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Analysis of Potential Storm Surge Barrier Impacts during Normal Tidal Conditions

Tate O. McAlpin and Anthony G. Emiren

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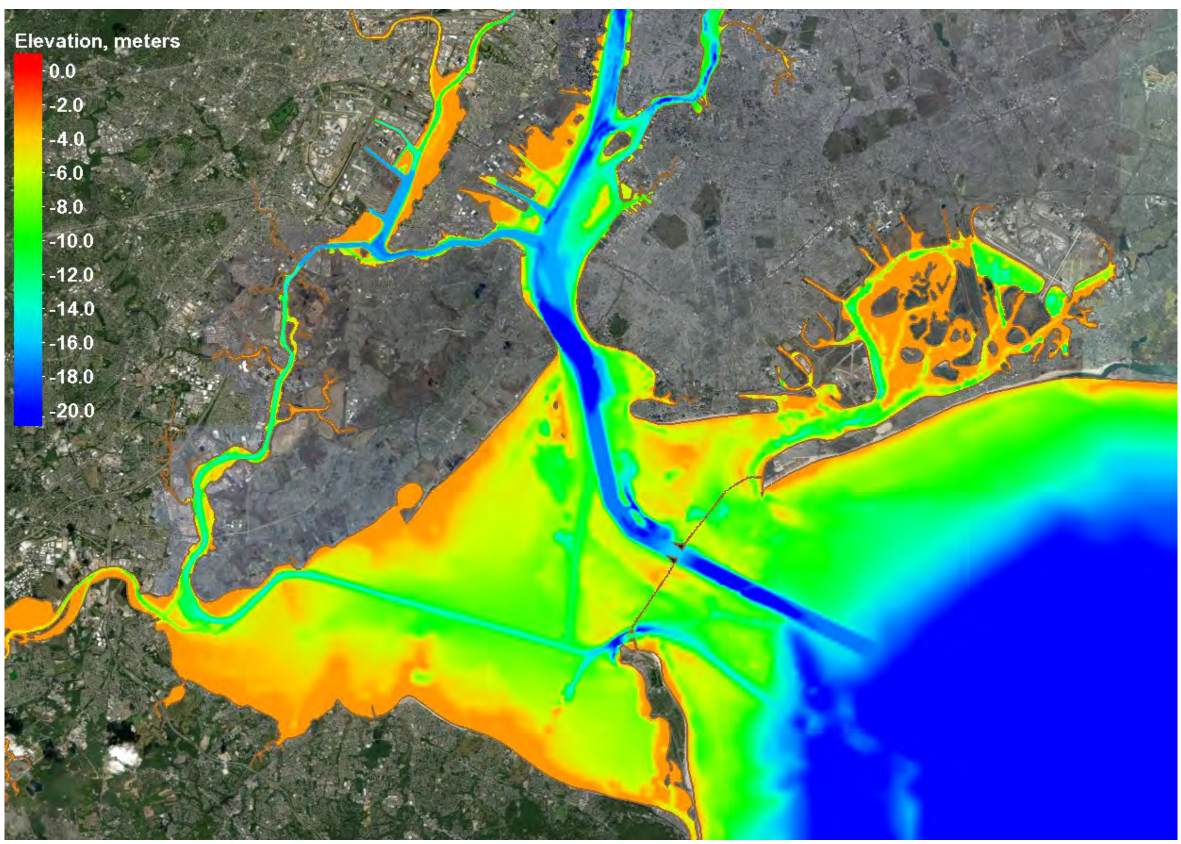

Analysis of Potential Storm Surge Barrier Impacts during Normal Tidal Conditions

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Final report

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Monitored by Coastal and Hydraulics Laboratory
US Army Engineer Research and Development Center
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Abstract

This numerical modeling study investigates the impacts associated with proposed surge barriers in the New York/New Jersey Harbor during normal tidal conditions with all the structures open to flow. Year-long Adaptive Hydraulics three-dimensional numerical model simulations were performed for each barrier alternative as well as a base model simulation without the structures in place. The results included from this study are point velocity and water surface elevation model comparisons, velocity percentiles, spatial figures of the 50th and 75th percentile velocities and salinity, and tidal prism percentiles for the areas affected by the structures. Analysis also included sediment transport and sea level rise impacts.

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Preface

This study was conducted for the USACE New York District under the "New York & New Jersey Harbor & Tributaries Focus Area Feasibility Study (HATS)". The technical monitor was Mr. Jamal Sulayman.

The work was performed by the Rivers and Estuarine Engineering Branch of the Flood and Coastal Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Mr. David P. May was chief of the Rivers and Estuarine Engineering Branch; Dr. Cary Talbot was chief of the Flood and Coastal Division; and Dr. Julie Dean Rosati was the technical director for Flood and Coastal Risk Management Program. The Deputy Director of ERDC-CHL was Mr. Keith Flowers and the Director was Dr. Ty V. Wamsley.

COL Christian Patterson was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
angstroms	0.1	nanometers
atmosphere (standard)	101.325	kilopascals
bars	100	kilopascals
British thermal units (International Table)	1,055.056	joules
centipoises	0.001	pascal seconds
centistokes	1.0 E-06	square meters per second
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
fathoms	1.8288	meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
gallons (US liquid)	3.785412 E-03	cubic meters
hectares	1.0 E+04	square meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
kilotons (nuclear equivalent of TNT)	4.184	terajoules
knots	0.5144444	meters per second
microinches	0.0254	micrometers
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
ounces (US fluid)	2.957353 E-05	cubic meters
pints (US liquid)	4.73176 E-04	cubic meters
pints (US liquid)	0.473176	liters
pounds (force)	4.448222	newtons

Multiply	By	To Obtain
pounds (force) per foot	14.59390	newtons per meter
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
quarts (US liquid)	9.463529 E-04	cubic meters
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
tons (force)	8,896.443	newtons
tons (force) per square foot	95.76052	kilopascals
tons (long) per cubic yard	1,328.939	kilograms per cubic meter
tons (nuclear equivalent of TNT)	4.184 E+09	joules
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

1 Introduction

The U.S. Army Corps of Engineers New York District (NAN) are considering proposed surge barrier configurations in the New York/New Jersey Harbor (NYNJH). This hydrodynamic and salinity intrusion numerical model study investigates the impacts associated with these proposed surge barriers in the NYNJH during normal tidal conditions with all the structures open to flow.

Year-long Adaptive Hydraulics (AdH) three-dimensional numerical model simulations were performed for each alternative as well as a base model simulation without the structures in place. The AdH mesh used and modified in these simulations is the “With Project” mesh from McAlpin et al. 2020. The “Base” mesh utilized in this study is a representation of the 2004 bathymetric conditions with all deepening components associated with the 50 ft NYNJH project included (even those constructed after 2004) (see McAlpin et al. 2020 for additional details). Additional projects constructed or approved after this time are not included in the numerical mesh utilized in this study. Additional system modifications (if any have been constructed) will need to be included in future refinements of the tentatively selected plan. A mesh was made for each alternative by modifying the geometry of the original mesh to include the surge barriers. Water does not overtop the piers or barrier walls in these simulations. These areas are considered infinitely high. This should be an adequate assumption given storm conditions are not being modeled as part of this endeavor.

The inflow and tidal condition data are the 1995 conditions as detailed in McAlpin et al. 2020. There are no large storm events during this year, so the model is simulating normal or typical hydrologic and tidal conditions with only minor storm events making this an appropriate simulation time period considering the purposes of this study.

Note the McAlpin et al. 2020 study investigated the sediment transport behavior in the harbor and as such was not focused on resolving some peripheral areas. An example of this is the salinity intrusion up the Hudson River. This was not a primary concern for the sedimentation study and was considered sufficiently accurate for the purposes of the previous model study. This model should be reasonable for relative changes in salinity but will be deficient in predicting the absolute salinity values and extents of salinity intrusion up the Hudson River. Since the NYNJH was the focus area of the previous study, some resolution and schematization were utilized for peripheral areas to reduce time and computational demands during the NYNJH sedimentation study. The representation of the New Jersey Meadowlands marsh areas and associated schematization are an example of an engineering decision made to reduce the computational burden that was appropriate for the sedimentation study but may not be appropriate for evaluating tidal exchange associated with a structure on the Hackensack River. This study is in the feasibility stage and as such the aforementioned limitations do not preclude the use of this model. Depending on the chosen alternative, targeted model improvements can be completed to improve the model results for design level considerations.

Currently, there are four barrier alignments being considered (Alternative 2, Alternative 3a, Alternative 3b and Alternative 4). This set of alternatives are modifications of previous alternatives that have evolved based on other information and model results. This set is considered as alternative Set 4.

The emphasis of this study is to examine how each alternative will impact the system. Results will include point velocity, salinity, and water surface elevation model percentile comparisons, discharge comparisons, spatial figures of the 50th and 75th percentile velocities and salinities, and tidal prism percentiles for the areas impacted by the structures. Sediment transport simulations were completed and analyzed to investigate the impact of the structures on the sediment transport behavior. An analysis was also performed to determine the impact of sea level rise.

2 Alternative Configurations

Four alternative alignments were evaluated to determine the hydrodynamic and salinity transport impacts due to the system modifications.

2.1 Alternatives

The four alternatives included alignments that ranged from large scale bay-wide protection (Sandy Hook to Rockaway structures in Alignment 2) to smaller scale more localized protection of individual inlets/channels. Profile views of the structures are provided in Appendix A. Note structures present in multiple alternatives are equivalent in all of the alternatives. An example would be Jamaica Bay. This structure is consistent in Alternatives 3a, 3b, and 4. Table 1 provides a summary of the number of gates along with sill elevations for all of the structures. Table 2 lists which structures are included in which alternatives. Subsequent sections include figures illustrating the spatial locations of the structures.

Table 1. Structure Gate Numbers and Elevations.

Sandy Hook to Rockaway		
Gate Series	Number of Gates	Sill Elevation (Meters, MSL)
A	2	-4.504
B	1	-7.552
C	3	-4.504
D	12	-4.504
E	12	-6.028
F	27	-9.076
G	27	-4.504
H	1	-17.610
I	18	-4.504
J	6	-2.978
K	5	-4.502
L	35	-7.550
M	1	-12.122
Verrazano-Narrows		

A	1	-6.039
B	12	-18.231
C	1	-17.621
D	1	-13.659
E	2	-7.563
Throgs Neck		
A	1	-10.615
B	2	-13.663
C	7	-10.615
D	1	-12.139
E	5	-10.615
F	1	-7.567
G	1	-2.995
Kill Van Kull		
A	2	-8.482
B	3	-9.092
C	1	-16.712
Arthur Kill		
A	1	-3.021
B	1	-12.165
C	1	-3.021
Jamaica Bay		
A	1	-4.506
B	3	-6.030
C	3	-9.078
D	2	-5.725
E	8	-7.554
Hackensack River		
A	1	-2.993
B	8	-6.041
C	1	-6.955
D	4	-6.041
E	4	-2.993

Gawanus Canal		
A	1	-6.631
Newton Creek		
A	1	-5.731
Flushing Creek		
A	1	-2.9945
B	1	-6.3475
C	1	-2.9945
Sheepshead Bay		
A	1	-6.0292
B	1	-6.0292
C	1	-6.0292
Gerritsen Creek		
A	1	-2.9806
B	1	-5.7238
Coney Island Creek		
A	8	-3.000

Table 2. Alternative Structure List.

Structures	Alt 2	Alt 3a	Alt 3b	Alt 4
Sandy Hook to Rockaway	✓			
Verrazano Narrows		✓		
Throgs Neck	✓	✓		
Kill Van Kull			✓	
Arthur Kill		✓	✓	
Jamaica Bay		✓	✓	✓
Hackensack River				✓
Gowanus Canal			✓	✓
Newton Creek			✓	✓
Flushing Creek			✓	✓
Sheepshead Bay		✓	✓	✓
Gerritsen Creek		✓	✓	✓
Coney Island Creek		✓	✓	✓

2.1.1 Alternative 2

Alternative 2 consists of two structures with the proposed structures all shown in Figure 1. Figure 2 shows the Sandy Hook to Rockaway structure configuration. Figure 3 shows the Throgs Neck structure configuration.

Figure 1. Alternative 2 Alignment.

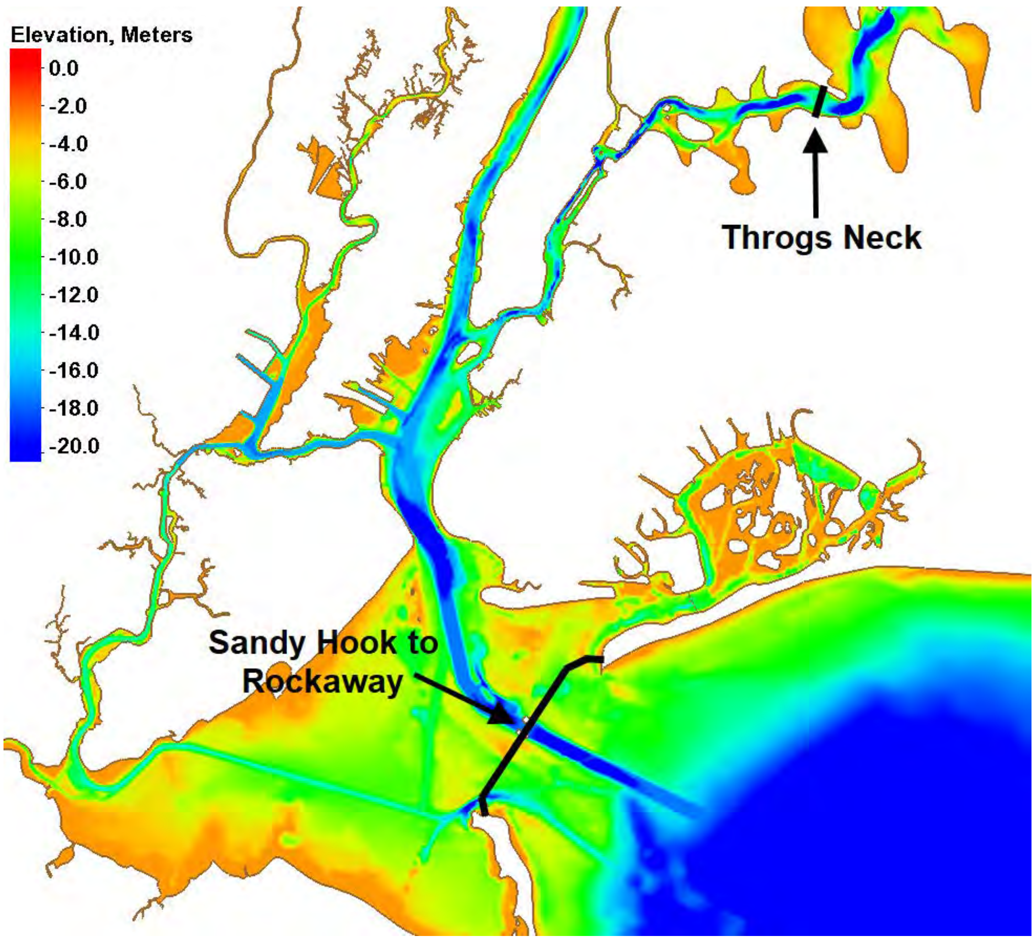


Figure 2. Alternative 2 Sandy Hook to Rockaway Structure.

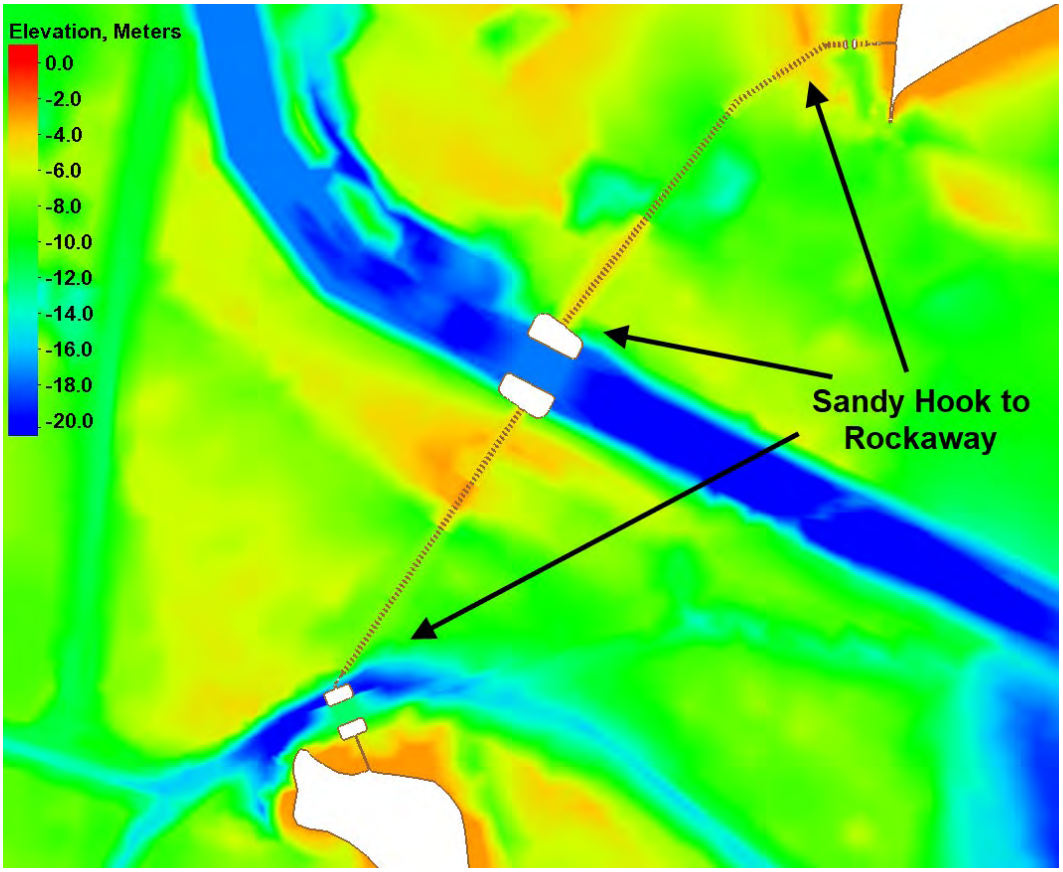
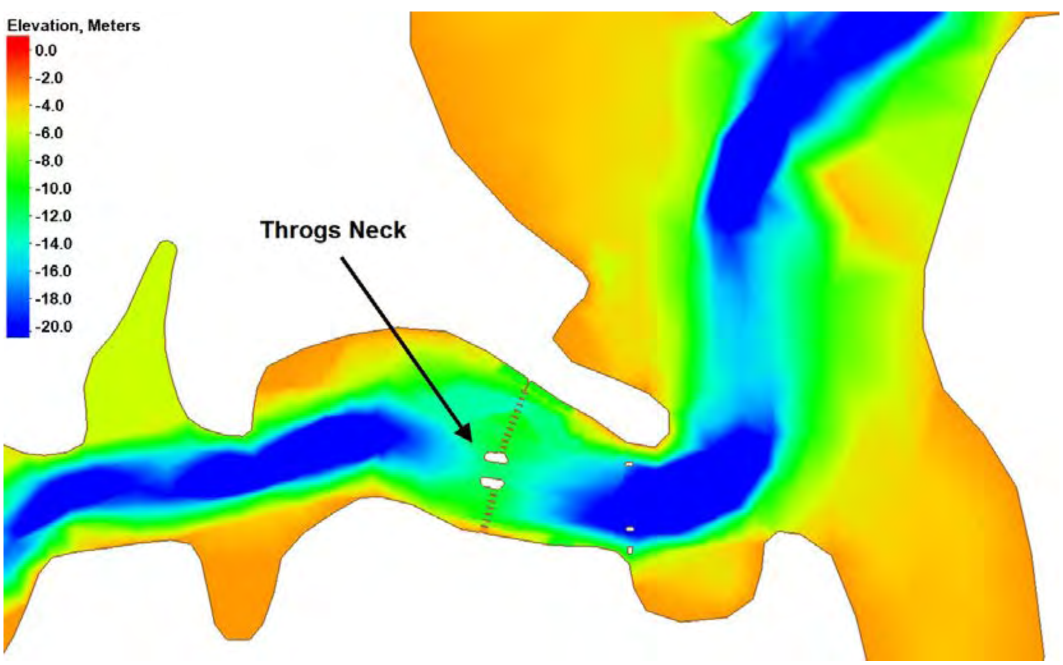


Figure 3. Alternative 2 Throgs Neck Structure.



2.1.2 Alternative 3a

Alternative 3a consists of seven structures with the proposed structures all shown in Figure 4. The Throgs Neck Structure in Alternative 3a is aligned the same as Alternative 2 as previously depicted in Figure 3. The Arthur Kill, Verrazano Narrows, Jamaica Bay, Gerritsen Creek and Sheepshead Bay, and Coney Island structures are shown in Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9, respectively.

Figure 4. Alternative 3a Alignment.

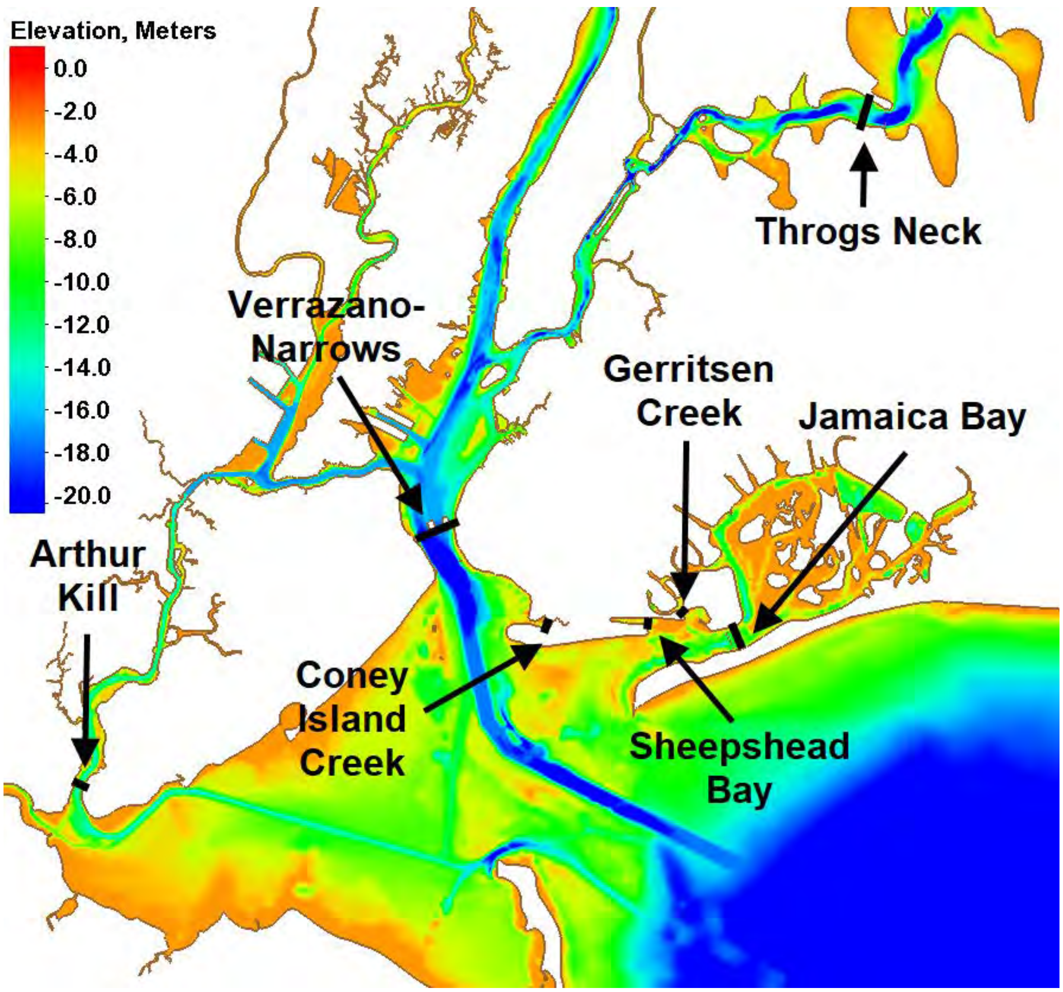


Figure 5: Alternative 3a Arthur Kill Structure.

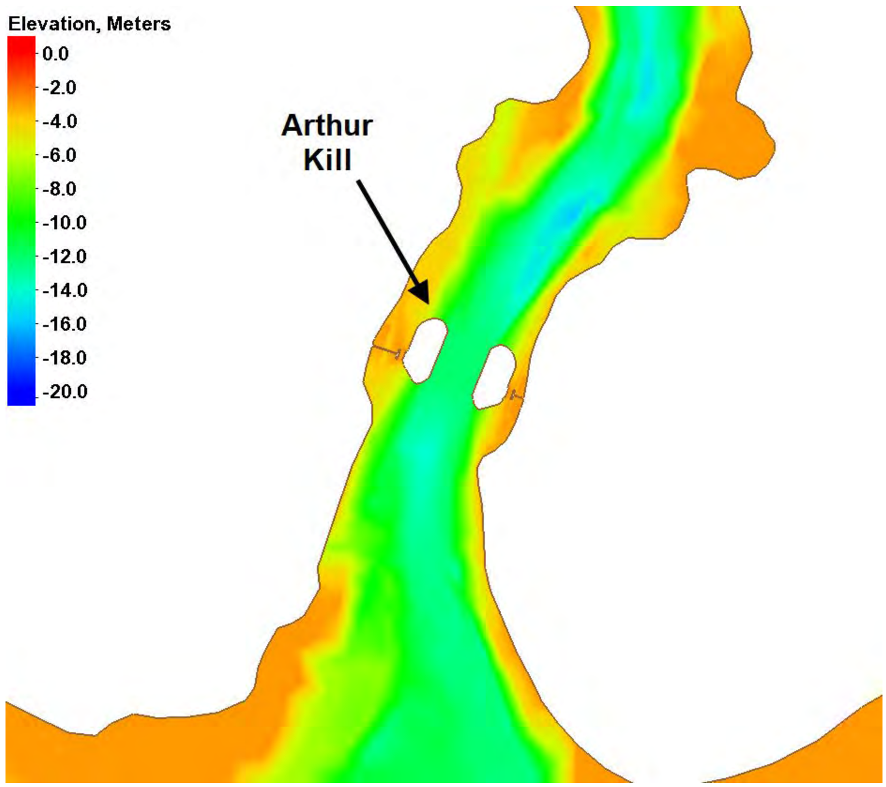


Figure 6: Alternative 3a Verrazano-Narrows Structure.

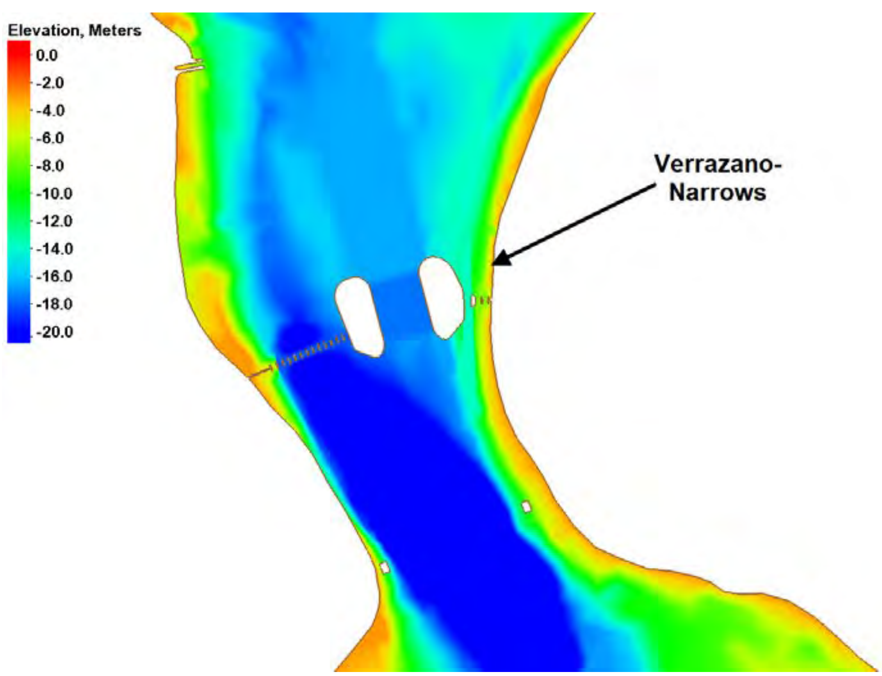


Figure 7. Alternative 3a Jamaica Bay Structure (piers on left are associated with the existing Marine Parkway bridge).

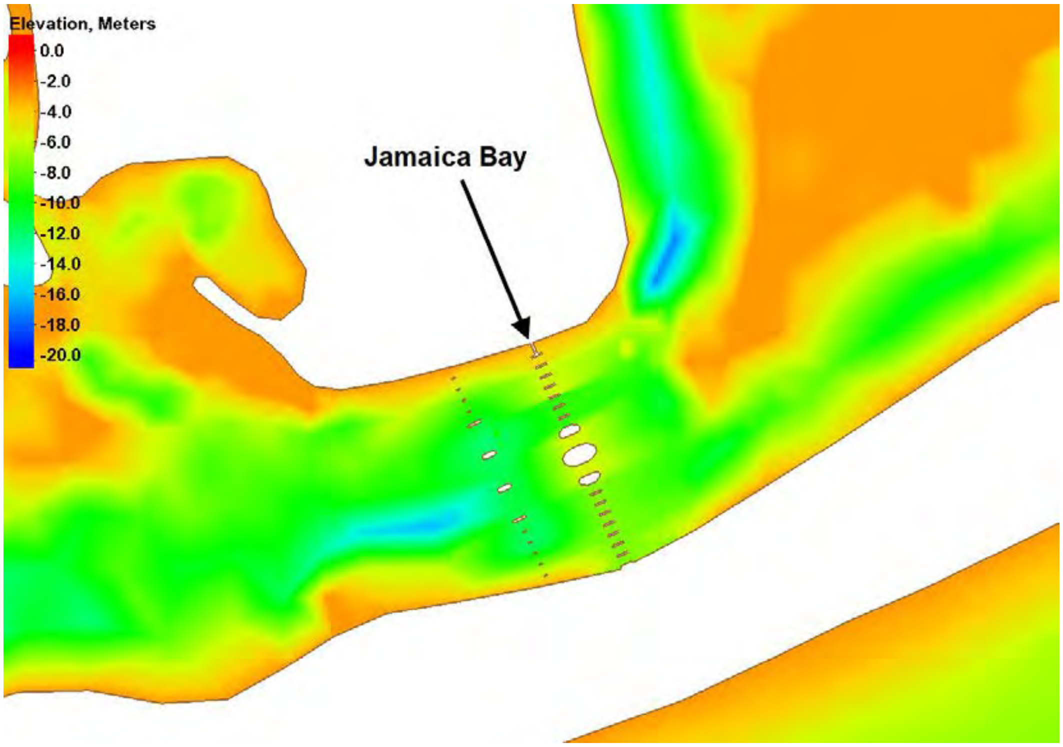
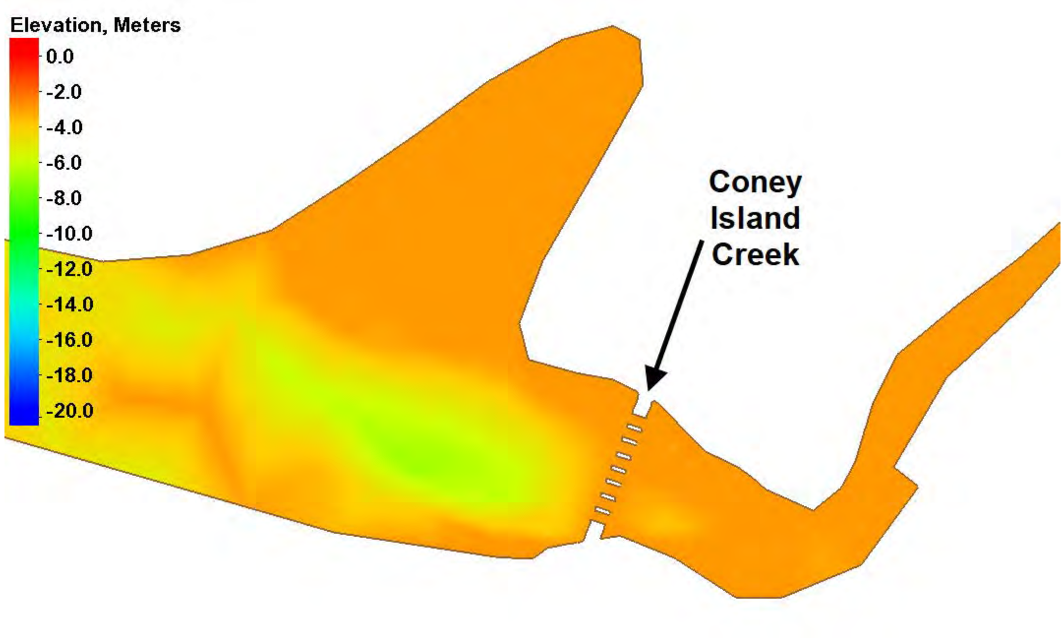


Figure 8. Alternative 3a Gerritsen Creek and Sheepshead Bay Structures.

Figure 9. Alternative 3a Coney Island Creek Structure.



2.1.3 Alternative 3b

Alternative 3b consists of nine structures with the proposed structures all shown in Figure 10. The Arthur Kill, Jamaica Bay, Gerritsen Creek, Sheepshead Bay, and Coney Island Structures in Alternative 3b are aligned the same as previously shown in Alternative 3a. The Kill Van Kull, Gowanus Canal, Newton Creek and Flushing Creek structures are shown in Figure 11, Figure 12, Figure 13, and Figure 14, respectively.

Figure 10. Alternative 3b Alignment.

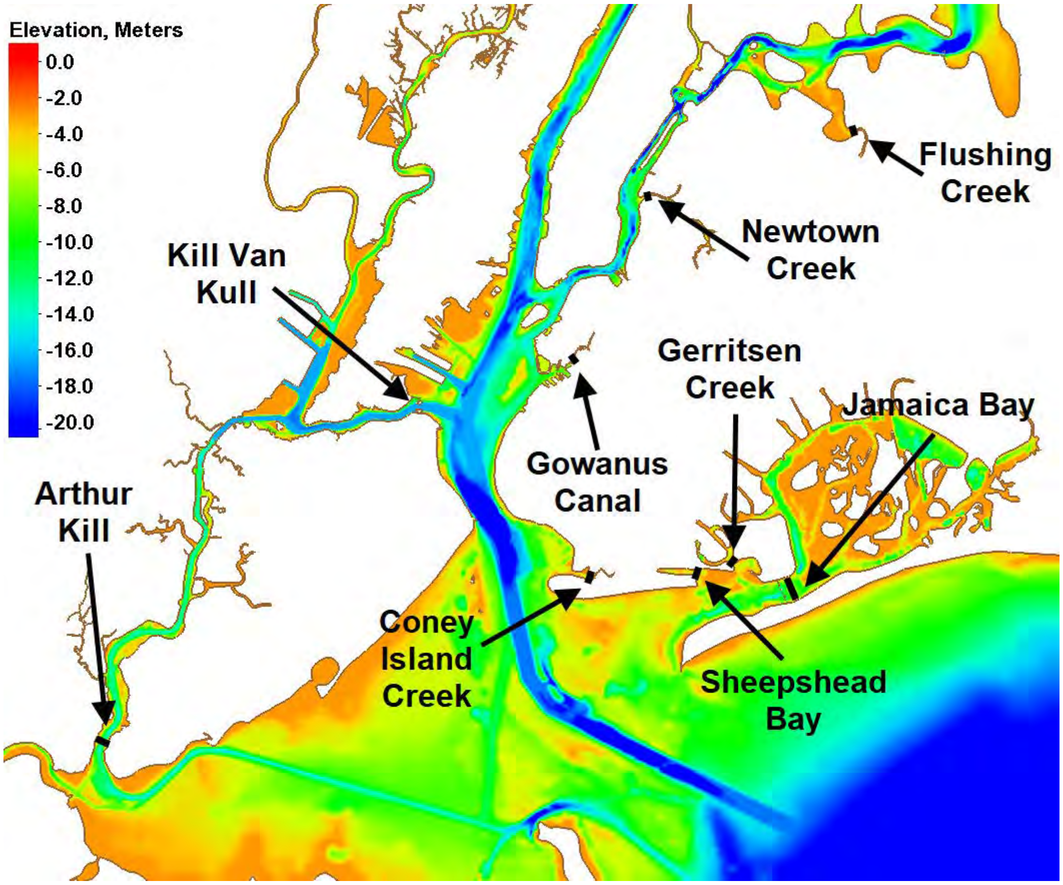


Figure 11. Alternative 3b Kill Van Kull Structure.

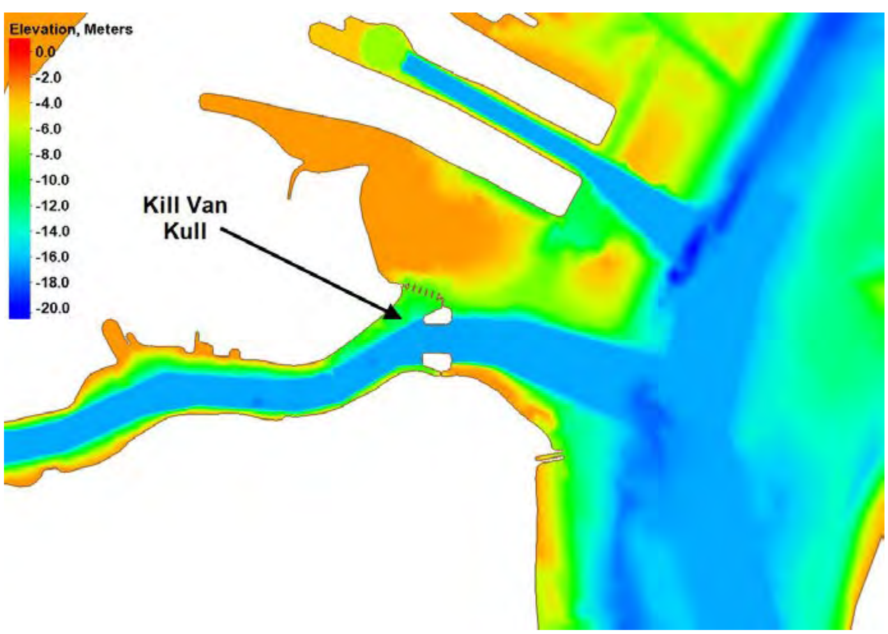


Figure 12. Alternative 3b Gowanus Canal Structure.

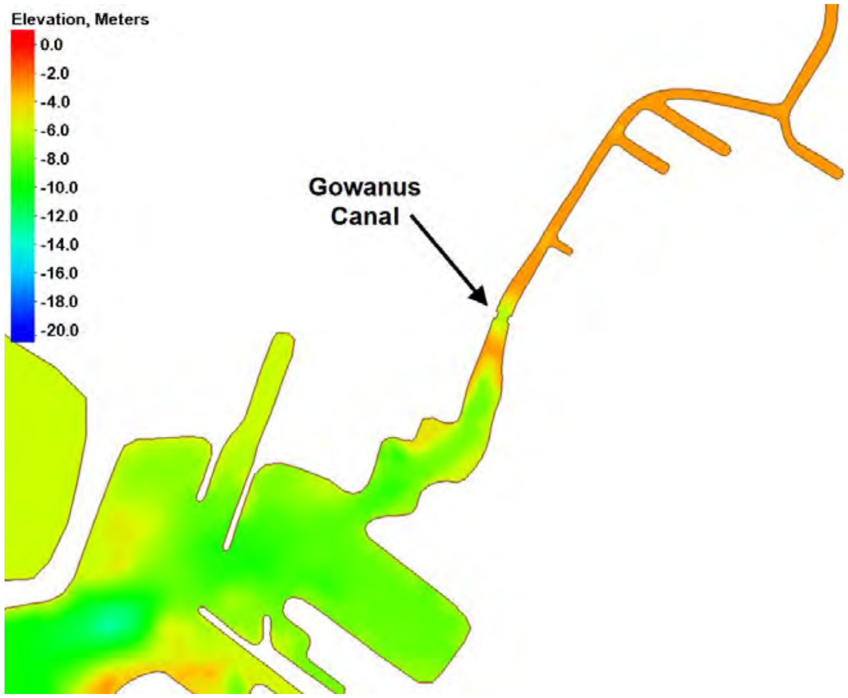


Figure 13. Alternative 3b Newton Creek Structure.

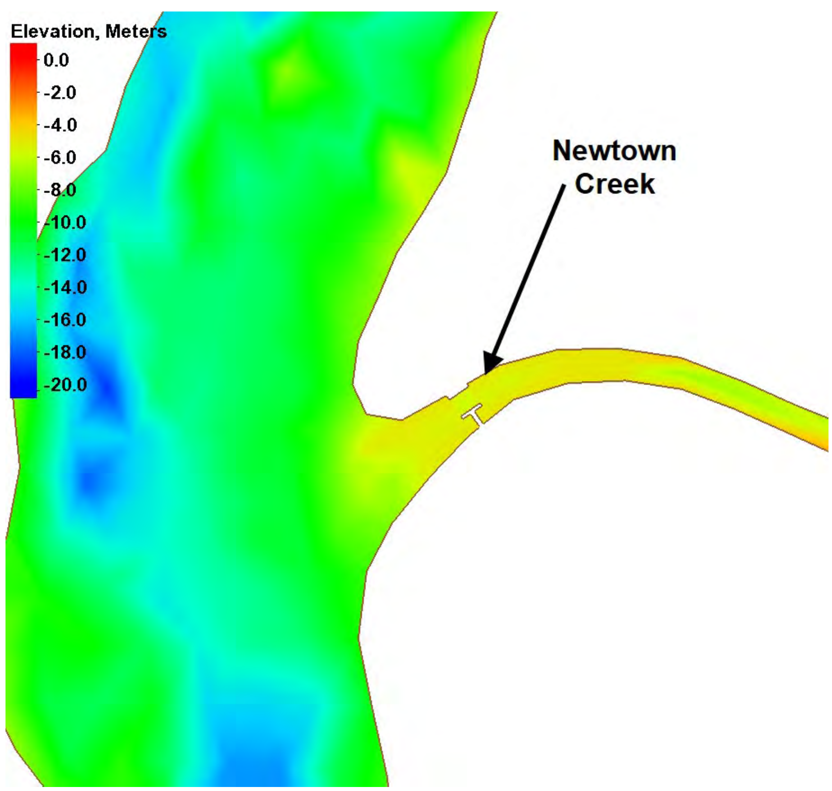
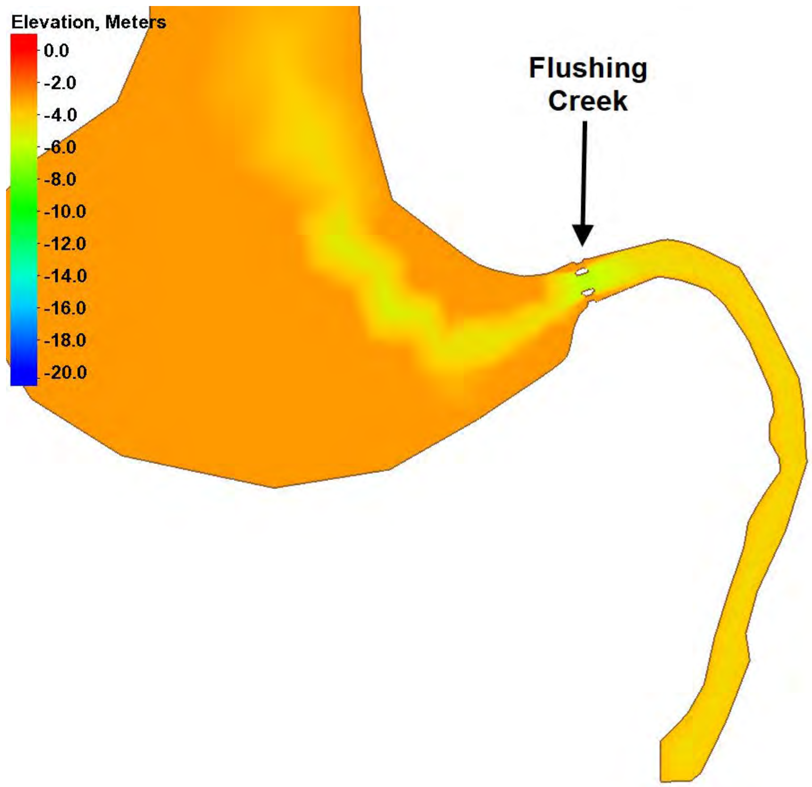


Figure 14. Alternative 3b Flushing Creek Structure.



2.1.4 Alternative 4

Alternative 4 consisted of eight structures with the proposed structures all shown in Figure 15. The Jamaica Bay, Sheepshead Bay, Gerritsen Creek, Coney Island, Gowanus Canal, Newtown Creek, and Flushing Creek Structures in Alternative 4 are aligned the same as previously shown in Alternatives 3a and 3b. The Hackensack River structure is shown in Figure 16.

Figure 15. Alternative 4 Alignment.

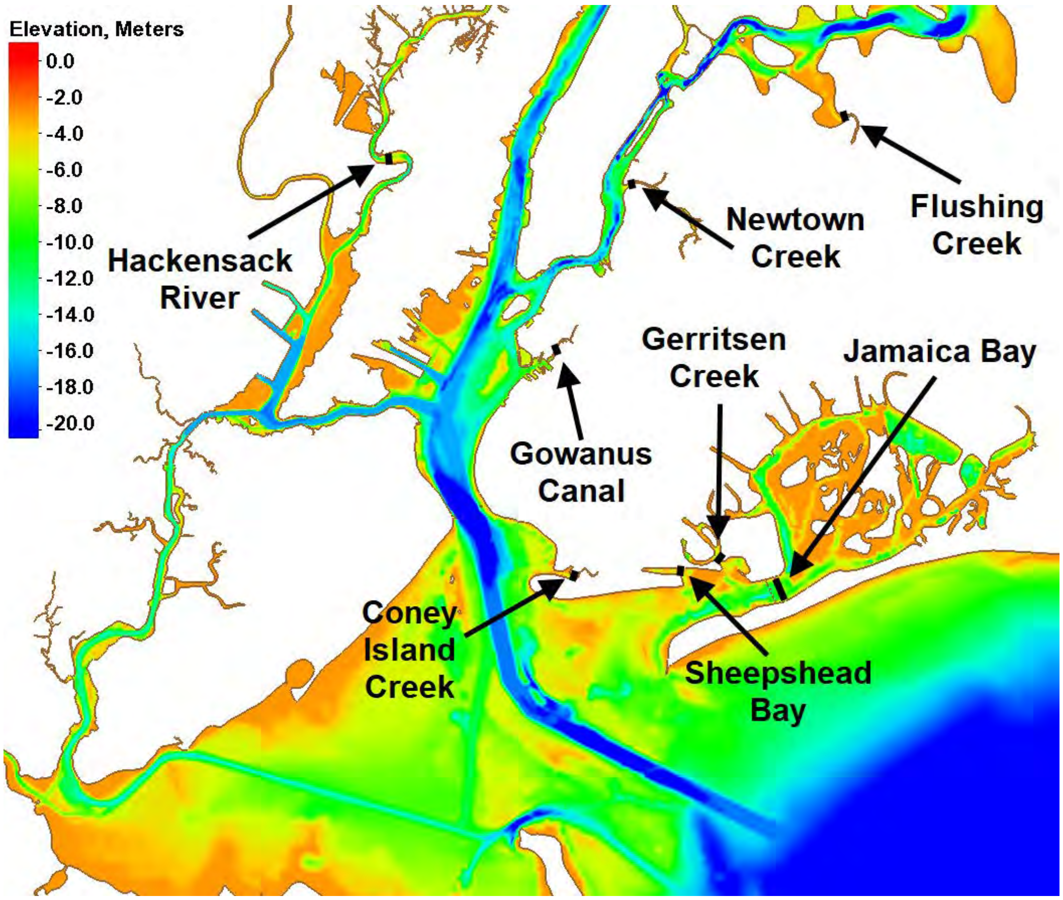
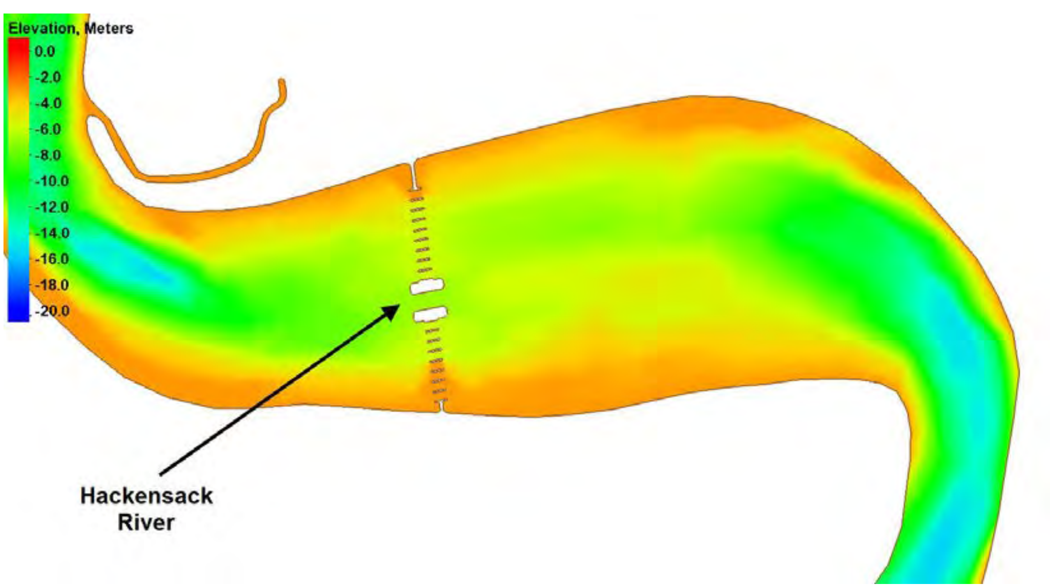


Figure 16. Alternative 4 Hackensack Structure.



3 Model Results

3.1 Model Results and Analysis

The four alternatives were compared to the without project/base simulation to determine the impact of the alternatives on water levels, velocities, salinities, and tidal prisms/exchange. The analysis for the alternatives is provided in the following sections and consist of point water surface elevation percentiles, velocity percentiles, salinity percentiles, spatial comparisons of the 50th and 75th percentile velocities and salinities, discharges, and tidal prism percentiles for the areas impacted by the proposed structures.

3.1.1 Point Comparisons

Point information was extracted from the model results at the locations shown in Figure 17 to Figure 20. The State Plane, New Jersey, NAD83, Meters coordinates for the comparison points are provided in Table 3.

Figure 17. Analysis Point Locations.

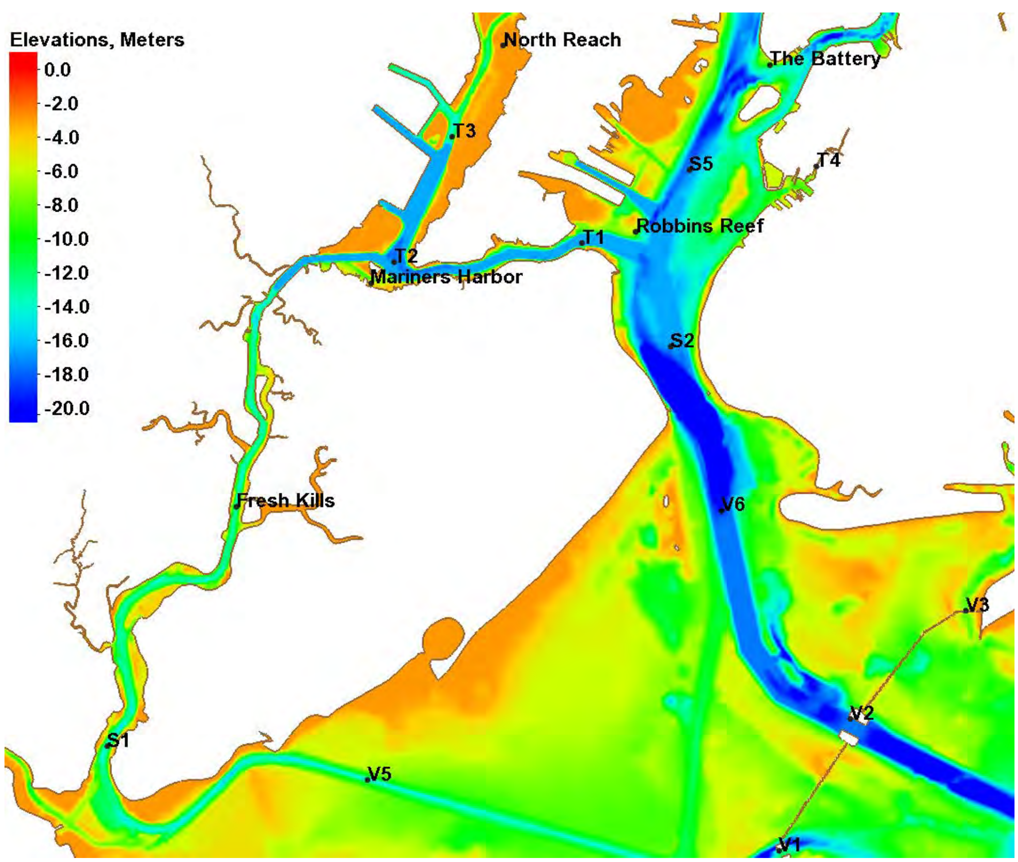


Figure 18. Analysis Point Locations.

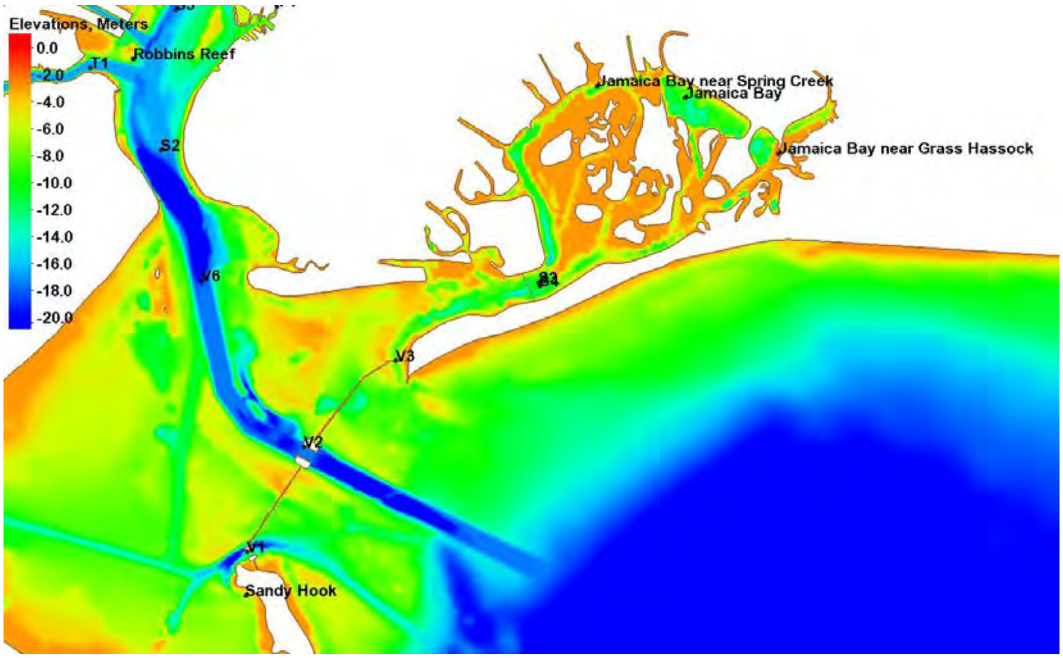


Figure 19. Analysis Point Locations.

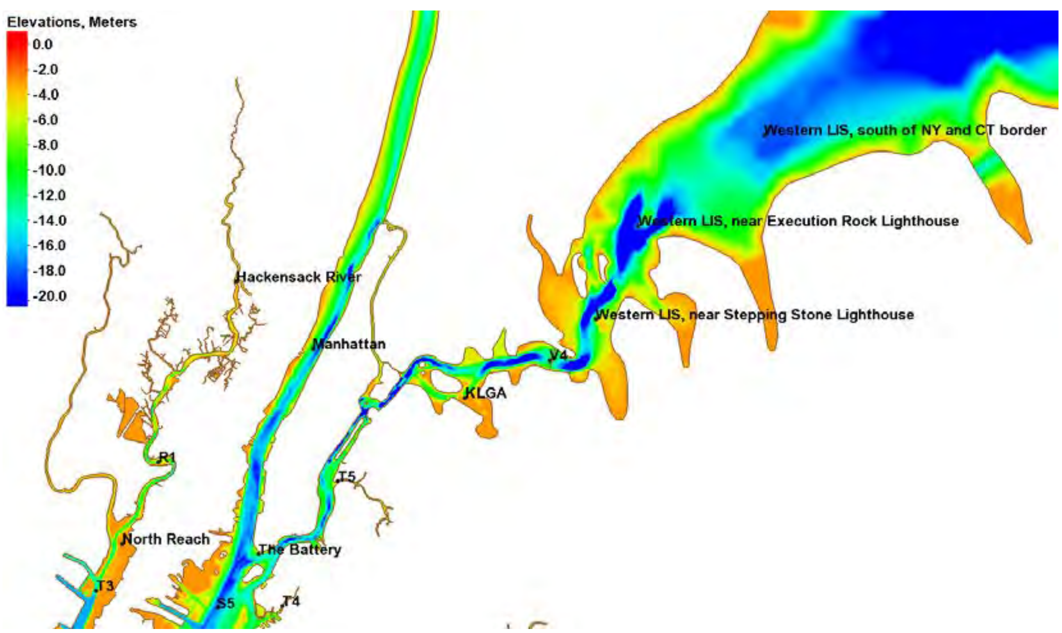


Figure 20. Analysis Point Locations.

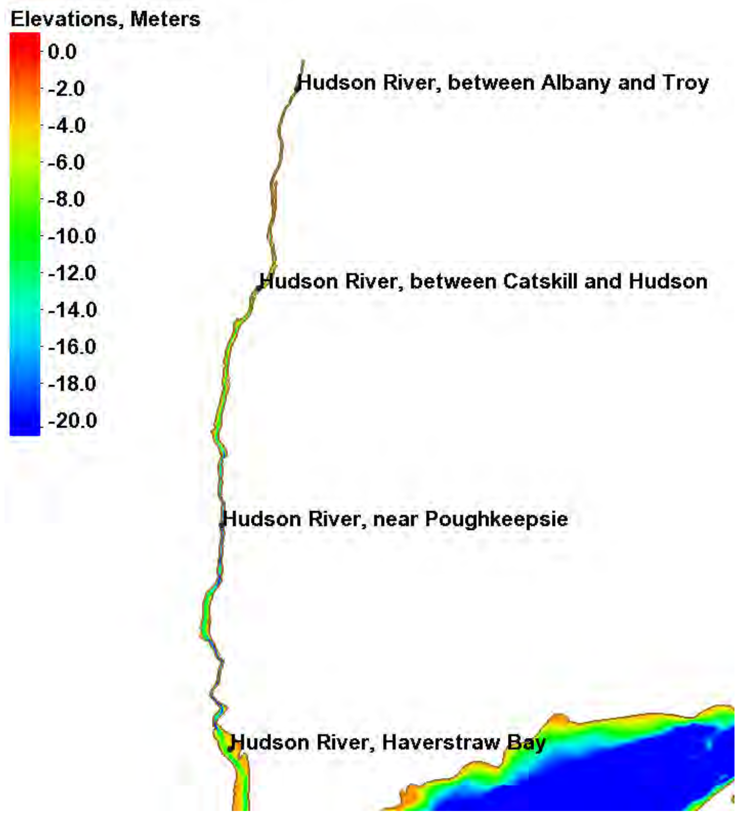


Table 3. Comparison Point Locations (Coordinates are in New Jersey State Plane, Meters).

Point Name	X Coordinate, Meters	Y Coordinate, Meters
V1	191234.602	183154.848
V2	193417.614	187203.309
V3	196963.184	190522.773
V4	208416.48	218892.716
V5	178600	185324
V6	189470	193590
S1	170615.825	186363.017
S2	187907.969	198626.074
S3	202472.5	193523.2
S4	202516.407	193399.149
S5	188484	204042
T1	185179.201	201804.443

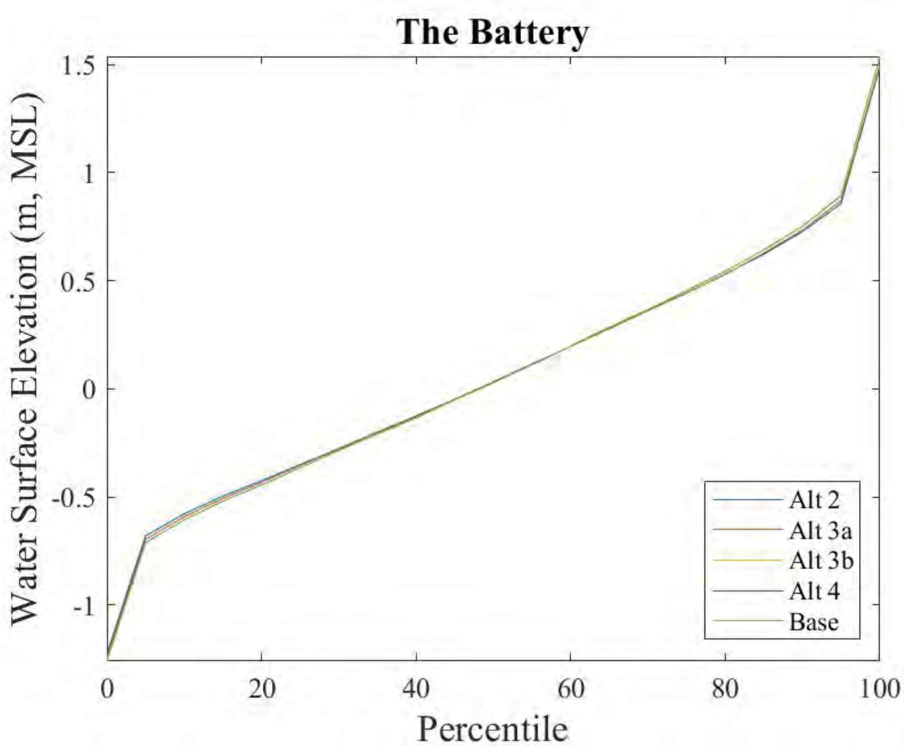
T2	179415	201218
T3	181198	205065
T4	192376.34	204154.95
T5	195705.4	211632.7
R1	184926.453	212774.886
Fresh Kills	174577.201	193709.679
Sandy Hook	191179.86	181472.903
Jamaica Bay	208109.77	200637.052
Jamaica Bay near Spring Creek	204729.5	201095.2
Jamaica Bay near Grass Hassock	211710.5	198495.8
Robbins Reef	186830.1	202145.6
Battery	190949.272	207264.687
KLGA	203326.106	216629.785
Mariners Harbor	178710.9	200567.6
North Reach	182763.8	207867.2
Manhattan	194225.799	219580.685
Hackensack River	189586.2	223603.5
Western LIS, near Stepping Stone Lighthouse	211180.8	221349.4
Western LIS, near Execution Rock Lighthouse	213720	226935
Western LIS, south of NY and CT border	221282	232377
Hudson River, Haverstraw Bay	198261	262168
Hudson River, near Poughkeepsie	196115	318986
Hudson River, between Catskill and Hudson	205472.4	379109.5
Hudson River, between Albany and Troy	215182	429604

3.1.1.1 Water Surface Elevation Point Comparisons

An analysis of the water surface elevation impacts of the proposed barriers was performed through the investigation of water surface elevation percentiles for the locations previously discussed in this chapter. The locations near field of structures were not analyzed as the draw down in water levels due to the increased velocities through the structures impacted results differently for the various alternatives. To prevent misleading conclusions, these locations were omitted.

Figure 21 shows the percentile water surface elevations for The Battery. This figure illustrates the slight reduction in the high and low water levels associated with Alternatives 2 and 3a with Alternatives 3b and 4 having minimal impact. Plots of the remaining locations are provided in Appendix B.

Figure 21. Water Surface Elevation Percentiles for The Battery.



An analysis of the tide ranges and amplification/reduction in tide ranges was also determined. In order to analyze the impact solely on the tide itself, each water surface elevation time series from the model was first decomposed into harmonic constituents. The harmonic constituents used were the M2, K1, O1, S2, N2, M4, and M6. These constituents were chosen because they are the major contributors at The Battery, NY NOAA Station. The decomposition process was done using a least squares regression with the following equations:

$$R_i = \sqrt{{a_i}^2 + {b_i}^2}$$

$$\omega_i = \frac{360^{\circ}}{T_i}$$

$$\xi_i = \tan^{-1} \frac{b_i}{a_i}$$

where

$$R = \text{amplitude}$$

$$\omega = \text{speed}$$

$$T = \text{period}$$

$$\xi = \text{phase}$$

$$i = \text{constituent}$$

$a \ and \ b =$ coefficients for the least squares regression used in the following equation

$$h(t) = H_0 + \sum_{i=1}^{K} a_i \cos(\omega_i \cdot t) + \sum_{i=1}^{K} b_i \sin(\omega_i \cdot t)$$

where

$$t = \text{time}$$

$$h = \text{height}$$

$$H_0 = \text{mean height}$$

$$K = \text{total number of constituents}$$

Then, using the amplitude, speed, and phase, a new water surface elevation time series was generated with Equation 3.1 from Parker (2007). From the newly generated water surface elevation series, an average of the high and low water surface elevations was calculated. The average tide range was determined by taking the difference between the average high and average low water surface elevations. The percentage changes in the tide ranges are provided in Table 4 with areas of larger changes highlighted in red and lesser changes in pink. For this analysis, differences of less than 0.25 % are considered insignificant.

Table 4. Tide Range changes due to the proposed alternatives.

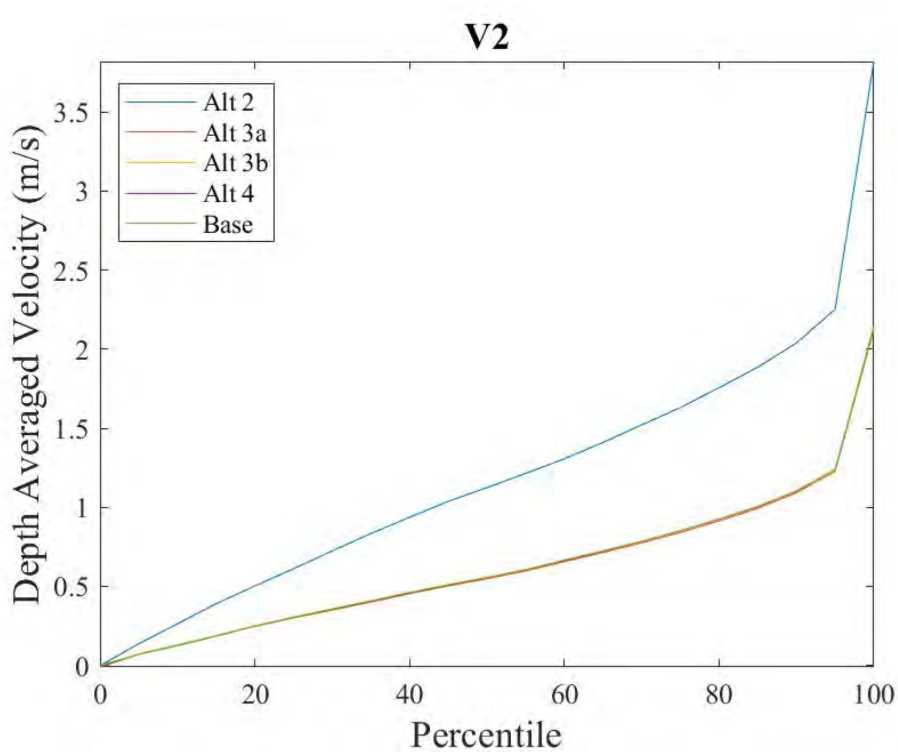
Tide Range Differences (%)				
Point Name	Alt 2	Alt 3a	Alt 3b	Alt 4
Sandy Hook	-4.3	-0.1	-0.1	0.0
V5	-4.4	-0.1	-0.1	0.0
V6	-4.3	0.0	-0.1	0.0
Fresh Kills	-4.1	-1.6	-0.3	-0.1
Mariners Harbor	-3.7	-2.5	-0.1	-0.1
T2	-3.7	-2.5	-0.1	-0.1
T3	-3.6	-2.5	-0.1	-0.1
North Reach	-3.5	-2.5	-0.1	-0.2
Hackensack River	-2.9	-2.3	-0.1	-1.3
Robbins Reef	-3.7	-2.9	-0.1	0.0
S2	-3.9	-1.1	-0.1	0.0
S5	-3.6	-2.8	-0.1	0.0
The Battery	-3.3	-2.6	-0.1	-0.1
Manhattan	-3.1	-2.5	-0.1	-0.1
Jamaica Bay	-3.0	-0.7	-0.7	-0.7
Jamaica Bay, near Spring Creek	-2.9	-0.7	-0.6	-0.6
Jamaica Bay, near Grass Hassock	-3.07	-0.8	-0.7	-0.7
KLGA	-0.7	-1.0	0.0	0.0
Western LIS, near Stepping Stone Lighthouse	0.0	-0.2	0.0	0.0
Western LIS, near Execution Rock Lighthouse	0.0	-0.2	0.0	0.0
Western LIS, south of NY and CT border	0.0	-0.2	0.0	0.0
Hudson River, Haverstraw Bay	-1.8	-1.7	-0.1	-0.1
Hudson River, near Poughkeepsie	-1.8	-1.7	-0.1	-0.1
Hudson River, between Catskill and Hudson	-1.0	-1.1	0.0	0.0
Hudson River, between Albany and Troy	-0.9	-1.1	-0.1	-0.1

Red – Differences larger than 2 %, Pink – Differences between 0.5 and 2 %.

3.1.1.2 Velocity Percentiles

The three-dimensional velocities were depth averaged with a percentile exceedance analysis performed to determine the impact of the structures on velocity values both in the structures and far field of the structures. An example of the results is provided in Figure 22 for location V2 with the remaining percentile plots provided in Appendix C. In Figure 22, notice the increase in velocities for Alternative 2. This is due to the presence of the Ambrose channel structure at this location. The remaining alternatives are essentially unchanged from the without project configuration.

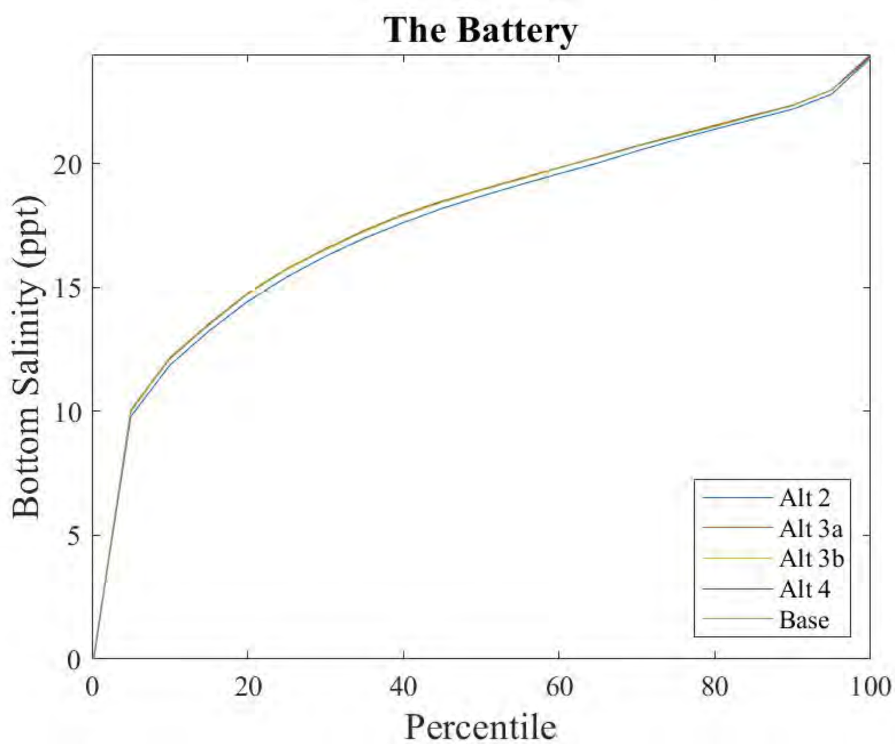
Figure 22. Velocity percentile plot for location V2.



3.1.1.1 Salinity Percentiles

The bottom layer salinities from the three-dimensional model were utilized with a percentile exceedance analysis to determine the impact of the structures on bottom water layer salinity values. An example of the results is provided in Figure 23 for The Battery with the remaining percentile plots provided in Appendix D. Figure 23 illustrates the reduced salinity intrusion for Alternative 2.

Figure 23. Bottom Salinity percentile analysis for The Battery location.



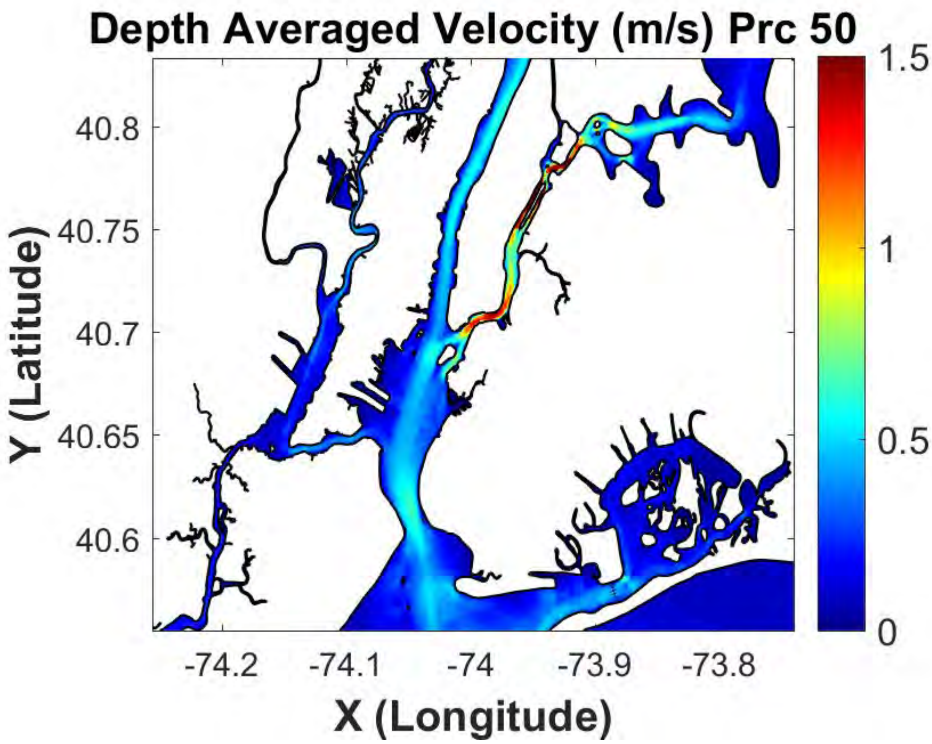
3.1.2 Spatial Percentile Analysis

The 50th and 75th percentile depth average velocities and bottom water layer salinities throughout the entire mesh were calculated to create spatial figures of these parameters. This gives visual indications of the more global impacts of the barriers on the velocities and salinity transport in the system.

3.1.2.1 Spatial Velocity Percentiles

The spatial plots of the 50th and 75th percentiles of the depth averaged velocities for the without project conditions are provided in Figure 24 and Figure 25 for Lower and Upper Bay. The spatial plots for the alternatives are provided in Appendix E.

Figure 24. Base, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Averaged Velocities.



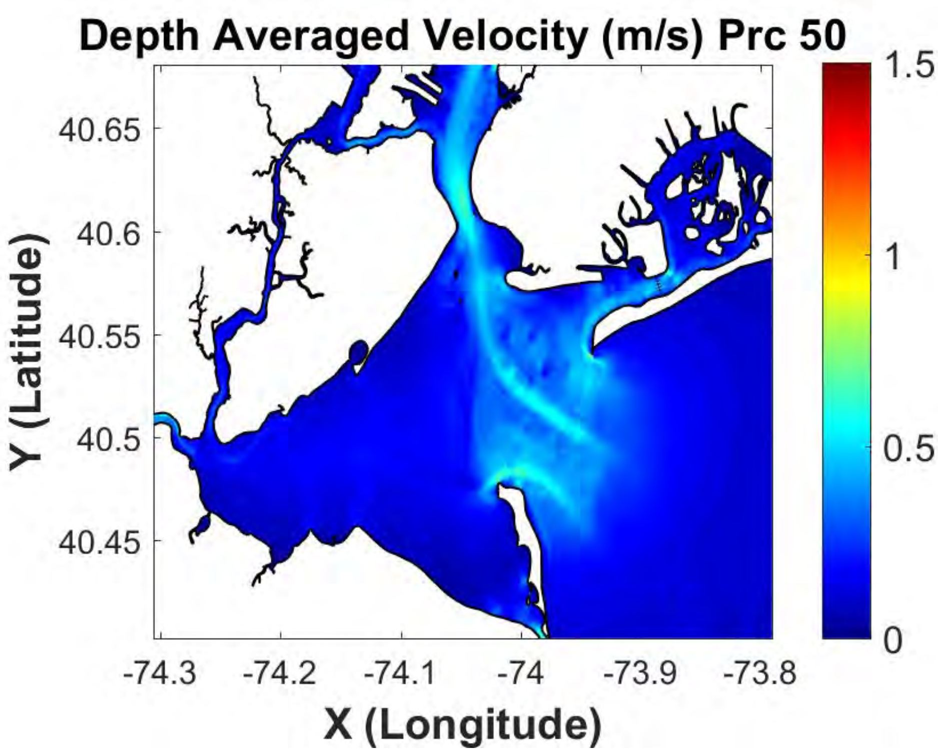
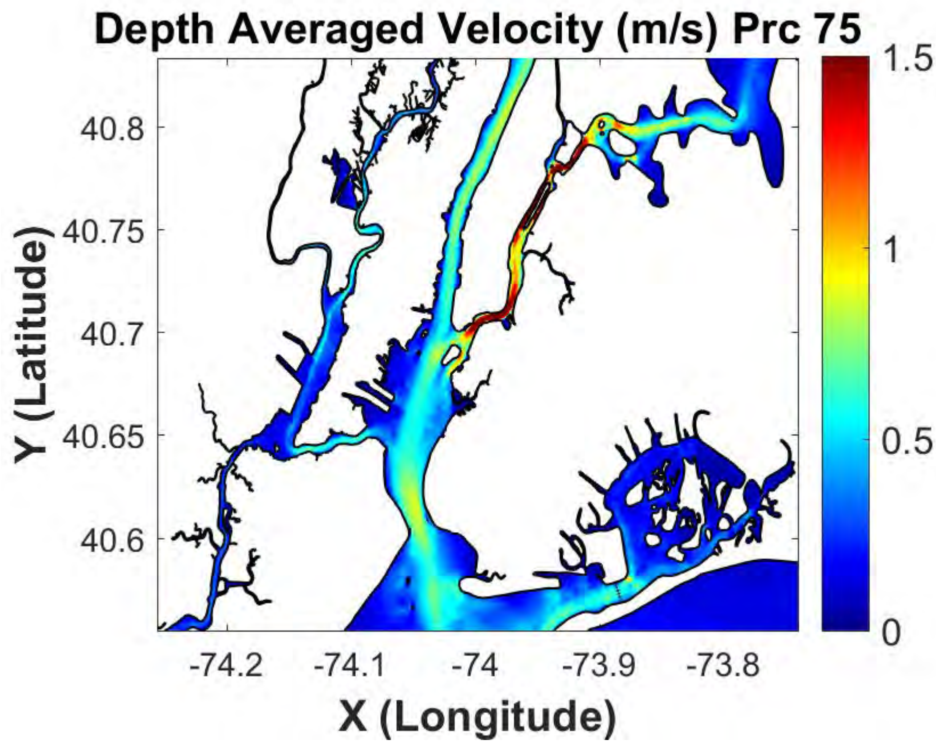
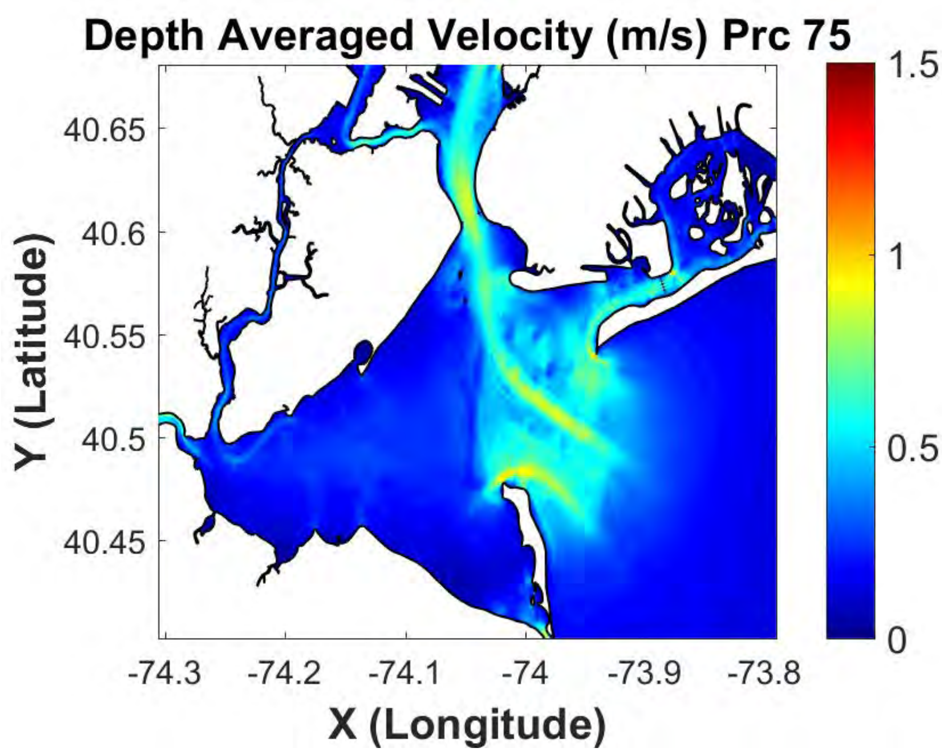


Figure 25. Base, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Averaged Velocities.

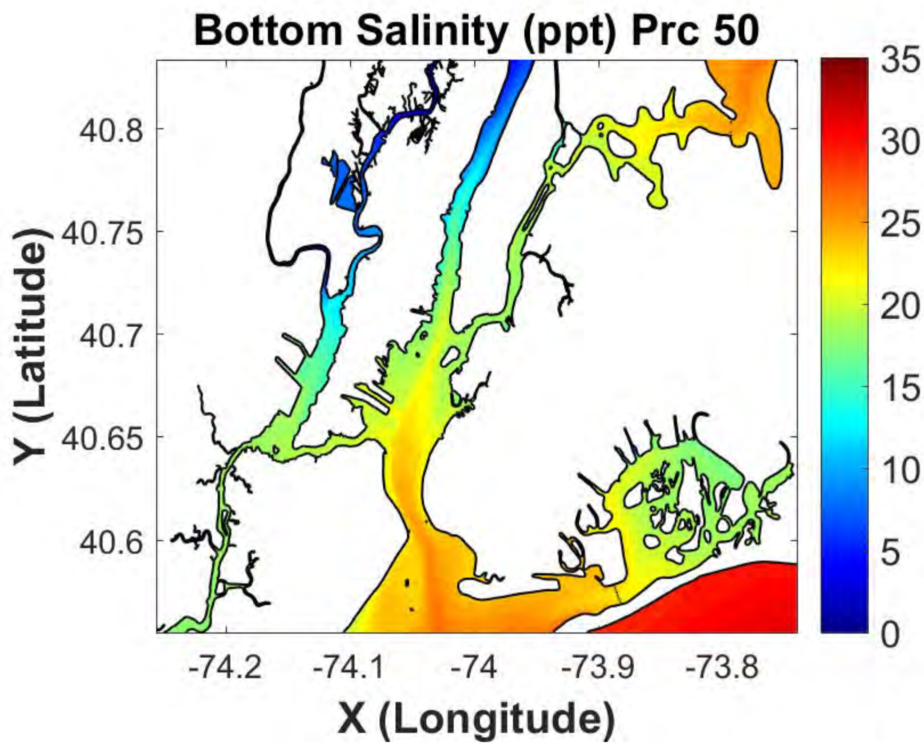




3.1.2.2 Spatial Salinity Percentiles

The spatial plots of the 50th and 75th percentiles of the bottom salinity for the without project conditions are provided in Figure 26 and Figure 27 for Lower and Upper Bay. The spatial plots for the alternatives are provided in Appendix F.

Figure 26. Base, Upper Bay (top) and Lower Bay (bottom) 50th percentile bottom salinities.



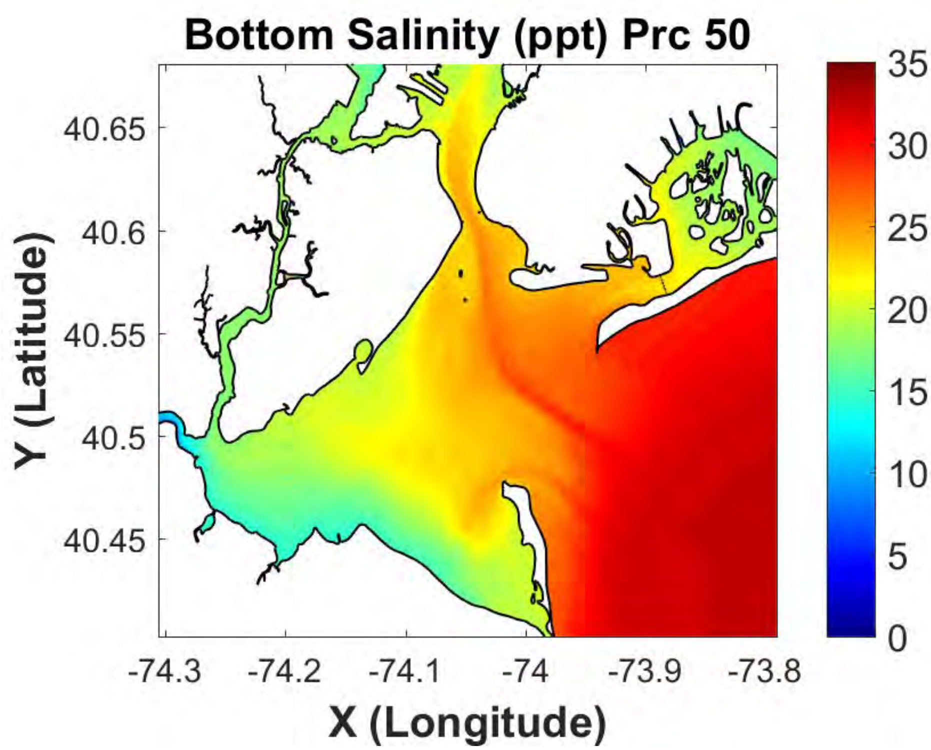
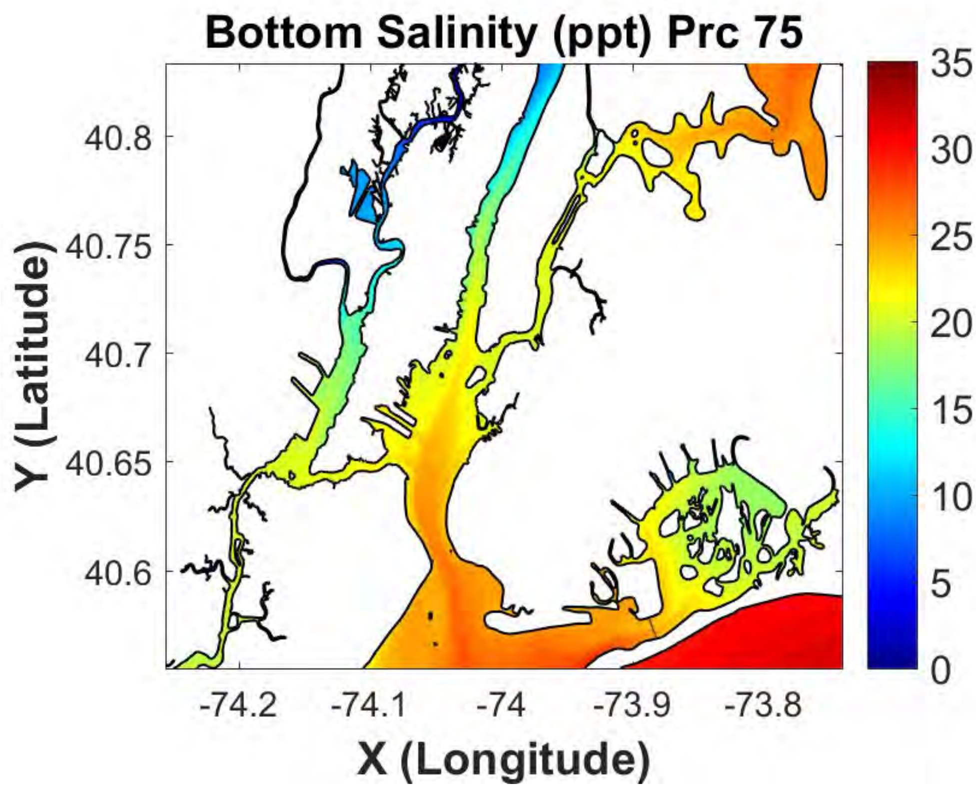
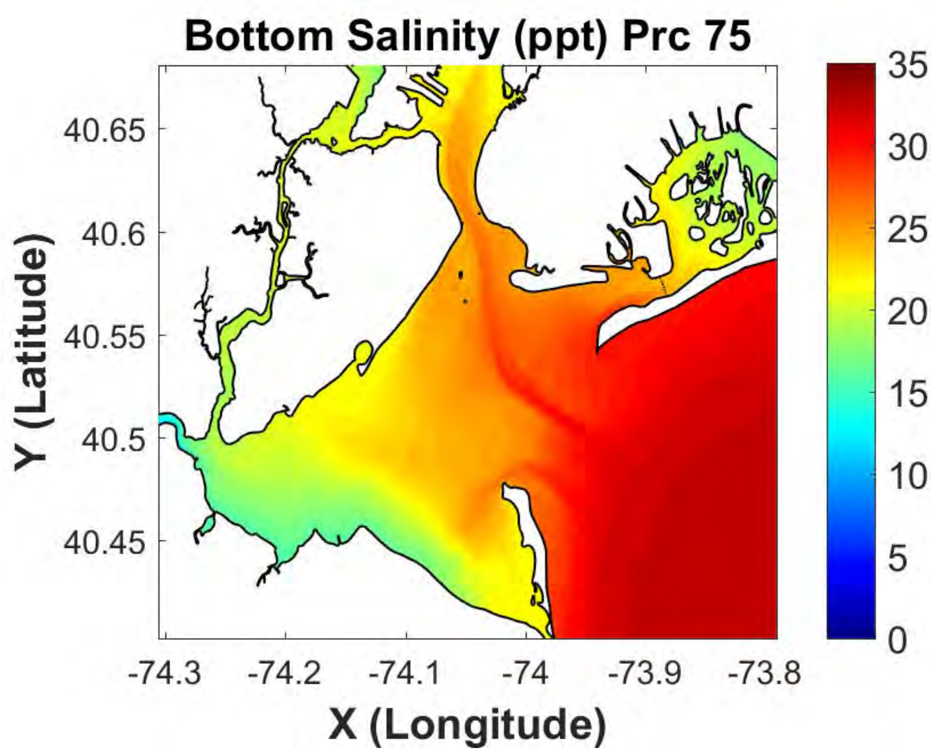


Figure 27. Base, Upper Bay (top) and Lower Bay (bottom) 75th percentile bottom salinities.





3.1.3 Water Flux Analysis

The numerical model output was utilized to calculate the flux of water at several locations (Figure 28) for each outputted time step (1-hour increments) to investigate the impact of the barrier alternatives on the water flow pathways. A percentile analysis was performed on those flux values and plotted for the base and alternative conditions. The Throgs Neck, Verrazano Narrows, Kill Van Kull, and Arthur Kill discharge percentiles are provided in Figure 29, Figure 30, Figure 31, and Figure 32, respectively. Mean flows are provided in Table 5.

Figure 28. Locations with discharge calculations.

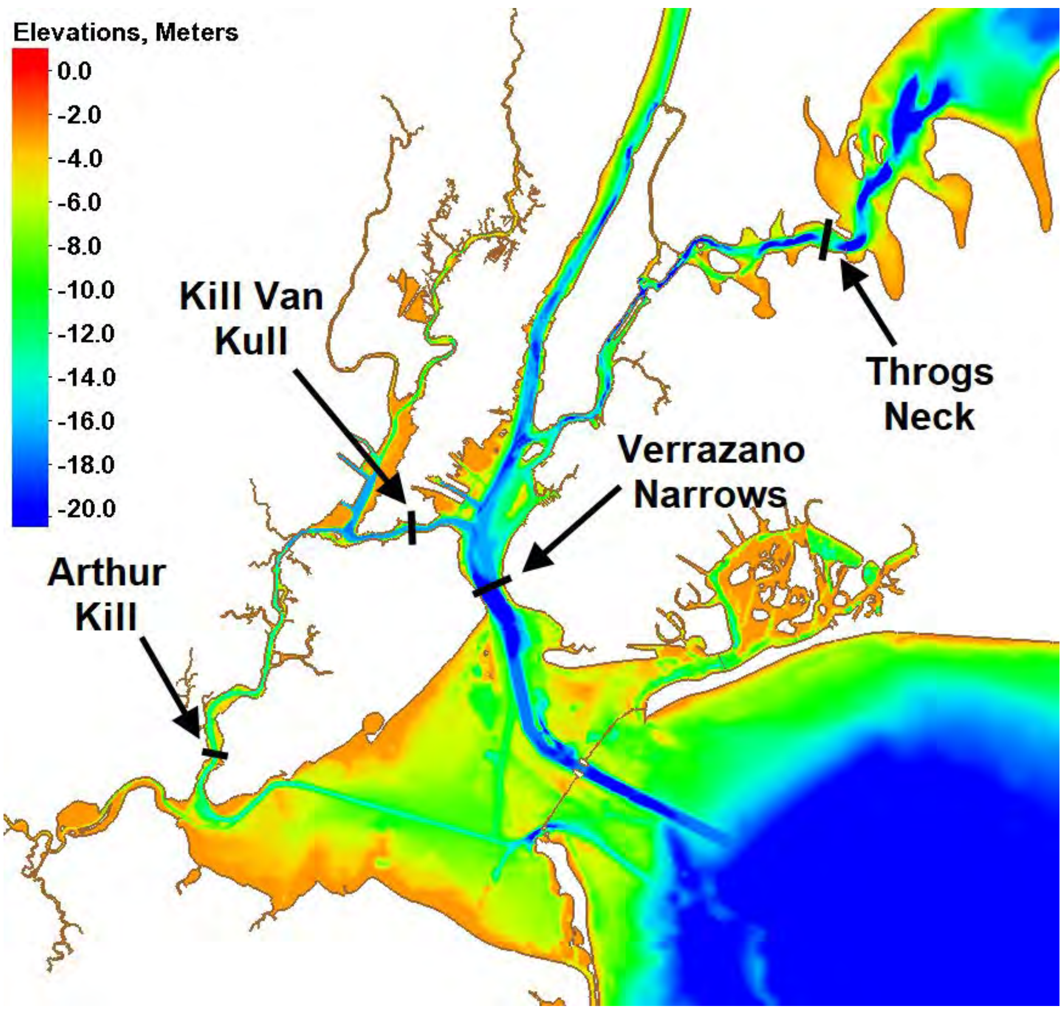


Figure 29. Discharge Percentiles for the Throgs Neck Location.

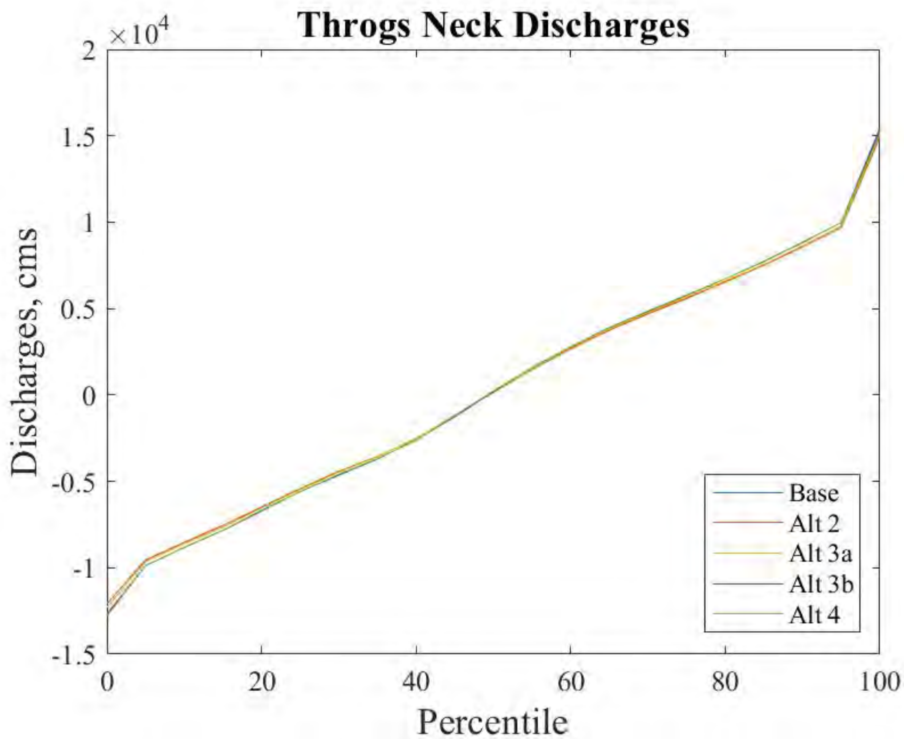


Figure 30. Discharge Percentiles for the Verrazano Narrows Location.

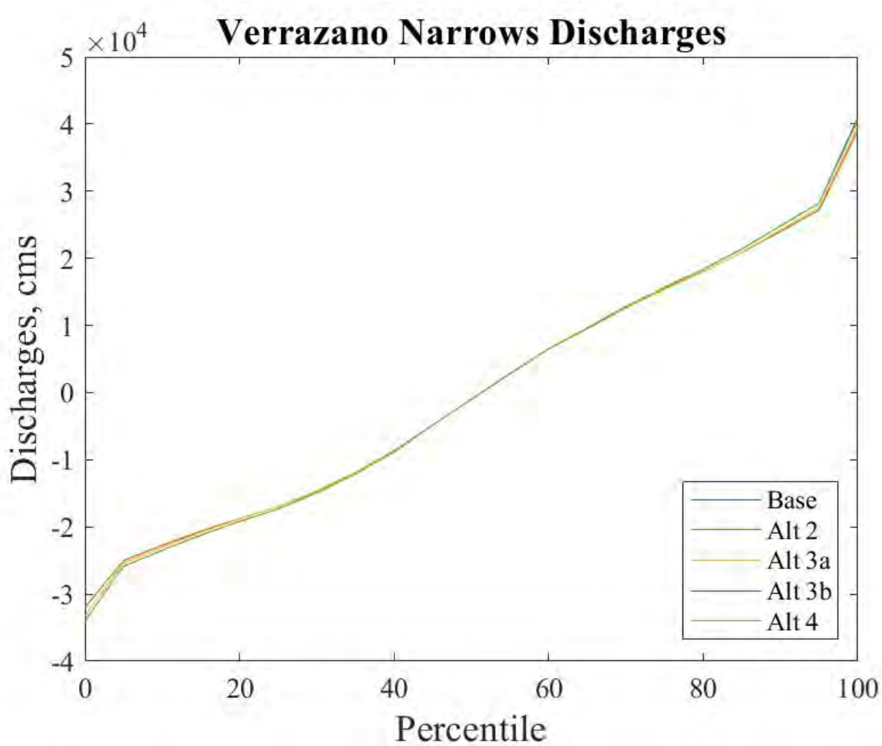


Figure 31. Discharge Percentiles for the Kill Van Kull Location.

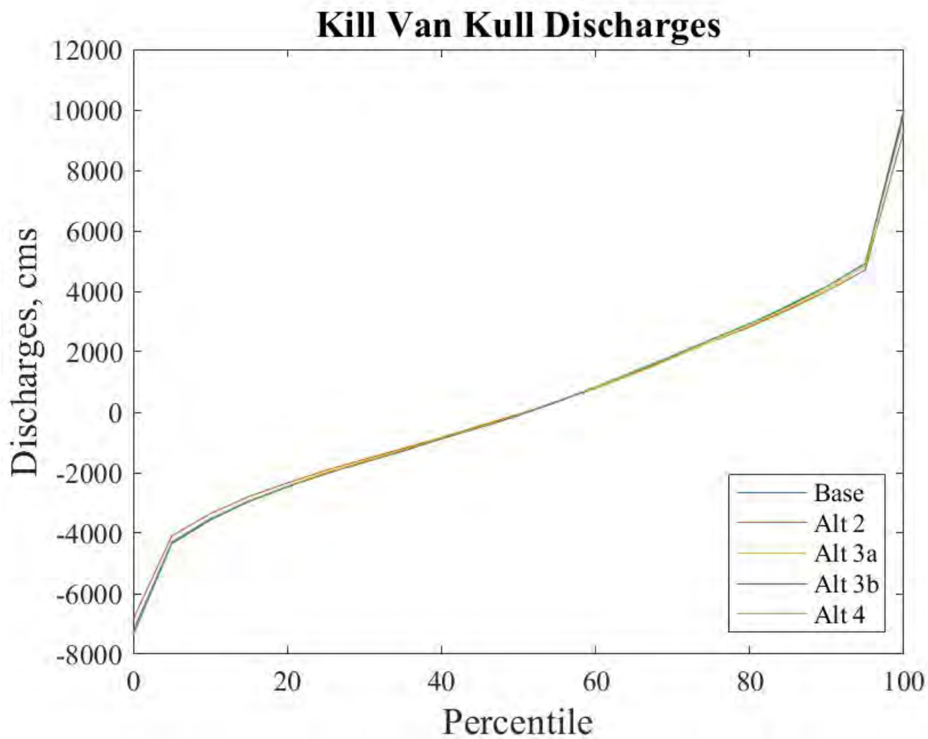


Figure 32. Discharge Percentiles for the Arthur Kill Location.

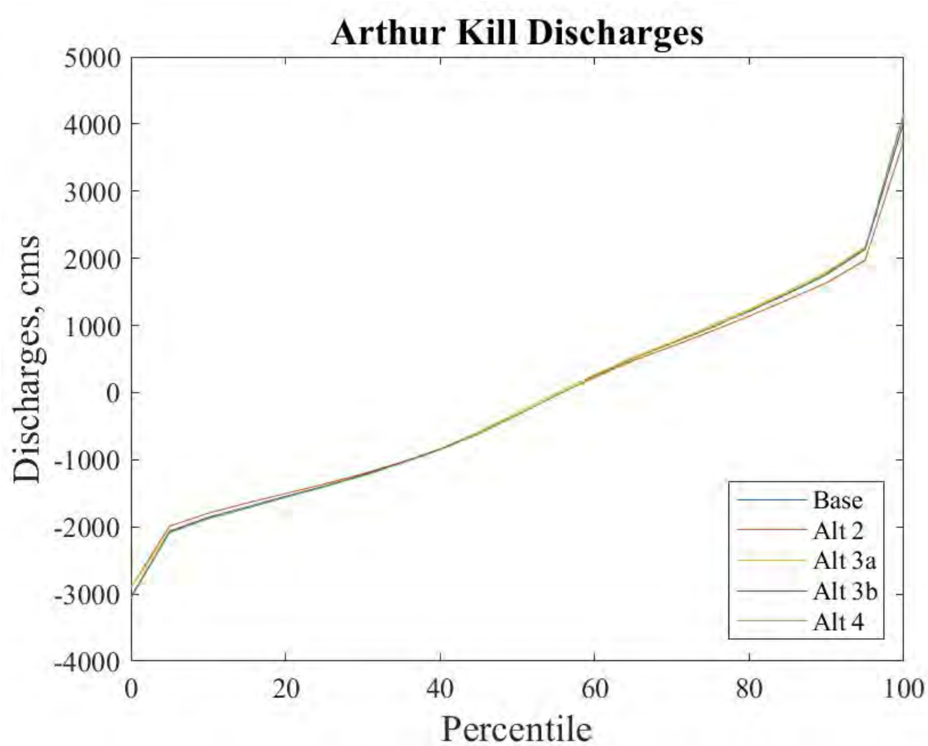


Table 5. Mean Fluxes.

Location	Mean Discharges, cms (positive is flood/negative is ebb)				
	Base	Alt 2	Alt 3a	Alt 3b	Alt 4
Throgs Neck	80	86	95	80	81
Verrazano Narrows	-302	-286	-332	-302	-305
Kill Van Kull	152	167	129	146	152
Newark Bay	-22	-22	-22	-22	-22
Arthur Kill	-178	-193	-158	-177	-179

3.1.4 Tidal Prism Analysis

A tidal prism percentile analysis was performed for the areas in the mesh that are impounded by the barriers and then compared to the tidal prism for the same area in the without project mesh. The tidal prism provides an indication of the amount of water exchange between the inside and outside of the proposed structures. These impacts can also be observed in the point comparisons of the water levels through tide range changes as well. Impacts to the tidal prism can be important when considering water quality impacts that could be negatively impacted by reduced mixing with offshore waters.

3.1.4.1 Alternative 2

Figure 33 is a schematic of the area used to calculate the tidal prism, and Figure 34 is the percentile analysis for the impounded area for Alternative 2. Note that the Material 1 area extends all the way up the Hudson River to Troy Lock and Dam. Figure 34 indicates there is a reduction in the tidal prism for the impounded area and therefore a corresponding reduction in the tidal exchange and tide ranges as previously illustrated in Table 4.

Figure 33. Alternative 2 Material Region Specification for Tidal Prism Analysis.

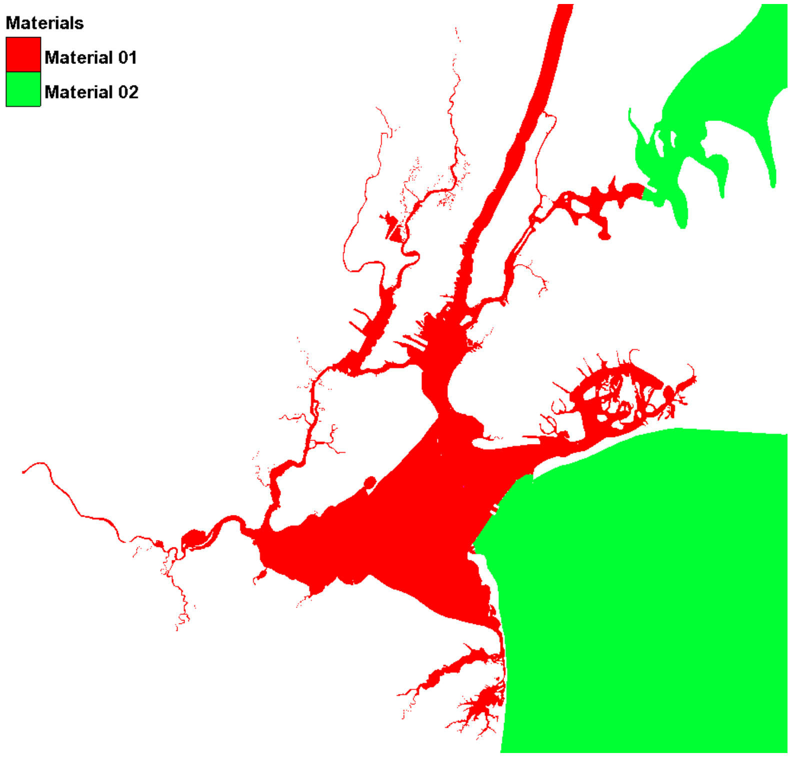
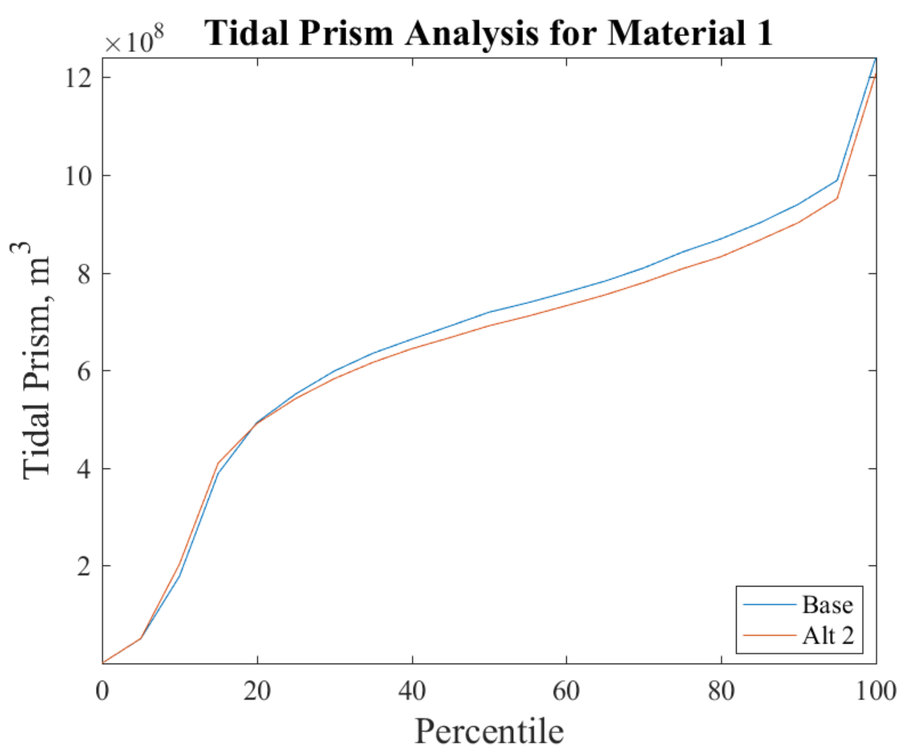


Figure 34. Tidal Prism Percentiles for the Material 1 Region in Alternative 2.



3.1.4.2 Alternative 3a

Figure 35 is a schematic of the area used to calculate the tidal prism for Alternative 3a. Figure 36 shows the tidal prism reduction for Alternative 3a north of the Verrazano Narrows structure. Similar to Alternative 2, this indicates a reduction in the tidal exchange and tide ranges for the protected areas. Figure 37 shows the impact of the Jamaica Bay structure on the tidal prism for that area.

Figure 35. Alternative 3a Material Region Specification for Tidal Prism Analysis.

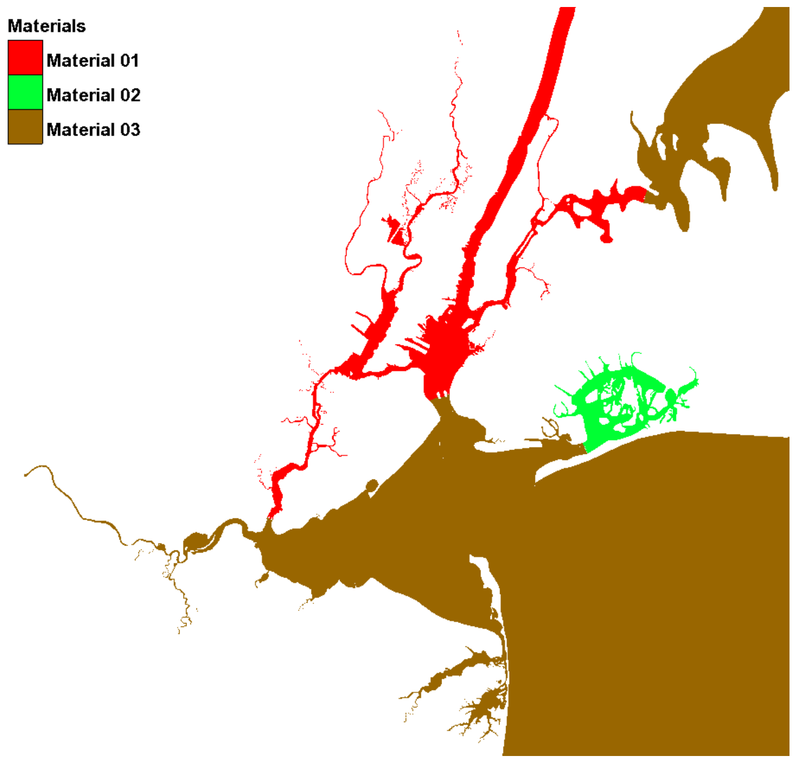


Figure 36. Tidal Prism Percentiles for the Material 1 Region in Alternative 3a.

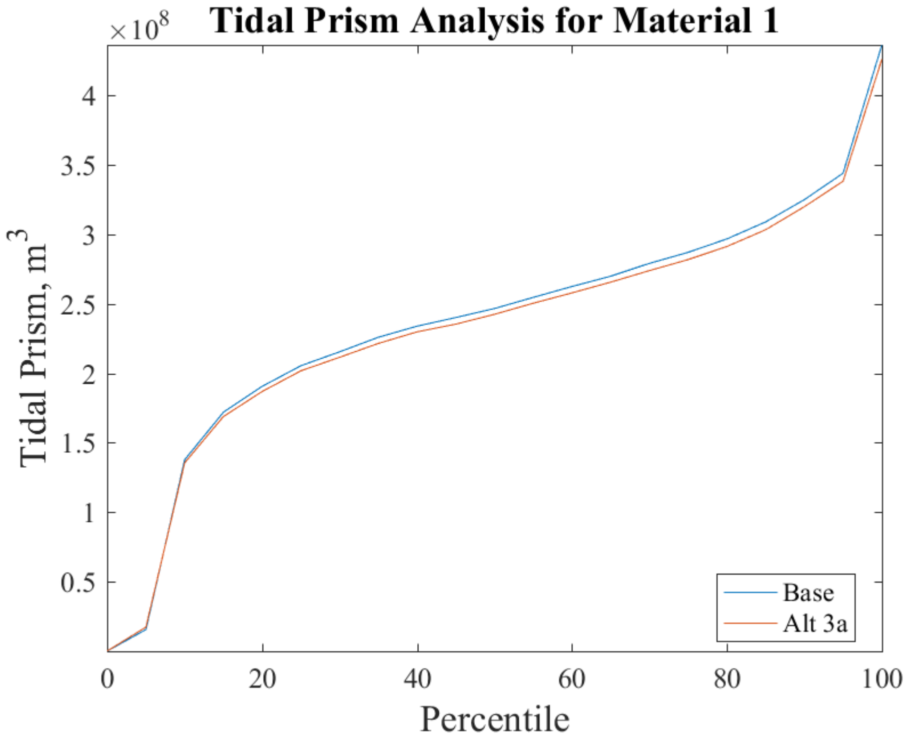
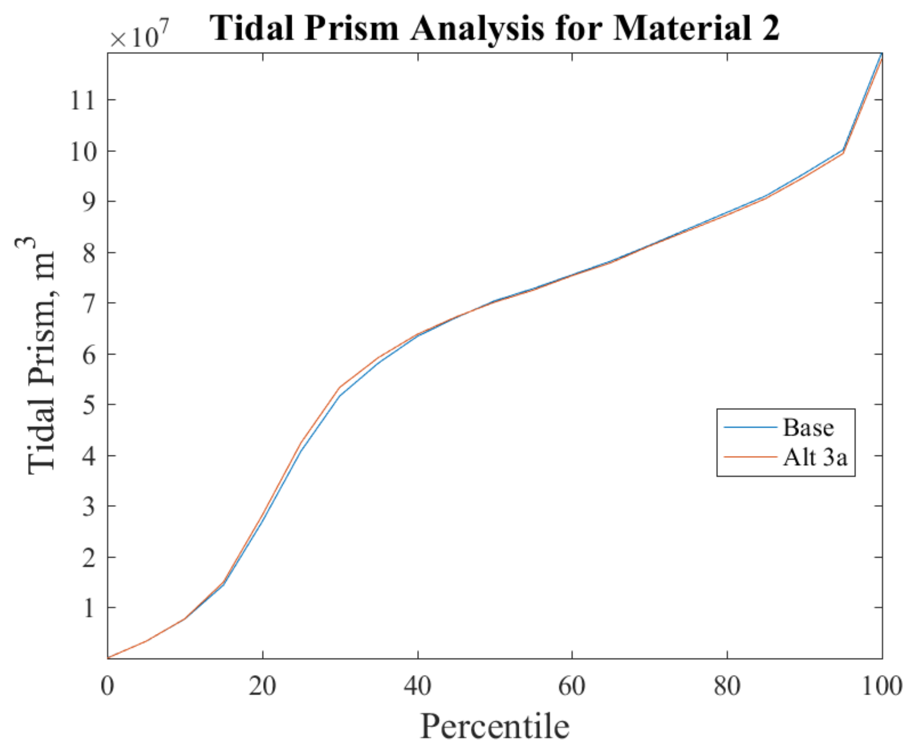


Figure 37. Tidal Prism Percentiles for the Material 2 Region in Alternative 3a.



3.1.4.3 Alternative 3b

Figure 38 is a schematic of the area used to calculate the tidal prism for Alternative 3b. Figure 39 shows the change in the tidal prism for the area protected by Alternative 3b. The impacts for this alternative are minimal. Figure 40 shows the change in tidal prism for the Jamaica Bay area. This minimal change in tidal prism is in agreement with the minimal tidal range impacts previously shown in Table 4. The change in tidal prism for this area is similar to Alternative 3a.

Figure 38. Alternative 3b Material Region Specification for Tidal Prism Analysis.

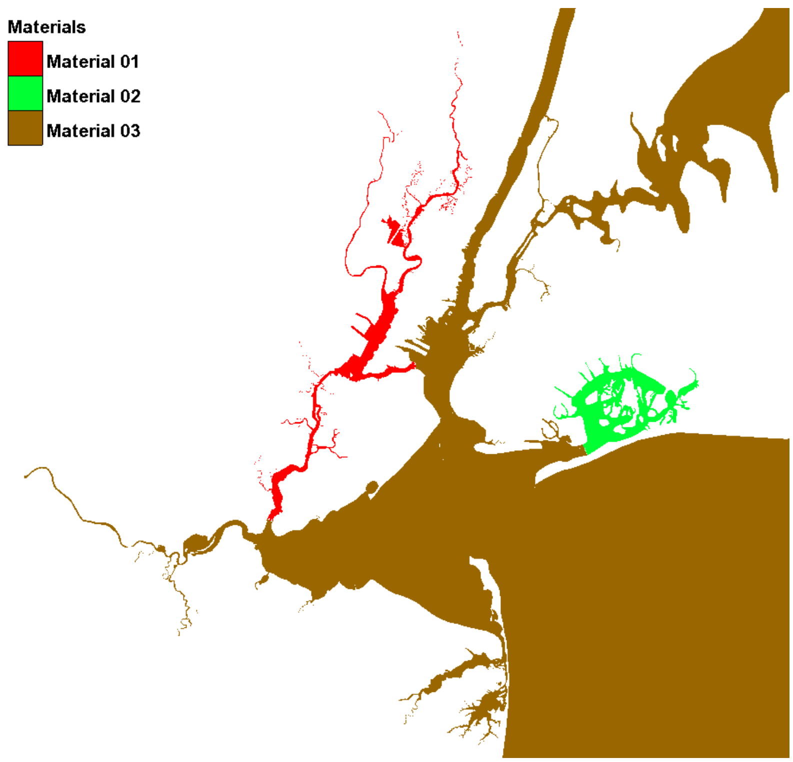


Figure 39. Tidal Prism Percentiles for the Material 1 Region in Alternative 3b.

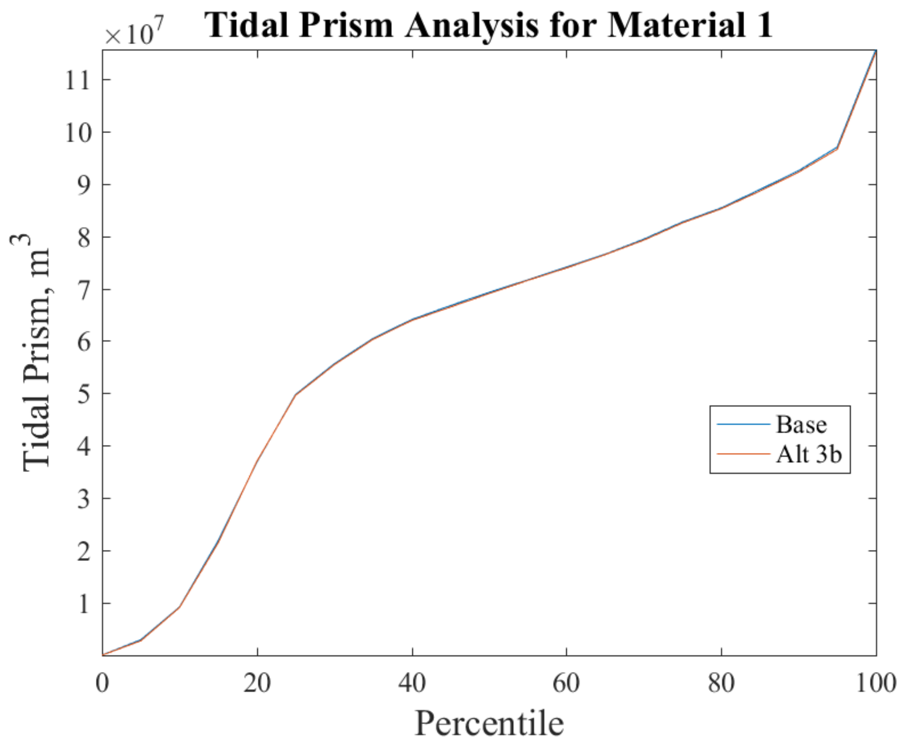
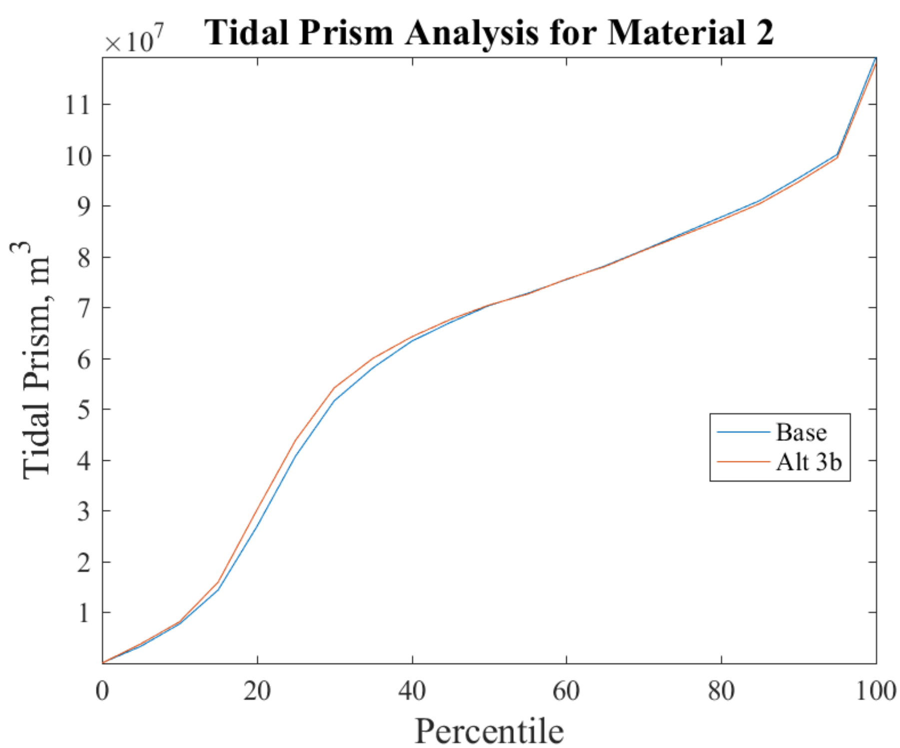


Figure 40. Tidal Prism Percentiles for the Material 2 Region in Alternative 3b.



3.1.4.4 Alternative 4

Figure 41 is a schematic of the area used to calculate the tidal prism for Alternative 4. Figure 42 shows the tidal prism differences due to the Hackensack River structure. This figure indicates the structure has minimal impact for the lower tide ranges but does serve to reduce the tidal prism (and tidal exchange) for the larger tidal events. The Jamaica Bay tidal prism (Figure 43) analysis is again similar to Alternatives 3a and 3b.

Figure 41. Alternative 4 Material Region Specification for Tidal Prism Analysis.

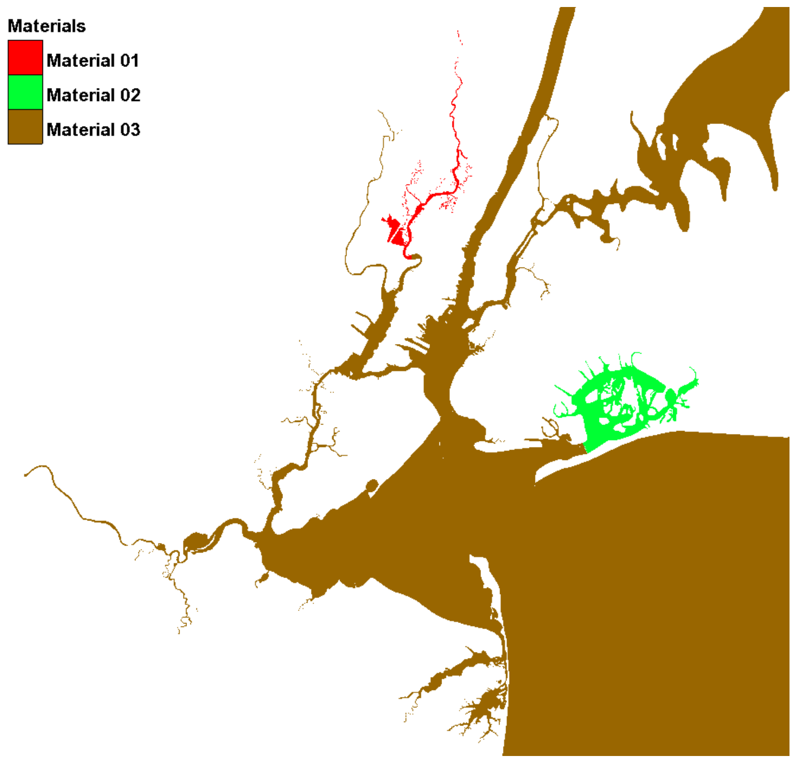


Figure 42. Tidal Prism Percentiles for the Material 1 Region in Alternative 4.

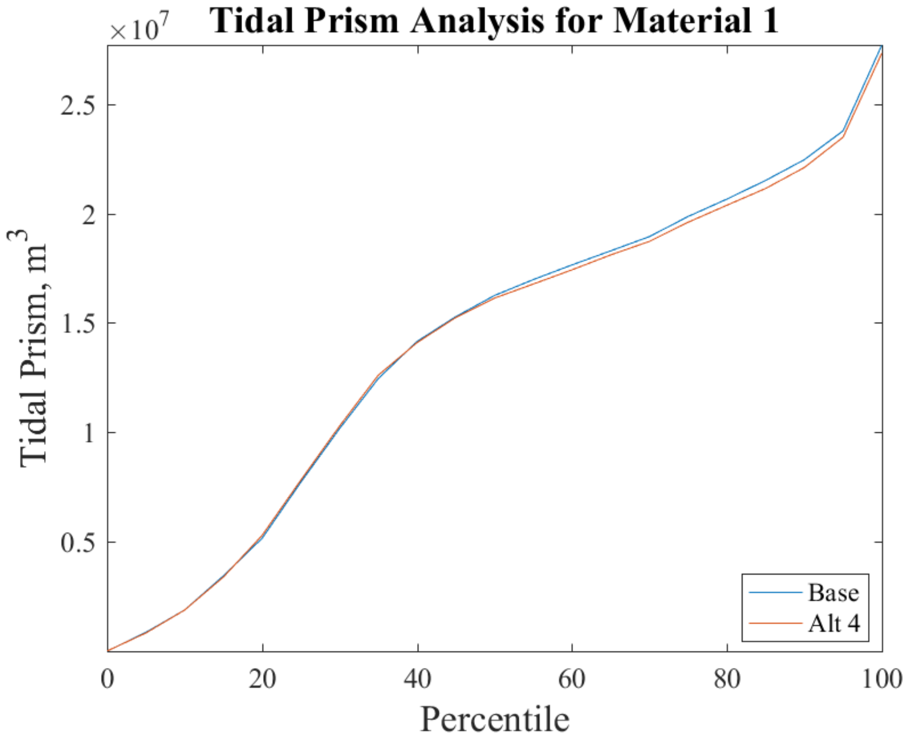
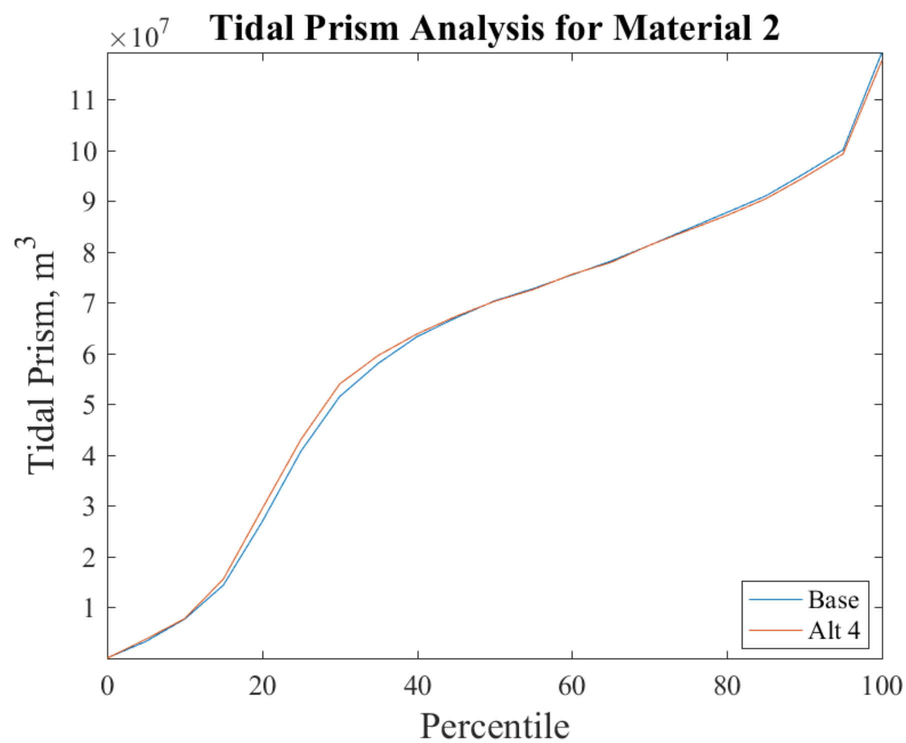


Figure 43. Tidal Prism Percentiles for the Material 2 Region in Alternative 4.



3.1.5 Summary of Results

The alternatives considered in this report range from extremely large structures for widespread flood protection (Alternative 2) to relatively small structures intended for more localized flood protection (Alternative 4). This section provides a summary of the impacts of the individual proposed alternatives in terms of hydrodynamics and salinity transport. Note the results detailed in this report are the larger scale, basin wide impacts and therefore some more localized impacts due to the smaller structures may be omitted from discussion.

3.1.5.1 Alternative 2

Alternative 2 is the largest barrier with the greatest spatial protection extents. As such, it is a massive structure across a wide opening that reduces the flow area by approximately 47%. This results in a reduction of the tide ranges inside the system as well as the tidal prism and associated tidal exchange. Figure 34 illustrates the change in tidal prism with numerous figures in Appendix B demonstrating local tidal range reductions (as well as Table 4). This reduction in tidal exchange with the higher salinity offshore waters results in an overall freshening of the system. This is readily evident in the salinity percentile points and to a lesser extent in the spatial salinity plots. It is less obvious in the spatial plots as the changes are relatively small (~1 ppt or less).

An additional impact to the system is associated with changes to the flow pathways. The flood flow for Throgs Neck (to the west) is increased slightly (see Table 5). There is also a decrease in the ebb flow for the Verrazano Narrows (to the south) and an increase in the flood flow for the Kill Van Kull (to the west).

The reduction in tidal exchange also results in slight reductions in velocities throughout the system. These are relatively minor but can be observed in the point velocity percentiles and to a lesser degree in the spatial velocity percentile figures.

3.1.5.2 Alternative 3a

Alternative 3a consists of structures across the Verrazano Narrows, Throgs Neck, and Jamaica Bay along with other smaller structures. While it possesses a smaller footprint than Alternative 2, some similar behavior is observed between these two alternatives. Alternative 3a also reduces tidal prism/tidal exchange for the impounded areas north of the Verrazano Narrows structure (see Figure 36) along with the increased flow through the Throgs Neck structure from Western Long Island Sound (see Table 5). The increased flow through Throgs Neck is larger for Alternative 3a than Alternative 2. The salinity results also reinforce the Throgs Neck conclusion by indicating increased salinity intrusion from Western Long Island Sound (see Figure 130).

The tide range reductions are not as large as Alternative 2 (see Table 4). While Alternative 3a reduces the flux ranges through the Verrazano Narrows (see Figure 30), the mean flow is increased (see Table 5). Initially, this would seem counterintuitive, but the reduction in flow area associated with the Verrazano Narrows structure creates an increased flood flow for Arthur Kill (see Figure 32). This increased tidal flood flow (to the north) for Arthur Kill compensates for the reduced flow through the Verrazano Narrows while also reducing the net flow through Kill Van Kull and Arthur Kill. This increases the net flow out through the Verrazano Narrows (see Table 5). The increased tidal flood flow through Arthur Kill can also be observed in the salinity values as an increased salinity intrusion toward Arthur Kill (compare Base salinity in Figure 26/Figure 27 to Alternative 3a salinity in Figure 169/Figure 170 in Lower Bay toward Arthur Kill). This increased salinity intrusion is also evident in the salinity percentile comparison for Point V5 (see Figure 130). The increased net flow through the Verrazano Narrows also reduces the salinity in the Lower Bay just south of the structure (compare Figure 26/Figure 27 and Figure 169/Figure 170 and see Figure 132).

The Jamaica Bay structure results in a change to the tidal prism (see Figure 37) with a reduction in the tide ranges (see Table 4). The smaller percentile tidal prism values are larger for the alternative, but the larger tidal exchange events are reduced by the structure. The results also indicate a slight increase in the salinity intrusion into Jamaica Bay. This could be due to a redistribution of the flow entering/leaving the bay thereby resulting in higher salinity values in the bay even with the lower tide ranges (see Table 4). See Figure 44 and Figure 45 as an illustration of the impact of the structure on the flood/ebb flows. There is a noticeable reduction in flow for the center bridge opening for the alternatives with flows being redistributed to the outer bridge openings. Given the lateral variability in the salinity, this modification of the flow distribution results in an associated change in the salinity entering Jamaica Bay. From Figure 44 and Figure 45, it appears the proposed structure interacts with the existing bridge piers to change the salinity entering/leaving the system. Modification of the proposed structure in terms of pier locations could reduce this impact or possibly modify it in a more advantageous manner depending on the most desired salinity/tidal exchange conditions.

Figure 44. Impact of Jamaica Bay structure on ebb flow distribution into Jamaica Bay.

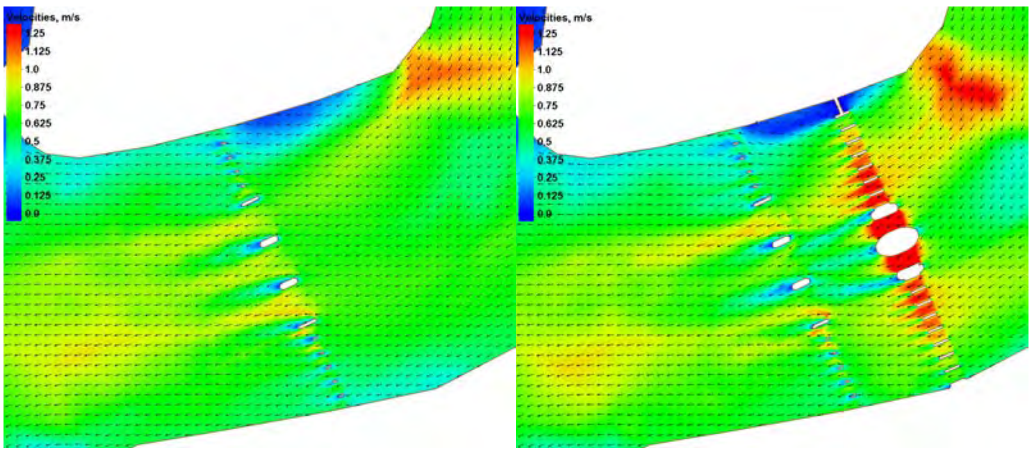
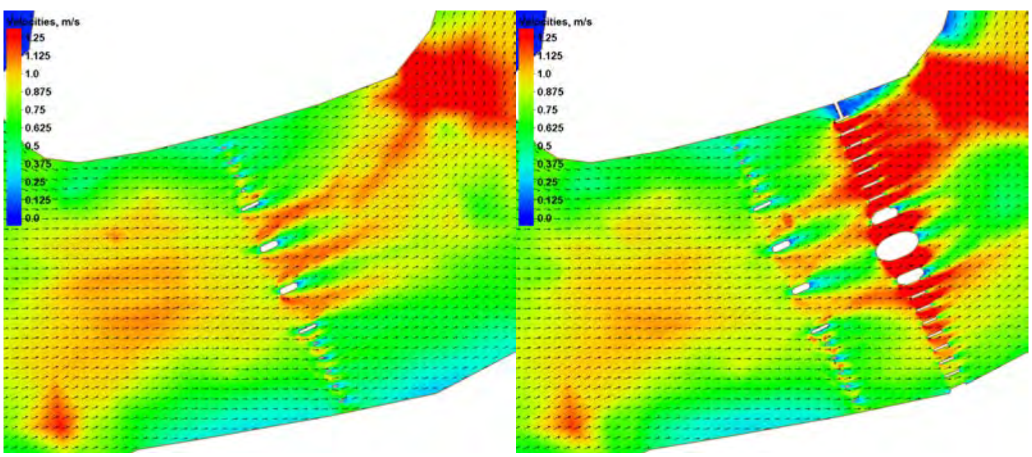


Figure 45. Impact of Jamaica Bay structure on flood flow distribution into Jamaica Bay.



3.1.5.3 Alternative 3b

Alternative 3b results in relatively minor changes to the overall system. The tidal prism (Figure 39) for the areas west of the Kill Van Kull structure and north of the Arthur Kill structure are negligibly impacted. There is a slight reduction in the net flow west along Kill Van Kull (Table 5) but again this change is a small percentage of the Base flow.

For Jamaica Bay, the impacts are similar to Alternative 3a, but the absolute salinity values are larger for Alternative 3b as the net flow increase through the Verrazano Narrows for Alternative 3a (which slightly freshened the Lower Bay south of the Verrazano Narrows) is not replicated in Alternative 3b.

3.1.5.4 Alternative 4

Alternative 4 avoids any structures for the major navigation channels with the largest structures being the Hackensack River and Jamaica Bay structures. The Hackensack River structure has minimal influence on the tidal exchange for the smaller and even median tidal events but does serve to damp the tidal exchange for the larger tidal events (see Figure 42). For Jamaica Bay, the impacts are similar to Alternative 3b. The remaining structures associated with Alternative 4 are relatively small and have insignificant impacts on the overall system.

4 Sediment Transport Simulations

The previously discussed simulations and results did not include sediment transport. The results in this chapter are for the 1995 water level and include sediment transport and associated sediment interaction with the bed via erosion and deposition. The hydrodynamics and salinity transport results are very similar to the previous results, but some very minor differences are possible as the bed elevations are being updated during these simulations.

4.1 Bed Initialization

The development of the sediment transport model requires the specification of the characteristics of the sediment in the bottom surface of the estuary, the vertical structure of the subsurface layers within the bed and the sediment size class concentration distribution in tributary inflows. The initial specification of the bed was completed as discussed in McAlpin et al. 2020. Also as discussed in McAlpin et al. 2020, “spin up” simulations were completed.

A one-year model simulation (1995 forcings) was completed to “spin up” the bed composition without allowing the bed elevations to change. This process initializes the bed by allowing the grain size distribution to vary spatially in a manner consistent with the local bed shear stresses. This procedure was deemed necessary in order to minimize the impacts of discontinuous specification and localized discrepancies between the specifications and the local hydrodynamic conditions. The data used to develop the bed specification were collected over a variety of hydrodynamic conditions and there is no way to determine “accuracy” of the initialization of the bed. This process was repeated for both the base and alternative configurations. This adjusted bed distribution was utilized as the initial bed (base/alternatives as appropriate) for the subsequent sediment transport model simulations discussed in this report.

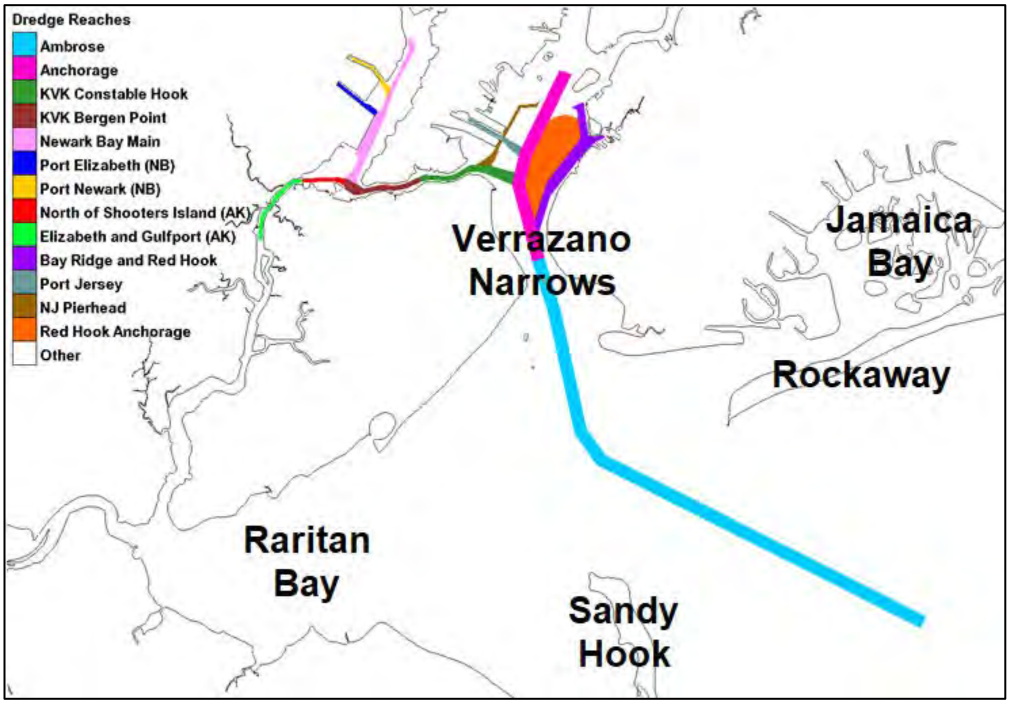
Note the areas in/near the proposed structures were armored to eliminate scour below the initial bed elevations. Deposition can occur in these areas and then resuspension of the deposited sediment is allowed but scour below the initial elevation is not.

4.2 Dredge Volume Comparisons

The Port of New York and New Jersey is the third busiest port in the United States with approximately 60.9 million tons of bulk cargo at a value of almost $48 billion U.S. dollars (PANYNJ, 2010) with 5,000 ship arrivals per year (Caplow et al. 2003). The Port supports 279,200 jobs with wages of over $11 billion and contributes more than $19 billion to the New York/New Jersey gross regional product (PANYNJ, 2010).

NYNJH includes numerous navigation channels and various ports resulting in a complex system of navigation channels extending from offshore, inland to the individual ports of call. Over the years, NYNJH has evolved continuously with numerous channels being deepened and widened to better facilitate navigational safety and efficiency. The dredging requirements for the NYNJH are extensive but required to maintain this important port of call. It is important to consider the impact of proposed barrier alternatives on the dredging requirements for the NYNJH as this would be a continual, recurring expense. Figure 46 illustrates the locations of some of the commonly dredged channels. Figure 47 shows a comparison of the dredge volumes at the end of the model simulations for the commonly dredged locations in Figure 46. These dredged volumes are only for the navigation channel and does not reflect any deposition occurring outside of the channels. Note the dredge volumes vary slightly from those reported in McAlpin et al. 2020. This variation is due to a combination of changing the sediment “spin up” year from 2012 to 1995 and performing these simulations without the wind wave forcings.

Figure 46. Commonly dredged channels for NY/NJ Harbor (McAlpin et al. 2020)



In general, the dredge volumes for Alternatives 3a, 3b, and 4 are not significantly impacted by the barrier systems. Alternative 2 has the largest impact with a reduction in the expected dredge volumes, especially in the more coastal areas. This is believed to be associated with reduced shear stresses, which result in reduced erosion in some areas and therefore less sediment resuspension/movement into more depositional areas.

4.3 Bed Change

This section provides figures illustrating the change in bed elevation at the end of the one-year simulation for the base (Figure 48) and alternative configurations (Figure 49 to Figure 52).

Figure 47. Comparison of Dredge Volumes.

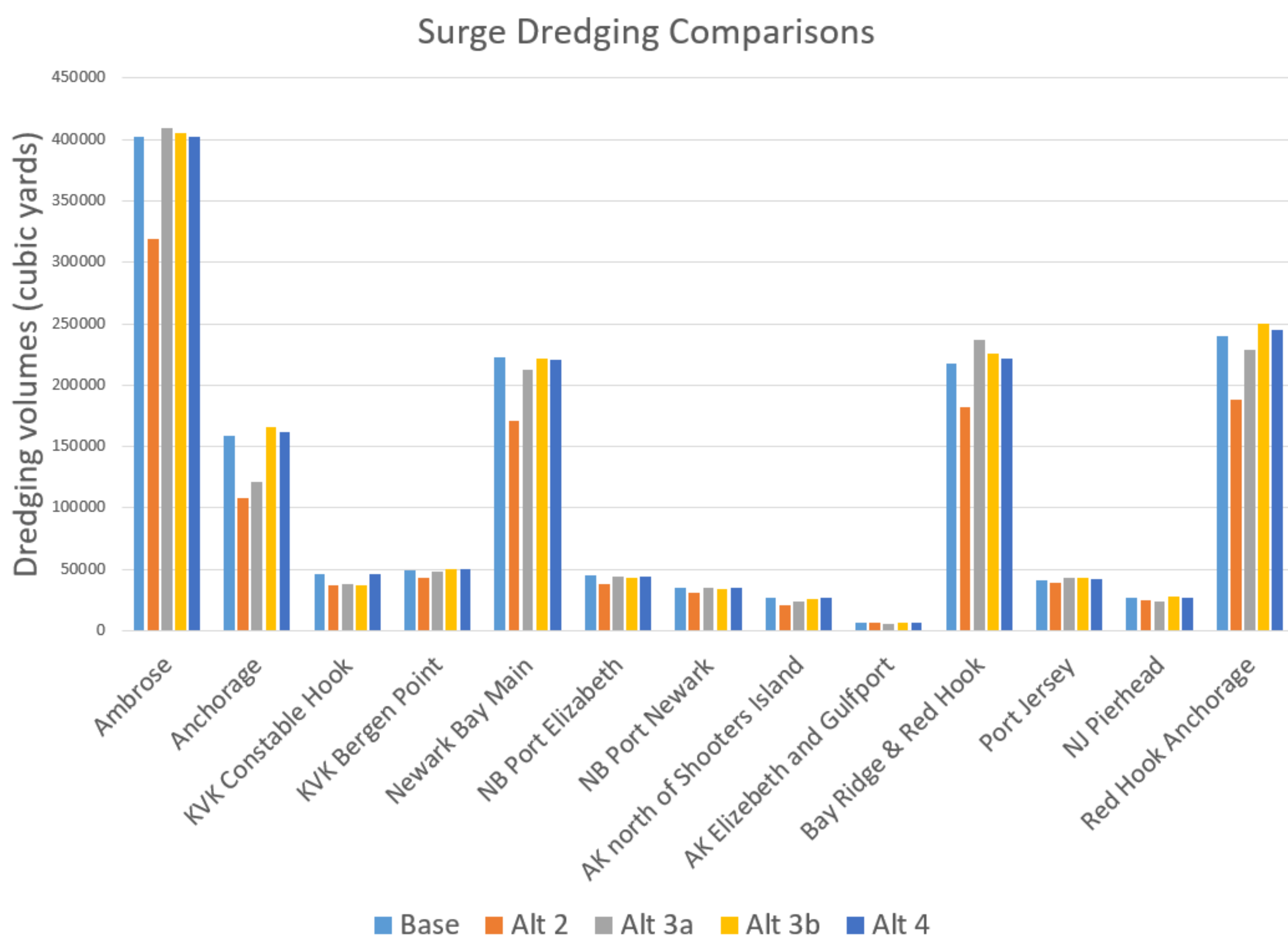


Figure 48. Bed Displacement for Base Conditions for Upper Bay (top) and Lower Bay (bottom).

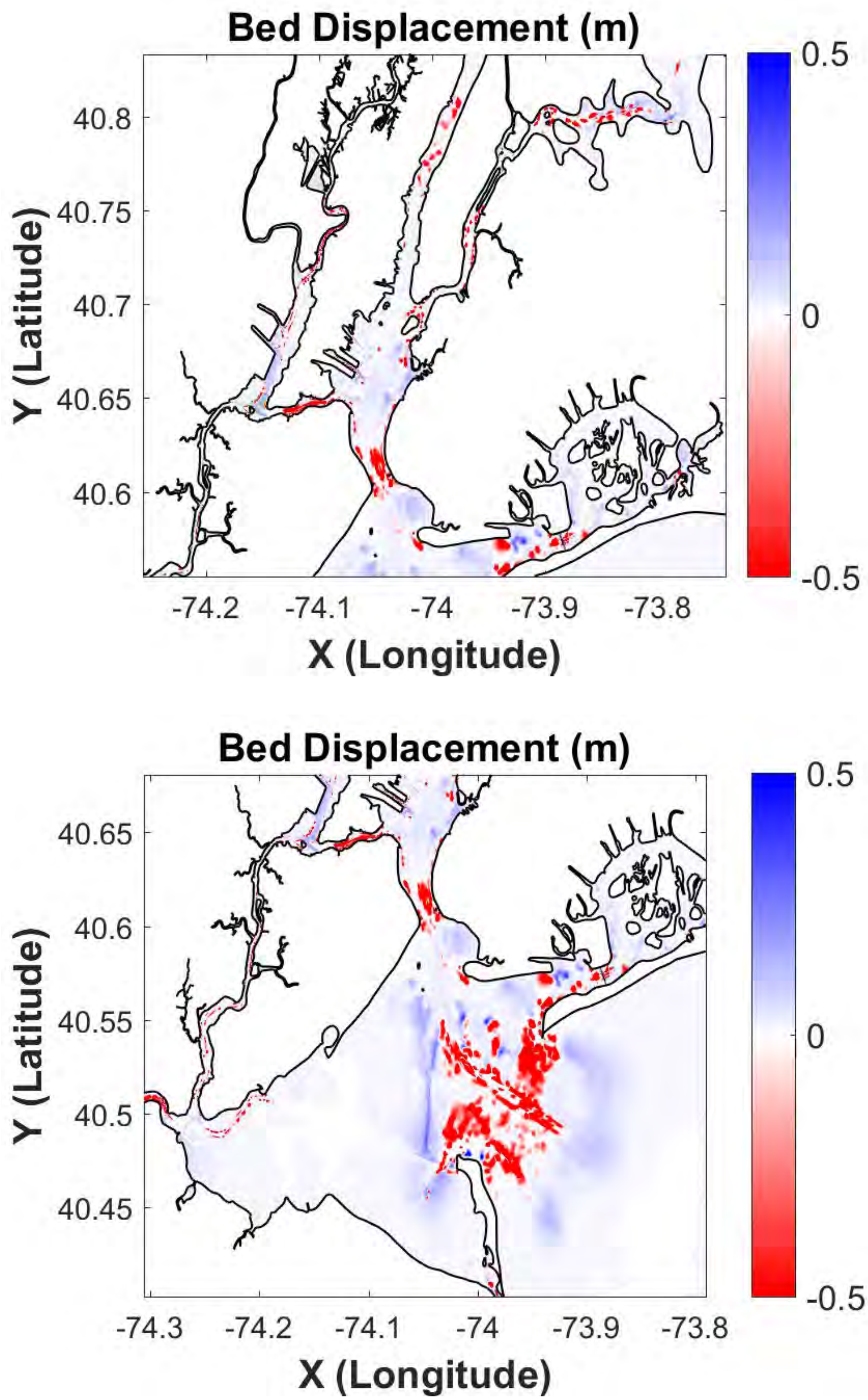


Figure 49. Bed Displacement for Alternative 2 for Upper Bay (top) and Lower Bay (bottom).

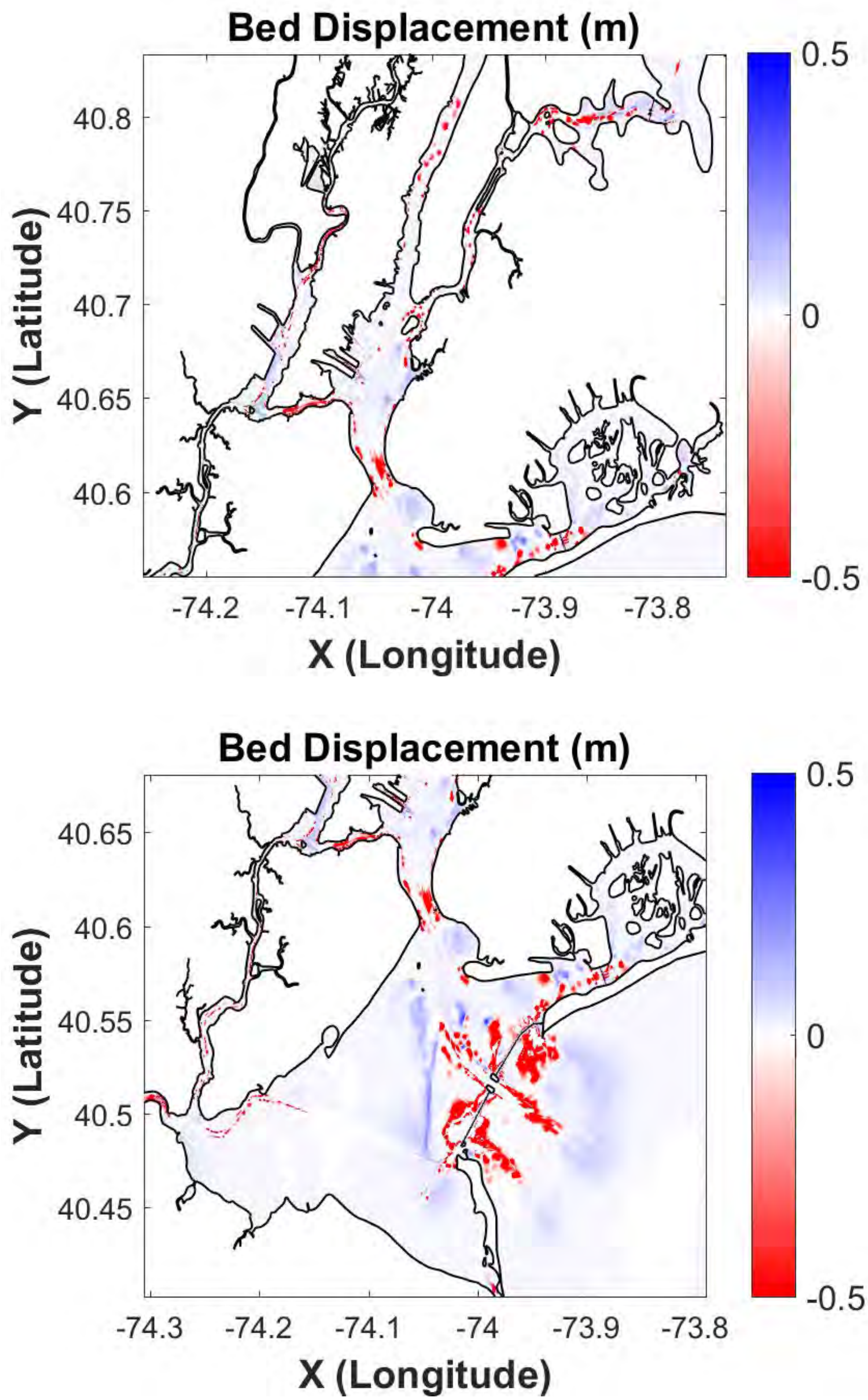


Figure 50. Bed Displacement for Alternative 3a for Upper Bay (top) and Lower Bay (bottom).

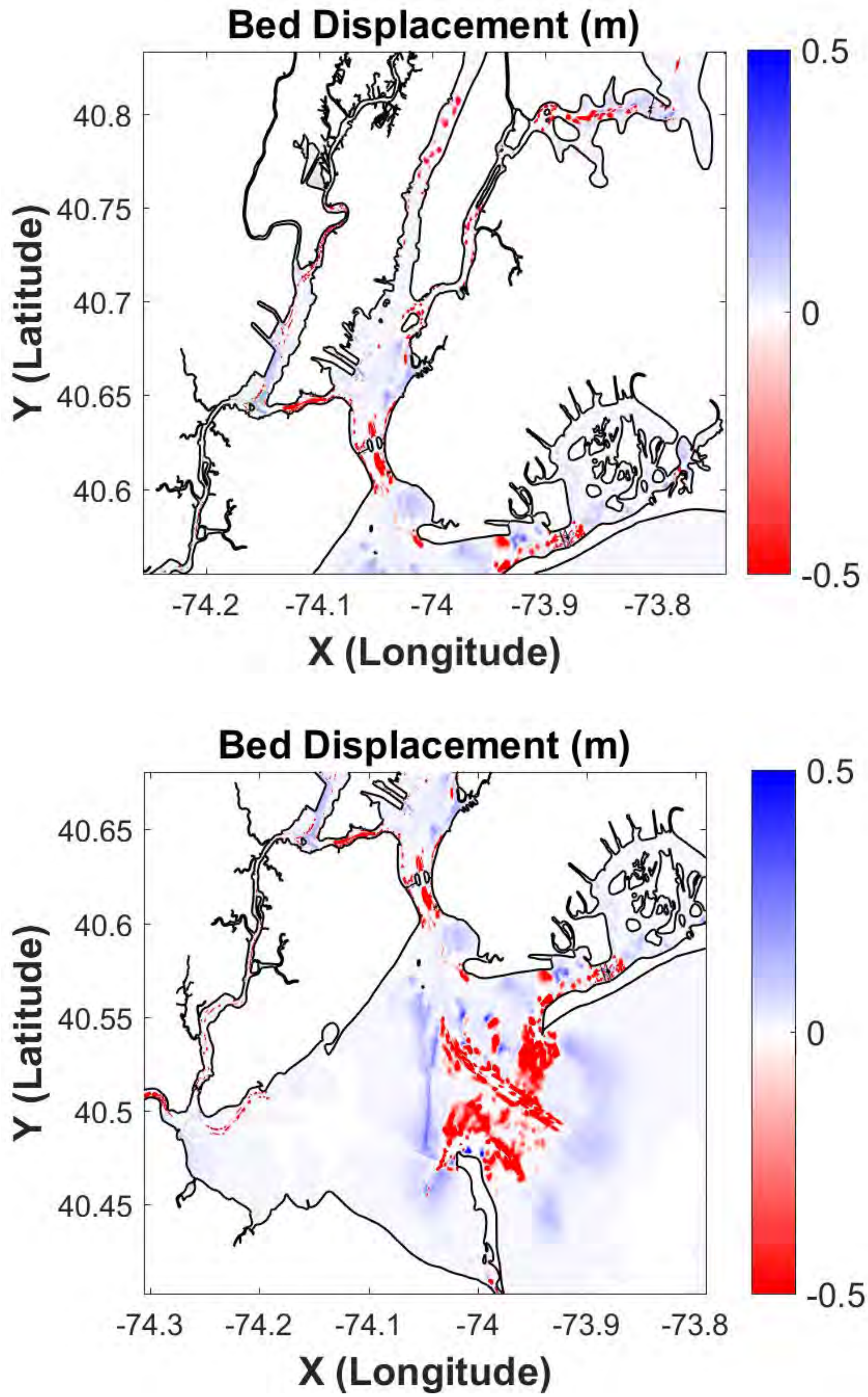
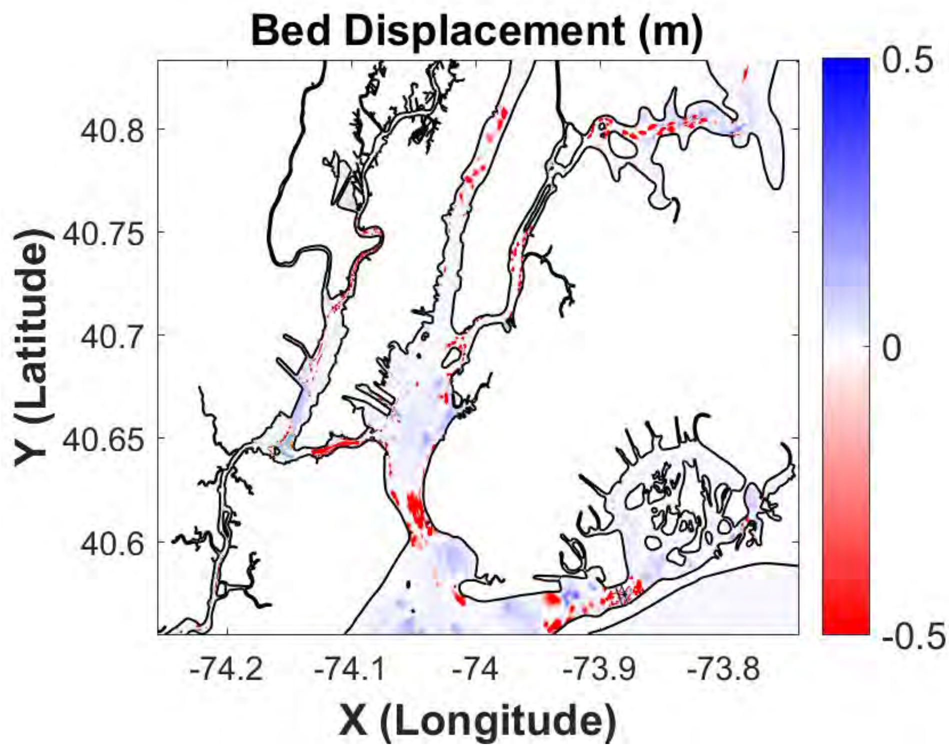


Figure 51. Bed Displacement for Alternative 3b for Upper Bay (top) and Lower Bay (bottom).



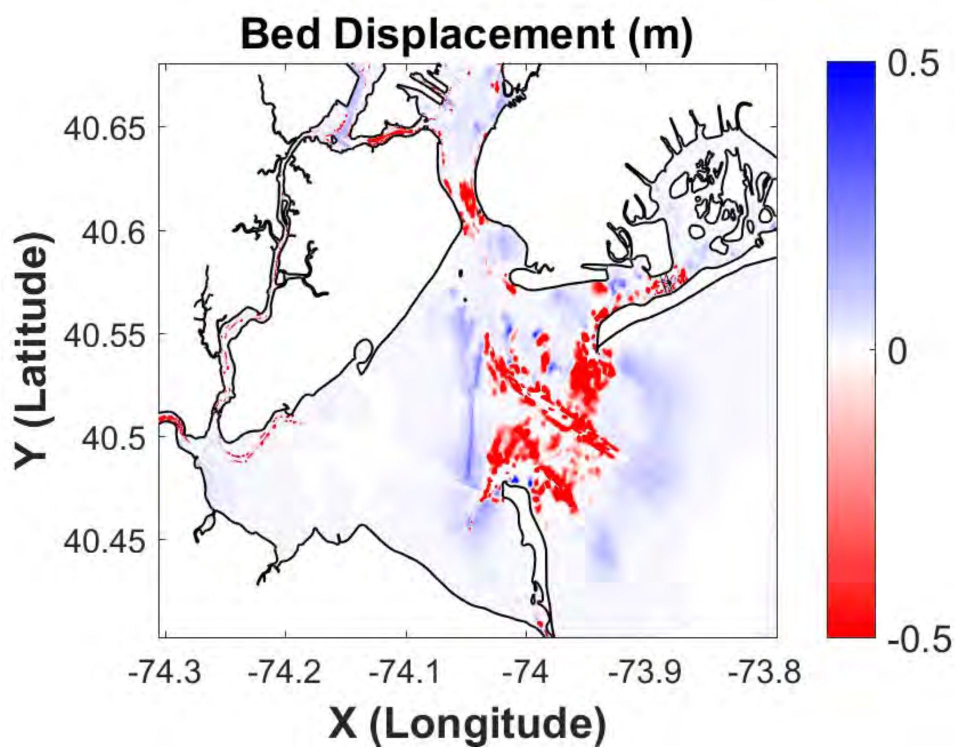
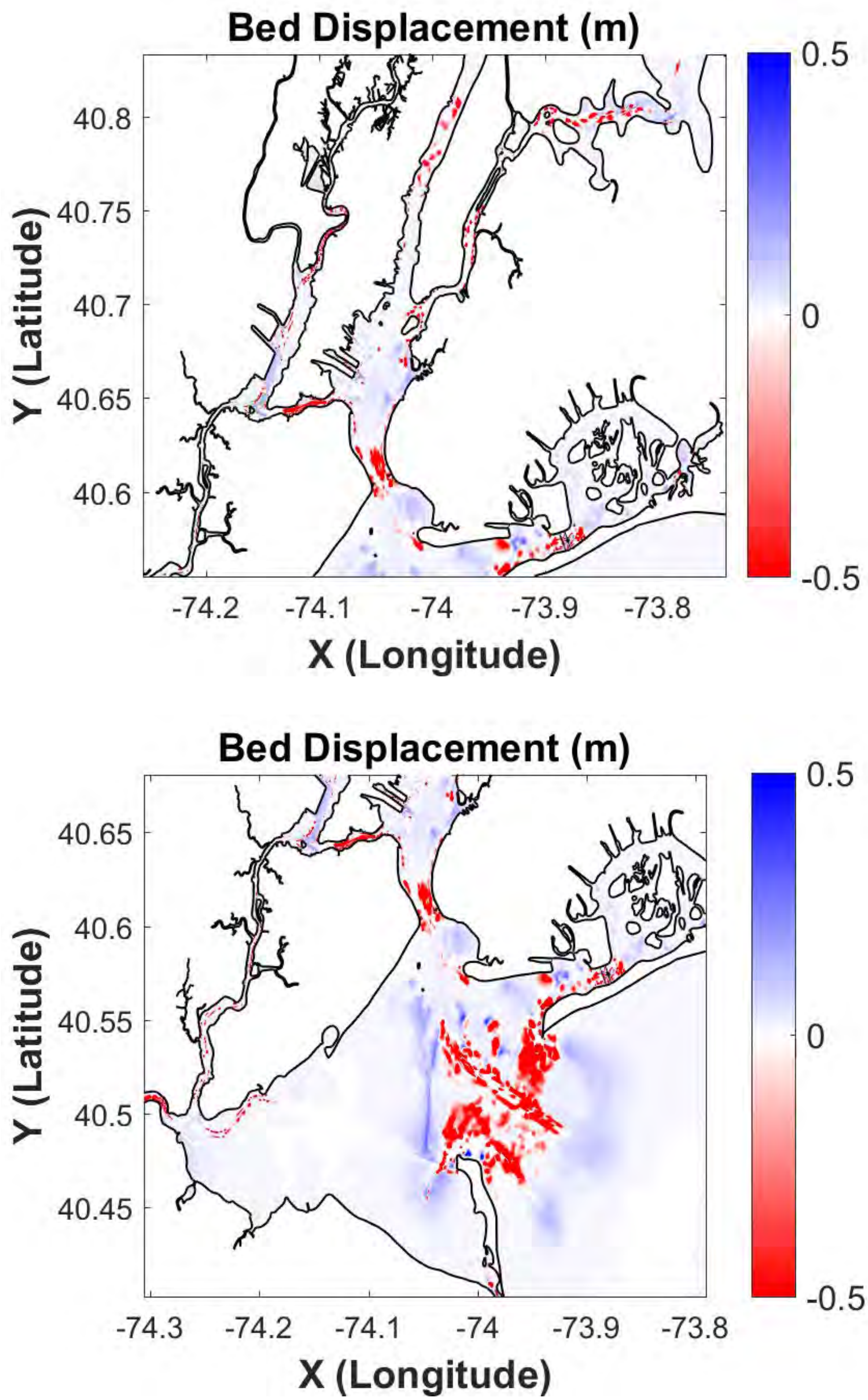


Figure 52. Bed Displacement for Alternative 4 for Upper Bay (top) and Lower Bay (bottom).



4.4 Sediment Transport Summary

The previous chapter provided comparisons of the water flow pathways for the base and alternative configurations. For the primary reaches of interest for dredging, the changes due to the proposed structures are relatively minor with the largest impacts associated with Alternative 2 and Alternative 3a. These two alternatives have the largest impacts on the system in terms of flow pathway modifications and reduction in tidal exchange. The reduction in tidal exchange also reduces the velocities and shear stresses present in the system. These reductions in tidal exchange tend to be more pronounced for the higher energy events resulting in increased impacts for sediment resuspension. Alternative 2 results in the largest reduction in tidal exchange and also has the largest reduction in dredge volumes. The impact of Alternative 3a is primarily associated with reduced dredge volumes in the Anchorage area along with slight reductions for the Newark Bay region through reduced tidal exchange. Note the reductions in dredge volumes associated with Alternative 2 in particular are associated with reduced erosion in other portions of the model. These impacts observed in the model are directly related to the bed specification and as such could be more/less impactful in the real system. Note these simulations also do not include ship propeller or ship wave impacts. The incorporation of these processes could result in more resuspension for all alternatives equally.

5 Sea Level Rise Simulations

All previous model results were associated with the 1995 calendar year forcing conditions and mean sea level. The impact of sea level rise on the NYNJH system was investigated by simulating various sea level rise alternatives. These simulations consisted of simply raising the mean water level and tidal boundary by the associated sea level rise amounts. All other remaining boundary forcings (wind field, pressure field, and river flows) were left unchanged. This allowed for independent analysis of the sea level rise impacts as the water level was the only modified parameter. If other parameters were modified, then the impact of the increase in water level could not be isolated. An important limitation of these results is omission of wetting/drying in the model simulations. Therefore, areas that would have been newly wetted due to increased sea level values were not included in these simulations or analysis. If additional areas were wetted due to sea level rise that would result in increased tidal exchange and velocities over those presented in this section.

Four sea level rise amounts were considered for the life of the project. There values were 0.3048 m (1 ft), 0.6096 m (2 ft), 1.22 m (4 ft) and 1.83 m (6 ft). These values were added on top of the mean sea level projected for the project construction completion time (2030). The projected sea level rise from 1995 (simulated year) to 2030 was projected to be 0.14 m (0.46 ft) using the USACE sea level rise calculator (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html#) using the intermediate sea level rise curve at The Battery (see Appendix G for more details). When this value was incorporated into the previously chosen sea level rise amounts, sea level rise amounts from 1995 were chosen as 0.1402 m (0.46 ft), 0.4451 (1.46 ft), 0.7500 m (2.46 ft), 1.3598 m (4.46 ft), and 1.9695 m (6.46 ft). The specific yearly values these sea level rise amounts would equate to would depend on the curve and base year chosen. By picking a range of sea level rise amounts as opposed to specific curves and year values, simulation of similar sea level rise amounts for different years/curves was avoided. The drawback of this approach is specific year/curve values may not be simulated exactly and some interpolation method might be required.

Appendix H provides figures comparing the impact of the sea level rise on the individual alternatives. The impact between alternatives may change slightly in magnitude but the general trends are similar. Some observations on the impact of sea level rise are provided as follows:

- In general, the impacts for specific alternatives as discussed in the previous chapter were similar across sea level values but the actual magnitude of those changes might increase/decrease slightly.

- Sea level rise increases the tidal exchange with the higher salinity offshore waters. This is facilitated by the increased flow area and decreased friction due to larger depths. This has a couple of implications, namely the salinity intrusion is increased, and the velocities are impacted as well. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prism/exchange.

- Sea Level Rise increases the mean flow (to the south) through the Verrazano Narrows for all alternatives by approximately 13 % for the highest sea level rise amount.

- Throgs Neck shows an increase (~40 %) in the mean flow (to west) with sea level rise. This is relatively constant across alternatives with Alternative 3a possessing a slightly smaller increase over the other alternatives.

- A reduction in flow of approximately 2 – 6 % is observed for Kill Van Kull for the largest sea level rise depending on the Alternative. Alternative 2 shows the largest reduction for sea level rise while Alternative 3b has the lowest reduction.

- Similar to Kill Van Kull, Arthur Kill shows a slight decrease in mean flow (to south) associated with sea level rise.

6 Conclusions

Numerous simulations were completed to evaluate the impact of the proposed barriers on hydrodynamics, salinity, and sediment transport along with the impact of various levels of sea level rise. The conclusions in this chapter are separated into the following subsections.

6.1 Impacts of the Proposed Alternatives on Hydrodynamics and Salinity Transport

The alternatives considered in this report range from extremely large structures for widespread flood protection (Alternative 2) to relatively small structures intended for more localized flood protection (Alternative 4). This section provides a summary of the impacts of the individual proposed alternatives in terms of hydrodynamics and salinity transport.

6.1.1.1 Alternative 2

Alternative 2 is the largest barrier with the greatest spatial protection extents. As such, it is a massive structure across a wide opening that reduces the flow area by approximately 47%. This results in a reduction of the tide ranges inside the system as well as the tidal prism and associated tidal exchange. This reduction in tidal exchange with the higher salinity offshore waters results in an overall freshening of the system (~1 ppt or less). An additional impact to the system is associated with changes to the flow pathways. The flood flow for Throgs Neck (to the west) is increased slightly. There is also a decrease in the ebb flow for the Verrazano Narrows (to the south) and an increase in the flood flow for Kill Van Kull (to the west). The reduction in tidal exchange also results in slight reductions in velocities throughout the system.

6.1.1.2 Alternative 3a

Alternative 3a also reduces tidal prism/tidal exchange for the impounded areas north of the Verrazano Narrows structure along with the increased flow through the Throgs Neck structure from Western Long Island Sound. The increased flow through Throgs Neck is larger for Alternative 3a than Alternative 2. The tide range reductions for the impounded areas are not as large as Alternative 2 but are larger than Alternatives 3b and 4. While Alternative 3a reduces the flux ranges through the Verrazano Narrows, the mean flow is increased. Initially, this would seem counterintuitive, but the reduction in flow area associated with the Verrazano Narrows structure creates an increased flood flow for Arthur Kill. This increased flood flow (to the north) for Arthur Kill compensates for the reduced flow through the Verrazano Narrows while also reducing the net flow through Kill Van Kull and Arthur Kill. This increases the net flow out through the Verrazano Narrows. The increased tidal flood flow through Arthur Kill results in increased salinity intrusion on the western side of Lower Bay with a corresponding decrease in salinity on the eastern side of Lower Bay due to the increased net flow through the Verrazano Narrows. The Jamaica Bay structure results in a change to the tidal prism with a reduction in the tide ranges. The results also indicate a slight increase in the salinity intrusion into Jamaica Bay. This could be due to a redistribution of the flow entering/leaving the bay thereby resulting in higher salinity values in the bay even with the lower tide ranges. Modification of the proposed structure in terms of pier locations could reduce this impact or possibly modify it in a more advantageous manner depending on the most desired salinity/tidal exchange conditions.

6.1.1.3 Alternative 3b

Alternative 3b results in relatively minor changes to the overall system. The tidal prism for the areas west of the Kill Van Kull structure and north of the Arthur Kill structure is minimally impacted. There is a slight reduction in the net flow west along Kill Van Kull but again this change is a small percentage of the Base flow. For Jamaica Bay, the impacts are similar to Alternative 3a, but the absolute salinity values are larger for Alternative 3b as the net flow increase through the Verrazano Narrows for Alternative 3a (which slightly freshened the Lower Bay south of the Verrazano Narrows) is not replicated in Alternative 3b.

6.1.1.4 Alternative 4

Alternative 4 avoids any structures for the major navigation channels with the largest structures being the Hackensack River and Jamaica Bay structures. The Hackensack River structure has minimal influence on the tidal exchange for the smaller and even median tidal events but does serve to damp the tidal exchange for the larger tidal events. For Jamaica Bay, the impacts are similar to Alternative 3b. The remaining structures associated with Alternative 4 are relatively small and have minimal impacts on the overall system.

6.2 Barrier Impacts on Sediment Transport

For the primary reaches of interest, the changes due to the proposed structures are relatively minor with the exception of Alternative 2. For the previously shown reaches (Figure 47), the dredge volume changes were:

- Alternative 2 – 20% reduction in dredge volumes
- Alternative 3a – 3% reduction in dredge volumes
- Alternative 3b – 1% increase in dredge volumes
- Alternative 4 – 0.5% increase in dredge volumes

Alternative 2 and Alternative 3a have the largest impacts on the system in terms of flow pathway modifications and reduction in tidal exchange. The reductions in tidal exchange also reduce the velocities and shear stresses present in the system. These reductions in tidal exchange tend to be more pronounced for the higher energy events resulting in increased impacts on sediment resuspension. Alternative 2 results in the largest reduction in tidal exchange and also has the largest reduction in dredge volumes. The impact of Alternative 3a is primarily associated with reduced dredge volumes in the Anchorage area along with slight reductions for the Newark Bay region through reduced tidal exchange. Note the reductions in dredge volumes associated with Alternative 2 in particular are associated with reduced erosion in other portions of the model. These impacts observed in the model are directly related to the bed specification and as such could be more/less impactful in the real system. The impact of ship navigation (ship waves and propeller wash) is not included in the model and therefore could impact these results.

6.3 Impacts of Sea Level Rise

The impact of sea level rise was isolate in the numerical model simulations by only increasing the tidal boundary forcing. All other parameters were left unchanged. This allowed for the impact of sea level to be quantified independent of other forcings. The existing 1995 sea level along with five additional sea levels were utilized for this analysis (0.1402 m/0.46 ft, 0.4451 m/1.46 ft, 0.7500 m/2.46 ft, 1.3598 m/4.46 ft, and 1.9695 m/6.46 ft). The following determinations were made:

- In general, the impacts for specific alternatives as discussed previously were similar across sea level values but the actual magnitude of those changes might increase/decrease slightly.

- Sea Level Rise increases the tidal exchange with the higher salinity offshore waters. This is facilitated by the increased flow area and decreased friction due to larger depths. This has a couple of implications, namely the salinity intrusion is increased, and the velocities are impacted as well. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prism/exchange.

- Sea Level Rise increases the mean flow (to south) through the Verrazano Narrows for all alternatives by approximately 13 % for the highest sea level rise amount.

- Throgs Neck shows an increase (~40 %) in the mean flow (to west) with sea level rise. This is relatively constant across alternatives with Alternative 3a possessing a slightly smaller increase over the other alternatives.

- A reduction in flow of approximately 2 – 6 % is observed for Kill Van Kull for the largest sea level rise depending on the Alternative. Alternative 2 shows the largest reduction for sea level rise while Alternative 3b has the lowest reduction.

- Similar to Kill Van Kull, Arthur Kill shows a slight decrease in mean flow (to south) associated with sea level rise.

7 References

Caplow, Theodore, Schlosser, Peter, Ho, David T., and Nicholas Santella (2003). "Transport Dynamics in a Sheltered Estuary and Connecting Tidal Straits: SF_6 Tracer Study in New York Harbor." Environmental Science and Technology. Vol. 37, No. 22, 5116-5126

McAlpin, Tate O, Joseph V Letter, Mary Bryant, Gary L Brown, Gaurav Savant, Bryce W Wisemiller, Jamal A Sulayman, Corey J Trahan, and Anthony G Emiren. 2017. "New York/New Jersey Harbor Sedimentation Study: Numerical Modeling of Hydrodynamics and Sediment Transport." Technical Report.

Parker, Bruce B. 2007. *Tidal Analysis and Prediction*. Silver Spring, Maryland: NOAA Special Publication NOS CO-OPS 3.

8 Appendix A – Profile View of structure design

The figures in this appendix are of the preliminary structure designs in comparison to the without project bathymetry. All elevations are relative to Mean Sea Level. Table 6 includes a comparison of the reduction in area for each structure relative to a water level of Mean Sea Level (0.0 m). Flushing Creek was not included in the without project model domain, so no area was included in the existing conditions model. Figure 53 to Figure 65 provides an illustration on the change in area for the proposed conditions along with illustrations of the sill elevations relative to the without project conditions.

Table 6. Without Project and proposed structure areas.

