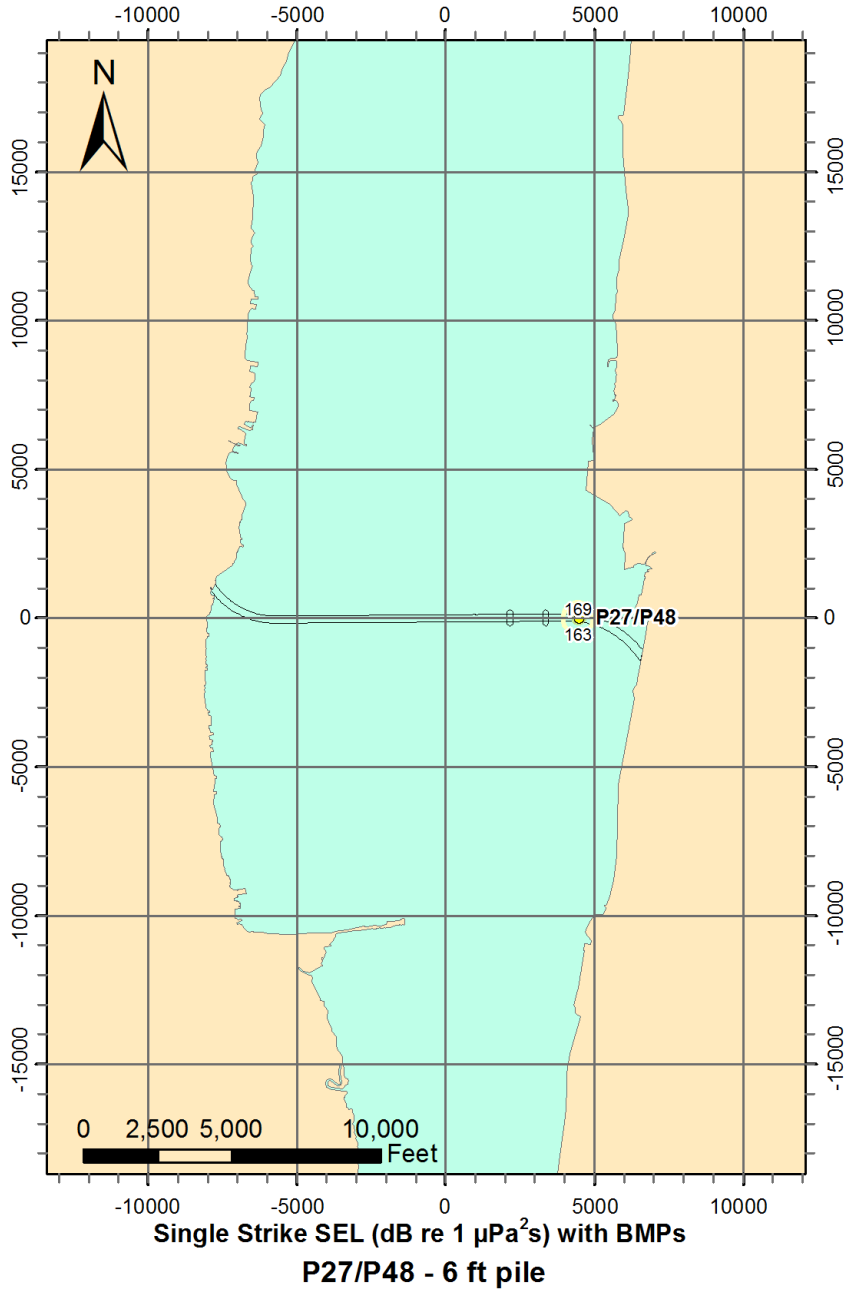


Figure 25: Single strike SEL contour map for Scenario 22: 6 ft pile at P27/P48 with BMPs.

4.4. Peak SPL Metric

Peak SPLs for the single strike scenarios (17-24) were computed using VSTACK according to the methodology described in Section 3.7. Peak SPLs were modeled for 4, 6, 8, and 10 ft piles with and without BMPs. Estimates from the VSTACK model are valid in the near-field zone and explicitly account for sound transmitted from the substrate into the water including vibration of the riverbed interface induced by the pile. The modeling results were used to generate curves of peak SPL, maximized over three depths, versus distance from the pile (Figure 26 and Figure 27). Distances corresponding to specific peak SPL thresholds, from 214 dB to 184 dB re 1 µPa in 6 dB steps, were extracted from the level versus range curves and are shown in Table 9.

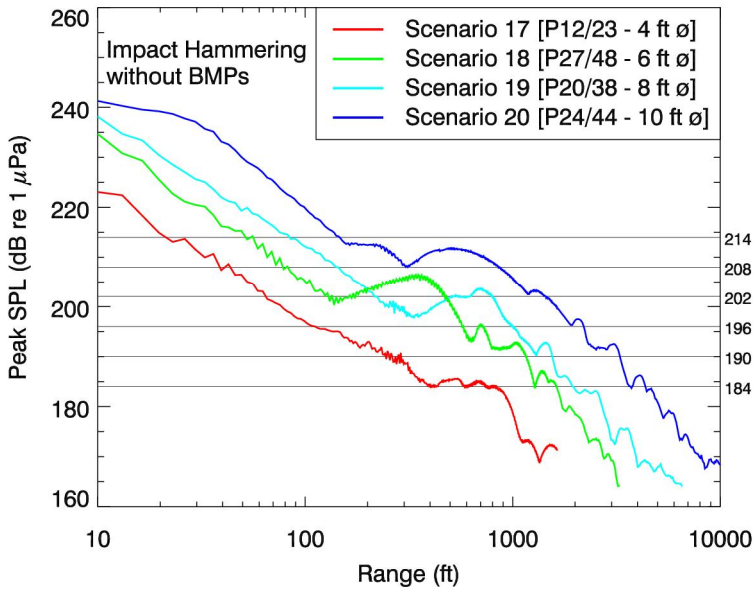


Figure 26: Peak SPL versus distance for scenarios 17-20, impact hammering of 4, 6, 8, and 10 ft diameter piles without BMPs. Gray lines indicate peak SPL thresholds from 214 dB to 184 dB re 1 µPa in 6 dB steps.

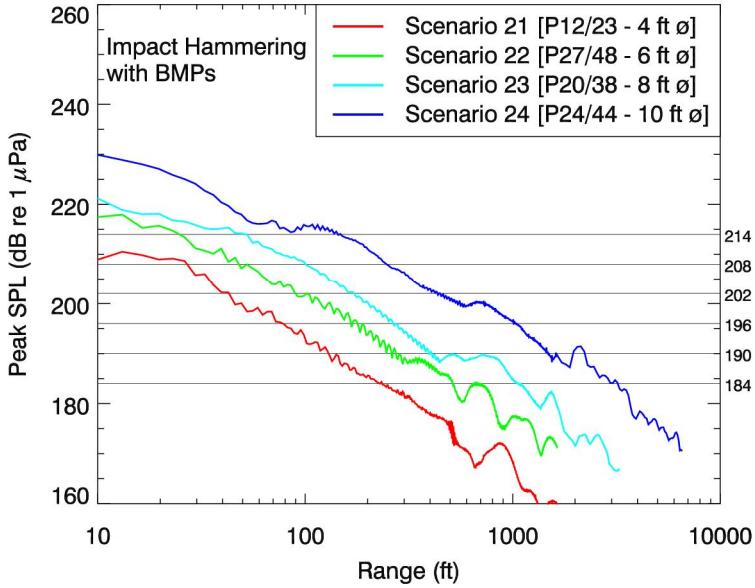


Figure 27: Peak SPL versus distance for scenarios 21-24, impact hammering of 4, 6, 8, and 10 ft diameter piles with BMPs. Gray lines indicate peak SPL thresholds from 214 dB to 184 dB re 1 µPa in 6 dB steps.

Table 9. Distances to peak level thresholds for impact hammering 4, 6, 8, and 10 ft diameter piles without BMPs.

Scenario	Pile Diameter (ft)	*Distance to peak SPL threshold (ft)* 214 dB re 1 µPa	208 dB re 1 µPa	202 dB re 1 µPa	196 dB re 1 µPa	190 dB re 1 µPa	184 dB re 1 µPa
Single and Dual Level Bridge without BMPs							
17	4	21	43	64	111	289	834
18	6	56	82	479	718	1,157	1,626
19	8	84	144	800	1,007	1,553	1,949
20	10	146	861	1,447	2,201	3,289	4,364
Single and Dual Level Bridge with BMPs							
21	4	4	26	42	77	129	234
22	6	24	47	102	178	273	686
23	8	51	100	171	265	407	1,061
24	10	148	247	446	1,043	2,226	3,210

4.5. rms SPL Metric: Pile Driving Scenarios

For the single strike impact pile driving scenarios (17-24), *rms* SPL was computed using MONM and FWRAM according to the methodology described in Section 3.6. The *rms* SPL model results were converted to maximum-over-depth contours, in 6 dB steps from 198 dB to 138 dB re 1 µPa, and rendered on thematic maps (Appendix C). Example contour maps of *rms* SPL for two selected scenarios (18 and 22) are presented below. Additionally, *rms* SPL values were extracted along the radial of maximum sound propagation for each scenario. The resulting functions of *rms* SPL versus range were plotted down to the 80 dB re 1 µPa threshold (Figure 28 and Figure 29). The threshold of audibility is roughly defined by the range at which the *rms* SPL falls below the ambient background SPL.

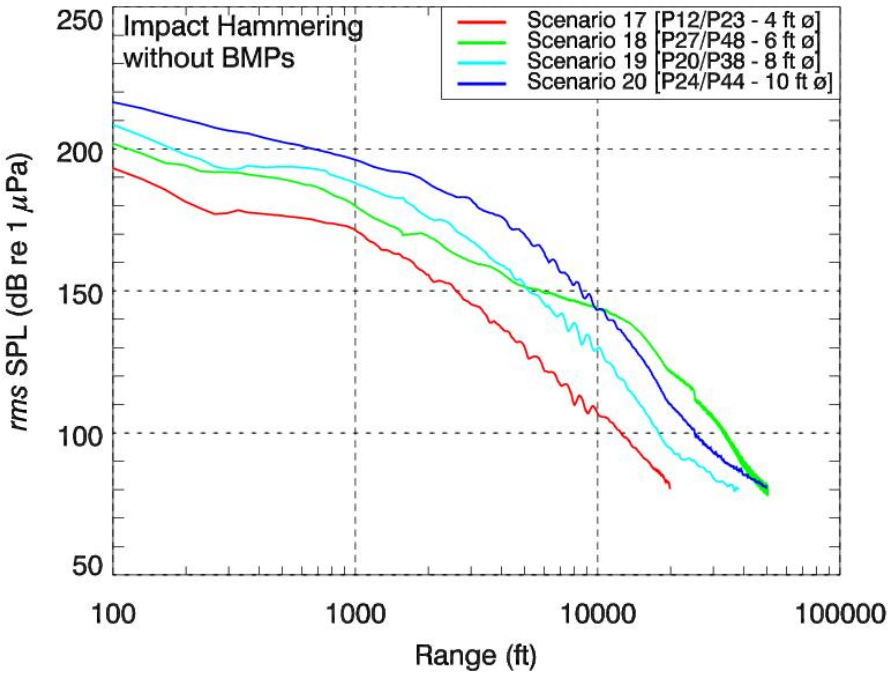


Figure 28: Max-over-depth *rms* SPL as a function of distance along the radial of maximum sound propagation (Scenario 17-20, impact pile driving without BMPs).

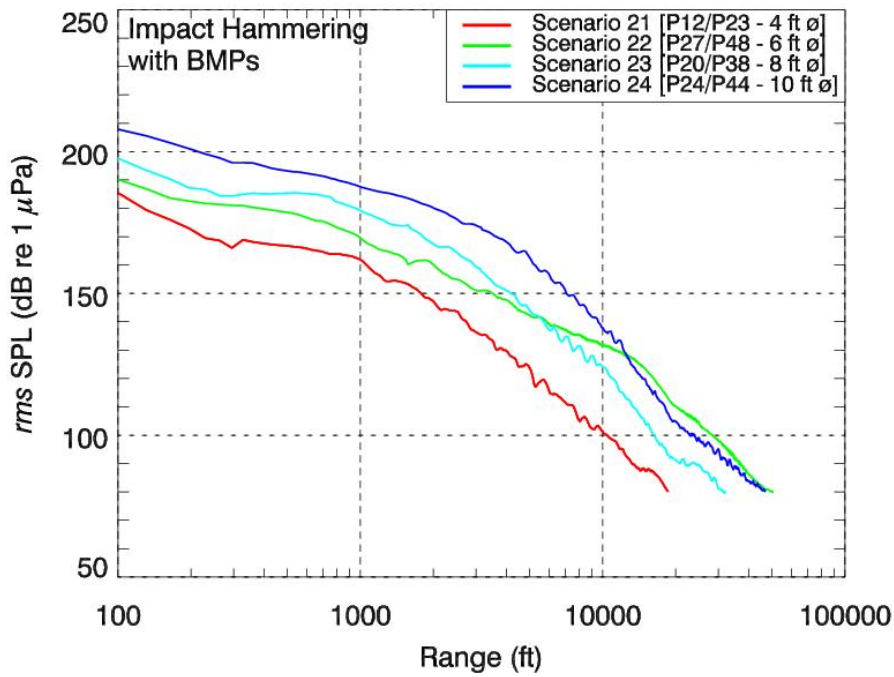


Figure 29: Max-over-depth *rms* SPL as a function of distance along the radial of maximum sound propagation (Scenario 21-24, impact pile driving with BMPs).

4.5.1. Single and Dual Level Bridge: No BMPs Applied

Figure 30 shows *rms* SPL contours for Scenario 18: 6 ft diameter pile at P27/P48 without BMPs. Refer to Appendix C.1 for the complete set of single strike *rms* SPL contour maps without BMPs (scenarios 17-20).

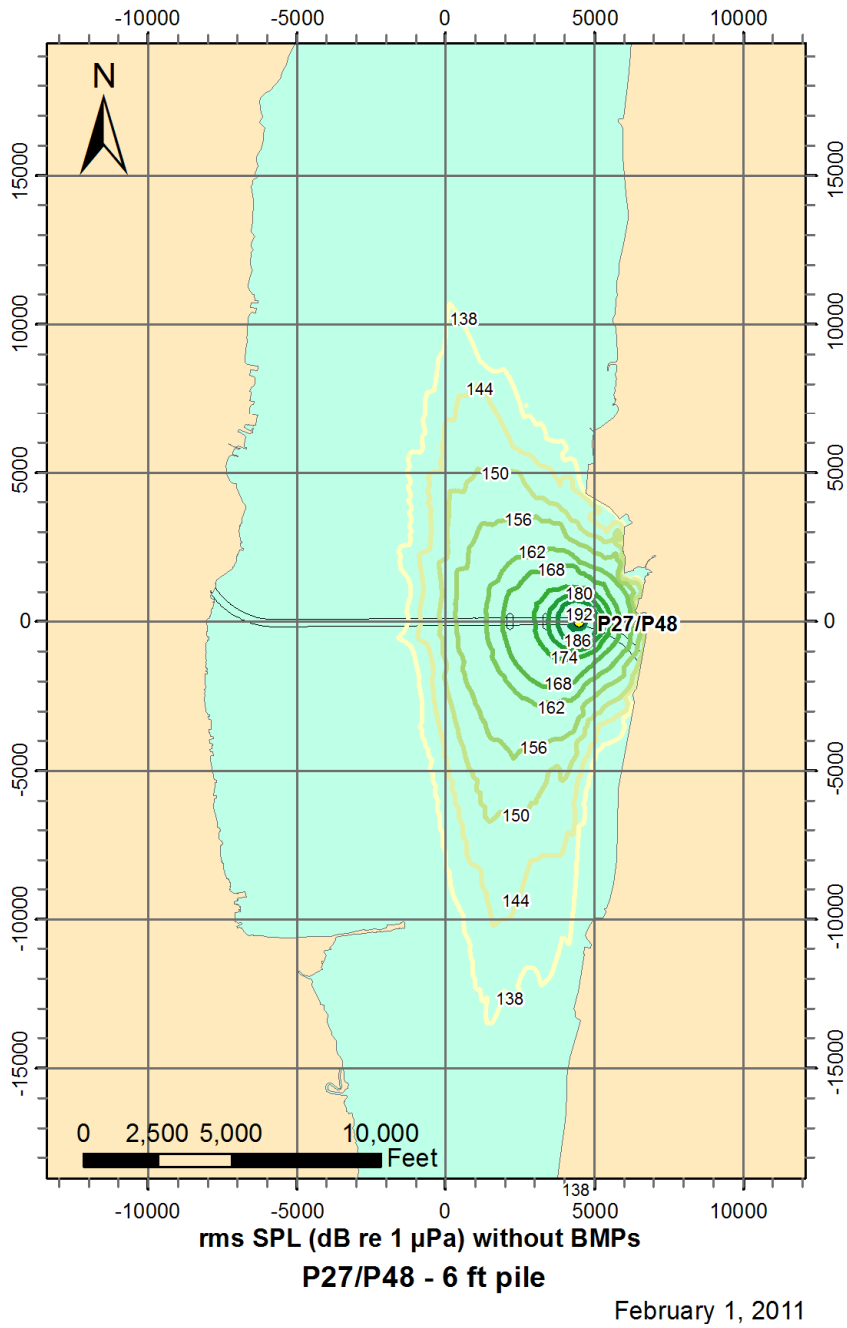


Figure 30: *rms* SPL contour map for Scenario 18: 6 ft pile at P27/P48 without BMPs.

4.5.2. Single and Dual Level Bridge: BMPs Applied

Figure 31 shows *rms* SPL contours for Scenario 22: 6 ft diameter pile at P27/P48 with BMPs. Refer to Appendix C.2 for the complete set of single strike *rms* SPL contour maps with BMPs (scenarios 21-24).

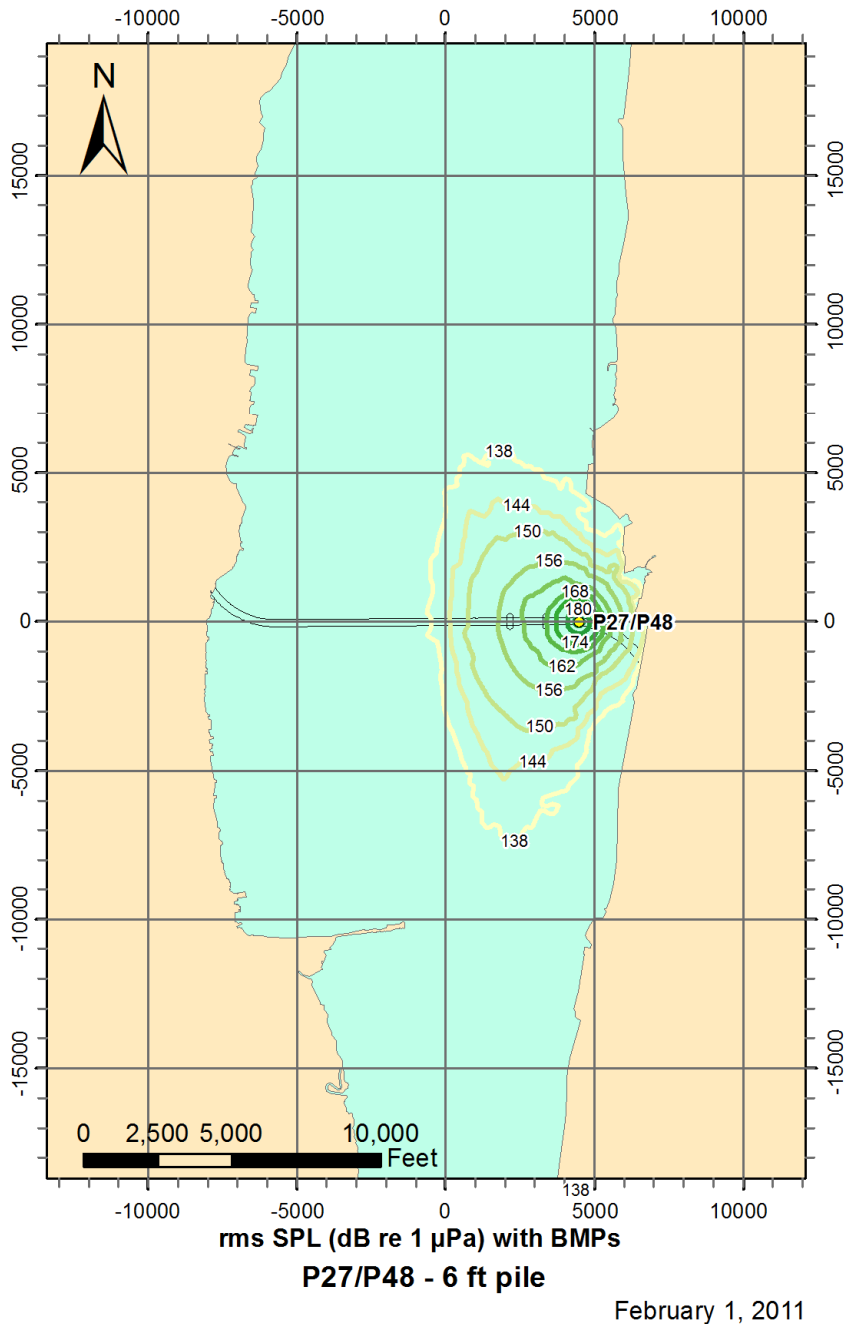


Figure 31: *rms* SPL contour map for Scenario 22: 6 ft pile at P27/P48 with BMPs.

4.6. Sound Power Spectral Density Levels

PSD levels for the single strike scenarios (17-24) were calculated at 14 fixed receiver stations (Figure 19). PSD levels were extracted at the depth of the maximum broadband level and presented as plots and tables of spectrum level versus frequency (Appendix D). Examples of PSD plots for two selected scenarios (18 and 22) are presented below (Figure 32 and Figure 33).

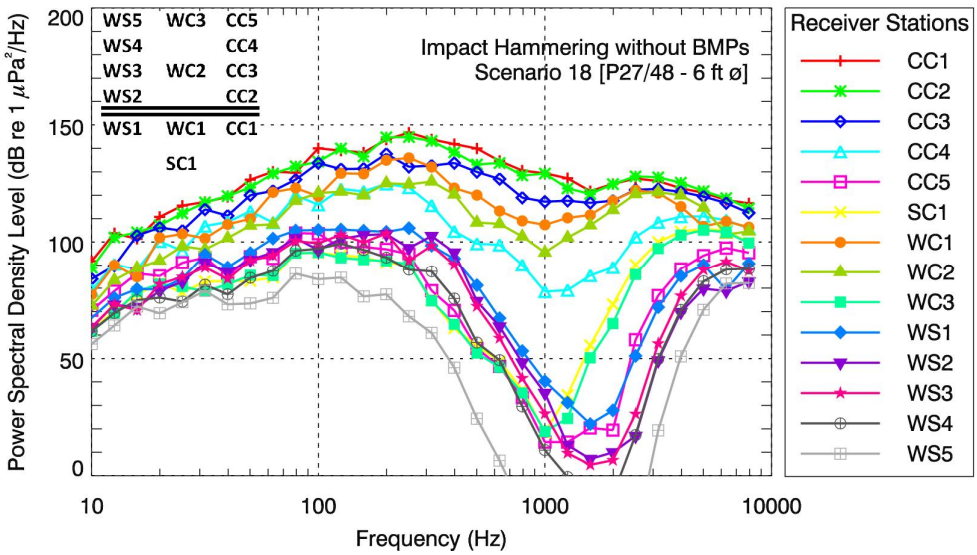


Figure 32: Power spectral density levels (at the depth where broadband level is highest) for Scenario 18: 6 ft diameter pile at P27/P48 without BMPs. Plot annotation shows receiver locations in relation to the bridge span (not to scale). See Figure 19 for a full scale map showing the locations of the receiver stations.

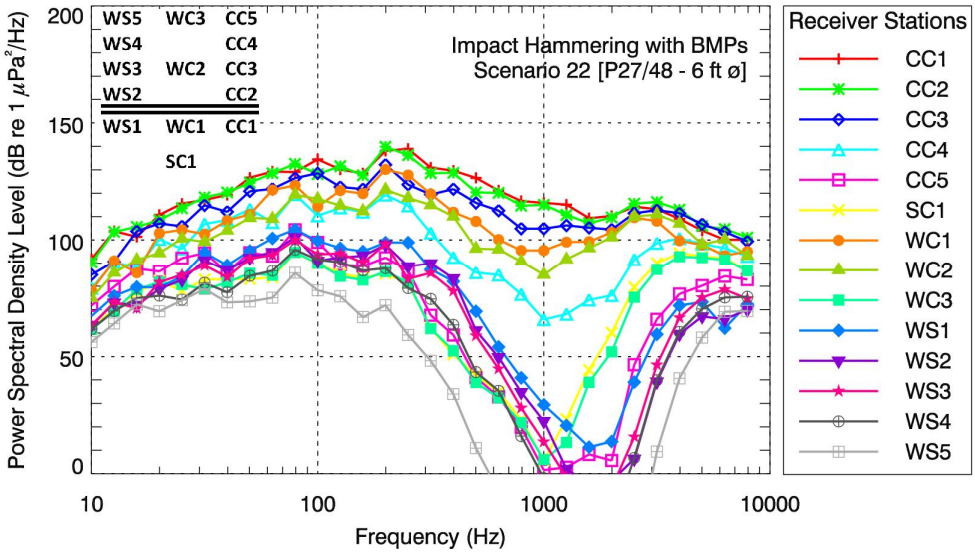


Figure 33: Power spectral density levels (at the depth where broadband level is highest) for Scenario 22: 6 ft diameter pile at P27/P48 with BMPs. Plot annotation shows receiver locations in relation to the bridge span (not to scale). See Figure 19 for a full scale map showing the locations of the receiver stations.

4.7. Single Strike Particle Motion

4.7.1. Single and Dual Level Bridge: No BMPs Applied

Peak particle velocity for three single strike scenarios (17, 18, and 20) was computed using VSTACK according to the methodology described in Section 3.8. Particle velocity was modeled for 4, 6, and 10 ft piles without BMPs only. Predictions of the VSTACK model are valid in the near-field zone and explicitly account for sound transmitted from the substrate into the water including vibration of the riverbed interface induced by the pile. The results of the modeling were used to generate curves of peak particle velocity versus distance from the pile (Figure 34). Peak particle velocity levels for each scenario were extracted from the level versus range curves at selected distances (Table 10).

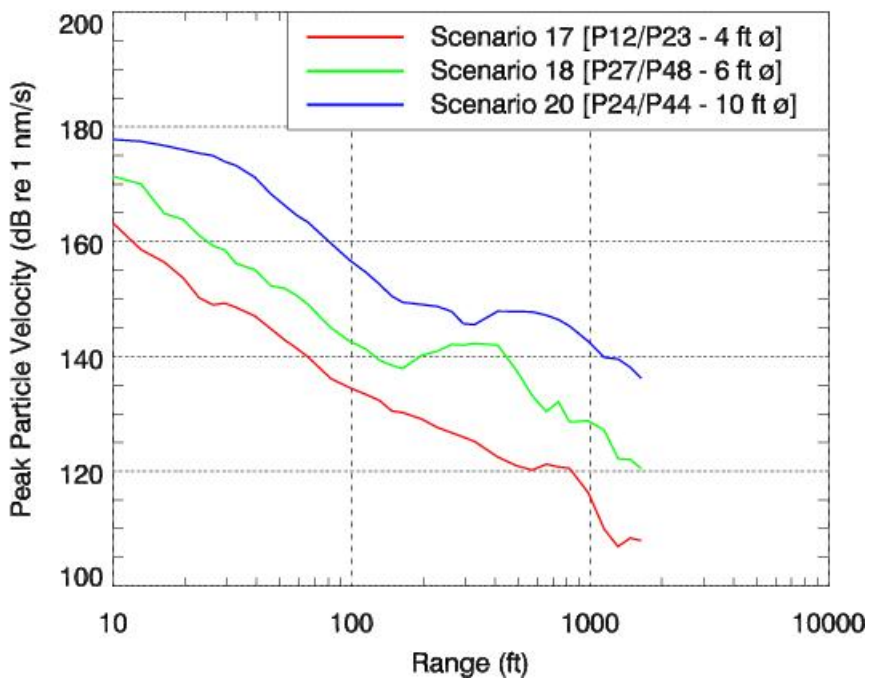


Figure 34. Peak particle velocity versus range for Scenarios 17, 18, and 20: impact hammering of 4, 6, and 10 ft piles without BMPs.

Table 10. Peak particle velocity at various distances from the source for Scenarios 17, 18, and 20: impact hammering of 4, 6, and 10 ft piles without BMPs.

		Peak particle velocity at specified range (dB re 1 nm/s)						
Scenario Number	Activity	10 ft	25 ft	50 ft	100 ft	200 ft	500 ft	1000 ft
17	4 ft ø pile driving @ P12/P23 without BMPs	163.3	149.5	143.6	134.4	129.0	120.9	115.6
18	6 ft ø pile driving @ P27/P48 without BMPs	171.4	160.0	152.0	142.5	140.3	137.1	128.6
20	10 ft ø pile driving @ P24/P44 without BMPs	177.8	175.1	167.1	156.5	149.0	147.8	142.3

5. Discussion

5.1. Sound Propagation in the River Environment

In Tappan Zee Reach the riverbed bathymetry and sub-bottom properties are the most important environmental factors governing propagation of sound from pile driving activities, because the dominant acoustic wavelengths are comparable in scale to the water depth. For example the acoustic wavelength of the 125 Hz band where sound levels from the 8-10 ft piles are highest (Figure 7) is approximately 40 ft (Equation 2). In shallow water, sound is continually reflected and absorbed by the river bottom as it propagates away from the source. At long ranges the absorption of sound energy into the riverbed (called “bottom loss”) becomes the primary attenuating mechanism. The bathymetric profile of the riverbed causes sound to propagate further along the deeper central channel than in the shallows to the east and west, resulting in sound level isopleths having a greater extent in the north-south direction.

The geoacoustic properties of the riverbed play an equally important role in influencing sound propagation in this environment. Whether the riverbed is absorptive or reflective depends upon the impedance contrast between the water and the substrate. Acoustic impedance is related to the density and speed of sound of a medium. If the impedance contrast between the water and the riverbed is low (i.e., if the densities and sound speeds are similar) then the riverbed is more absorptive. In the case of Tappan Zee Reach, the top sediment layer at the riverbed interface is composed of fine, water-saturated sediments (silty-clay) which have a relatively low impedance contrast with water. A rocky bottom, by contrast, would have a much higher impedance contrast than fine sediments and be more acoustically reflective. Propagation loss is generally higher over softer, more porous substrates.

The stratification of the riverbed sediments determines how bottom loss varies with frequency. Propagating sound waves in the water medium are coupled to the underlying sediments as they impinge onto the riverbed. The extent to which this coupling occurs is related to wavelength. Lower frequencies are coupled to deeper sediments, whereas higher frequencies are coupled to shallower sediments. Deeper sediments generally possess higher sound speeds, which can cause reflection (or refraction) of low frequencies back into the water column. On the other hand, volumetric absorption of acoustic energy is also much higher in sediments than in water; sound frequencies that are strongly coupled to the bottom, therefore, also tend to experience higher propagation loss (resulting in so called “leaky modes”). Finally, interference between reflections

from multiple sediment layers can both enhance and suppress certain frequencies. Due to these competing effects, bottom loss is a complex phenomenon that often goes against intuition.

An example of the strong influence of geoacoustics in the modeling of sound propagation in Tappan Zee Reach is the notch near 1 kHz observed in the PSD levels at long ranges (see Figure 32 and Figure 33). The notch corresponds to the transition from strongly bottom coupled sound propagation at low frequencies to weakly bottom coupled (i.e., primarily waterborne) sound propagation at higher frequencies. In this case, the mid-frequencies (0.3-2 kHz) are absorbed by the riverbed more strongly than the low frequencies (< 0.3 kHz) because sediment absorption increases with frequency; at higher frequencies (> 2 kHz), however, the sound energy is not strongly coupled to the riverbed and so bottom absorption becomes negligible. These competing mechanisms result in the model predicted notch in the PSD levels in the middle frequency range.

Another example of the influence of geoacoustics can be observed at short ranges, in the near-field peak level modeling. For the unmitigated piling (Figure 26), SPLs at distances between 200 ft and 480 ft rise to higher values for the 6 ft diameter pile (at P27/P48) than for the 8 ft diameter pile (at P20/P38). The cause for this phenomenon can be found in the markedly different thickness of the top sediment layer at the two locations, 25 ft and 85 ft respectively (see Table 4). In both cases sound is reflected from the interface between the first two sediment layers; at P27/P48, however, the condition of "critical reflection" (whereby sound is totally reflected at the interface for shallow angles of incidence) occurs at shorter range because of the thinner top sediment layer. The SPL, therefore, begins surging with range due to the onset of critical reflection at a distance of about 130 ft for the 6 ft pile compared to 300 ft for the 8 ft pile, causing the localized crossover. The same effect is not observed for the mitigated piling (Figure 27) due to the dominance of low frequencies (less attenuated by the bubble curtain) that do not "see" the shallow sediment layers.

As the previous case analyses have shown, the results of the sound propagation modeling are very sensitive to both the bathymetry and geoacoustic properties of the riverbed in Tappan Zee Reach. Precise, high-resolution bathymetric survey data are available for the Hudson River; the modeling uncertainty related to inaccuracies in bathymetry is therefore small. The uncertainty in model results associated with the geoacoustic properties of the riverbed, on the other hand, is more significant due to the fact that the acoustic properties of the riverbed sediments have not been directly measured at Tappan Zee Reach. The current study has presented a justifiable estimate of the sediment geoacoustic profiles based on available sediment stratigraphy from core samples and historical data for similar sediments. Nonetheless, a more rigorous estimation of the acoustic properties of the riverbed (either directly from coring studies or indirectly from transmission loss measurements) would significantly reduce uncertainty in the model estimates.

5.2. Pile Driving Sound Levels

The acoustic footprint of a single pile driving strike depends primarily on the following factors:

1. the energy and type of pile driving hammer,
2. the size and type of the pile, and
3. the water depth and substrate in which the pile is being driven.

The acoustic energy radiated into the aquatic environment by a struck pile is directly correlated to the kinetic energy that the impact hammer imparts to it. Engineering considerations about pile

penetration and load bearing capacity dictate that the impact hammer energy must be matched to the pile and to the resistance of the underlying soils (Parola, 1970). Greater hammer energy is generally required for larger diameter piles to achieve the desired load bearing capacity. The hammer energy must also be sufficient to overcome the local resistance of any substrate into which the pile is being driven. It is clear therefore that pile driving energy is largely imposed by the foundation load bearing requirements and cannot be arbitrarily reduced to shrink the acoustic footprint of pile driving operations.

The acoustic coupling between the pile and the water column is strongly influenced by the water depth at the piling location. In deep water, more of the pile is in contact with the water column and therefore more sound energy is injected directly into the aquatic environment. Furthermore, propagation loss is higher at shallow locations because more sound energy emanating from the pile is absorbed into the substrate. As a result, modeled footprints of SPL and single-strike SEL at Tappan Zee Reach were proportionately larger for piles driven in the deeper water of the river channel than on the shoals.

Source levels for the current study were based on published acoustic measurements of sound emission from impact driving of cylindrical steel piles in several projects (Table 2). Analysis of published pile driving data indicated that large diameter piles emit more sound energy at low frequencies than smaller piles (Figure 7). This is consistent with the physical expectation that larger structures should acoustically resonate at longer wavelengths (i.e., at lower frequencies). Modeled frequency spectra showed that in the Tappan Zee Reach environment 4-6 ft piles were subject to higher long range propagation loss than 8-10 ft piles because mid-frequencies were more strongly attenuated than low frequencies (see results in Appendix D).

5.3. Cumulative Sound Exposure

In addition to the source properties discussed in the previous section, cSEL footprints for the cumulative scenarios were influenced by the following two factors:

1. The number of pile driving strikes, and
2. The spatial distribution of the piling activity.

If a constant rate of hammering is assumed, then the number of pile driving strikes increases linearly with time. The cSEL, however, increases logarithmically in decibels with number of strikes (Equation 12). For example, the dB increase in cSEL during the first 10 minutes of pile driving is roughly equivalent to the dB increase in cSEL over the following two hours (assuming the activity is not disrupted). Similarly, driving two identical piles at the same site will always increase the total cSEL by 3 dB relative to a single pile, no matter the time required to install the piles. Pile driving at two separate locations, on the other hand, has a greater influence on the aggregate cSEL footprint than installing multiple piles at a single location. Footprints are larger for distributed operations because contours from different locations ensonify a greater total area for the same amount of activity.

The results from modeling of cumulative scenarios represent the total cSEL for a stationary receiver exposed to piling noise from multiple sites, regardless of whether these piles are being driven at the same time or in sequence. The only relevant assumption is that all the pile driving happens within a short enough time that the subject will not have started to recover from any temporary impact from the noise exposure. This is likely a very conservative assumption when the piling happens intermittently over an 8 hour work day. Another important consideration

regarding cumulative scenarios is that when piles from different piers are driven simultaneously it can readily be assumed that the sources are sufficiently uncorrelated and the noise sufficiently broadband that no coherent summing of individual pulses can ever take place.

5.4. Factors Influencing BMP Attenuation

As discussed in Section 3.3, while confined air-bubble curtains likely represent the best available technology for mitigating pile driving noise in Tappan Zee Reach, the quantitative effectiveness of this management practice reported in the literature is highly variable. Several factors are thought to influence the performance of confined air-bubble curtain systems:

1. Whether the bubble plume completely encloses the pile
2. The nature of the confinement barrier
3. The volume fraction of air inside the bubble plume
4. The performance of air compressors, hoses, and manifolds, and nozzles

The pile must be completely enclosed by bubbles in order to achieve maximum attenuation. If the coverage is incomplete, sound will escape from holes in the bubble curtain (Vagle, 2003). Confined bubble curtain systems specifically prevent the river flow from dispersing the bubble plume around the pile; full and consistent coverage may nonetheless be difficult to achieve when the riverbed is uneven or sloped, since the base of the curtain cannot sit flush on the riverbed.

Past projects have used both light fabric barriers and heavy rigid shells (such as steel pipes) to confine the bubble plume. Rigid shells hold up better to strong currents, but require heavy lifting machinery to deploy and recover. Light fabric barriers may be buffeted by currents and on occasion the bubbles plume itself may lift a fabric curtain off the base of the pile (CALTRANS, 2001). In general practice rigid shells are mostly found preferable; in addition a rigid barrier can be engineered to enhance noise attenuation by coating it with sound absorbing material or by incorporating an air space between concentric walls (MacGillivray et al., 2006).

Bubble curtains achieve sound attenuation by introducing a highly compressible fluid layer between the pile and the water column (Hannay, 2008). Increasing the air volume fraction inside the barrier creates a larger impedance mismatch at the pile wall, thereby better decoupling the pile from the water column. If insufficient air is injected into the confined volume between the barrier and the pile wall, the mitigation will be ineffective.

Adequate air injection and bubble plume confinement both depend critically on the design and construction of the bubble curtain, which must be tested under realistic conditions to verify its effectiveness. Hoses, manifolds, nozzles and compressors must continuously supply a sufficient amount of air to the system for it to be effective. Furthermore, an air bubble curtain system must be reasonably easy to set up at the job site or it may be deployed improperly by the construction contractor thus compromising its efficacy.

A review of published measurements of bubble curtain attenuation showed that performance at low frequencies, below 100 Hz, was poorer than at higher frequencies (Figure 10). Because the peak SPL metric is influenced primarily by high frequencies, air bubble curtains tend to be most effective at reducing peak levels close to the pile (Figure 27). At long ranges, however, the effectiveness of bubble curtains may be less. The modeling performed in this study has shown that high frequencies become spread out at longer propagation ranges, causing long-range SPLs

to depended more strongly on the low frequencies which are less attenuated by air-bubble curtains. In the modeling results BMPs were observed to be less effective at attenuating SPLs from pile driving at ranges longer than 10,000 ft (Figure 31).

6. Summary and Conclusions

This report has presented results from a noise modeling study carried out in support of the Tappan Zee/I-287 Corridor Project Environmental Impact Statement. This study used three different numerical sound propagation models to estimate underwater noise levels that would be produced by impact pile driving activities associated with construction of the proposed bridge in Tappan Zee Reach. The acoustic models used wave-equation based algorithms (parabolic equation and wavenumber integration) to simulate sound propagation in the Hudson River environment, accounting for the frequency composition of the source signal and the acoustic properties of the water column and riverbed substrates. Sound propagation was modeled in three dimensions (range, depth and azimuth) at ranges up to 50,000 ft from the proposed bridge.

Use of three sound propagation models with complementary features and realms of applicability allowed for efficient modeling of sound propagation in multiple domains (near-field, far-field, time-domain, and frequency-domain). This was a necessity in order to be able to compute five different sound level metrics required for the noise impact assessment (SEL, cSEL, *rms* SPL, peak SPL, and particle velocity). Near-field metrics (peak SPL and particle velocity) were modeled using a time-domain wavenumber integration model (VSTACK) that was valid at short range from the piles. The wavenumber integration model simulated the pile as a vertically distributed source, taking into account the acoustic contribution of pile segments in the water and in the substrate. Far-field energy metrics (SEL, cSEL) were modeled using a frequency-domain parabolic equation model (MONM) that was able to account for three-dimensional bathymetry variations and range-dependent environmental parameters. Pulse lengths were computed using a time-domain PE model (FWRAM) in order to derive *rms* SPL results from the SEL modeling. The longer range modeling neglected the distributed nature of the pile in computing propagation loss, which is a valid assumption in the far-field zone where the acoustic radiation from the pile is indistinguishable from that of a point-source. Power spectral density levels for the pile driving were computed from the frequency resolved *rms* SPL model results.

Impact pile driving source levels in 1/3-octave bands were derived via back-propagation of published measurements for piles > 3 ft diameter. An ensemble of reported measurements, obtained at different locations and distances, were averaged in order to reduce uncertainty associated with the back-propagation. The source level estimates included corrections to adjust for pile diameter and hammer energy. Furthermore, different frequency distributions were derived for 8-10 ft diameter and 4-6 ft diameter piles since the published data showed that larger piles produced proportionately higher low frequency sound energy than smaller piles. Time-domain source levels were derived from spectral factorization of the 1/3-octave band source levels, which is expected to produce conservative estimates of SPLs from pile driving.

Environmental models of bathymetry, geoacoustics profiles, and water sound speed profiles were used as input to the acoustic propagation models. Water depths for the Hudson River were derived from high resolution bathymetry mapping survey data. The sound speed in water was

estimated based on temperature and salinity measurements for the month of October. October conditions were selected as representative for the modeling, because of the prominent lack of stratification in the water column, yielding a uniform profile that was expected to best represent average sound propagation conditions in Tappan Zee Reach. Geoacoustic profiles were derived from sediment stratigraphy data underneath the bridge span. Five distinct sedimentary units were identified in the stratigraphy cross-sections. For each of these sediment units, the acoustic properties were estimated based on the classification of the component soils. Eight different geoacoustic profiles were derived, one for each unique source location along the bridge span, plus an average profile used for long-range modeling.

Confined air bubble curtains were identified as the likely best BMP strategy for mitigating pile driving noise in Tappan Zee Reach. Published measurements were collected and analyzed to estimate a mean frequency attenuation curve for confined air bubble curtain systems. A review of the available data indicated that these systems have best performance at frequencies above 100 Hz, although the total broadband attenuation varied considerably between studies. Strong currents and variable water depths are present in Tappan Zee Reach, which could influence bubble curtain performance. In accordance with assessment guidelines published by WSDOT and CALTRANS, the assumed broadband BMP attenuation (at the source) was limited to 10 dB in the modeling. While some studies have reported higher broadband attenuation values, this is believed to be a realistic BMP performance target for the proposed construction project.

While model results were computed in three spatial dimensions, sound levels were reduced to two-dimensional contours for presentation by taking the maximum sound level over all depths at each receiver location. This approach is conservative, as it makes no assumption as to the depth where an organism is present in the water column.

Bathymetry was found to have a large influence on modeled sound levels in Tappan Zee Reach because sound absorption into the bottom, and therefore transmission loss, is much greater in shallow water. Pile driving isopleths extended significantly further along the central channel than along the east and west shoals; as a result, the contours were often asymmetrical around the piles. Similarly, propagation loss was much lower for piles driven in the central channel than for piles driven on the shoals. This tended to enhance levels from the largest piles located in the central channel. Furthermore, frequency dependent propagation effects tended to attenuate levels from 4-6 ft piles at shorter ranges than levels from 8-10 ft piles due to their different frequency composition.

Application of BMPs was found to significantly reduce pile driving sound levels, although BMPs were more effective in the near-field, due to frequency dependent propagation effects. For the cumulative scenarios, cSEL contour areas without BMPs at the 197 dB re 1 $\mu Pa^2 \cdot s$ threshold level ranged from 4,100 to 53,000 thousands of ft^2. cSEL contour areas with BMPs at the 197 dB re 1 $\mu Pa^2 \cdot s$ threshold level ranged from 180 to 30,000 thousands of ft^2. Cumulative sound levels were not appreciably different between scenarios representing the two different bridge design options. For the single-strike scenarios, unmitigated peak SPLs at the 208 dB re 1 µPa threshold level ranged from 43-861 ft. Mitigated peak SPLs ranged from 26-247 ft.

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Appendix F: Ecology

F-5B Appendix to Underwater Ambient Sound Level in the Hudson River near the Tappan Zee Bridge: Short and Long Span Ambient Noise Modeling (Jasco, July 2011)

Tappan Zee Bridge Construction Hydroacoustic Noise Modeling

Appendices

Submitted to:
AECOM
One World Financial Center
200 Liberty St, 25th Floor
New York, NY 10281

Authors:
Alexander MacGillivray
Graham Warner
Roberto Racca
Caitlin O'Neill

JASCO Applied Sciences
Suite 2101, 4464 Markham St.
Victoria, BC, V8Z 7X8, Canada
Phone: +1.250.483.3300
Fax: +1.250.483.3301
www.jasco.com

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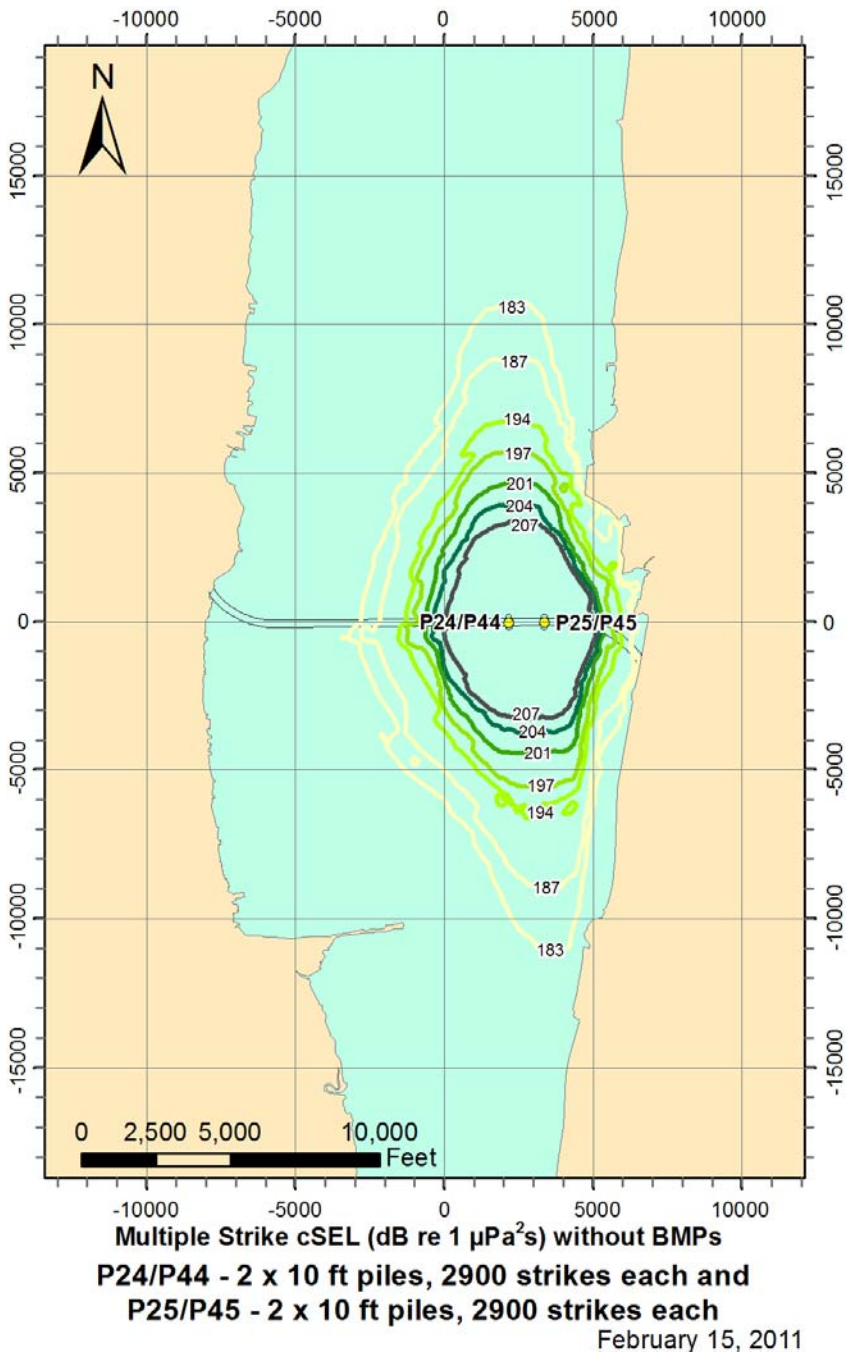
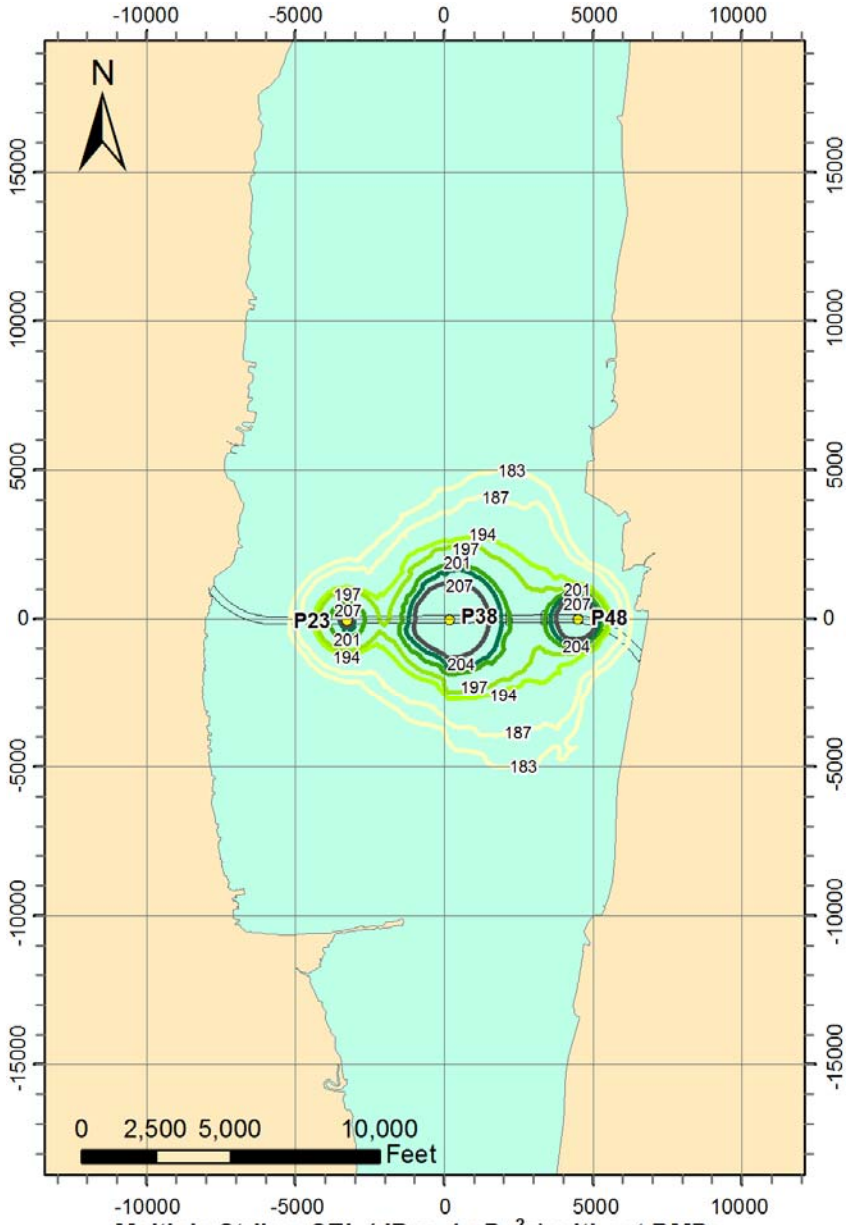
Appendix A. Cumulative cSEL Scenario Maps

A.1. Single Level Bridge: No BMPs Applied

A.1.1. Max Case 1 (also dual level bridge)



A.1.2. Max Case 2A

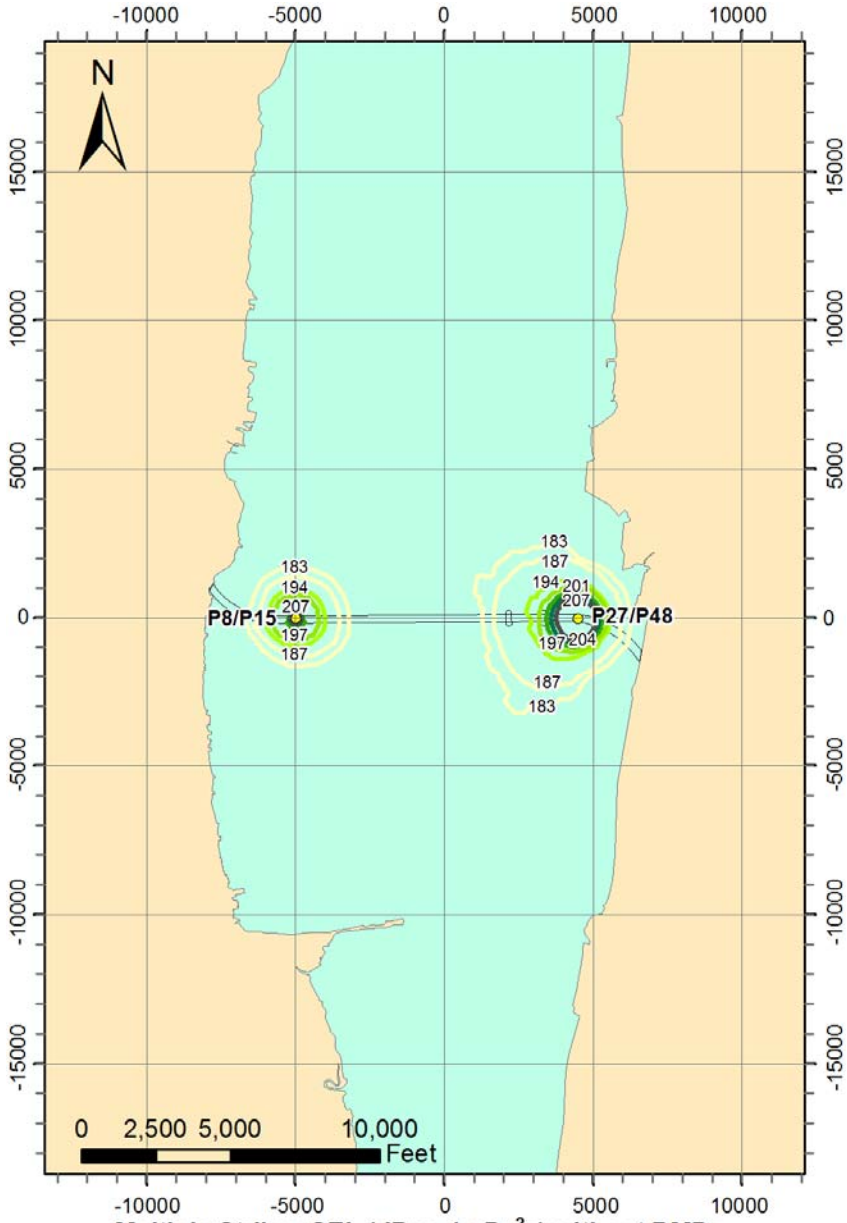


Multiple Strike cSEL (dB re 1 μPa^{2}s) without BMPs

P23 - 3 x 4 ft piles, 3800 strikes each,
P38 - 3 x 8 ft piles, 2100 strikes each, and
P48 - 4 x 6 ft piles, 1000 strikes each

January 27, 2011

A.1.3. Max Case 3 (also dual level bridge)

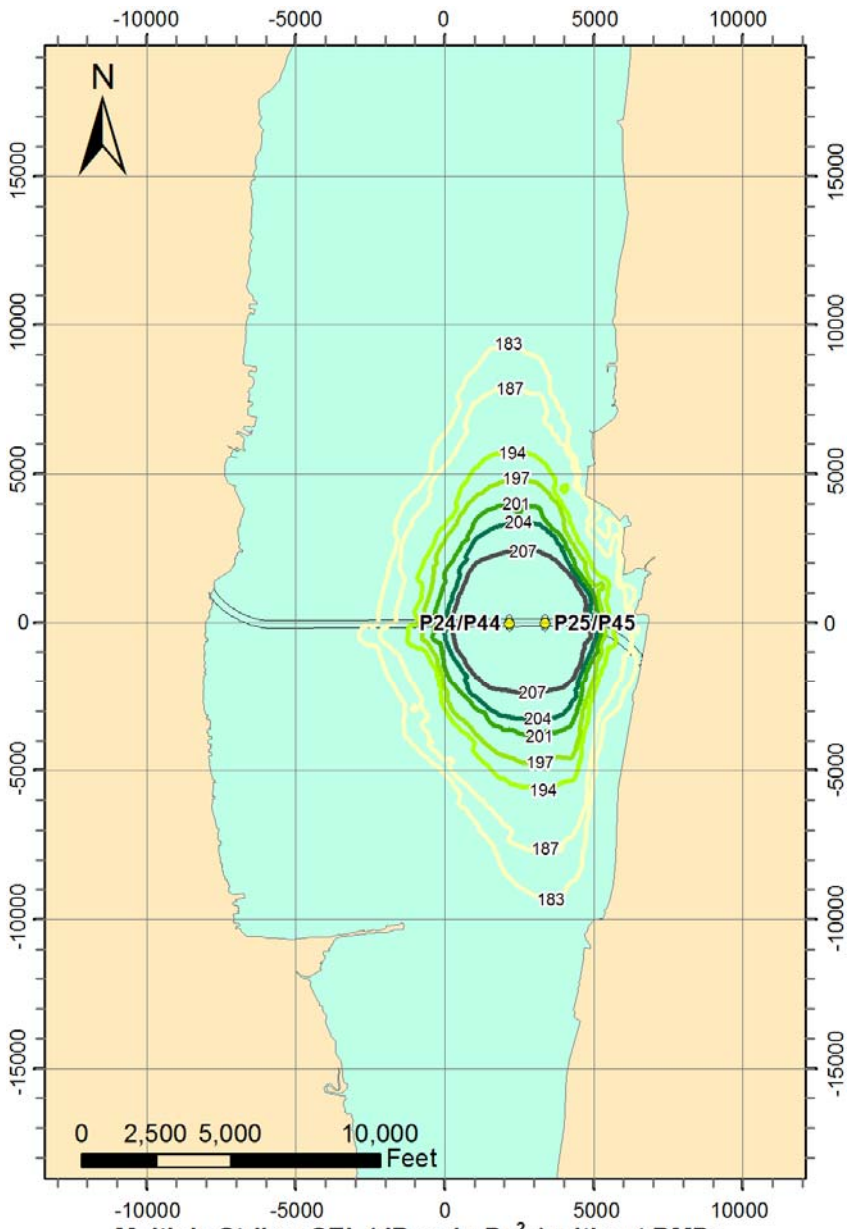


Multiple Strike cSEL (dB re 1 μPa^{2}s) without BMPs

P8/P15 - 3 x 4 ft piles, 3800 strikes each and
P27/P48 - 4 x 6 ft piles, 1000 strikes each

January 27, 2011

A.1.4. Typical Case 1 (also dual level bridge)

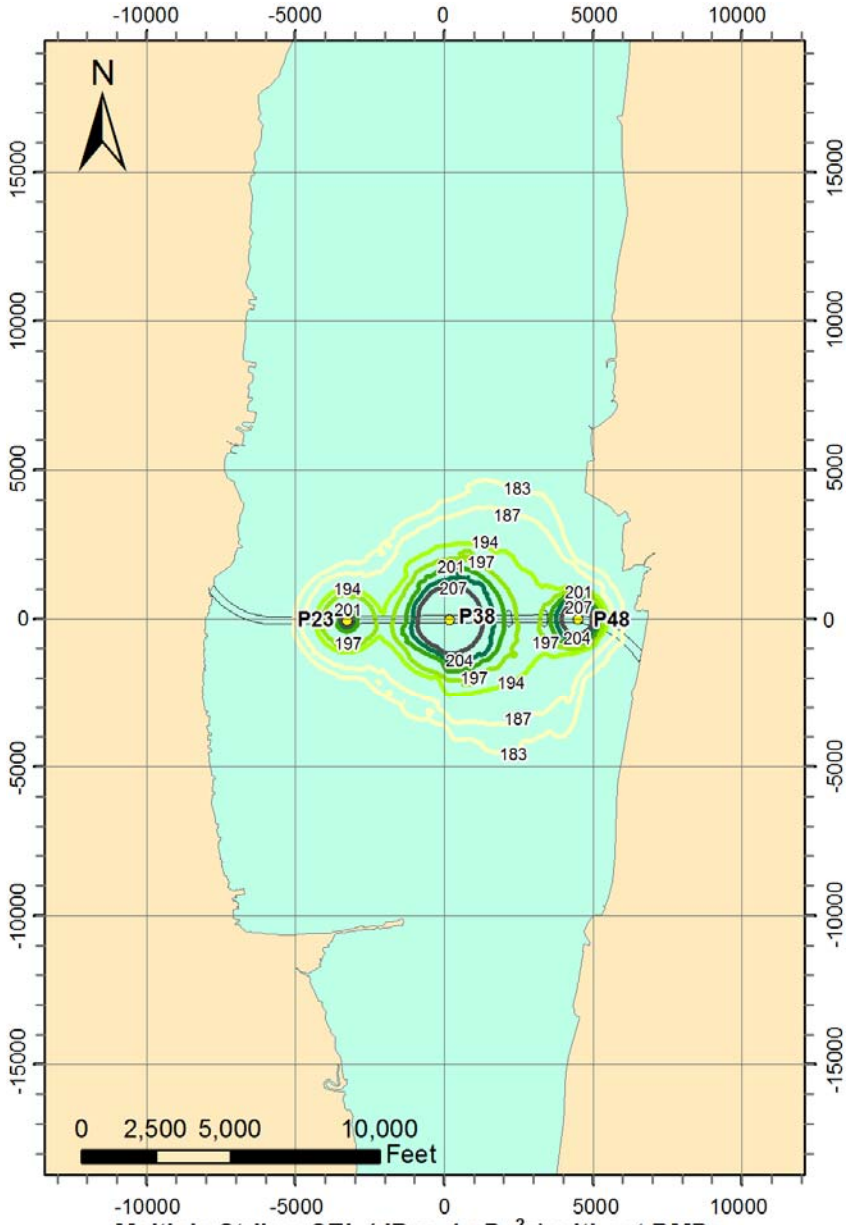


Multiple Strike cSEL (dB re 1 μPa²s) without BMPs

P24/P44 - 1 x 10 ft pile, 2900 strikes each and
P25/P45 - 1 x 10 ft pile, 2900 strikes each