Structure	Existing Area (m^2)	Design Area (m^2)	Percentage (Design/Existing)*100
Sandy Hook to Rockaway	96,050	51,077	53
Throgs Neck	14,898	9,655	65
Kill Van Kull	11,687	6,098	52
Verrazano Narrows	33,453	19,368	58
Arthur Kill	5,283	2,355	45
Jamaica Bay	10,279	5,738	56
Gerritsen Creek	533	246	46
Sheepshead Bay	1,943	735	38
Coney Island Creek	695	260	37
Gowanus Canal	119	181	151
Newton Creek	592	297	50
Flushing Creek	N/A	344	N/A
Hackensack River	2,522	1,544	61

Figure 53: Sandy Hook to Rockaway Cross Section

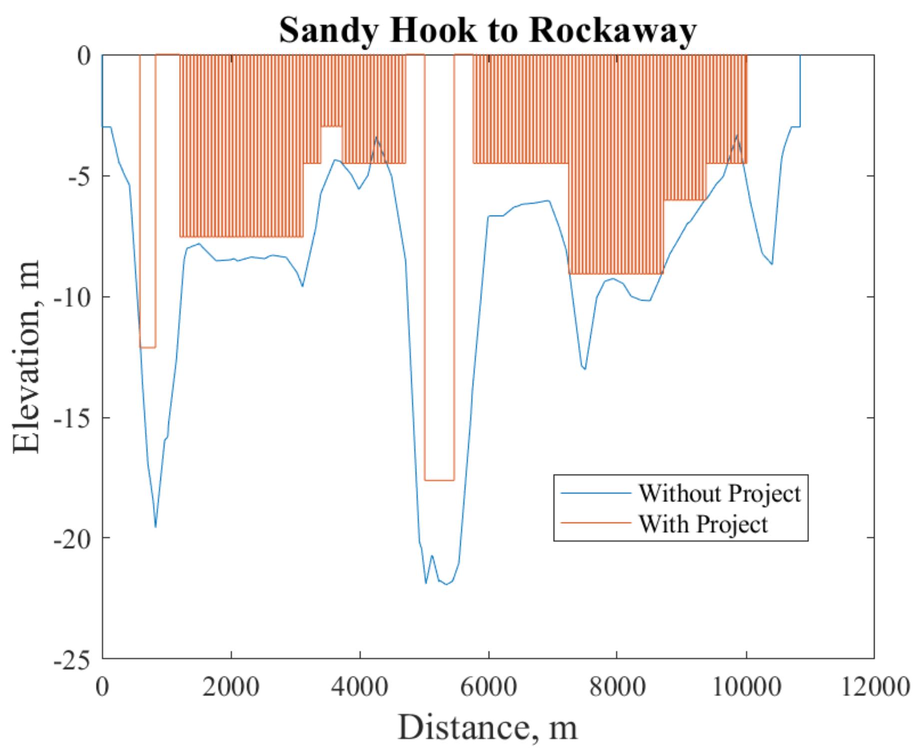


Figure 54: Throgs Neck Cross Section

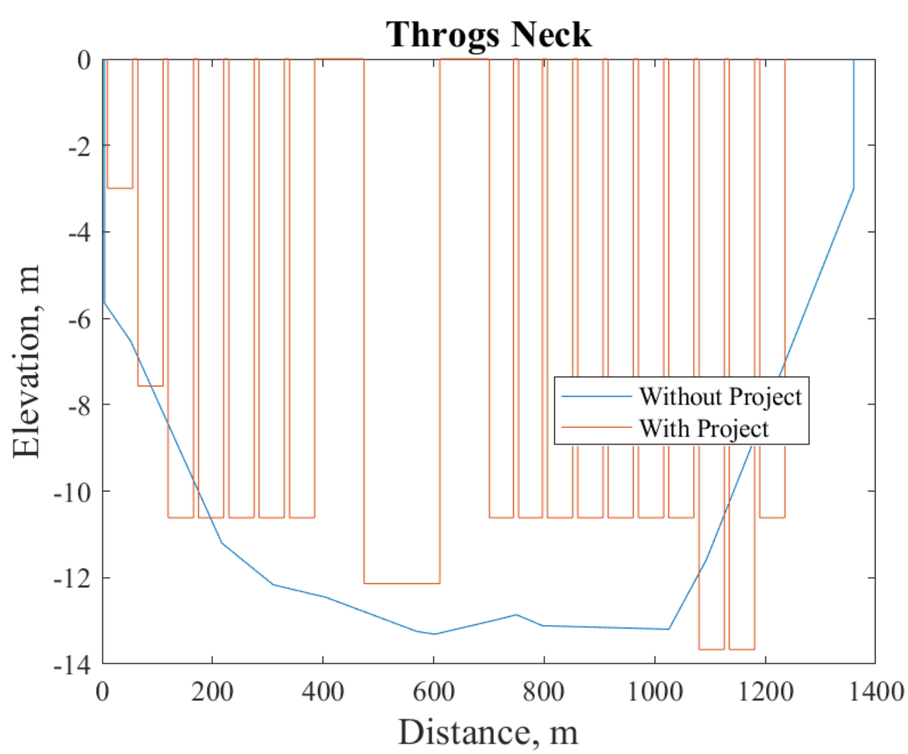


Figure 55: Arthur Kill Cross Section

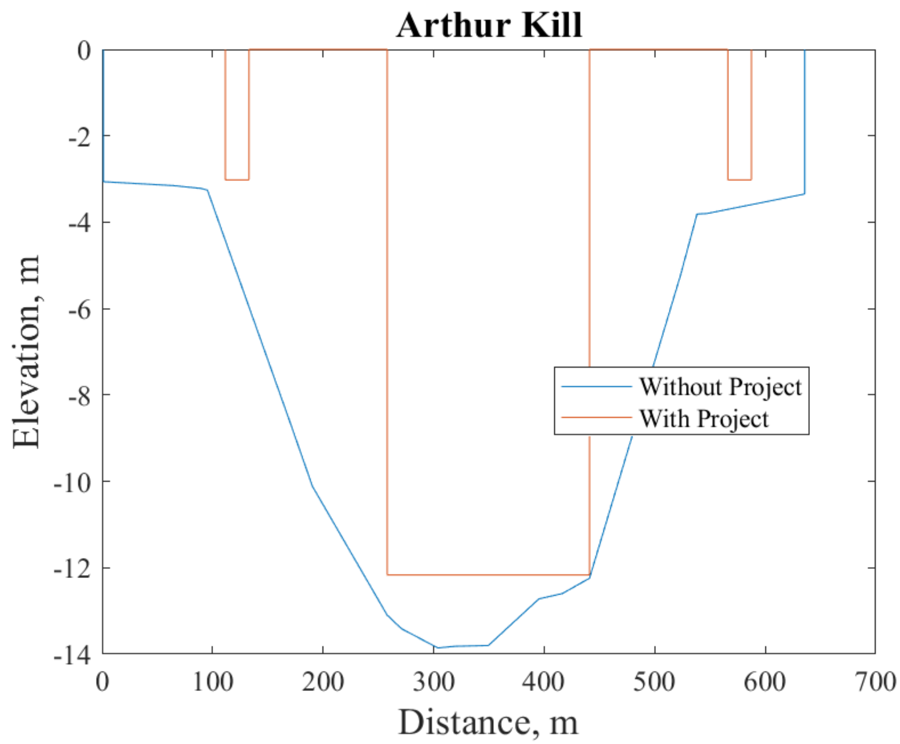


Figure 56: Jamaica Bay Cross Section

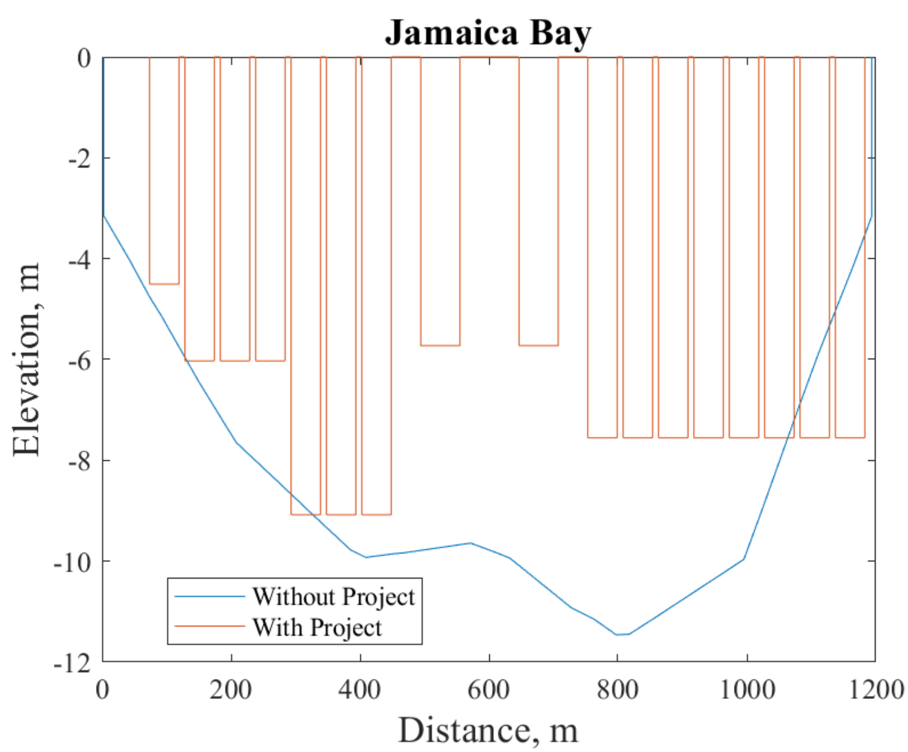


Figure 57: Verrazano Narrows Cross Section

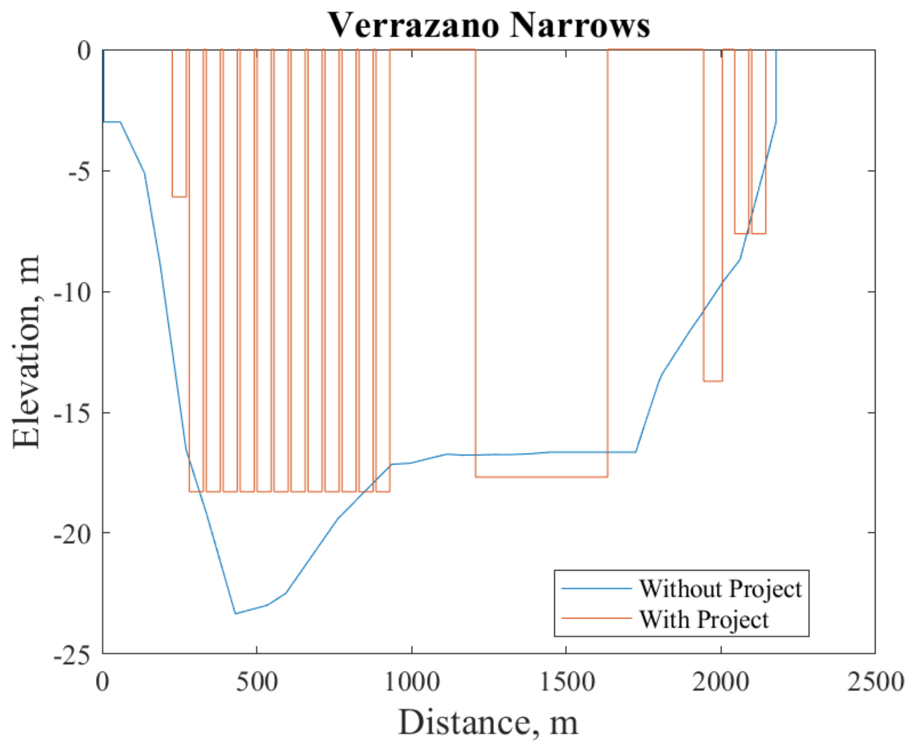


Figure 58: Kill van Kull Cross Section

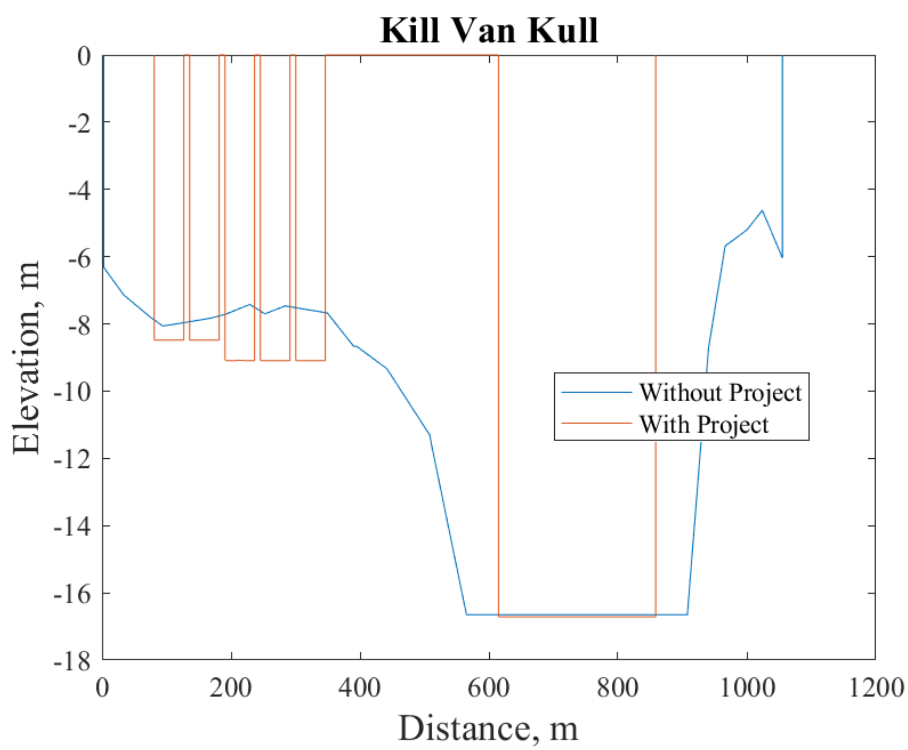


Figure 59: Hackensack Cross Section

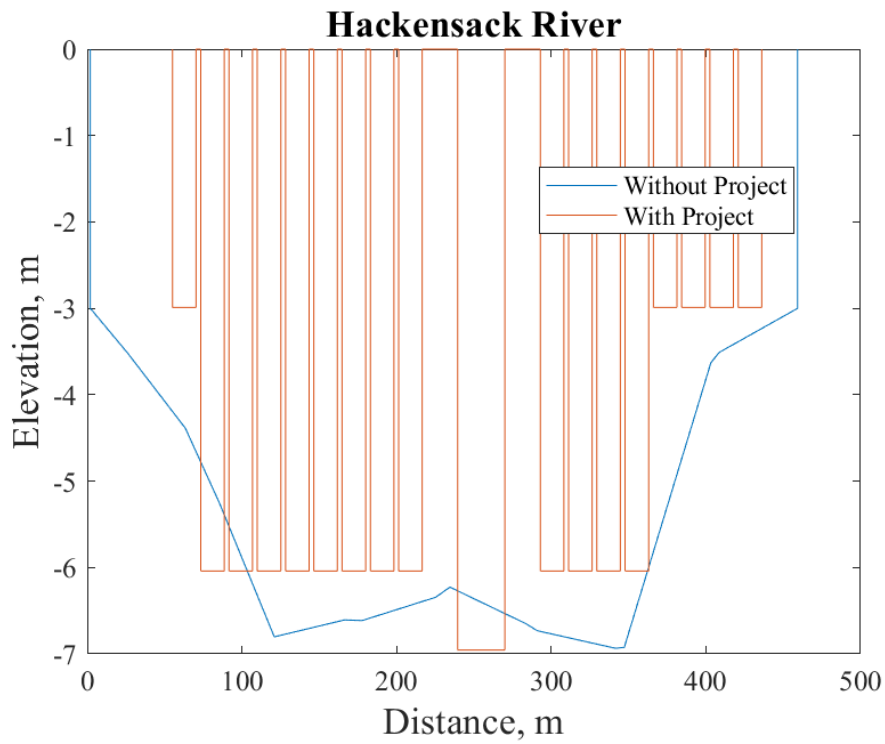


Figure 60. Coney Island Creek Cross Section

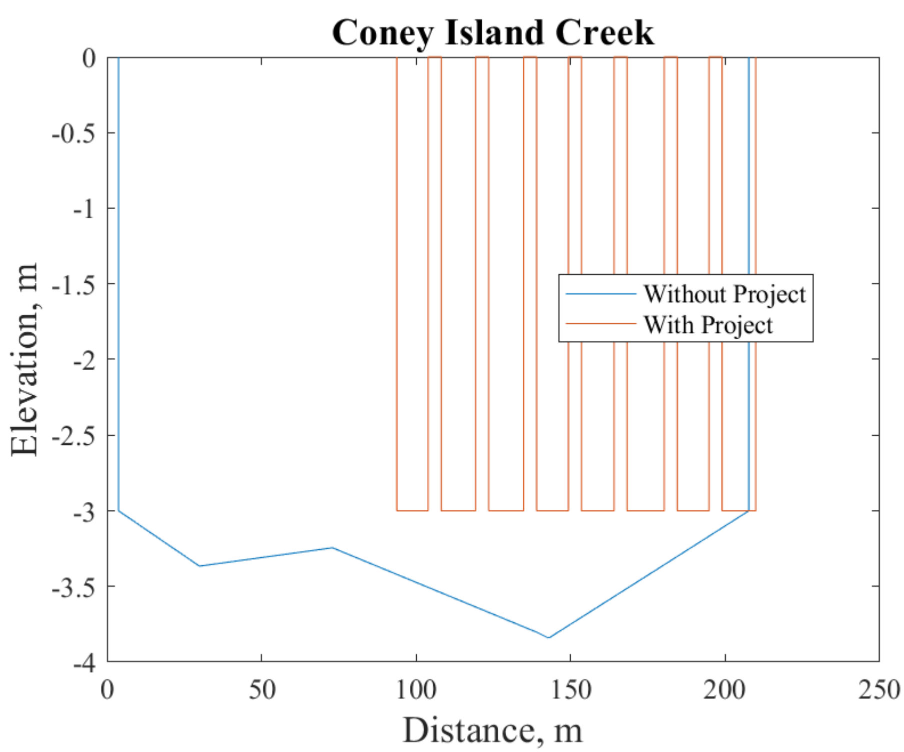


Figure 61. Flushing Creek Cross Section (Note: the existing mesh did not include this area and as such there is no representation of the existing conditions).

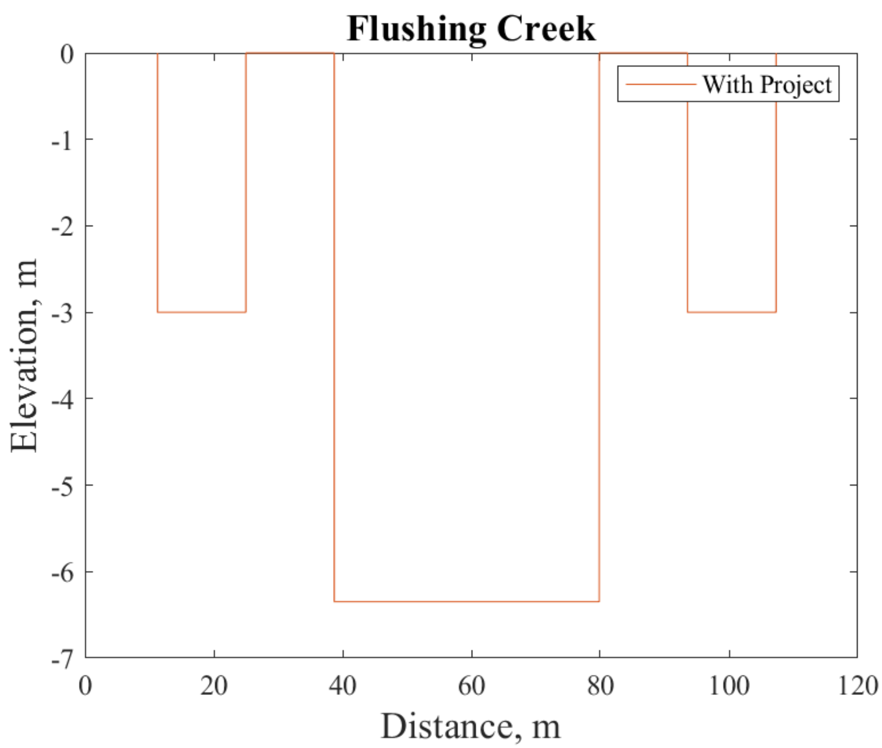


Figure 62. Gerritsen Creek Cross Section

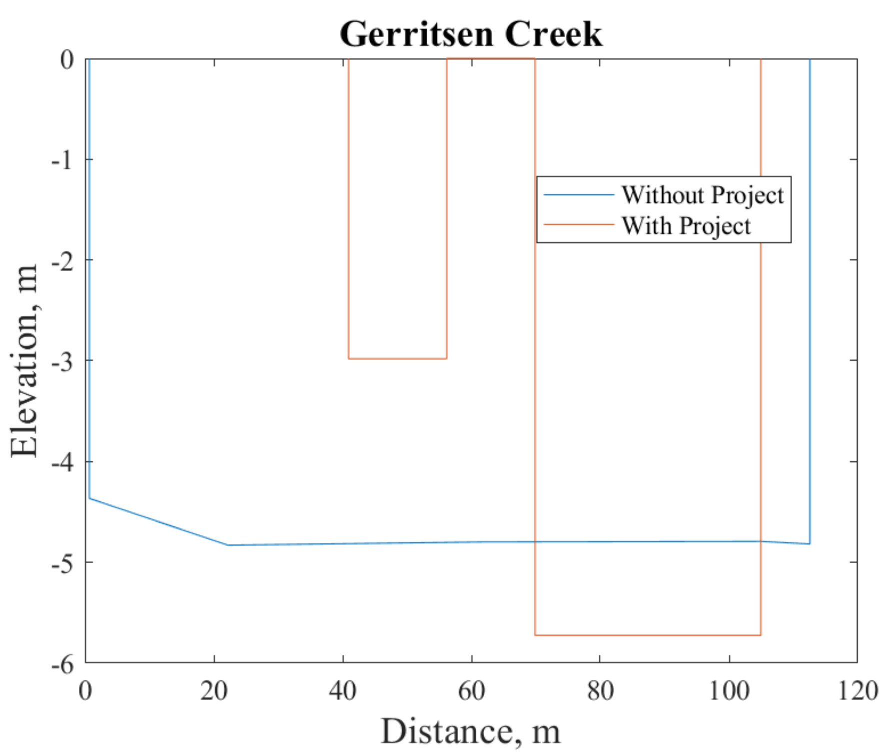


Figure 63. Gowanus Canal Cross Section

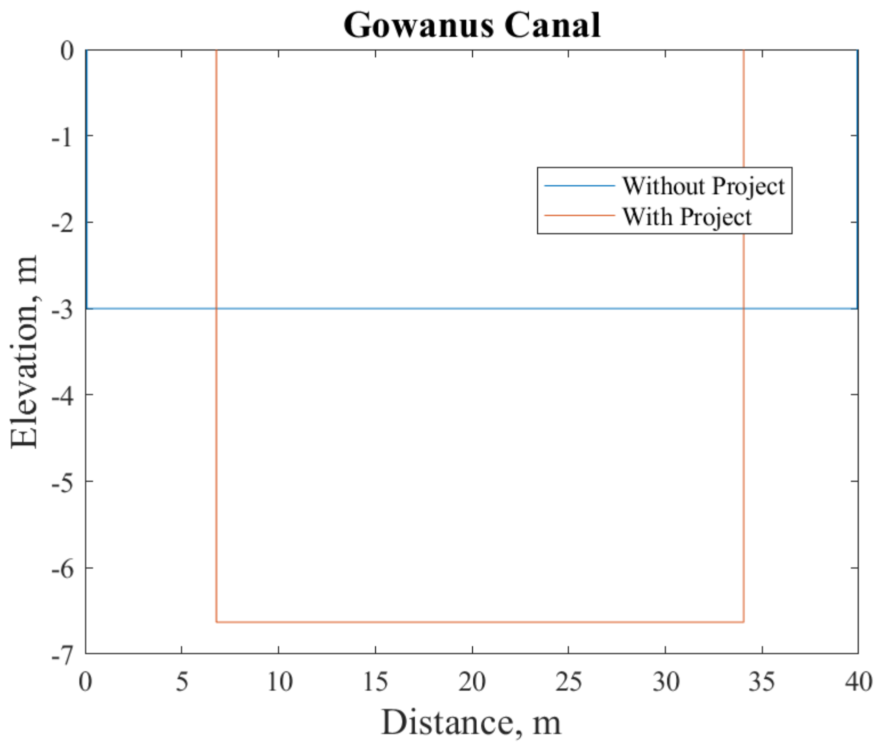


Figure 64. Newton Creek Cross Section

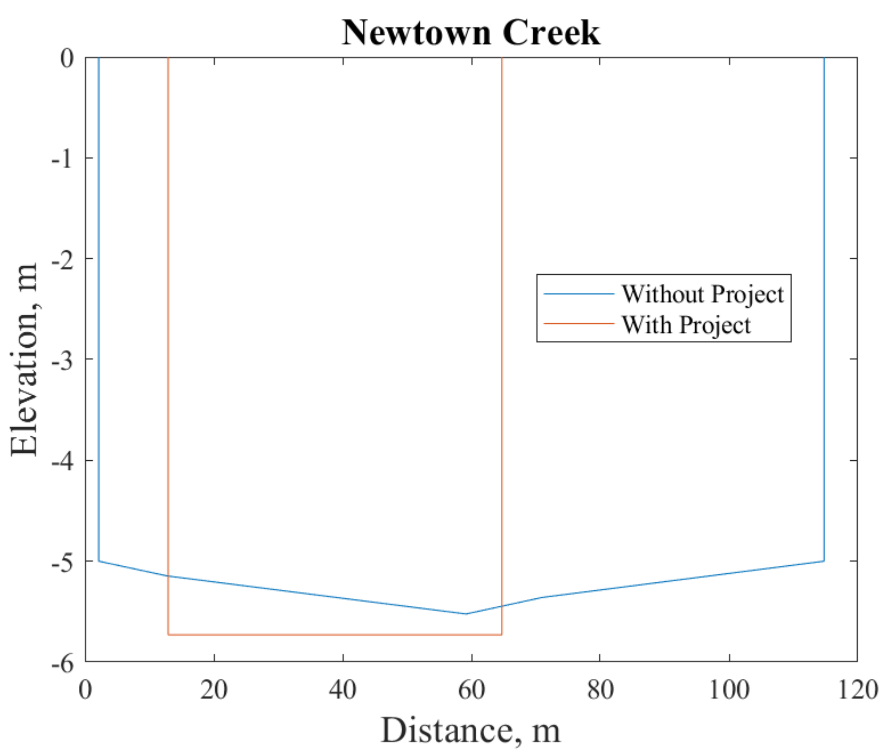
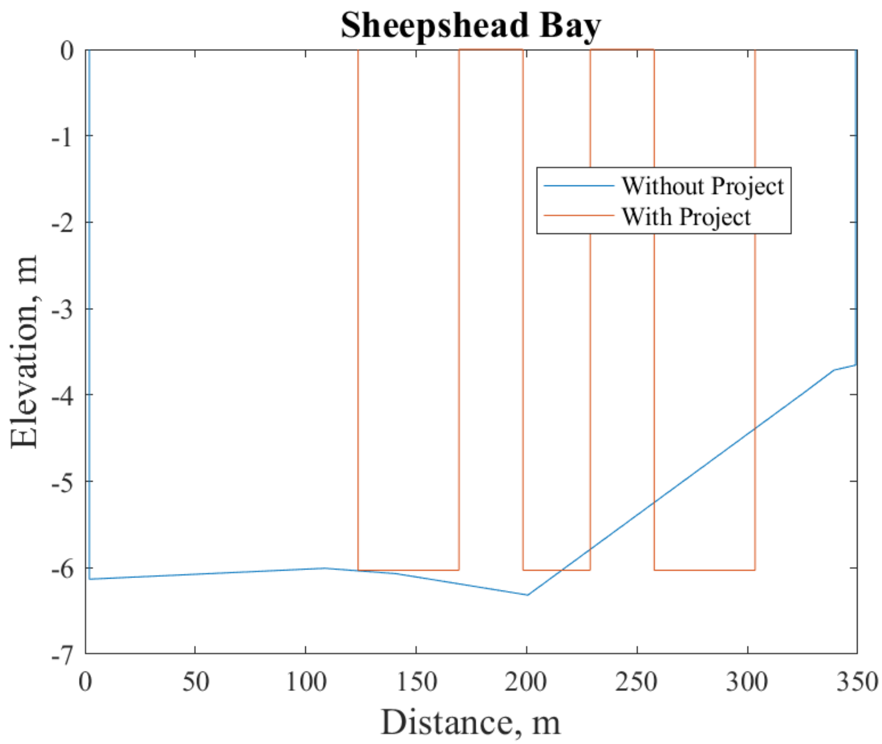


Figure 65. Sheepshead Bay Cross Section



9 Appendix B – Water Surface Elevation Percentiles

The figures (Figure 66 to Figure 90) in this appendix are the water surface elevation percentiles for the point comparison locations previously shown in Figure 17 to Figure 20 with coordinates provided in Table 3. These results were calculated based on 1 hour output information for the entire 1995 calendar year simulation. An increase in the low percentile water levels (~20) and a decrease in the high percentile water levels (~80) is indicative of a reduction in the tide range. This can be observed in Figure 66 for Sandy Hook for Alternative 2.

Figure 66. Sandy Hook Water Surface Elevation Percentiles.

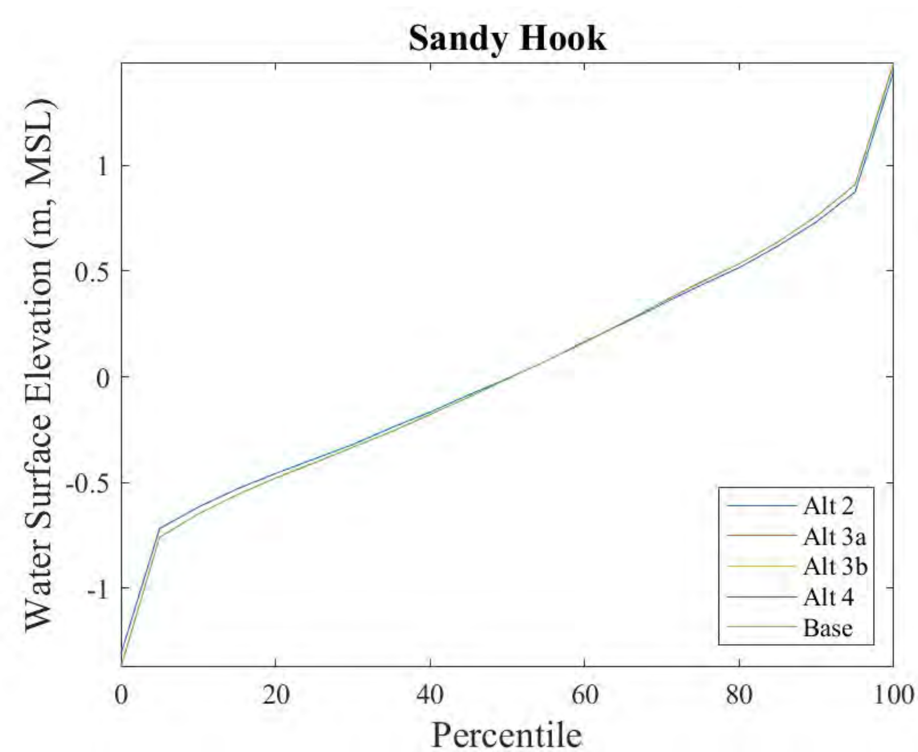


Figure 67. V5 Water Surface Elevation Percentiles.

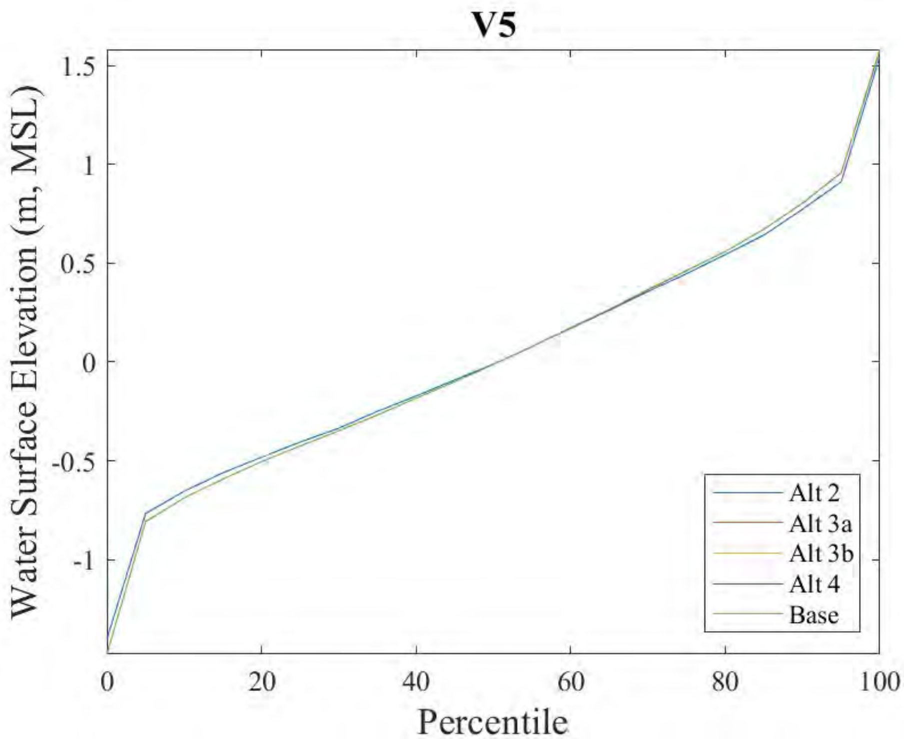


Figure 68. V6 Water Surface Elevation Percentiles.

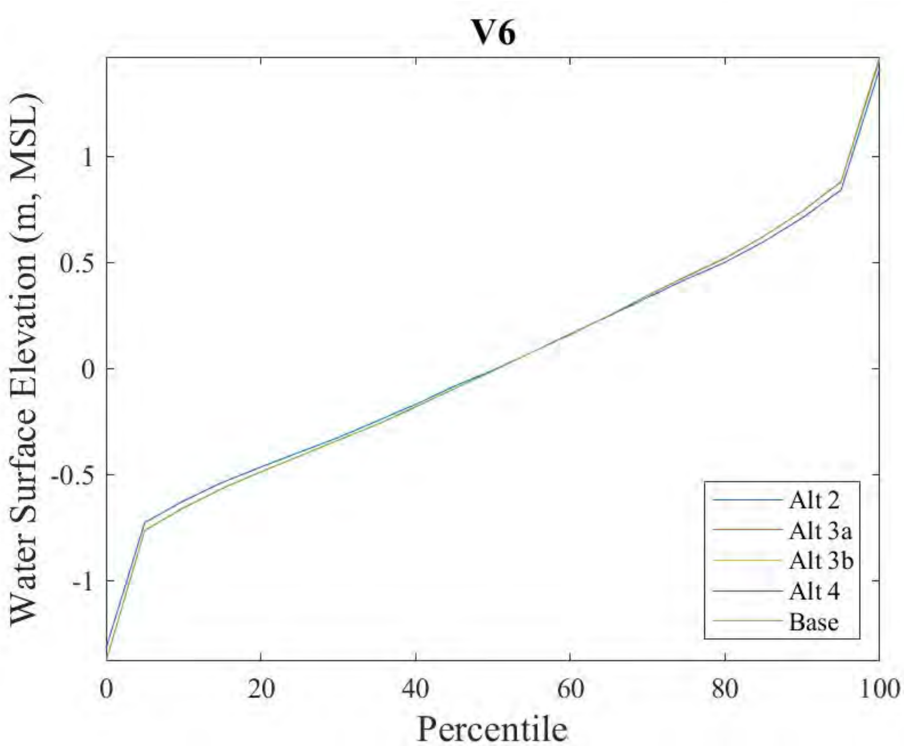


Figure 69. Fresh Kills Water Surface Elevation Percentiles.

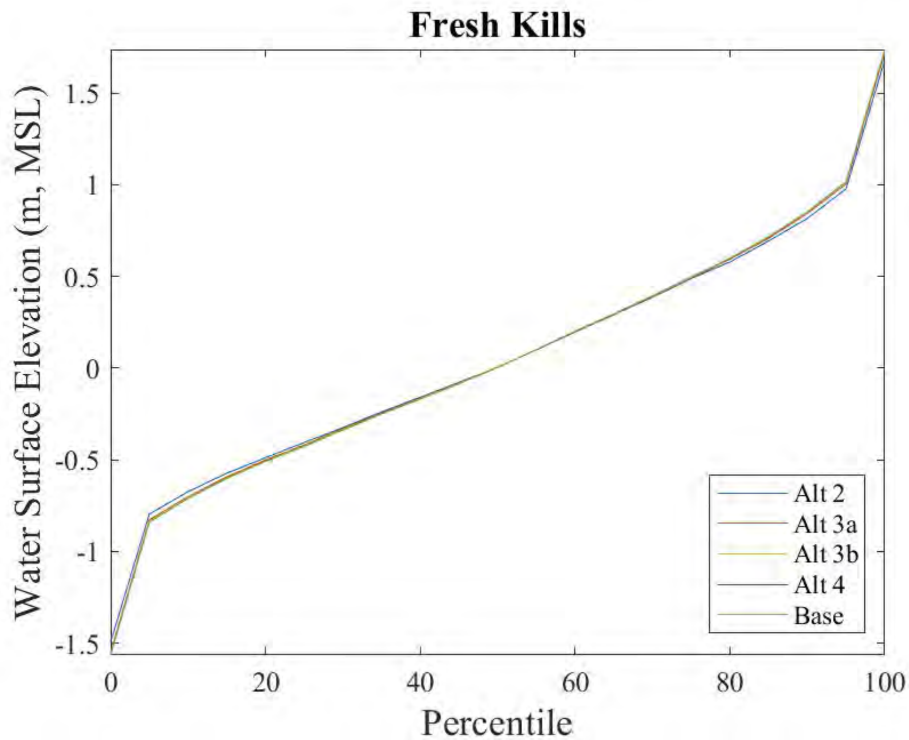


Figure 70. Mariners Harbor Water Surface Elevation Percentiles.

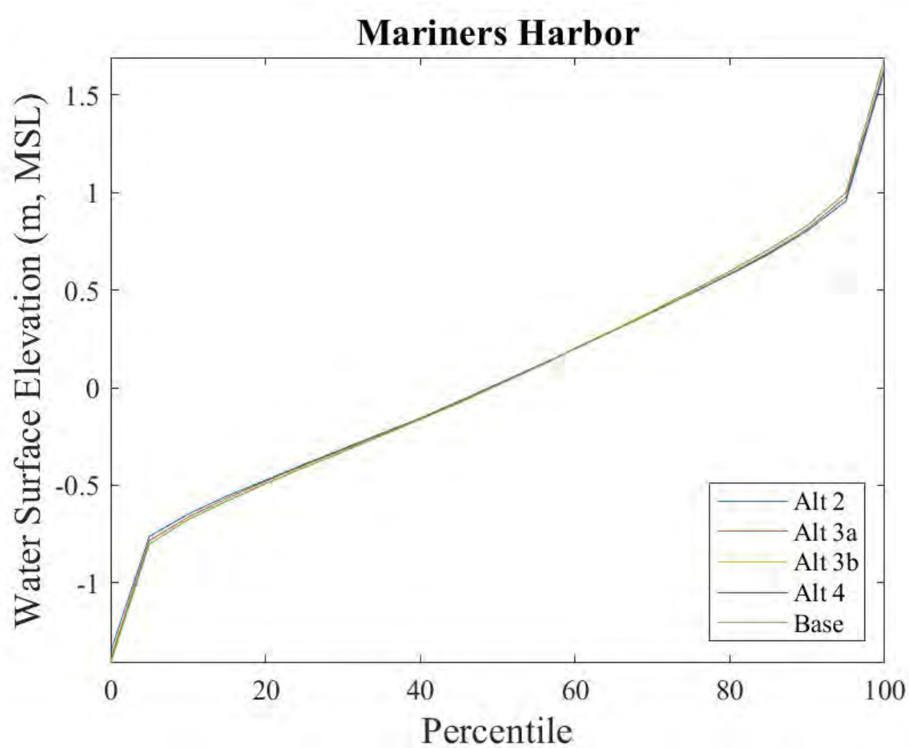


Figure 71. T2 Water Surface Elevation Percentiles.

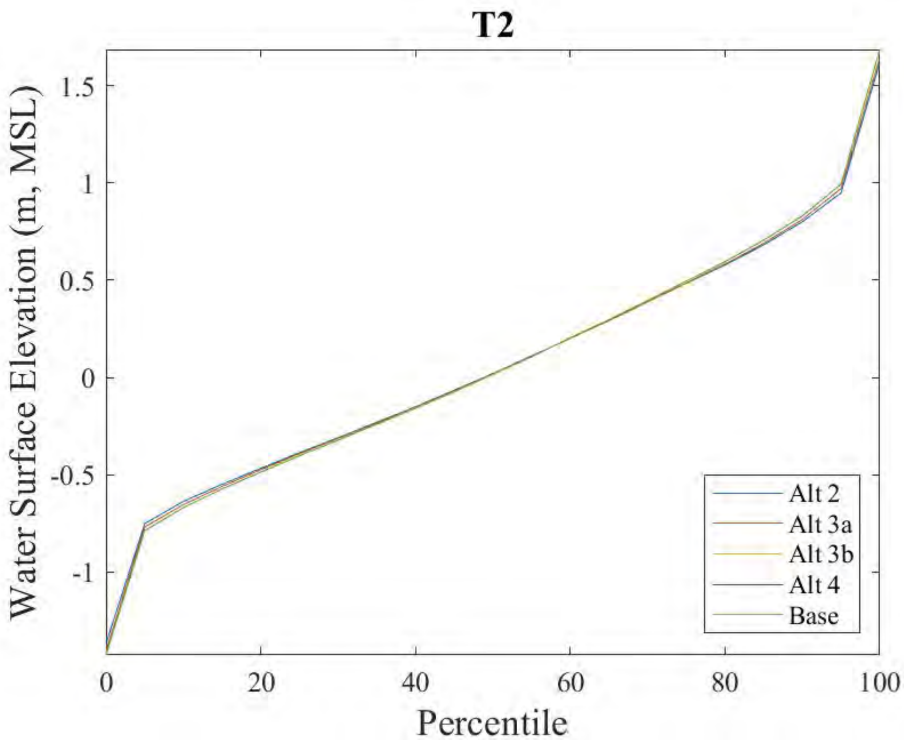


Figure 72. T3 Water Surface Elevation Percentiles.

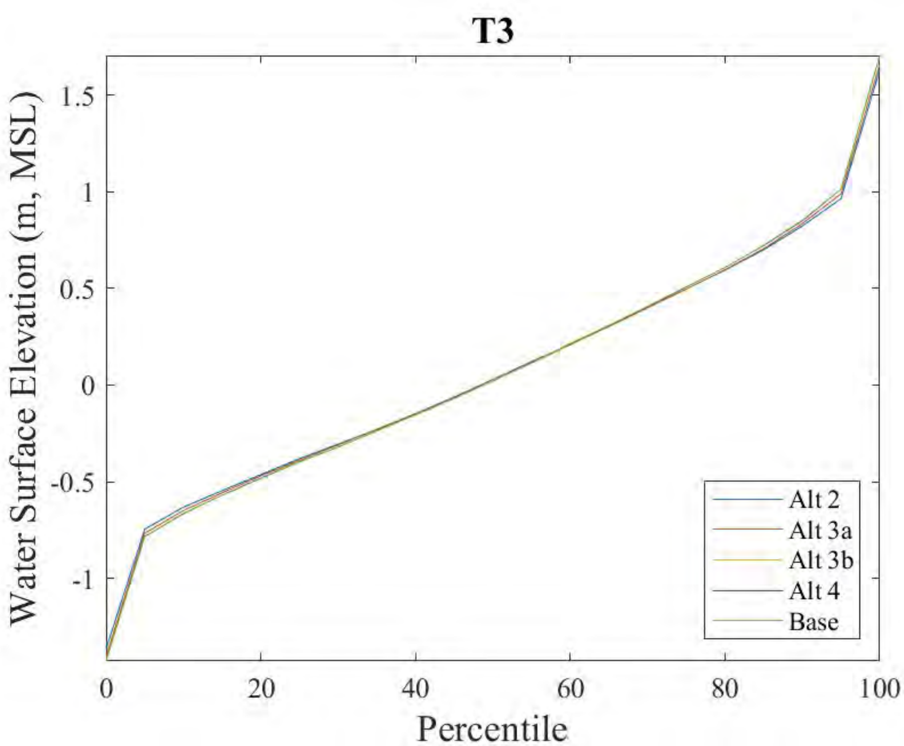


Figure 73. North Reach Water Surface Elevation Percentiles.

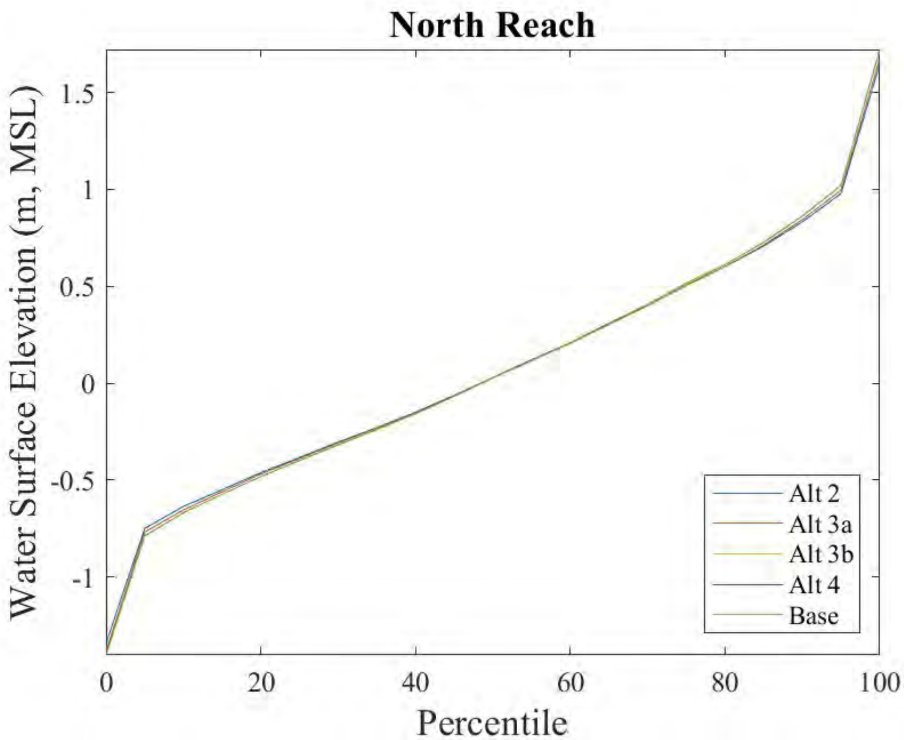


Figure 74. Hackensack River Water Surface Elevation Percentiles.

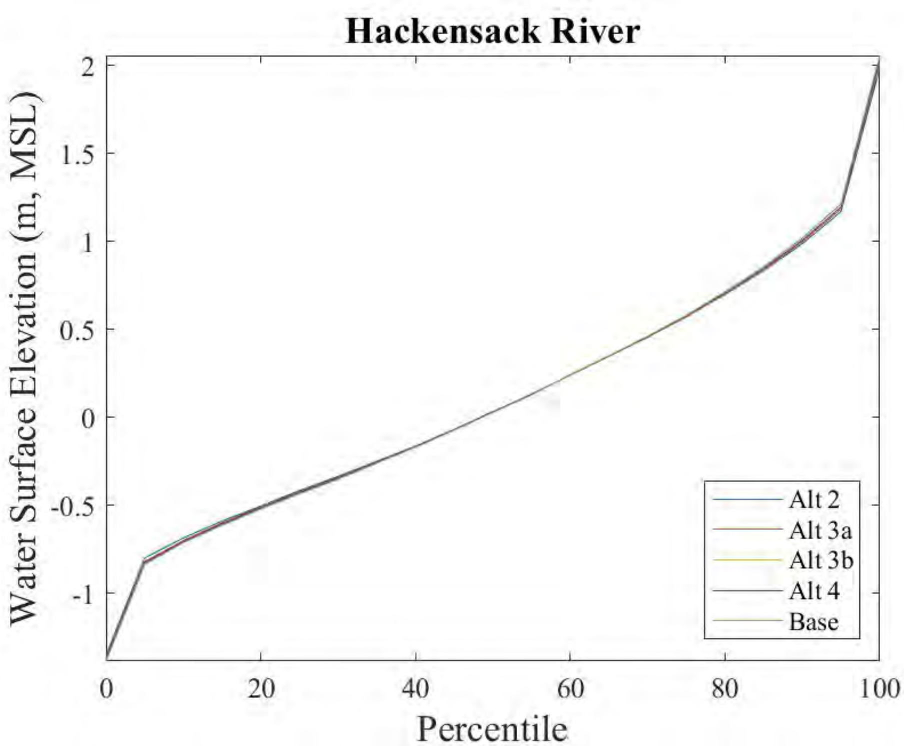


Figure 75. Robbins Reef Water Surface Elevation Percentiles.

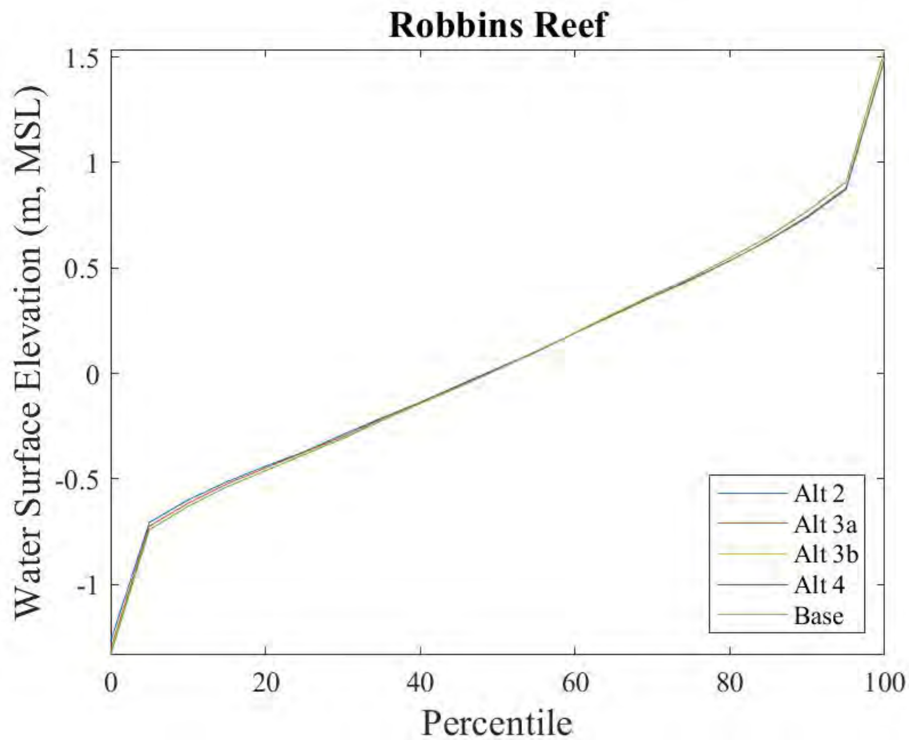


Figure 76. S2 Water Surface Elevation Percentiles.

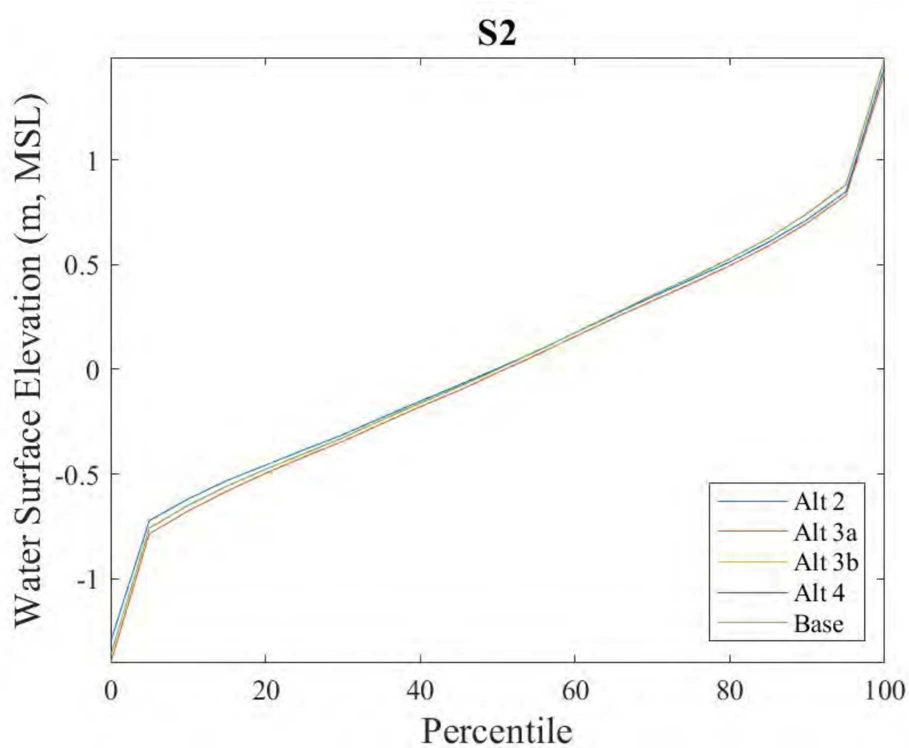


Figure 77. S5 Water Surface Elevation Percentiles.

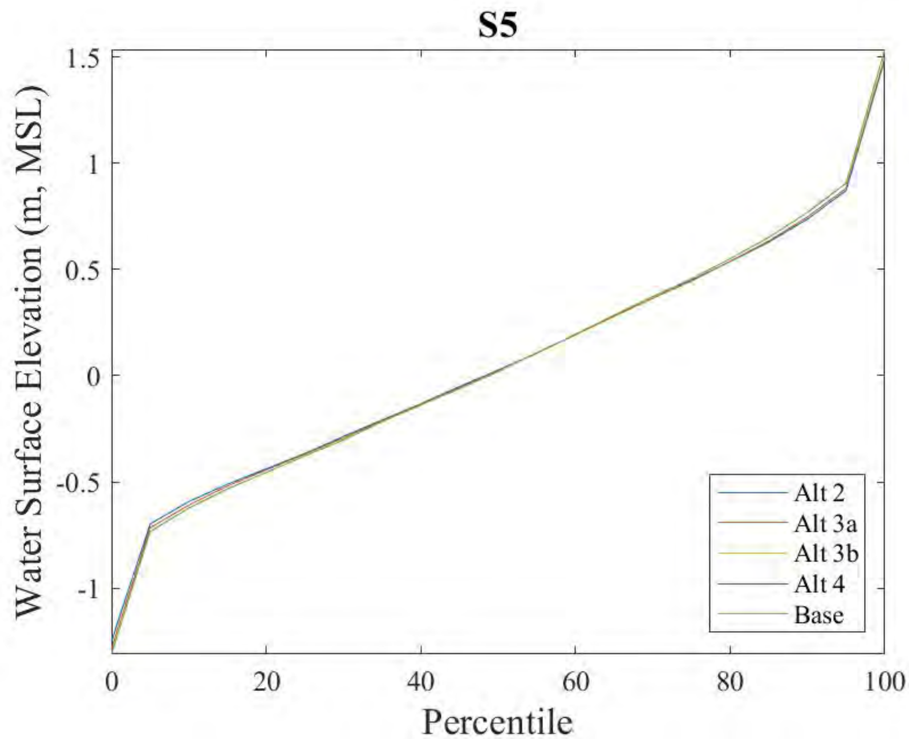


Figure 78. The Battery Water Surface Elevation Percentiles.

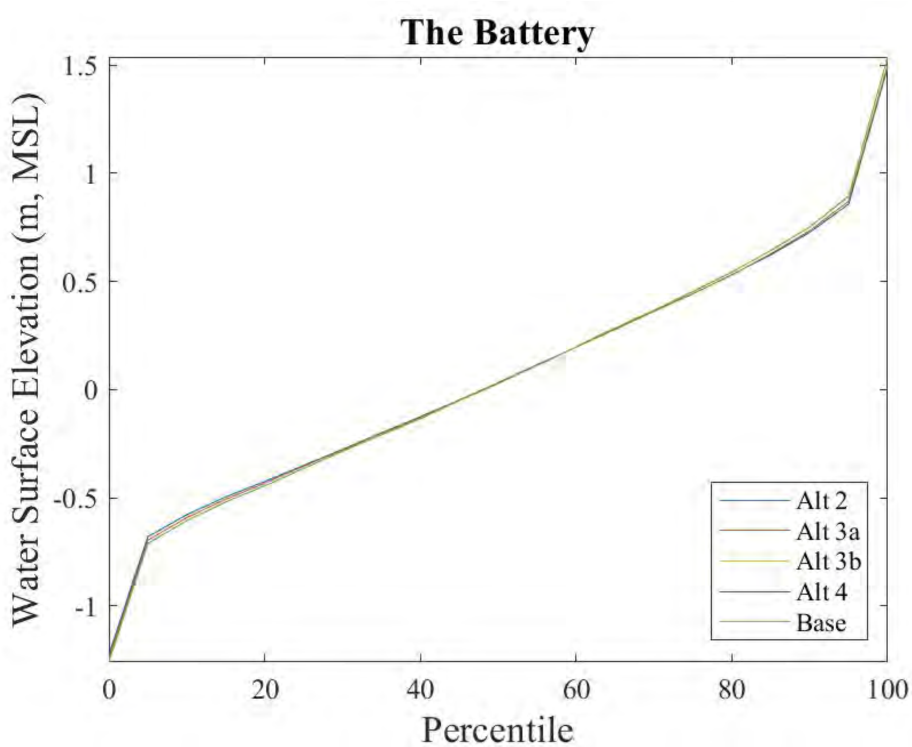


Figure 79. Manhattan Water Surface Elevation Percentiles.

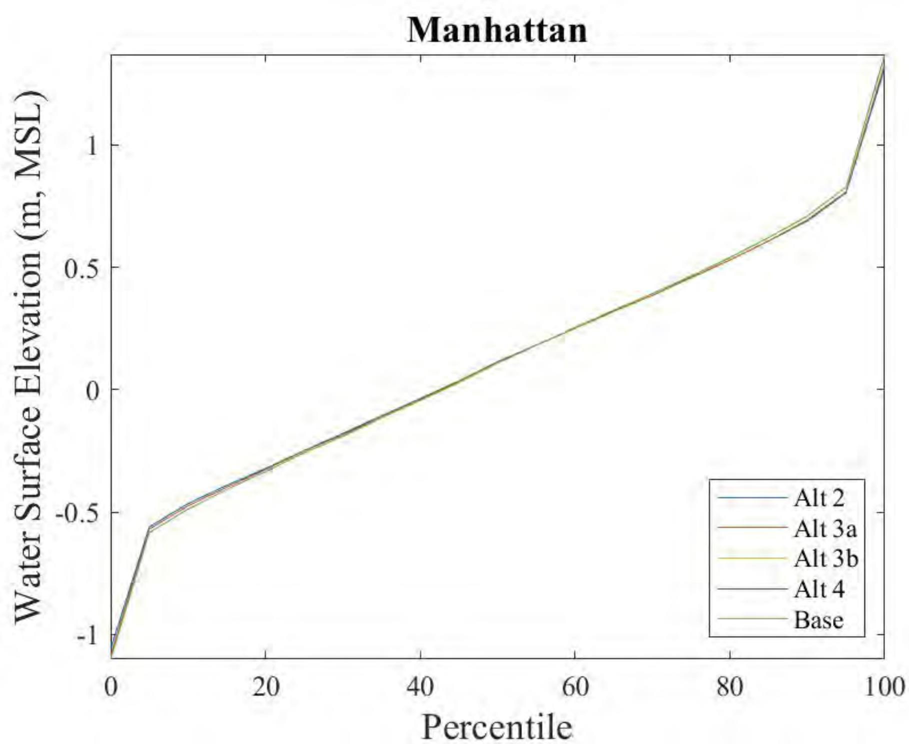


Figure 80. Jamaica Bay Water Surface Elevation Percentiles.

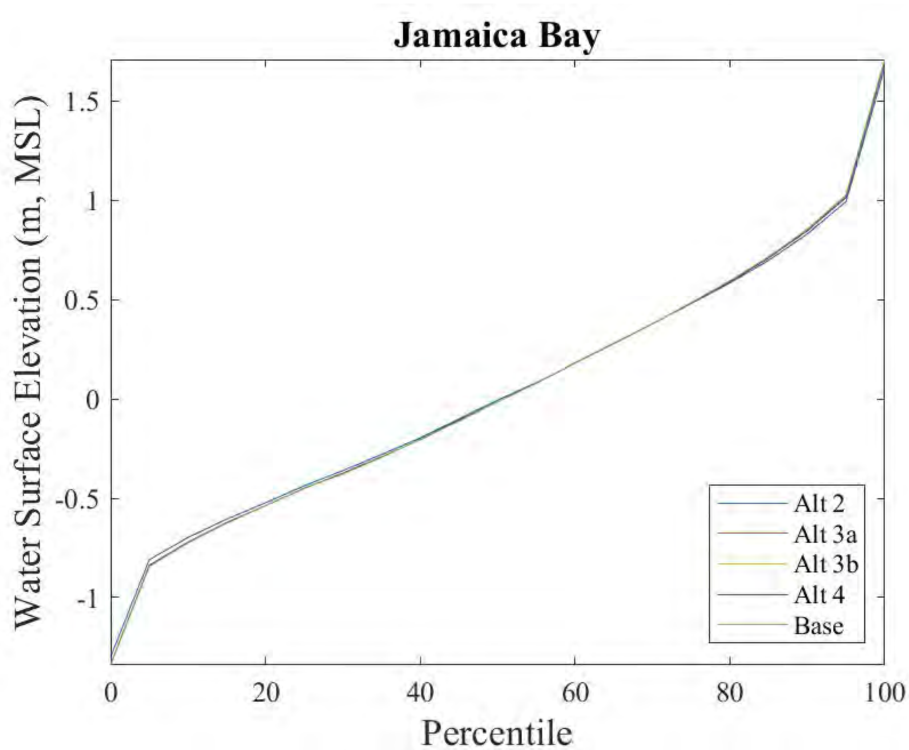


Figure 81. Jamaica Bay near Spring Creek Water Surface Elevation Percentiles.

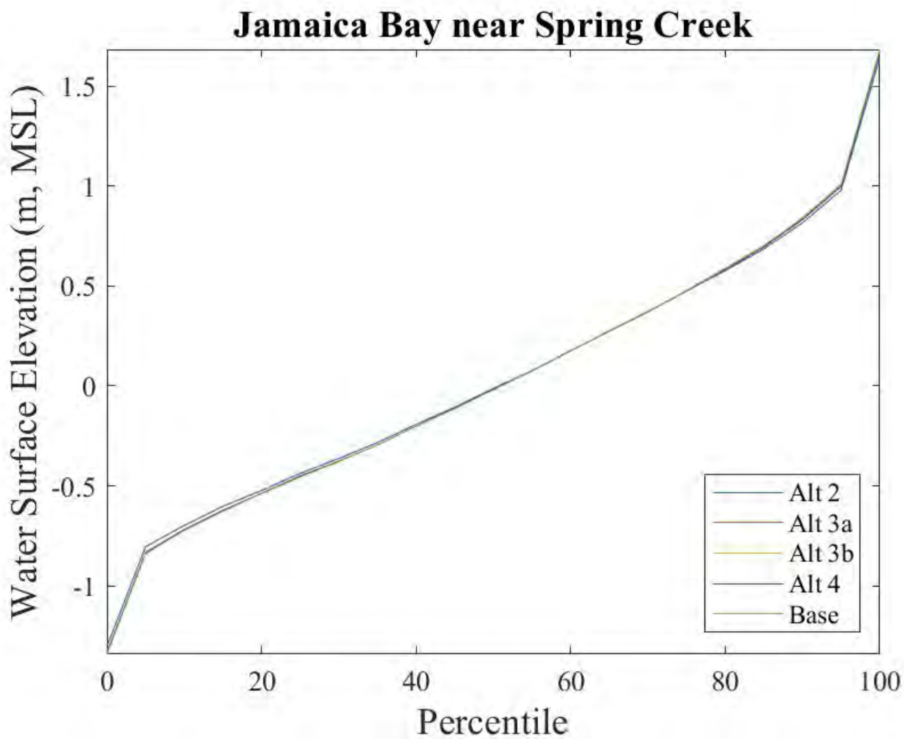


Figure 82. Jamaica Bay near Grass Hassock Water Surface Elevation Percentiles.

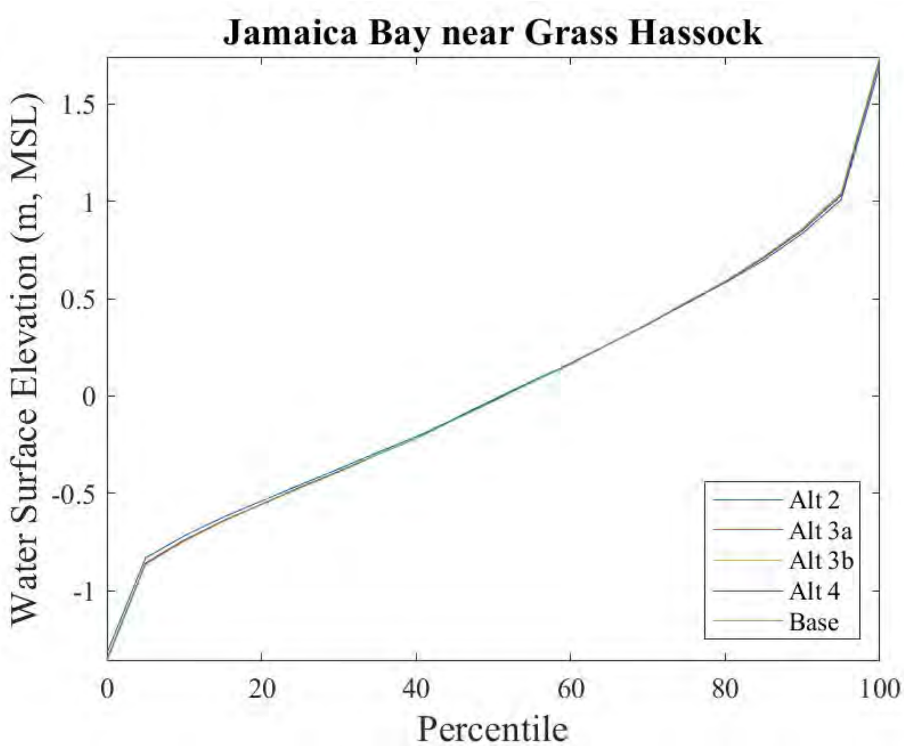


Figure 83. KLGA Water Surface Elevation Percentiles.

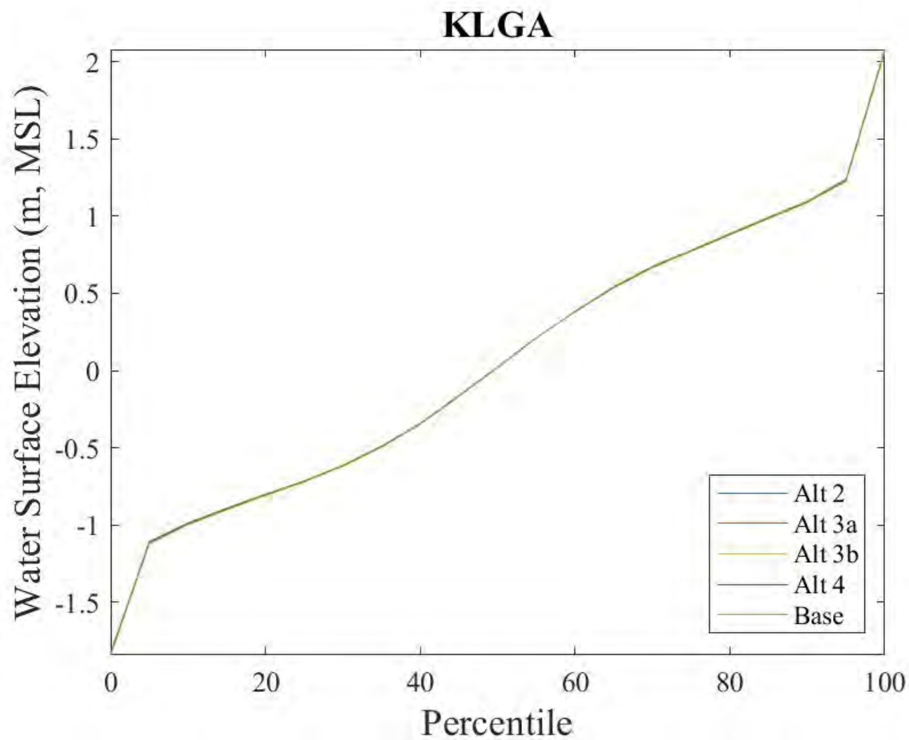


Figure 84. Western LIS, near Stepping Stone Lighthouse Water Surface Elevation Percentiles.

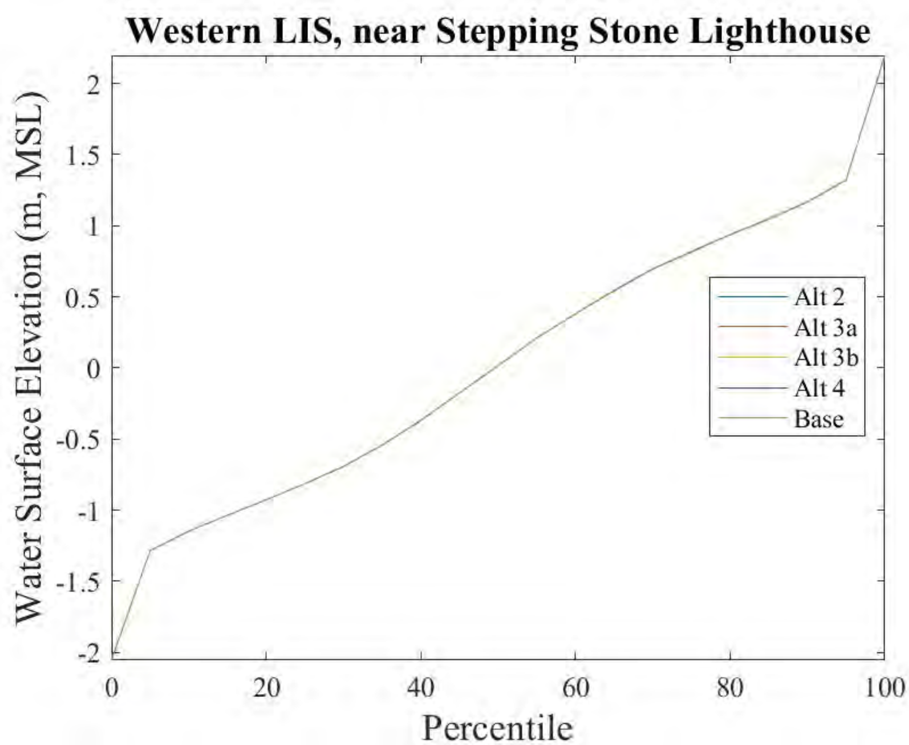


Figure 85. Wester LIS, near Execution Rock Lighthouse Water Surface Elevation Percentiles.

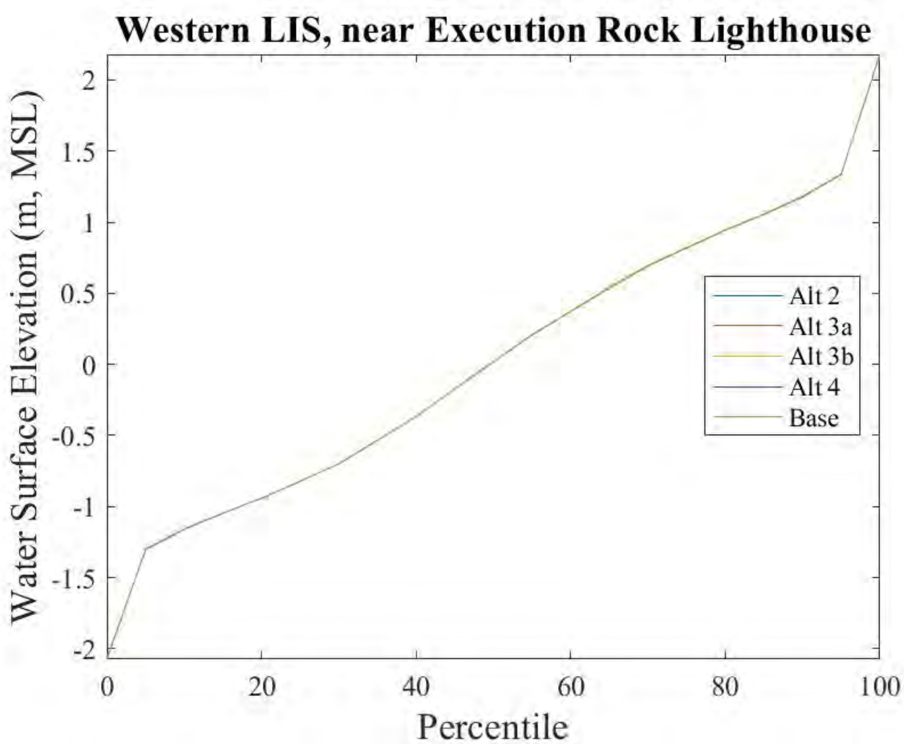


Figure 86. Western LIS, south of NY and CT Border Water Surface Elevation Percentiles.

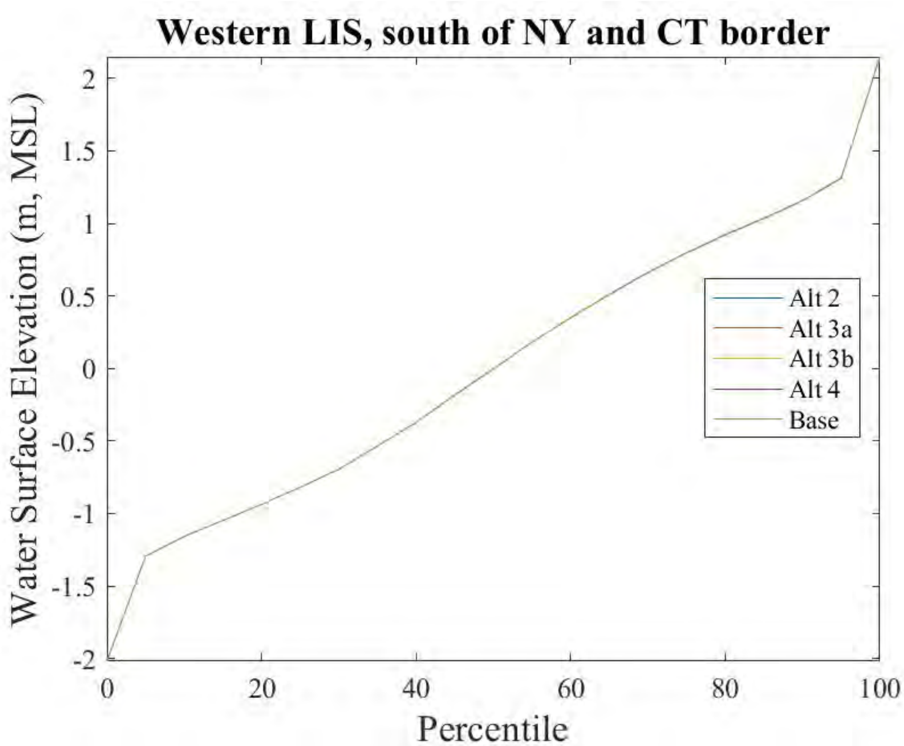


Figure 87. Hudson River, Haverstraw Bay Water Surface Elevation Percentiles.

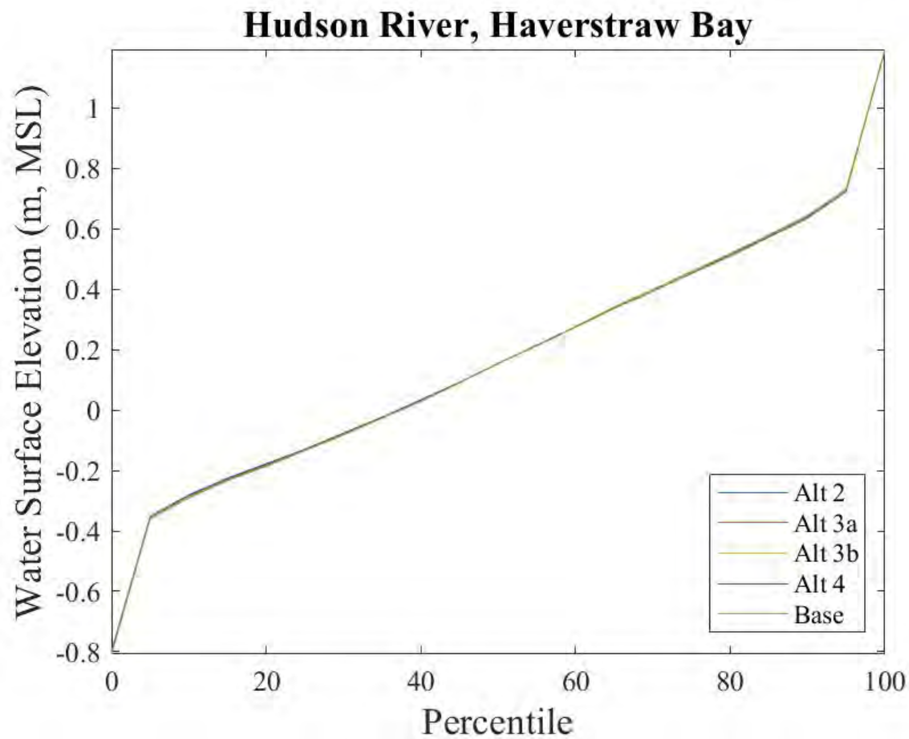


Figure 88. Hudson River, near Poughkeepsie Water Surface Elevation Percentiles.

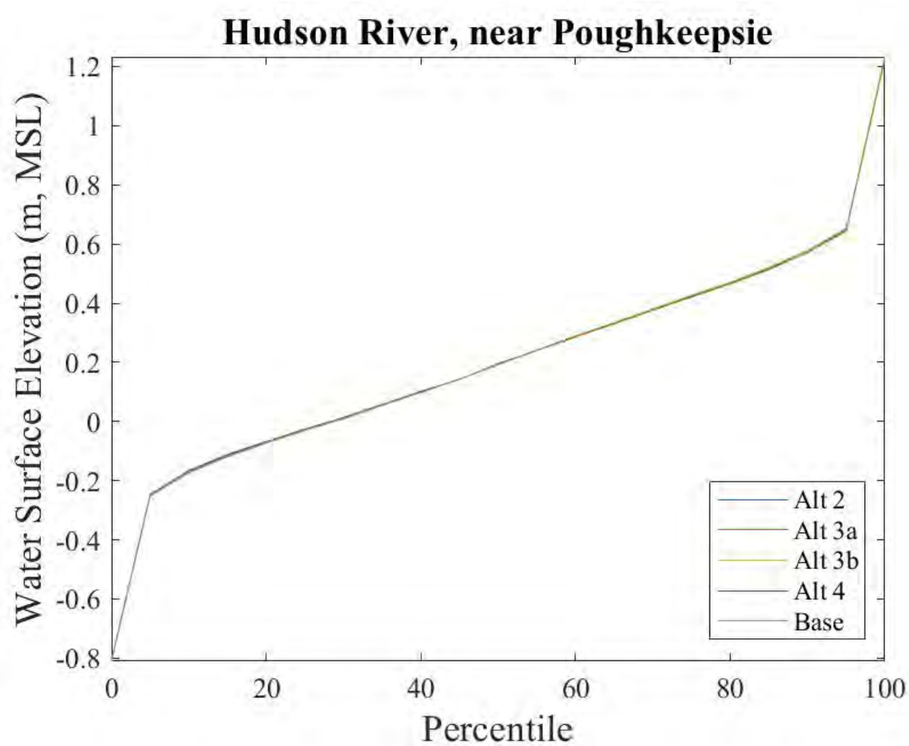


Figure 89. Hudson River, between Catskill and Hudson Water Surface Elevation Percentiles.

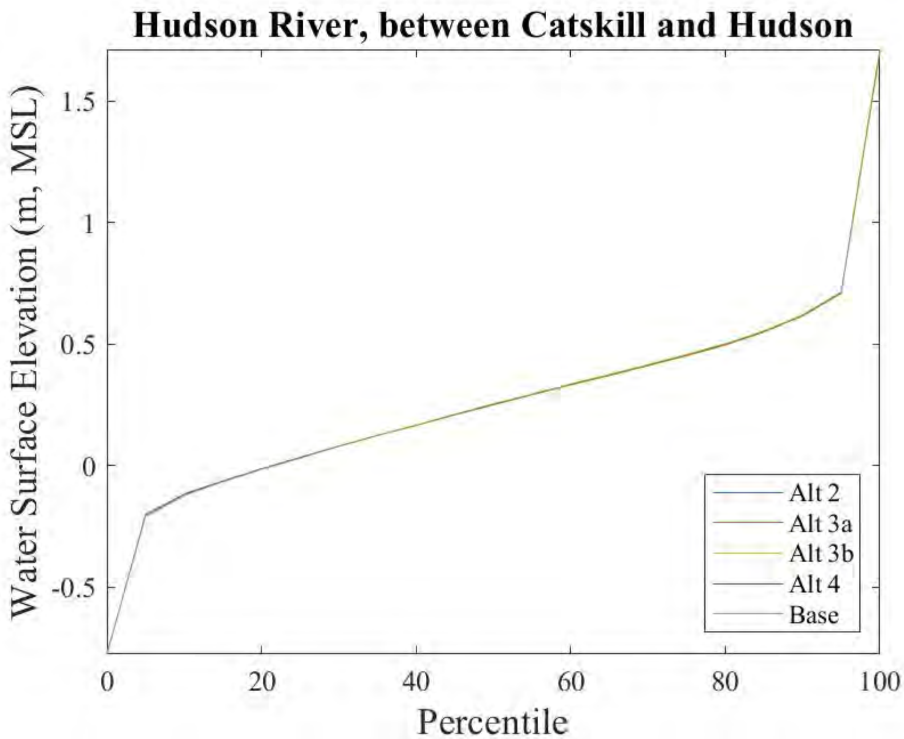
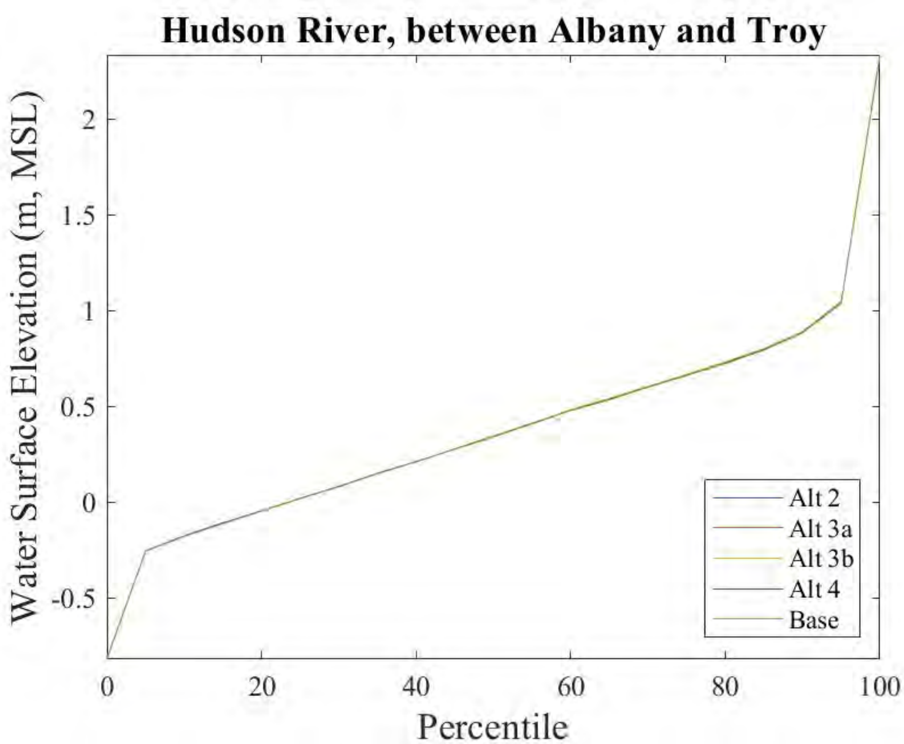


Figure 90. Hudson River, between Albany and Troy Water Surface Elevation Percentiles.



10 Appendix C – Velocity Percentiles

The figures (Figure 91 to Figure 126) in this appendix are the velocity percentiles for the point comparison locations previously shown in Figure 17 to Figure 20 with coordinates provided in Table 3. These results were calculated based on 1 hour output information for the entire 1995 calendar year simulation. These figures indicate both the system wide velocity changes along with the local velocity increases near field of the structures. Figure 91 illustrates the near field velocity increase for Alternative 2 at the Sandy Hook structure location. In general, locations away from the proposed structures experience negligible change in velocities with localized increases in velocity apparent in/near structures.

Figure 91. V1 Location Velocity Percentiles.

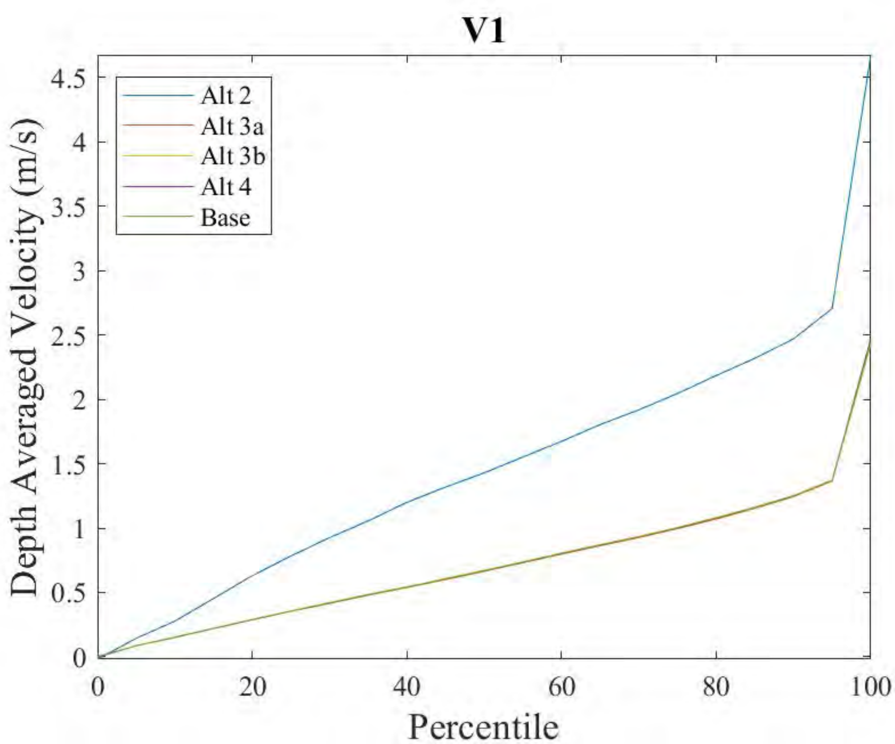


Figure 92. V2 Location Velocity Percentiles.

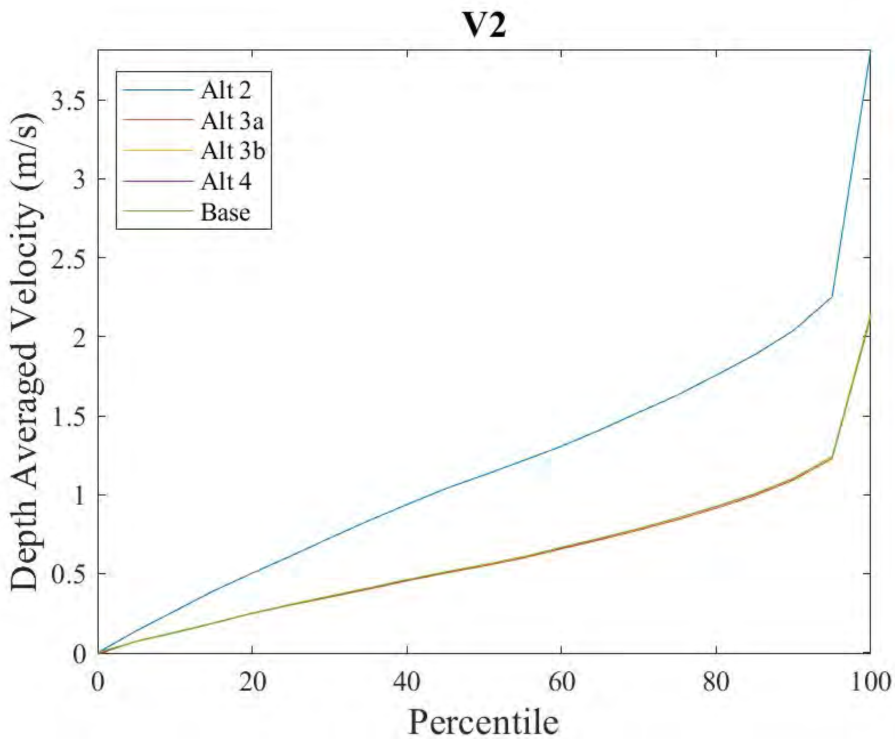


Figure 93. V3 Location Velocity Percentiles.

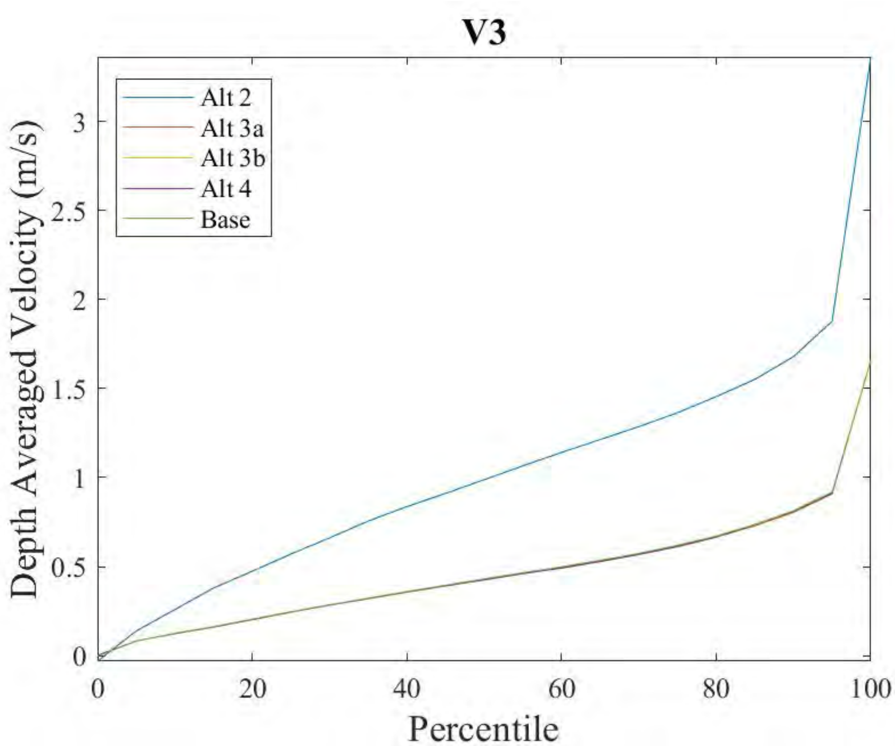


Figure 94. V4 Location Velocity Percentiles.

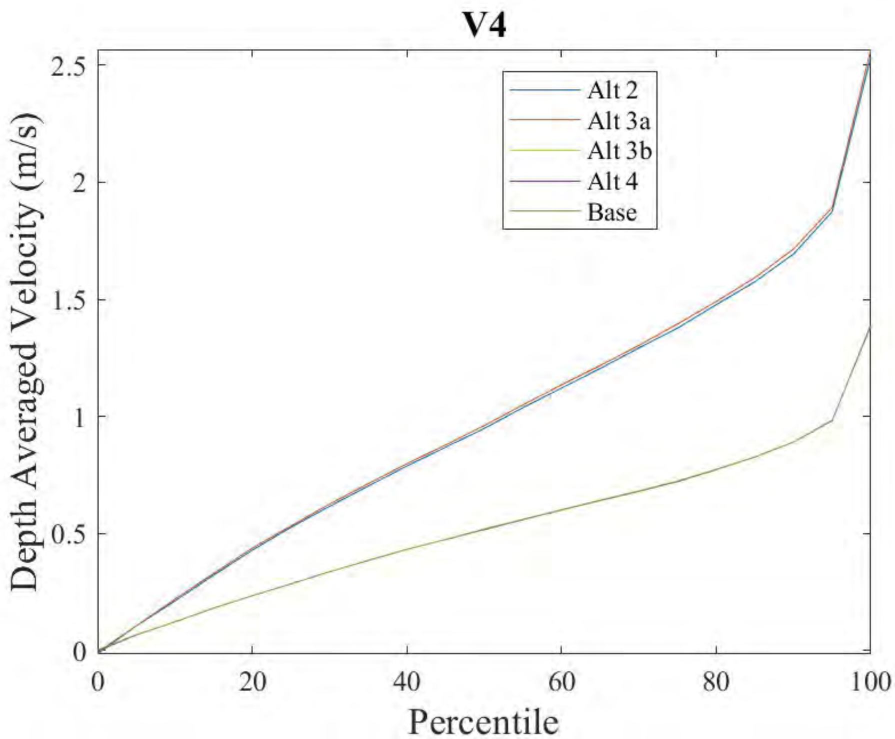


Figure 95. V5 Location Velocity Percentiles.

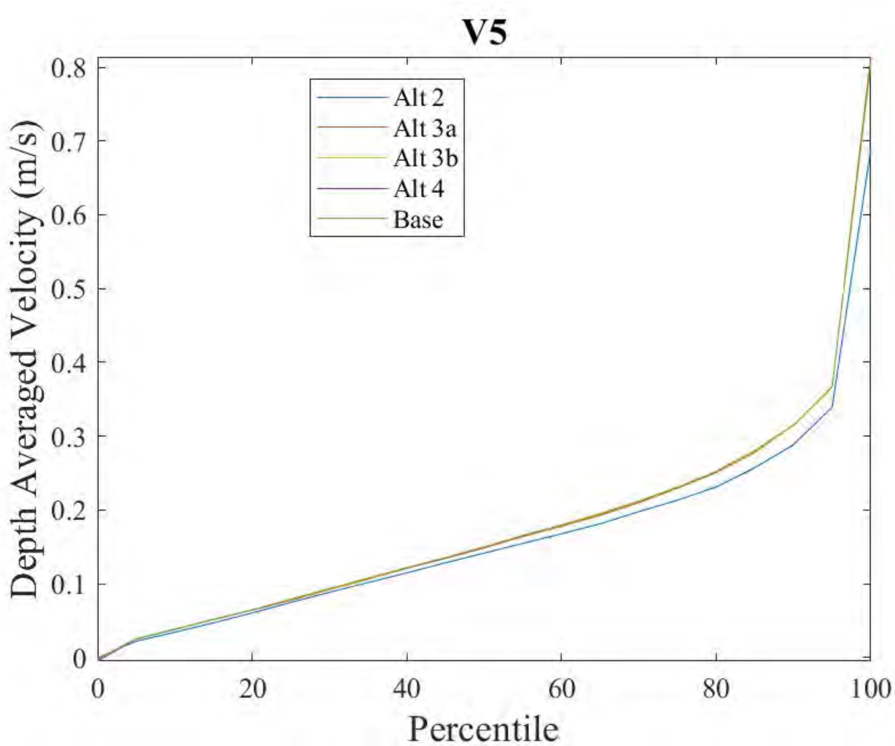


Figure 96. V6 Location Velocity Percentiles.

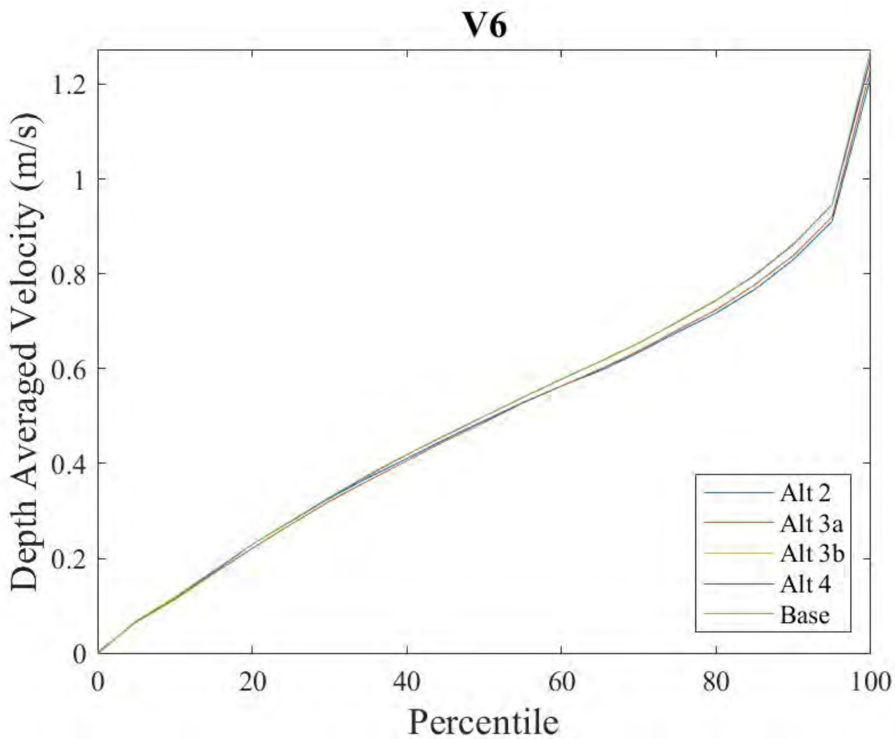


Figure 97. S1 Location Velocity Percentiles.

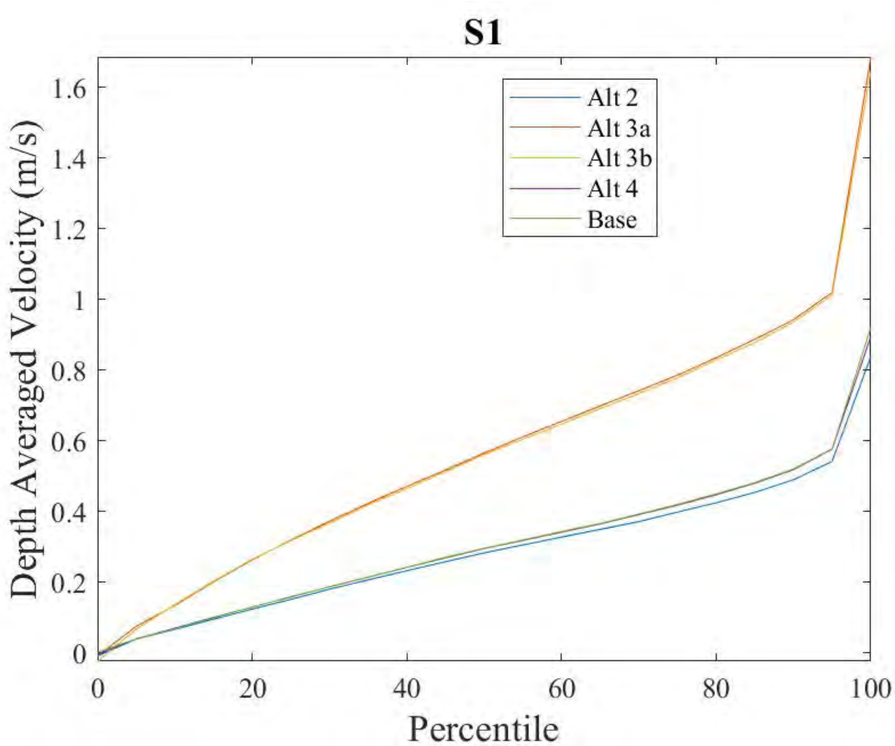


Figure 98. S2 Location Velocity Percentiles.

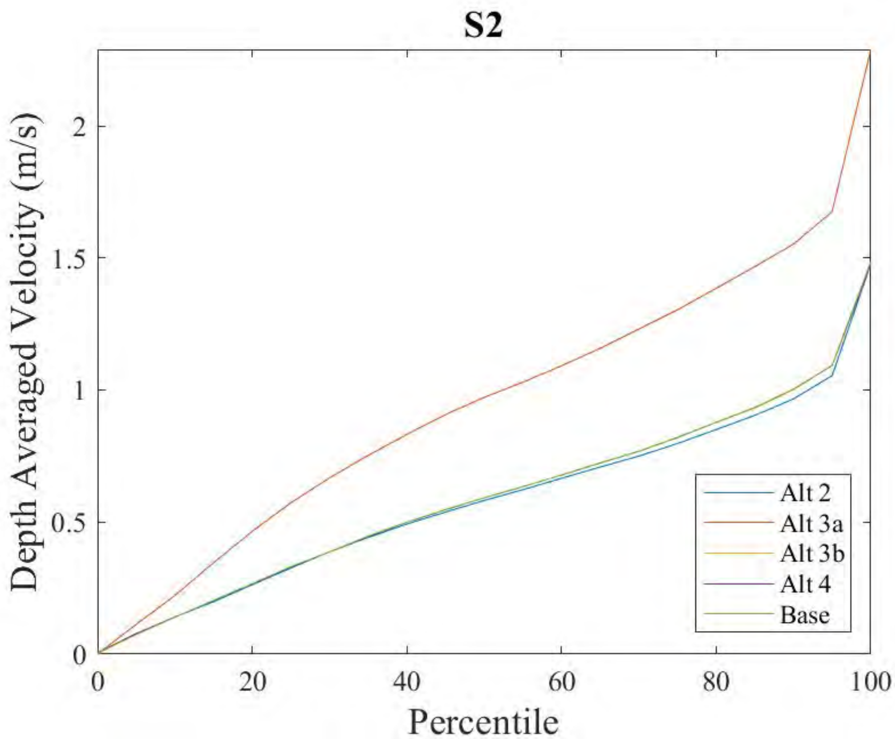


Figure 99. S3 Location Velocity Percentiles.

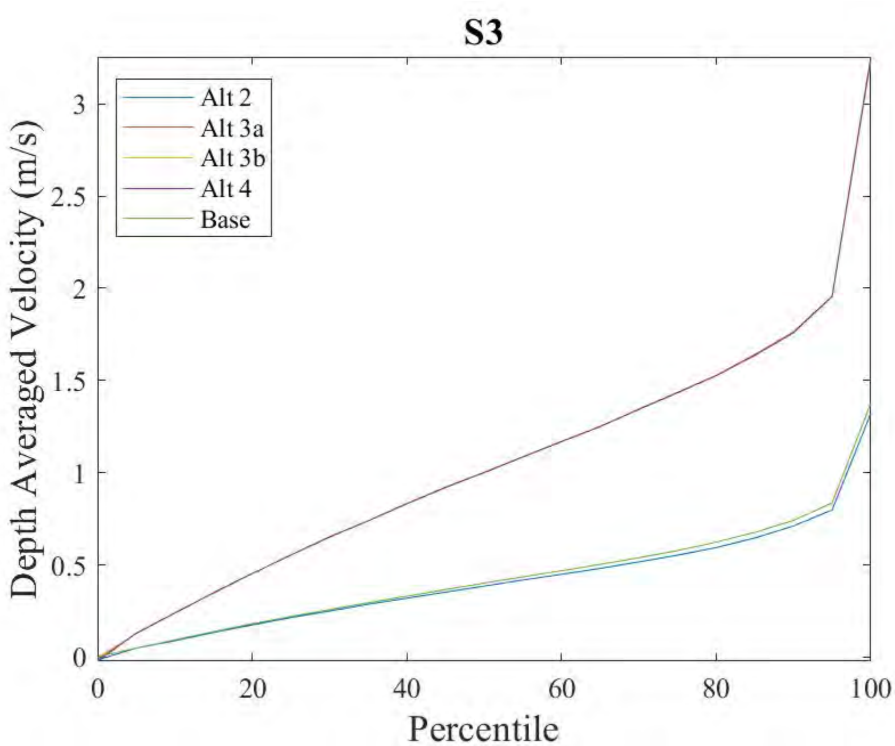


Figure 100. S4 Location Velocity Percentiles.

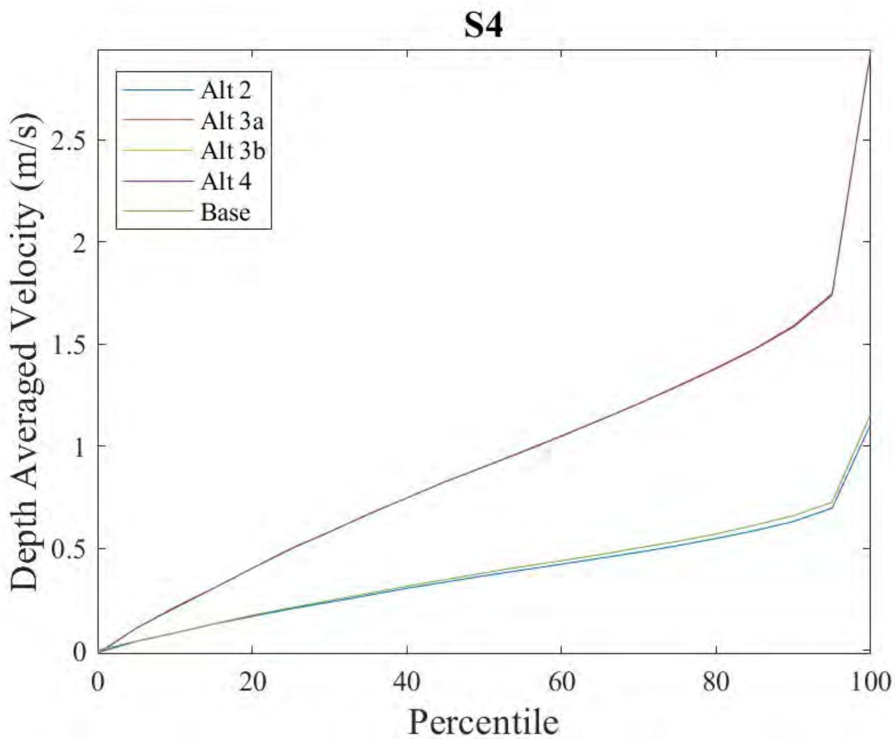


Figure 101. S5 Location Velocity Percentiles.

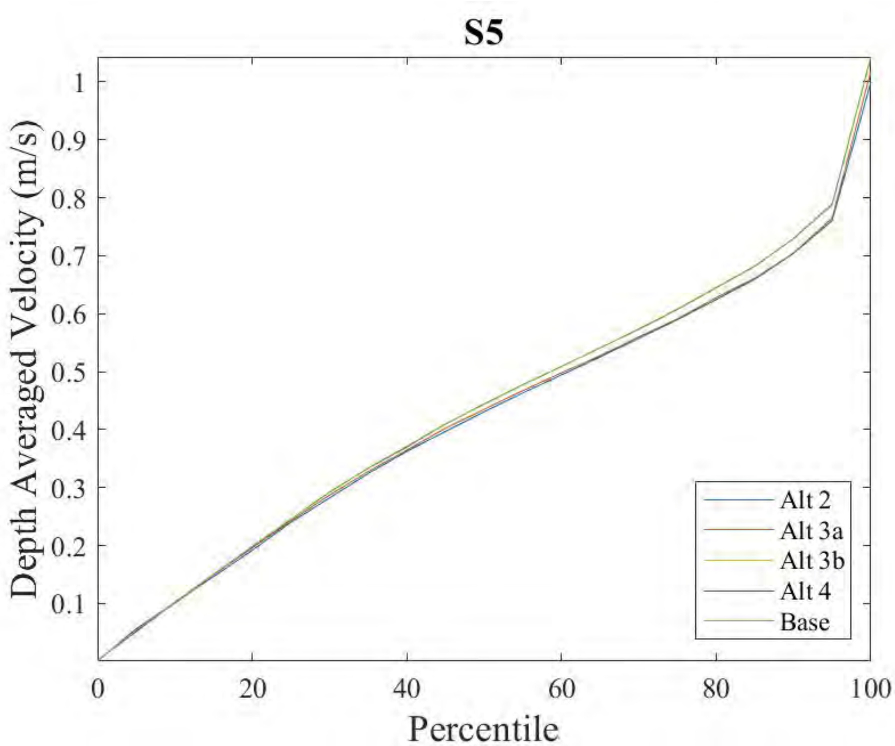


Figure 102. T1 Location Velocity Percentiles.

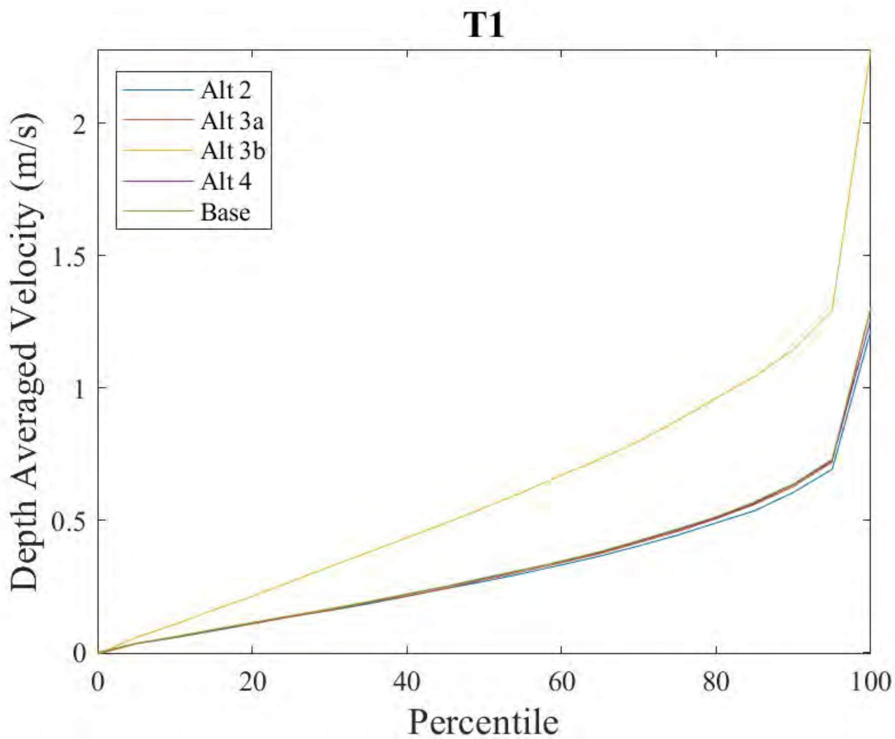


Figure 103. T2 Location Velocity Percentiles.

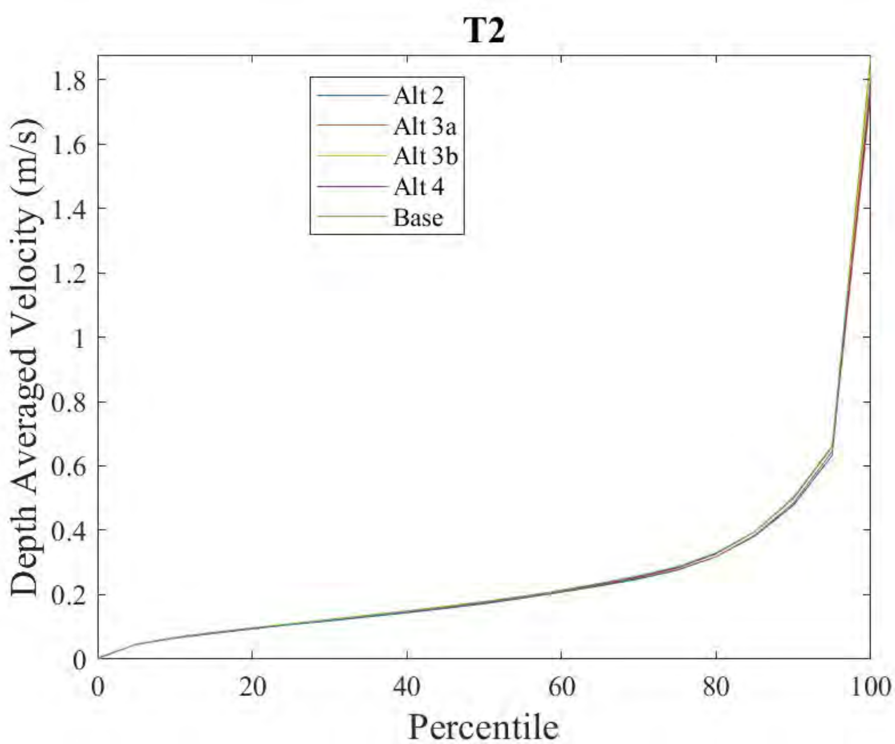


Figure 104. T3 Location Velocity Percentiles.

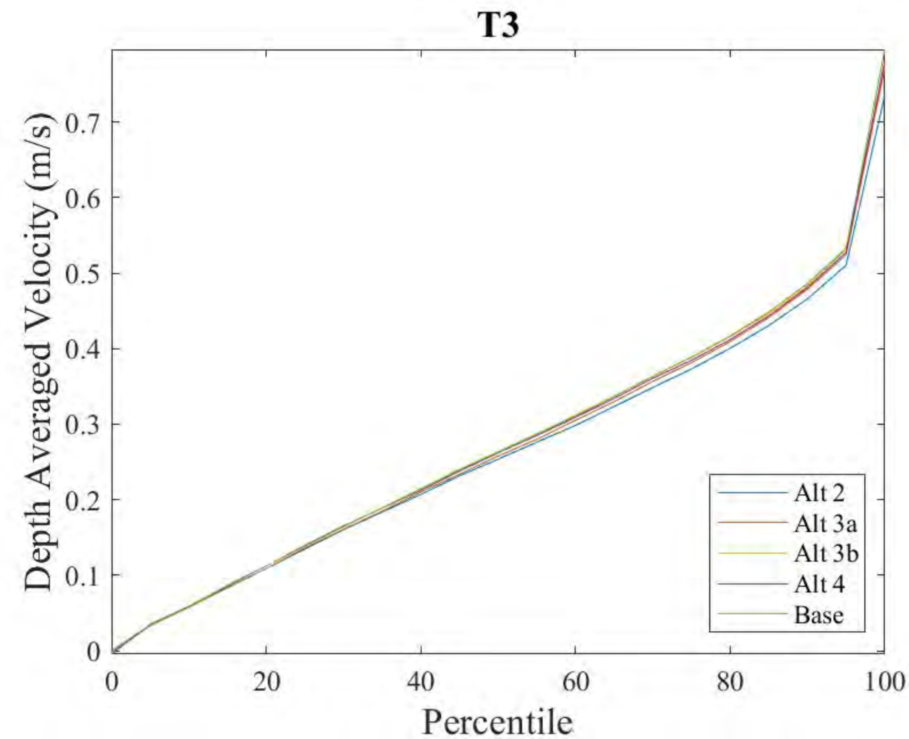


Figure 105. T4 Location Velocity Percentiles.

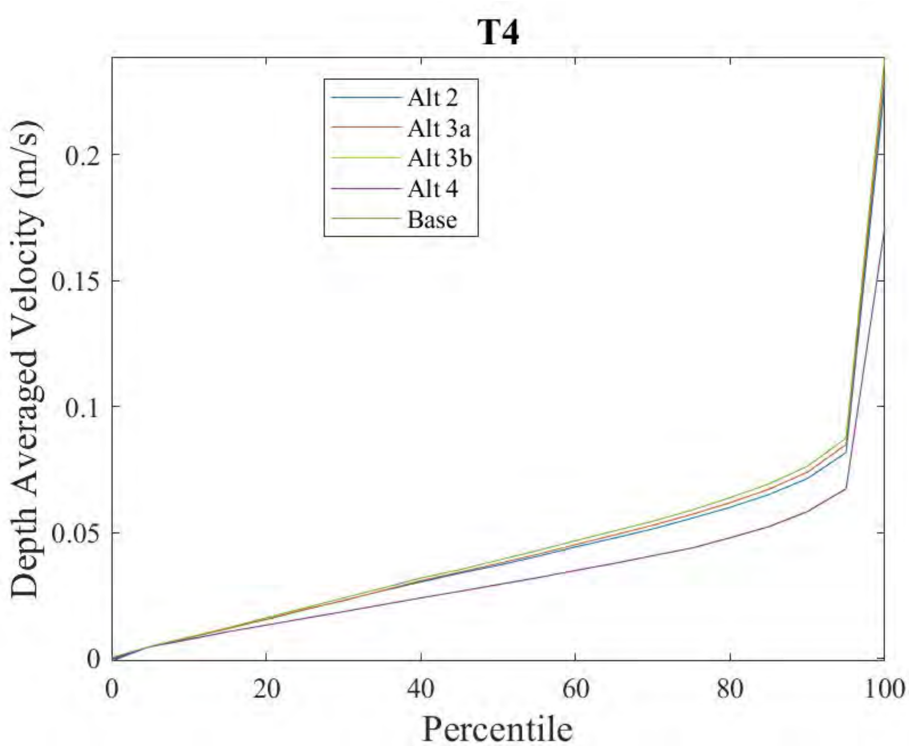


Figure 106. T5 Location Velocity Percentiles.

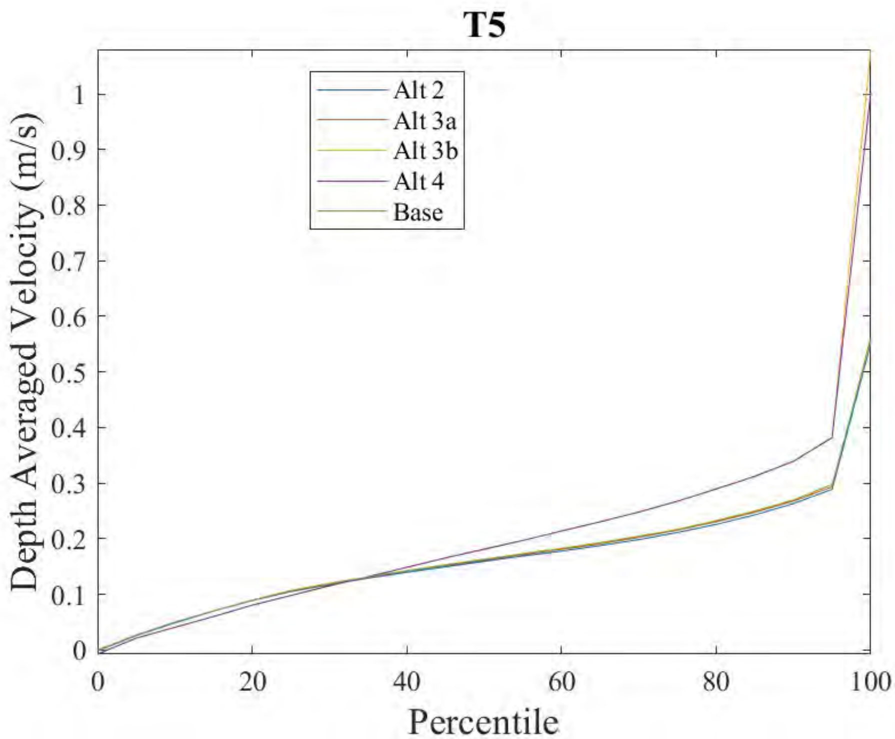


Figure 107. R1 Location Velocity Percentiles.

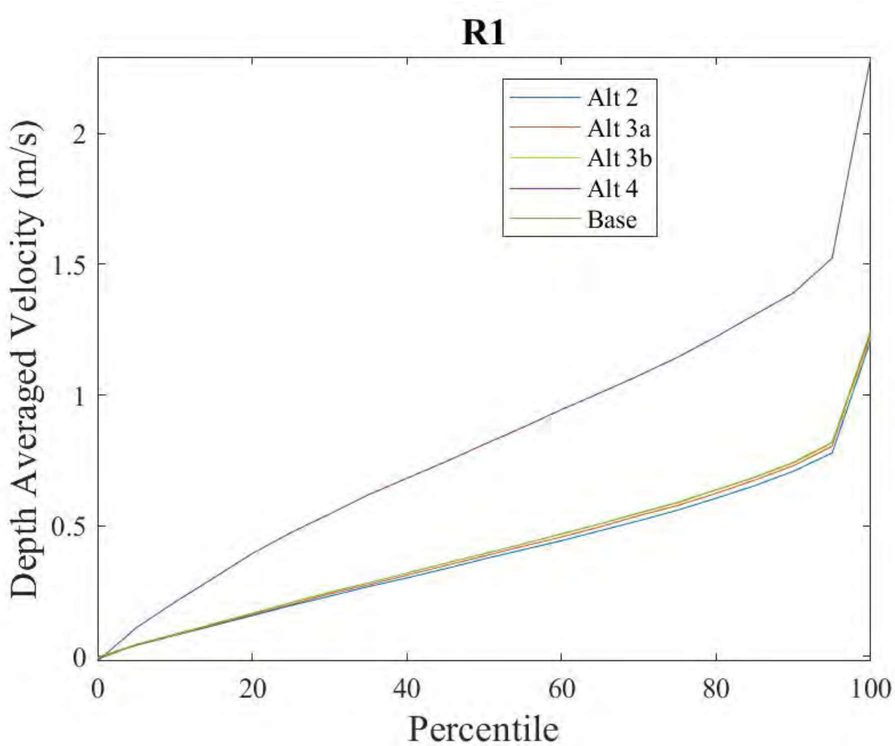


Figure 108. Sandy Hook Location Velocity Percentiles.

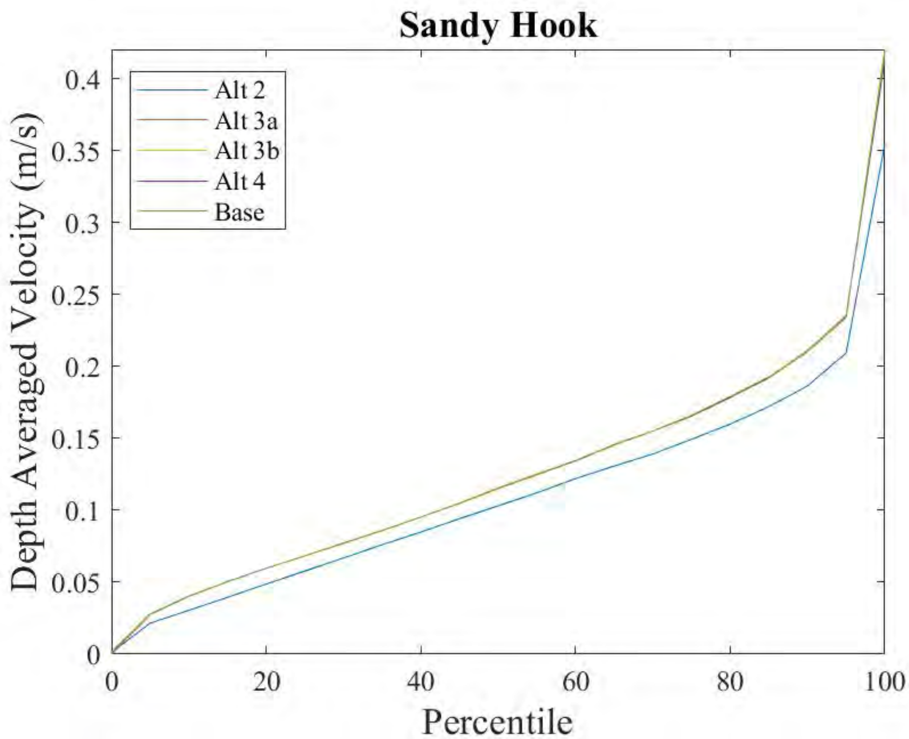


Figure 109. Fresh Kills Location Velocity Percentiles.

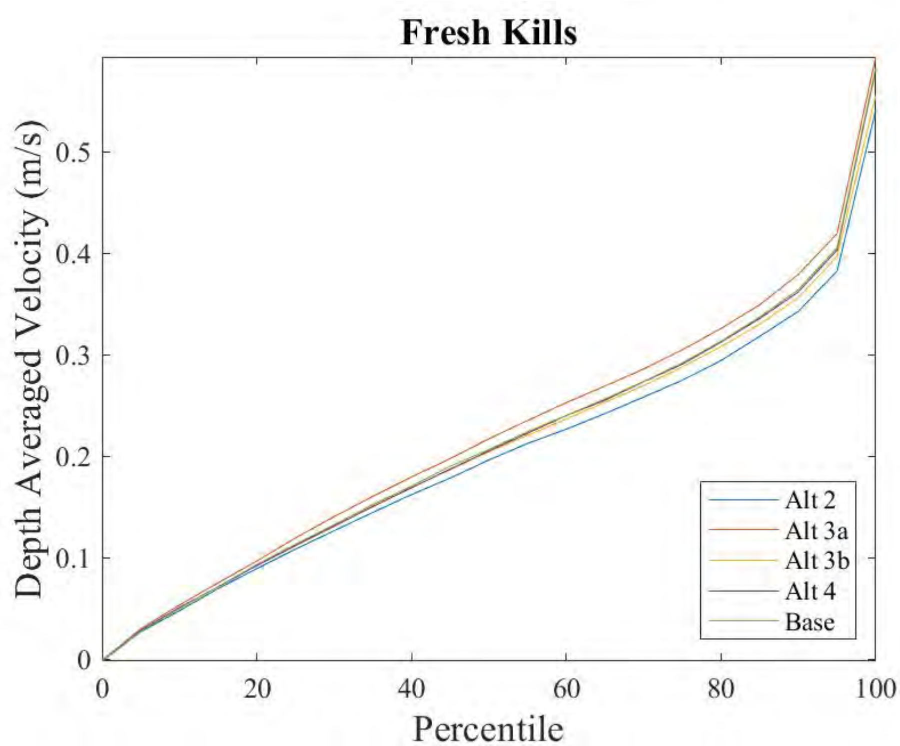


Figure 110. Mariners Harbor Location Velocity Percentiles.

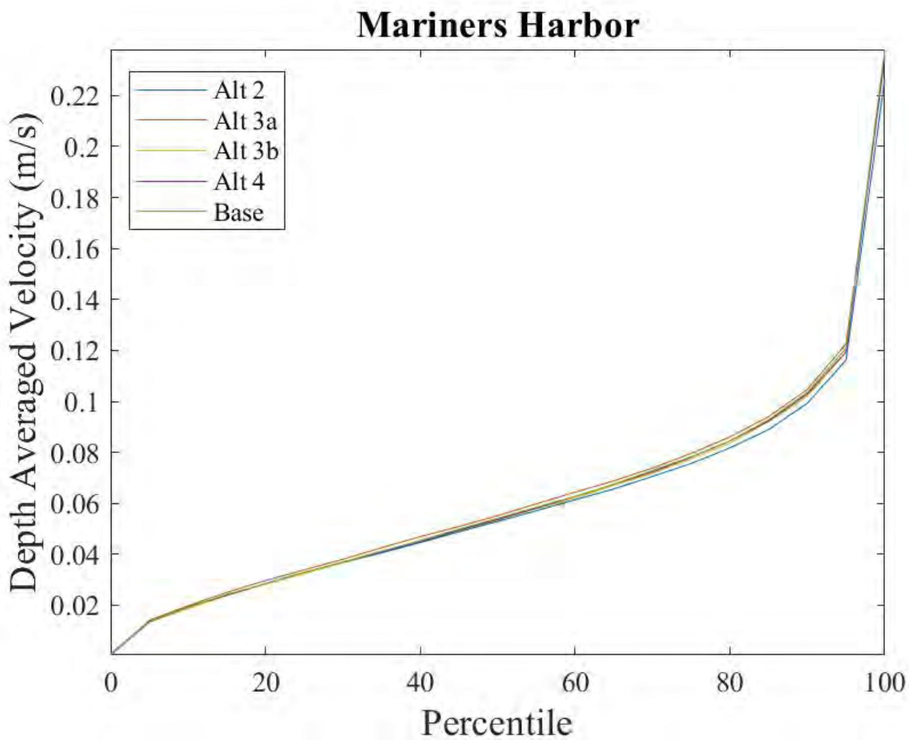


Figure 111. North Reach Location Velocity Percentiles.

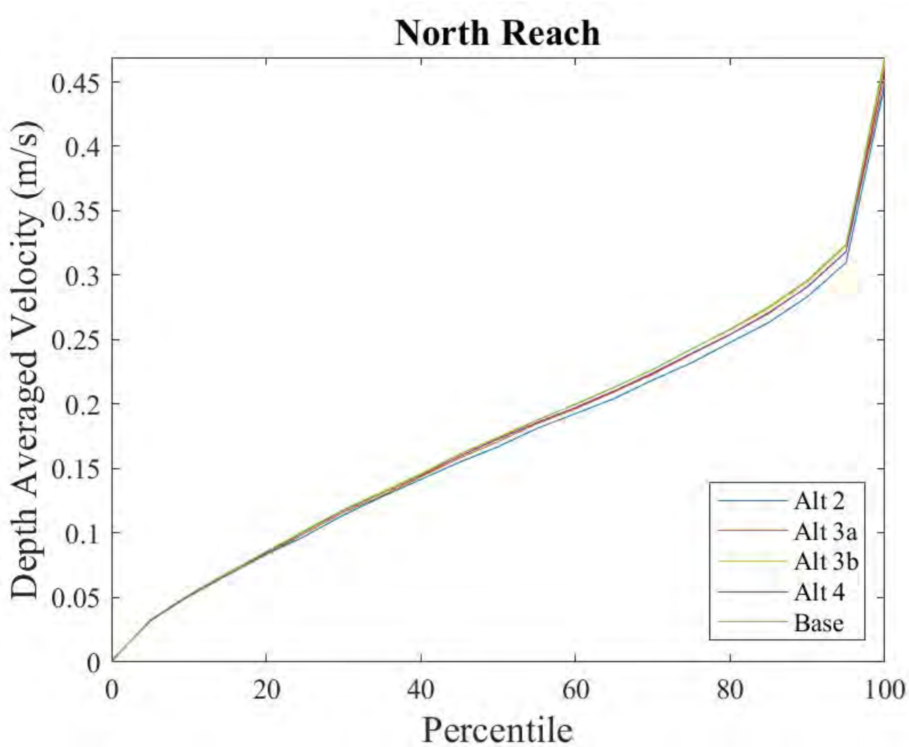


Figure 112. Hackensack River Location Velocity Percentiles.

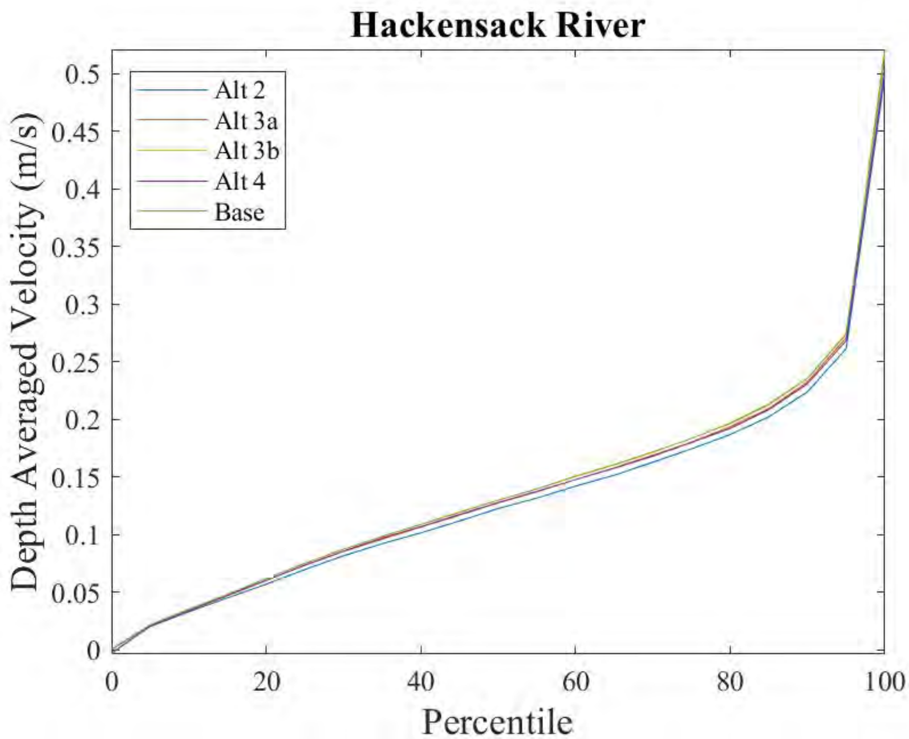


Figure 113. Robbins Reef Location Velocity Percentiles.

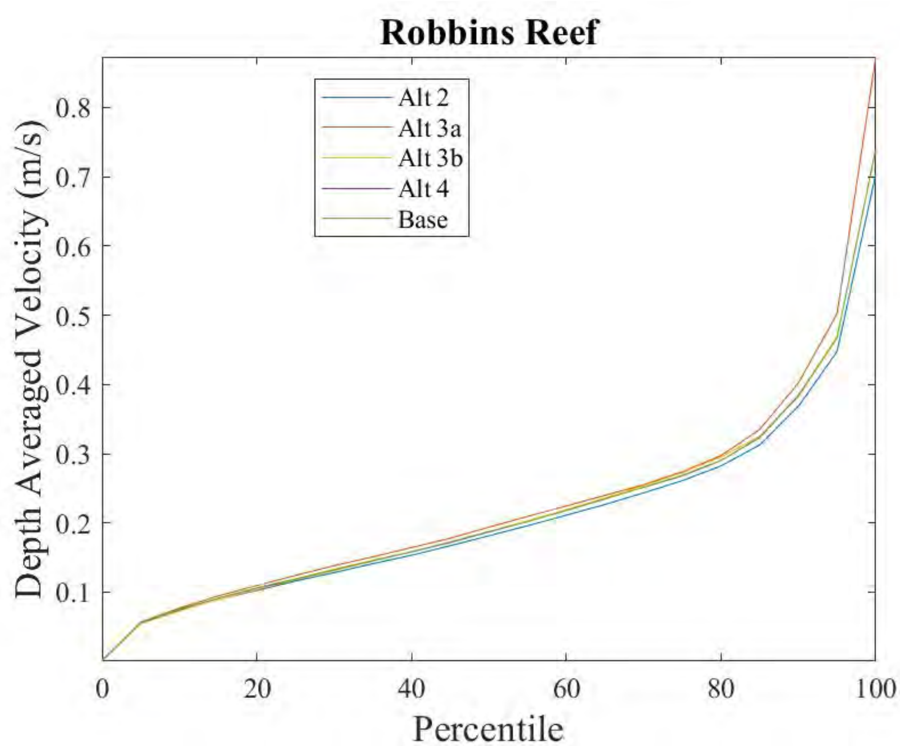


Figure 114. The Battery Location Velocity Percentiles.

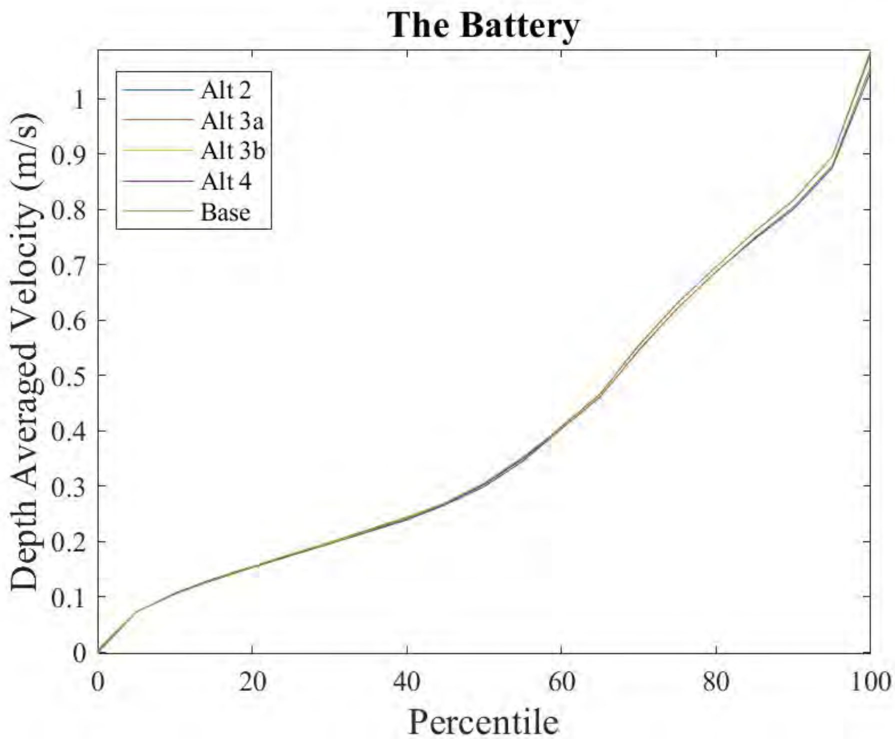


Figure 115. Manhattan Location Velocity Percentiles.

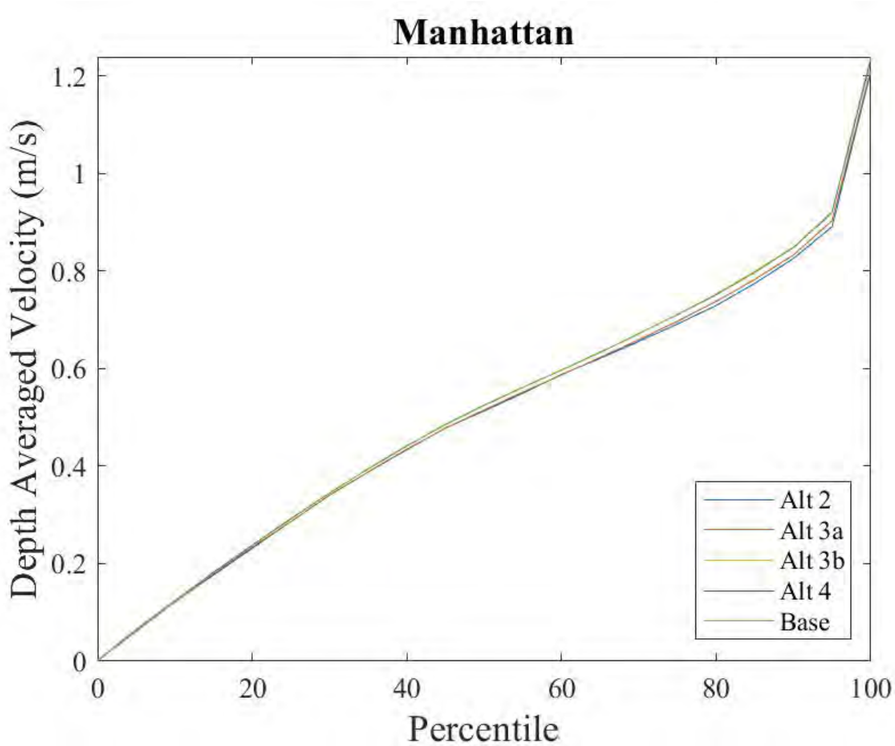


Figure 116. Hudson River, Haverstraw Bay Location Velocity Percentiles.

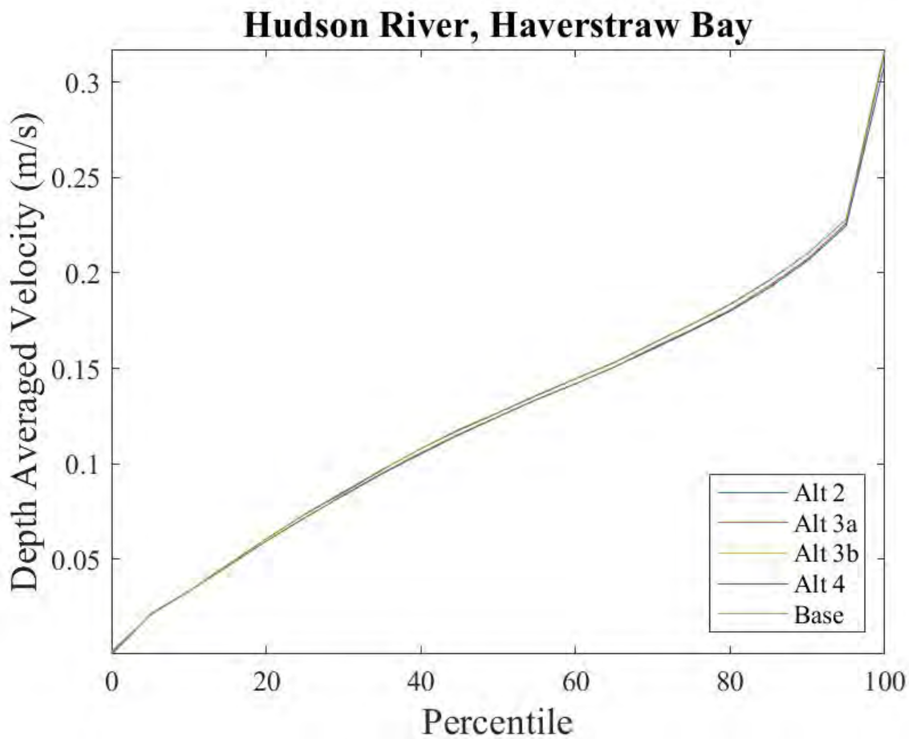


Figure 117. Hudson River, near Poughkeepsie Location Velocity Percentiles.

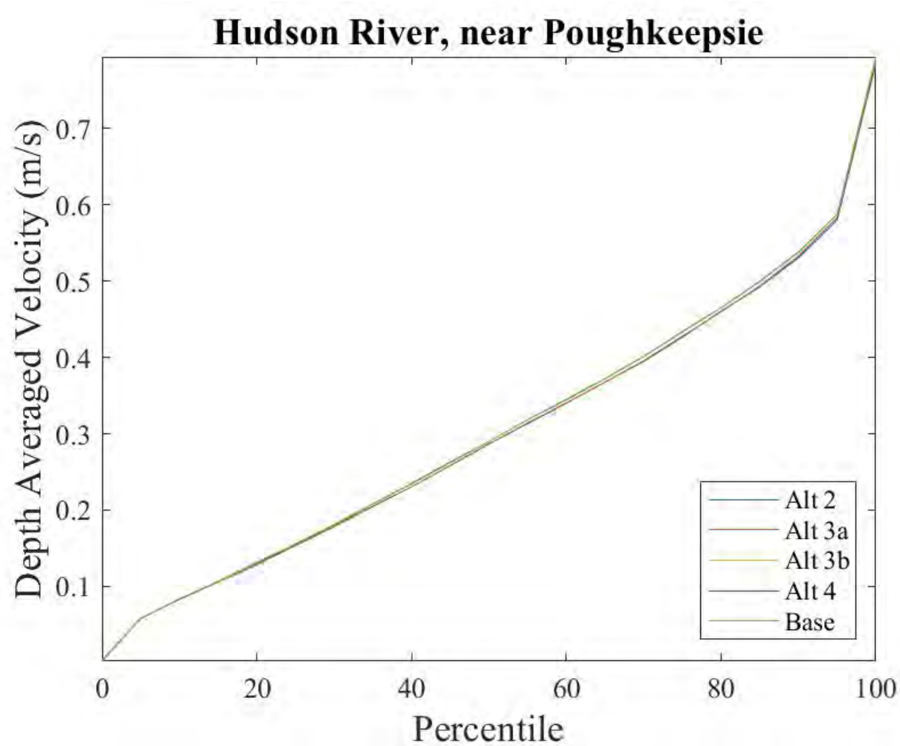


Figure 118. Hudson River, between Catskill and Hudson Location Velocity Percentiles.

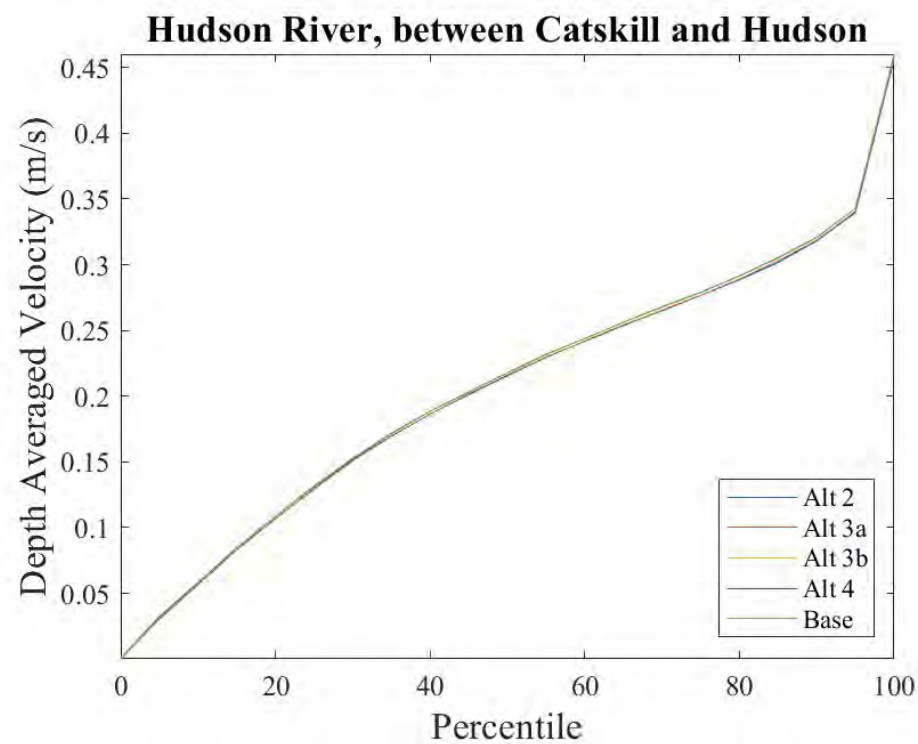


Figure 119. Hudson River, between Albany and Troy Location Velocity Percentiles.

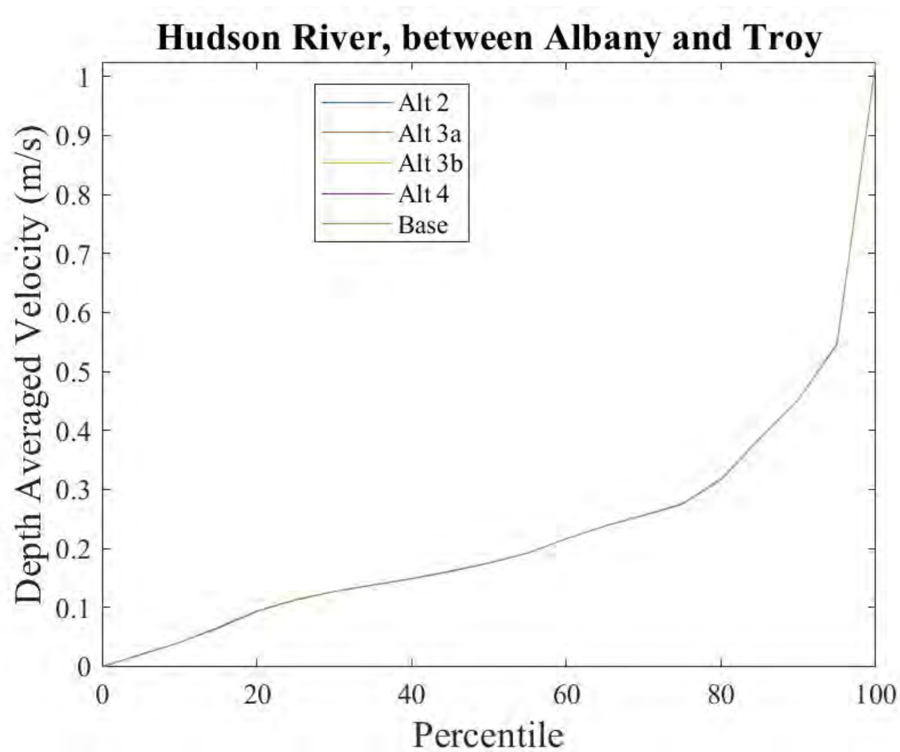


Figure 120. KLGA Location Velocity Percentiles.

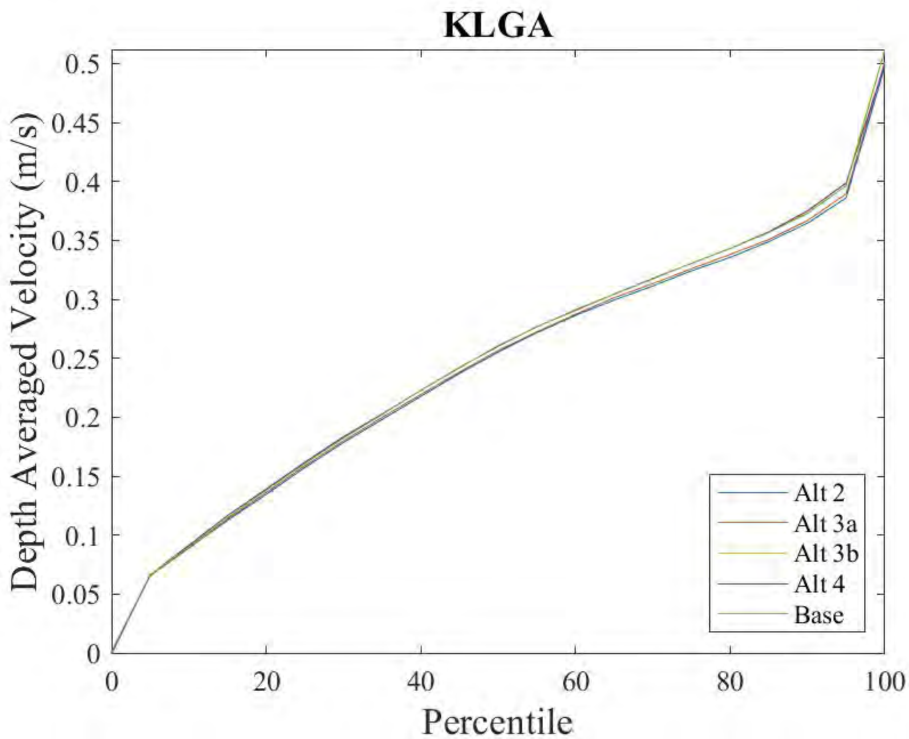


Figure 121. Wester LIS, near Stepping Stone Lighthouse Location Velocity Percentiles.

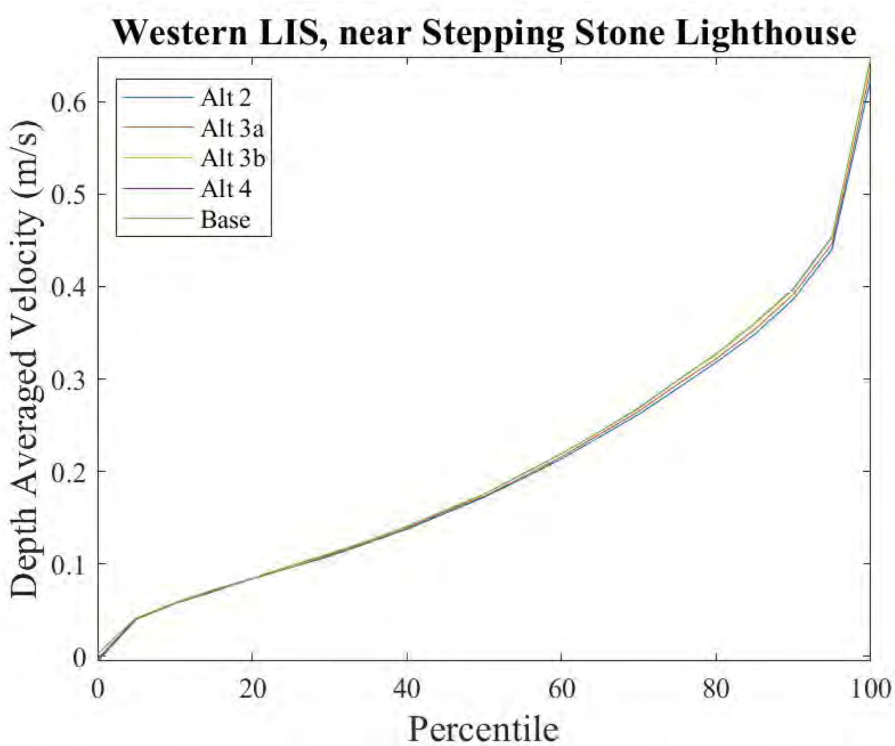


Figure 122. Western LIS, near Execution Rock Lighthouse Location Velocity Percentiles.

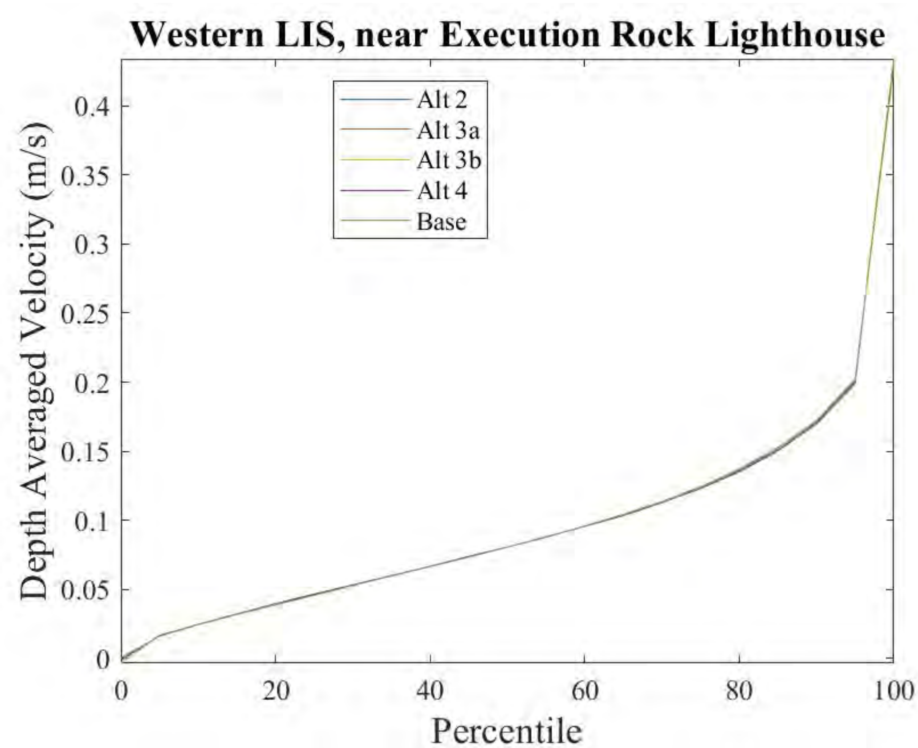


Figure 123. Western LIS, south of NY and CT border Location Velocity Percentiles.

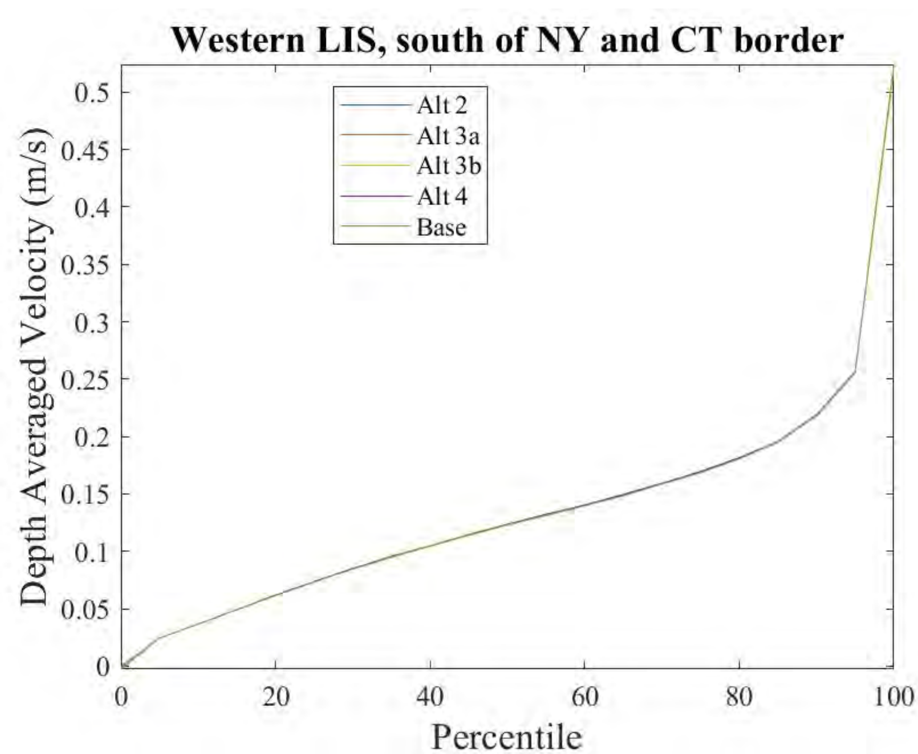


Figure 124. Jamaica Bay Location Velocity Percentiles.

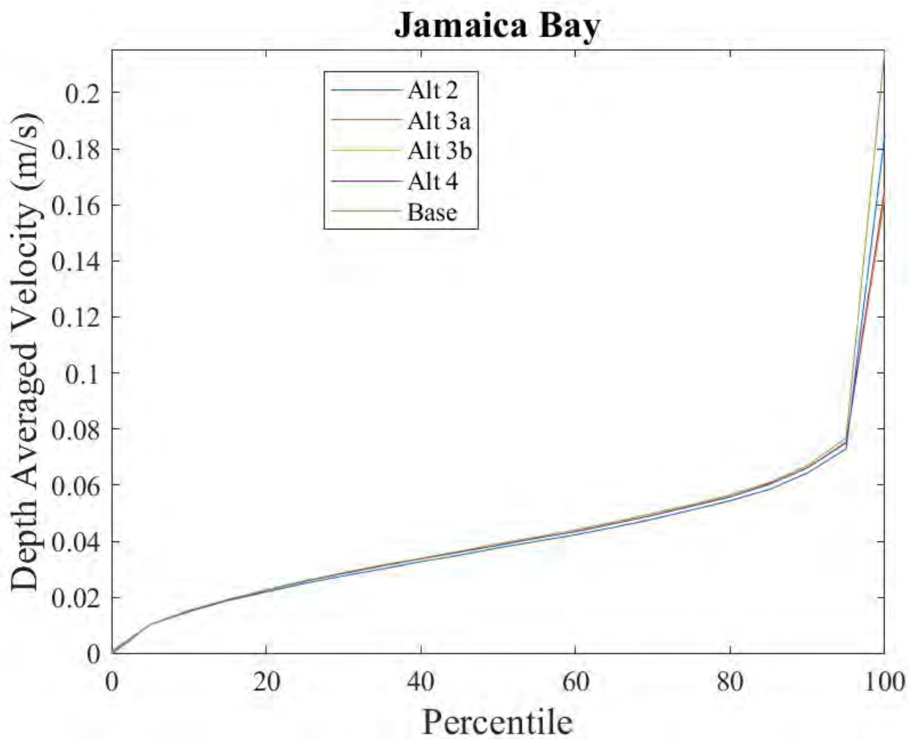


Figure 125. Jamaica Bay near Spring Creek Location Velocity Percentiles.

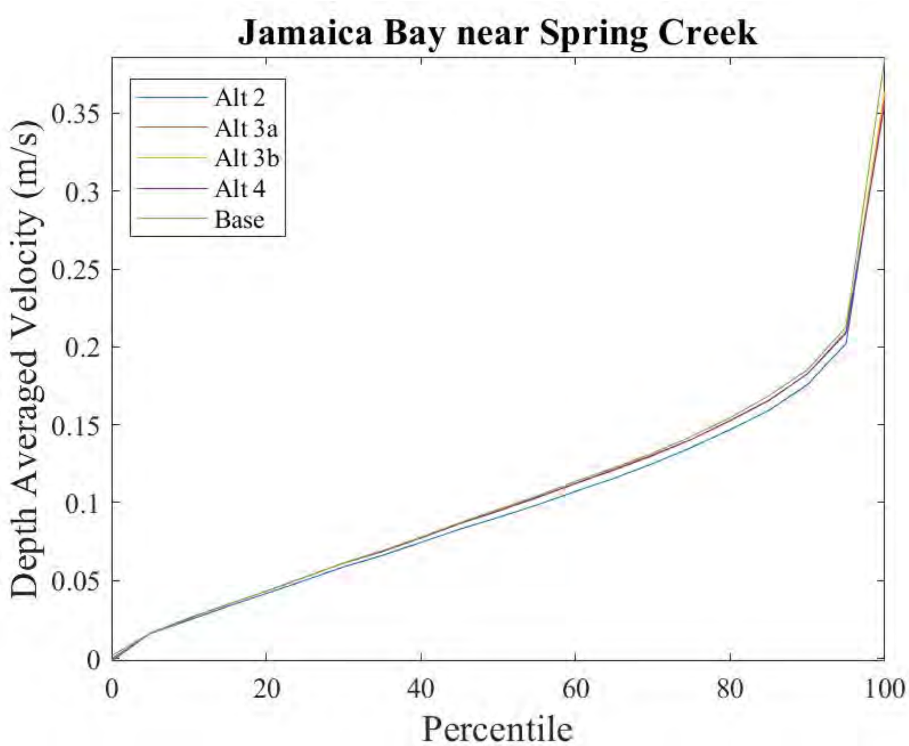
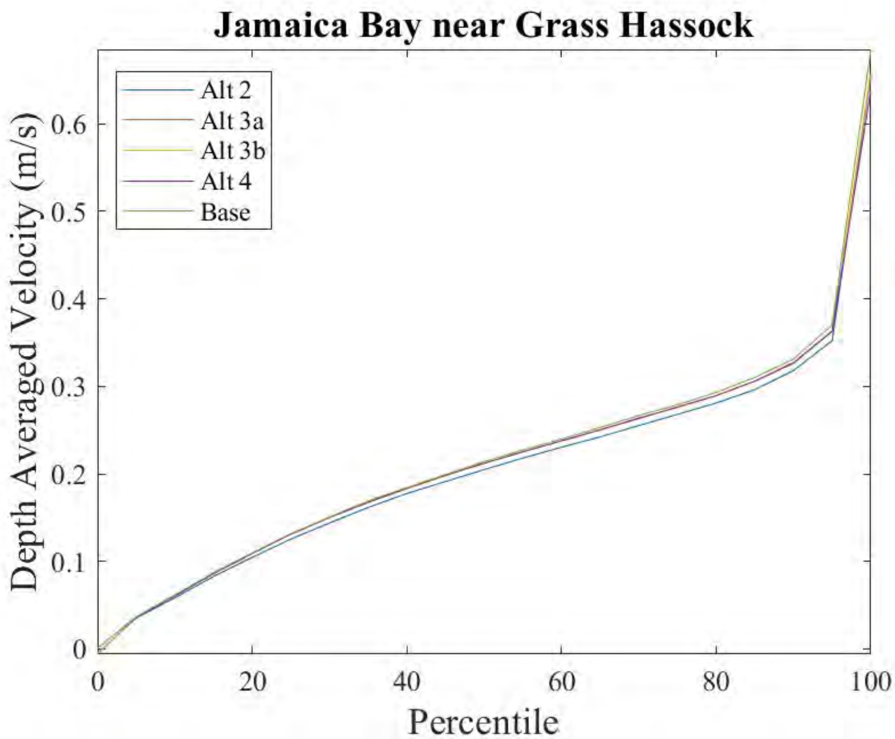


Figure 126. Jamaica Bay near Grass Hassock Location Velocity Percentiles.



11 Appendix D – Salinity Percentiles

The figures (Figure 127 to Figure 158) in this appendix are the salinity percentiles for the point comparison locations previously shown in Figure 17 to Figure 20 with coordinates provided in Table 3. These results were calculated based on 1 hour output information for the entire 1995 calendar year simulation. These plots can provide indications of flow redistributions and also changes in offshore tidal mixing when evaluated with water surface elevation, discharge, and tidal prism changes.

The Hudson River locations were not plotted in this Appendix as they were always completely fresh and as such their percentiles were flat lines.

Figure 127. V1 Location Bottom Salinity Percentiles.

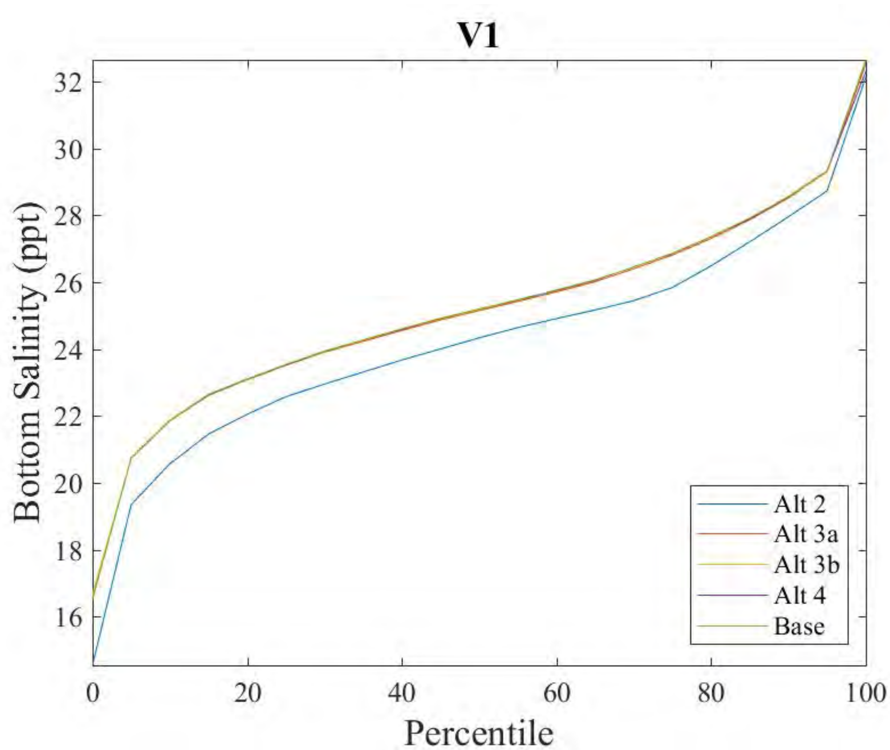


Figure 128. V2 Location Bottom Salinity Percentiles.

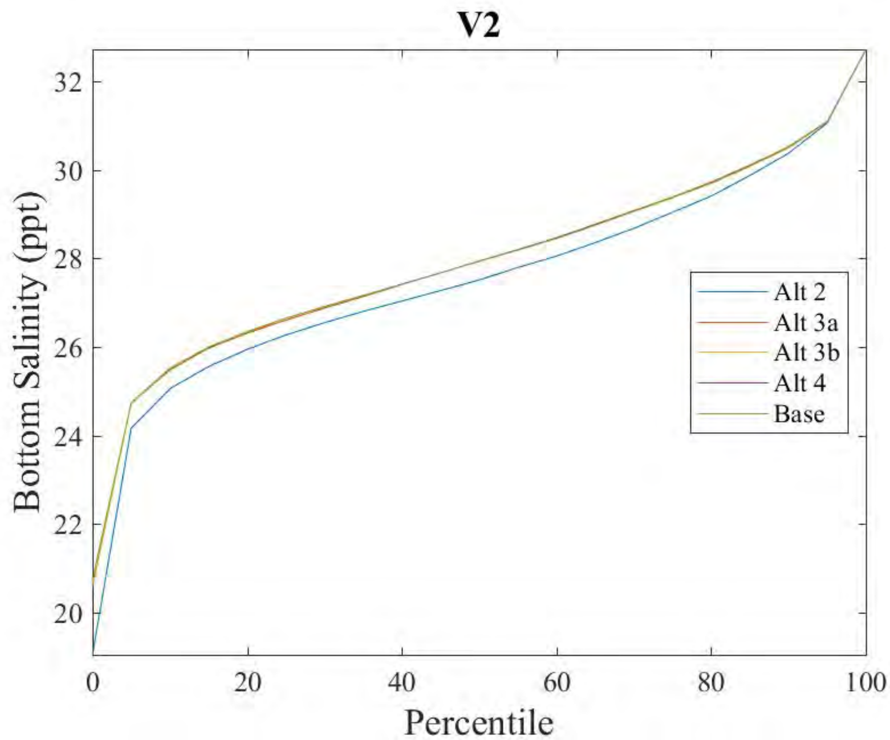


Figure 129. V3 Location Bottom Salinity Percentiles.

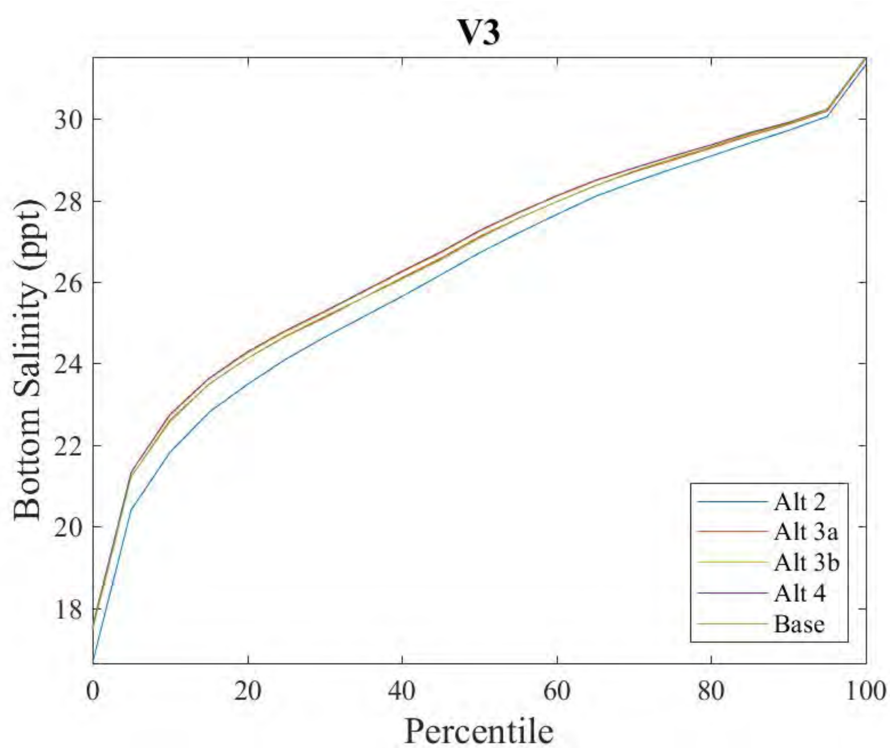


Figure 130. V4 Location Bottom Salinity Percentiles.

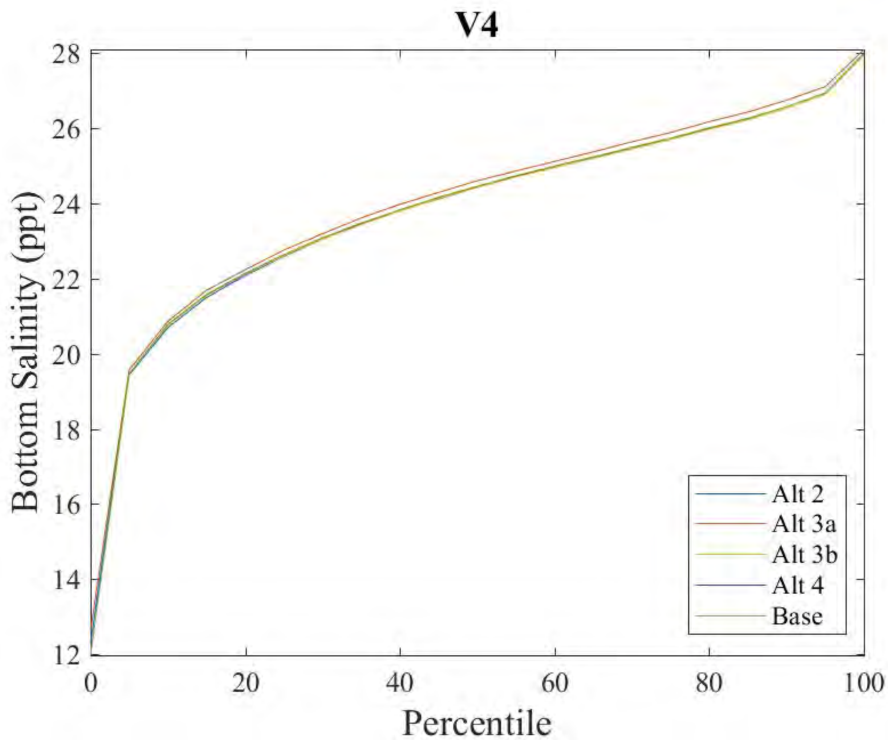


Figure 131. V5 Location Bottom Salinity Percentiles.

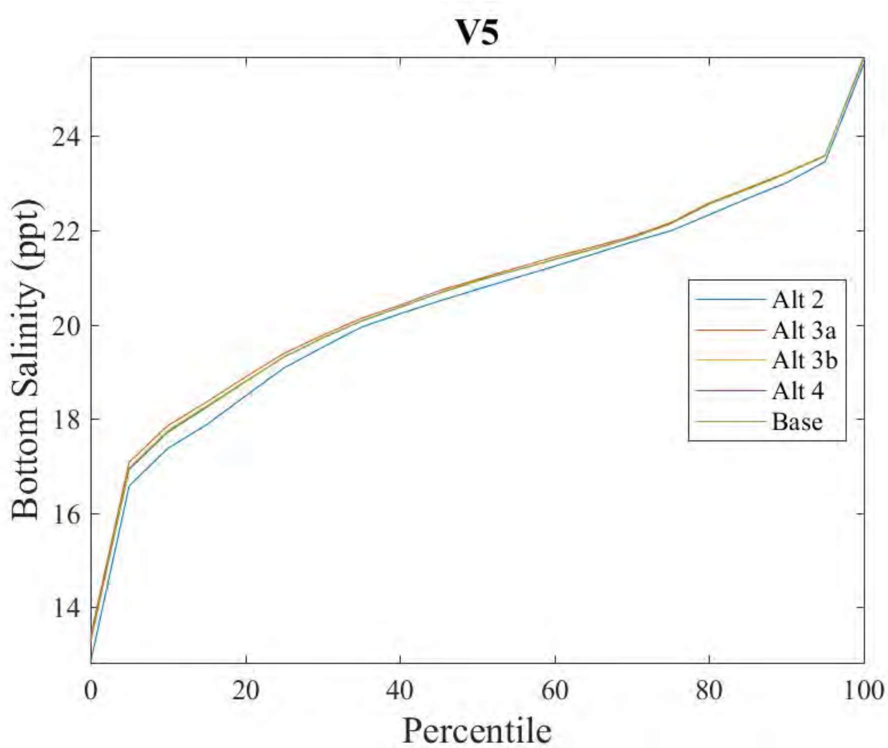


Figure 132. V6 Location Bottom Salinity Percentiles.

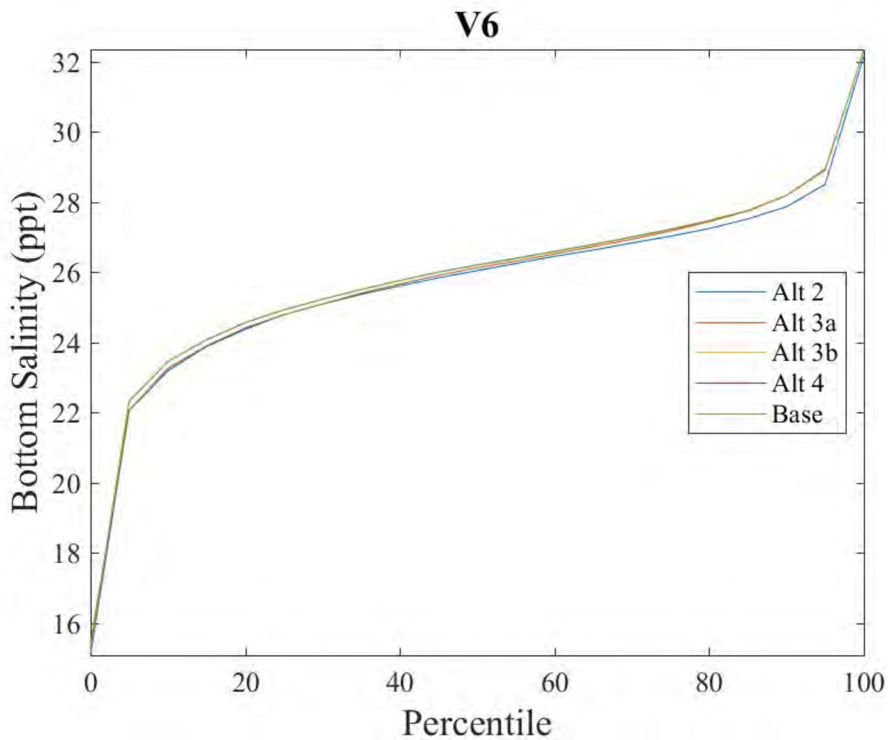


Figure 133. S1 Location Bottom Salinity Percentiles.

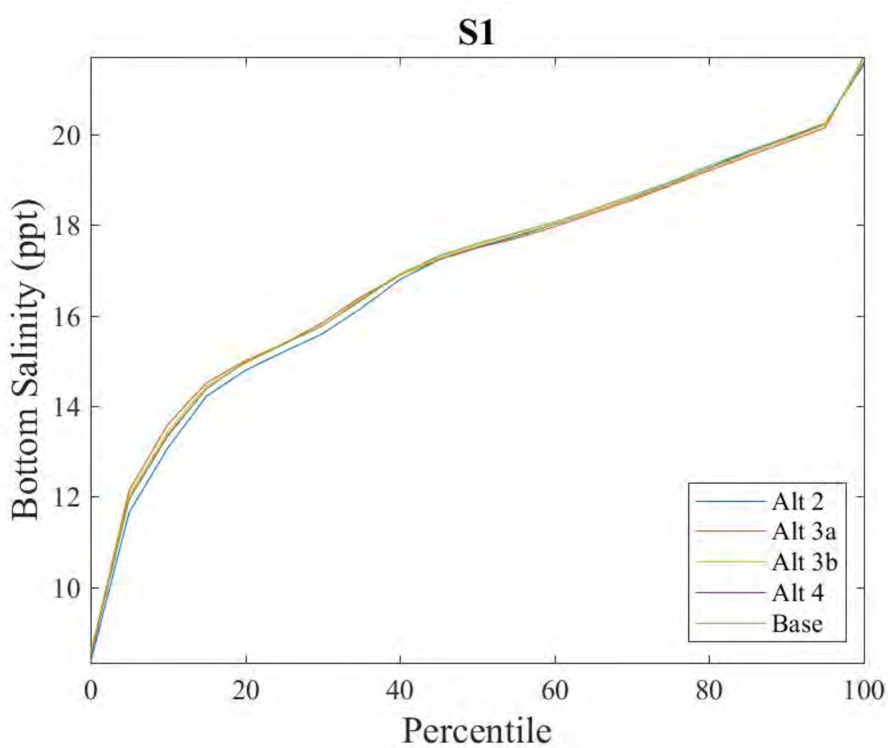


Figure 134. S2 Location Bottom Salinity Percentiles.

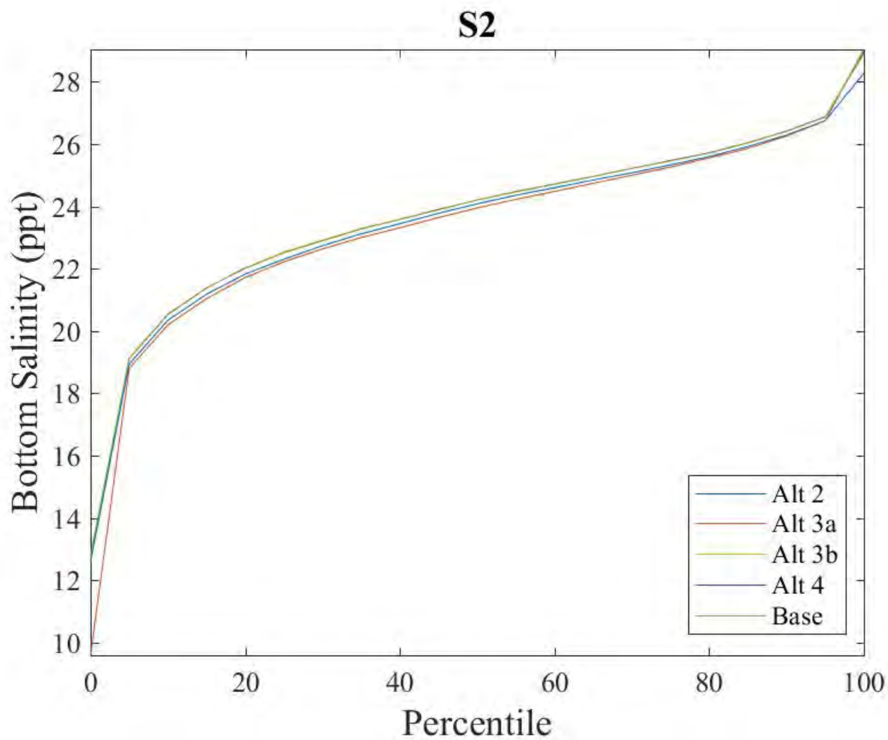


Figure 135. S3 Location Bottom Salinity Percentiles.

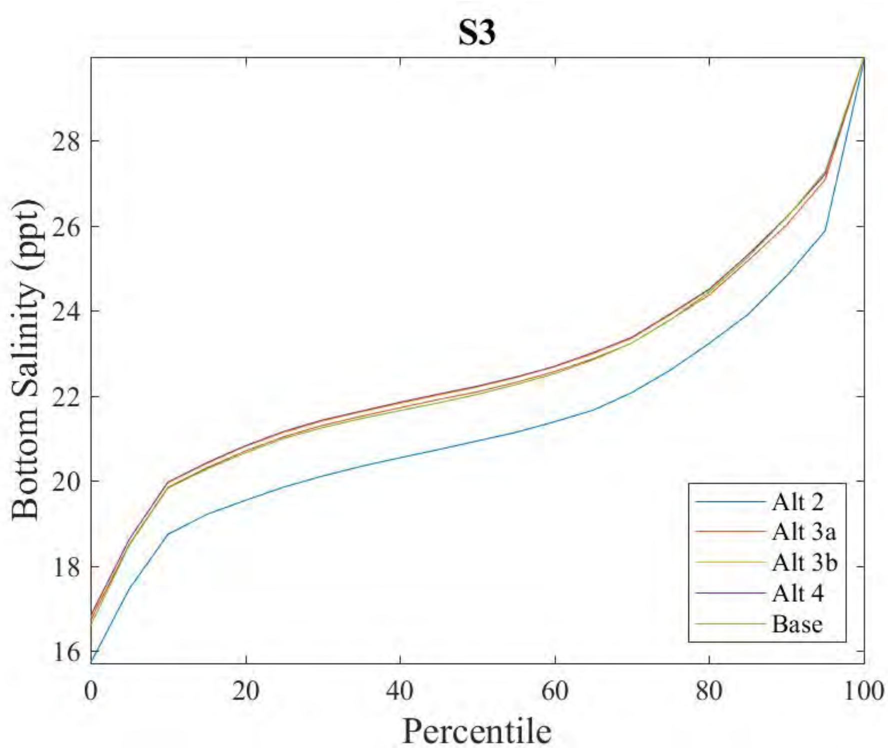


Figure 136. S4 Location Bottom Salinity Percentiles.

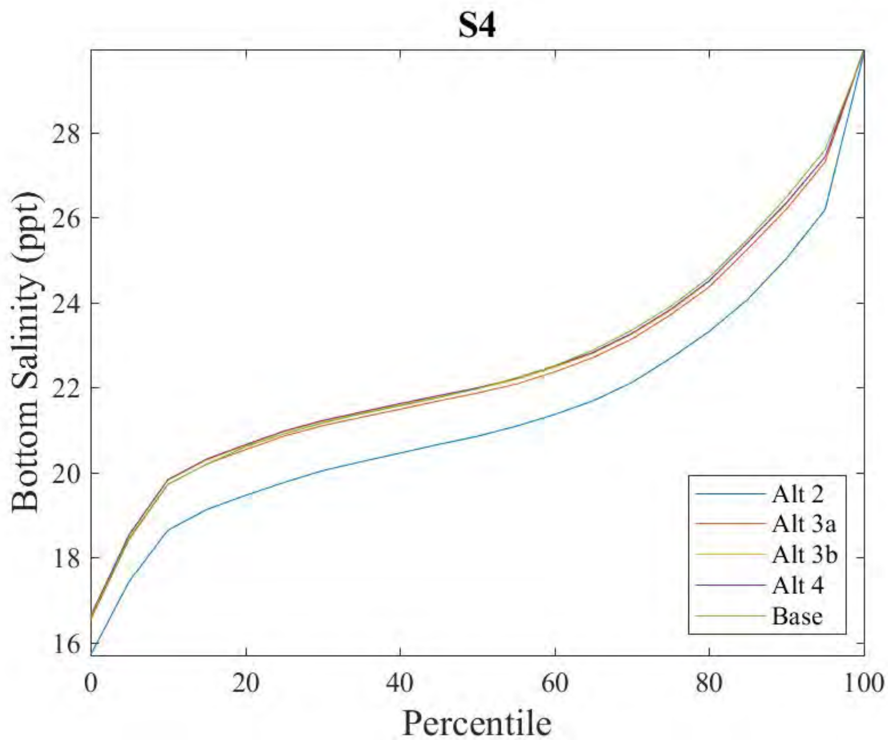


Figure 137. S5 Location Bottom Salinity Percentiles.

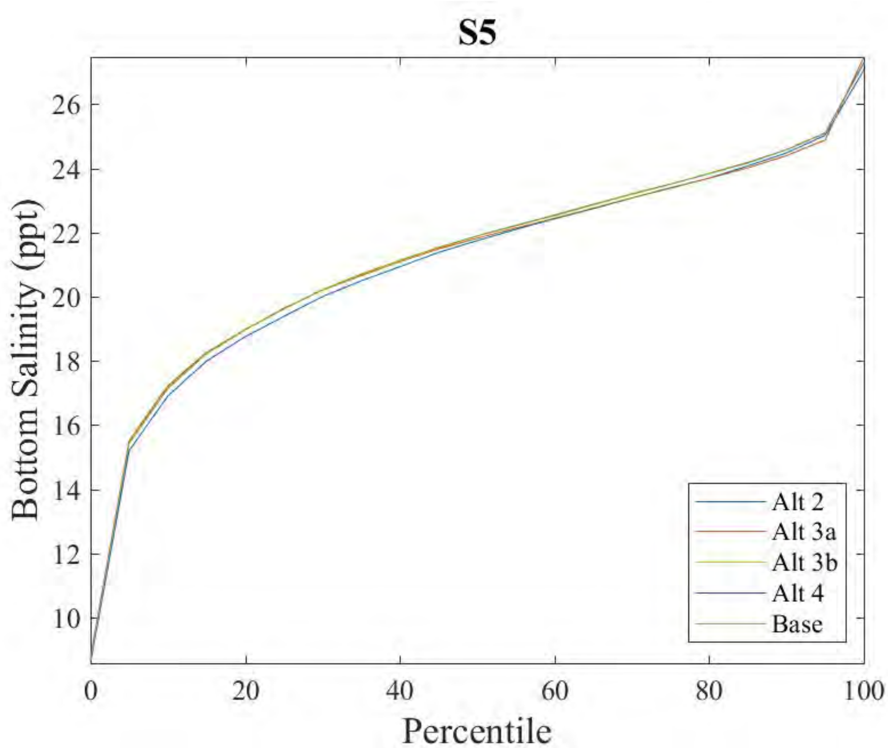


Figure 138. T1 Location Bottom Salinity Percentiles.

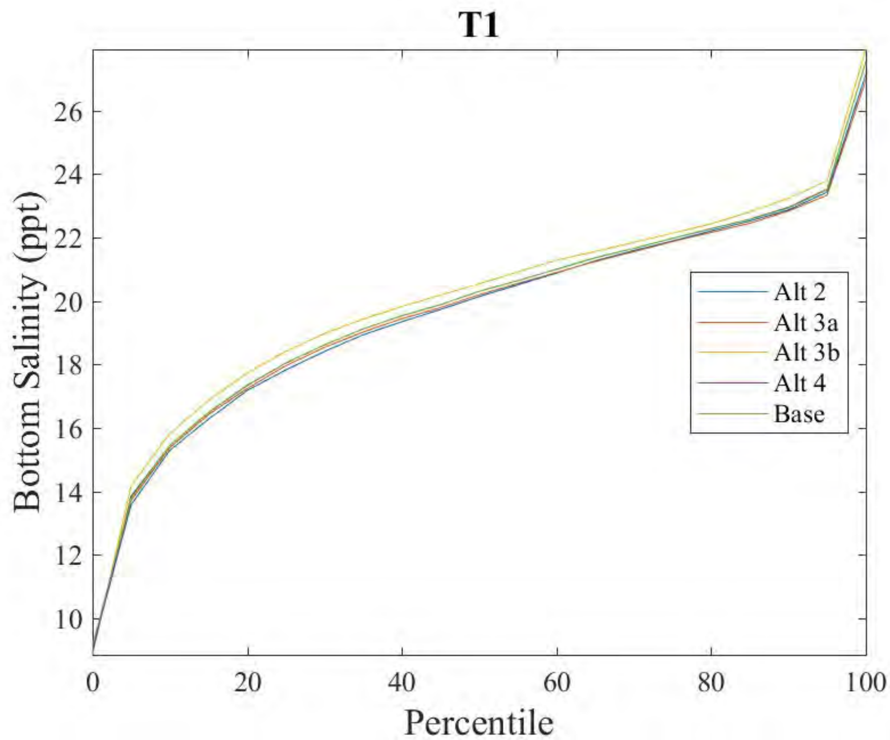


Figure 139. T2 Location Bottom Salinity Percentiles.

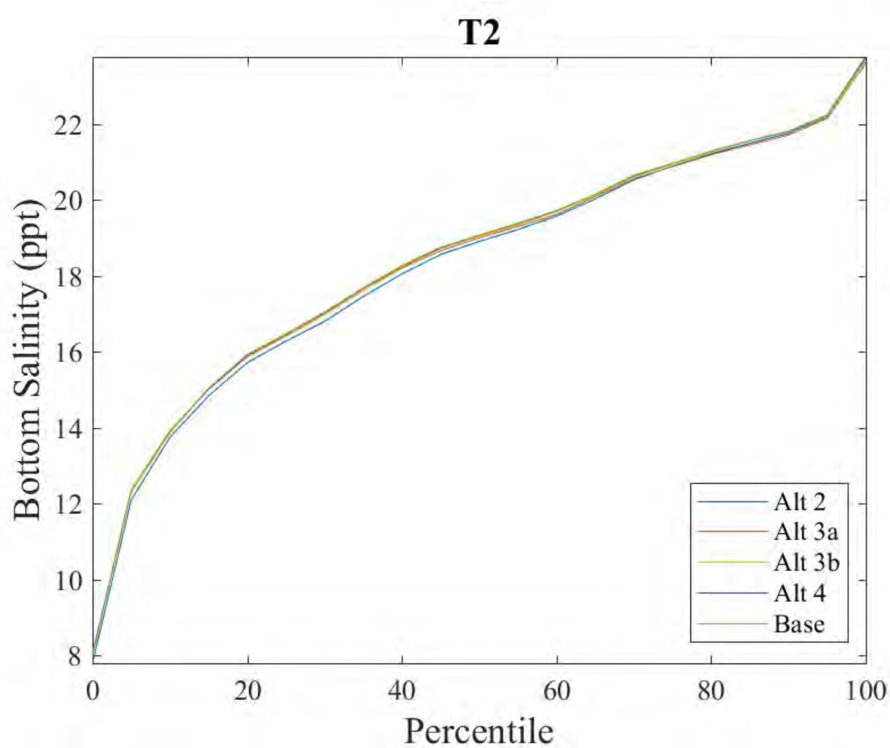


Figure 140. T3 Location Bottom Salinity Percentiles.