January 27, 2011

A.1.5. Typical Case 2A

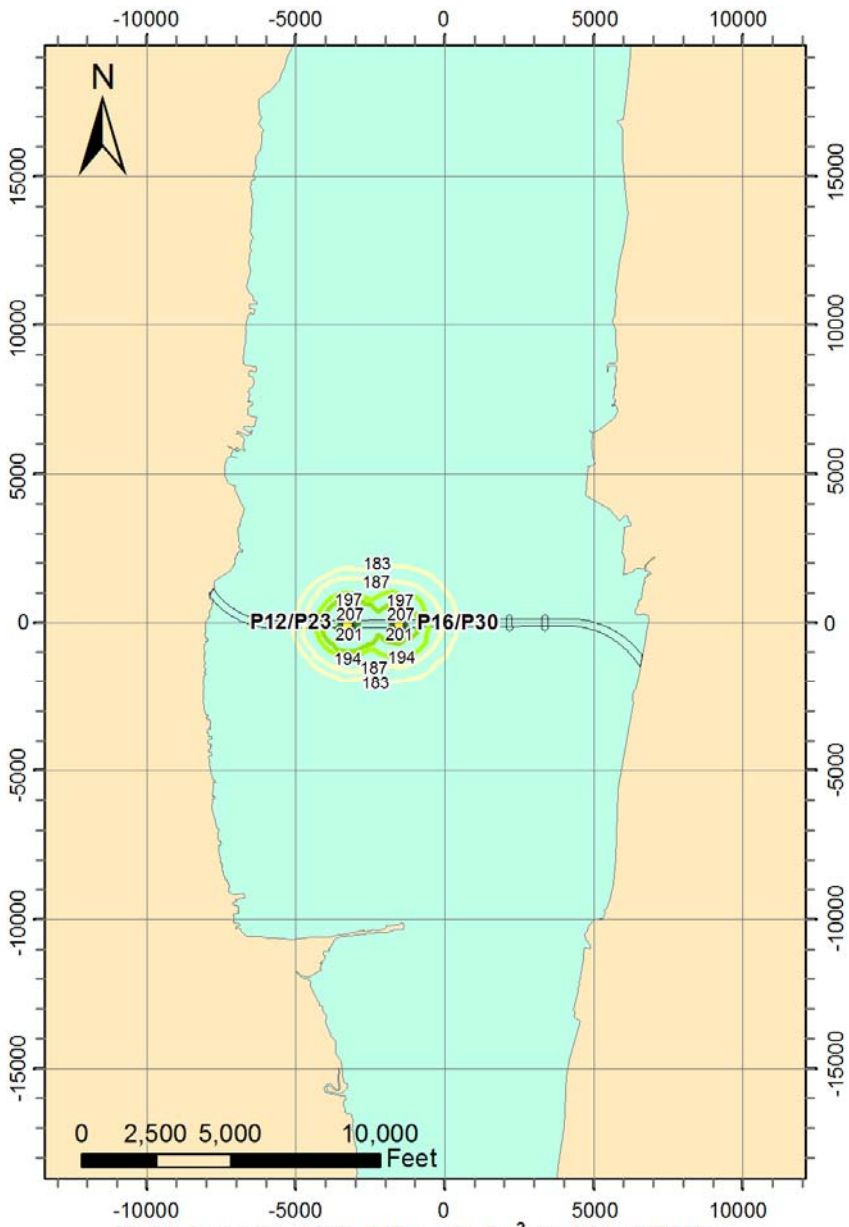


Multiple Strike cSEL (dB re 1 μPa^{2}s) without BMPs

P23 - 2 x 4 ft piles, 3800 strikes each,
P38 - 2 x 8 ft piles, 2100 strikes each, and
P48 - 2 x 6 ft piles, 1000 strikes each

January 27, 2011

A.1.6. Typical Case 3 (also dual level bridge)



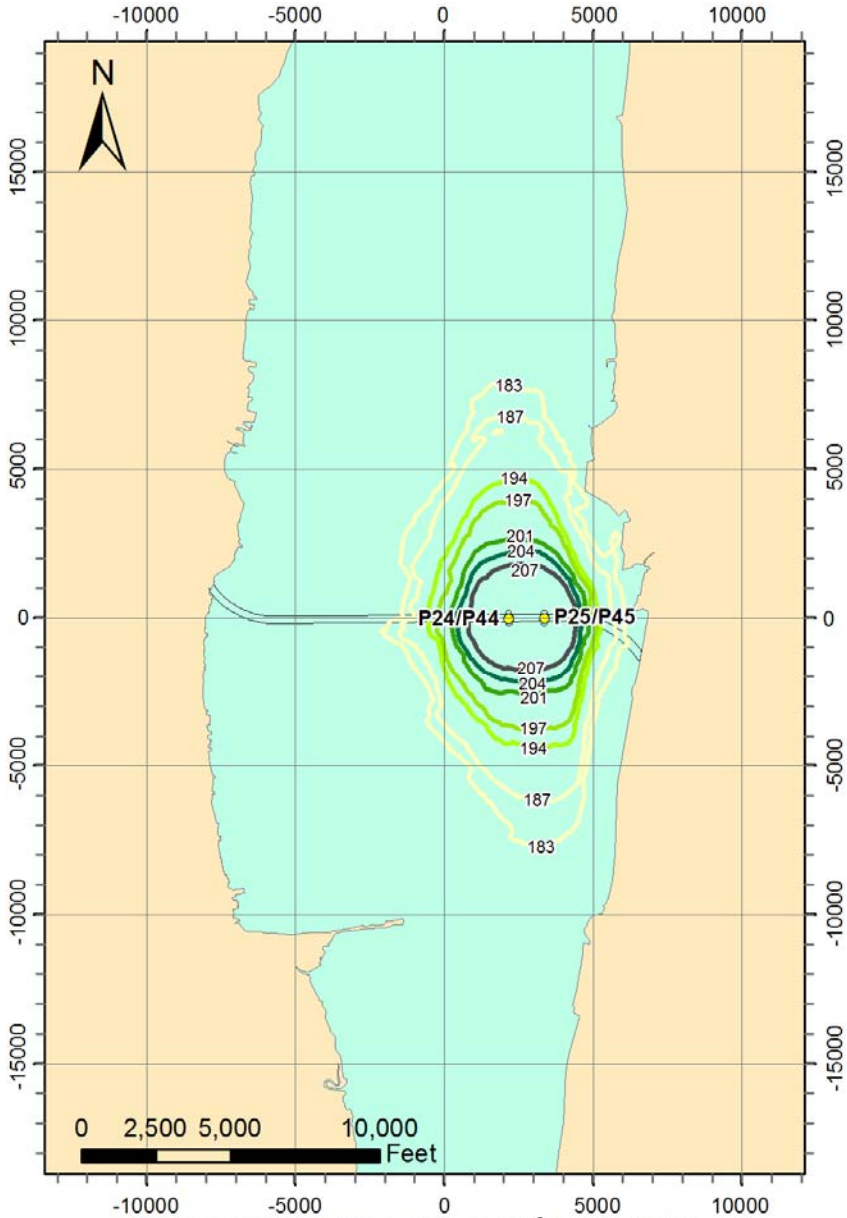
Multiple Strike cSEL (dB re 1 μPa²s) without BMPs

P12/P23 - 2 x 4 ft piles, 3800 strikes each and
P16/P30 - 2 x 4 ft piles, 3800 strikes each

January 27, 2011

A.2. Single Level Bridge: BMPs Applied

A.2.1. Max Case 1 (also dual level bridge)

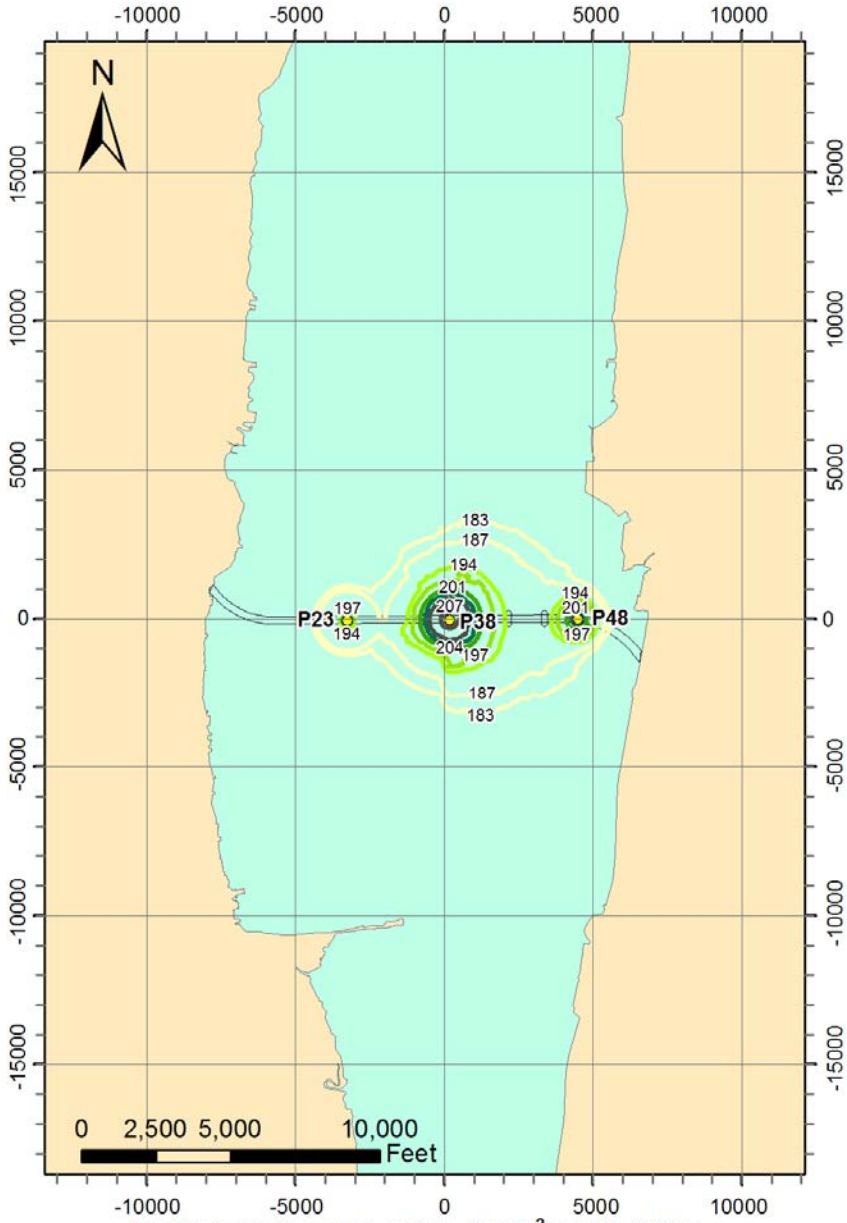


Multiple Strike cSEL (dB re 1 μPa^{2}s) with BMPs

P24/P44 - 2 x 10 ft piles, 2900 strikes each and
P25/P45 - 2 x 10 ft piles, 2900 strikes each

January 27, 2011

A.2.2. Max Case 2A

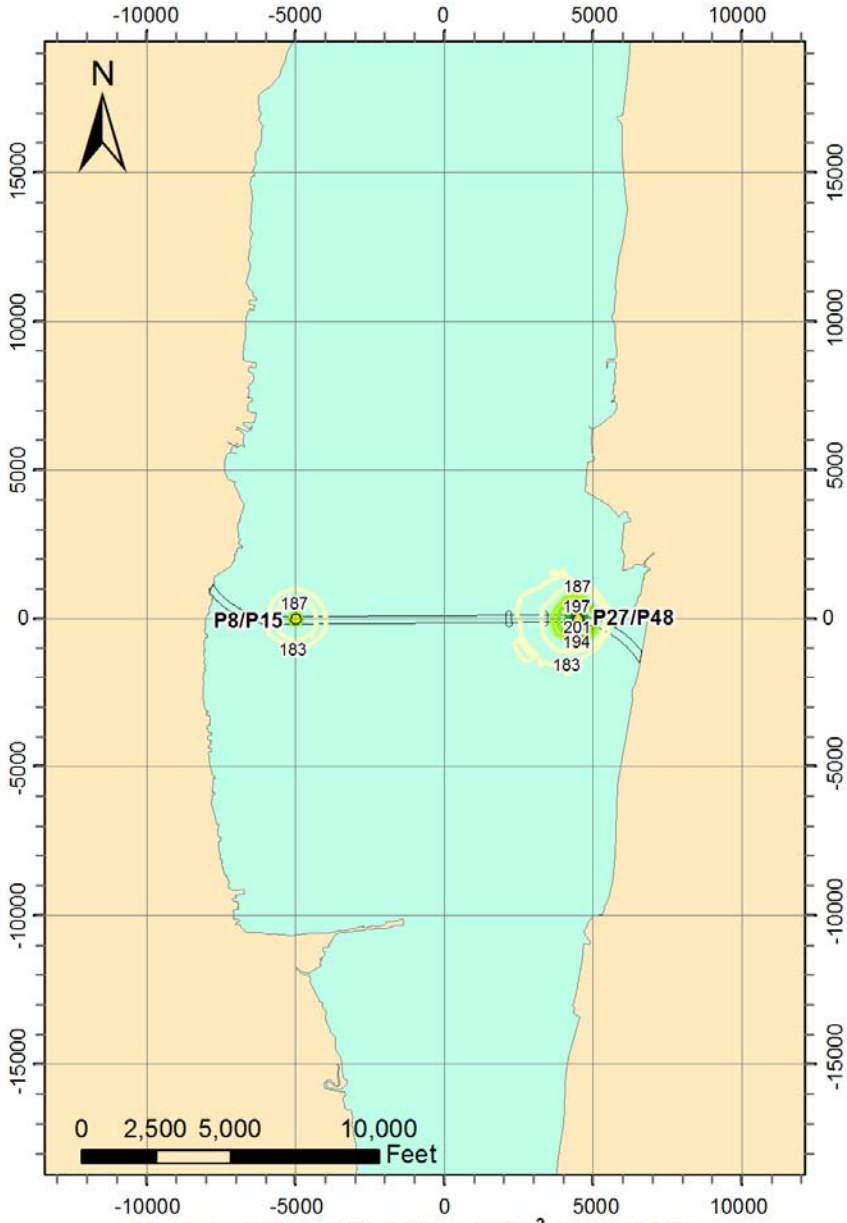


Multiple Strike cSEL (dB re 1 μPa^{2}s) with BMPs

P23 - 3 x 4 ft piles, 3800 strikes each,
P38 - 3 x 8 ft piles, 2100 strikes each, and
P48 - 4 x 6 ft piles, 1000 strikes each

January 27, 2011

A.2.3. Max Case 3 (also dual level bridge)

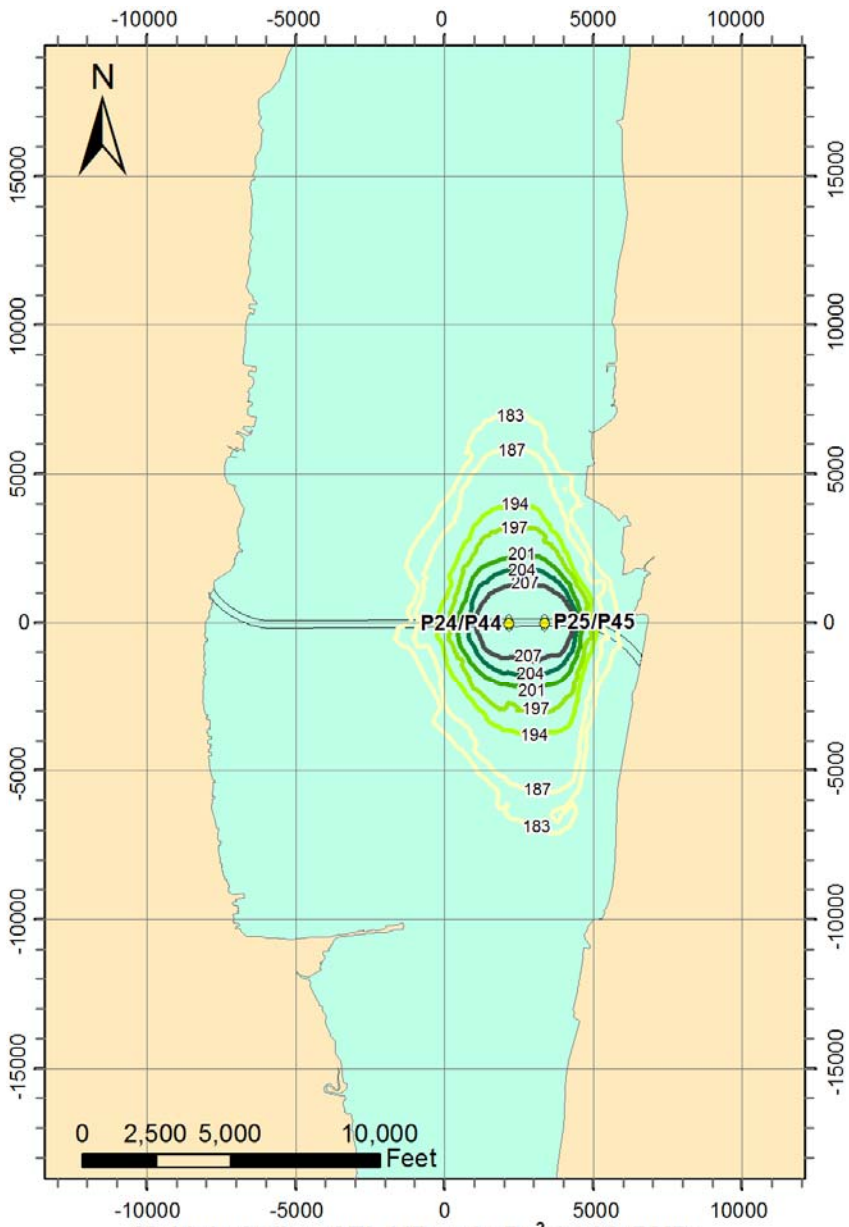


Multiple Strike cSEL (dB re 1 μPa^{2}s) with BMPs

P8/P15 - 3 x 4 ft piles, 3800 strikes each and
P27/P48 - 4 x 6 ft piles, 1000 strikes each

January 27, 2011

A.2.4. Typical Case 1 (also dual level bridge)

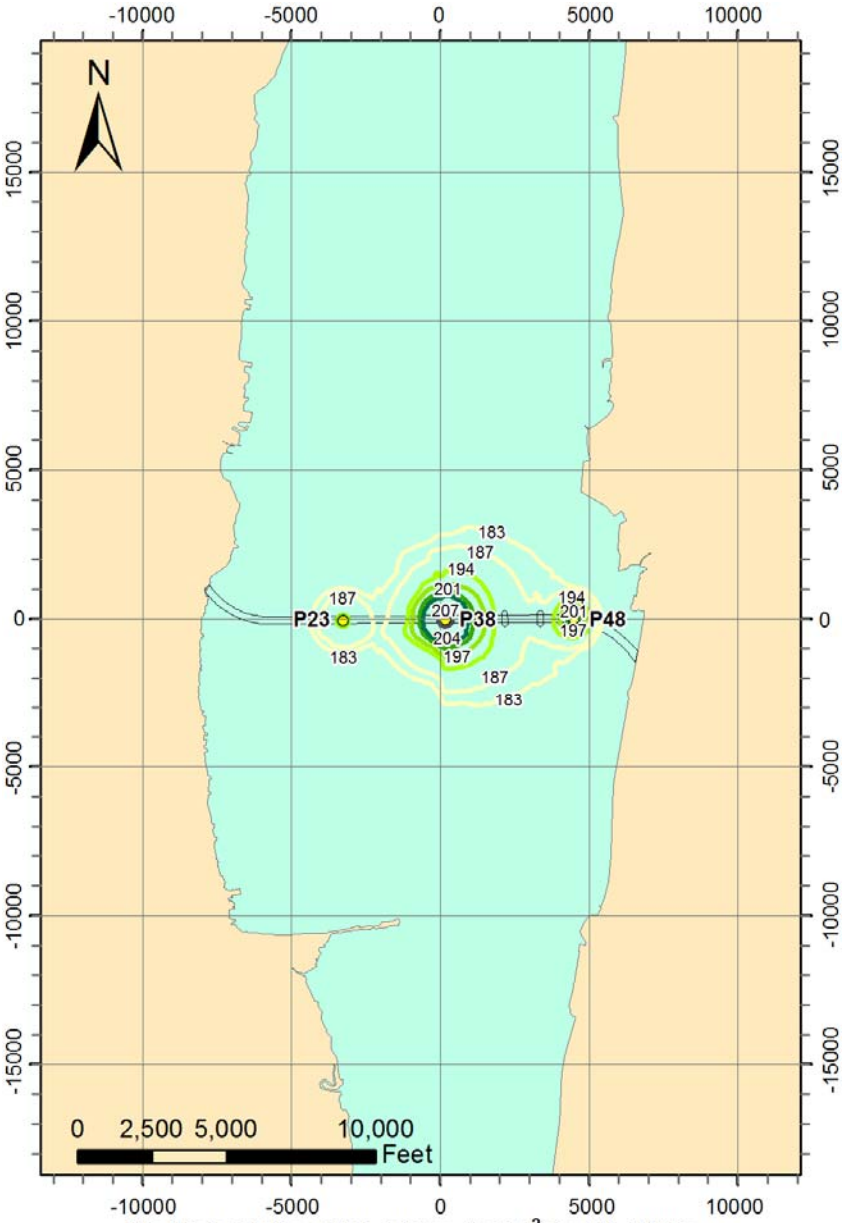


Multiple Strike cSEL (dB re 1 μPa^{2}s) with BMPs

P24/P44 - 1 x 10 ft pile, 2900 strikes each and
P25/P45 - 1 x 10 ft pile, 2900 strikes each

January 27, 2011

A.2.5. Typical Case 2A

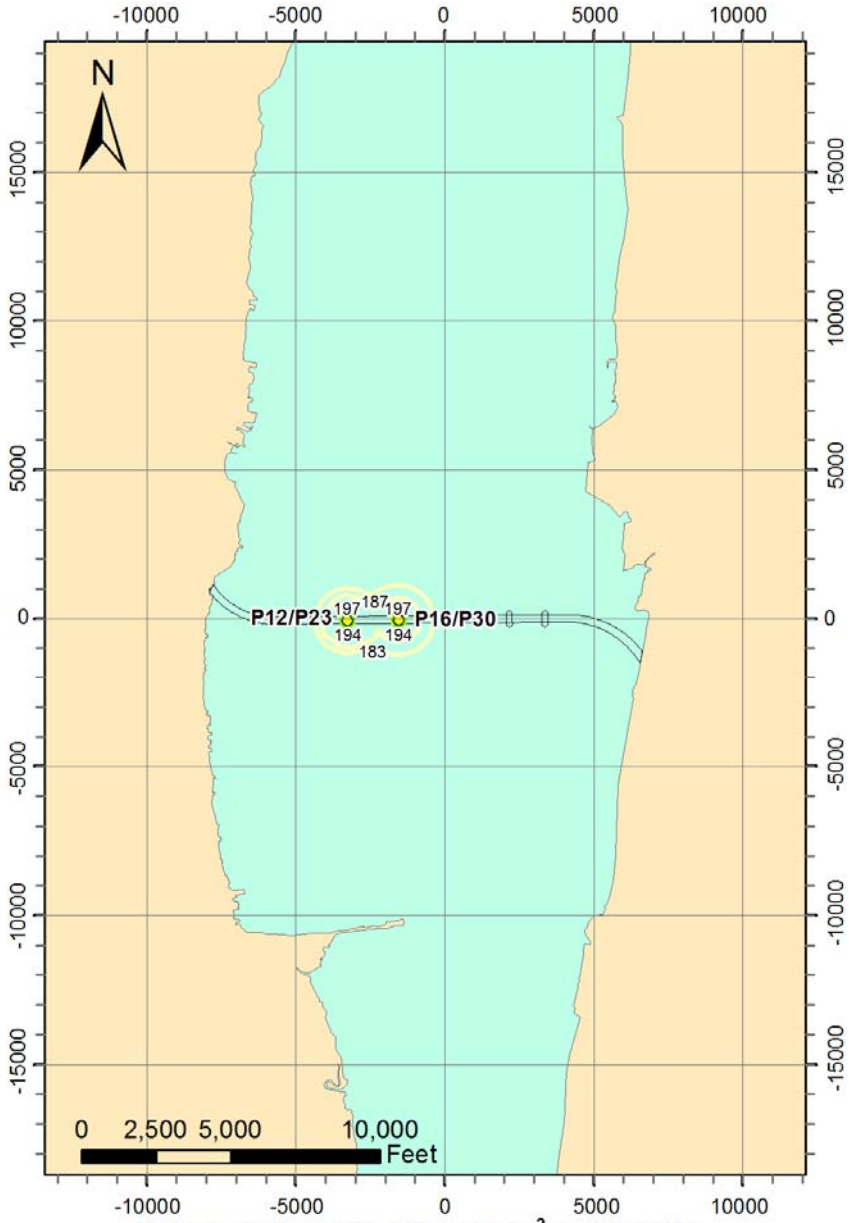


Multiple Strike cSEL (dB re 1 μPa^{2}s) with BMPs

P23 - 2 x 4 ft piles, 3800 strikes each,
P38 - 2 x 8 ft piles, 2100 strikes each, and
P48 - 2 x 6 ft piles, 1000 strikes each

January 27, 2011

A.2.6. Typical Case 3 (also dual level bridge)



Multiple Strike cSEL (dB re 1 μPa²s) with BMPs

P12/P23 - 2 x 4 ft piles, 3800 strikes each and
P16/P30 - 2 x 4 ft piles, 3800 strikes each

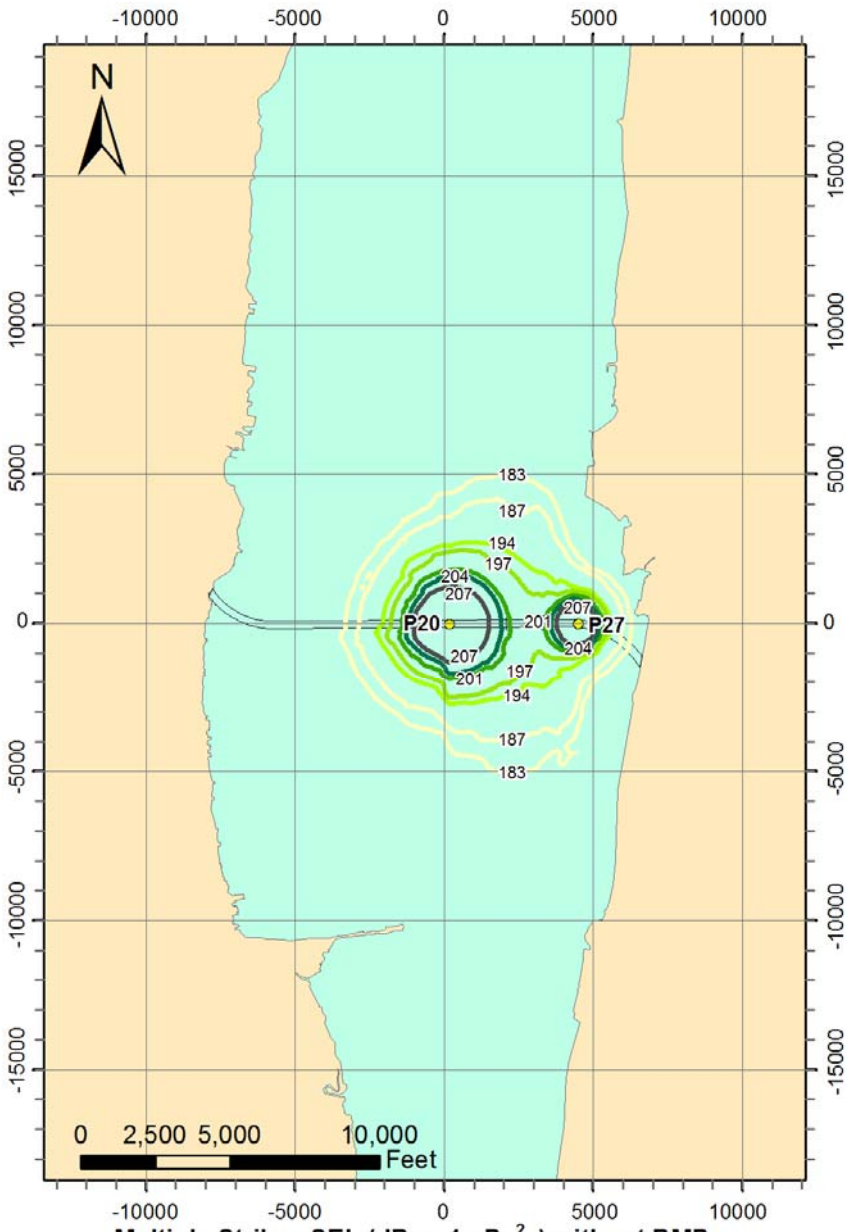
January 27, 2011

A.3. Dual Level Bridge: No BMPs Applied

A.3.1. Max Case 1

Sound level contours are identical to those of the single level bridge in section A.1.1. Max Case 1 (also dual level bridge).

A.3.2. Max Case 2B



Multiple Strike cSEL (dB re 1 μPa²s) without BMPs

P20 - 3 x 8 ft piles, 2100 strikes each and
P27 - 4 x 6 ft piles, 1000 strikes each

January 21, 2011

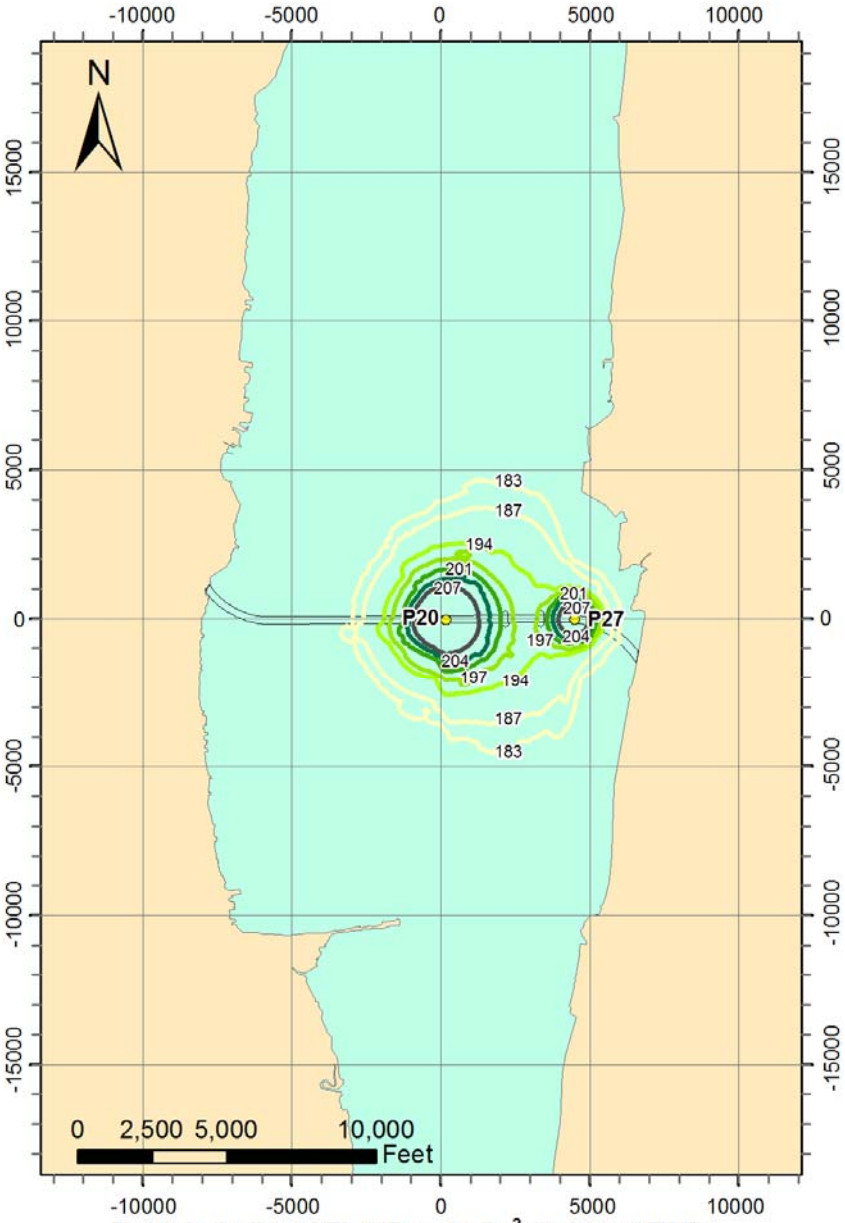
A.3.3. Max Case 3

Sound level contours are identical to those of the single level bridge in section A.1.3. Max Case 3 (also dual level bridge).

A.3.4. Typical Case 1

Sound level contours are identical to those in of the single level bridge section A.1.4. Typical Case 1 (also dual level bridge).

A.3.5. Typical Case 2B



Multiple Strike cSEL (dB re 1 μPa^{2}s) without BMPs

P20 - 2 x 8 ft piles, 2100 strikes each and
P27 - 2 x 6 ft piles, 1000 strikes each

January 27, 2011

A.3.6. Typical Case 3

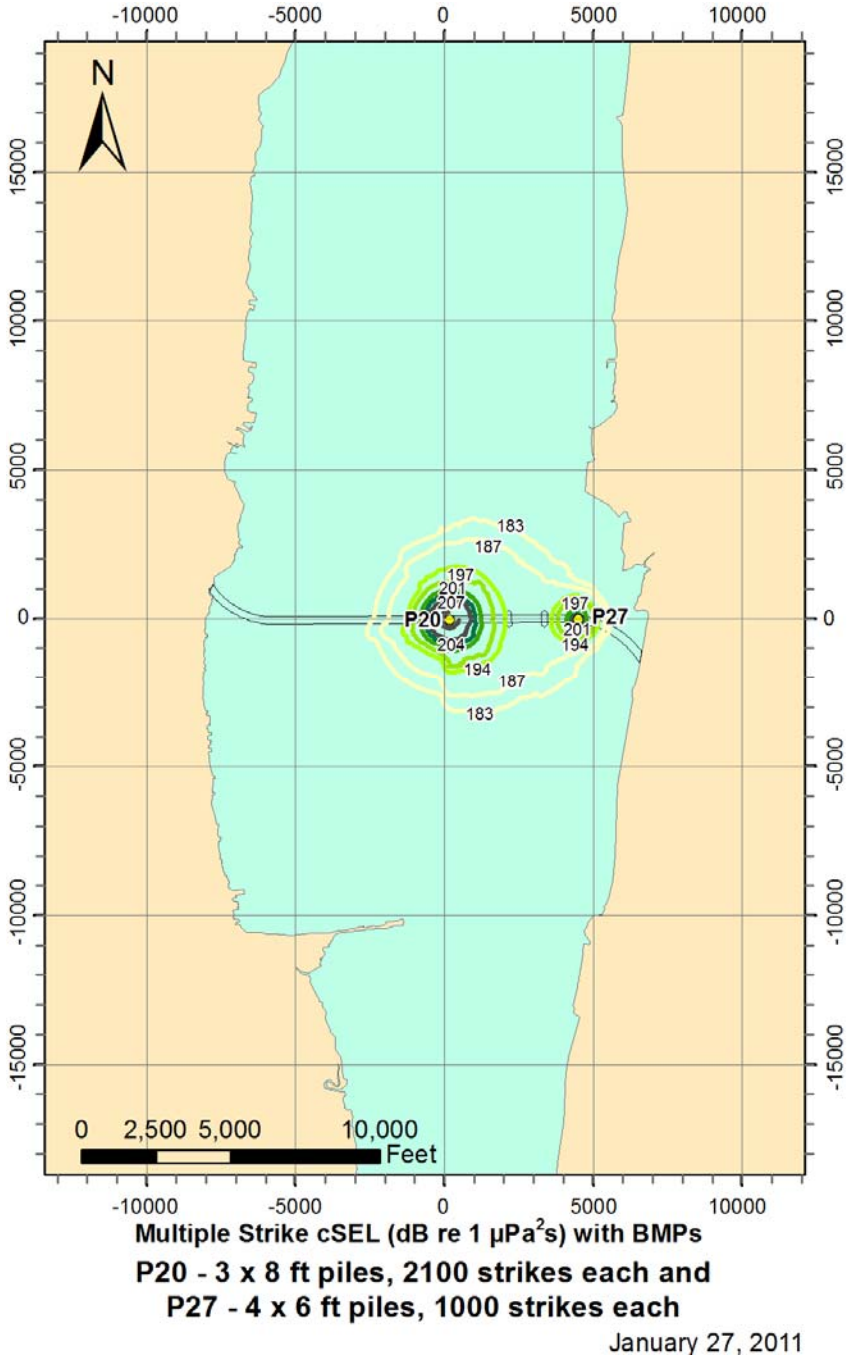
Sound level contours are identical to those of the single level bridge in section A.1.6. Typical Case 3 (also dual level bridge).

A.4. Dual Level Bridge: BMPs Applied

A.4.1. Max Case 1

Sound level contours are identical to those of the single level bridge in section A.2.1. Max Case 1 (also dual level bridge).

A.4.2. Max Case 2B



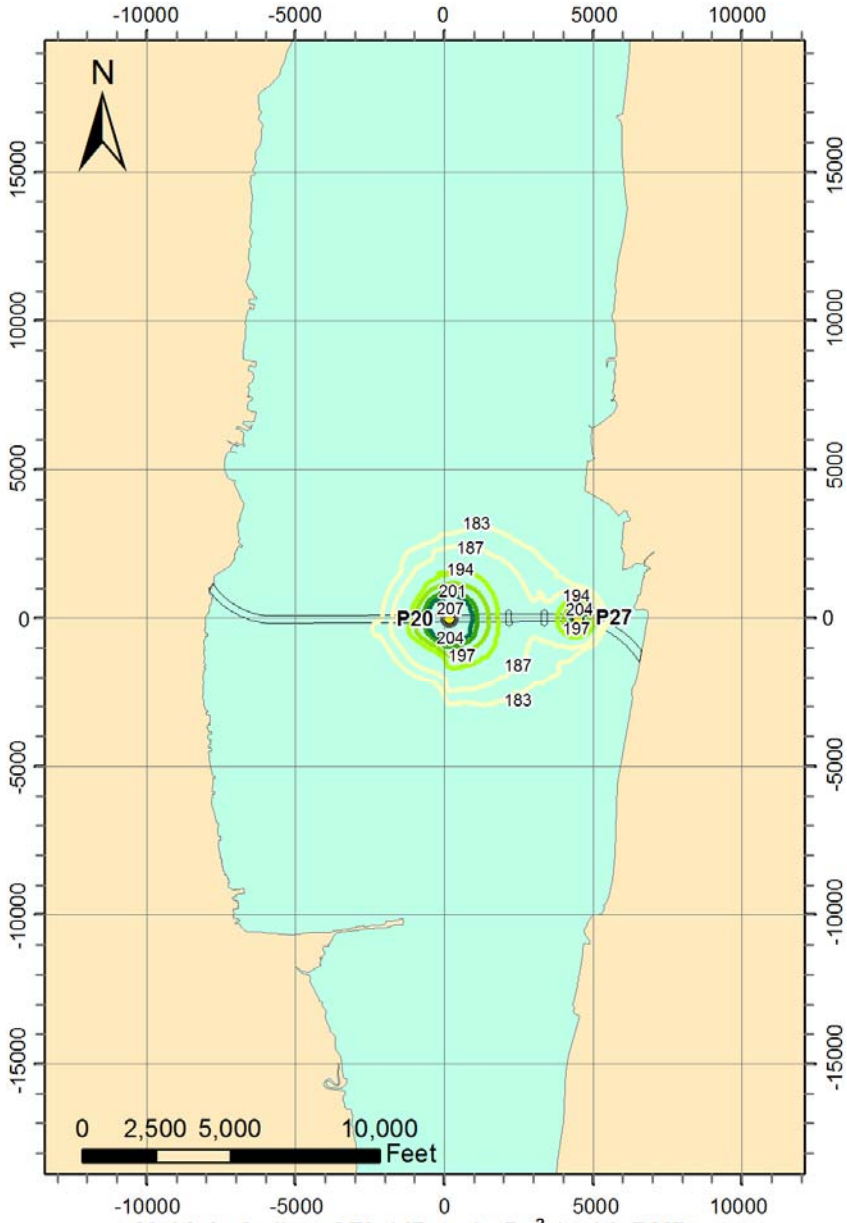
A.4.3. Max Case 3

Sound level contours are identical to those of the single level bridge in section A.2.3. Max Case 3 (also dual level bridge).

A.4.4. Typical Case 1

Sound level contours are identical to those of the single level bridge in section A.2.4. Typical Case 1 (also dual level bridge).

A.4.5. Typical Case 2B



Multiple Strike cSEL (dB re 1 μPa²s) with BMPs

P20 - 2 x 8 ft piles, 2100 strikes each and
P27 - 2 x 6 ft piles, 1000 strikes each

January 27, 2011

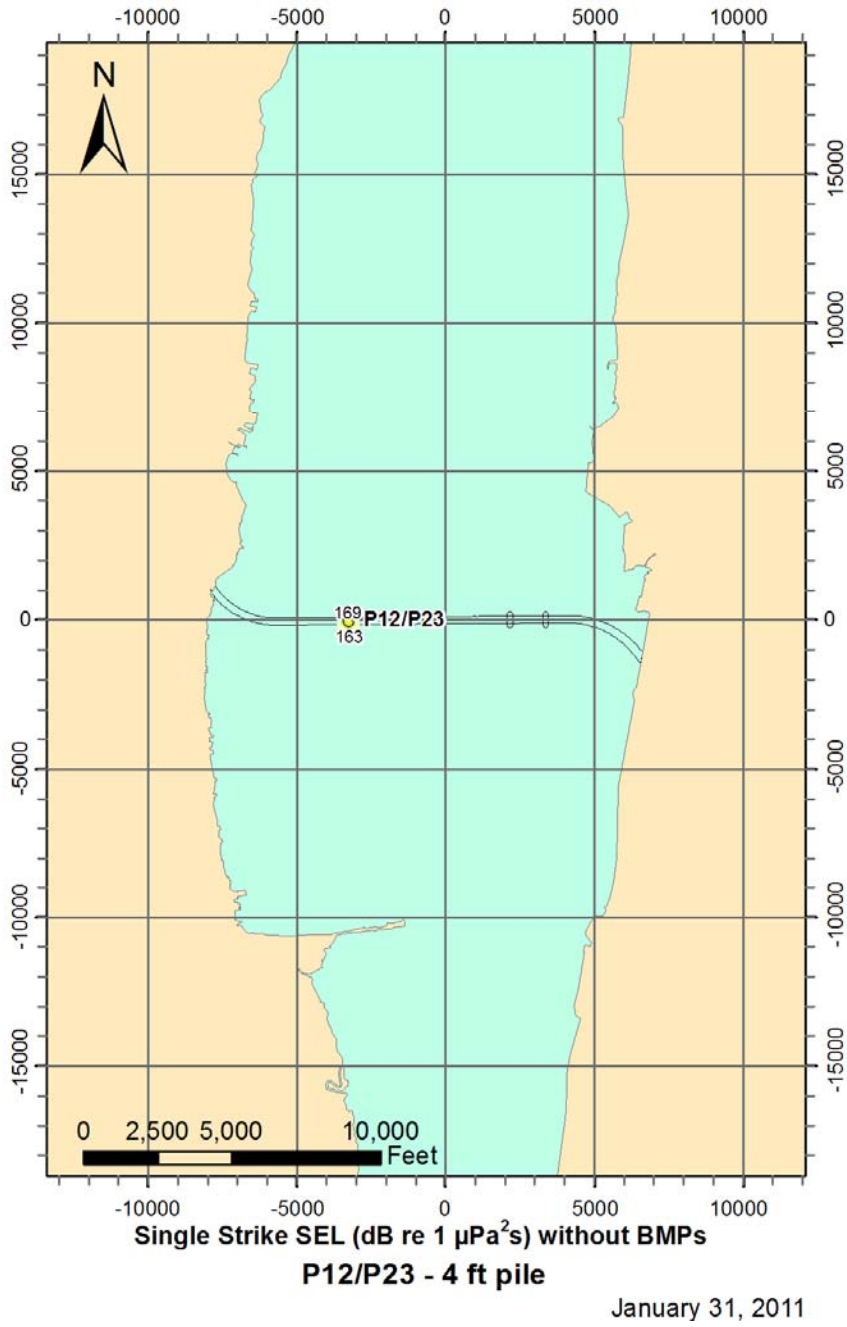
A.4.6. Typical Case 3

Sound level contours are identical to those of the single level bridge in section A.2.6. Typical Case 3 (also dual level bridge).

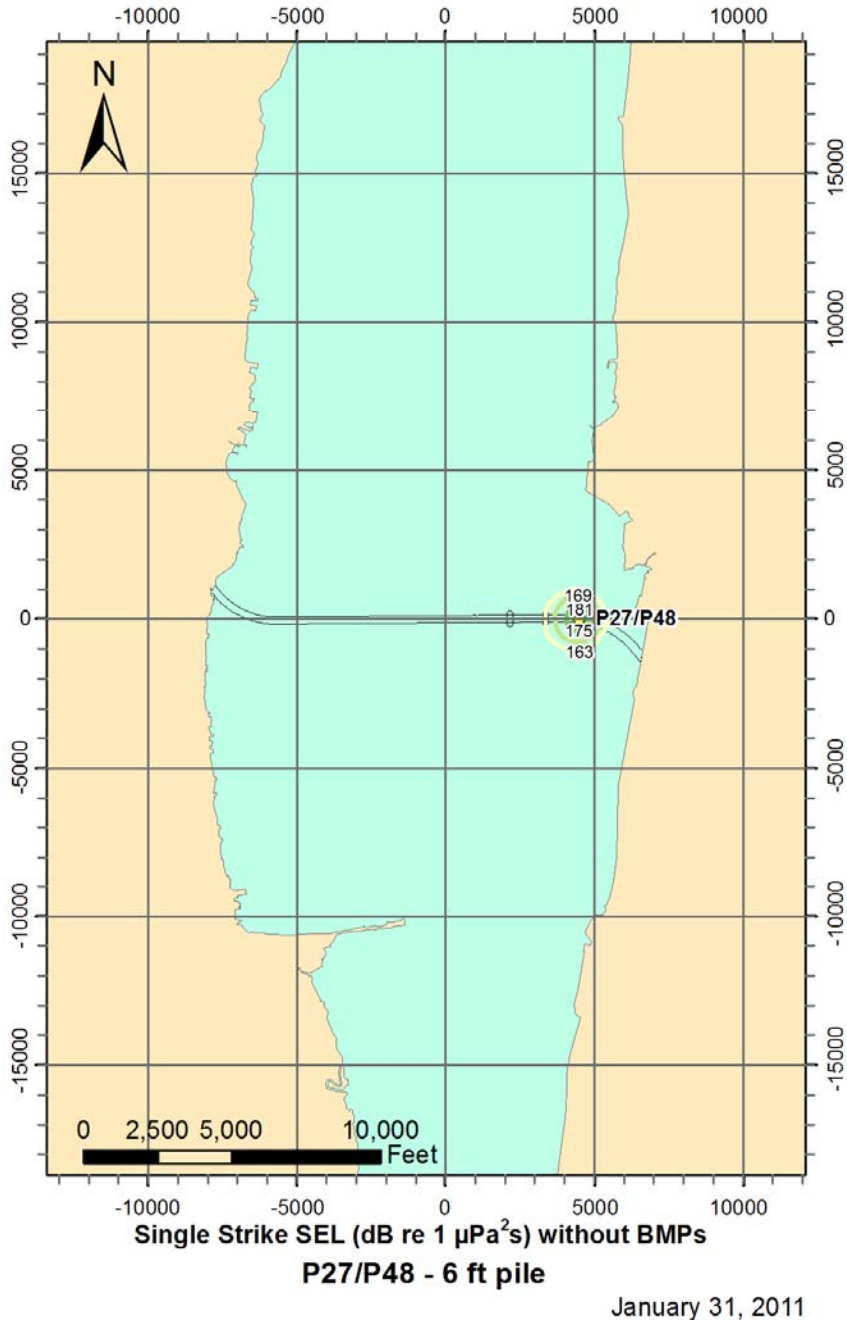
Appendix B. Single Strike SEL Scenario Maps