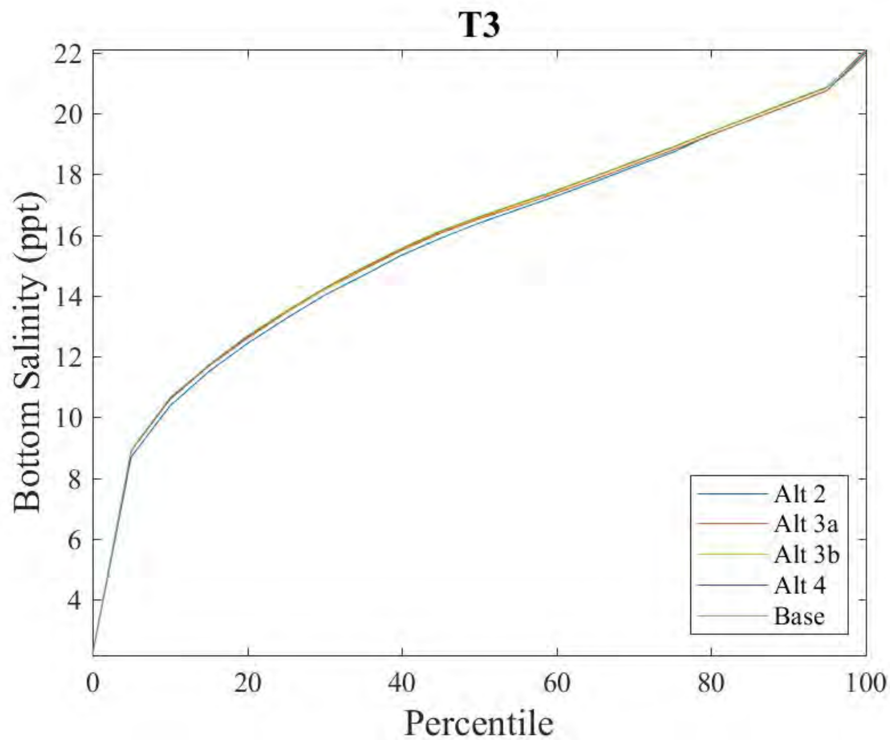


Figure 141. T4 Location Bottom Salinity Percentiles.

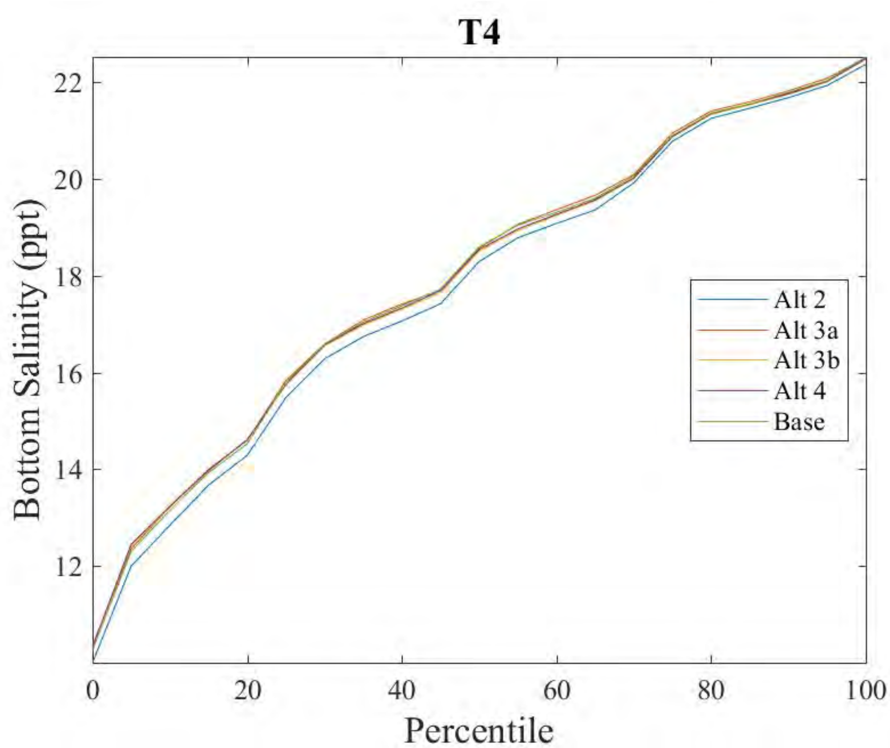


Figure 142. T5 Location Bottom Salinity Percentiles.

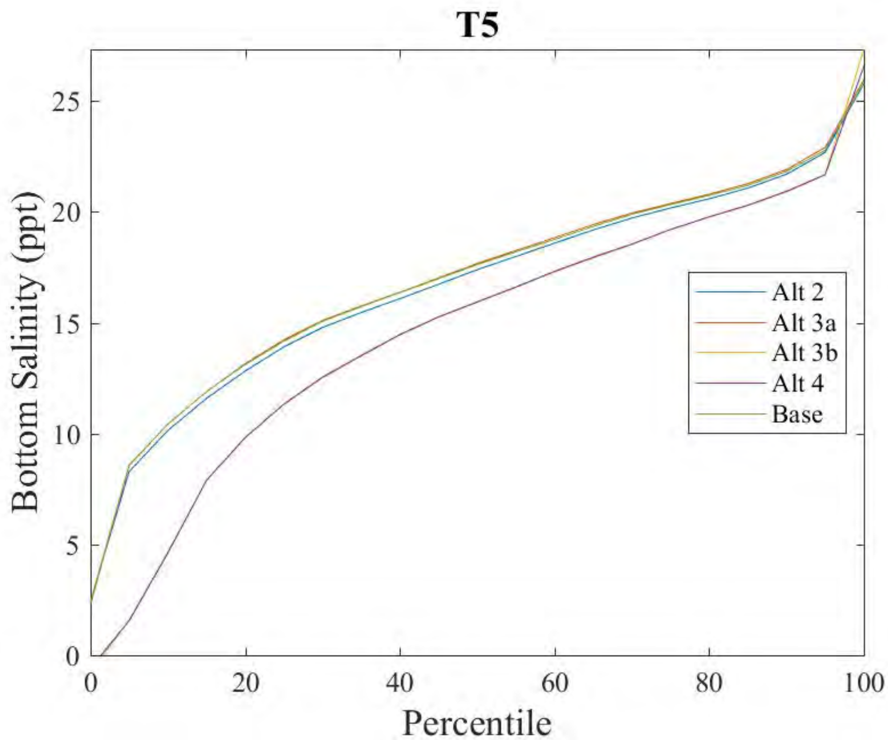


Figure 143. R1 Location Bottom Salinity Percentiles.

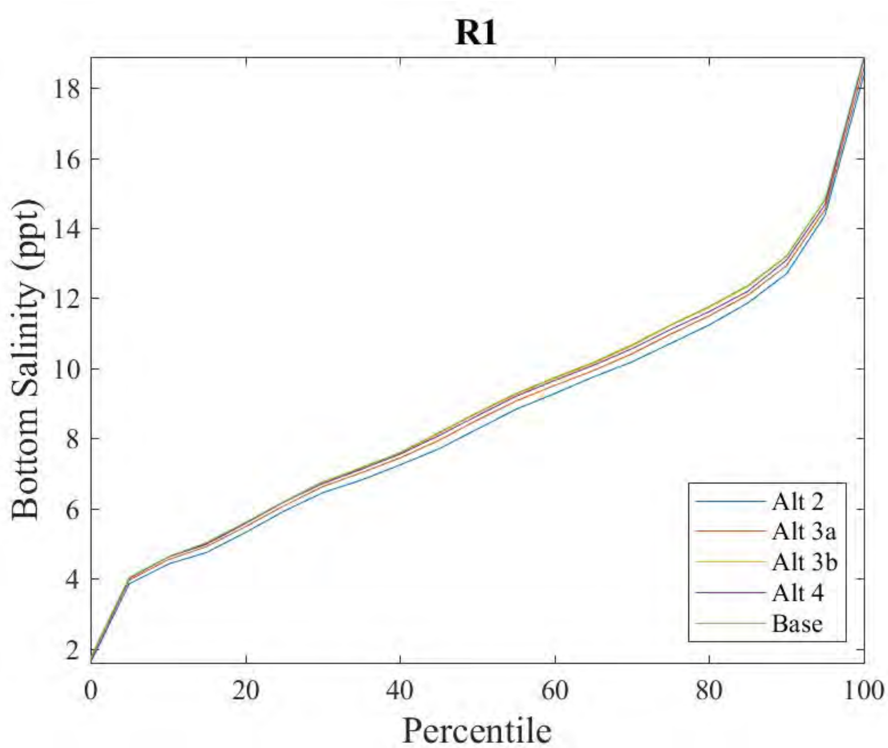


Figure 144. Sandy Hook Location Bottom Salinity Percentiles.

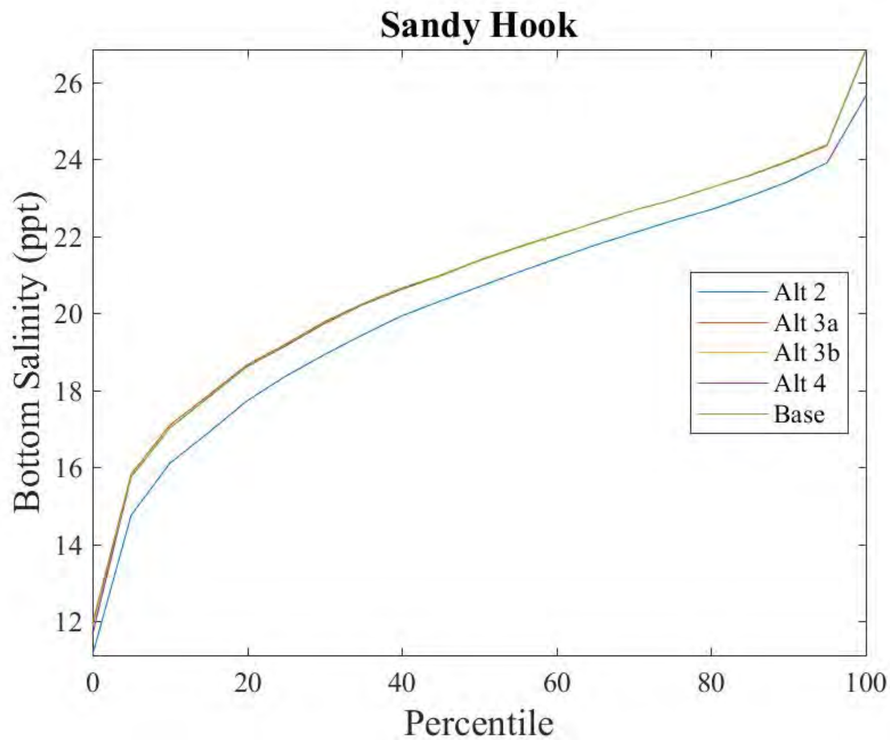


Figure 145. Fresh Kills Location Bottom Salinity Percentiles.

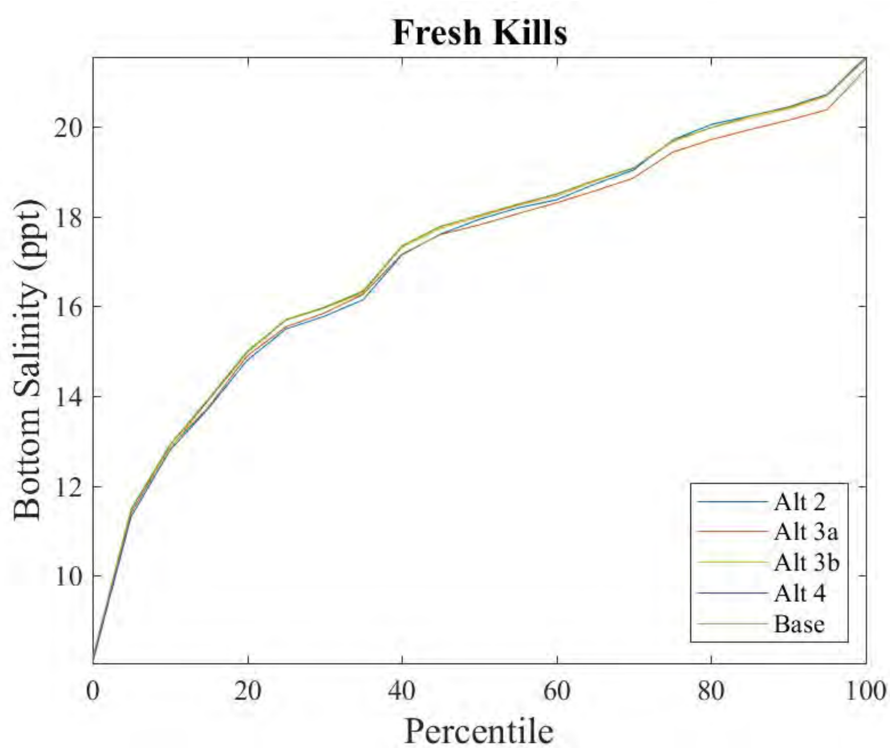


Figure 146. Mariners Harbor Location Bottom Salinity Percentiles.

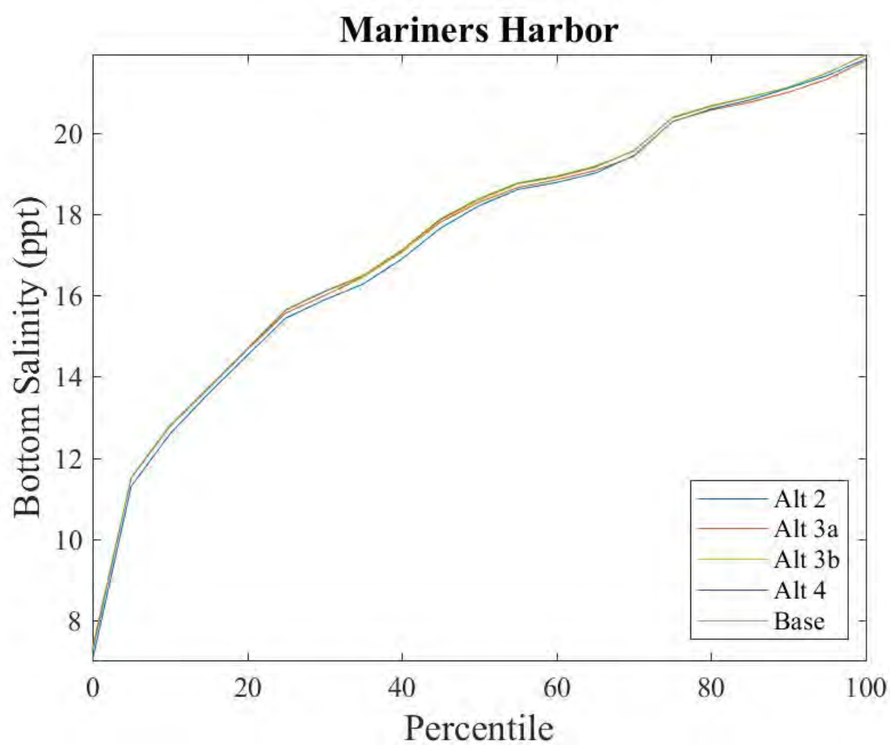


Figure 147. North Reach Location Bottom Salinity Percentiles.

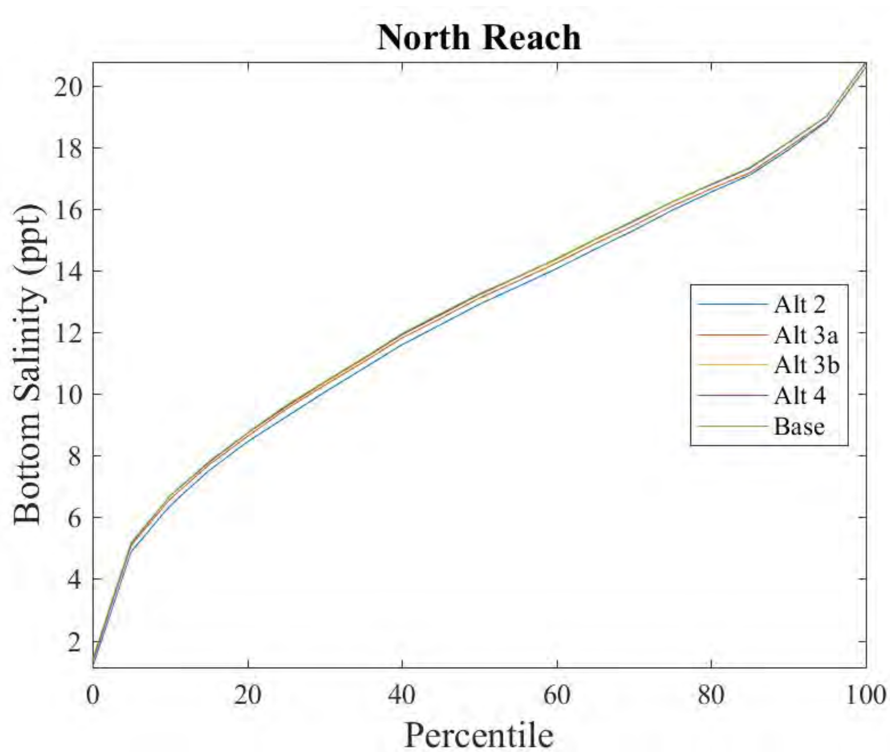


Figure 148. Hackensack River Location Bottom Salinity Percentiles.

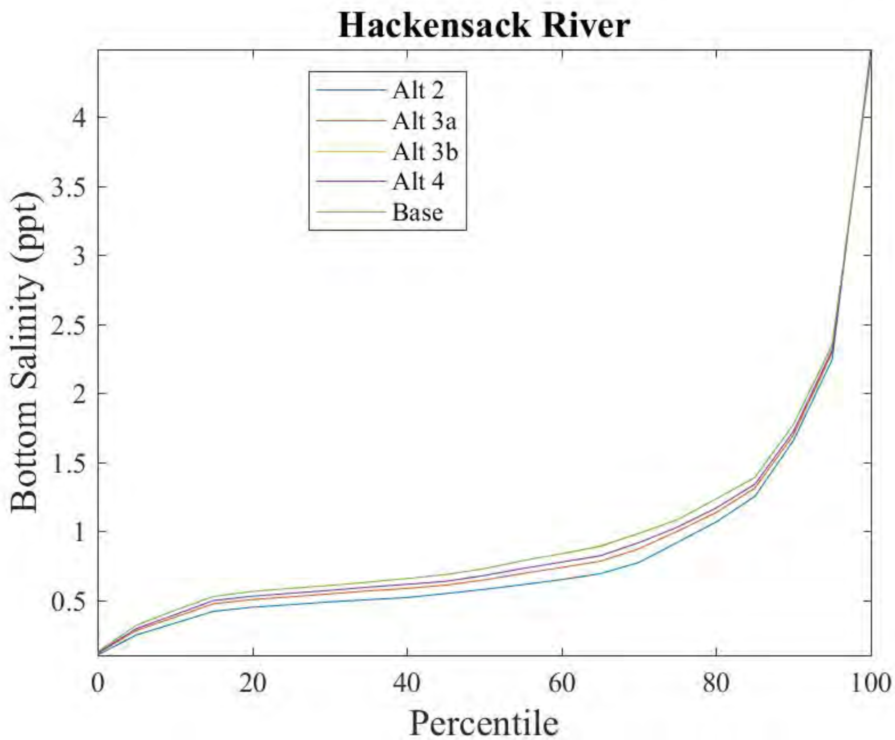


Figure 149. Robbins Reef Location Bottom Salinity Percentiles.

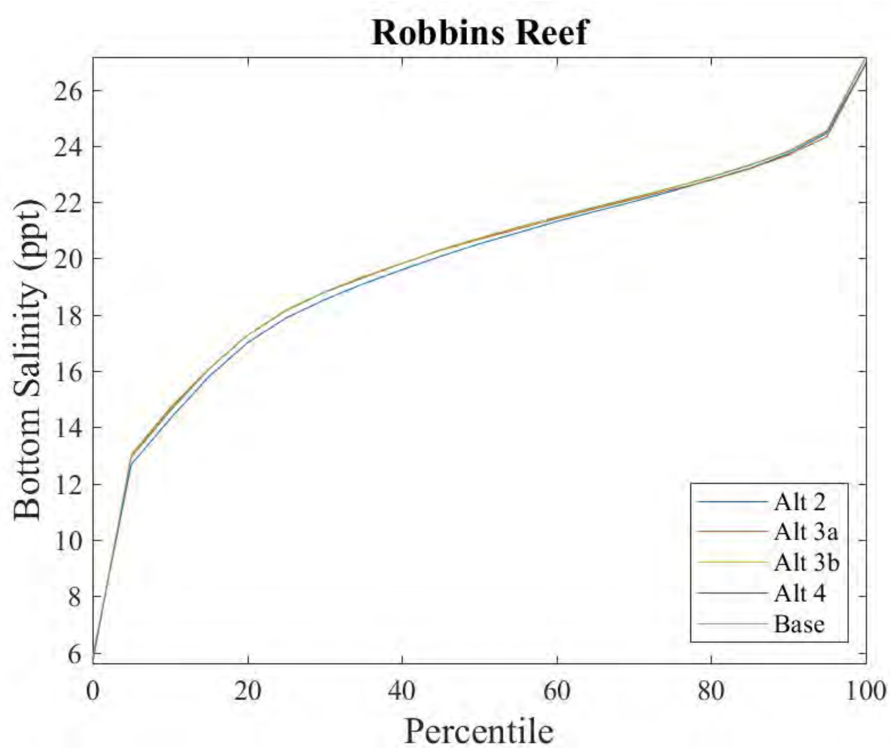


Figure 150. The Battery Location Bottom Salinity Percentiles.

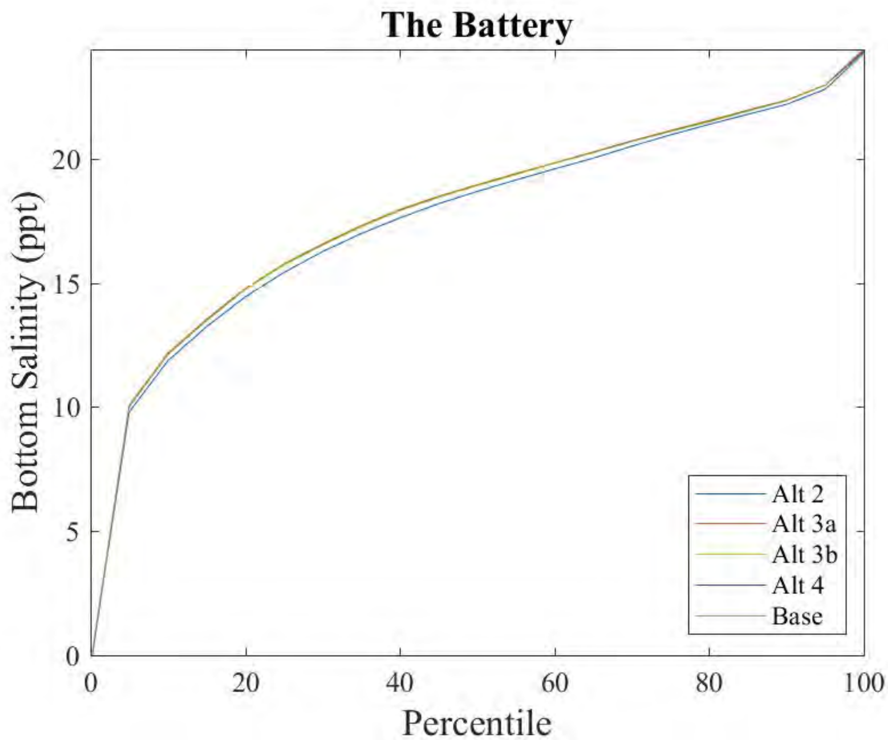


Figure 151. Manhattan Location Bottom Salinity Percentiles.

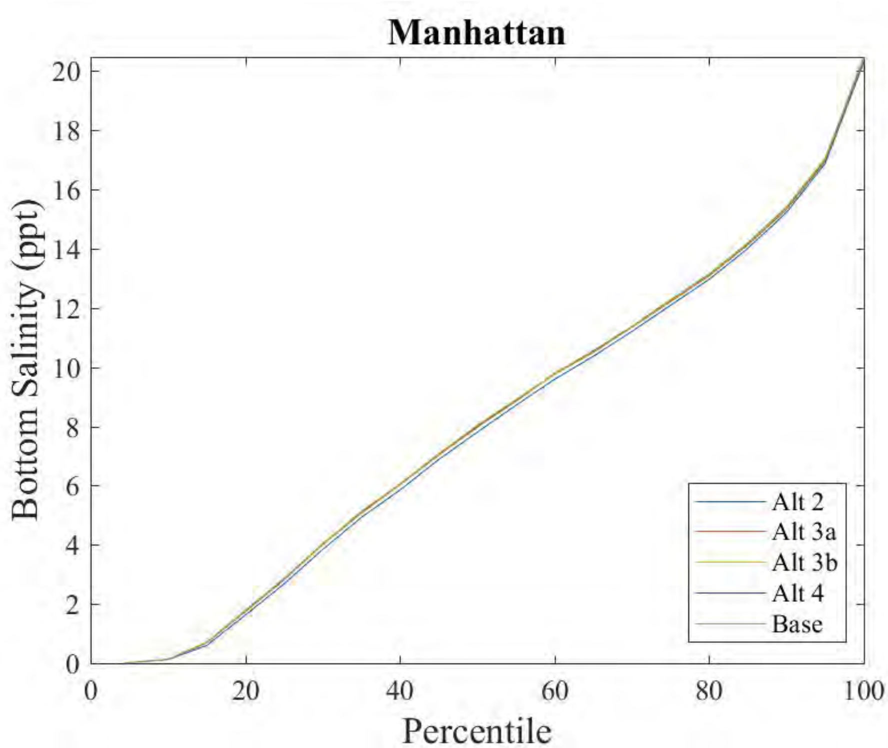


Figure 152. KLGA Location Bottom Salinity Percentiles.

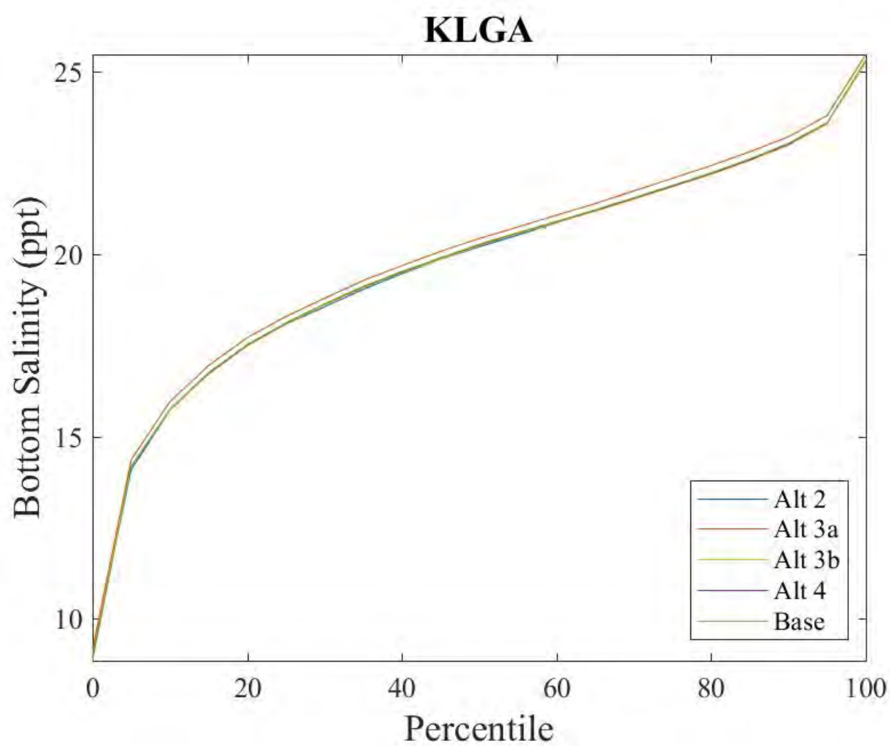


Figure 153. Western LIS, near Stepping Stone Lighthouse Location Bottom Salinity Percentiles.

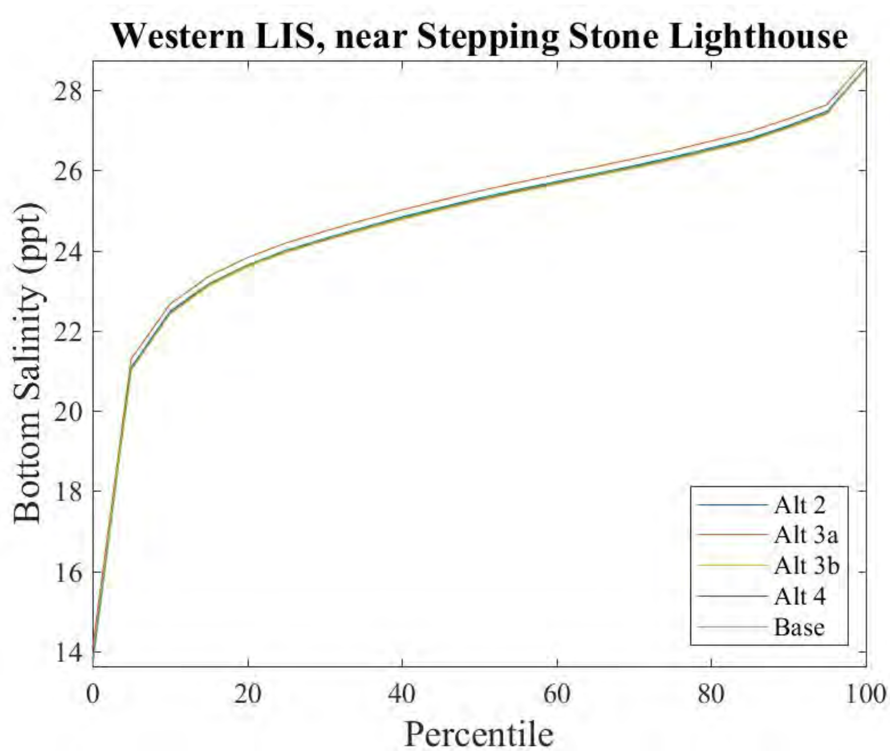


Figure 154. Western LIS, near Execution Rock Lighthouse Location Bottom Salinity Percentiles.

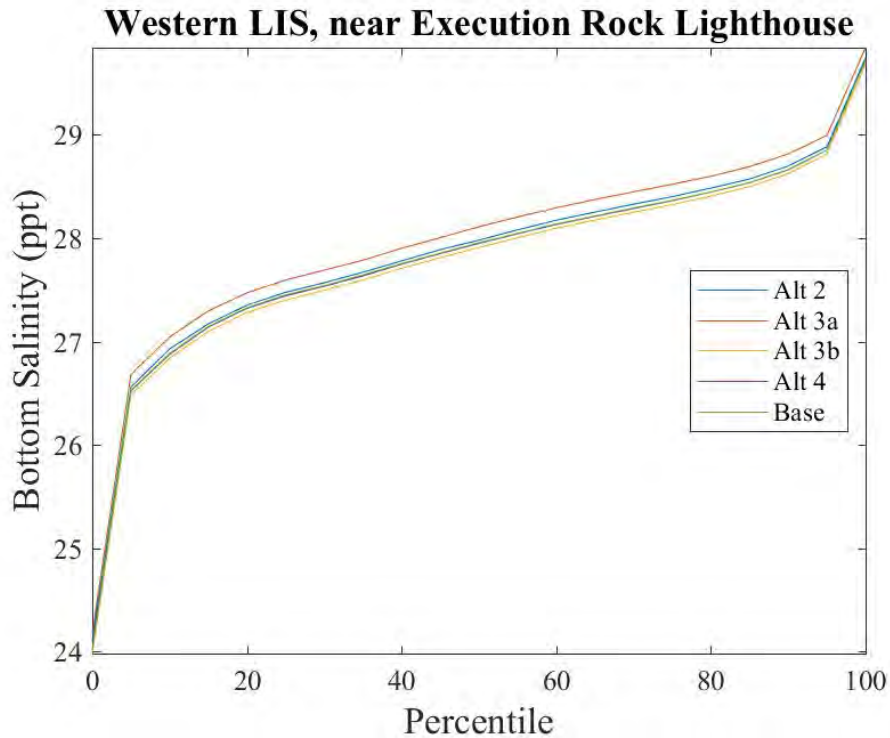


Figure 155. Western LIS, South of NY and CT Border Location Bottom Salinity Percentiles.

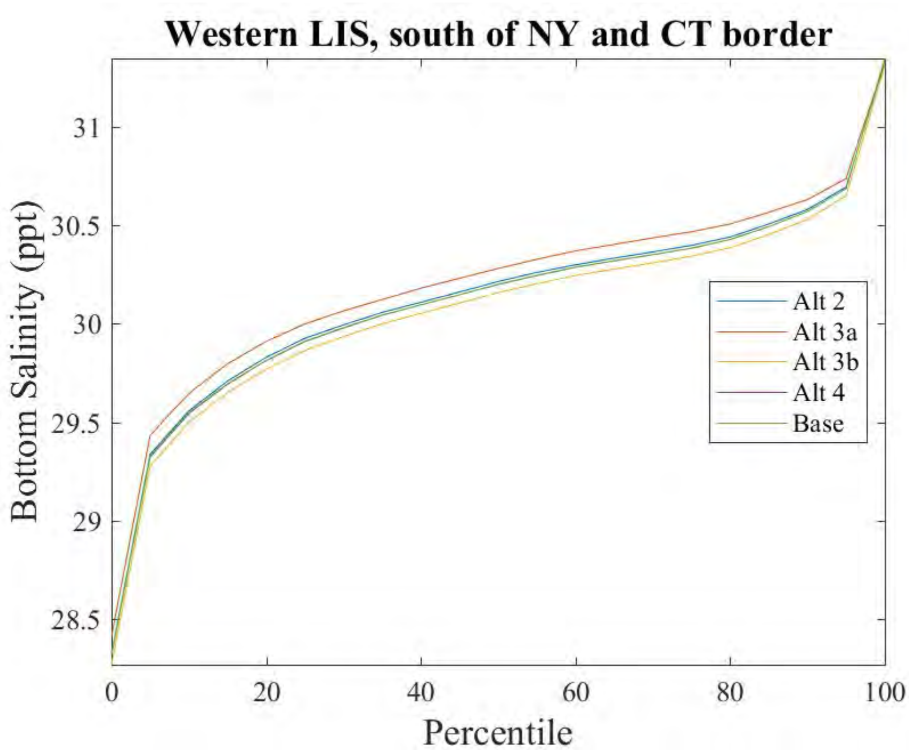


Figure 156. Jamaica Bay Location Bottom Salinity Percentiles.

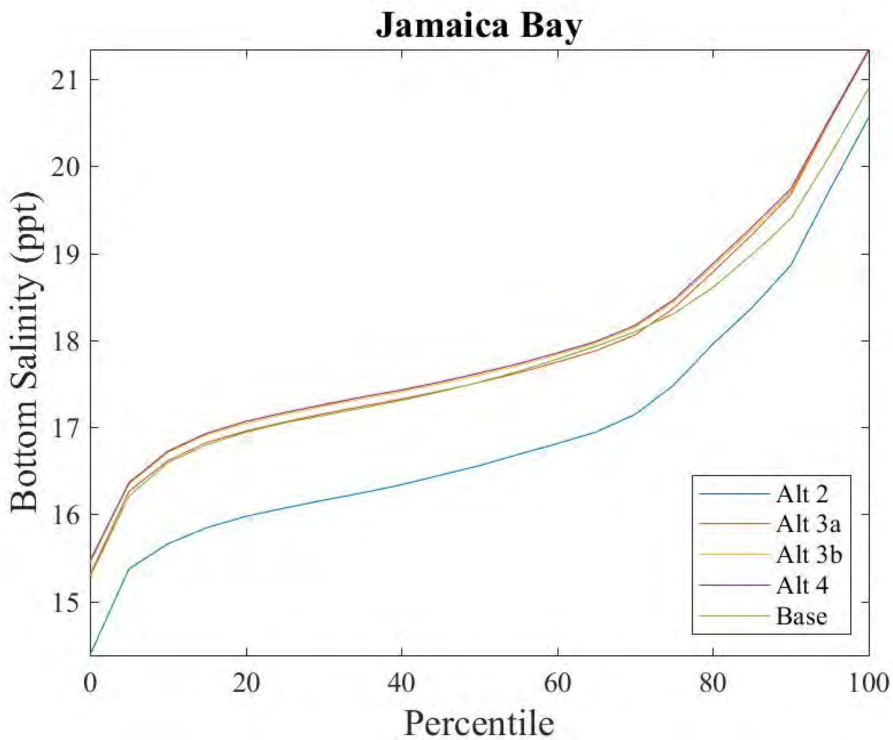


Figure 157. Jamaica Bay near Spring Creek Location Bottom Salinity Percentiles.

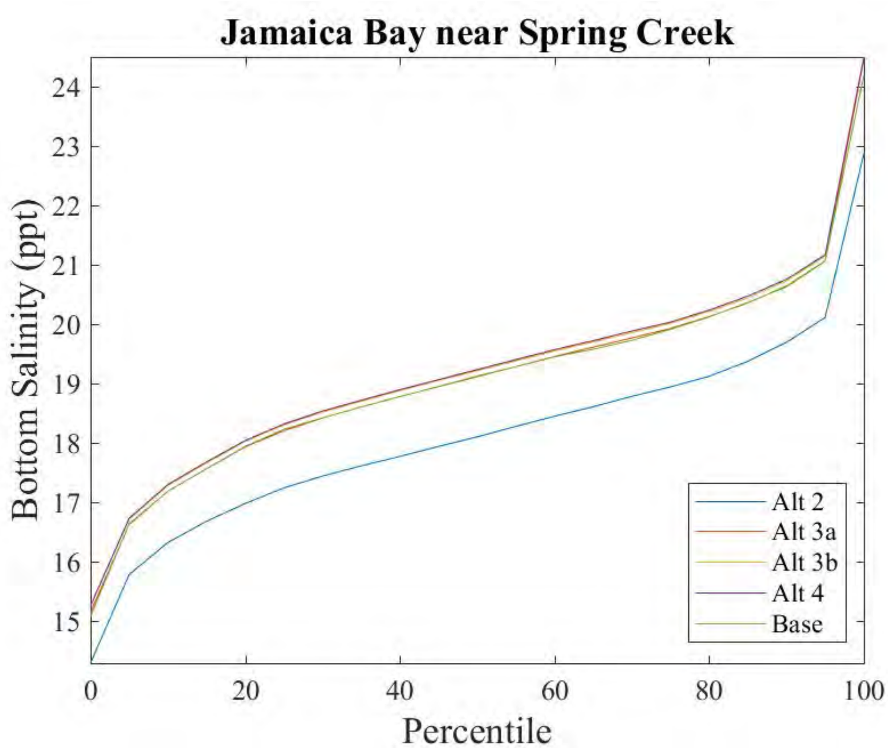
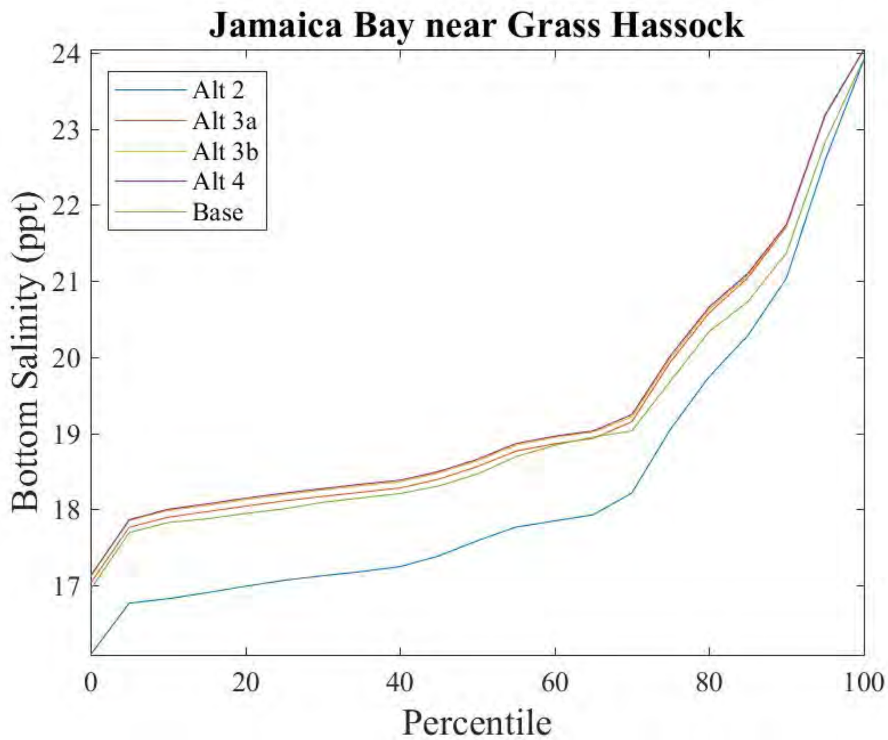


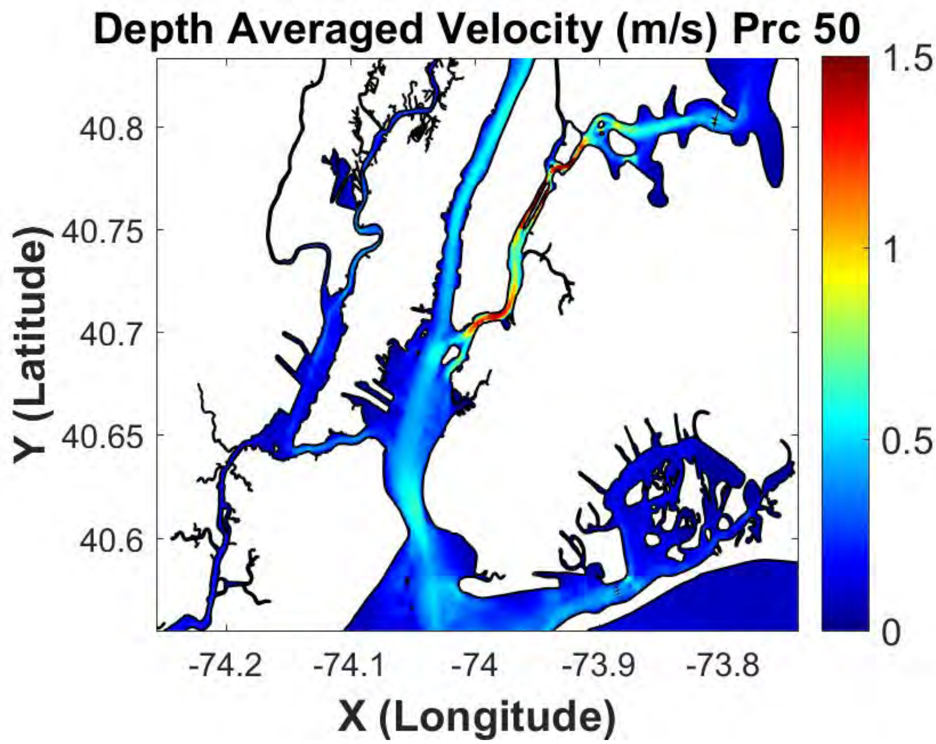
Figure 158. Jamaica Bay near Grass Hassock Location Bottom Salinity Percentiles.



12 Appendix E – Spatial Depth Averaged Velocity Percentiles for All Alternatives

The figures (Figure 159 to Figure 166) in this appendix are the spatial velocity percentile plots for Upper and Lower Bay. These results were calculated based on 1 hour output information for the entire 1995 calendar year simulation. These figures indicate both the system wide velocity changes along with the local velocity increases near field of the structures. In general, these results are similar across the Base and all alternatives with the only noticeable exceptions being near field of proposed structures.

Figure 159. Alternative 2, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Averaged Velocities.



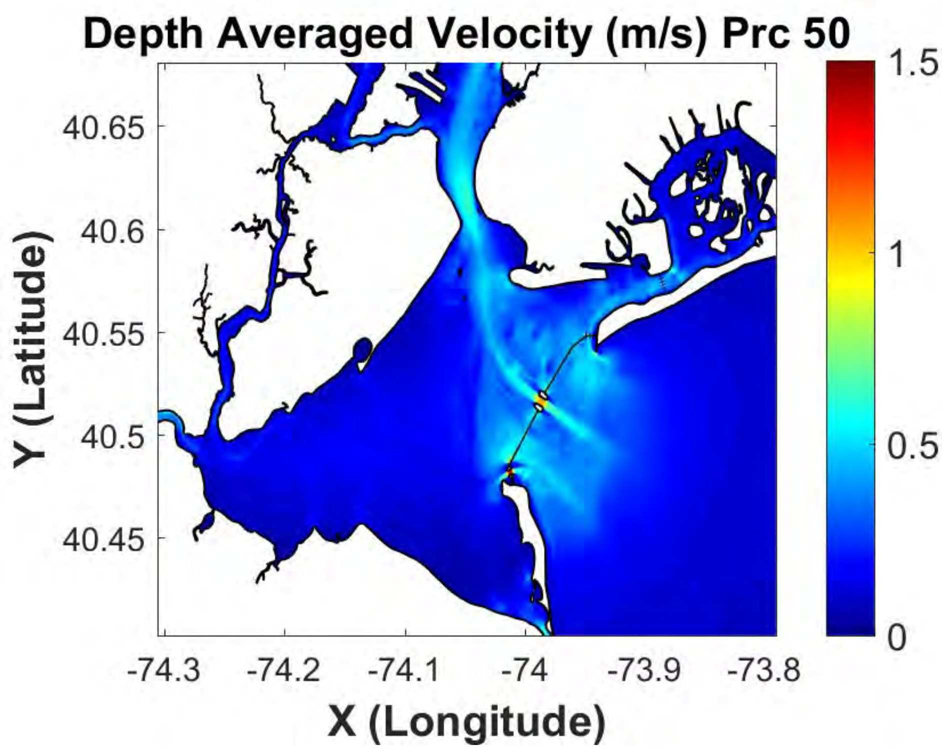


Figure 160. Alternative 2, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Averaged Velocities.

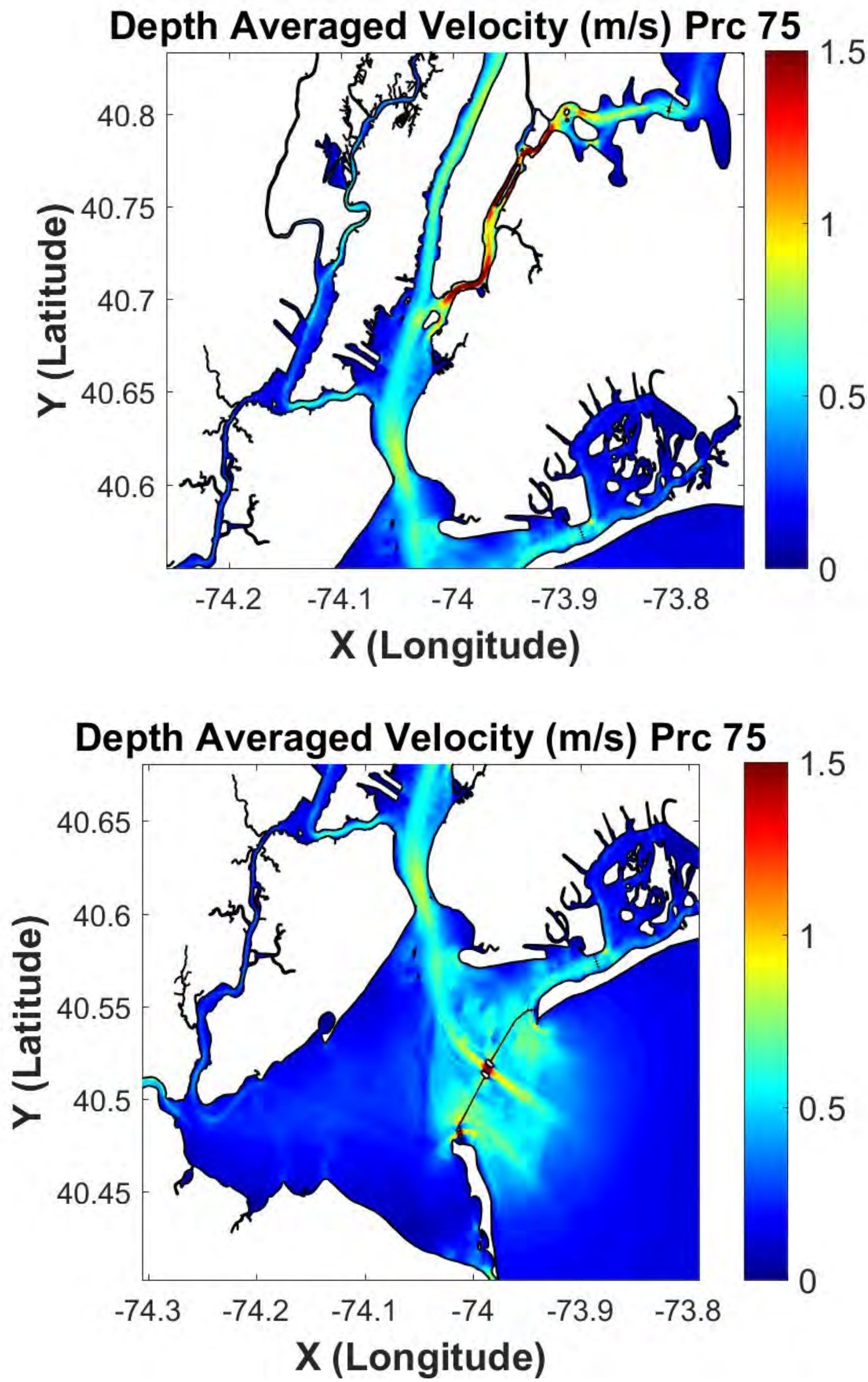


Figure 161. Alternative 3a, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Averaged Velocities.

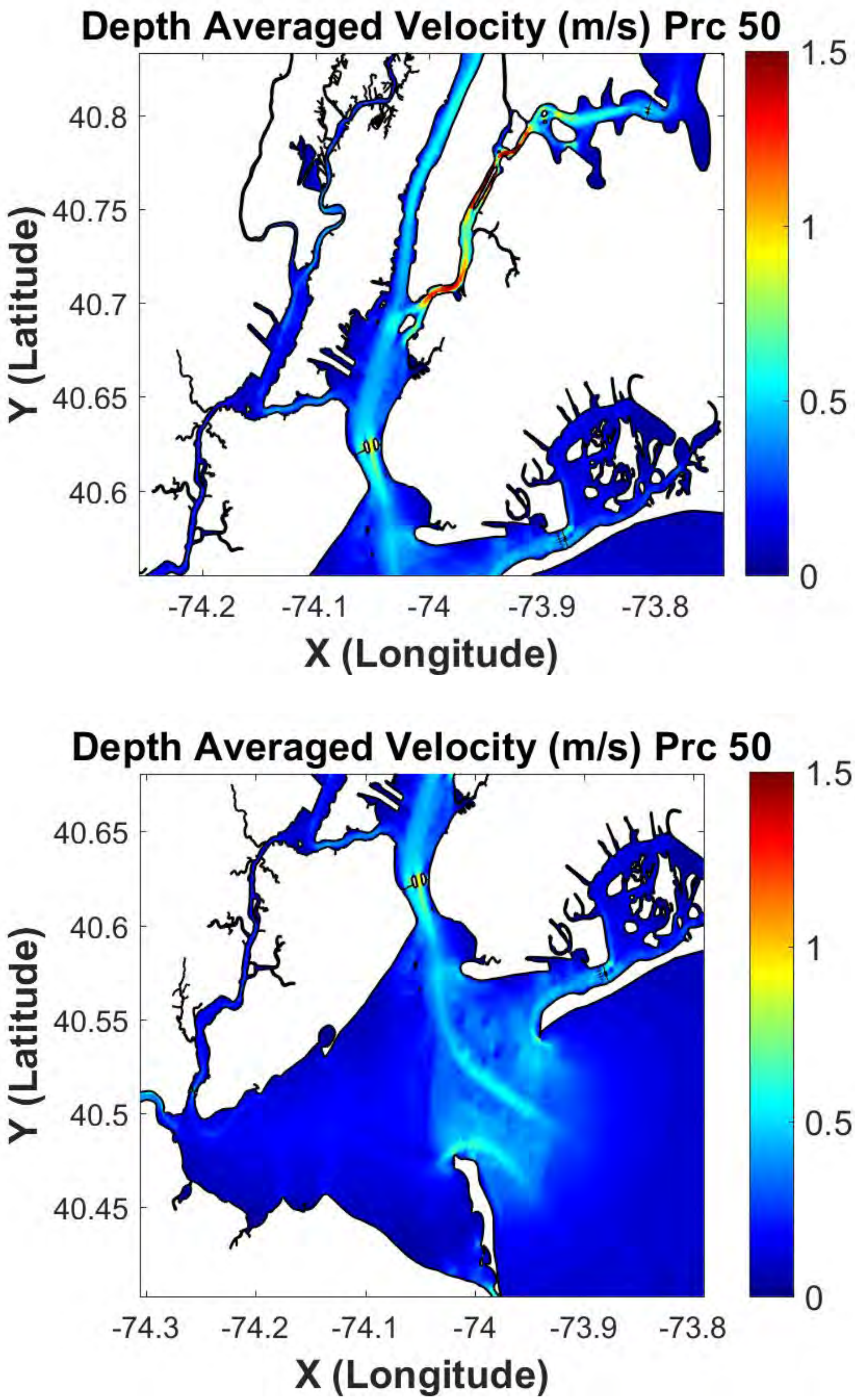


Figure 162. Alternative 3a, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Averaged Velocities.

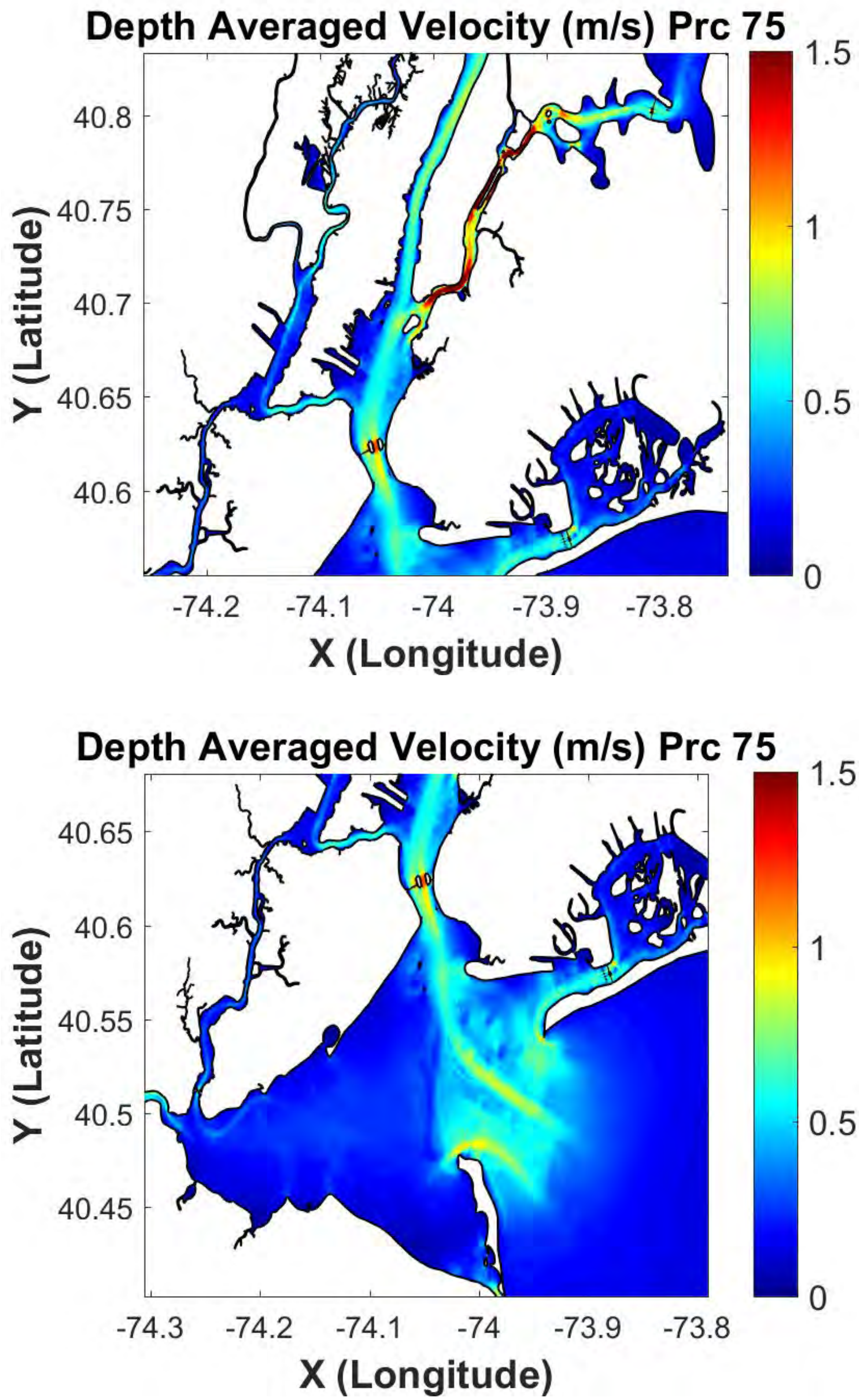
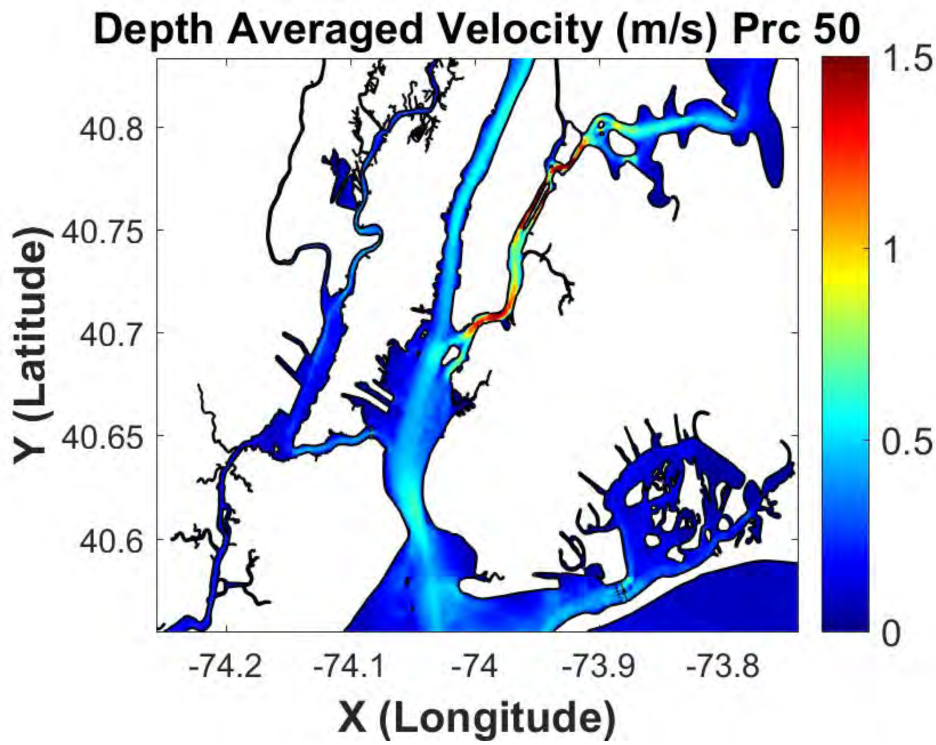


Figure 163. Alternative 3b, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Averaged Velocities.



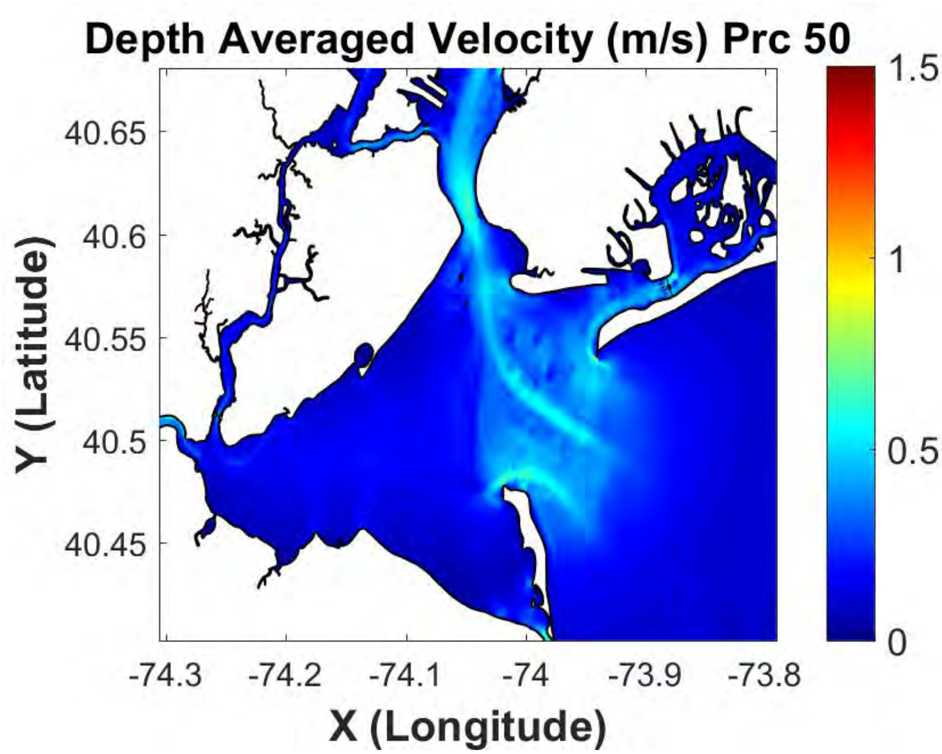
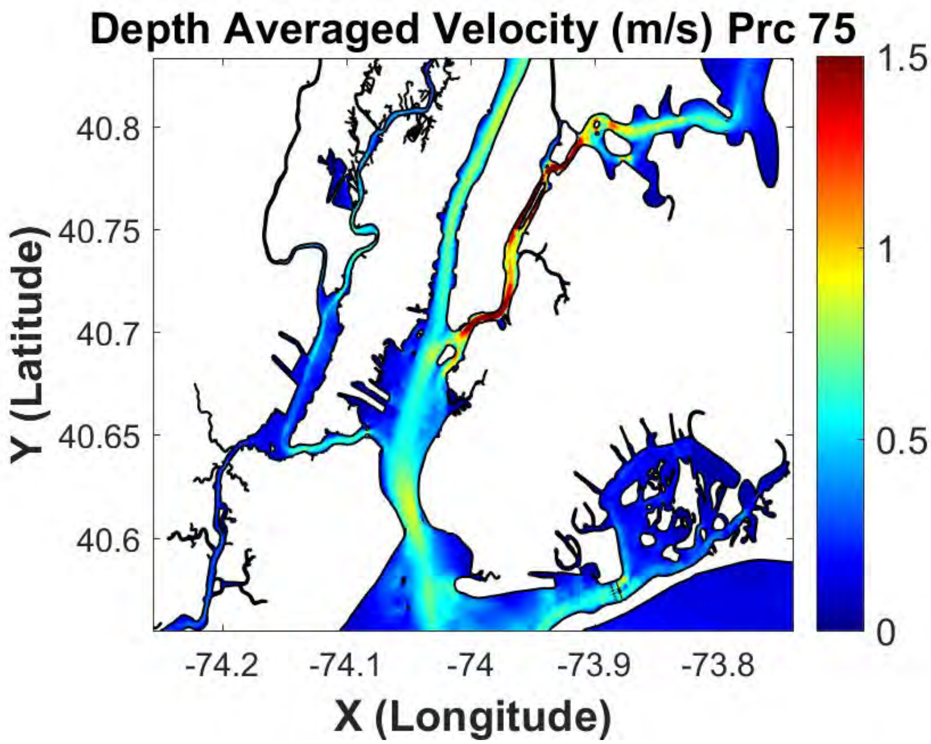


Figure 164. Alternative 3b, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Averaged Velocities.



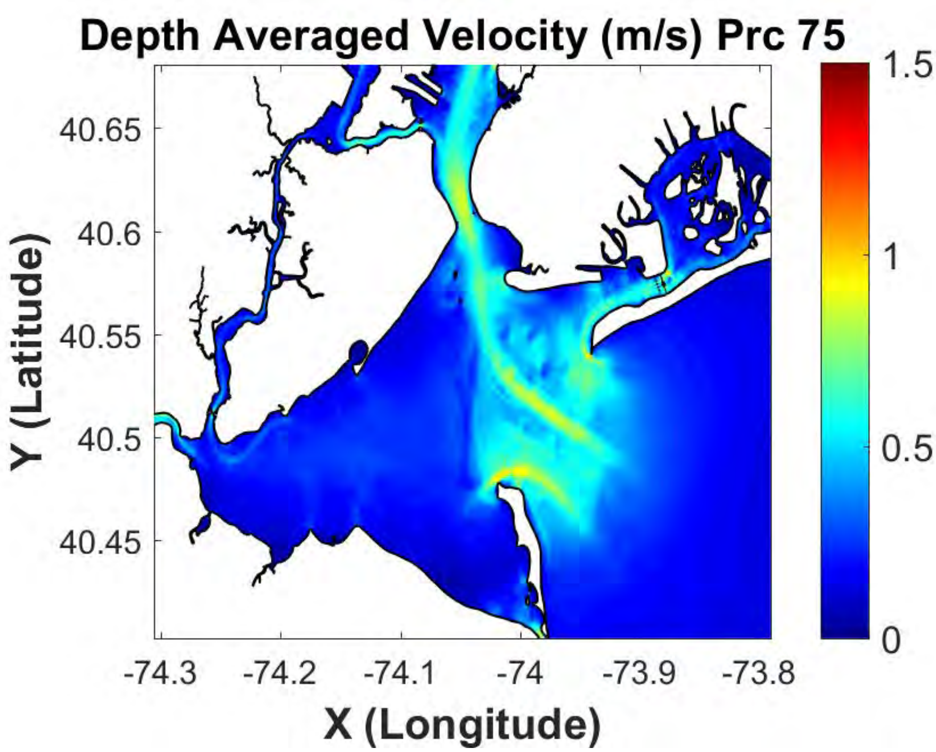


Figure 165. Alternative 4, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Averaged Velocities.

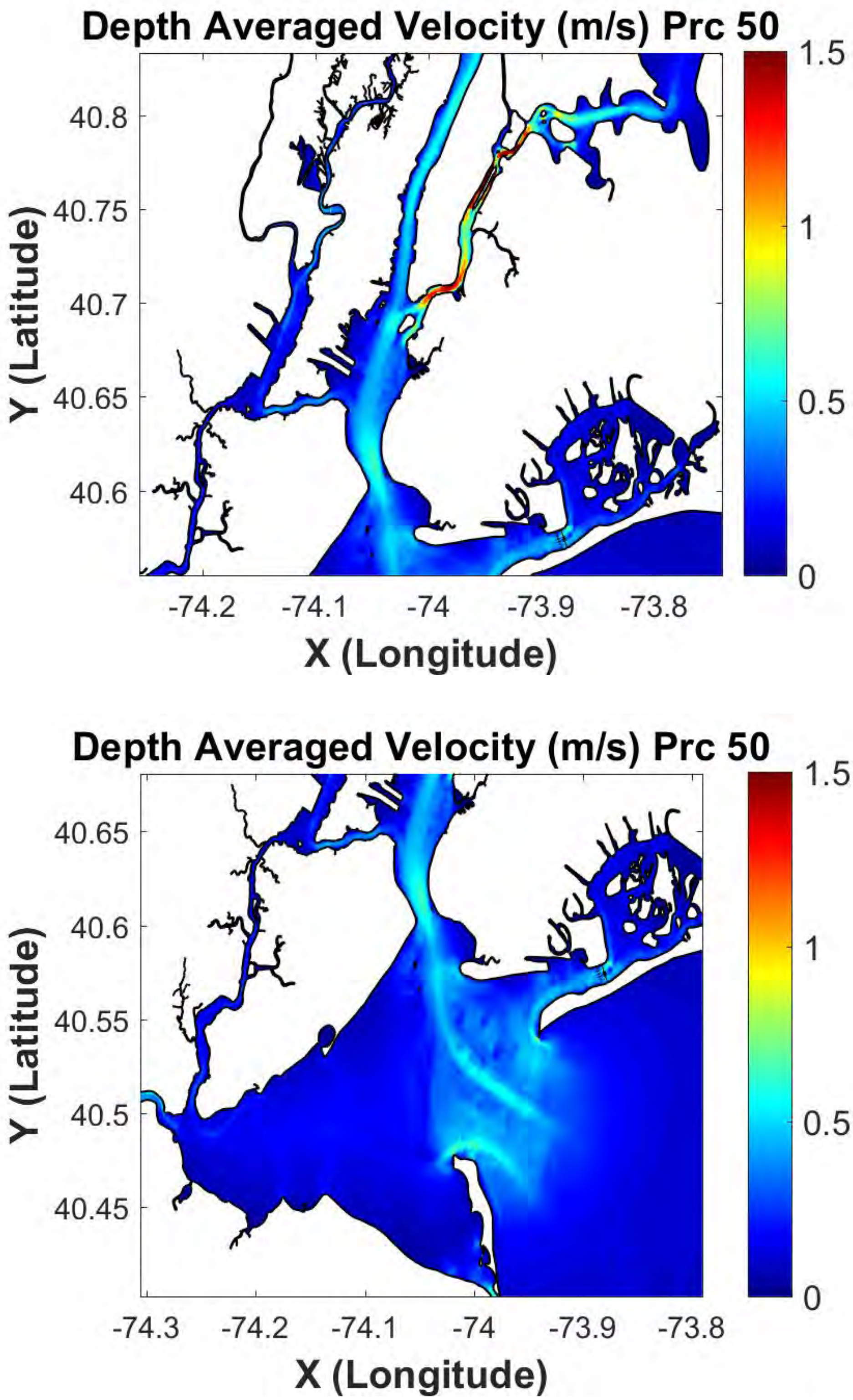
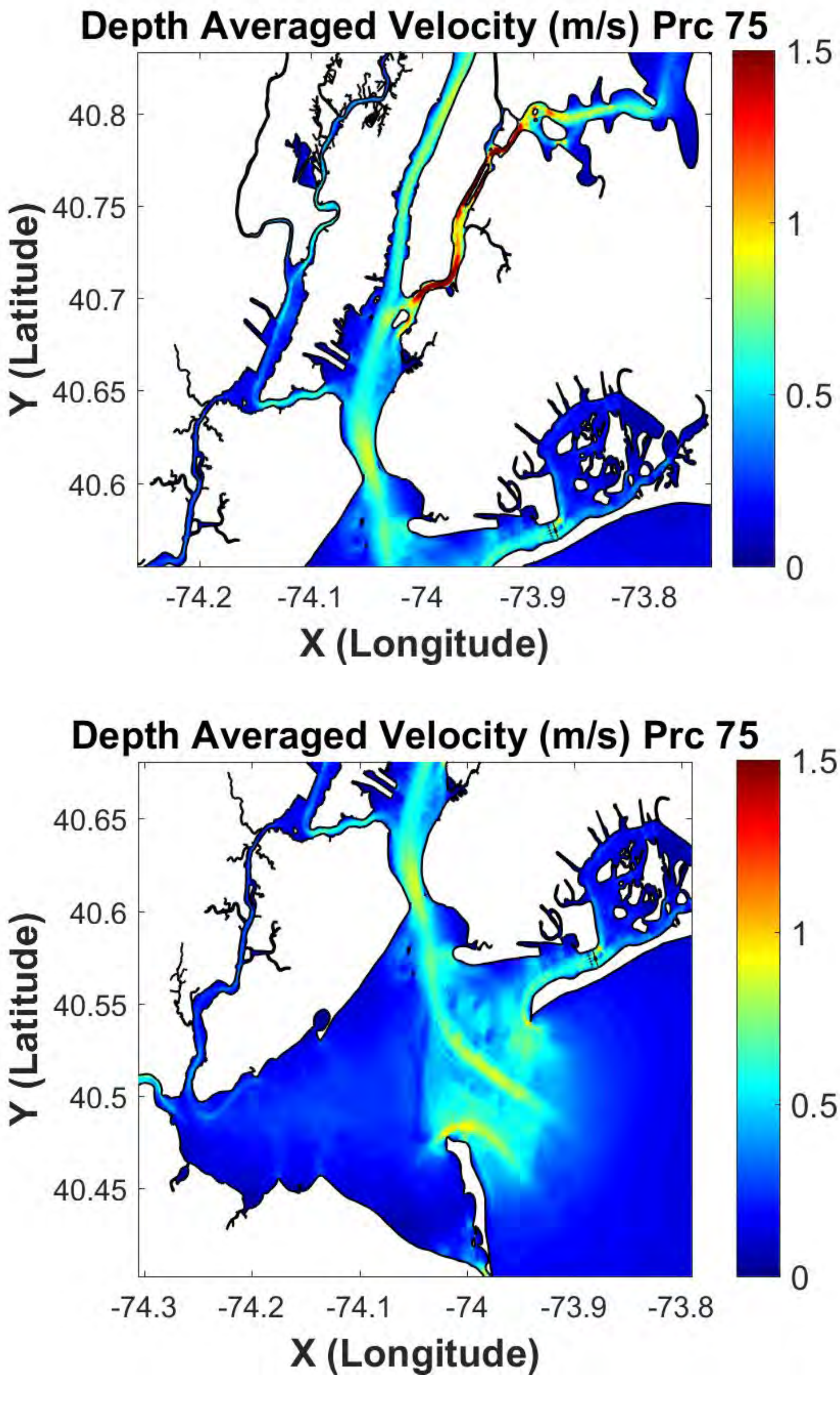


Figure 166. Alternative 4, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Averaged Velocities.



13 Appendix F – Spatial Bottom Salinity Percentiles for All Alternatives

The figures (Figure 167 to Figure 174) in this appendix are the spatial salinity percentile plots for Upper and Lower Bay. These results were calculated based on 1 hour output information for the entire 1995 calendar year simulation. These figures illustrate the spatial impact of reduced tidal exchange (Alternative 2) along with impacts associated with flow redistribution (Alternative 3a).

Figure 167. Alternative 2, Upper Bay (top) and Lower Bay (bottom) 50th percentile bottom salinities.

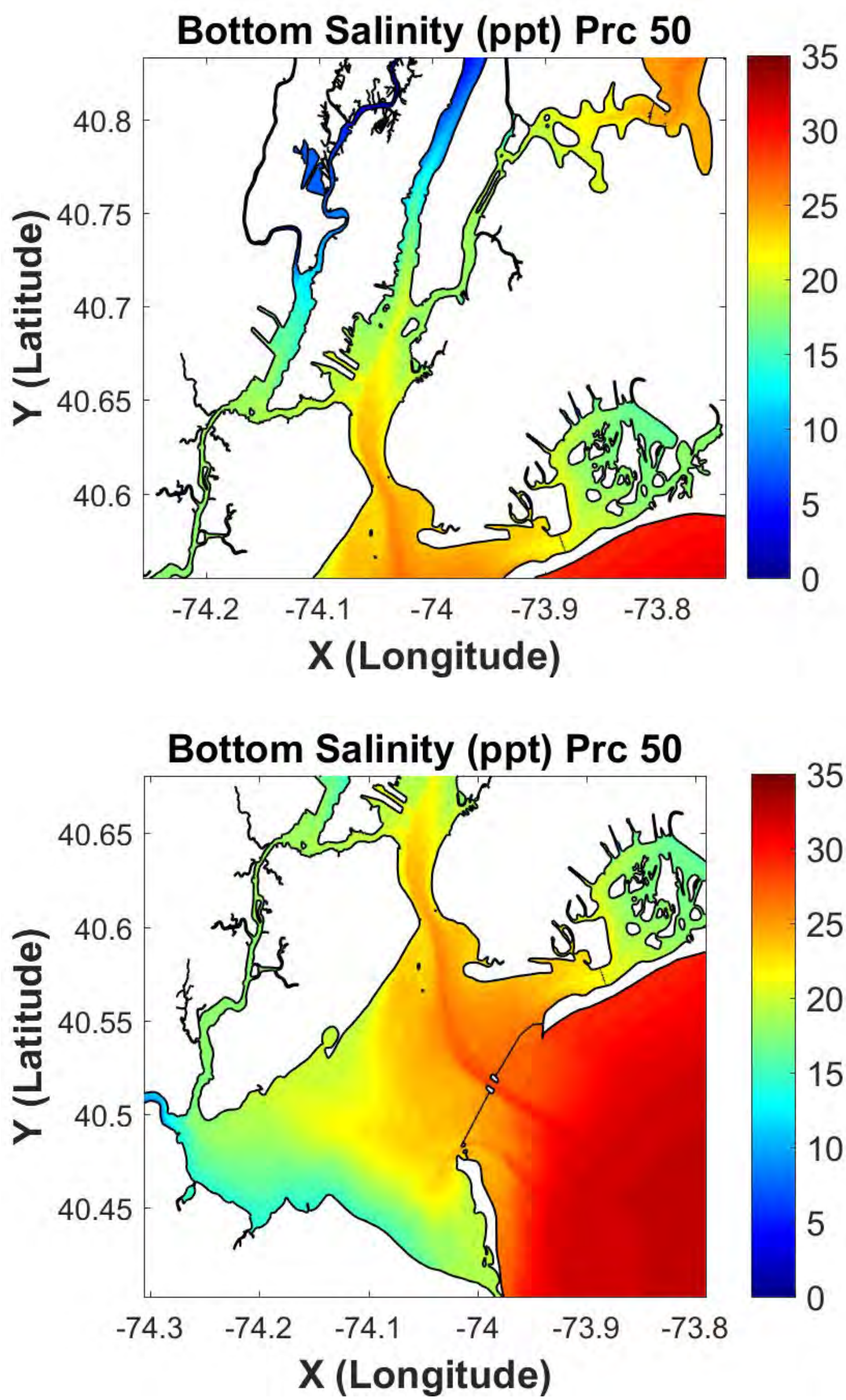
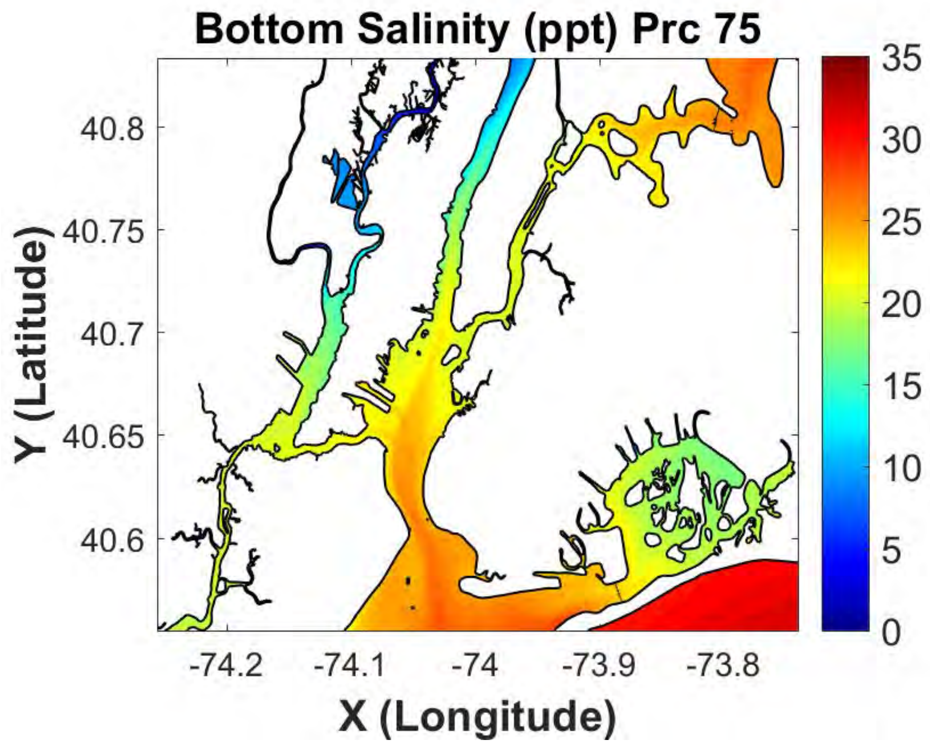


Figure 168. Alternative 2, Upper Bay (top) and Lower Bay (bottom) 75th percentile bottom salinities.



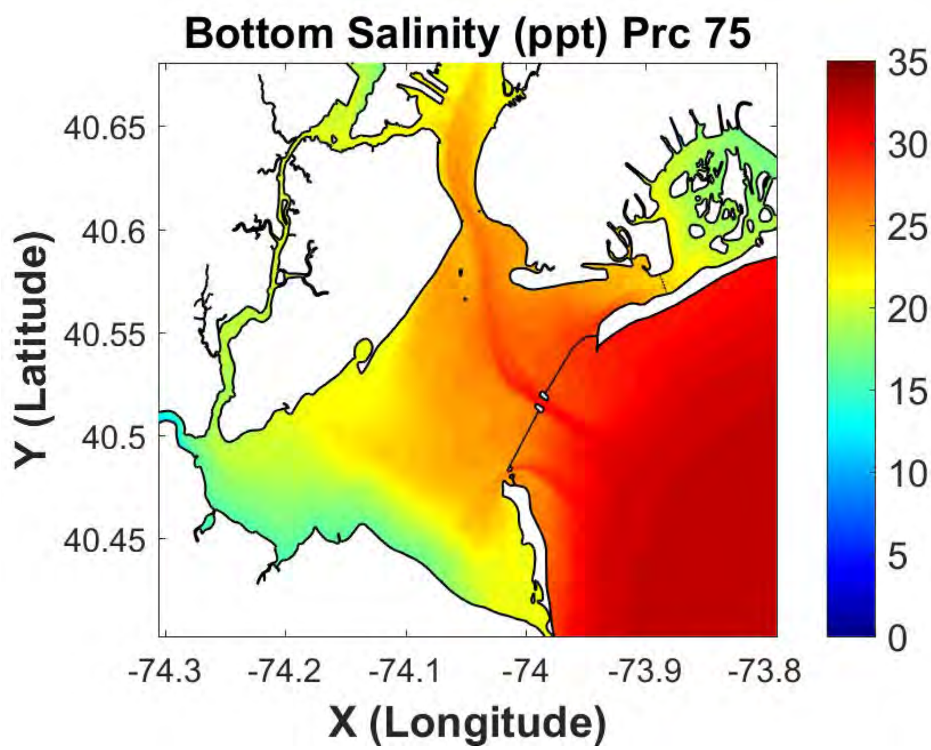


Figure 169. Alternative 3a, Upper Bay (top) and Lower Bay (bottom) 50th percentile bottom salinities.

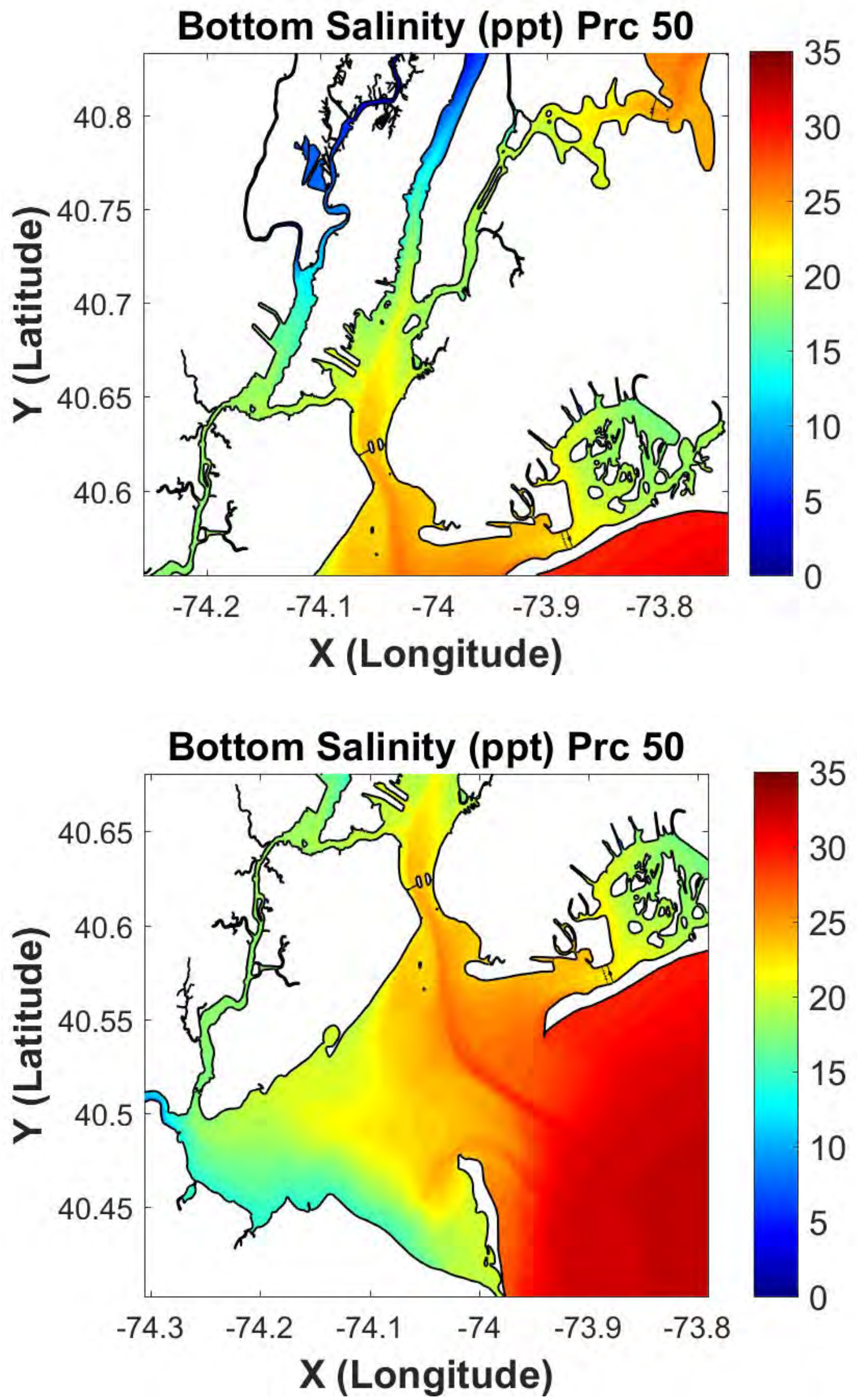


Figure 170. Alternative 3a, Upper Bay (top) and Lower Bay (bottom) 75th percentile bottom salinities.

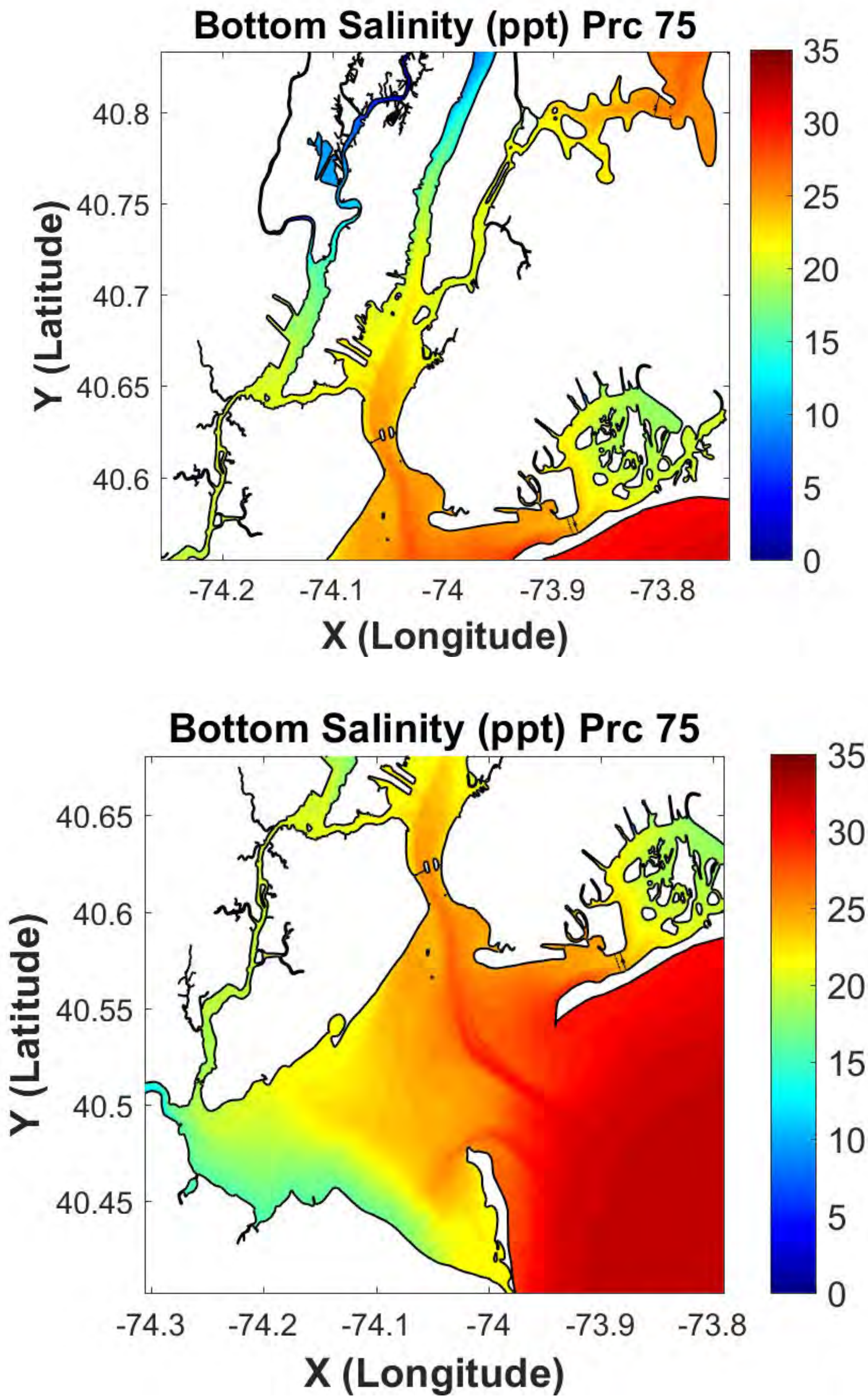
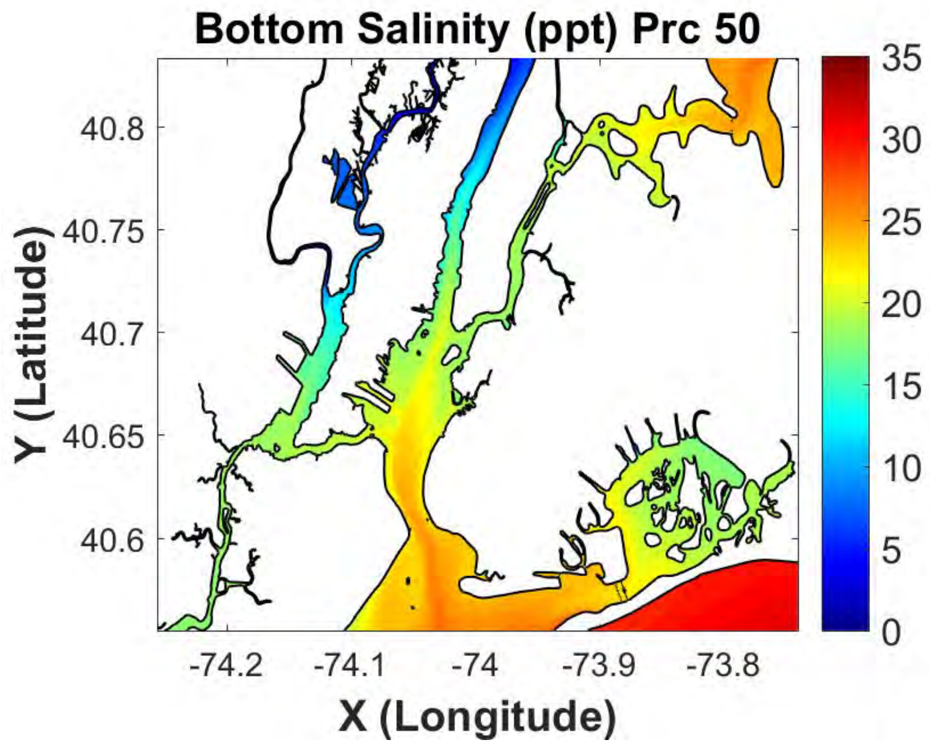


Figure 171. Alternative 3b, Upper Bay (top) and Lower Bay (bottom) 50th percentile bottom salinities.



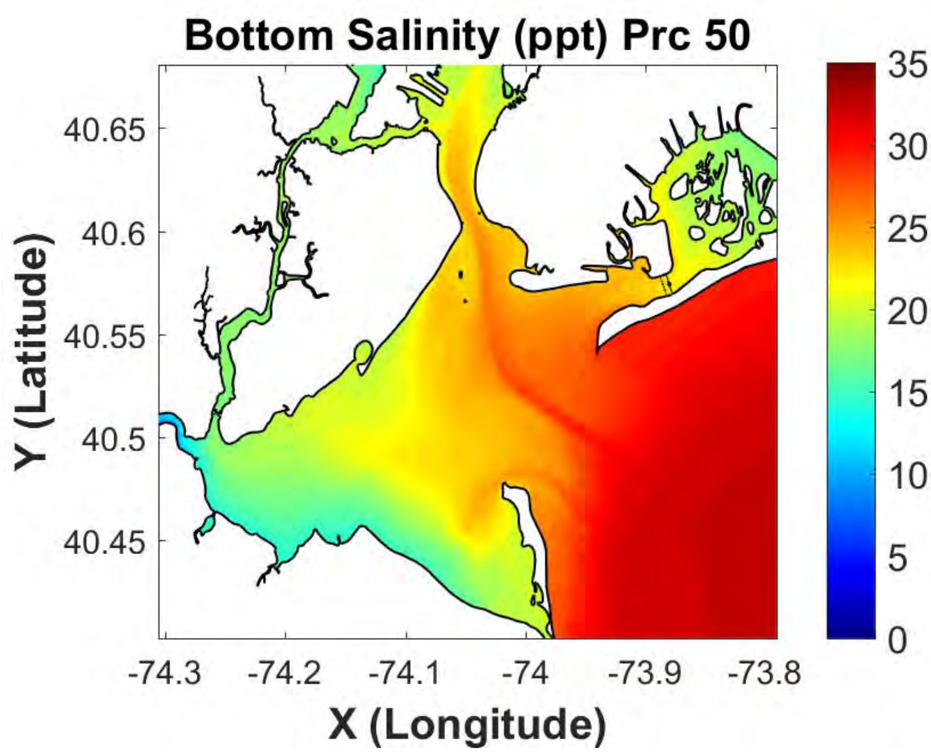


Figure 172. Alternative 3b, Upper Bay (top) and Lower Bay (bottom) 75th percentile bottom salinities.

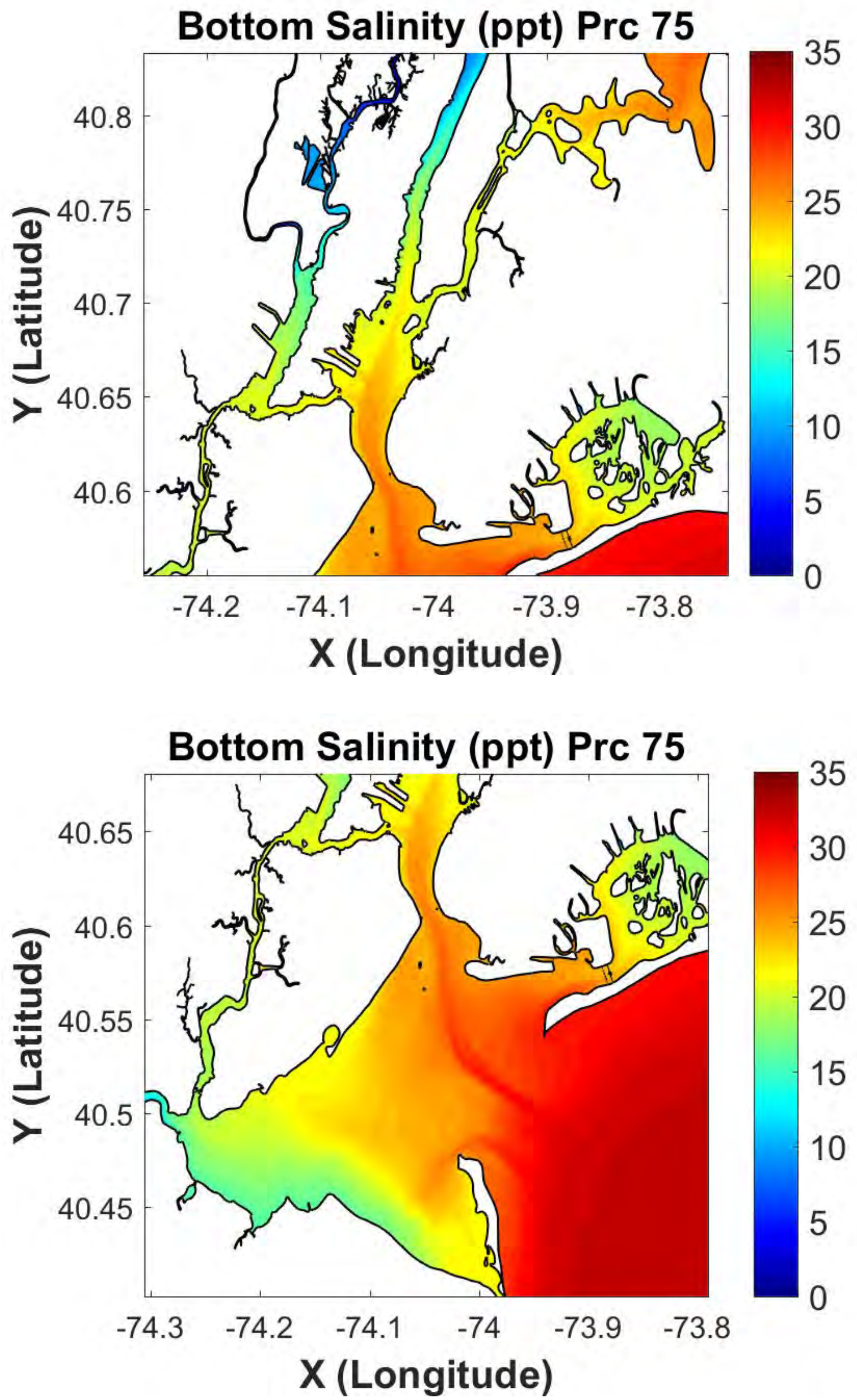
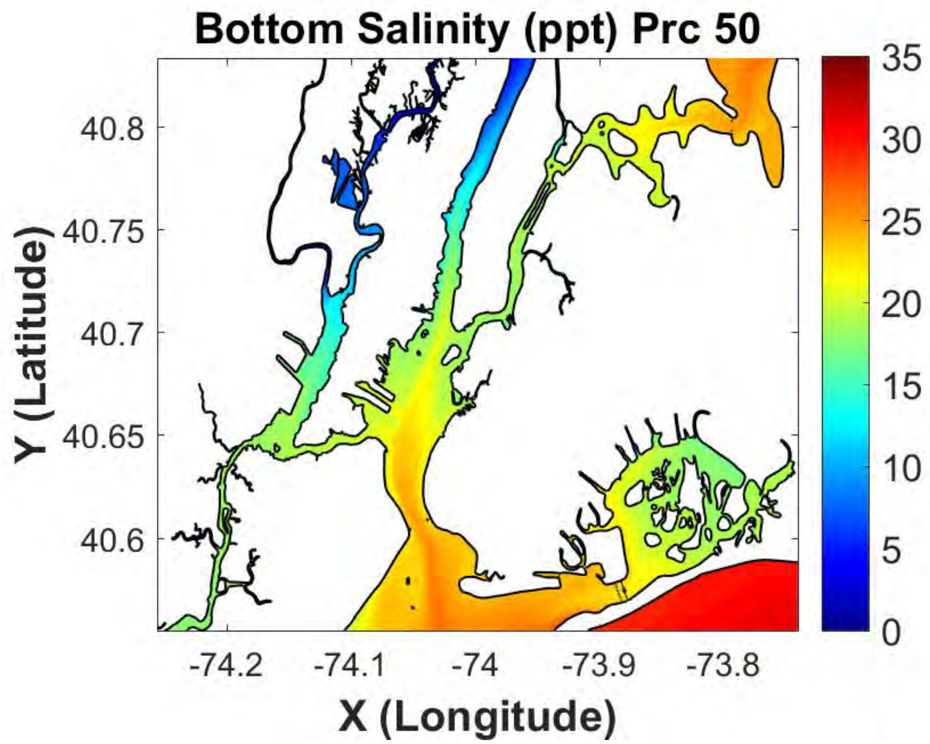


Figure 173. Alternative 4, Upper Bay (top) and Lower Bay (bottom) 50th percentile bottom salinities.



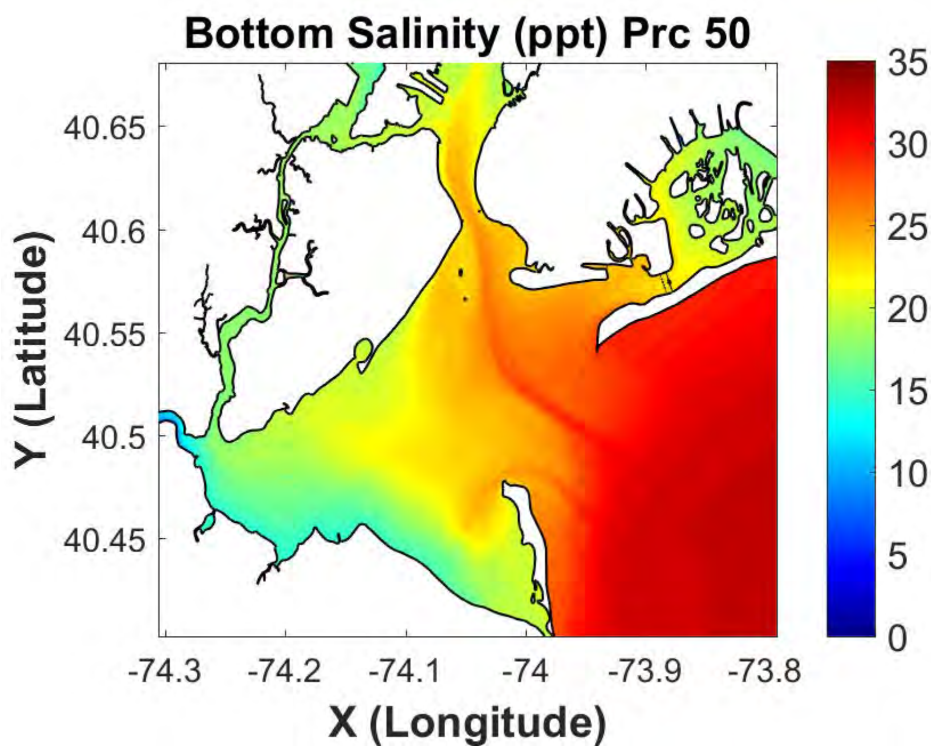
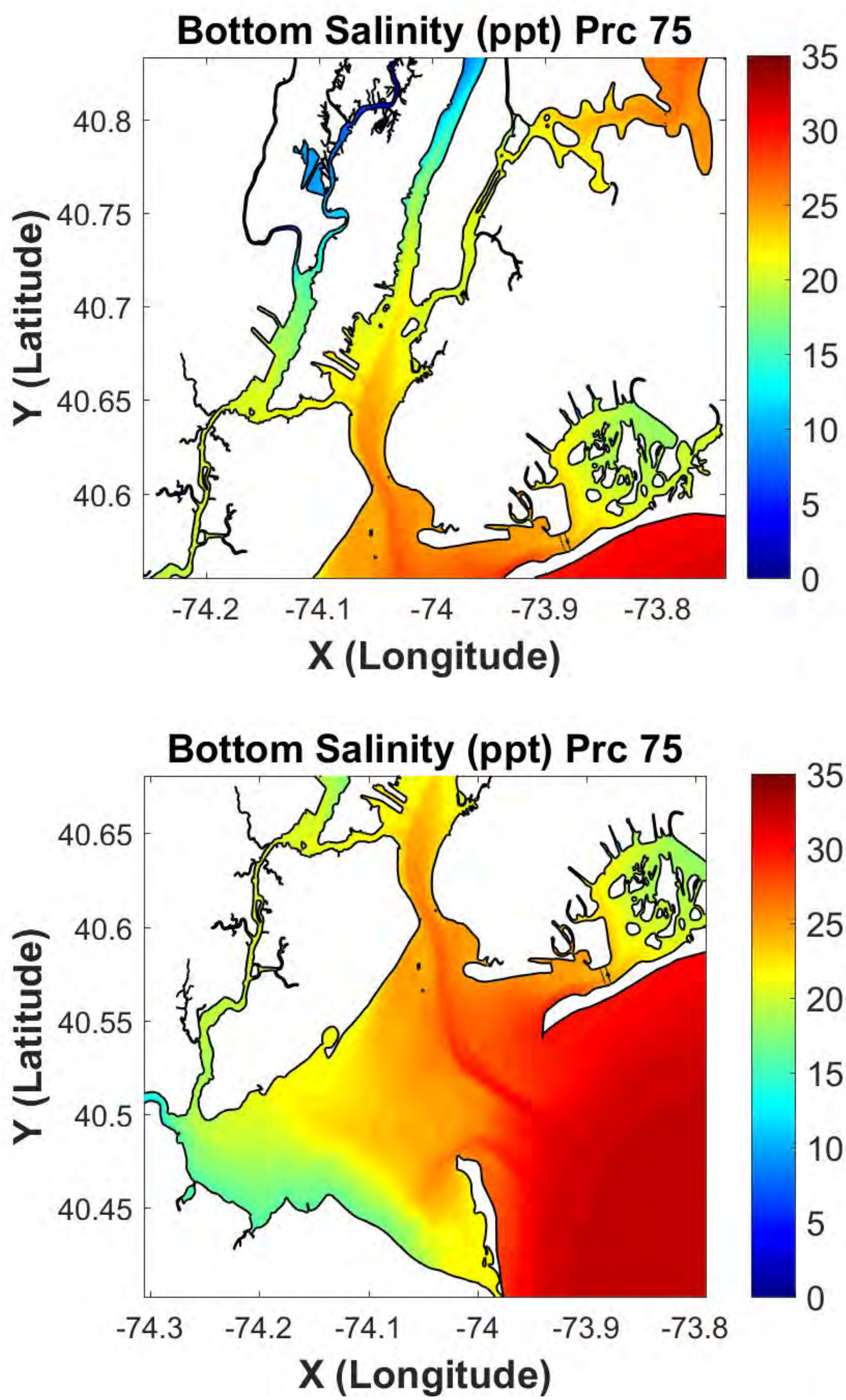
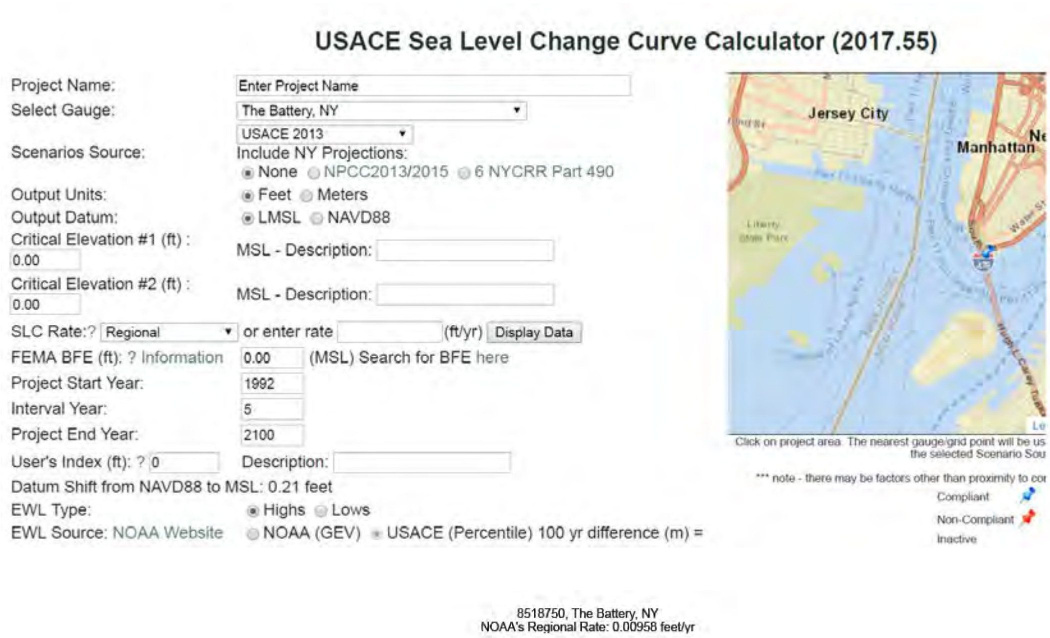


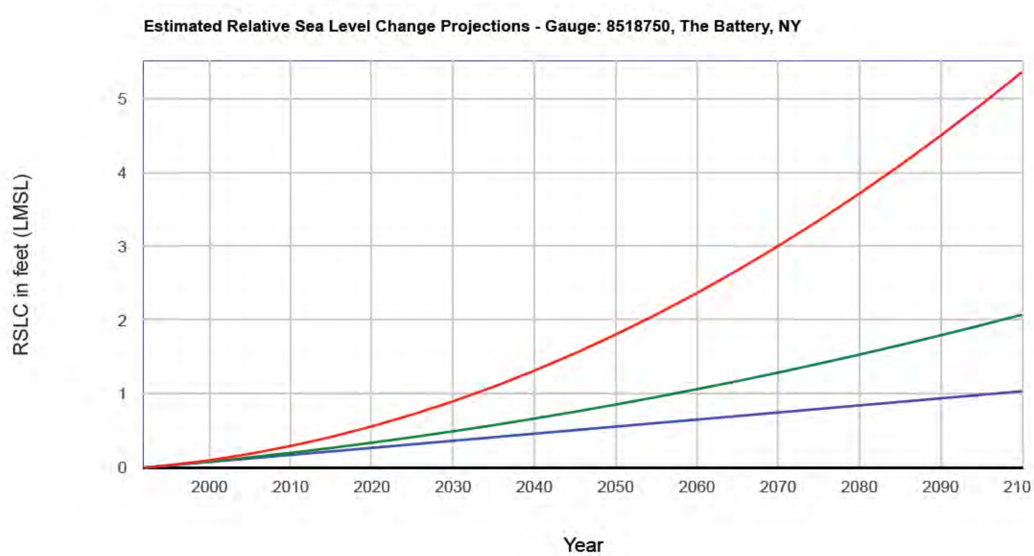
Figure 174. Alternative 4, Upper Bay (top) and Lower Bay (bottom) 75th percentile bottom salinities.



14 Appendix G – Sea Level Rise Calculations

This appendix provides screen captures of the Sea Level Rise calculations using the U.S. Army Corps of Engineers Sea Level Change Curve Calculator (http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html#). Our base year was 1995 and the projected constructed year is 2030. Using the Intermediate curve, this indicates a sea level rise amount of 0.46 ft (0.14 m) from 1995 to 2030.





8518750, The Battery, NY
NOAA's Regional Rate: 0.00958 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low	USACE Int	USACE High
1992	0.00	0.00	0.00
1995	0.03	0.03	0.03
2000	0.08	0.08	0.10
2005	0.13	0.14	0.19
2010	0.17	0.20	0.29
2015	0.22	0.27	0.42
2020	0.27	0.34	0.56
2025	0.32	0.41	0.72
2030	0.36	0.49	0.90
2035	0.41	0.58	1.10
2040	0.46	0.67	1.31
2045	0.51	0.76	1.55
2050	0.56	0.86	1.80
2055	0.60	0.96	2.08
2060	0.65	1.06	2.37
2065	0.70	1.17	2.68
2070	0.75	1.29	3.00
2075	0.80	1.41	3.35
2080	0.84	1.53	3.71
2085	0.89	1.66	4.10
2090	0.94	1.79	4.50
2095	0.99	1.93	4.92
2100	1.03	2.07	5.36

15 Appendix H – Impact of Sea Level Rise

This appendix provides figures illustrating the impact of sea level rise on the individual alternatives. This analysis is similar to the previously shown comparisons but in this appendix the comparisons are for the particular alternative across sea level values as opposed to comparing the impacts of the alternatives. In general, increased sea level results in increased tidal exchange, tide ranges, and salinity intrusion. Some localized variations are possible if flow pathways are influenced by the higher sea levels, but these would be the exceptions. The impact of sea level rise on the velocities was inconsistent with some locations possessing larger velocities for higher sea levels and some locations possessing lower velocities. The velocity impact is associated with the interaction of increased tidal exchange/tidal prism and increased depths. Increased tidal exchange results in increased velocities whereas increased depths reduce velocities. The magnitude change for these parameters determines if the velocities increase/decrease with sea level rise making this a localized variation that is inconsistent spatially.

15.1 Without Project/Base

For increased sea levels, the without project/base conditions possess increased tidal exchange, tide ranges, and salinity intrusion.

15.1.1 Water Surface Elevation Point Percentiles

Water surface elevation (WSE) percentiles for Base conditions for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 175 to Figure 199. The datum in these plots is relative to Mean Sea Level for 1995. The datum Mean Sea Level will increase with sea level rise (SLR) but for the purposes of these comparisons it is held constant, so all water levels are relative 0.0 MSL for 1995.

Figure 175. Base, Sandy Hook WSE Variation with SLR.

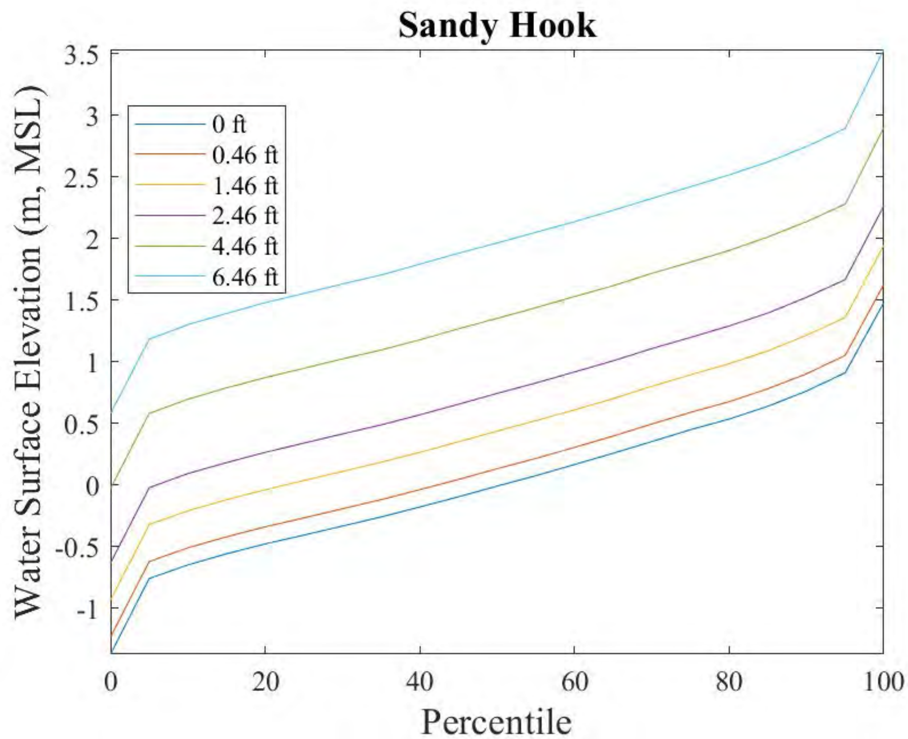


Figure 176. Base, V5 WSE Variation with SLR.

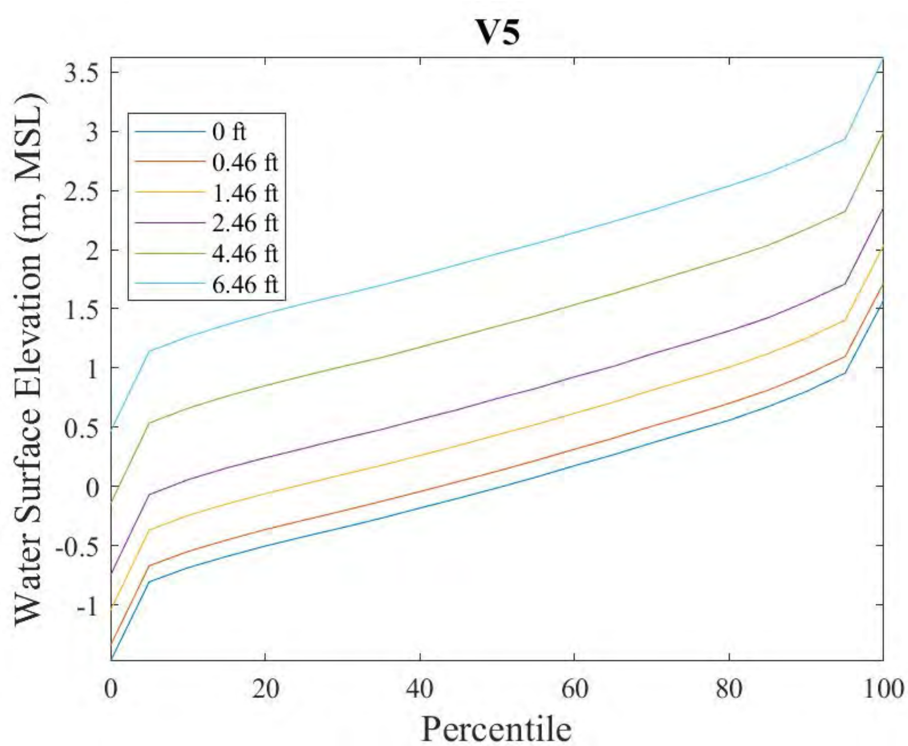


Figure 177. Base, V6 WSE Variation with SLR.

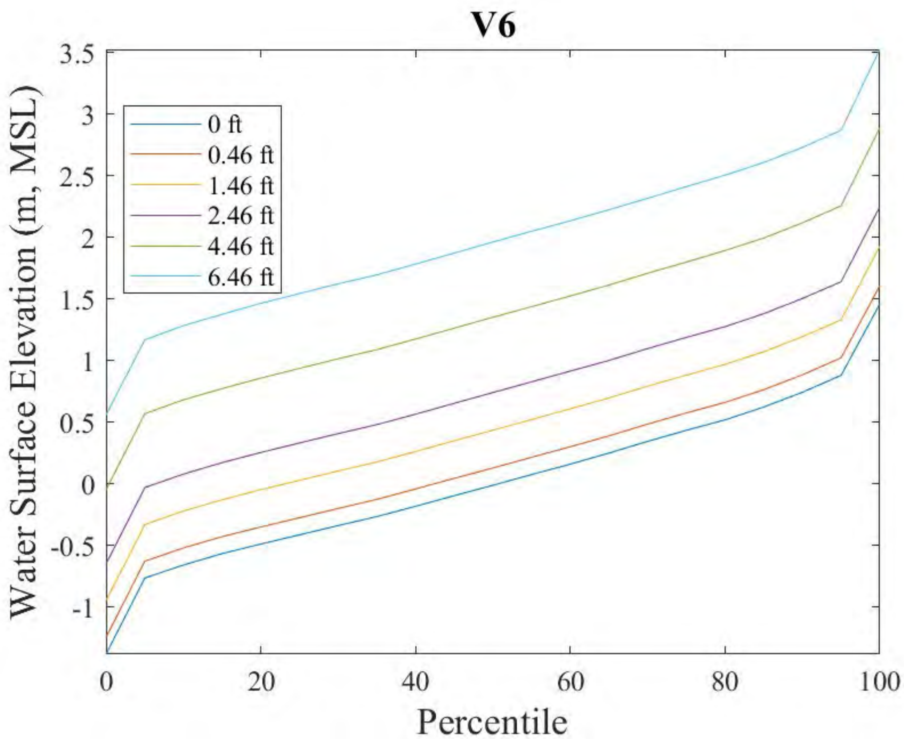


Figure 178. Base, Fresh Kills WSE Variation with SLR.

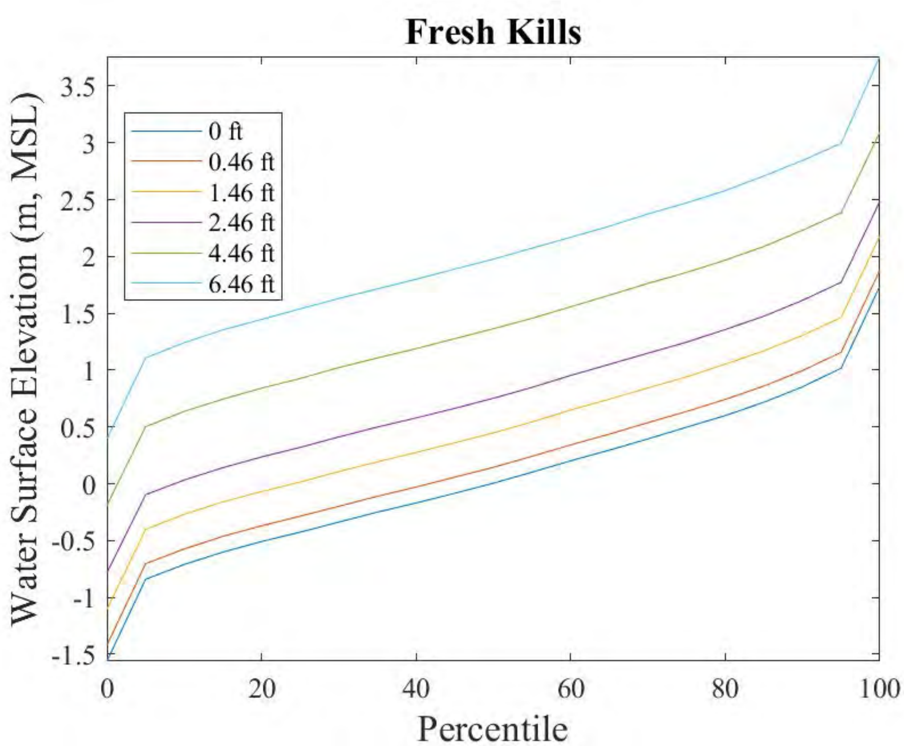


Figure 179. Base, Mariners Harbor WSE Variation with SLR.

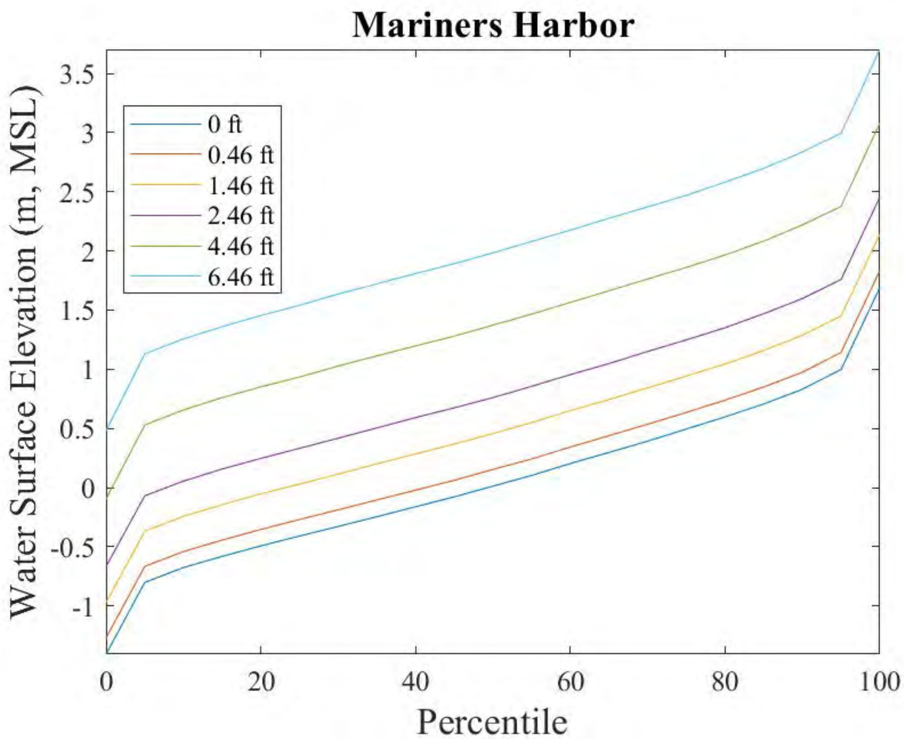


Figure 180. Base, T2 WSE Variation with SLR.

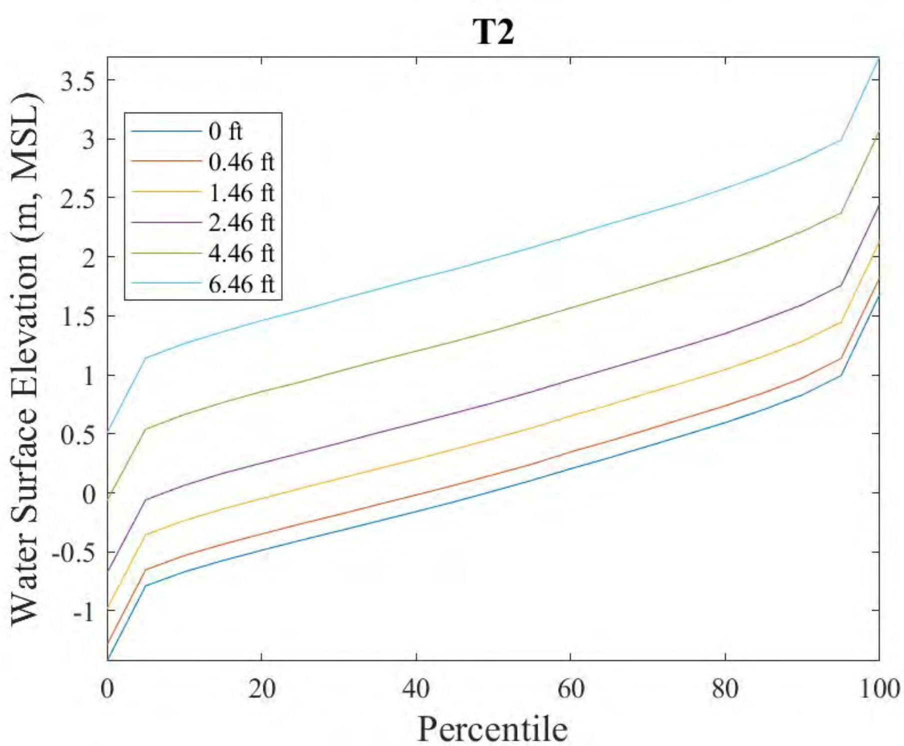


Figure 181. Base, T3 WSE Variation with SLR.

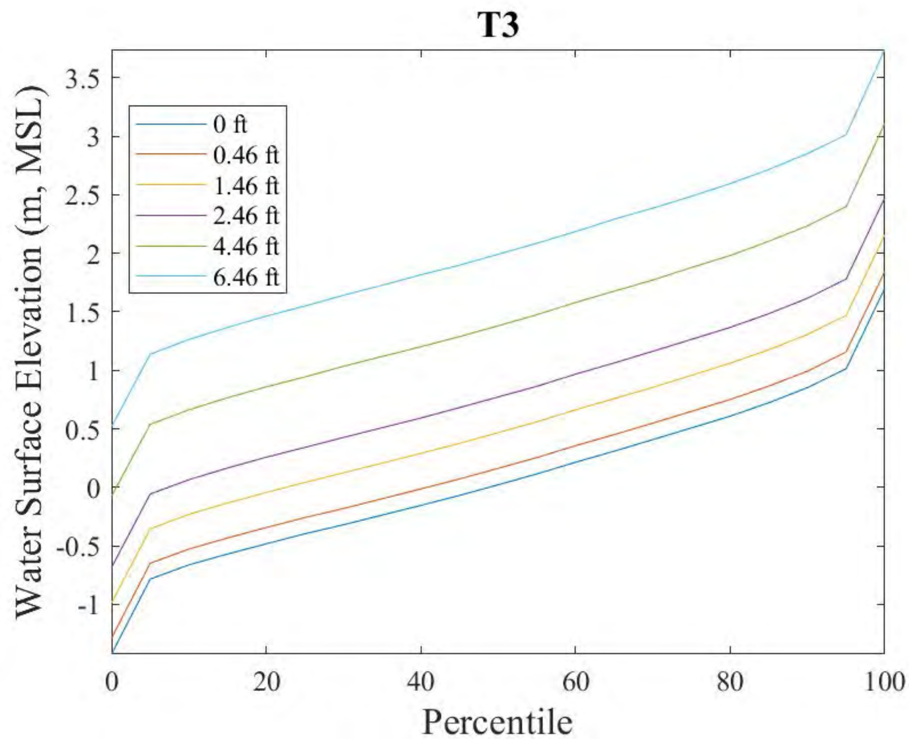


Figure 182. Base, North Reach WSE Variation with SLR.

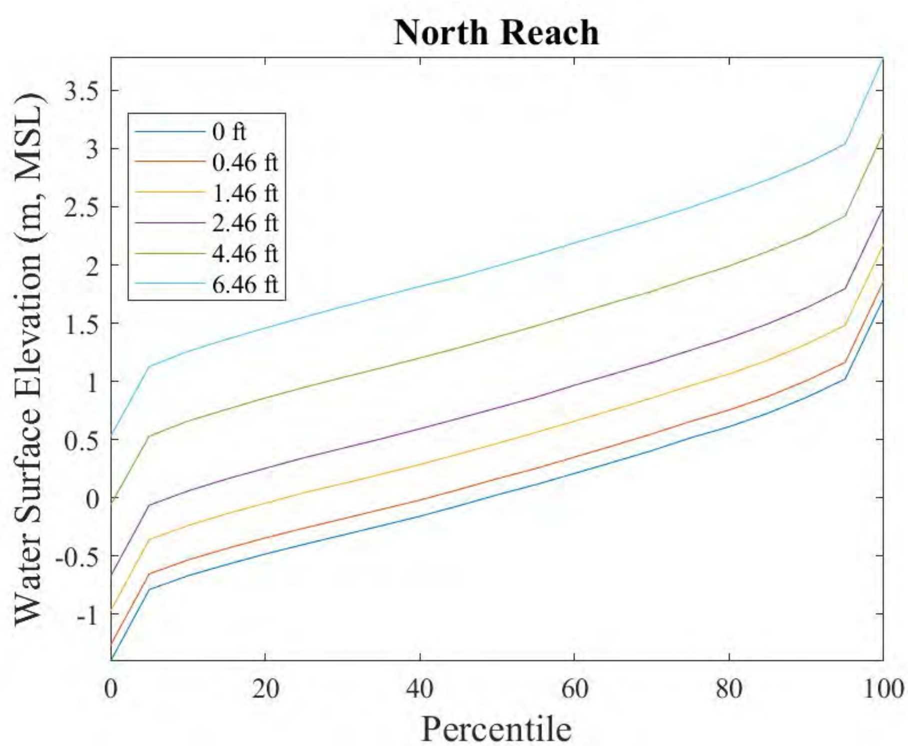


Figure 183. Base, Hackensack River WSE Variation with SLR.

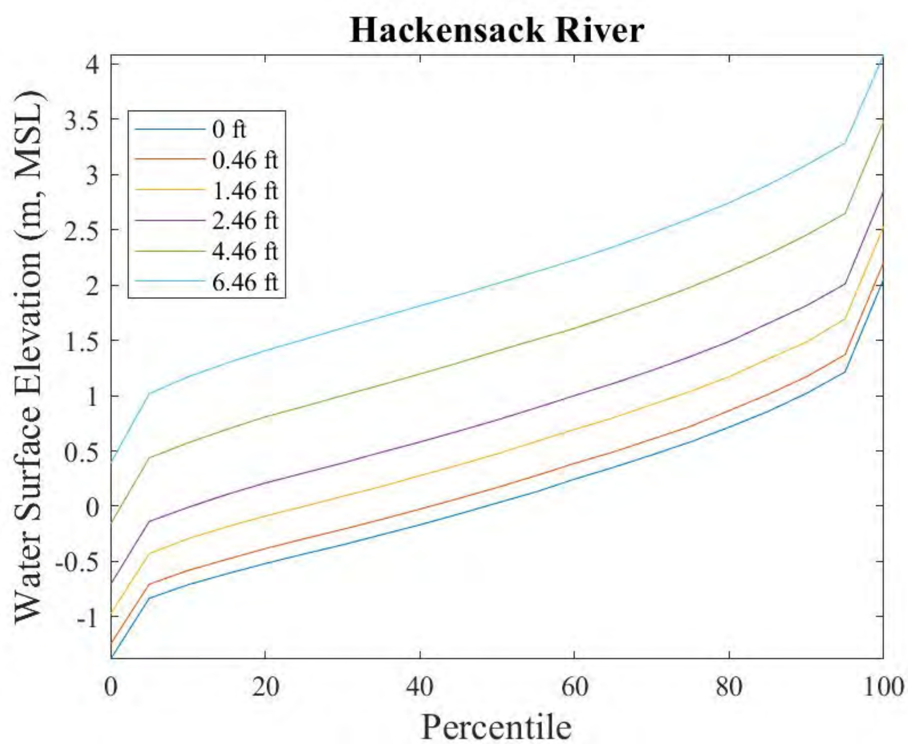


Figure 184. Base, Robbins Reef WSE Variation with SLR.

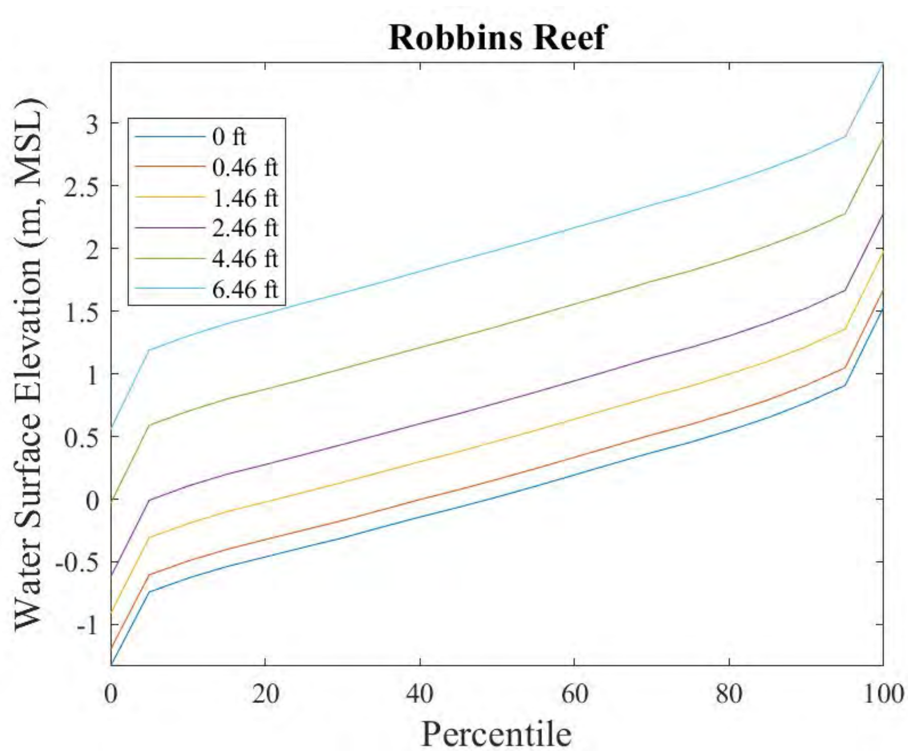


Figure 185. Base, S2 WSE Variation with SLR.

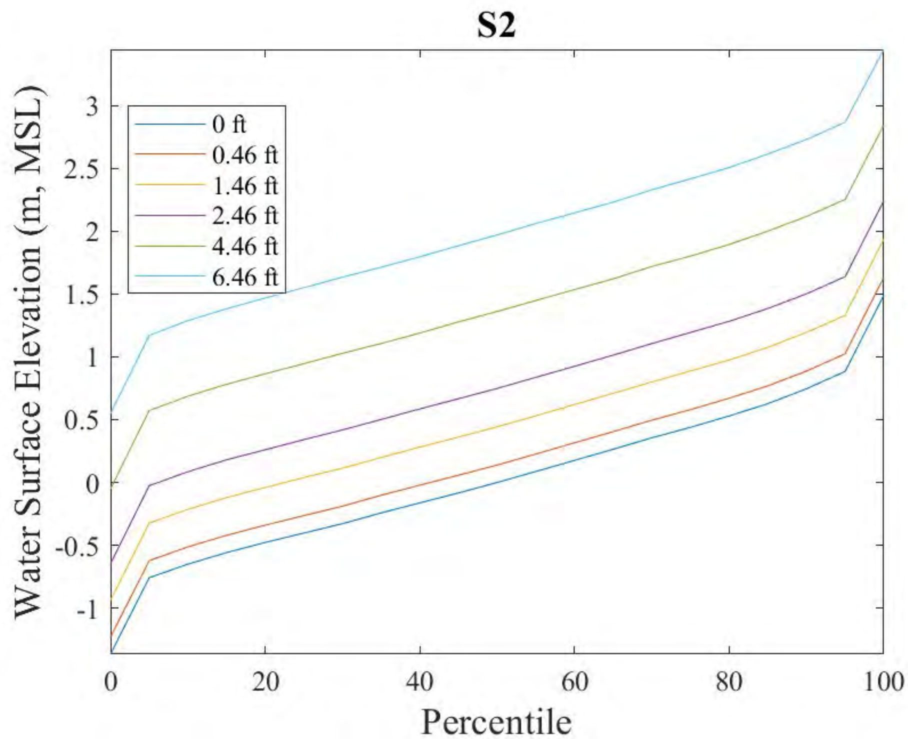


Figure 186. Base, S5 WSE Variation with SLR.

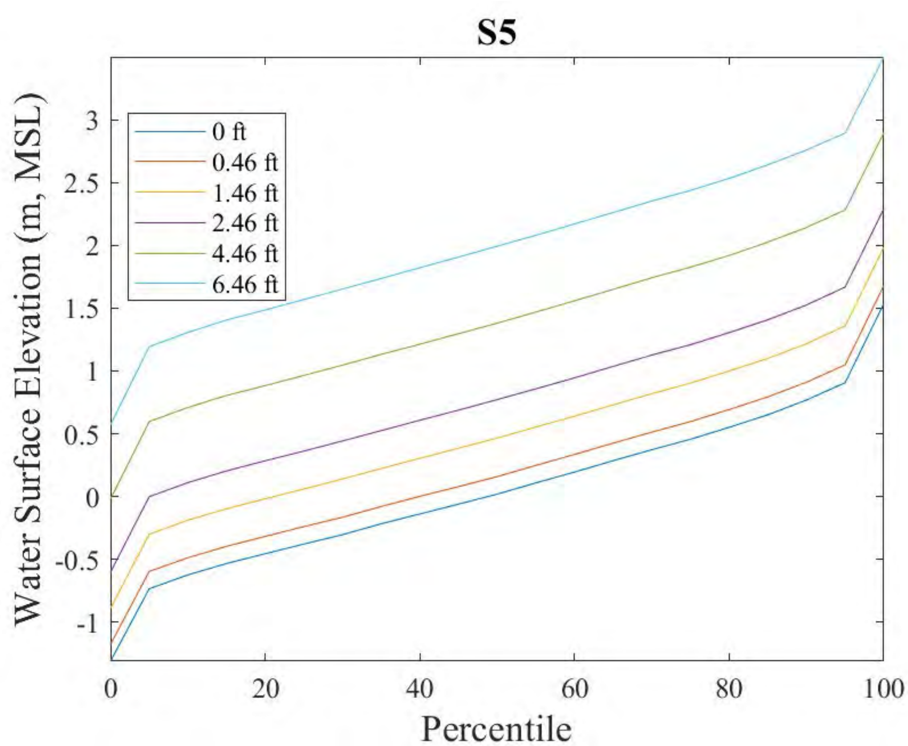


Figure 187. Base, The Battery WSE Variation with SLR.

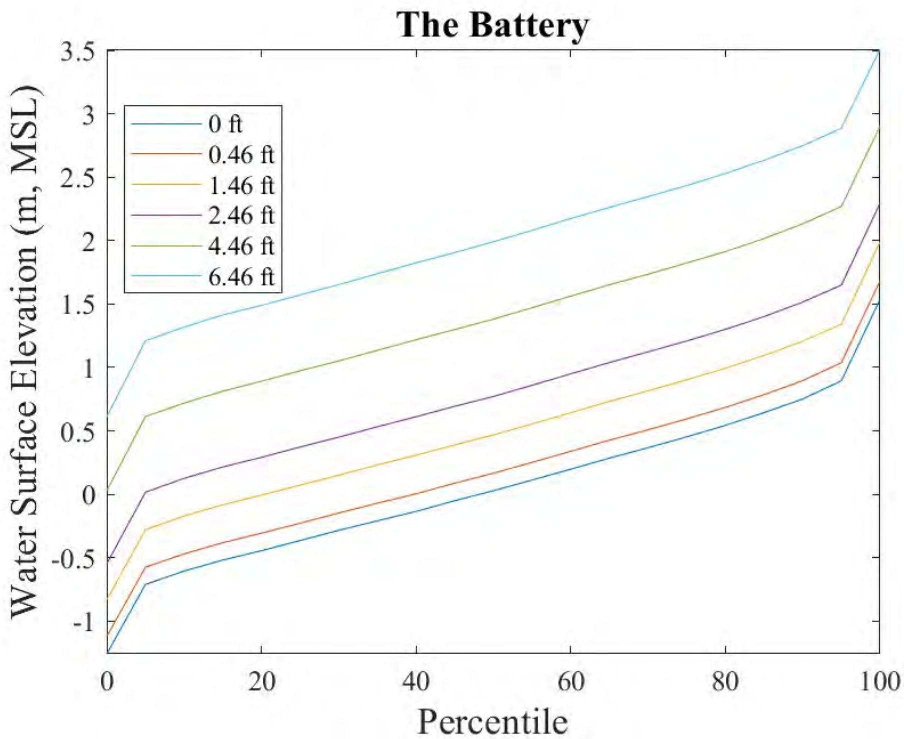


Figure 188. Base, Manhattan WSE Variation with SLR.

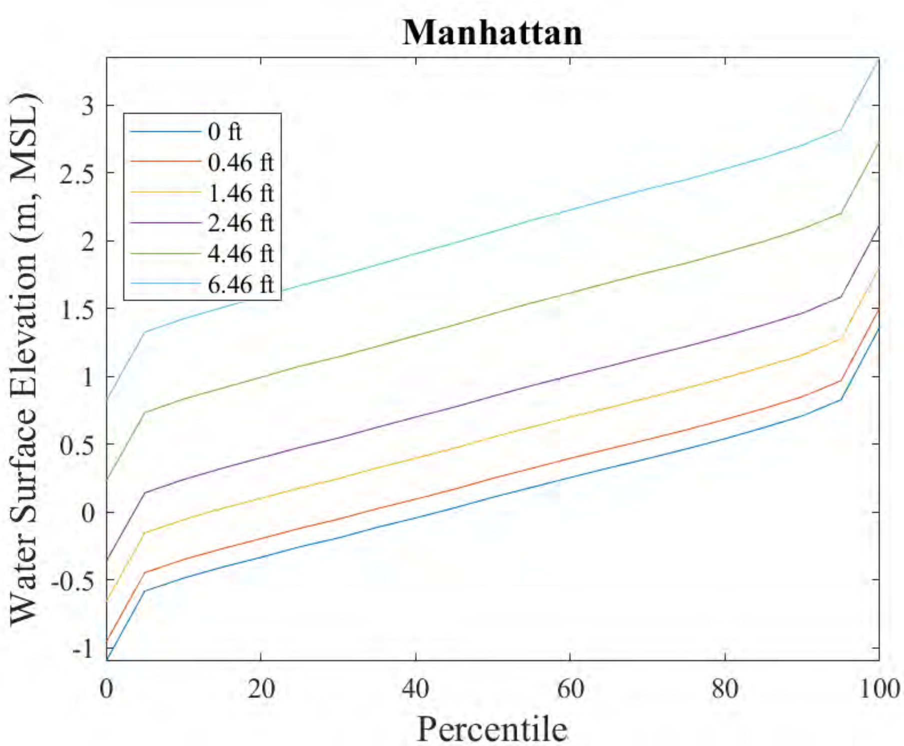


Figure 189. Base, Jamaica Bay WSE Variation with SLR.

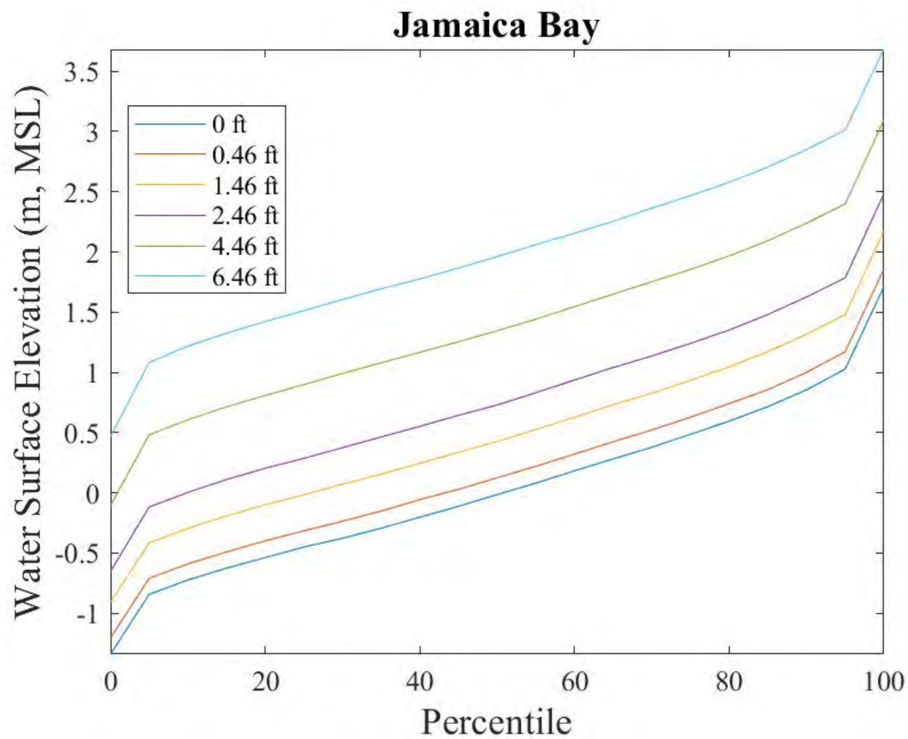


Figure 190. Base, Jamaica Bay near Spring Creek WSE Variation with SLR.

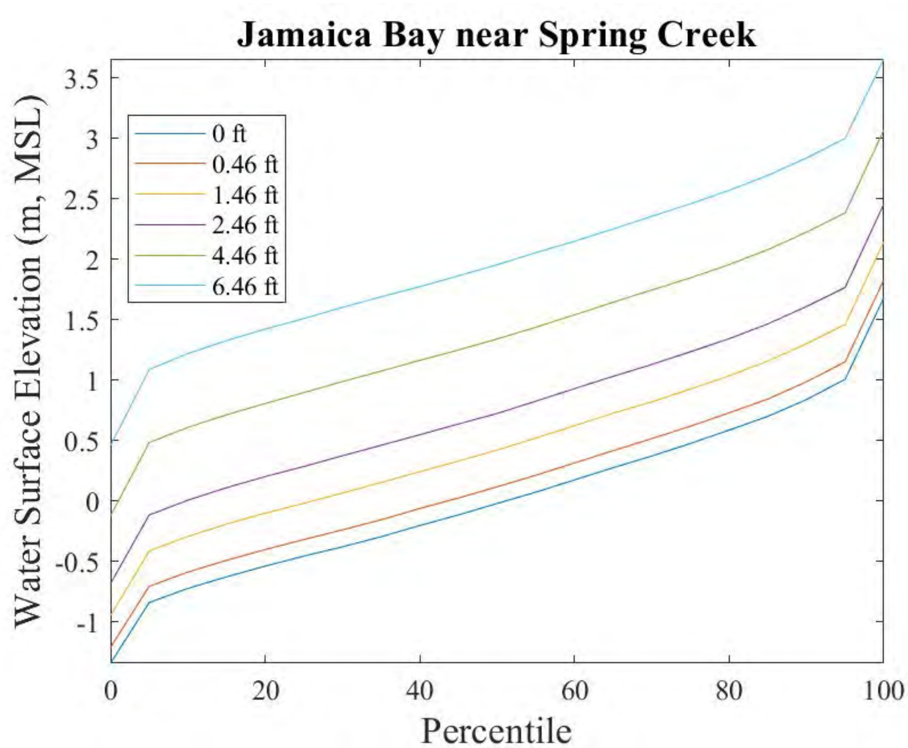


Figure 191. Base, Jamaica Bay near Grass Hassock WSE Variation with SLR.

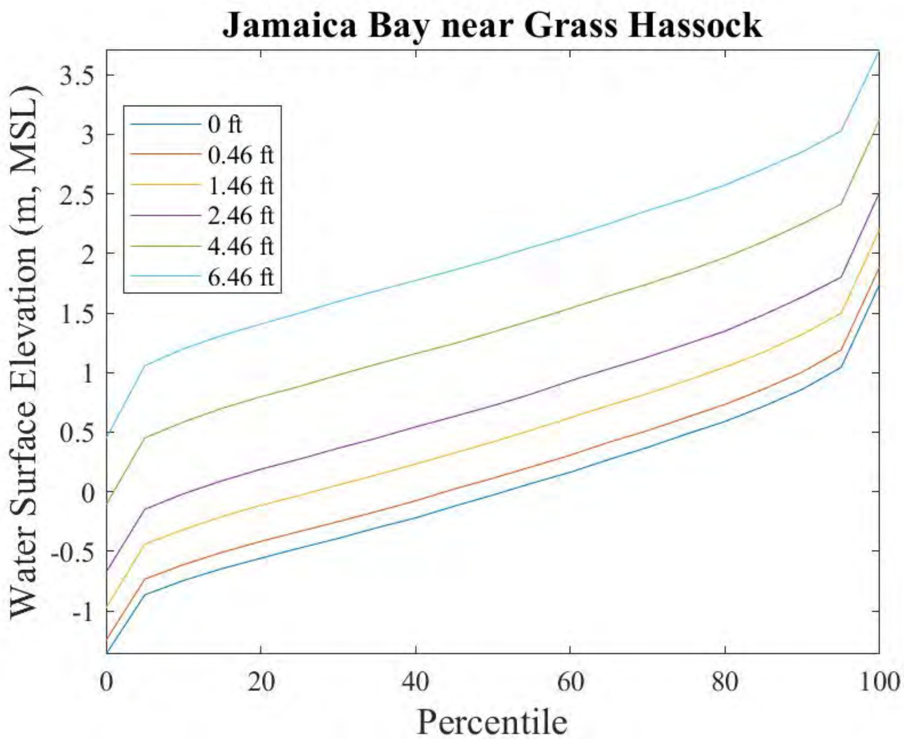


Figure 192. Base, KLGA WSE Variation with SLR.

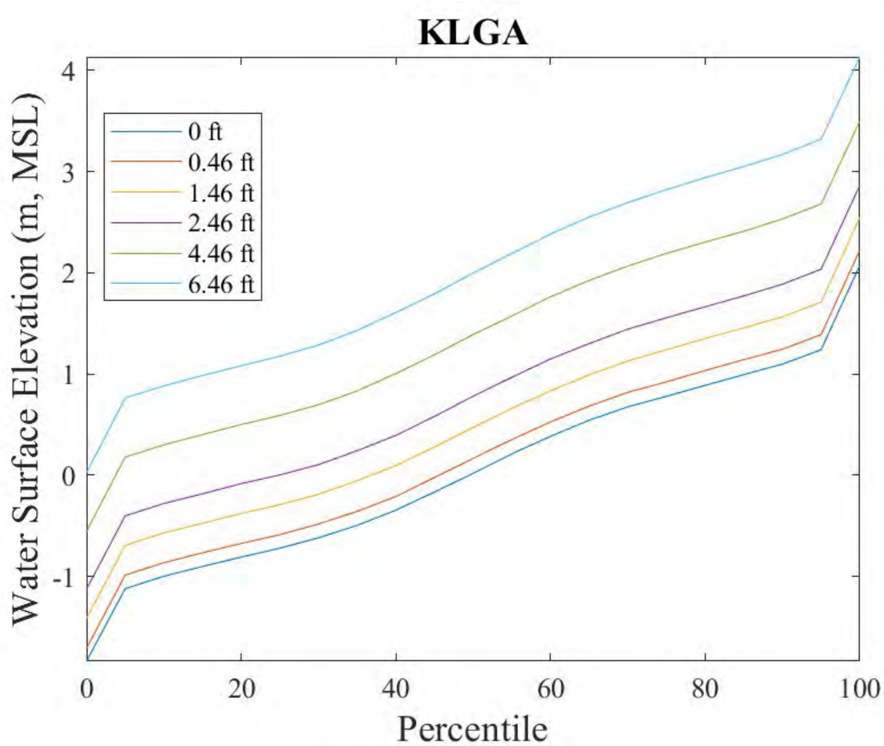


Figure 193. Base, LIS near Stepping Stone Lighthouse WSE Variation with SLR.

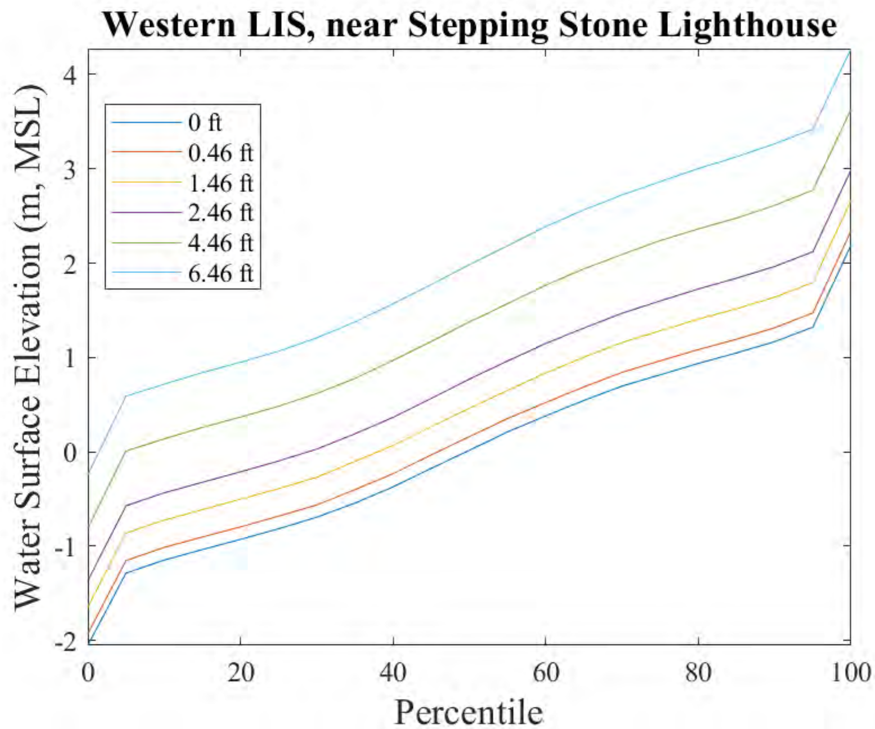


Figure 194. Base, LIS near Execution Rock Lighthouse WSE Variation with SLR.

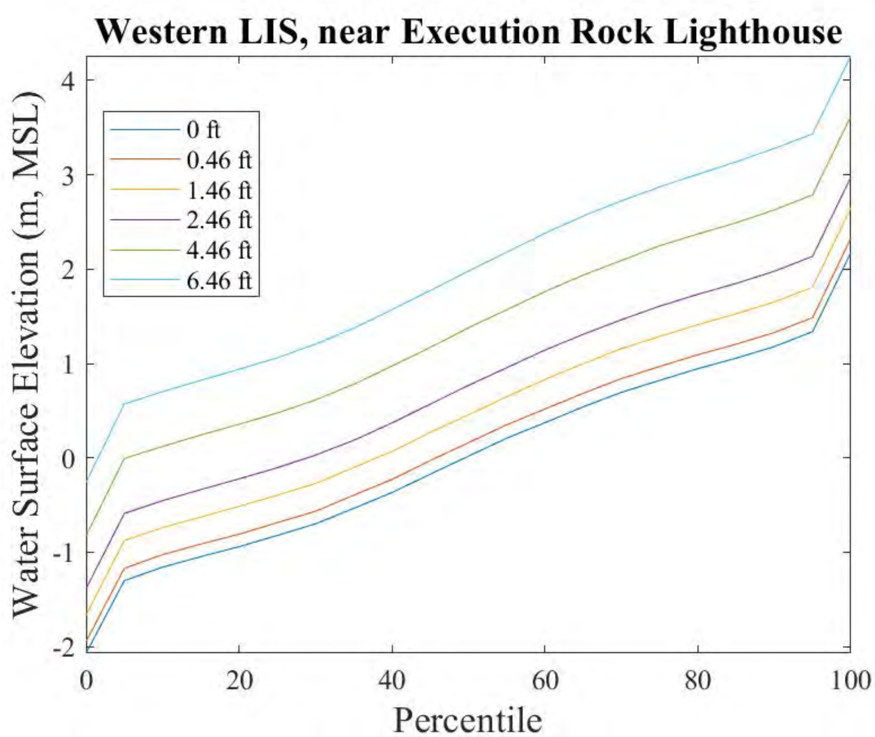


Figure 195. Base, LIS south of NY and CT border WSE Variation with SLR.

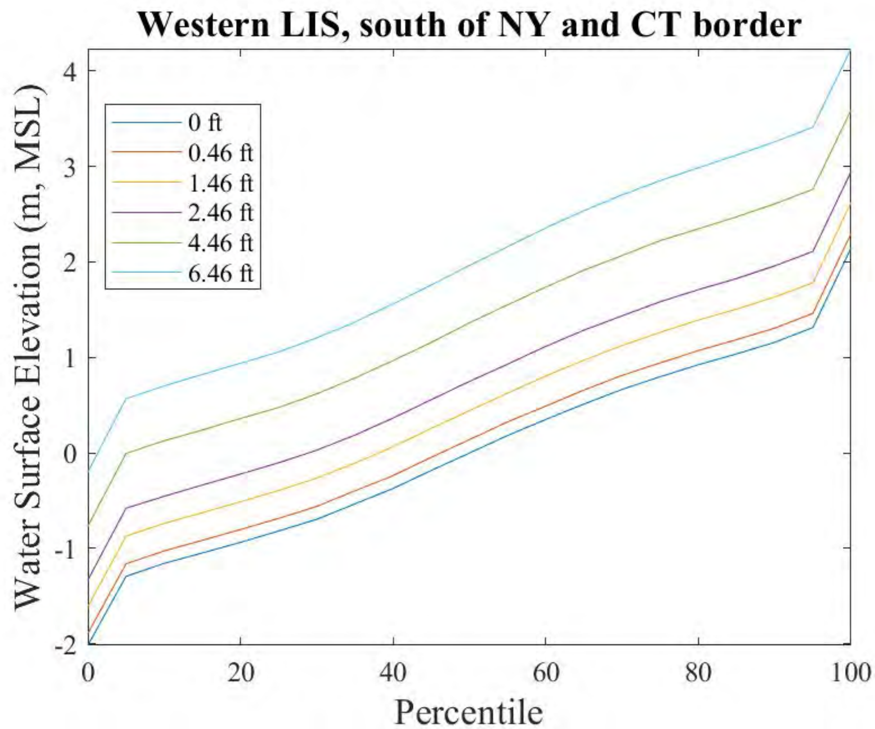


Figure 196. Base, Hudson River, Haverstraw Bay WSE Variation with SLR.

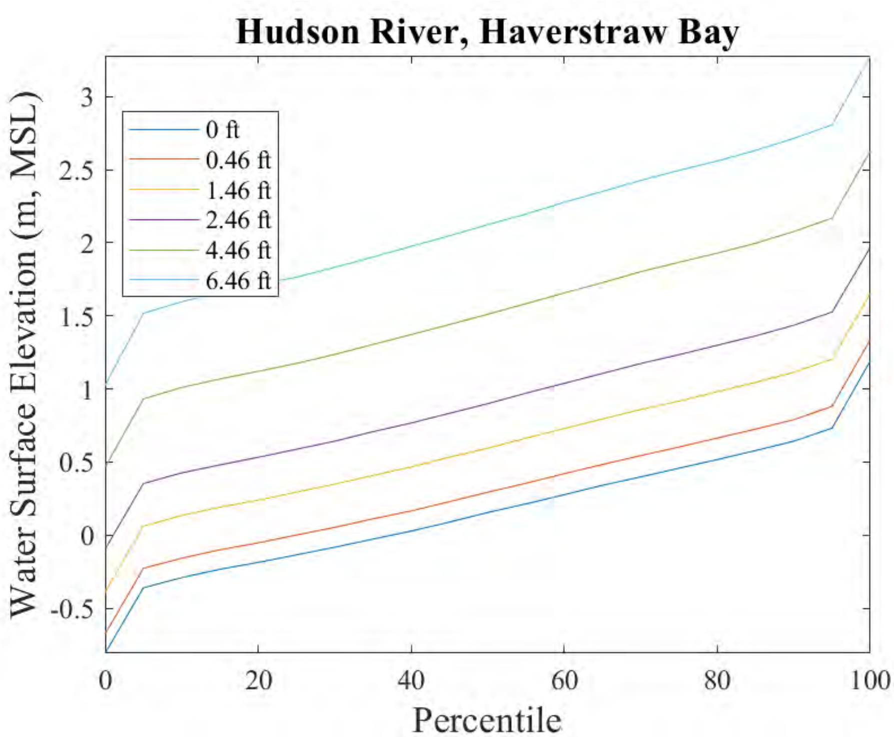


Figure 197. Base, Hudson River, Poughkeepsie WSE Variation with SLR.

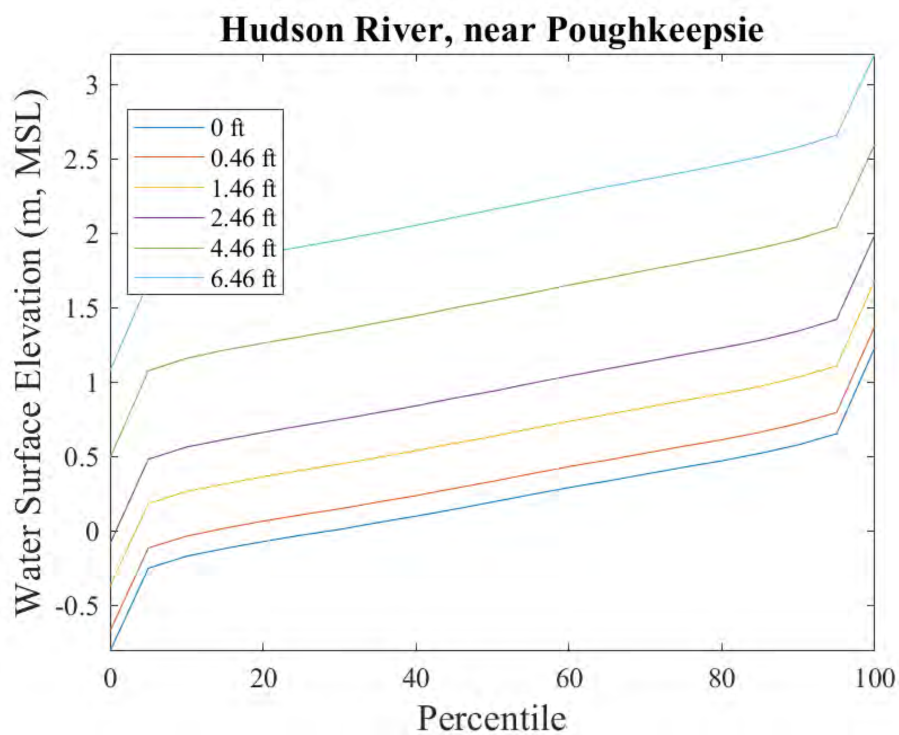


Figure 198. Base, Hudson River between Catskill and Hudson WSE Variation with SLR.

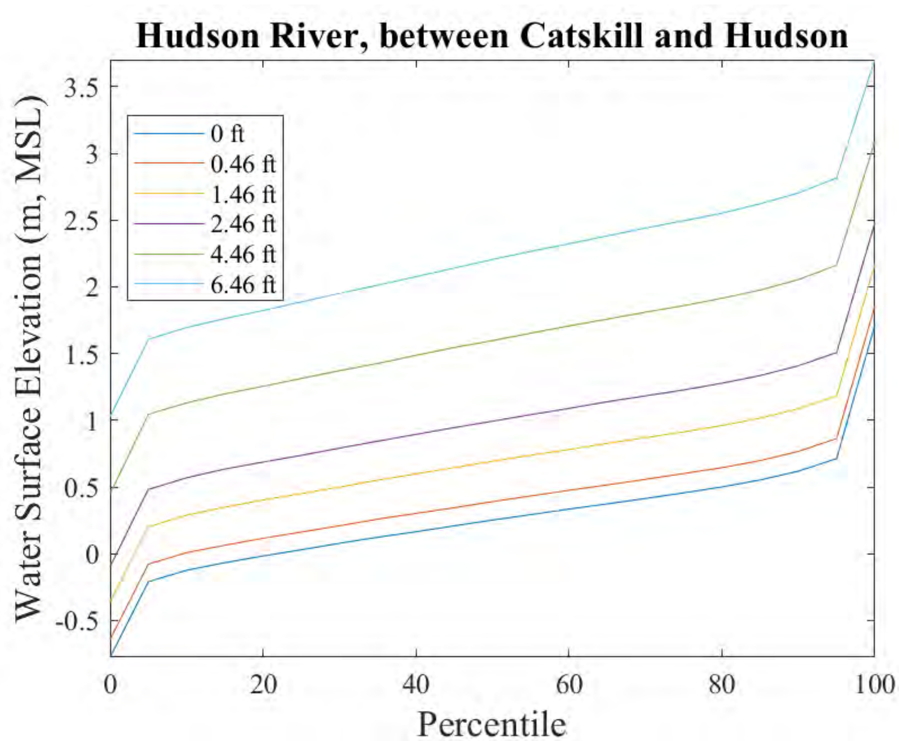
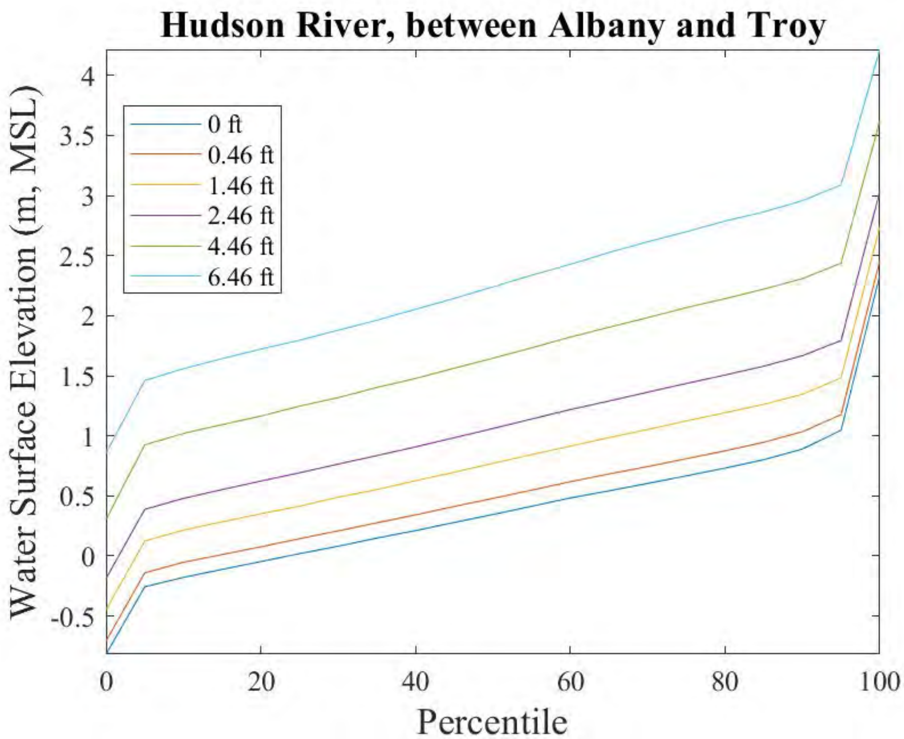


Figure 199. Base, Hudson River between Albany and Troy WSE Variation with SLR.



15.1.2 Velocity Point Percentiles

Velocity percentiles for the Base Conditions for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 200 to Figure 235. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prisms.

Figure 200. Base, V1 Velocity Variation with SLR.

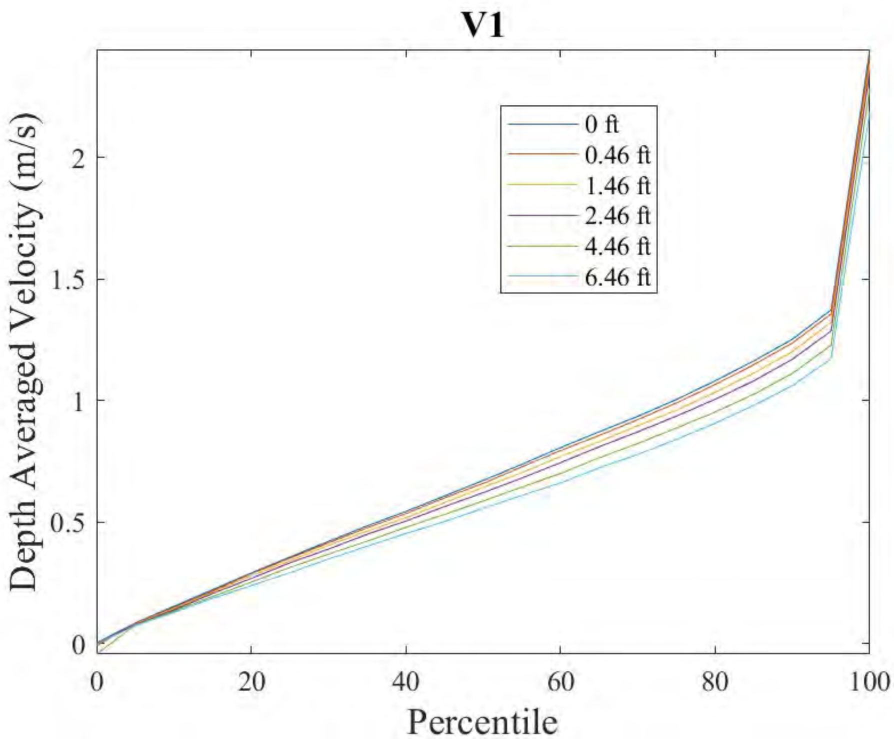


Figure 201. Base, V2 Velocity Variation with SLR.

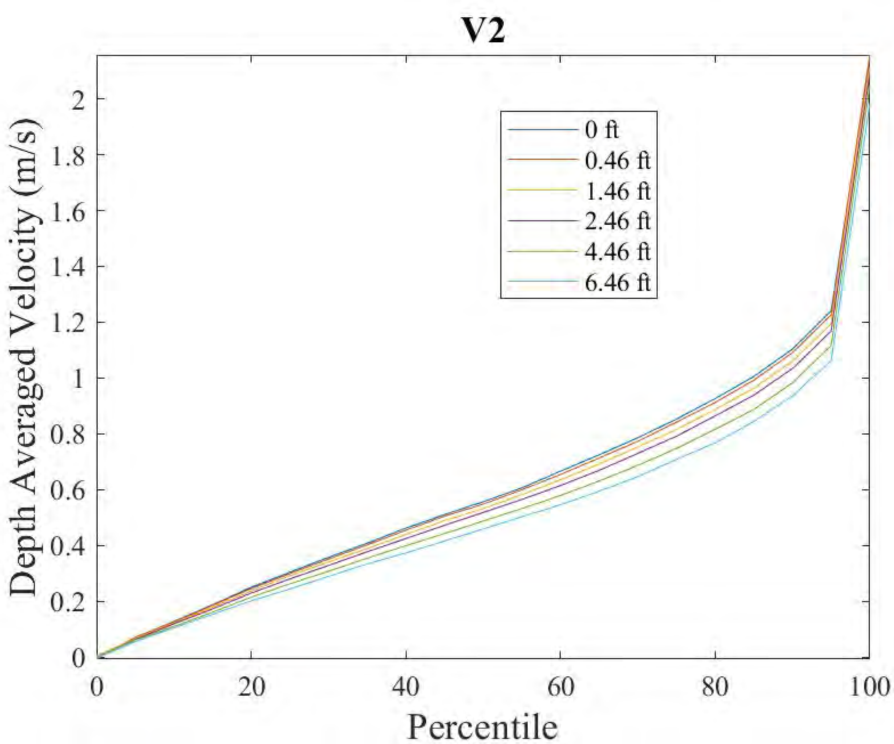


Figure 202. Base, V3 Velocity Variation with SLR.

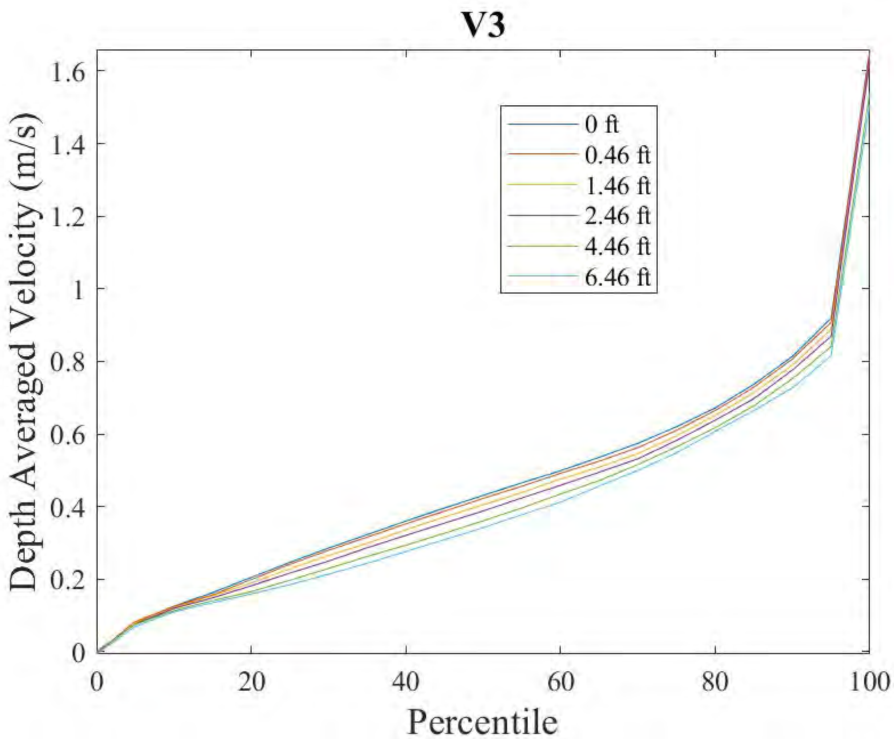


Figure 203. Base, V4 Velocity Variation with SLR.

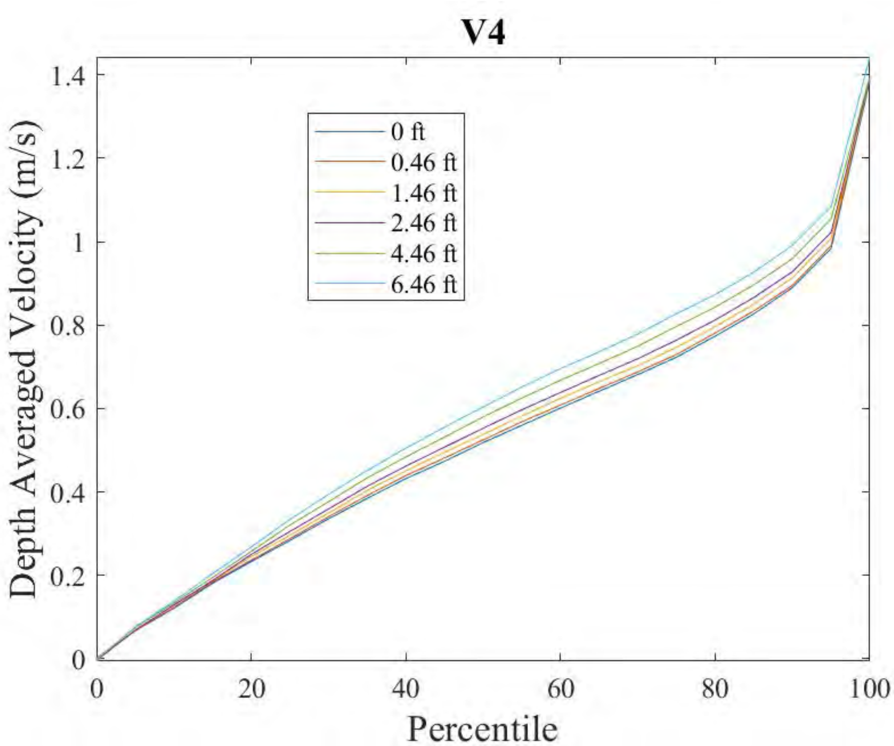


Figure 204. Base, V5 Velocity Variation with SLR.

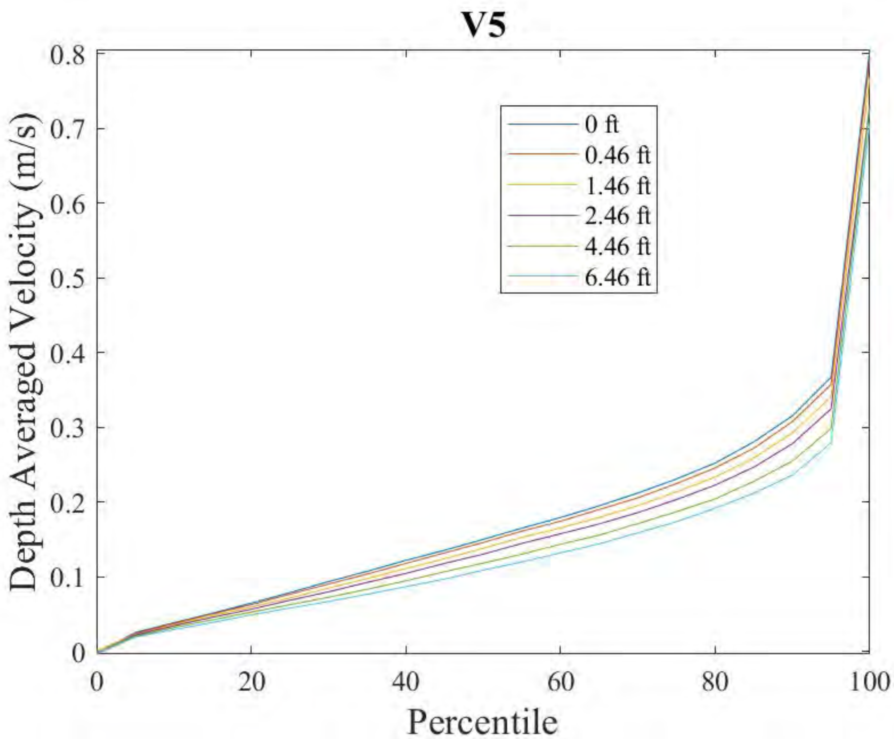


Figure 205. Base, V6 Velocity Variation with SLR.

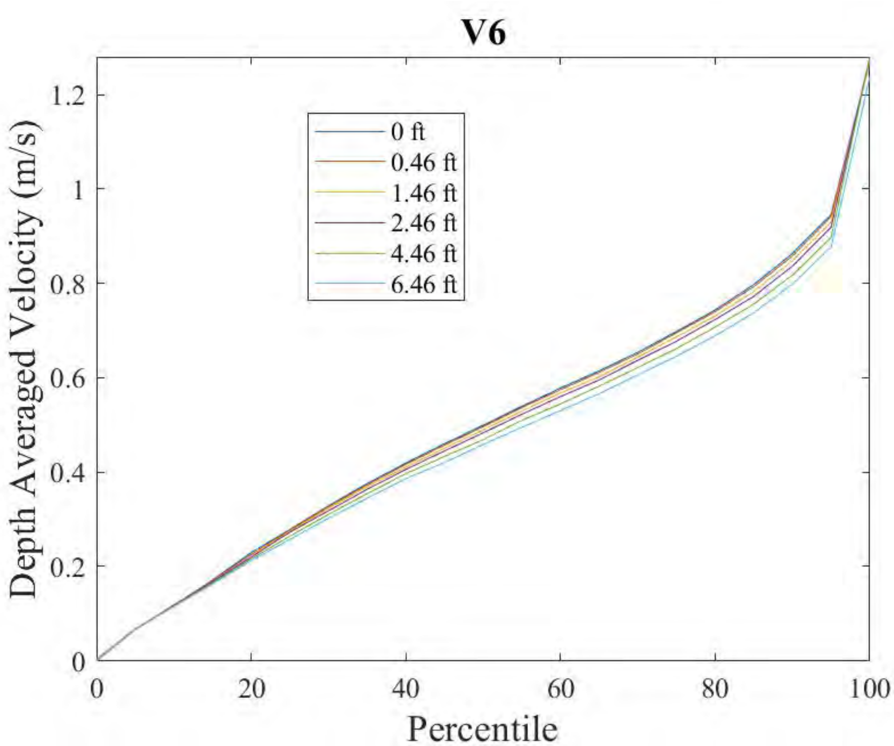


Figure 206. Base, S1 Velocity Variation with SLR.

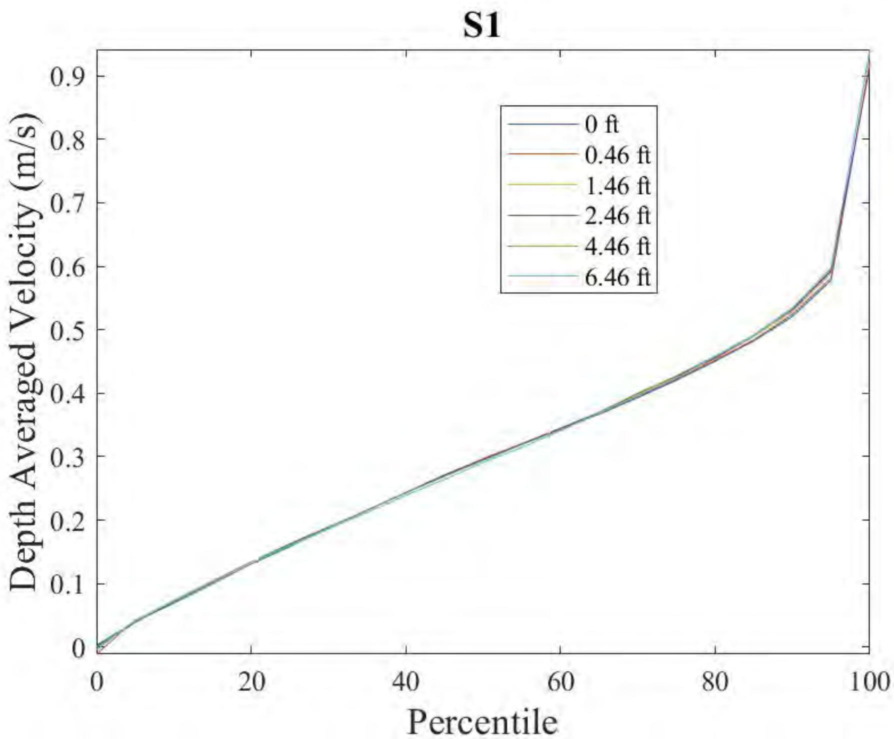


Figure 207. Base, S2 Velocity Variation with SLR.

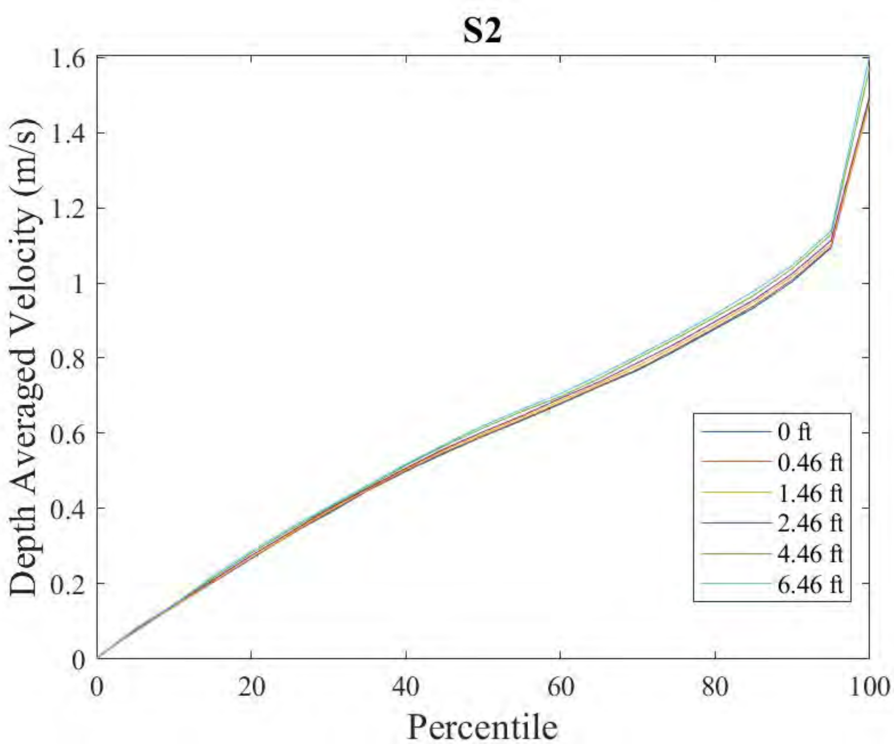


Figure 208. Base, S3 Velocity Variation with SLR.

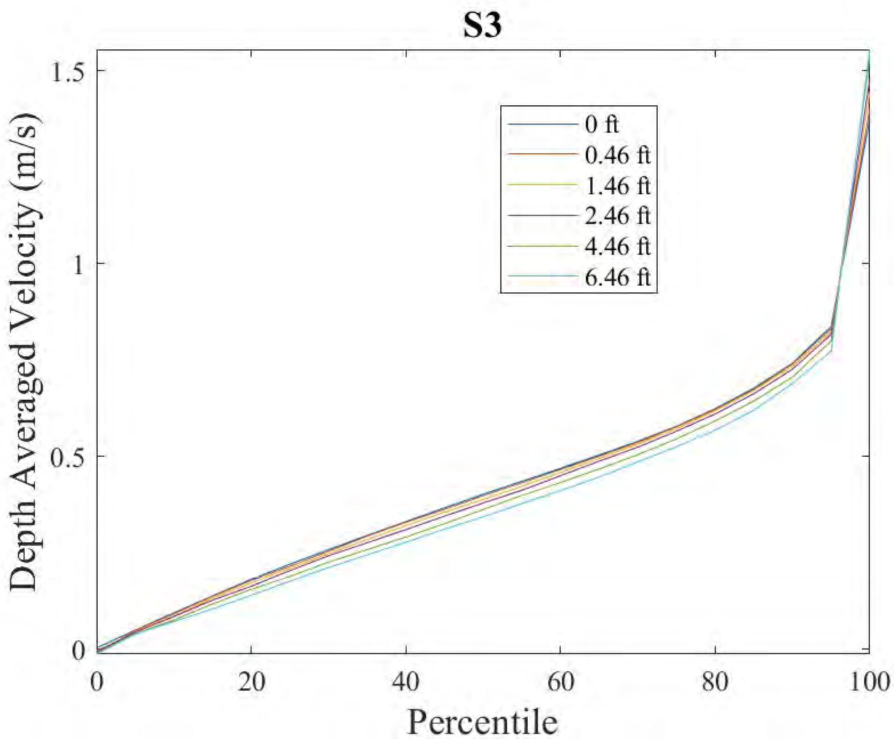


Figure 209. Base, S4 Velocity Variation with SLR.