B.1. Single and Dual Level Bridge: No BMPs Applied

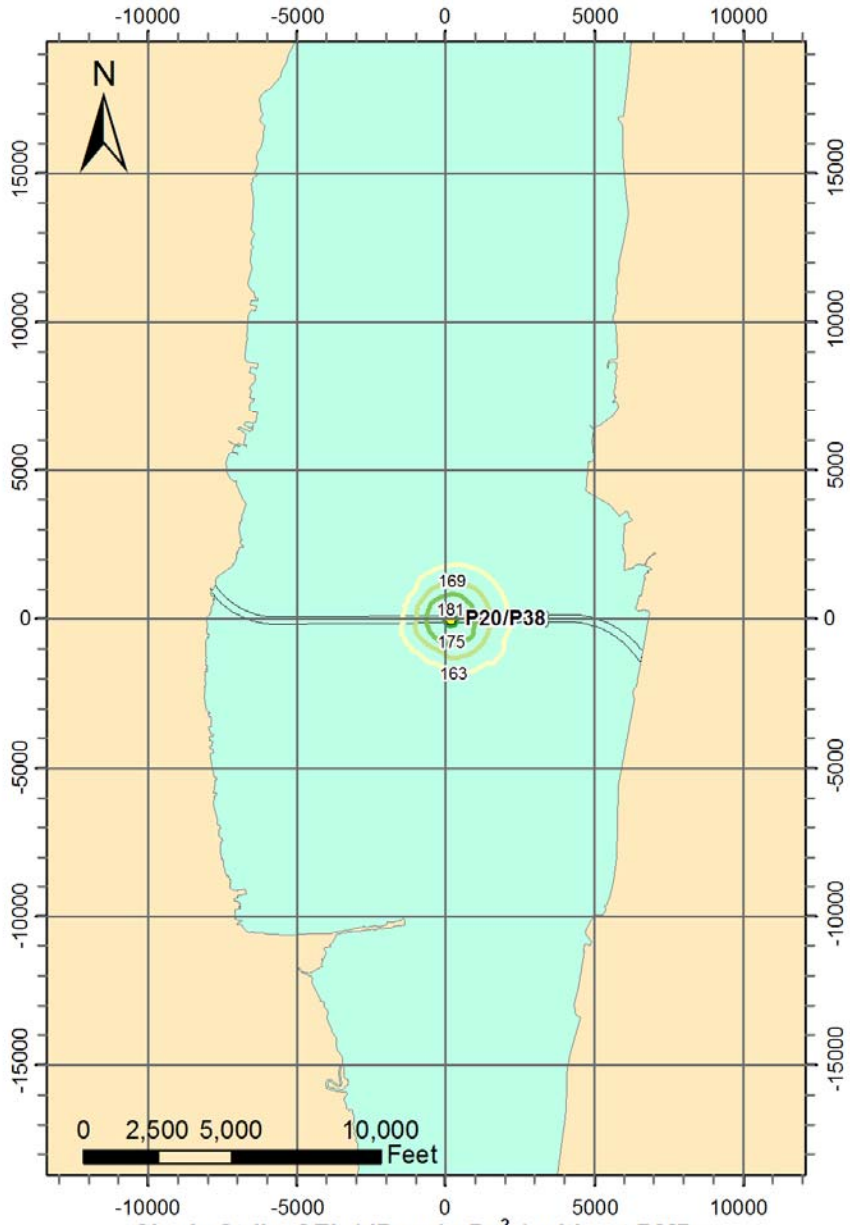
B.1.1. 4' pile size



B.1.2. 6' pile size



B.1.3. 8' pile size

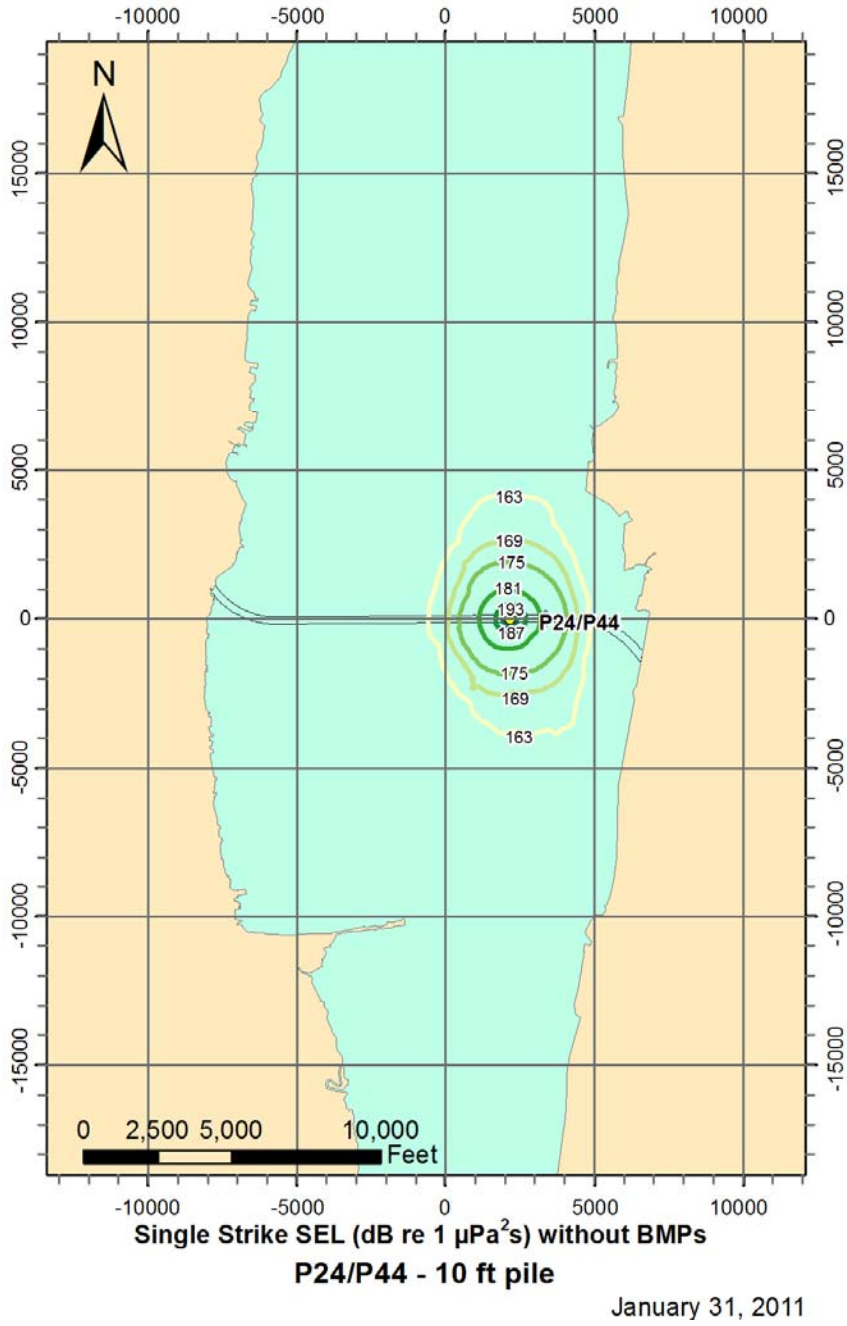


Single Strike SEL (dB re 1 μPa^{2}s) without BMPs

P20/P38 - 8 ft pile

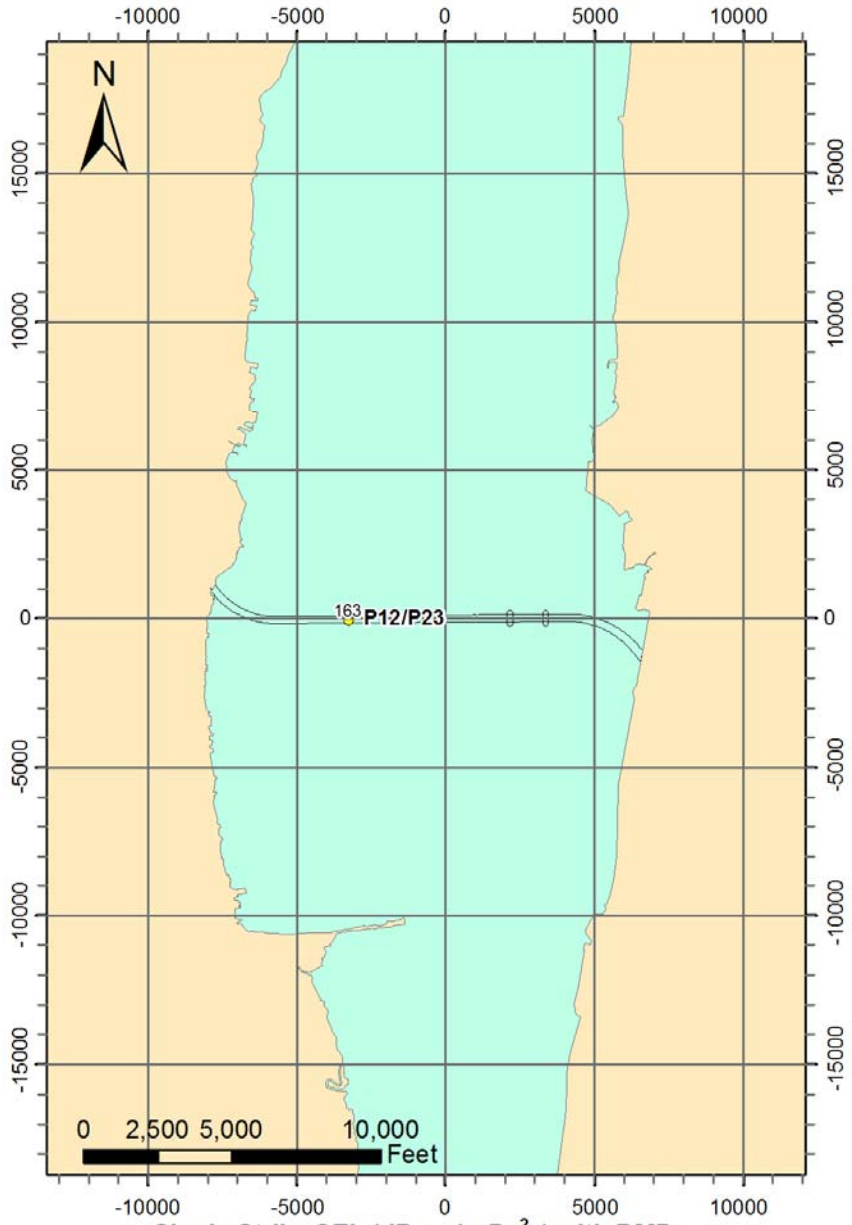
January 31, 2011

B.1.4. 10' pile size



B.2. Single and Dual Level Bridge: BMPs Applied

B.2.1. 4' pile size

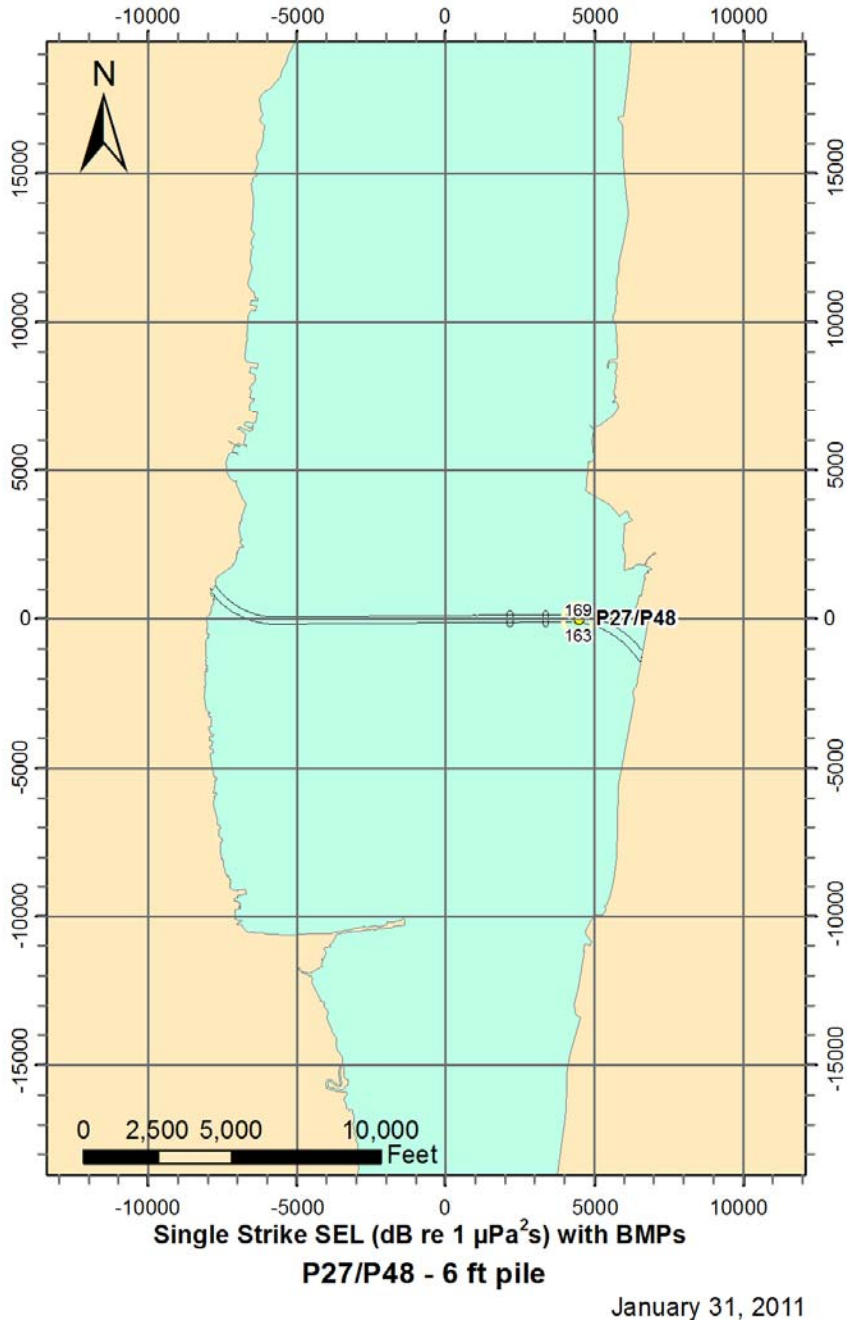


Single Strike SEL (dB re 1 μPa^{2}s) with BMPs

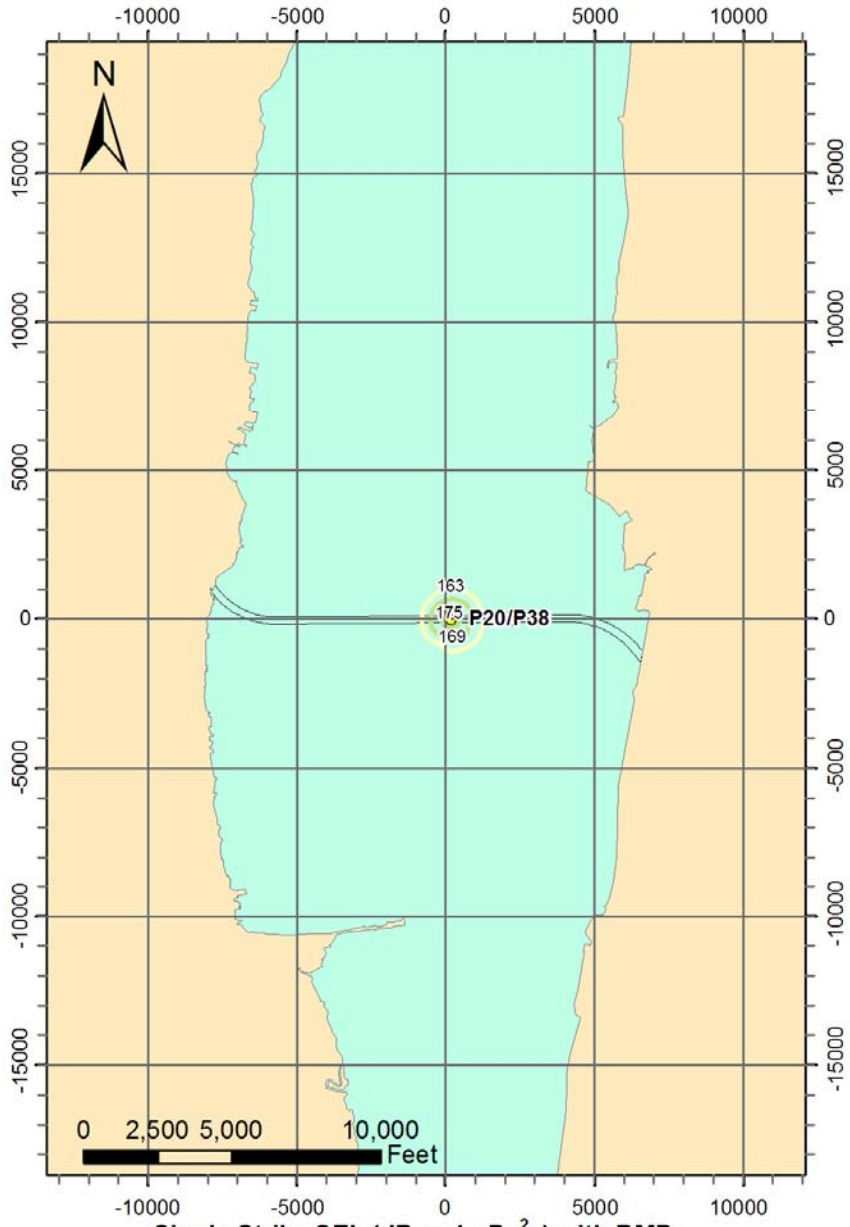
P12/P23 - 4 ft pile

January 31, 2011

B.2.2. 6' pile size



B.2.3. 8' pile size

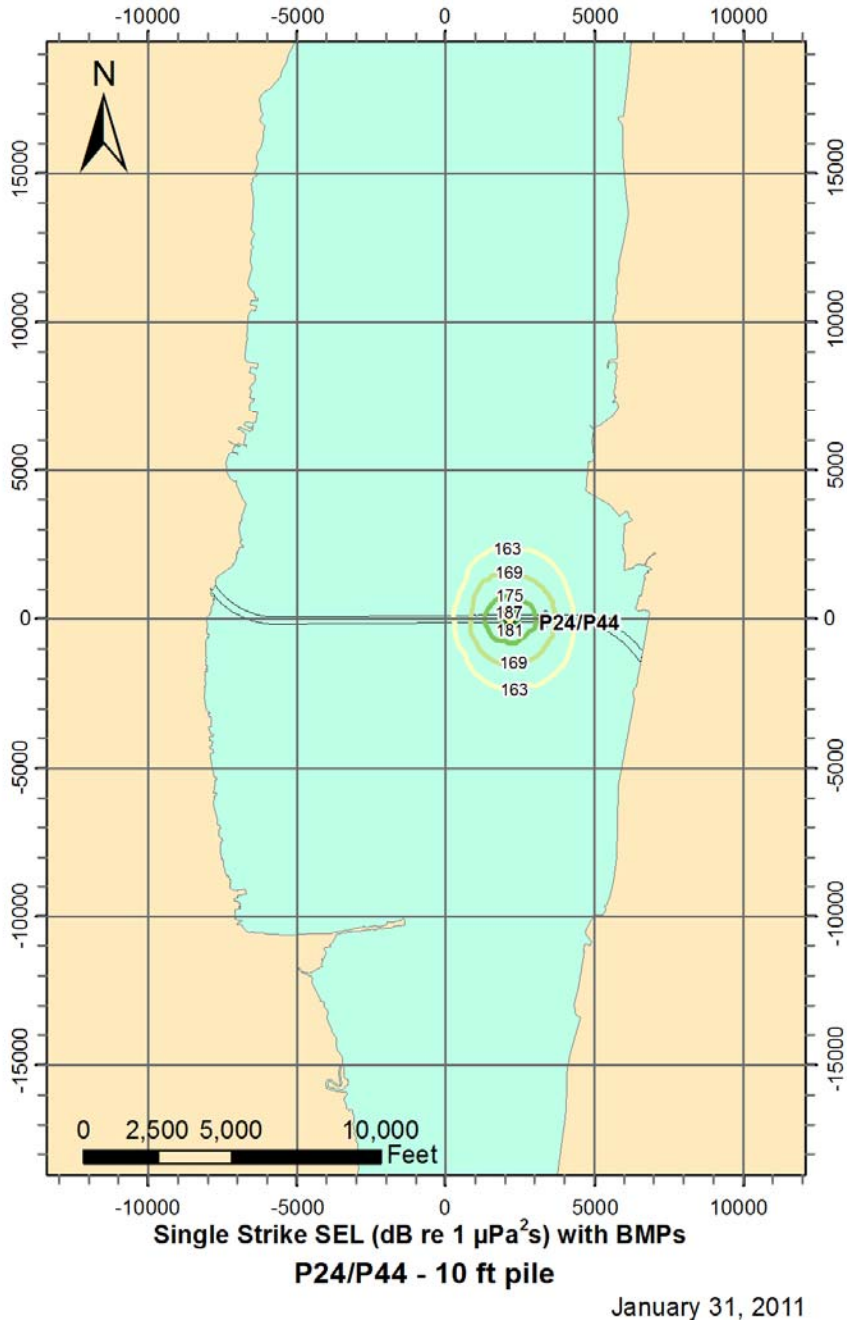


Single Strike SEL (dB re 1 μPa^{2}s) with BMPs

P20/P38 - 8 ft pile

January 31, 2011

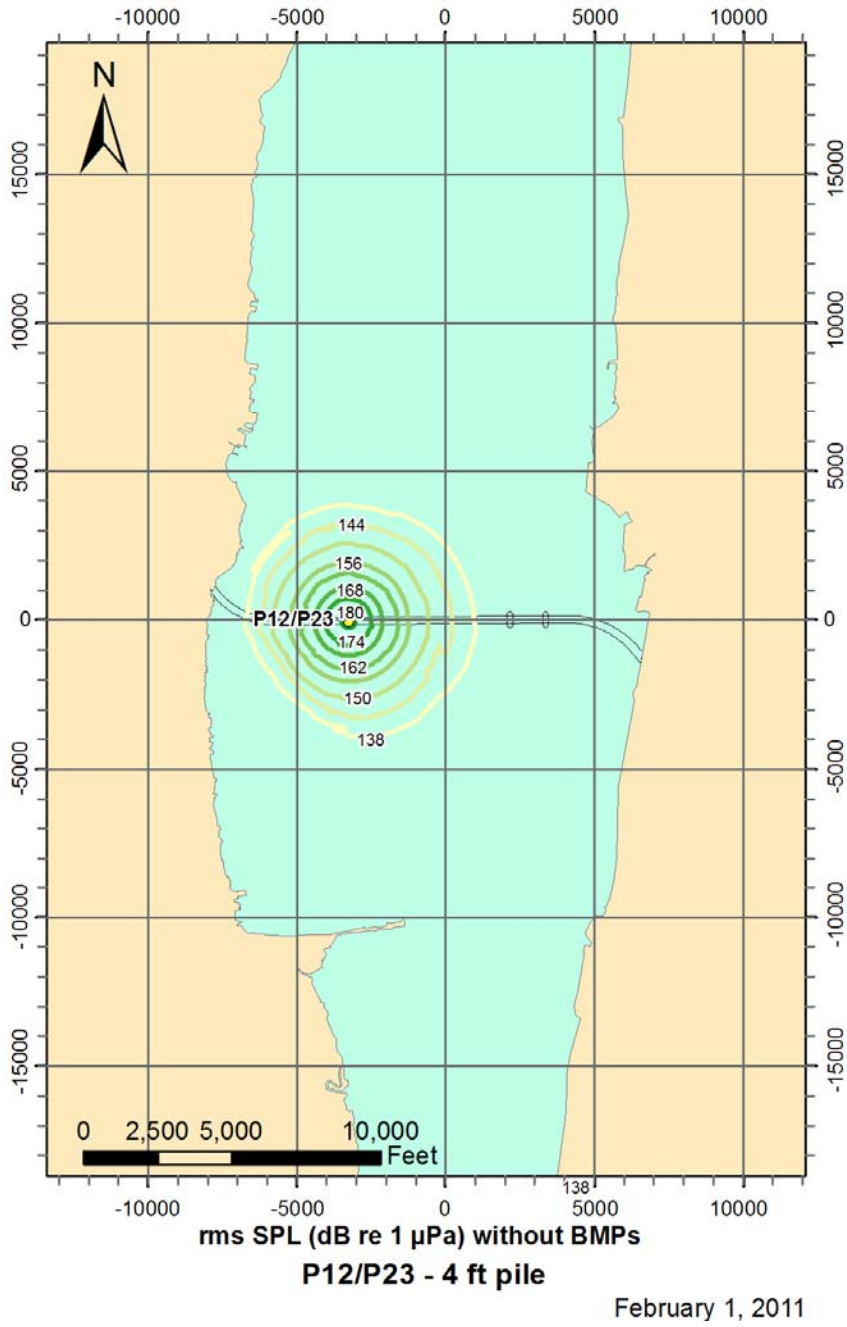
B.2.4. 10' pile size



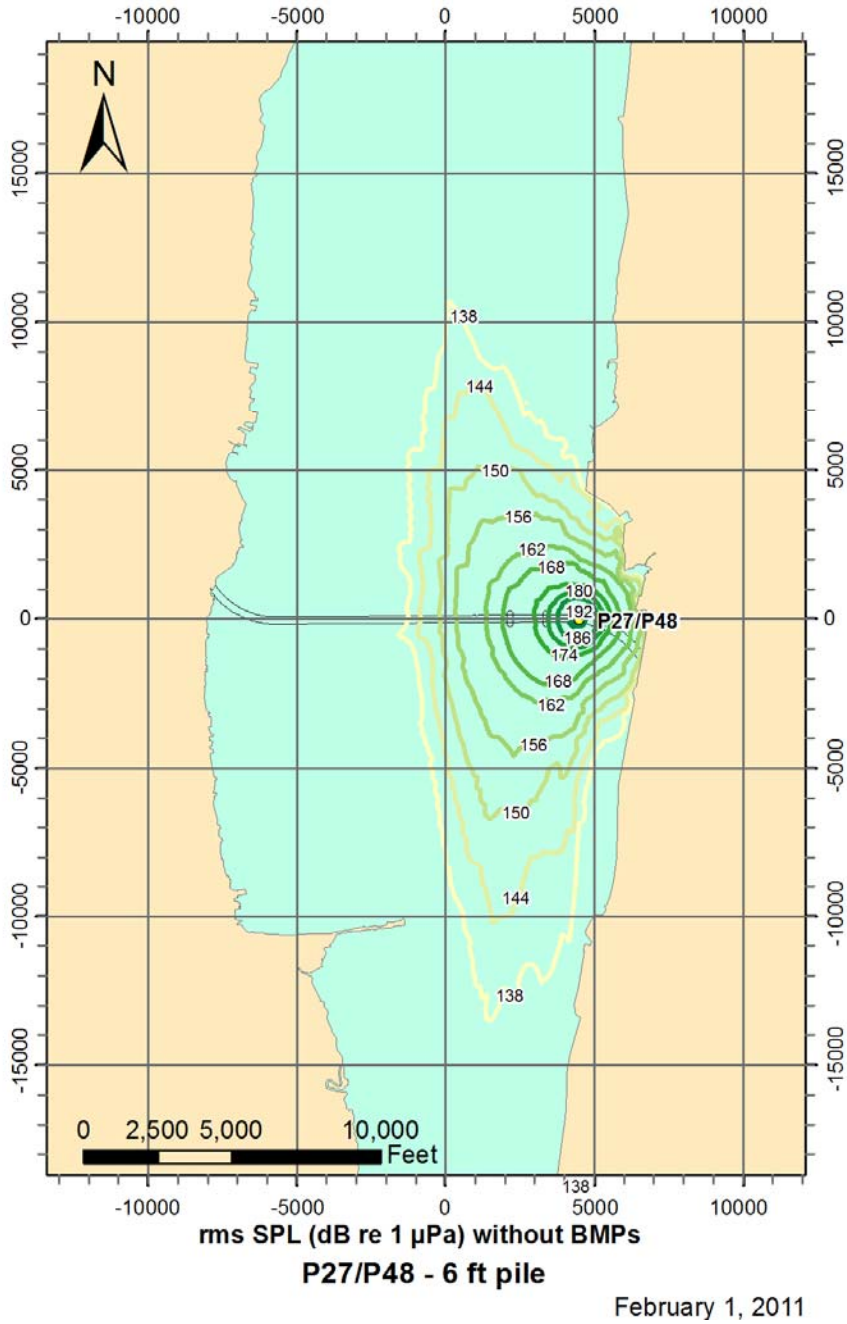
Appendix C. *rms* SPL Scenario Maps

C.1. Single and Dual Level Bridge: No BMPs Applied

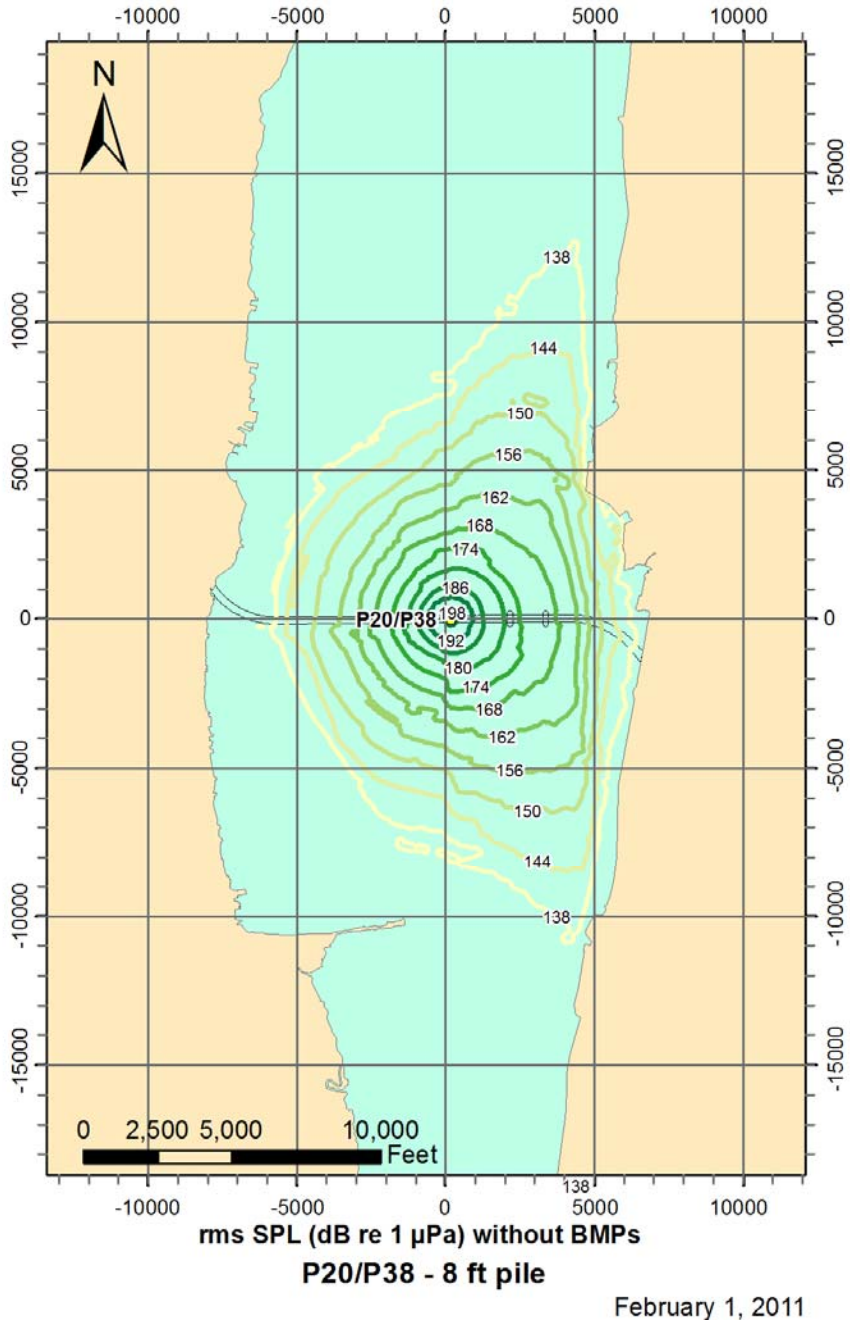
C.1.1. 4' pile size



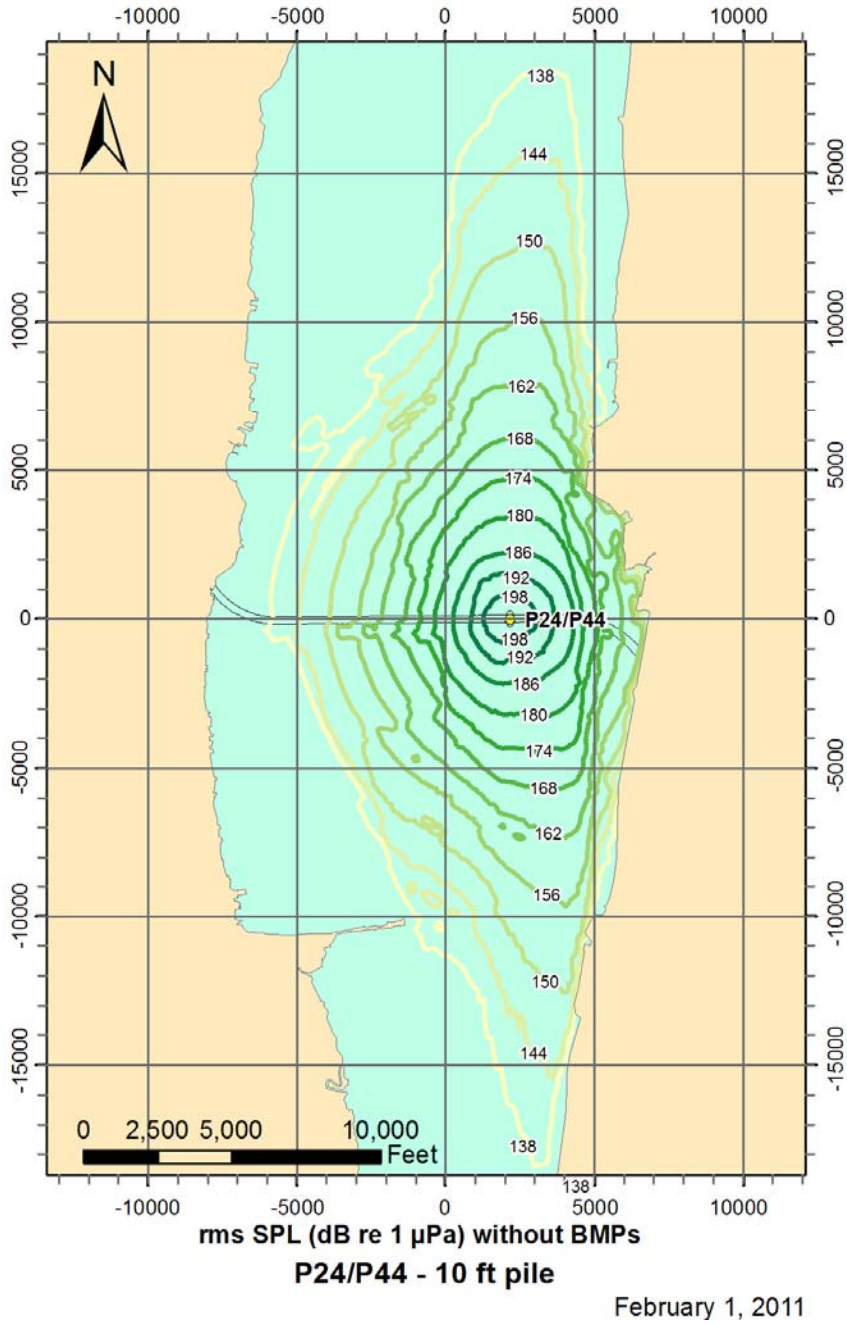
C.1.2. 6' pile size



C.1.3. 8' pile size

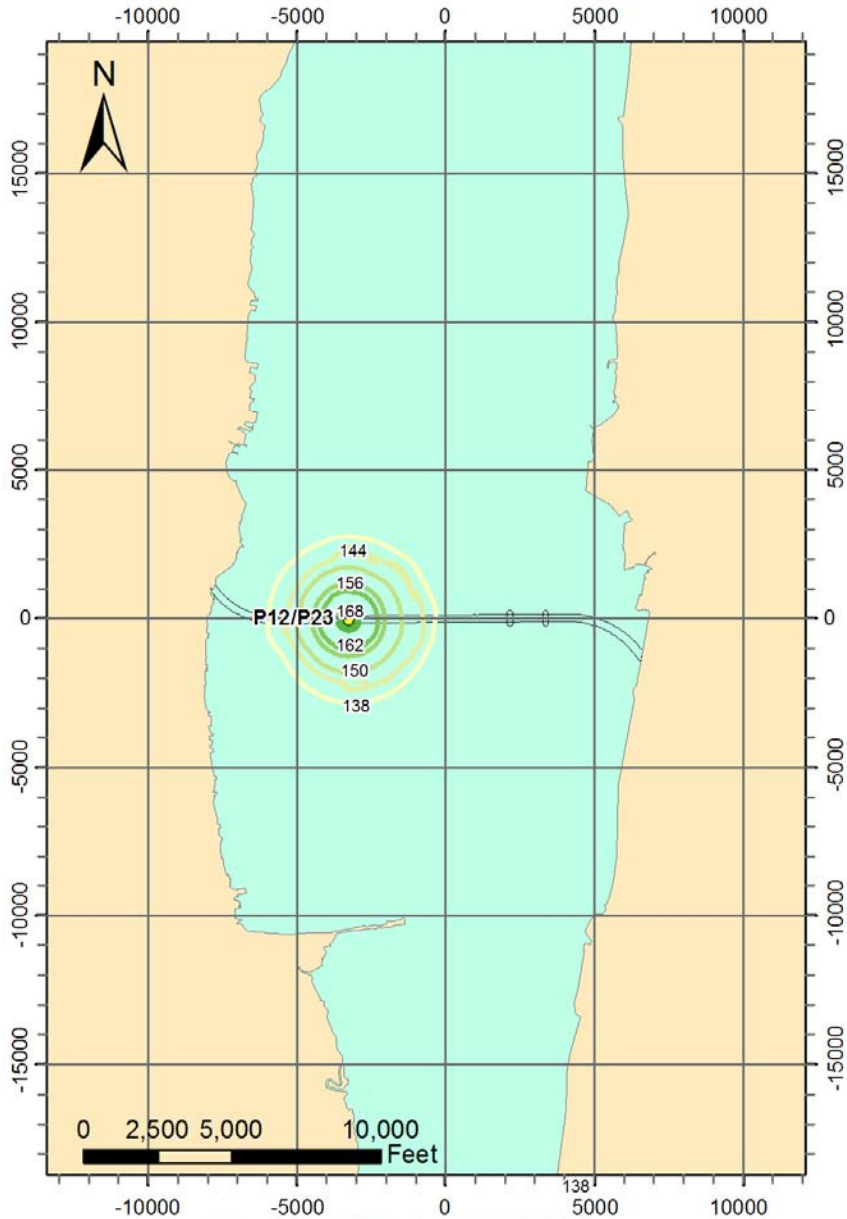


C.1.4. 10' pile size



C.2. Single and Dual Level Bridge: BMPs Applied

C.2.1. 4' pile size

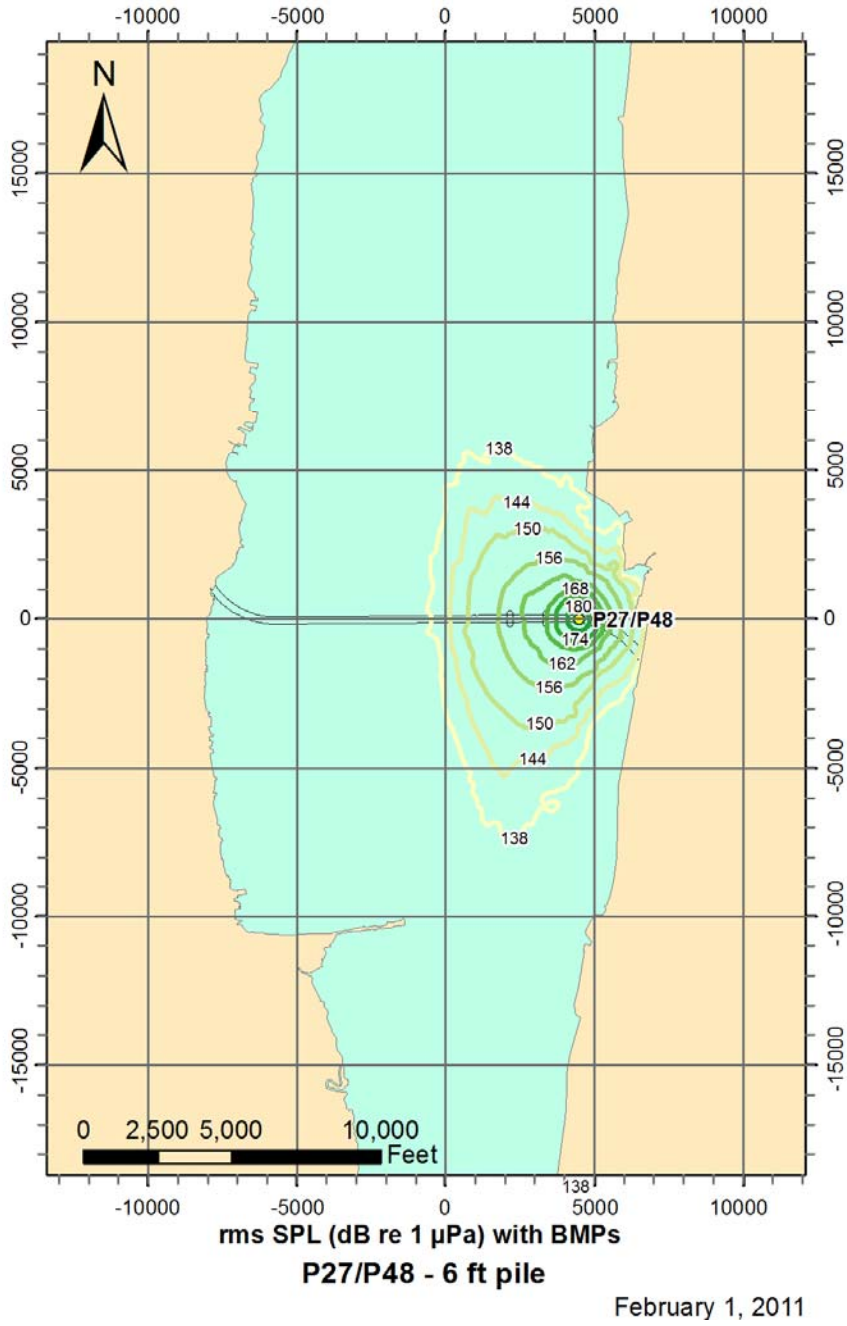


rms SPL (dB re 1 µPa) with BMPs

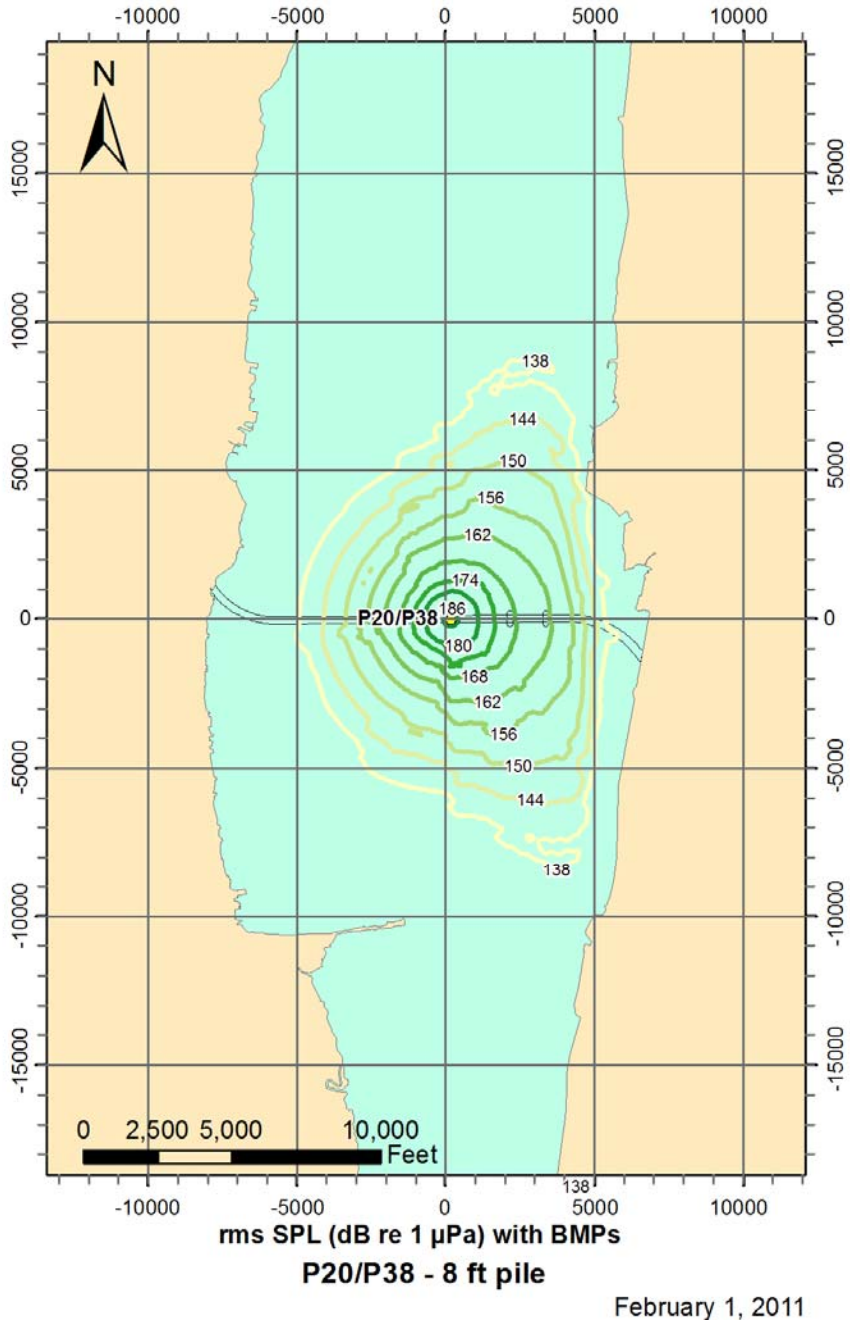
P12/P23 - 4 ft pile

February 1, 2011

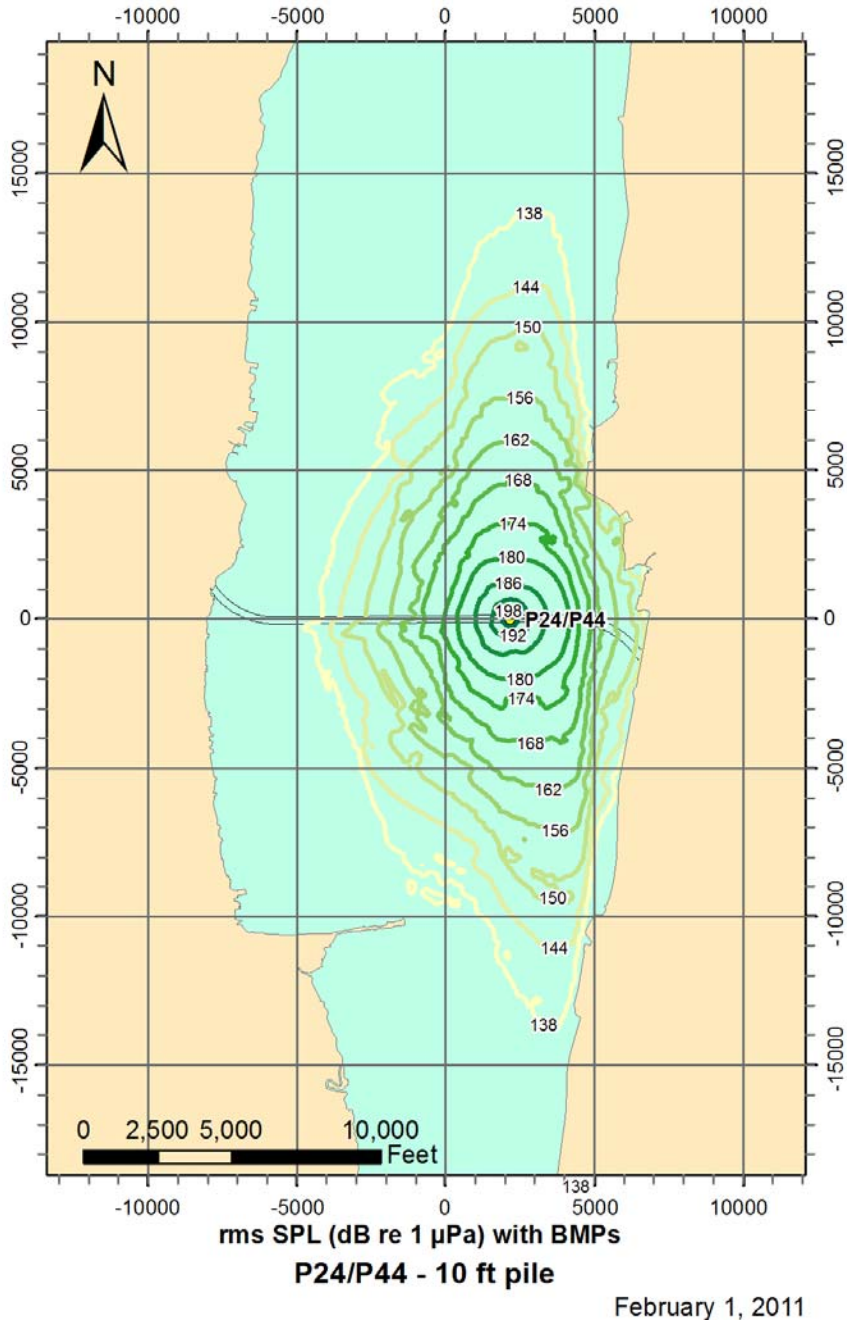
C.2.2. 6' pile size



C.2.3. 8' pile size



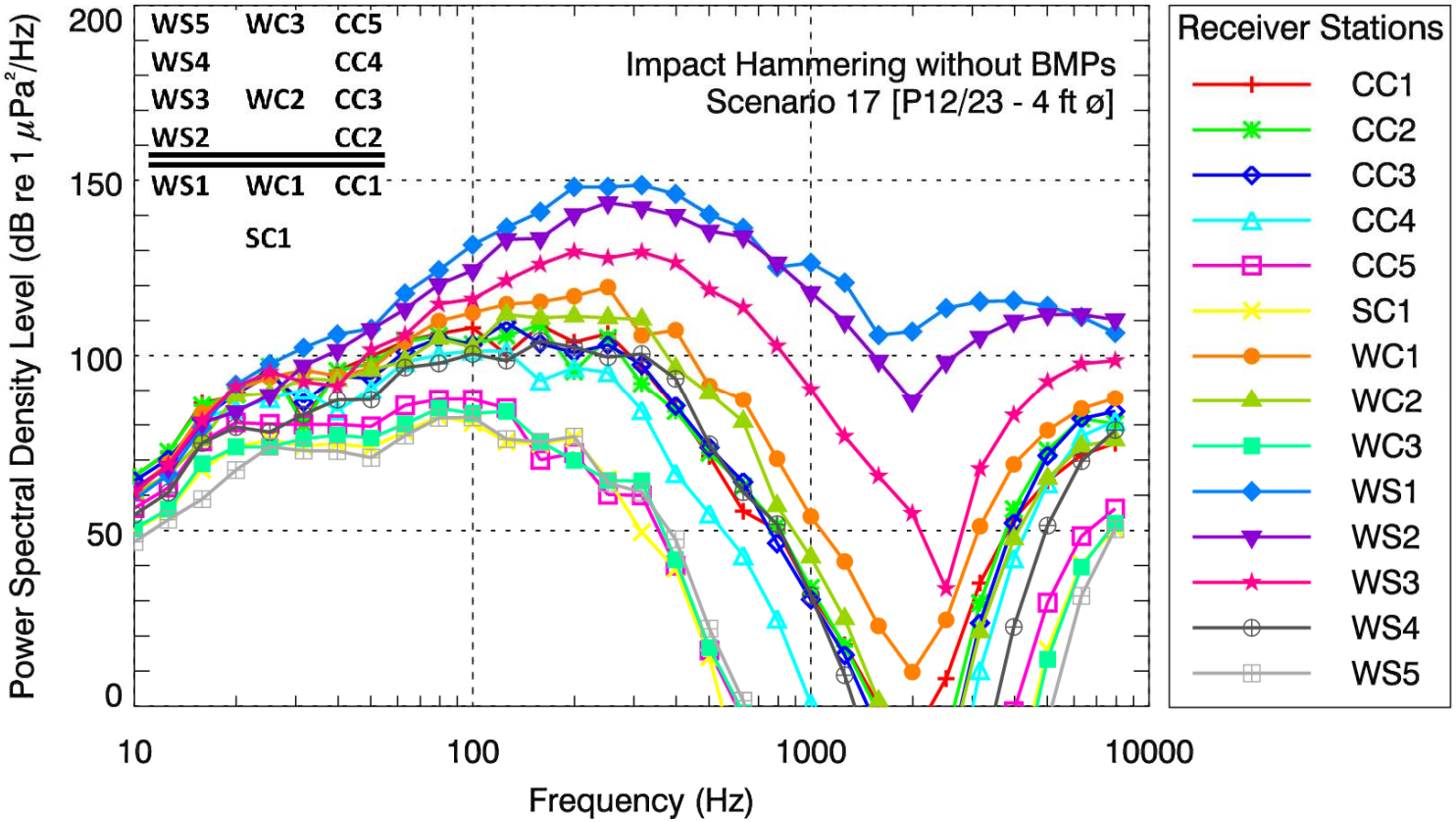
C.2.4. 10' pile size



Appendix D. Power Spectral Density Levels in 1/3-Octave Bands

D.1. Single and Dual Level Bridge: No BMPs Applied

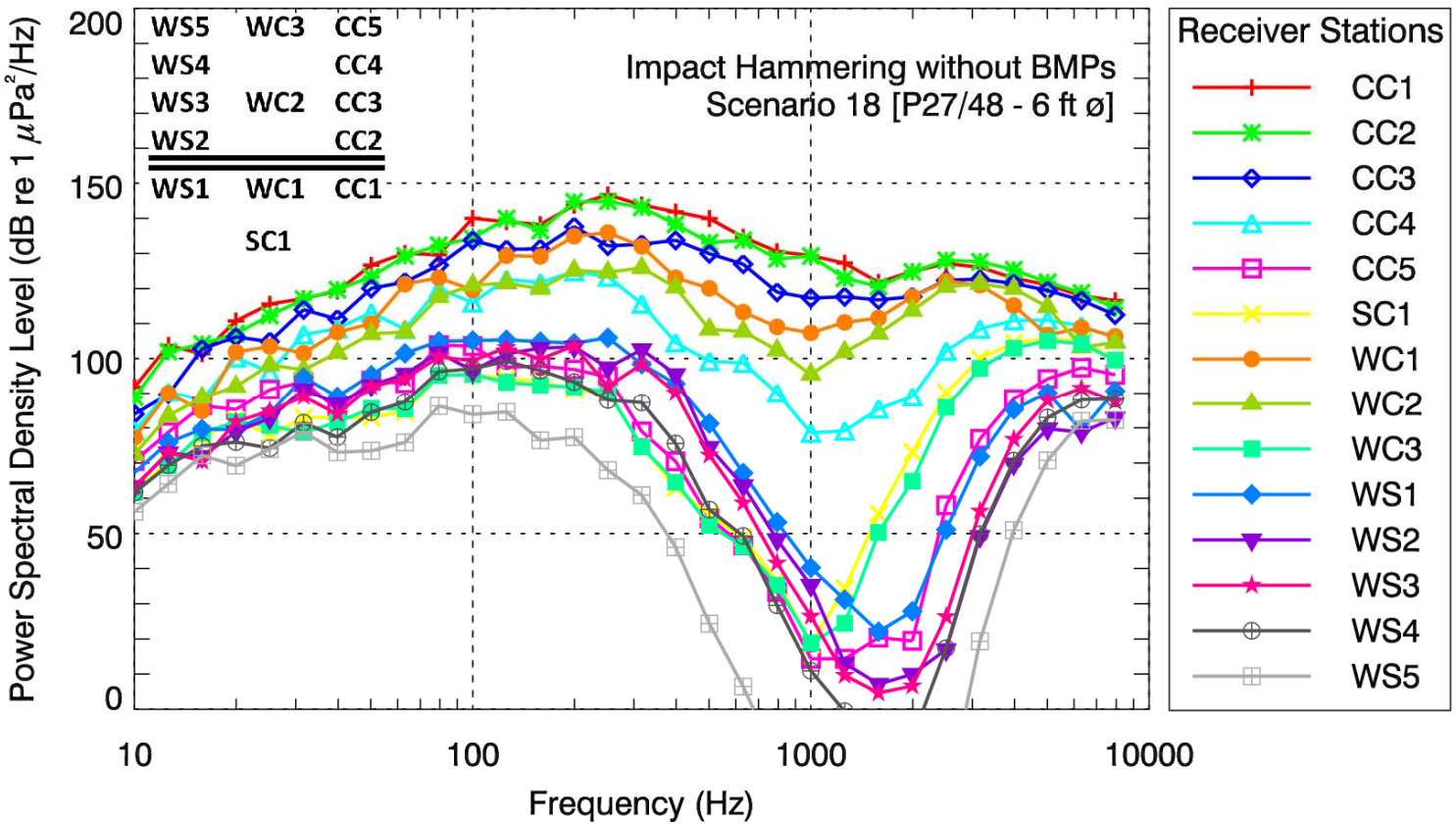
D.1.1. 4' pile size



Power spectral density levels (dB re 1 µPa2/Hz) for Scenario 17: Impact hammering a 4 ft diameter pile at Pier 12/23 without BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	69.1	68.9	67.7	64.8	60.0	53.7	65.3	64.2	54.1	62.4	65.7	64.5
13	76.8	77.0	74.9	73.1	66.8	60.2	73.6	70.4	60.7	70.5	72.6	73.2
16	91.9	91.2	87.2	87.7	80.9	72.9	89.0	81.3	74.6	84.9	86.2	86.9
20	94.9	95.3	95.7	91.2	87.3	80.4	96.8	95.0	80.4	98.3	90.4	97.7
25	104.6	104.5	102.2	95.2	87.9	83.3	101.4	96.7	81.3	105.2	96.2	102.9
32	89.7	88.8	95.1	98.7	88.7	82.6	104.5	102.1	84.7	110.9	105.7	101.1
40	105.3	105.3	103.8	93.7	89.8	84.3	103.8	102.5	86.7	115.7	111.1	100.8
50	110.4	108.4	104.1	101.0	90.2	84.2	106.9	106.4	86.9	118.3	118.1	112.3
63	115.7	115.6	112.8	109.8	97.2	89.7	115.6	110.2	91.9	129.4	124.9	117.5
79	118.9	118.3	117.5	112.9	100.0	95.1	122.5	117.5	97.4	137.0	132.9	127.4
100	121.6	116.9	116.8	115.0	101.0	94.2	125.9	116.0	96.9	145.3	138.0	129.8
126	114.9	120.3	124.1	115.9	99.4	89.8	129.3	126.4	98.5	151.2	147.8	136.1
159	124.3	124.5	119.1	108.4	85.7	90.2	131.0	126.4	90.9	156.7	149.1	141.7
200	120.5	112.1	117.5	113.2	88.6	92.8	133.6	127.9	86.5	164.8	156.9	146.3
251	123.9	122.7	120.7	112.8	77.8	82.3	137.2	128.4	81.8	165.8	161.3	145.5
316	115.4	110.6	116.0	102.8	78.6	68.1	124.4	129.0	82.7	167.3	160.9	148.2
398	104.5	103.6	105.1	85.9	59.6	58.7	126.9	116.0	61.3	165.8	159.7	146.2
501	91.7	92.7	94.2	75.4	36.5	34.6	111.9	109.7	37.3	160.9	156.2	139.4
631	77.1	84.2	85.4	64.5	18.1	-1.2	108.9	102.6	19.8	158.1	155.6	135.4
794	72.8	74.0	69.0	47.5	-11.3	-32.2	93.0	79.6	-14.5	147.9	149.1	125.4
1000	55.7	57.3	54.0	24.5	-45.2	-66.6	77.6	66.0	-56.6	150.1	141.7	113.9
1259	42.1	41.8	39.2	10.1	-63.7	-104.4	65.8	49.5	-93.0	145.5	134.3	101.4
1585	25.9	23.8	19.0	-7.5	-90.2	-153.7	48.5	27.1	-140.7	131.5	124.1	91.1
1995	17.5	13.2	7.0	-16.0	-103.0	-168.2	36.4	14.5	-163.0	133.5	113.5	81.5
2512	35.5	18.6	9.4	-10.2	-83.6	-142.6	52.2	9.4	-144.3	141.2	125.8	61.1
3162	63.7	58.0	52.3	38.9	-19.6	-56.8	79.8	49.8	-62.4	144.1	133.9	96.2
3981	82.8	85.7	81.7	71.7	28.2	5.2	98.4	77.2	0.8	145.3	139.5	112.5
5012	94.7	103.4	101.9	94.0	60.1	46.8	109.1	95.4	44.0	144.8	142.4	123.2
6310	103.1	113.4	113.4	108.4	80.0	72.1	116.3	105.6	71.2	142.7	143.4	129.3
7943	107.4	113.0	116.5	113.7	88.8	83.1	120.3	108.3	84.7	139.1	142.9	131.2

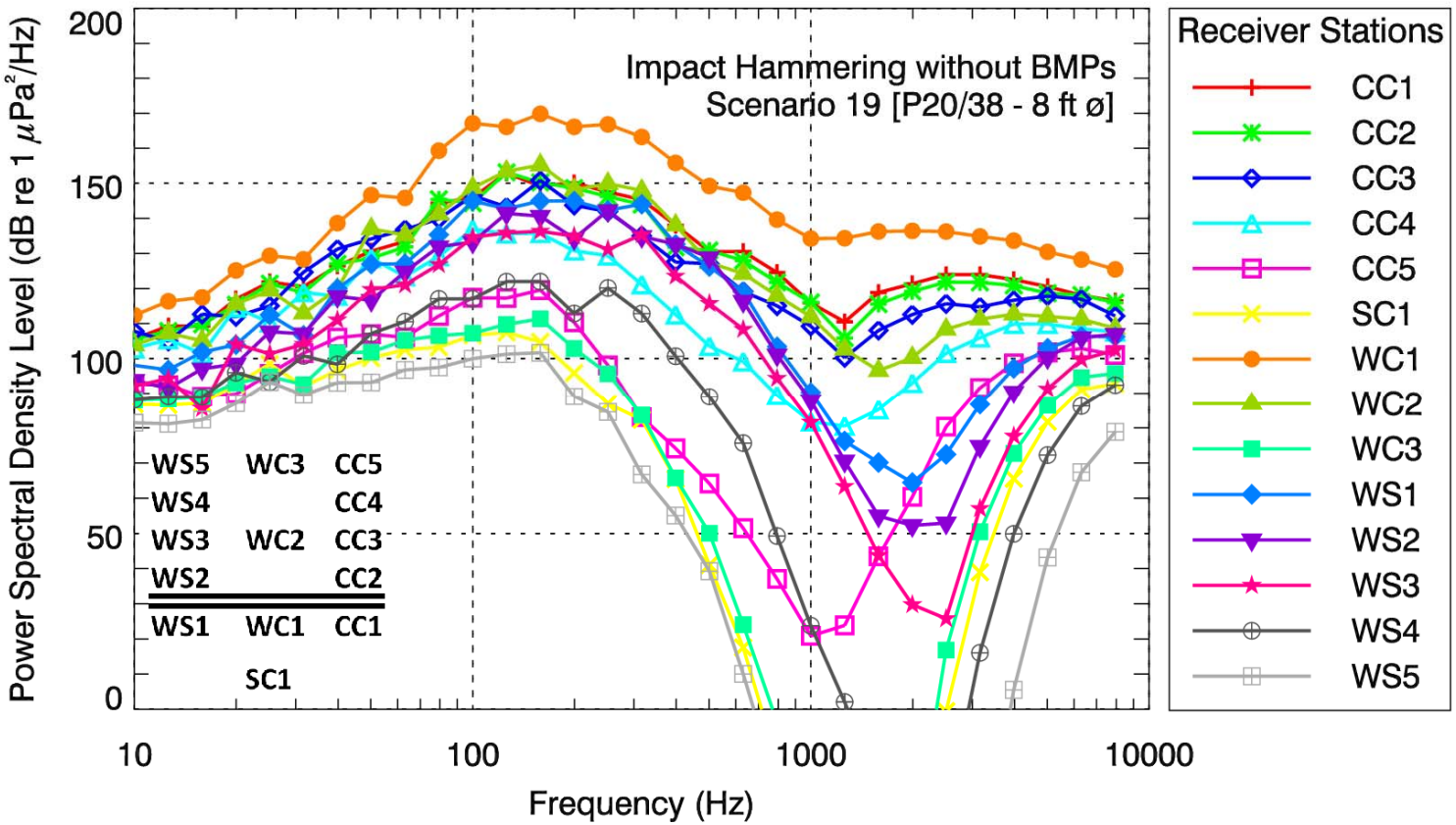
D.1.2. 6' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 18: Impact hammering a 6 ft diameter pile at Pier 27/48 without BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	95.4	92.4	87.6	82.8	74.2	65.5	80.9	76.1	65.2	70.9	67.0	66.7
13	108.4	106.6	94.3	95.0	83.4	75.0	94.6	88.1	73.9	80.5	77.5	77.7
16	107.0	109.8	108.4	93.7	92.0	82.9	90.5	94.4	84.2	85.3	77.5	76.2
20	117.4	113.8	112.8	106.9	91.9	88.9	108.5	98.6	88.4	86.1	85.5	88.4
25	123.2	119.9	112.5	103.8	98.7	85.7	111.1	105.8	88.3	91.8	90.4	92.5
32	125.8	125.6	122.6	115.5	101.9	91.5	110.2	105.4	87.3	103.2	99.7	97.6
40	128.9	129.3	120.9	118.2	94.9	92.7	117.2	111.3	91.3	98.7	96.5	93.6
50	137.3	134.0	130.7	123.8	104.3	93.7	120.6	117.7	96.2	105.9	102.9	102.6
63	141.7	140.9	133.5	120.0	104.5	96.2	132.9	119.2	97.1	113.1	107.2	105.8
79	142.3	145.0	139.3	132.6	116.5	107.8	135.7	130.3	107.8	117.6	114.3	113.1
100	153.7	148.0	147.4	129.6	117.2	109.0	133.2	134.6	109.1	118.8	110.2	113.0
126	153.7	154.6	145.8	137.3	112.2	108.9	144.0	136.2	107.8	120.0	116.0	117.8
159	153.9	152.2	147.0	137.3	113.5	109.1	144.8	135.6	108.0	120.5	118.6	115.5
200	160.4	161.4	154.3	141.5	113.5	107.6	151.6	141.8	108.4	121.0	120.0	120.3
251	164.4	162.5	149.8	141.0	112.4	107.8	153.6	142.3	108.1	123.6	115.0	109.6
316	162.5	161.8	151.3	134.3	97.6	93.4	150.7	144.5	93.2	117.0	121.2	117.0
398	161.5	158.0	153.4	124.2	90.1	82.6	142.7	140.0	84.2	112.4	115.1	109.7
501	160.6	153.8	150.6	119.9	74.9	76.0	140.7	129.0	72.9	101.9	95.1	92.9
631	156.3	155.4	148.6	120.4	68.2	70.4	134.9	129.4	67.9	88.8	85.2	80.3
794	153.2	151.1	141.6	112.7	56.0	59.2	131.7	125.0	57.9	75.8	70.9	64.2
1000	153.0	152.9	140.9	102.2	38.0	42.1	131.0	119.1	42.5	63.9	58.9	50.1
1259	151.9	147.6	142.3	103.8	39.0	59.0	135.0	126.5	49.1	55.8	37.7	34.3
1585	147.4	146.2	142.4	111.1	46.0	81.2	137.2	132.8	75.9	47.7	32.8	30.3
1995	151.5	151.4	144.3	115.6	46.1	99.7	144.3	140.4	91.5	54.5	36.6	33.3
2512	154.8	155.7	150.0	129.8	85.6	117.8	149.8	148.2	113.5	78.7	44.6	54.0
3162	154.7	156.3	151.3	137.1	105.5	128.6	149.6	150.0	125.8	100.5	77.8	85.0
3981	152.6	155.0	151.1	140.5	118.0	134.1	144.8	149.6	132.6	114.9	99.4	106.4
5012	151.7	152.4	150.1	141.6	124.8	136.3	137.3	145.4	135.7	120.7	110.4	118.5
6310	149.6	150.4	148.3	141.0	129.0	136.6	140.5	134.9	135.9	111.0	110.4	123.1
7943	149.2	147.0	145.1	138.5	128.0	132.3	139.0	137.2	132.2	123.3	115.5	120.2

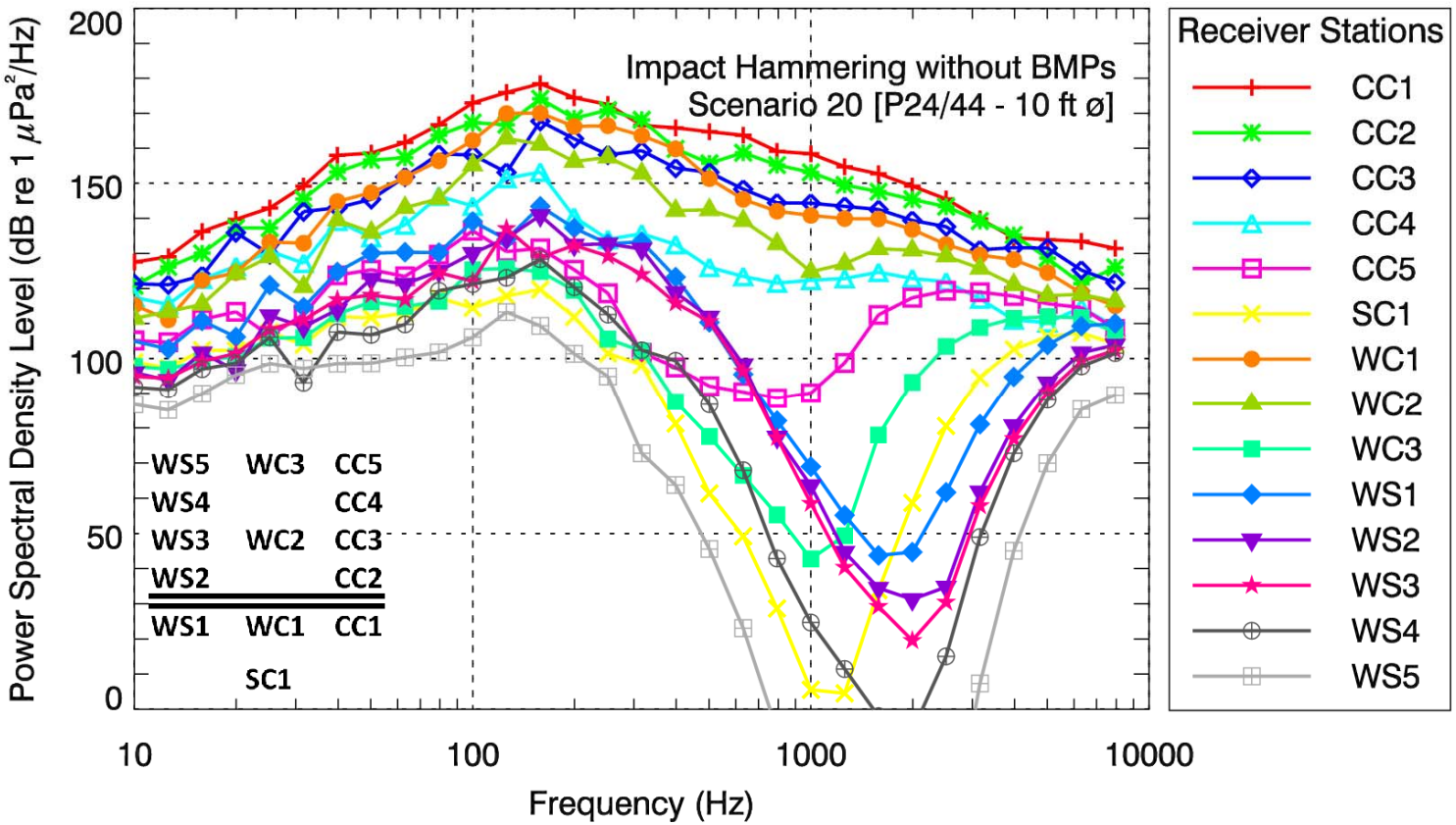
D.1.3. 8' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 19: Impact hammering an 8 ft diameter pile at Pier 20/38 without BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	109.3	109.1	111.4	106.5	96.3	90.4	116.0	107.5	91.6	101.7	97.4	95.8
13	113.9	112.5	109.6	110.1	97.0	91.2	121.0	111.9	92.9	101.4	96.1	98.9
16	114.9	115.4	118.3	107.0	94.7	92.7	123.1	110.7	94.5	107.5	102.7	91.2
20	123.6	122.0	118.6	121.2	96.4	99.2	131.8	122.2	99.6	110.6	105.1	110.8
25	129.5	129.0	122.7	117.9	103.3	106.1	137.0	127.1	102.5	120.1	115.3	109.0
32	129.2	127.5	133.3	127.5	110.2	100.6	137.0	121.6	101.2	115.3	115.7	112.7
40	136.1	136.7	140.9	127.5	115.6	106.3	148.3	129.5	111.3	129.6	127.4	120.7
50	141.3	139.3	144.8	139.3	117.6	110.8	157.3	147.7	112.5	137.6	127.3	130.4
63	145.1	143.5	148.5	135.1	117.7	114.2	157.5	146.9	116.9	138.7	136.4	132.7
79	157.0	158.1	152.5	141.8	124.8	115.9	172.0	153.9	119.2	148.0	144.6	139.5
100	159.6	158.0	160.2	150.6	131.0	120.3	180.8	162.4	120.9	158.6	146.9	148.3
126	167.6	167.8	157.9	150.3	131.9	122.1	180.8	168.1	124.4	157.4	156.1	150.5
159	164.9	165.9	166.5	151.4	135.2	120.4	185.5	170.9	127.0	160.6	156.3	152.0
200	166.8	165.3	160.4	147.4	127.0	112.5	182.8	164.8	119.5	161.6	150.9	151.6
251	165.2	163.9	159.6	147.0	115.7	104.6	184.5	167.6	113.3	160.0	159.9	148.8
316	164.0	162.6	153.7	139.8	101.7	101.0	181.9	166.6	102.3	162.7	153.5	154.0
398	157.7	151.4	147.2	132.2	93.8	85.1	175.5	157.7	85.4	152.3	152.3	143.2
501	151.2	151.5	147.7	124.2	84.8	61.7	169.9	148.0	70.7	146.9	149.5	136.4
631	152.2	149.6	140.8	120.8	73.1	39.2	169.0	145.9	45.7	140.7	138.0	130.0
794	147.2	144.4	137.7	112.0	59.7	8.1	162.3	140.6	19.0	126.0	123.7	117.0
1000	139.5	139.7	132.9	105.4	44.5	-21.0	157.9	135.6	-5.5	113.9	111.5	105.3
1259	135.1	130.5	124.9	105.2	48.5	-43.8	159.0	127.3	-26.1	100.9	95.2	88.0
1585	144.5	141.2	133.7	110.9	69.1	-57.9	161.9	122.2	-34.5	95.8	80.6	69.4
1995	148.0	145.8	139.2	119.6	87.0	-44.9	163.1	126.9	-15.7	91.1	78.9	56.4
2512	151.6	149.5	143.3	129.2	108.0	27.1	163.9	136.0	44.5	100.1	80.6	53.4
3162	152.6	150.4	143.4	134.6	120.2	67.6	163.5	139.9	79.1	115.4	103.4	85.7
3981	152.2	150.5	146.3	139.5	128.3	95.2	163.3	142.3	102.4	126.8	120.0	107.3
5012	151.2	149.3	148.5	140.5	132.4	112.4	161.1	142.7	117.1	133.6	130.9	121.9
6310	149.7	149.8	148.6	140.1	134.5	122.7	159.9	142.9	126.2	138.0	137.6	131.3
7943	149.1	148.6	144.8	140.3	133.7	125.4	158.1	141.3	128.4	138.9	139.6	135.1