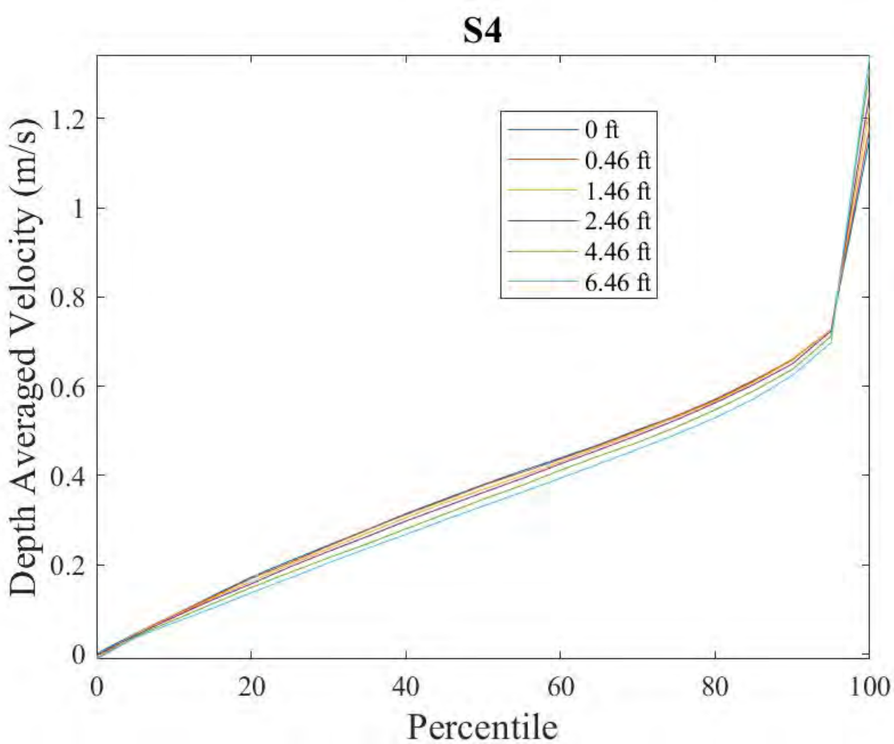


Figure 210. Base, S5 Velocity Variation with SLR.

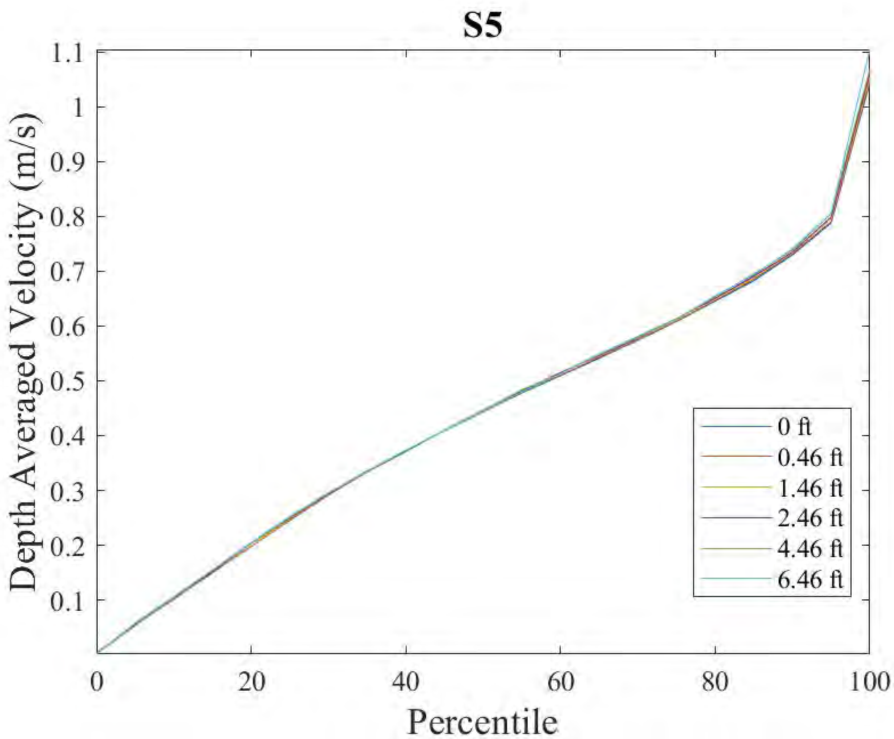


Figure 211. Base, T1 Velocity Variation with SLR.

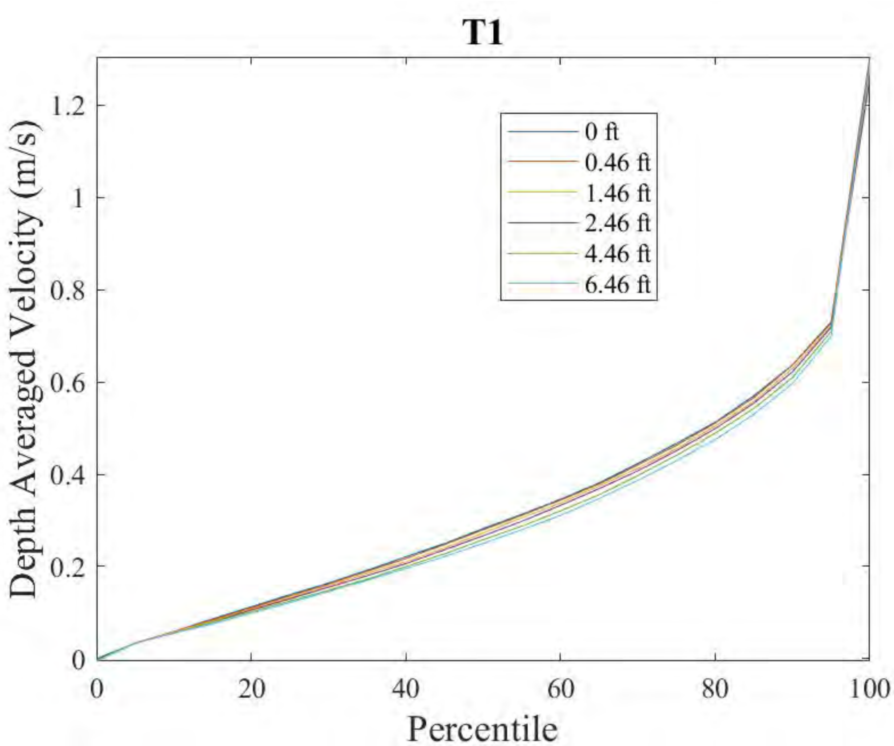


Figure 212. Base, T2 Velocity Variation with SLR.

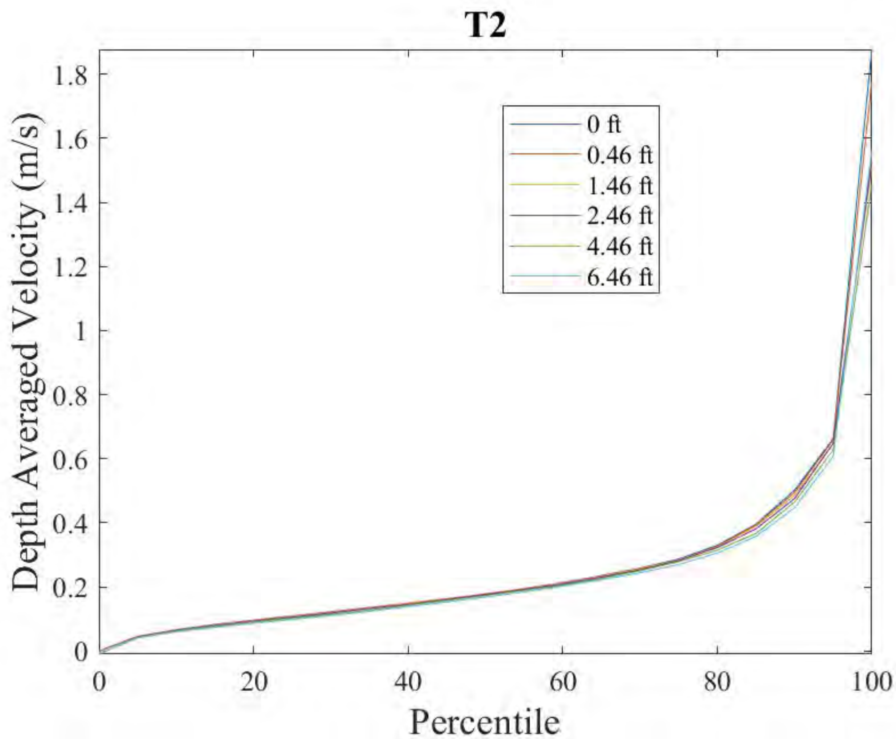


Figure 213. Base, T3 Velocity Variation with SLR.

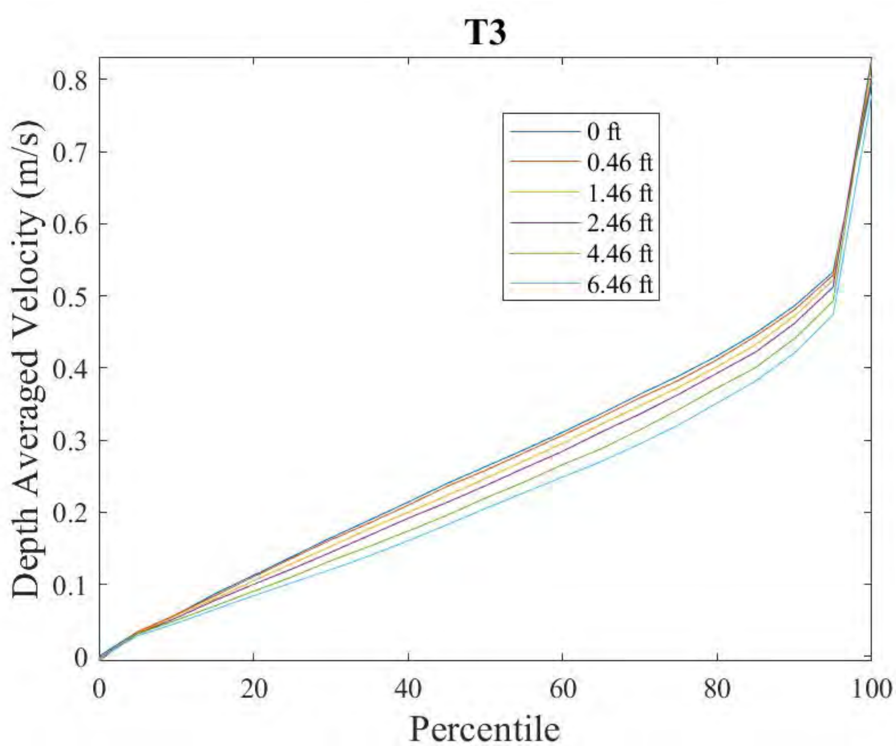


Figure 214. Base, T4 Velocity Variation with SLR.

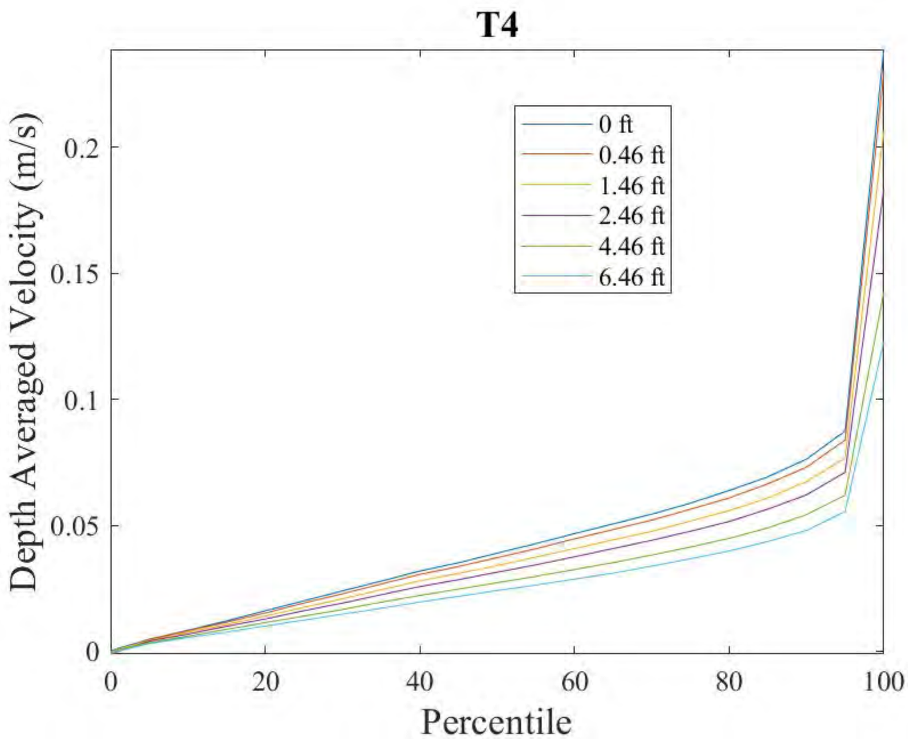


Figure 215. Base, T5 Velocity Variation with SLR.

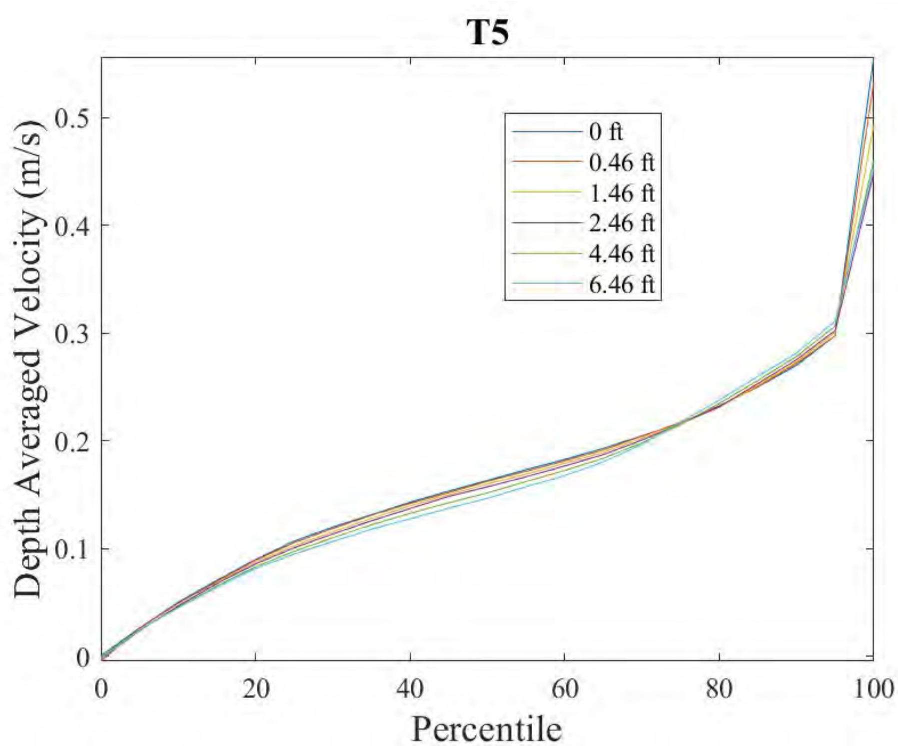


Figure 216. Base, R1 Velocity Variation with SLR.

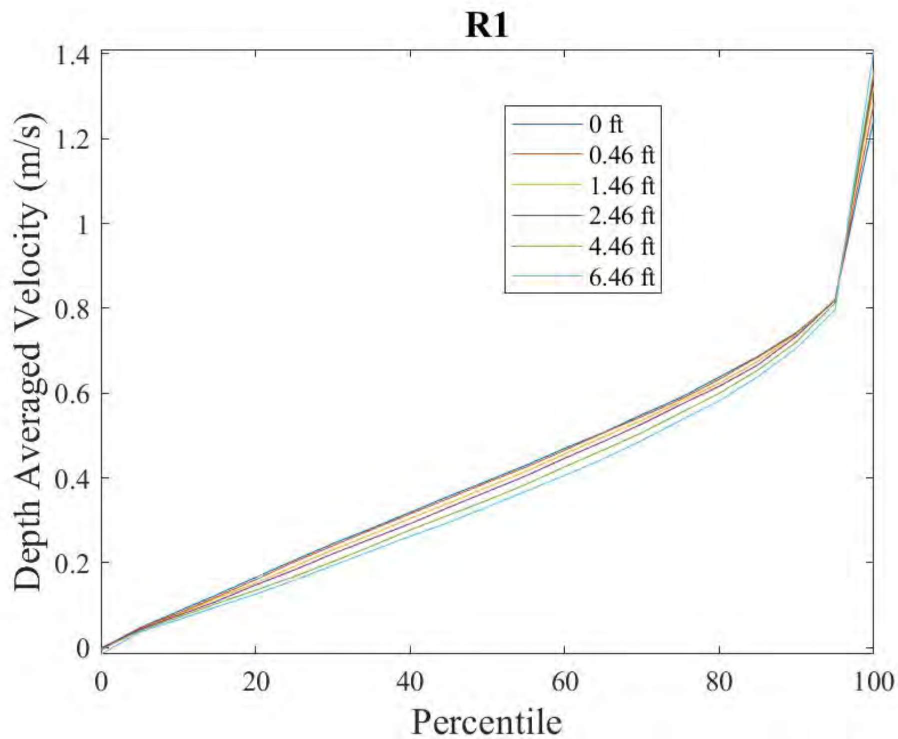


Figure 217. Base, Sandy Hook Velocity Variation with SLR.

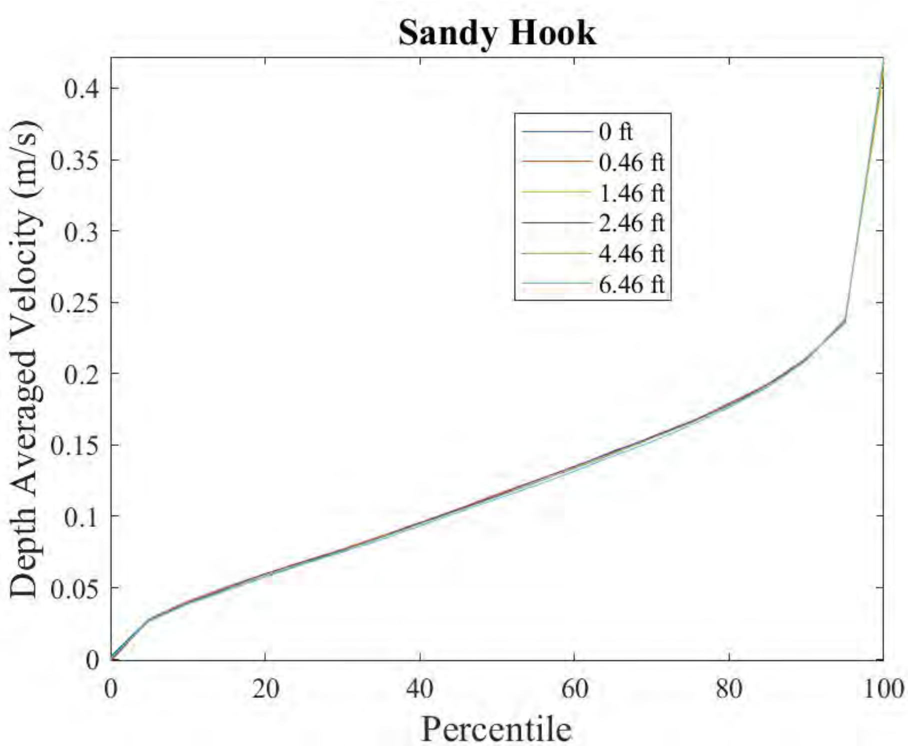


Figure 218. Base, Fresh Kills Velocity Variation with SLR.

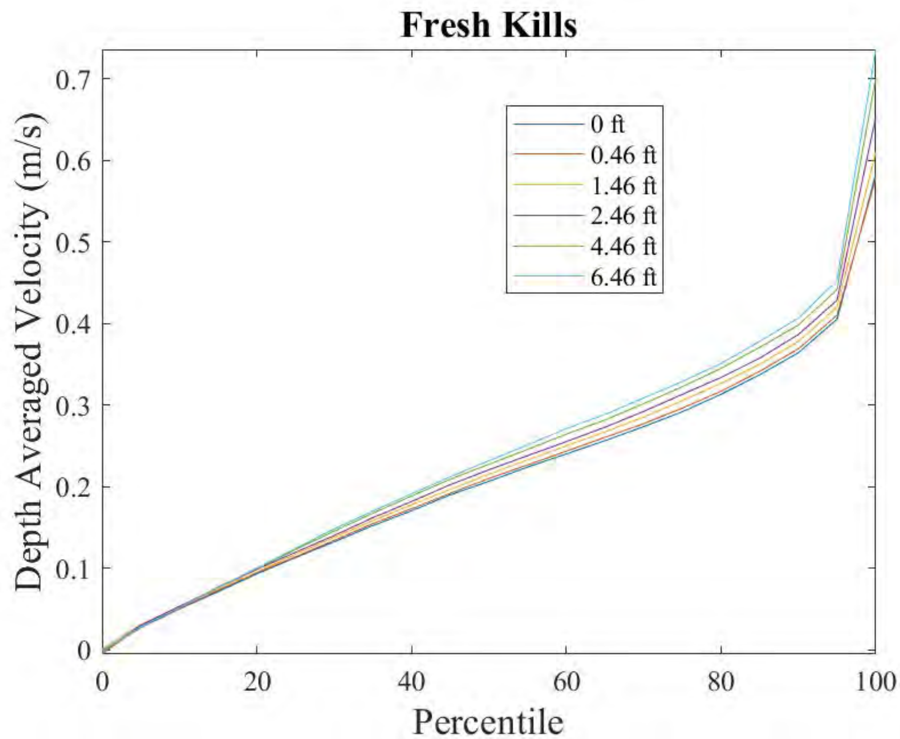


Figure 219. Base, Mariners Harbor Velocity Variation with SLR.

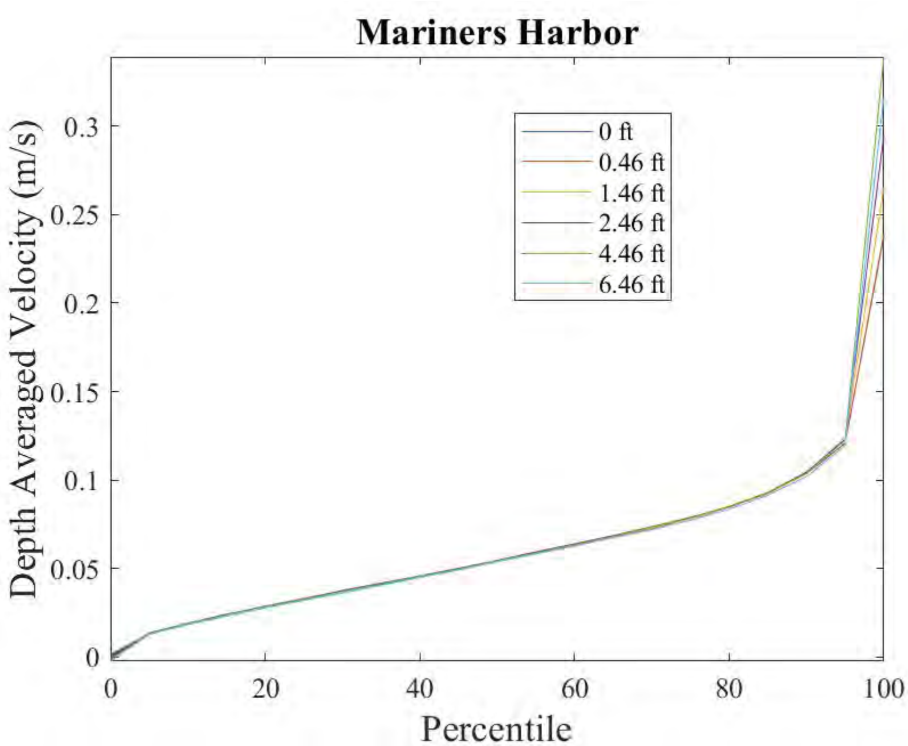


Figure 220. Base, North Reach Velocity Variation with SLR.

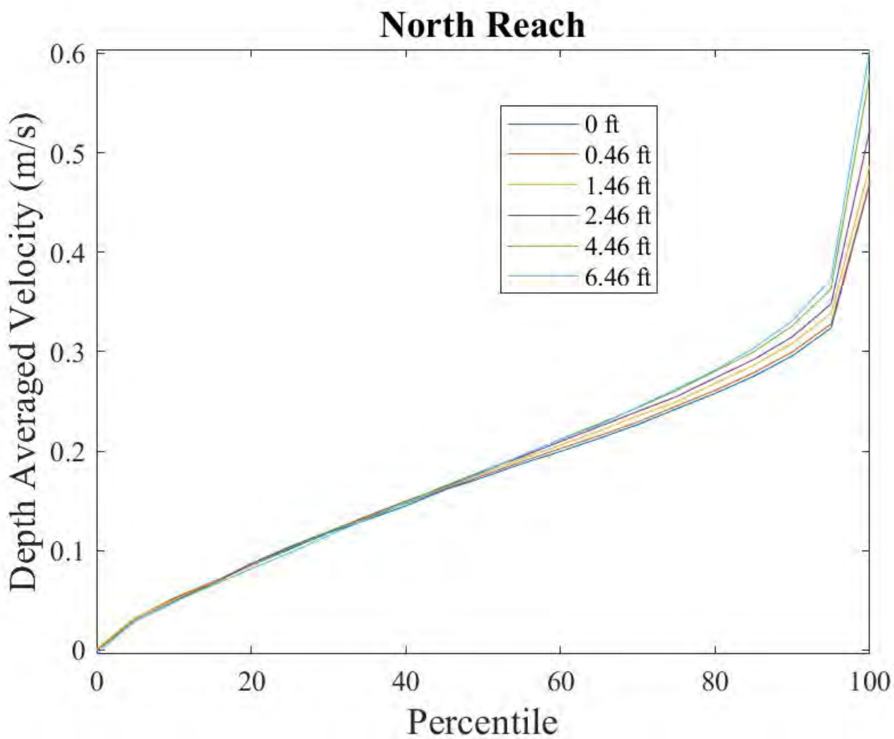


Figure 221. Base, Hackensack River Velocity Variation with SLR.

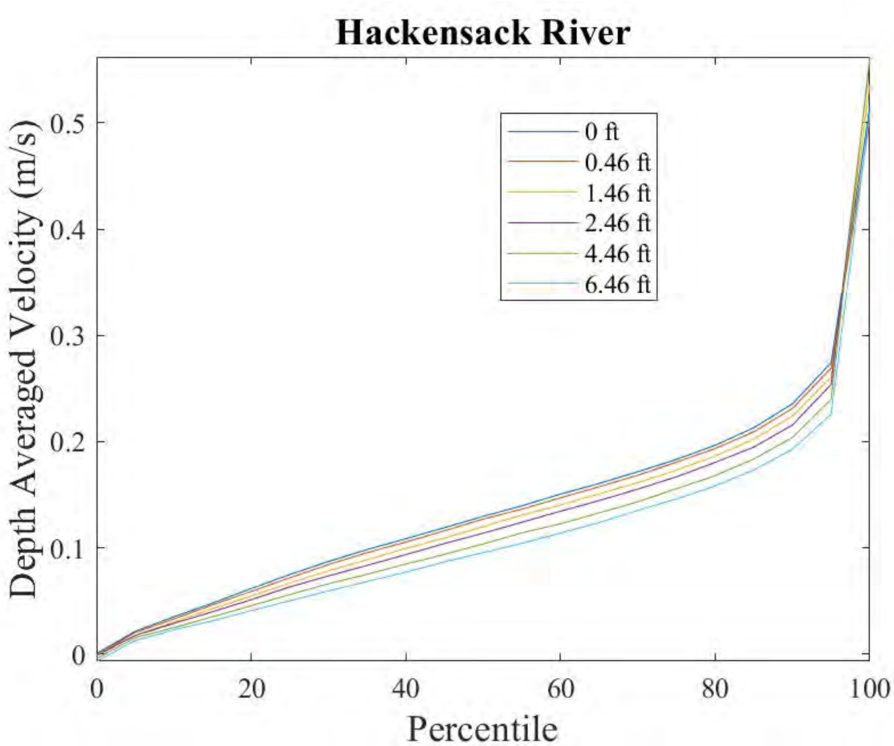


Figure 222. Base, Robbins Reef Velocity Variation with SLR.

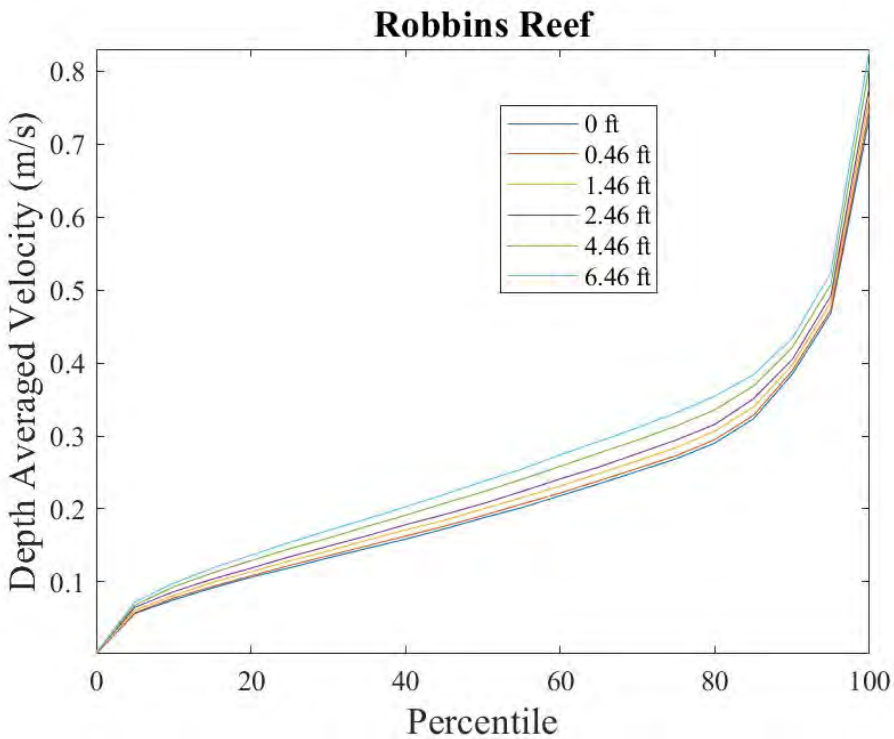


Figure 223. Base, The Battery Velocity Variation with SLR.

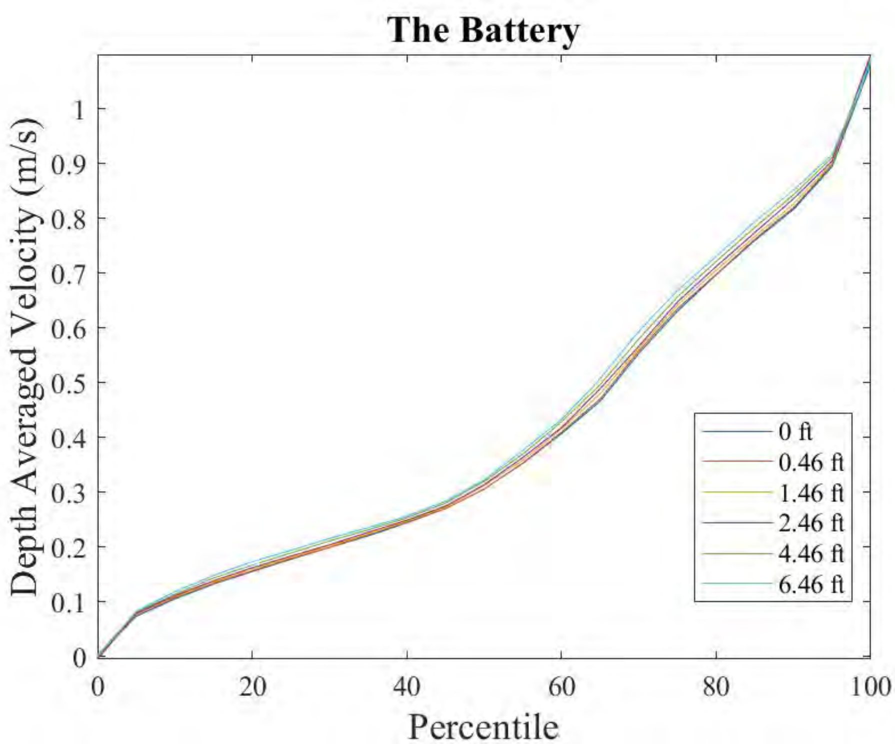


Figure 224. Base, Manhattan Velocity Variation with SLR.

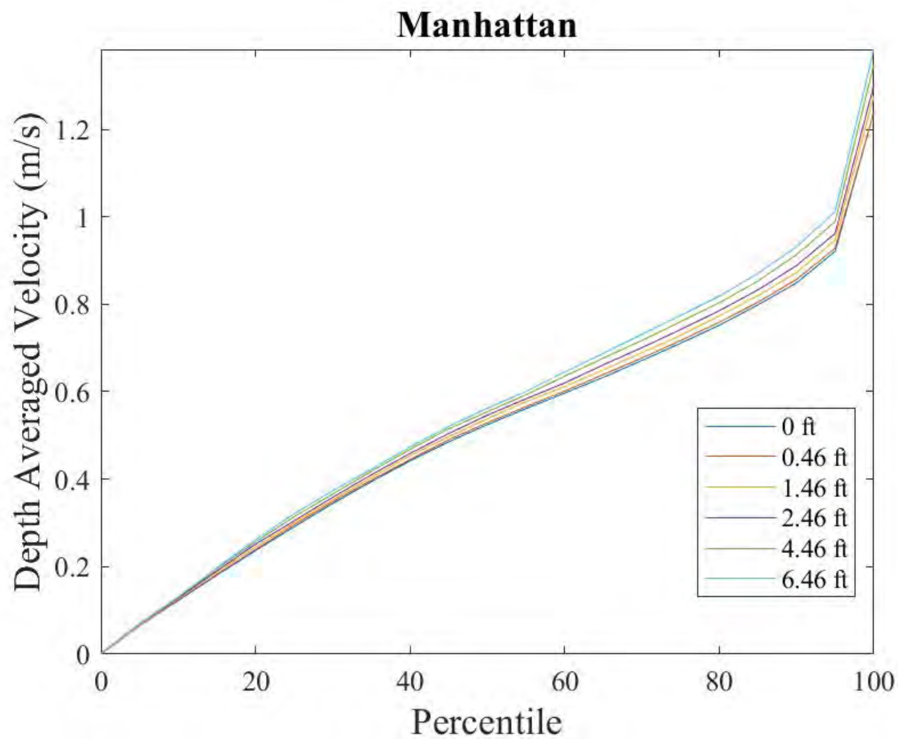


Figure 225. Base, Hudson River, Haverstraw Bay Velocity Variation with SLR.

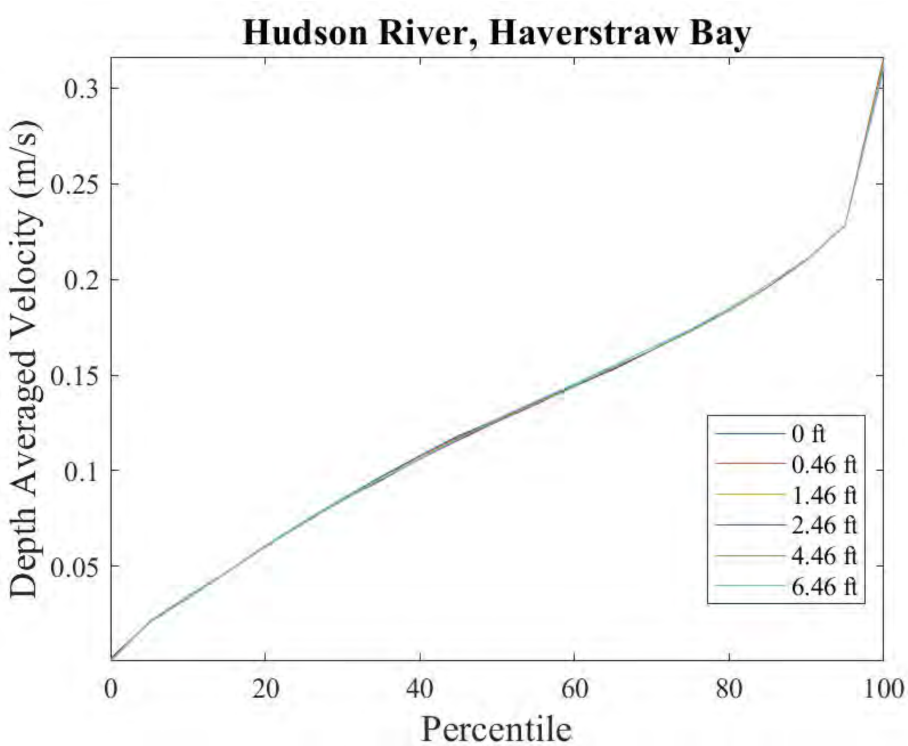


Figure 226. Base, Hudson River near Poughkeepsie Velocity Variation with SLR.

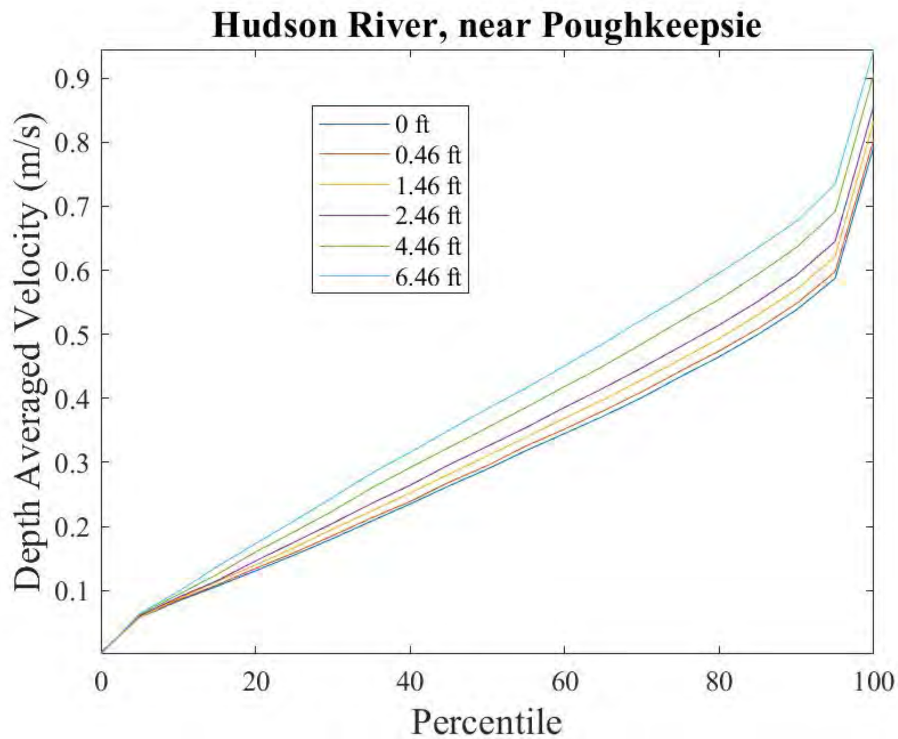


Figure 227. Base, Hudson River between Catskill and Hudson Velocity Variation with SLR.

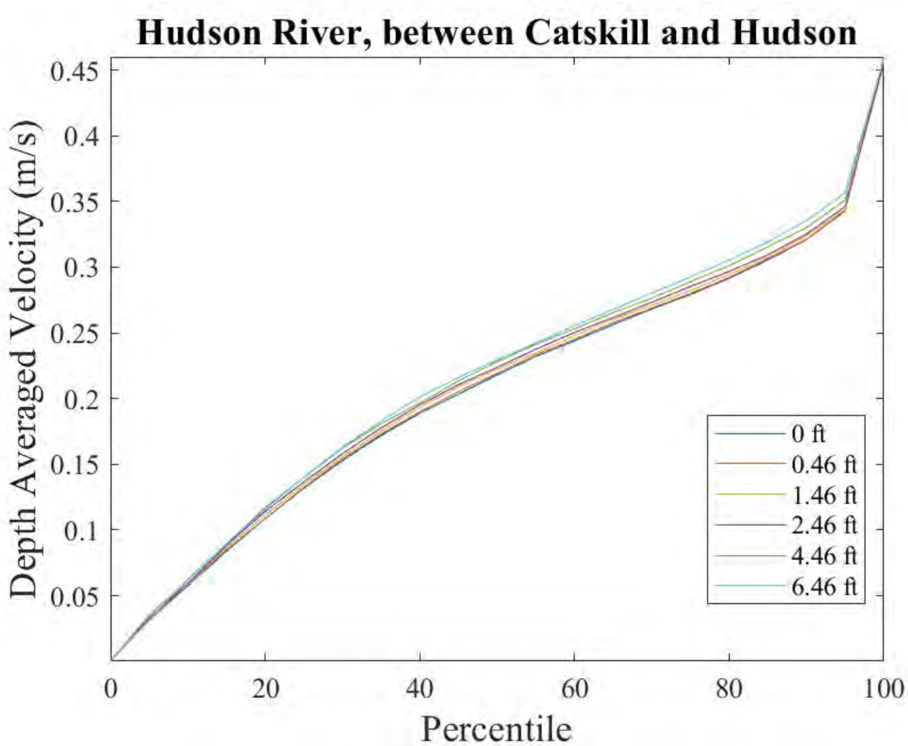


Figure 228. Base, Hudson River between Albany and Troy Velocity Variation with SLR.

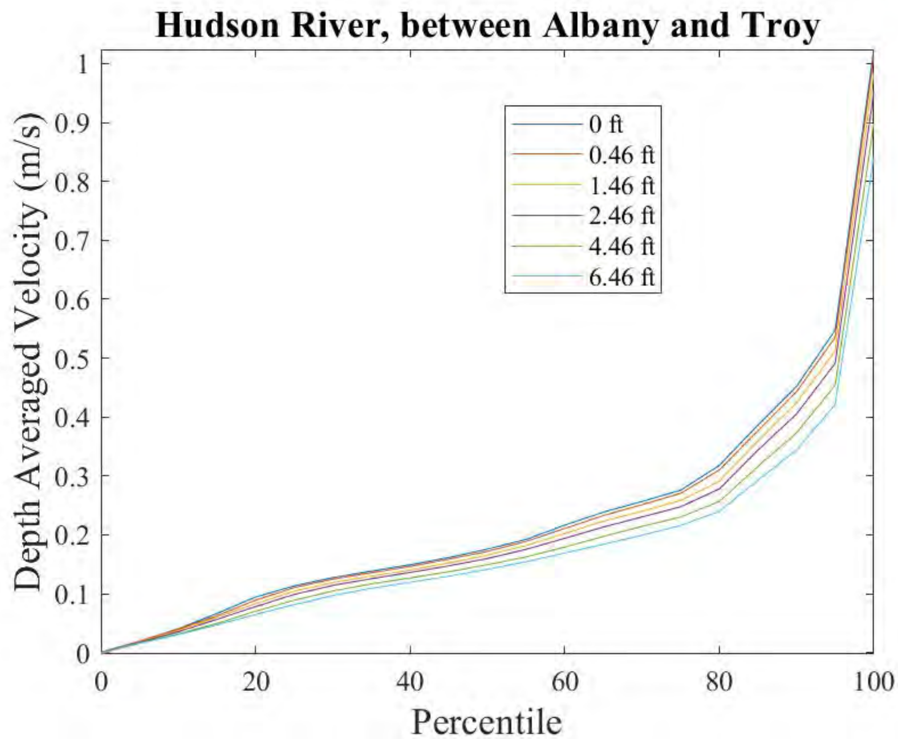


Figure 229. Base, KLGA Velocity Variation with SLR.

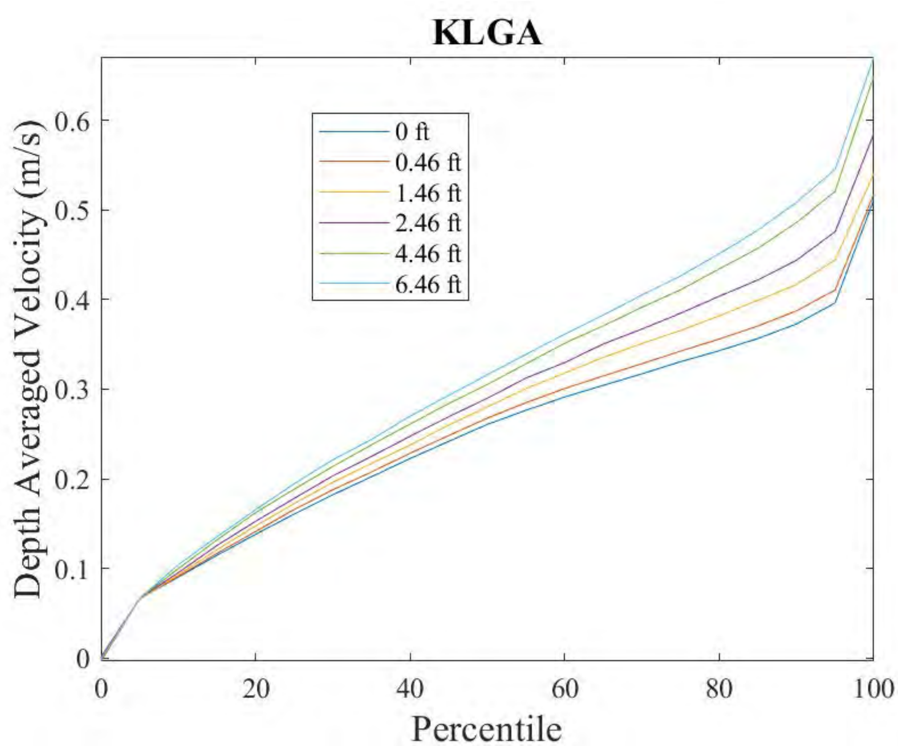


Figure 230. Base, LIS near Stepping Stone Lighthouse Velocity Variation with SLR.

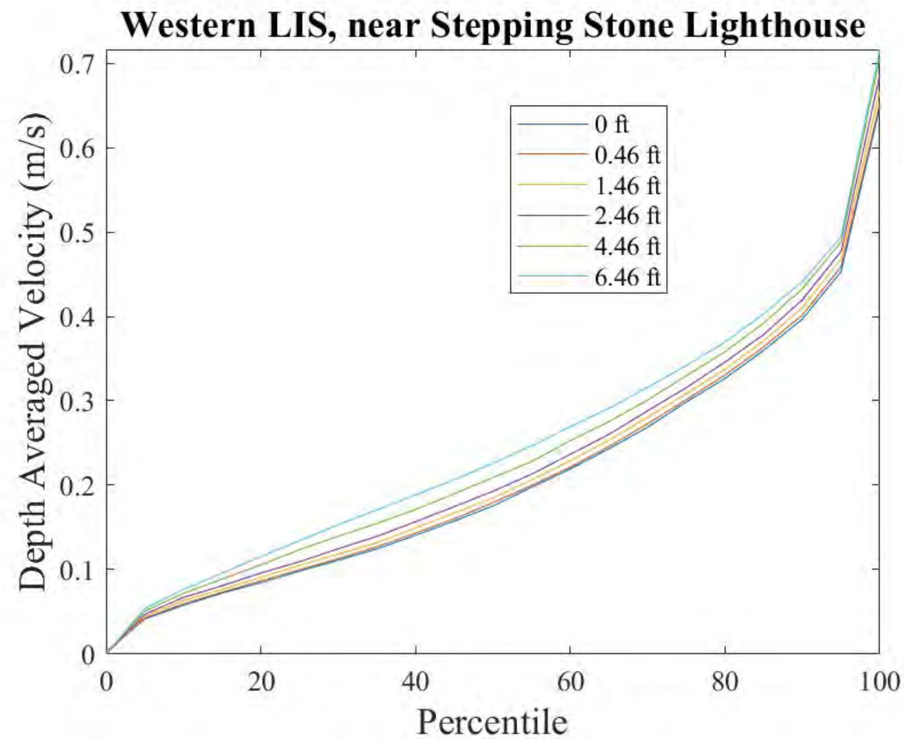


Figure 231. Base, LIS near Execution Rock Lighthouse Velocity Variation with SLR.

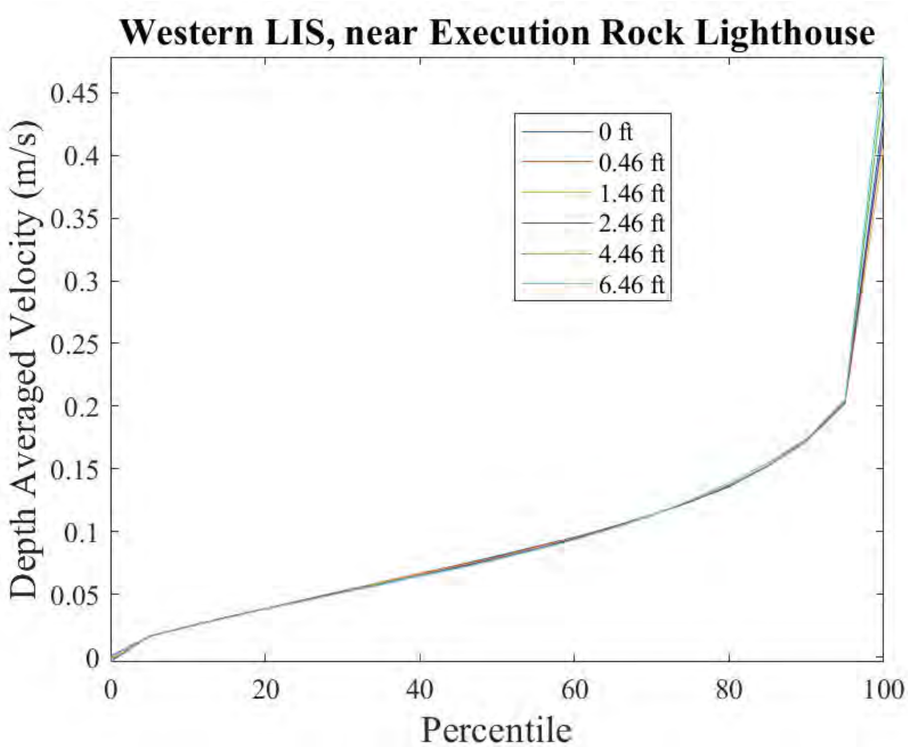


Figure 232. Base, LIS south of NY/CT border Velocity Variation with SLR.

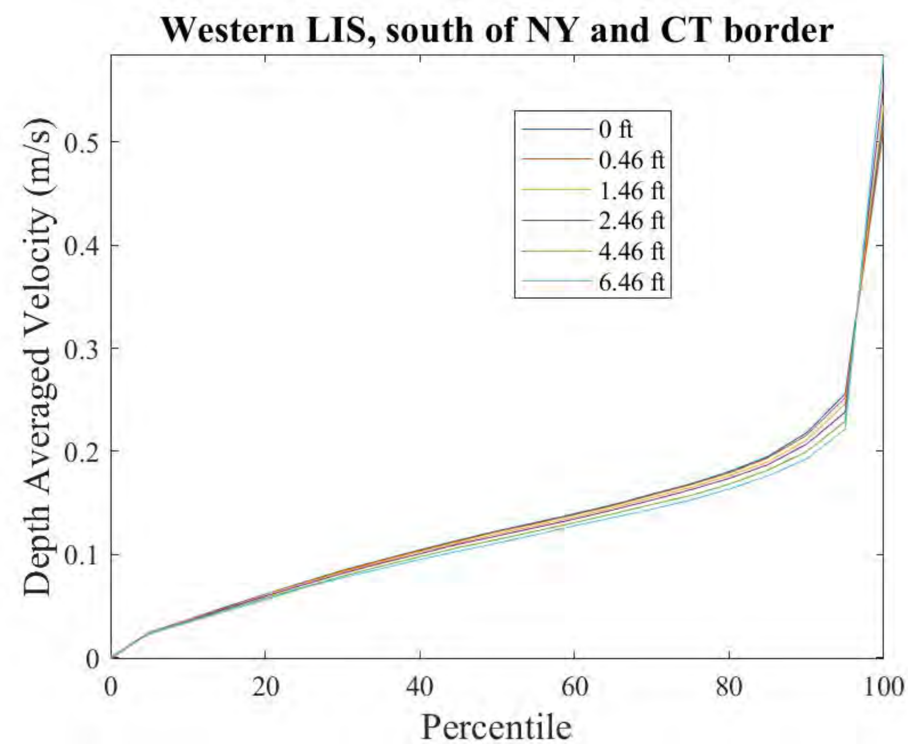


Figure 233. Base, Jamaica Bay Velocity Variation with SLR.

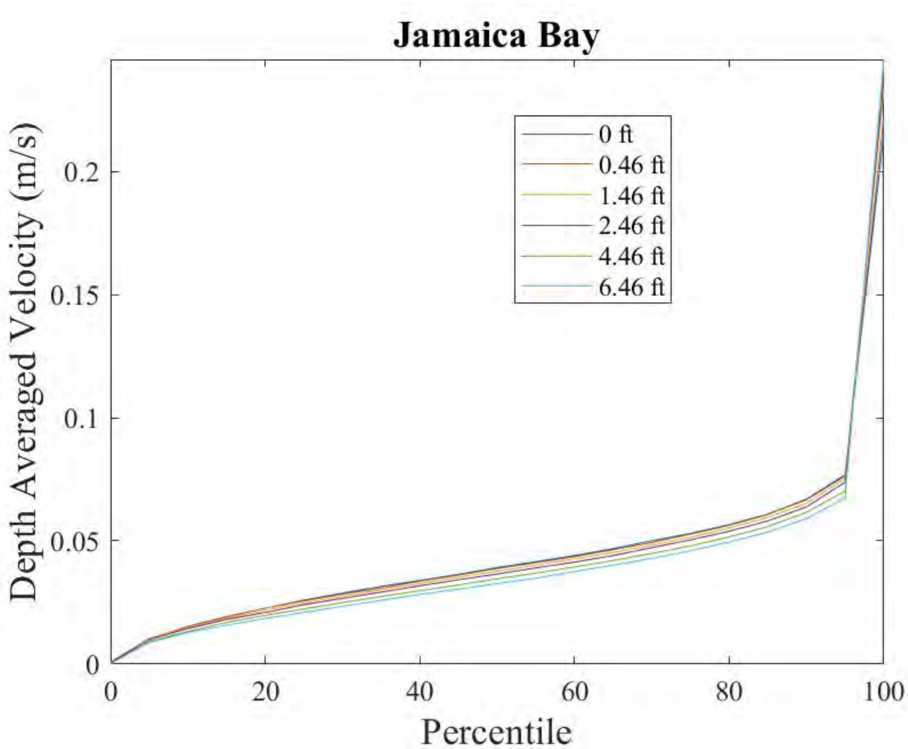


Figure 234. Base, Jamaica Bay near Spring Creek Velocity Variation with SLR.

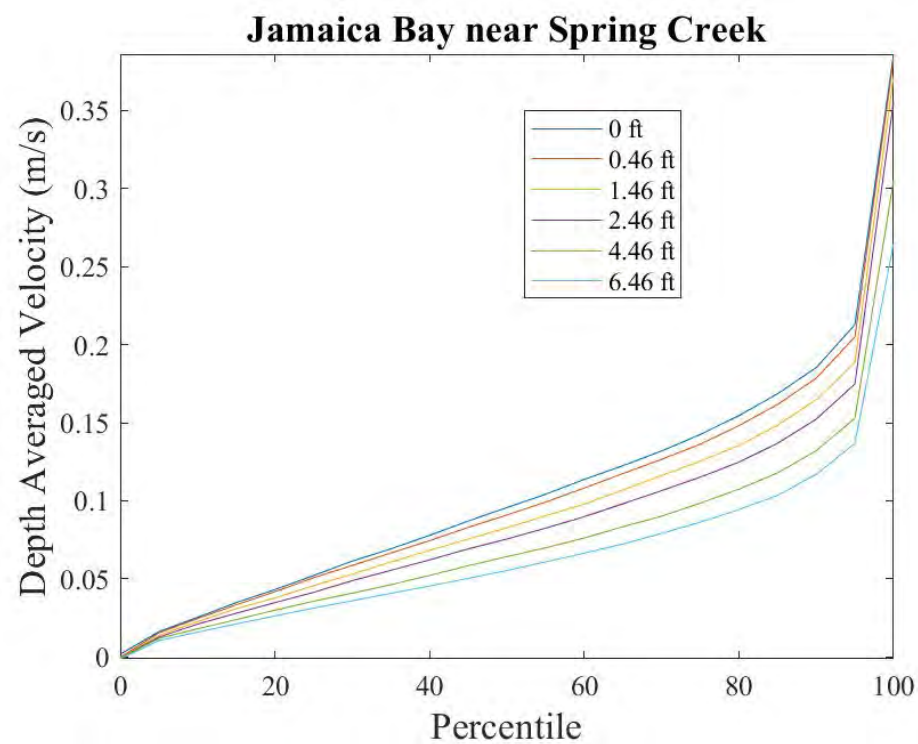
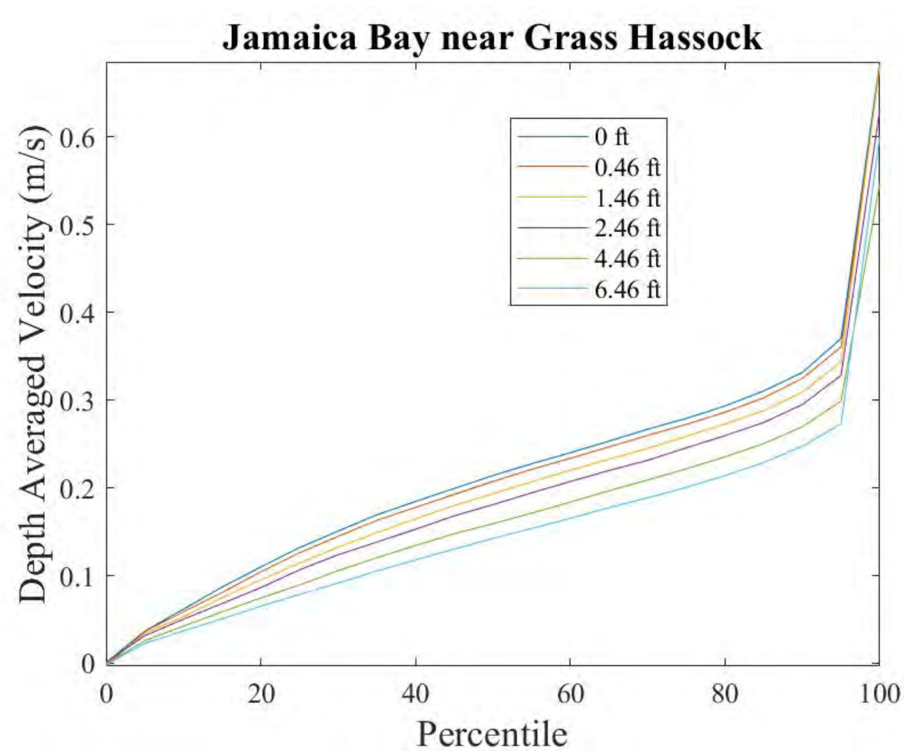


Figure 235. Base, Jamaica Bay near Grass Hassock Velocity Variation with SLR.



15.1.3 Salinity Point Percentiles

Salinity percentiles for the Base Conditions for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 236 to Figure 268. In general, increased sea levels result in increased salinities.

Figure 236. Base, V1 Salinity Variation with SLR.

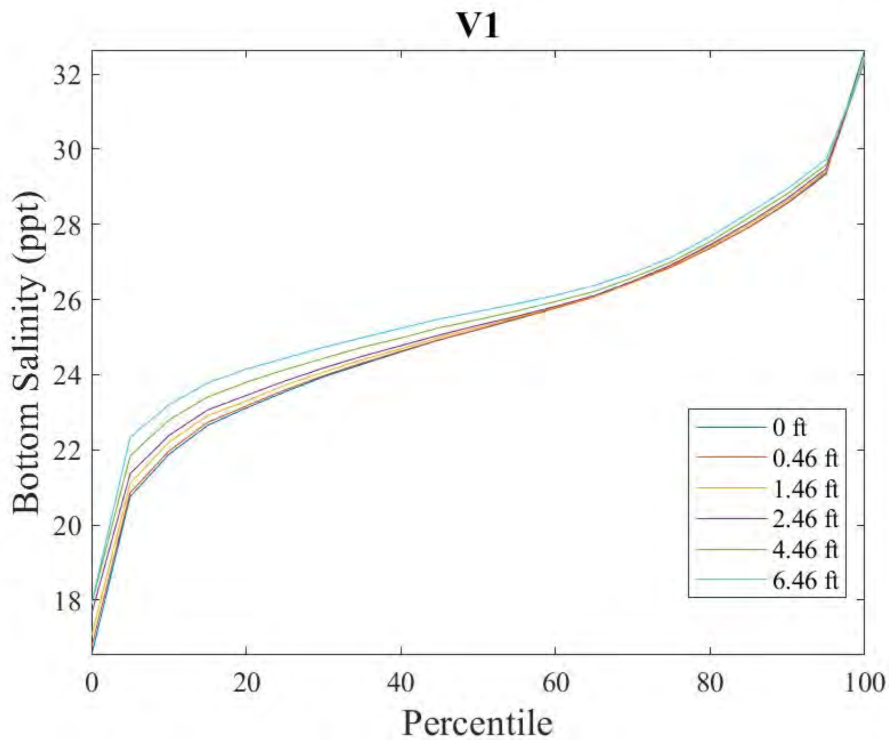


Figure 237. Base, V2 Salinity Variation with SLR.

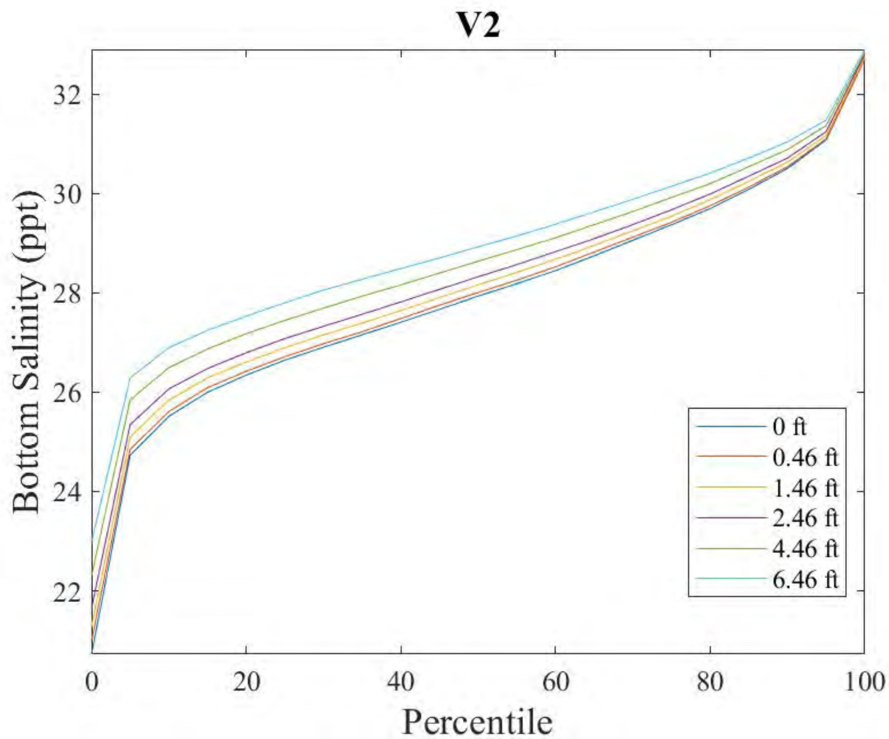


Figure 238. Base, V3 Salinity Variation with SLR.

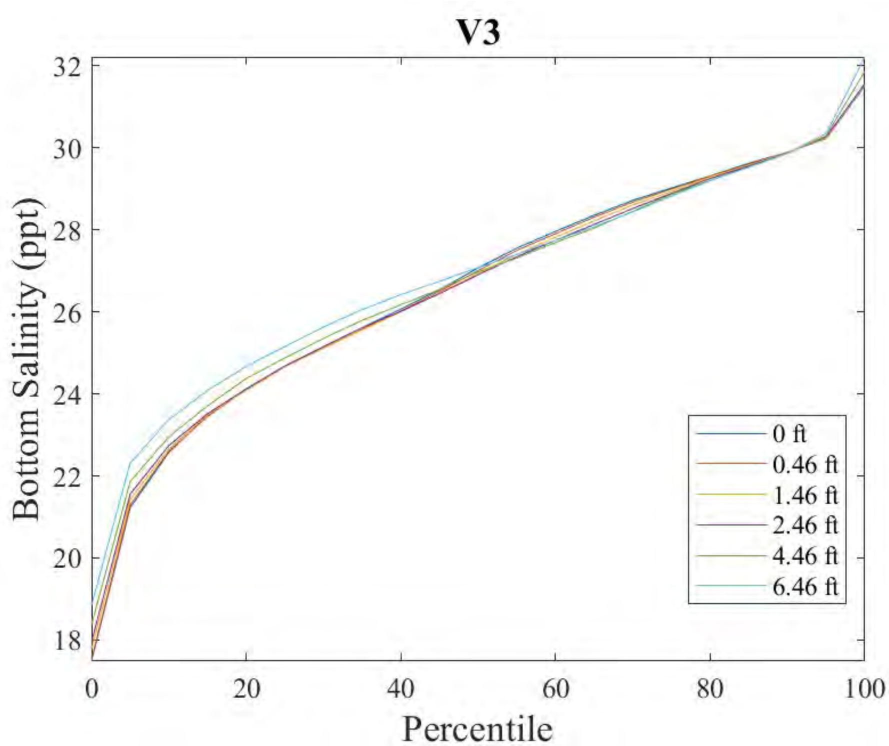


Figure 239. Base, V4 Salinity Variation with SLR.

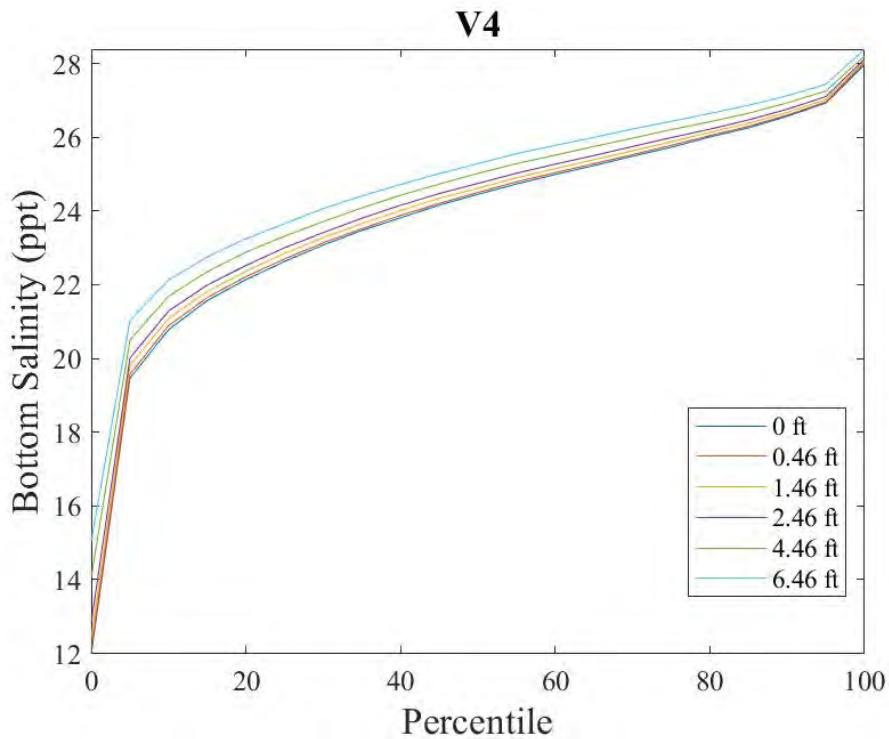


Figure 240. Base, V5 Salinity Variation with SLR.

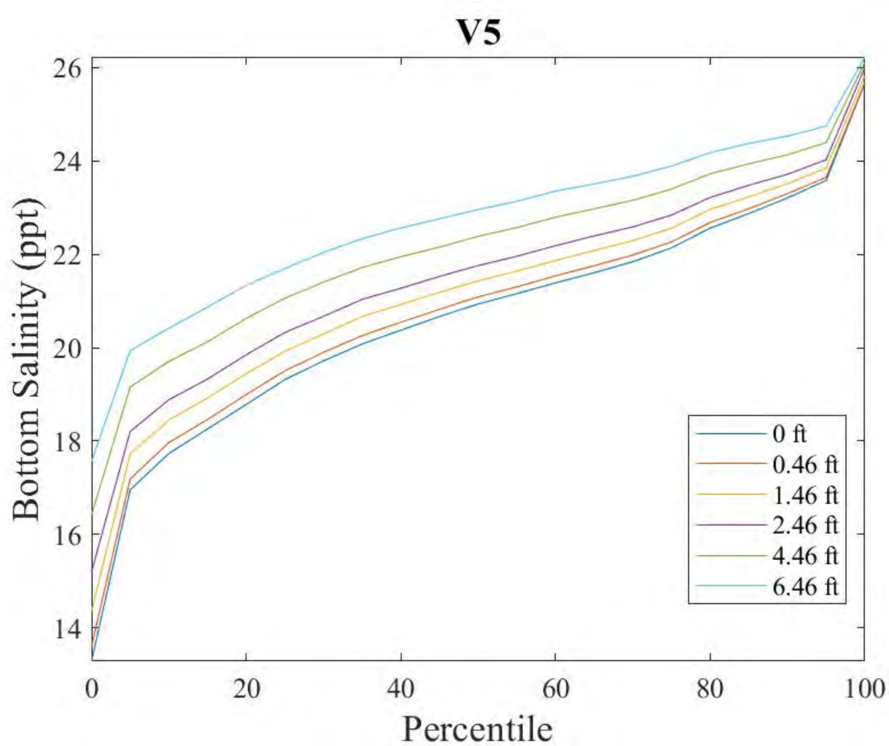


Figure 241. Base, V6 Salinity Variation with SLR.

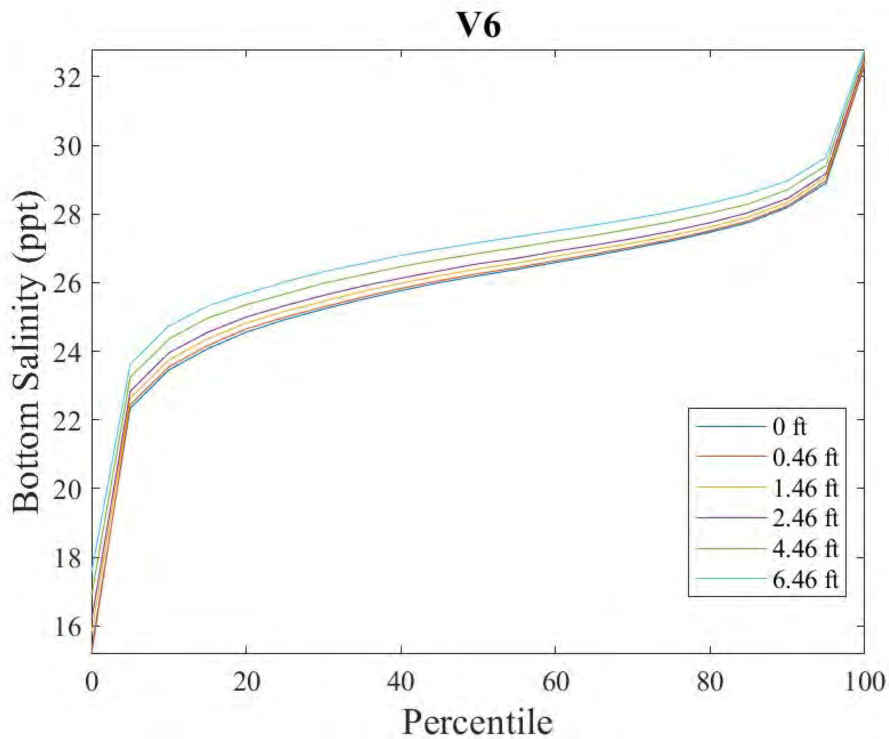


Figure 242. Base, T1 Salinity Variation with SLR.

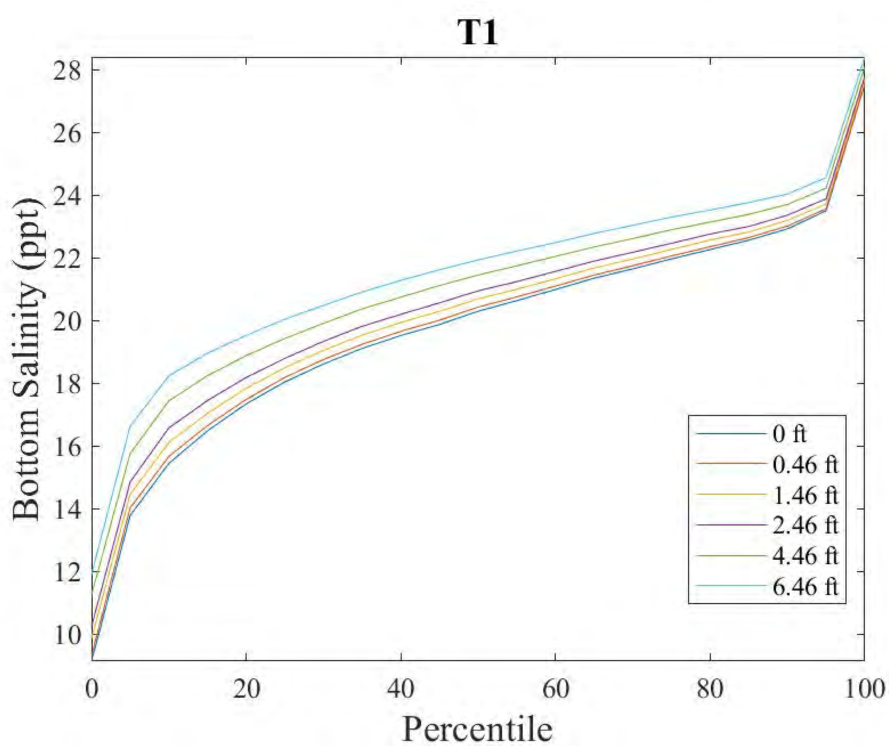


Figure 243. Base, T2 Salinity Variation with SLR.

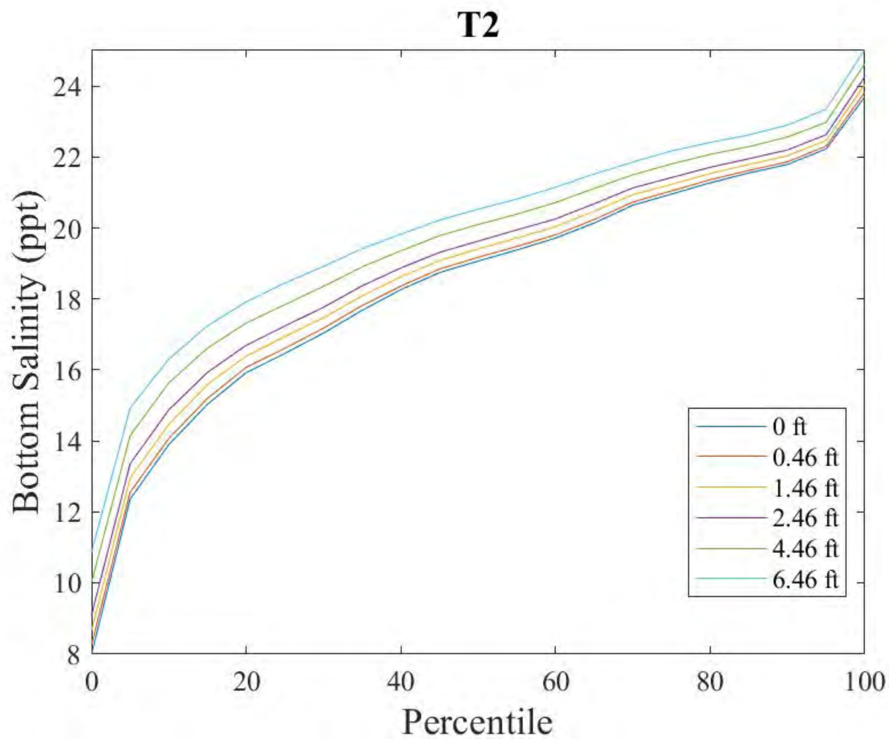


Figure 244. Base, T3 Salinity Variation with SLR.

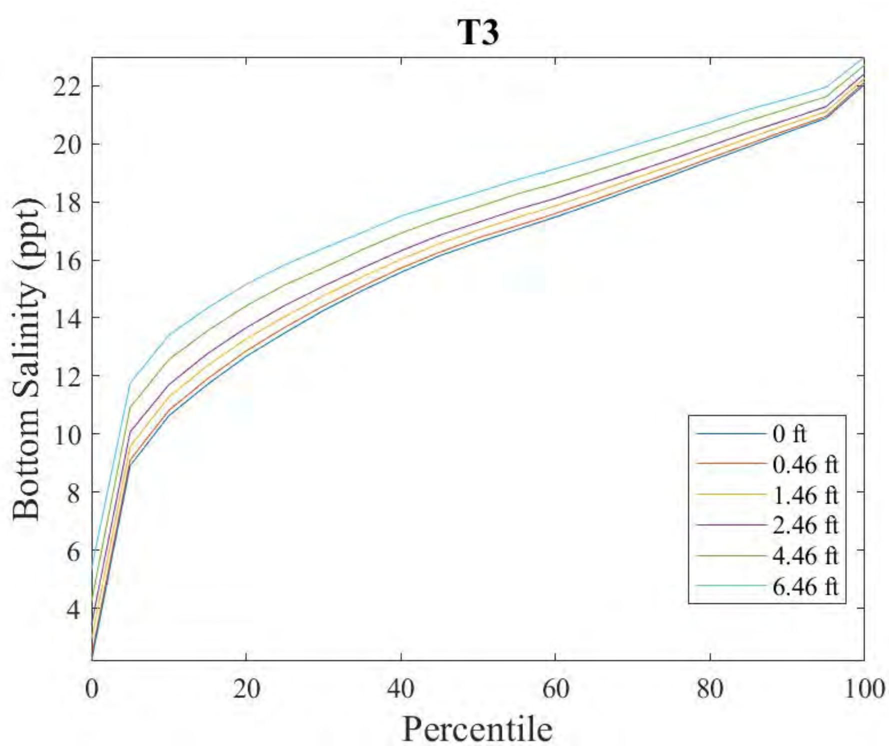


Figure 245. Base, T4 Salinity Variation with SLR.

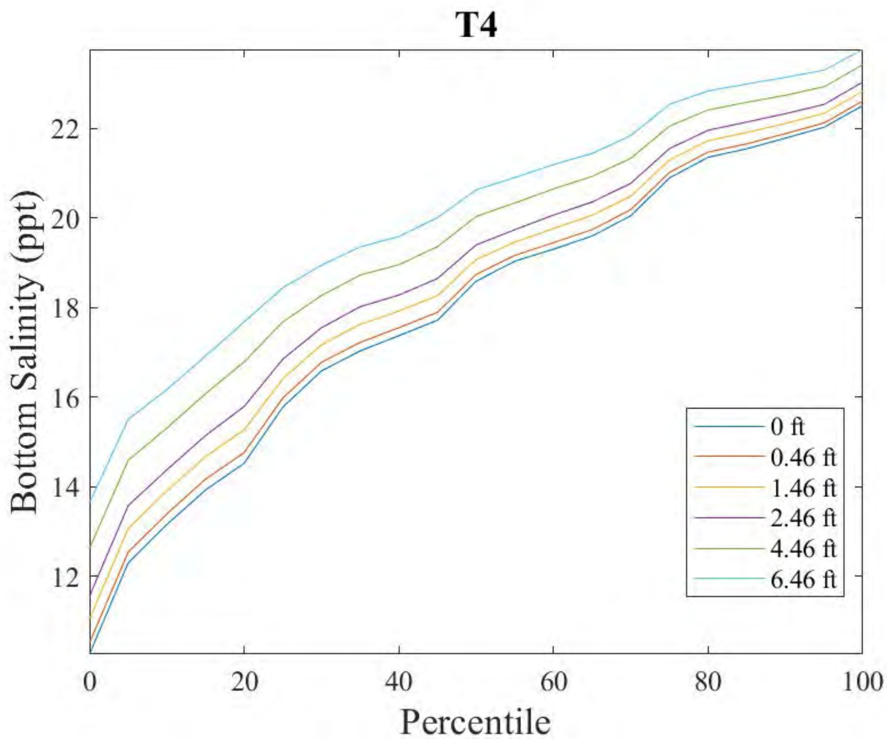


Figure 246. Base, T5 Salinity Variation with SLR.

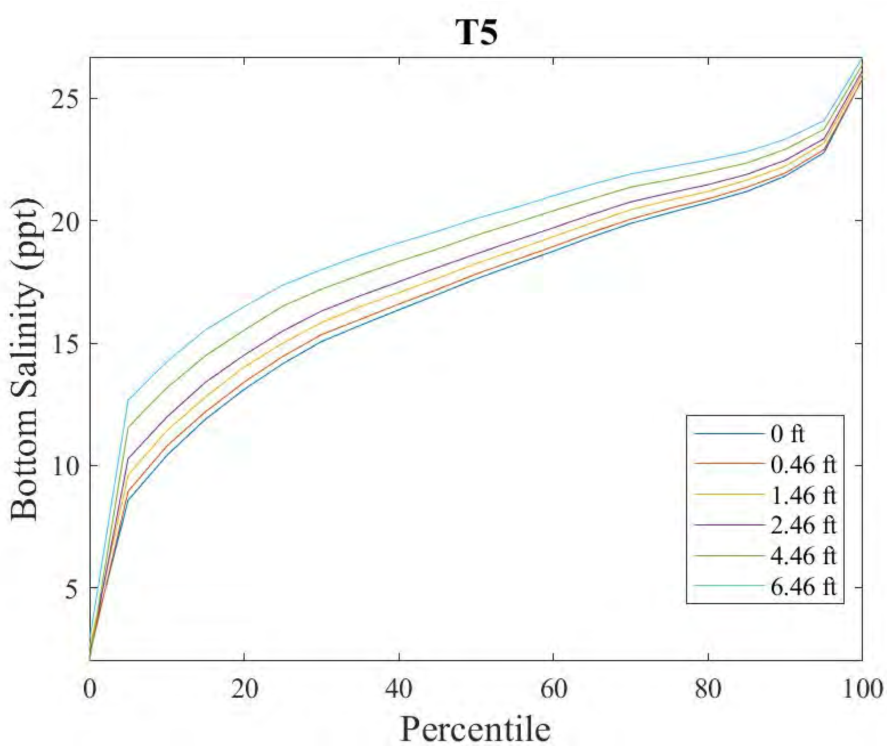


Figure 247. Base, S1 Salinity Variation with SLR.

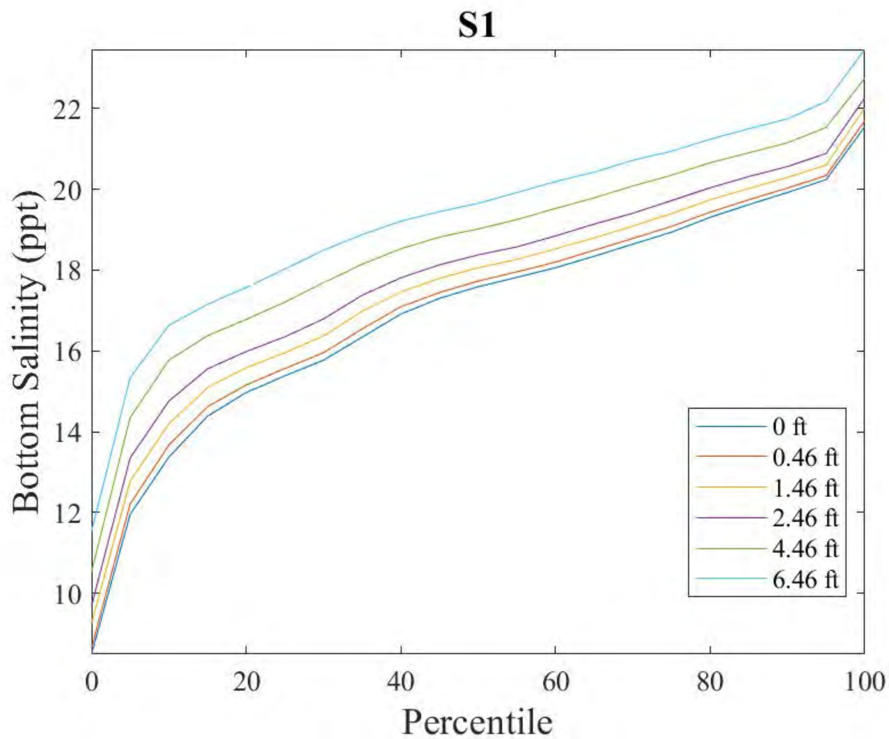


Figure 248. Base, S2 Salinity Variation with SLR.

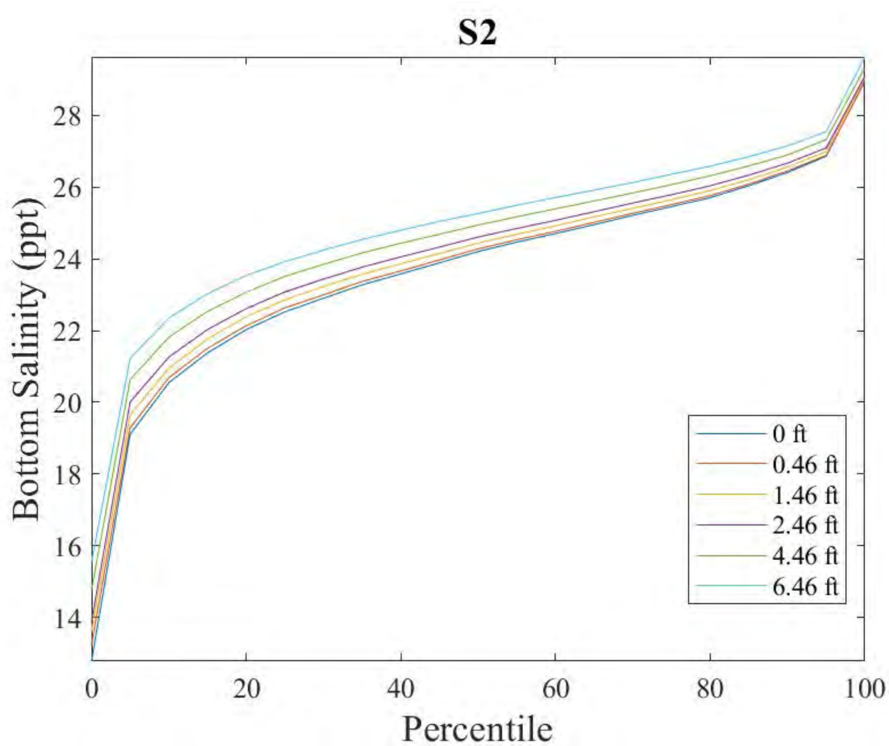


Figure 249. Base, S3 Salinity Variation with SLR.

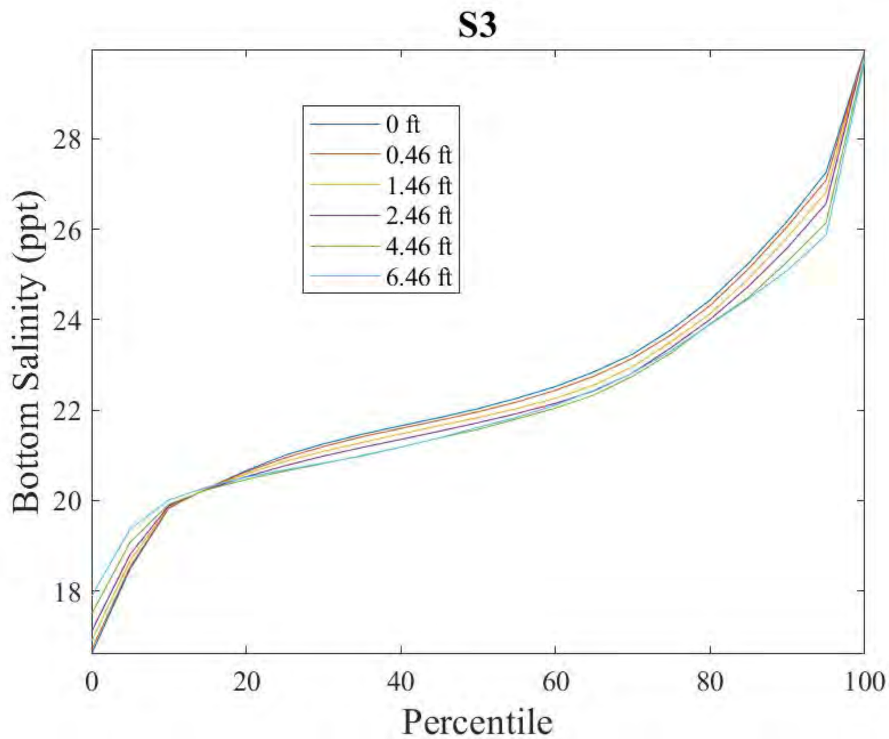


Figure 250. Base, S4 Salinity Variation with SLR.

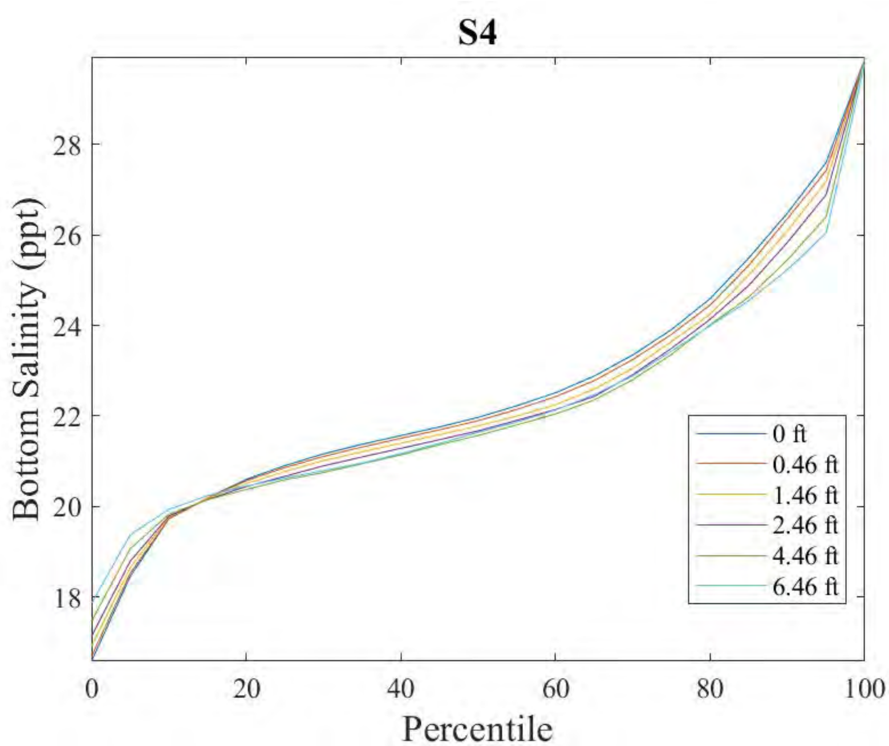


Figure 251. Base, S5 Salinity Variation with SLR.

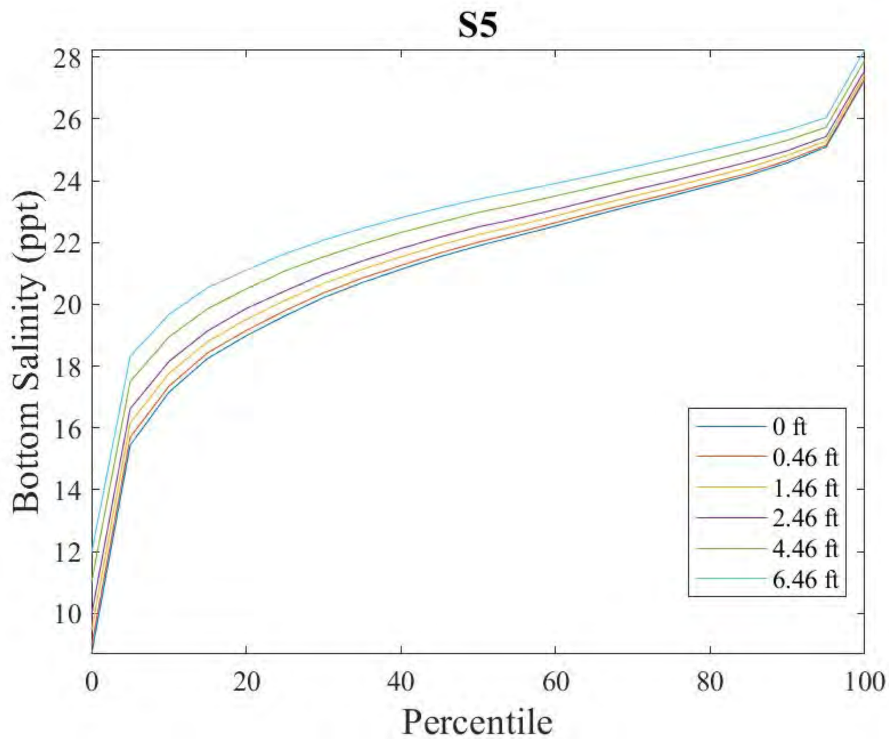


Figure 252. Base, R1 Salinity Variation with SLR.

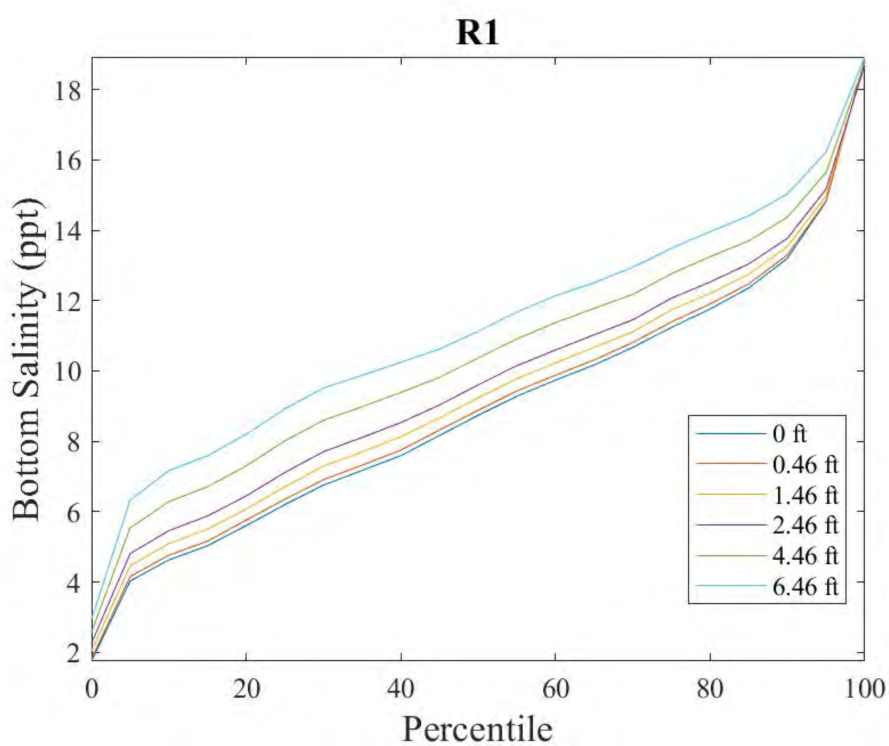


Figure 253. Base, Sandy Hook Salinity Variation with SLR.

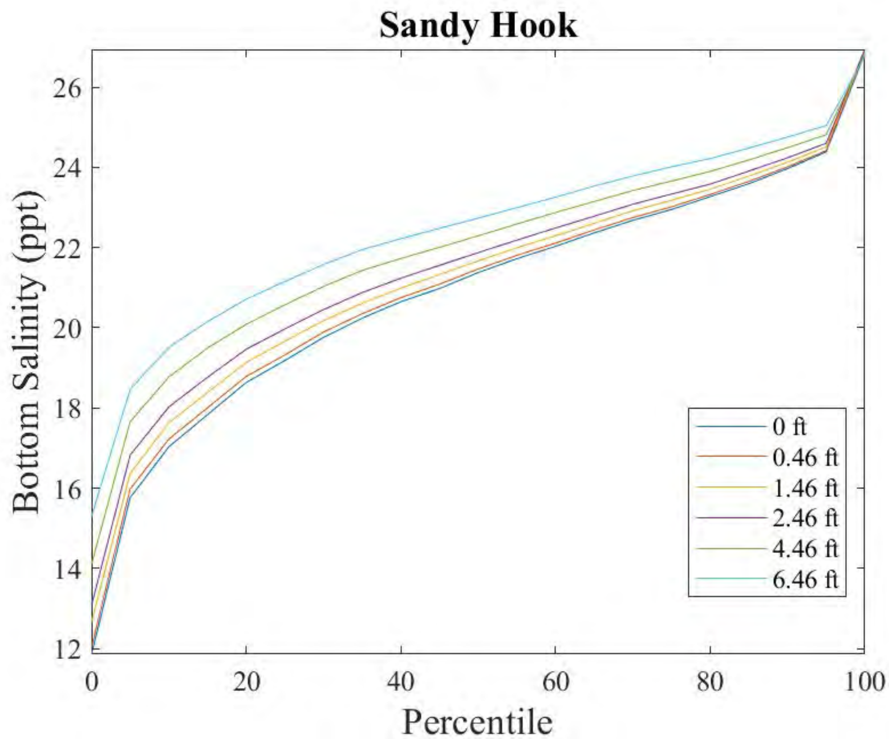


Figure 254. Base, Fresh Kills Salinity Variation with SLR.

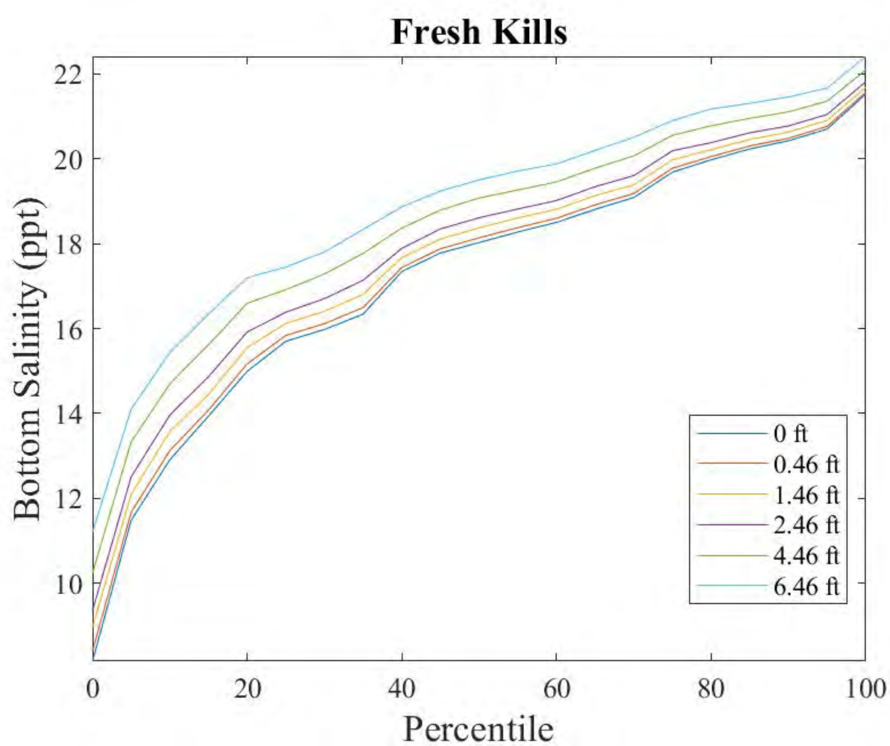


Figure 255. Base, Mariners Harbor Salinity Variation with SLR.

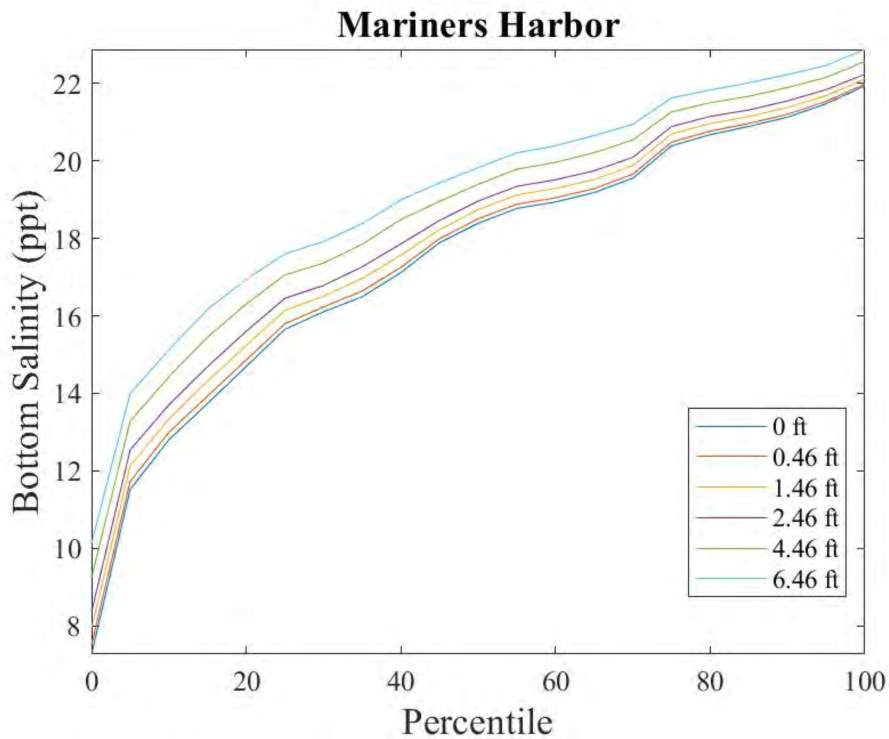


Figure 256. Base, North Reach Salinity Variation with SLR.

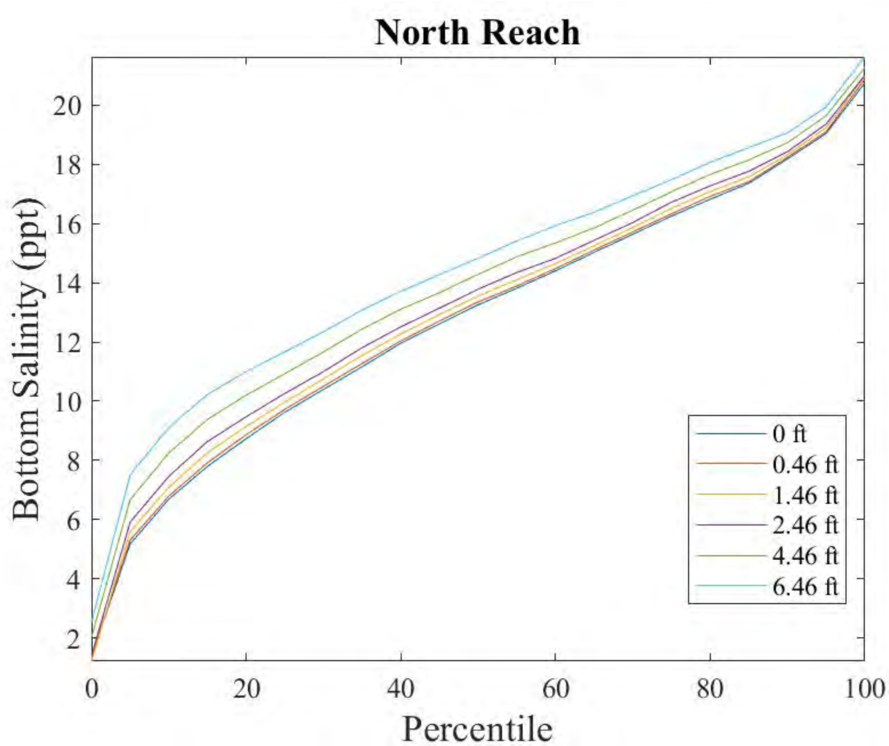


Figure 257. Base, Hackensack River Salinity Variation with SLR.

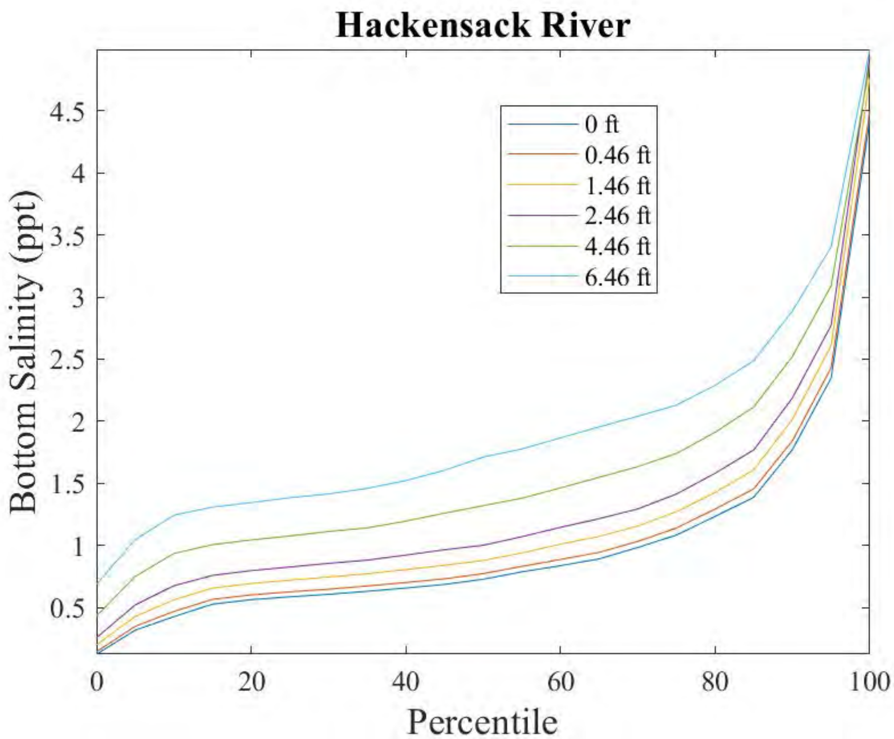


Figure 258. Base, Robbins Reef Salinity Variation with SLR.

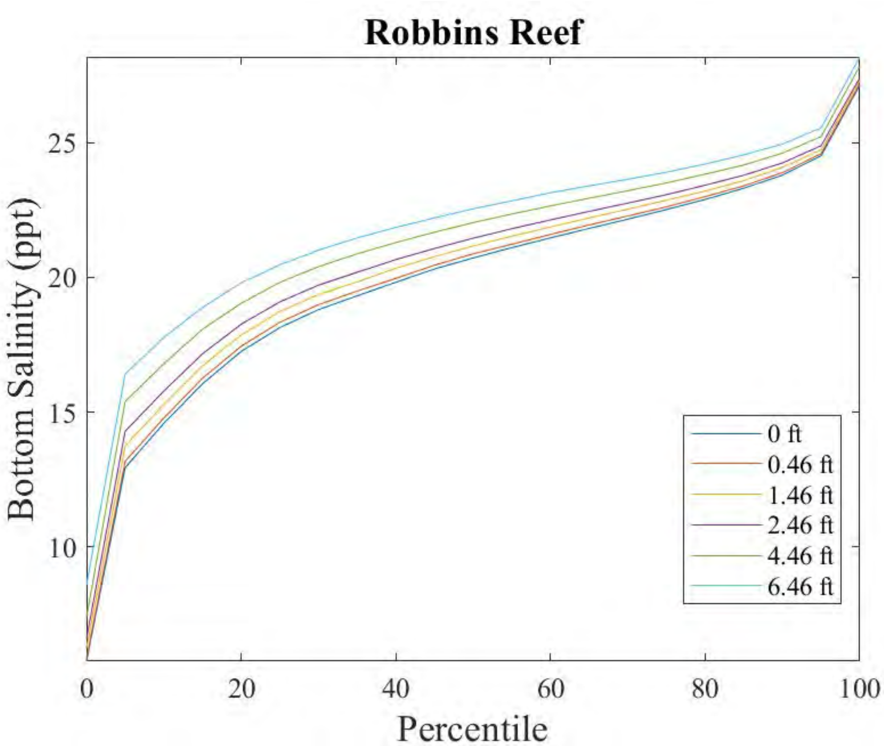


Figure 259. Base, The Battery Salinity Variation with SLR.

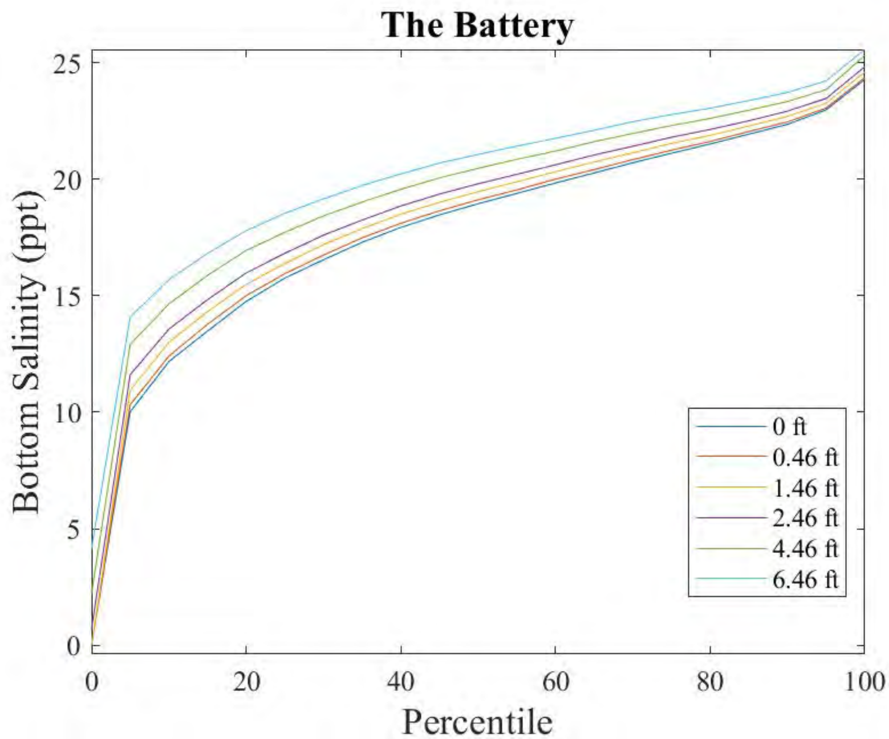


Figure 260. Base, Manhattan Salinity Variation with SLR.

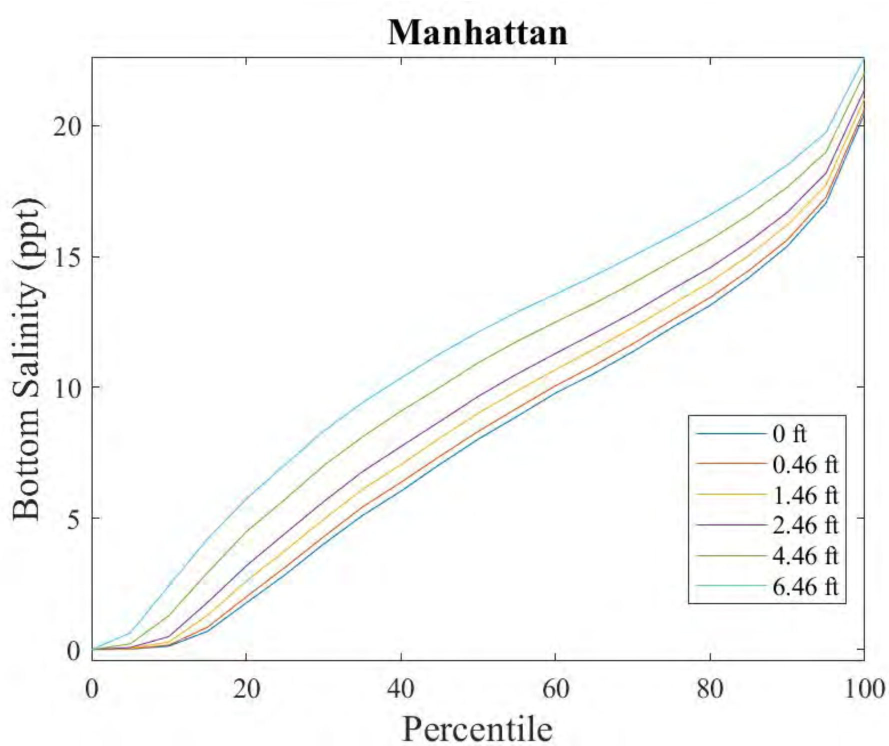


Figure 261. Base, Hudson River Haverstraw Bay Salinity Variation with SLR.

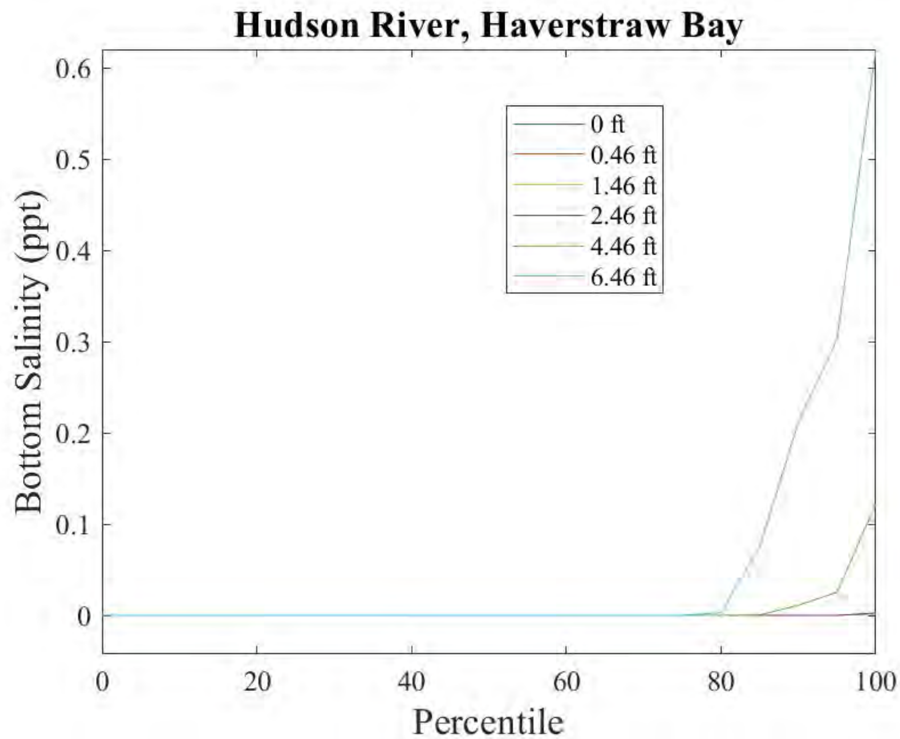


Figure 262. Base, KLGA Salinity Variation with SLR.

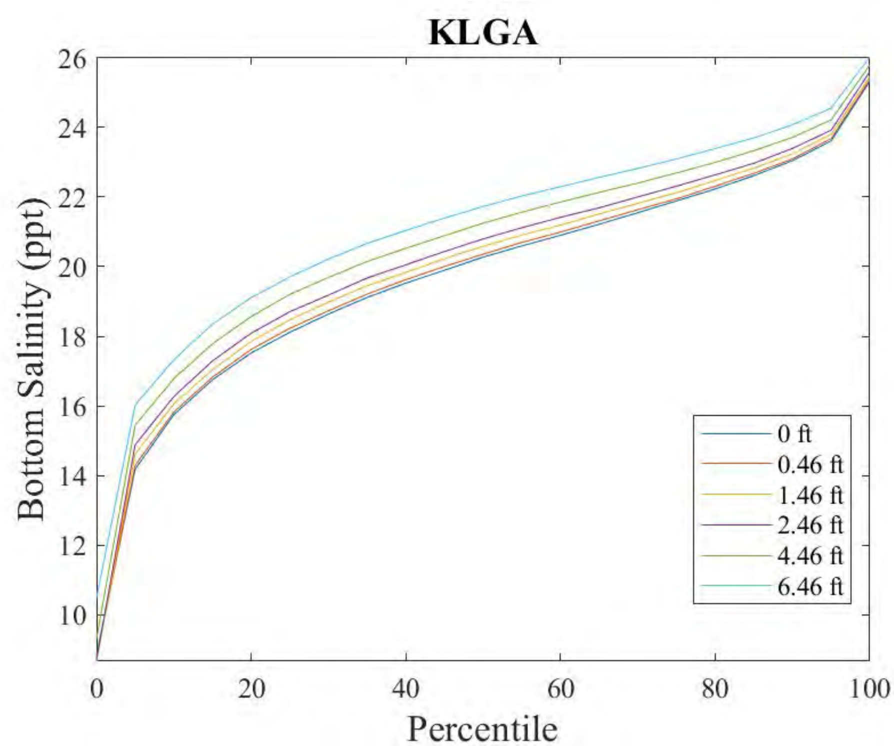


Figure 263. Base, Jamaica Bay Salinity Variation with SLR.

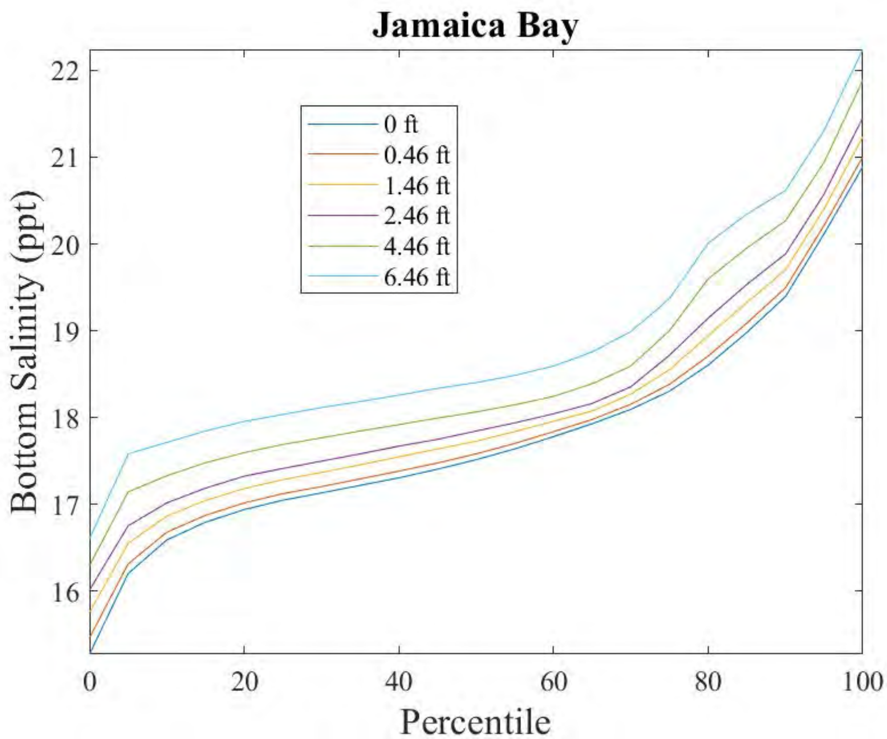


Figure 264. Base, Jamaica Bay near Spring Creek Salinity Variation with SLR.

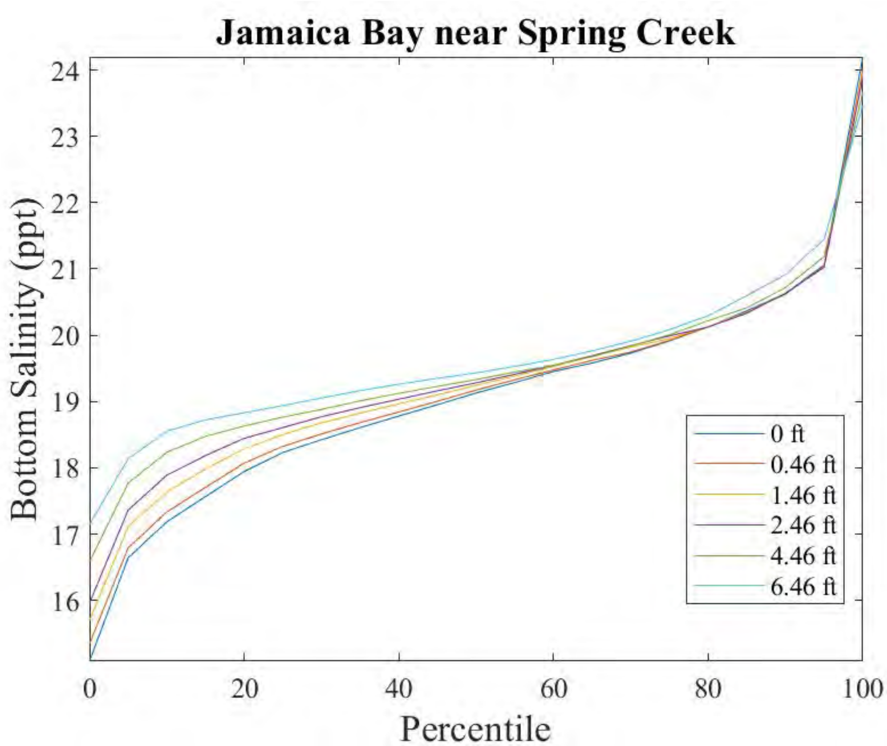


Figure 265. Base, Jamaica Bay near Grass Hassock Salinity Variation with SLR.

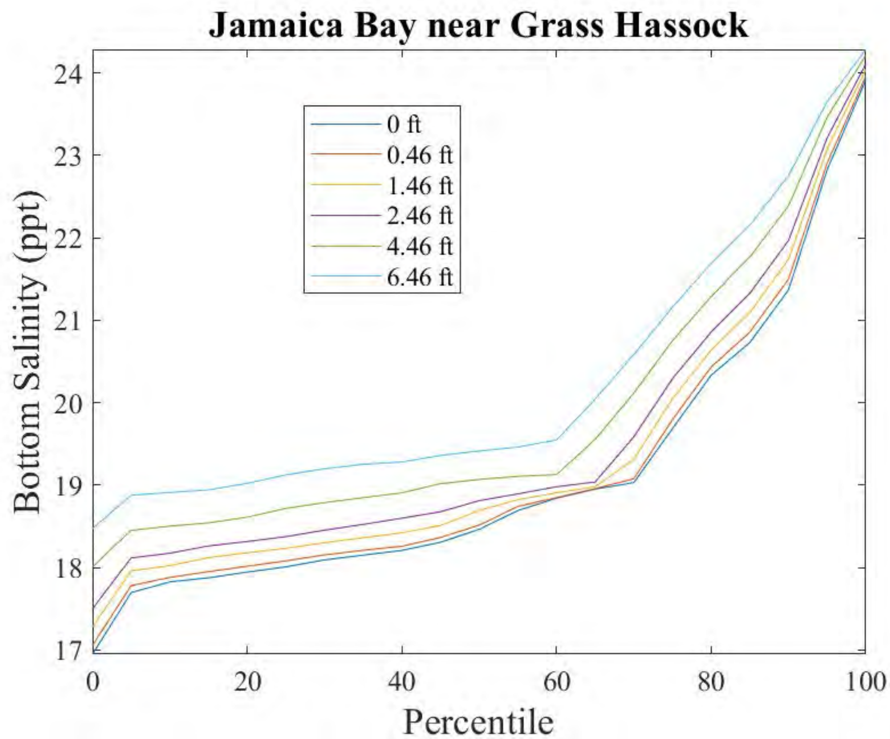


Figure 266. Base, LIS near Stepping Stone Lighthouse Salinity Variation with SLR.

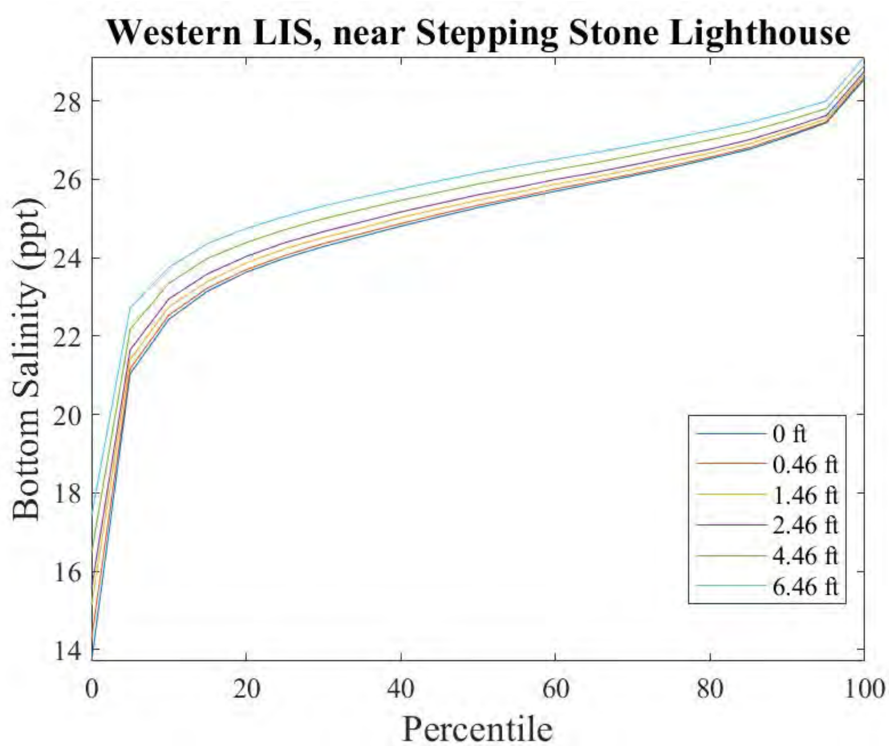


Figure 267. Base, LIS near Execution Rock Lighthouse Salinity Variation with SLR.

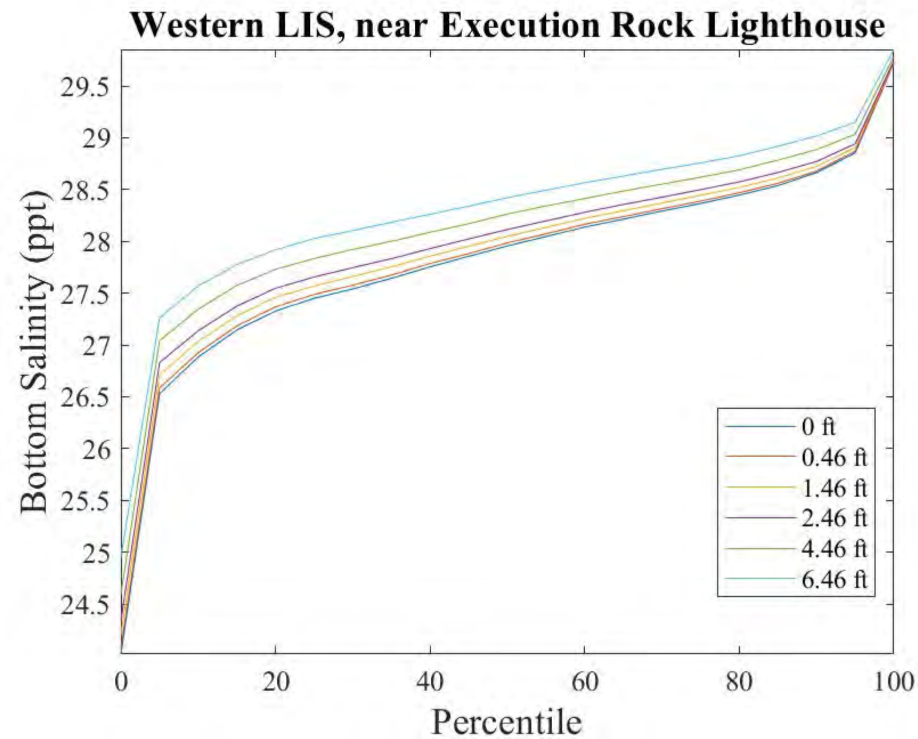
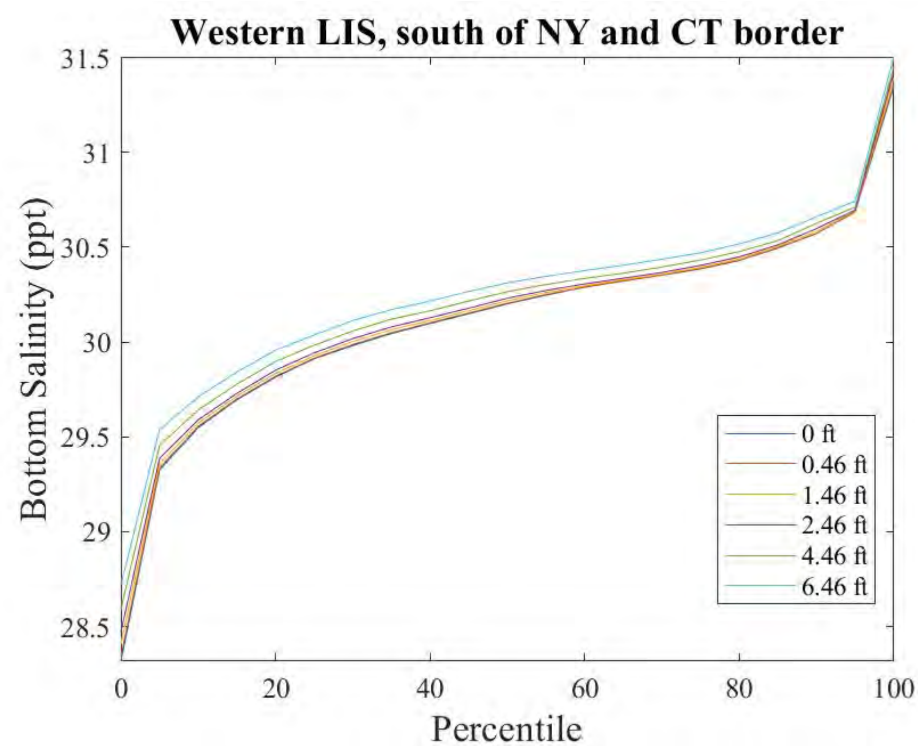


Figure 268. Base, LIS south of NY/CT border Salinity Variation with SLR.



15.1.4 Spatial Velocity Percentiles

Spatial figures of the velocity magnitude percentiles for the Base Conditions for the 50^{th} and 75^{th} percentiles are provided in Figure 269 to Figure 280.

Figure 269. Base/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

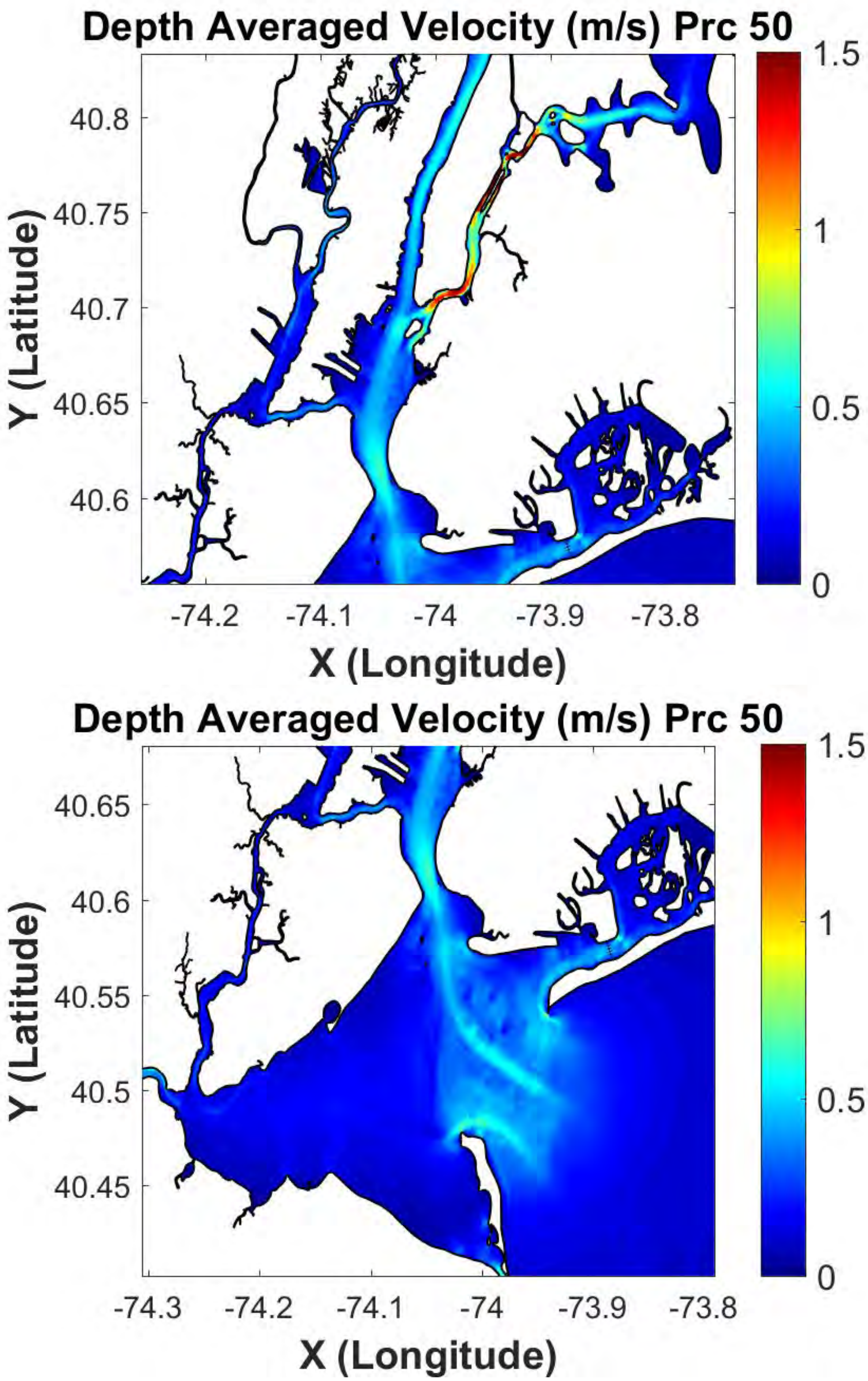


Figure 270. Base/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

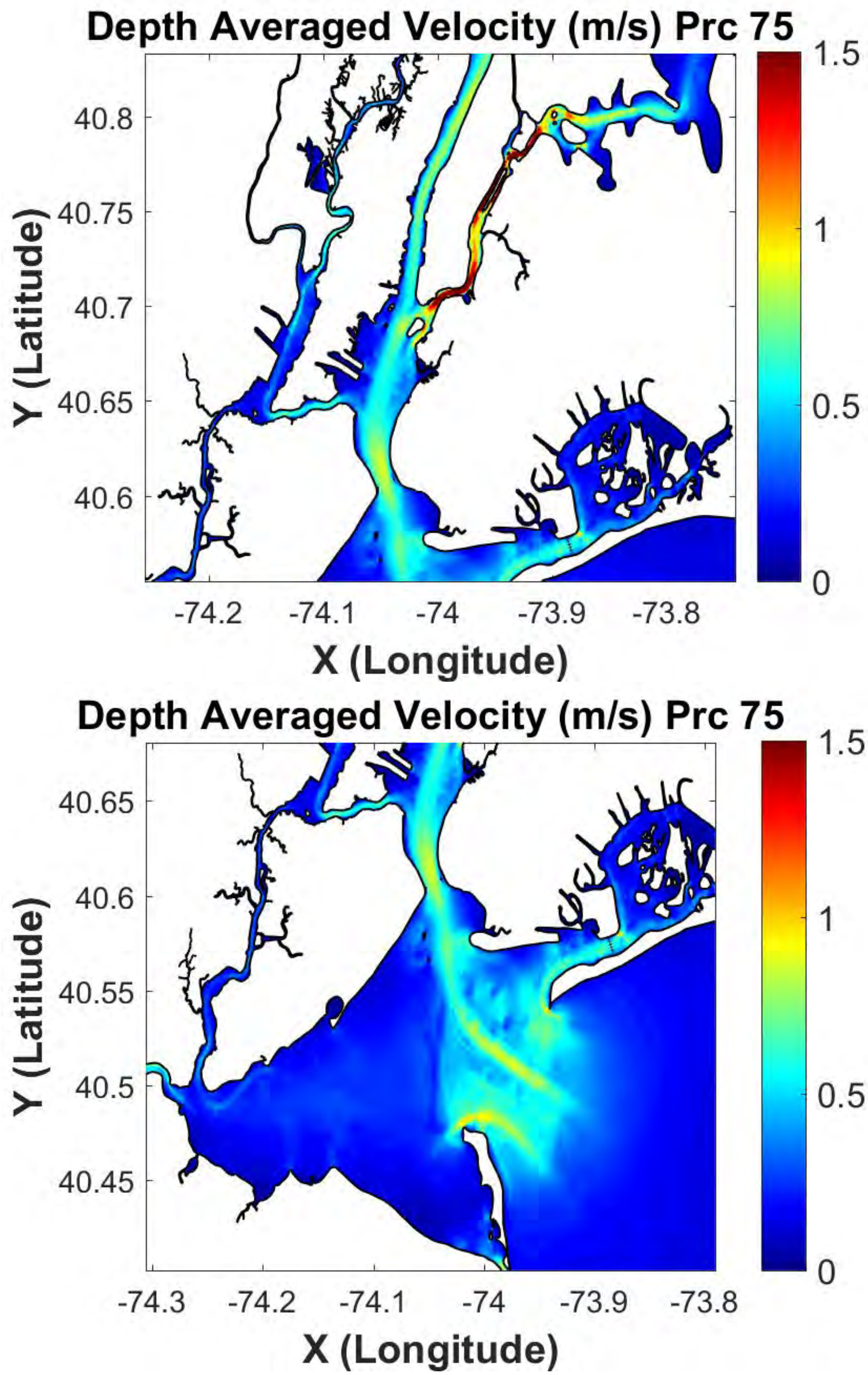


Figure 271. Base/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

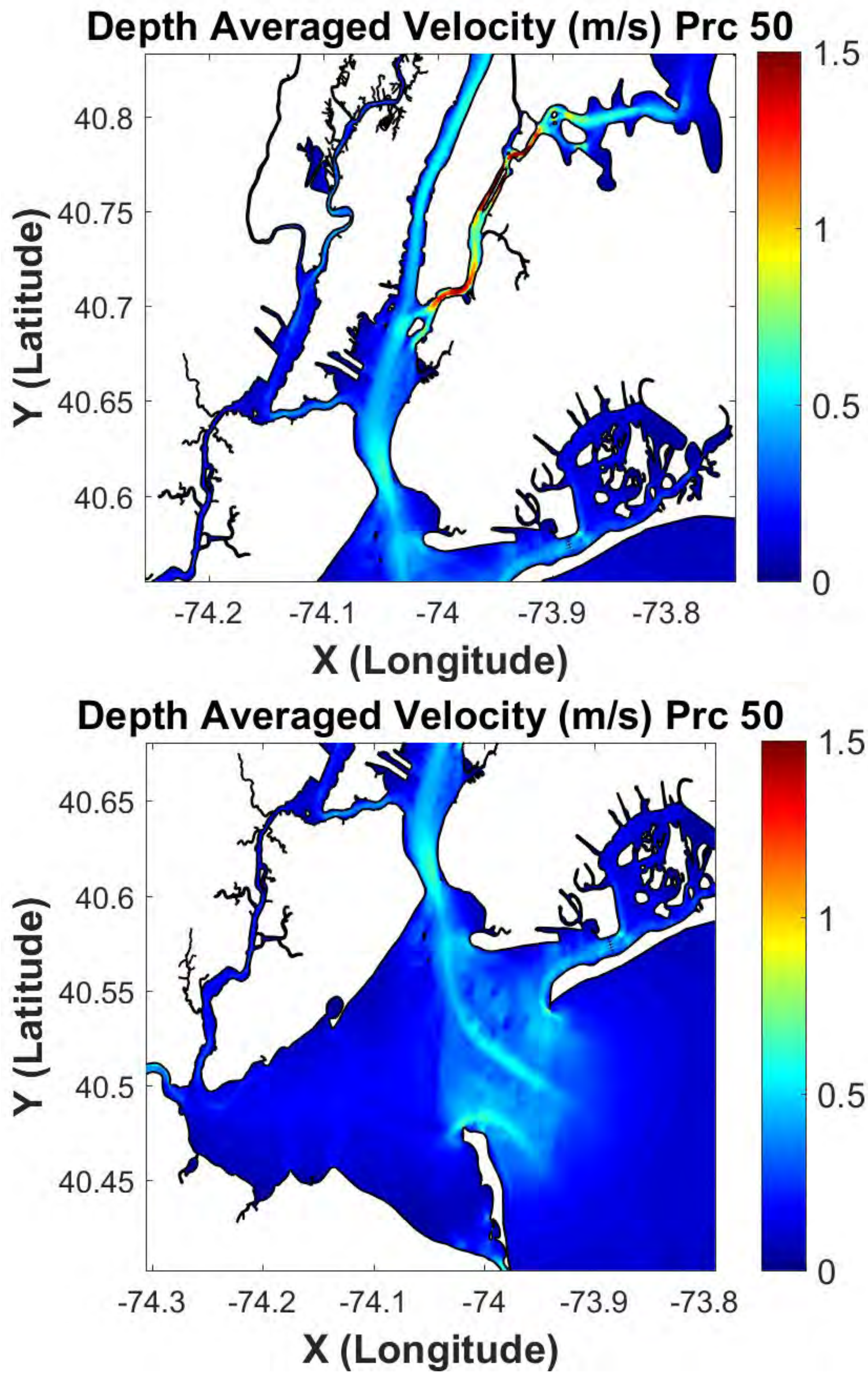


Figure 272. Base/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

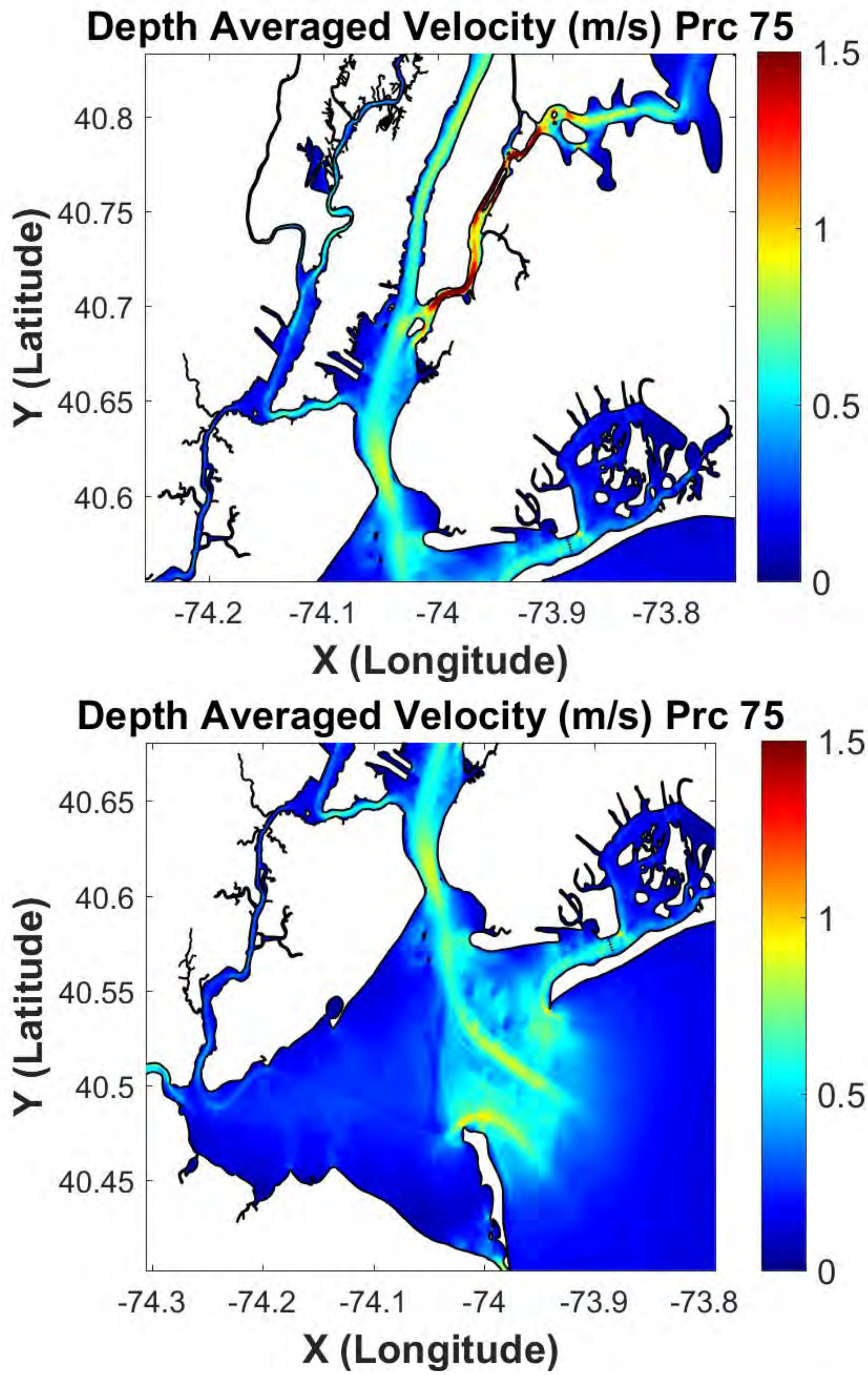


Figure 273. Base/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

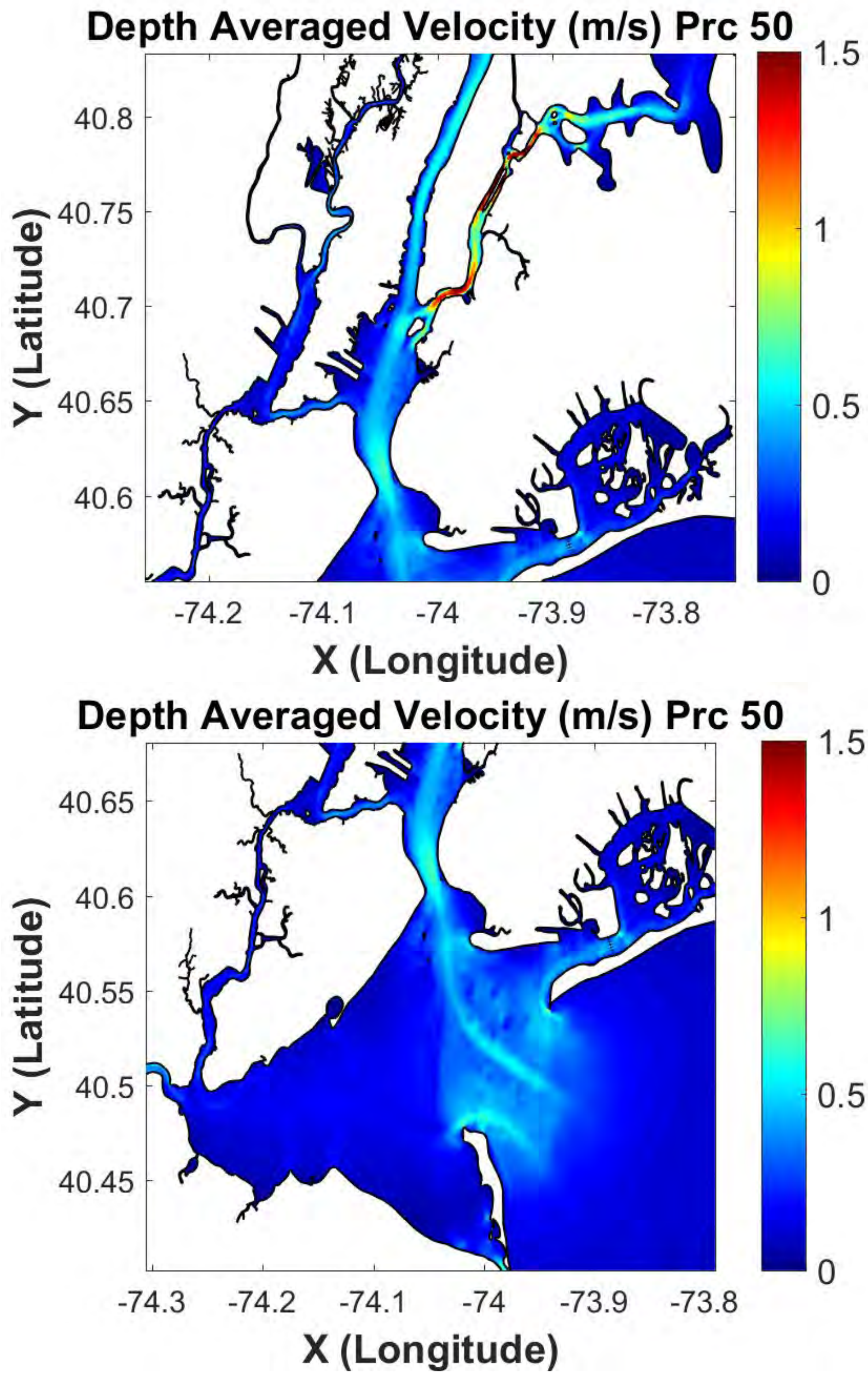


Figure 274. Base/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

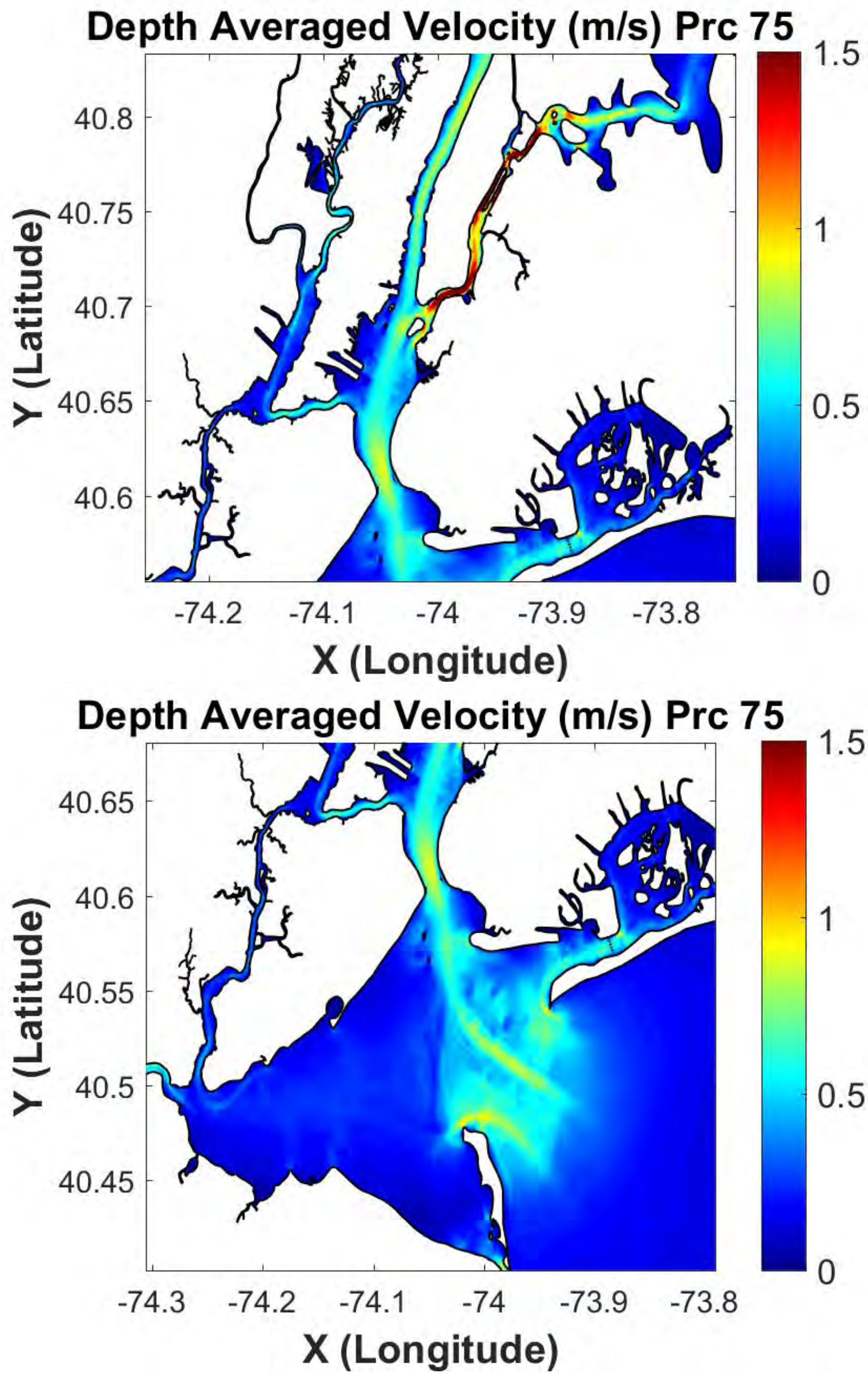


Figure 275. Base/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

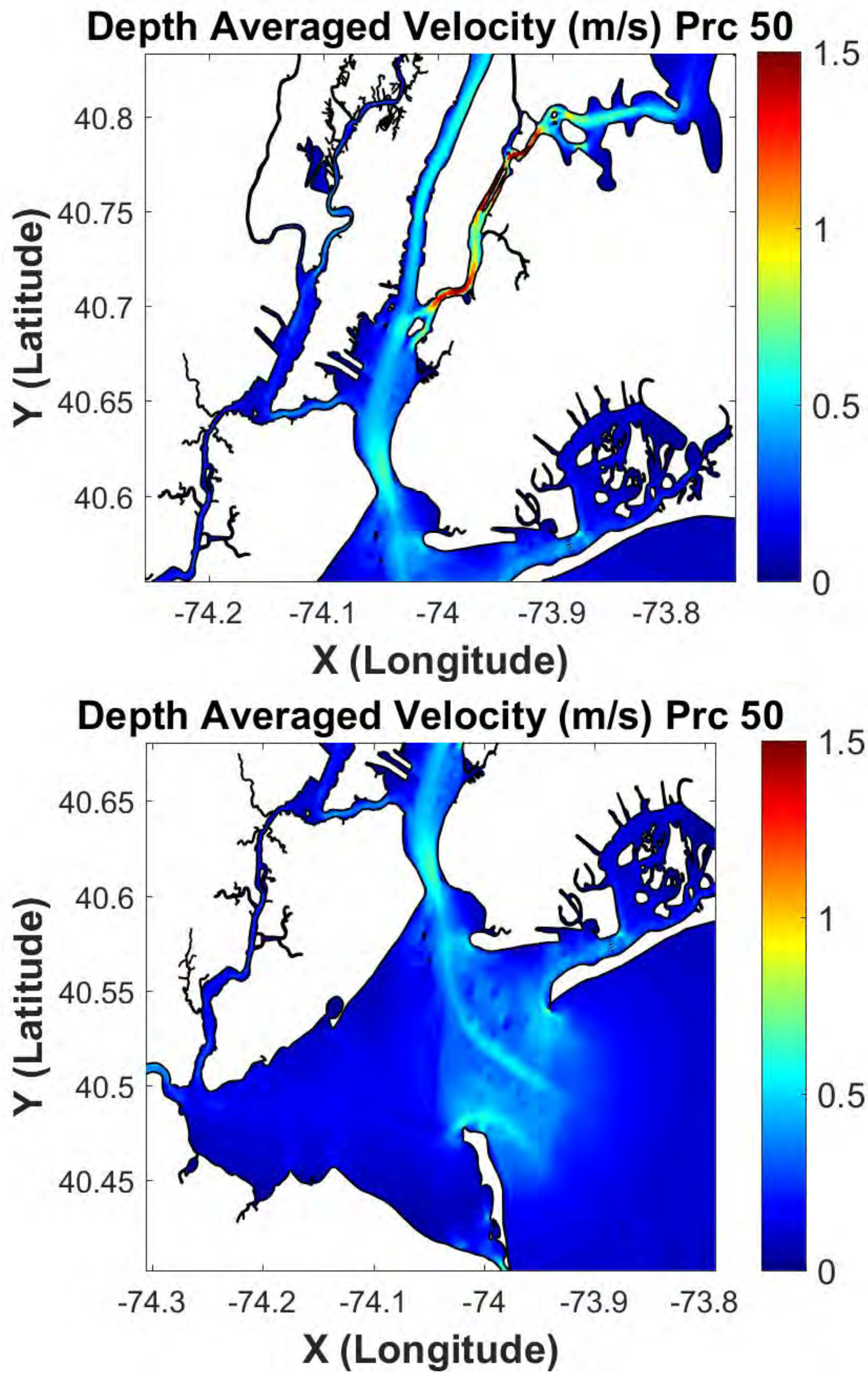


Figure 276. Base/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

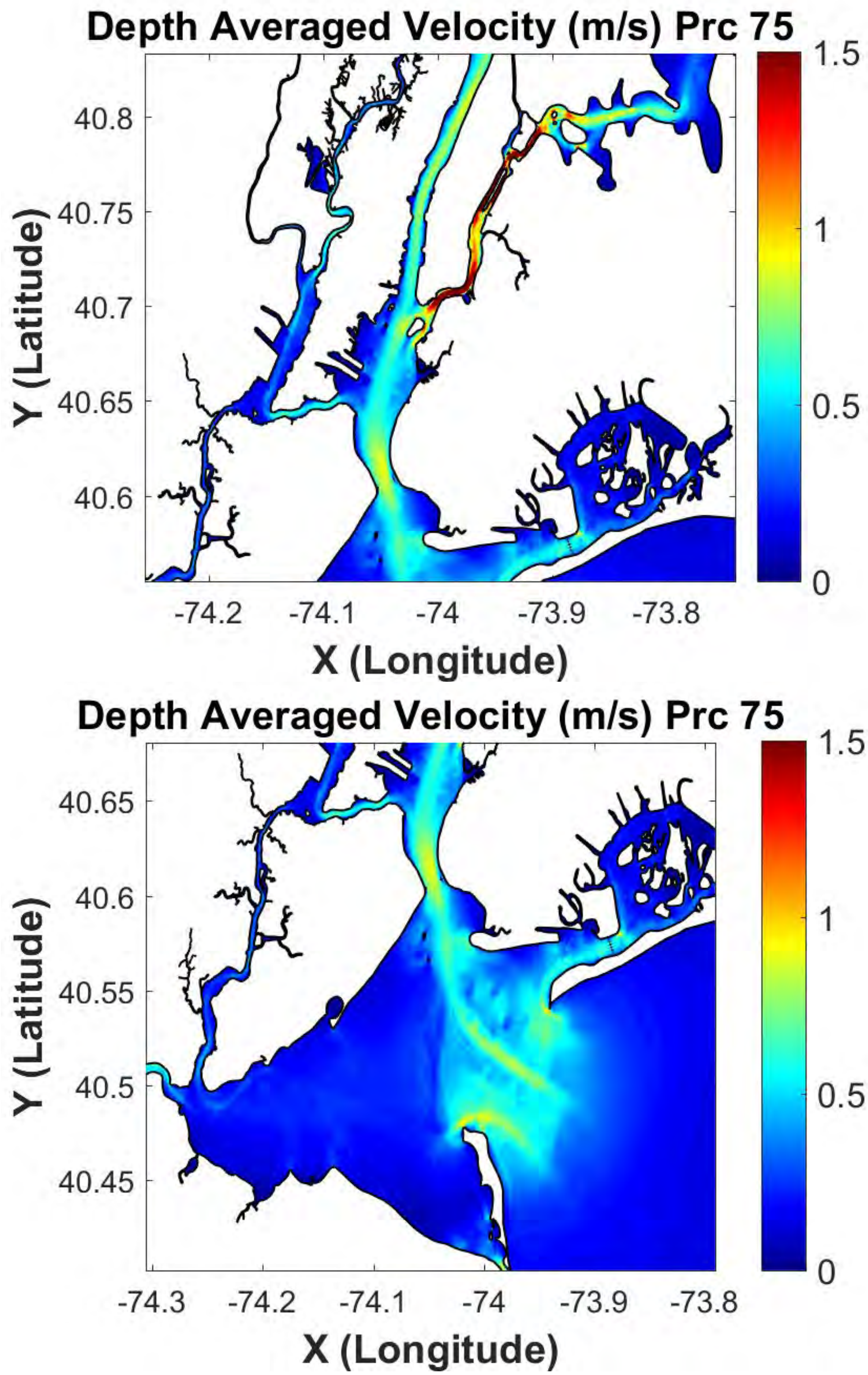


Figure 277. Base/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

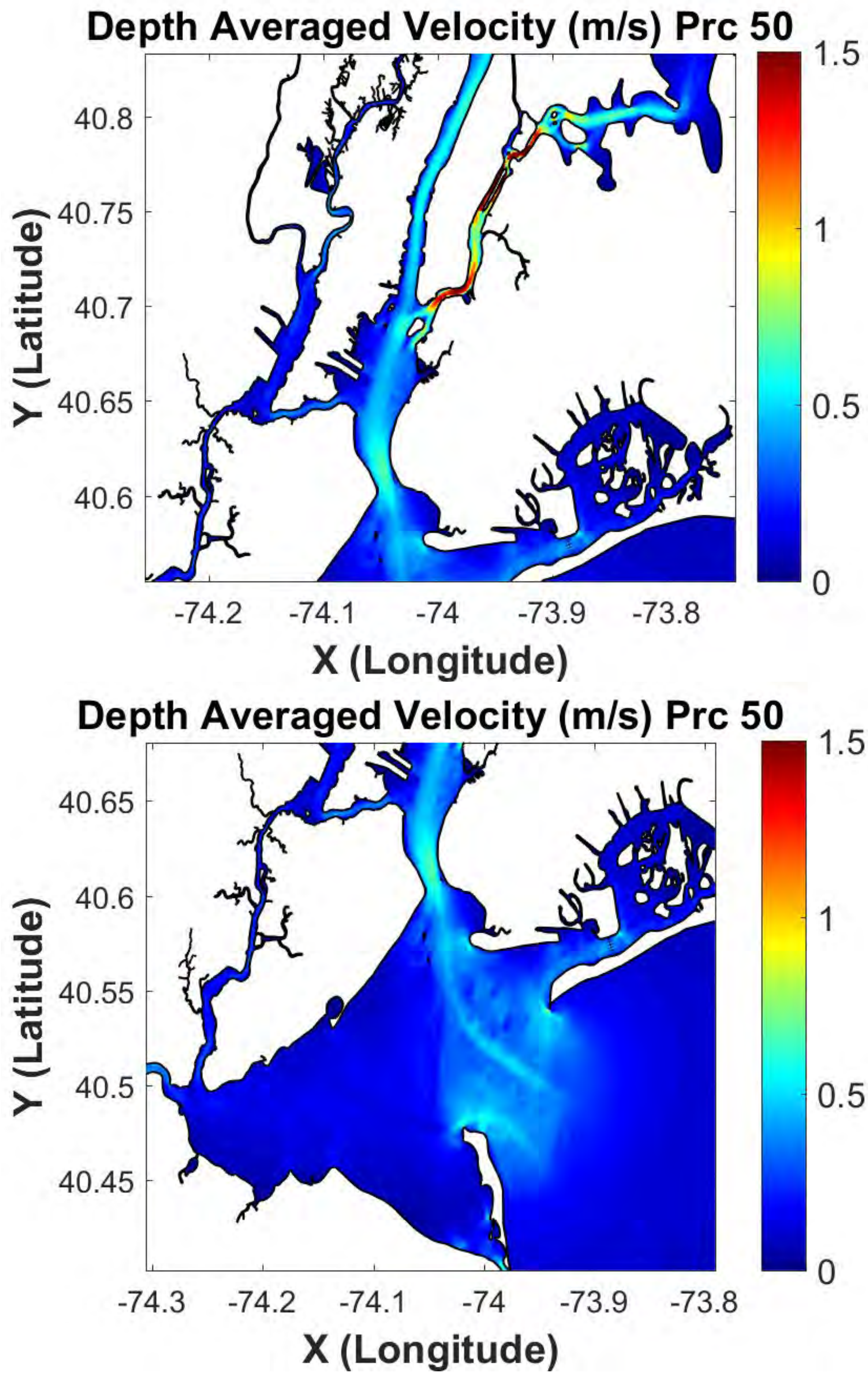
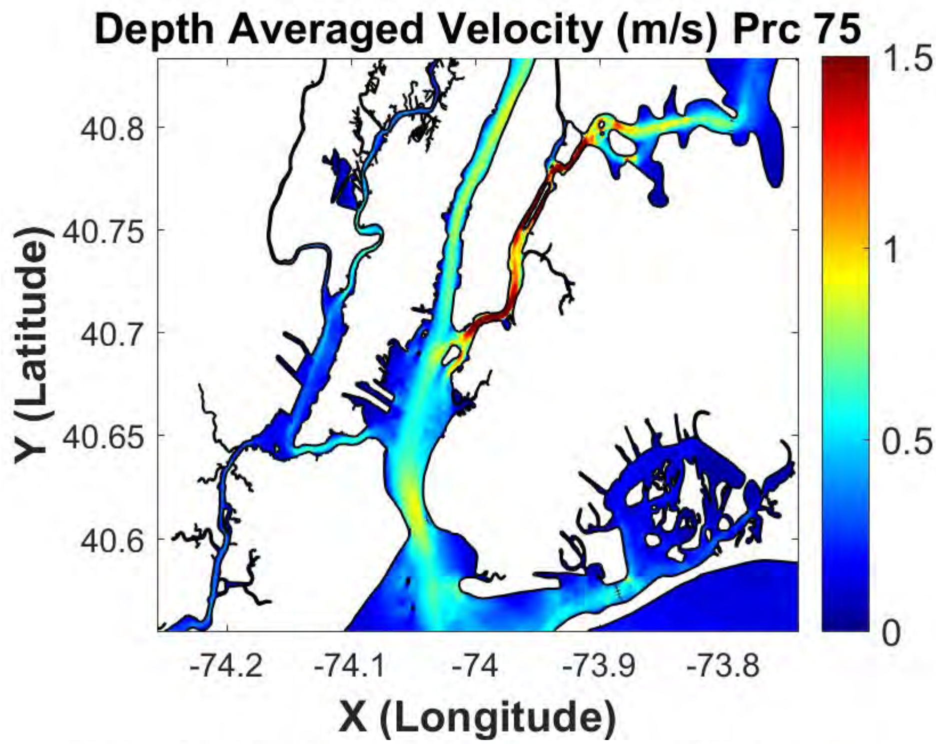


Figure 278. Base/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



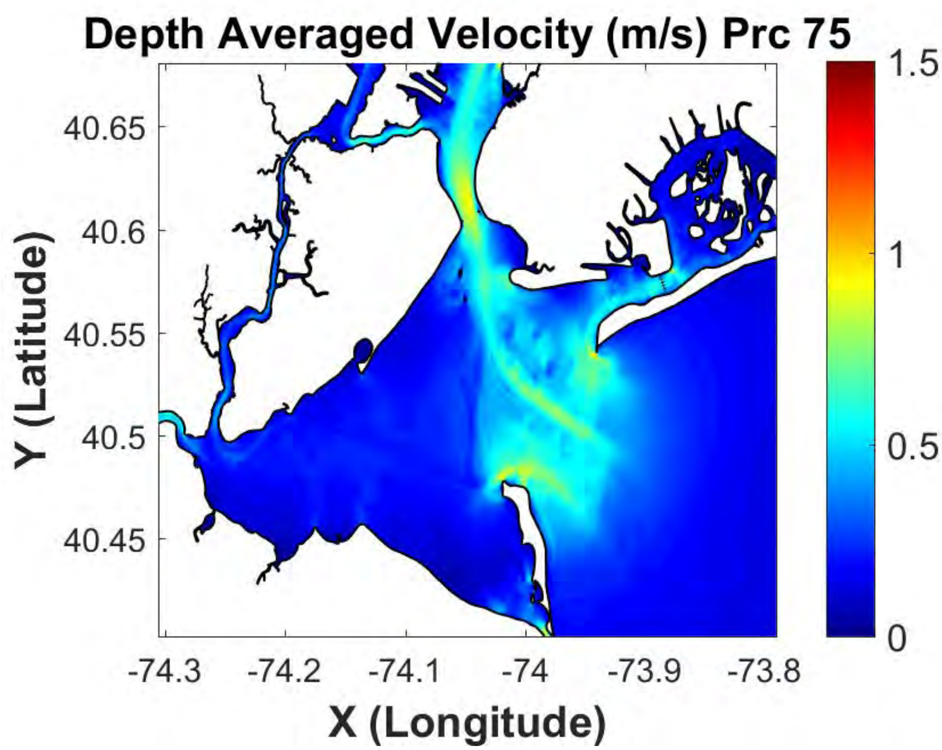
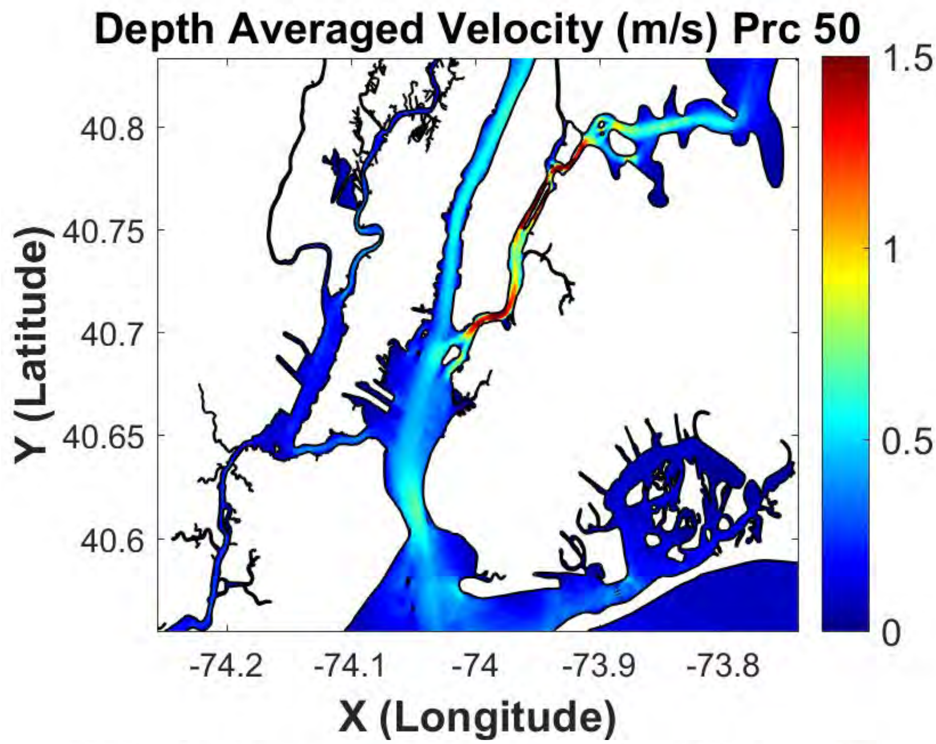


Figure 279. Base/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



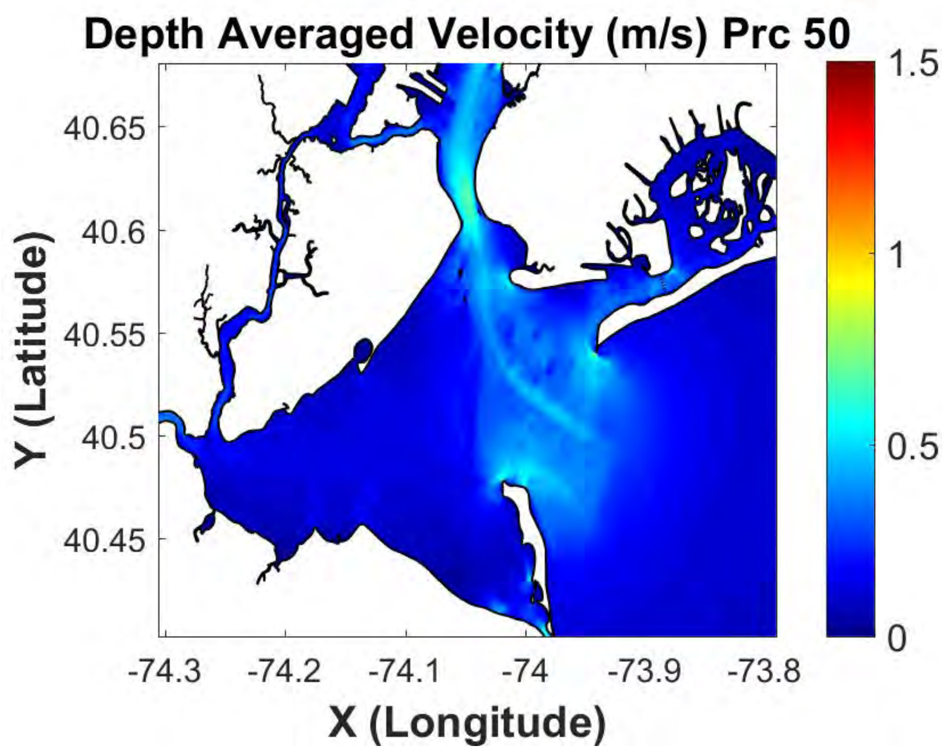
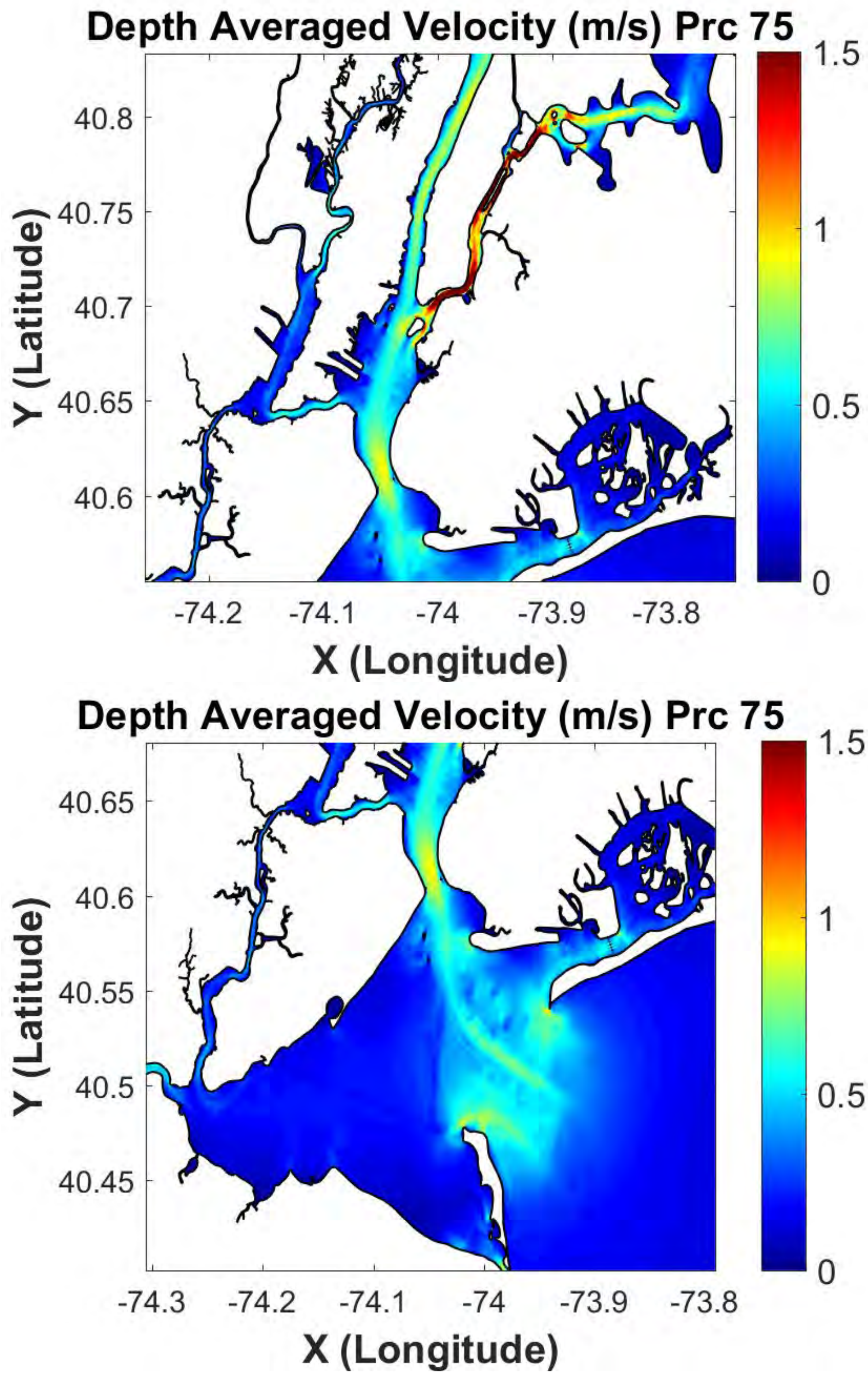


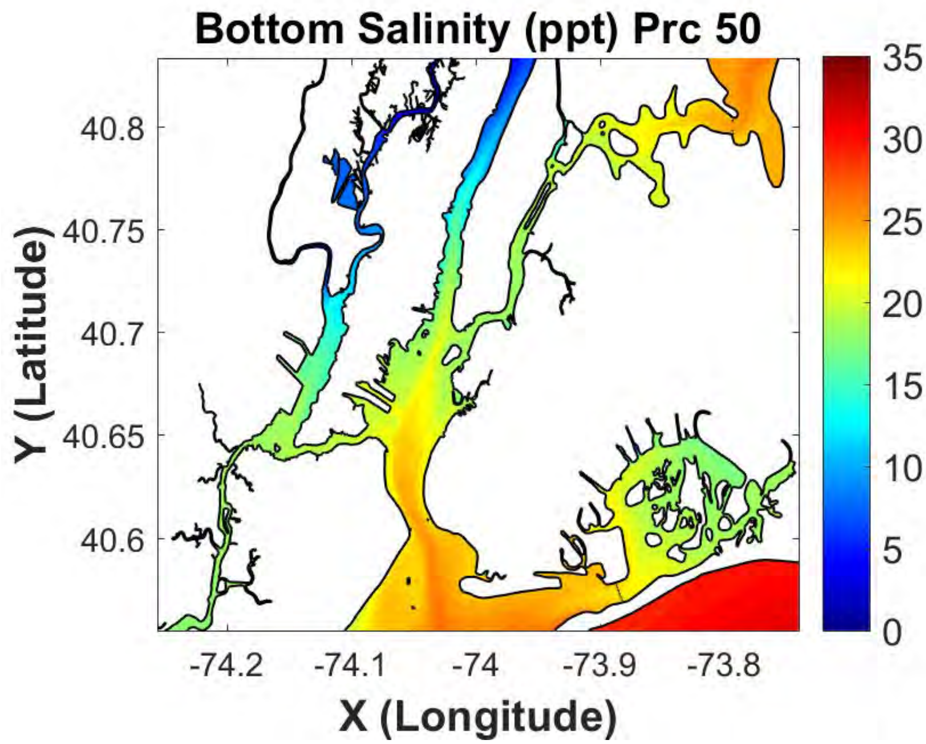
Figure 280. Base/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



15.1.5 Spatial Salinity Percentiles

Spatial figures of the salinity percentiles for the Base Conditions for the 50^{th} and 75^{th} percentiles are provided in Figure 281 to Figure 292.