D.1.4. 10' pile size

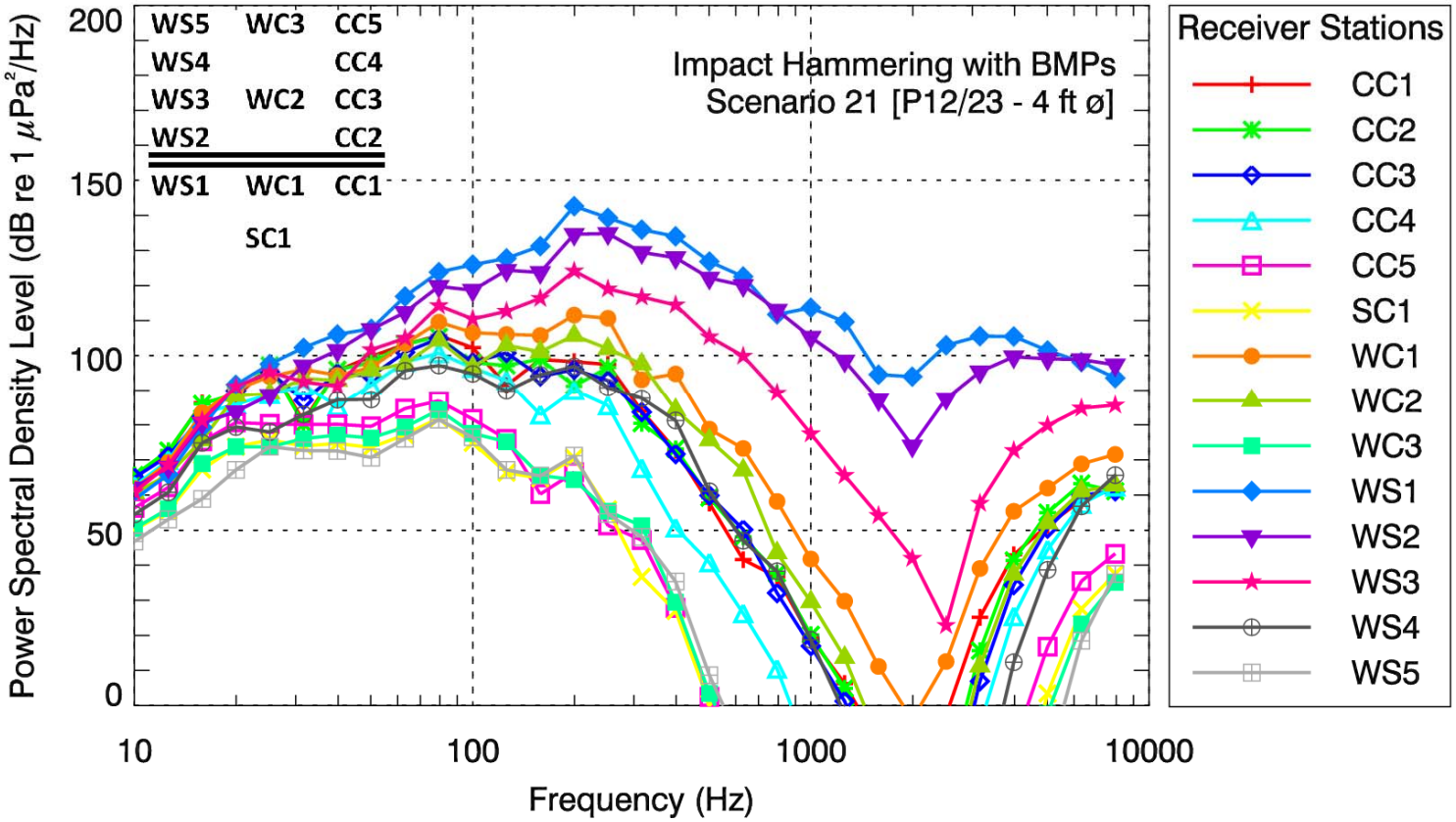


Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 20: impact hammering a 10 ft diameter pile at Pier 24/44 without BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	131.2	124.4	125.0	121.1	108.8	102.6	118.9	115.1	101.4	108.6	99.6	98.5
13	133.7	130.8	125.7	120.1	109.3	101.9	115.7	118.1	101.6	107.4	98.4	99.0
16	141.9	135.7	129.3	128.3	116.8	108.0	128.0	121.1	105.0	116.4	107.3	104.8
20	146.4	143.9	142.6	133.0	120.0	109.0	131.2	130.9	107.2	112.8	103.2	108.1
25	150.6	144.9	137.4	138.3	114.1	115.2	140.9	136.7	113.5	128.6	119.9	116.0
32	157.9	154.2	150.6	135.9	121.3	112.6	141.6	129.1	114.6	123.3	117.7	119.7
40	167.7	162.9	152.7	148.9	133.4	121.6	154.5	149.2	122.4	134.4	123.6	126.5
50	169.3	167.3	156.1	145.2	136.0	122.3	158.0	146.7	126.8	140.7	133.4	128.8
63	173.3	169.0	163.5	149.8	135.1	124.6	163.3	154.7	126.5	142.0	132.9	128.5
79	179.4	176.4	171.0	159.0	142.3	130.0	169.1	158.3	129.0	142.9	137.6	137.2
100	186.6	181.0	171.8	157.2	150.1	128.1	175.9	168.9	139.0	152.8	143.7	135.7
126	190.6	181.4	167.8	166.1	145.2	132.5	184.6	177.5	140.4	148.7	149.0	151.8
159	194.1	189.8	183.4	168.9	147.1	135.4	185.7	176.8	140.5	159.1	156.5	144.5
200	191.1	185.2	179.4	157.1	142.0	128.5	182.9	172.9	136.1	153.9	149.1	149.0
251	190.2	188.6	175.8	151.7	136.3	119.1	184.1	175.1	123.2	150.4	150.4	146.9
316	185.2	186.8	178.0	154.3	120.3	116.8	182.3	171.5	120.8	152.0	149.9	142.7
398	185.5	179.5	174.0	152.2	117.1	100.9	179.5	161.9	107.2	142.9	138.5	135.5
501	185.4	176.4	173.8	146.7	112.7	82.0	172.0	163.1	98.2	131.0	132.5	131.2
631	185.4	180.4	170.0	145.1	112.0	70.8	167.1	161.0	88.1	117.1	119.9	118.0
794	181.8	177.9	167.1	144.2	111.2	51.3	164.7	155.4	77.9	104.7	100.0	99.9
1000	182.1	176.8	168.0	146.0	113.7	29.2	164.5	148.4	66.4	92.6	87.2	82.2
1259	179.4	174.2	168.1	147.5	123.4	29.2	164.6	151.7	74.0	79.8	69.3	65.0
1585	178.4	173.3	168.2	150.3	138.1	59.5	165.5	157.0	103.6	69.4	60.1	54.9
1995	175.9	172.1	166.1	149.5	144.0	85.3	163.5	157.6	119.8	71.3	57.9	46.2
2512	173.2	171.0	165.3	149.6	147.0	108.2	160.2	156.9	131.1	89.3	62.4	58.1
3162	168.5	167.9	159.7	145.7	147.6	123.1	158.2	154.4	137.5	109.7	90.4	86.5
3981	164.1	164.9	161.3	140.7	147.5	132.3	157.9	150.7	141.1	124.4	110.3	106.6
5012	164.6	159.3	162.2	140.9	146.3	136.9	155.2	148.6	142.6	134.5	123.7	120.9
6310	165.1	153.0	156.9	146.2	146.2	139.0	150.3	150.0	143.3	140.9	133.3	130.9
7943	164.1	158.7	154.3	141.8	141.1	136.8	147.7	149.0	140.1	142.7	136.5	135.0

D.2. Single and Dual Level Bridge: BMPs Applied

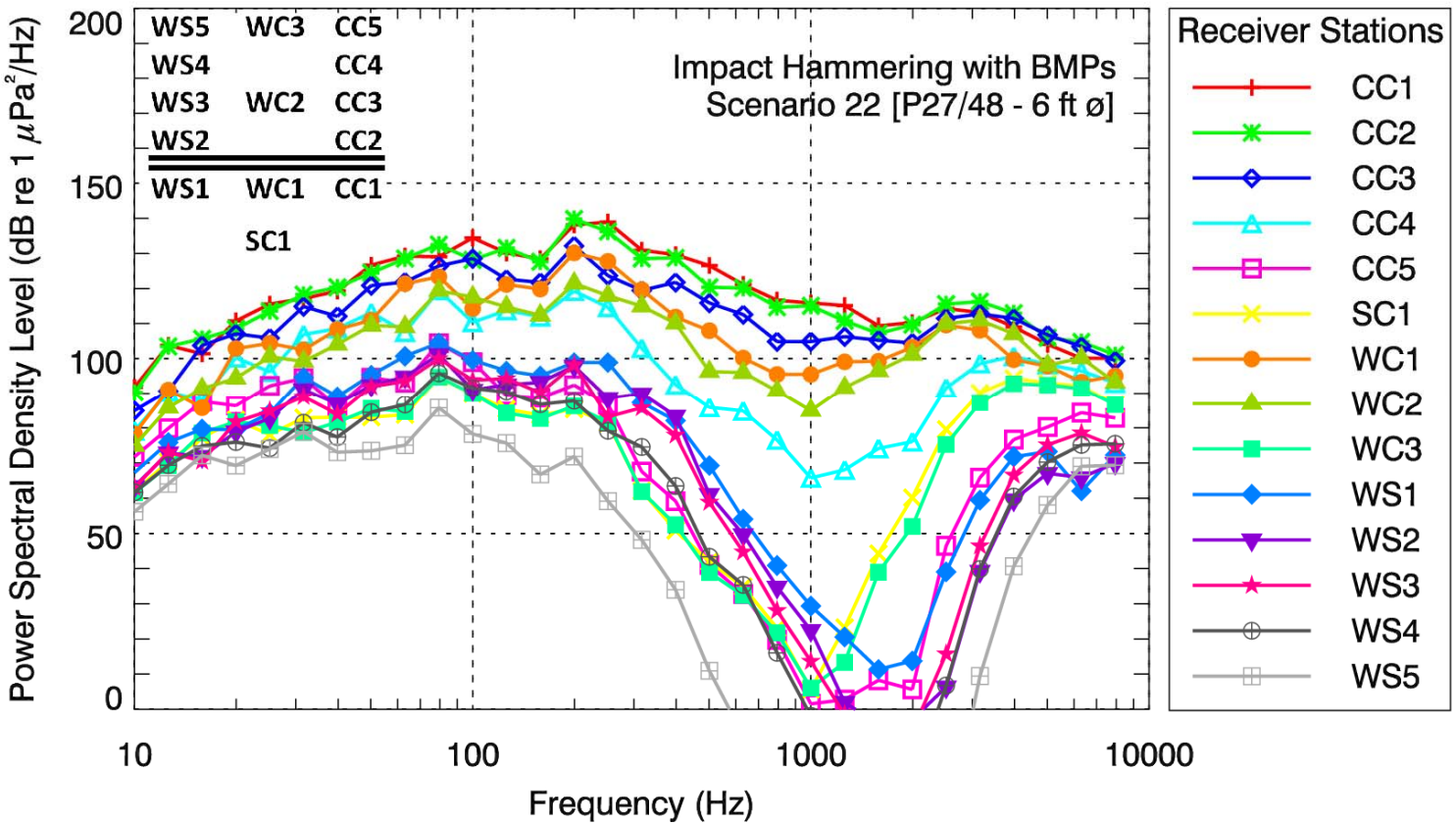
D.2.1. 4' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 21: Impact hammering a 4 ft diameter pile at Pier 12/23 with BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	69.1	69.3	68.6	66.2	60.0	53.7	65.5	64.2	54.1	62.4	65.7	64.5
13	76.8	77.3	75.8	74.5	66.8	60.2	73.9	70.4	60.7	70.5	72.6	73.2
16	91.9	91.6	88.0	89.0	80.9	72.9	89.1	81.3	74.6	84.9	86.2	86.9
20	94.9	95.6	96.5	92.5	87.3	80.4	96.9	95.0	80.4	98.3	90.4	97.7
25	104.6	104.8	103.0	96.4	87.9	83.3	101.6	96.7	81.3	105.2	96.2	102.9
32	89.7	88.9	95.7	100.0	88.7	82.6	104.7	102.1	84.7	110.9	105.7	101.1
40	105.3	105.6	104.5	95.0	89.8	84.3	104.0	102.5	86.7	115.7	111.1	100.8
50	110.4	108.6	104.8	102.1	90.2	84.2	107.2	106.4	86.9	118.3	118.1	112.3
63	114.8	114.9	112.6	109.8	96.3	88.8	115.0	109.3	91.0	128.5	124.0	116.6
79	118.4	118.0	117.5	113.3	99.5	94.6	122.2	117.0	96.9	136.5	132.4	126.9
100	115.9	111.6	111.7	110.1	95.3	88.5	120.2	110.3	91.2	139.6	132.3	124.1
126	106.1	111.8	115.4	107.5	90.6	81.0	120.7	117.6	89.8	142.4	139.0	127.3
159	114.5	114.6	109.7	98.6	75.9	80.4	121.4	116.7	81.2	146.9	139.4	132.0
200	114.9	107.9	112.6	106.6	83.1	87.2	128.2	122.4	81.0	159.3	151.3	140.8
251	115.1	114.2	110.5	103.2	69.0	73.5	128.3	119.6	73.0	157.0	152.5	136.7
316	102.6	99.1	102.3	86.3	65.8	55.3	111.7	116.2	69.9	154.6	148.1	135.4
398	92.4	92.8	91.3	70.3	47.5	46.6	114.4	103.9	49.1	153.7	147.6	134.1
501	78.3	79.9	80.5	61.4	23.1	21.2	99.4	96.3	24.1	147.5	142.8	126.0
631	63.2	69.7	71.8	47.9	4.2	-15.1	94.9	88.7	5.7	144.2	141.7	121.5
794	59.3	60.3	54.7	33.1	-24.8	-45.7	80.8	66.1	-27.9	134.4	135.6	111.9
1000	42.9	43.8	40.6	9.0	-58.0	-79.4	65.4	53.2	-69.0	137.3	128.9	101.1
1259	30.9	29.6	25.9	-3.6	-74.9	-115.6	54.4	38.3	-105.2	134.3	123.1	90.2
1585	14.6	10.8	4.4	-22.5	-101.5	-165.0	36.8	15.8	-152.7	120.2	112.8	79.8
1995	4.6	-2.2	-10.4	-33.4	-115.9	-181.1	22.6	1.6	-176.3	120.6	100.6	68.6
2512	24.9	4.7	-6.8	-26.1	-94.2	-153.2	40.2	-1.2	-156.0	130.6	115.2	50.5
3162	53.8	44.3	35.6	23.1	-29.5	-66.7	67.7	39.9	-73.9	134.2	124.0	86.3
3981	72.6	71.0	64.0	55.1	18.0	-5.0	85.0	67.0	-11.6	135.1	129.3	102.3
5012	82.0	85.6	81.1	75.1	47.4	34.1	92.6	82.7	28.4	132.1	129.7	110.5
6310	90.2	94.9	91.6	89.1	67.1	59.2	100.5	92.7	54.9	129.8	130.5	116.4
7943	94.5	93.7	93.7	95.0	75.9	70.2	104.2	95.4	67.7	126.2	130.0	118.3

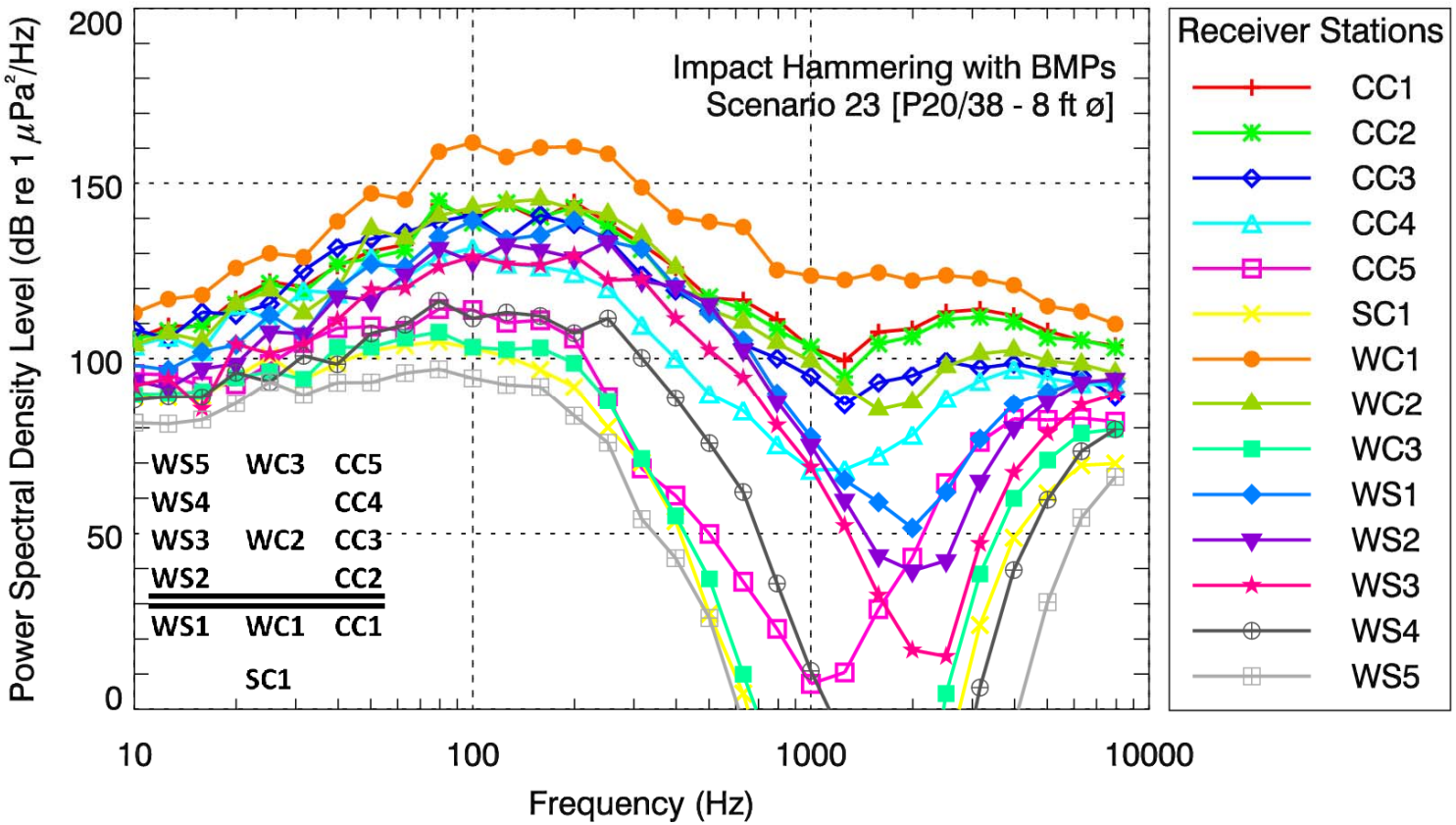
D.2.2. 6' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 22: Impact hammering a 6 ft diameter pile at Pier 27/48 with BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	95.4	93.9	88.6	82.8	75.4	65.5	81.9	78.6	65.2	70.9	67.0	66.7
13	108.4	108.1	95.3	95.0	84.5	75.0	95.6	90.5	73.9	80.5	77.5	77.7
16	107.0	111.3	109.4	93.7	93.2	82.9	91.4	97.0	84.2	85.3	77.5	76.2
20	117.4	115.1	113.7	106.9	93.0	88.9	109.5	101.0	88.4	86.1	85.5	88.4
25	123.2	121.2	113.5	103.8	99.8	85.7	112.0	108.2	88.3	91.8	90.4	92.5
32	125.8	126.9	123.5	115.5	103.0	91.5	111.1	107.8	87.3	103.2	99.7	97.6
40	128.9	130.0	121.7	118.2	95.8	92.7	118.0	113.7	91.3	98.7	96.5	93.6
50	137.3	135.1	131.5	123.8	105.2	93.7	121.6	120.1	96.2	105.9	102.9	102.6
63	140.9	140.2	133.5	119.2	104.7	95.4	133.0	120.7	96.3	112.3	106.4	105.1
79	141.7	145.2	139.1	132.1	117.0	107.3	136.0	132.0	107.3	117.1	113.8	112.6
100	148.1	141.8	142.2	124.0	112.6	103.4	127.9	131.2	103.5	113.2	104.6	107.4
126	144.8	146.2	137.3	128.4	104.0	100.0	135.8	129.4	98.9	111.1	107.1	108.9
159	144.1	143.3	137.4	127.6	104.3	99.3	135.5	128.0	98.3	110.7	108.8	105.8
200	154.8	156.5	148.8	135.9	109.0	102.0	146.8	138.1	102.9	115.5	114.5	114.8
251	156.6	153.9	141.3	132.3	104.4	99.0	145.4	135.6	99.3	116.5	106.2	100.8
316	149.6	147.2	138.1	121.6	86.2	80.7	138.3	133.6	80.5	105.9	108.5	104.4
398	149.3	148.4	141.4	112.1	78.8	70.5	131.5	129.7	72.1	101.7	103.0	97.6
501	147.2	141.0	136.5	106.5	61.7	62.6	128.6	116.9	59.5	89.9	81.7	79.5
631	142.8	141.8	134.2	106.5	54.4	56.5	121.8	117.6	54.0	75.7	71.3	66.4
794	139.3	137.3	127.5	99.2	42.4	45.7	118.1	113.3	44.4	63.5	57.4	50.7
1000	139.5	138.7	128.5	89.4	25.2	29.3	119.1	108.6	29.7	53.0	46.1	37.3
1259	139.8	135.4	130.9	92.7	27.4	47.9	123.7	116.3	38.0	45.2	26.6	23.2
1585	135.0	132.8	130.9	99.8	33.9	69.9	124.9	122.1	64.6	37.0	21.5	19.0
1995	136.9	136.3	131.1	102.7	32.3	86.8	129.9	127.8	78.6	40.4	23.7	20.4
2512	141.9	143.2	139.1	119.2	74.1	107.2	137.2	137.6	102.9	66.7	34.0	43.4
3162	141.8	144.9	141.4	127.2	94.5	118.7	136.7	139.6	115.9	88.1	67.9	75.1
3981	138.7	142.6	141.1	130.3	106.3	123.9	129.3	136.7	122.4	101.4	89.2	96.2
5012	134.7	136.6	137.4	128.9	110.9	123.6	128.5	128.7	123.0	103.9	97.7	105.8
6310	131.7	136.4	135.1	128.1	116.0	123.7	124.9	131.8	123.0	93.7	97.5	110.2
7943	132.8	133.7	132.0	125.6	115.5	119.4	127.7	125.8	119.3	104.9	102.6	107.3

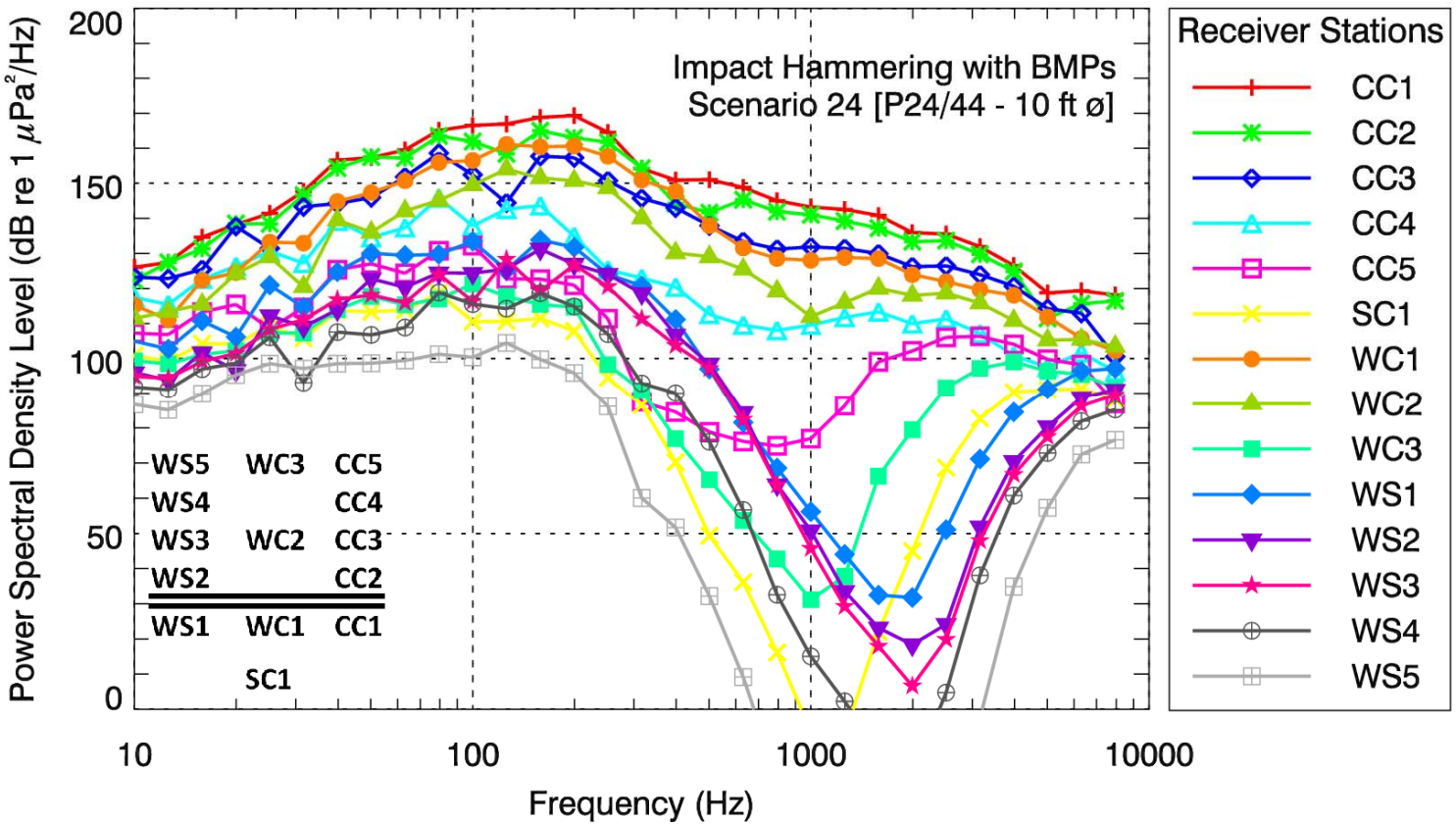
D.2.3. 8' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 23: Impact hammering an 8 ft diameter pile at Pier 20/38 with BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	109.3	109.1	112.0	107.3	99.3	92.5	116.7	107.5	93.2	101.7	97.4	95.8
13	113.9	112.5	110.3	110.8	100.0	93.4	121.6	111.9	94.5	101.4	96.1	98.9
16	114.9	115.4	118.9	107.8	97.7	94.8	123.8	110.7	96.1	107.5	102.7	91.2
20	123.6	122.0	119.2	121.9	99.3	101.3	132.5	122.2	101.1	110.6	105.1	110.8
25	129.5	129.0	123.2	118.6	106.1	108.2	137.7	127.1	103.9	120.1	115.3	109.0
32	129.2	127.5	133.8	128.1	113.1	102.6	137.6	121.6	102.7	115.3	115.7	112.7
40	136.1	136.7	141.3	128.2	118.3	108.3	148.8	129.5	112.9	129.6	127.4	120.7
50	141.3	139.3	144.8	139.6	119.8	112.9	157.8	147.7	113.9	137.6	127.3	130.4
63	144.2	142.6	147.7	134.7	119.6	115.4	157.0	146.0	117.5	137.8	135.5	131.8
79	156.5	157.6	151.7	141.8	126.8	117.5	171.7	153.4	120.2	147.4	144.1	138.9
100	154.0	152.4	154.6	145.2	127.5	116.6	175.3	156.8	116.9	153.0	141.3	142.7
126	158.8	159.0	148.6	141.7	124.9	115.3	172.2	159.3	117.2	148.6	147.2	141.7
159	155.2	156.1	156.6	141.9	126.6	112.4	175.9	161.1	118.7	150.9	146.6	142.3
200	161.3	159.7	155.1	141.1	122.4	108.5	177.1	159.2	115.3	156.0	145.4	146.1
251	156.4	155.1	151.8	137.7	106.6	97.8	176.1	158.8	105.4	151.2	151.1	140.0
316	151.3	149.9	142.5	128.2	87.1	88.8	167.5	153.9	89.9	150.0	140.8	141.3
398	145.6	139.3	139.1	119.7	80.4	73.1	160.1	145.6	74.6	140.2	140.2	131.1
501	137.9	138.2	134.2	110.4	70.5	47.8	159.7	134.7	57.7	133.6	136.2	123.1
631	138.3	135.7	125.7	106.6	57.9	26.1	159.2	132.0	31.6	126.8	124.1	116.1
794	133.7	130.9	122.7	97.9	45.5	-4.5	147.9	127.1	6.6	112.5	110.2	103.5
1000	126.7	126.9	118.5	91.7	30.9	-36.0	147.3	122.8	-18.5	101.1	98.7	92.5
1259	124.0	119.4	111.4	92.8	35.1	-57.0	147.1	116.2	-37.8	89.8	84.1	76.9
1585	133.2	129.9	118.8	97.8	54.1	-70.9	150.2	110.9	-46.4	84.5	69.3	58.1
1995	135.1	132.9	121.7	104.6	69.7	-60.2	148.9	114.0	-29.6	78.2	66.0	43.5
2512	140.9	138.8	126.8	116.2	91.9	12.6	151.4	125.3	32.1	89.4	69.9	42.7
3162	142.7	140.5	125.9	122.2	104.6	52.6	151.5	130.0	67.1	105.5	93.5	75.8
3981	141.9	140.2	128.2	126.6	112.2	78.4	150.6	132.0	89.6	116.5	109.7	97.0
5012	138.5	136.6	127.3	125.0	112.9	92.0	145.6	130.0	101.5	120.9	118.2	109.2
6310	136.8	136.9	126.7	124.5	114.4	101.0	145.1	130.0	110.1	125.1	124.7	118.4
7943	136.3	135.8	121.6	125.0	114.4	102.5	142.5	128.5	112.3	126.1	126.8	122.3

D.2.4. 10' pile size



Power spectral density levels (dB re 1 µPa^2/Hz) for Scenario 24: Impact hammering a 10 ft diameter pile at Pier 24/44 with BMPs.