Figure 281. Base/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



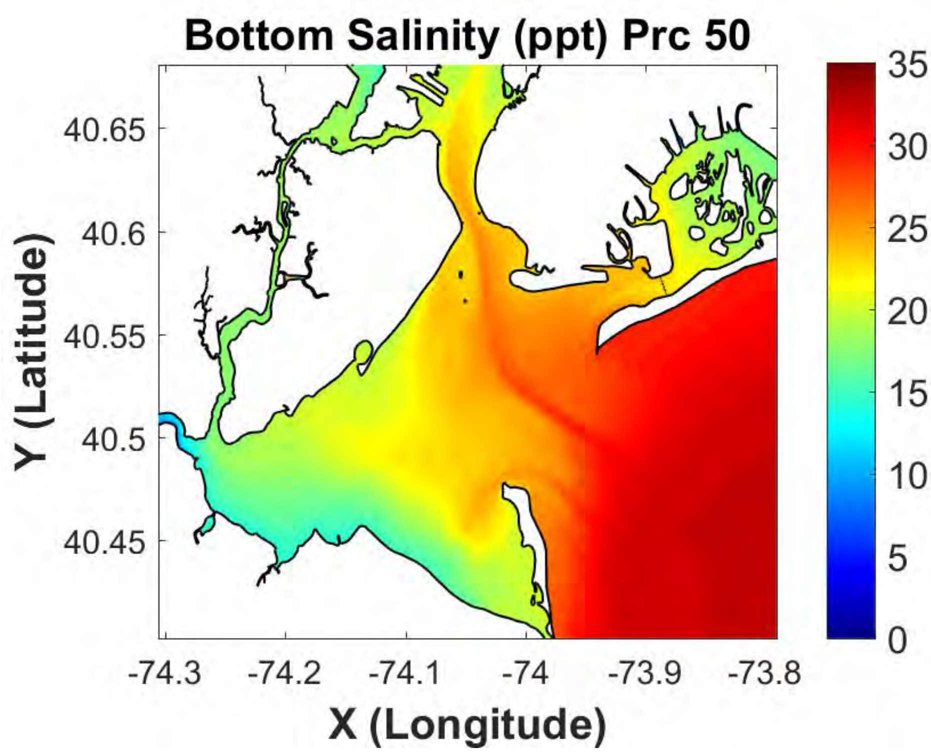
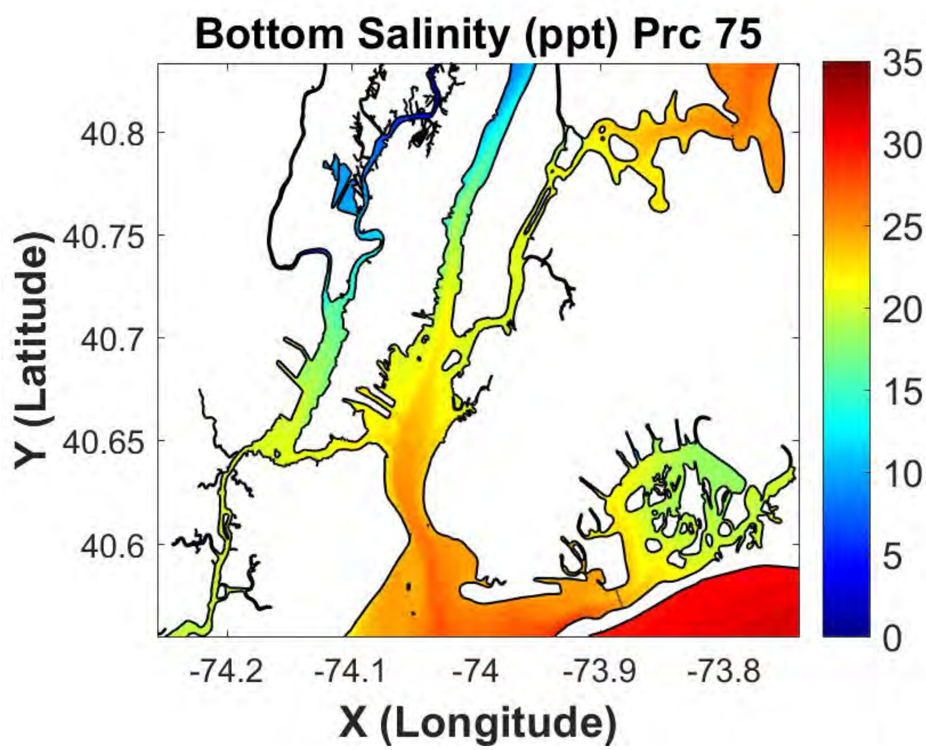


Figure 282. Base/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



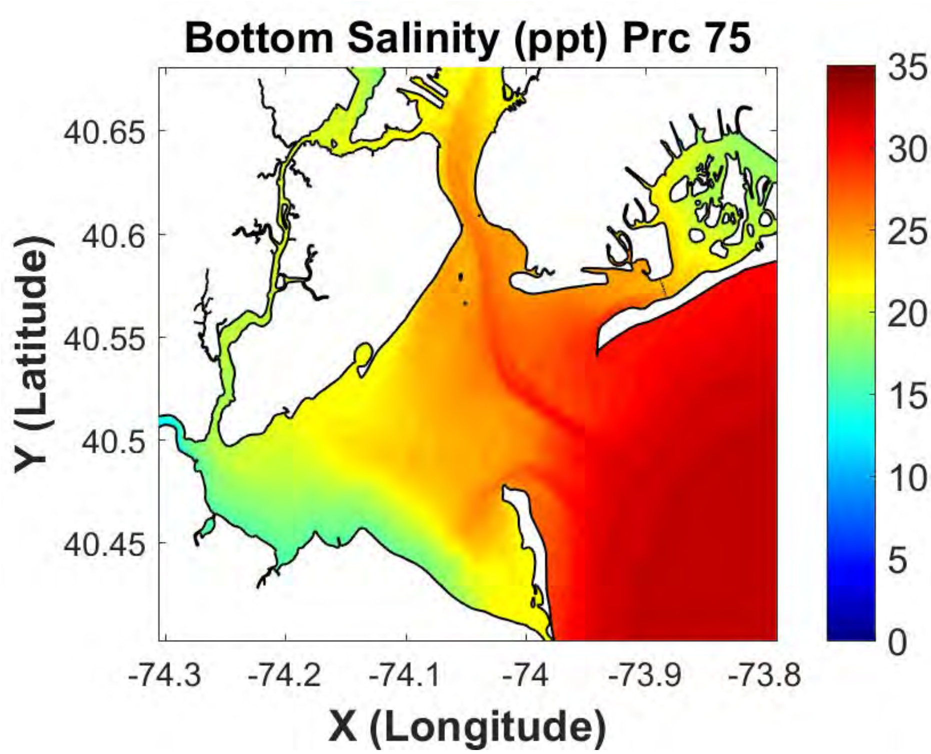
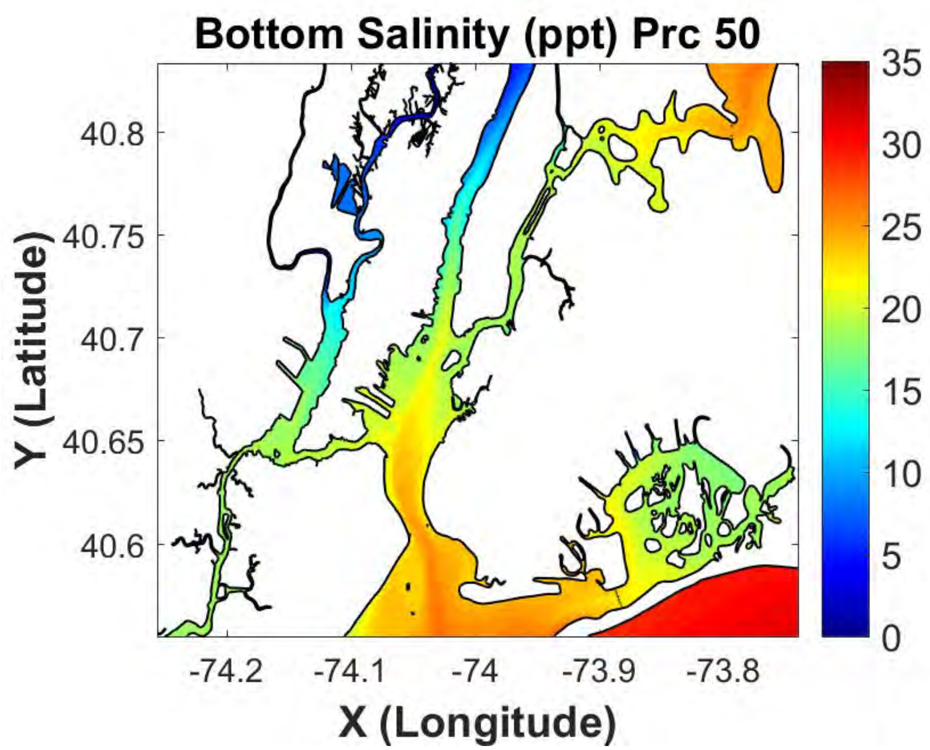


Figure 283. Base/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



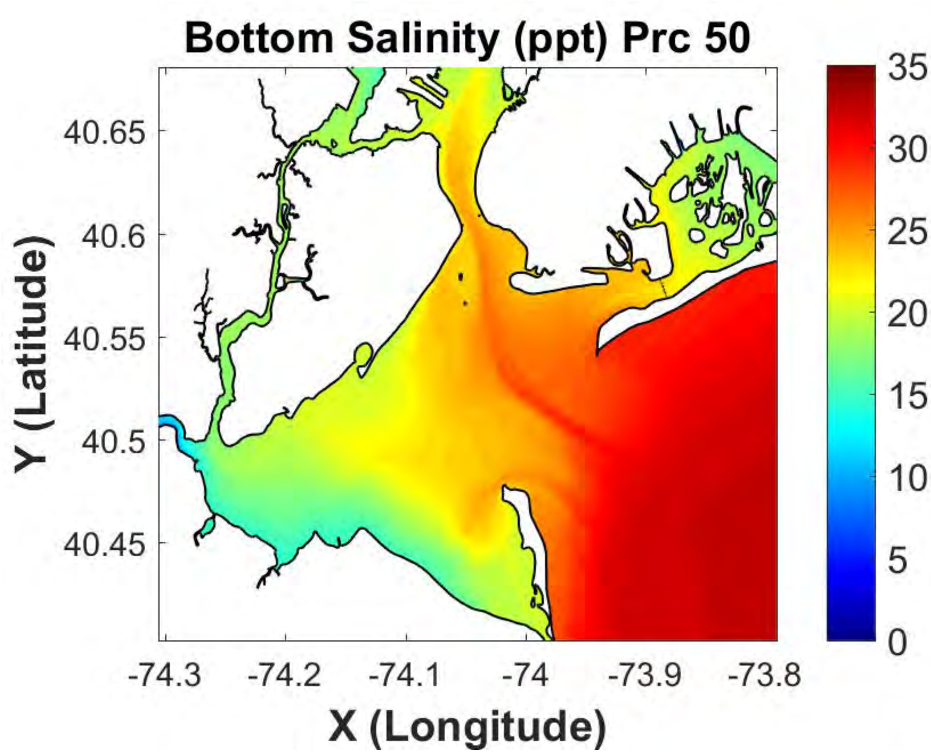
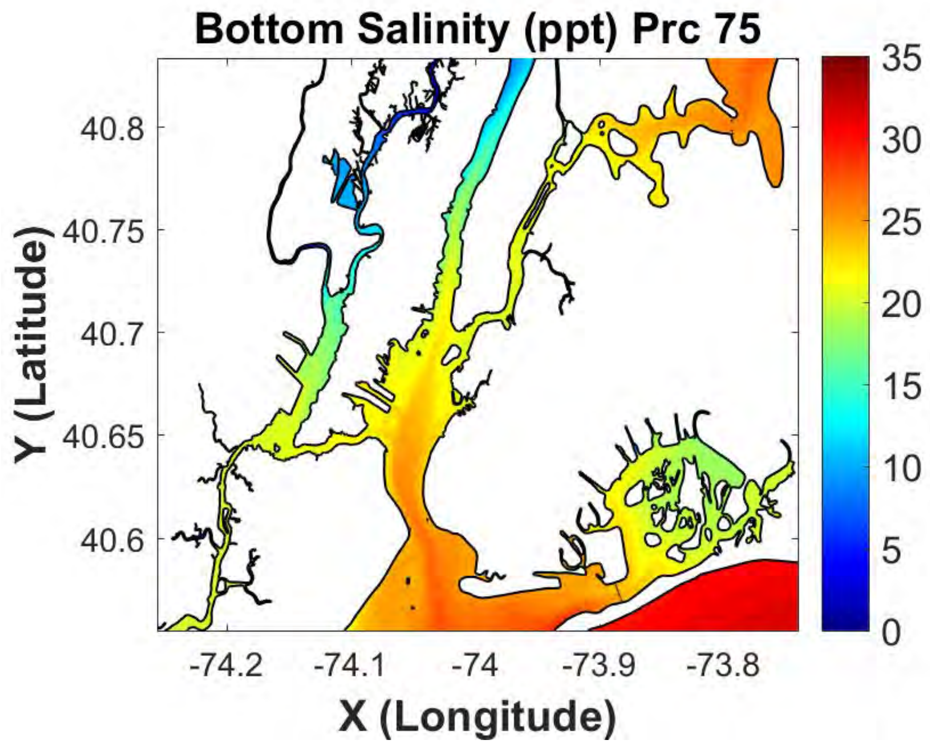


Figure 284. Base/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



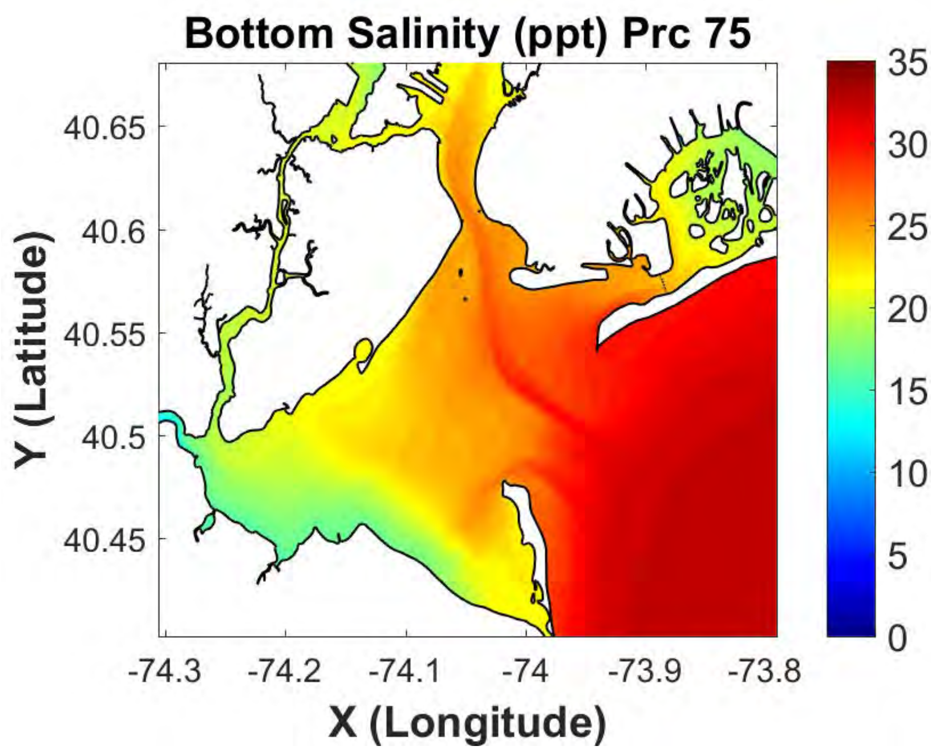


Figure 285. Base/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

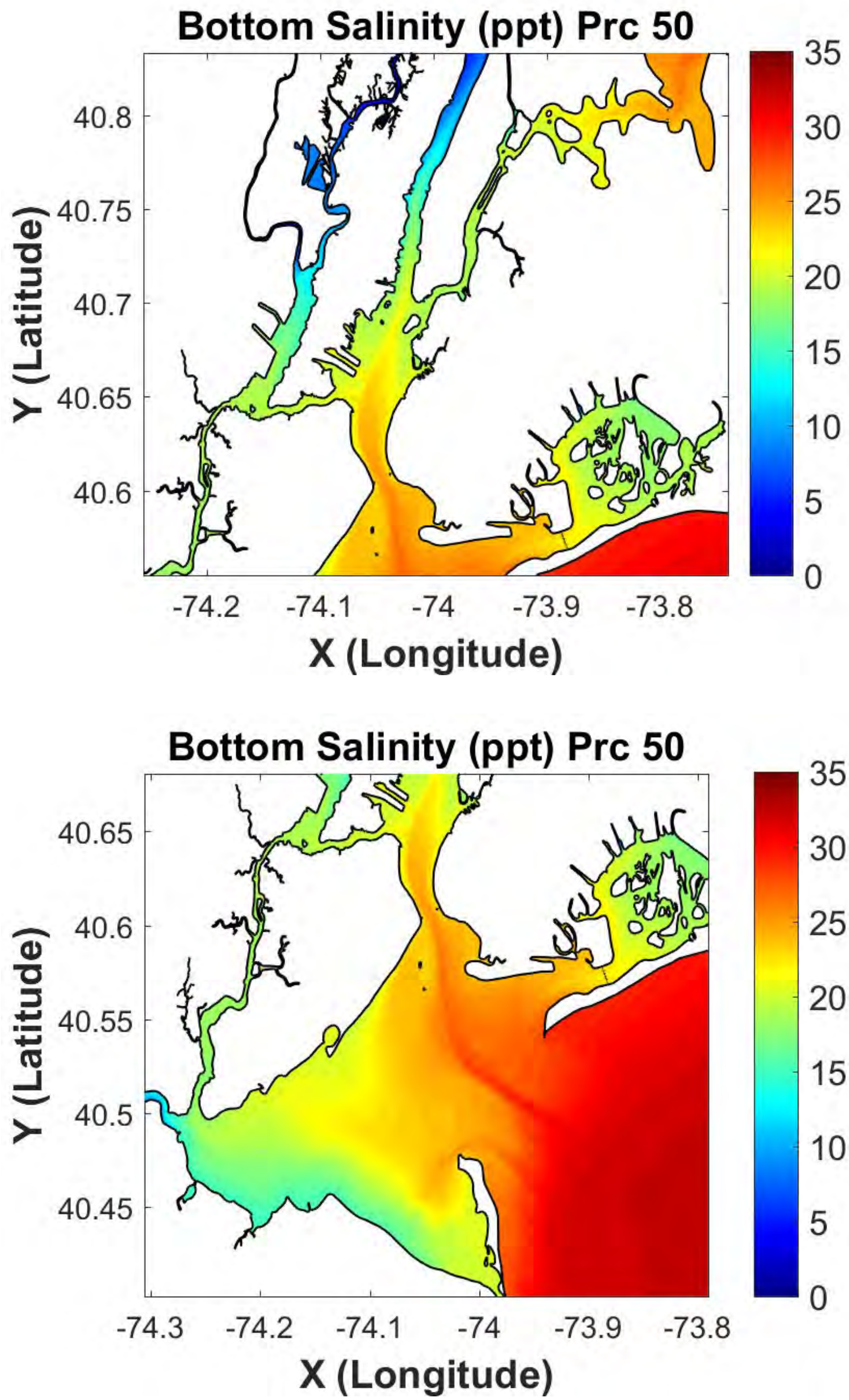
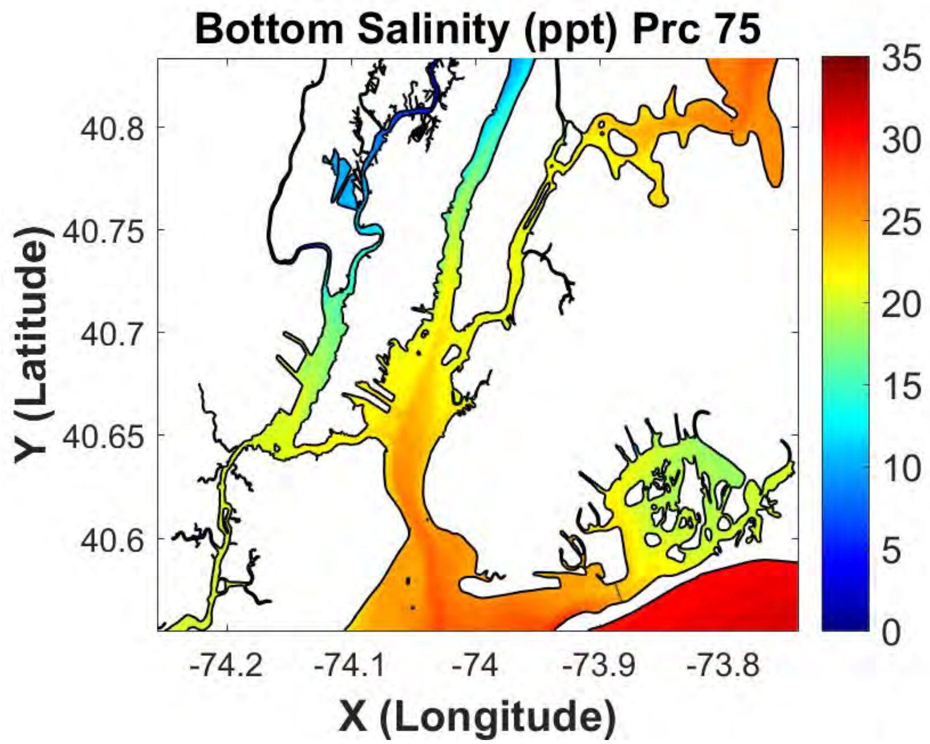


Figure 286. Base/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



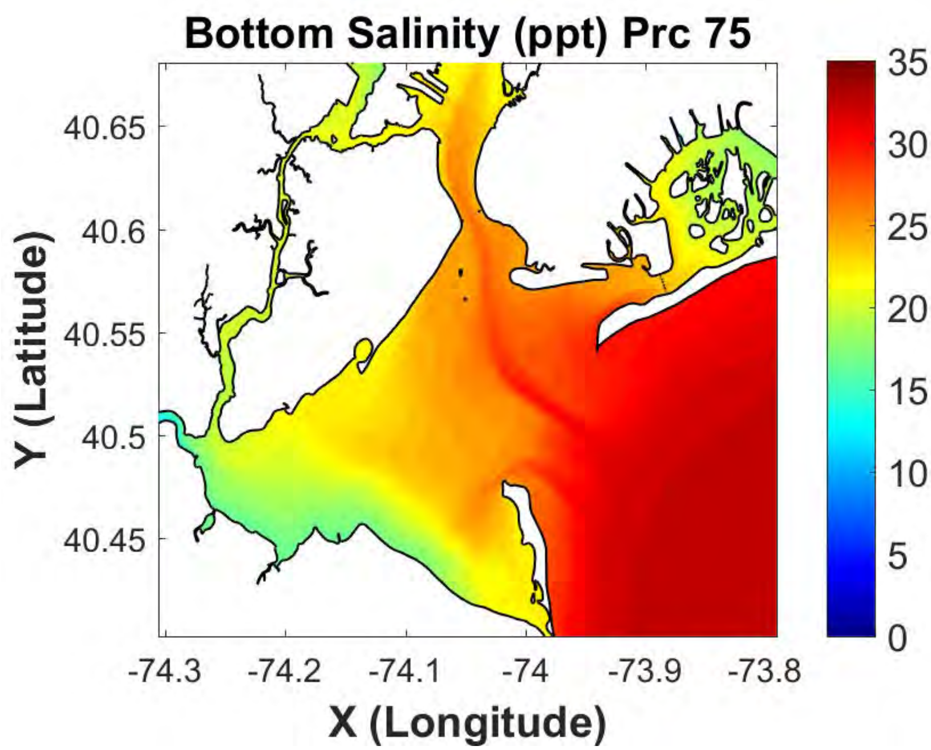
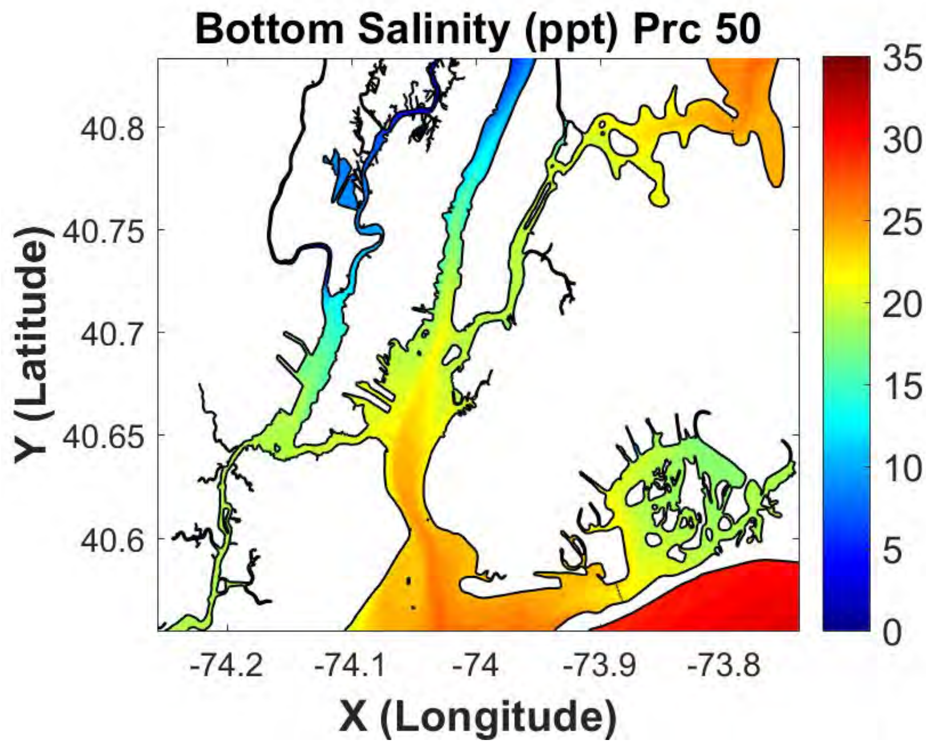


Figure 287. Base/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



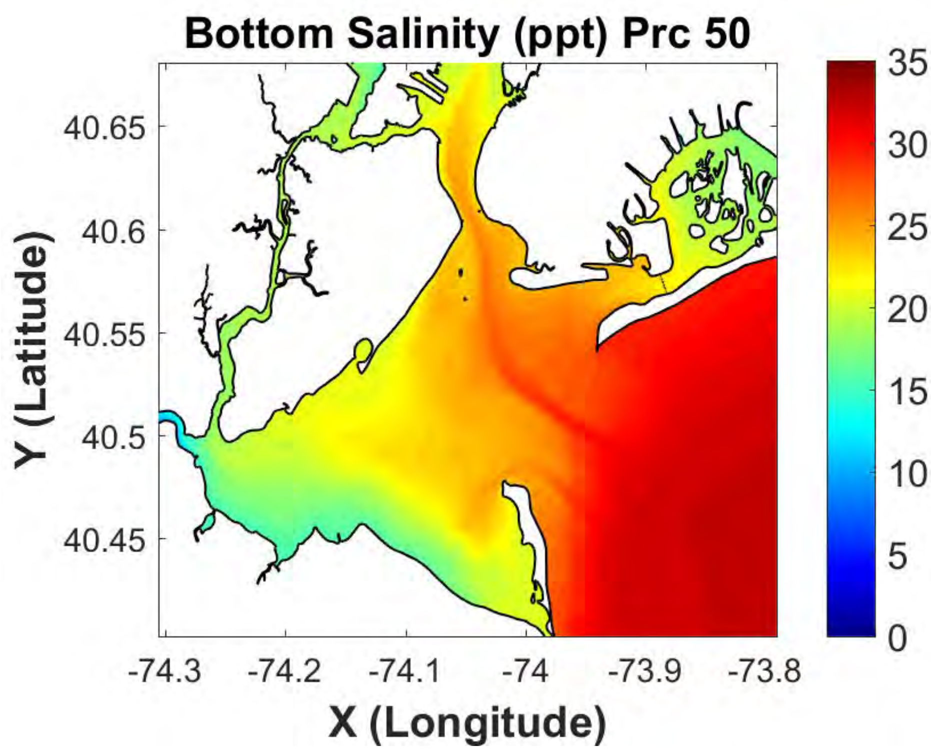
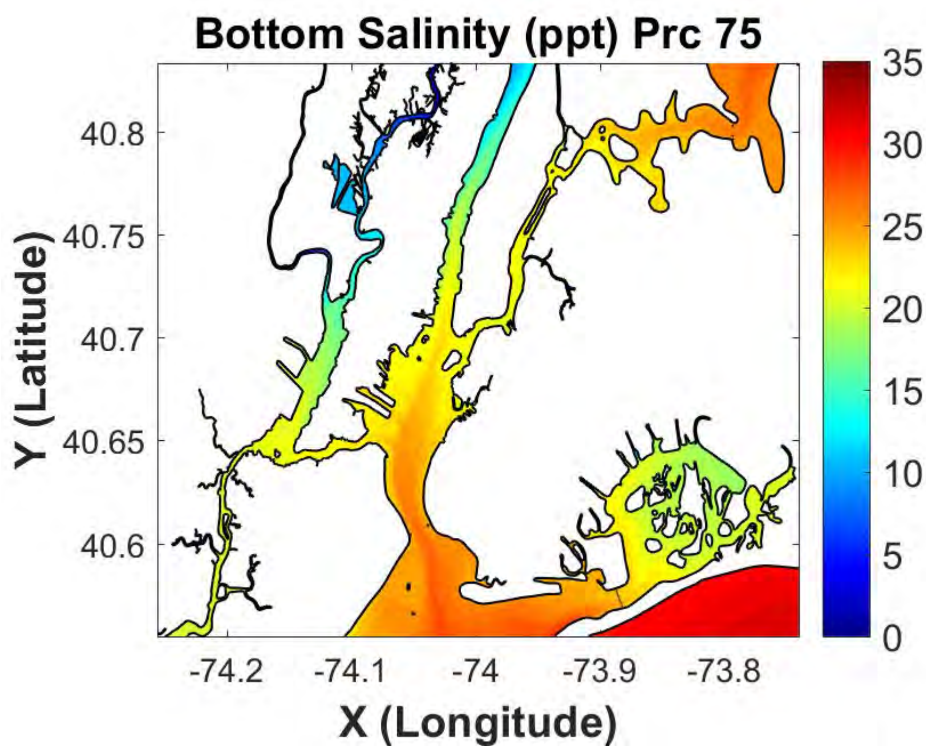


Figure 288. Base/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



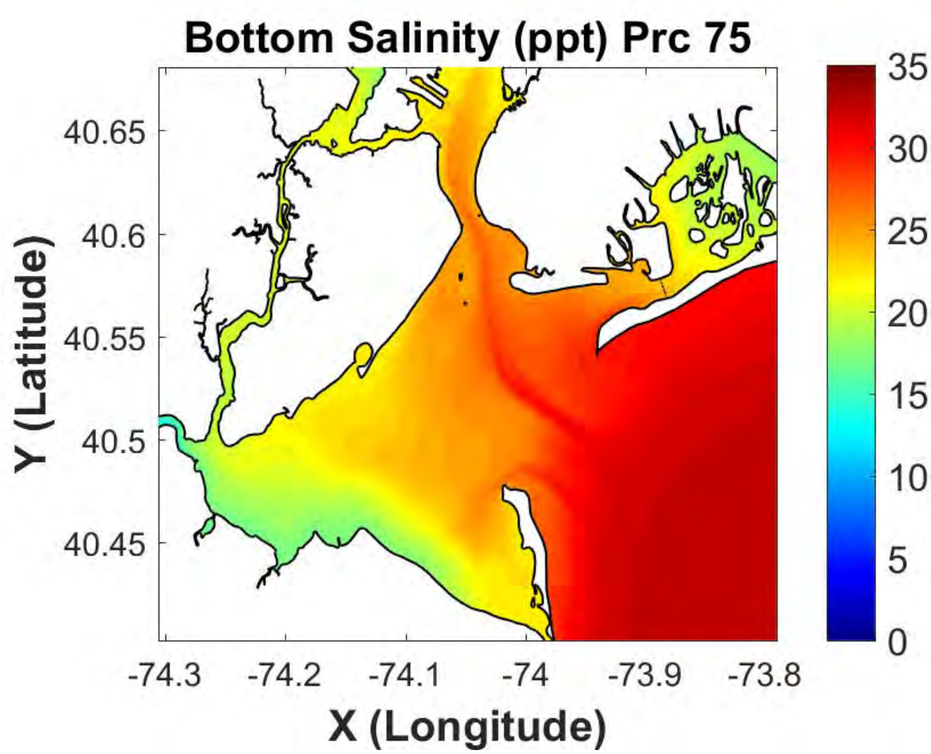
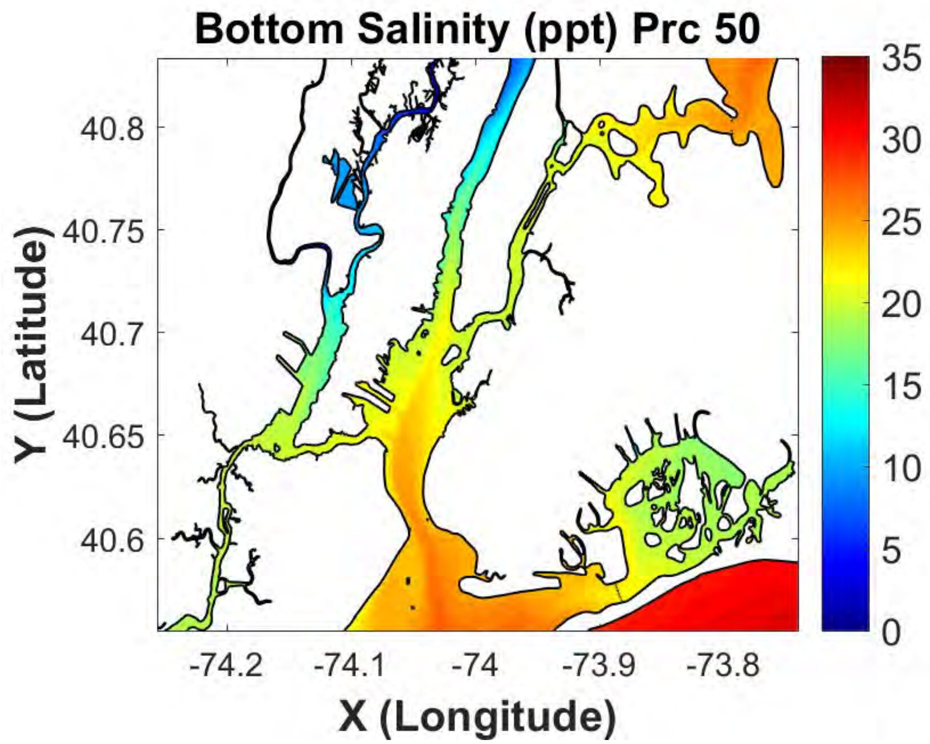


Figure 289. Base/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



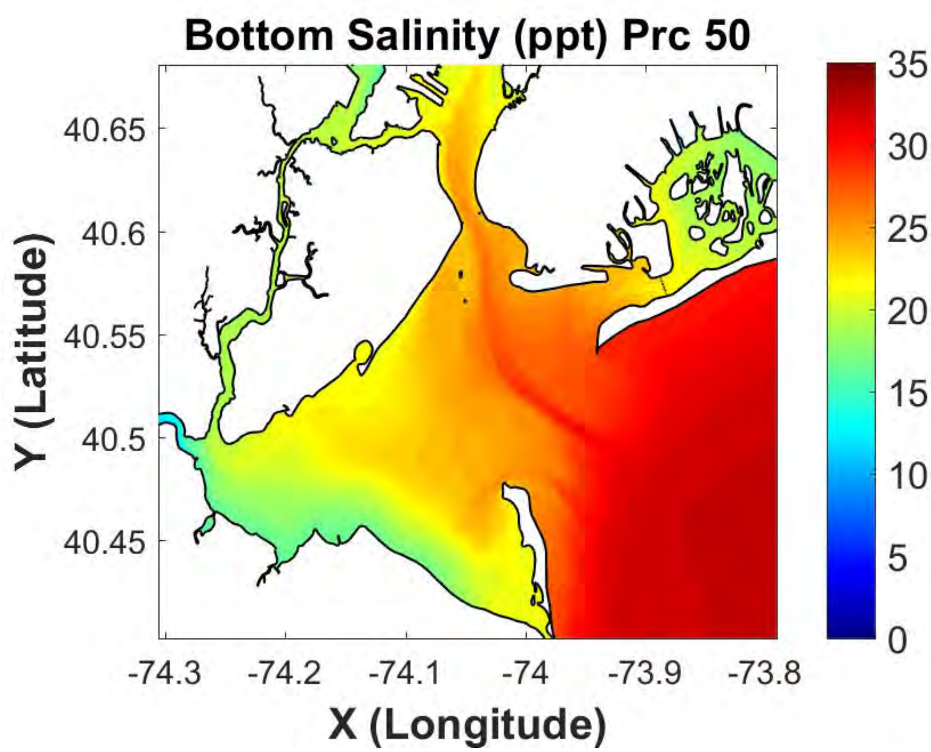
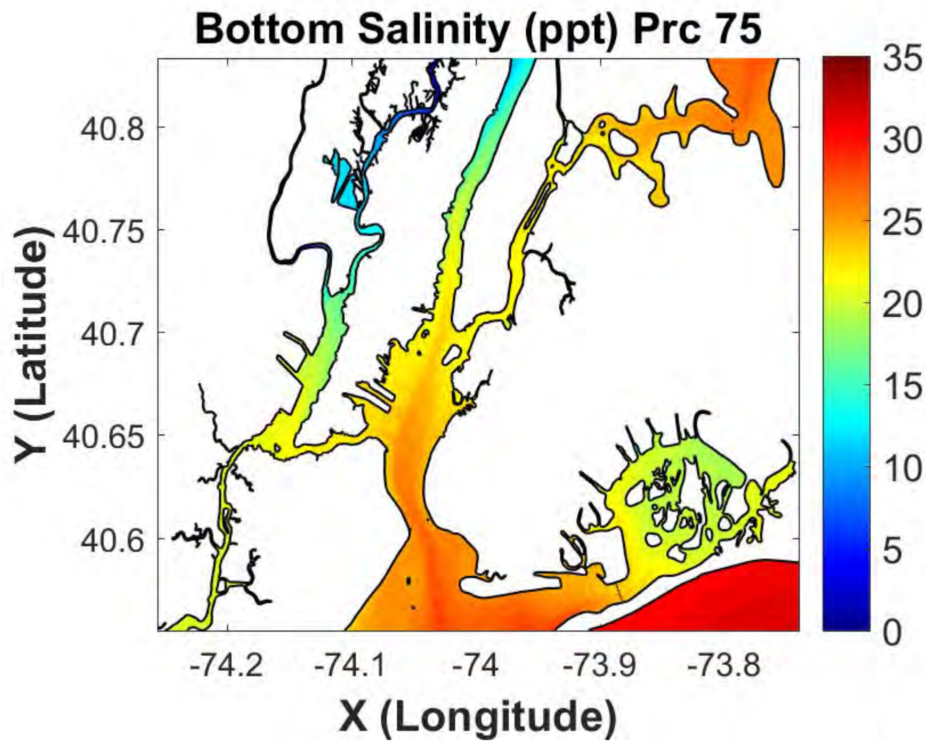


Figure 290. Base/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



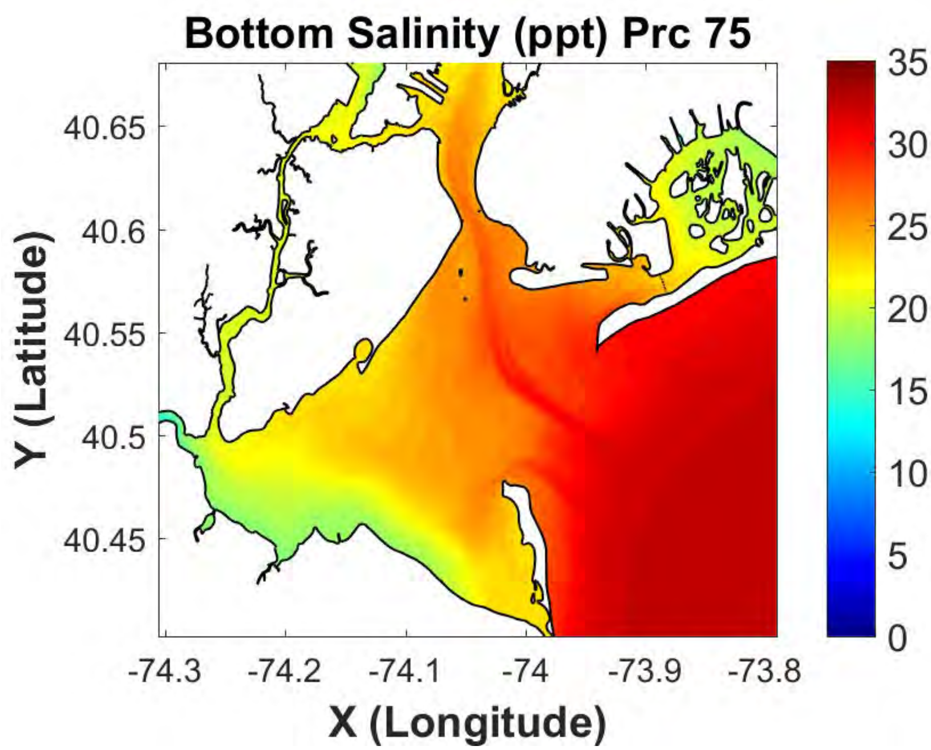


Figure 291. Base/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

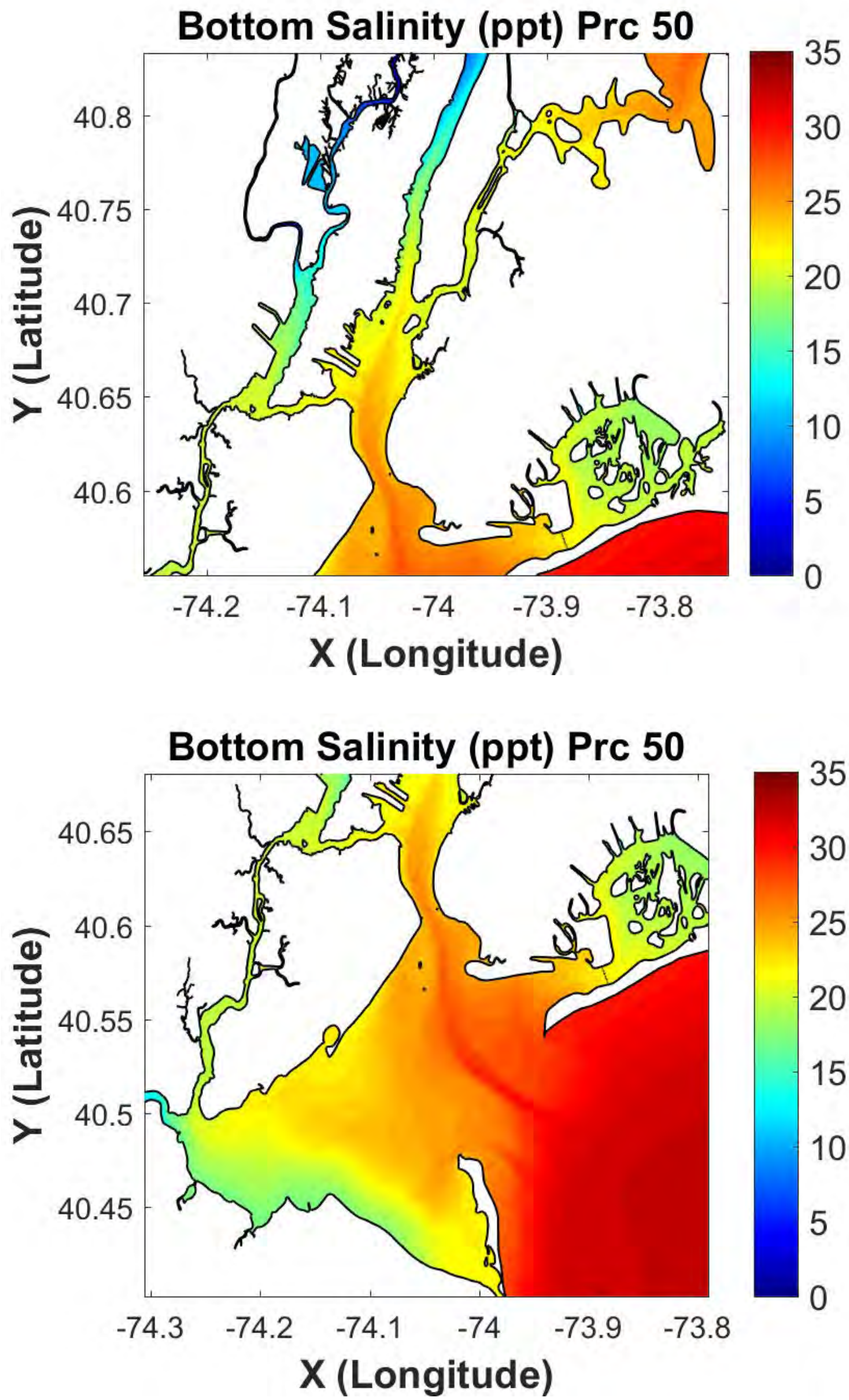
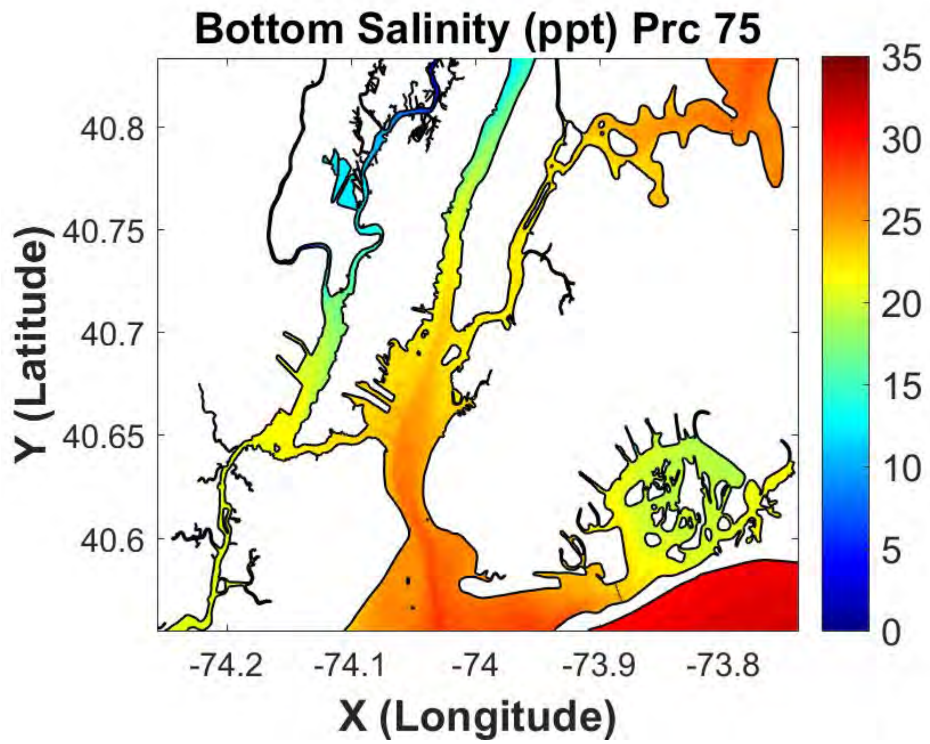
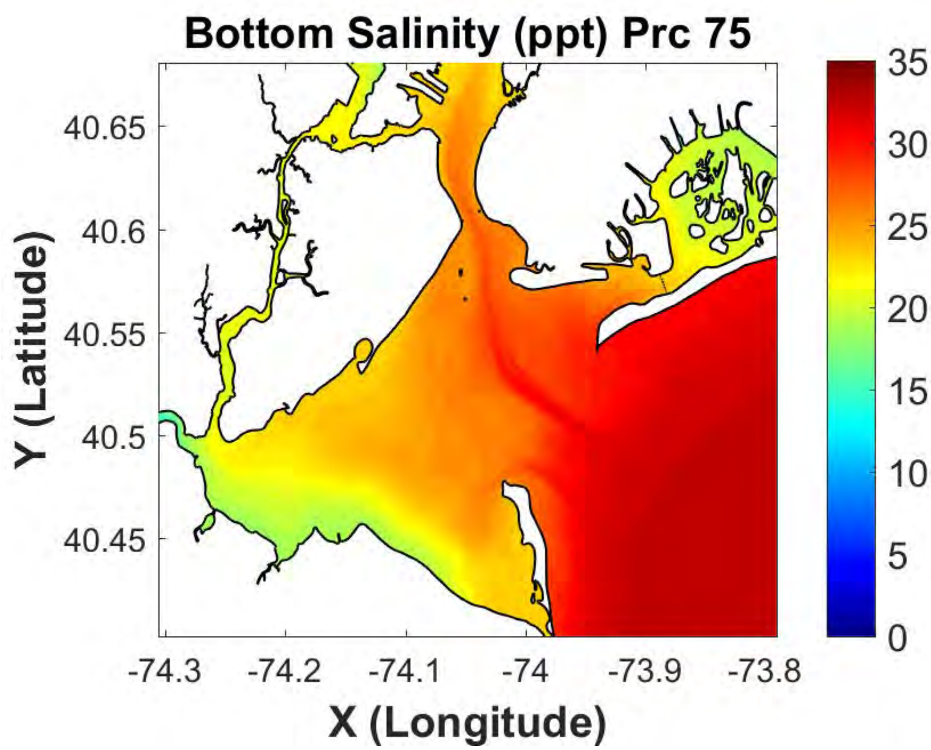


Figure 292. Base/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.





15.1.6 Water Flux Analysis

Discharge percentiles for the Base Conditions for the previously shown locations (Figure 28) are provided in Figure 293 to Figure 296. These locations indicate increased tidal exchange for increasing water levels. Table 7 shows the mean flows for the various pathways and sea levels.

Figure 293. Existing Condition Variation in Throgs Neck Discharges with sea level.

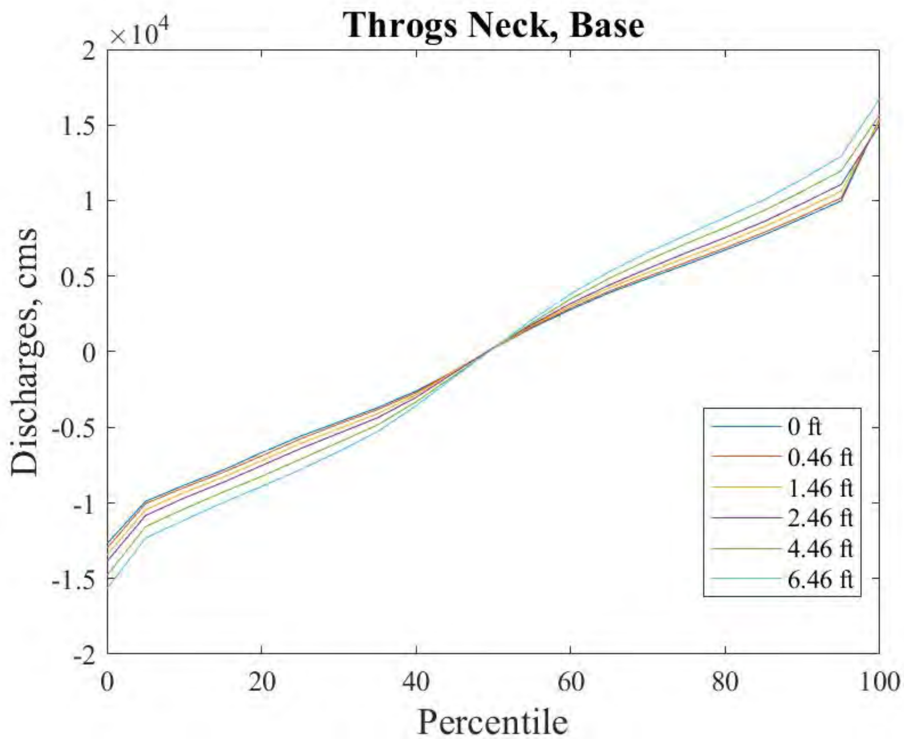


Figure 294. Existing Condition Variation in Verrazano Narrows Discharges with sea level.

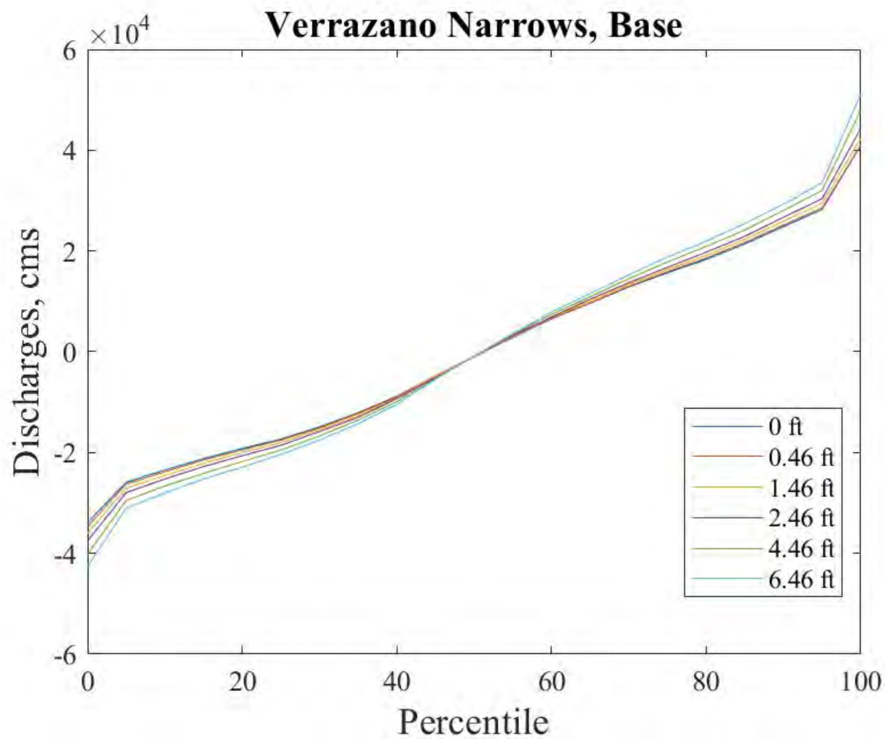


Figure 295. Existing Condition Variation in Kill Van Kull Discharges with sea level.

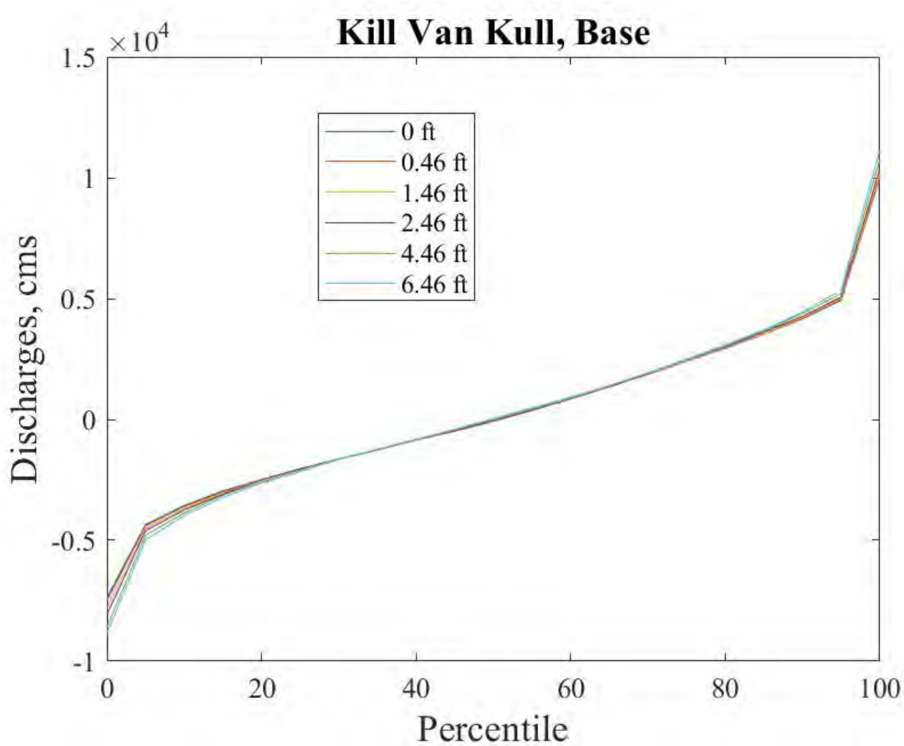


Figure 296. Existing Condition Variation in Arthur Kill Discharges with sea level.

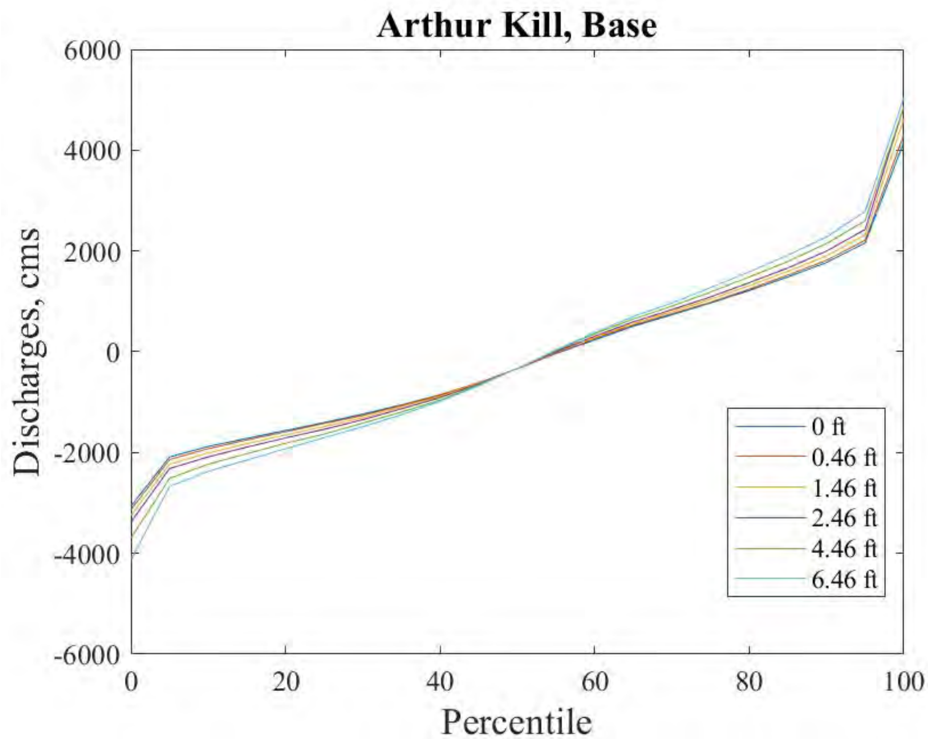


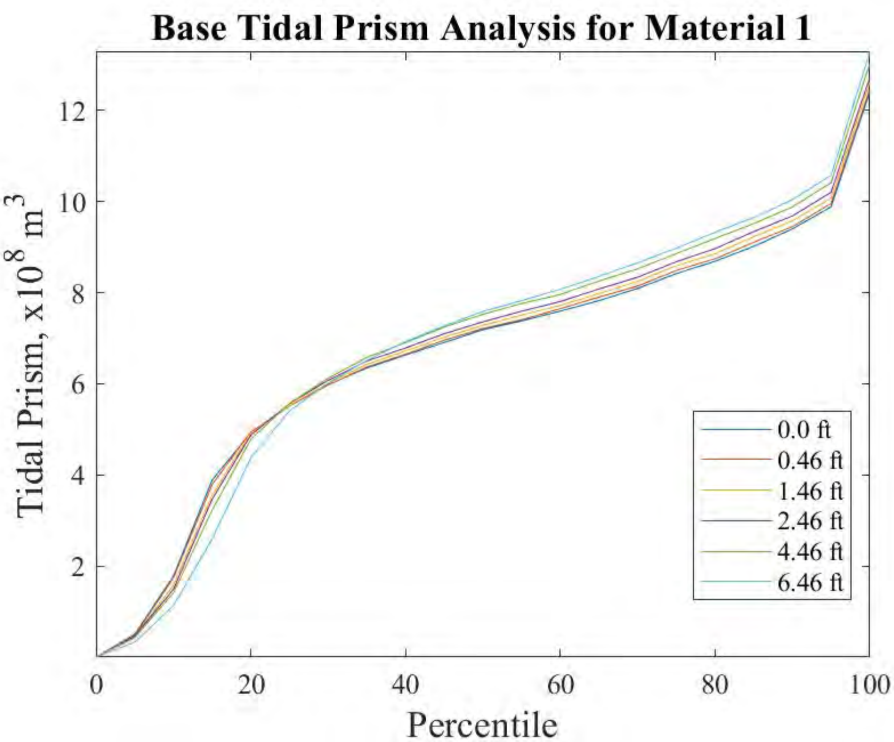
Table 7. Base, Sea Level Rise Impacts of Flows in CMS.

Location	0.0 ft. MSL	0.46 ft. MSL	1.46 ft. MSL	2.46 ft. MSL	4.46 ft. MSL	6.46 ft. MSL
Throgs Neck	80	82	86	90	102	116
Verrazano Narrows	-302	-305	-310	-316	-327	-341
Kill Van Kull	152	151	149	148	147	147
Arthur Kill	-178	-177	-175	-174	-173	-173

15.1.7 Tidal Prism Analysis

Tidal prisms were calculated, and a percentile analysis was performed to evaluate the impact of sea level rise on the tidal exchange. Figure 297 shows the tidal prism for all sea level values for the base conditions for the area previously shown in Figure 33. These results indicate higher sea level values result in higher tidal prisms and associated tidal exchange/mixing.

Figure 297. Tidal Prism Percentile Analysis for Base Conditions for Material 1.



15.2 Alternative 2

For increased sea levels, Alternative 2 possesses increasing tidal exchange, tide ranges, and salinity intrusion. The velocities are also increased as the increases in the tidal exchange override the increased depths also present in the sea level rise alternatives.

15.2.1 Water Surface Elevation Point Percentiles

Water surface elevation (WSE) percentiles for Alternative 2 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 298 to Figure 322. The datum in these plots is relative to Mean Sea Level for 1995. The datum Mean Sea Level will increase with sea level rise (SLR) but for the purposes of these comparisons it is held constant, so all water levels are relative 0.0 MSL for 1995.

Figure 298. Alt 2, Sandy Hook WSE Variation with SLR.

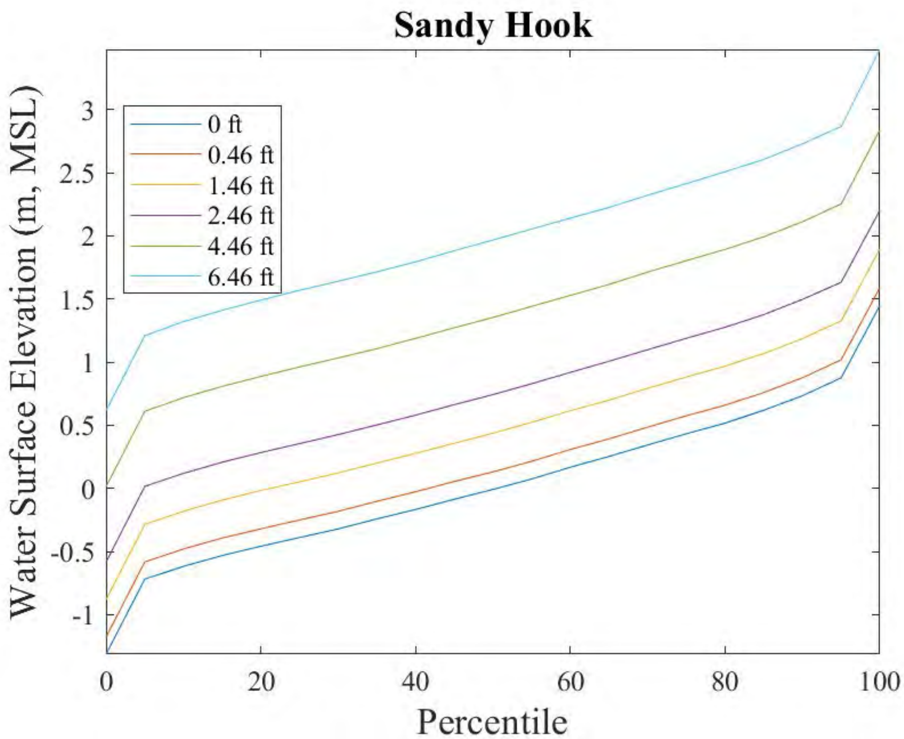


Figure 299. Alt 2, V5 WSE Variation with SLR.

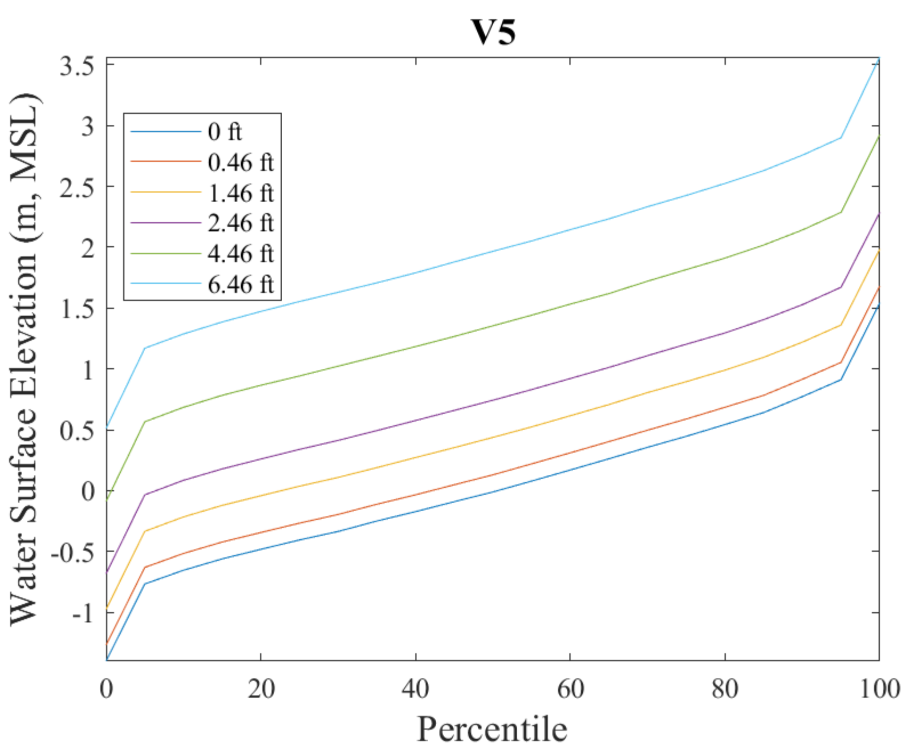


Figure 300. Alt 2, V6 WSE Variation with SLR.

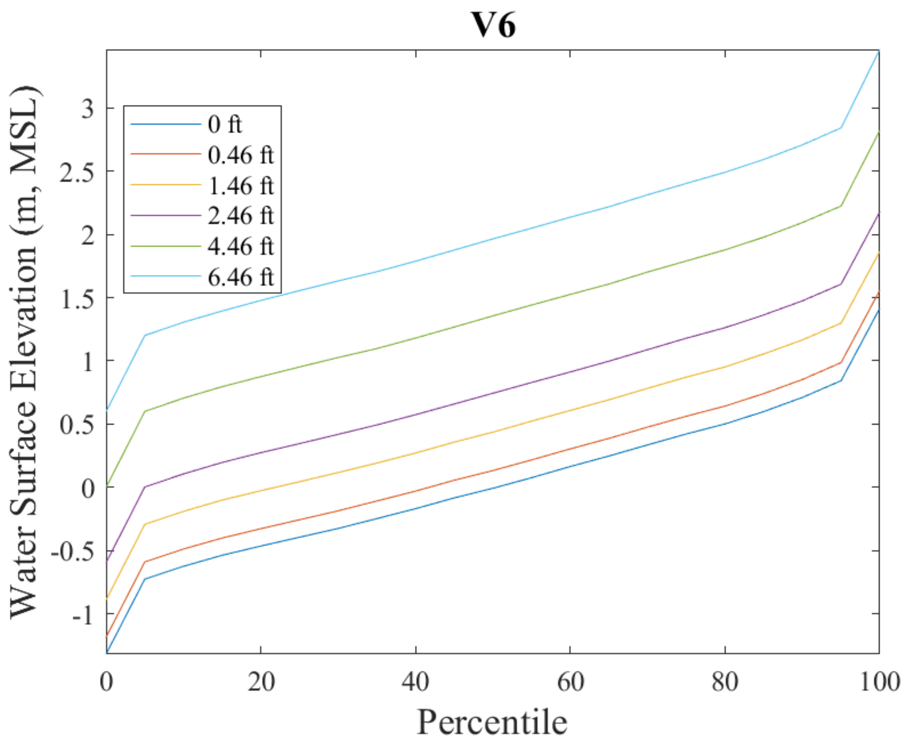


Figure 301. Alt 2, Fresh Kills WSE Variation with SLR.

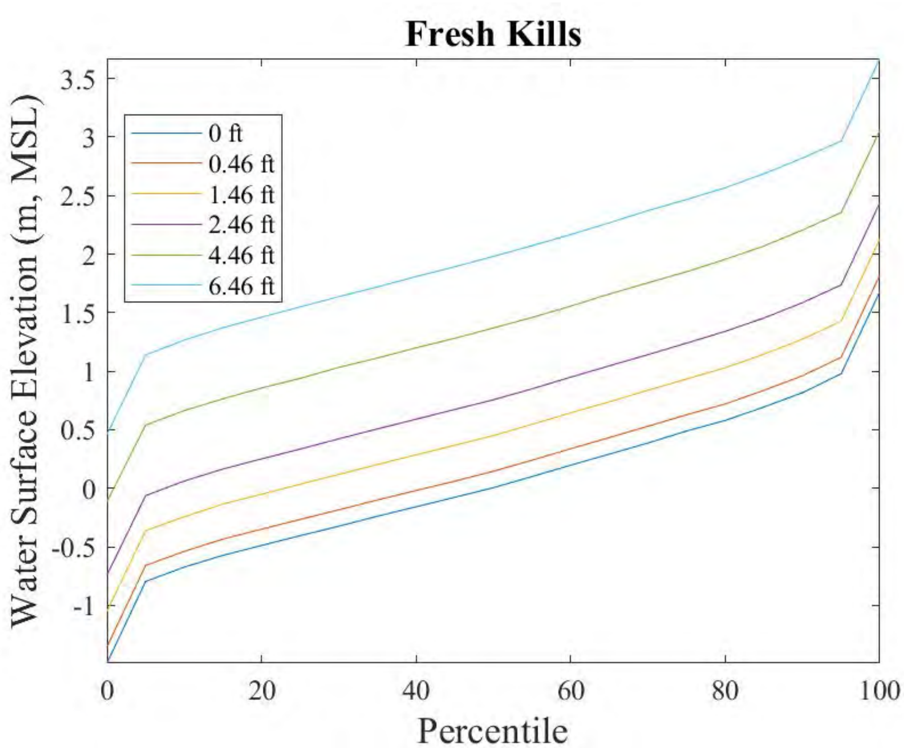


Figure 302. Alt 2, Mariners Harbor WSE Variation with SLR.

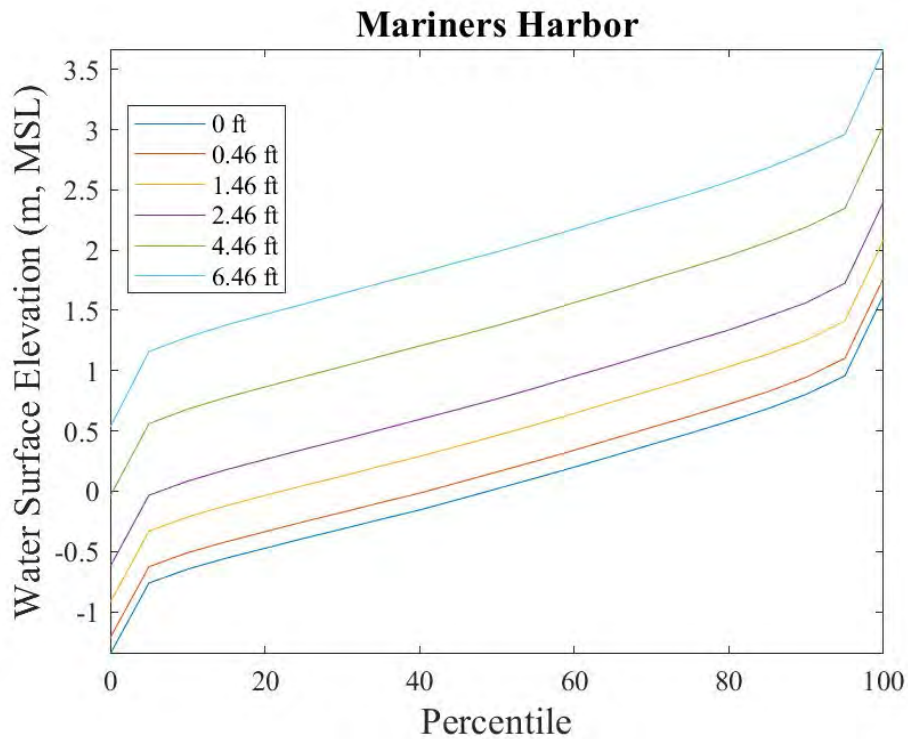


Figure 303. Alt 2, T2 WSE Variation with SLR.

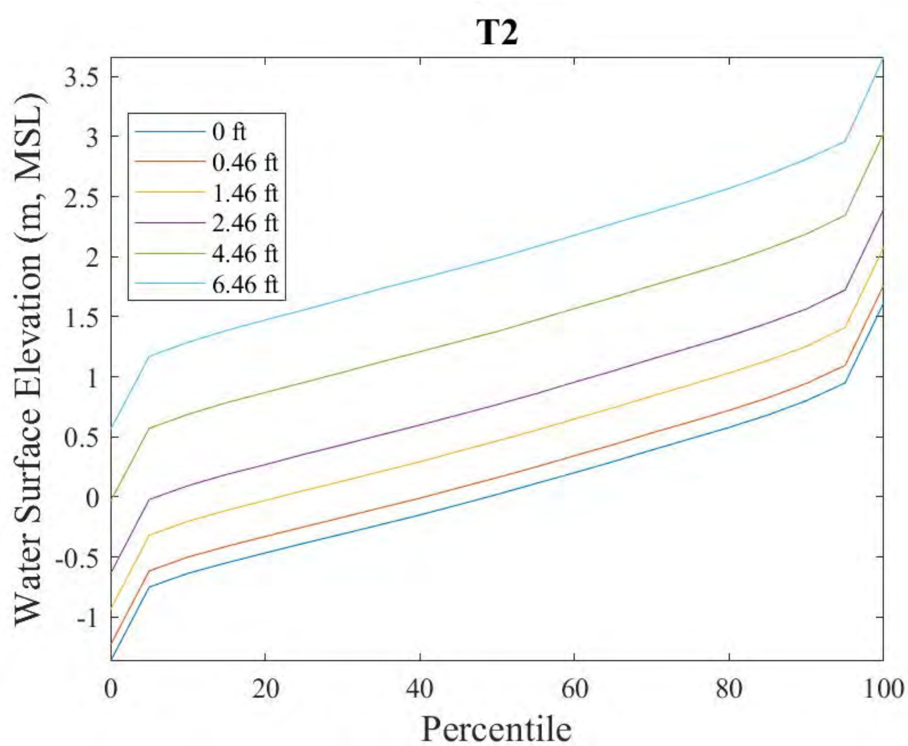


Figure 304. Alt 2, T3 WSE Variation with SLR.

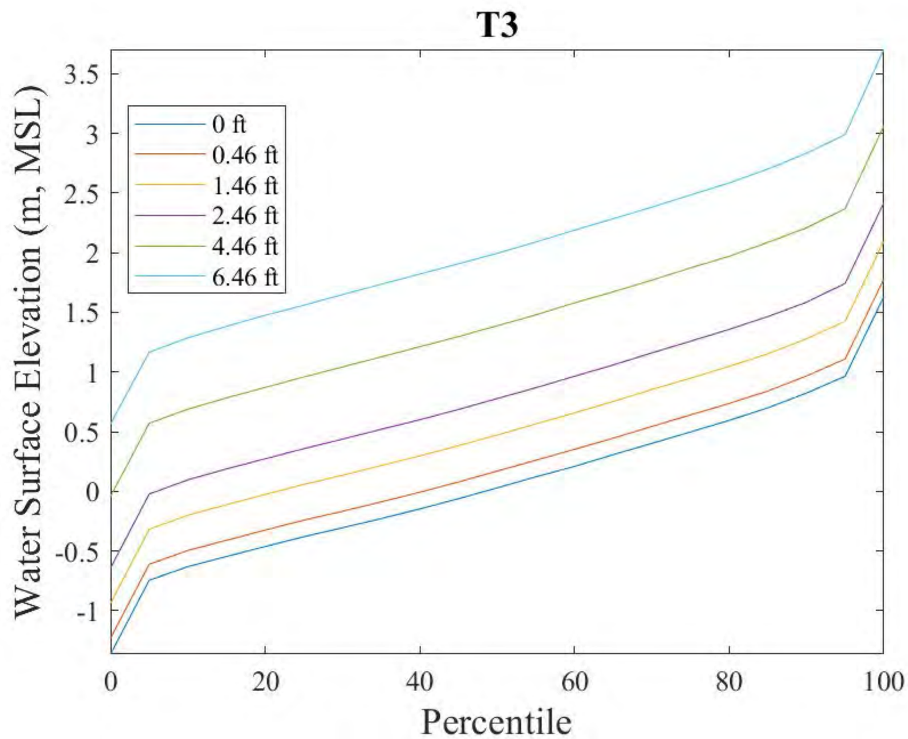


Figure 305. Alt 2, North Reach WSE Variation with SLR.

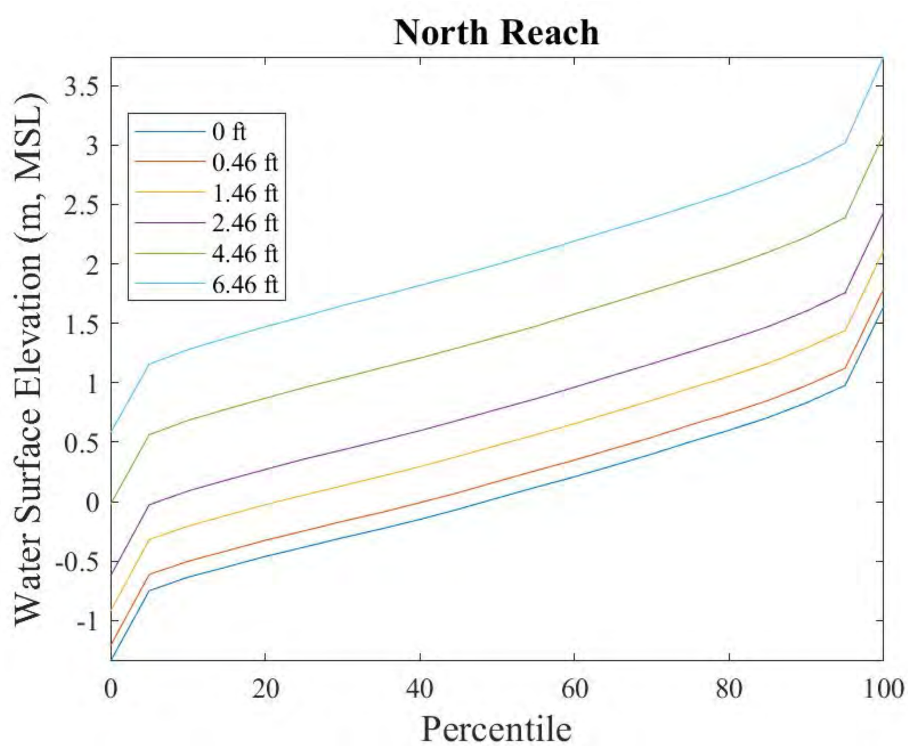


Figure 306. Alt 2, Hackensack River WSE Variation with SLR.

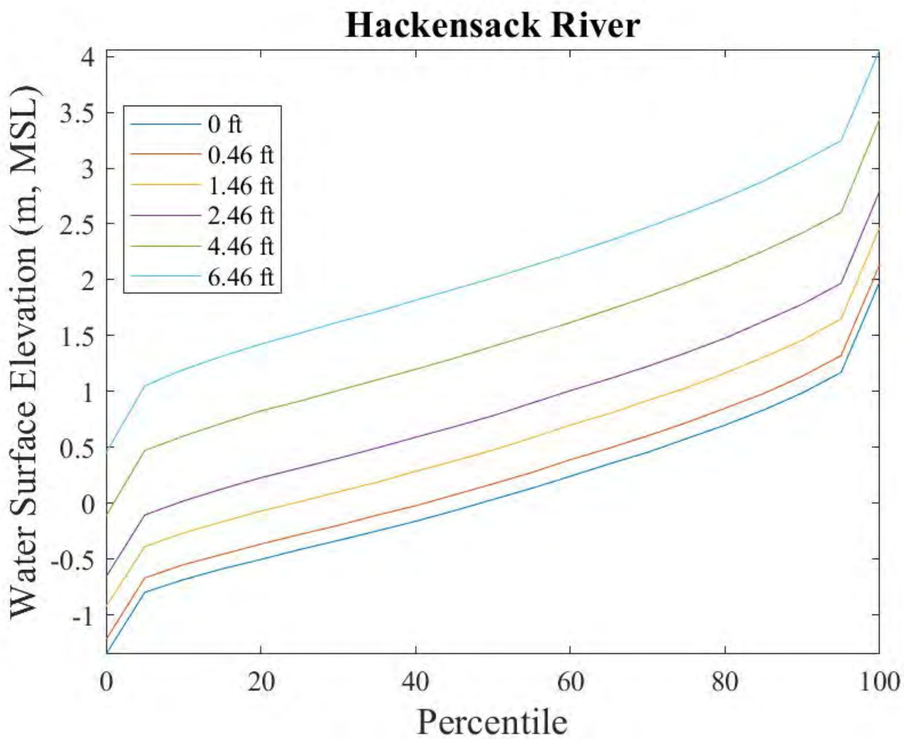


Figure 307. Alt 2, Robbins Reef WSE Variation with SLR.

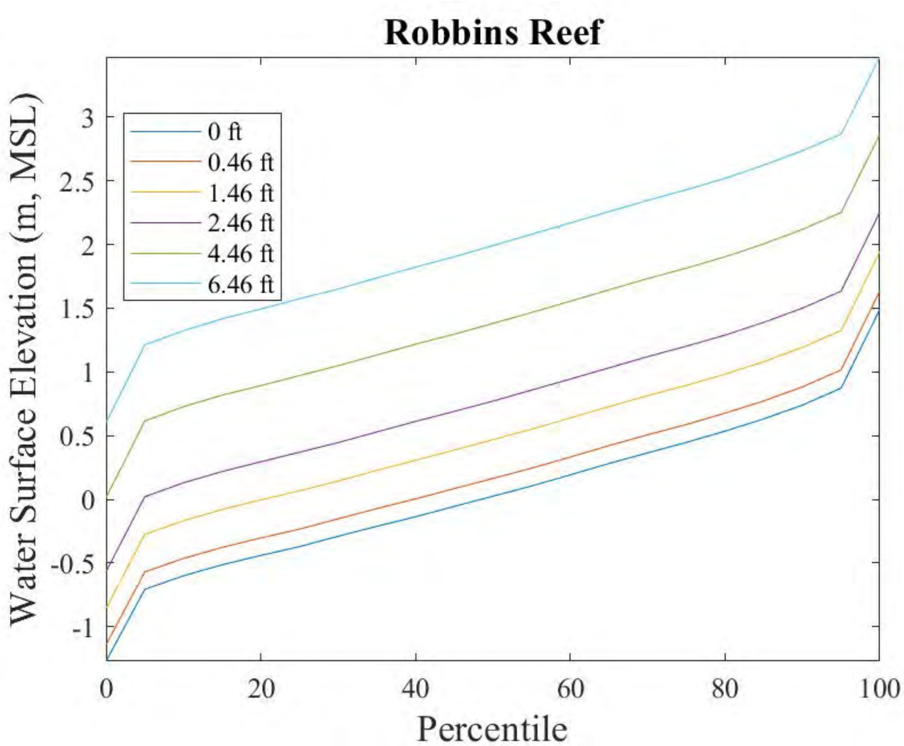


Figure 308. Alt 2, S2 WSE Variation with SLR.

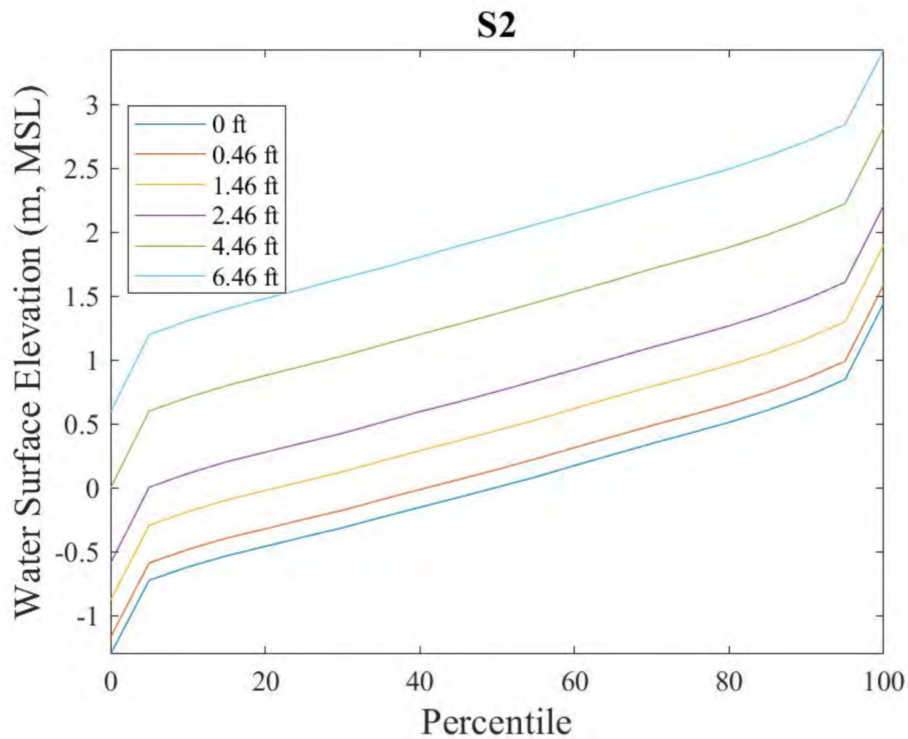


Figure 309. Alt 2, S5 WSE Variation with SLR.

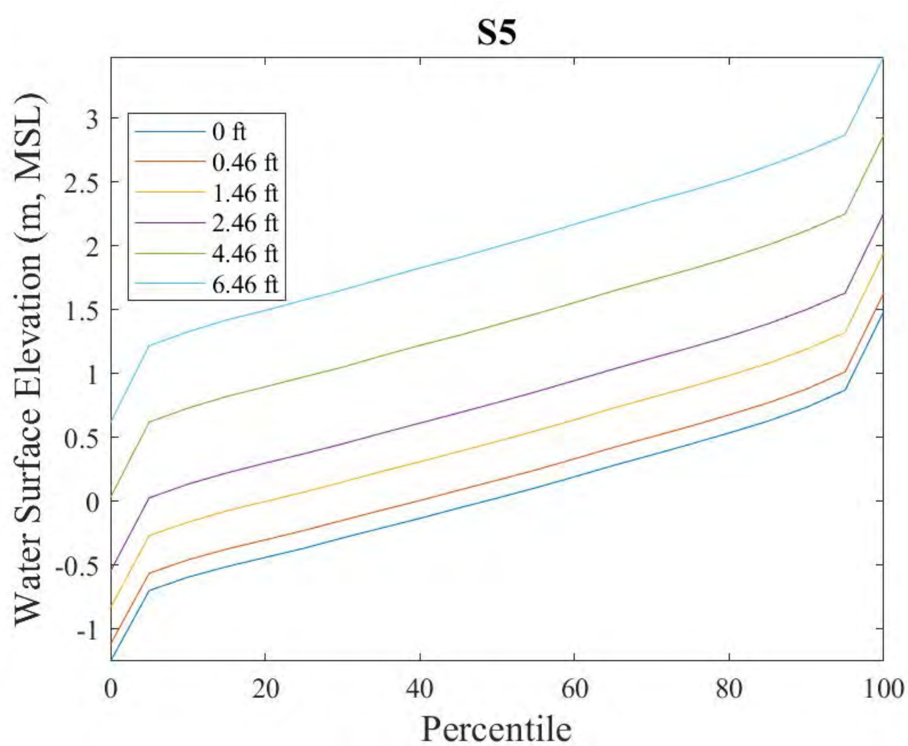


Figure 310. Alt 2, The Battery WSE Variation with SLR.

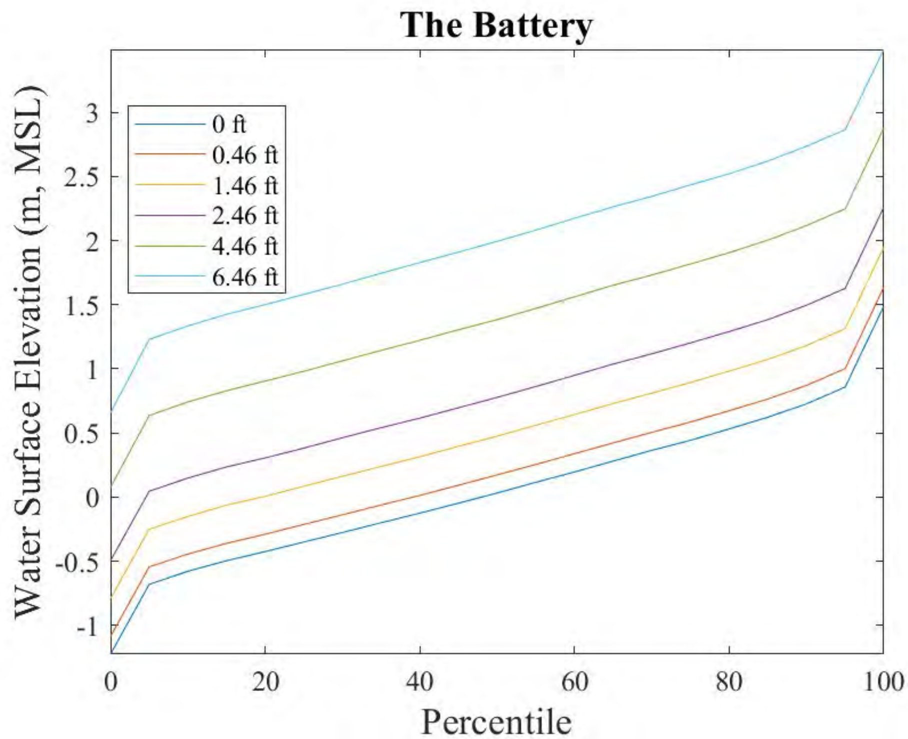


Figure 311. Alt 2, Manhattan WSE Variation with SLR.

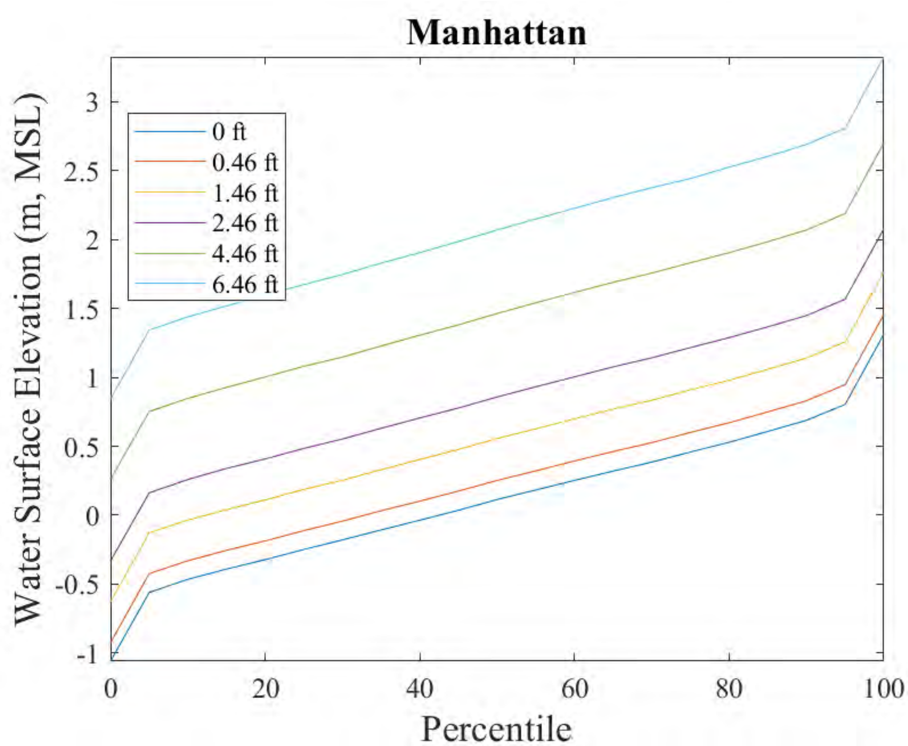


Figure 312. Alt 2, Jamaica Bay WSE Variation with SLR.

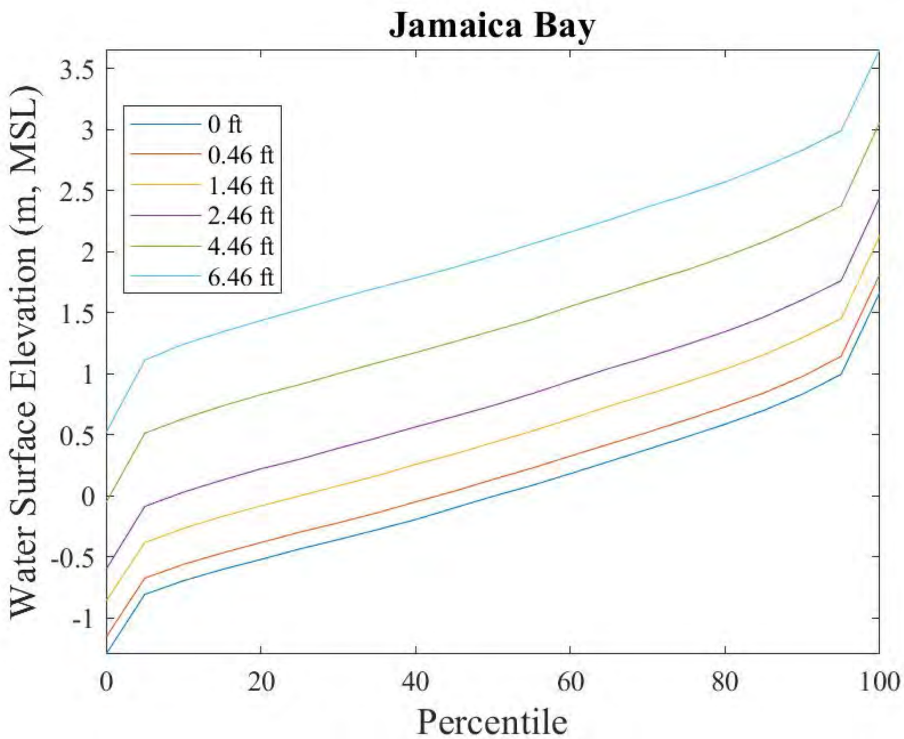


Figure 313. Alt 2, Jamaica Bay near Spring Creek WSE Variation with SLR.

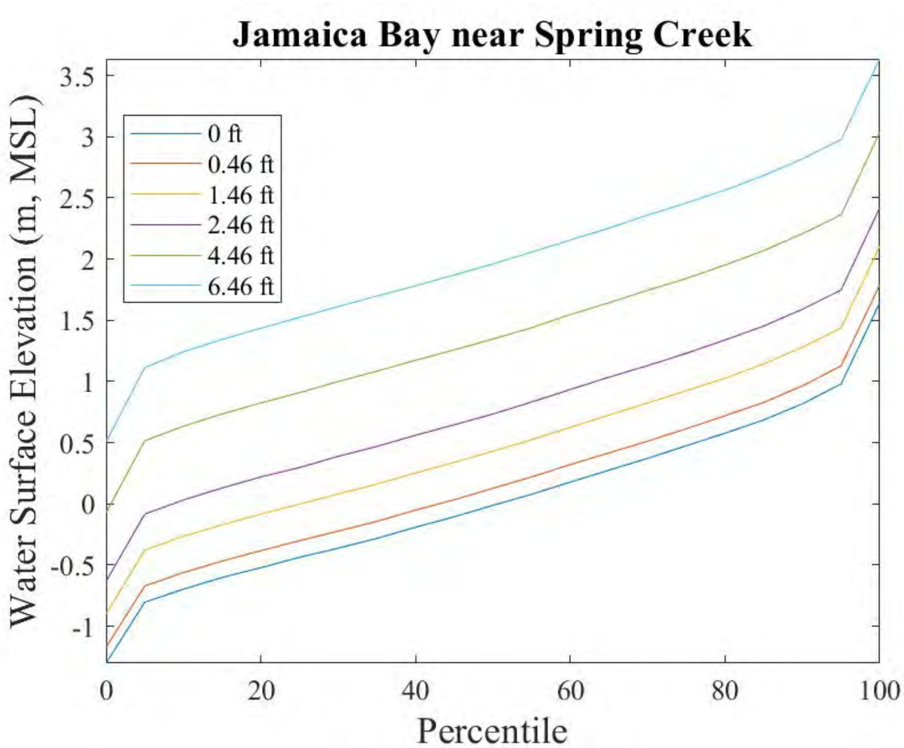


Figure 314. Alt 2, Jamaica Bay near Grass Hassock WSE Variation with SLR.

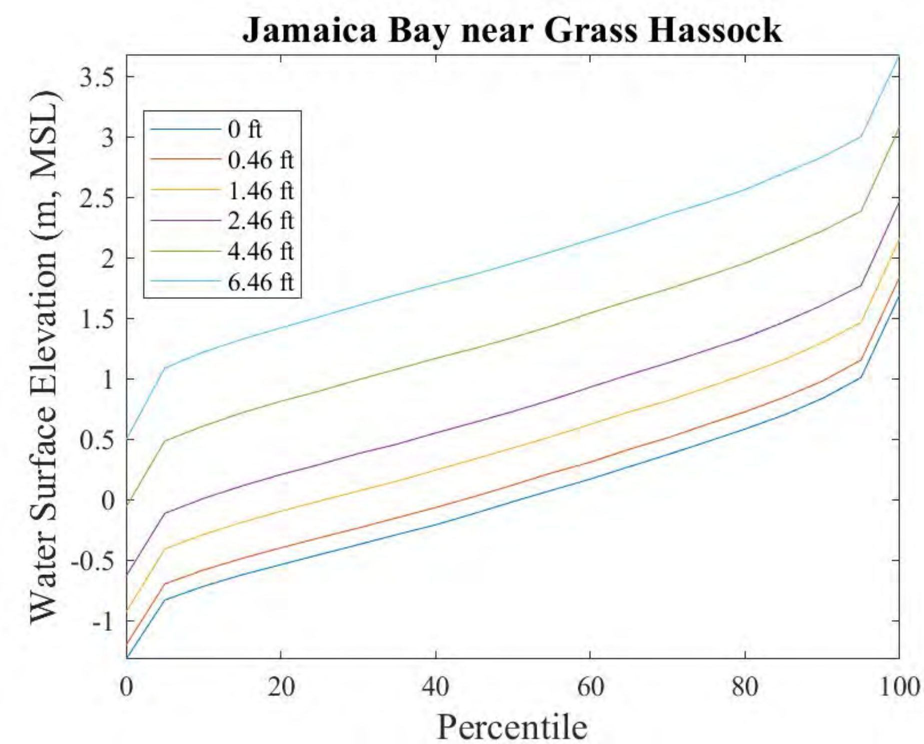


Figure 315. Alt 2, KLGA WSE Variation with SLR.

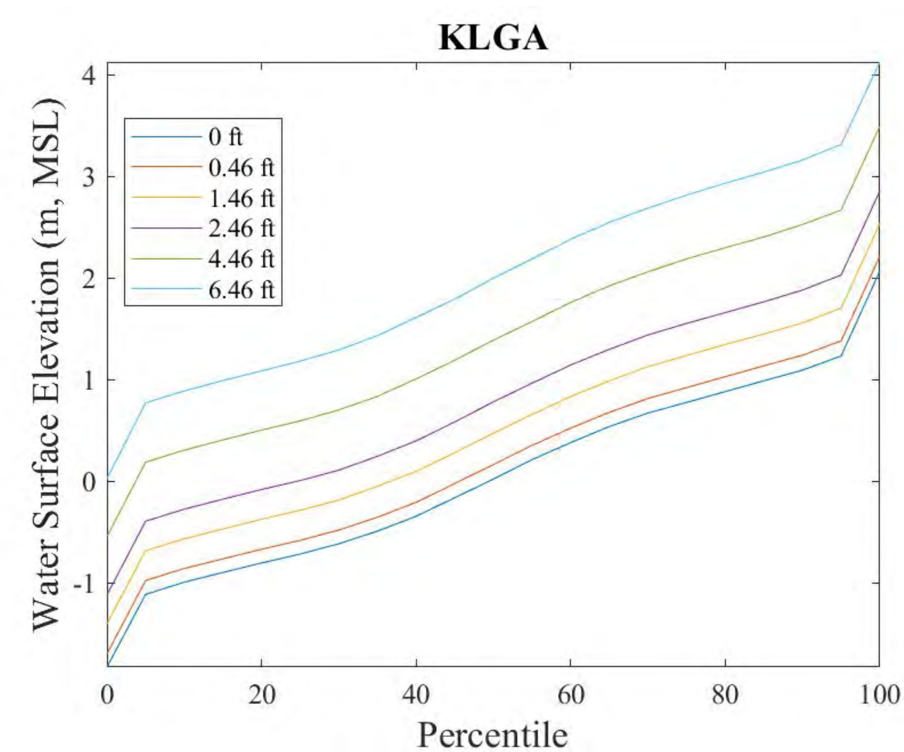


Figure 316. Alt 2, LIS near Stepping Stone Lighthouse WSE Variation with SLR.

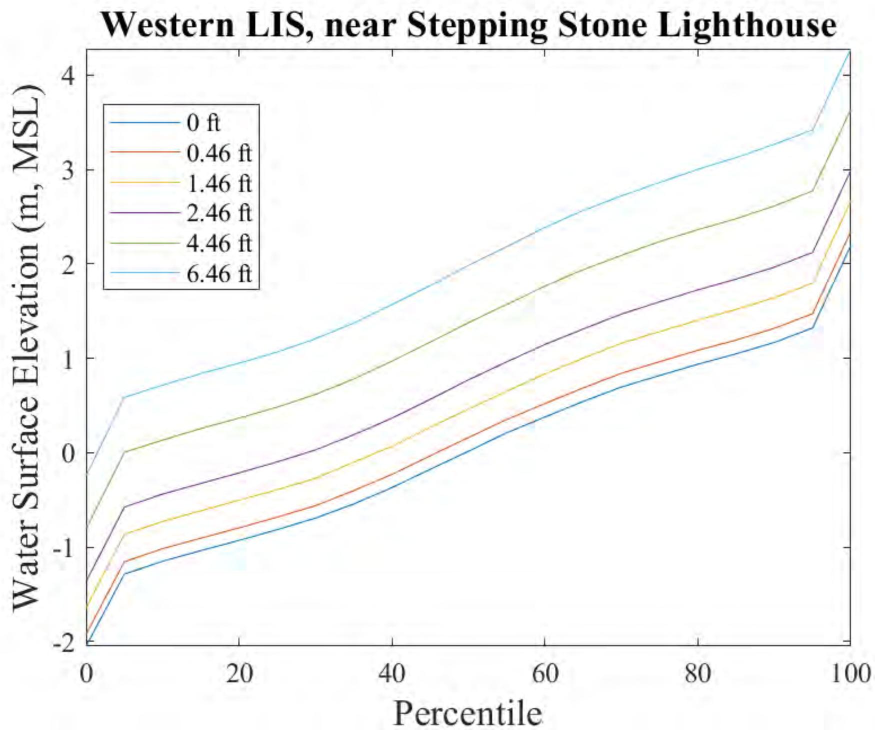


Figure 317. Alt 2, LIS near Execution Rock Lighthouse WSE Variation with SLR.

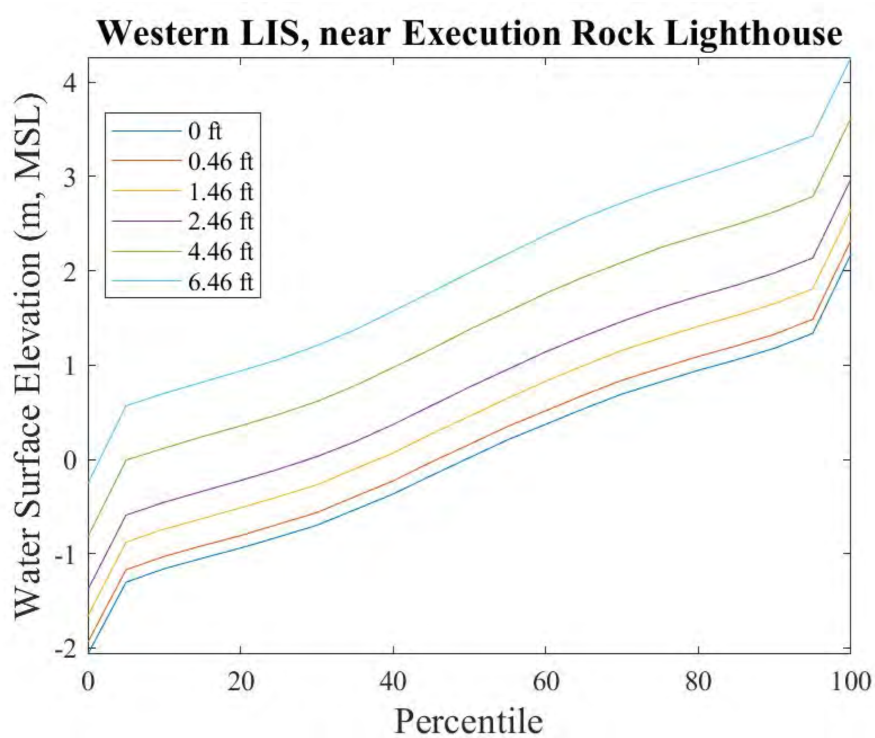


Figure 318. Alt 2, LIS south of NY/CT border WSE Variation with SLR.

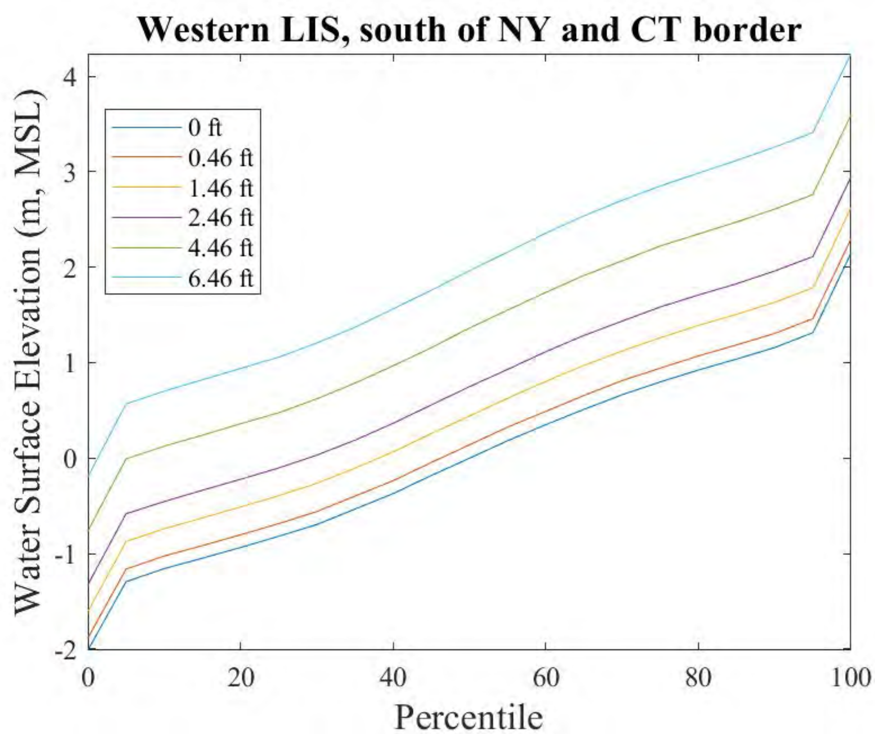


Figure 319. Alt 2, Hudson River, Haverstraw Bay WSE Variation with SLR.

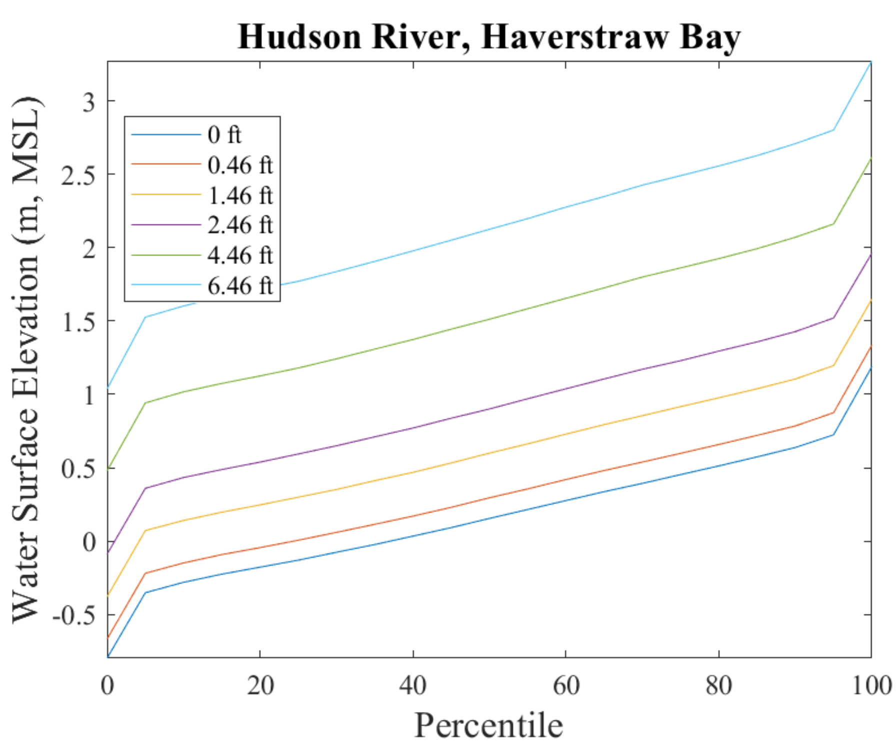


Figure 320. Alt 2, Hudson River near Poughkeepsie WSE Variation with SLR.

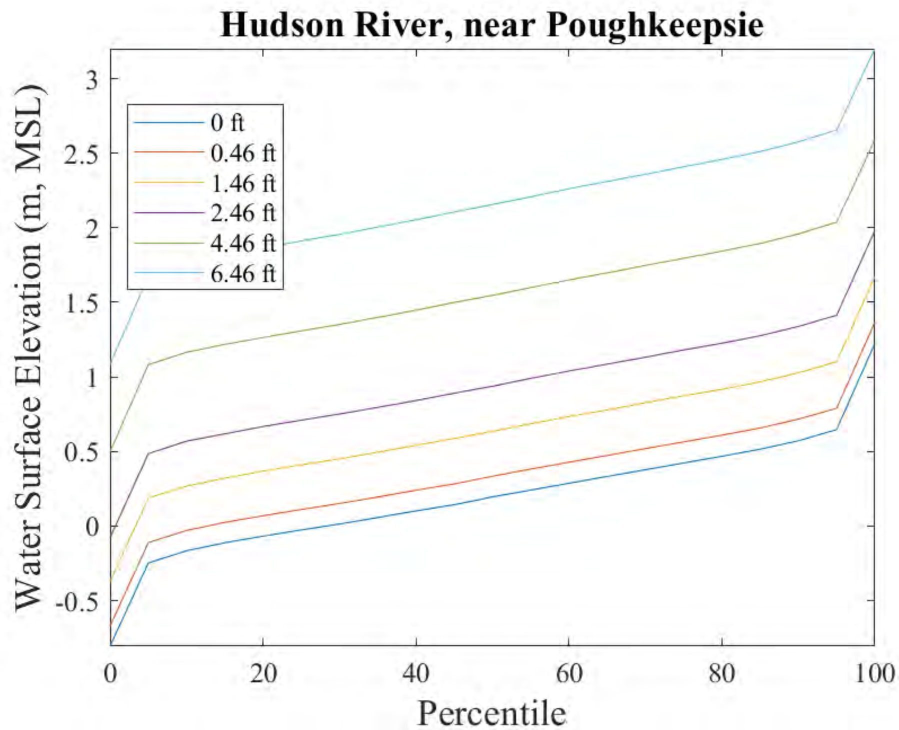


Figure 321. Alt 2, Hudson River between Catskill and Hudson WSE Variation with SLR.

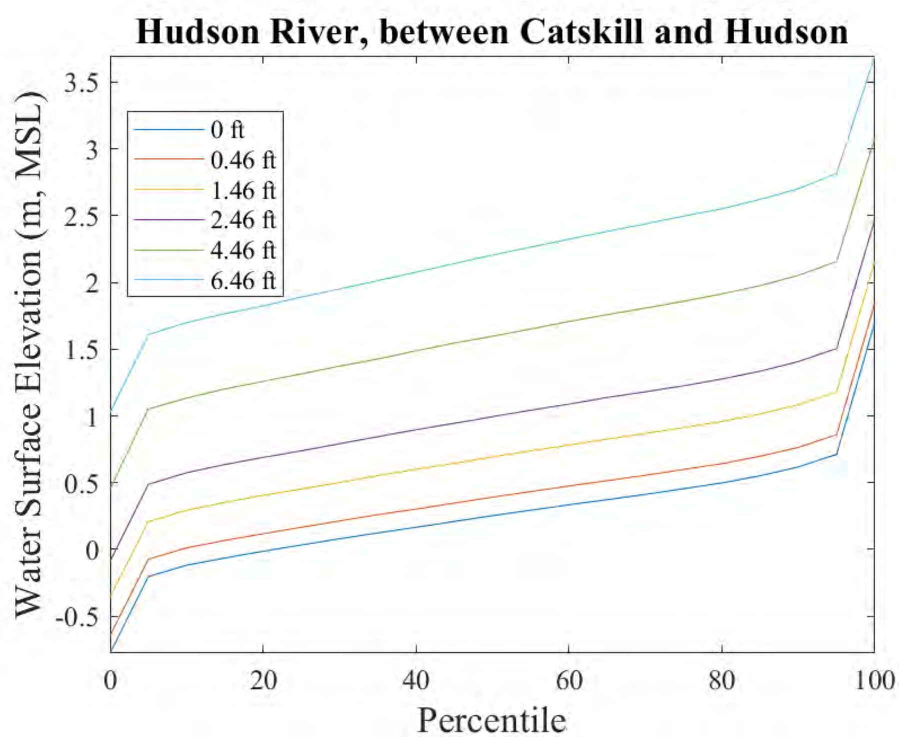
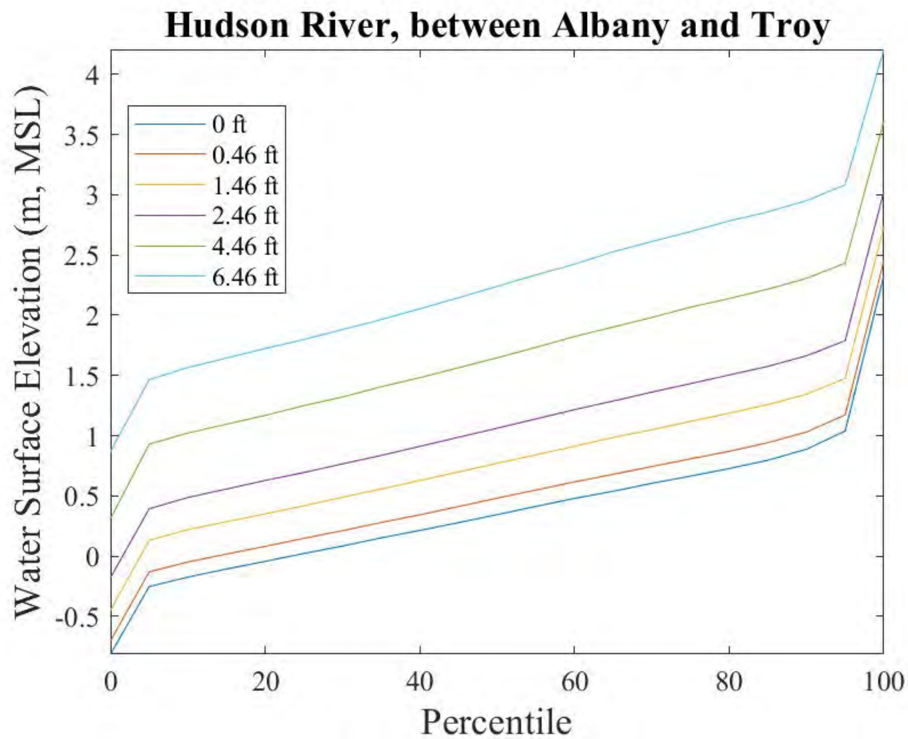


Figure 322. Alt 2, Hudson River between Albany and Troy WSE Variation with SLR.



15.2.2 Velocity Point Percentiles

Velocity percentiles for Alternative 2 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 323 to Figure 358. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prisms.

Figure 323. Alt 2, V1 Velocity Variation with SLR.

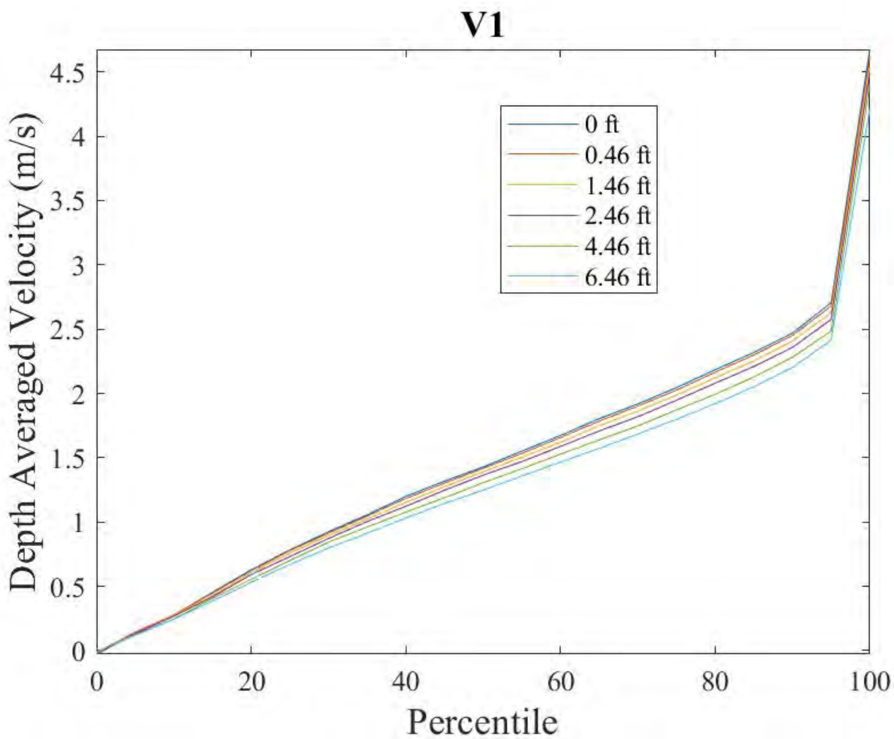


Figure 324. Alt 2, V2 Velocity Variation with SLR.

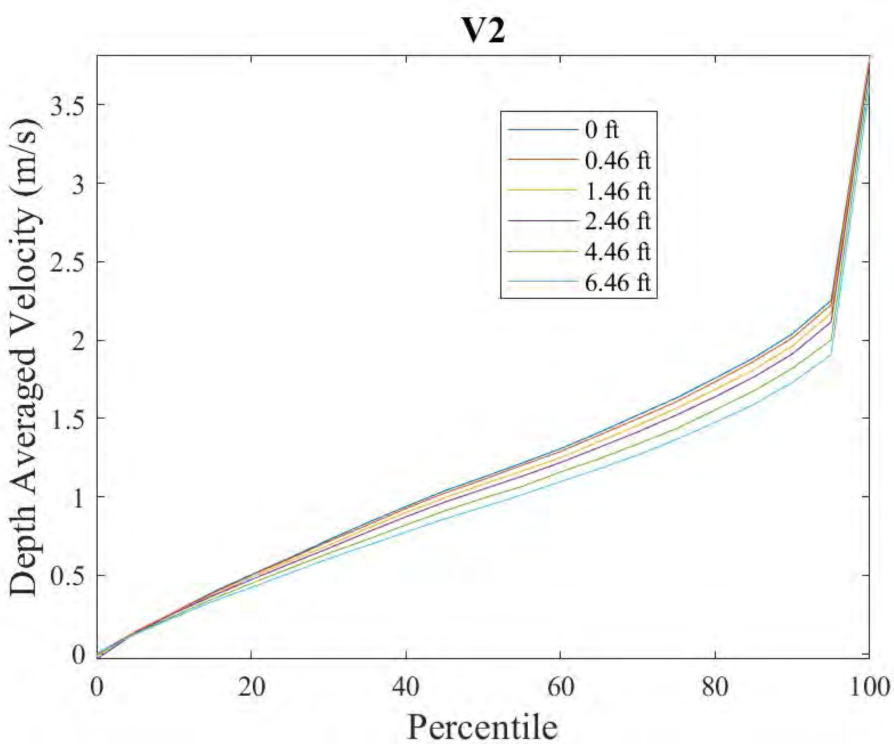


Figure 325. Alt 2, V3 Velocity Variation with SLR.

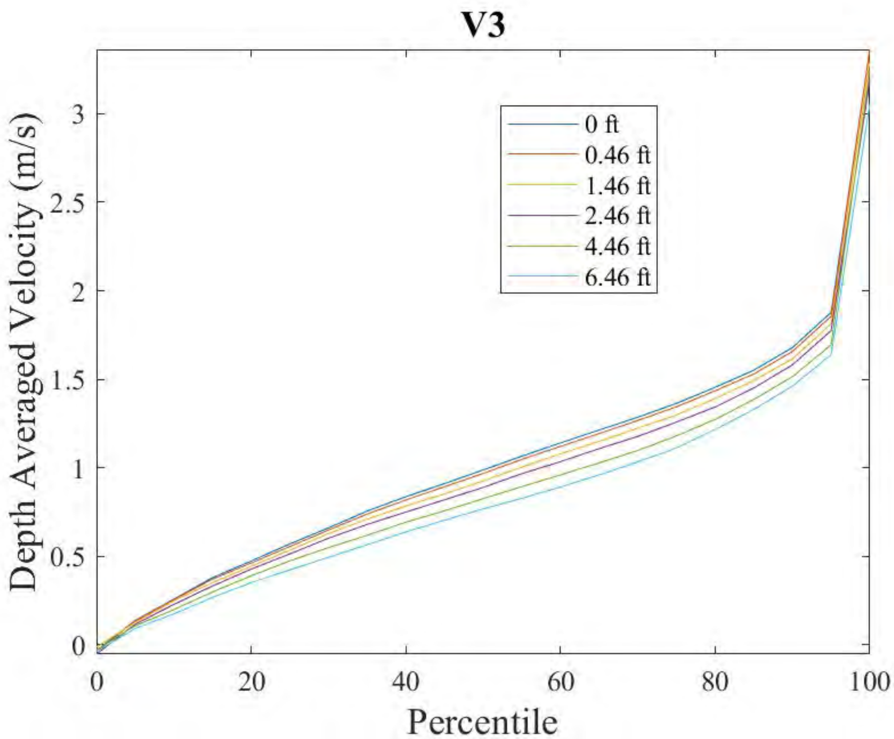


Figure 326. Alt 2, V4 Velocity Variation with SLR.

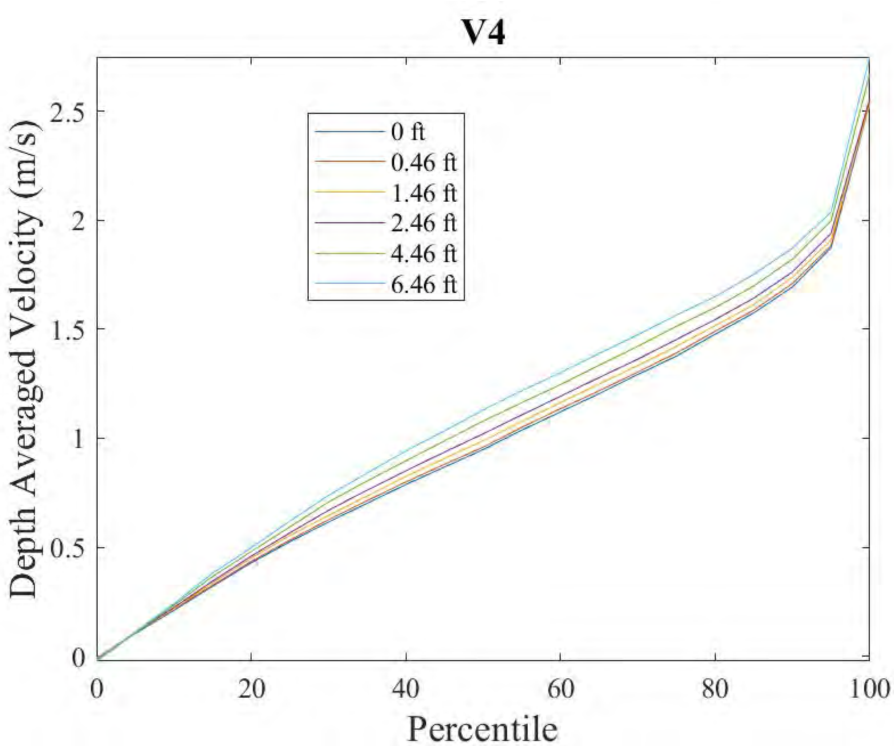


Figure 327. Alt 2, V5 Velocity Variation with SLR.

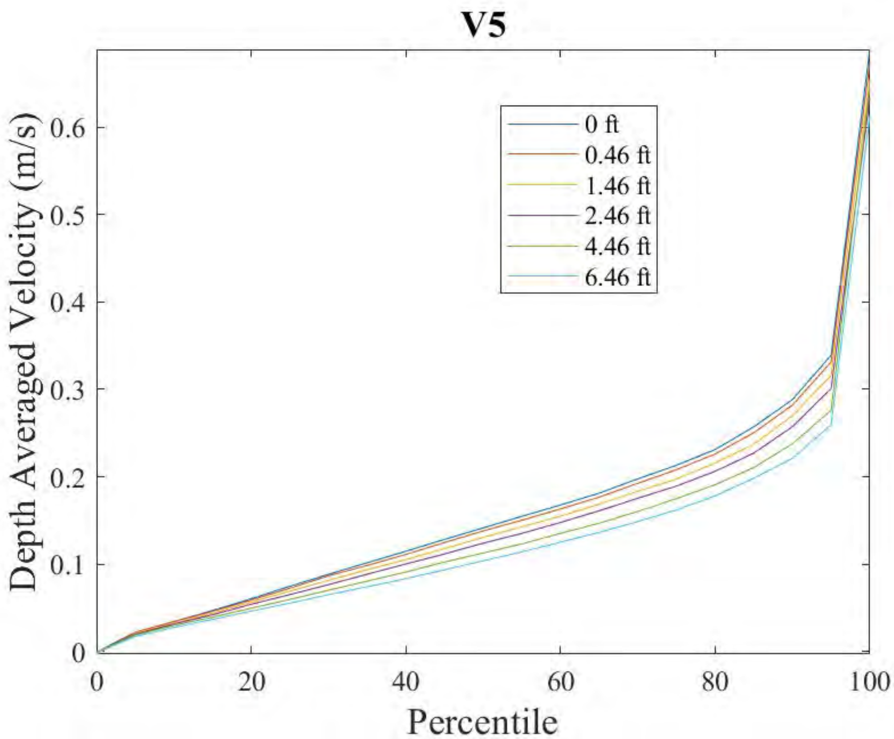


Figure 328. Alt 2, V6 Velocity Variation with SLR.

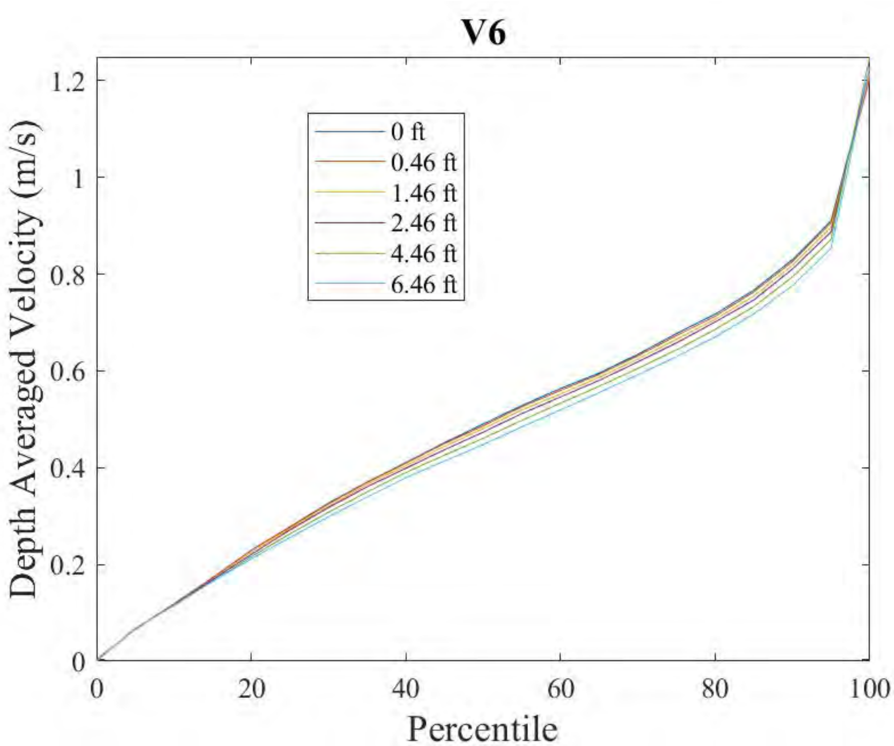


Figure 329. Alt 2, S1 Velocity Variation with SLR.

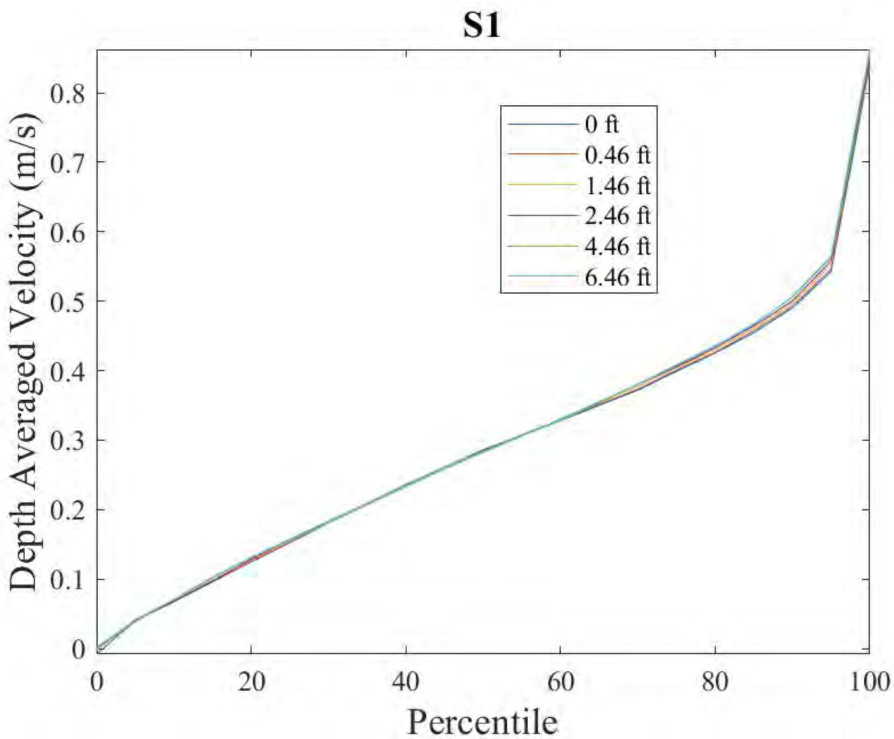


Figure 330. Alt 2, S2 Velocity Variation with SLR.

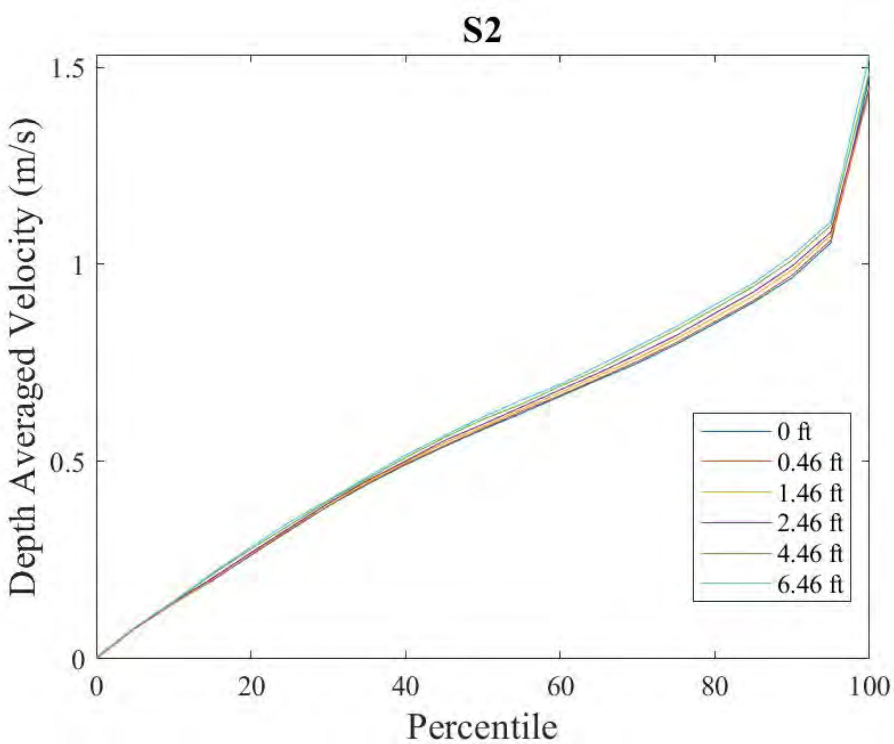


Figure 331. Alt 2, S3 Velocity Variation with SLR.

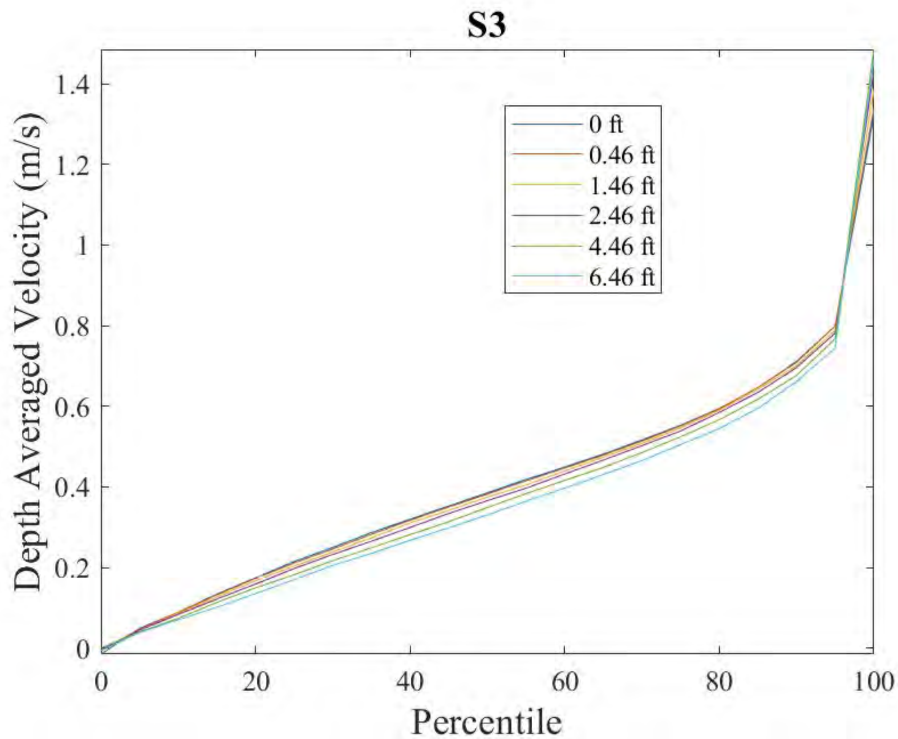


Figure 332. Alt 2, S4 Velocity Variation with SLR.

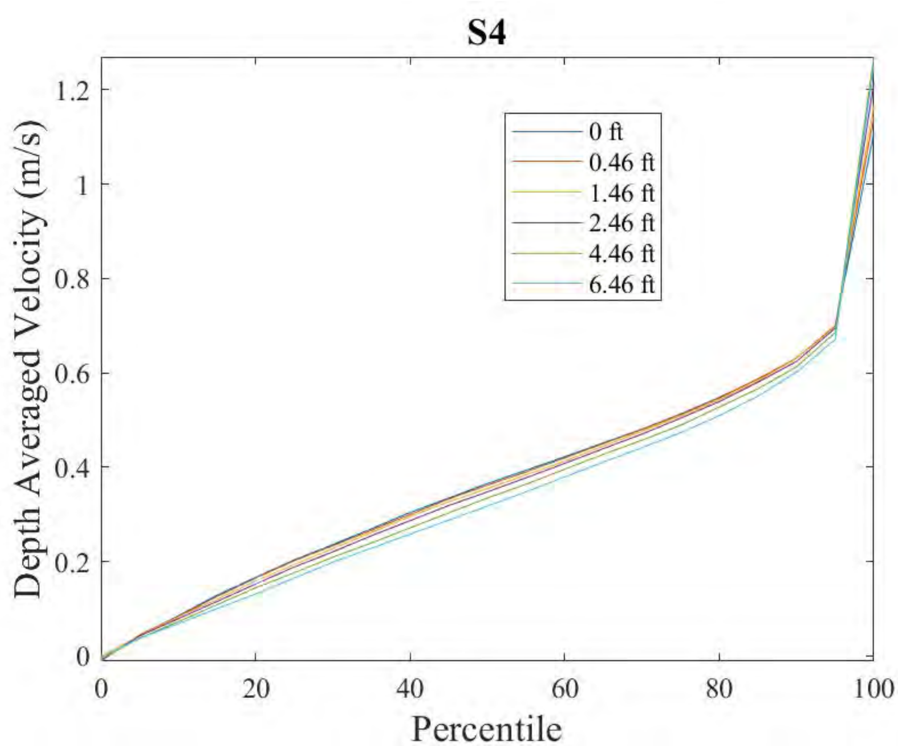


Figure 333. Alt 2, S5 Velocity Variation with SLR.

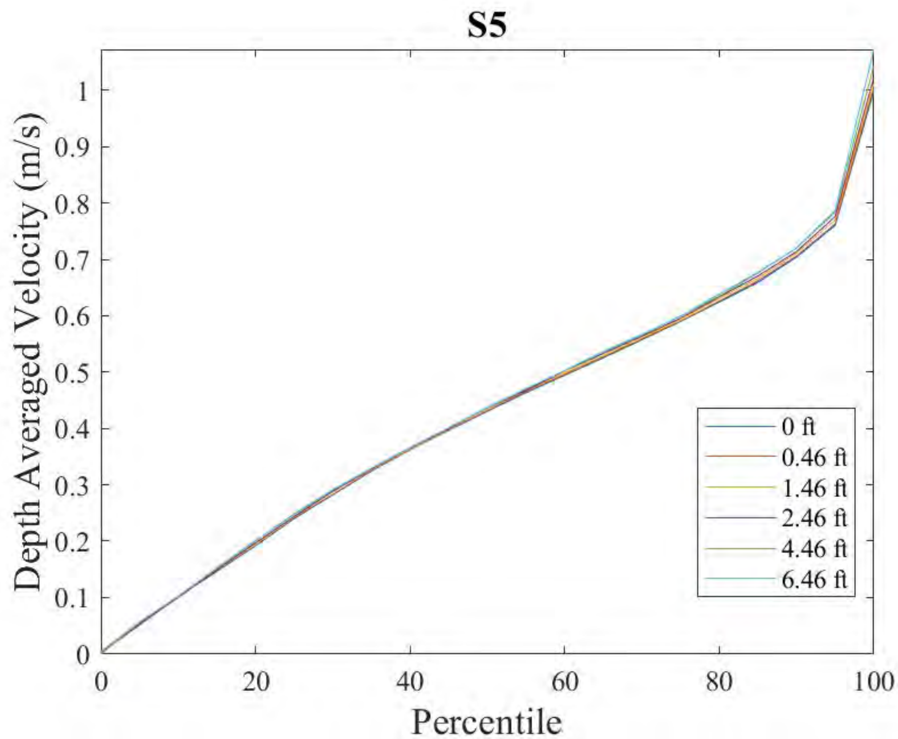


Figure 334. Alt 2, T1 Velocity Variation with SLR.

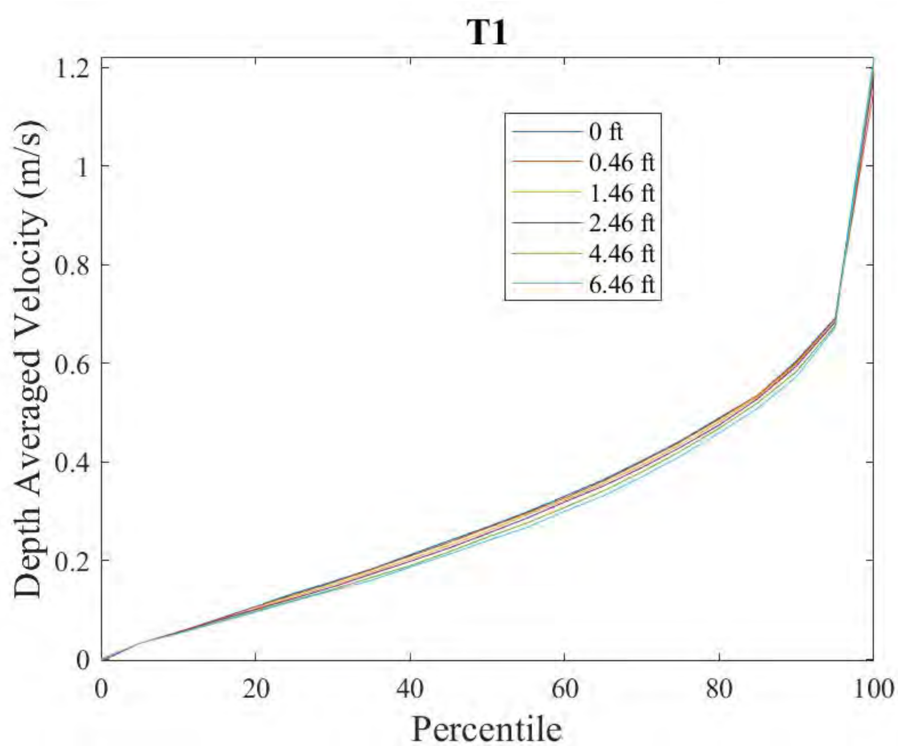


Figure 335. Alt 2, T2 Velocity Variation with SLR.

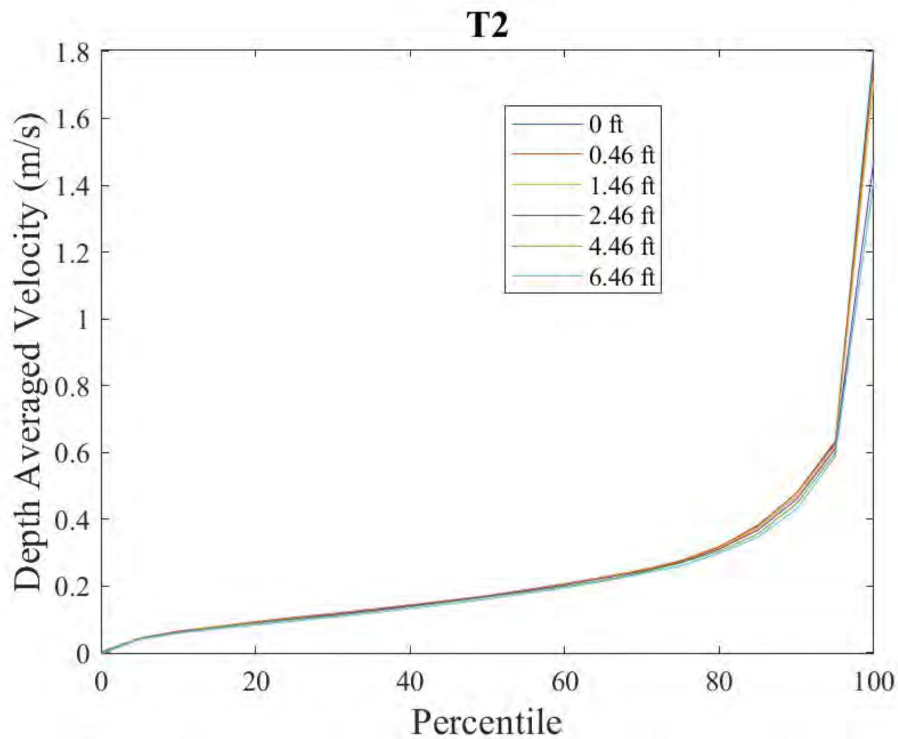


Figure 336. Alt 2, T3 Velocity Variation with SLR.

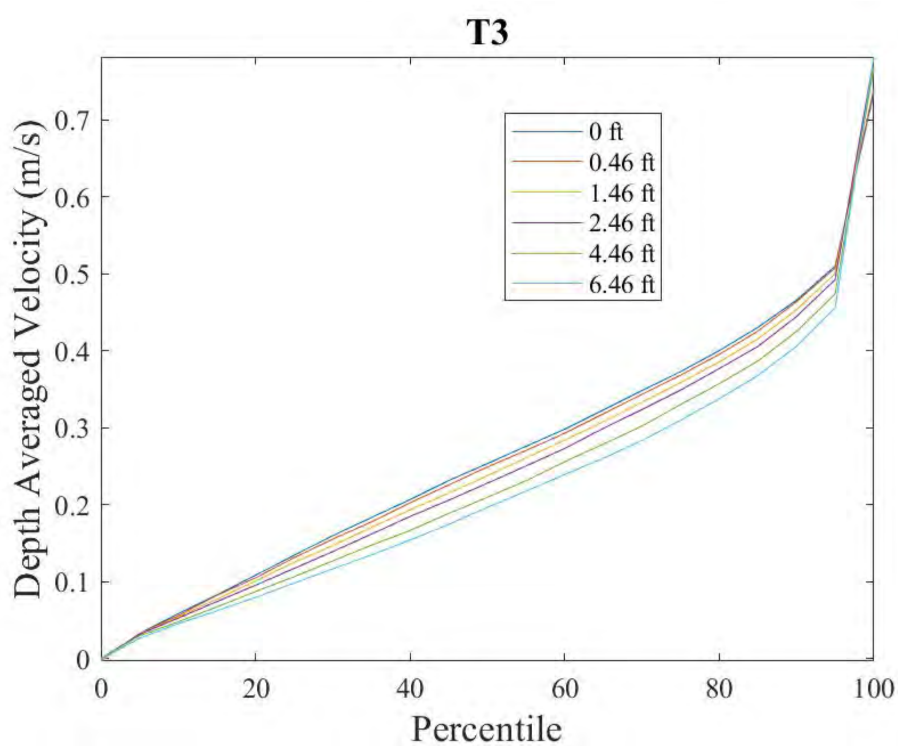


Figure 337. Alt 2, T4 Velocity Variation with SLR.

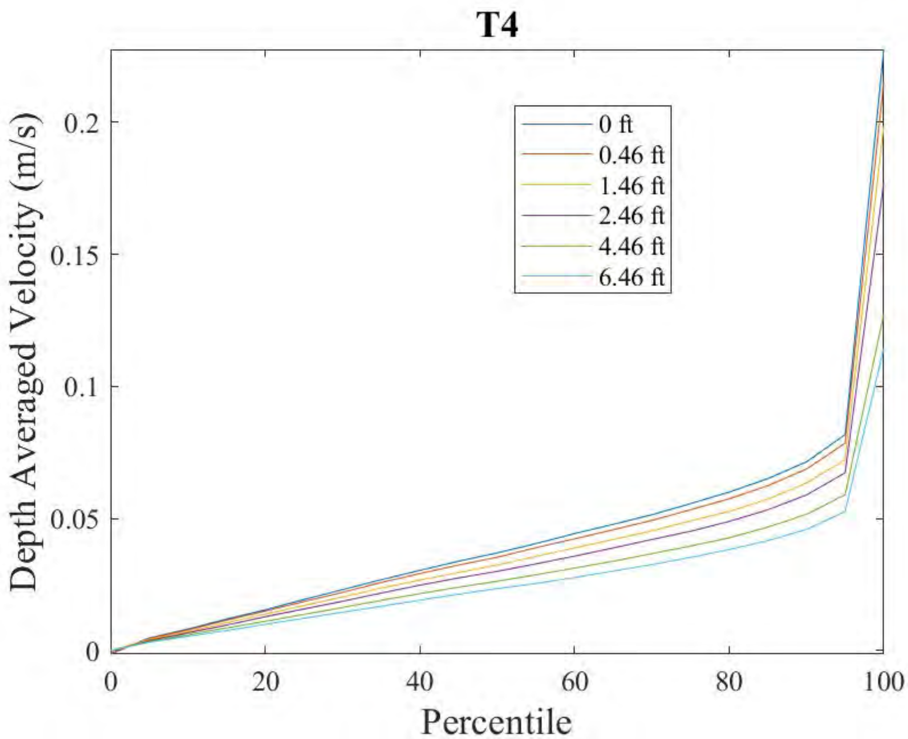


Figure 338. Alt 2, T5 Velocity Variation with SLR.

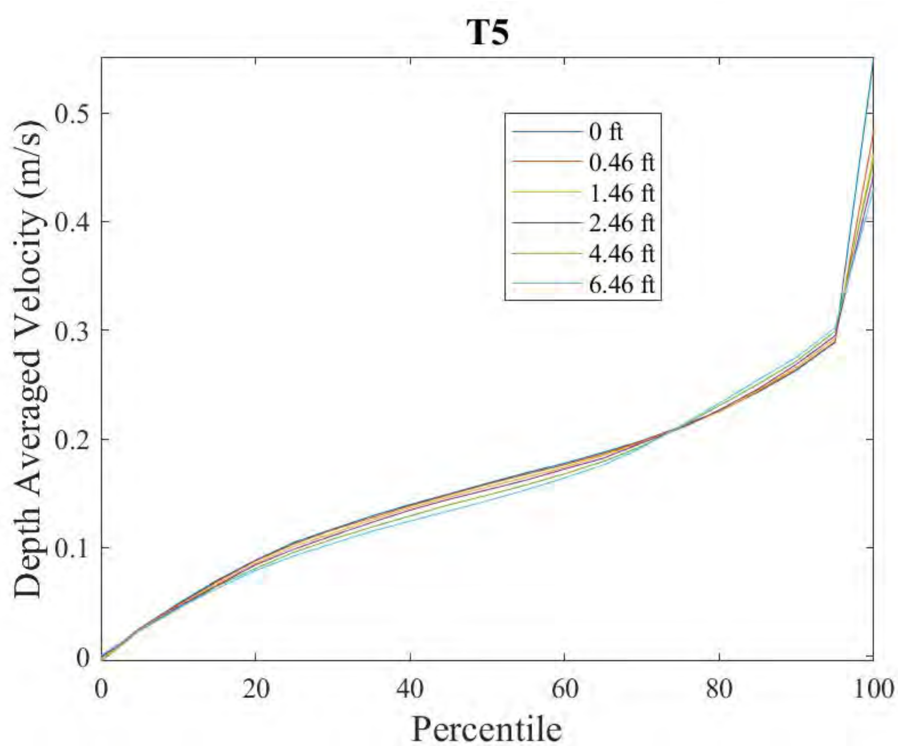


Figure 339. Alt 2, R1 Velocity Variation with SLR.

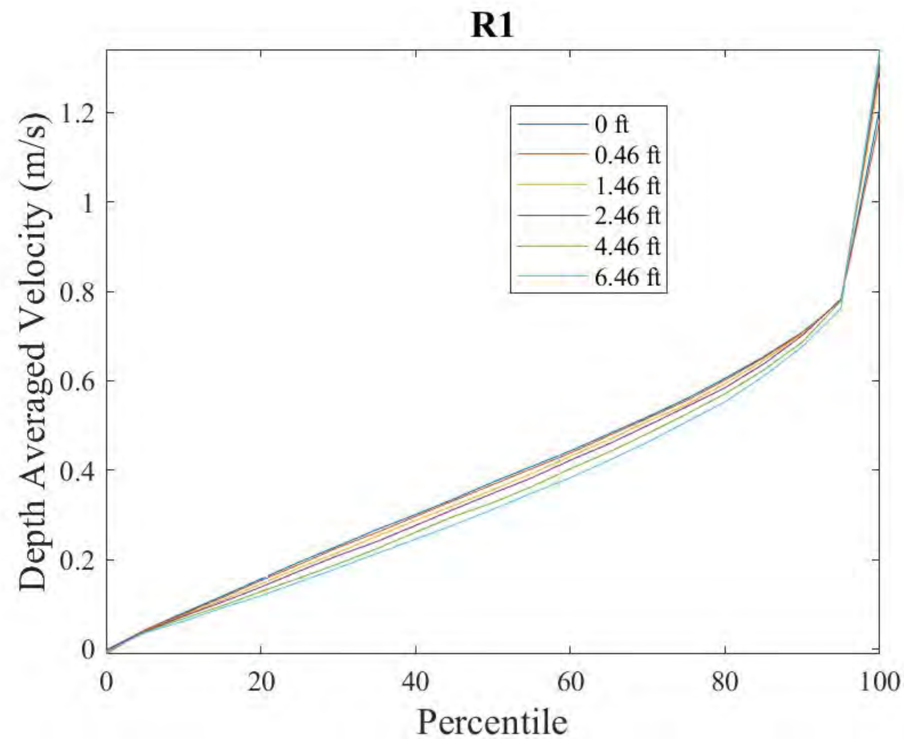


Figure 340. Alt 2, Sandy Hook Velocity Variation with SLR.

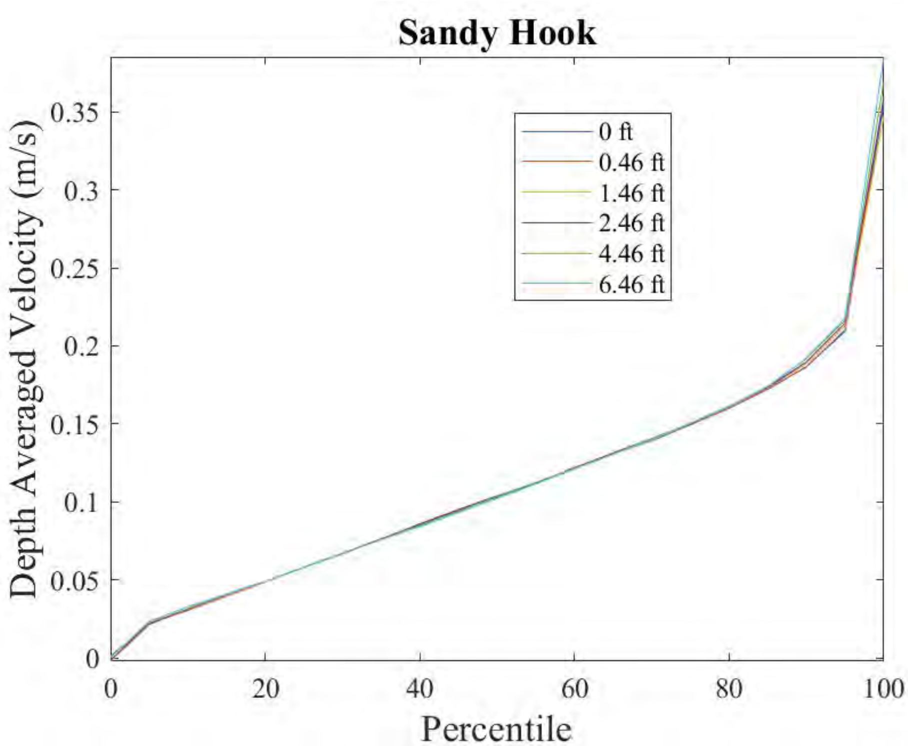


Figure 341. Alt 2, Fresh Kills Velocity Variation with SLR.

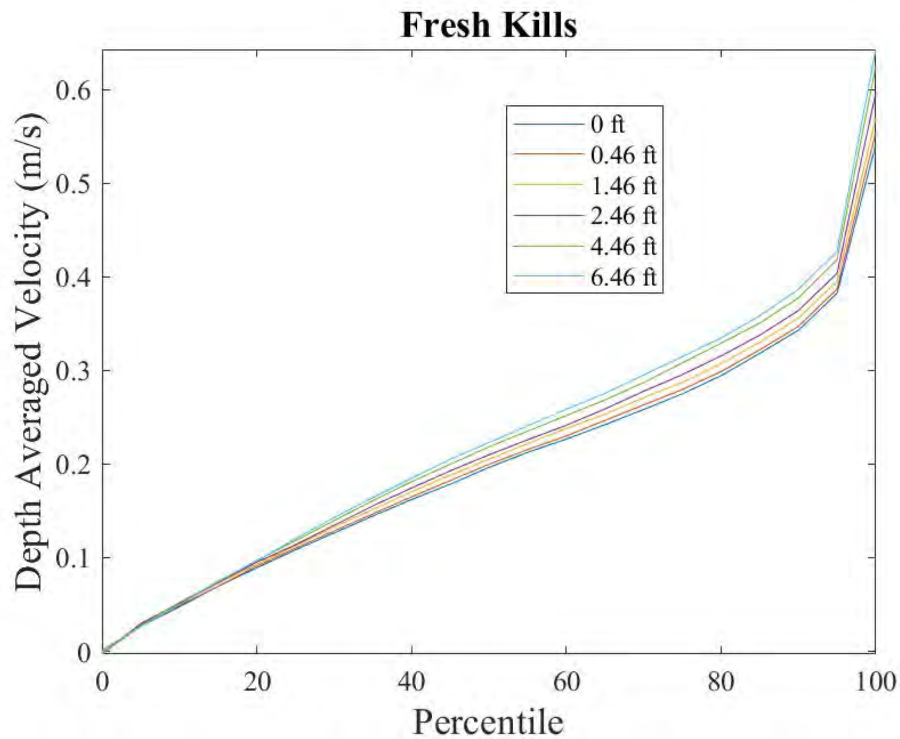


Figure 342. Alt 2, Mariners Harbor Velocity Variation with SLR.

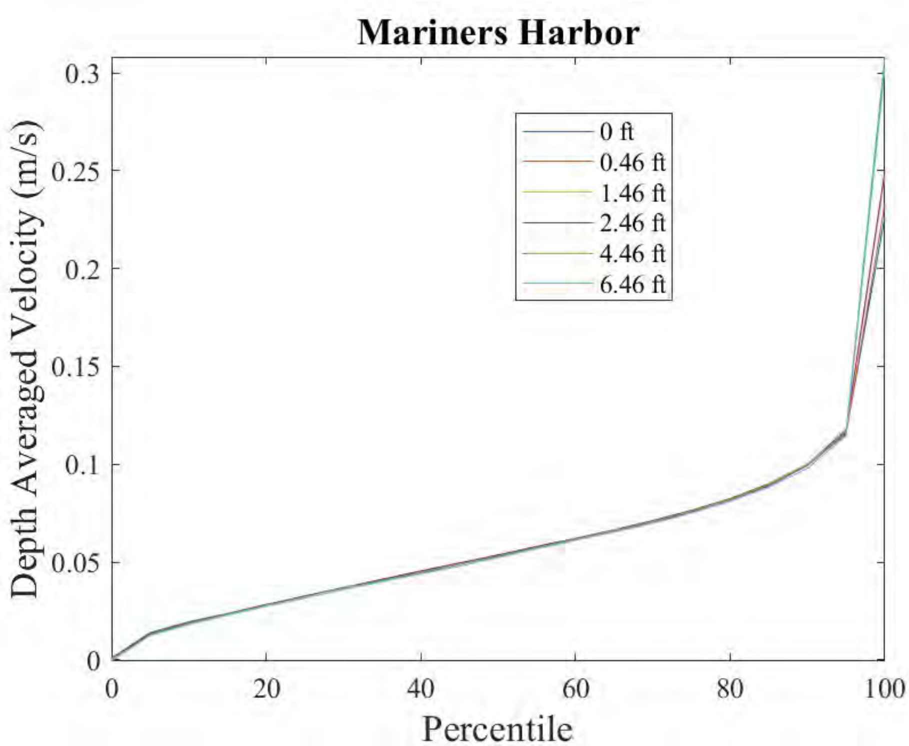


Figure 343. Alt 2, North Reach Velocity Variation with SLR.

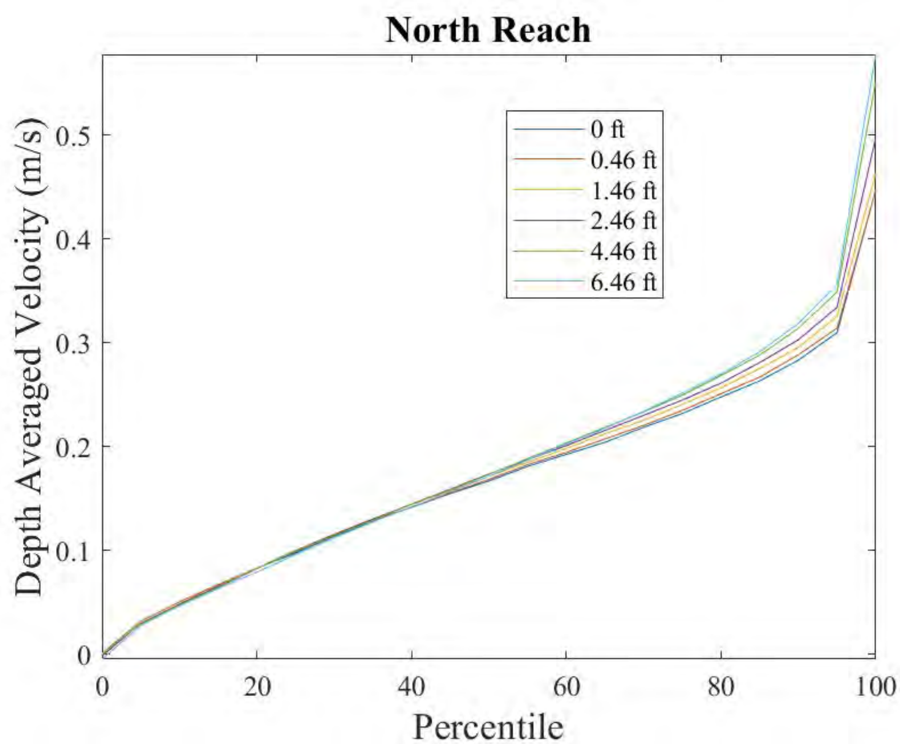


Figure 344. Alt 2, Hackensack River Velocity Variation with SLR.

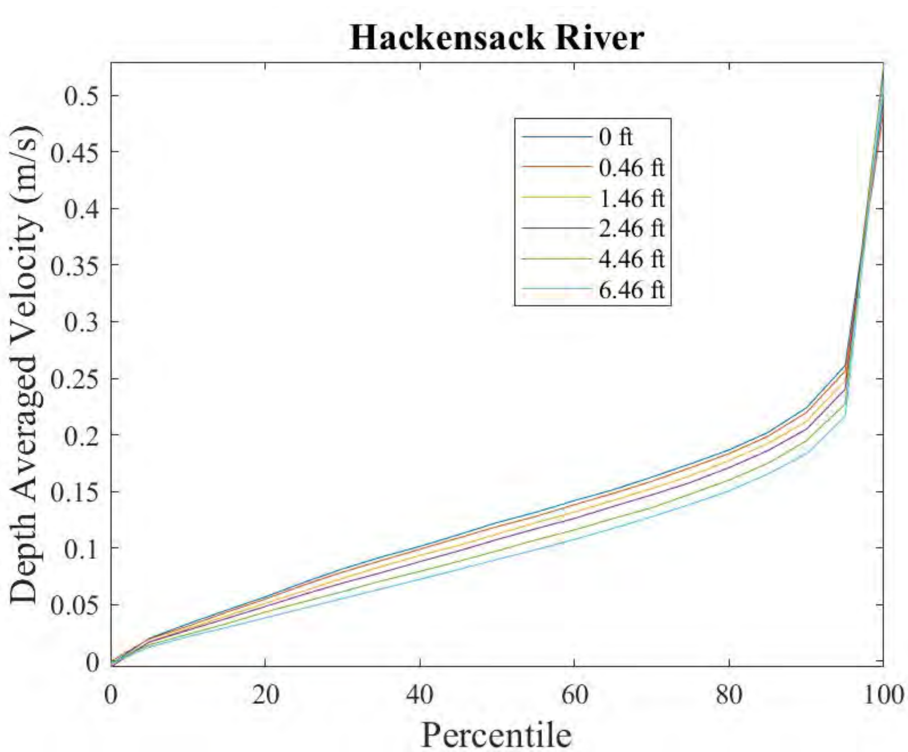


Figure 345. Alt 2, Robbins Reef Velocity Variation with SLR.

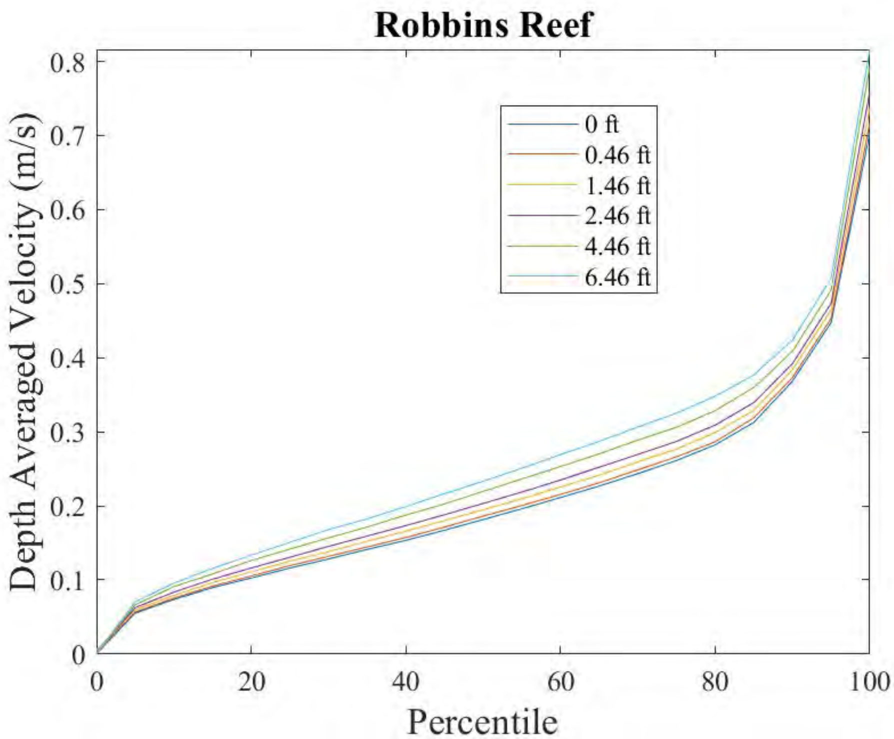


Figure 346. Alt 2, The Battery Velocity Variation with SLR.

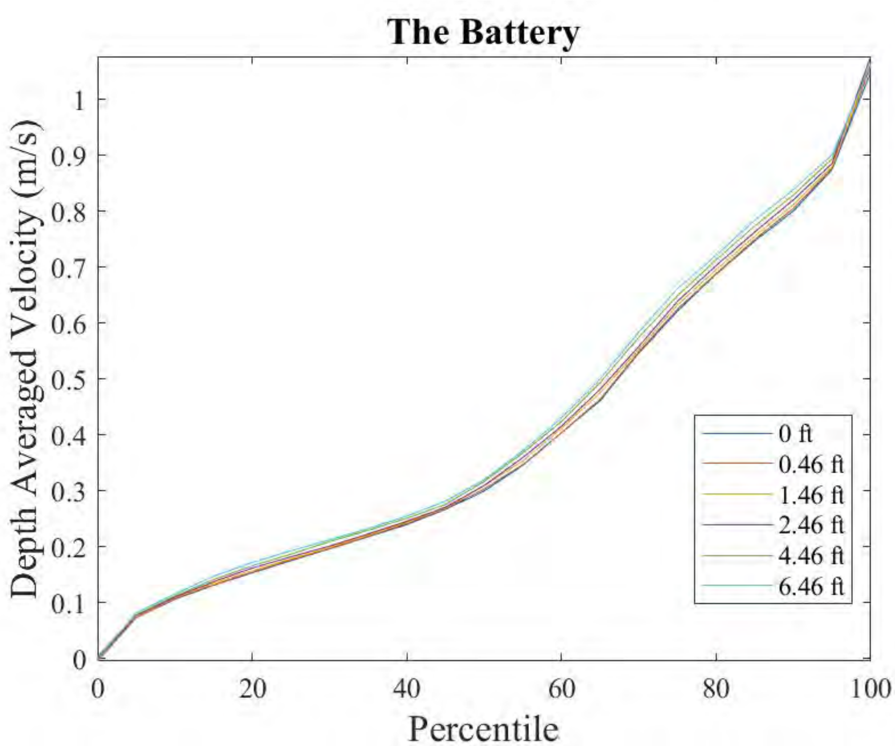


Figure 347. Alt 2, Manhattan Velocity Variation with SLR.

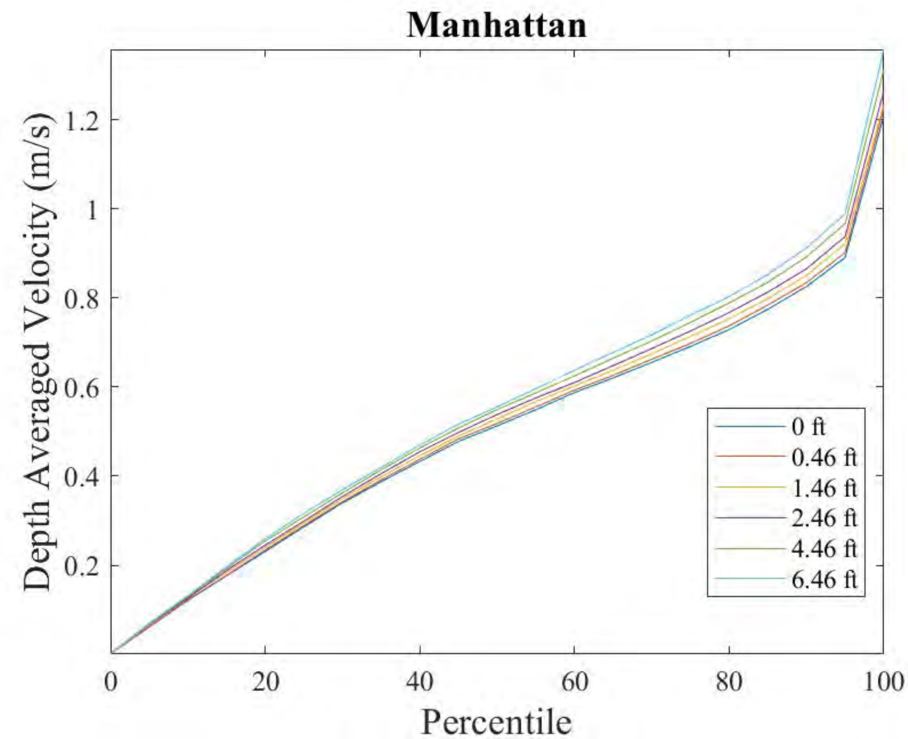


Figure 348. Alt 2, Hudson River, Haverstraw Bay Velocity Variation with SLR.

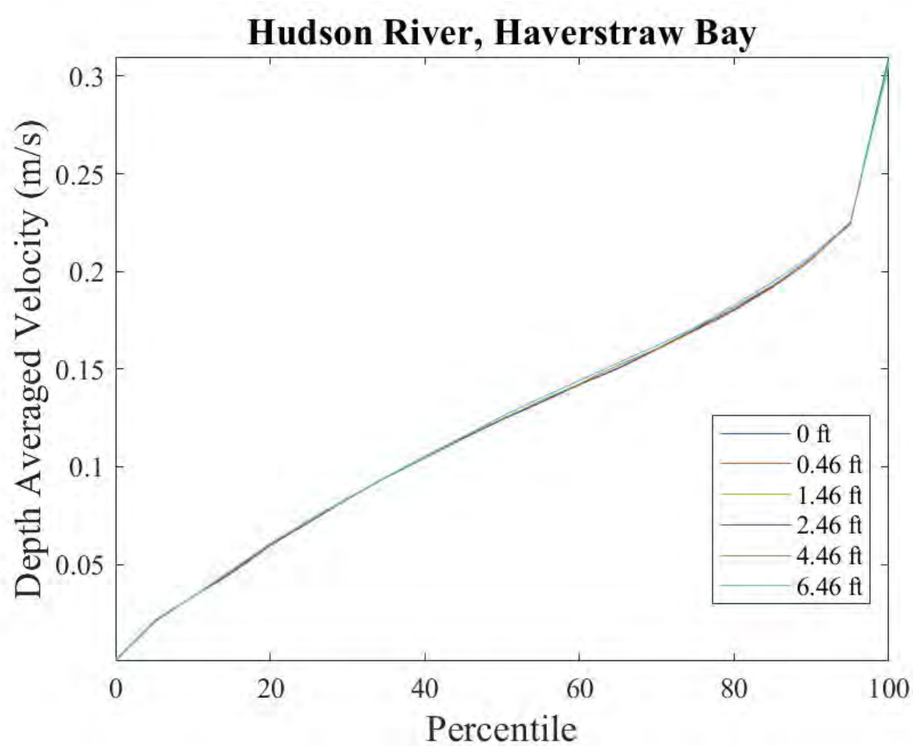


Figure 349. Alt 2, Hudson River near Poughkeepsie Velocity Variation with SLR.

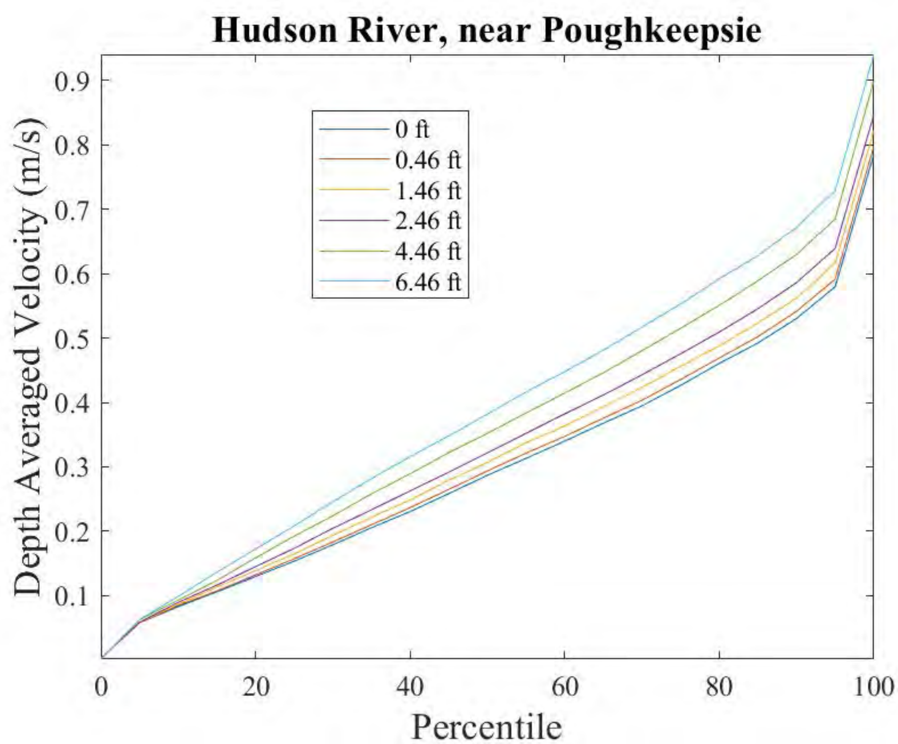


Figure 350. Alt 2, Hudson River between Catskill and Hudson Velocity Variation with SLR.

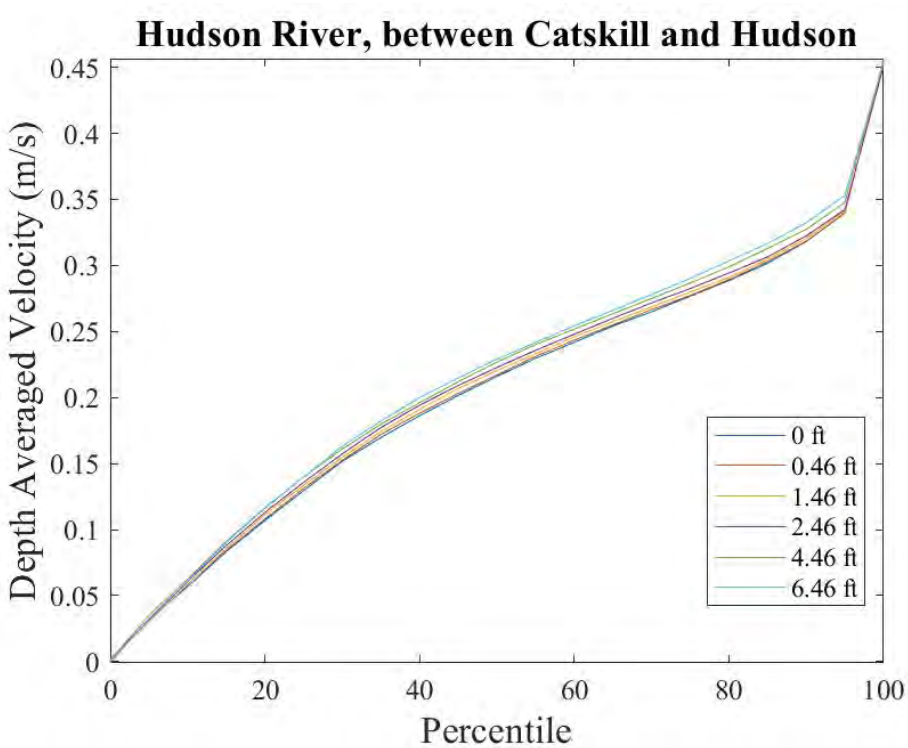


Figure 351. Alt 2, Hudson River between Albany and Troy Velocity Variation with SLR.

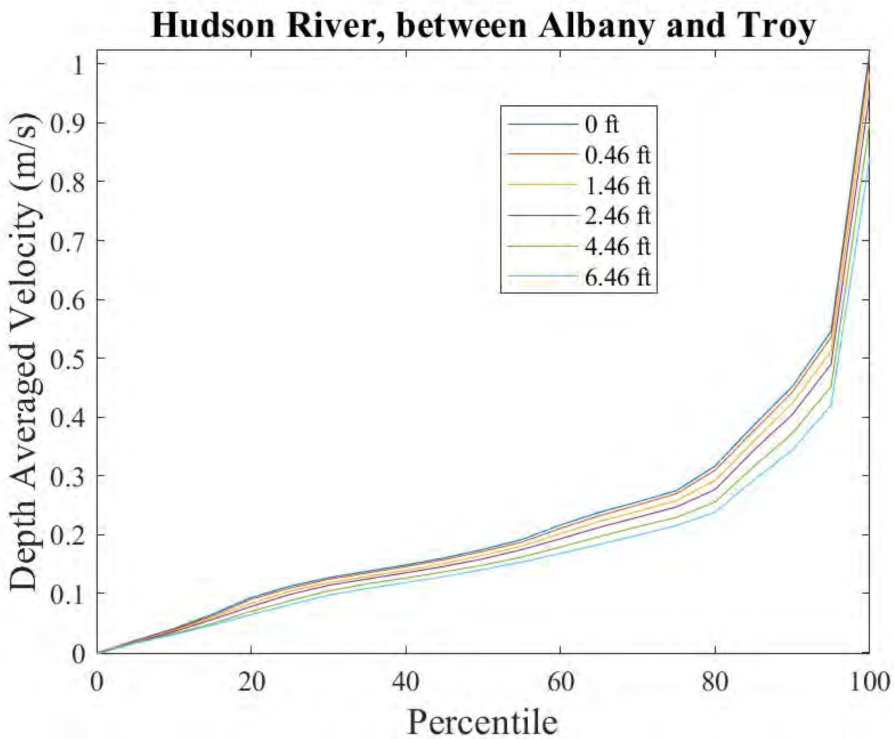


Figure 352. Alt 2, KLGA Velocity Variation with SLR.

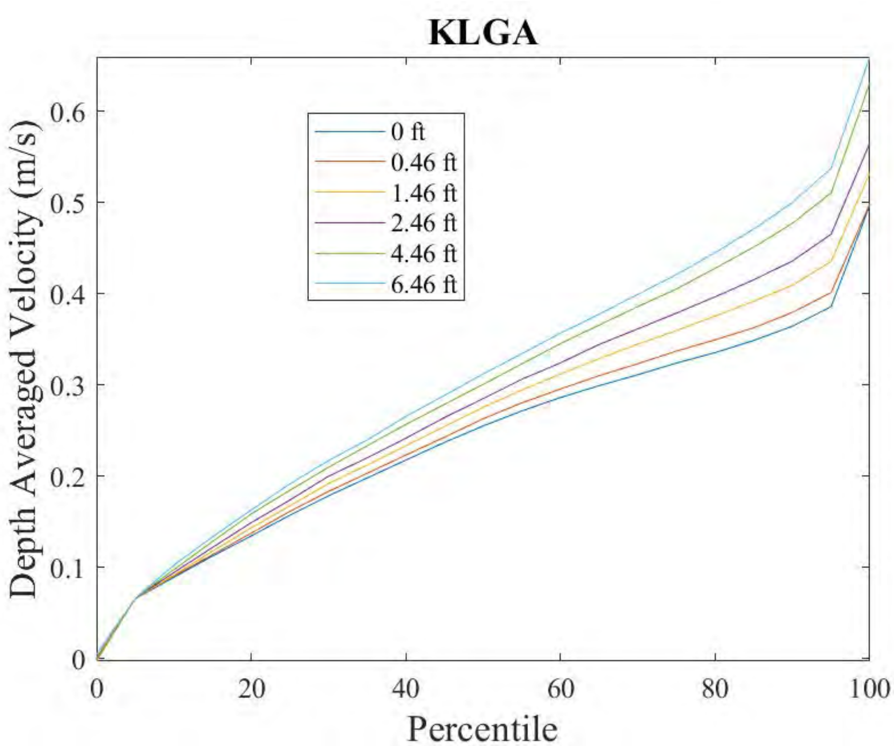


Figure 353. Alt 2, LIS near Stepping Stone Lighthouse Velocity Variation with SLR.

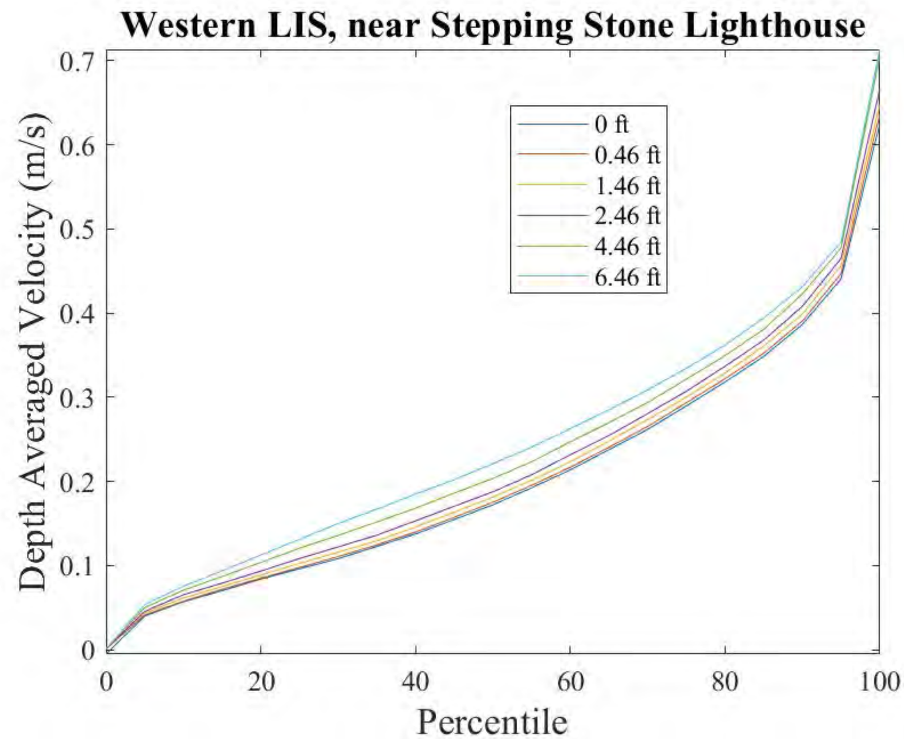


Figure 354. Alt 2, LIS near Execution Rock Lighthouse Velocity Variation with SLR.

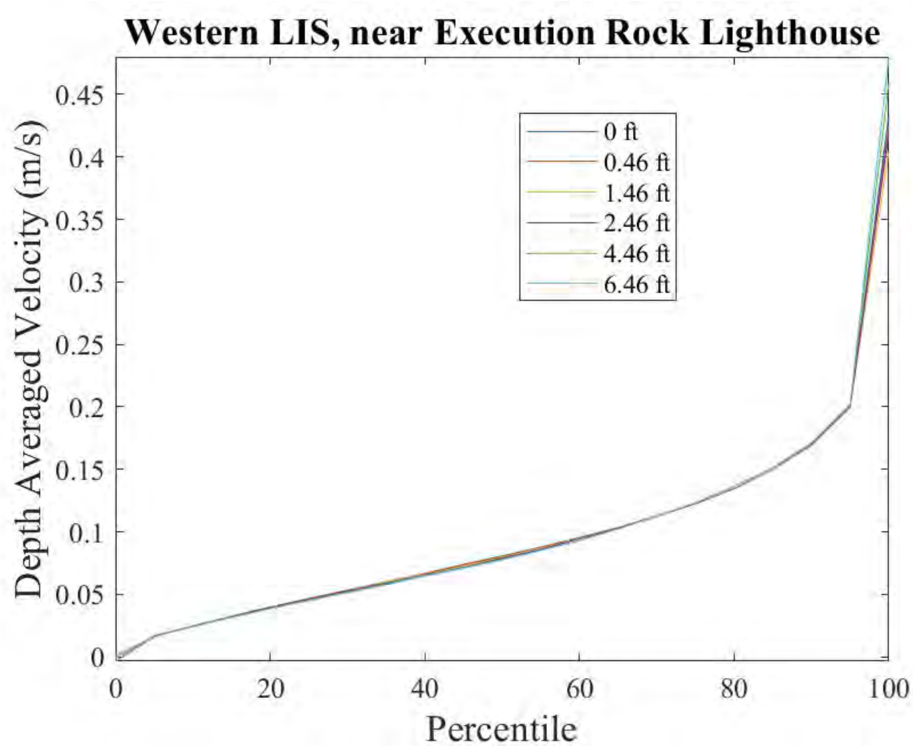


Figure 355. Alt 2, LIS south of NY/CT border Velocity Variation with SLR.

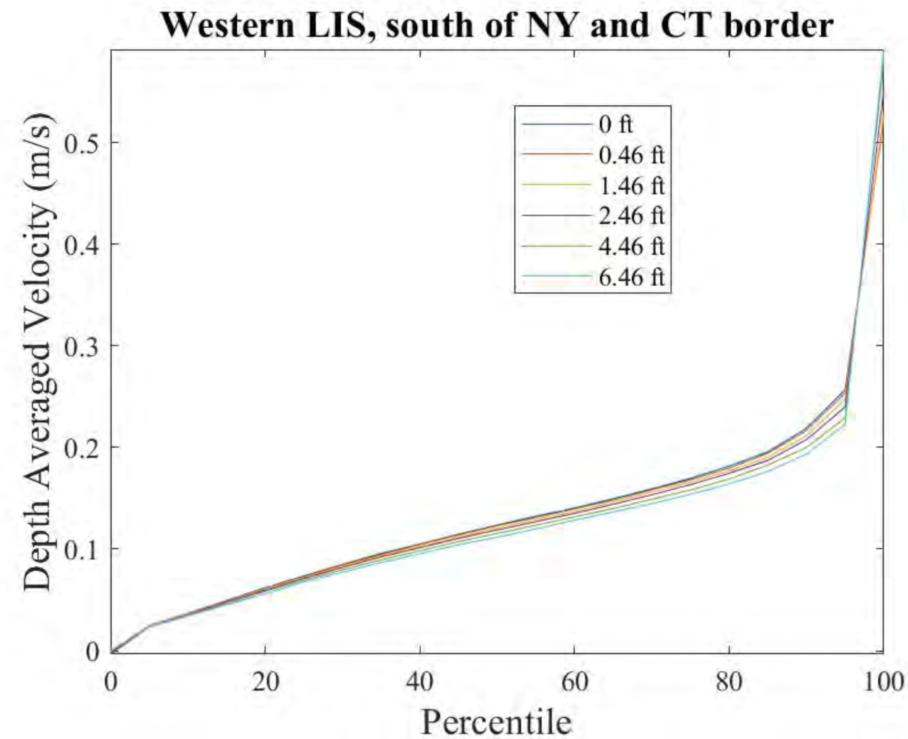


Figure 356. Alt 2, Jamaica Bay Velocity Variation with SLR.

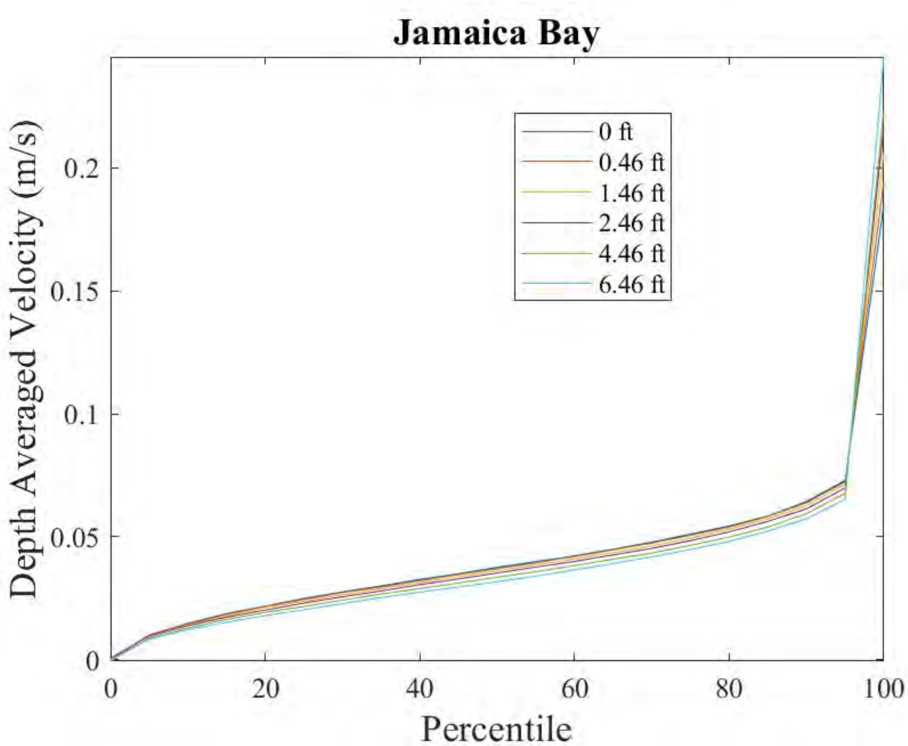


Figure 357. Alt 2, Jamaica Bay near Spring Creek Velocity Variation with SLR.

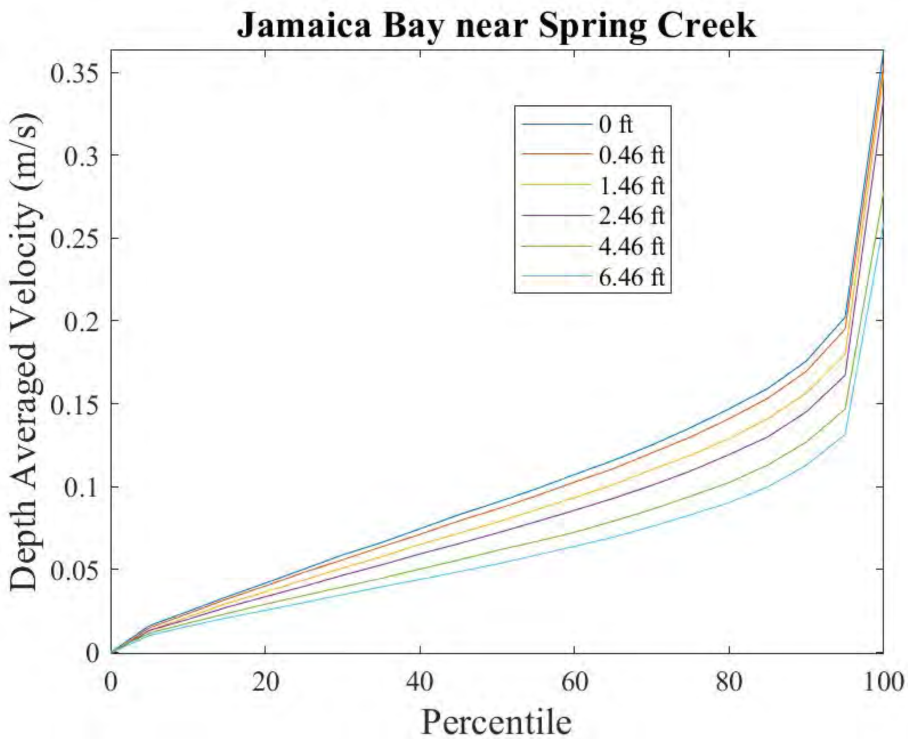
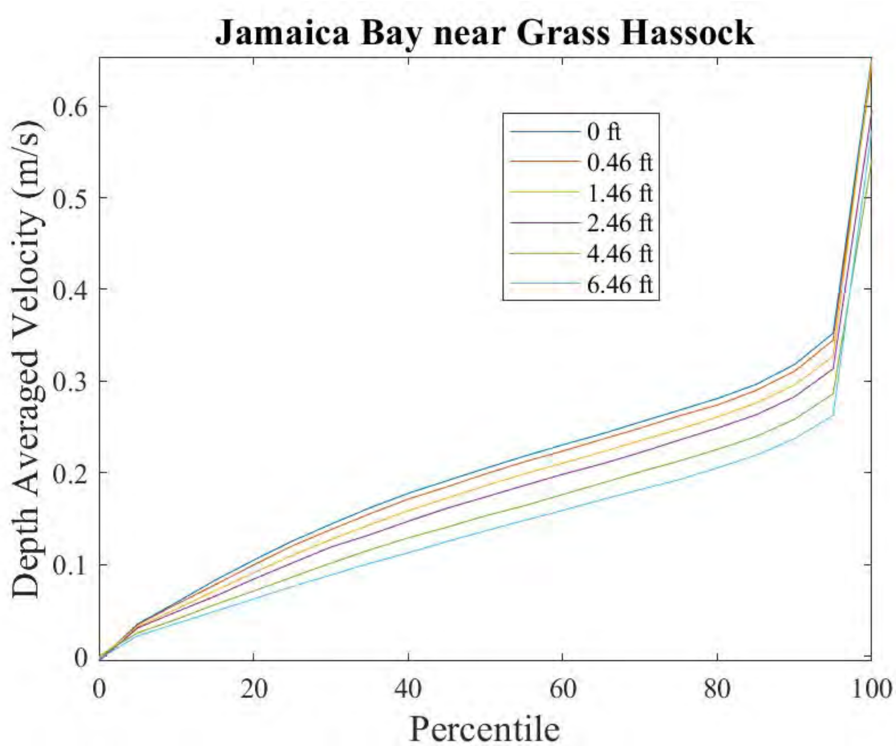


Figure 358. Alt 2, Jamaica Bay near Grass Hassock Velocity Variation with SLR.



15.2.3 Salinity Point Percentiles

Salinity percentiles for Alternative 2 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 359 to Figure 391. In general, increased sea levels result in increased salinities.

Figure 359. Alt 2, V1 Salinity Variation with SLR.

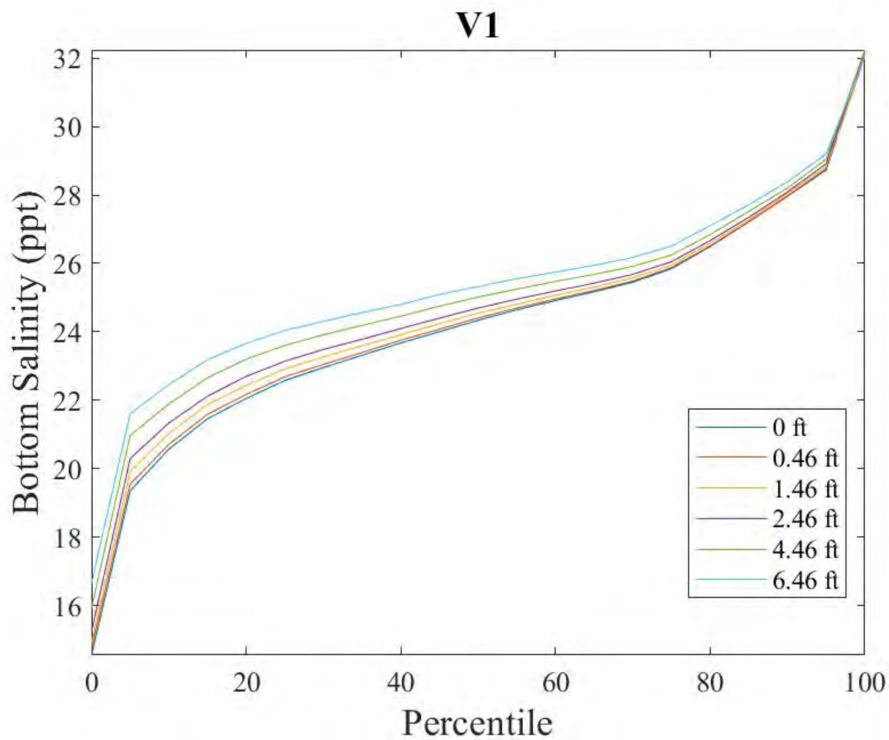


Figure 360. Alt 2, V2 Salinity Variation with SLR.

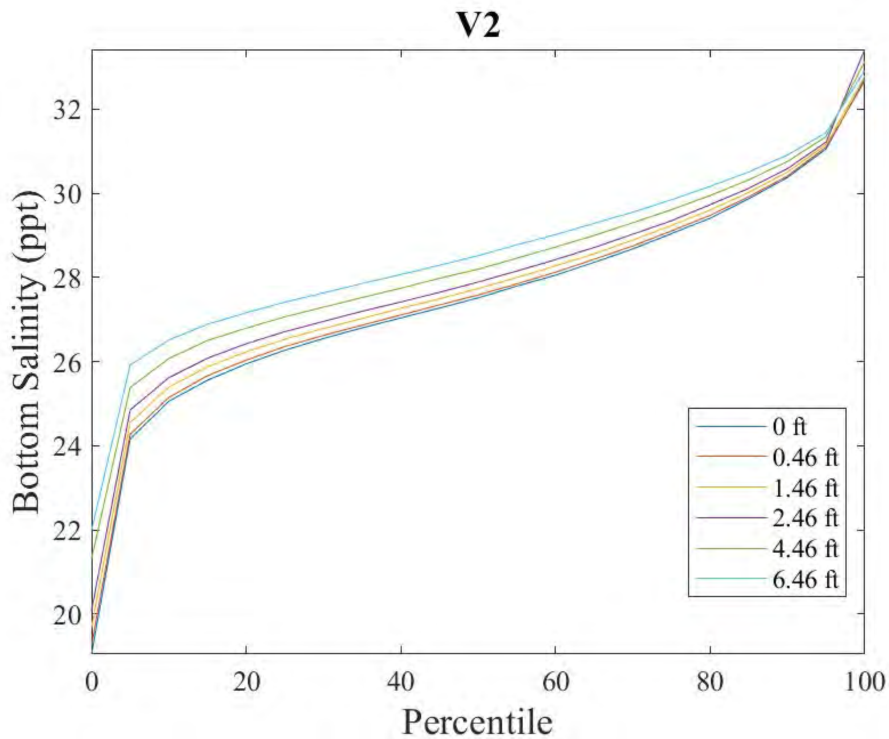


Figure 361. Alt 2, V3 Salinity Variation with SLR.

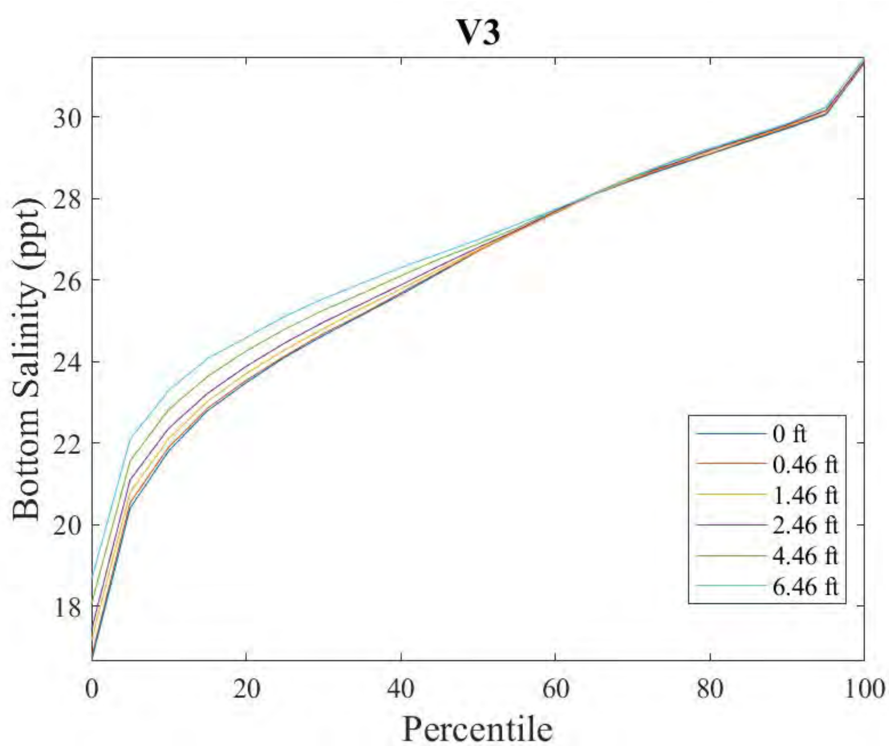


Figure 362. Alt 2, V1 Salinity Variation with SLR.

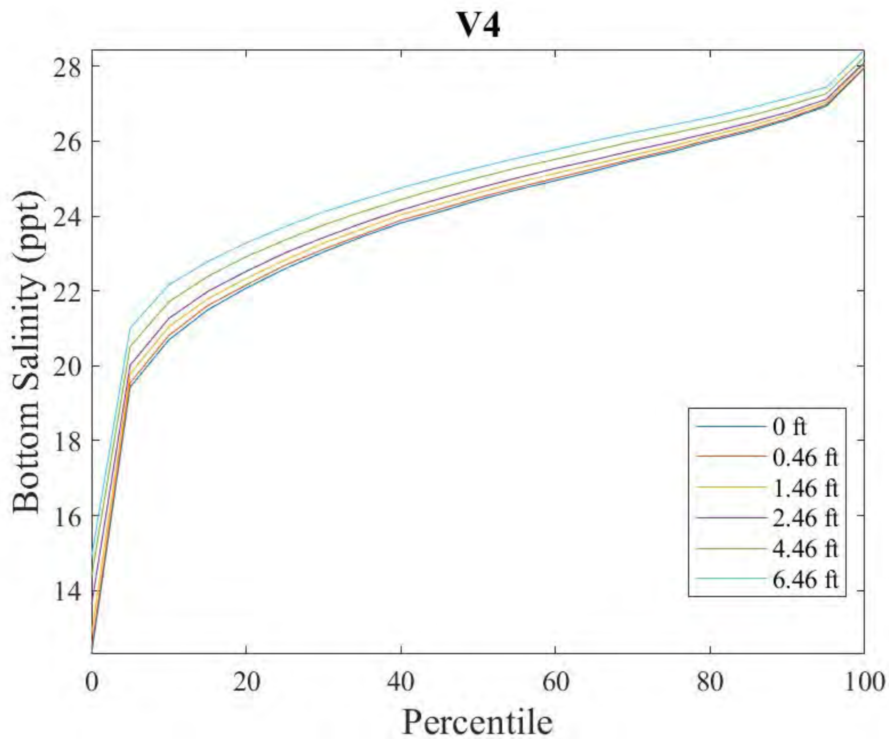


Figure 363. Alt 2, V5 Salinity Variation with SLR.

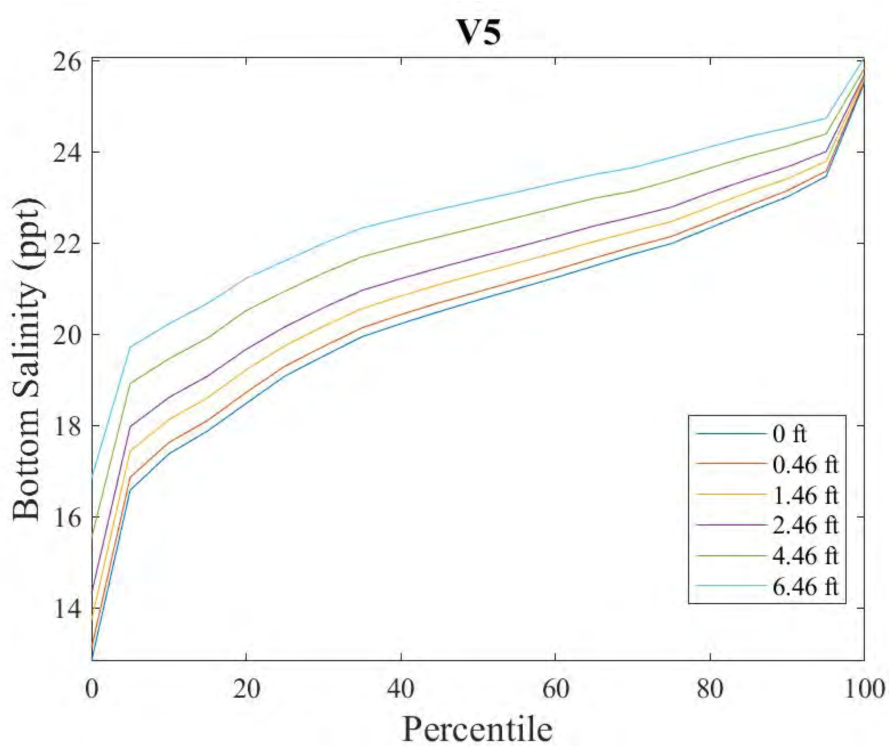


Figure 364. Alt 2, V6 Salinity Variation with SLR.

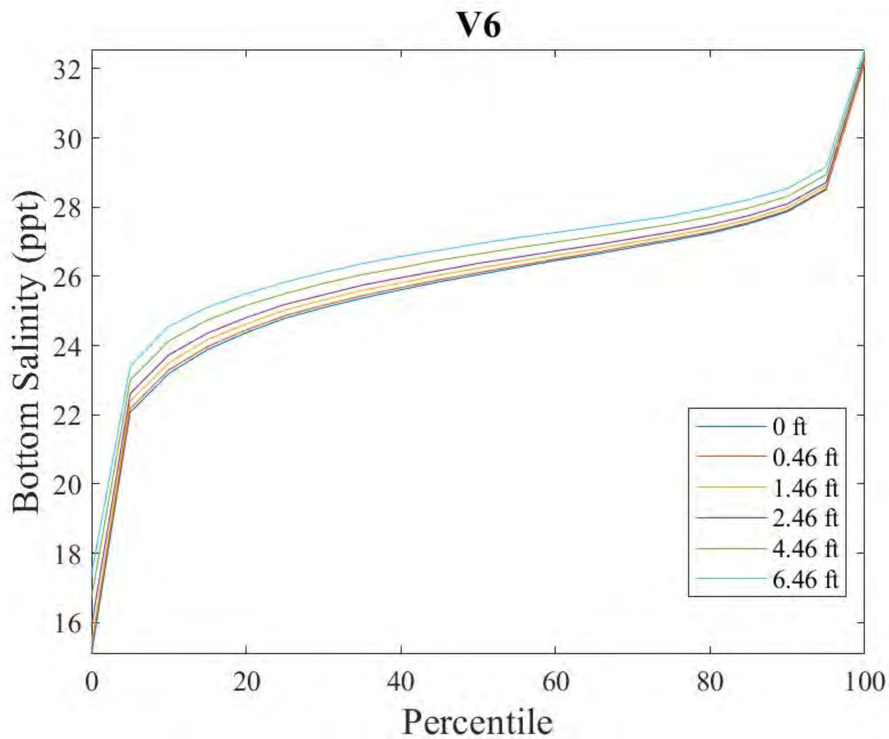


Figure 365. Alt 2, S1 Salinity Variation with SLR.

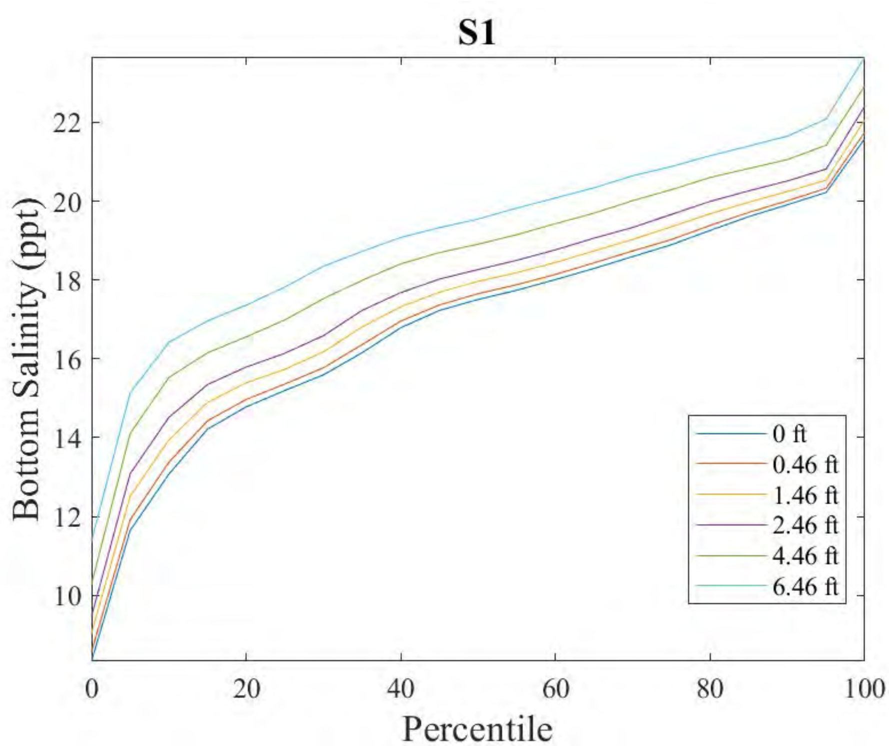


Figure 366. Alt 2, S2 Salinity Variation with SLR.

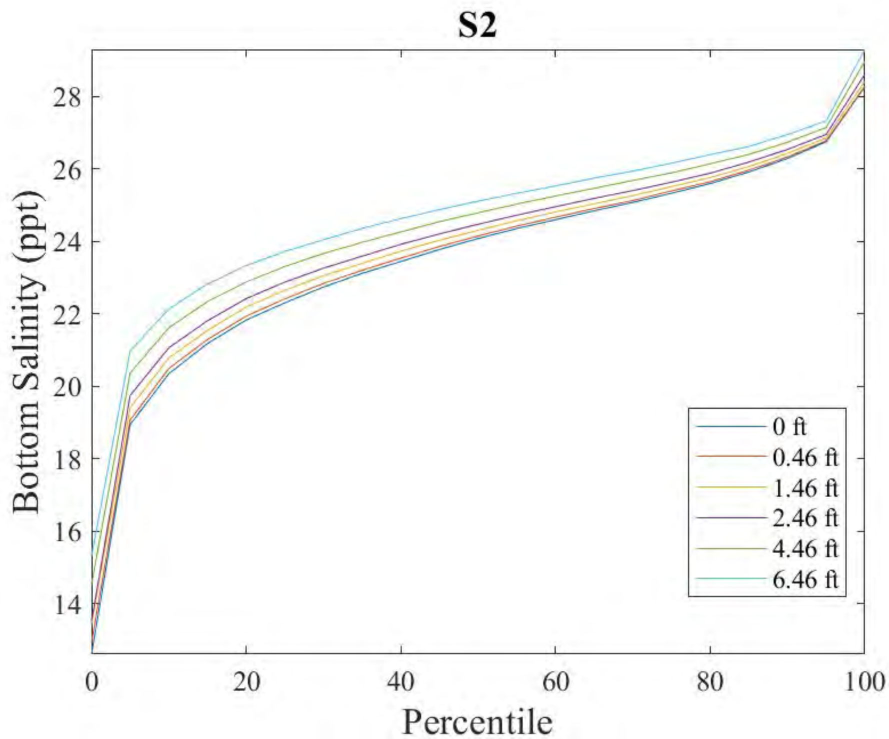


Figure 367. Alt 2, S3 Salinity Variation with SLR.

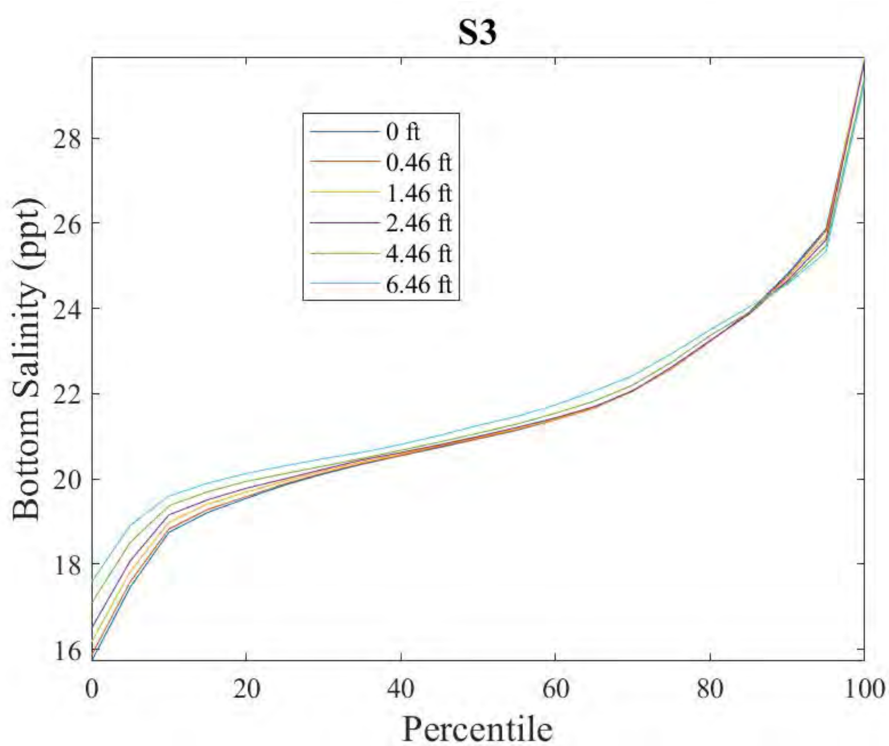


Figure 368. Alt 2, S4 Salinity Variation with SLR.

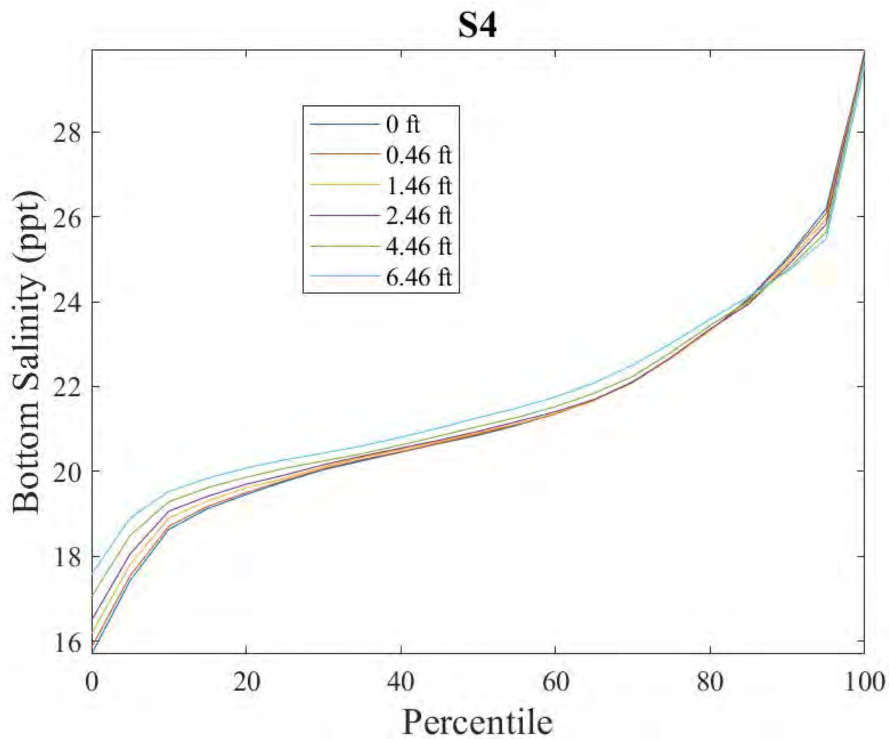


Figure 369. Alt 2, S5 Salinity Variation with SLR.

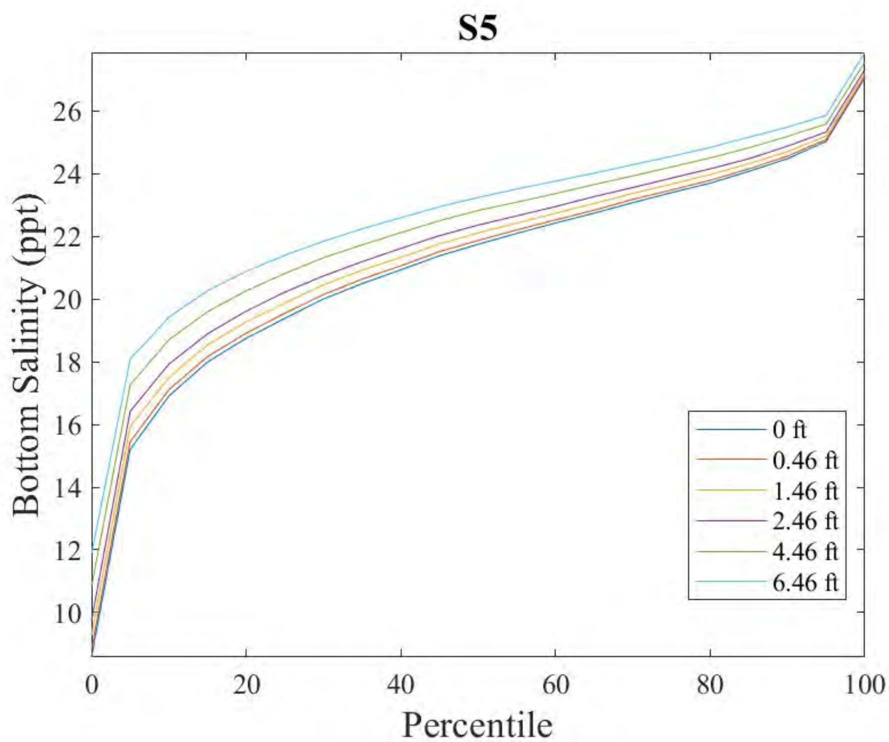


Figure 370. Alt 2, T1 Salinity Variation with SLR.

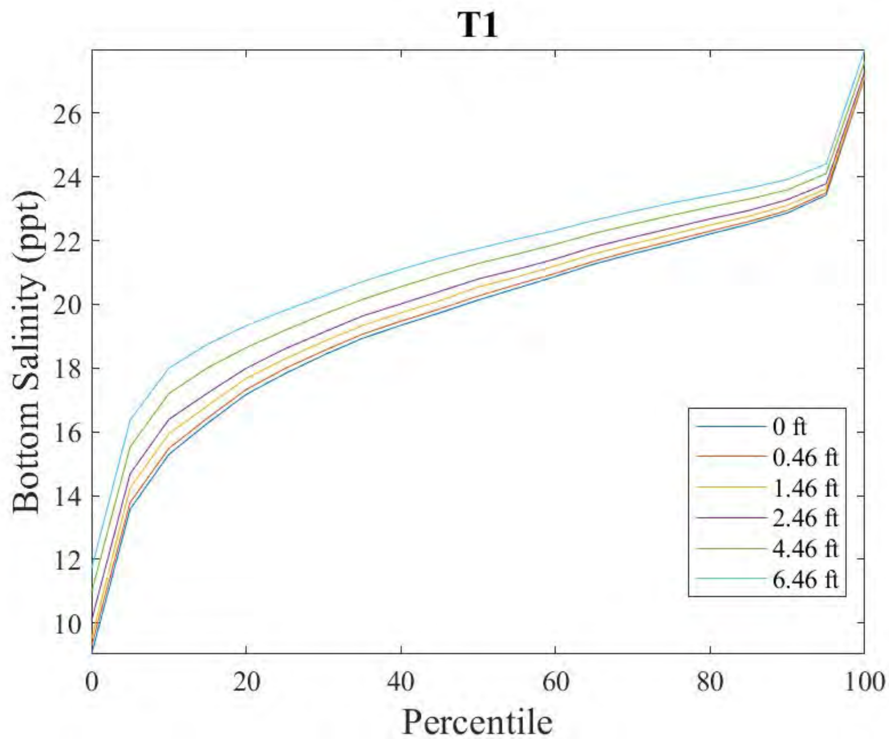


Figure 371. Alt 2, T2 Salinity Variation with SLR.

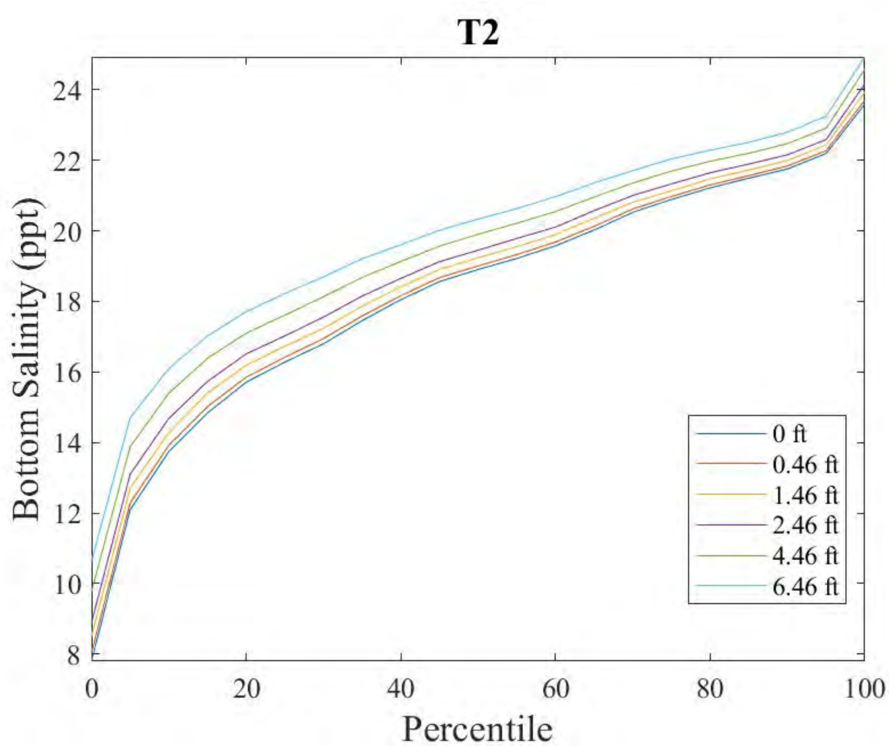


Figure 372. Alt 2, T3 Salinity Variation with SLR.

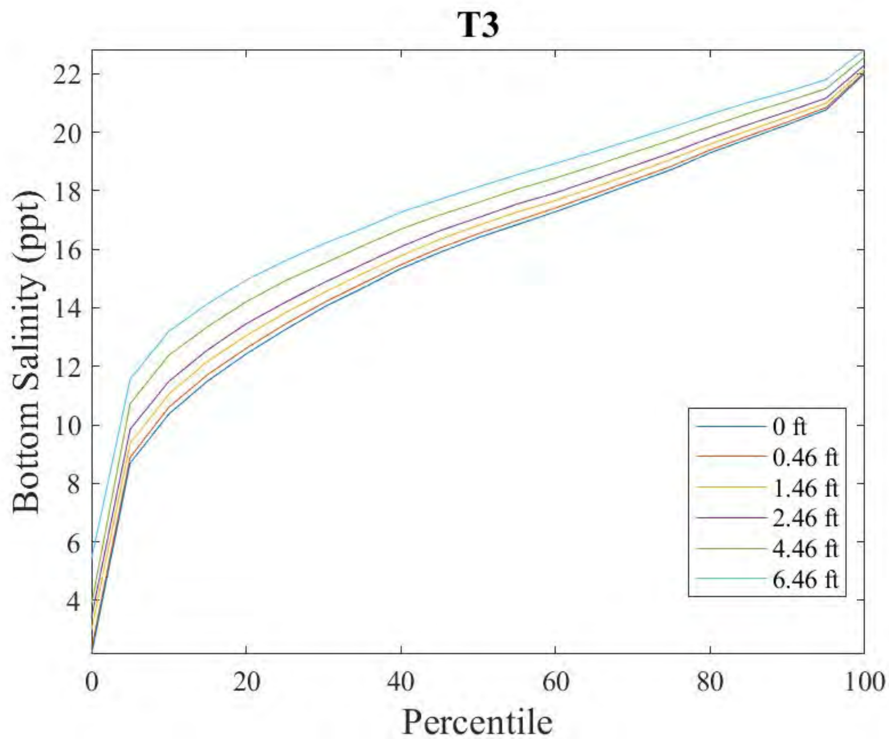


Figure 373. Alt 2, T4 Salinity Variation with SLR.

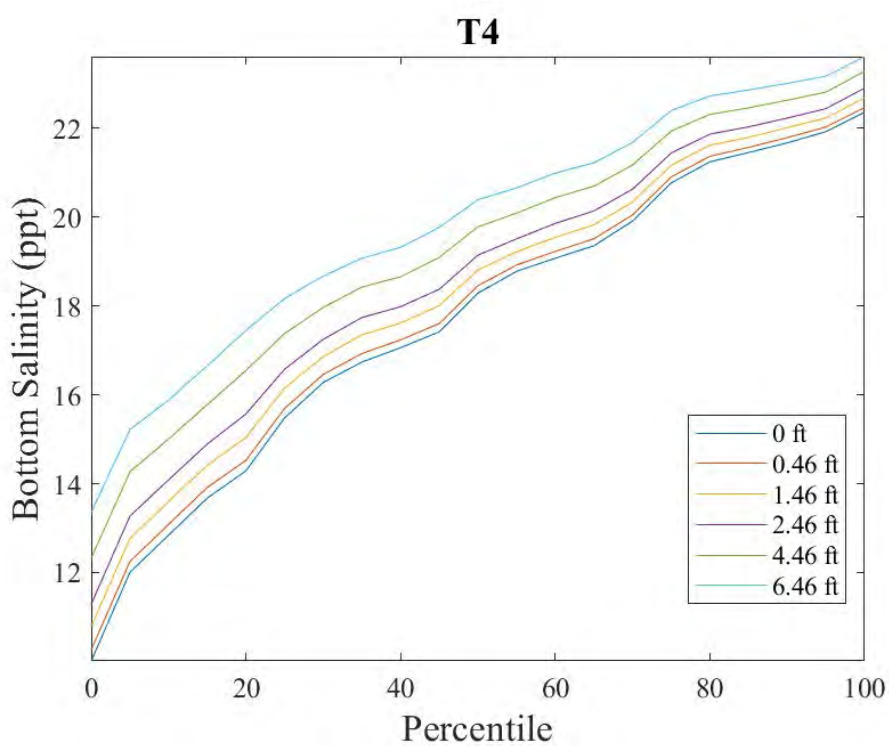


Figure 374. Alt 2, T5 Salinity Variation with SLR.

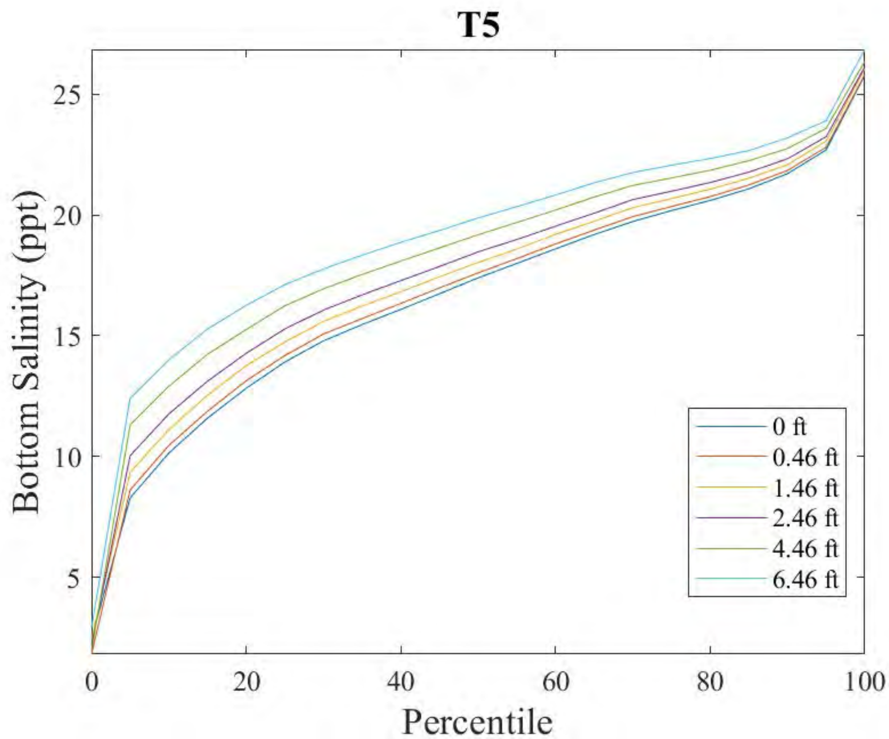


Figure 375. Alt 2, R1 Salinity Variation with SLR.

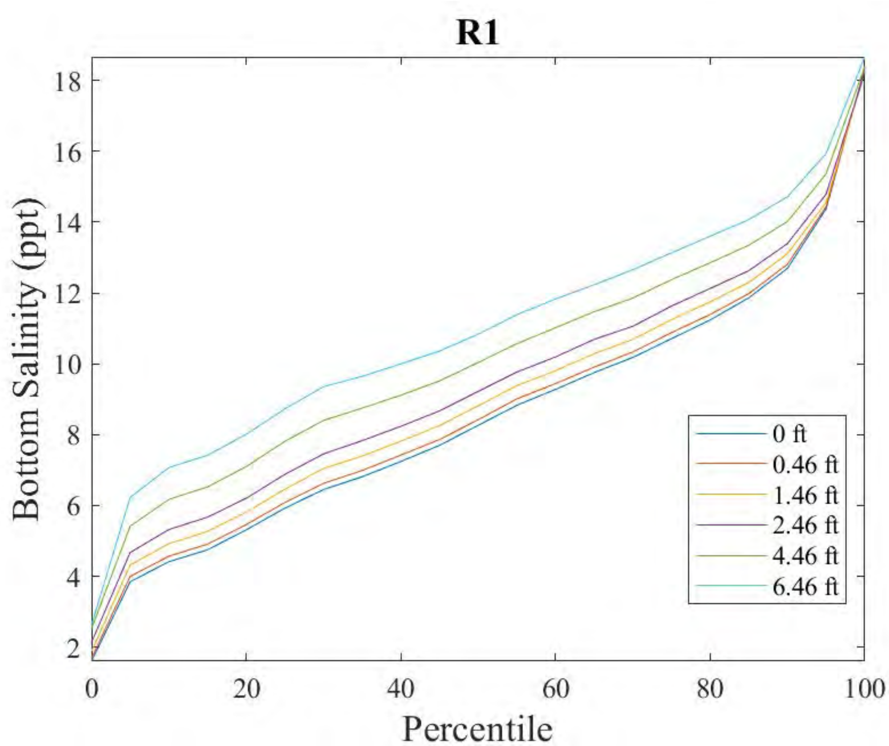


Figure 376. Alt 2, Sandy Hook Salinity Variation with SLR.

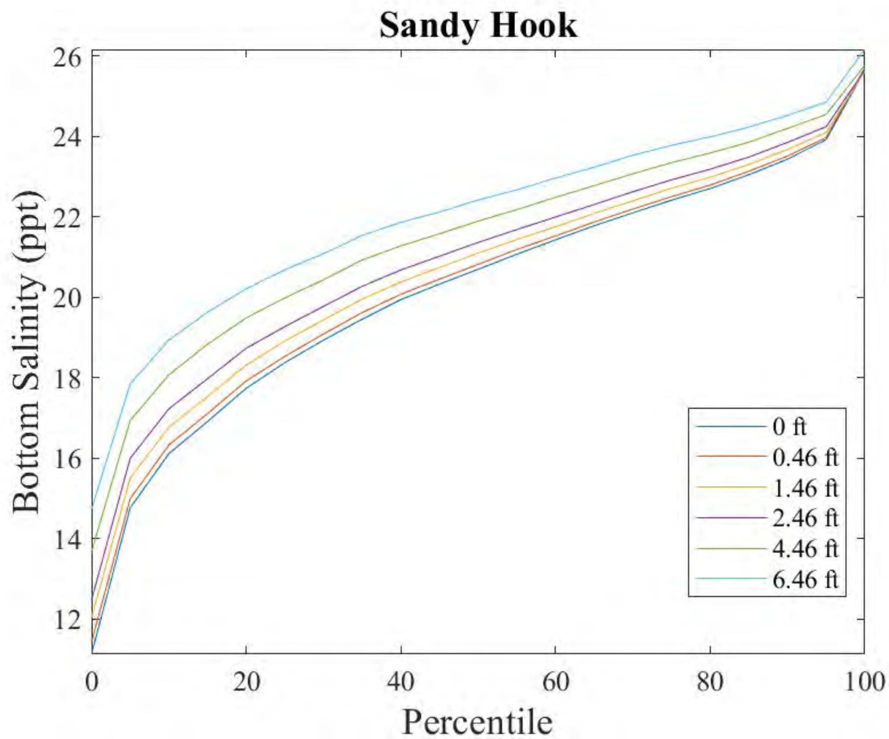


Figure 377. Alt 2, Fresh Kills Salinity Variation with SLR.

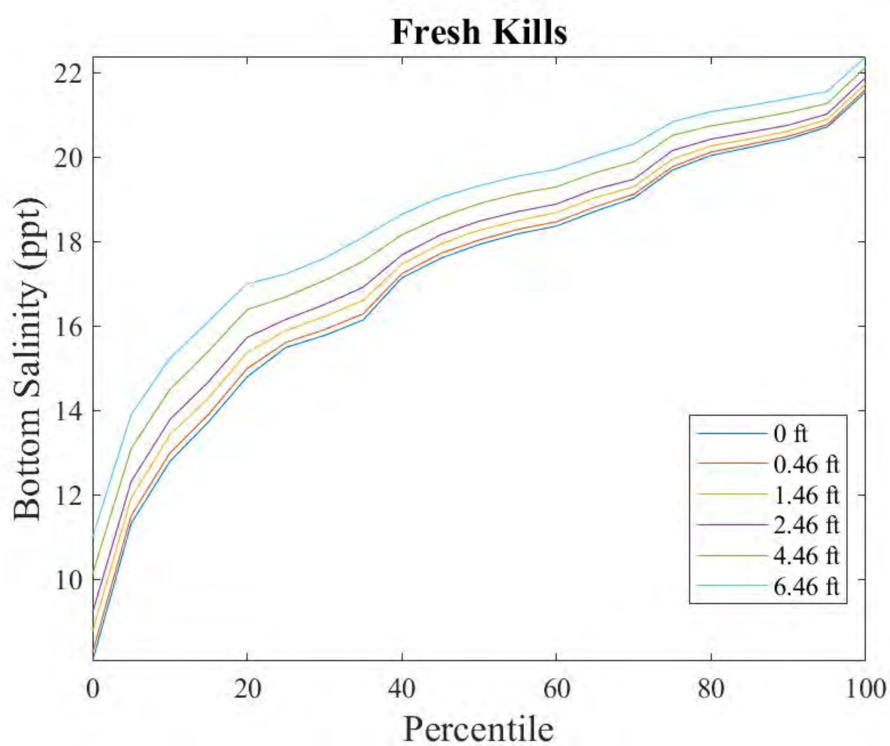


Figure 378. Alt 2, Mariners Harbor Salinity Variation with SLR.

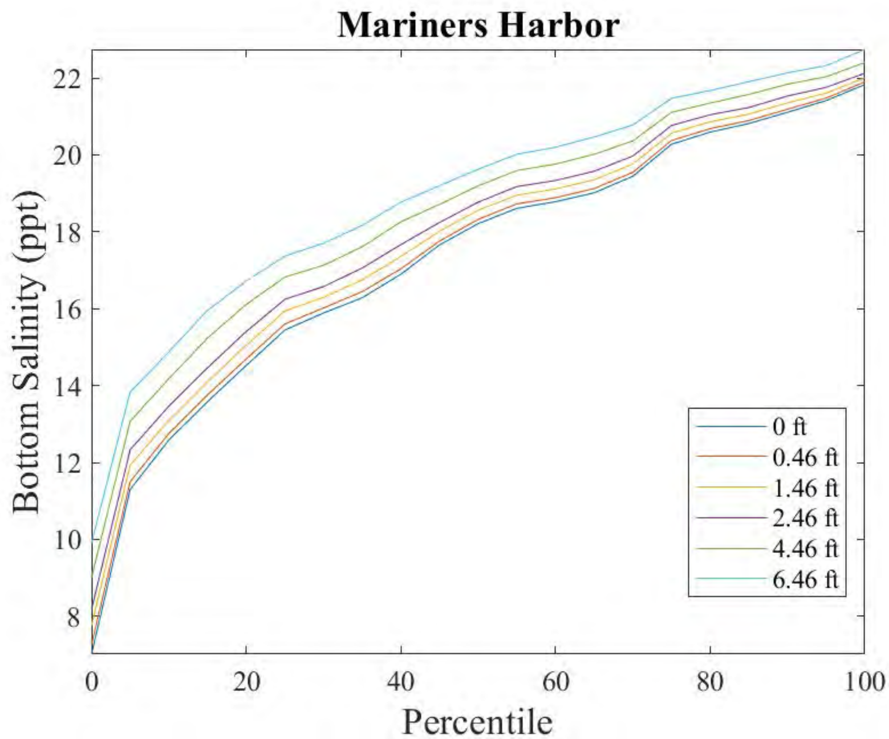


Figure 379. Alt 2, North Reach Salinity Variation with SLR.

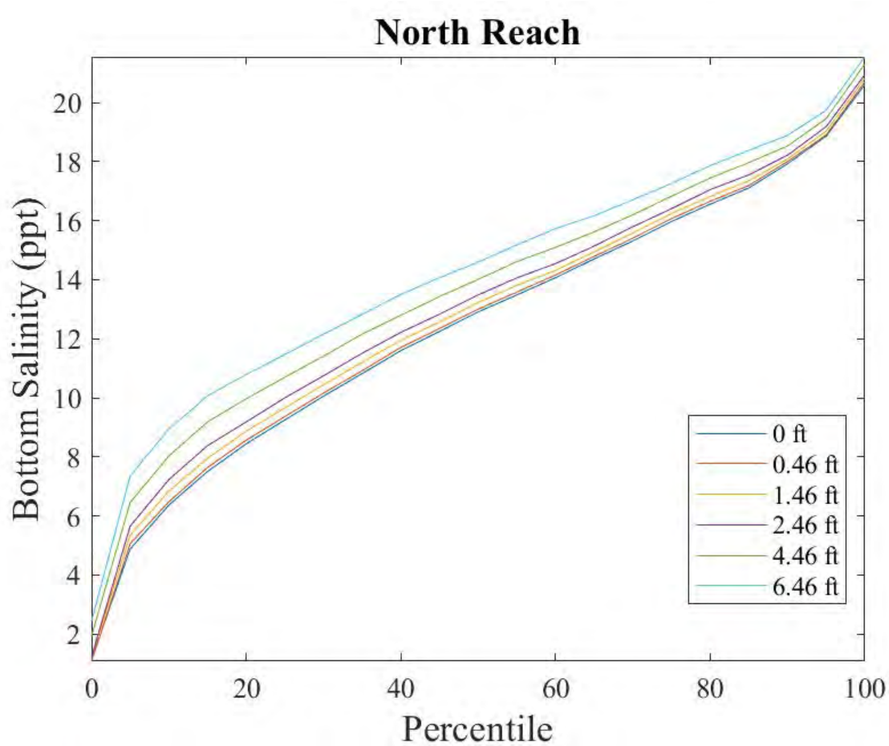


Figure 380. Alt 2, Hackensack River Salinity Variation with SLR.

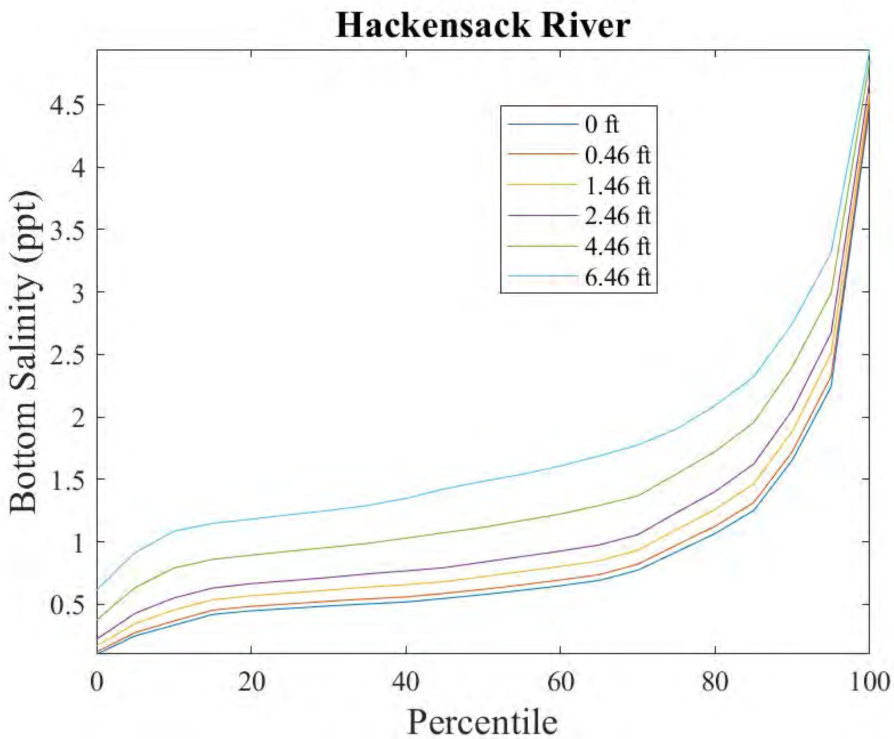


Figure 381. Alt 2, Robbins Reef Salinity Variation with SLR.

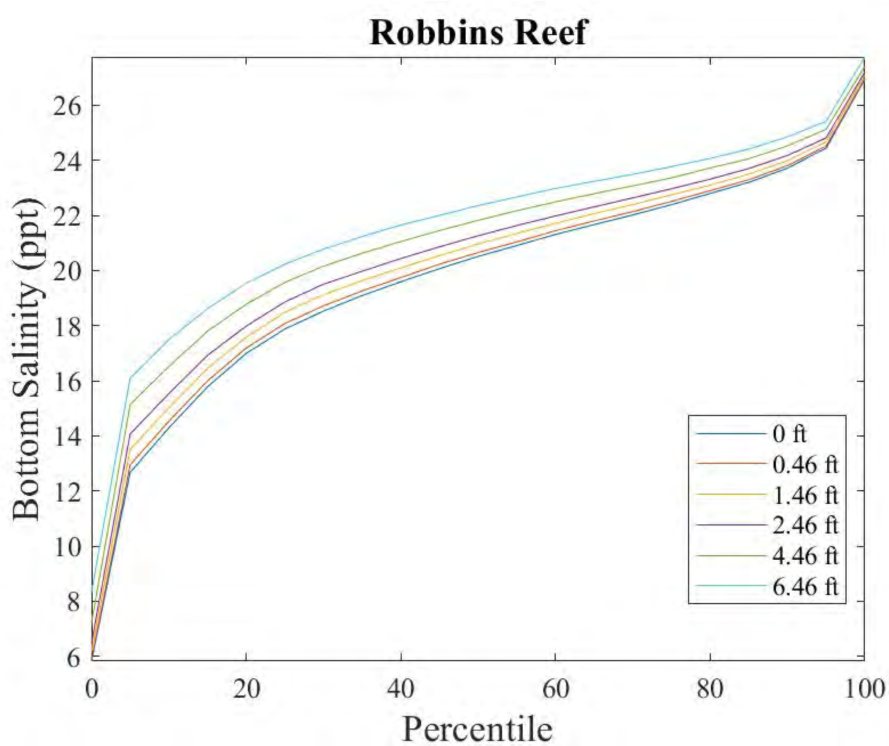


Figure 382. Alt 2, The Battery Salinity Variation with SLR.

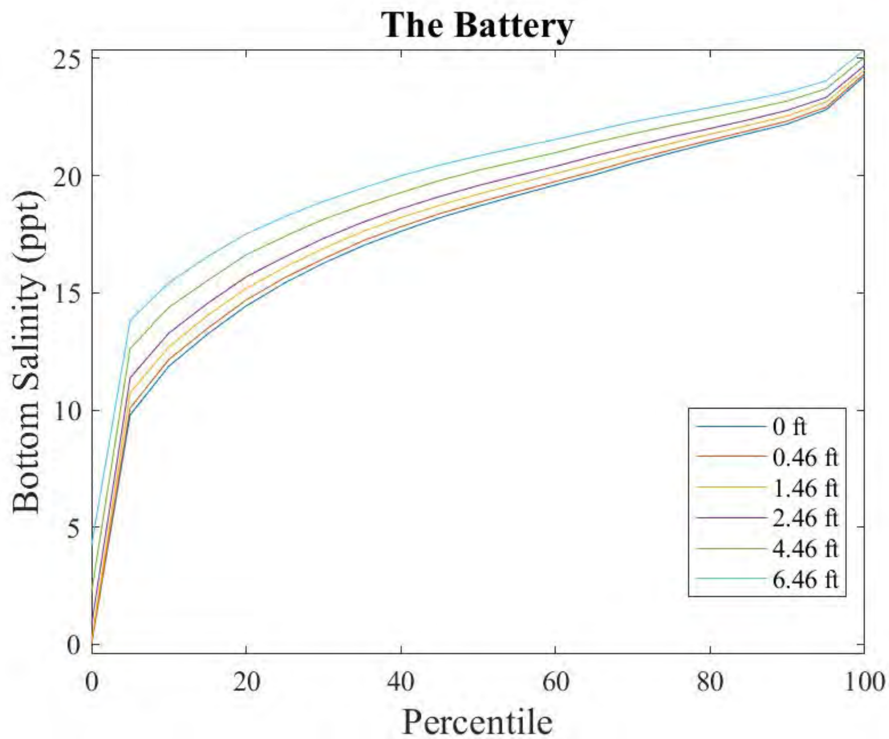


Figure 383. Alt 2, Manhattan Salinity Variation with SLR.

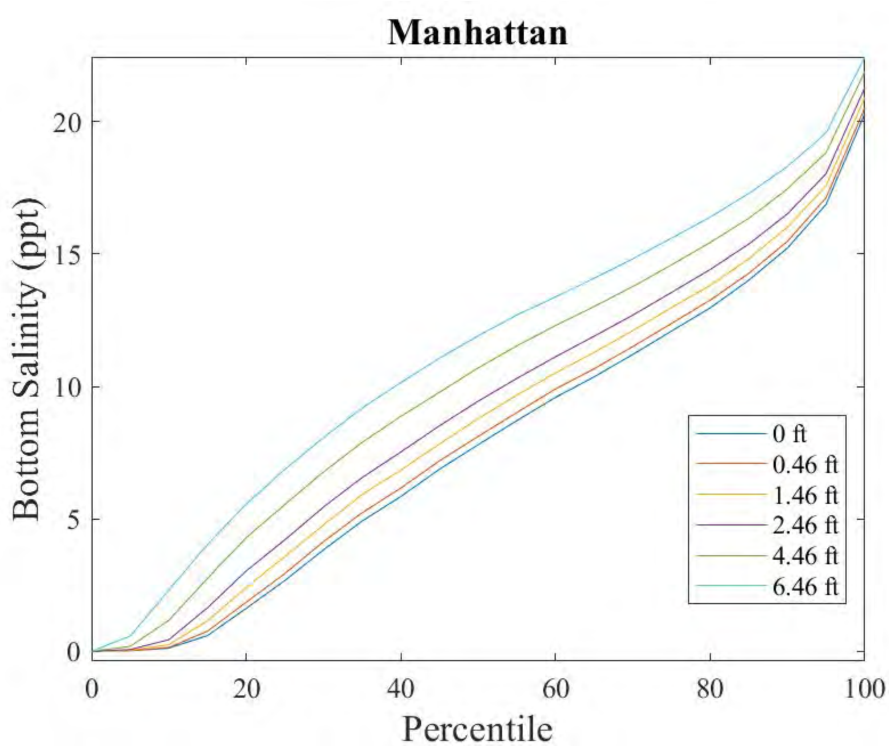


Figure 384. Alt 2, Hudson River Haverstraw Bay Salinity Variation with SLR.

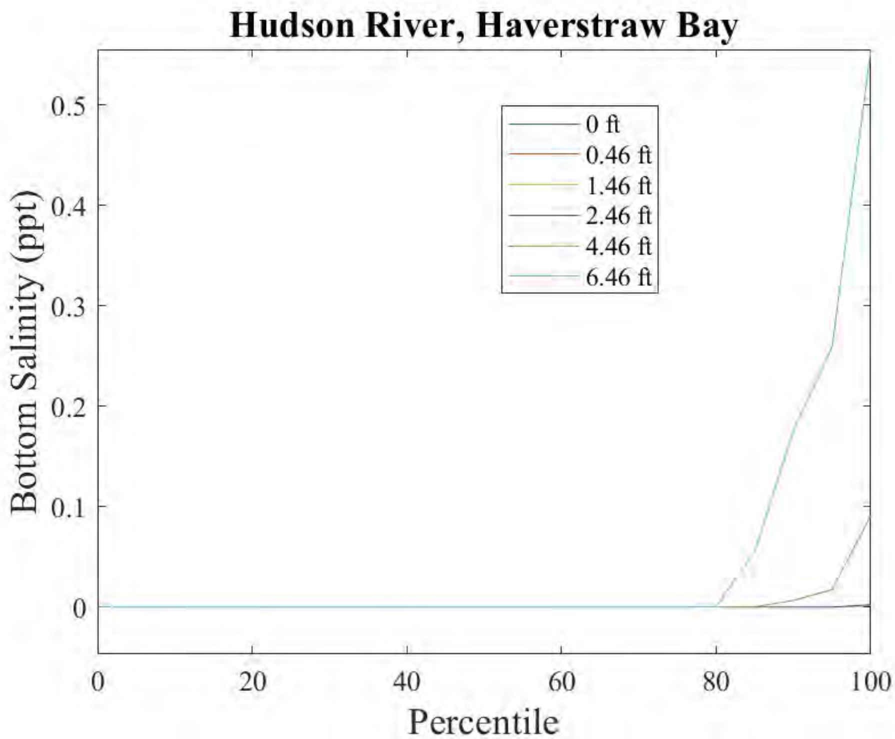


Figure 385. Alt 2, KLGA Salinity Variation with SLR.

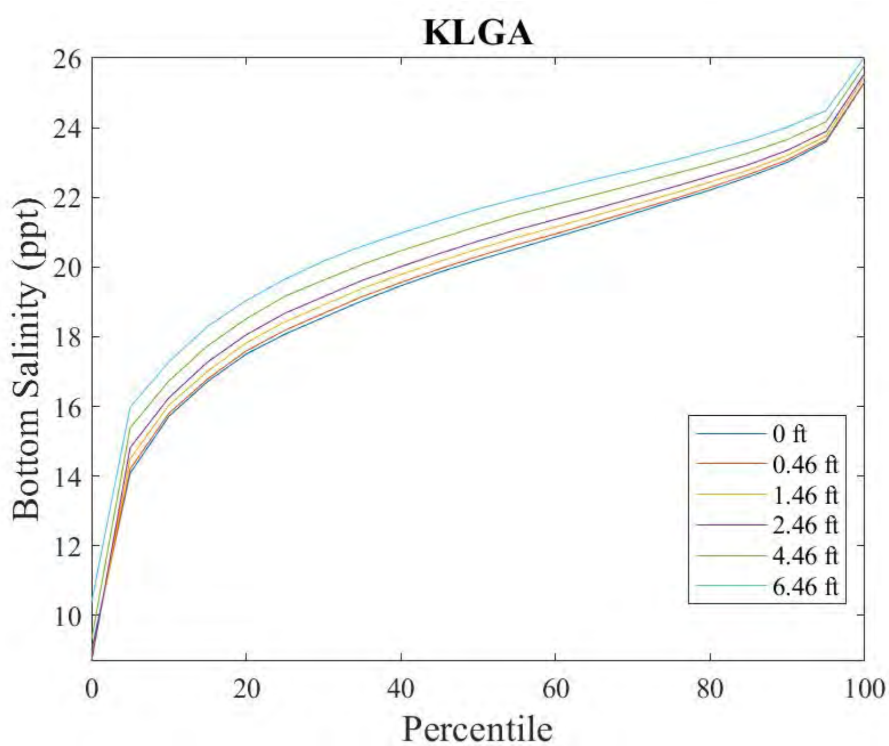


Figure 386. Alt 2, LIS near Stepping Stone Lighthouse Salinity Variation with SLR.

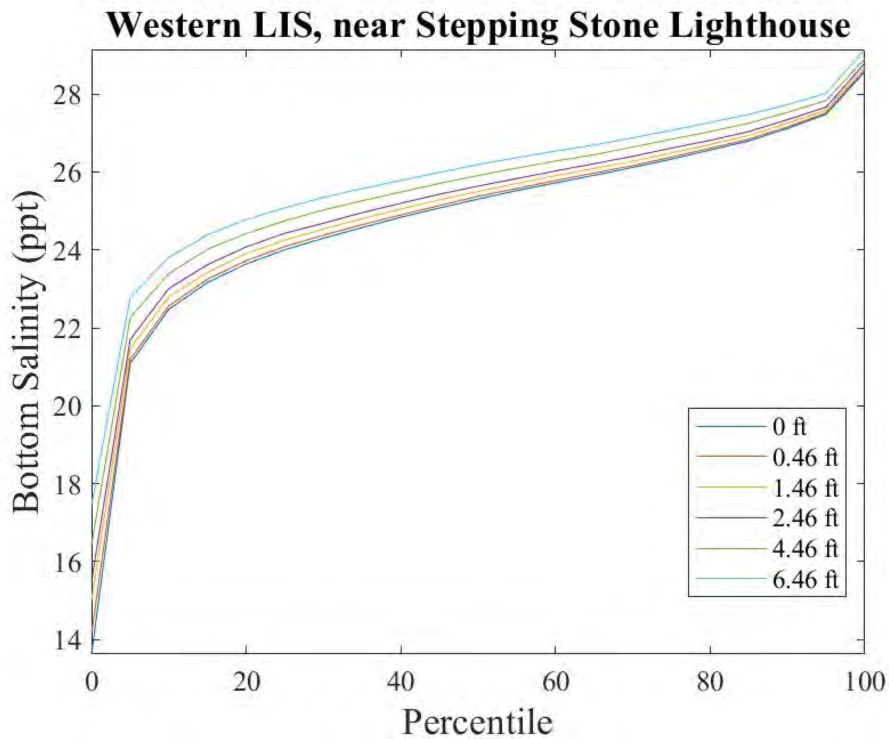


Figure 387. Alt 2, LIS near Execution Rock Lighthouse Salinity Variation with SLR.

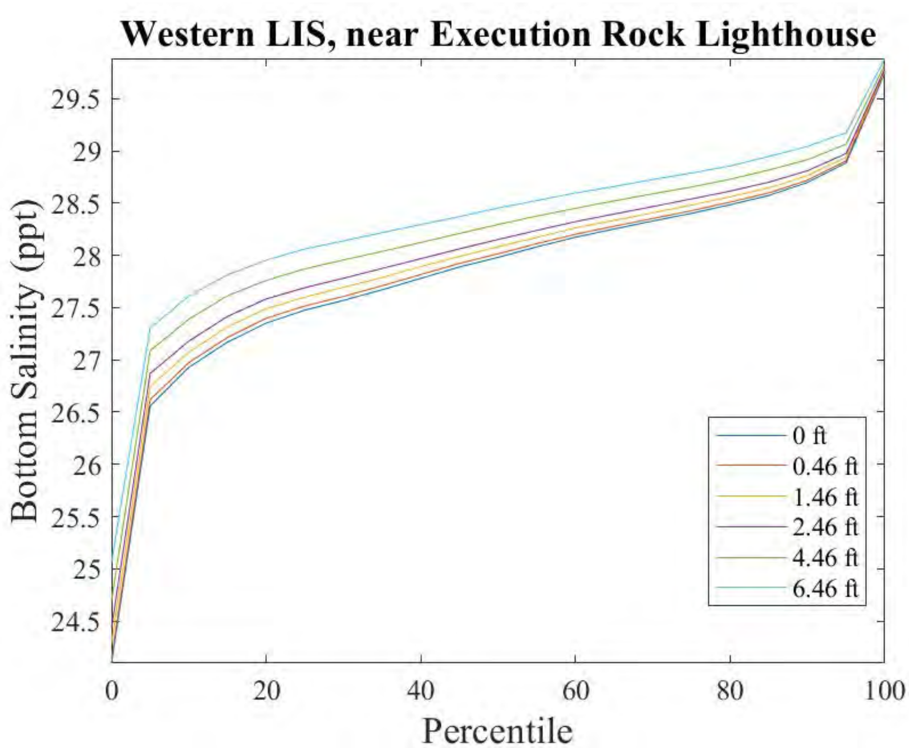


Figure 388. Alt 2, LIS south of NY/CT border Salinity Variation with SLR.

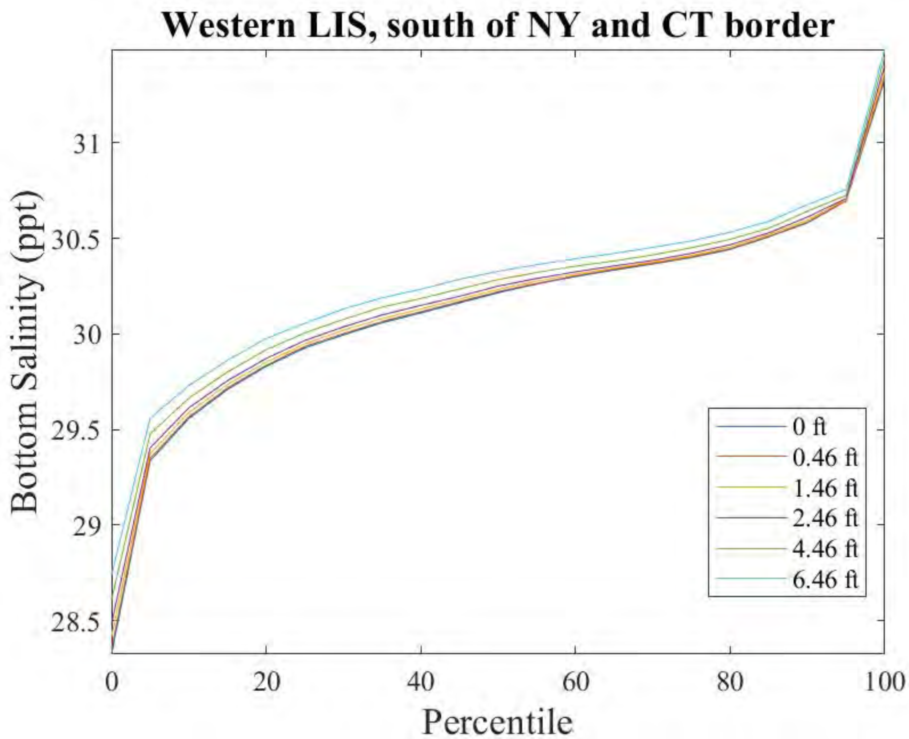


Figure 389. Alt 2, Jamaica Bay Salinity Variation with SLR.

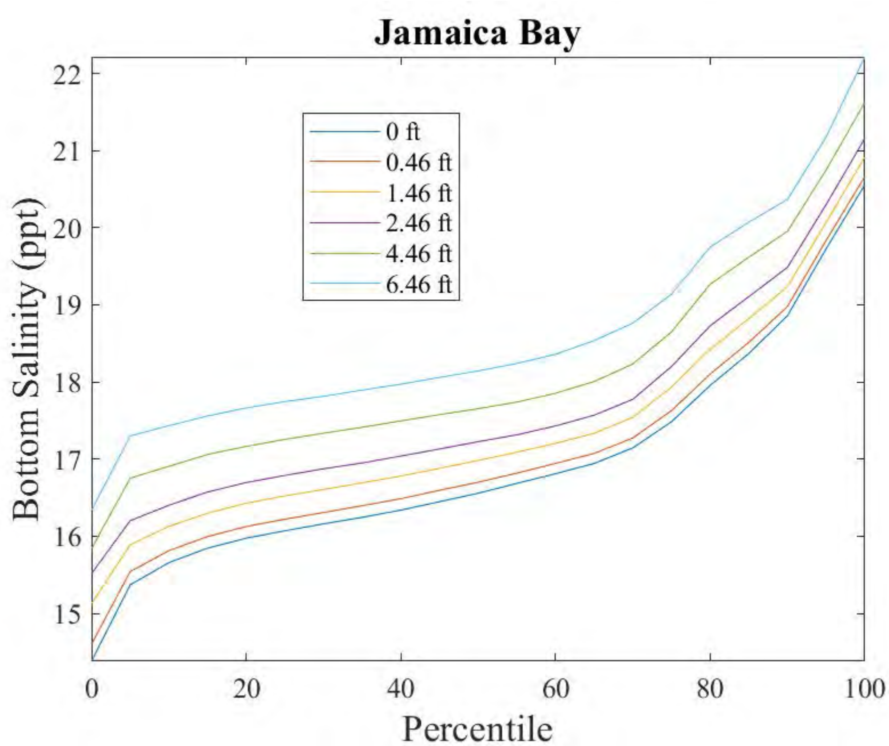


Figure 390. Alt 2, Jamaica Bay near Spring Creek Salinity Variation with SLR.

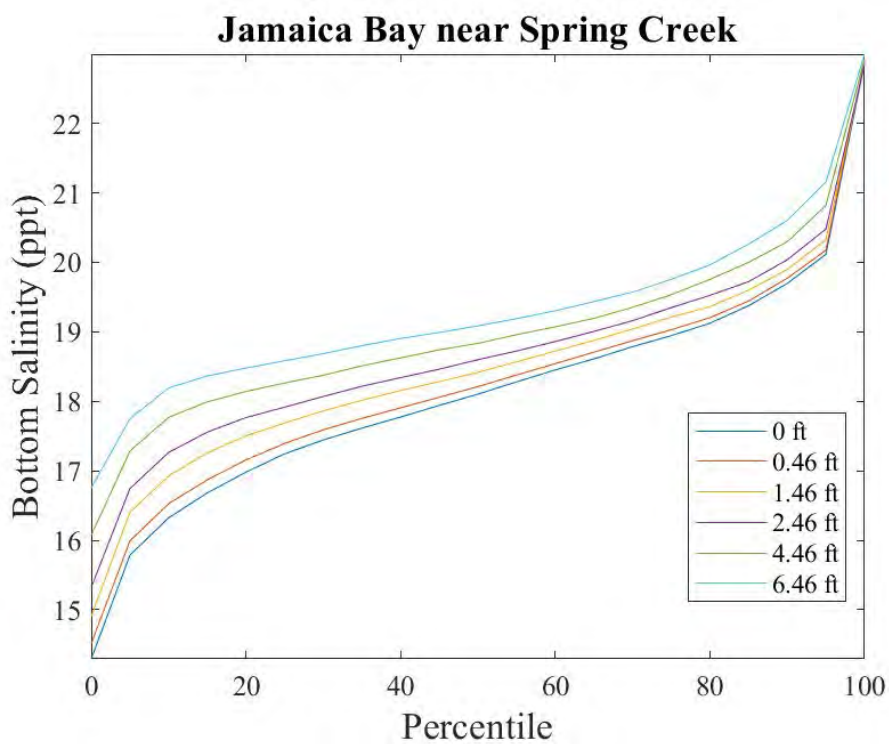
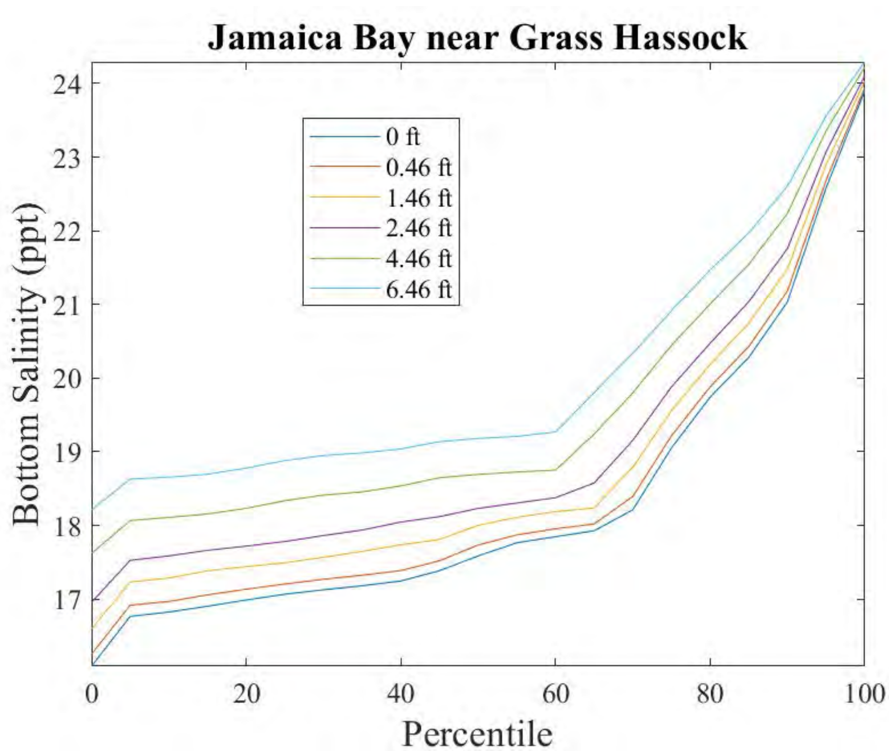


Figure 391. Alt 2, Jamaica Bay near Grass Hassock Salinity Variation with SLR.



15.2.4 Spatial Velocity Percentiles

Spatial figures of the velocity magnitude percentiles for Alternative 2 for the 50th and 75th percentiles are provided in Figure 392 to Figure 403.

Figure 392. Alternative 2/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

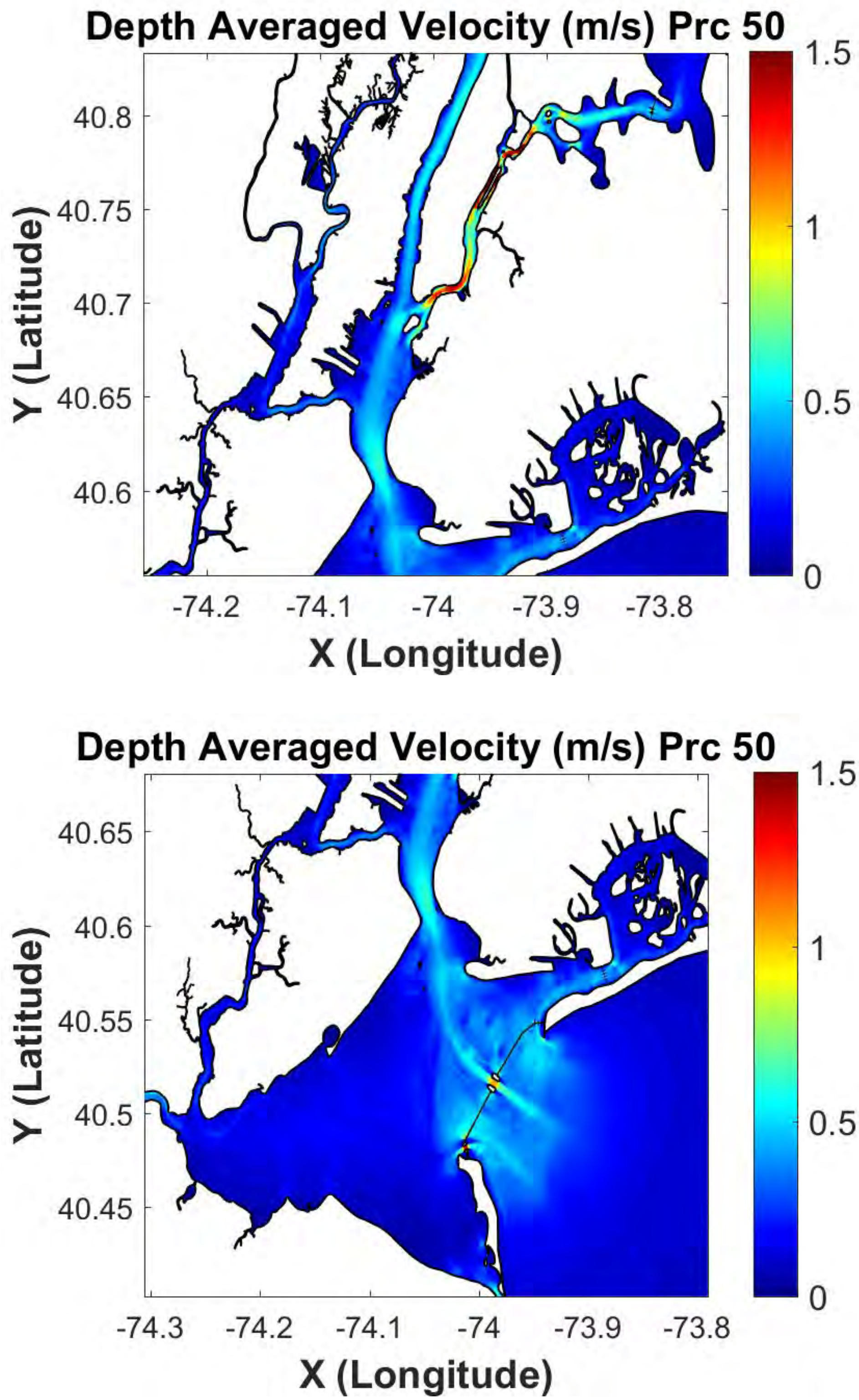


Figure 393. Alternative 2/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

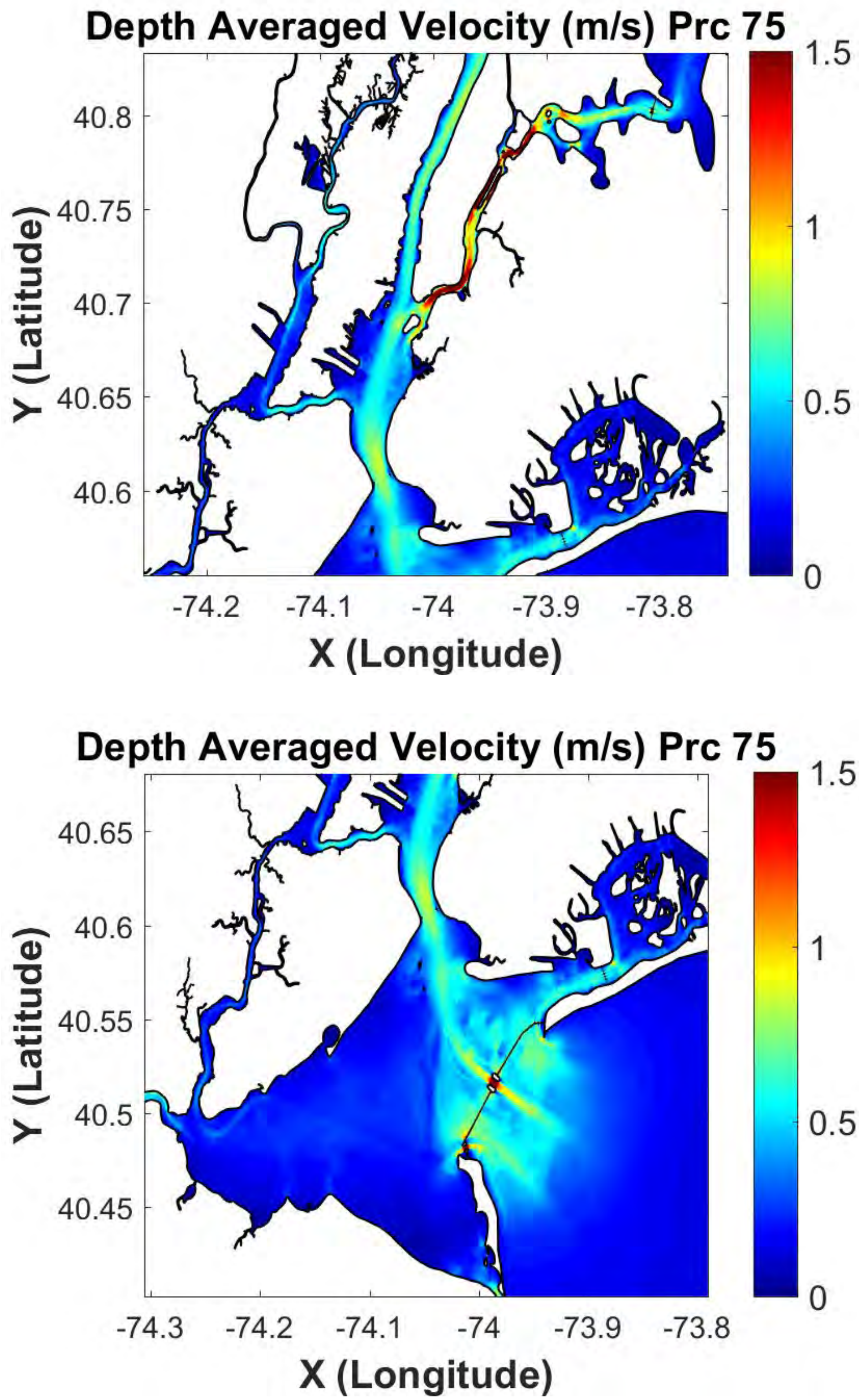
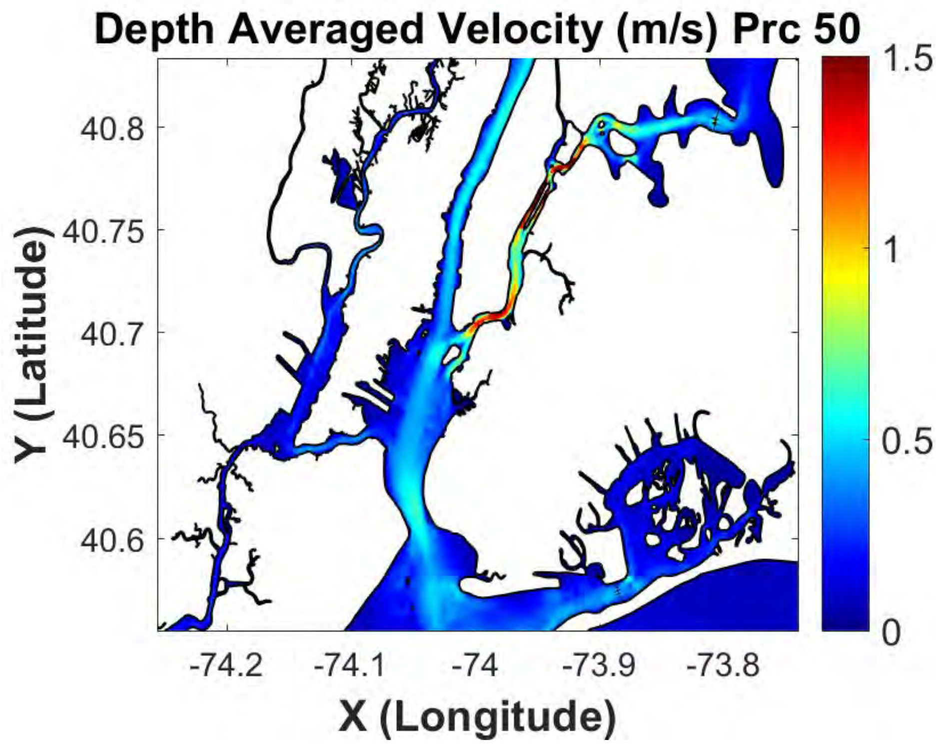


Figure 394. Alternative 2/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



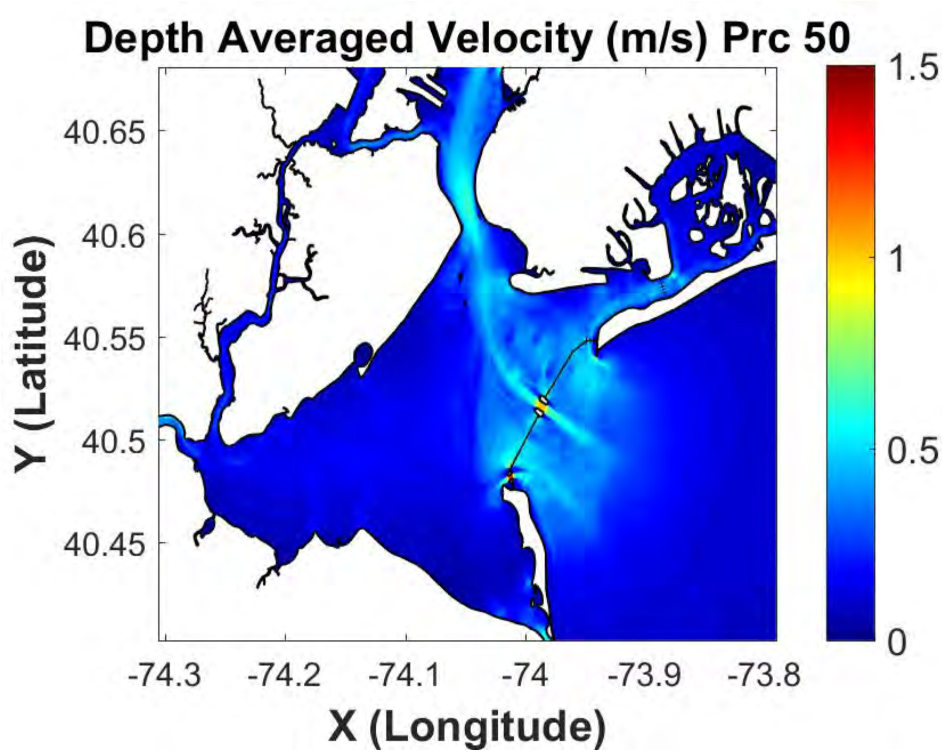


Figure 395. Alternative 2/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

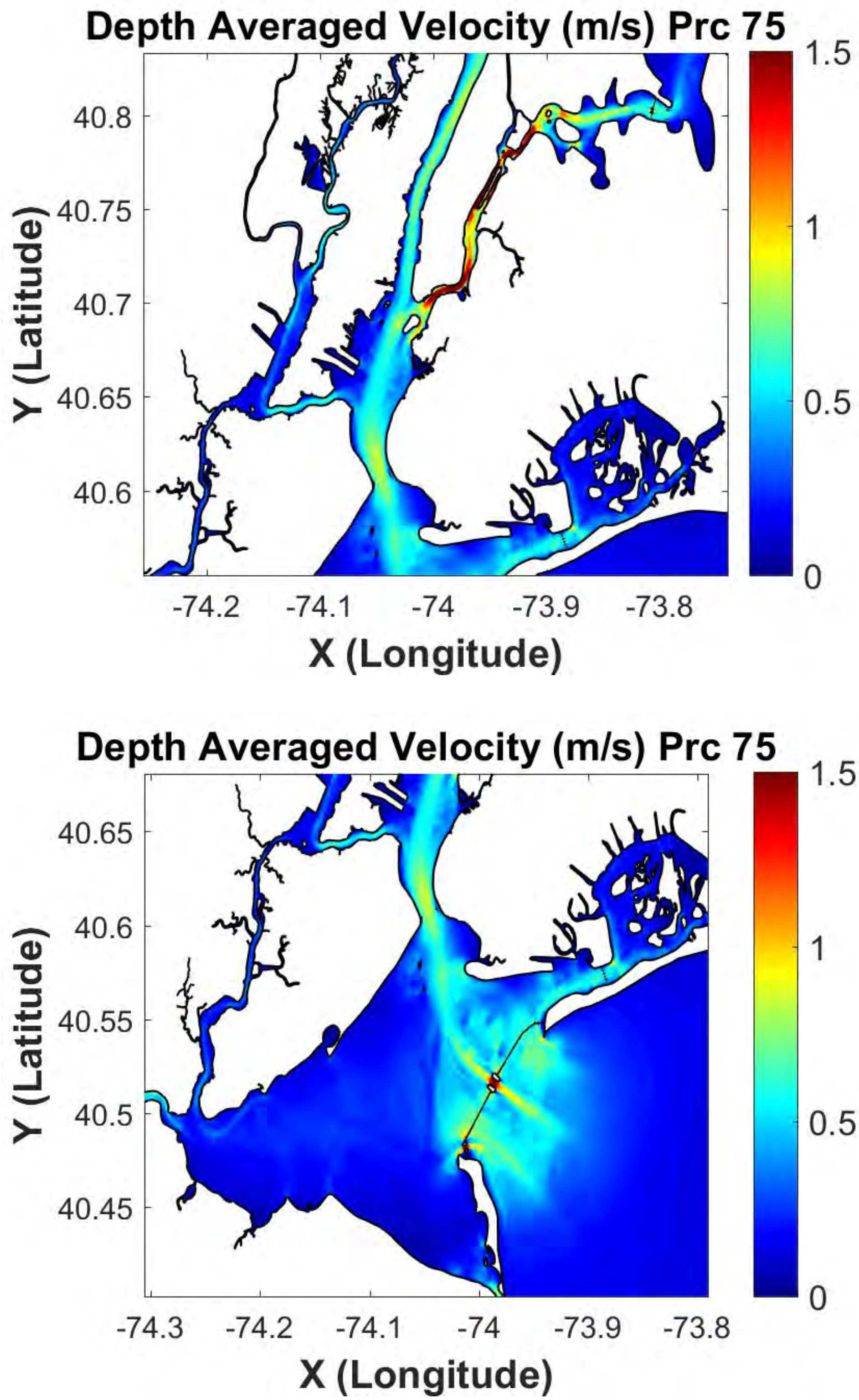
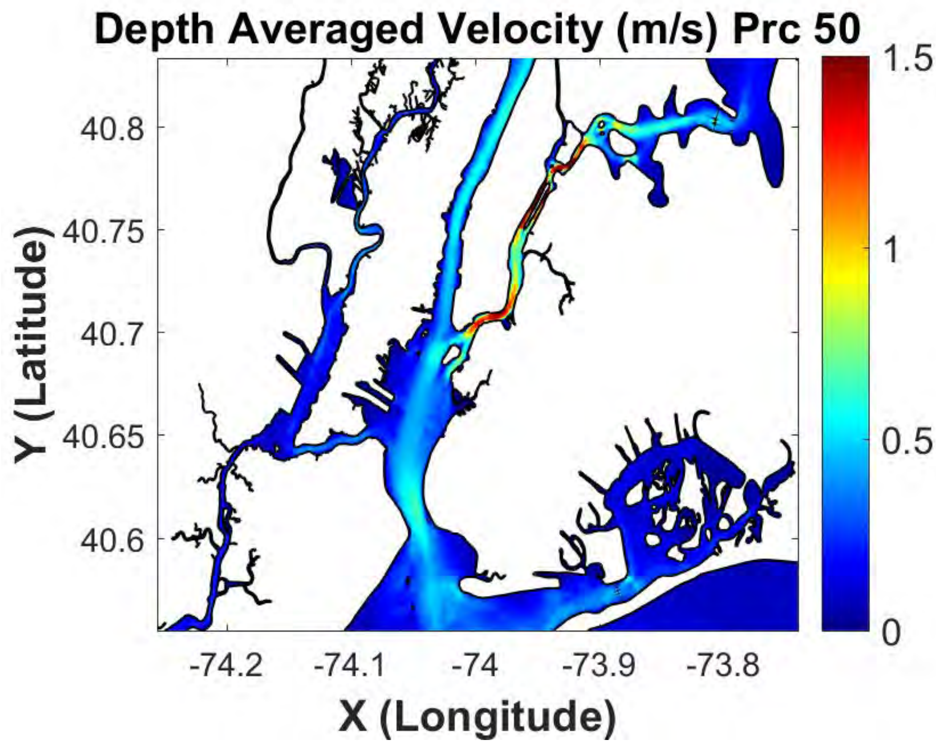


Figure 396. Alternative 2/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



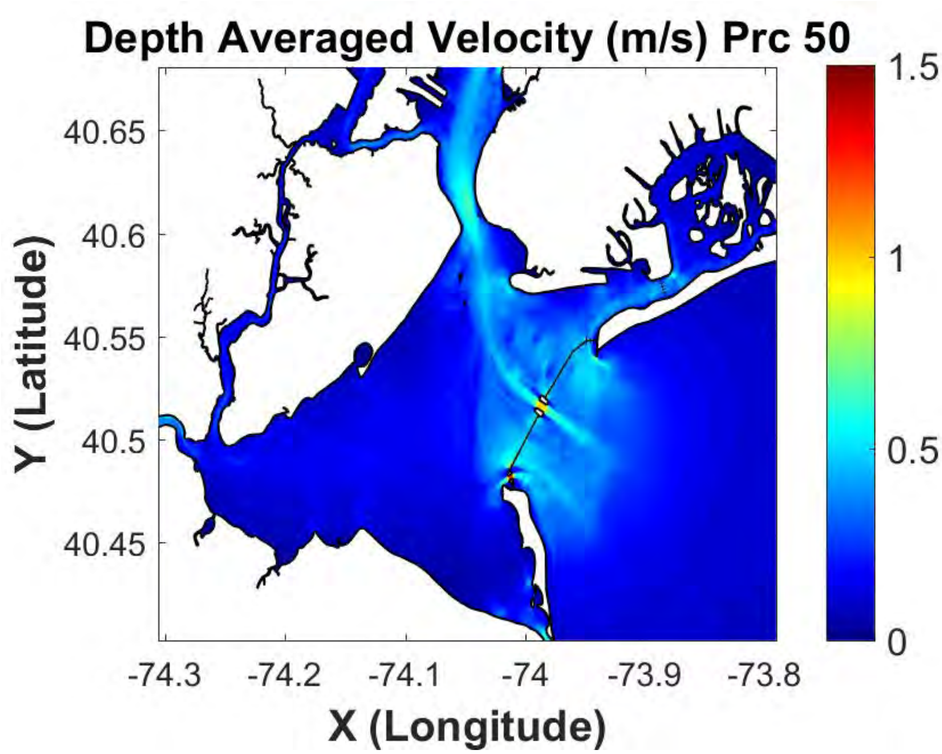
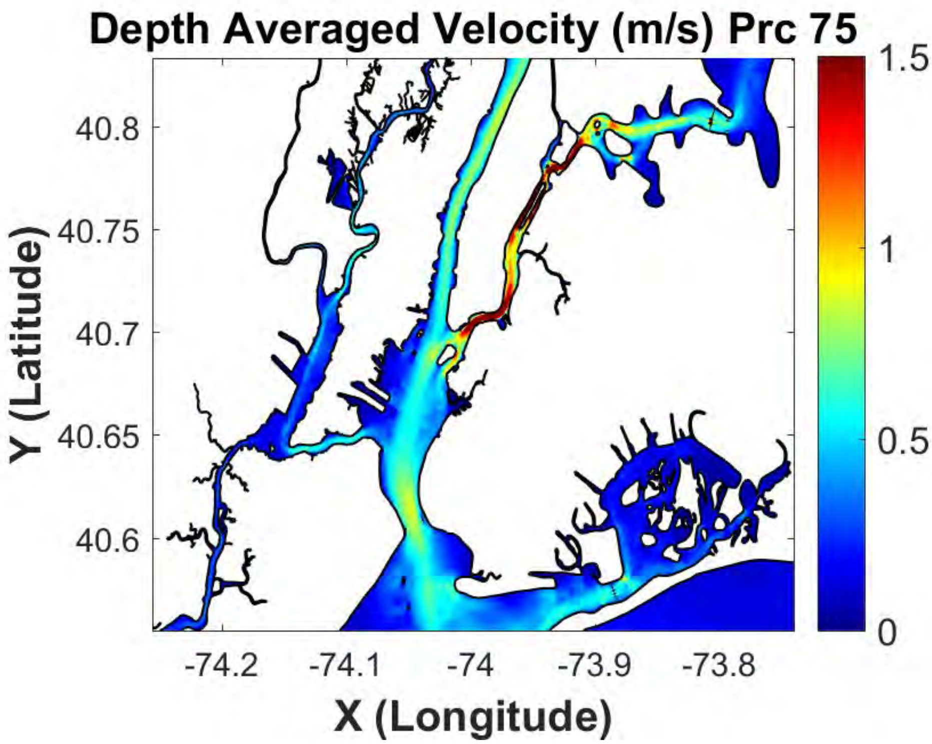
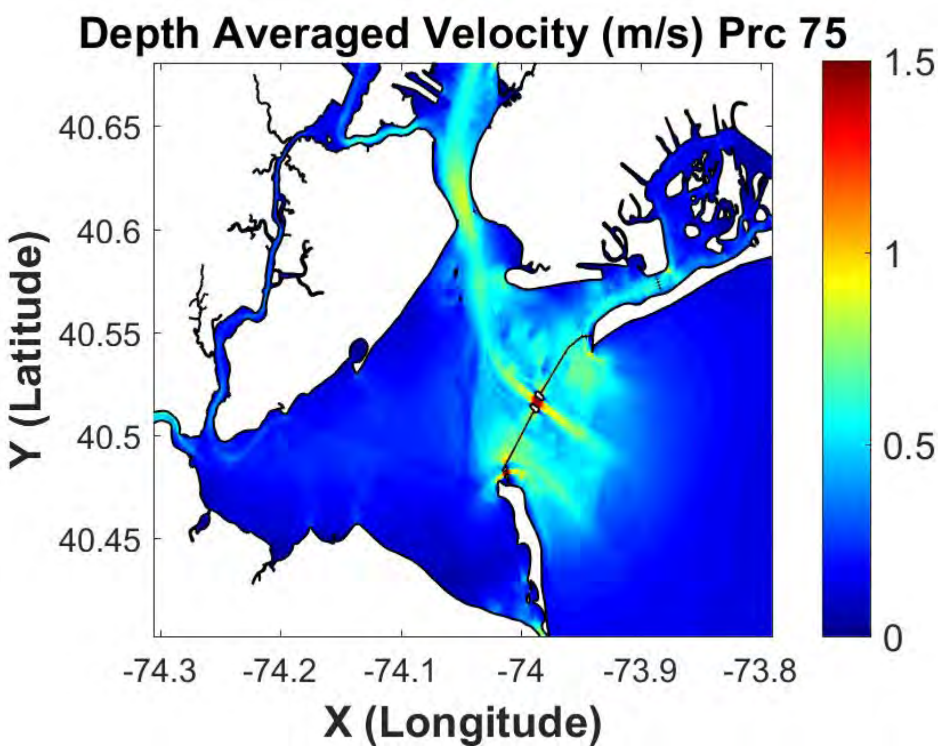


Figure 397. Alternative 2/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.





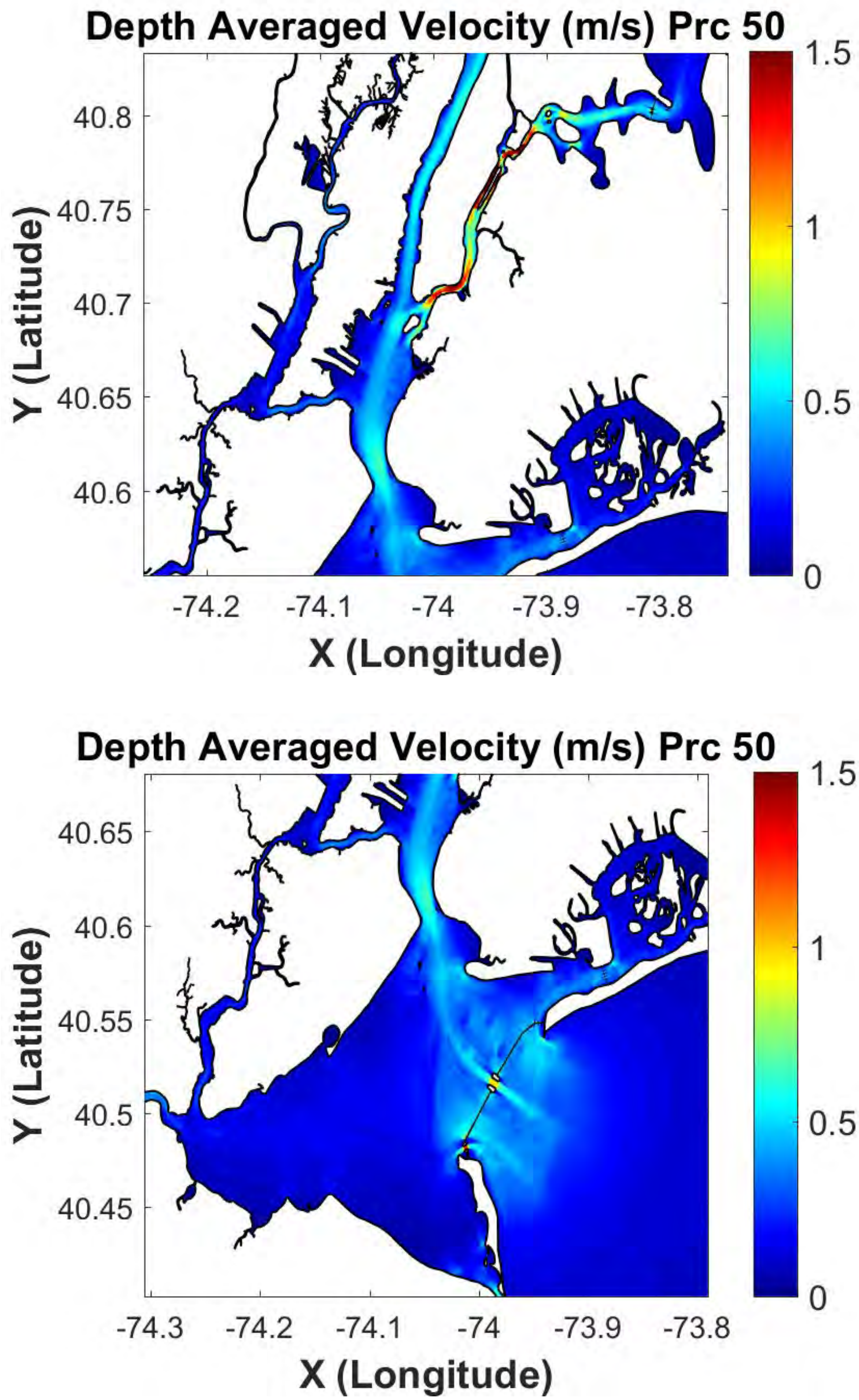


Figure 398. Alternative 2/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

Figure 399. Alternative 2/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

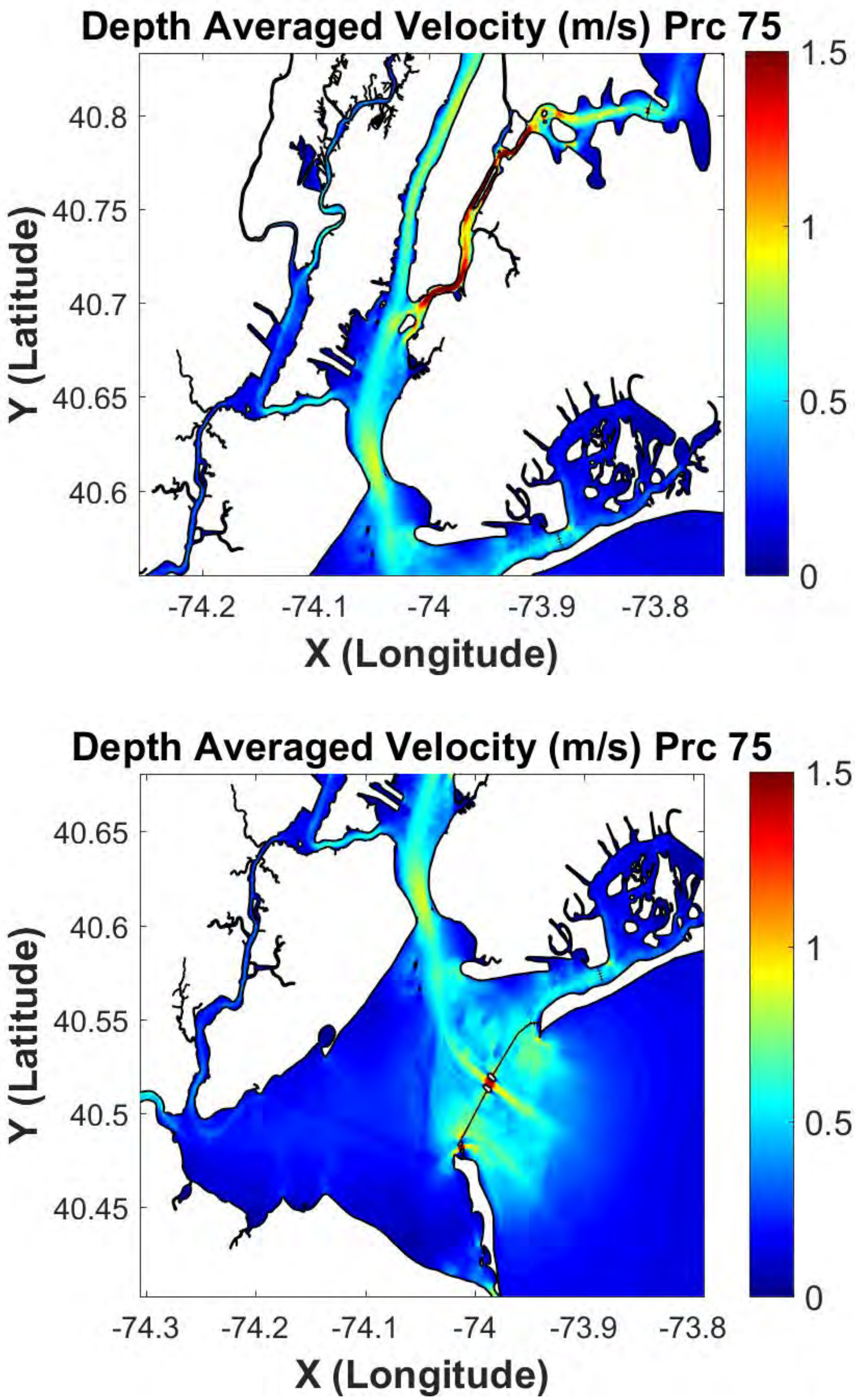
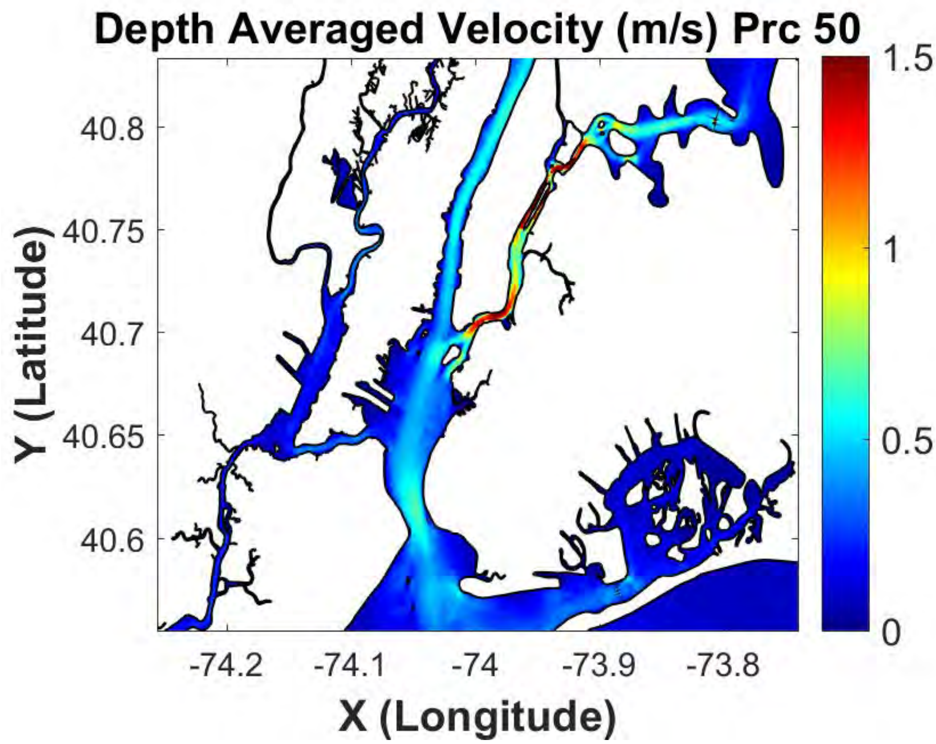


Figure 400. Alternative 2/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



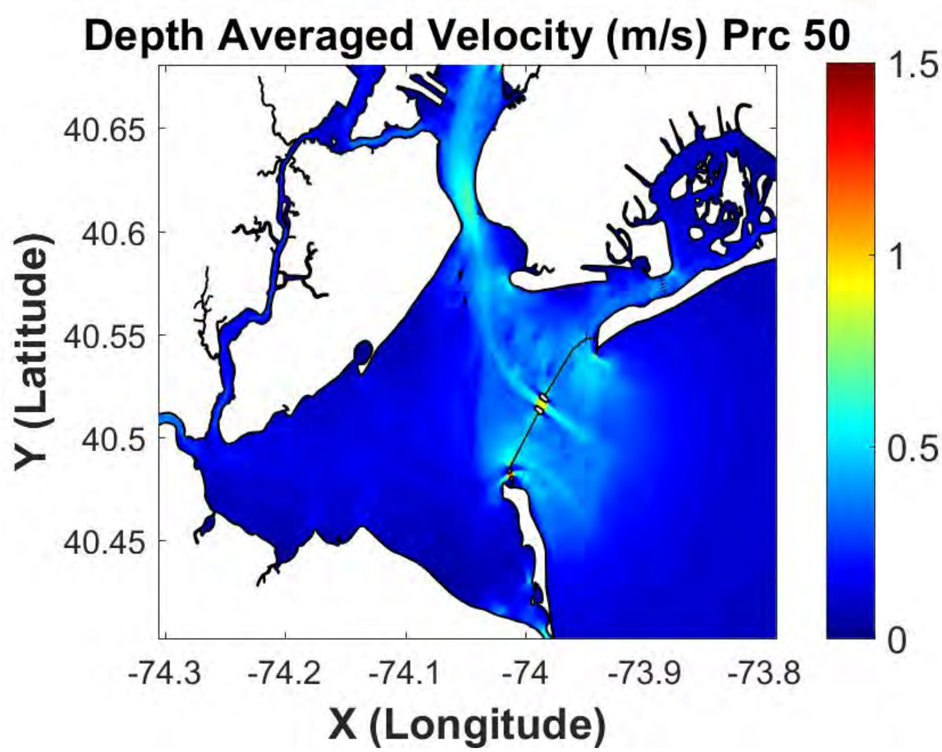
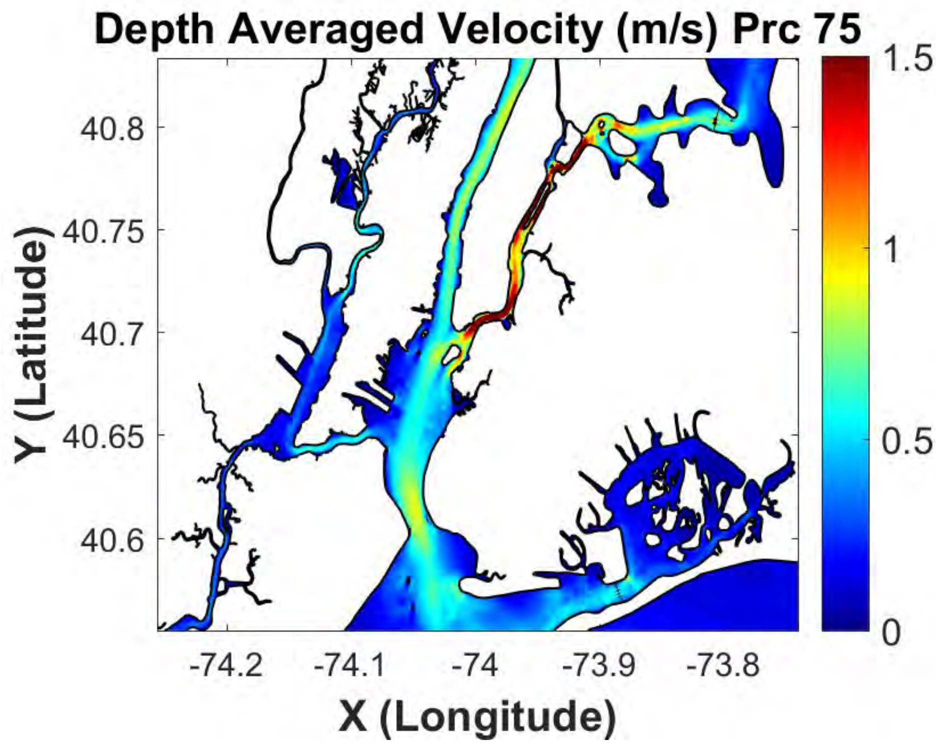


Figure 401. Alternative 2/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



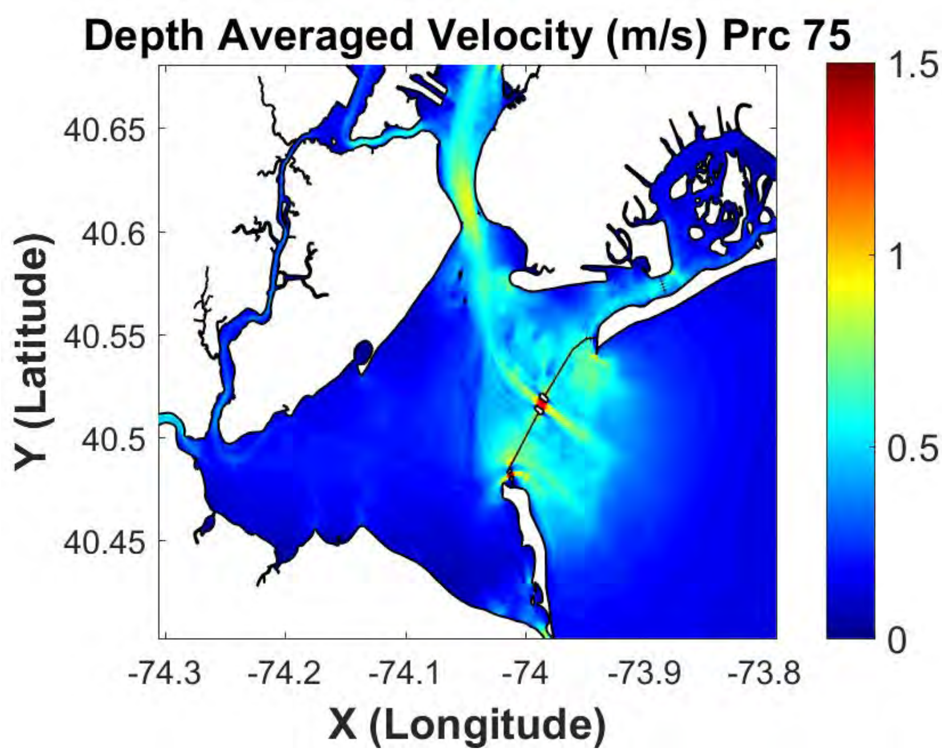
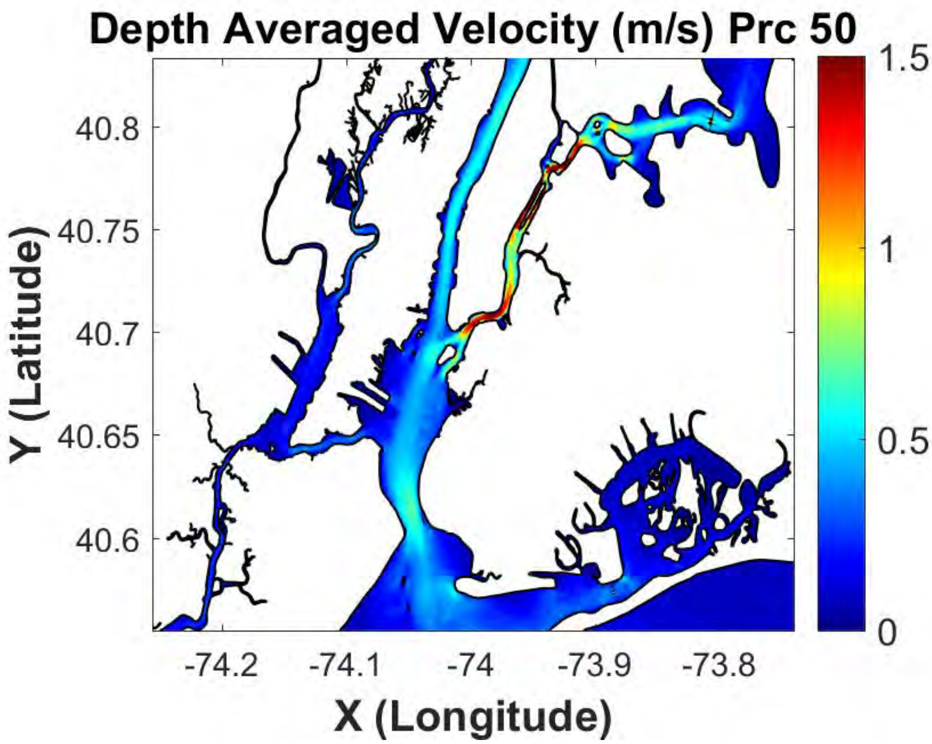


Figure 402. Alternative 2/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



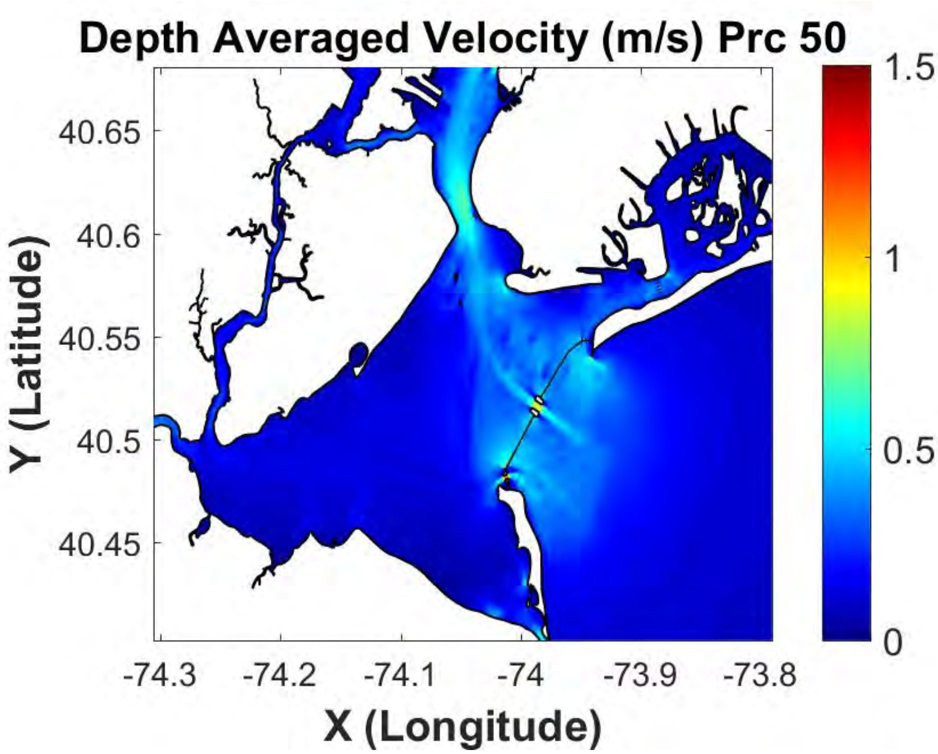
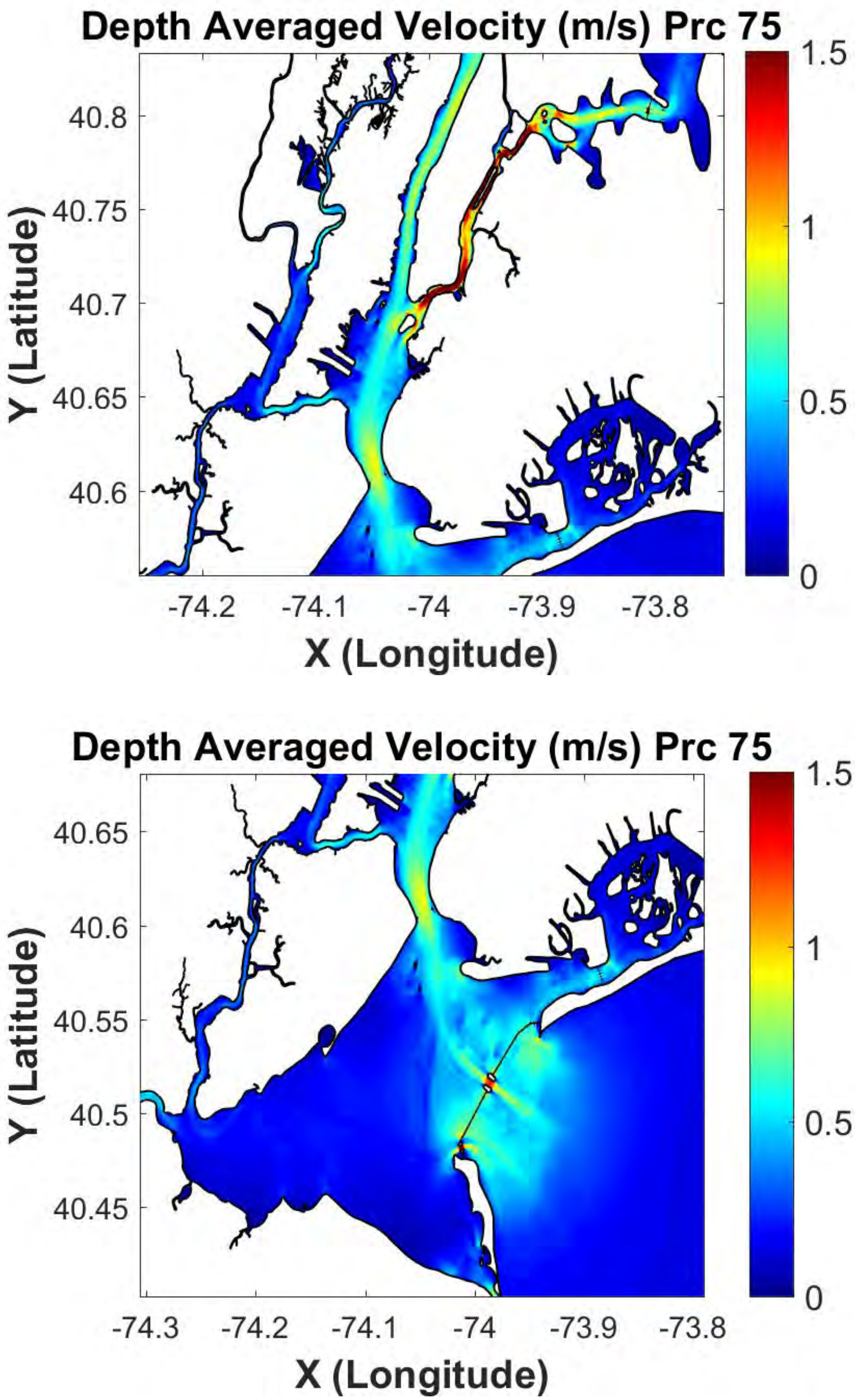


Figure 403. Alternative 2/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



15.2.5 Spatial Salinity Percentiles

Spatial figures of the salinity percentiles for Alternative 2 for the 50th and 75th percentiles are provided in Figure 404 to Figure 415.

Figure 404. Alternative 2/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

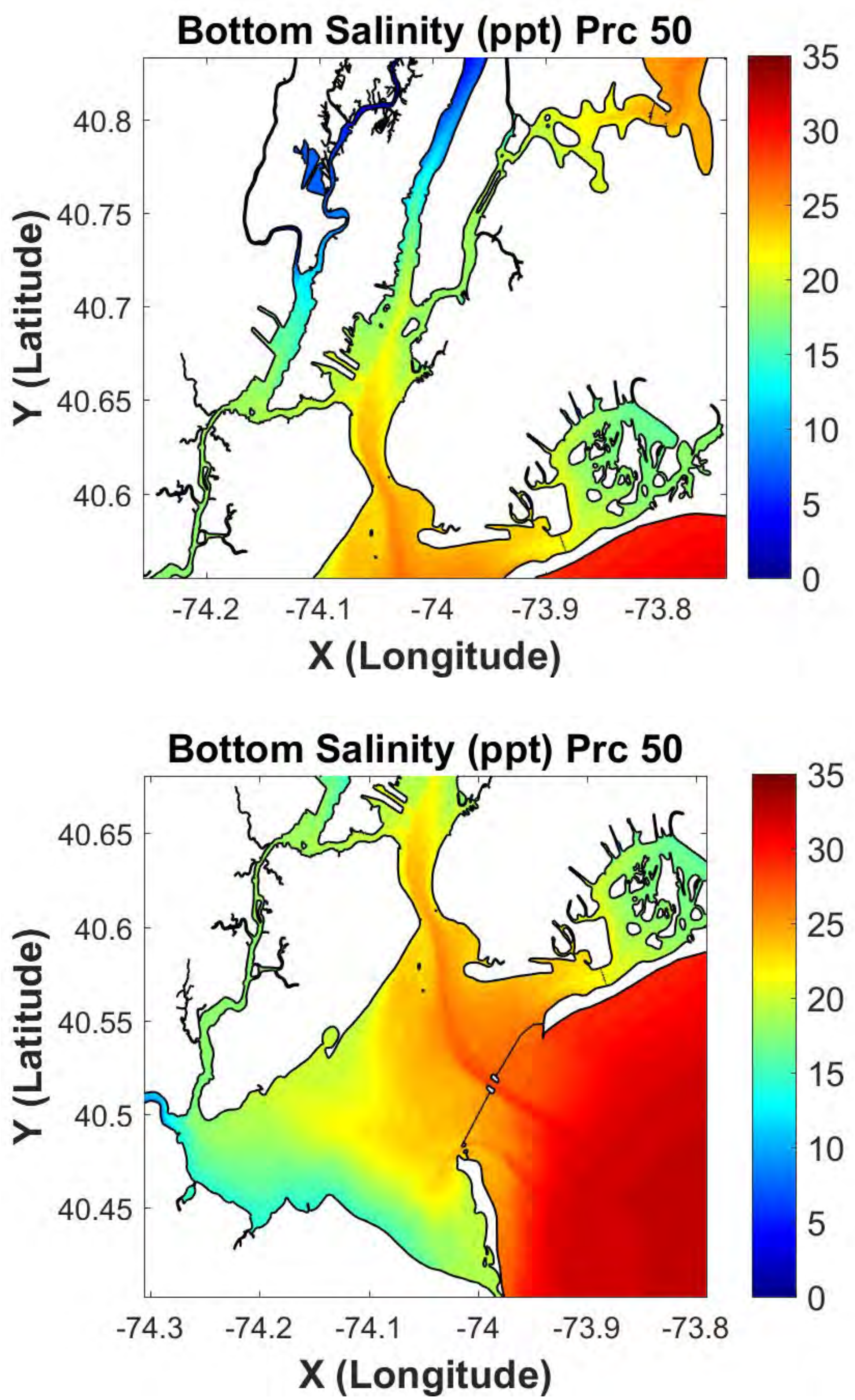
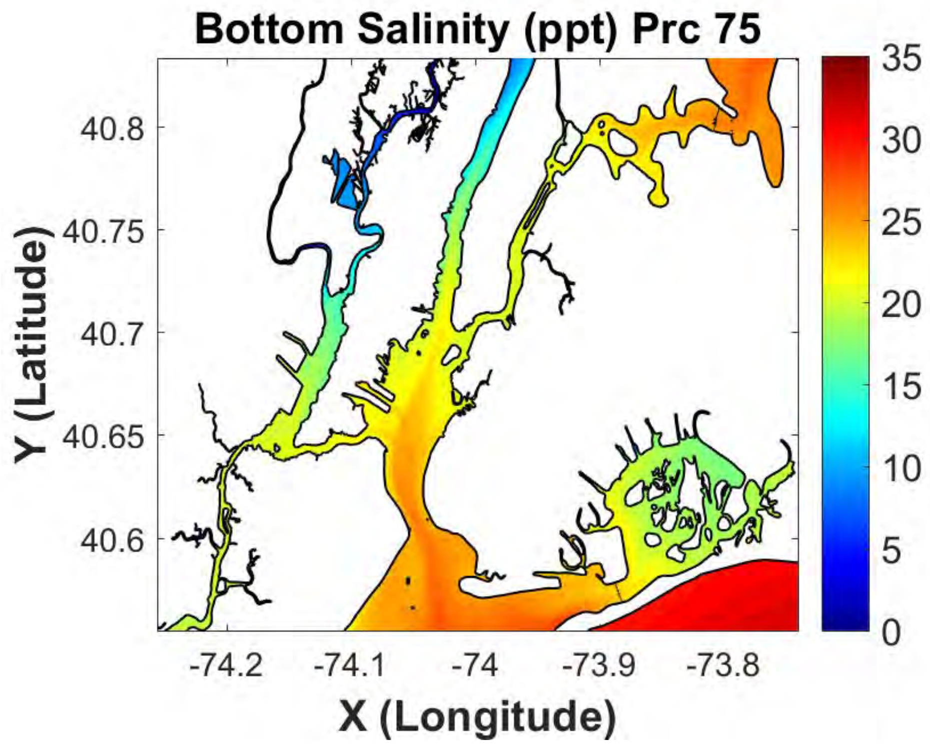


Figure 405. Alternative 2/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



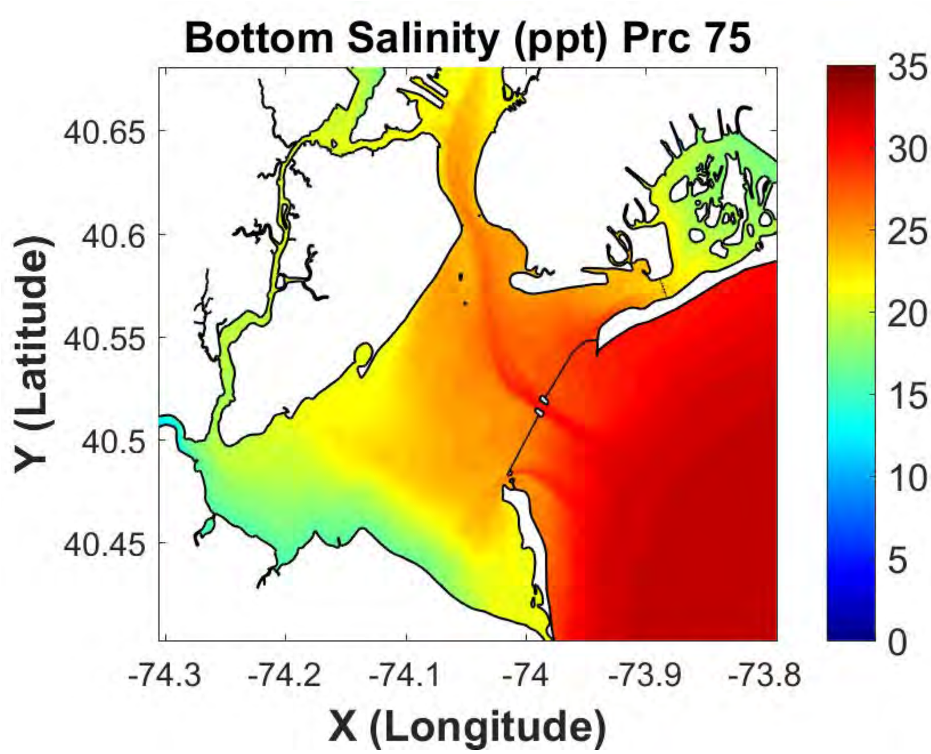


Figure 406. Alternative 2/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

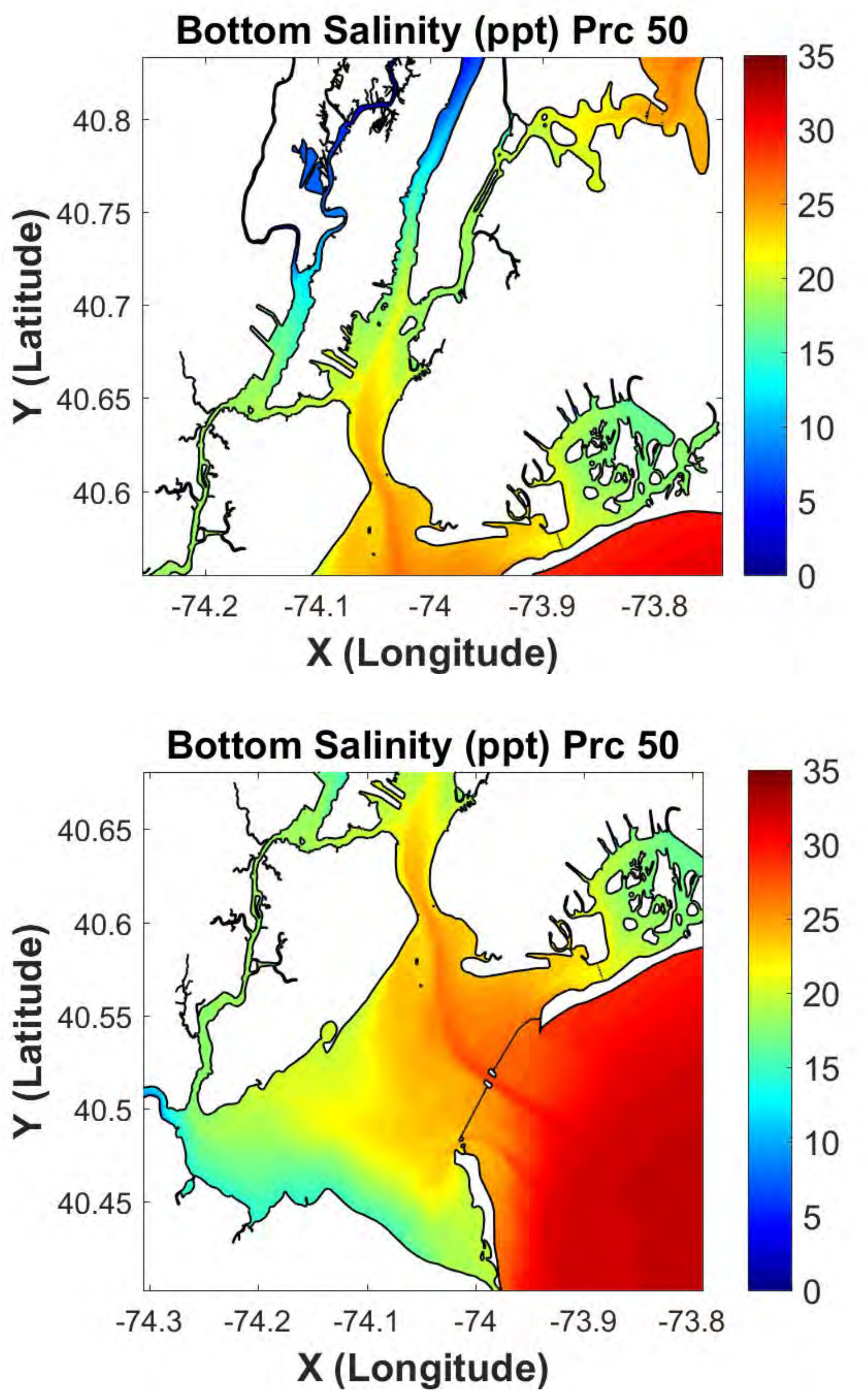
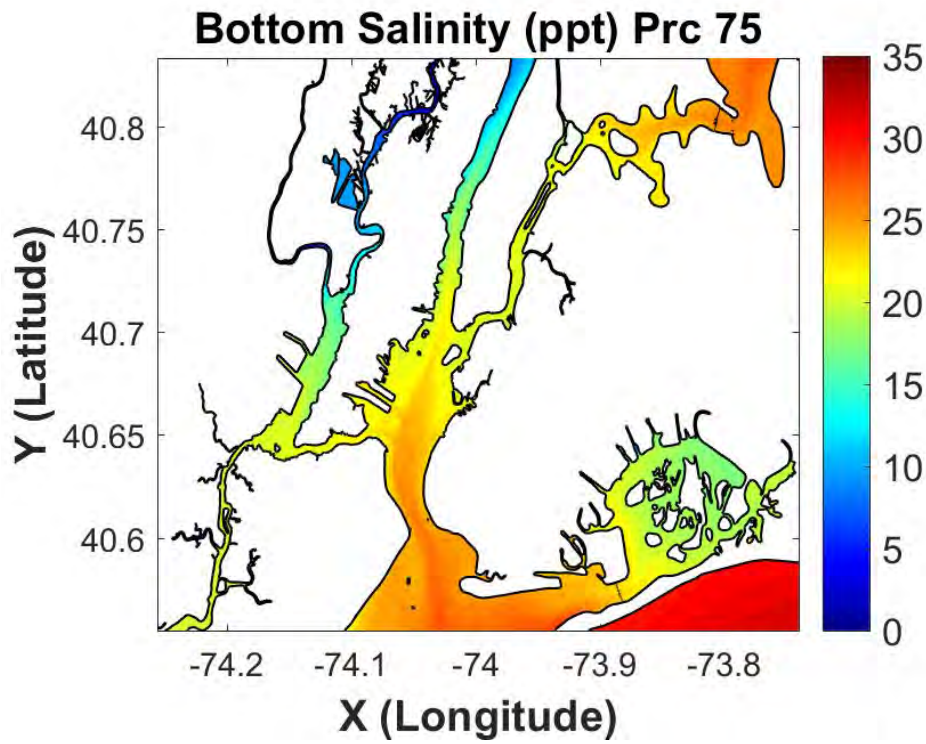


Figure 407. Alternative 2/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



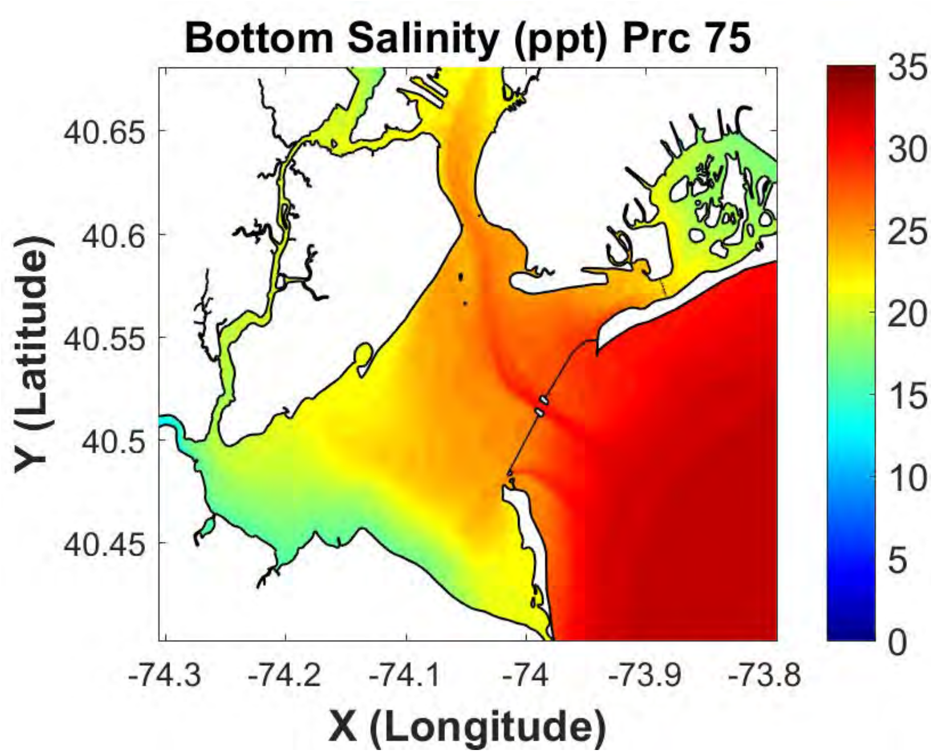
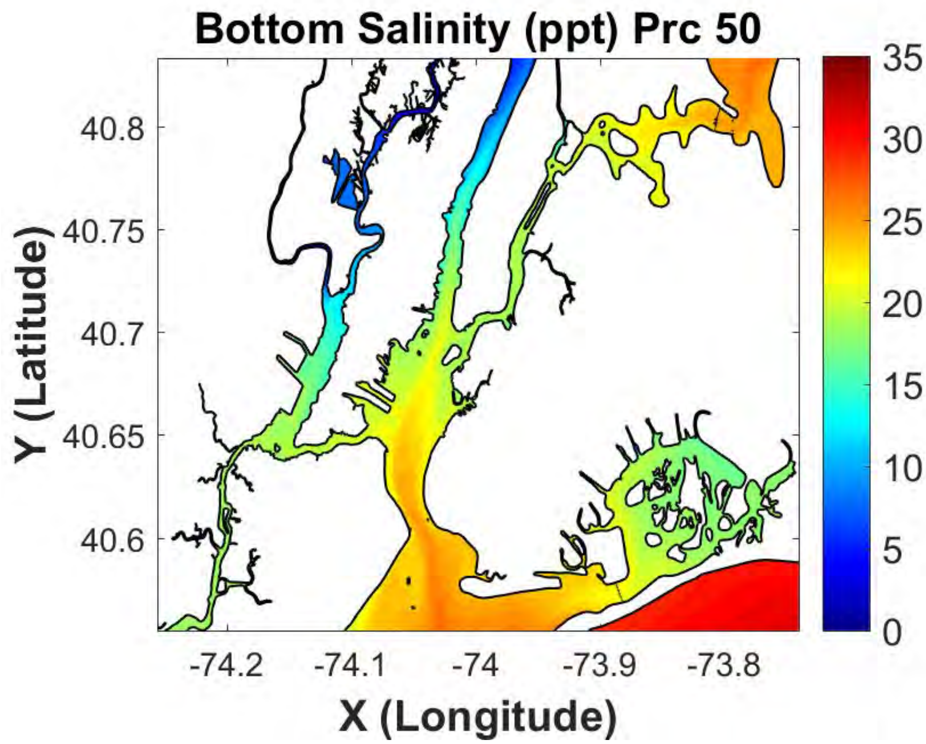


Figure 408. Alternative 2/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



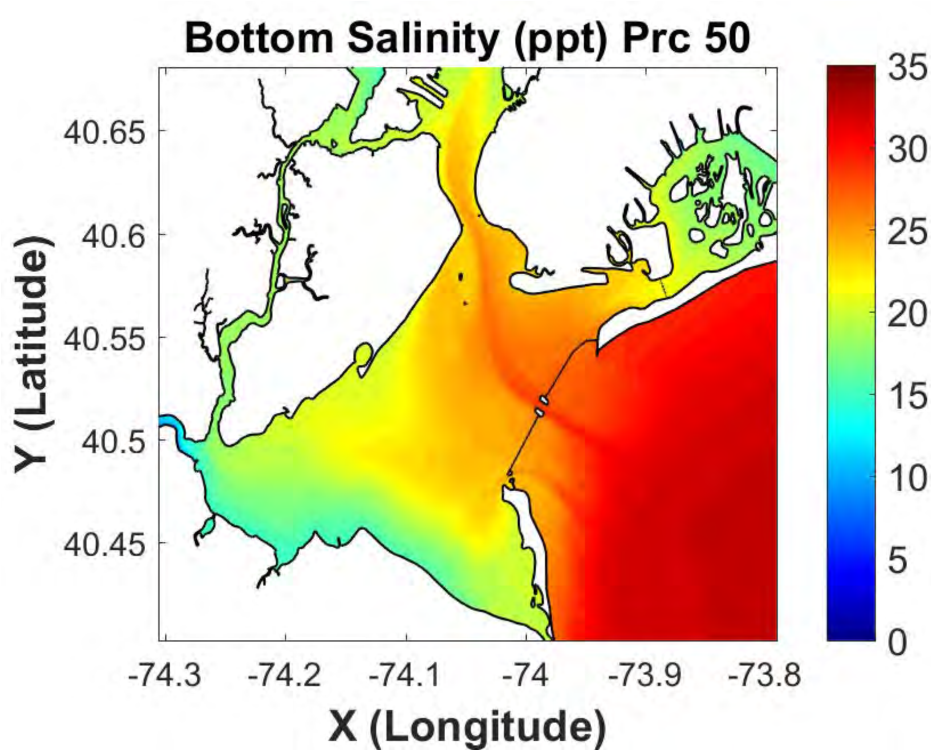
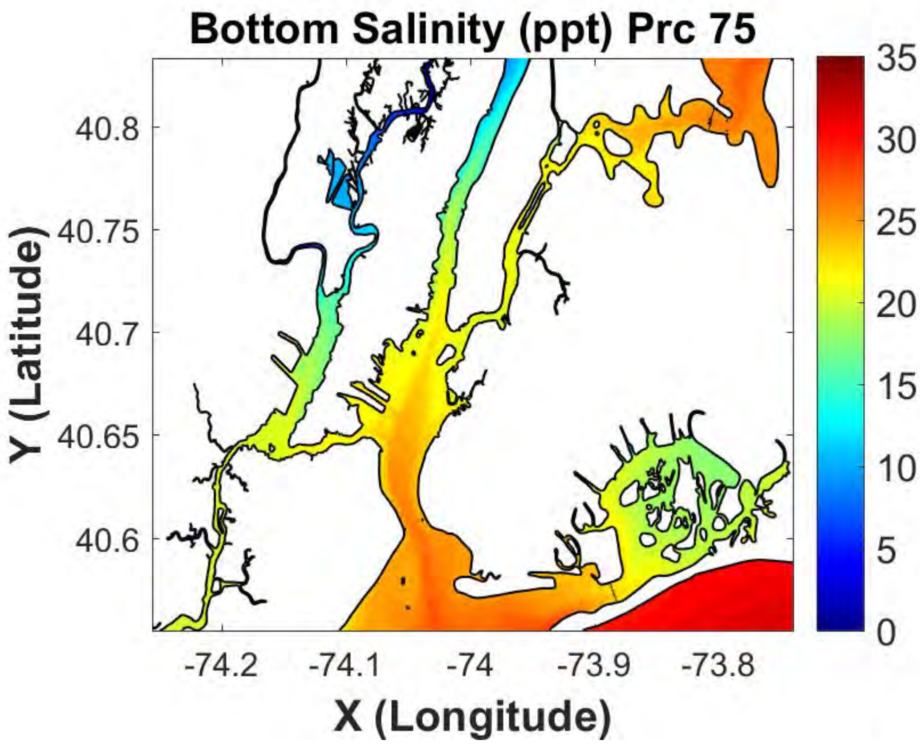


Figure 409. Alternative 2/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



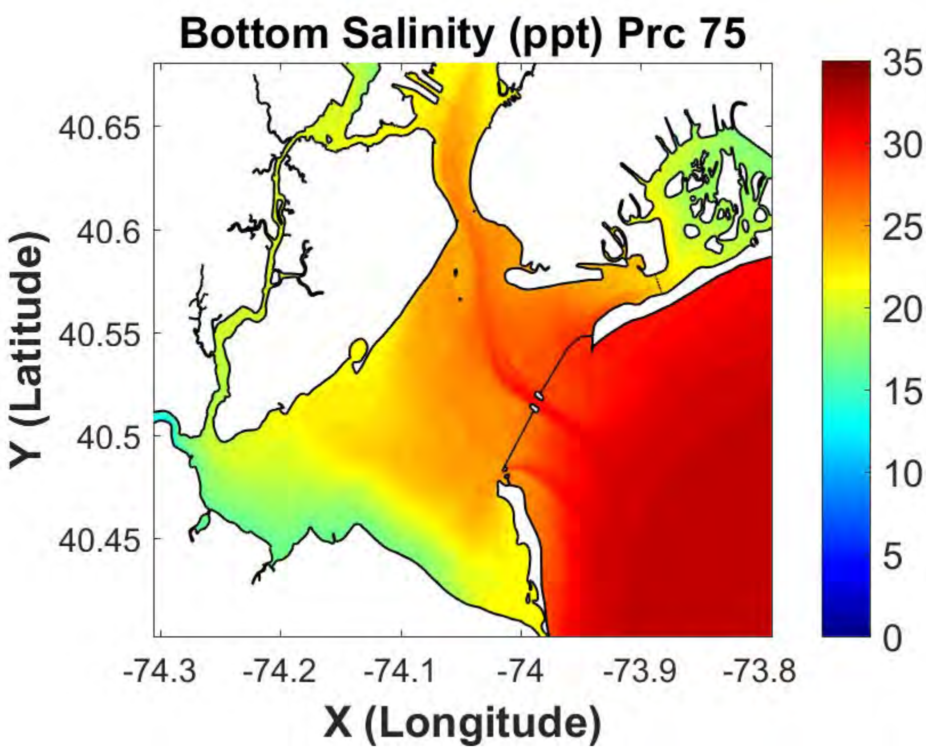
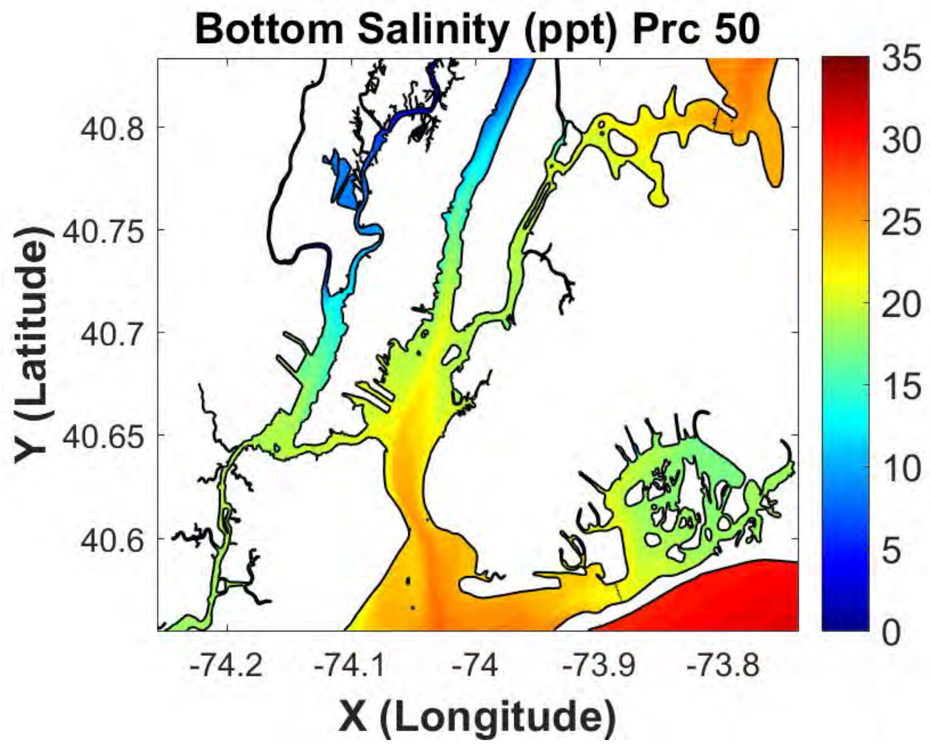


Figure 410. Alternative 2/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



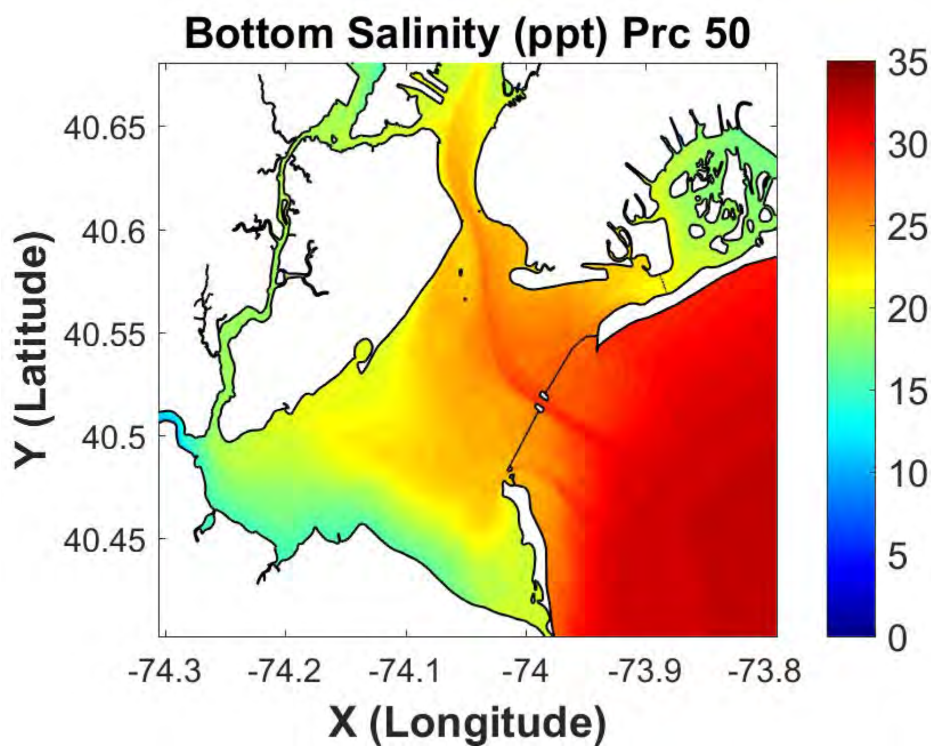


Figure 411. Alternative 2/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

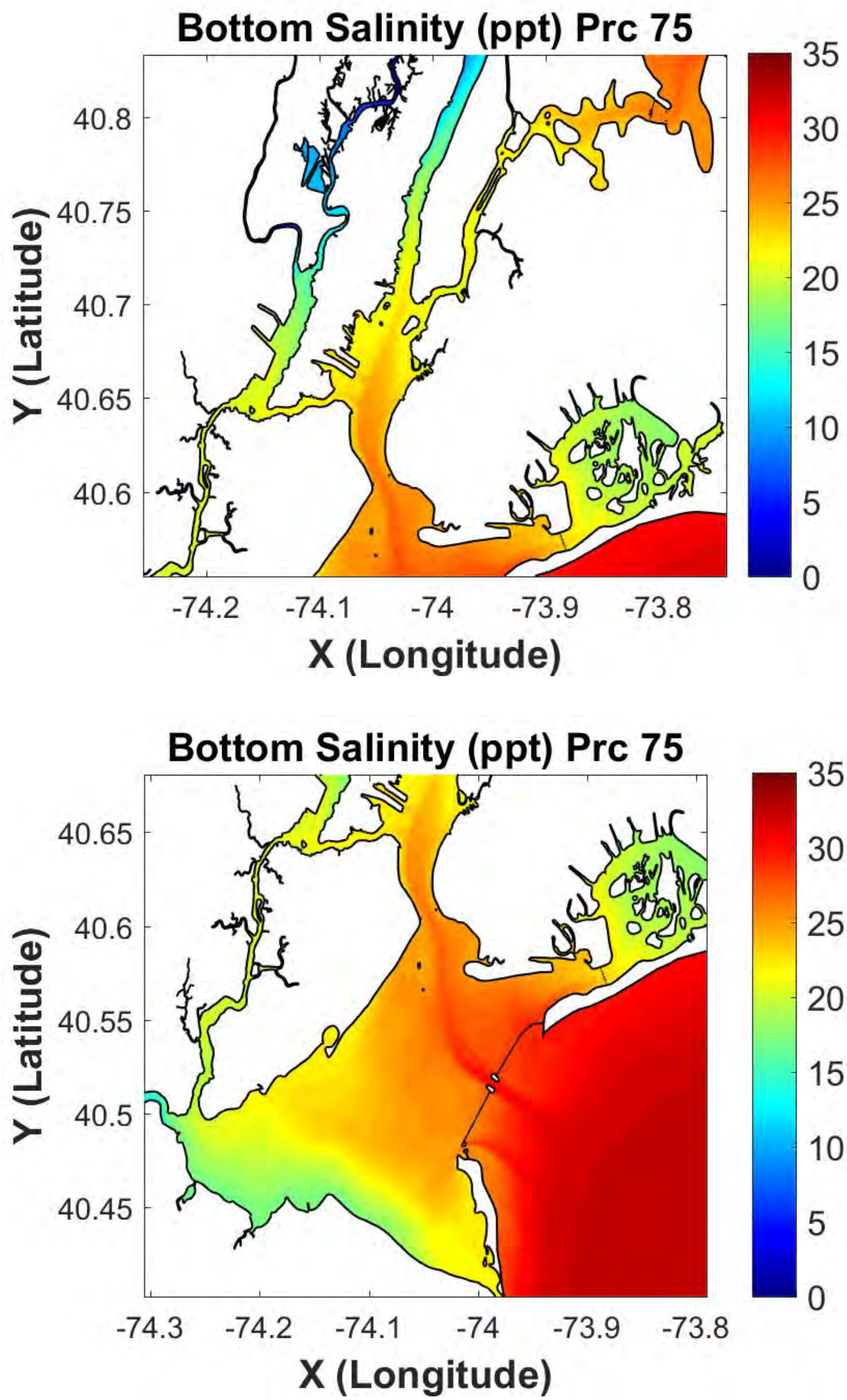
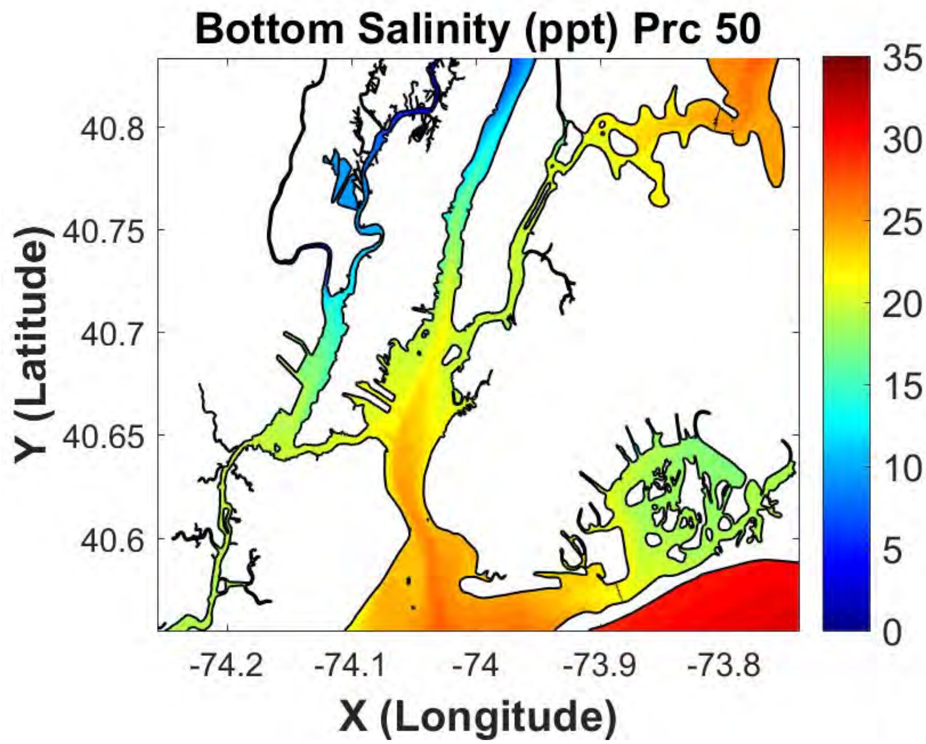


Figure 412. Alternative 2/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



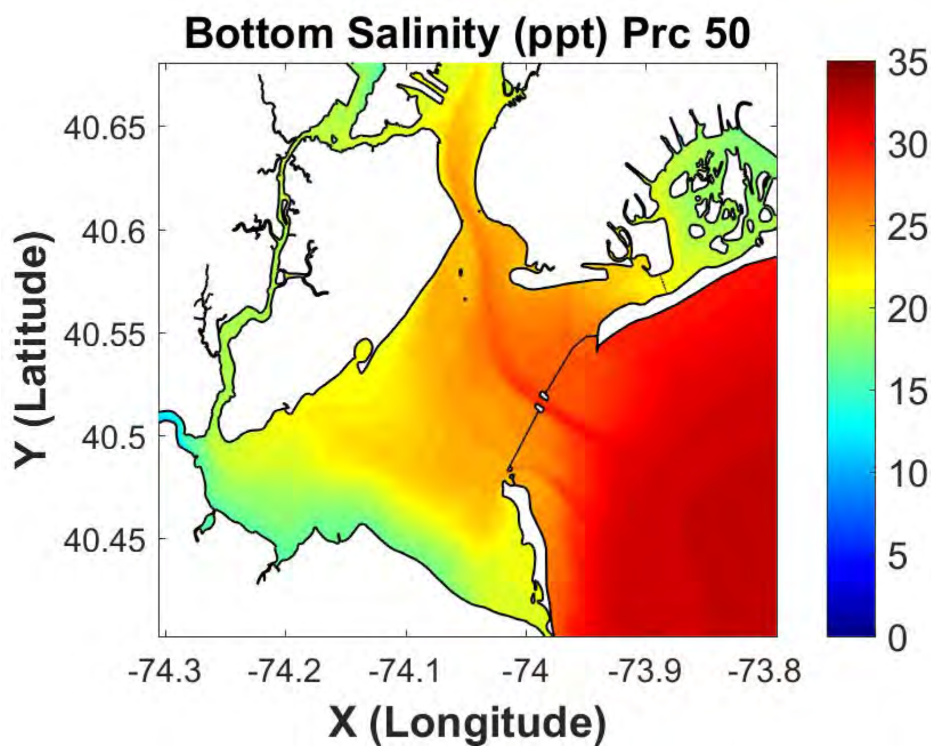
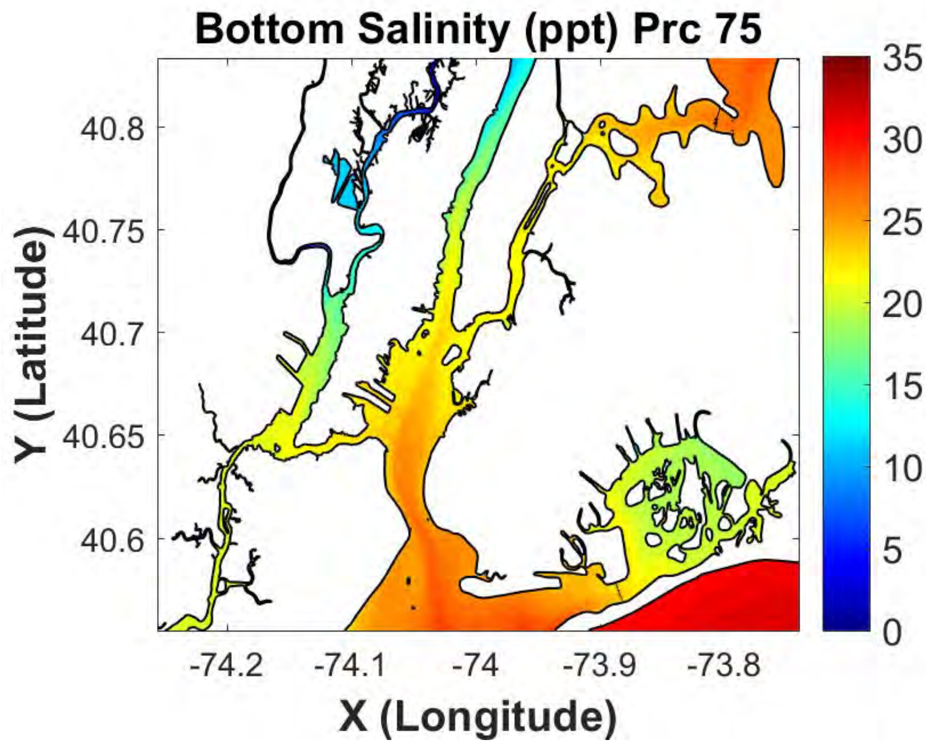


Figure 413. Alternative 2/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



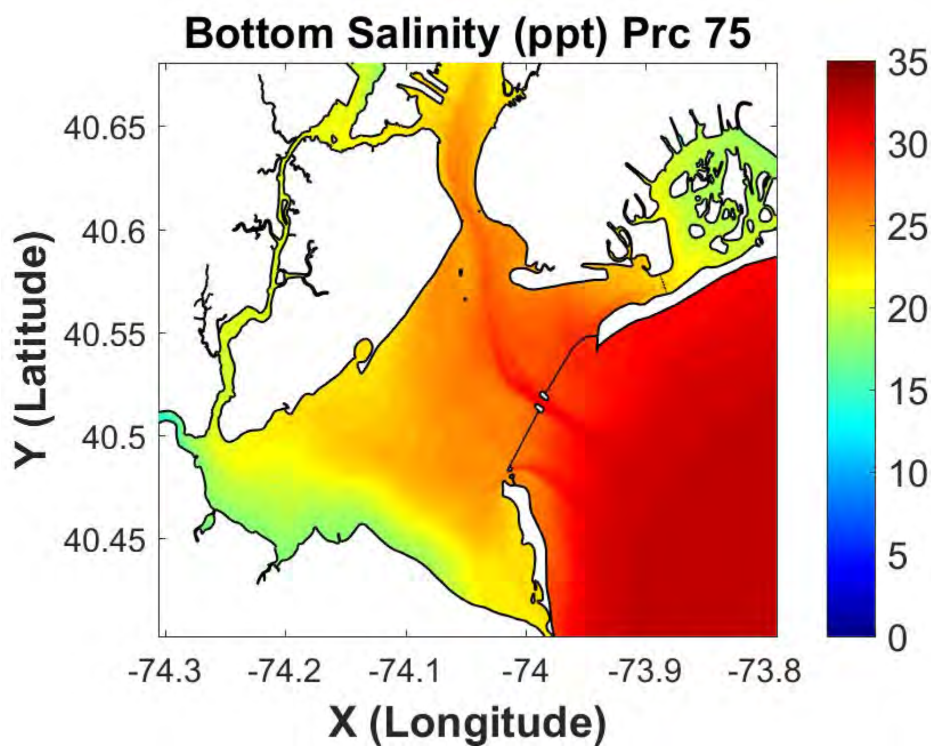


Figure 414. Alternative 2/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

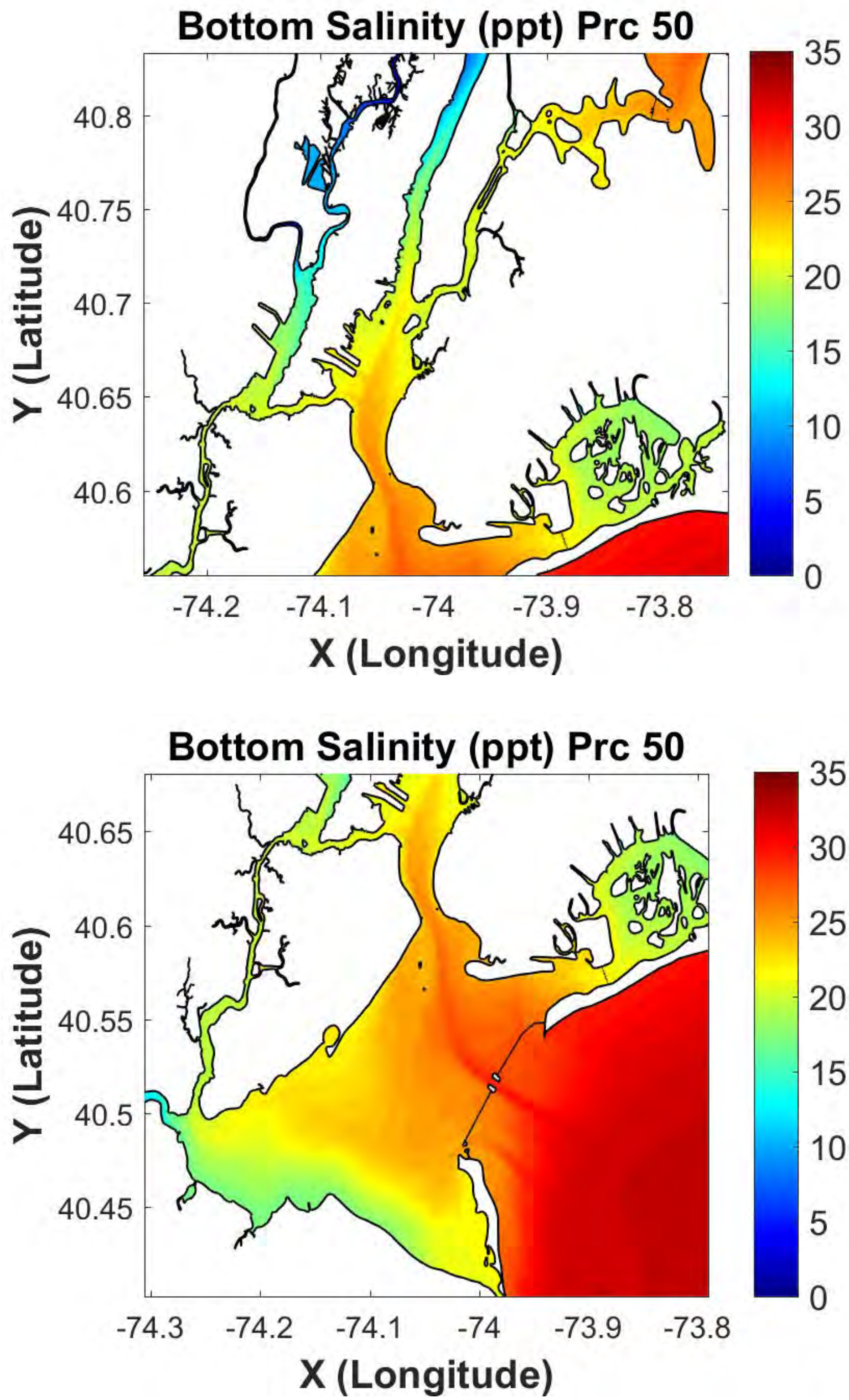
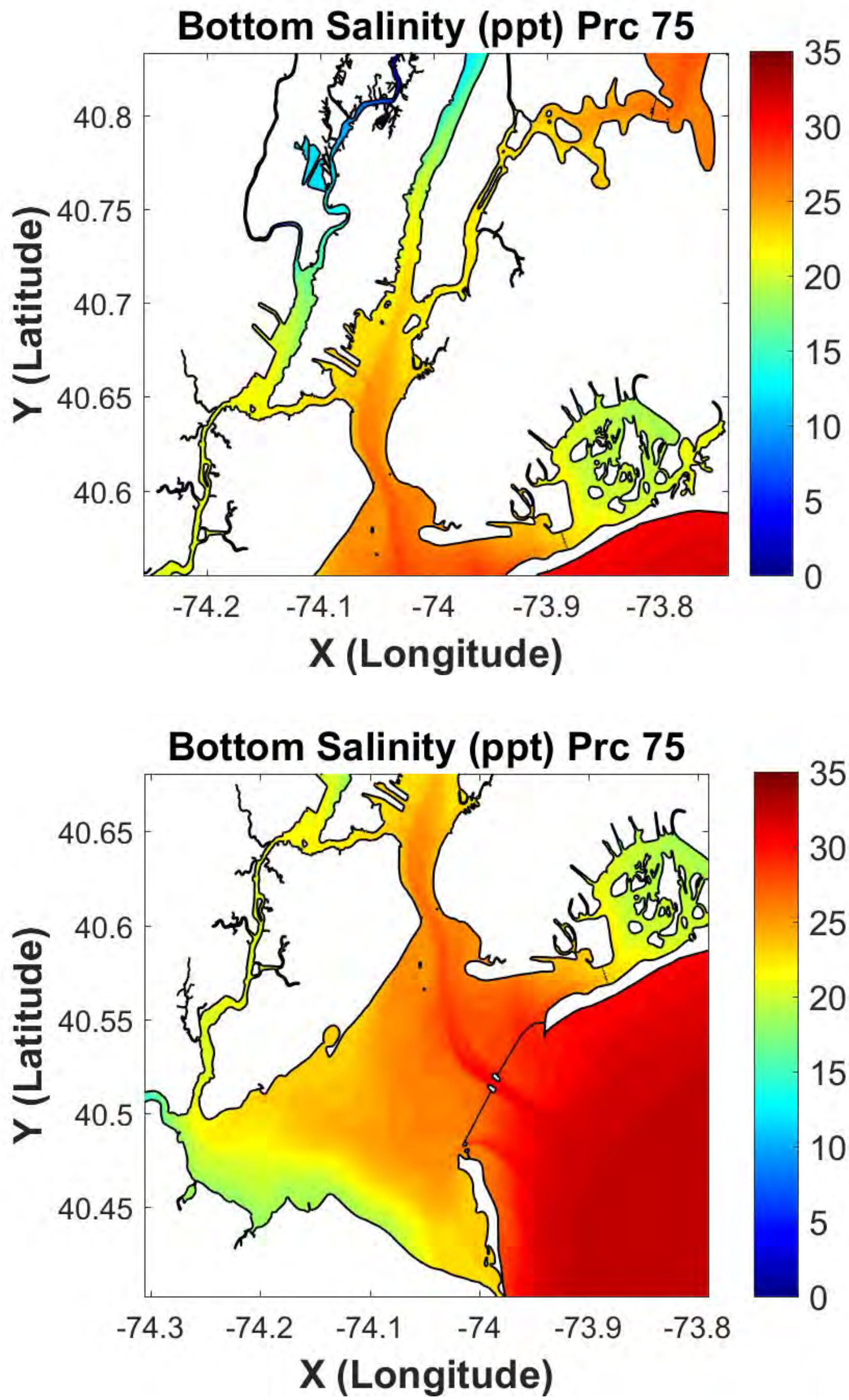


Figure 415. Alternative 2/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



15.2.6 Water Flux Analysis

Discharge percentiles for Alternative 2 for the previously shown locations (Figure 28) are provided in Figure 416 to Figure 419. These locations indicate increased tidal exchange for increasing water levels. Table 8 shows the mean flows for the various pathways and sea levels.

Figure 416. Alternative 2 Variation in Throgs Neck Discharges with sea level.

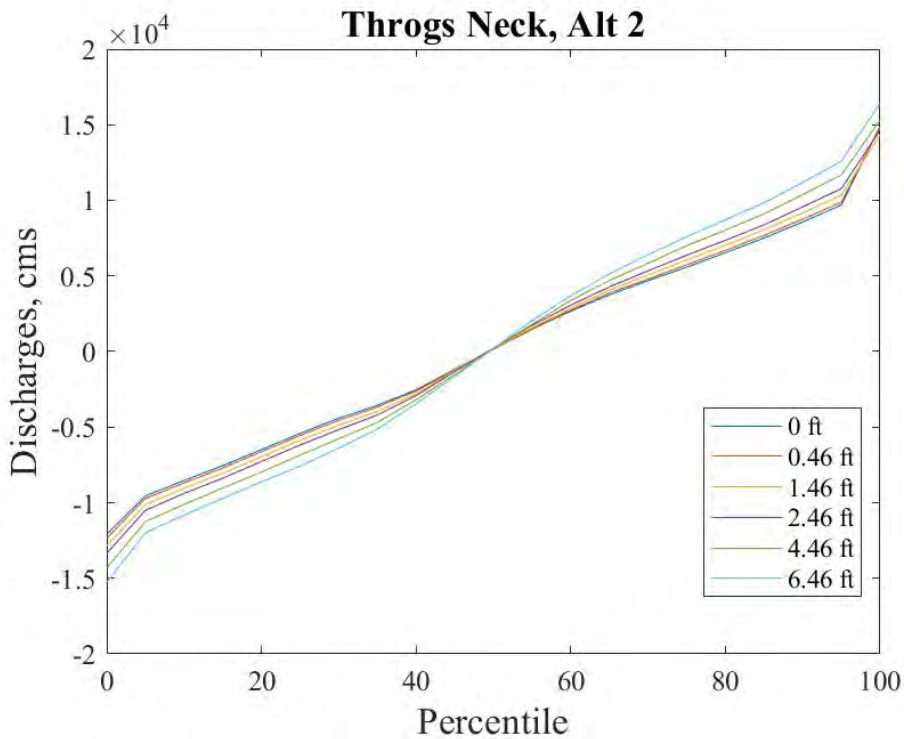


Figure 417. Alternative 2 Variation in Verrazano Narrows Discharges with sea level.

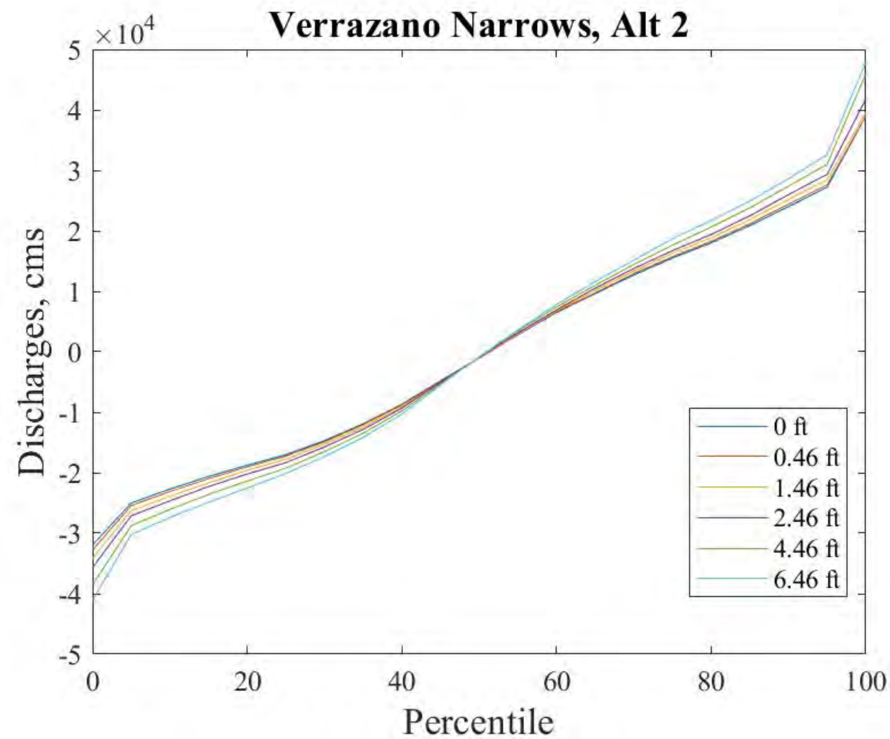


Figure 418. Alternative 2 Variation in Kill Van Kull Discharges with sea level.

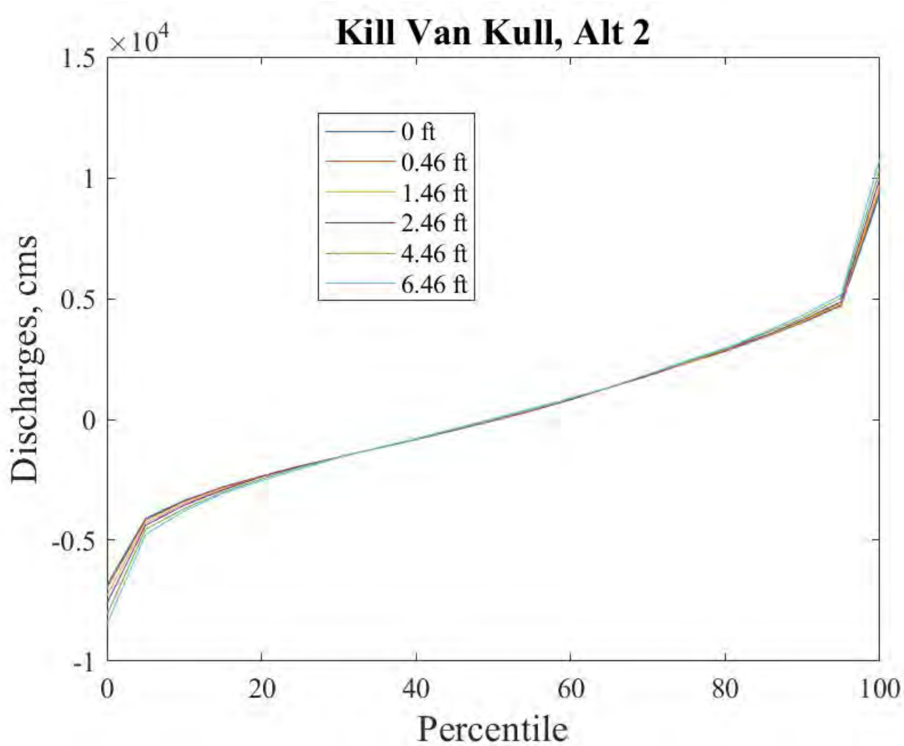


Figure 419. Alternative 2 Variation in Arthur Kill Discharges with sea level.

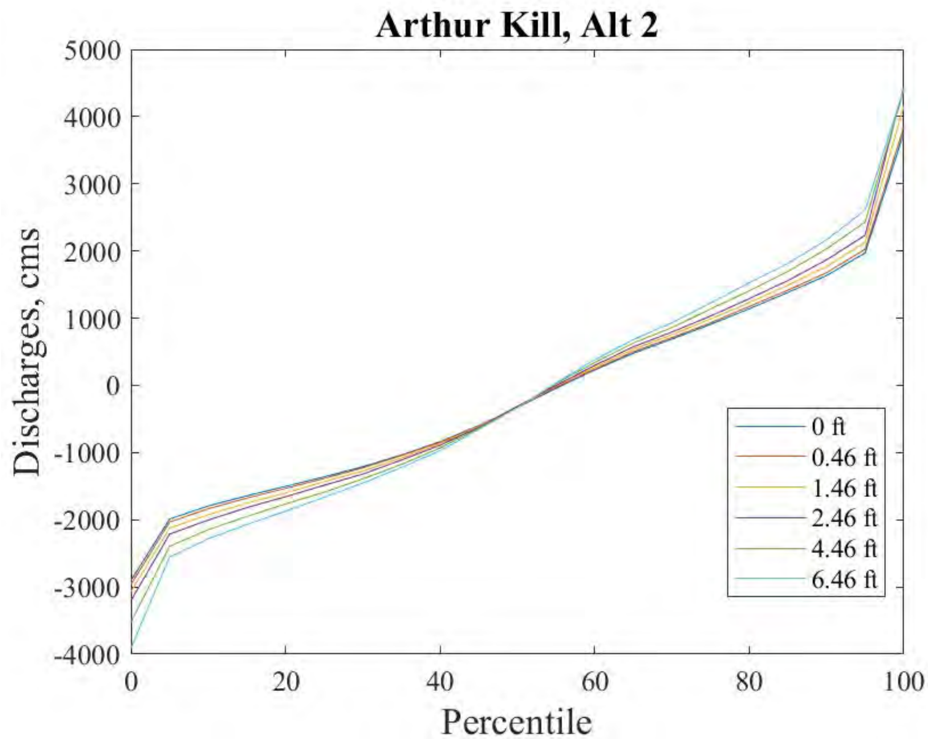


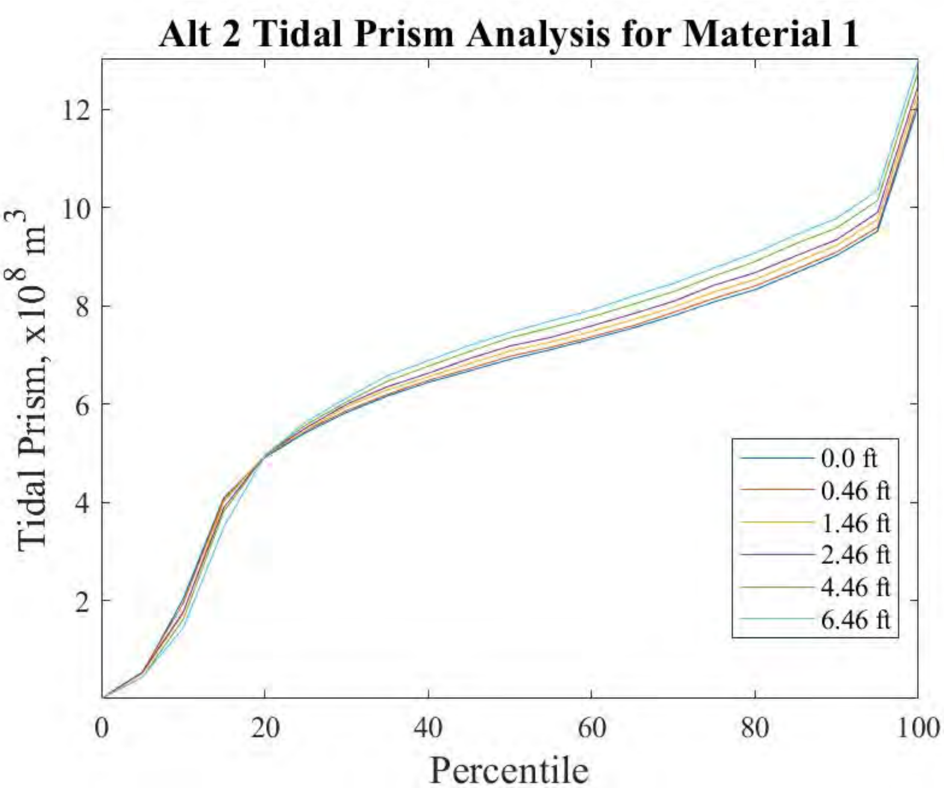
Table 8. Alternative 2, Sea Level Rise Impacts of Flows in CMS.