	Receiver Station											
Frequency (Hz)	*CC1*	*CC2*	*CC3*	*CC4*	*CC5*	*SC1*	*WC1*	*WC2*	*WC3*	*WS1*	*WS2*	*WS3*
10	129.7	126.0	126.9	121.1	110.9	104.5	118.9	115.1	103.0	108.6	99.6	98.5
13	132.1	132.1	127.5	120.1	111.5	103.8	115.7	118.1	103.1	107.4	98.4	99.0
16	140.3	137.0	131.1	128.3	118.9	109.9	128.0	121.1	106.8	116.4	107.3	104.8
20	144.9	145.2	144.4	133.0	122.1	110.8	131.2	130.9	108.9	112.8	103.2	108.1
25	149.1	146.1	139.1	138.3	116.1	117.0	140.9	136.7	115.0	128.6	119.9	116.0
32	156.4	155.3	152.0	135.9	123.2	114.4	141.6	129.1	115.9	123.3	117.7	119.7
40	166.3	164.0	153.9	148.9	135.0	123.3	154.5	149.2	123.6	134.4	123.6	126.5
50	168.0	168.2	156.6	145.2	137.7	124.0	158.0	146.7	128.4	140.7	133.4	128.8
63	171.2	168.9	163.5	149.0	136.0	125.5	162.4	153.8	127.0	141.1	132.0	127.6
79	177.8	176.2	171.3	158.5	143.4	131.3	168.6	157.8	129.7	142.4	137.1	136.7
100	180.2	175.6	166.1	151.5	145.9	124.2	170.2	163.2	134.9	147.1	138.0	130.0
126	181.6	173.1	159.1	157.3	137.4	125.3	175.8	168.7	132.4	139.9	140.2	143.0
159	184.5	180.7	173.4	159.3	138.3	127.1	176.1	167.2	131.1	149.5	146.9	134.9
200	186.0	179.7	174.0	151.6	137.6	124.5	177.3	167.4	131.3	148.4	143.6	143.4
251	182.2	179.4	168.4	143.0	129.0	112.1	175.4	166.4	115.9	141.7	141.7	138.2
316	172.9	173.0	164.4	141.6	106.1	105.2	169.6	158.8	109.4	139.4	137.2	130.0
398	170.6	163.9	162.7	140.1	104.2	89.9	167.4	149.8	96.6	130.8	126.4	123.4
501	171.7	162.3	158.6	133.3	99.5	70.0	158.6	149.7	85.9	117.6	119.1	117.8
631	170.5	167.0	155.1	131.2	97.8	57.8	153.2	147.1	75.3	103.2	106.0	104.1
794	167.7	164.6	153.9	130.7	97.5	38.8	151.2	141.9	65.4	91.2	86.5	86.4
1000	166.9	164.7	155.5	133.2	100.6	17.4	151.7	135.6	54.8	79.8	74.4	69.4
1259	167.2	163.9	156.1	136.4	111.0	17.5	153.5	140.6	62.5	68.7	58.2	53.9
1585	166.5	162.9	155.6	139.0	124.7	47.7	154.2	145.7	91.9	58.1	48.8	43.6
1995	162.6	160.0	152.9	136.6	128.8	71.6	150.6	144.7	106.1	58.4	45.0	33.3
2512	163.2	161.3	154.1	139.0	133.7	96.3	149.6	146.3	119.2	78.7	51.8	47.5
3162	160.6	158.4	152.6	135.8	135.0	111.4	148.3	144.5	125.8	99.8	80.5	76.6
3981	156.2	154.5	150.3	130.5	133.7	120.0	147.7	140.5	128.7	114.2	100.1	96.4
5012	149.4	142.1	144.9	128.2	130.4	121.6	142.5	135.9	127.0	121.8	111.0	108.2
6310	151.0	147.3	144.6	133.3	129.9	122.9	137.4	137.1	127.1	128.0	120.4	118.0
7943	150.8	149.1	133.2	128.9	119.6	120.9	134.8	136.1	124.1	129.8	123.6	122.1

Appendix F: Ecology

F-6 Methodology for Estimating Potential Hydroacoustic Impacts to Abundant Hudson River Fish Species and Shortnose Sturgeon from Pile-driving Activities during Construction of the Tappan Zee Bridge Replacement Project and a Summary of Analysis Results

APPENDIX F-6

Methodology For Estimating Potential Hydroacoustic Impacts To Abundant Hudson River Fish Species And Shortnose Sturgeon From Pile-Driving Activities During Construction Of The Tappan Zee Hudson River Crossing Project, And A Summary Of Analysis Results

January 2012

Primary Agency and Contact:
Jonathan McDade, New York Division Administrator
Federal Highway Administration

In Coordination with:
New York State Department of Transportation
New York State Thruway Authority

Prepared by:
AKRF, Inc.
440 Park Avenue South
New York, NY 10016

METHODOLOGY FOR ESTIMATING POTENTIAL HYDROACOUSTIC IMPACTS TO ABUNDANT HUDSON RIVER FISH SPECIES AND SHORTNOSE STURGEON FROM PILE-DRIVING ACTIVITIES DURING CONSTRUCTION OF THE TAPPAN ZEE BRIDGE REPLACEMENT PROJECT, AND A SUMMARY OF ANALYSIS RESULTS.

Underwater noise created by pile-driving activities during construction of the Tappan Zee Crossing has the potential to impact the local fish community by exposing fishes to cumulative noise. At low levels, the cumulative sound exposure may cause behavioral avoidance of the ensonified area or, at higher levels, physical injury and mortality.

Different approaches were used to assess these potential impacts., The first approach (**Trawl Approach**) used biological data collected with trawl nets during annual utilities-sponsored fish surveys from 1998-2007 throughout the Hudson River, including the Tappan Zee region. This approach was used to estimate the potential impacts as a percentage of the total riverwide standing crop of fish, as well as the potential impacts to the seven most abundant species. The second approach (**Gill-Net Approach**) was used to examine potential impacts specifically for shortnose sturgeon and used data collected by the project's consultants from 2007-2008 during gill-net sampling at the project site immediately upstream of the existing Tappan Zee Bridge. This approach was considered appropriate for assessing shortnose sturgeon because gill nets are one of the more effective gears for sampling sturgeon and because sampling was conducted recently at the project site.

Both the Trawl Approach and Gill-Net Approach provide an estimate of the number of fish that are likely to occur within an ensonified area with a cumulative sound exposure level ($SEL_{cum)}$ of 187dB re 1μPa^2-s during the onset of construction. For these analyses the $SEL_{cum)}$ of 187dB re 1μPa^2-s was selected as a threshold for the onset of physiological effects to fish based on the interim West Coast criteria agreed to in a Memorandum of Agreement (MOA) by FHWA, USFWS, NMFS, CalTrans, and the Washington Department of Transportation on June 12, 2008. However, recent research strongly suggests that the onset for physiological effects actually occurs at SEL_{cum} levels considerably higher than 187 dB re 1μPa^2-s (See Biological Assessment Appendix F-4).

Due to behavioral avoidance of the ensonified area by fishes during pile-driving activities, it is likely that fish densities will be temporarily reduced in the ensonified area relative to surrounding areas, particularly when pile driving occurs on consecutive days over the course of the first several months of construction. However it is likely that fish that temporarily avoided the area or new fish migrating through the area would return to the previously ensonified areas following the end of the day's construction. A more detailed description of analytical methods used for each of these approaches is given below.

A. Trawl Approach

A hydroacoustic model was developed by JASCO (JASCO 2011) to delineate the spatial extent of noise impacts generated during pile-driving activities over each week of construction. Noise isopleths were superimposed on bathymetric data of the project area collected by NOAA and the State University of New York at Stony Brook (NYS GIS Clearinghouse 2011) to estimate the water volumes contained by the 187dB isopleths during driving of 4, 6, 8 and 10-foot diameter piles. To account for depth-related differences in habitat use by various fish species, three-dimensional volumes were partitioned into habitats that corresponded to those recognized by the Hudson River Utilities Monitoring Program (ASA 2009). These habitats included:

- **Shoal** (0-20-ft depth),
- **Bottom** (0-10-ft from the bottom where water is >20-ft deep), and
- **Channel** (water column above the bottom where water is >20-ft deep).

For each bridge pier to be constructed (each containing a series of piles), the number of fish potentially affected can be estimated using the mean fish density during the weeks of construction and the volume of each habitat contained within the 187dB re $1\mu Pa^2$-s acoustic isopleths during those weeks.

The Hudson River Utilities Monitoring Program provides the most comprehensive available spatial and temporal database on Hudson River fish resources. This database includes over three decades of monitoring data with considerable sampling within the Tappan Zee region. Fish community data collected as part of the Hudson River Utilities Fall Shoals Monitoring Program between 1998 and 2007 were used to estimate the number of fish by habitat within the 187dB isopleths. To do this, mean fish densities in the Tappan Zee region (river miles 24-33) were first calculated by habitat and sampling event for each of the 11 sampling events that typically occurred every other week from July through November, using the equations provided in the Utilities Year Class Reports (ASA 2009). Briefly, density was calculated per-unit volume sampled by the trawl for each region, habitat and sample event by dividing the number of fish caught by sample volume in cubic meters. Mean density per week was derived by averaging densities by the number of samples collected in each region, habitat and week during a given sample year. Riverwide weekly standing crop was calculated as the sum of the weekly regional standing crops, which were estimated as the product of weekly fish density and the regional volume.

Using the actual observed densities, densities were interpolated for "off" weeks during the survey year (July through November) when samples were not collected, as well as for weeks between survey years (December through June). Interpolations were performed for weeks during the survey year by averaging fish densities from the previous and following week. For weeks between survey years, a linear interpolation was performed based on the final measured density of the current survey year and the initial measured density of the following survey year. The resulting dataset included the mean density of

fishes by habitat in the Tappan Zee region for each of the 52 weeks during the calendar year.

Mean weekly fish densities were then applied to the water volumes affected by the SEL_{cum} 187dB re 1μPa^2-s noise isopleths during each week of the proposed construction schedule to estimate the total number of fish expected to be impacted by pile-driving activities on a weekly basis over the course of bridge construction. Impacted volumes were determined following the proposed construction schedule, which outlines the month, week and year during which specific piles are to be driven and allows fish-density estimates to be linked to the habitat and volume impacted by pile driving over the course of construction. This approach allowed us to account for the various combinations of pile sizes that will be driven simultaneously, their location along the span and their depth within the River. Fish numbers were expressed in terms of the Hudson River standing crop for all fish species combined. We then assessed the species composition of the fish community to determine those species most likely to be present in the project area by calculating proportional abundances for all species. Number of fish within the ensonified area were estimated at the species-level for the seven most abundant species, which included bay anchovy (*Anchoa mitchilli*), hogchoker (*Trinectes maculatus*), white perch (*Morone americana*), weakfish (*Cynoscion regalis*), striped bass (*Morone saxatilis*), Atlantic croaker (*Micropogonias undulatus*), and Atlantic menhaden (*Brevoortia tyrannus*).

Upper and lower bounds for the number of fish potentially impacted were estimated by first assuming that the Hudson River standing crop exists in a closed system (i.e., there is no immigration or emigration). Under this assumption, the same individual fish can be observed multiple times and the number of fish vulnerable to noise impacts can not exceed the maximum weekly average number of fish observed.

Therefore, the lower bounds were calculated as:

$$Impacted_{max} / SC_{max} \text{ X } 100$$

where,

$Impacted_{max}$ = the maximum weekly number of fish within the isopleth for SEL_{cum} at 187dB re 1μPa^2-s

SC_{max} = the maximum weekly standing crop of the Hudson River.

To estimate the upper bounds, it was assumed that the Hudson River standing crop exists in an open system with fish moving throughout the River. In this case, fish are never observed more than once and every fish observed within the project area is counted as a different individual. Under these assumptions, the number of fish within the ensonified area each week was summed across all weeks and divided by the number of weeks of pile driving. This average weekly number of fish was then multiplied by 52 weeks in a year to determine the number of impacted fish during an average construction year.

Therefore, the upper bounds are calculated as:

$$(\sum \text{Impacted}_{weekly} / n_{weeks}) * 52 / SC_{max} \text{ X } 100$$

where,

Impacted_{weekly} = the weekly number of fish within the isopleth for SEL_{cum} at 187dB re $1\mu Pa^2$-s

n_{weeks} = the number of weeks of pile driving during construction

Table 1 inidcates the percentage of the Hudson River standing crop within the SEL_{cum} at 187 dB re $1\mu Pa^2$-s ensonified area during an average construction year for the seven most abundant fish species and for all fish species combined.

B. Gill-Net Approach

As with the Trawl Approach, the results of the hydroacoustic model produced by JASCO (JASCO 2011) were used to delineate the spatial extent of noise impacts generated during pile-driving activities during each week of construction. For the Gill-Net Approach, the width of the 187dB re $1\mu Pa^2$-s isopleths was measured to scale sturgeon catch rates from 125-ft wide gill nets to isopleths widths.

Using abundance estimates for shortnose sturgeon ("sturgeon") from a 1-year gill-net sampling project conducted by AECOM (Appendix E-3), the encounter rate of sturgeon in the study area was estimated as the number of sturgeon collected per gill net per hour. From June 2007 – May 2008, 476 gill nets were deployed just upstream of the existing Tappan Zee Bridge (and within the project area) for a total sampling time of 679 hours. During this time, 12 sturgeon were collected: 7 in September and October, 4 in May and June and 1 in August. Based on the observed number of sturgeon collected over 647 gill-net hours, the encounter rate for sturgeon in the project area is 0.02 sturgeon encountered per hour.To estimate the potential number of sturgeon occurring within the 187dB re $1\mu Pa^2$-s ensonified area, it was necessary to scale gill-net encounter rates from a single gill-net sample to the width encompassed by the isopleth bounding the 187dB SEL_{cum}, which is used as the threshold for physical injury to fish (reviewed in Stadler and Woodbury 2009). To do this, isopleths widths derived from hydroacoustic modeling conducted for representative construction scenarios (JASCO 2011) were used to determine the number of sturgeon that might have been collected if multiple gill nets were deployed side-by-side across the width of the 187dB isopleth. The length of the gillnet is 125-ft. The widths of the 187-dB re $1\mu Pa^2$-s isopleth for each of the pile sizes ranges from 1,020 to 9,324 ft. Therefore, it would require 8 to 75 gill nets to span the width of the isopleths depending on the size of the pile being driven. Movement by shortnose sturgeon has been shown to be strongly oriented into or with river currents (McCleave et al. 1977). This is supported by data collected during the 2007-2008 gill net study, in which shortnose sturgeon were collected with greater frequency in gill nets deployed across the river current than in those placed with the current (Appendix E-2).

Based on these results, it was assumed that sturgeon moved in an upstream or downstream direction through the project area and at a constant rate and would thus be intercepted by gill nets spanning the width of the noise isopleth. it was also assumed that catch rates are proportional to sturgeon abundance, which is a central assumption of most fish-sampling gears, and that sturgeon were uniformly distributed throughout the Tappan Zee region. Under these assumptions, each gill net would encounter sturgeon at the same rate allowing the estimates of sturgeon number to be scaled to the width of the isopleth. The assumption of uniform sturgeon distribution provides a conservative estimate of encounter rate. This is because the high frequency of single sturgeon collected in the gill-net study suggests that sturgeon are distributed randomly (rather than uniformly or aggregated) and thus would actually be encountered at a lower rate than if they were uniformly distributed (i.e., adjacent gill nets should not each collect the same number of sturgeon when sturgeon are randomly distributed).

Tables 2 and 3 draws from the project's construction schedule and indicates the number of shortnose sturgeon that would encounter the 187 dB re 1μPa^2-s ensonified area during the construction period for the Short Span (482 shortnose sturgeon) and Long Span (365 shortnose sturgeon) Options.

The percentage of the total river width occupied by the 187dB re 1μPa^2-s ensonified width was plotted by week for both the Short Span Option and the Long Span Options over the proposed construction period. The results are shown in Figures 1 and 2.

Table 1
Percentage of Hudson River Fish Standing Crop Within the 187 dB Ensonified Area During an Average Construction Year for the Short Span and Long Span Design Options

Species	Option	Lower-bound estimate for number of fish in the 187 dB ensonified area	Upper-bound estimate for number of fish in the 187 dB ensonified area	Maximum standing crop	Lower bound (%)	Upper bound (%)
Bay anchovy	Long-span	1,320,249	6,002,479	283,753,295	0.47	2.12
Bay anchovy	Short-span	1,320,249	5,169,451	283,753,295	0.47	1.82
Hogchoker	Long-span	23,645	106,569	6,692,813	0.35	1.59
Hogchoker	Short-span	23,645	83,499	6,692,813	0.35	1.25
White perch	Long-span	26,892	146,274	6,235,262	0.43	2.35
White perch	Short-span	26,892	123,641	6,235,262	0.43	1.98
Weakfish	Long-span	8,494	65,430	9,237,259	0.09	0.71
Weakfish	Short-span	6,806	64,590	9,237,259	0.07	0.70
Striped bass	Long-span	12,383	156,084	21,191,428	0.06	0.74
Striped bass	Short-span	16,431	151,874	21,191,428	0.08	0.72
Atlantic croaker	Long-span	130,287	500,261	21,792,473	0.60	2.30
Atlantic croaker	Short-span	130,287	364,209	21,792,473	0.60	1.67
Atlantic menhaden	Long-span	35,035	66,005	6,130,635	0.57	1.08
Atlantic menhaden	Short-span	35,035	51,038	6,130,635	0.57	0.83
All fish species	Long-span	1,536,851	7,956,076	346,334,109	0.44	2.30
All fish species	Short-span	1,536,851	7,021,955	346,334,109	0.44	2.03

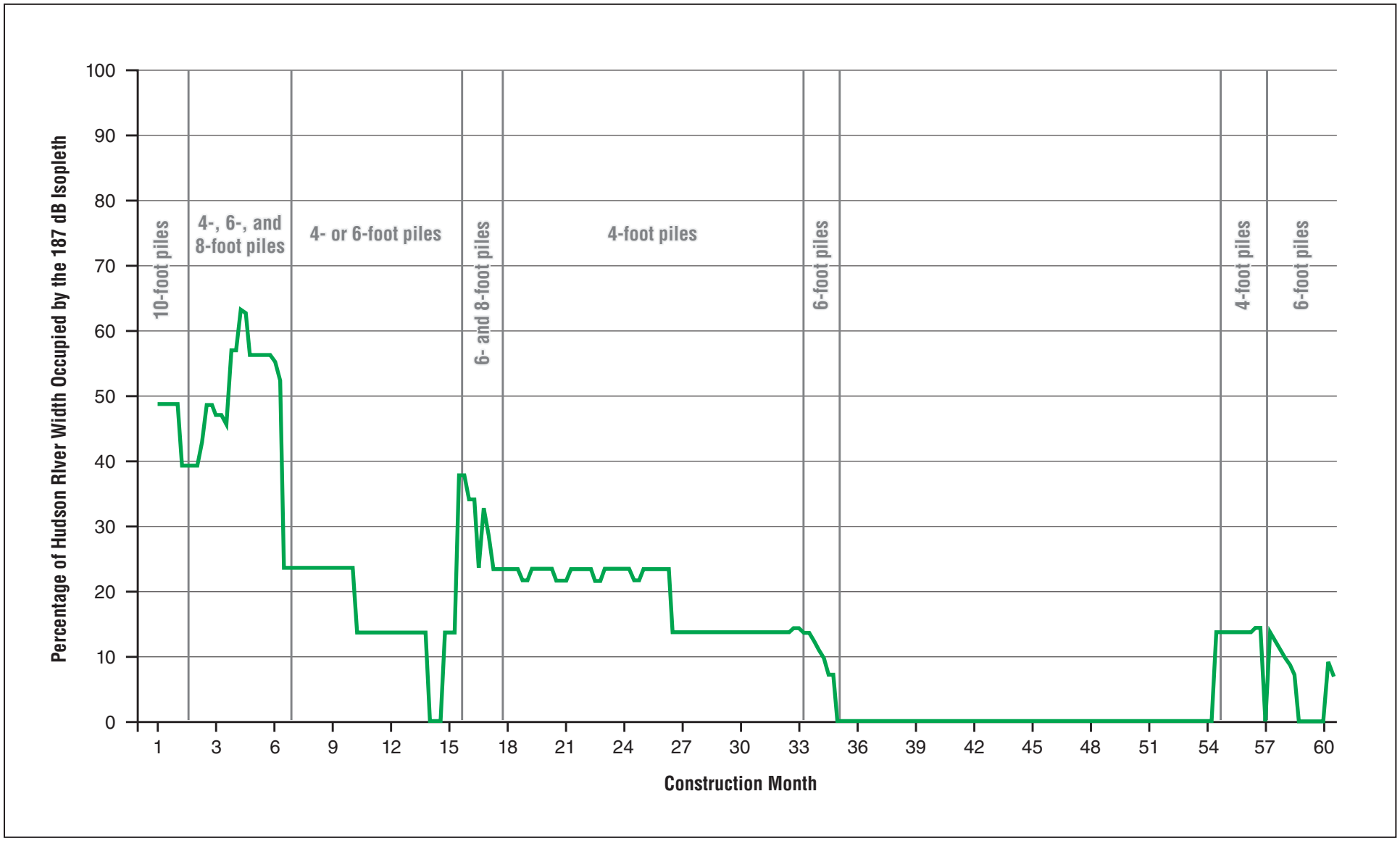


Figure 1

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Short Span Option

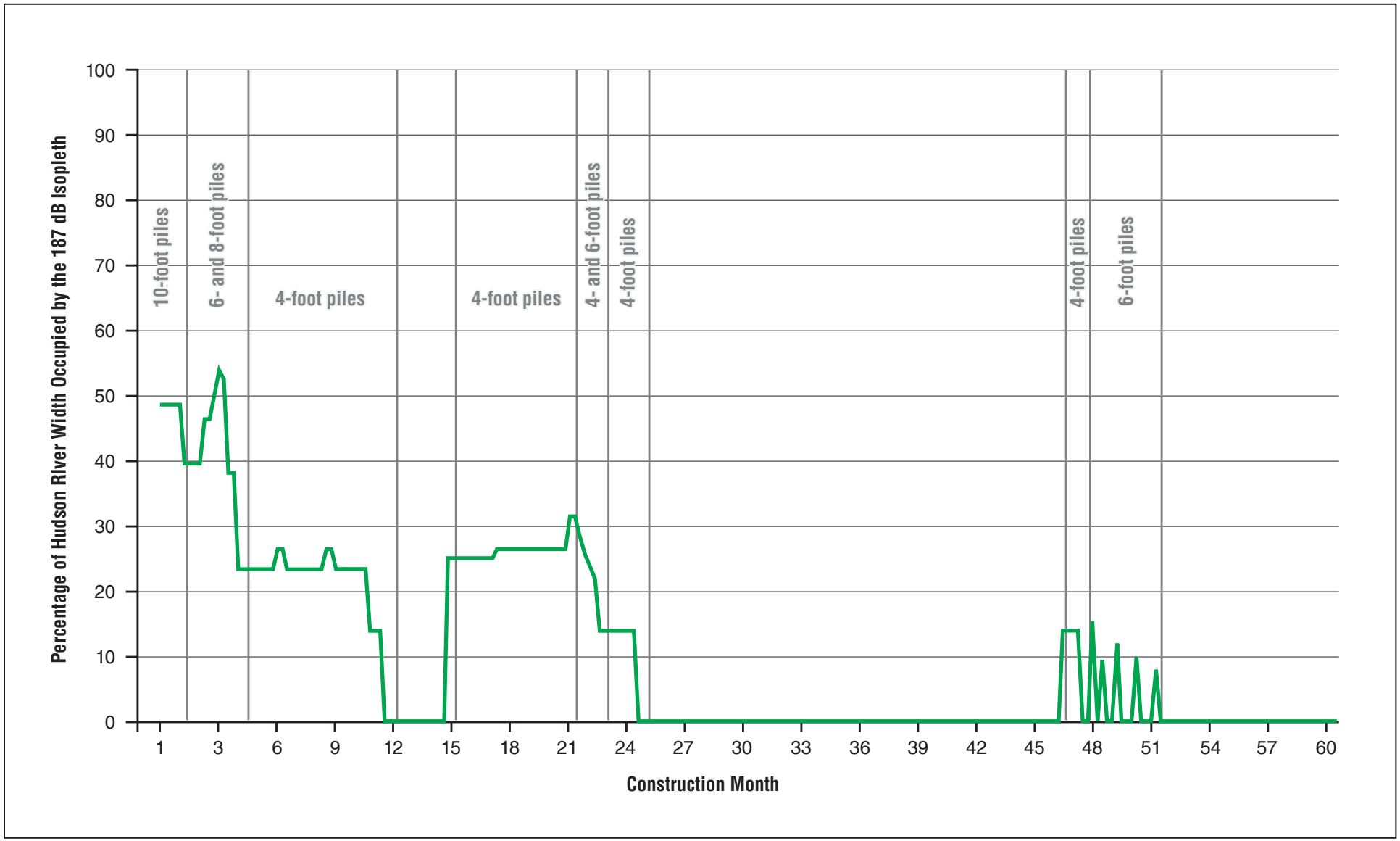


Figure 2

Percent of the Hudson River Width Occupied by the 187dB Isopleth During Pile Driving at the Proposed Tappan Zee Crossing Long Span Option

Table 2
Number of Shortnose Sturgeon Estimated to be Within the 187 dB Ensonified Area During the Construction Period for the Short Span Option

								With 10 dB BMPs			
Year	Week	Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	Width of isopleth for 187-db cSEL (ft)	Number of gill nets to span width of isopleth	Sturgeon encounter rate (fish/hr)	Number of shortnose sturgeon potentially affected by pile driving
1	40-44	10	50	4	1.55	2	38.75	7186	57	0.02	44.55
	45-48	6,8	20	7	1.11	2	11.1	5807	46	0.02	10.32
	49	6,8	8	7	1.11	2	4.44	6336	51	0.02	4.50
	50-51	4,8	20	6	1.14	2	11.4	7170	57	0.02	13.08
	52	4,8	10	6	1.14	2	5.7	6952	56	0.02	6.34
2	1	4,8	10	6	1.14	2	5.7	6952	56	0.02	6.34
	2	4,8	10	6	1.14	2	5.7	6735	54	0.02	6.14
	3-4	4,6,8	30	10	1.14	3	11.4	8418	67	0.02	15.36
	5	4,6,8	15	10	1.14	3	5.7	9324	75	0.02	8.50
	6	4,6,8	15	10	1.14	3	5.7	9253	74	0.02	8.44
	7	4,6,8	15	10	1.14	3	5.7	8312	66	0.02	7.58
	8-12	4,6,8	75	10	1.14	3	28.5	7732	62	0.02	35.25
	13	6,8	12	7	1.14	2	6.84	7732	62	0.02	8.46
	14-28	4,4	160	6	1.14	2	91.2	3490	28	0.02	50.9
	29-49	4	95	3	1.14	1	108.3	2024	16	0.02	35.15
	50-51	4,4,6	30	10	1.14	3	11.4	5581	45	0.02	10.18
	52	4,4,6	15	10	1.14	3	5.7	5036	40	0.02	4.59
3	1	4,4,6	15	10	1.14	3	5.7	5036	40	0.02	4.59
	2	4,4	10	6	1.14	2	5.7	3490	28	0.02	3.18
	3	4,4,6	15	10	1.14	3	5.7	4836	39	0.02	4.41
	4	4,4,6	16	10	1.14	3	6.08	4217	34	0.02	4.10
	5-10	4,4	65	6	1.14	2	37.05	3461	28	0.02	20.51
	11-12	4,4	22	6	1.14	2	12.54	3197	26	0.02	6.42

Table 2 (con't)
Number of Shortnose Sturgeon Estimated to be Within the 187 dB Ensonified Area During the Construction Period for the Short Span Option

								With 10 dB BMPs			
Year	Week	Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	Width of isopleth for 187-db cSEL (ft)	Number of gill nets to span width of isopleth	Sturgeon encounter rate (fish/hr)	Number of shortnose sturgeon potentially affected by pile driving
3 (con't)	13-17	4,4	53	6	1.14	2	30.21	3461	28	0.02	16.73
	18-20	4,4	30	6	1.14	2	17.1	3197	26	0.02	8.76
	21-25	4,4	55	6	1.14	2	31.35	3461	28	0.02	17.35
	26-27	4,4	20	6	1.14	2	11.4	3197	26	0.02	5.84
	28-33	4,4	60	6	1.14	2	34.2	3461	28	0.02	18.96
	34-35	4,4	20	6	1.14	2	11.4	3197	26	0.02	5.84
	36-41	4,4	60	6	1.14	2	34.2	3461	28	0.02	18.96
	42-52	4	60	3	1.14	1	68.4	2024	16	0.02	22.2
4	1-14	4	70	3	1.14	1	79.8	2024	16	0.02	25.9
	15-16	6	12	4	0.33	1	3.96	2120	17	0.02	1.34
	17-18	6	6	4	0.33	1	1.98	2019	16	0.02	0.64
	19	6	6	4	0.33	1	1.98	1821	15	0.02	0.58
	20	6	6	4	0.33	1	1.98	1624	13	0.02	0.51
	21	6	4	4	0.33	1	1.32	1440	12	0.02	0.30
	22-23	6	8	4	0.33	1	1.64	1060	8	0.02	0.44
5	50-52	4	15	3	1.14	1	17.1	2024	16	0.02	5.55
6	1-5	4	25	3	1.14	1	28.5	2024	16	0.02	1.85
	6-7	6	12	4	0.33	1	3.96	2120	17	0.02	1.34
	9	6	6	4	0.33	1	1.98	2019	16	0.02	0.64
	10	6	6	4	0.33	1	1.98	1821	15	0.02	0.58
	11	6	6	4	0.33	1	1.98	1624	13	0.02	0.51
	12	6	4	4	0.33	1	1.32	1440	12	0.02	0.30
	13	6	4	4	0.33	1	1.32	1280	10	0.02	0.27
	14	6	4	4	0.33	1	1.32	1060	8	0.02	0.22
	21	6	6	4	0.33	1	1.98	1346	11	0.02	0.43
	22	6	6	4	0.33	1	1.98	1020	8	0.02	0.32
Potential number of sturgeon affected											
Shortnose sturgeon affected											**482**
Percentage of shortnose sturgeon standing crop (60,000 fish)											**0.80**

Table 3

Number of Shortnose Sturgeon Estimated to be Within the 187 dB Ensonified Area During the Construction Period for the Long Span Option

Year	Week	Diameter (feet)	Number of piles	Number of piles driven/day	Pile driving time (hours/pile)	Number of concurrently driven piles	Estimated pile driving time (hours)	With 10 dB BMPs			
								Width of isopleth for 187-db cSEL (ft)	Number of gill nets to span width of isopleth	Sturgeon encounter rate (fish/hr)	Number of shortnose sturgeon potentially affected by pile driving
1	40-44	10	50	4	1.55	2	38.75	7186	57	0.02	44.55
	45-48	6,8	20	7	1.11	2	11.1	5866	47	0.02	10.42
	49-50	6,8	16	7	1.11	2	8.88	6862	55	0.02	9.75
	51	6,8	12	7	1.11	2	6.66	7387	59	0.02	7.87
	52	6,8	14	7	1.11	2	7.77	7965	64	0.02	9.90
2	1	6,8	10	7	1.11	2	5.55	7767	62	0.02	6.90
	2-3	8	12	3	1.11	1	13.32	5648	45	0.02	12.04
	4-11	4,4	88	6	1.14	2	50.16	3458	28	0.02	27.76
	12-13	4,4	20	6	1.14	2	11.4	3910	31	0.02	7.14
	14-21	4,4	80	6	1.14	2	45.6	3458	28	0.02	25.2
	22-23	4,4	22	6	1.14	2	12.54	3910	31	0.02	7.84
	24-30	4,4	73	6	1.14	2	41.61	3458	28	0.02	23.01
	31-33	4	45	3	1.14	1	51.3	2064	17	0.02	16.95
	47-52	4,4	60	6	1.14	2	34.2	3712	30	0.02	20.34
3	1-4	4,4	40	6	1.14	2	22.8	3712	30	0.02	13.56
	5-18	4,4	160	6	1.14	2	91.2	3910	31	0.02	57.1
	19	4,4,6	21	10	1.14	3	7.98	3910	31	0.02	4.99
	20-21	4,6	34	7	1.14	2	19.38	4653	37	0.02	14.43
	22	4,6	22	7	1.14	2	12.54	4200	34	0.02	8.43
	23	4,6	16	7	1.14	2	9.12	3784	30	0.02	5.52
	24	4,6	11	7	1.14	2	6.27	3512	28	0.02	3.52
	25	4,6	11	7	1.14	2	6.27	3240	26	0.02	3.25
	26-33	4	40	3	1.14	1	45.6	2064	17	0.02	15.04
5	17-20	4	20	3	1.14	1	22.8	2064	17	0.02	7.52
	23	6	6	4	0.33	1	1.98	2282	18	0.02	0.72
	25	6	4	4	0.33	1	1.32	1395	11	0.02	0.29
	28	6	6	4	0.33	1	1.98	1759	14	0.02	0.56
	32	6	6	4	0.33	1	1.98	1469	12	0.02	0.47
	36	6	6	4	0.33	1	1.98	1178	9	0.02	0.37
Potential number of sturgeon affected											
Shortnose sturgeon affected											**365**
Percentage of shortnose sturgeon standing crop (60,000 fish)											**0.61**

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