Location	0.0 ft. MSL	0.46 ft. MSL	1.46 ft. MSL	2.46 ft. MSL	4.46 ft. MSL	6.46 ft. MSL
Throgs Neck	86	88	92	97	108	122
Verrazano Narrows	-286	-289	-295	-303	-317	-330
Kill Van Kull	167	166	163	160	157	157
Arthur Kill	-193	-191	-188	-186	-183	-182

15.2.7 Tidal Prism Analysis

Tidal prisms were calculated, and a percentile analysis was performed to evaluate the impact of sea level rise on the tidal exchange. Figure 420 shows the tidal prism for all sea level values for the impounded area for Alternative 2 previously shown in Figure 33. These results indicate higher sea level values result in higher tidal prisms and associated tidal exchange/mixing.

Figure 420. Tidal Prism Percentile Analysis for Alternative 2 for Material 1.



15.3 Alternative 3a

For increased sea levels, Alternative 3a possesses increasing tidal exchange, tide ranges, and salinity intrusion. The velocities are also increased as the increases in the tidal exchange override the increased depths also present in the sea level rise alternatives.

15.3.1 Water Surface Elevation Point Percentiles

Water surface elevation (WSE) percentiles for Alternative 3a for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 421 to Figure 445. The datum in these plots is relative to Mean Sea Level for 1995. The datum Mean Sea Level will increase with sea level rise (SLR) but for the purposes of these comparisons it is held constant, so all water levels are relative 0.0 MSL for 1995.

Figure 421. Alt 3a, Sandy Hook WSE Variation with SLR.

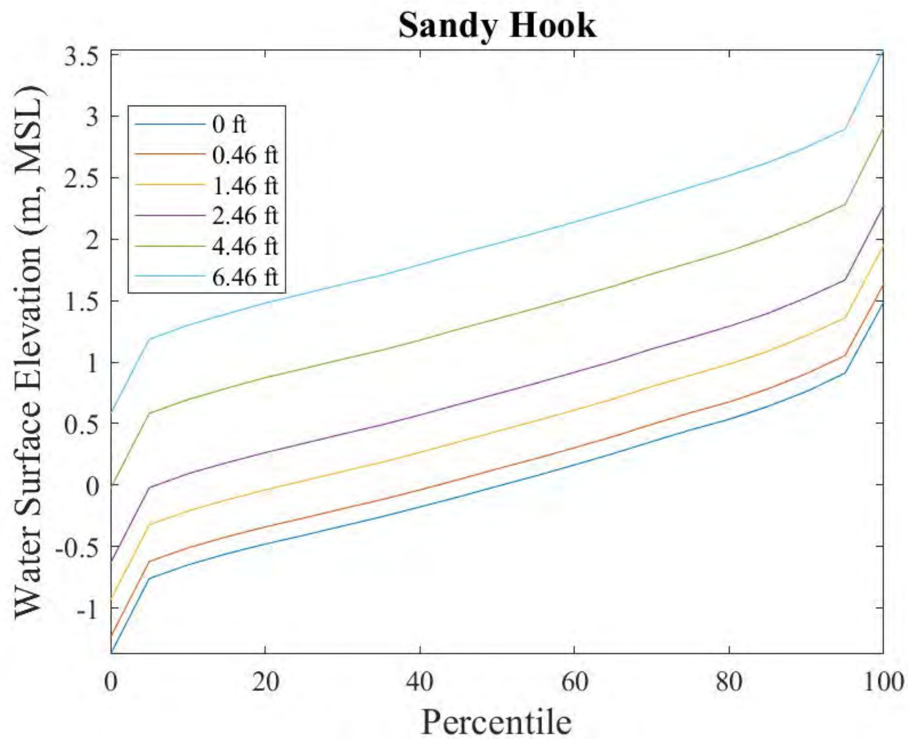


Figure 422. Alt 3a, V5 WSE Variation with SLR.

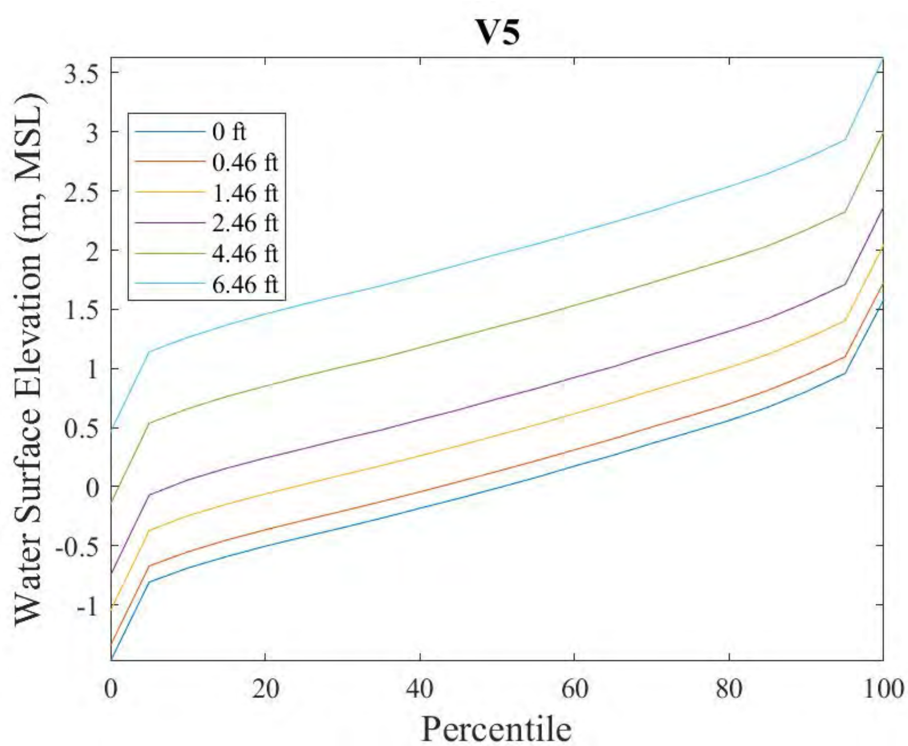


Figure 423. Alt 3a, V6 WSE Variation with SLR.

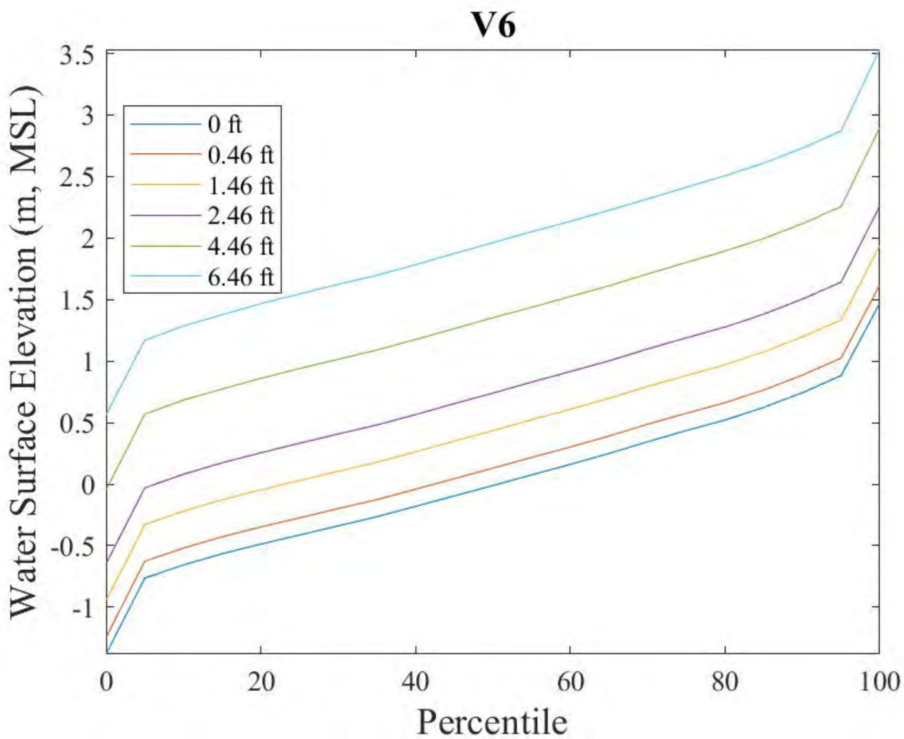


Figure 424. Alt 3a, Fresh Kills WSE Variation with SLR.

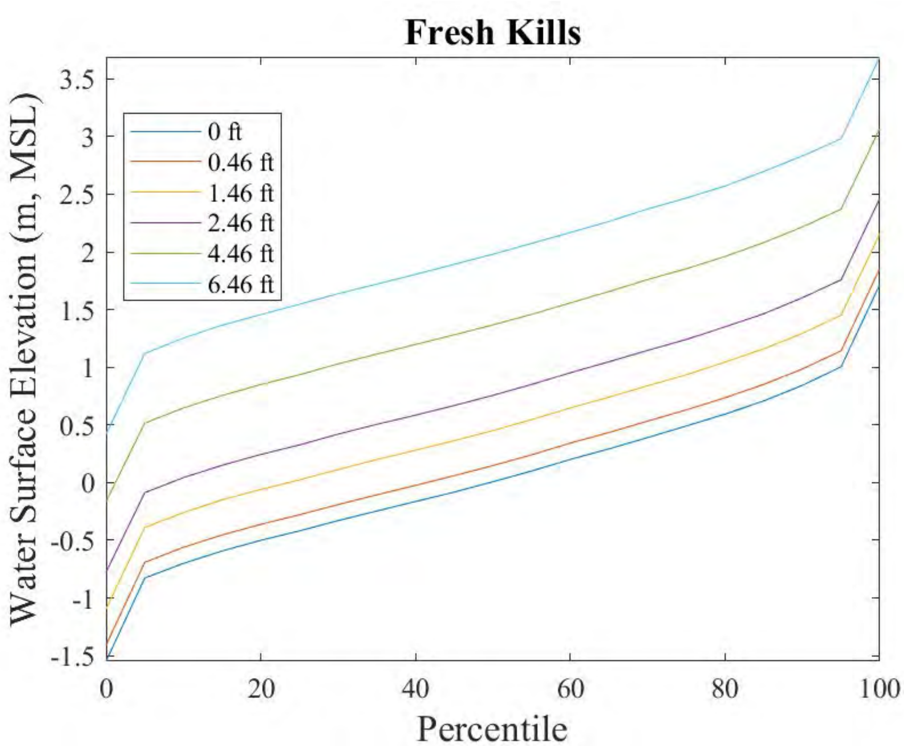


Figure 425. Alt 3a, Mariners Harbor WSE Variation with SLR.

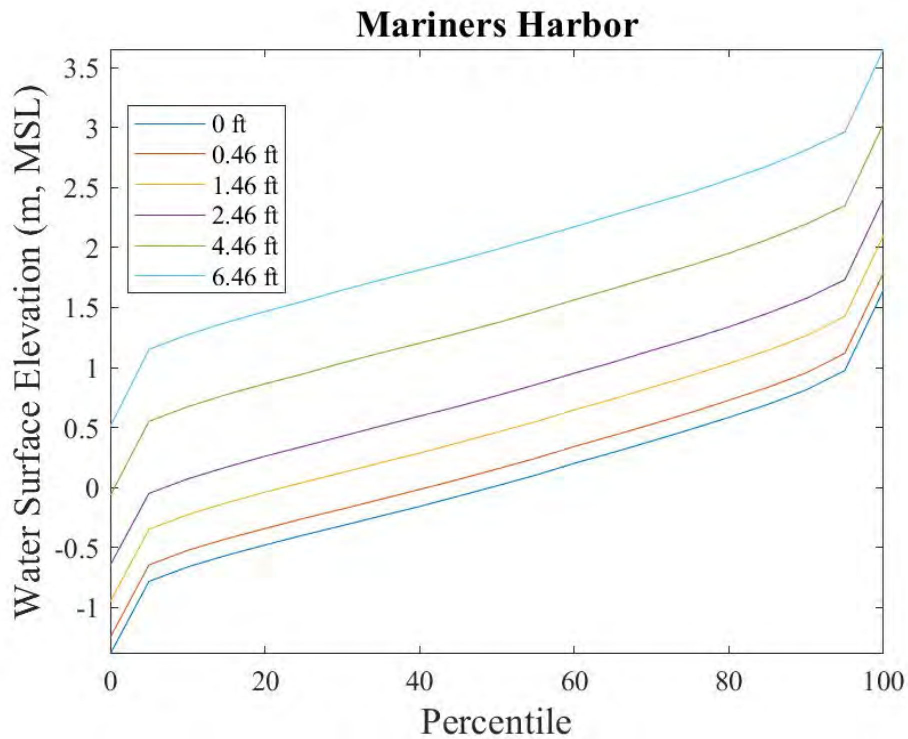


Figure 426. Alt 3a, T2 WSE Variation with SLR.

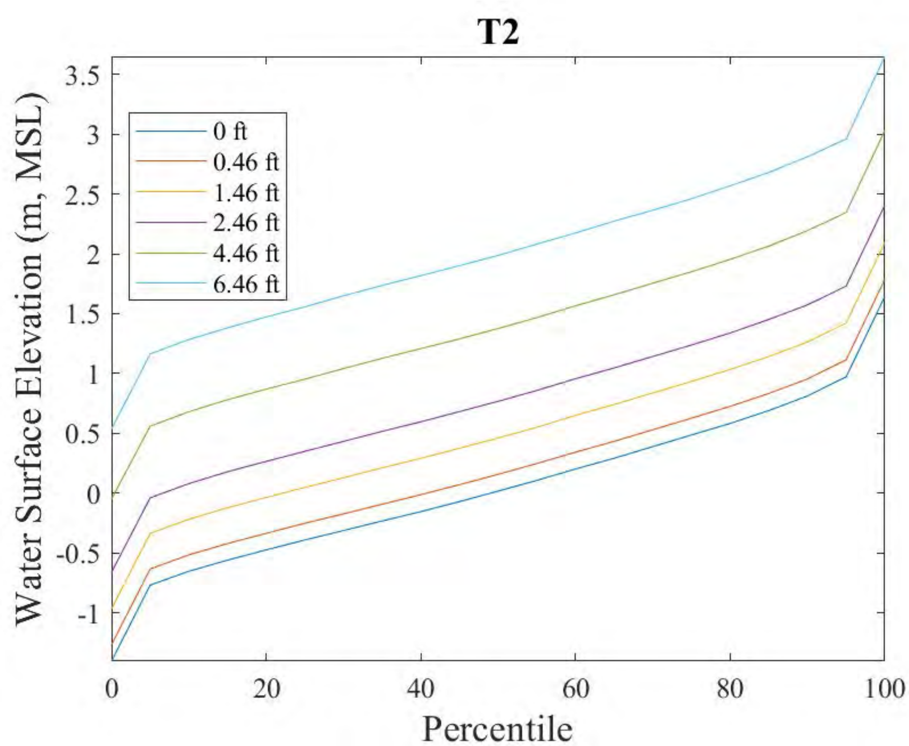


Figure 427. Alt 3a, T3 WSE Variation with SLR.

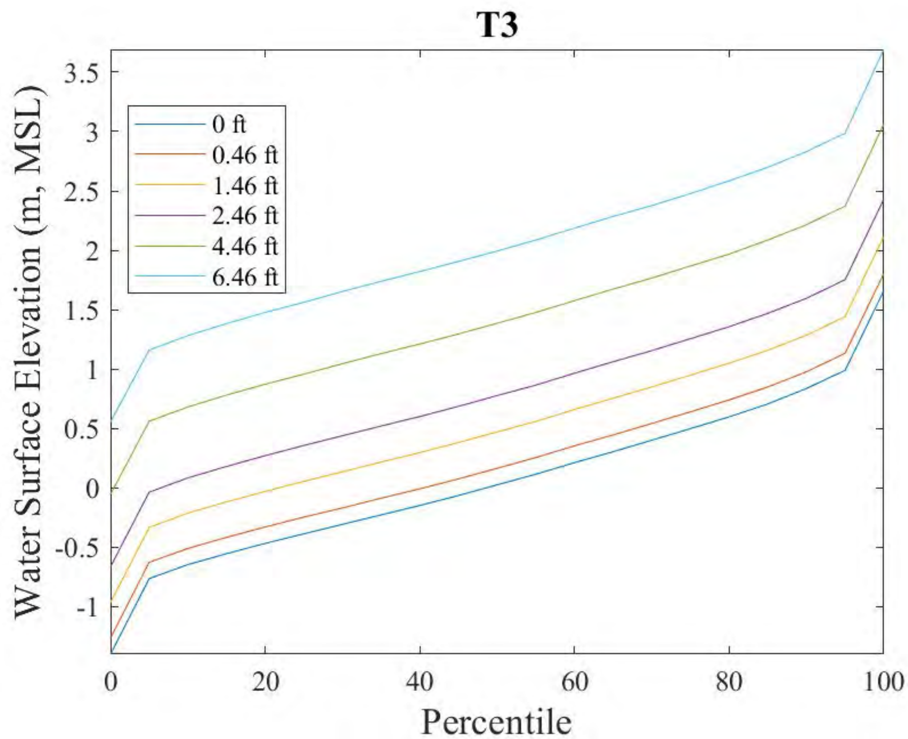


Figure 428. Alt 3a, North Reach WSE Variation with SLR.

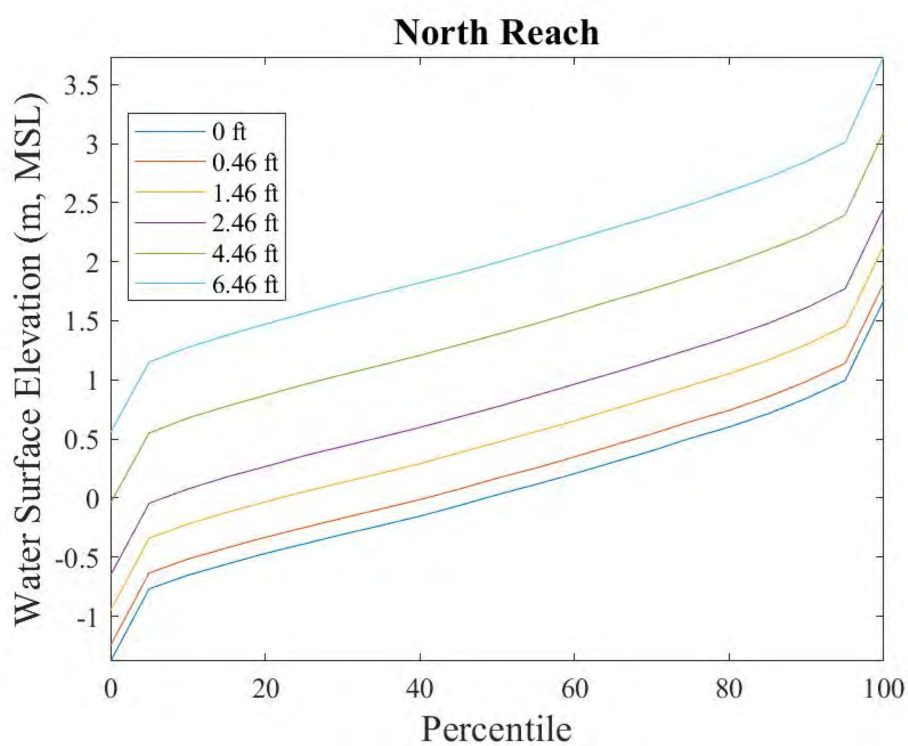


Figure 429. Alt 3a, Hackensack River WSE Variation with SLR.

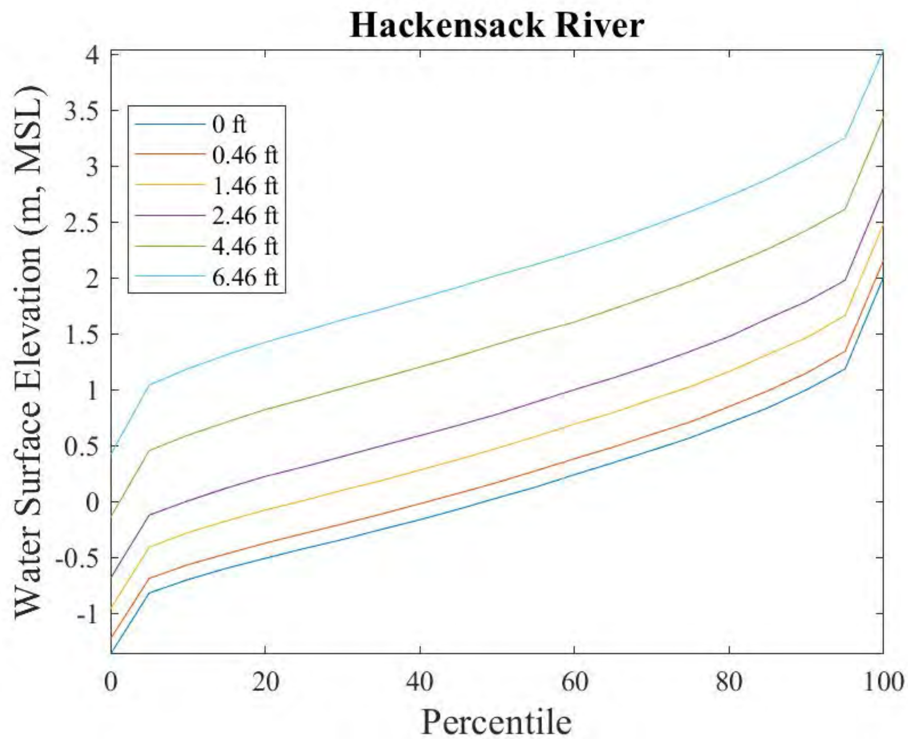


Figure 430. Alt 3a, Robbins Reef WSE Variation with SLR.

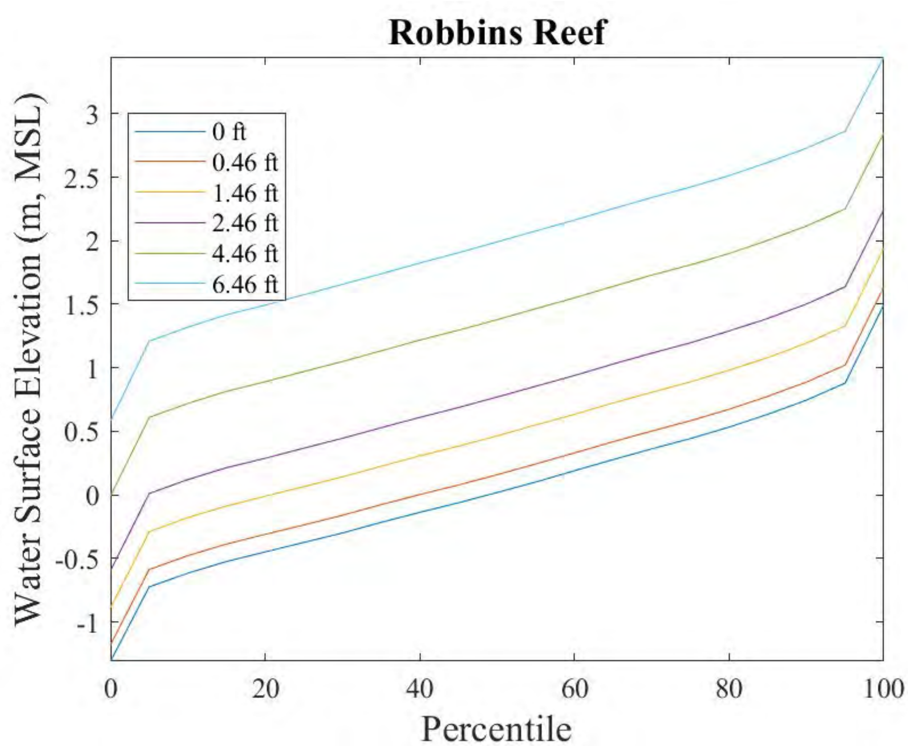


Figure 431. Alt 3a, S2 WSE Variation with SLR.

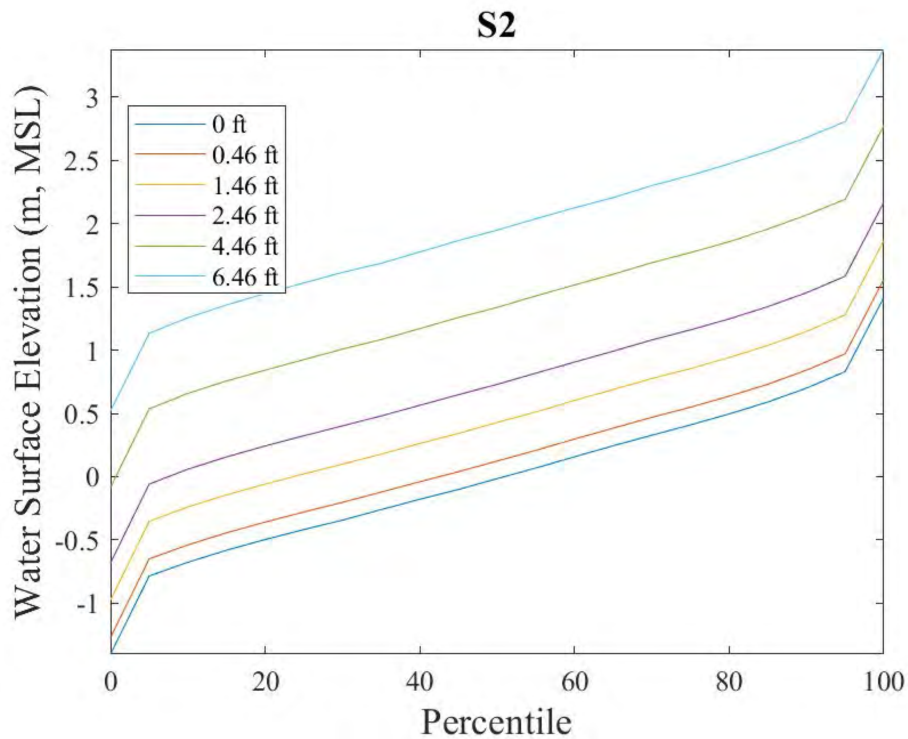


Figure 432. Alt 3a, S5 WSE Variation with SLR.

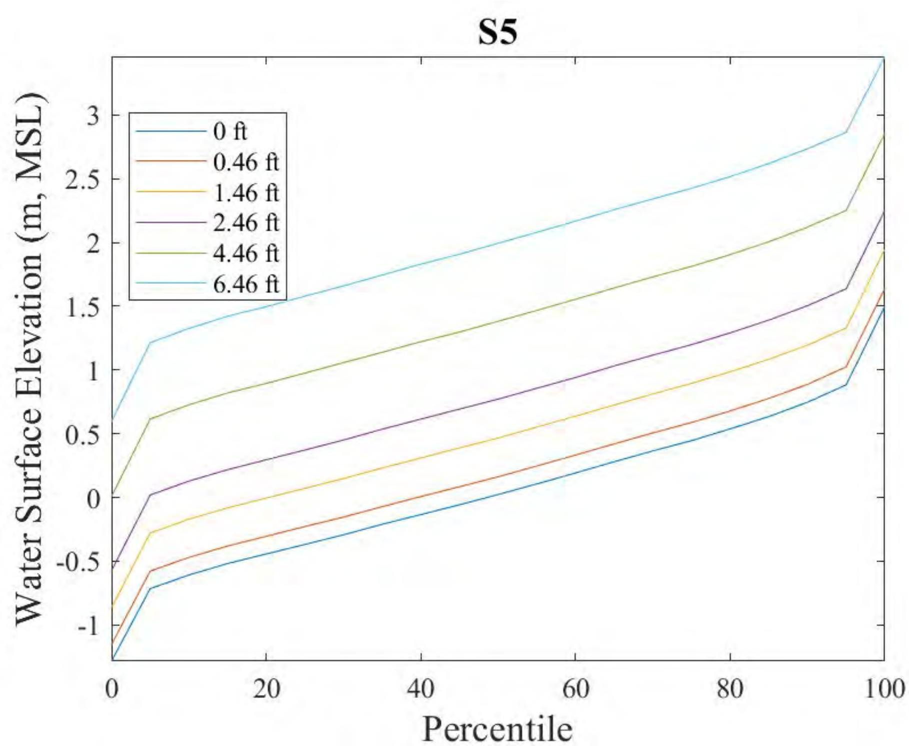


Figure 433. Alt 3a, The Battery WSE Variation with SLR.

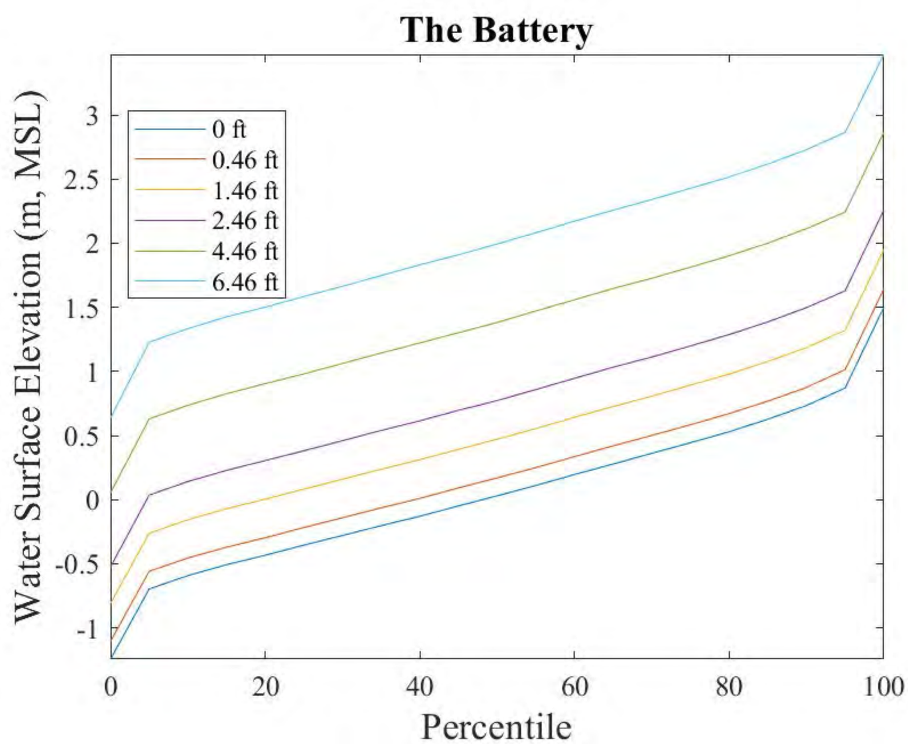


Figure 434. Alt 3a, Manhattan WSE Variation with SLR.

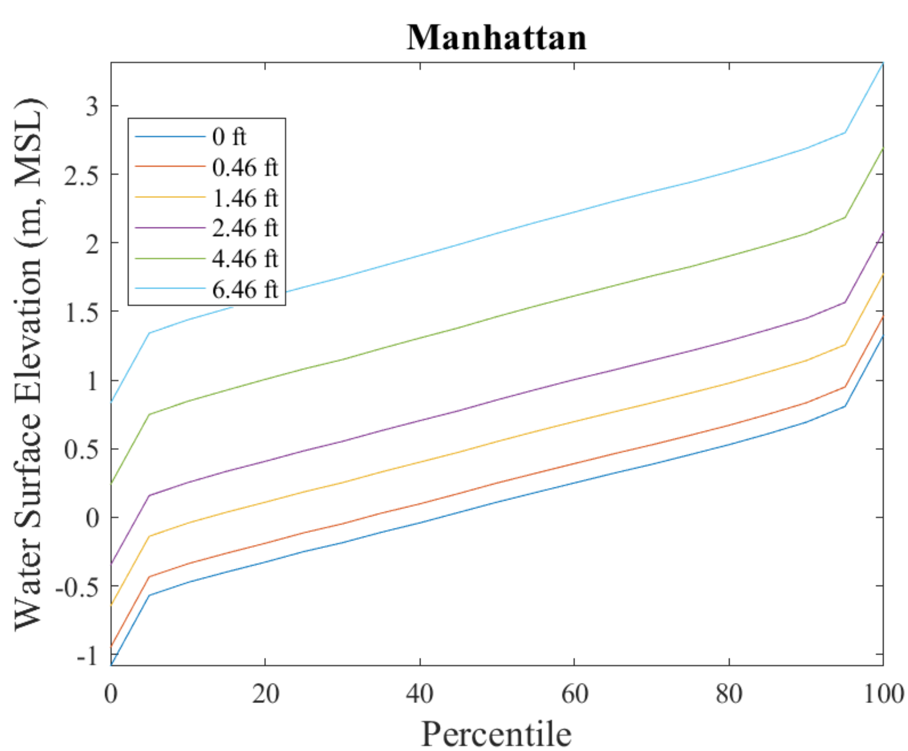


Figure 435. Alt 3a, Jamaica Bay WSE Variation with SLR.

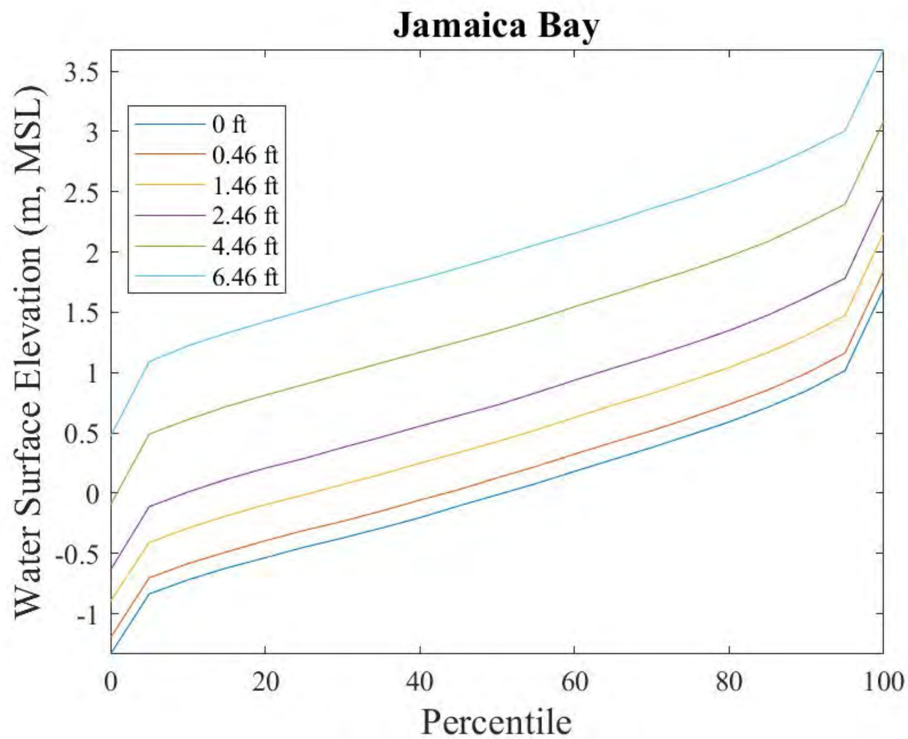


Figure 436. Alt 3a, Jamaica Bay near Spring Creek WSE Variation with SLR.

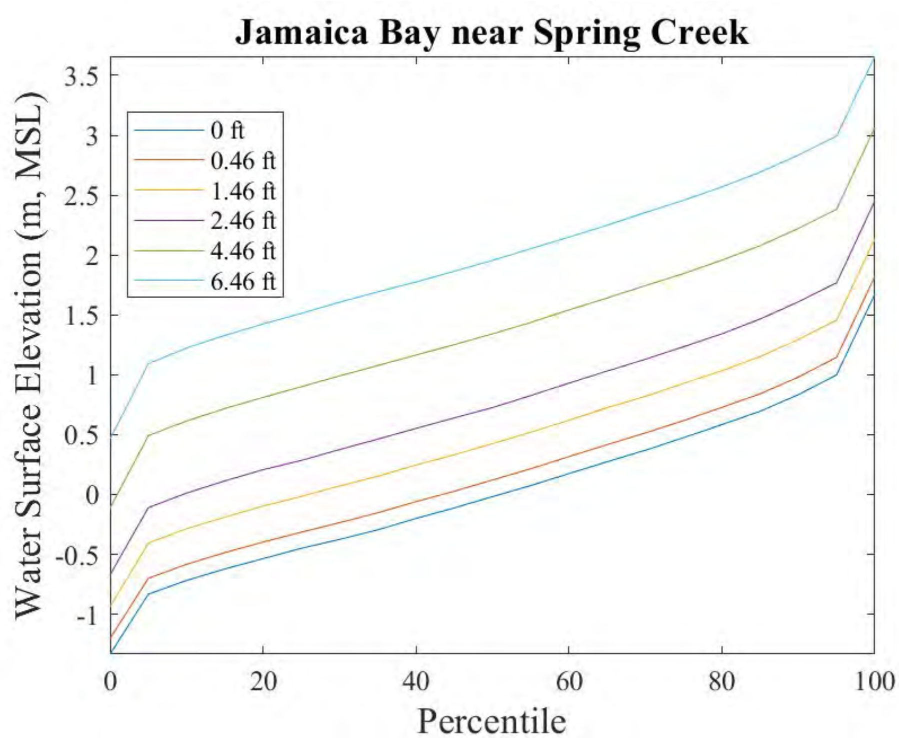


Figure 437. Alt 3a, Jamaica Bay near Grass Hassock WSE Variation with SLR.

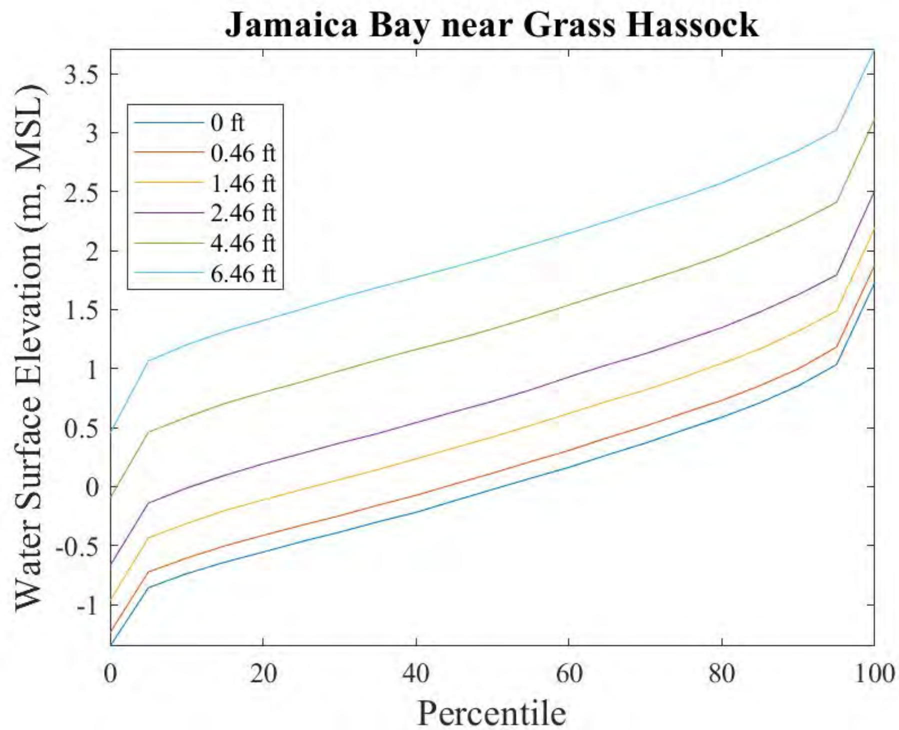


Figure 438. Alt 3a, KLGA WSE Variation with SLR.

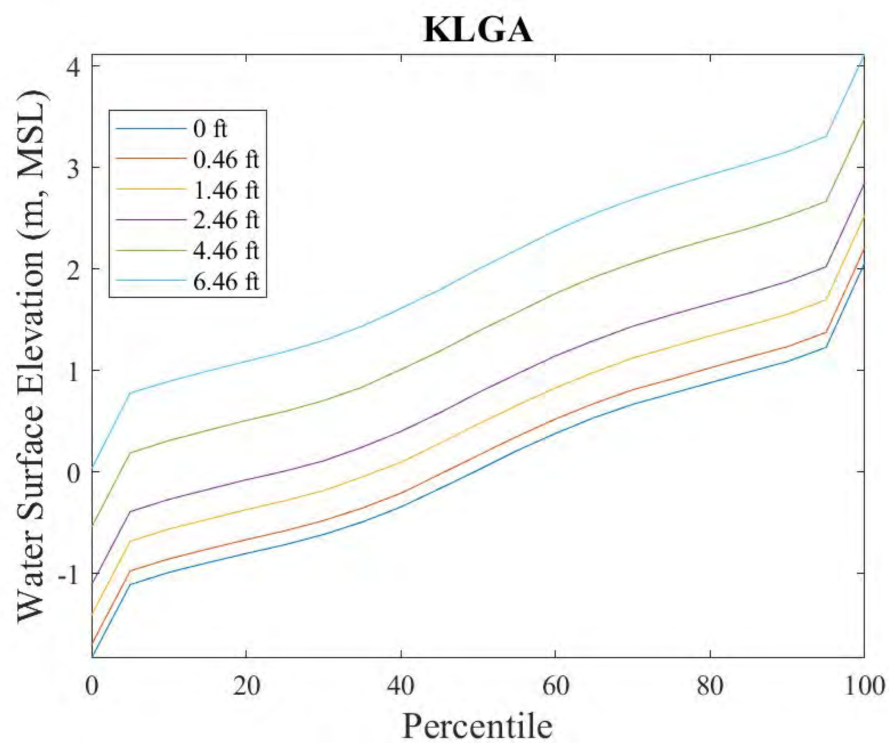


Figure 439. Alt 3a, LIS near Stepping Stone Lighthouse WSE Variation with SLR.

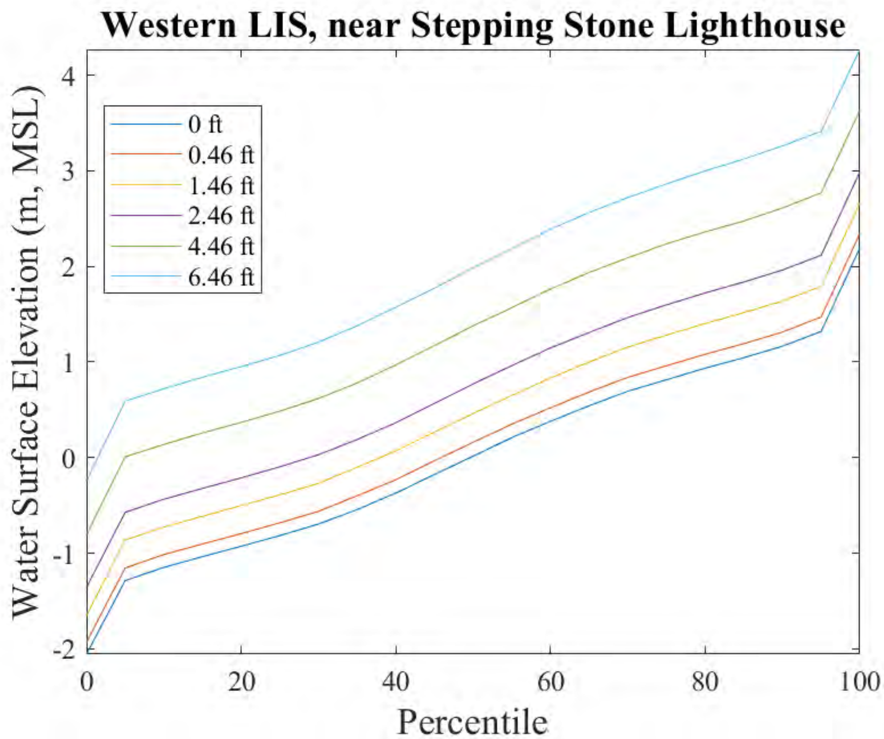


Figure 440. Alt 3a, LIS near Execution Rock Lighthouse WSE Variation with SLR.

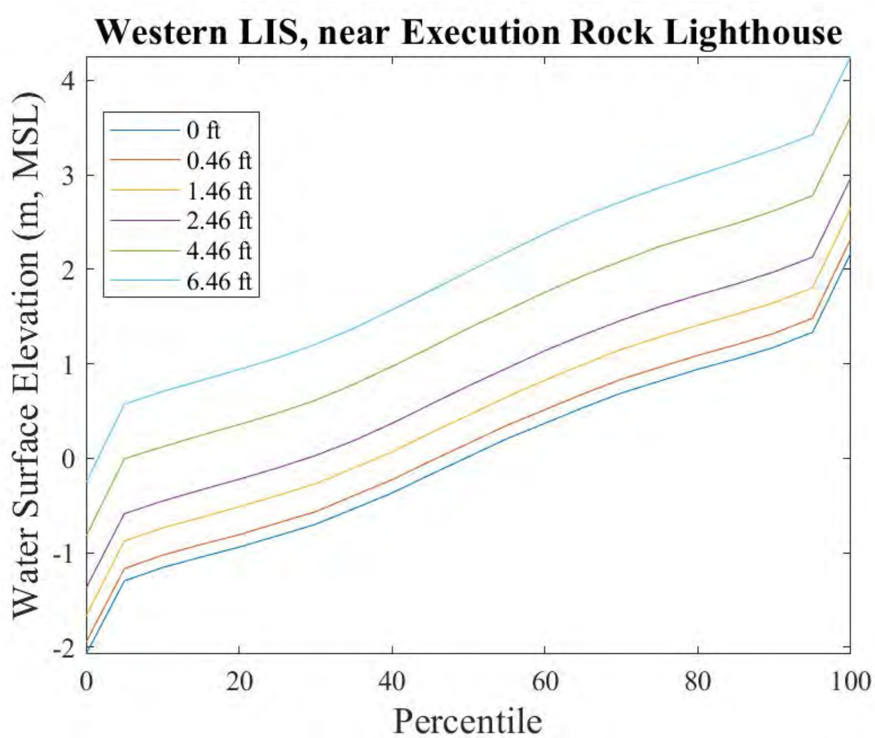


Figure 441. Alt 3a, LIS south of NY/CT border WSE Variation with SLR.

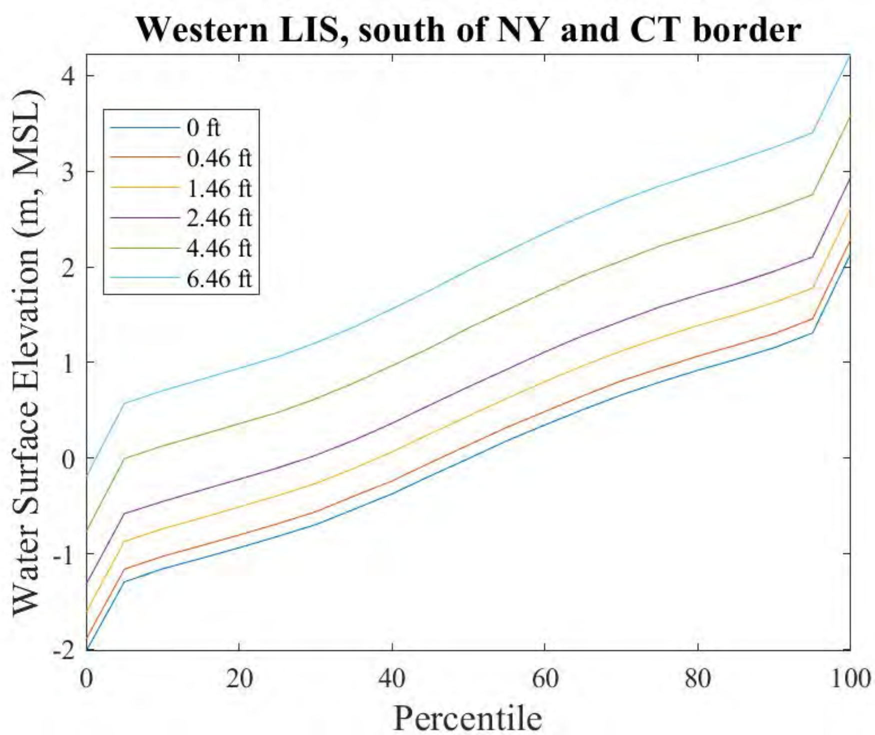


Figure 442. Alt 3a, Hudson River, Haverstraw Bay WSE Variation with SLR.

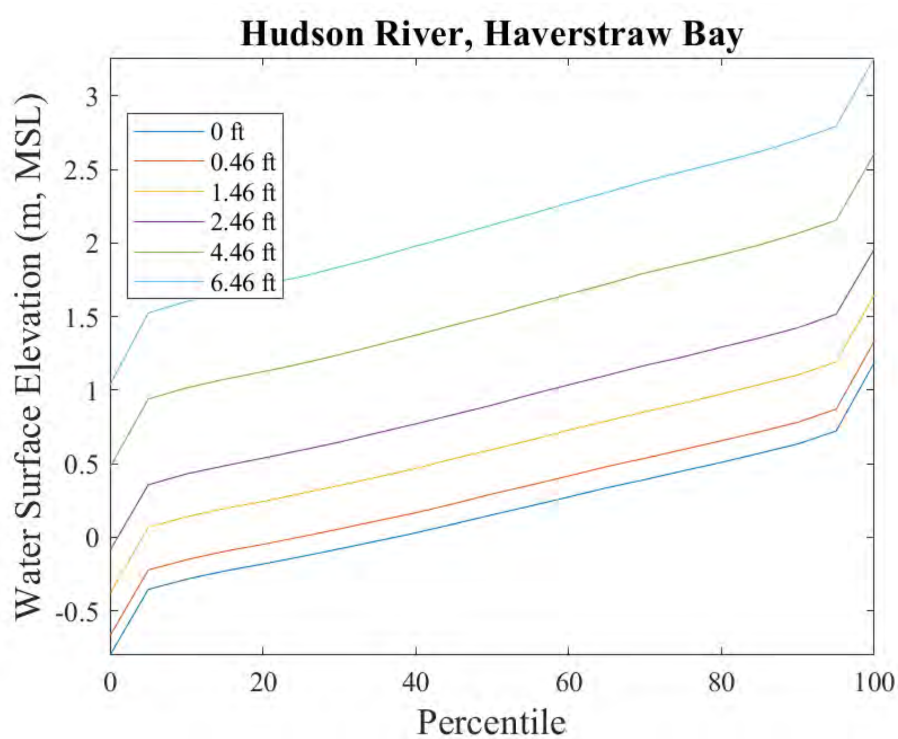


Figure 443. Alt 3a, Hudson River near Poughkeepsie WSE Variation with SLR.

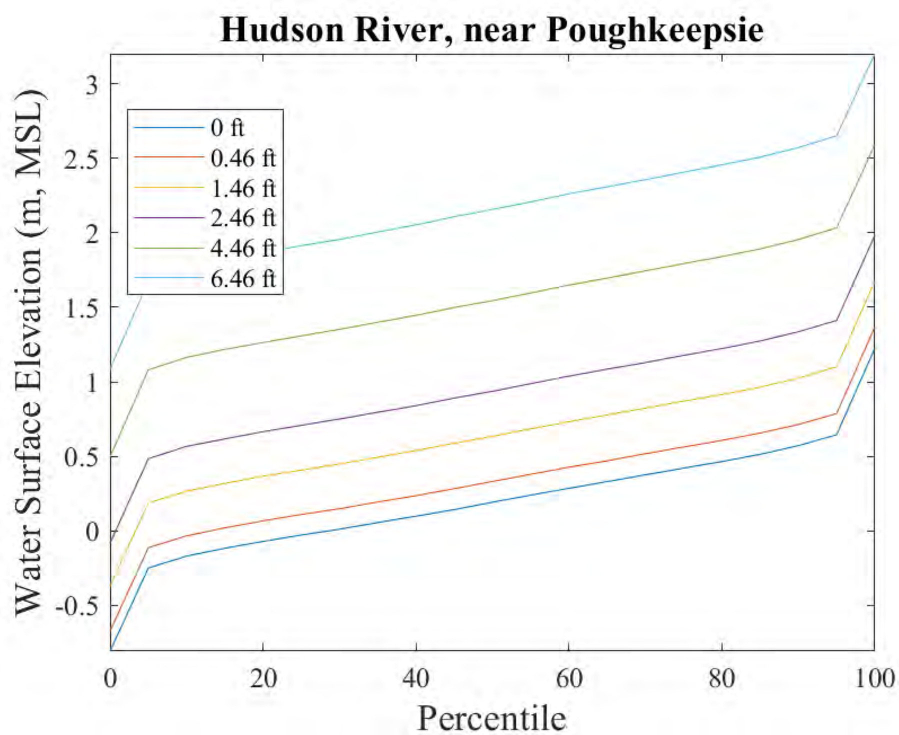


Figure 444. Alt 3a, Hudson River between Catskill and Hudson WSE Variation with SLR.

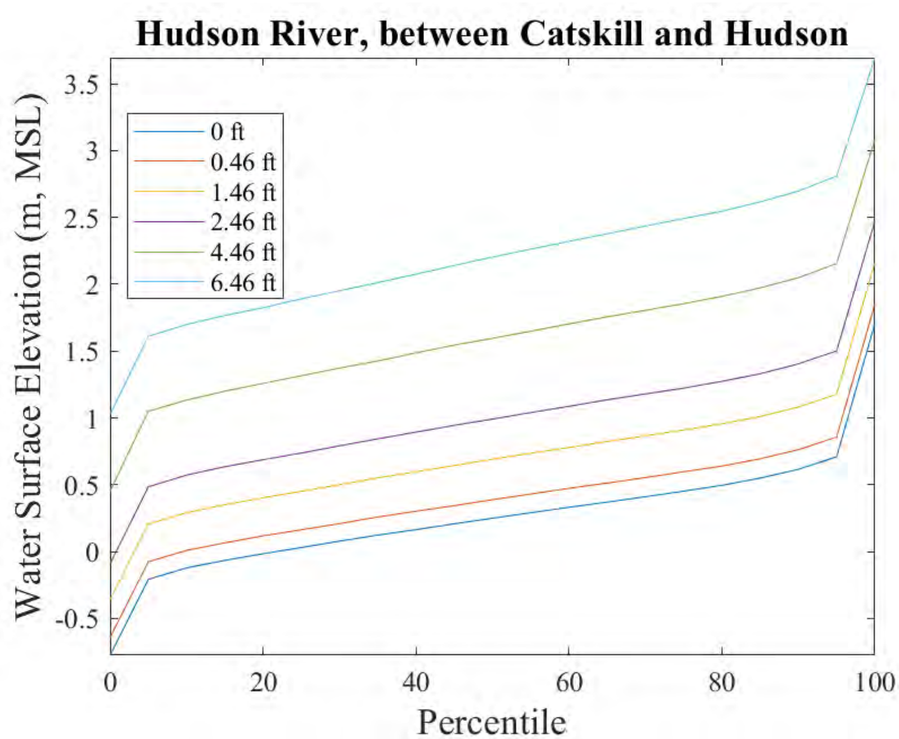
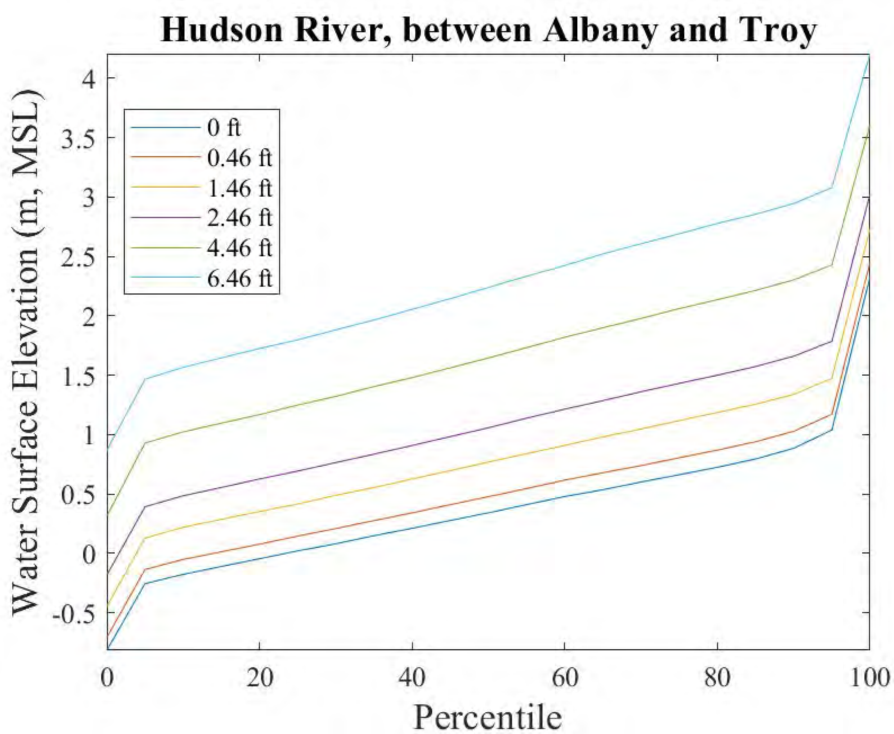


Figure 445. Alt 3a, Hudson River between Albany and Troy WSE Variation with SLR.



15.3.2 Velocity Point Percentiles

Velocity percentiles for Alternative 3a for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 446 to Figure 481. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prisms.

Figure 446. Alt 3a, V1 Velocity Variation with SLR.

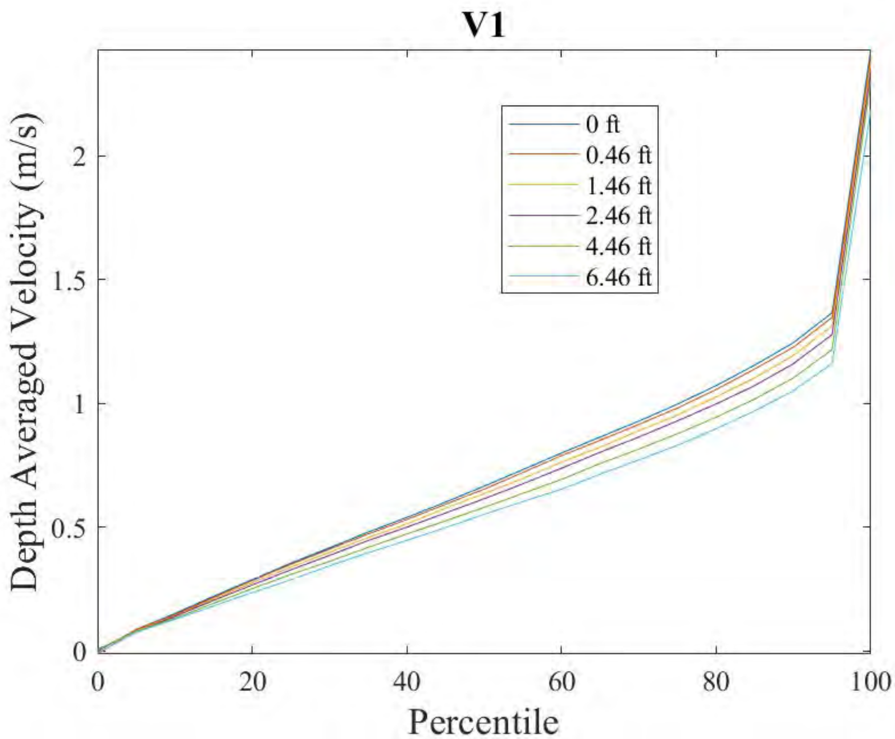


Figure 447. Alt 3a, V2 Velocity Variation with SLR.

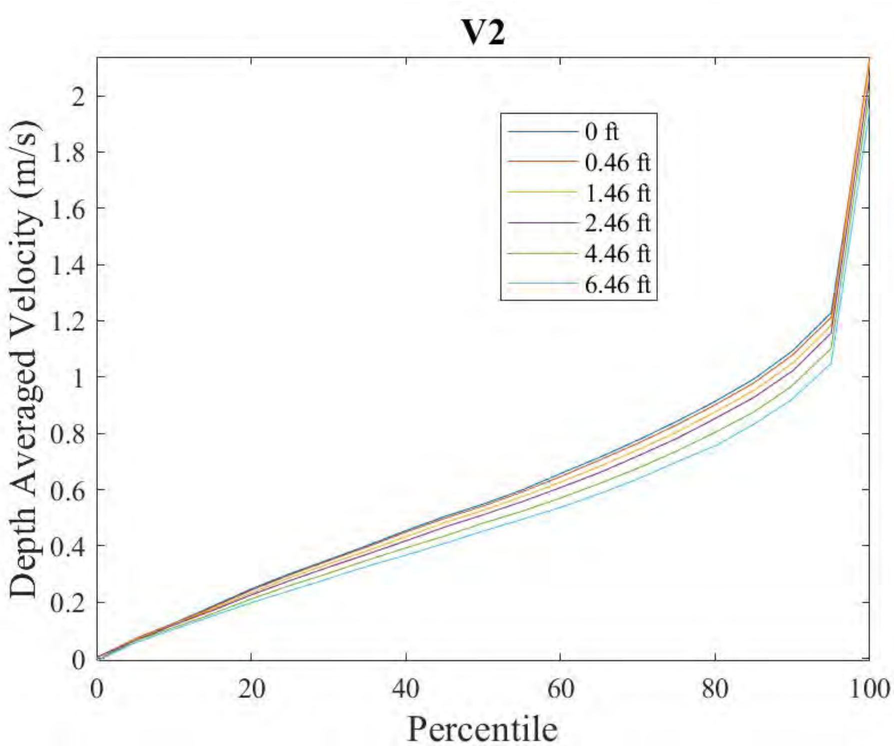


Figure 448. Alt 3a, V3 Velocity Variation with SLR.

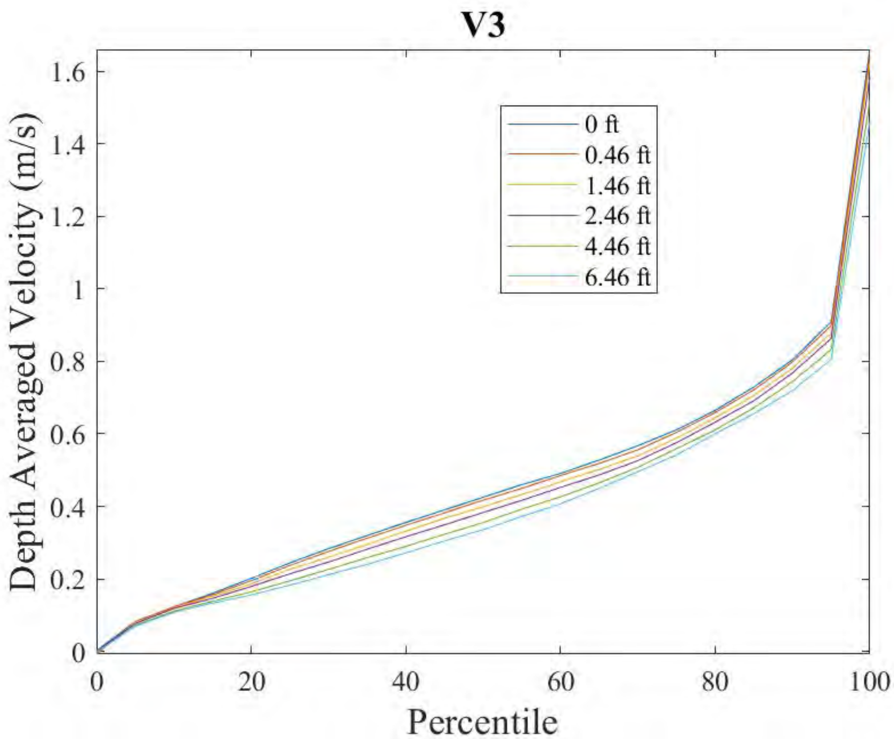


Figure 449. Alt 3a, V4 Velocity Variation with SLR.

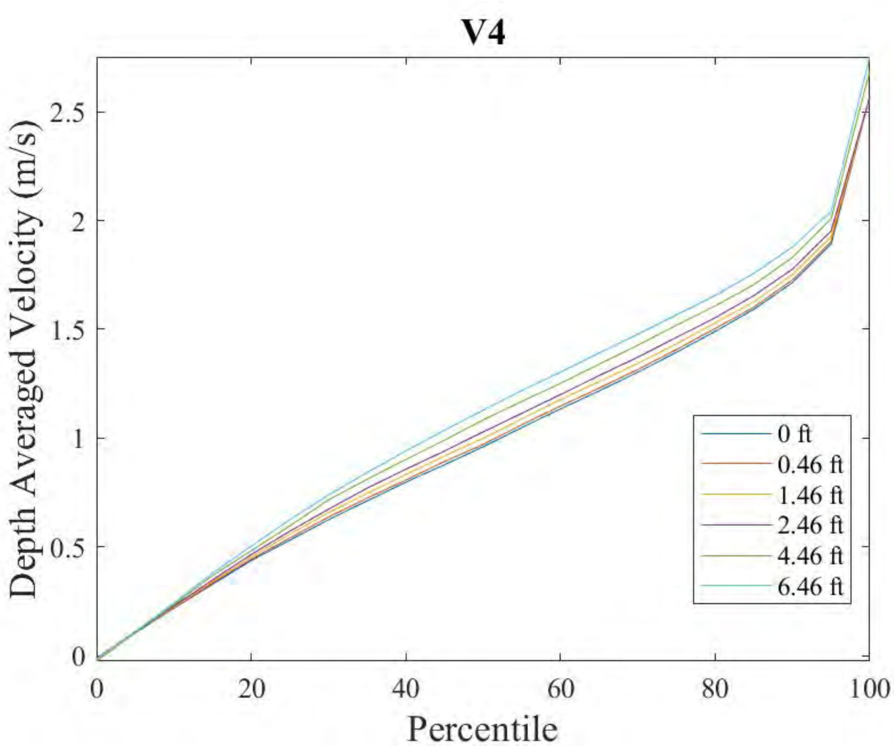


Figure 450. Alt 3a, V5 Velocity Variation with SLR.

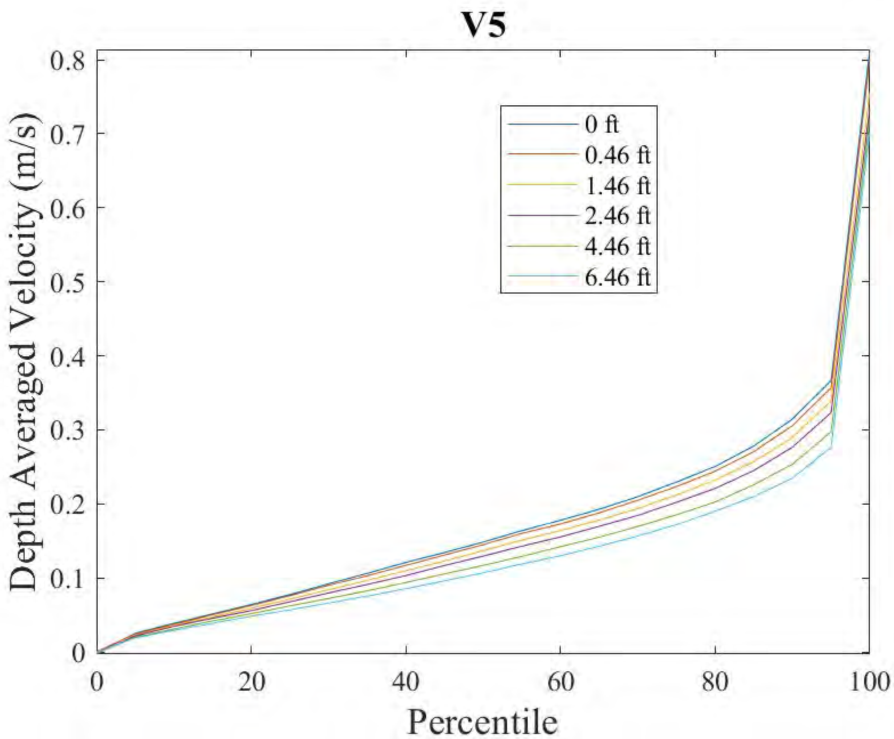


Figure 451. Alt 3a, V6 Velocity Variation with SLR.

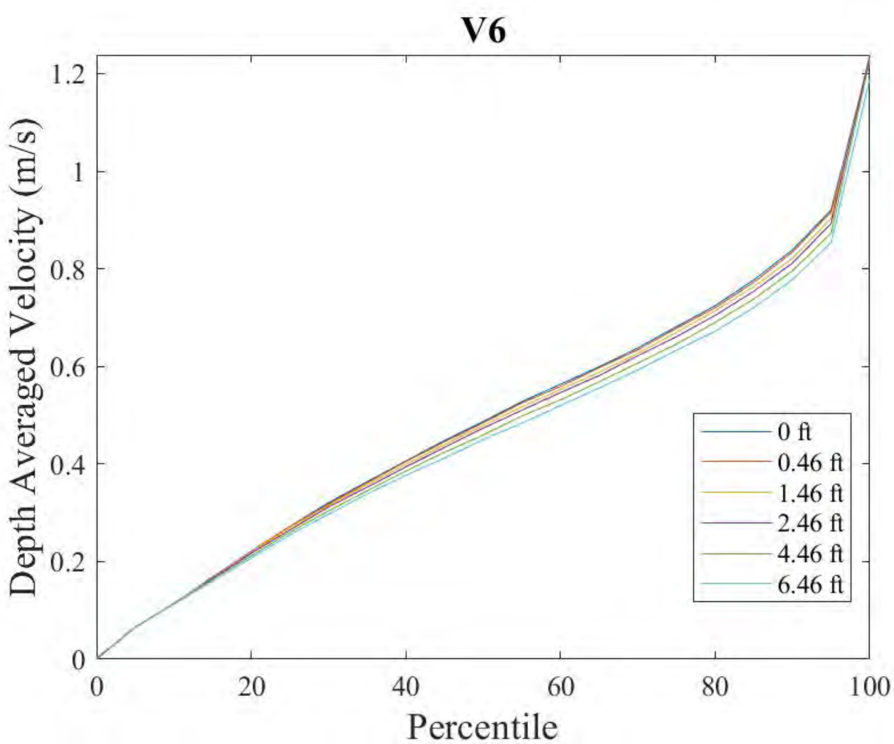


Figure 452. Alt 3a, S1 Velocity Variation with SLR.

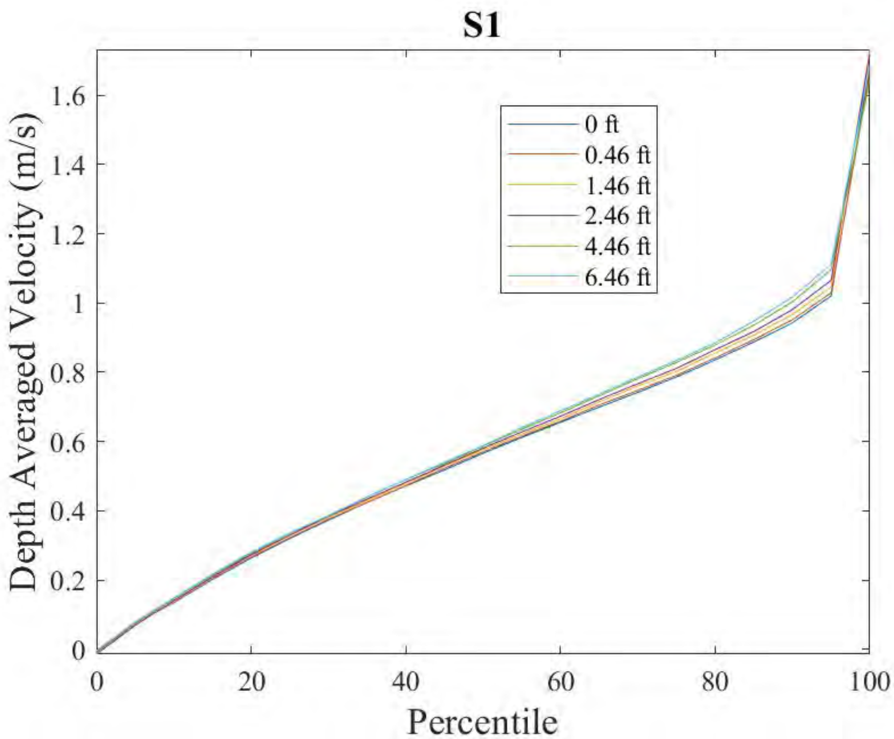


Figure 453. Alt 3a, S2 Velocity Variation with SLR.

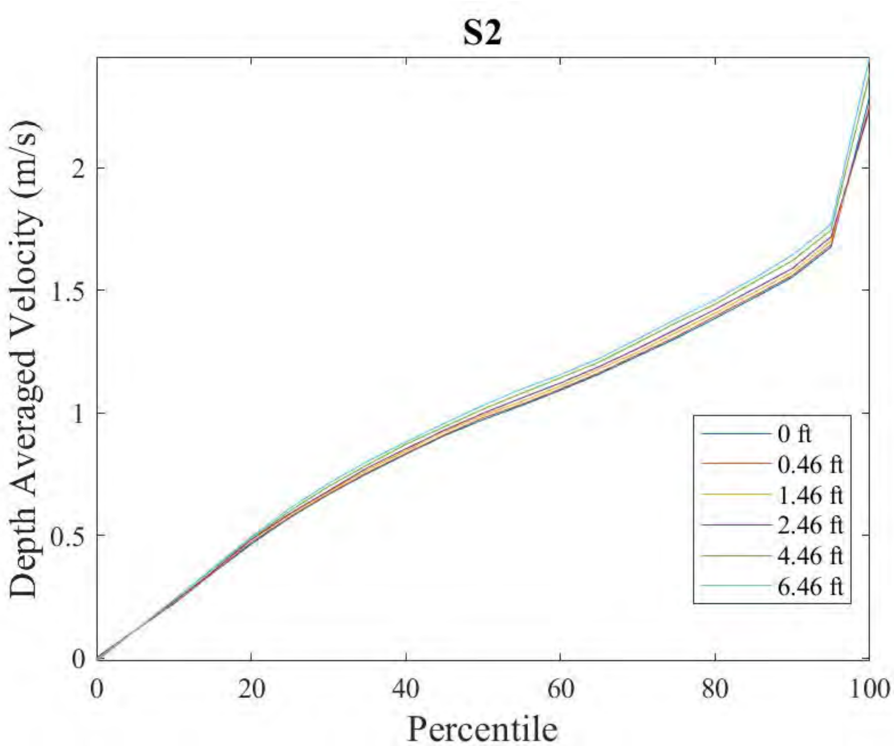


Figure 454. Alt 3a, S3 Velocity Variation with SLR.

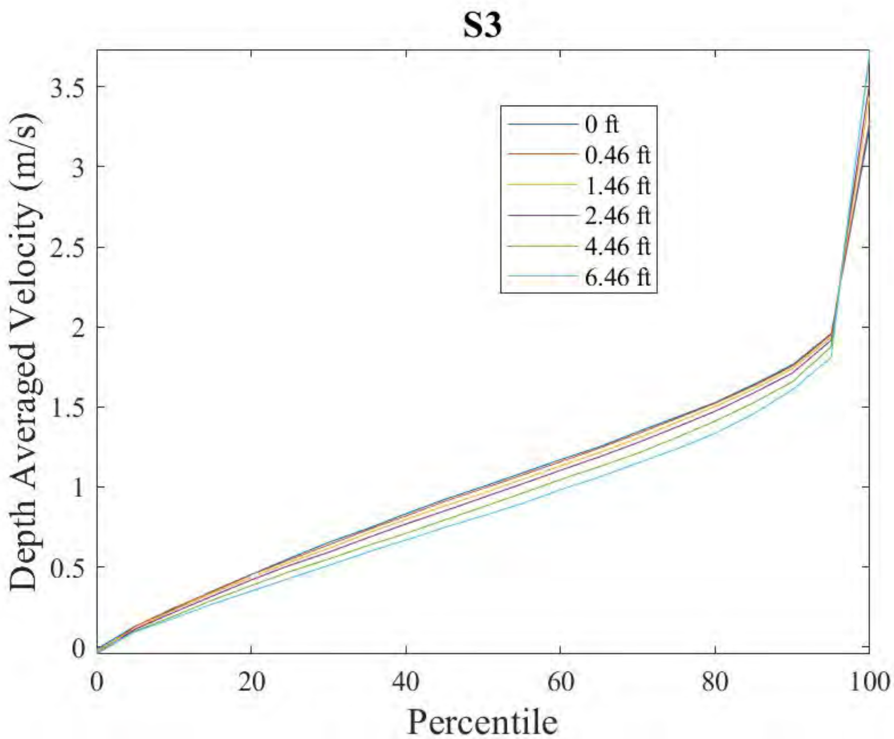


Figure 455. Alt 3a, S4 Velocity Variation with SLR.

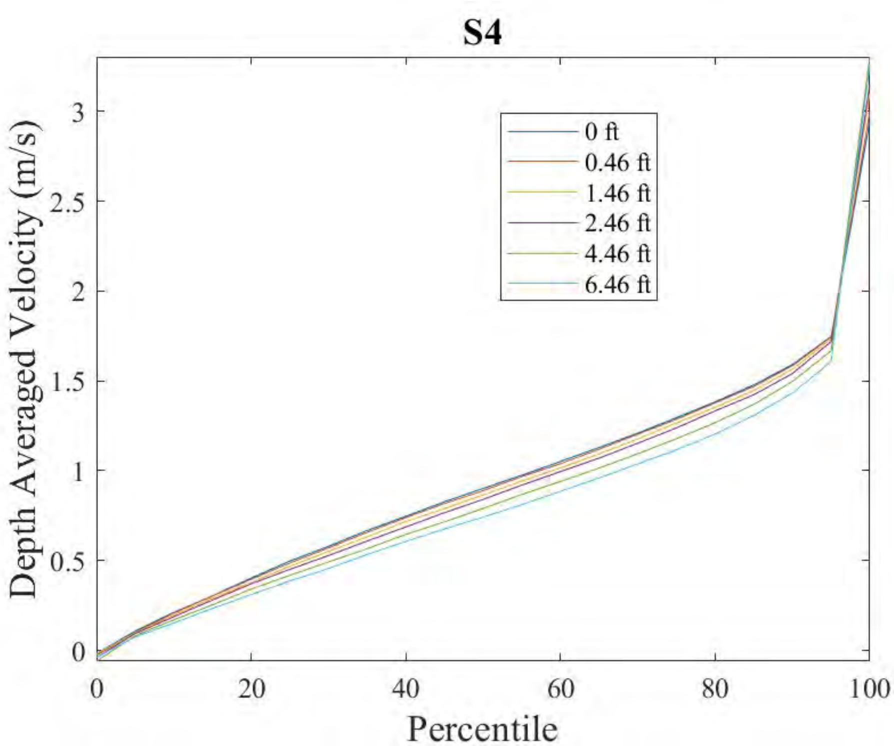


Figure 456. Alt 3a, S5 Velocity Variation with SLR.

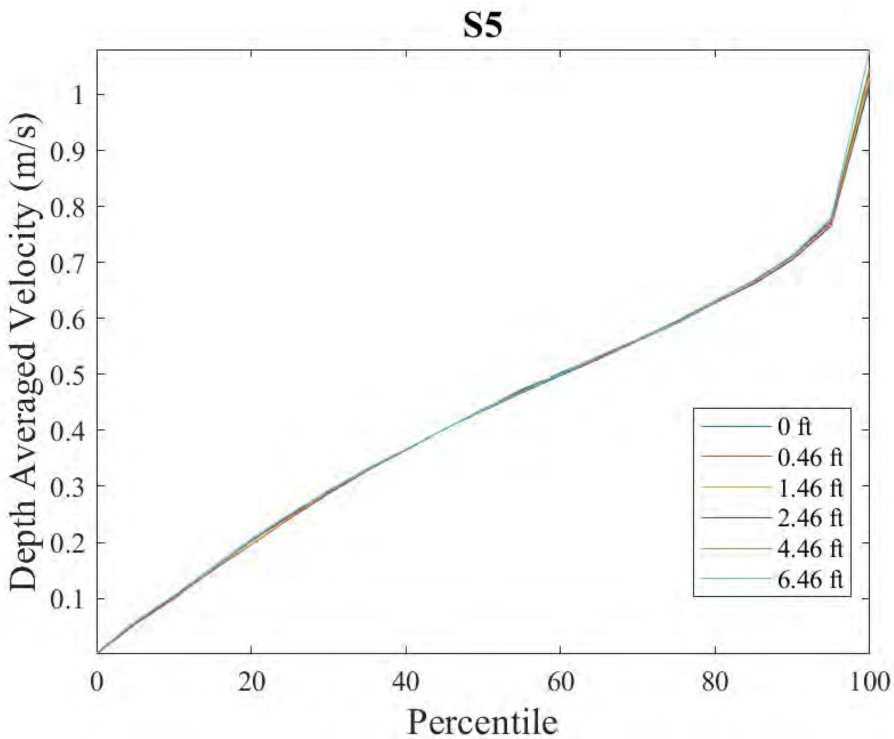


Figure 457. Alt 3a, T1 Velocity Variation with SLR.

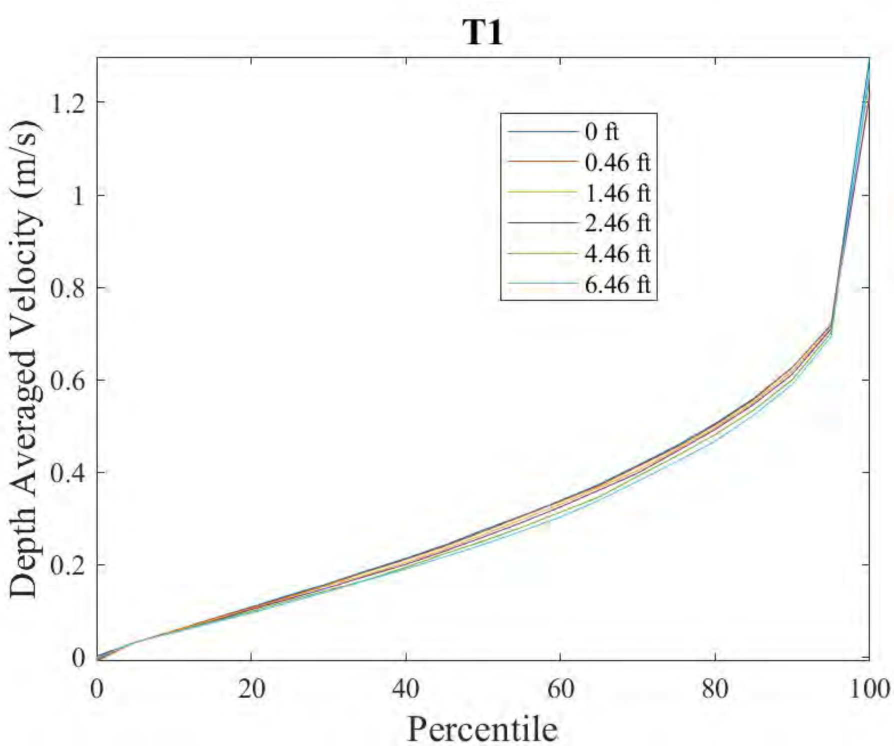


Figure 458. Alt 3a, T2 Velocity Variation with SLR.

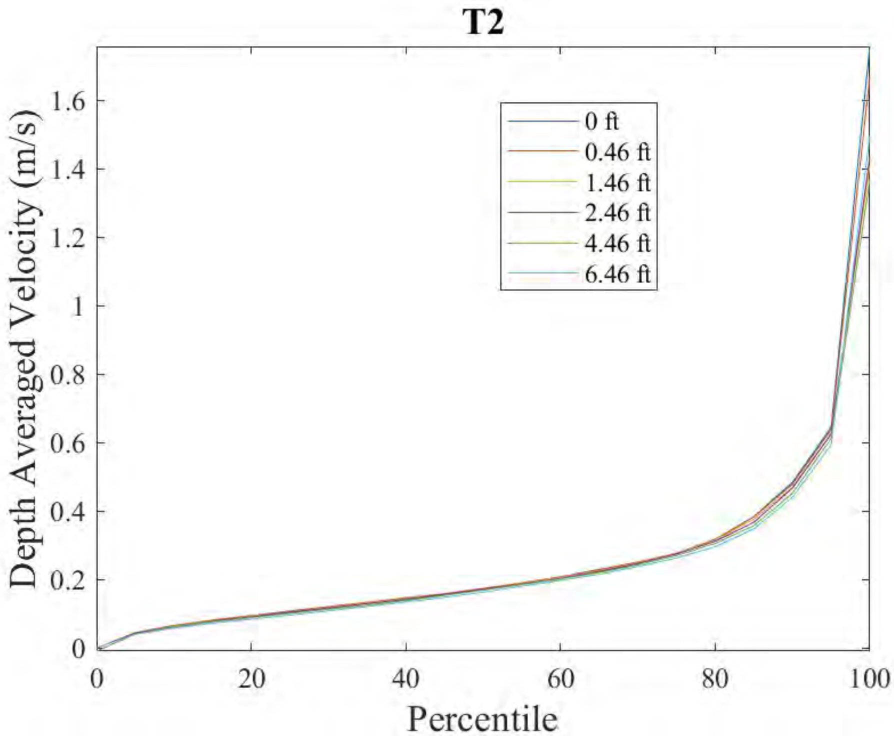


Figure 459. Alt 3a, T3 Velocity Variation with SLR.

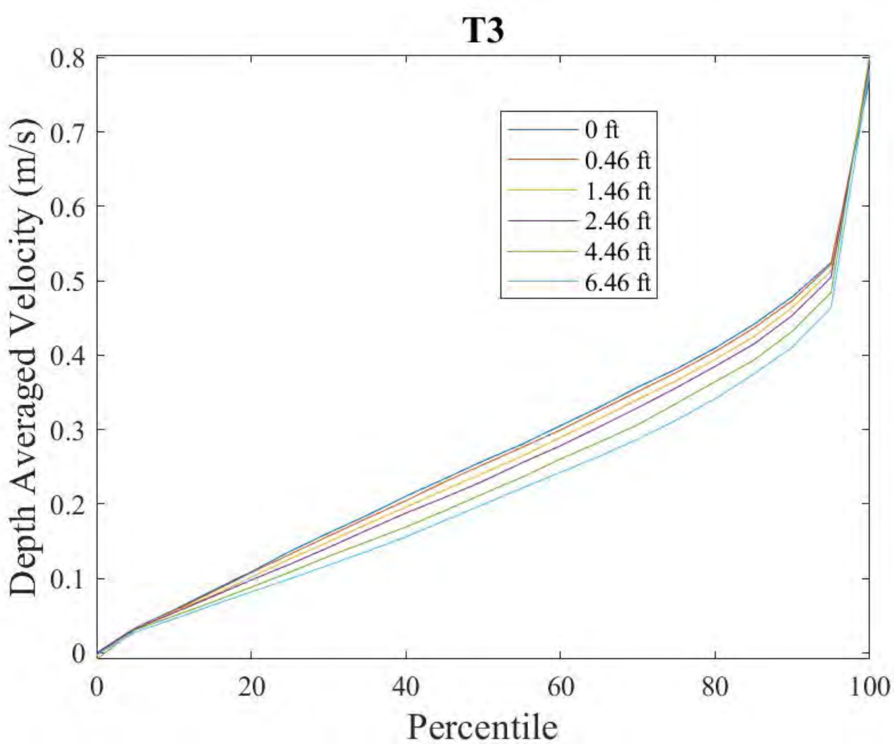


Figure 460. Alt 3a, T4 Velocity Variation with SLR.

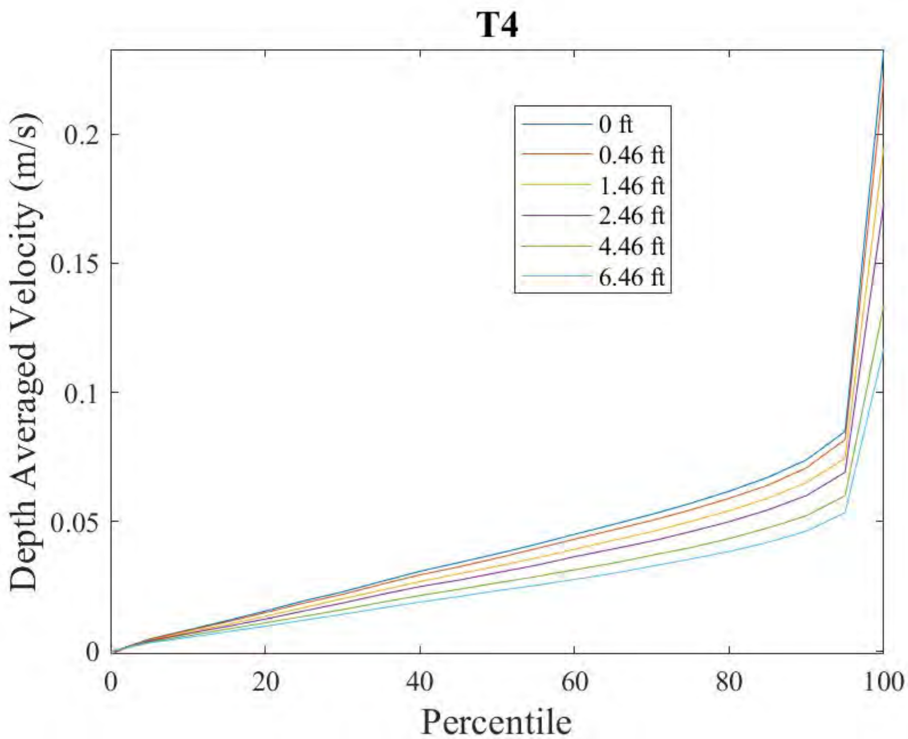


Figure 461. Alt 3a, T5 Velocity Variation with SLR.

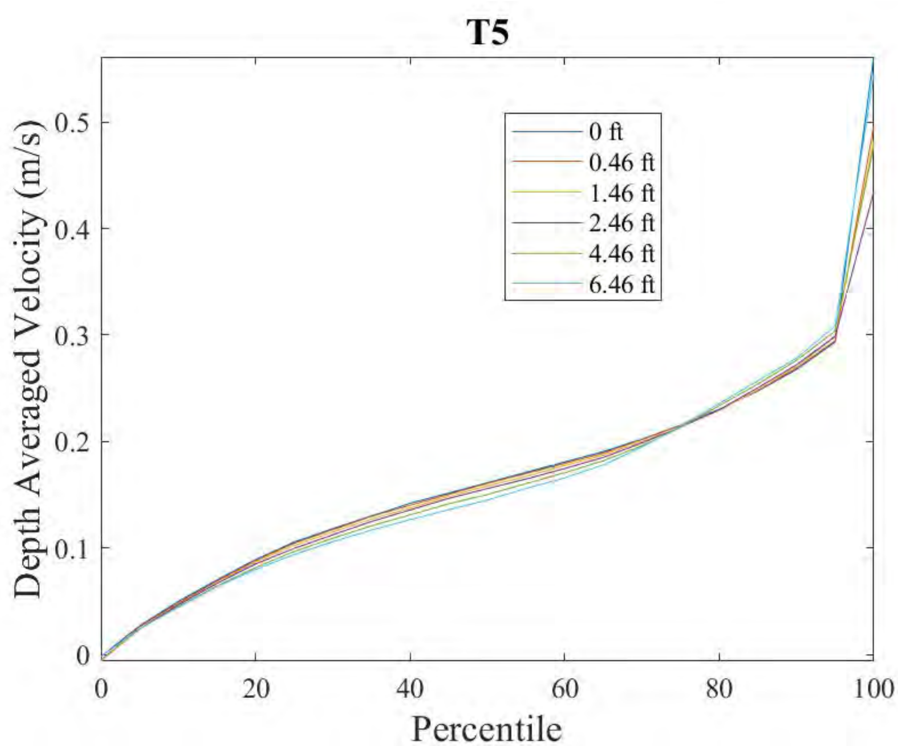


Figure 462. Alt 3a, R1 Velocity Variation with SLR.

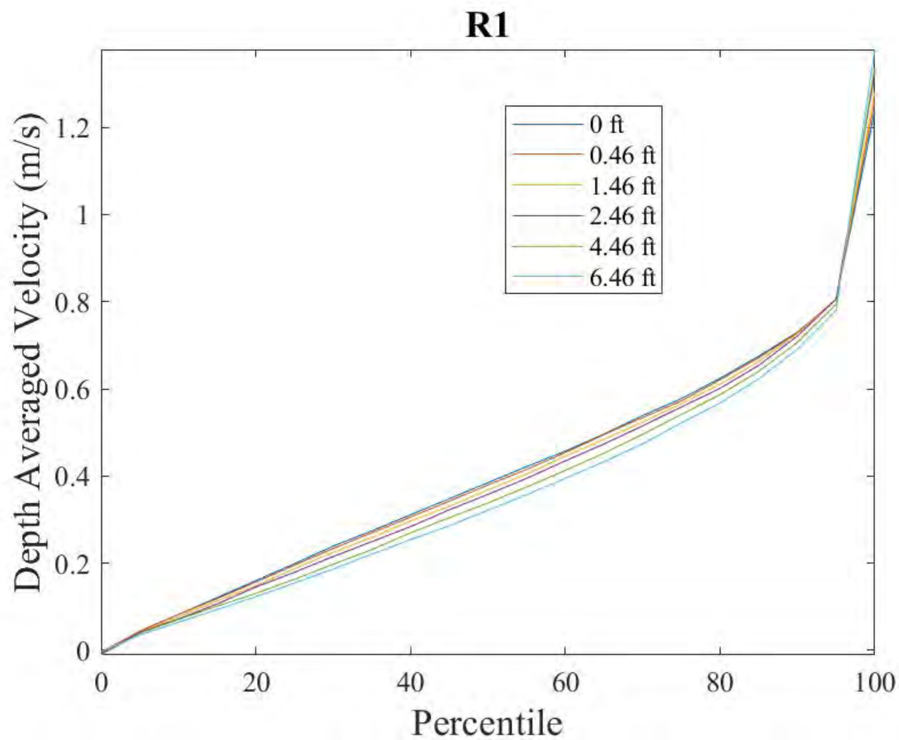


Figure 463. Alt 3a, Sandy Hook Velocity Variation with SLR.

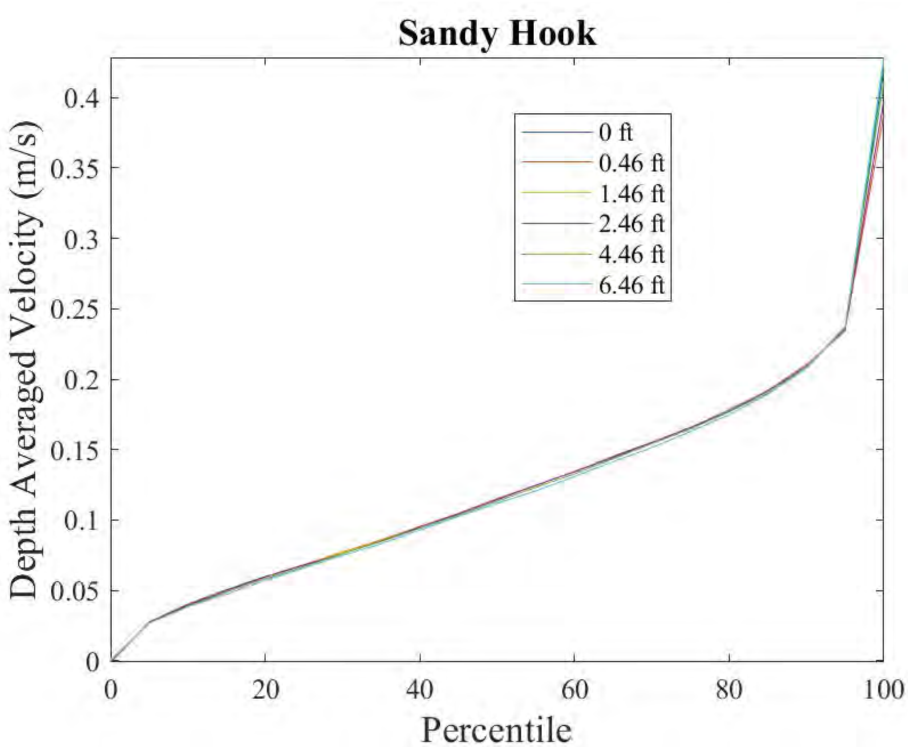


Figure 464. Alt 3a, Fresh Kills Velocity Variation with SLR.

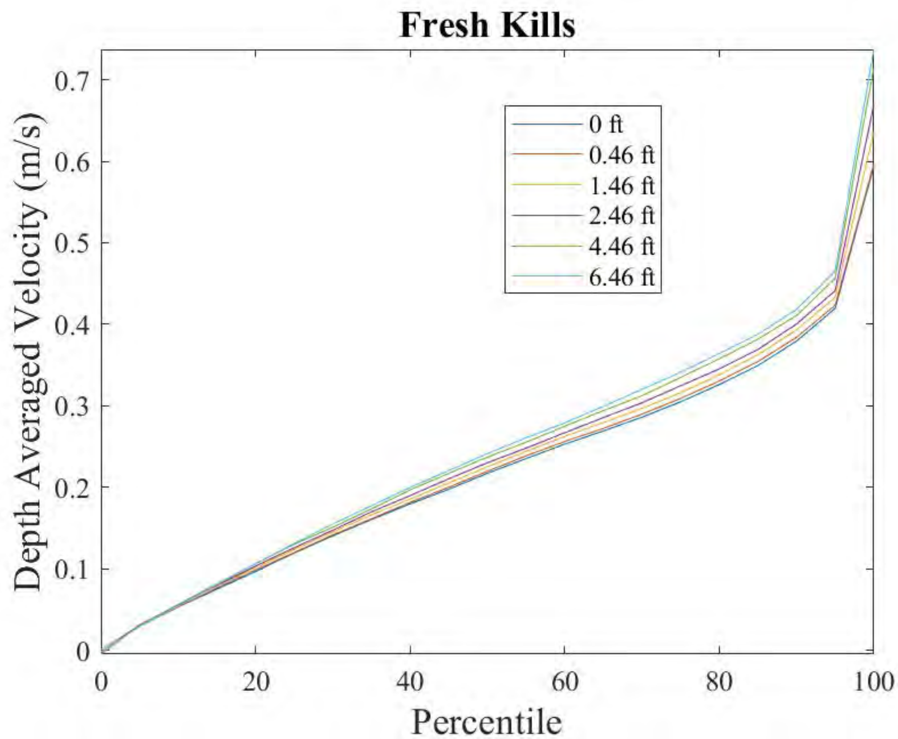


Figure 465. Alt 3a, Mariners Harbor Velocity Variation with SLR.

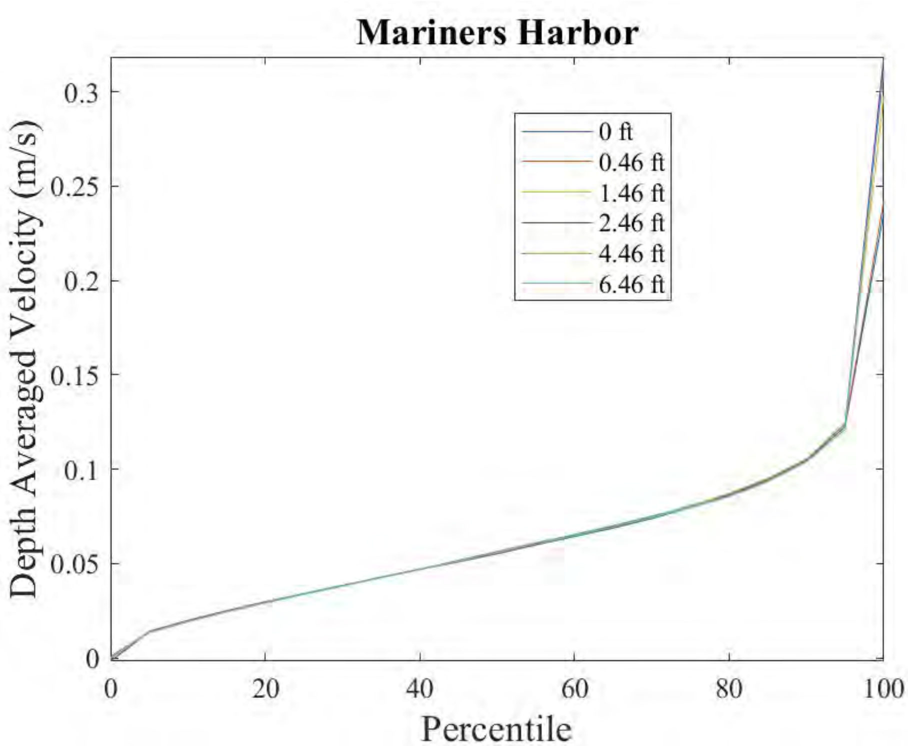


Figure 466. Alt 3a, North Reach Velocity Variation with SLR.

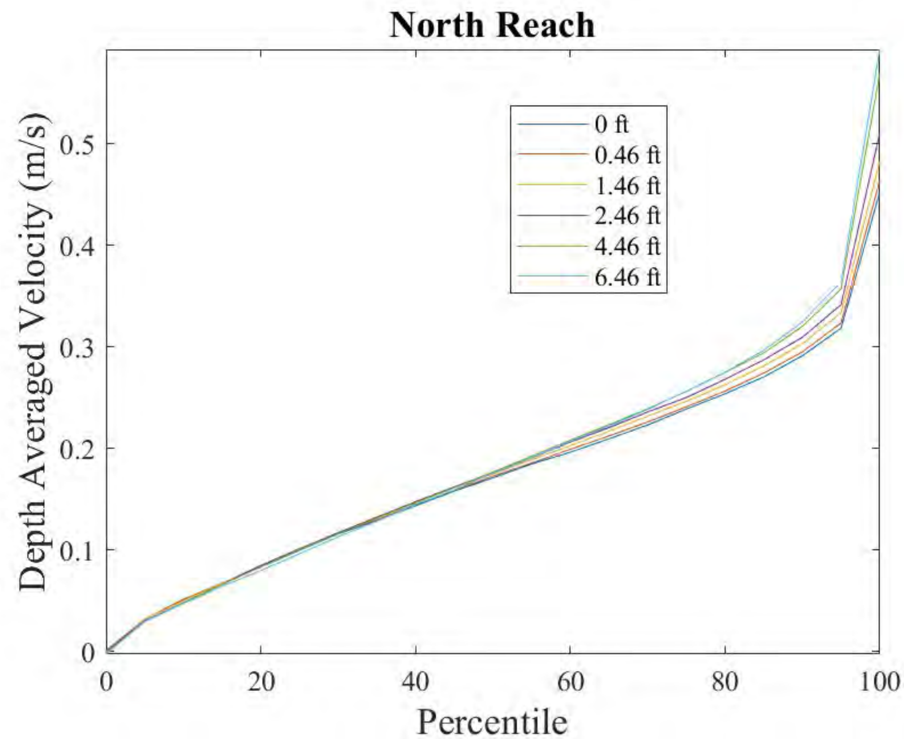


Figure 467. Alt 3a, Hackensack River Velocity Variation with SLR.

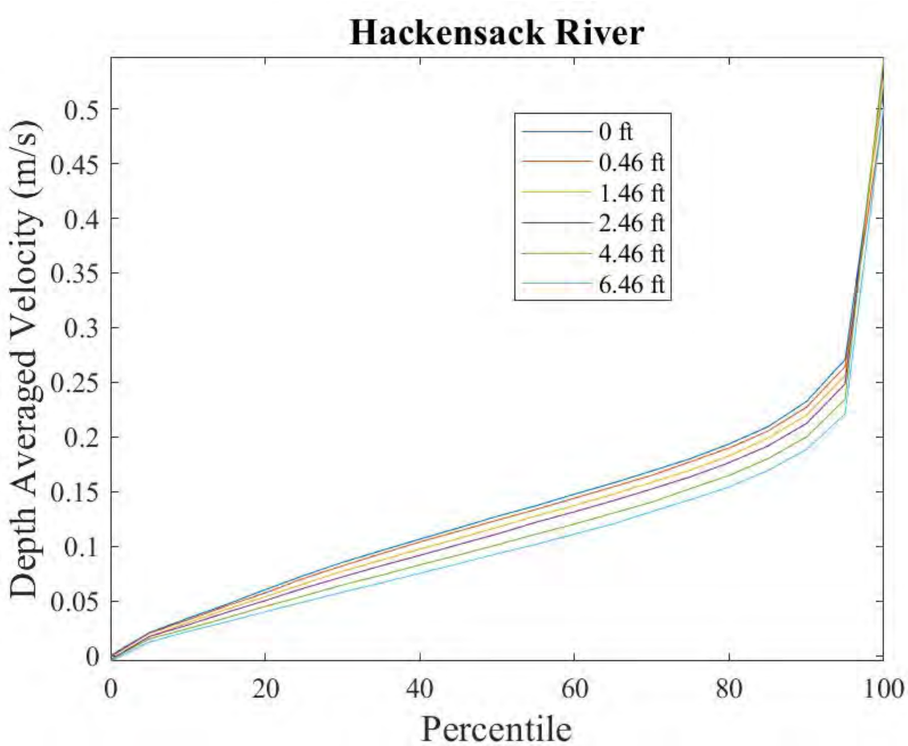


Figure 468. Alt 3a, Robbins Reef Velocity Variation with SLR.

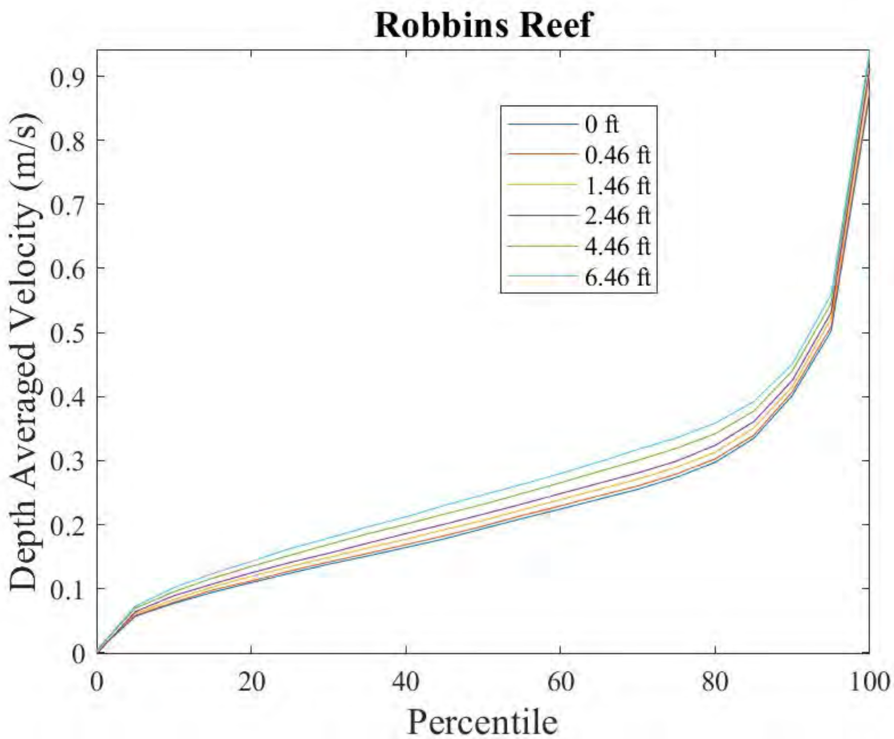


Figure 469. Alt 3a, The Battery Velocity Variation with SLR.

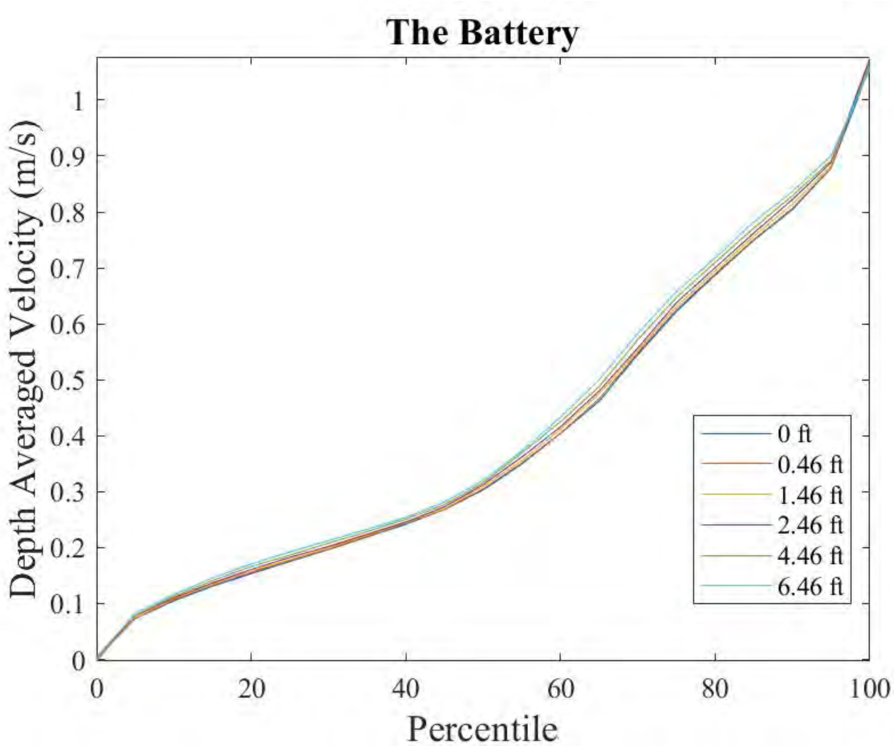


Figure 470. Alt 3a, Manhattan Velocity Variation with SLR.

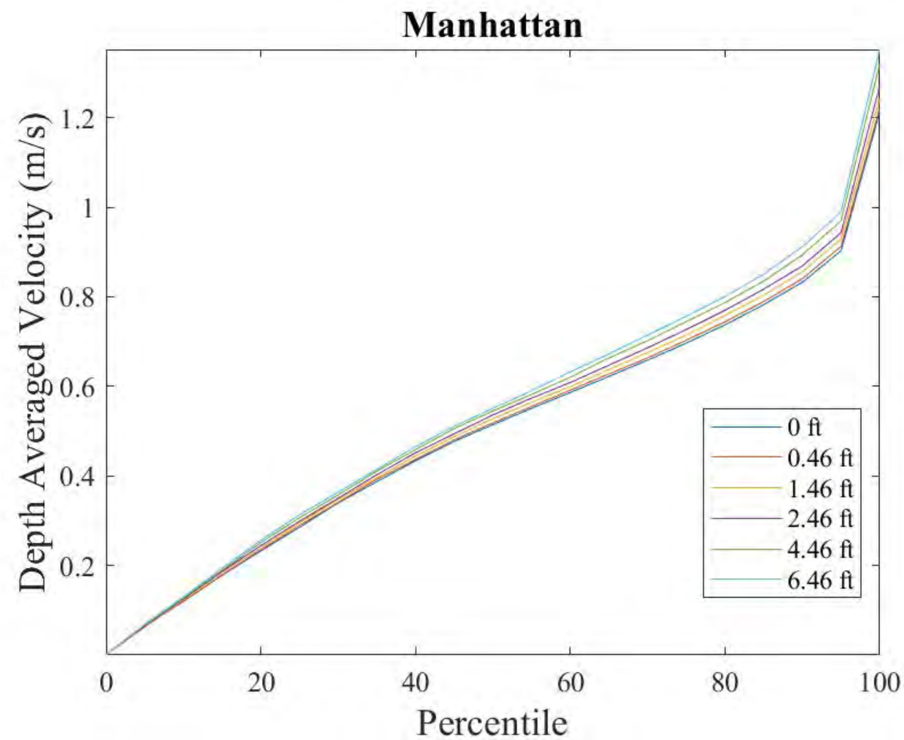


Figure 471. Alt 3a, Hudson River, Haverstraw Bay Velocity Variation with SLR.

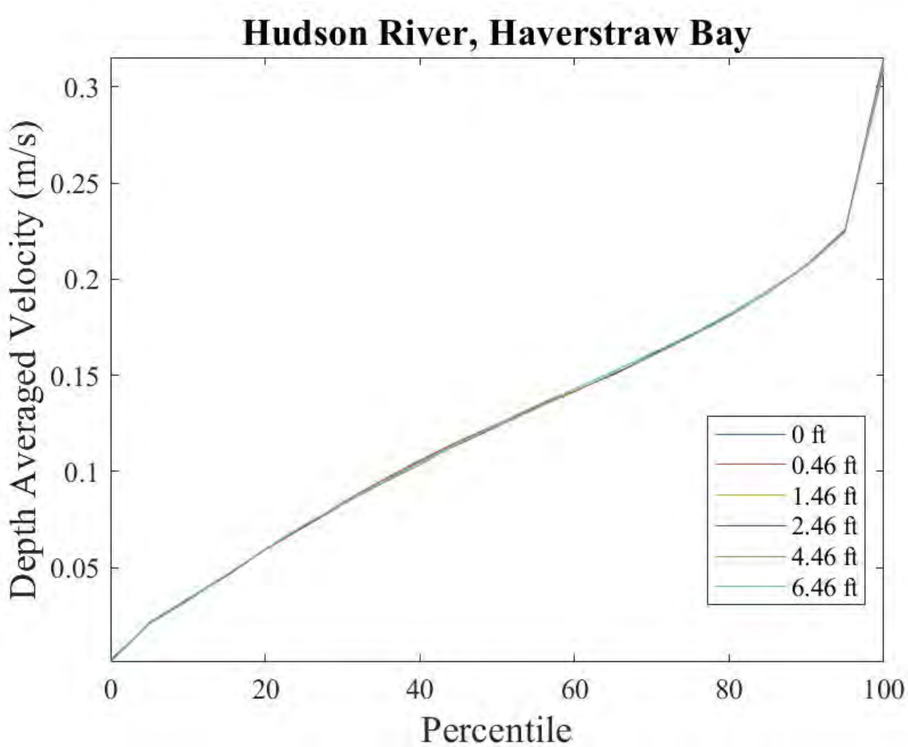


Figure 472. Alt 3a, Hudson River near Poughkeepsie Velocity Variation with SLR.

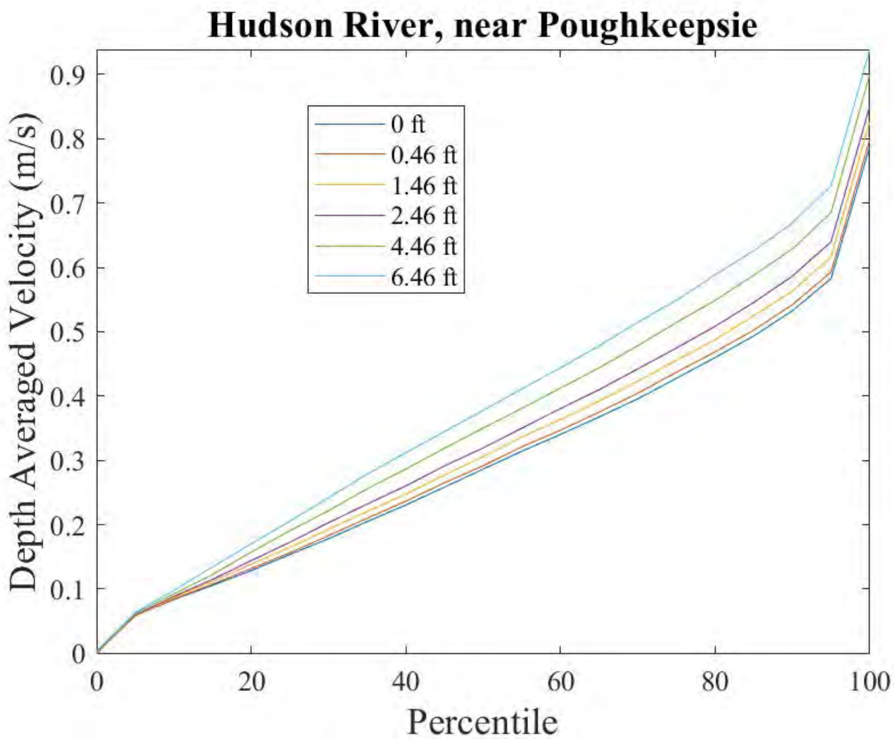


Figure 473. Alt 3a, Hudson River between Catskill and Hudson Velocity Variation with SLR.

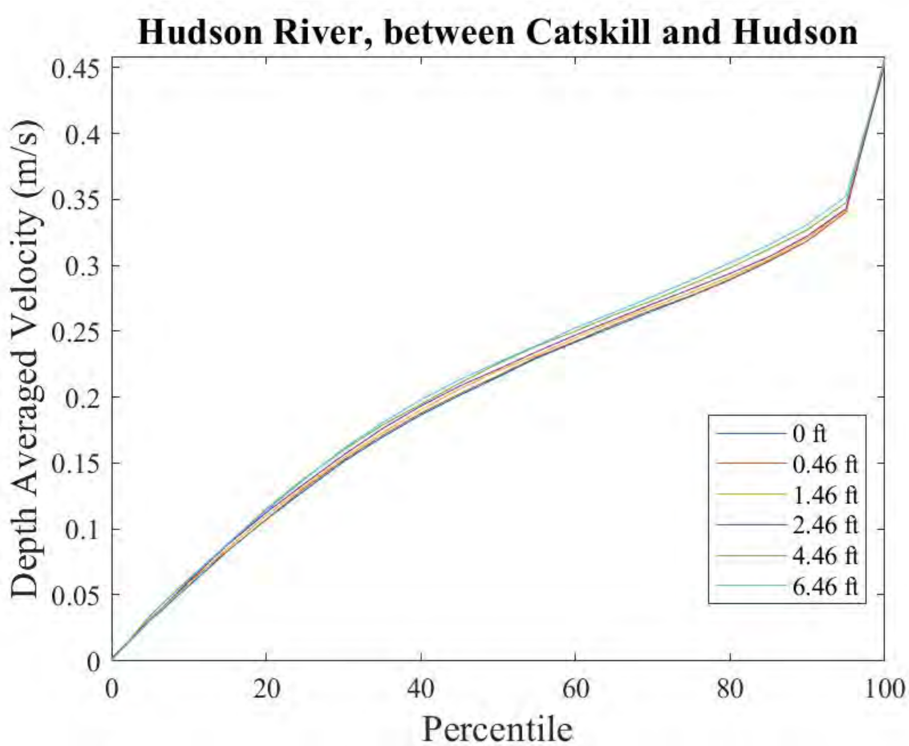


Figure 474. Alt 3a, Hudson River between Albany and Troy Velocity Variation with SLR.

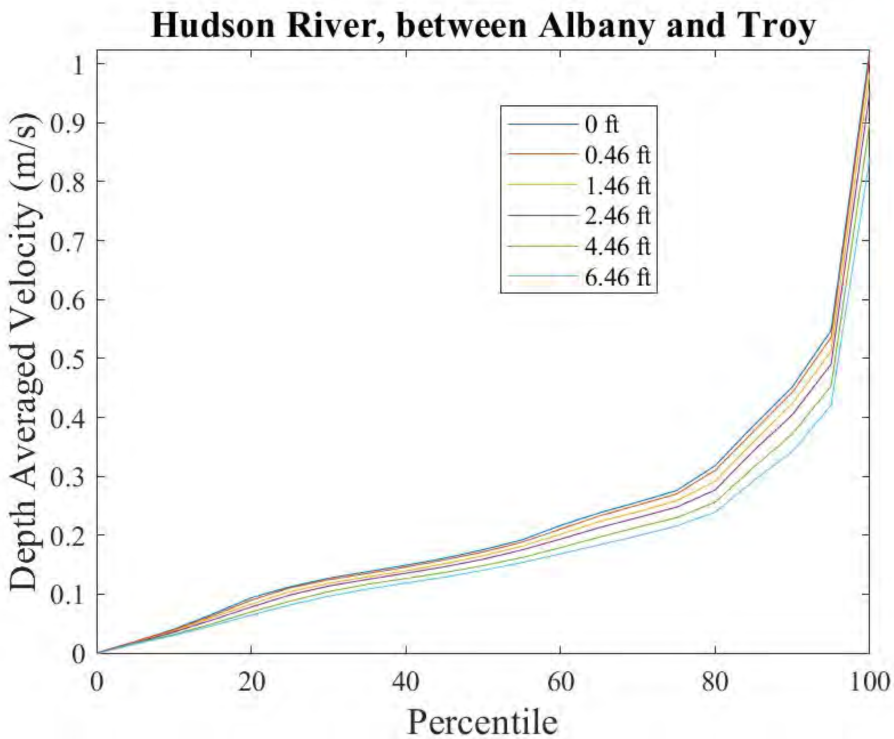


Figure 475. Alt 3a, KLGA Velocity Variation with SLR.

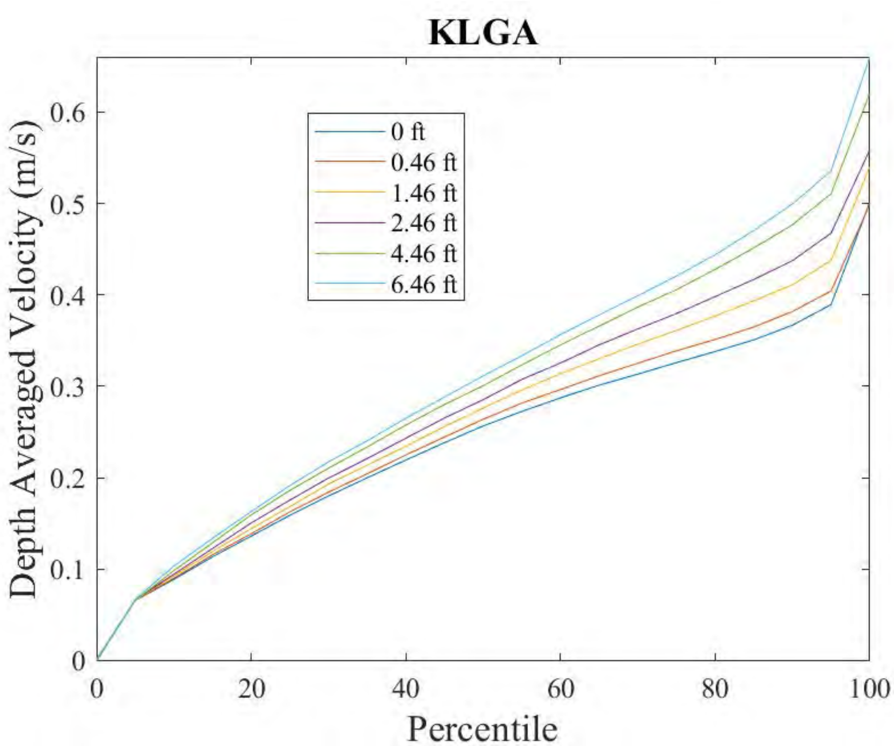


Figure 476. Alt 3a, LIS near Stepping Stone Lighthouse Velocity Variation with SLR.

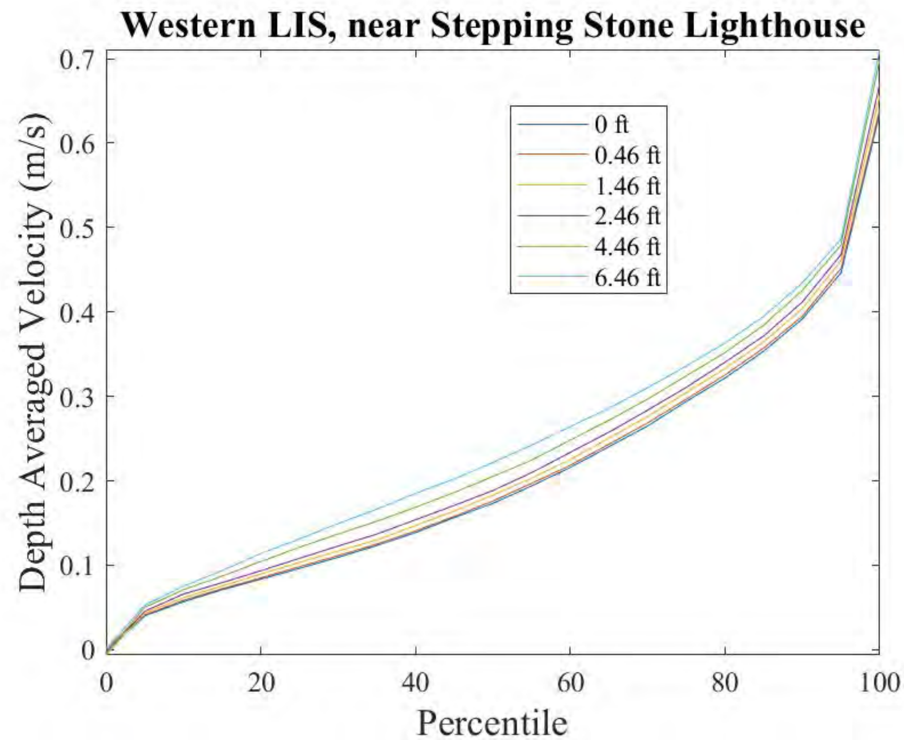


Figure 477. Alt 3a, LIS near Execution Rock Lighthouse Velocity Variation with SLR.

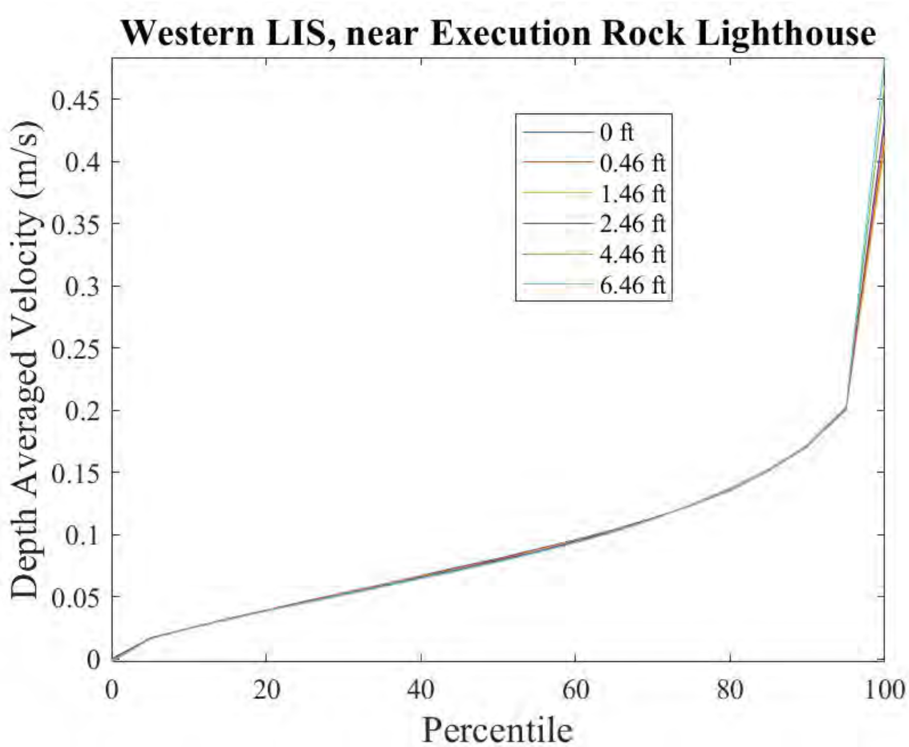


Figure 478. Alt 3a, LIS south of NY/CT border Velocity Variation with SLR.

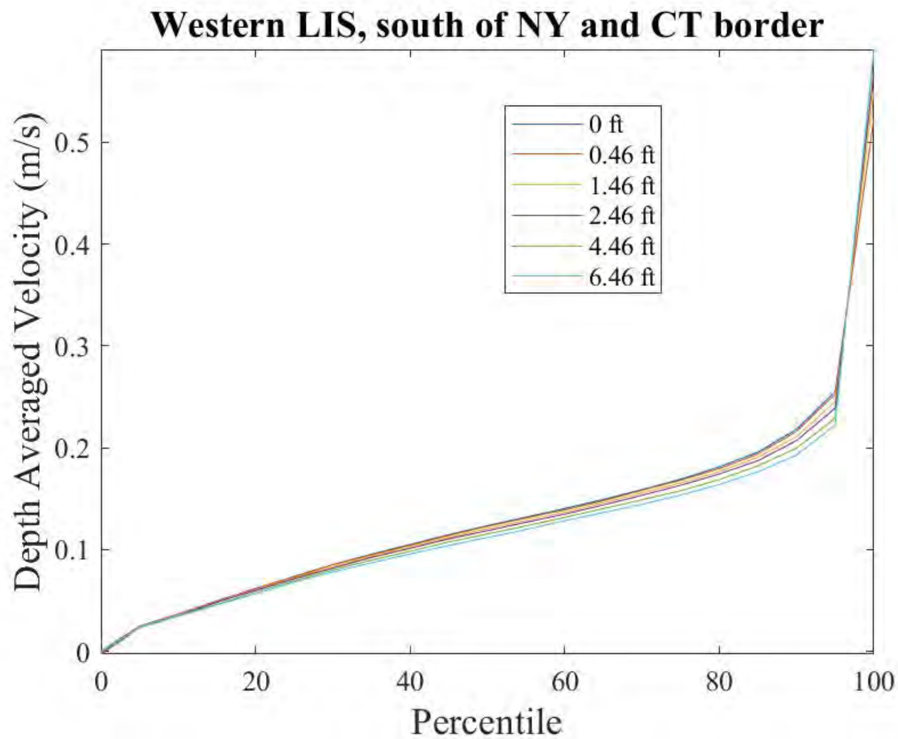


Figure 479. Alt 3a, Jamaica Bay Velocity Variation with SLR.

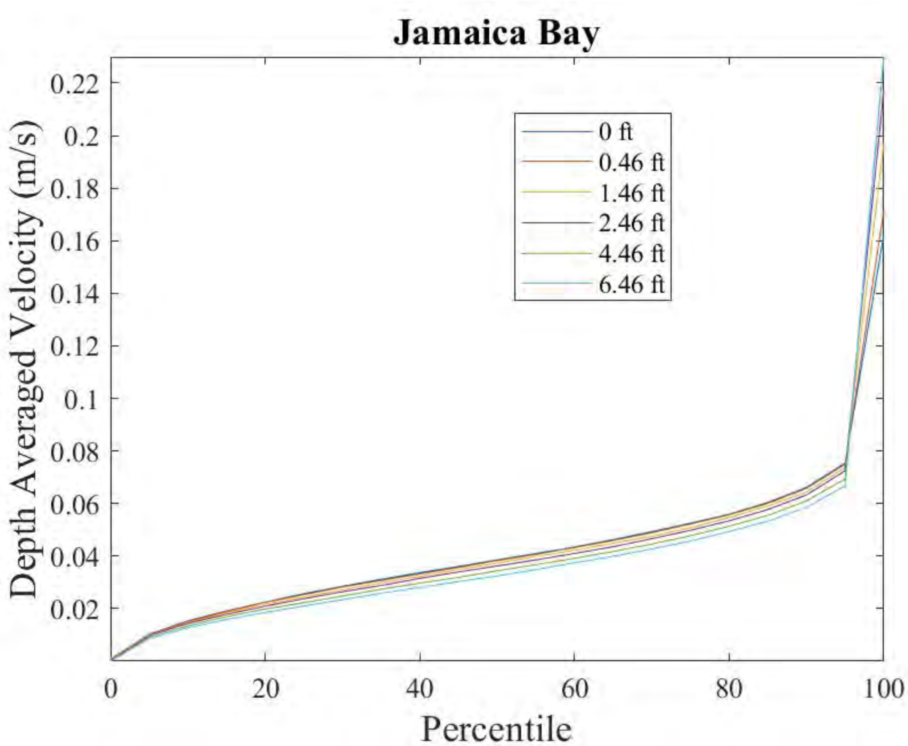


Figure 480. Alt 3a, Jamaica Bay near Spring Creek Velocity Variation with SLR.

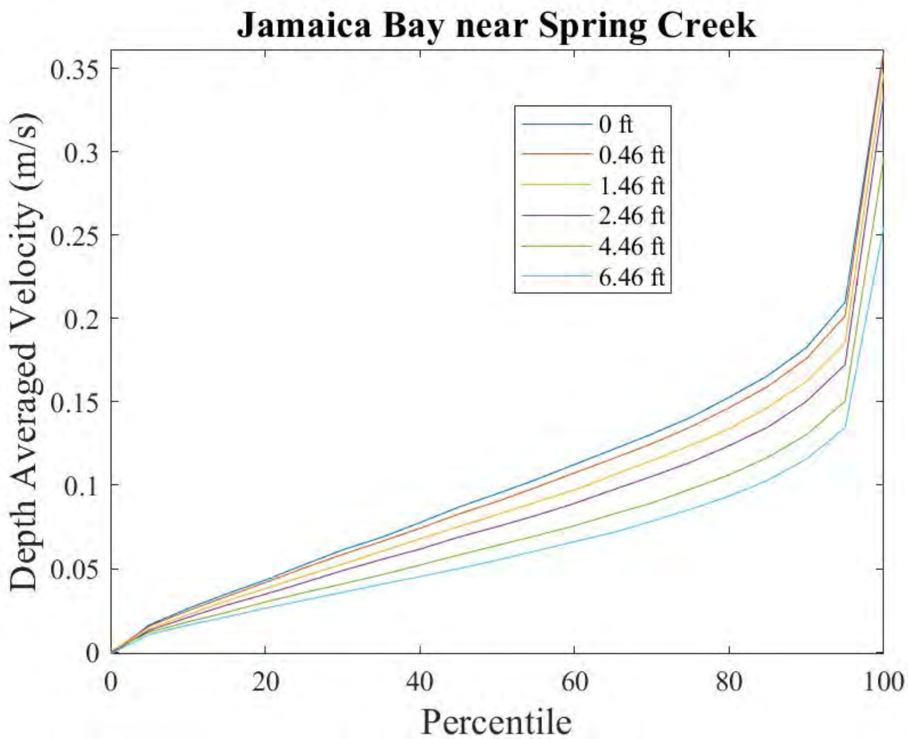
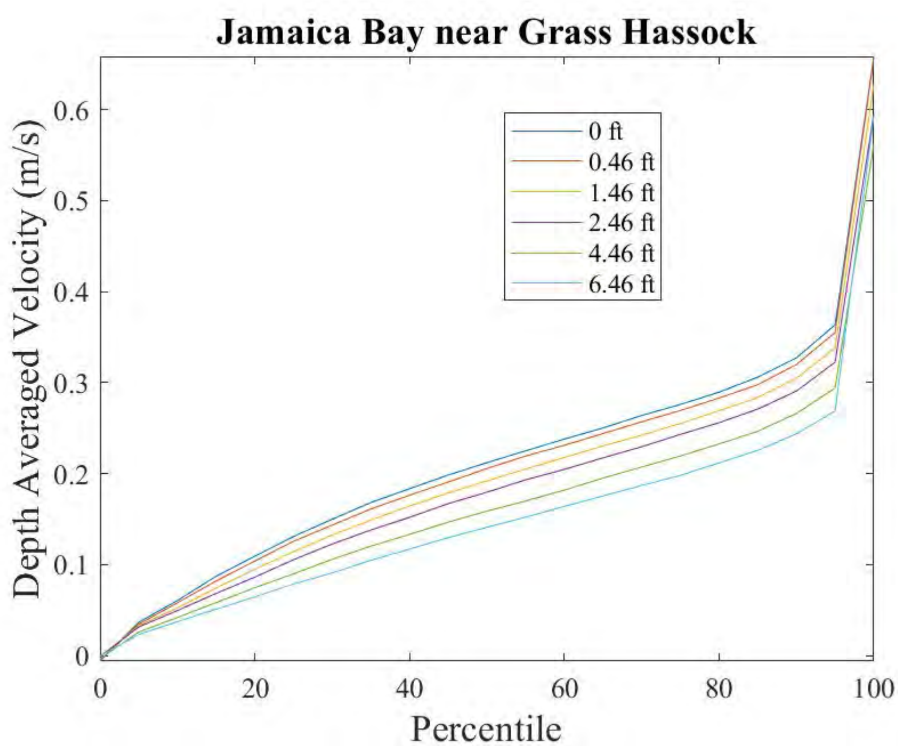


Figure 481. Alt 3a, Jamaica Bay near Grass Hassock Velocity Variation with SLR.



15.3.3 Salinity Point Percentiles

Salinity percentiles for Alternative 3a for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 482 to Figure 514. In general, increased sea levels result in increased salinities.

Figure 482. Alt 3a, V1 Salinity Variation with SLR.

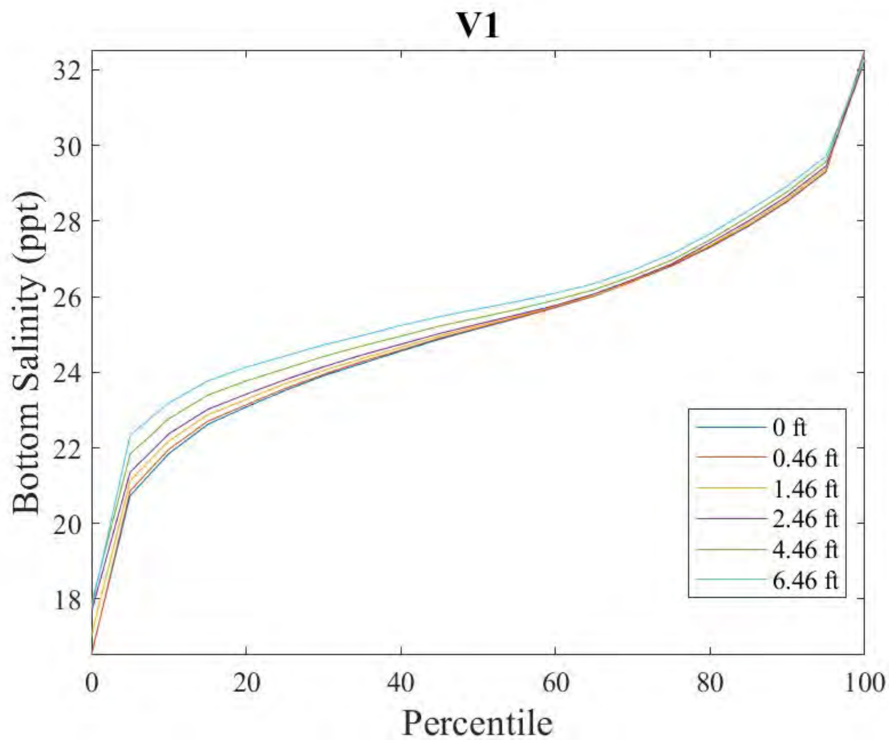


Figure 483. Alt 3a, V2 Salinity Variation with SLR.

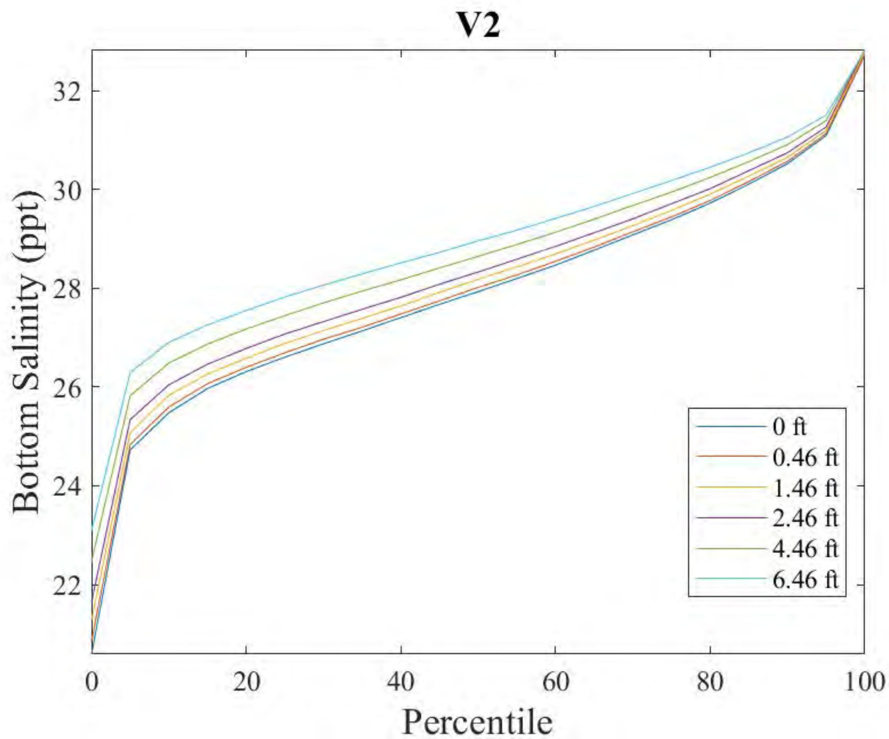


Figure 484. Alt 3a, V3 Salinity Variation with SLR.

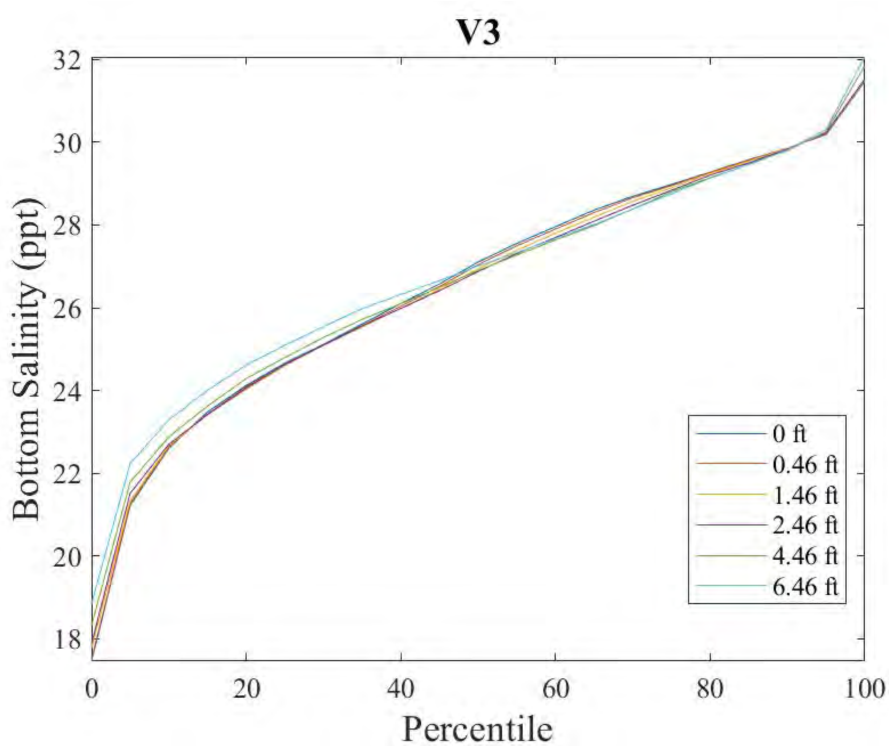


Figure 485. Alt 3a, V4 Salinity Variation with SLR.

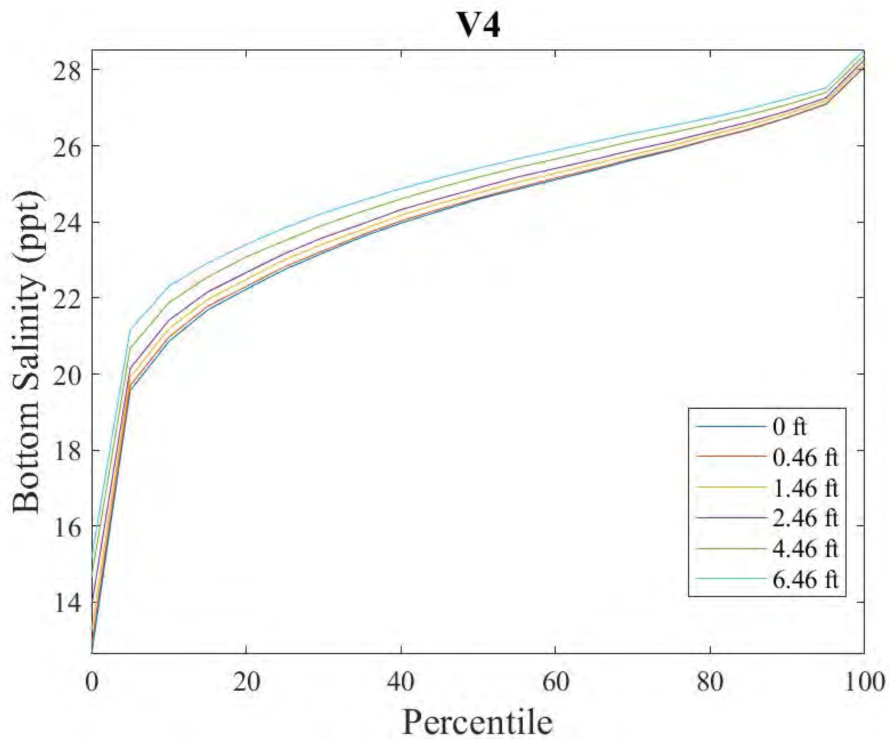


Figure 486. Alt 3a, V5 Salinity Variation with SLR.

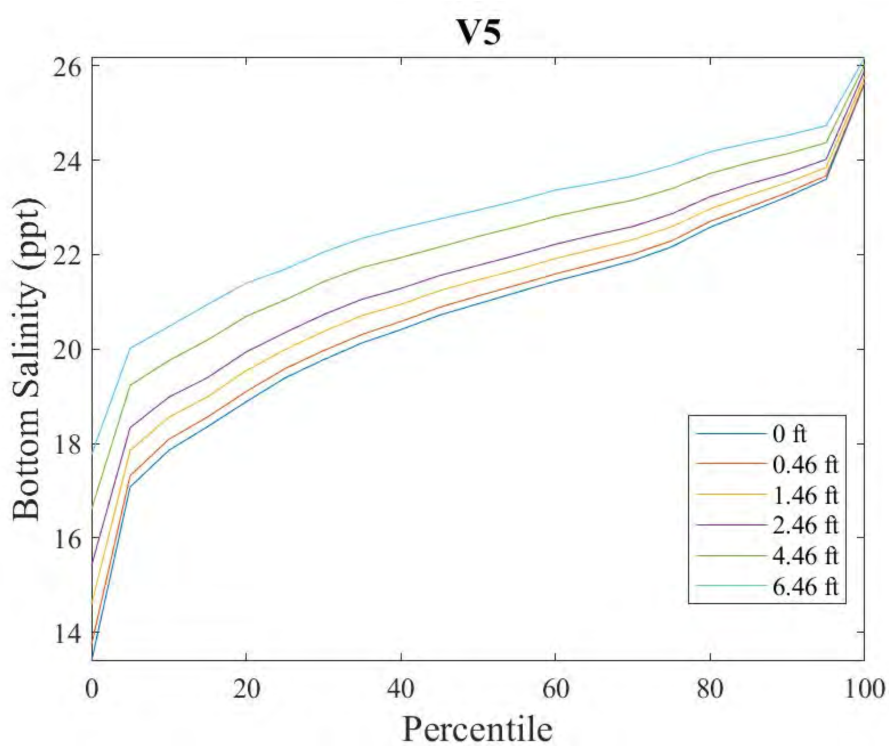


Figure 487. Alt 3a, V6 Salinity Variation with SLR.

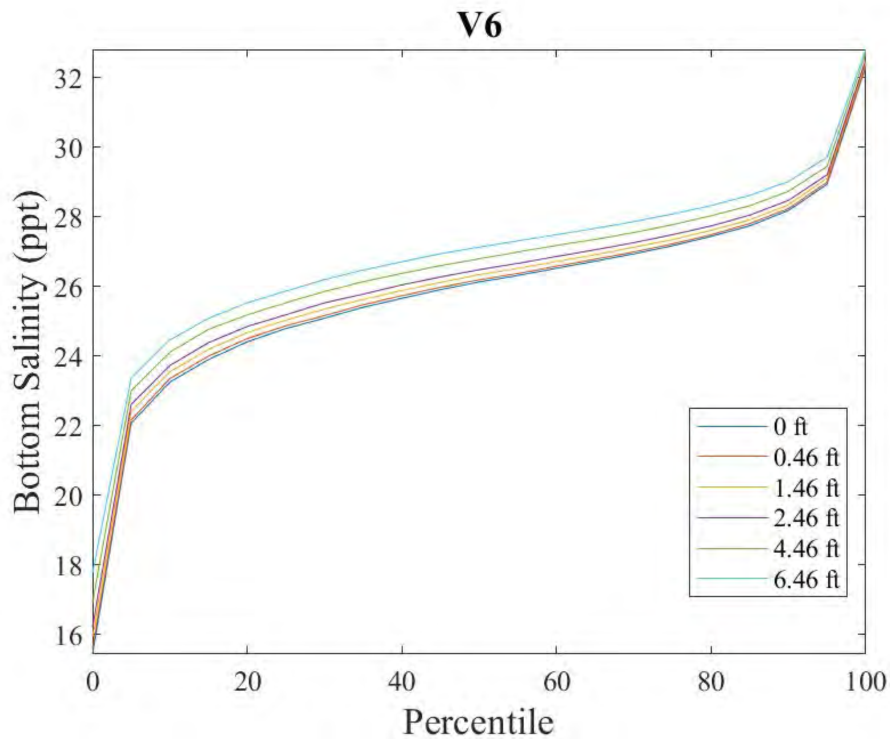


Figure 488. Alt 3a, S1 Salinity Variation with SLR.

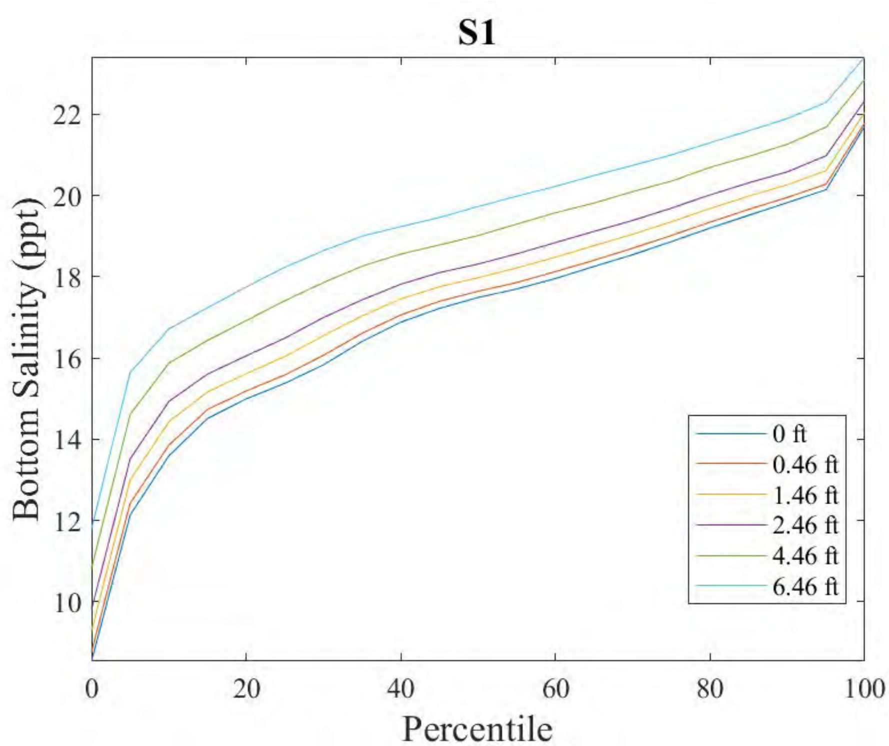


Figure 489. Alt 3a, S2 Salinity Variation with SLR.

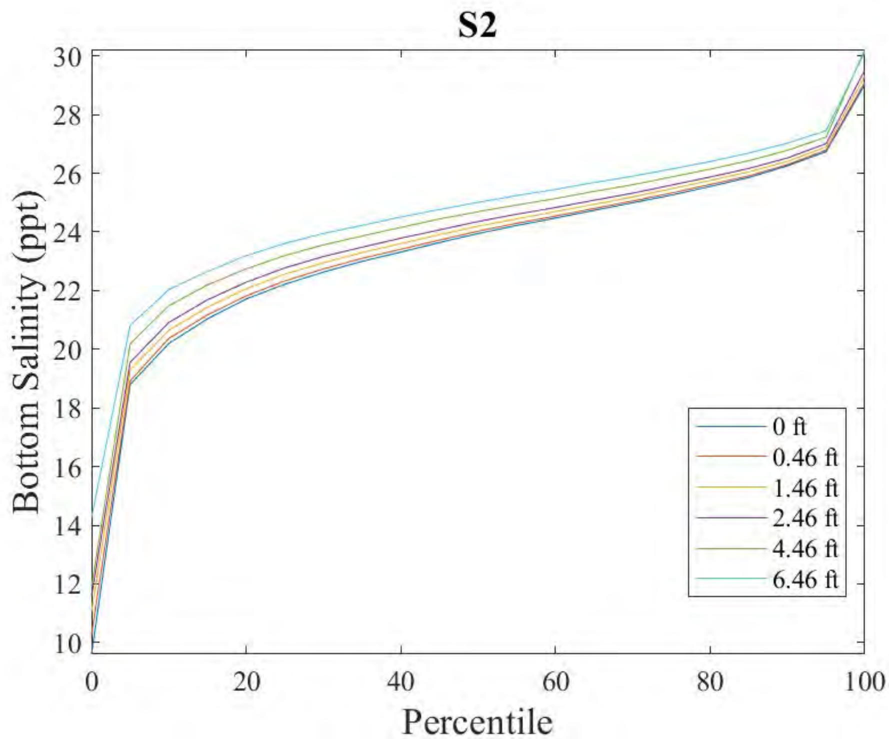


Figure 490. Alt 3a, S3 Salinity Variation with SLR.

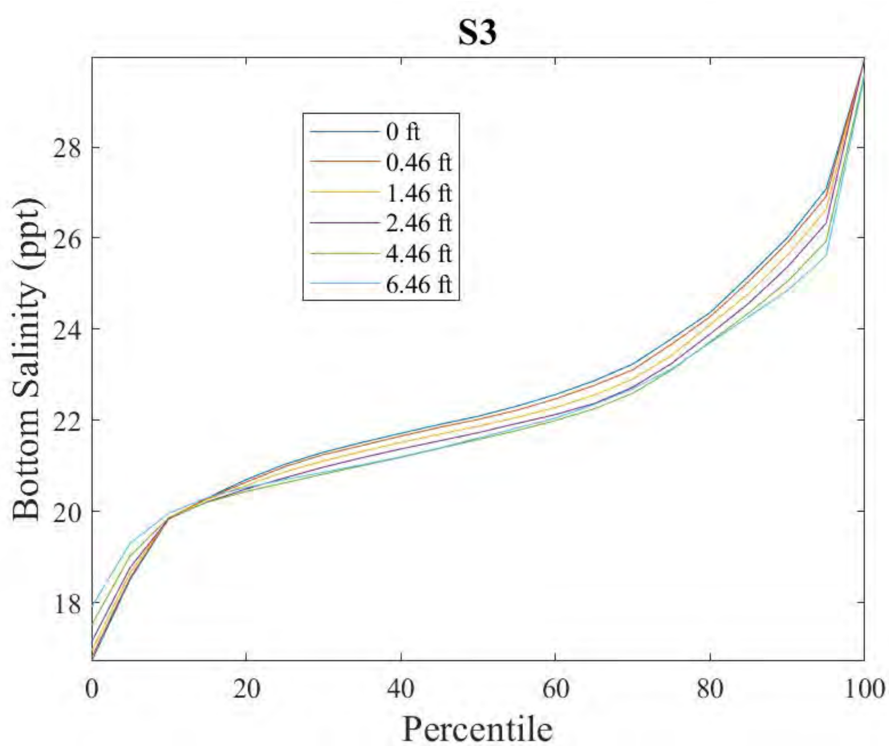


Figure 491. Alt 3a, S4 Salinity Variation with SLR.

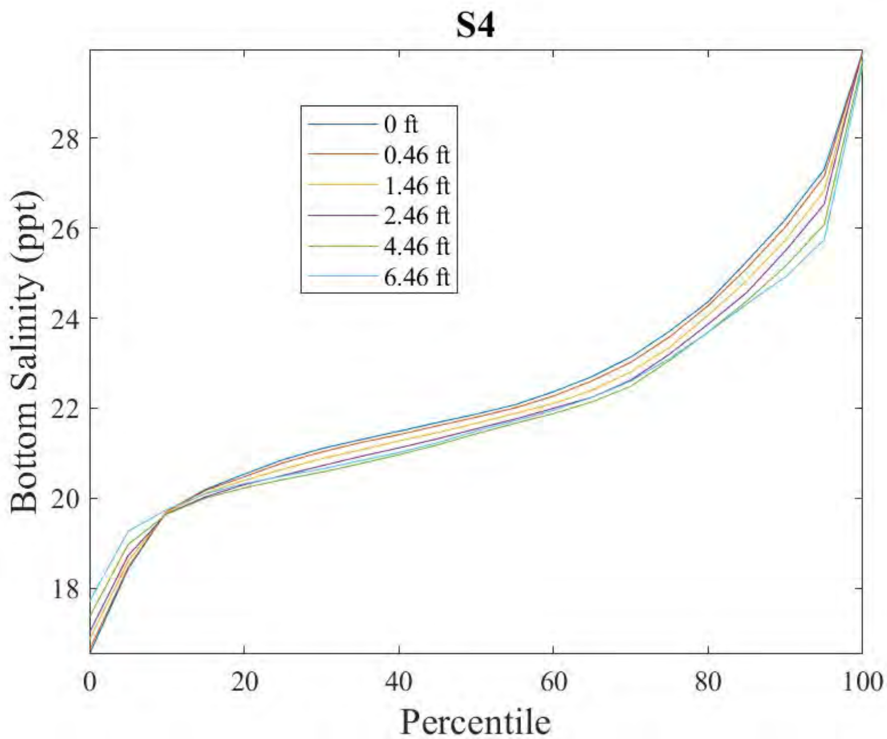


Figure 492. Alt 3a, S5 Salinity Variation with SLR.

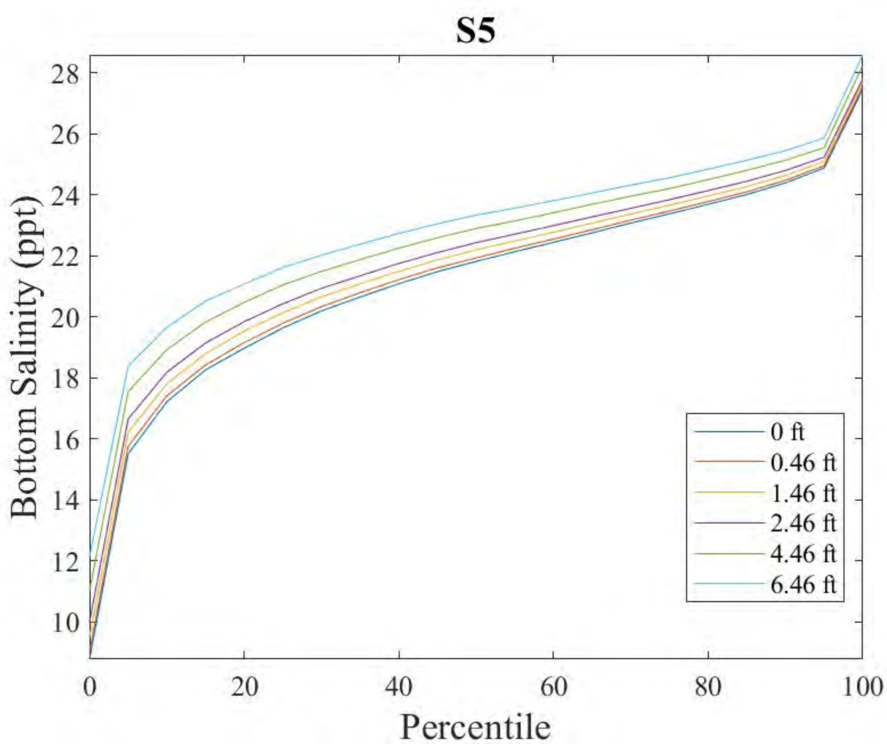


Figure 493. Alt 3a, T1 Salinity Variation with SLR.

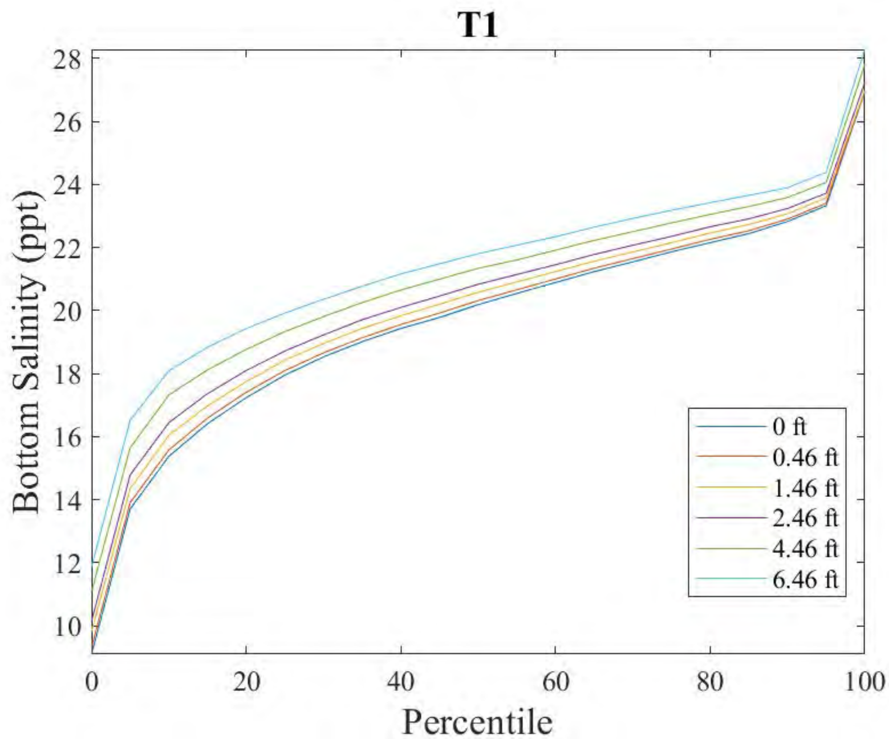


Figure 494. Alt 3a, T2 Salinity Variation with SLR.

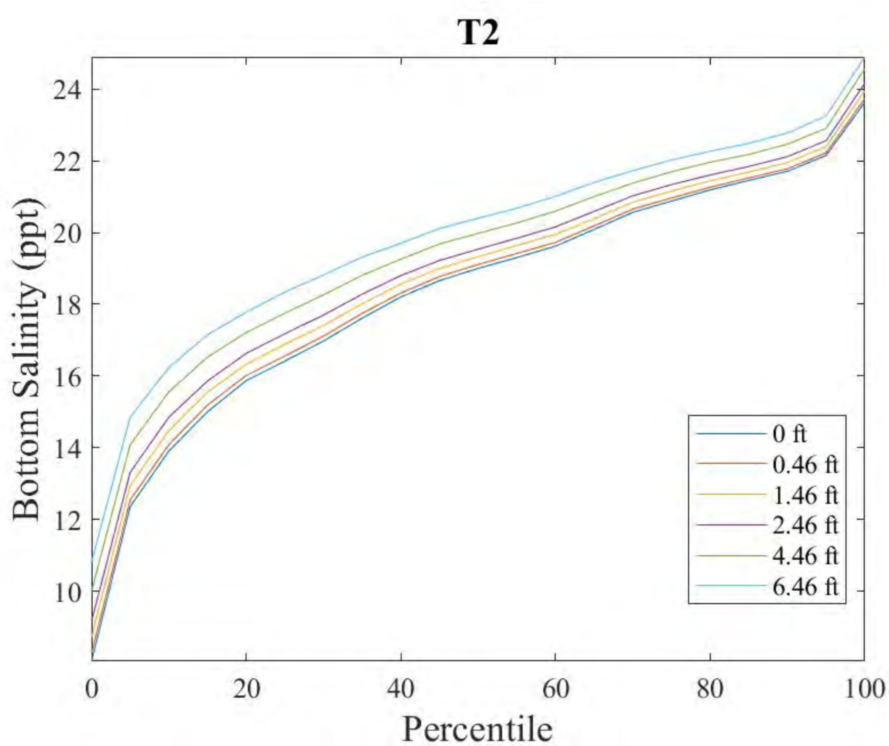


Figure 495. Alt 3a, T3 Salinity Variation with SLR.

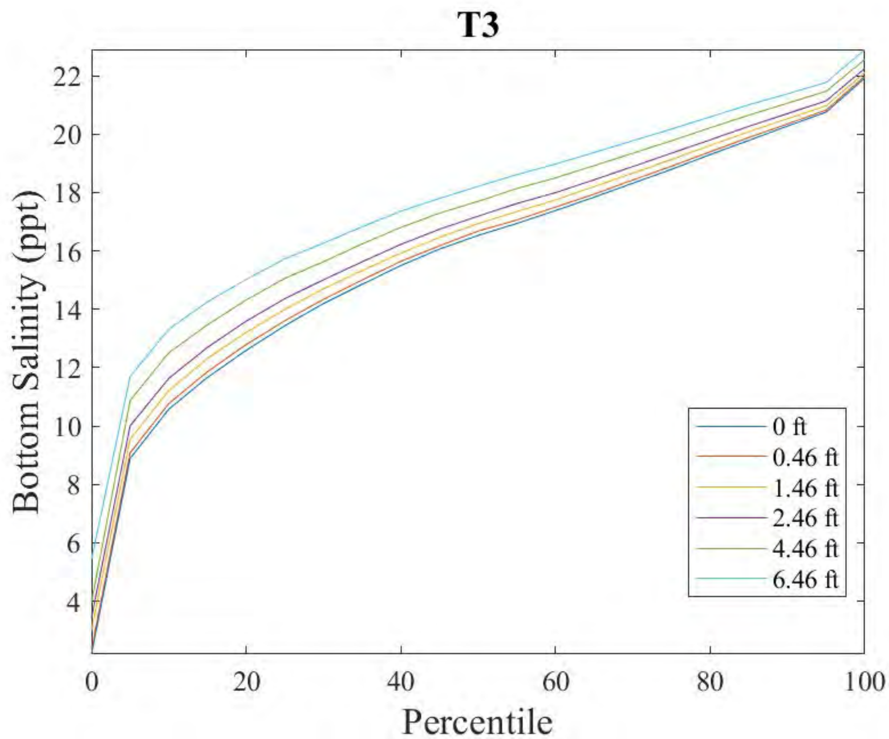


Figure 496. Alt 3a, T4 Salinity Variation with SLR.

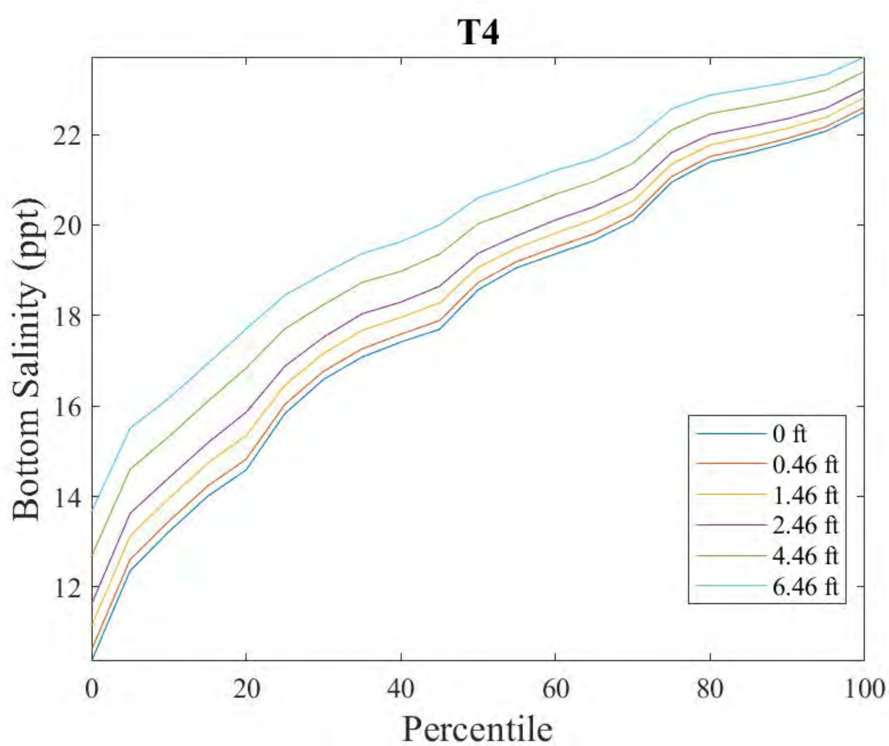


Figure 497. Alt 3a, T5 Salinity Variation with SLR.

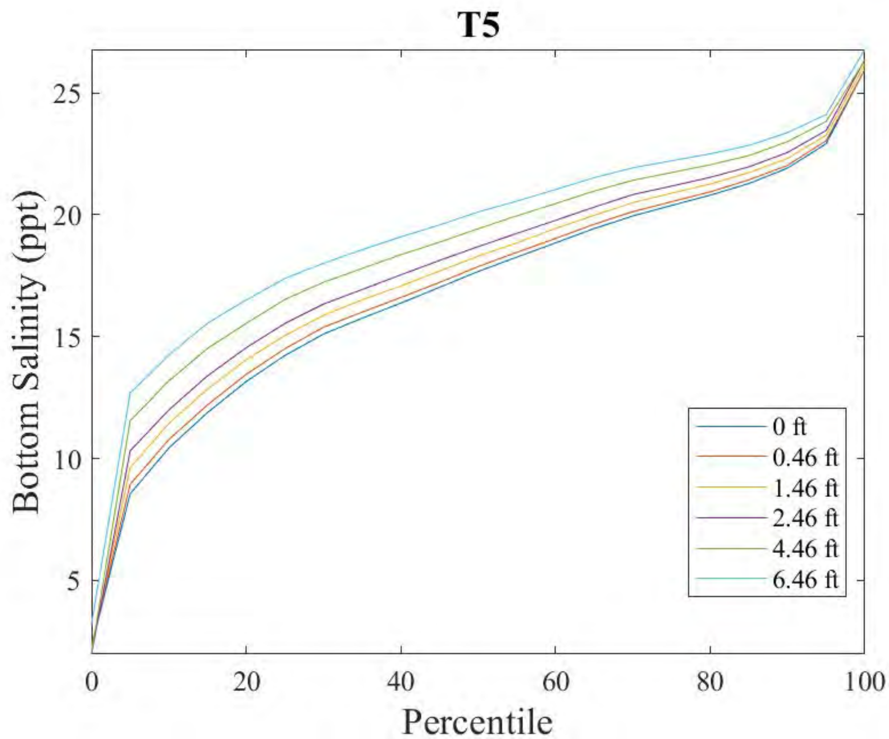


Figure 498. Alt 3a, R1 Salinity Variation with SLR.

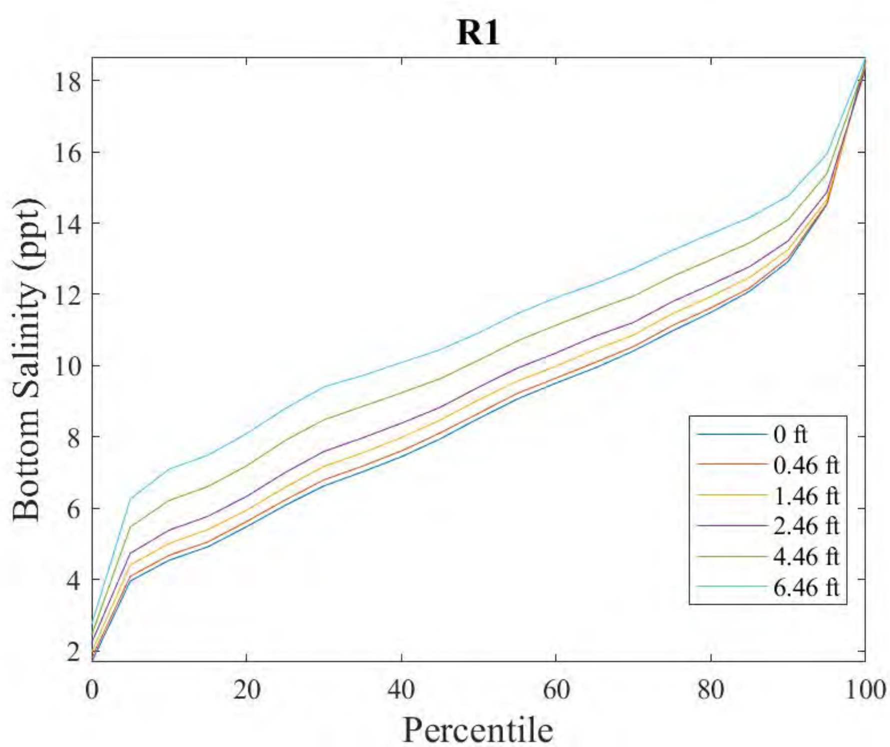


Figure 499. Alt 3a, Sandy Hook Salinity Variation with SLR.

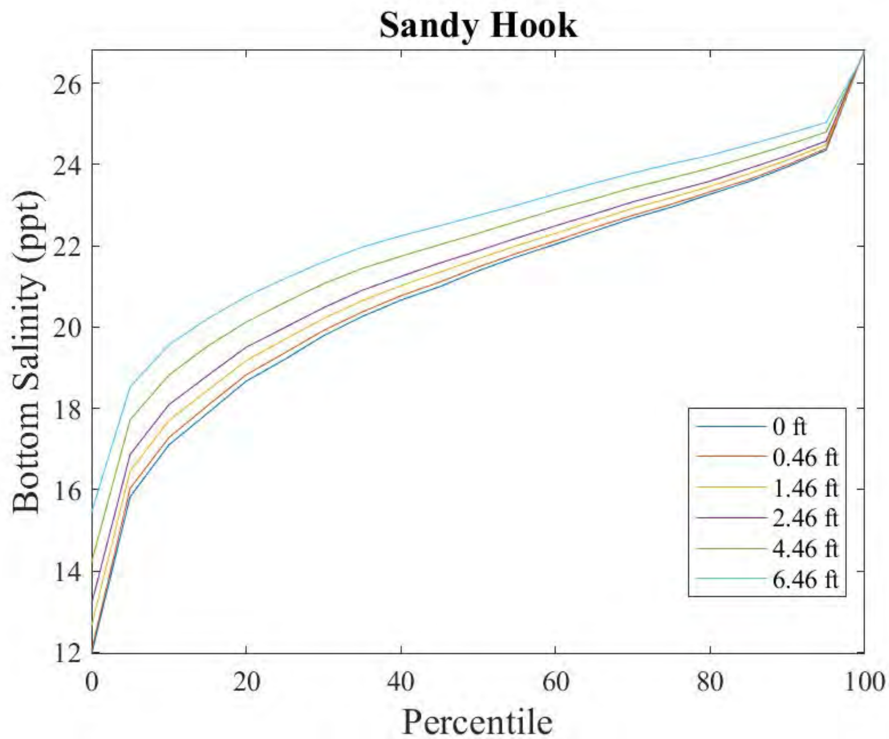


Figure 500. Alt 3a, Fresh Kills Salinity Variation with SLR.

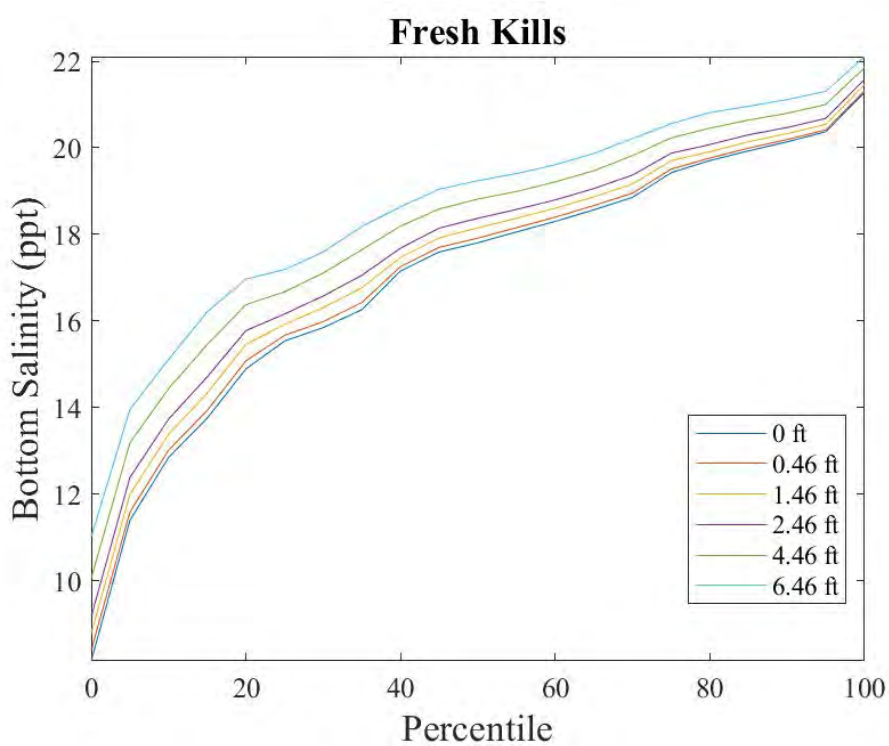


Figure 501. Alt 3a, Mariners Harbor Salinity Variation with SLR.

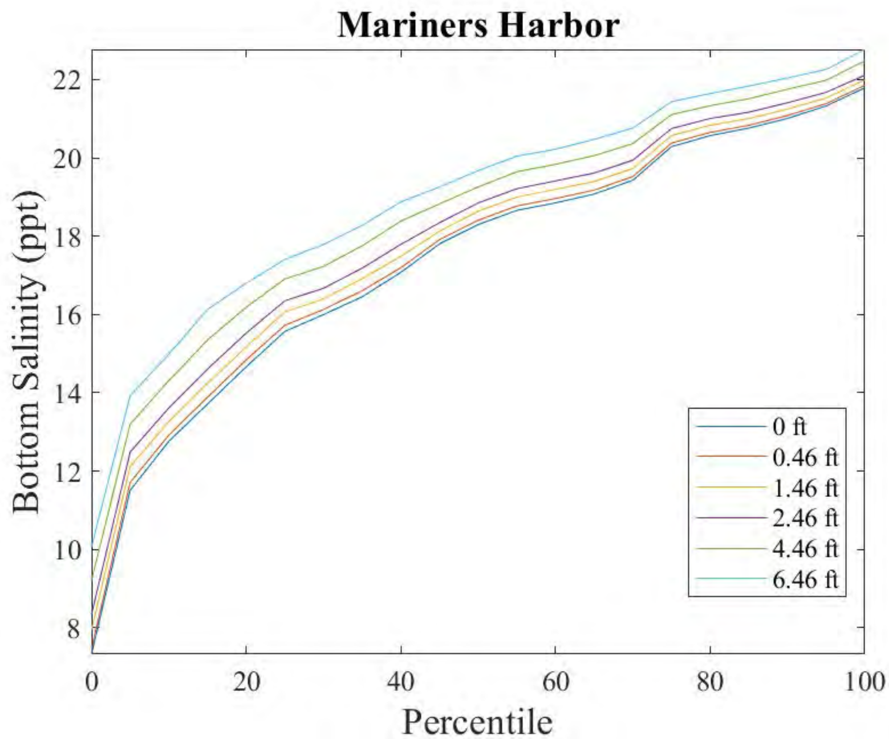


Figure 502. Alt 3a, North Reach Salinity Variation with SLR.

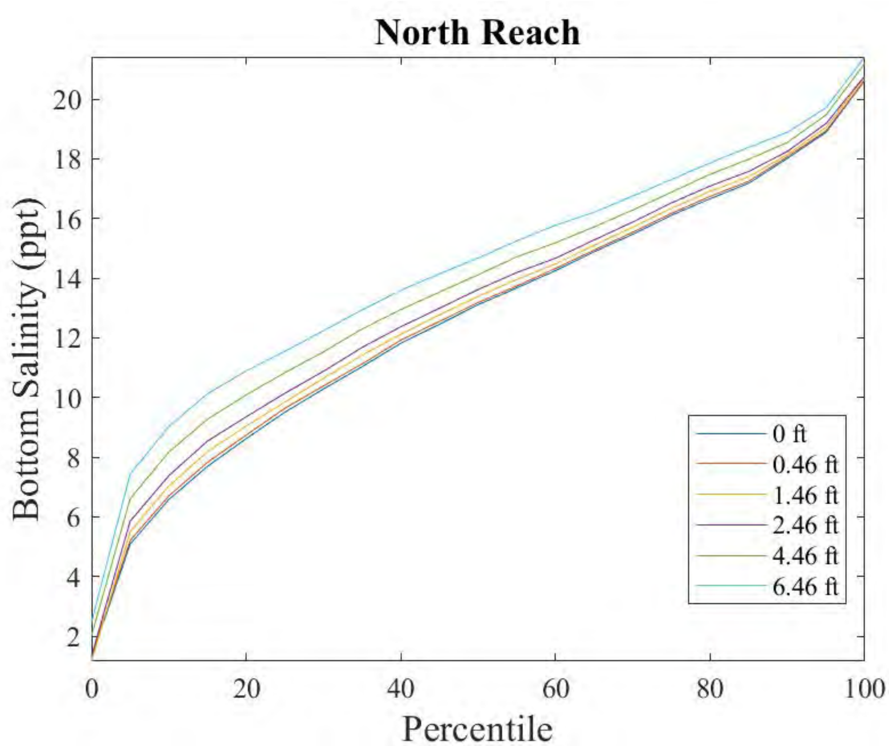


Figure 503. Alt 3a, Hackensack River Salinity Variation with SLR.

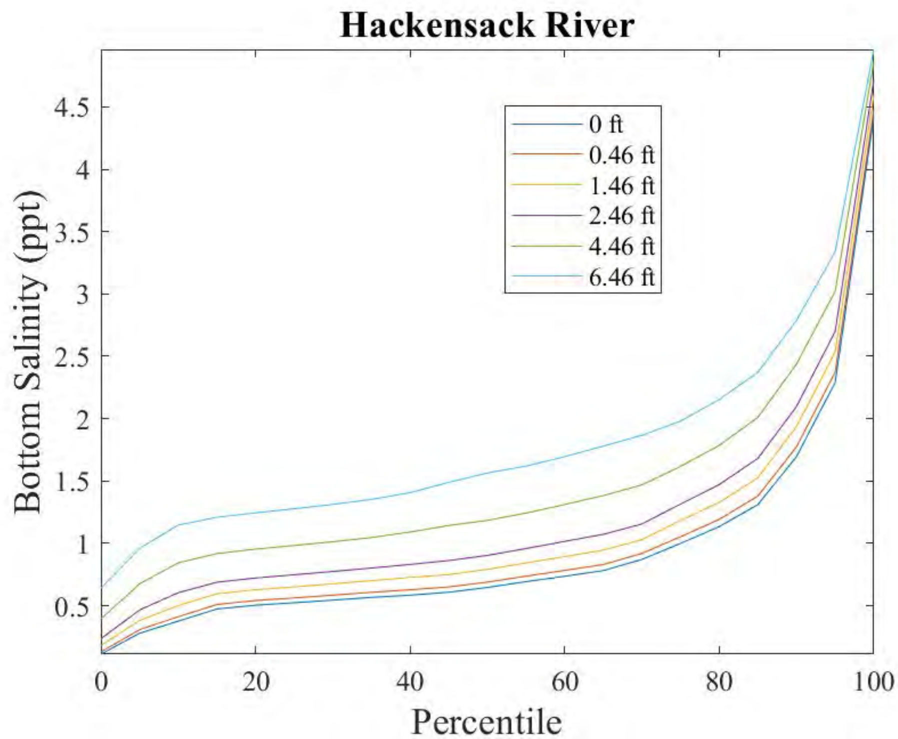


Figure 504. Alt 3a, Robbins Reef Salinity Variation with SLR.

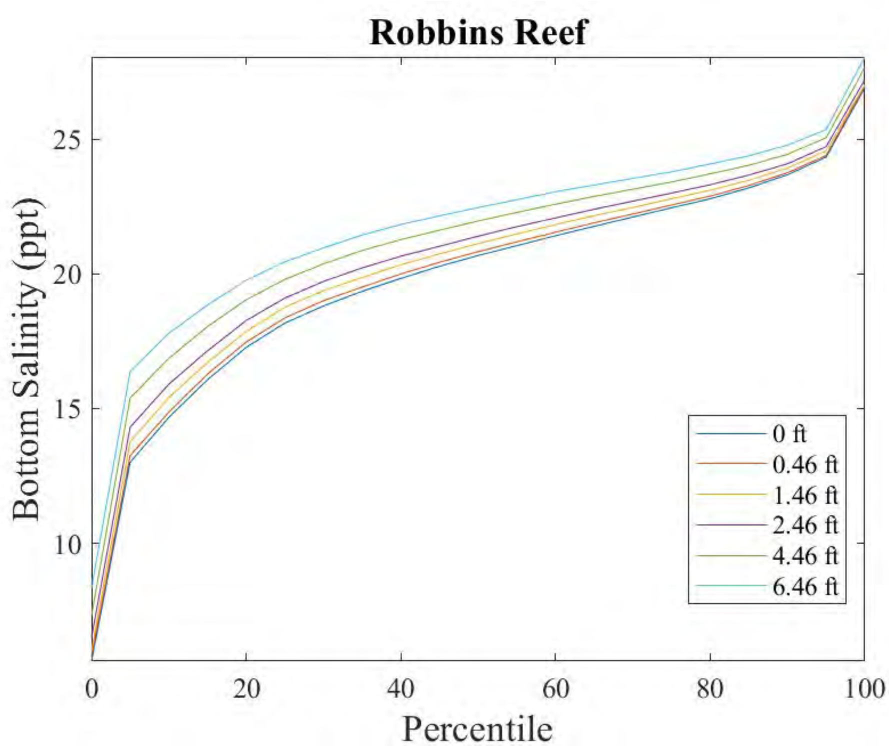


Figure 505. Alt 3a, The Battery Salinity Variation with SLR.

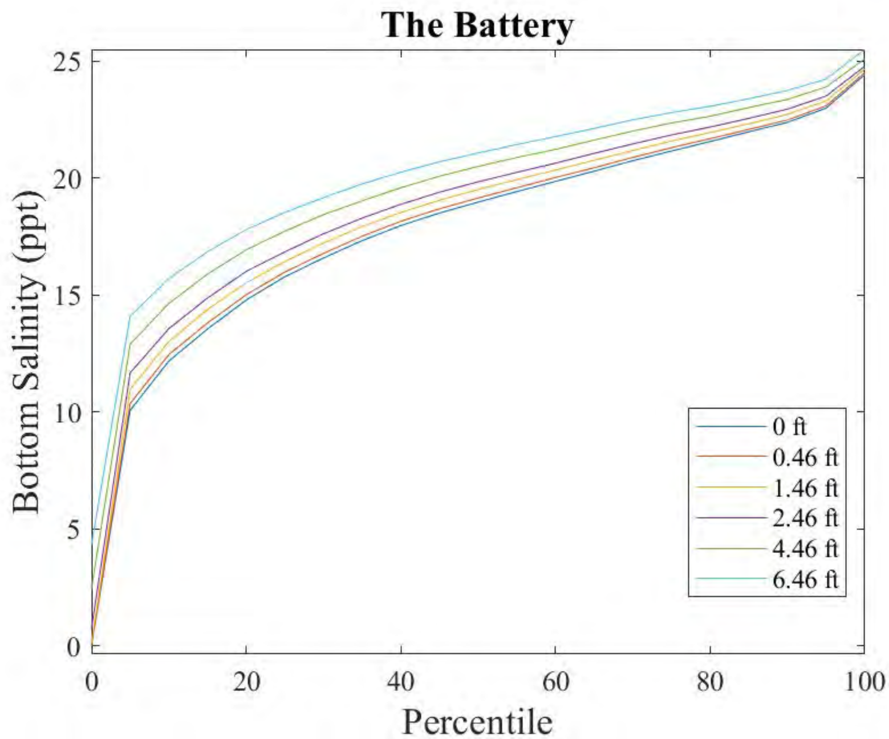


Figure 506. Alt 3a, Manhattan Salinity Variation with SLR.

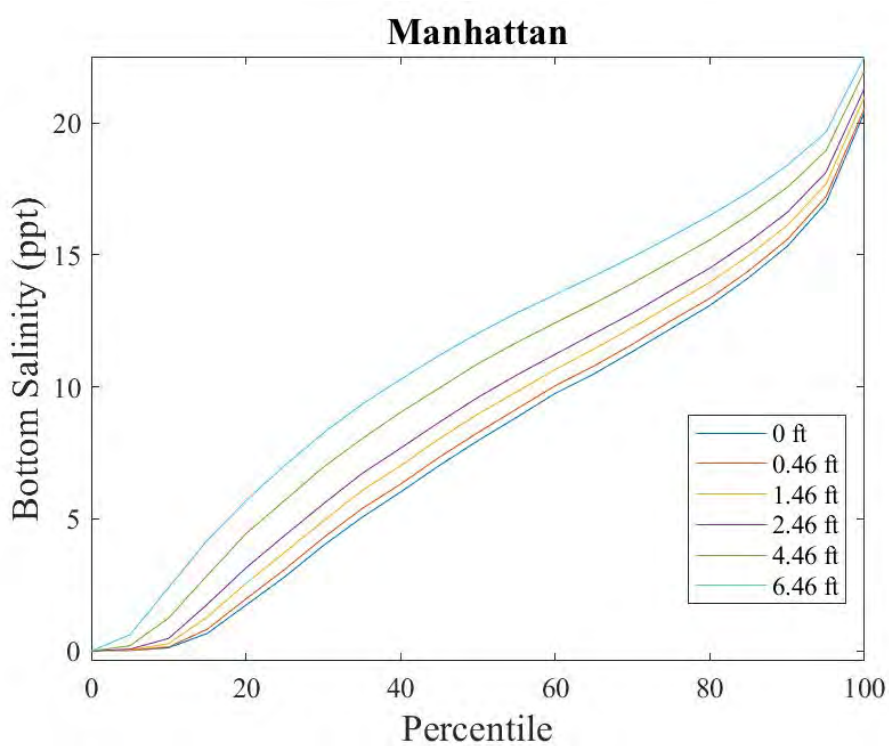


Figure 507. Alt 3a, Hudson River Haverstraw Bay Salinity Variation with SLR.

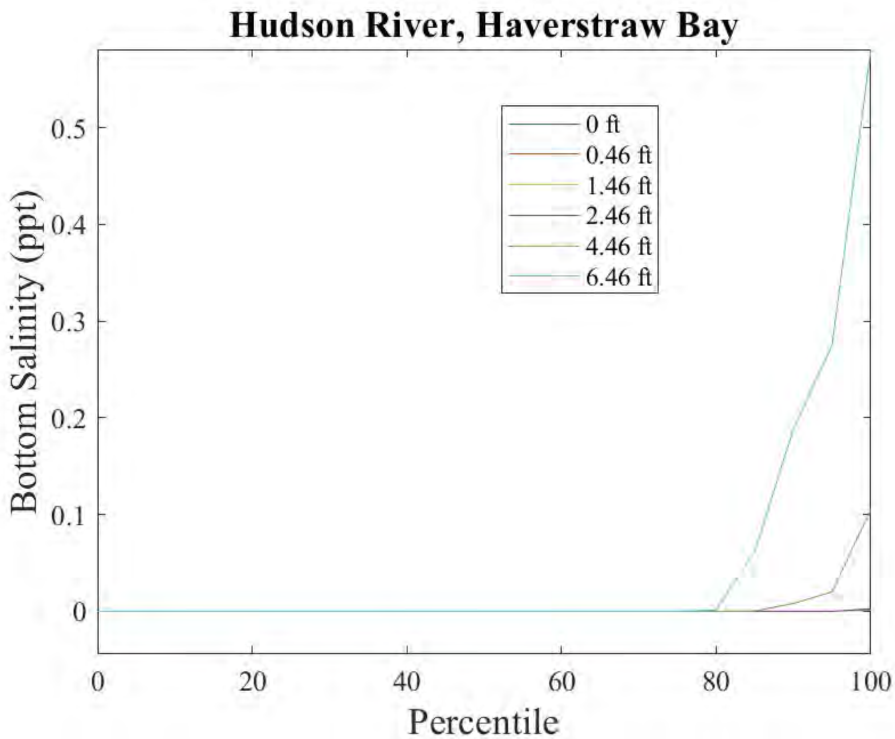


Figure 508. Alt 3a, KLGA Salinity Variation with SLR.

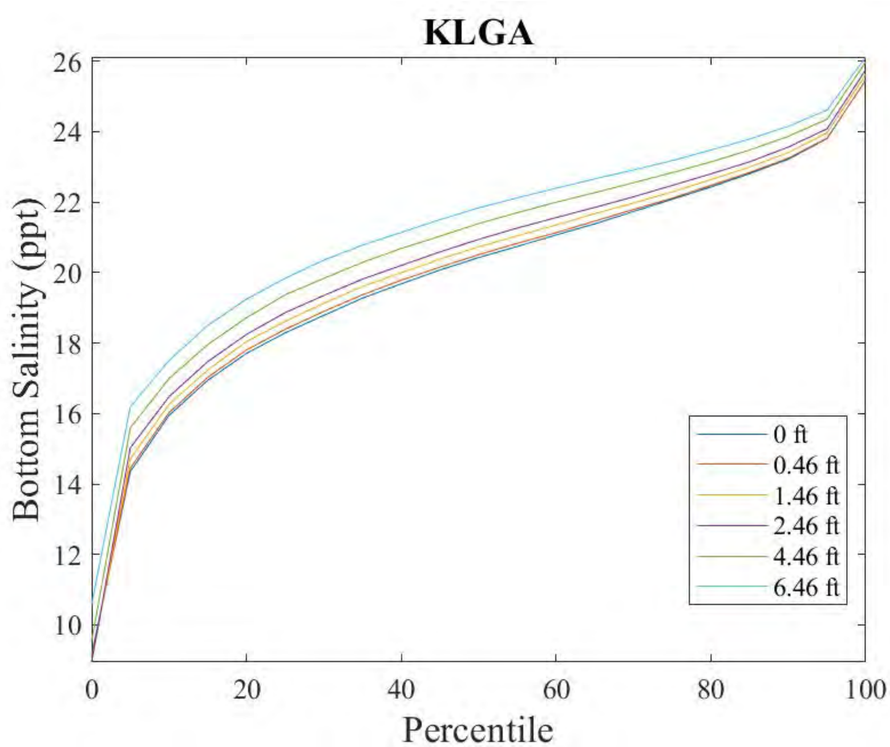


Figure 509. Alt 3a, LIS near Stepping Stone Lighthouse Salinity Variation with SLR.

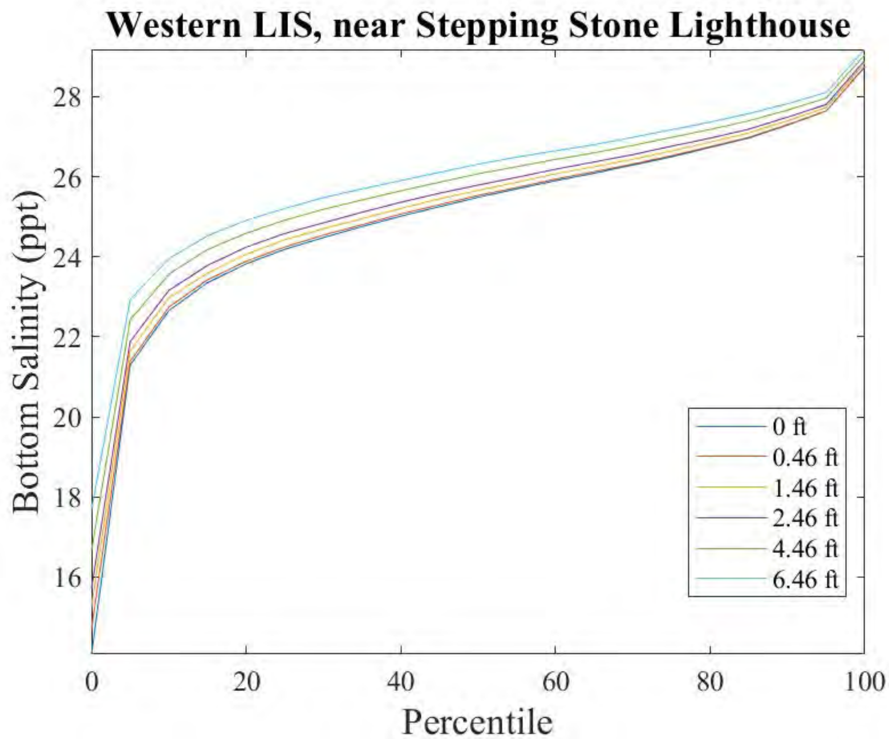


Figure 510. Alt 3a, LIS near Execution Rock Lighthouse Salinity Variation with SLR.

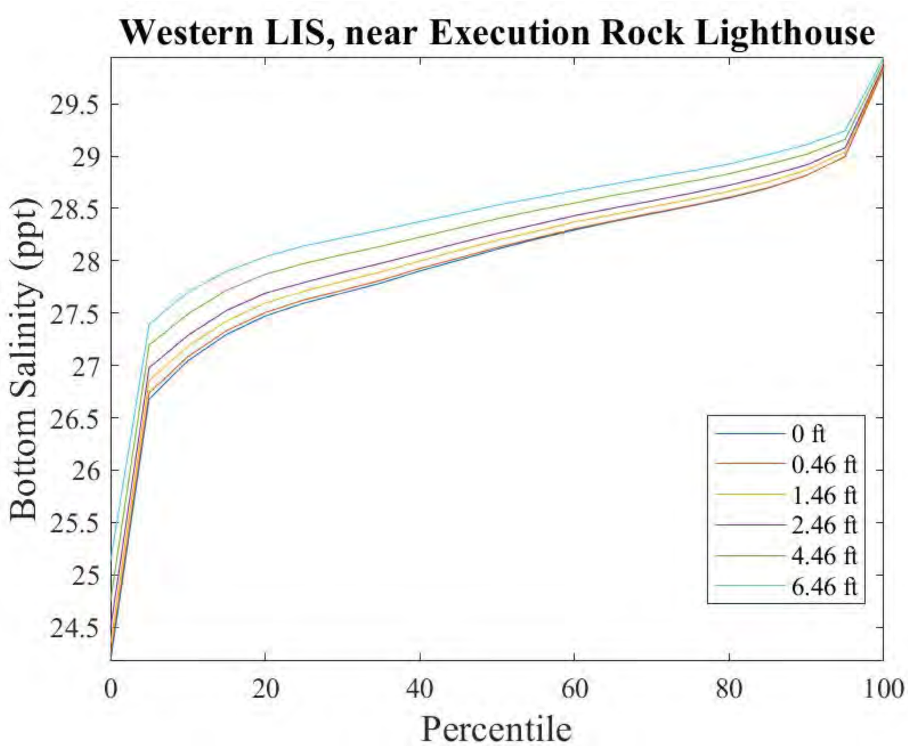


Figure 511. Alt 3a, LIS south of NY/CT border Salinity Variation with SLR.

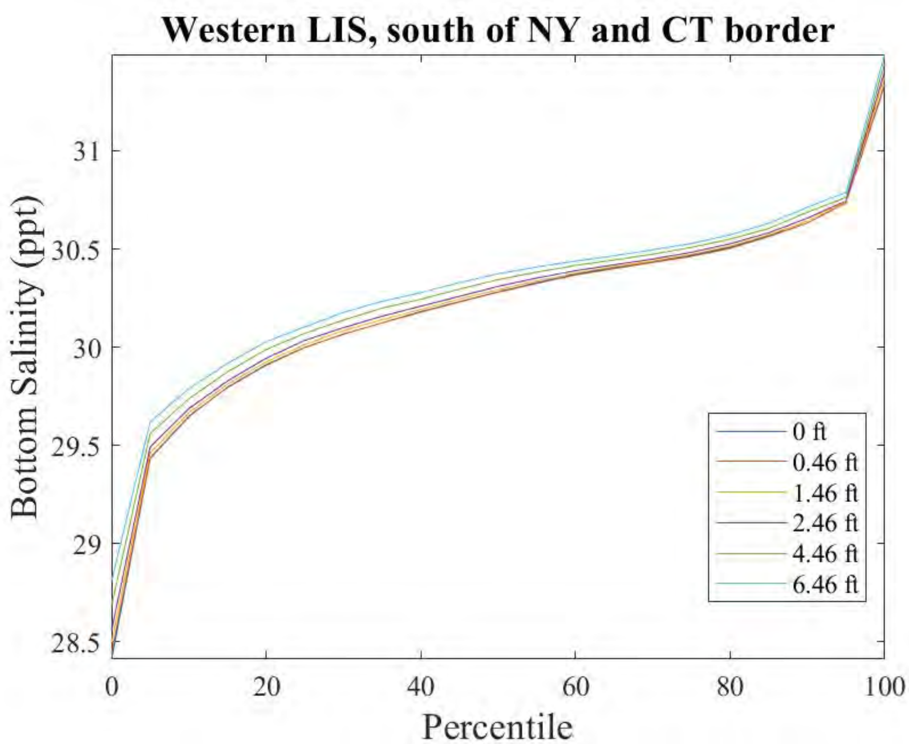


Figure 512. Alt 3a, Jamaica Bay Salinity Variation with SLR.

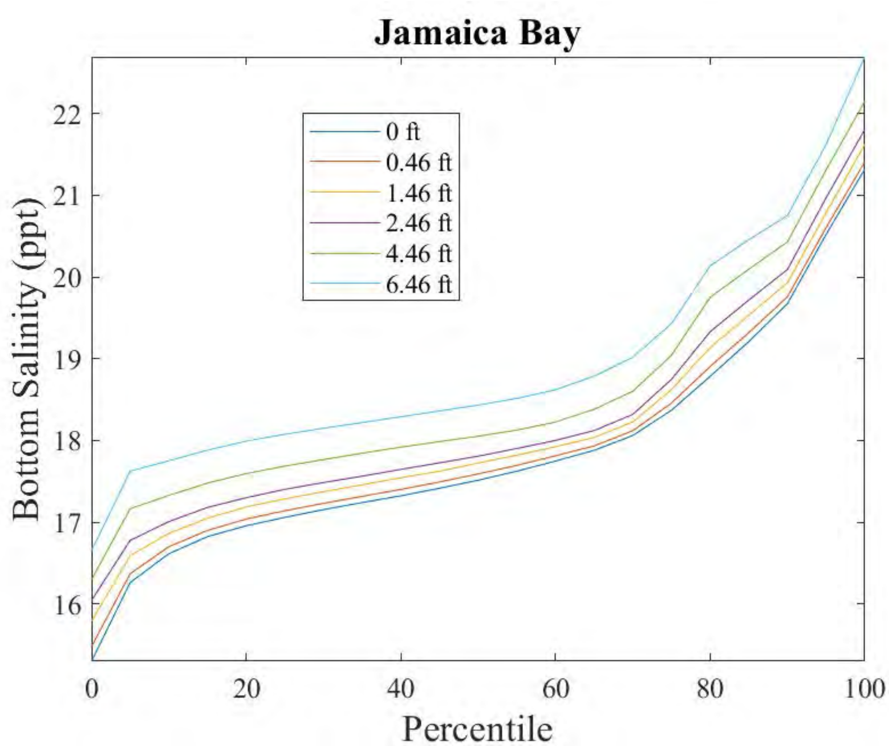


Figure 513. Alt 3a, Jamaica Bay near Spring Creek Salinity Variation with SLR.

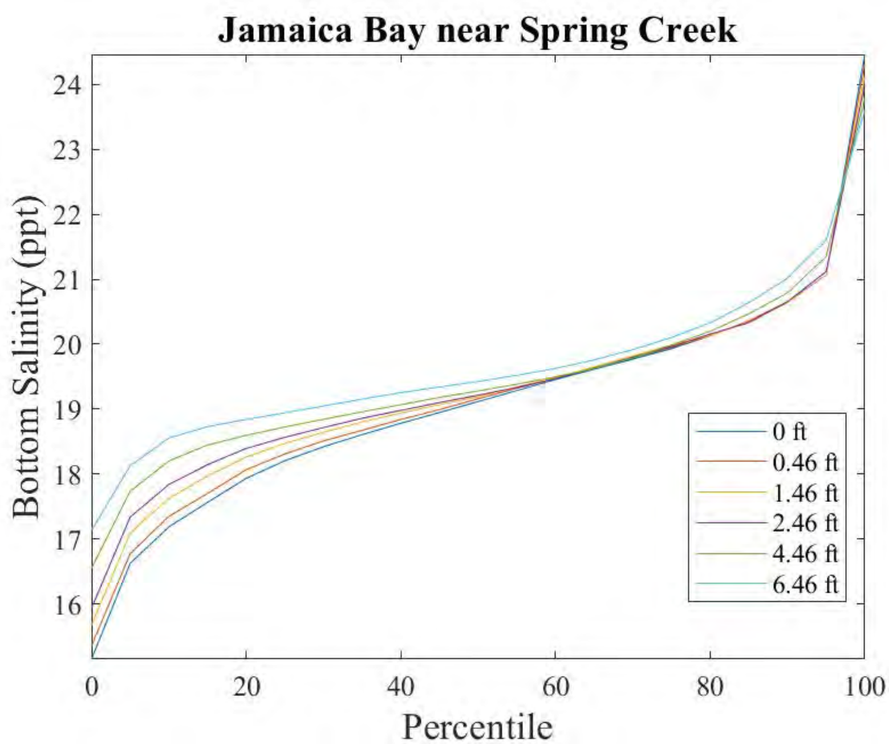
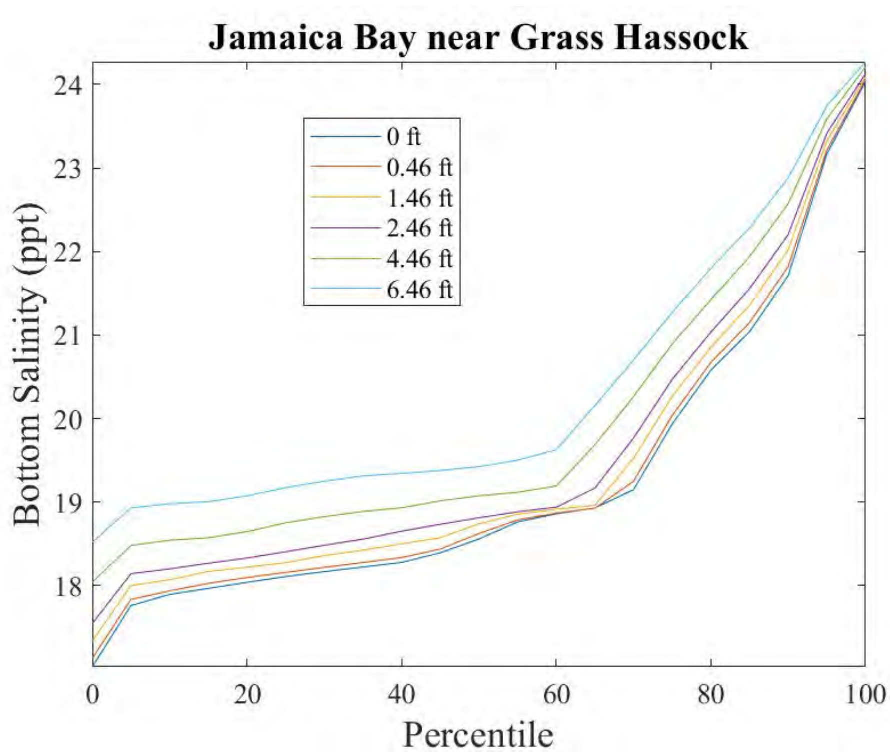


Figure 514. Alt 3a, Jamaica Bay near Grass Hassock Salinity Variation with SLR.



15.3.4 Spatial Velocity Percentiles

Spatial figures of the velocity magnitude percentiles for Alternative 3a for the 50th and 75th percentiles are provided in Figure 515 to Figure 526.

Figure 515. Alternative 3a/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

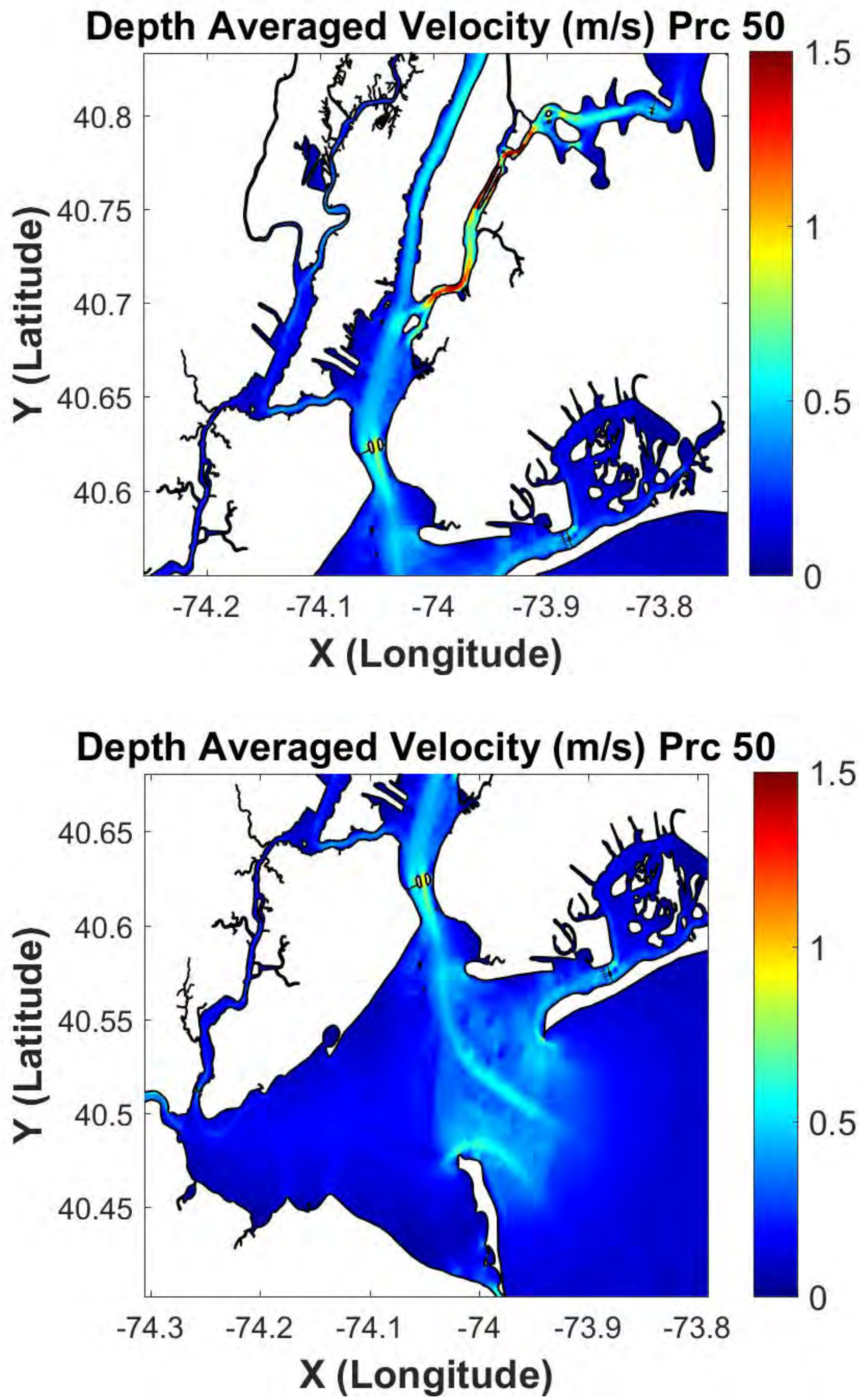


Figure 516. Alternative 3a/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

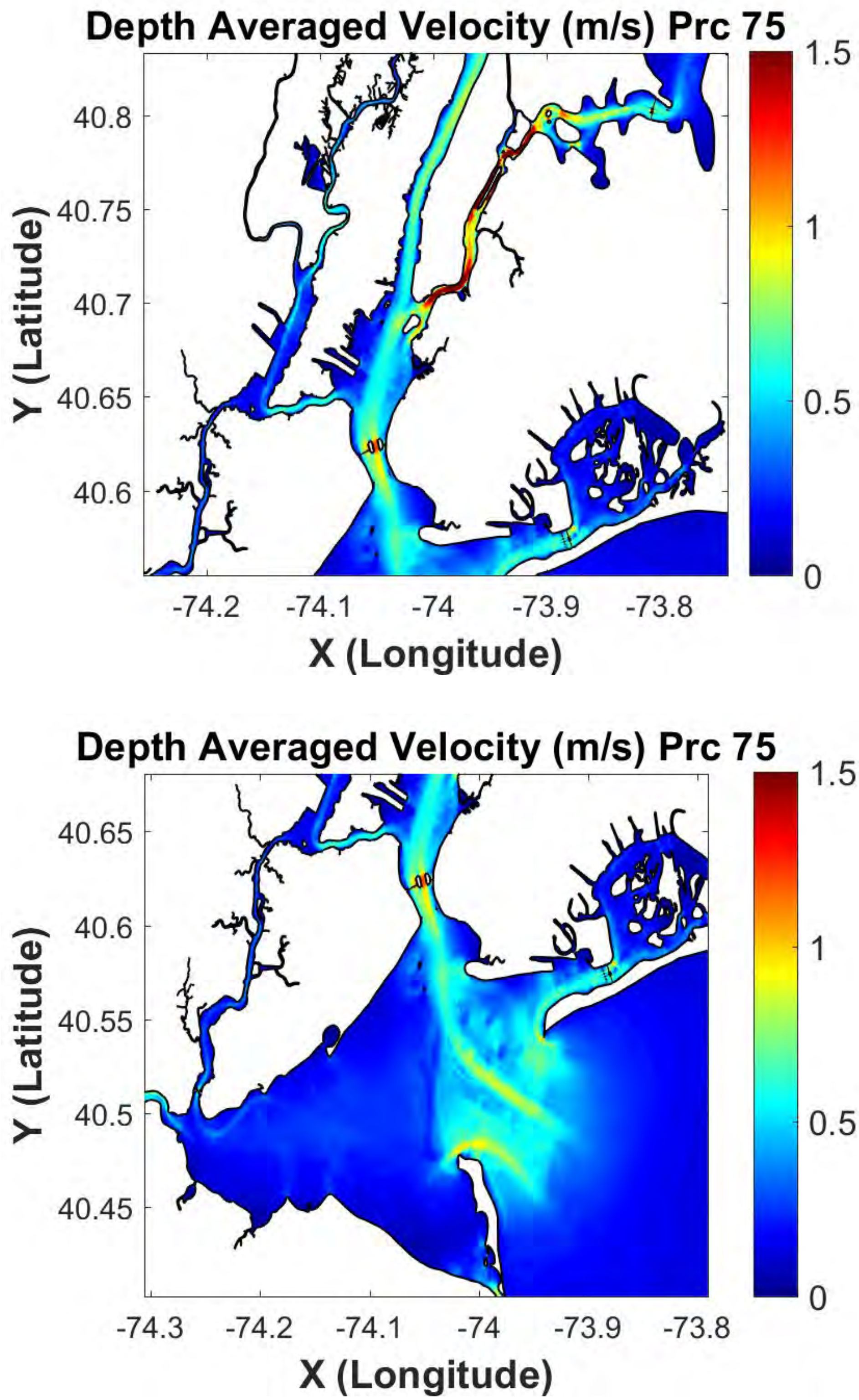


Figure 517. Alternative 3a/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

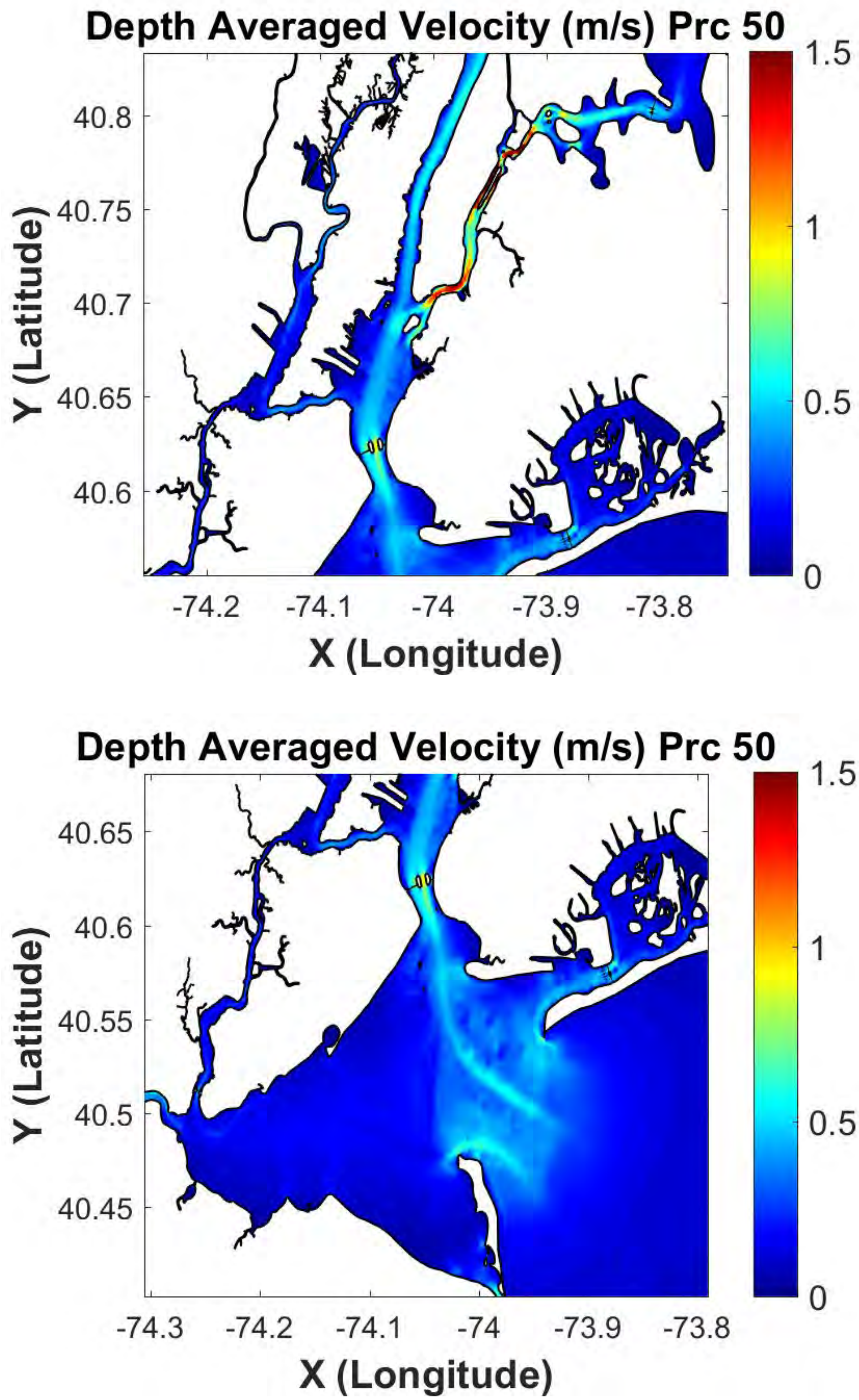


Figure 518. Alternative 3a/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

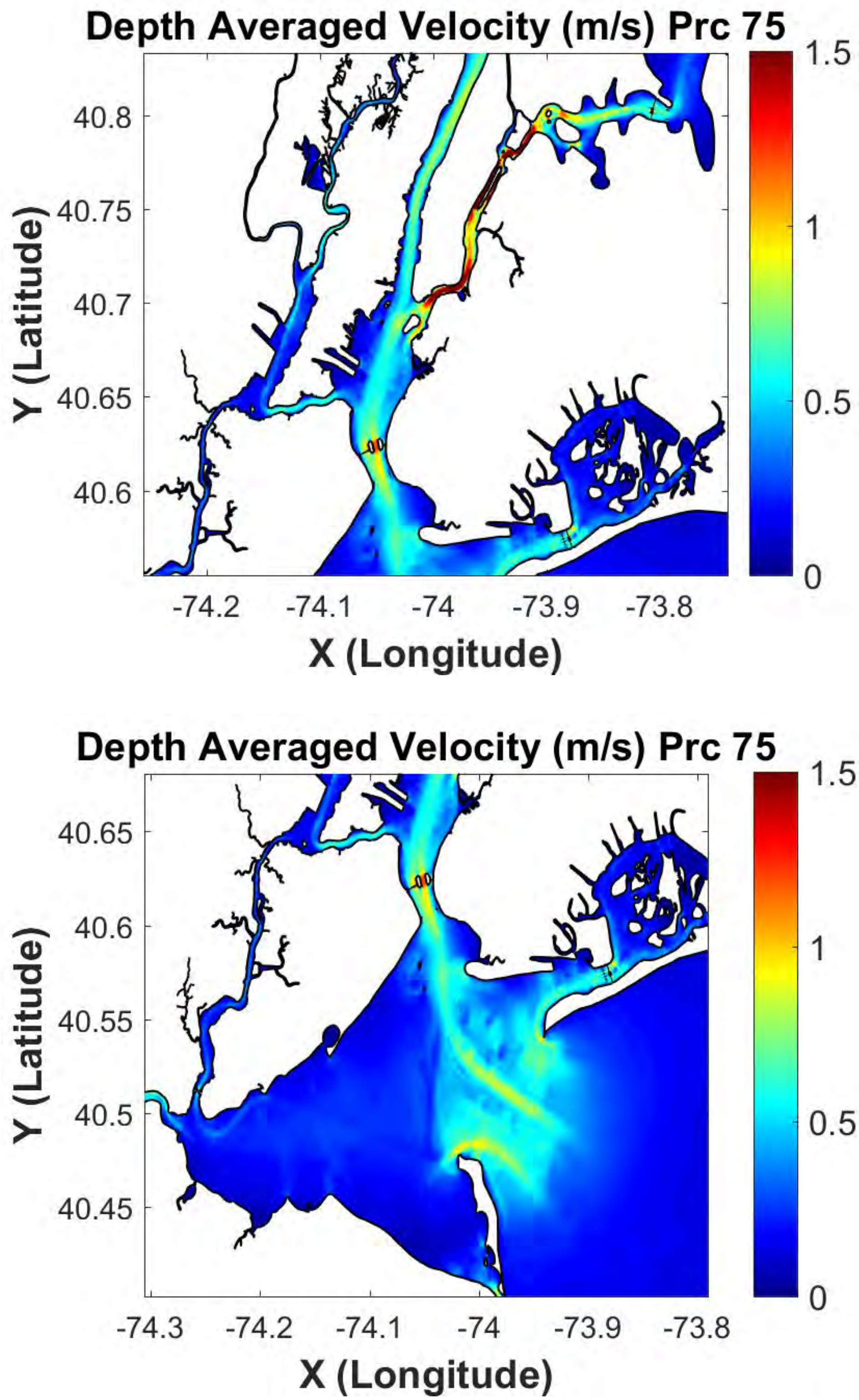


Figure 519. Alternative 3a/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

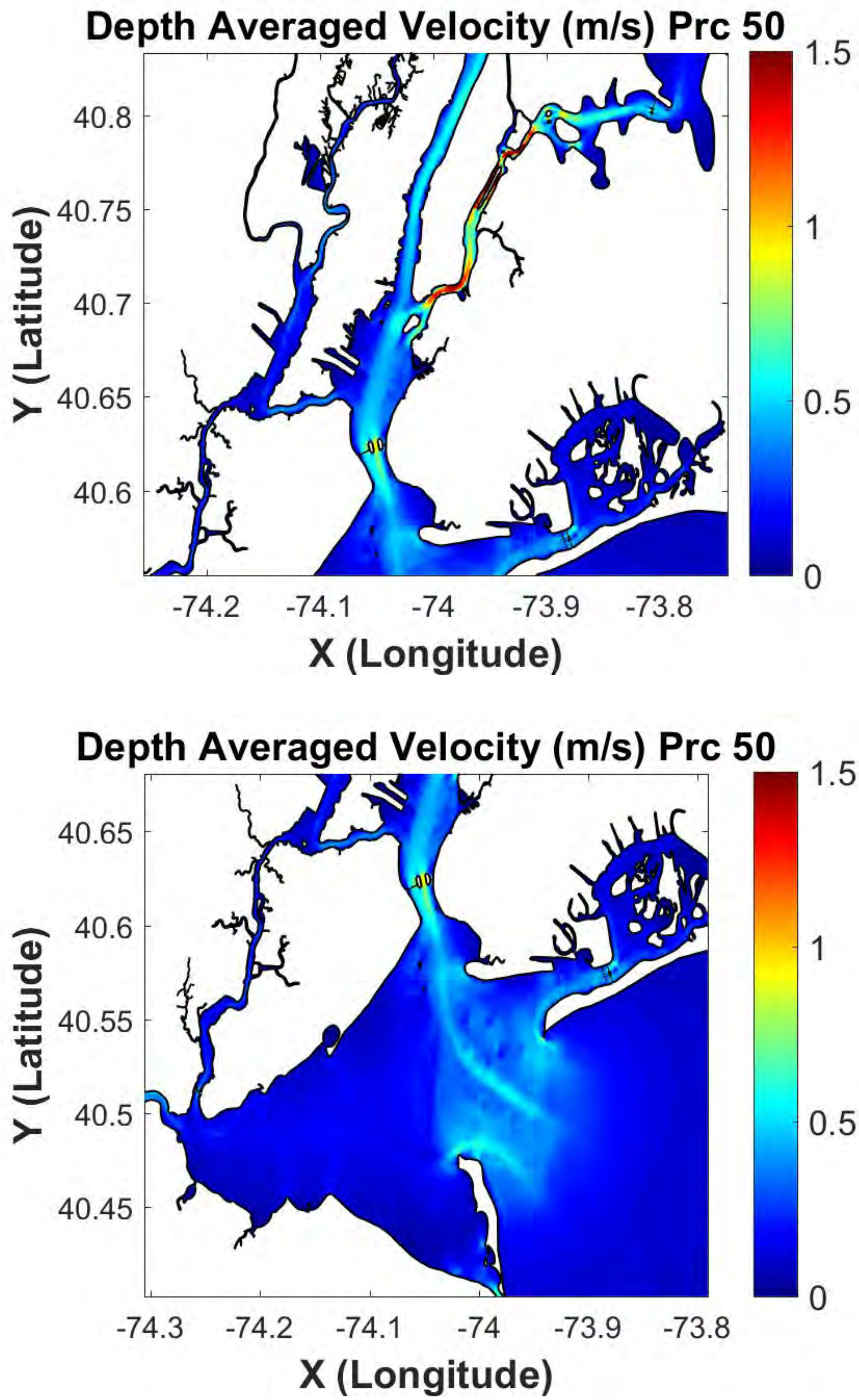


Figure 520. Alternative 3a/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

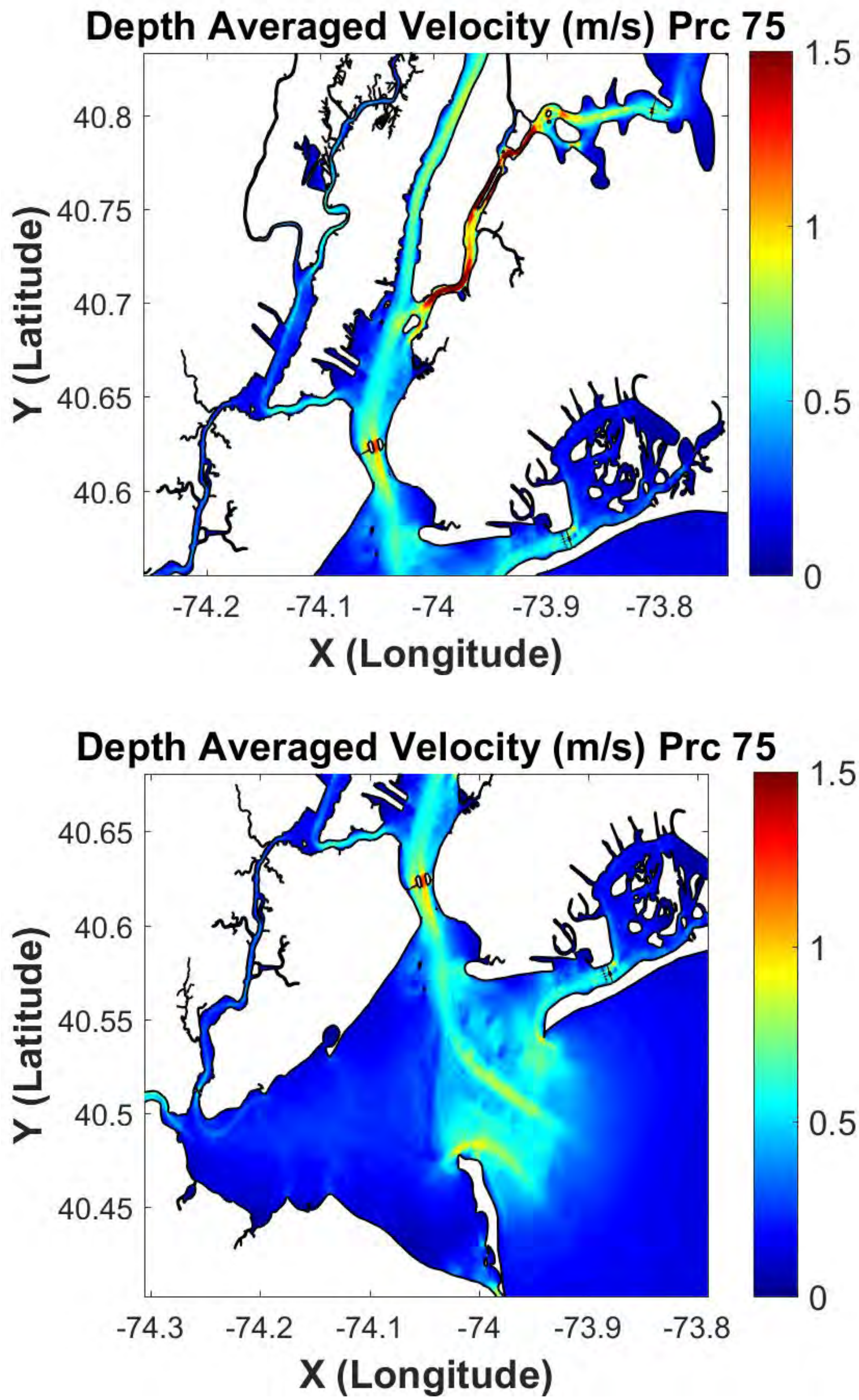
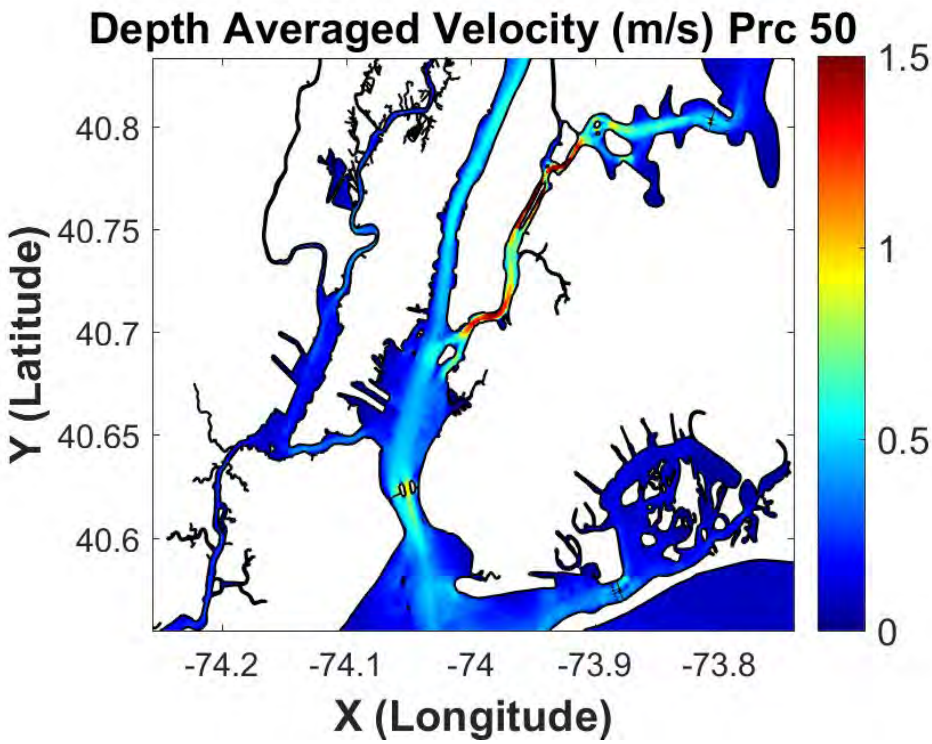


Figure 521. Alternative 3a/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



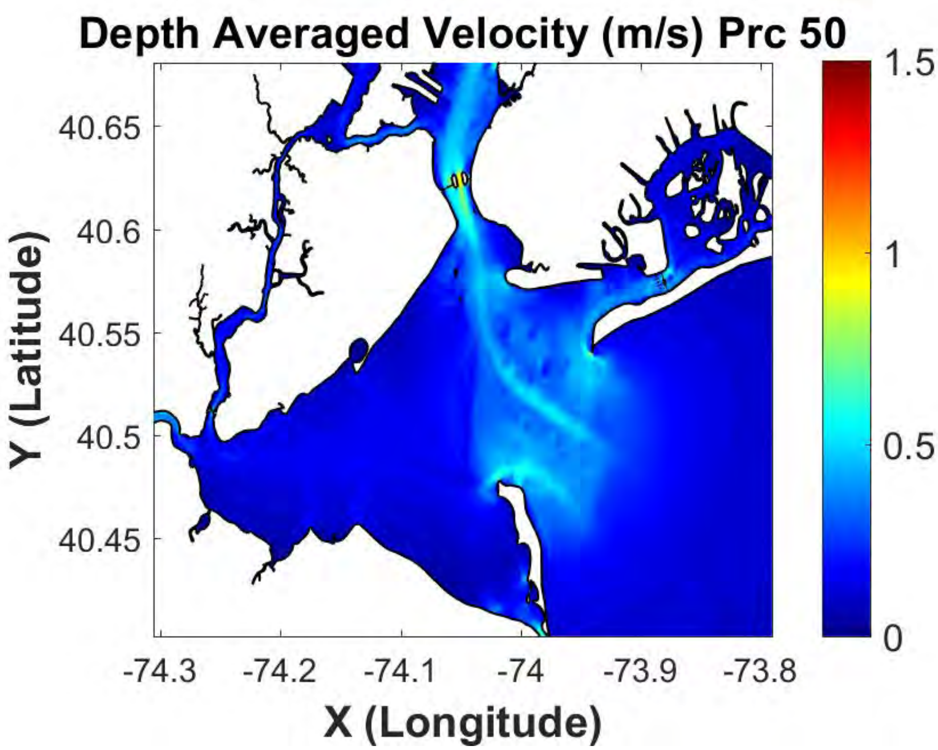


Figure 522. Alternative 3a/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

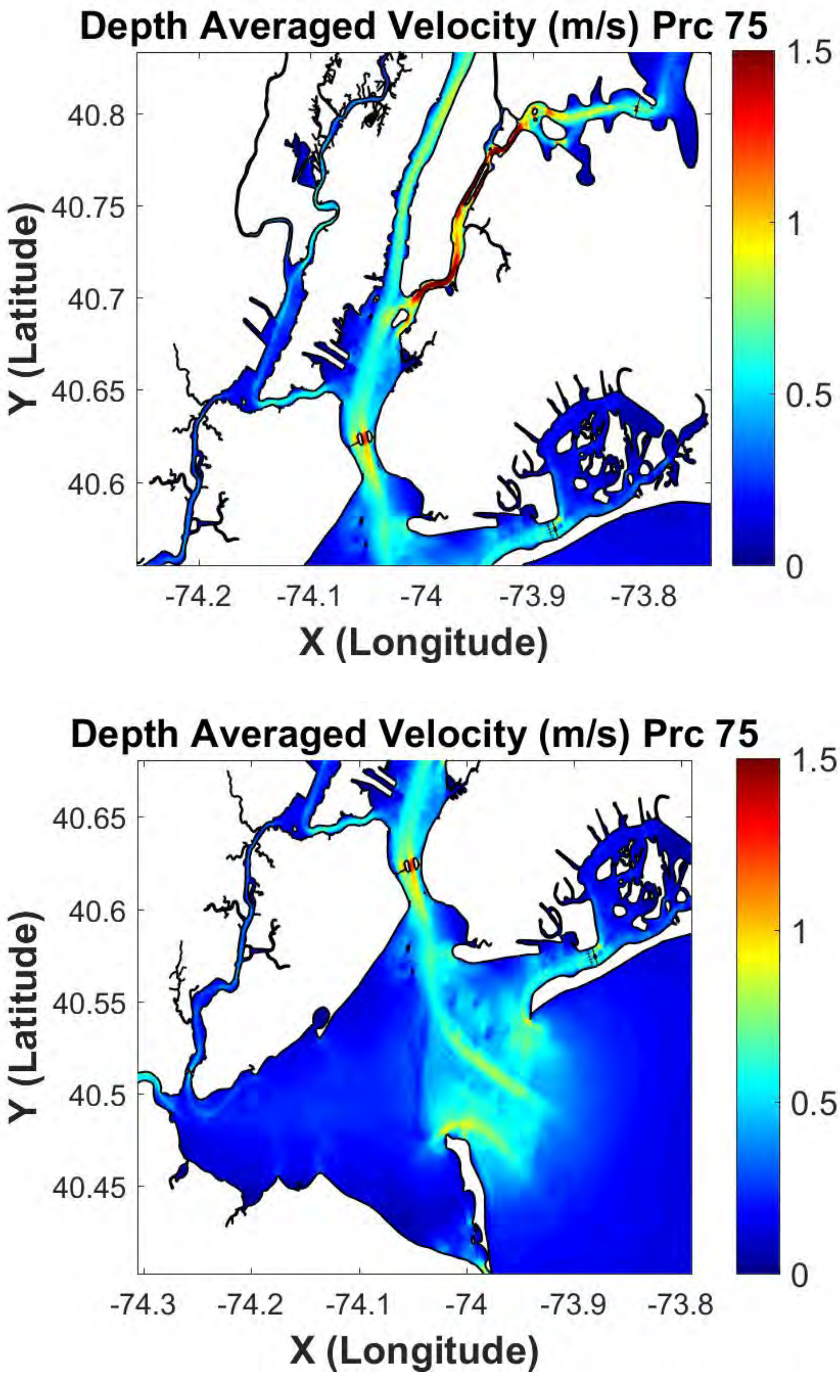


Figure 523. Alternative 3a/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

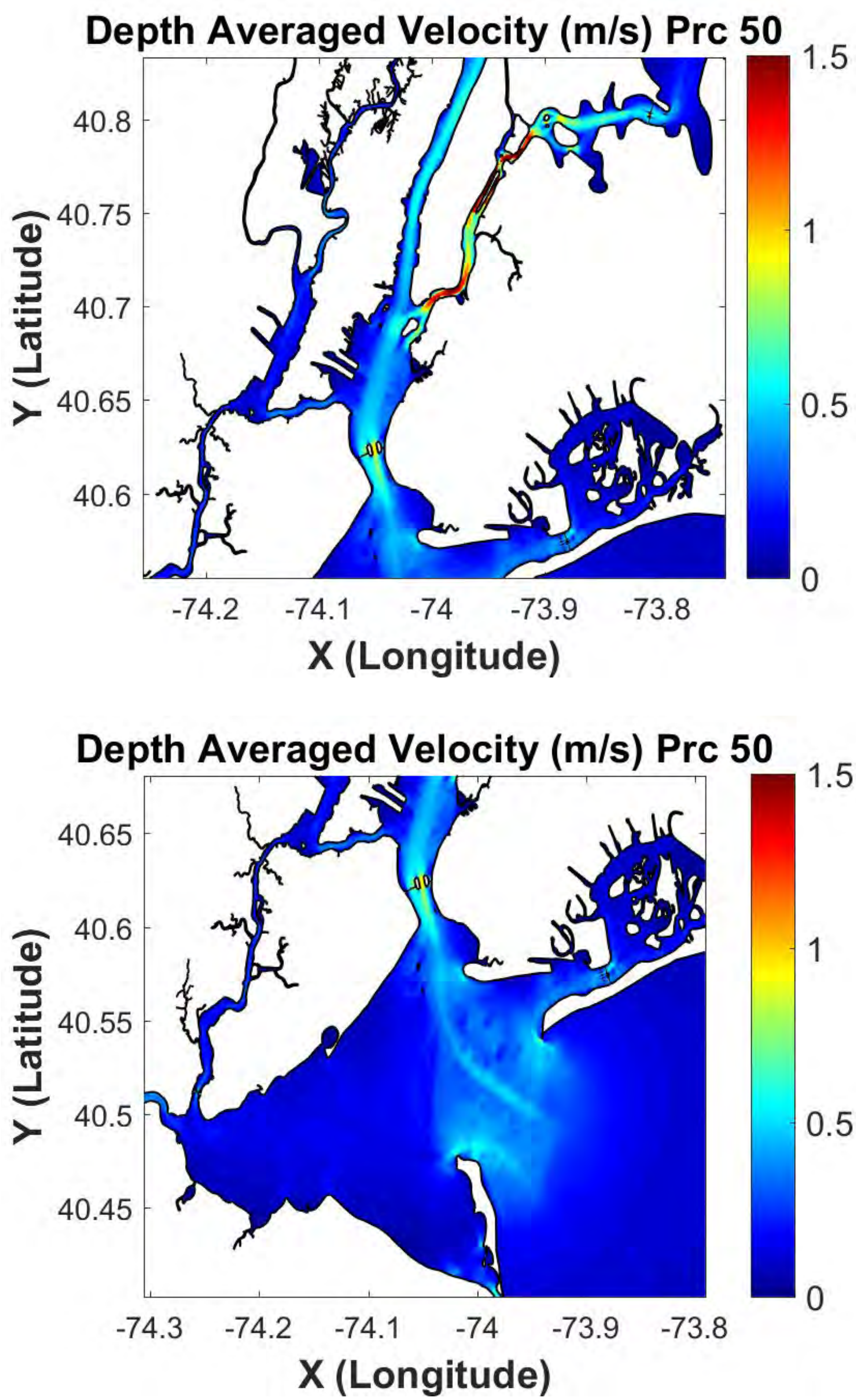


Figure 524. Alternative 3a/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

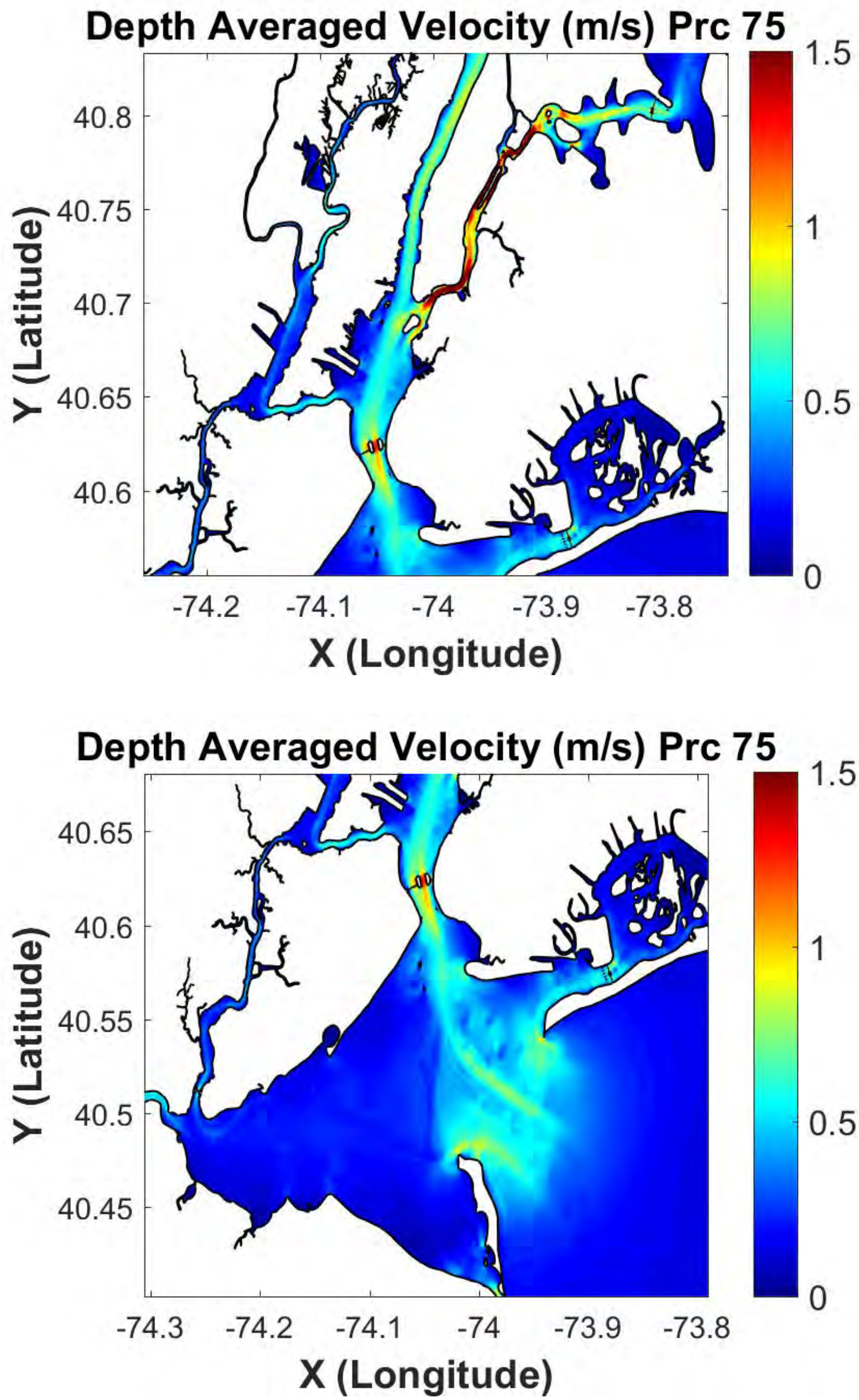


Figure 525. Alternative 3a/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

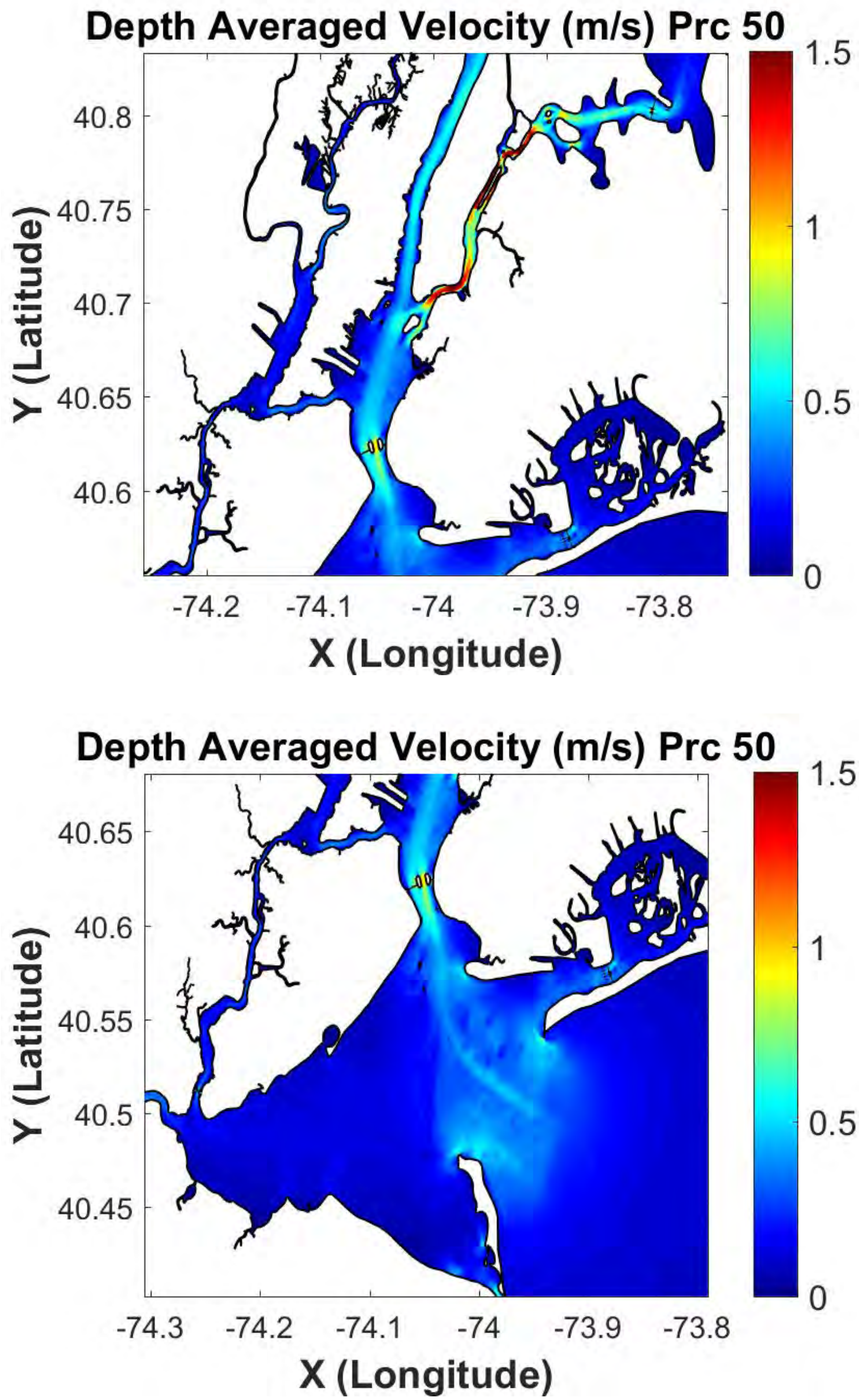
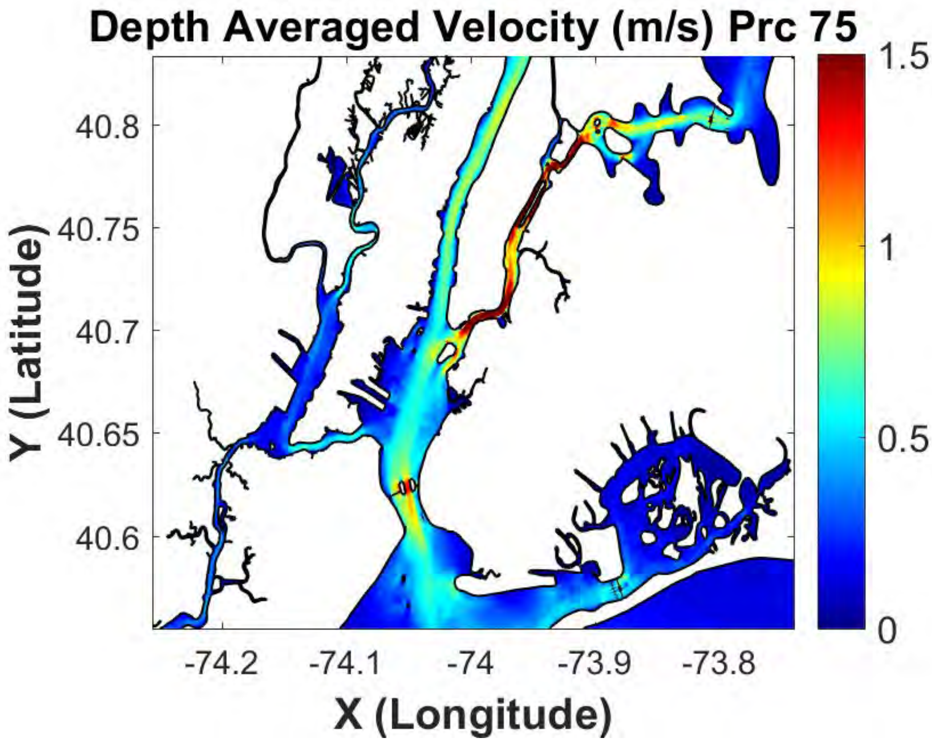
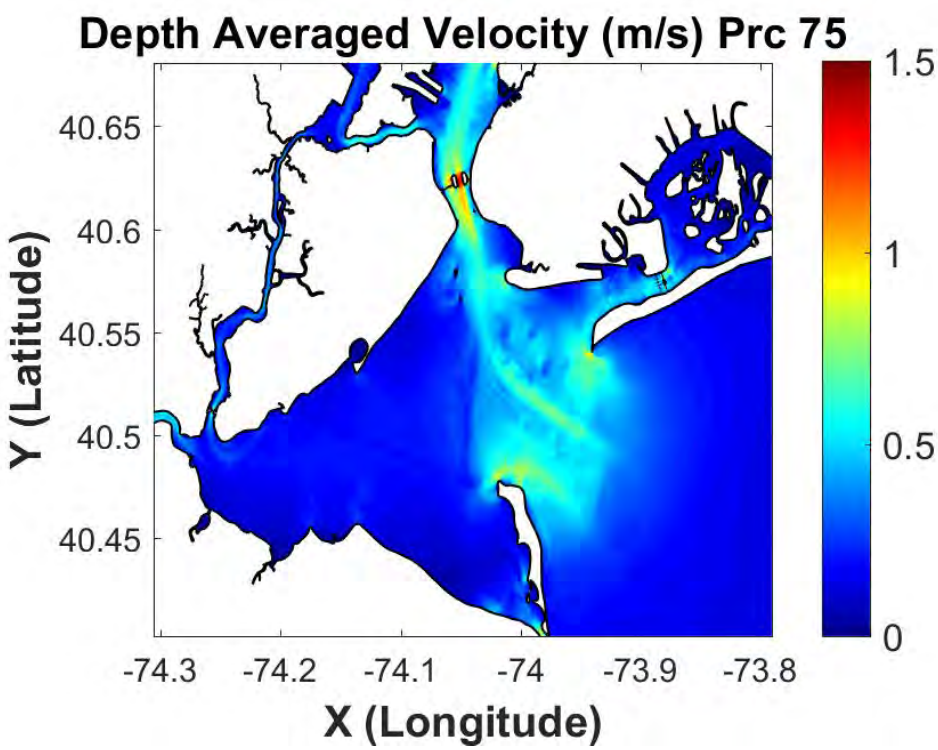


Figure 526. Alternative 3a/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

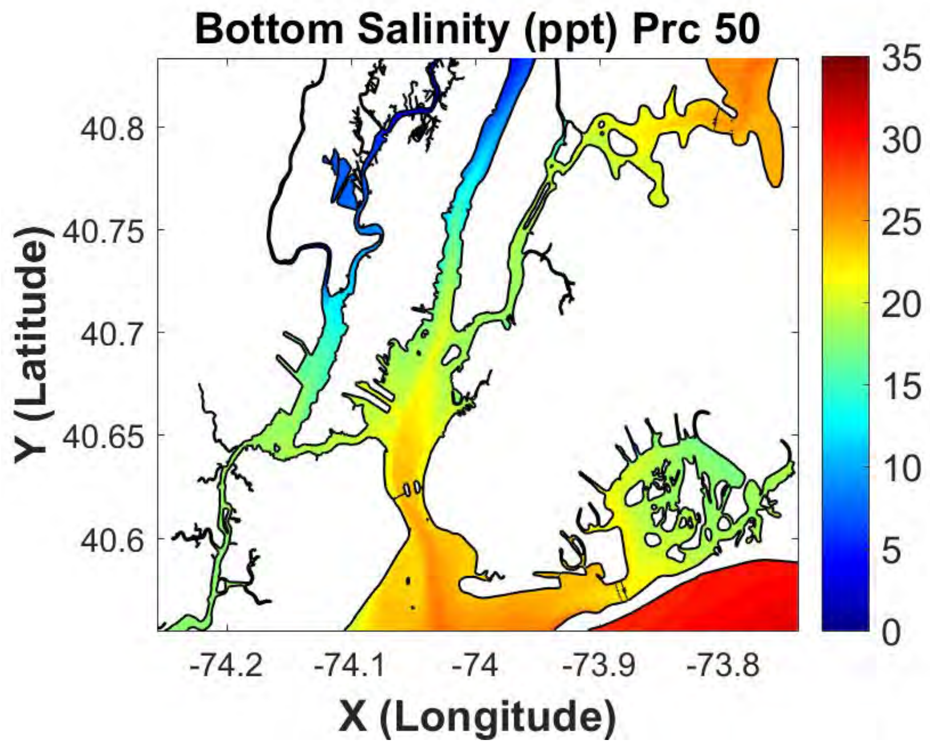




15.3.5 Spatial Salinity Percentiles

Spatial figures of the salinity percentiles for Alternative 3a for the 50^{th} and 75^{th} percentiles are provided in Figure 527 to Figure 538.

Figure 527. Alternative 3a/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



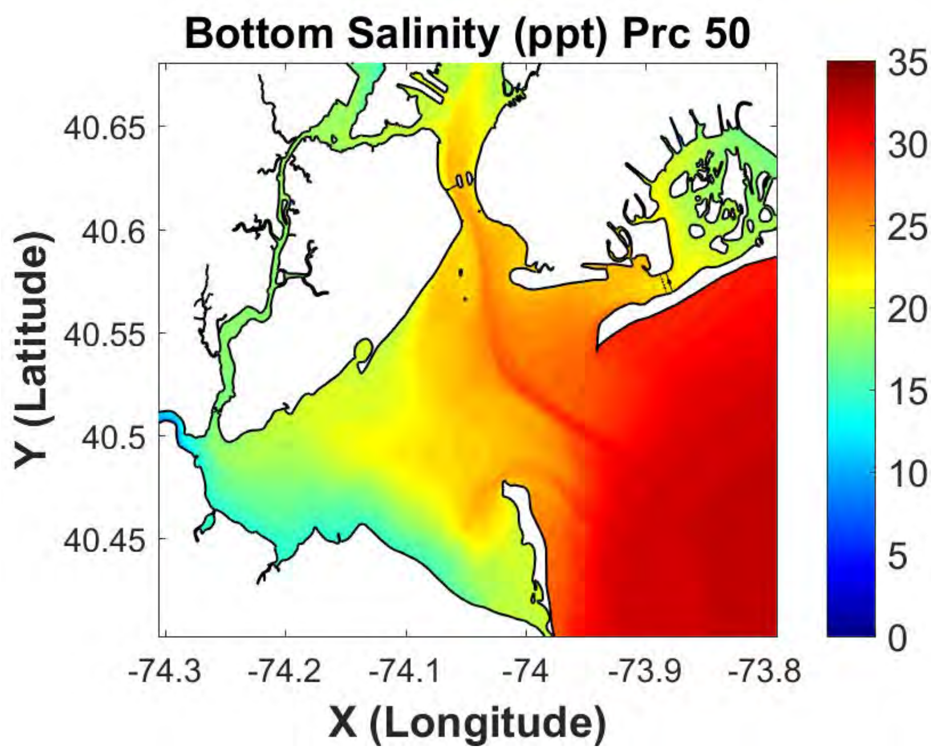
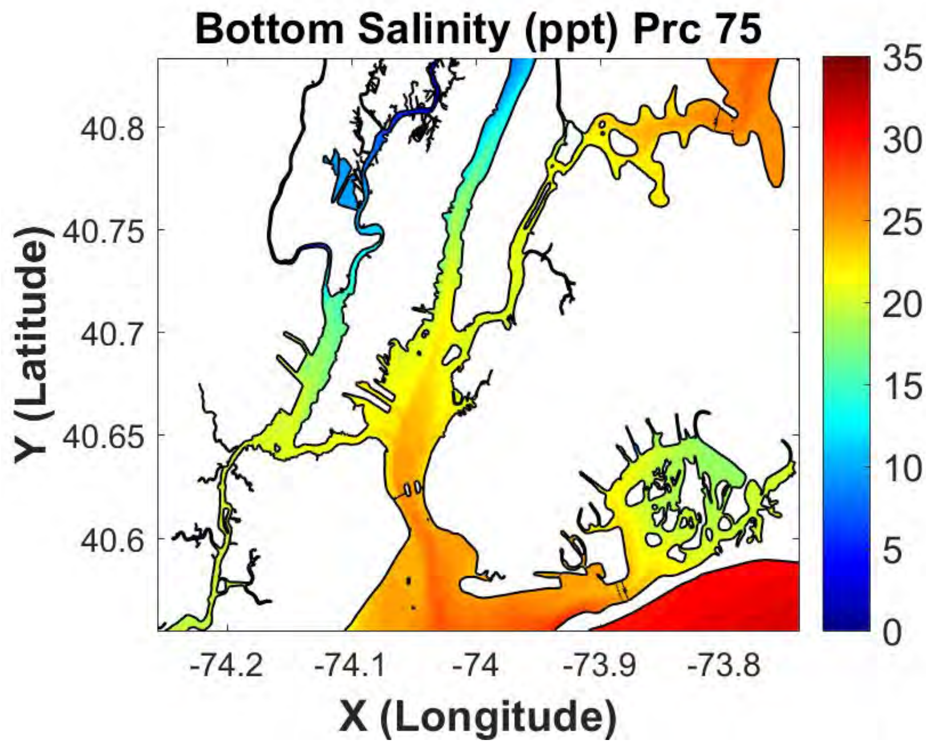


Figure 528. Alternative 3a/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



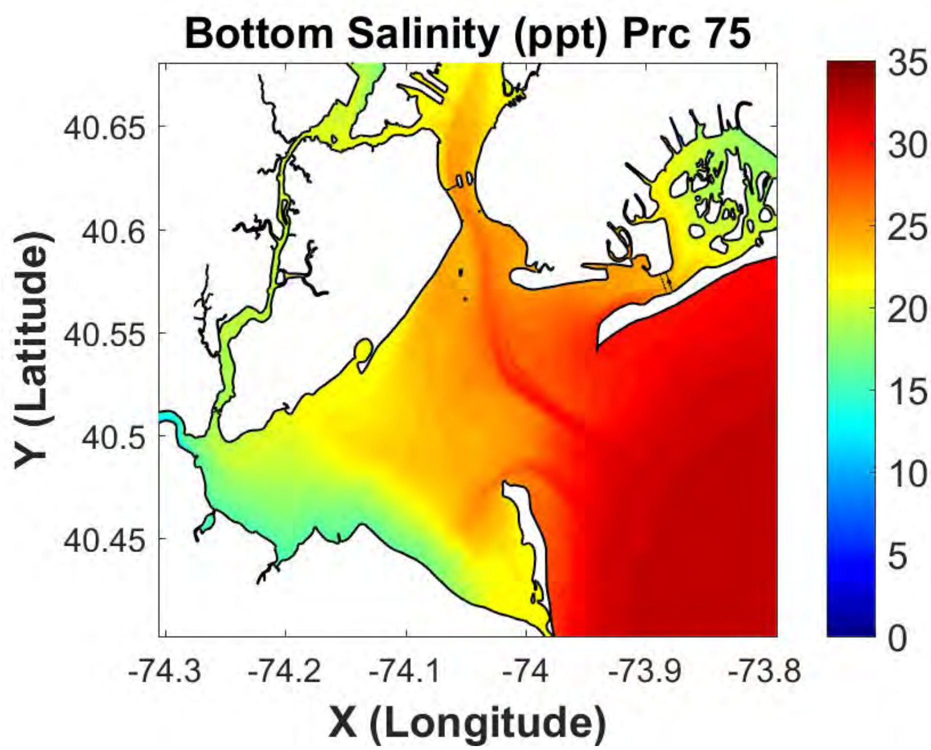


Figure 529. Alternative 3a/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

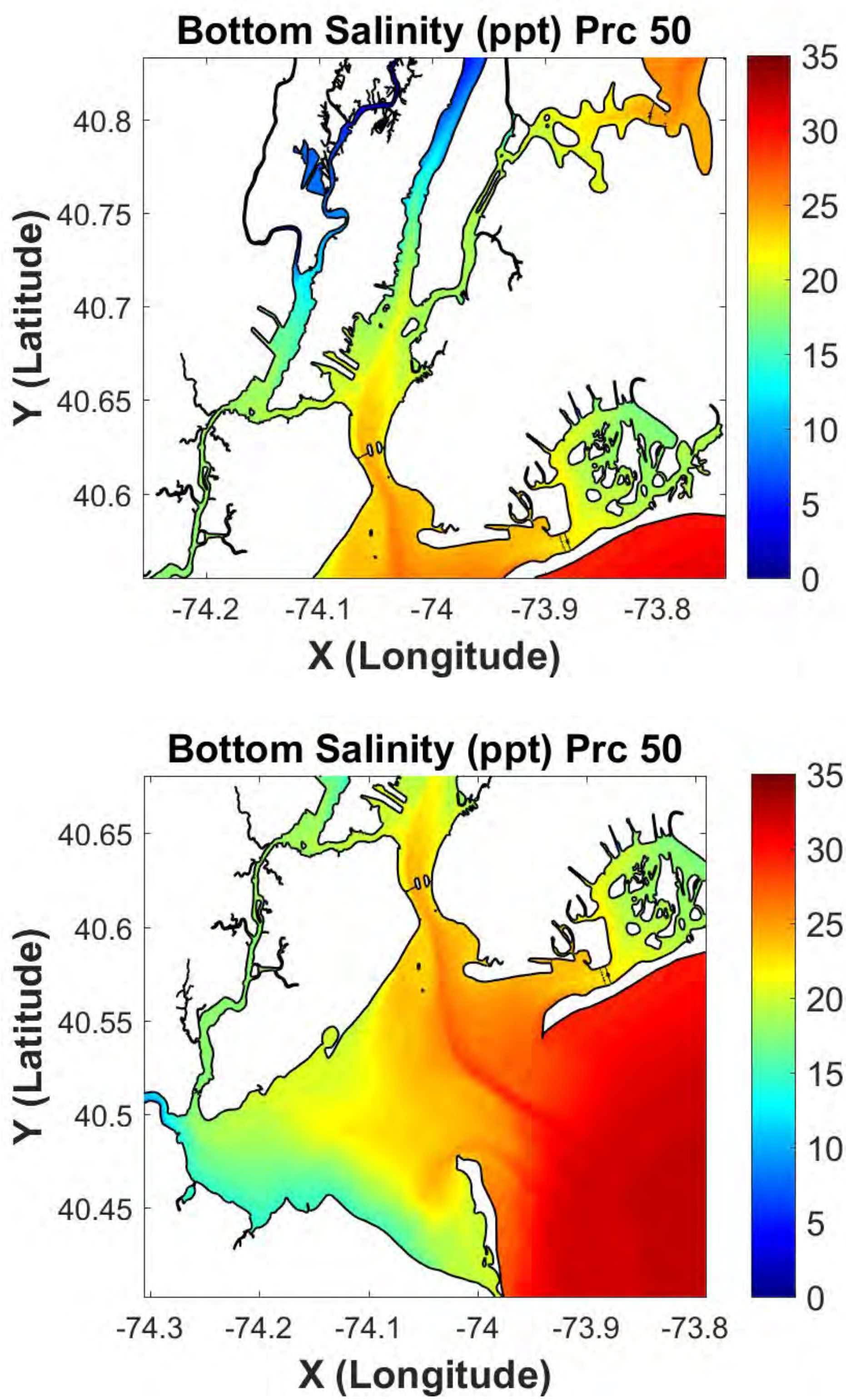
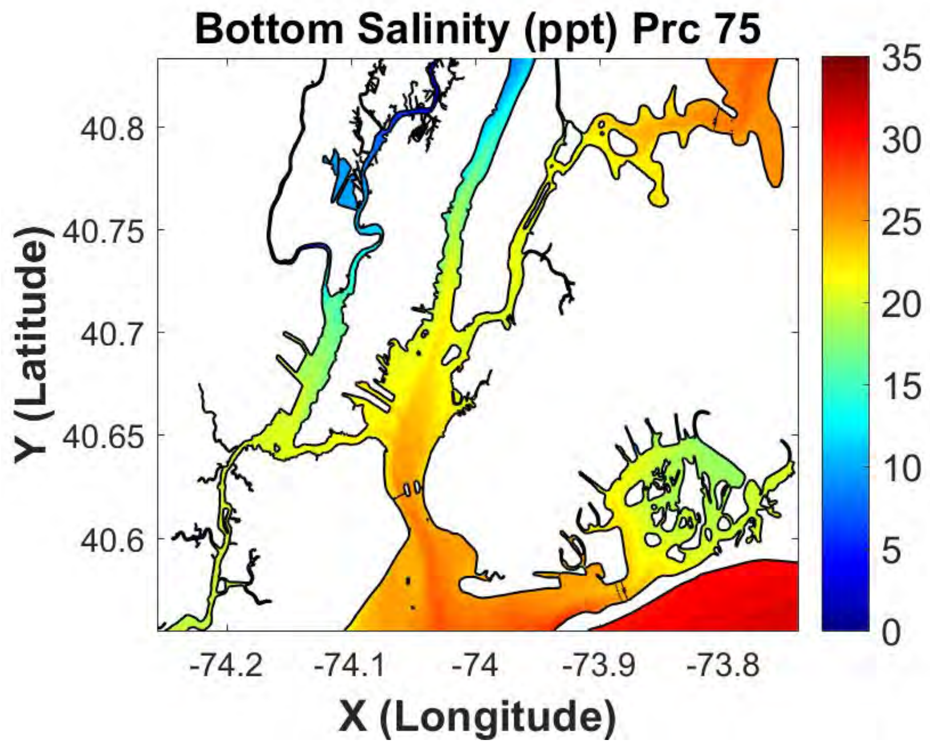


Figure 530. Alternative 3a/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



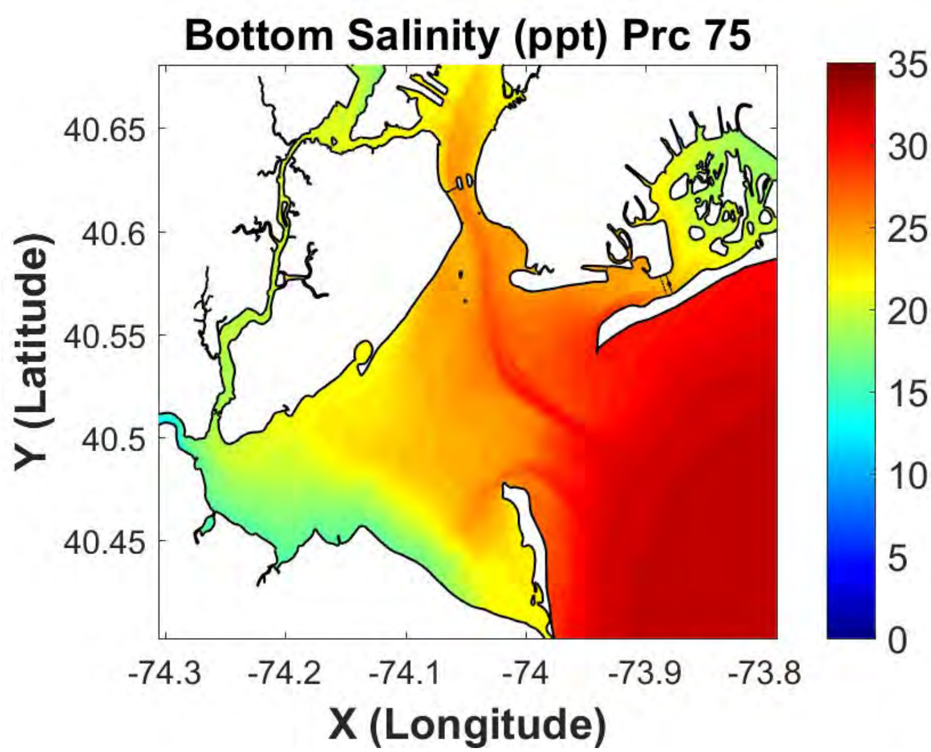
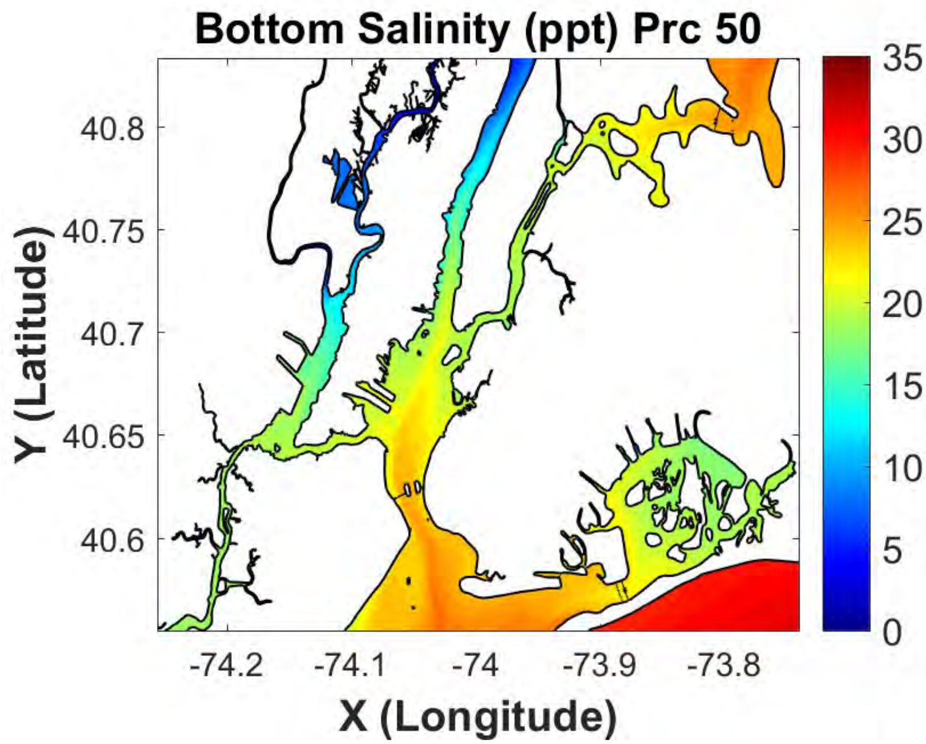


Figure 531. Alternative 3a/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



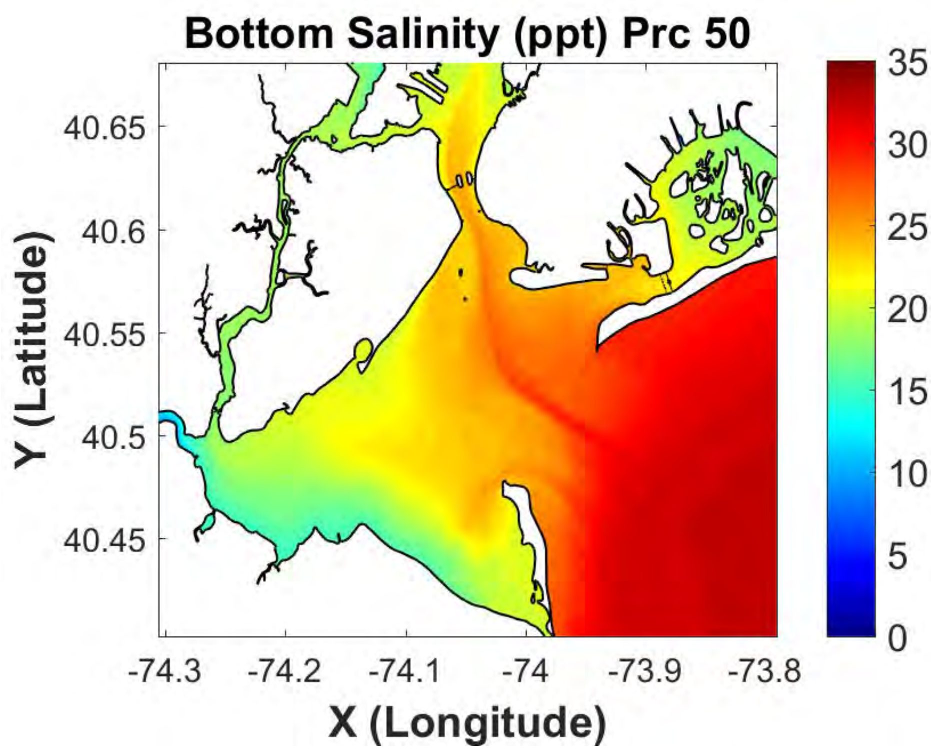
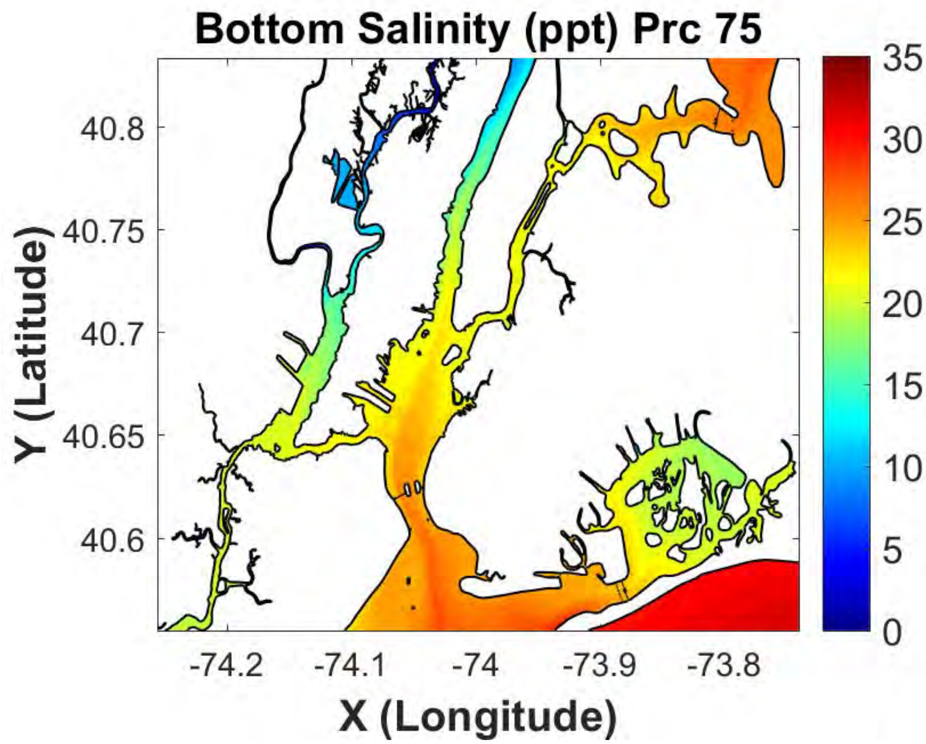


Figure 532. Alternative 3a/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



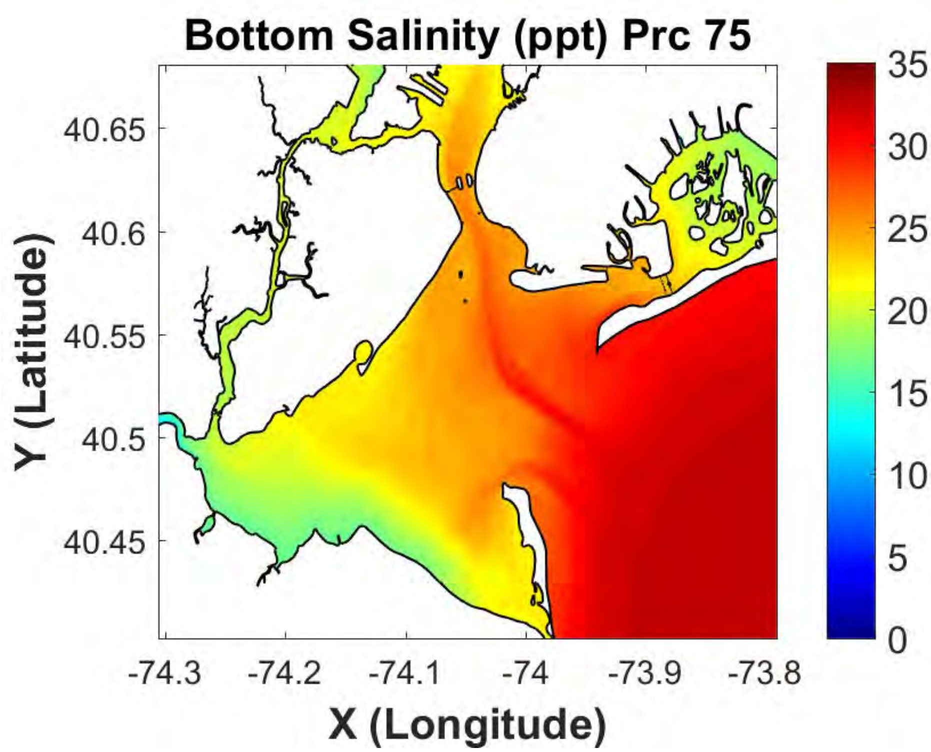


Figure 533. Alternative 3a/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

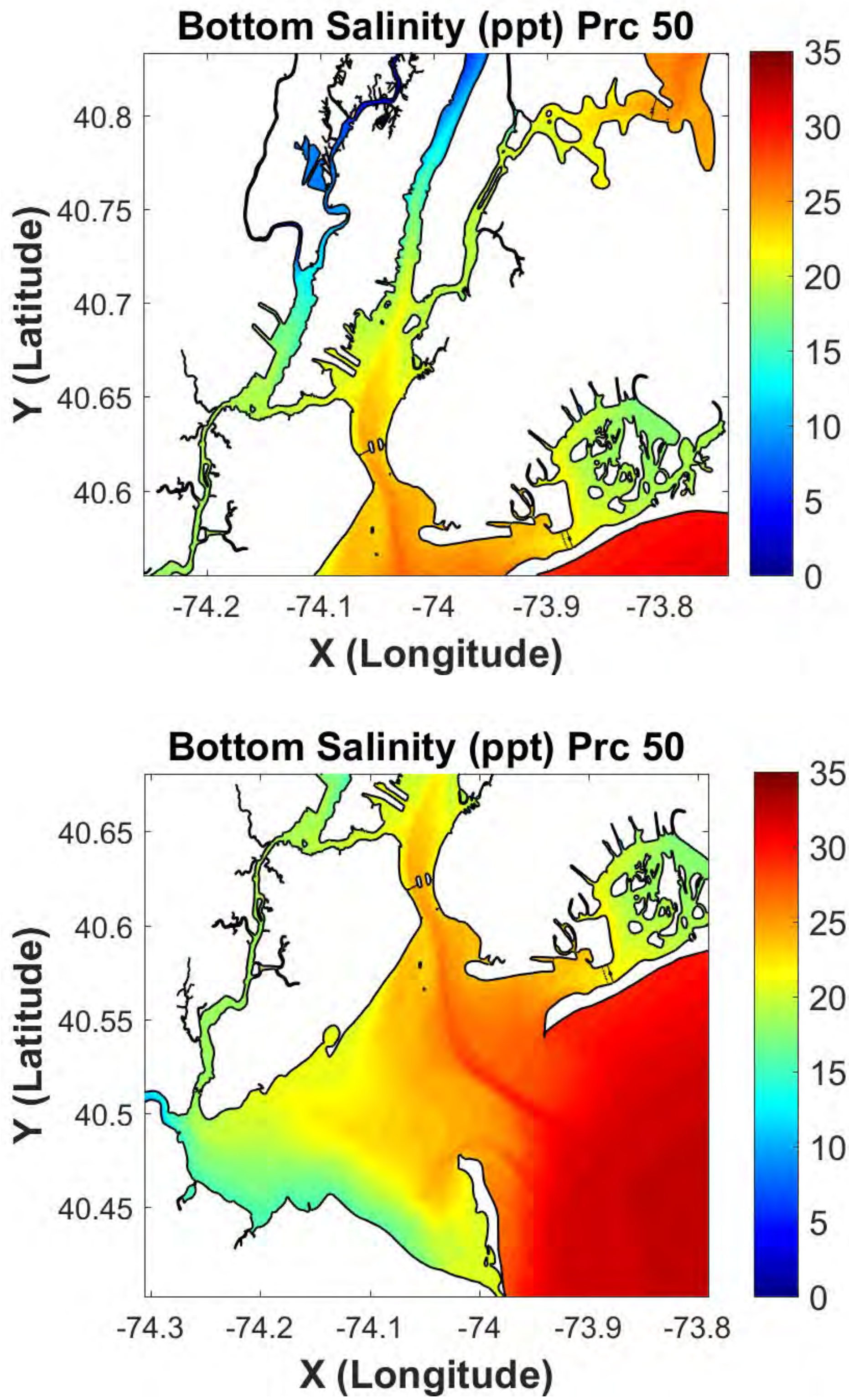
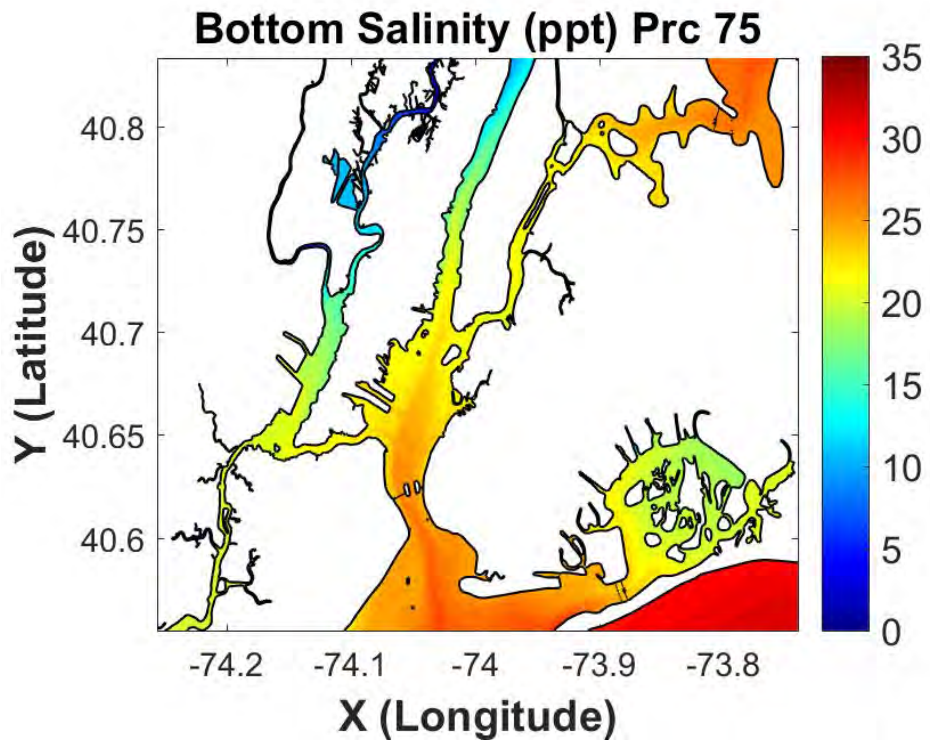


Figure 534. Alternative 3a/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



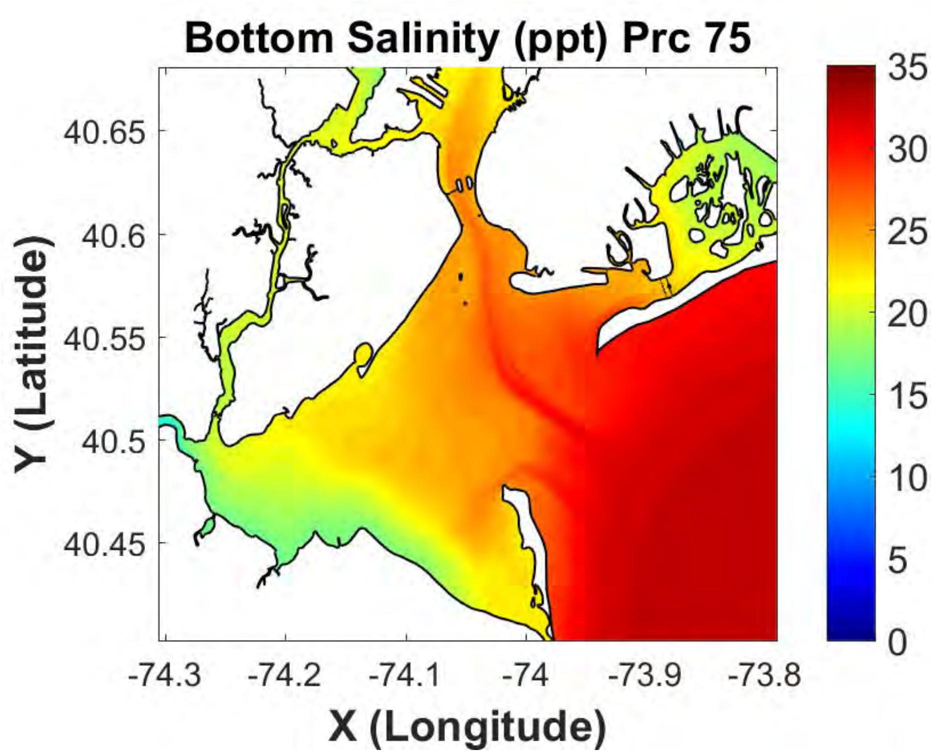
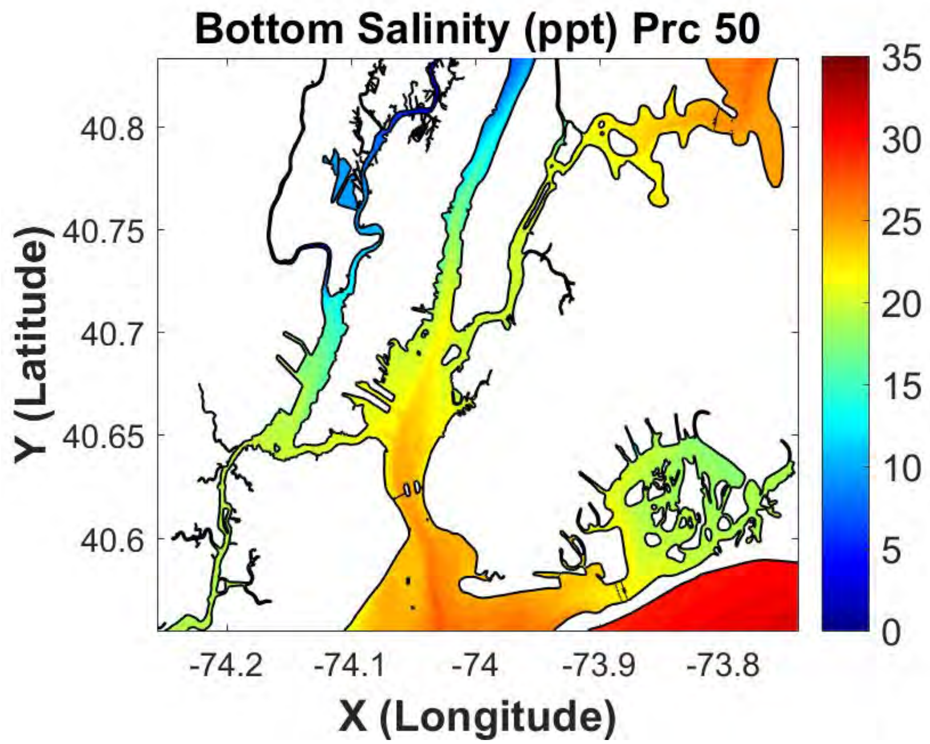


Figure 535. Alternative 3a/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



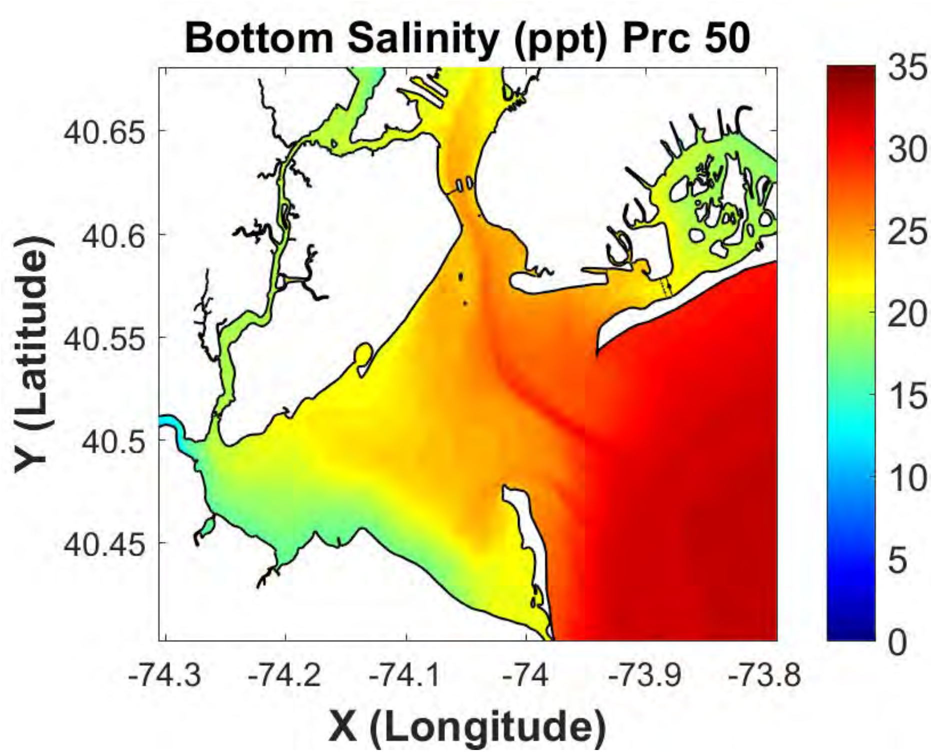
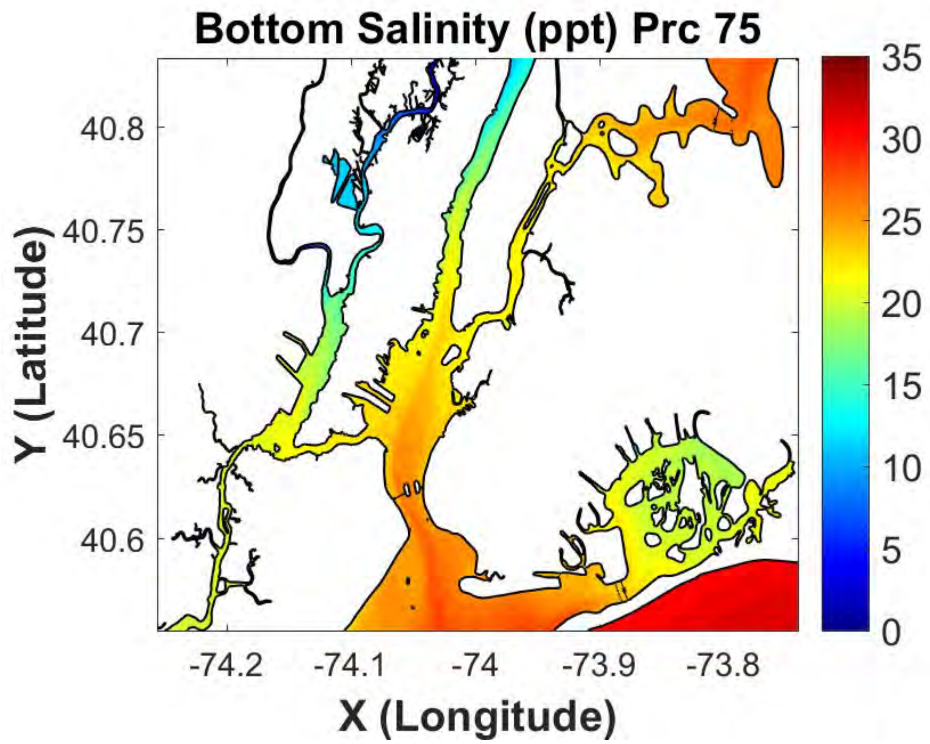


Figure 536. Alternative 3a/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



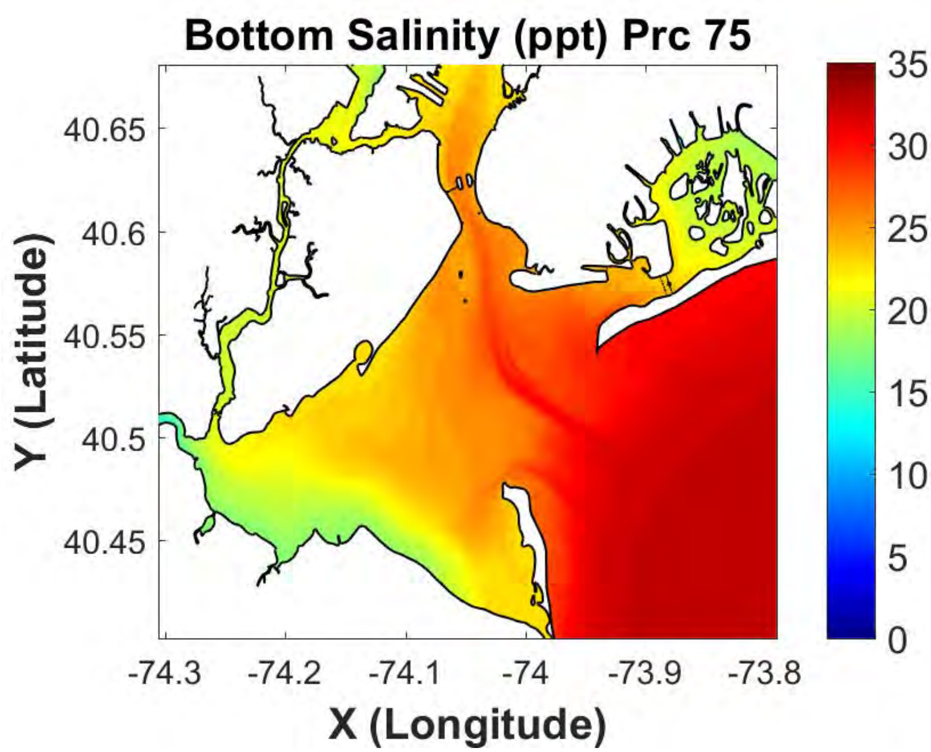


Figure 537. Alternative 3a/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

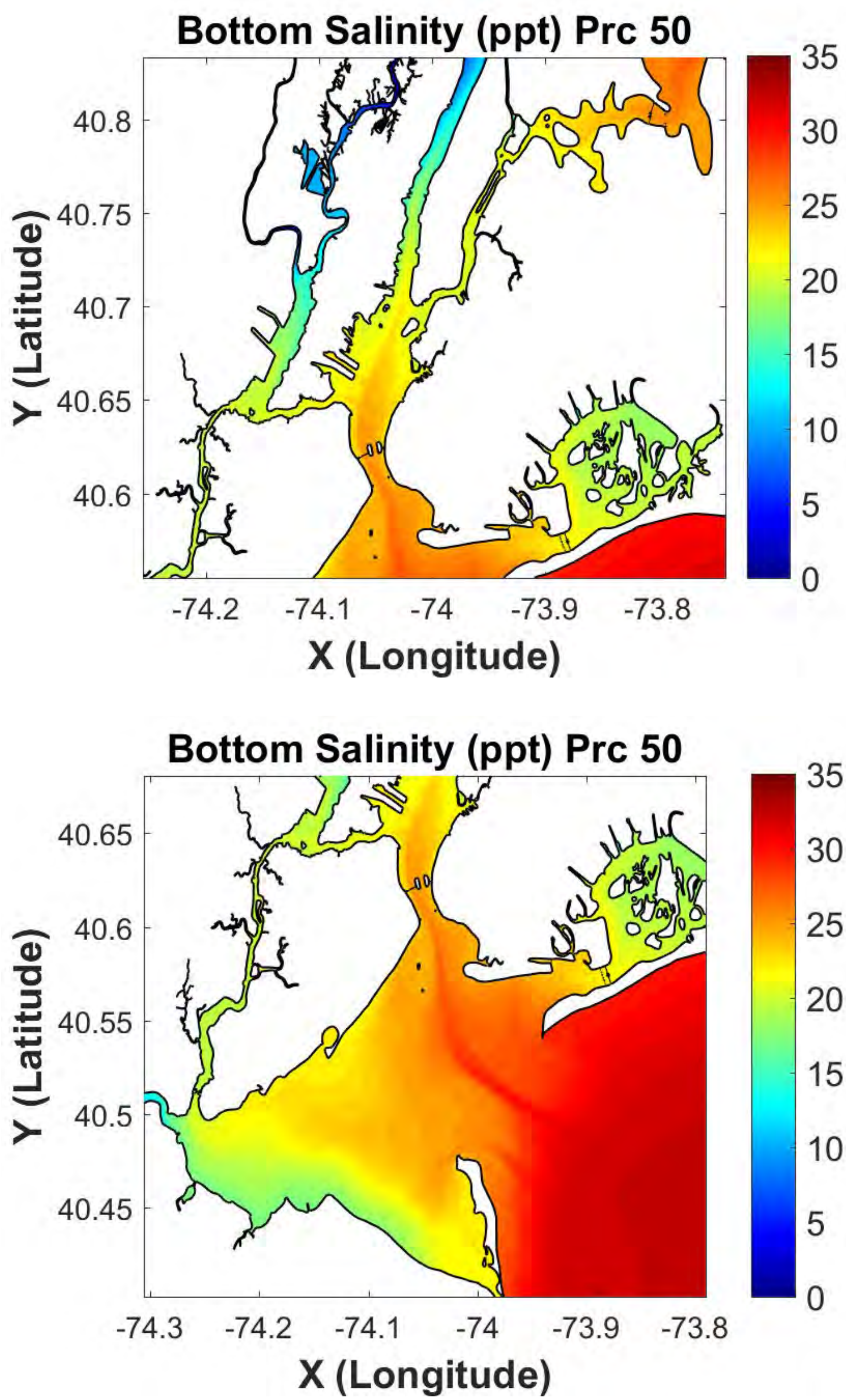
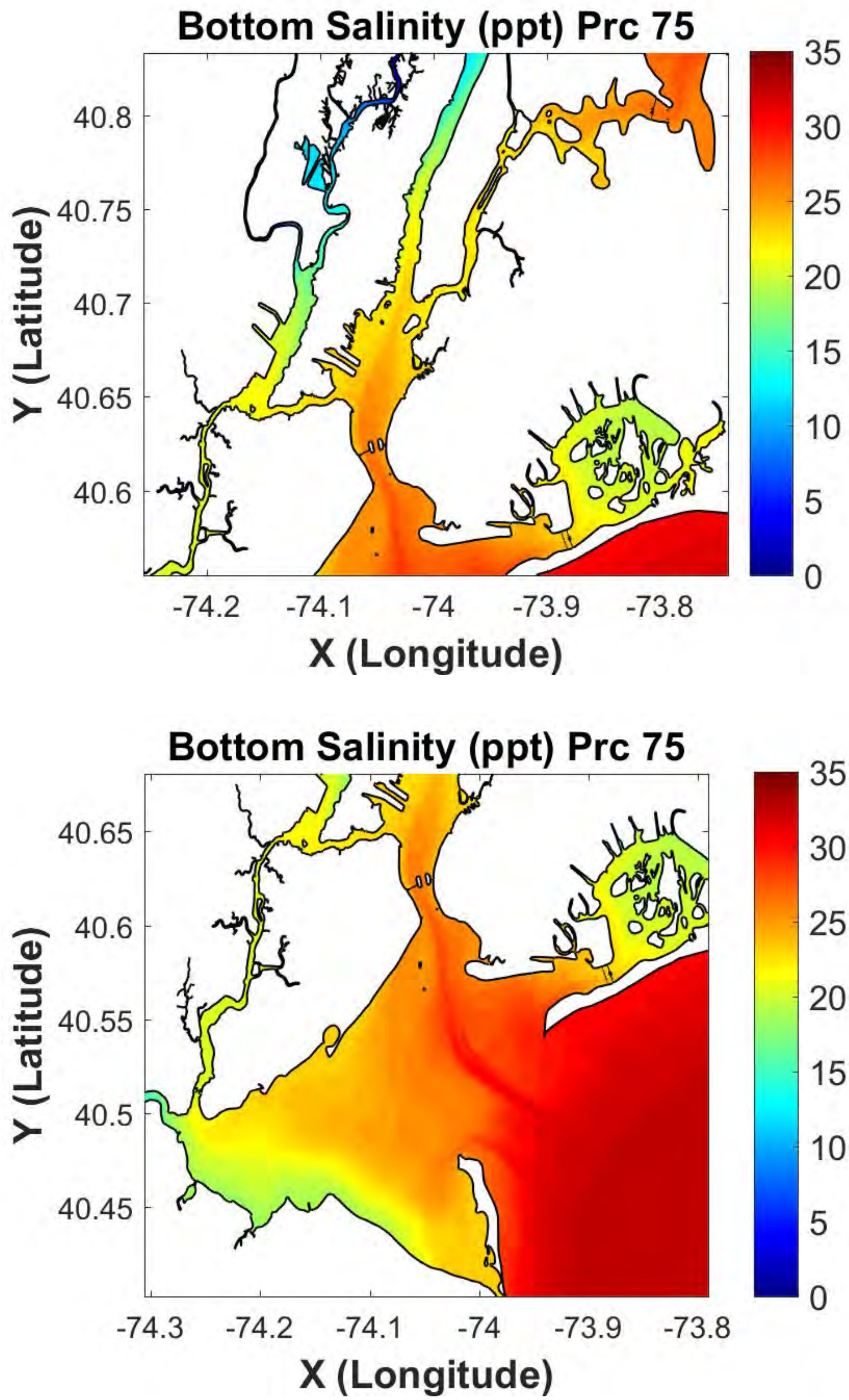


Figure 538. Alternative 3a/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



15.3.6 Water Flux Analysis

Discharge percentiles for Alternative 3a for the previously shown locations (Figure 28) are provided in Figure 539 to Figure 542. These locations indicate increased tidal exchange for increasing water levels. Table 9 shows the mean flows for the various pathways and sea levels.

Figure 539. Alternative 3a Variation in Throgs Neck Discharges with sea level.

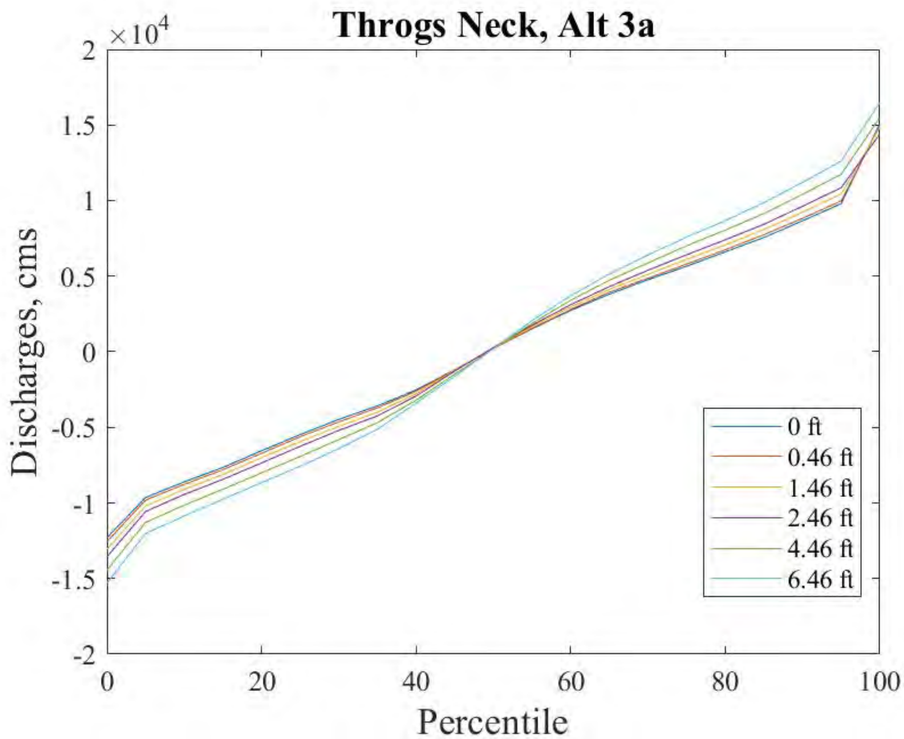


Figure 540. Alternative 3a Variation in Verrazano Narrows Discharges with sea level.

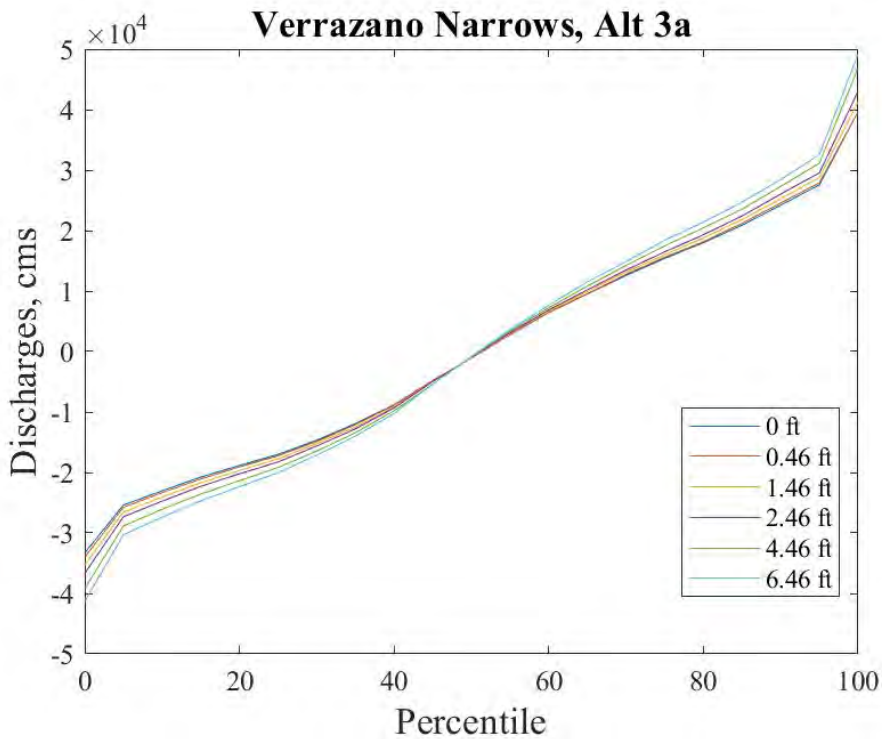


Figure 541. Alternative 3a Variation in Kill Van Kull Discharges with sea level.

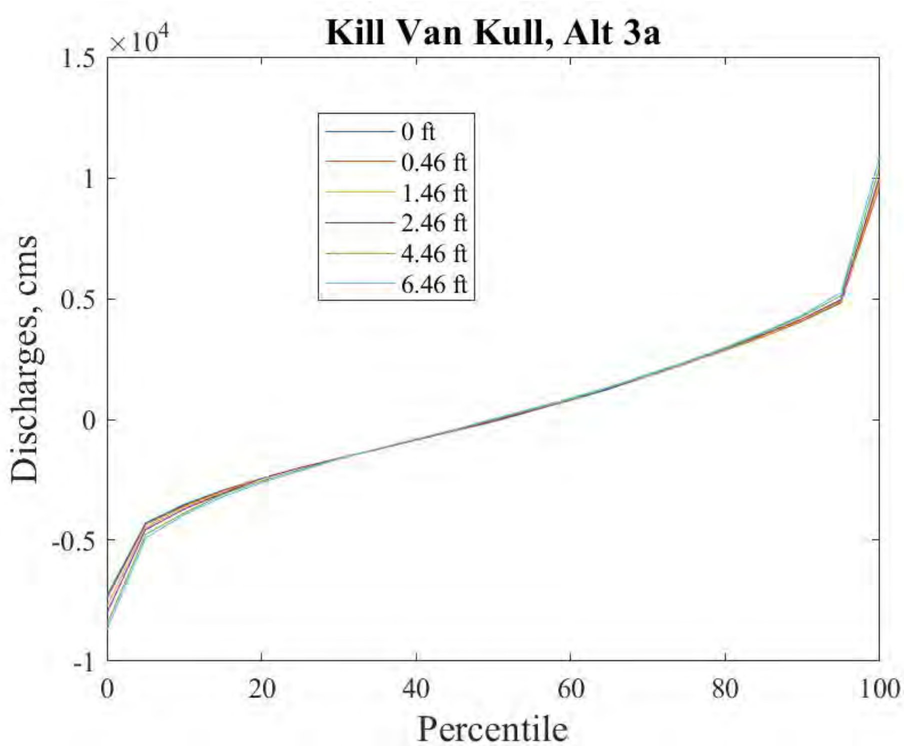


Figure 542. Alternative 3a Variation in Arthur Kill Discharges with sea level.

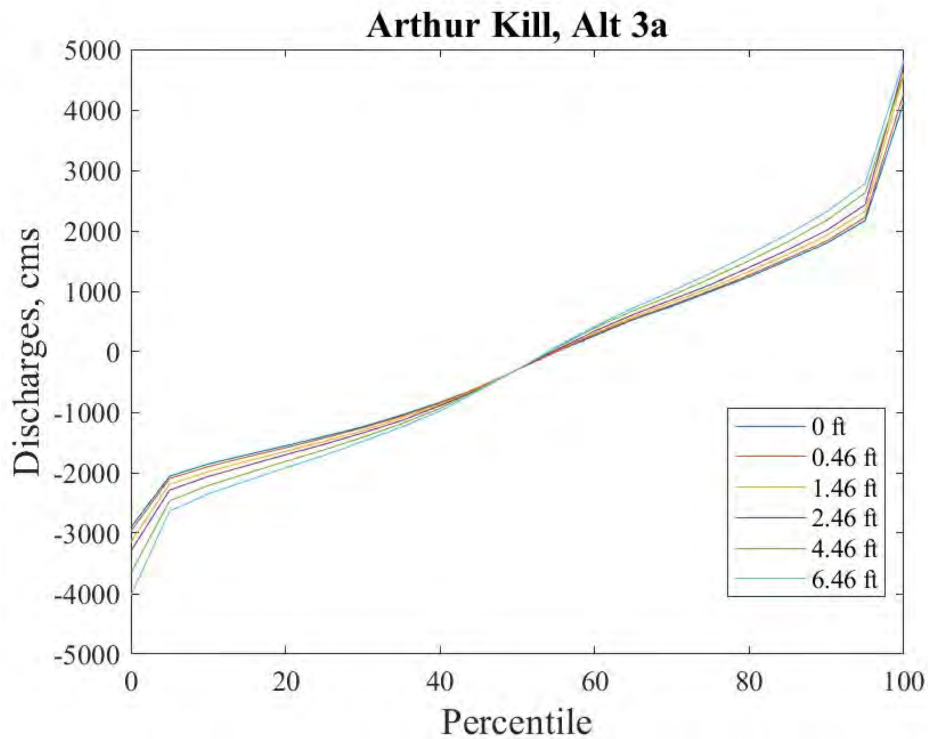


Table 9. Alternative 3a, Sea Level Rise Impacts of Flows in CMS.

Location	0.0 ft. MSL	0.46 ft. MSL	1.46 ft. MSL	2.46 ft. MSL	4.46 ft. MSL	6.46 ft. MSL
Throgs Neck	95	96	101	106	117	126
Verrazano Narrows	-332	-334	-345	-349	-362	-370
Kill Van Kull	129	128	125	124	121	122
Arthur Kill	-158	-157	-155	-154	-152	-151

15.3.7 Tidal Prism Analysis

Tidal prisms were calculated, and a percentile analysis was performed to evaluate the impact of sea level rise on the tidal exchange. Figure 543 and

Figure 544 show the tidal prism for all sea level values for the impounded areas for Alternative 3a previously shown in Figure 35. These results indicate higher sea level values result in higher tidal prisms and associated tidal exchange/mixing. The Jamaica Bay area behaves slightly different with lower tidal prism values for the lower percentiles and higher values for the higher percentiles.

Figure 543. Tidal Prism Percentile Analysis for Alternative 2 for Material 1.

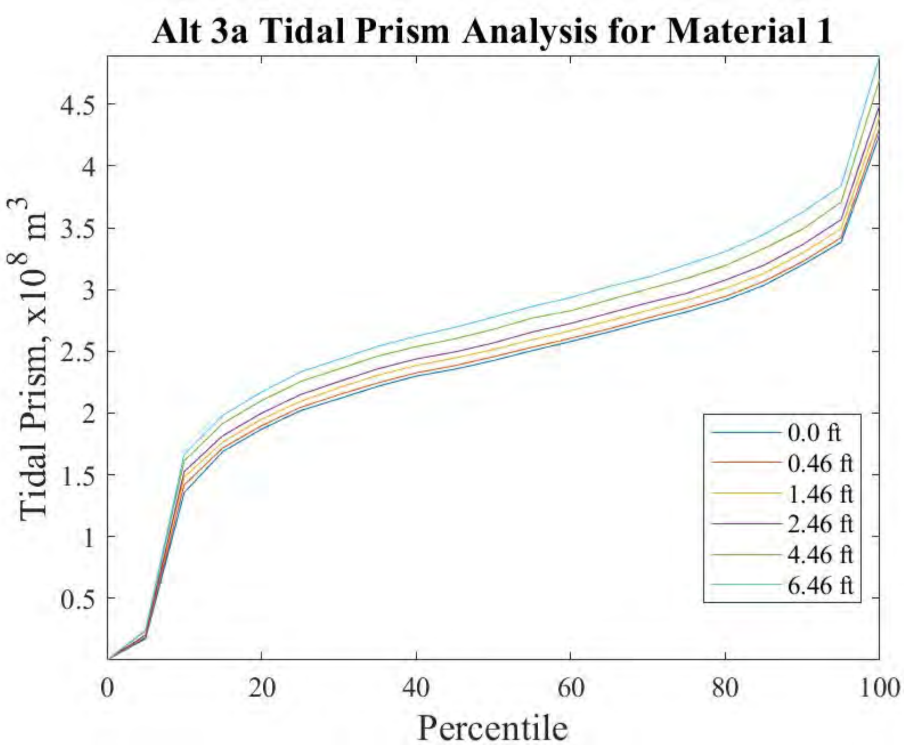
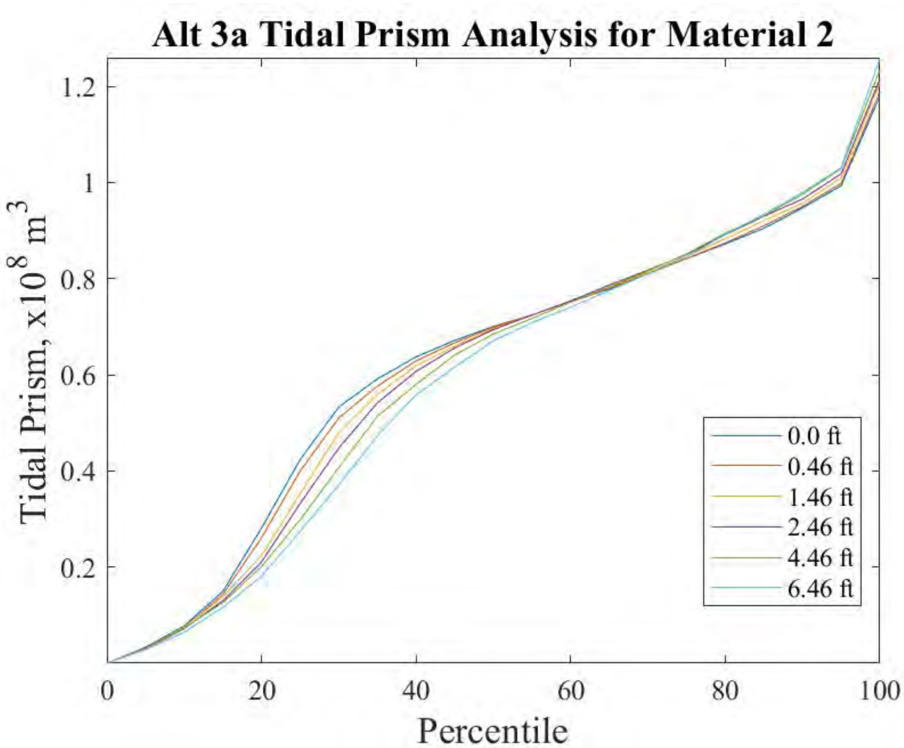


Figure 544. Tidal Prism Percentile Analysis for Alternative 2 for Material 2.



15.4 Alternative 3b

For increased sea levels, Alternative 3b possesses increasing tidal exchange, tide ranges, and salinity intrusion. The velocities are also increased as the increases in the tidal exchange override the increased depths also present in the sea level rise alternatives.

15.4.1 Water Surface Elevation Point Percentiles

Water surface elevation (WSE) percentiles for Alternative 3b for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 545 to Figure 569. The datum in these plots is relative to Mean Sea Level for 1995. The datum Mean Sea Level will increase with sea level rise (SLR) but for the purposes of these comparisons it is held constant, so all water levels are relative 0.0 MSL for 1995.

Figure 545. Alt 3b, Sandy Hook WSE Variation with SLR.

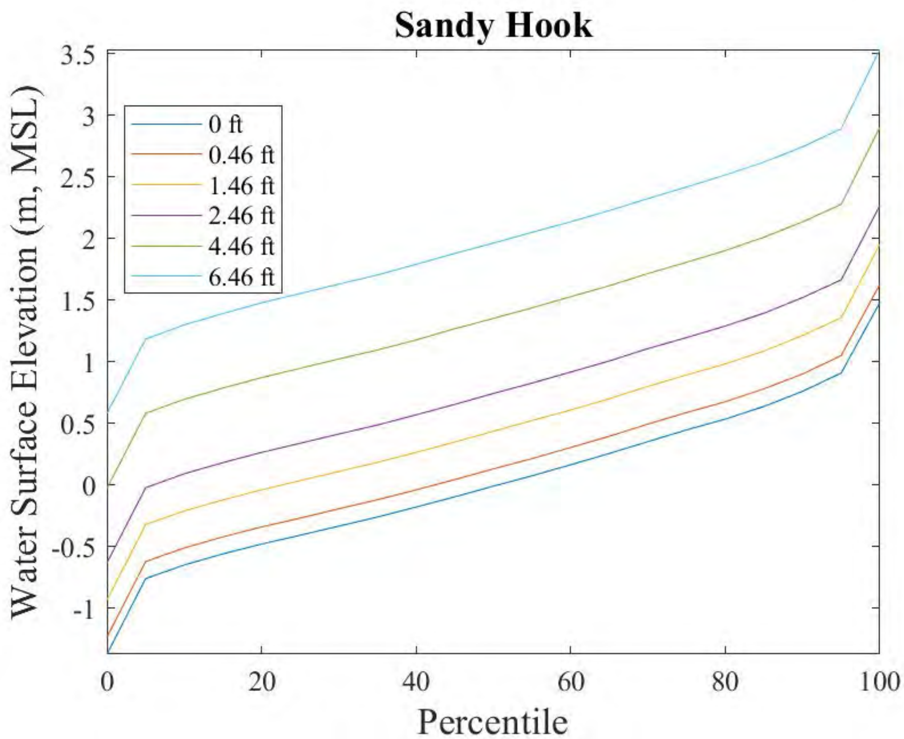


Figure 546. Alt 3b, V5 WSE Variation with SLR.

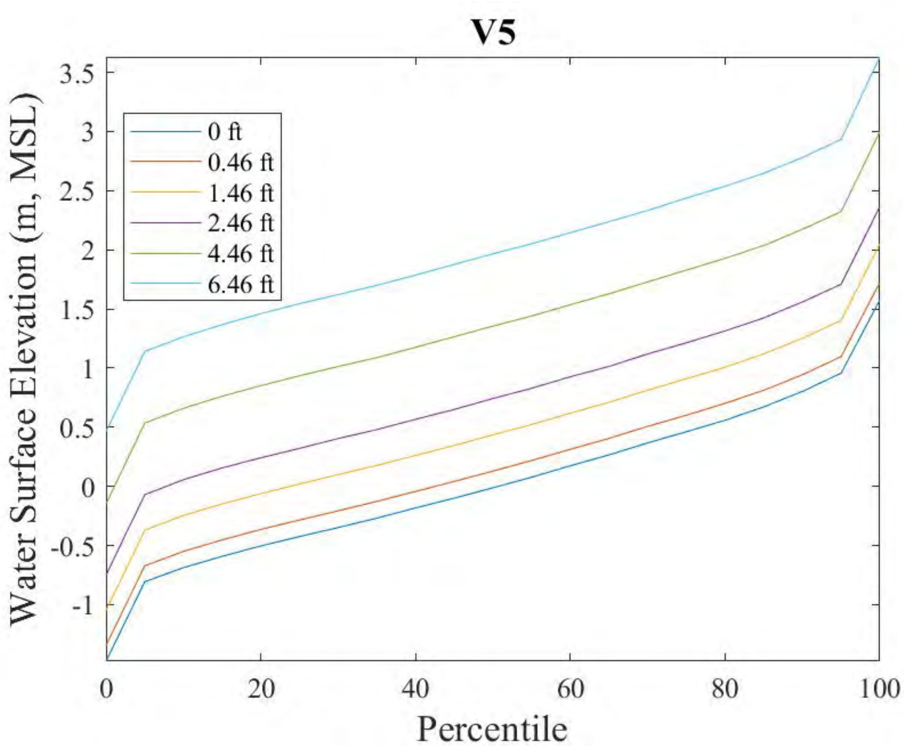


Figure 547. Alt 3b, V6 WSE Variation with SLR.

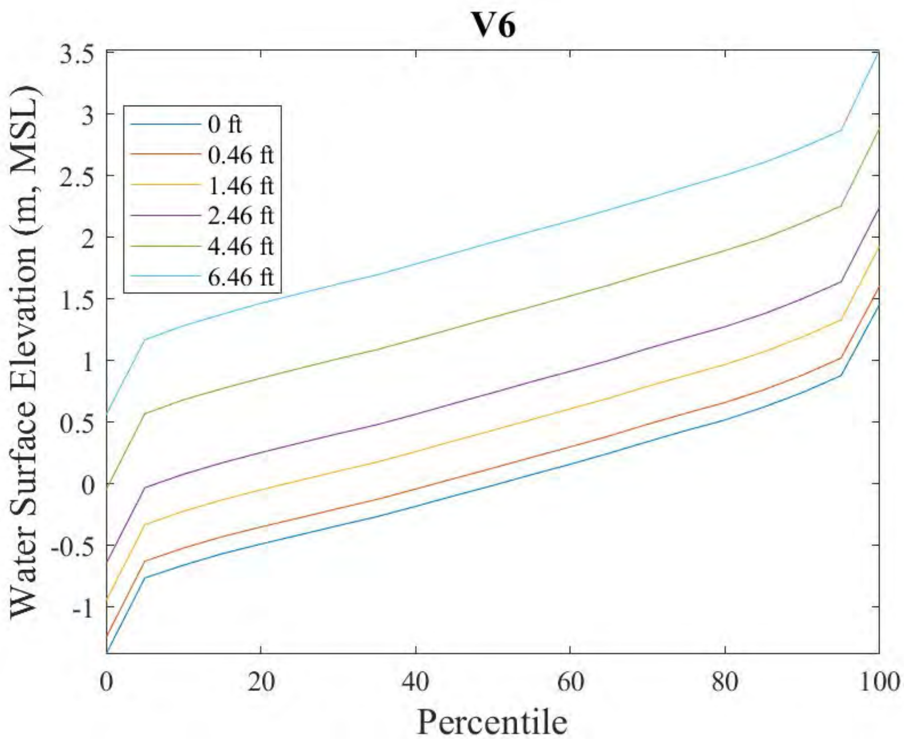


Figure 548. Alt 3b, Fresh Kills WSE Variation with SLR.

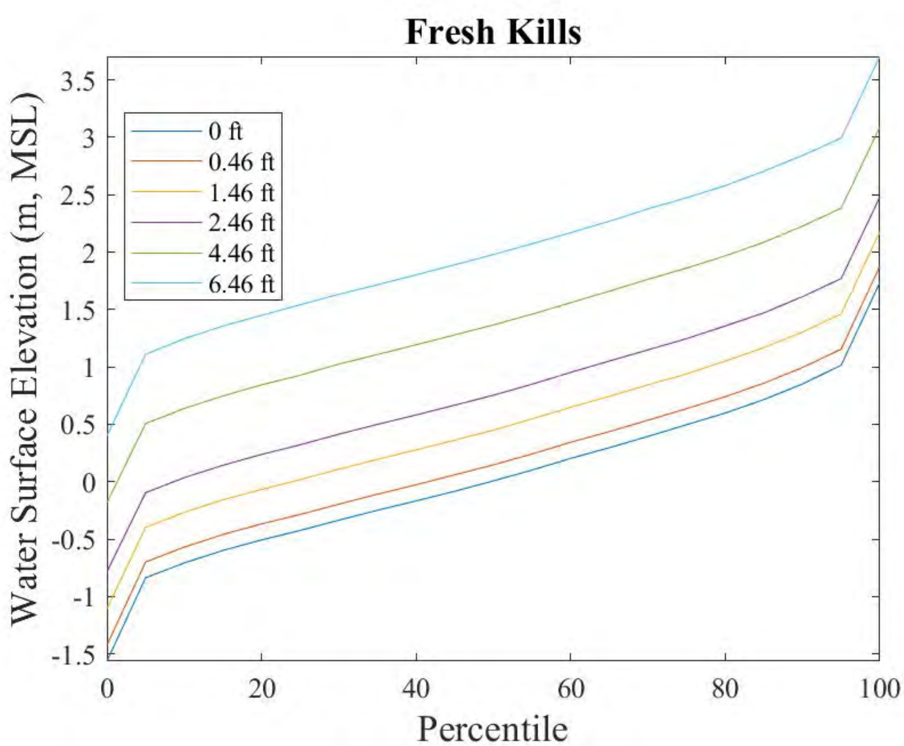


Figure 549. Alt 3b, Mariners Harbor WSE Variation with SLR.

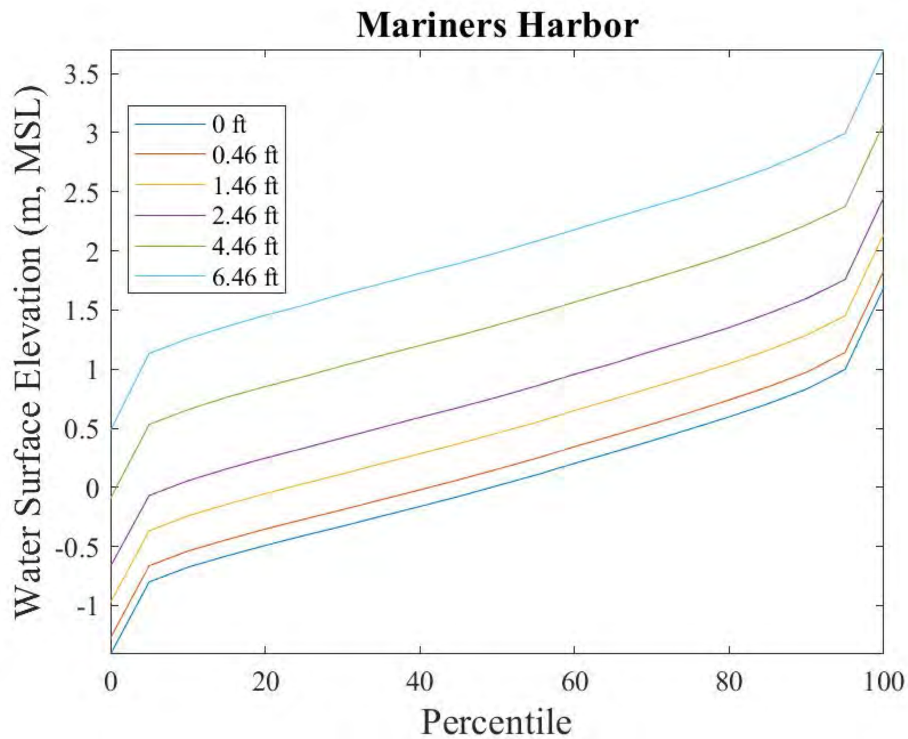


Figure 550. Alt 3b, T2 WSE Variation with SLR.

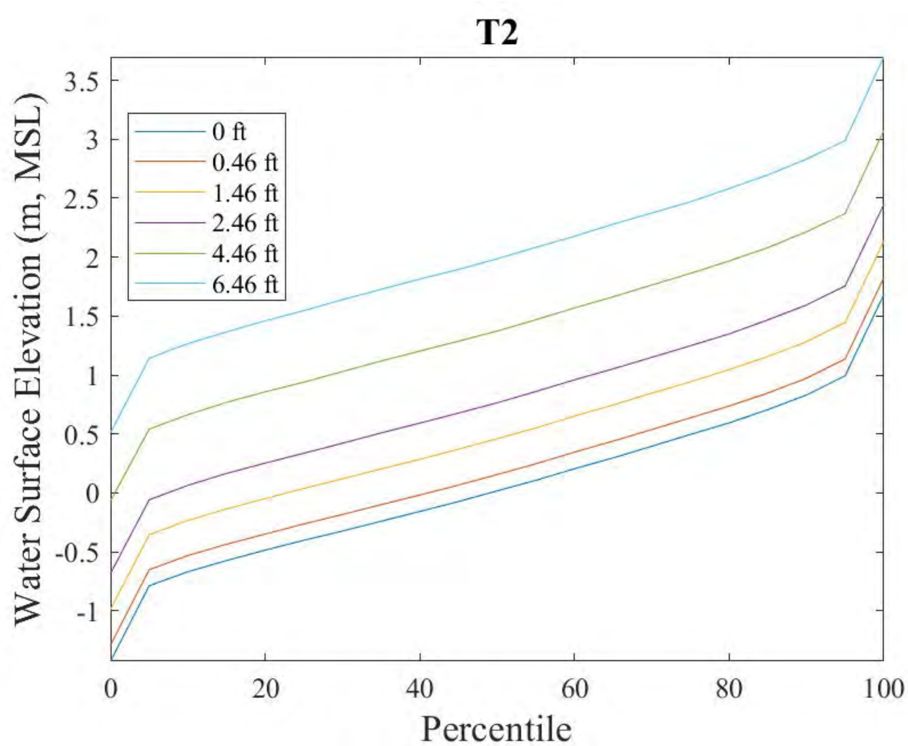


Figure 551. Alt 3b, T3 WSE Variation with SLR.

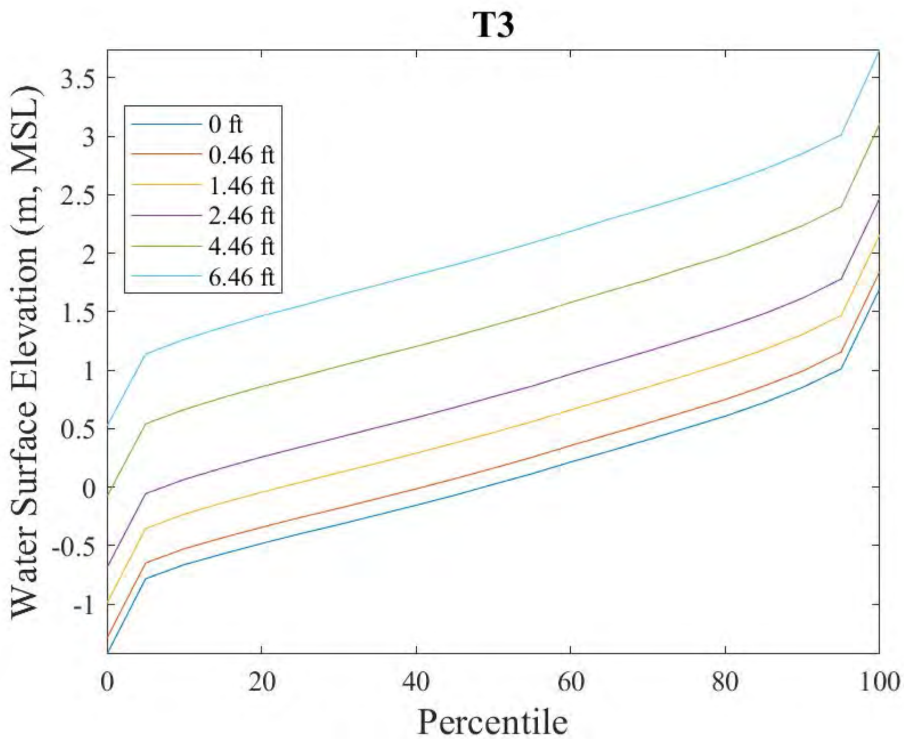


Figure 552. Alt 3b, North Reach WSE Variation with SLR.

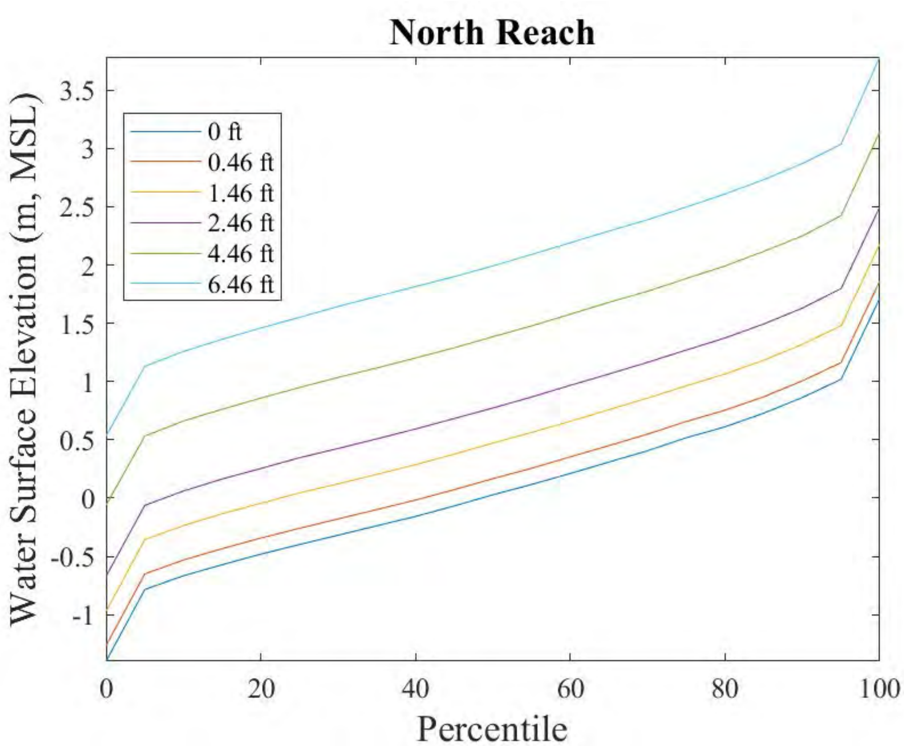


Figure 553. Alt 3b, Hackensack River WSE Variation with SLR.

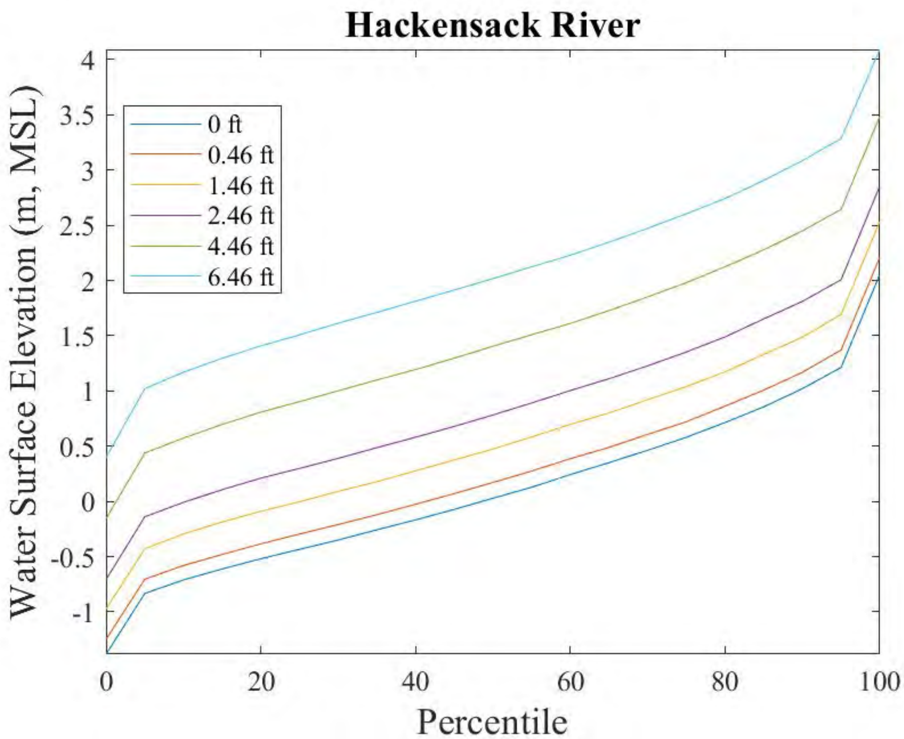


Figure 554. Alt 3b, Robbins Reef WSE Variation with SLR.

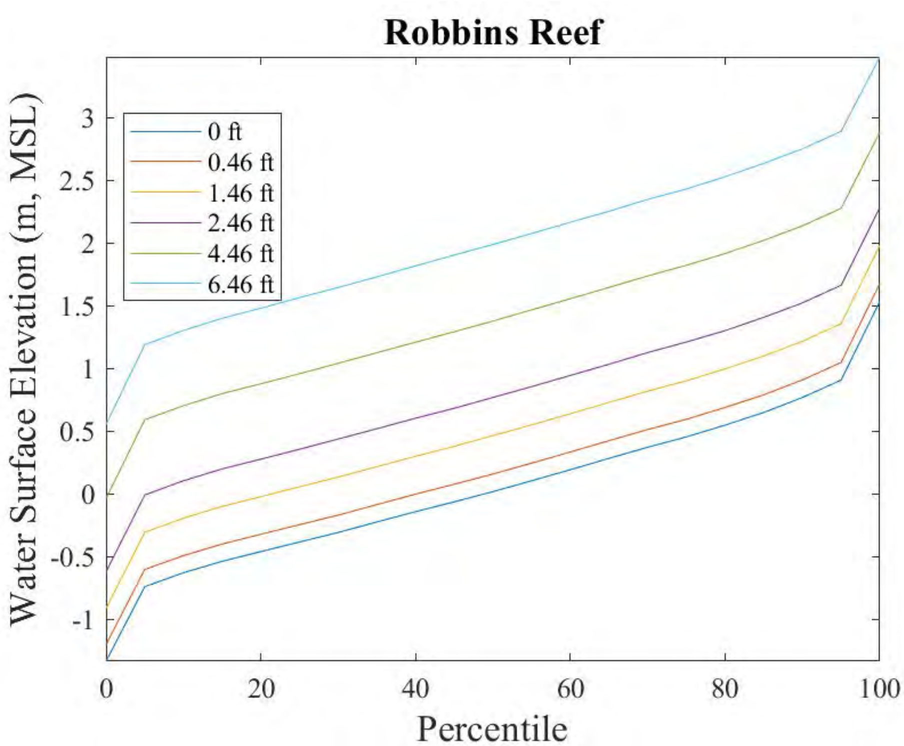


Figure 555. Alt 3b, S2 WSE Variation with SLR.

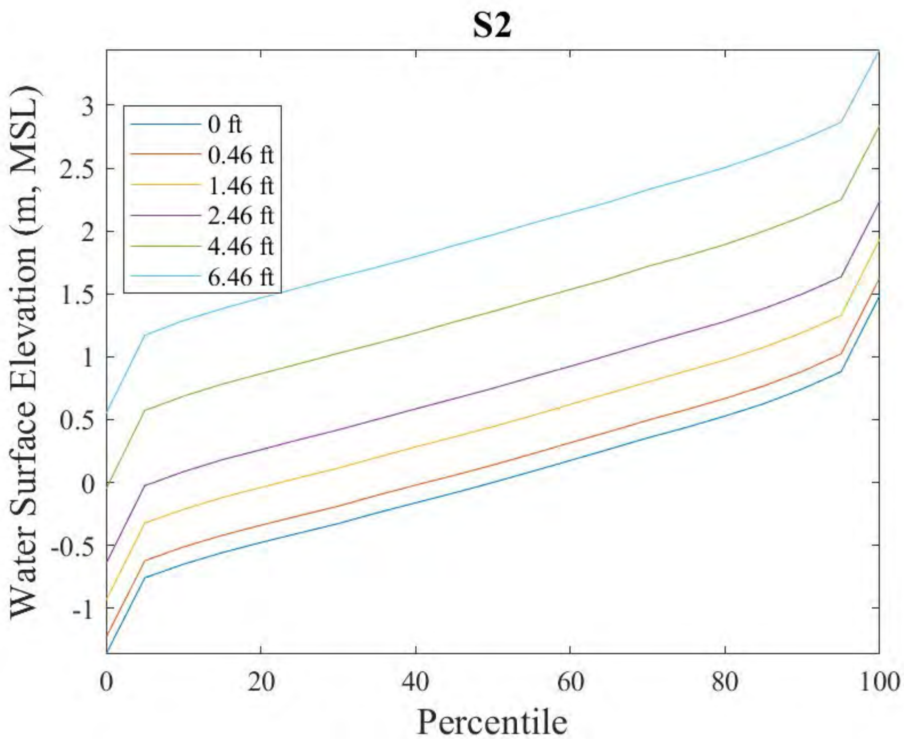


Figure 556. Alt 3b, S5 WSE Variation with SLR.

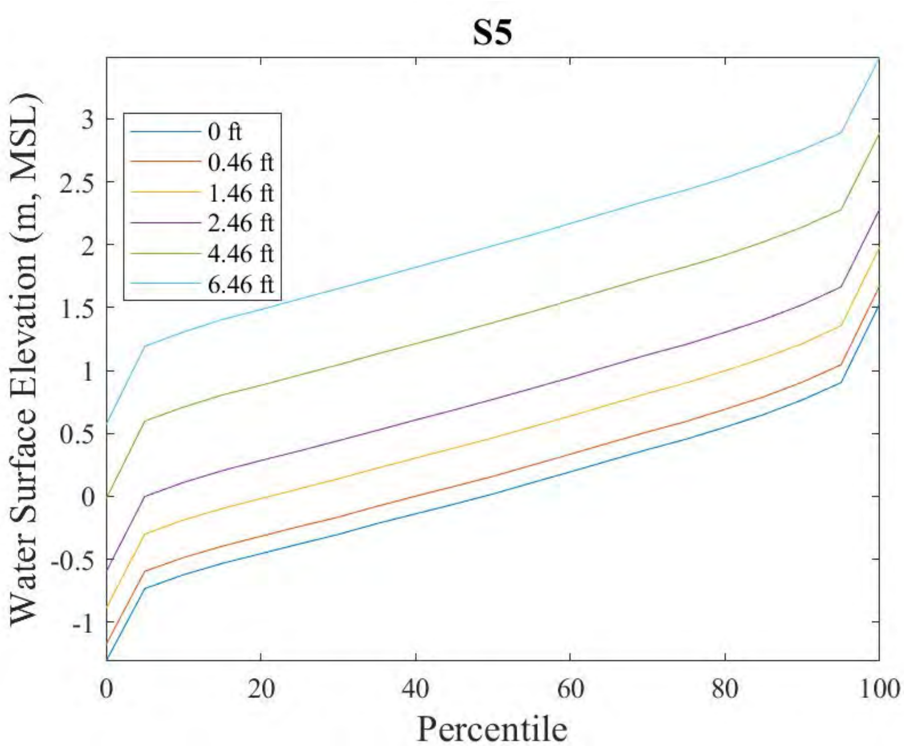


Figure 557. Alt 3b, The Battery WSE Variation with SLR.

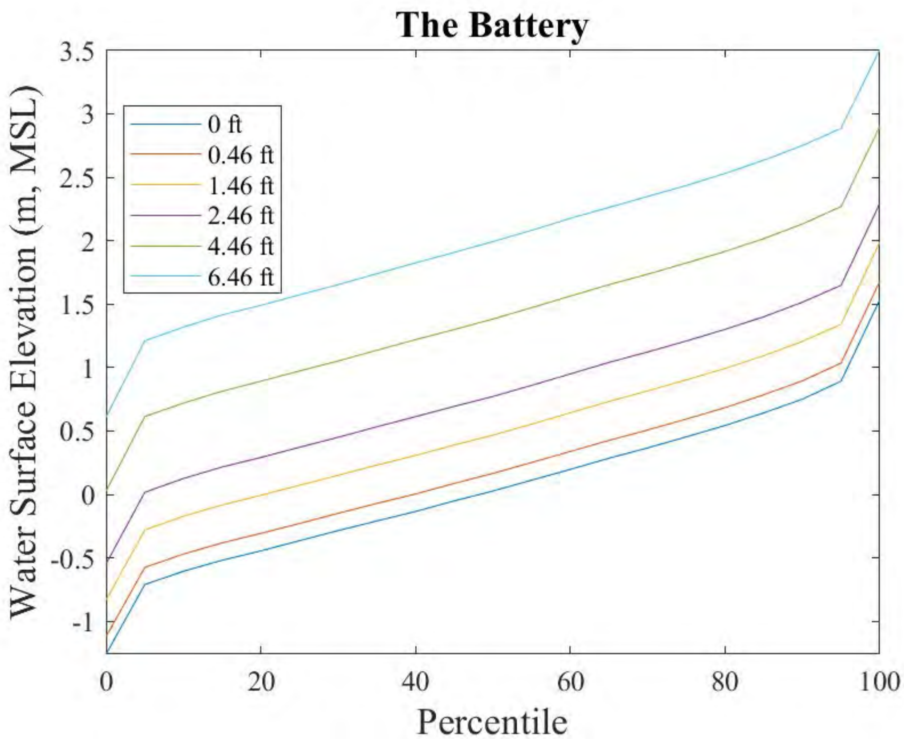


Figure 558. Alt 3b, Manhattan WSE Variation with SLR.

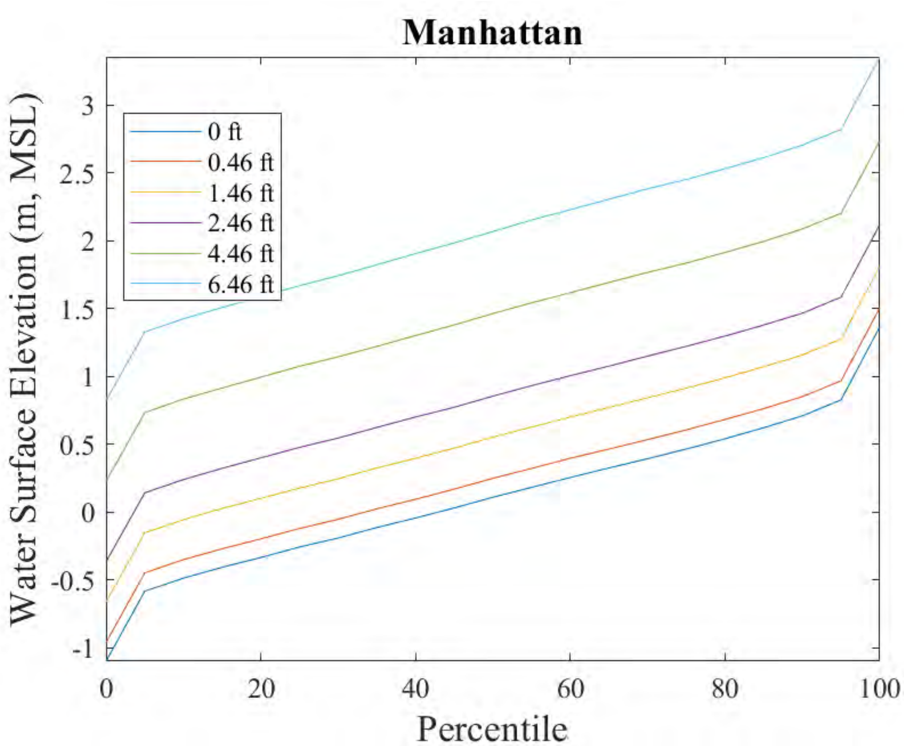


Figure 559. Alt 3b, Jamaica Bay WSE Variation with SLR.

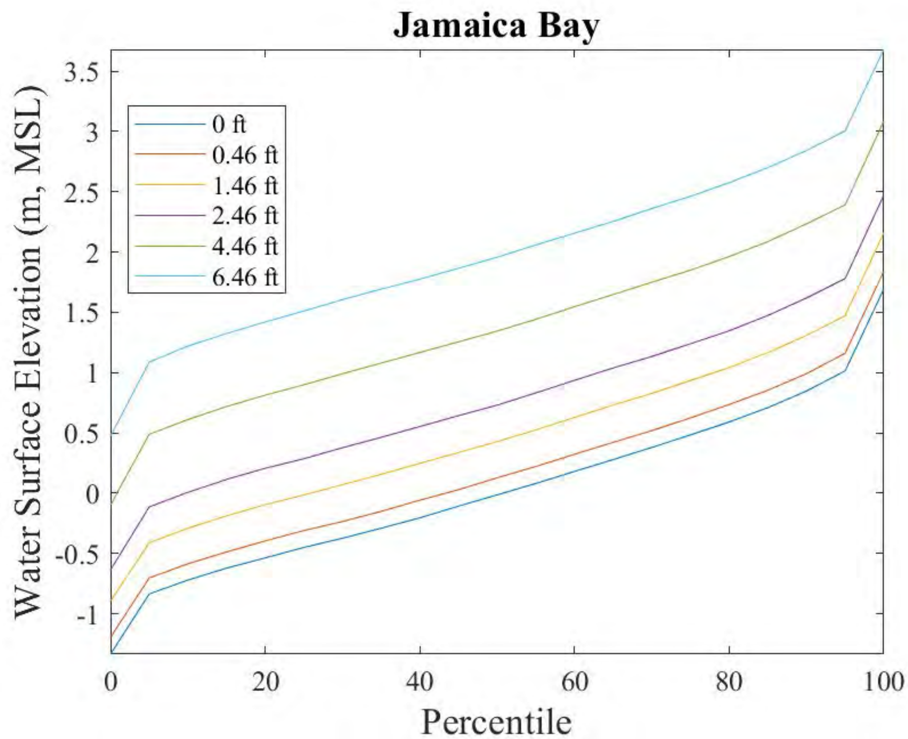


Figure 560. Alt 3b, Jamaica Bay near Spring Creek WSE Variation with SLR.

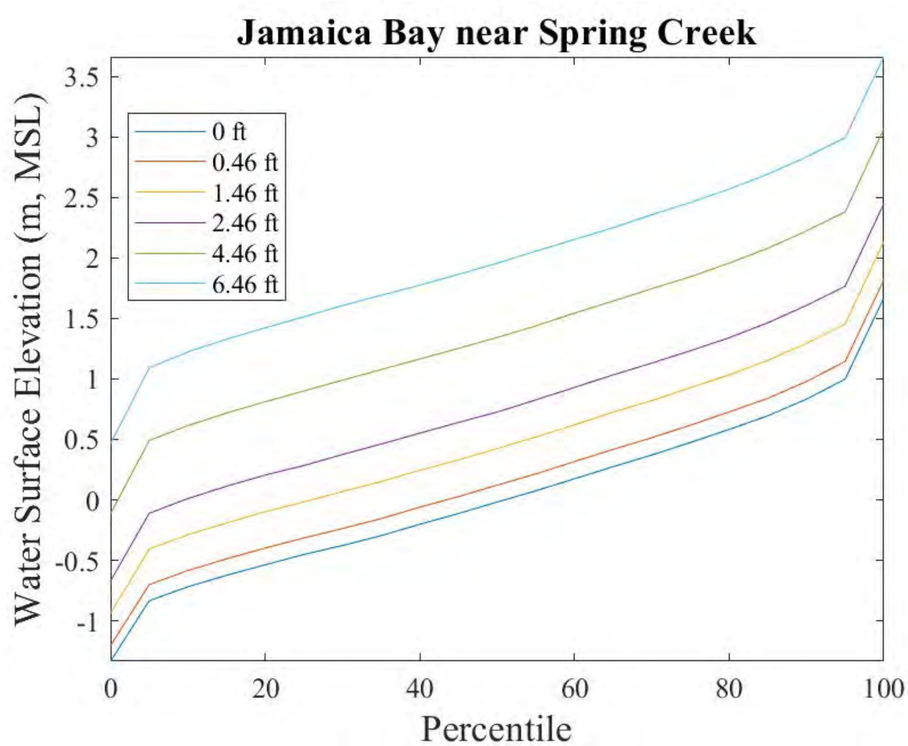


Figure 561. Alt 3b, Jamaica Bay near Grass Hassock WSE Variation with SLR.

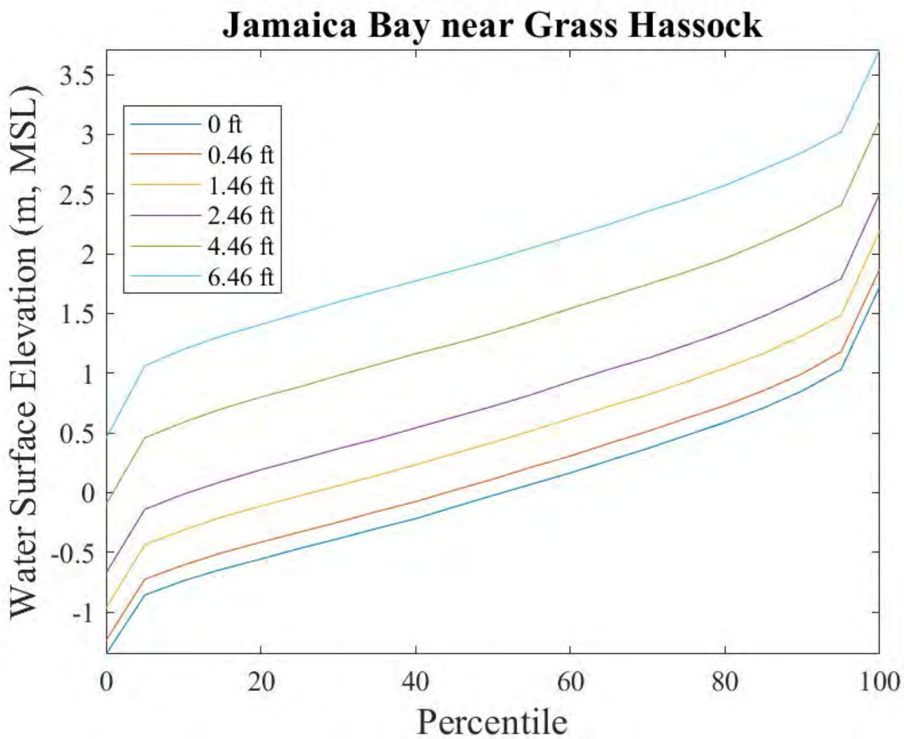


Figure 562. Alt 3b, KLGA WSE Variation with SLR.

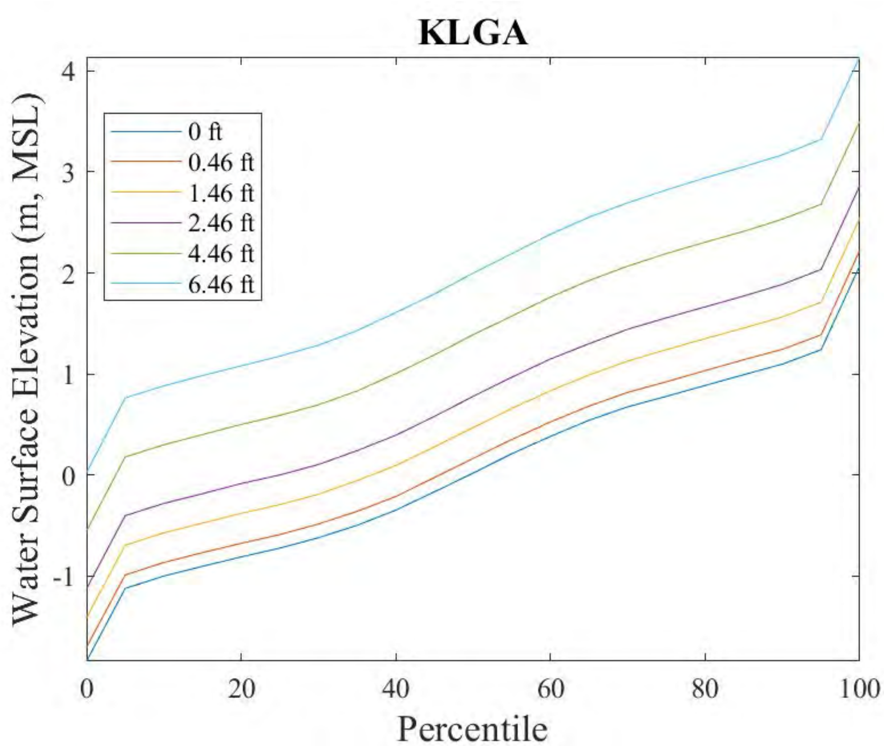


Figure 563. Alt 3b, LIS near Stepping Stone Lighthouse WSE Variation with SLR.

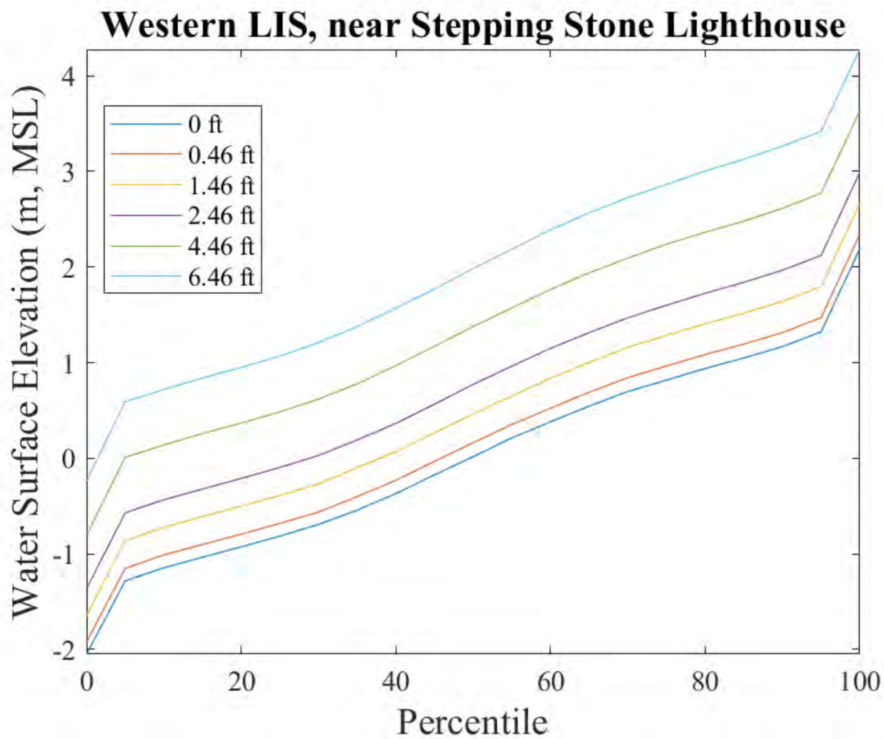


Figure 564. Alt 3b, LIS near Execution Rock Lighthouse WSE Variation with SLR.

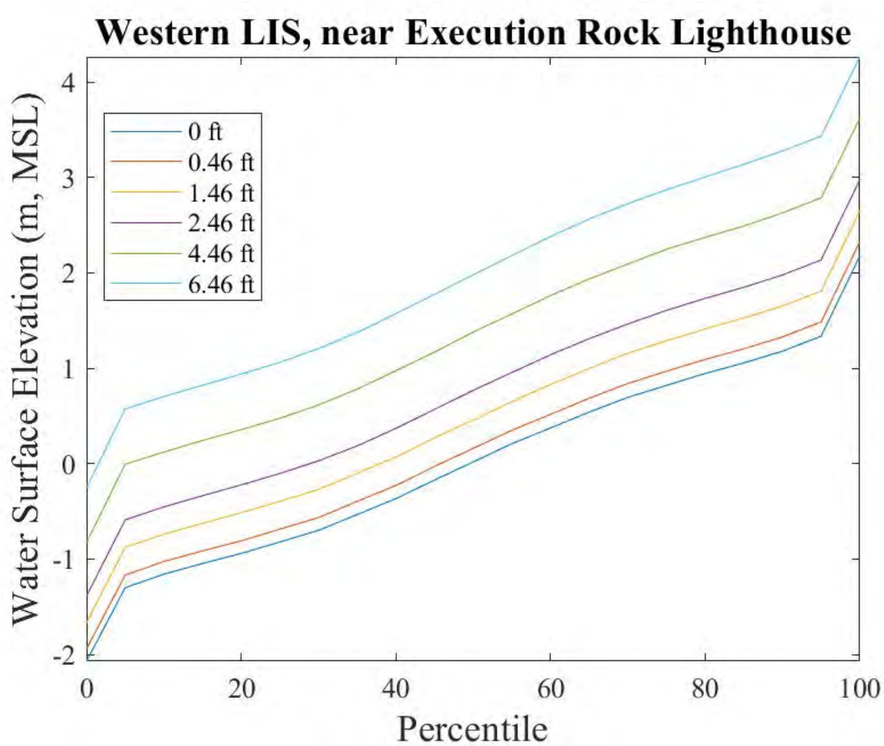


Figure 565. Alt 3b, LIS south of NY/CT border WSE Variation with SLR.

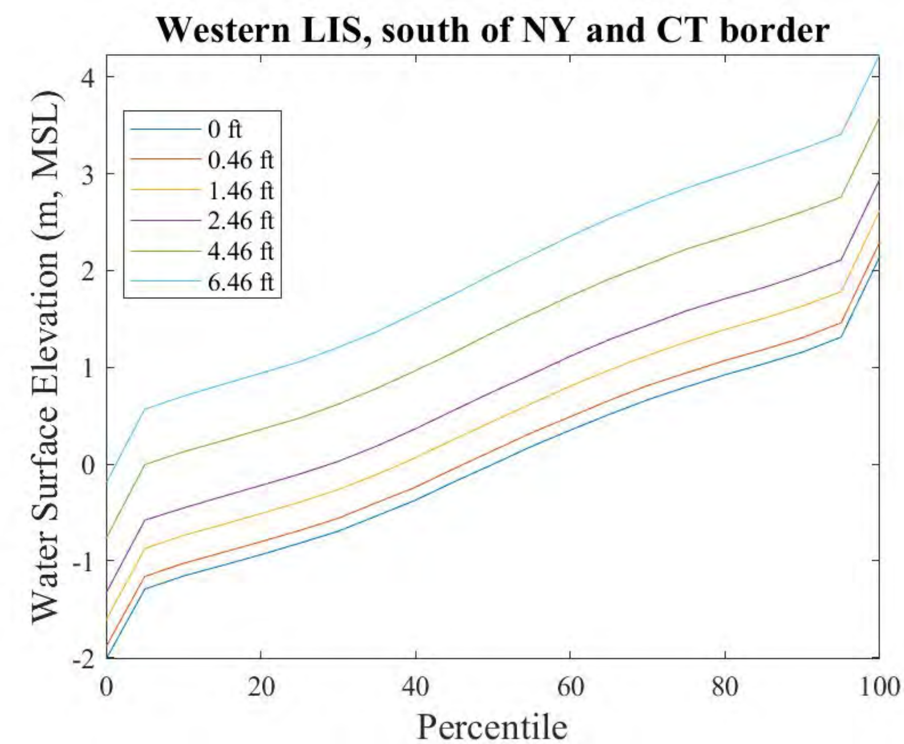


Figure 566. Alt 3b, Hudson River, Haverstraw Bay WSE Variation with SLR.

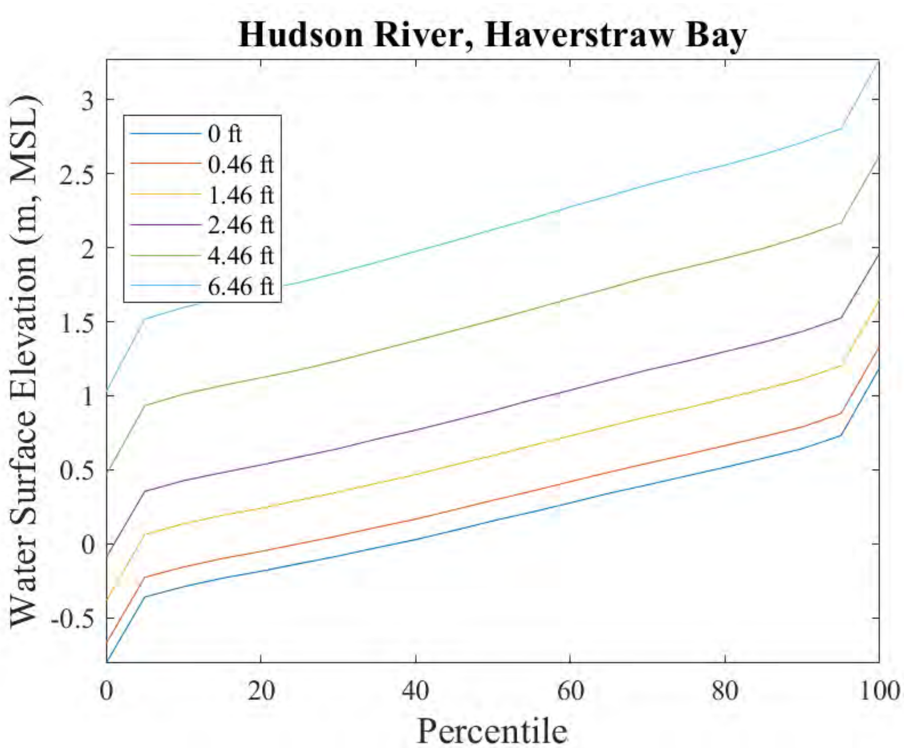


Figure 567. Alt 3b, Hudson River near Poughkeepsie WSE Variation with SLR.

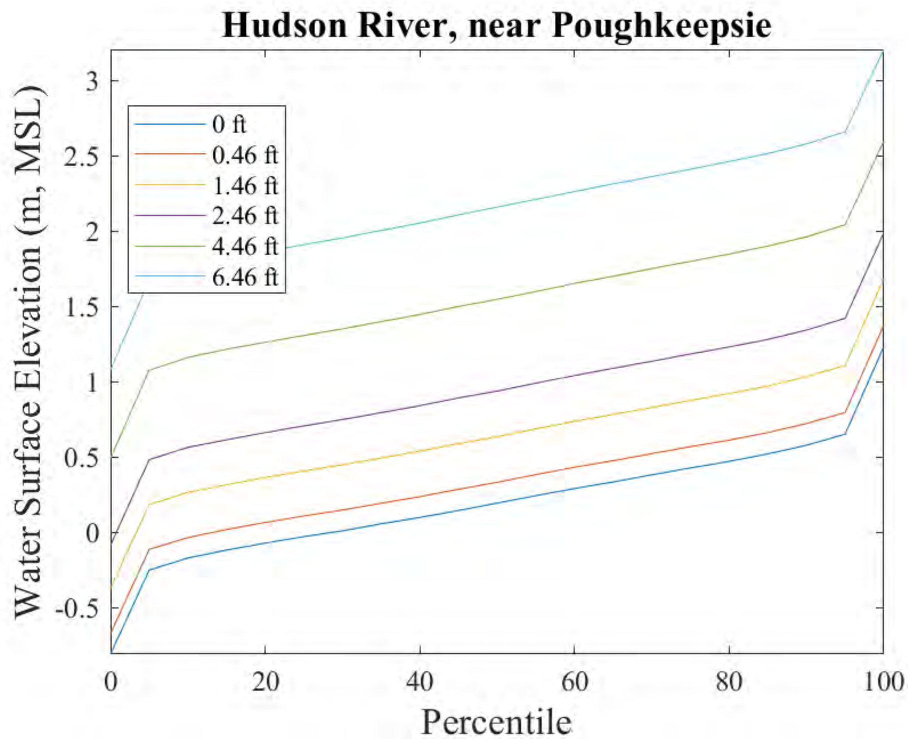


Figure 568. Alt 3b, Hudson River between Catskill and Hudson WSE Variation with SLR.

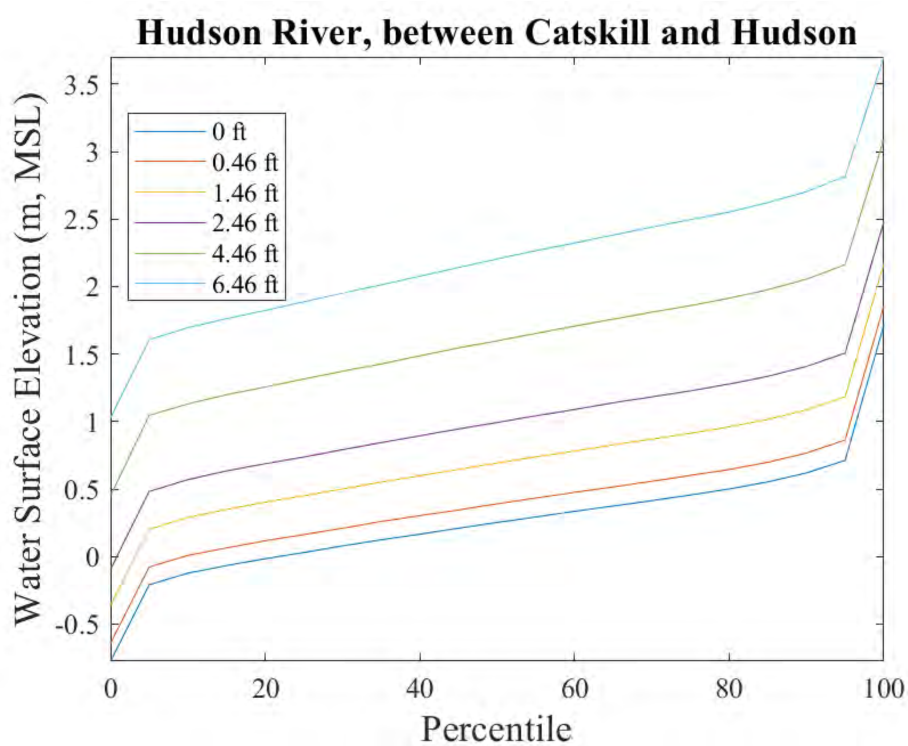
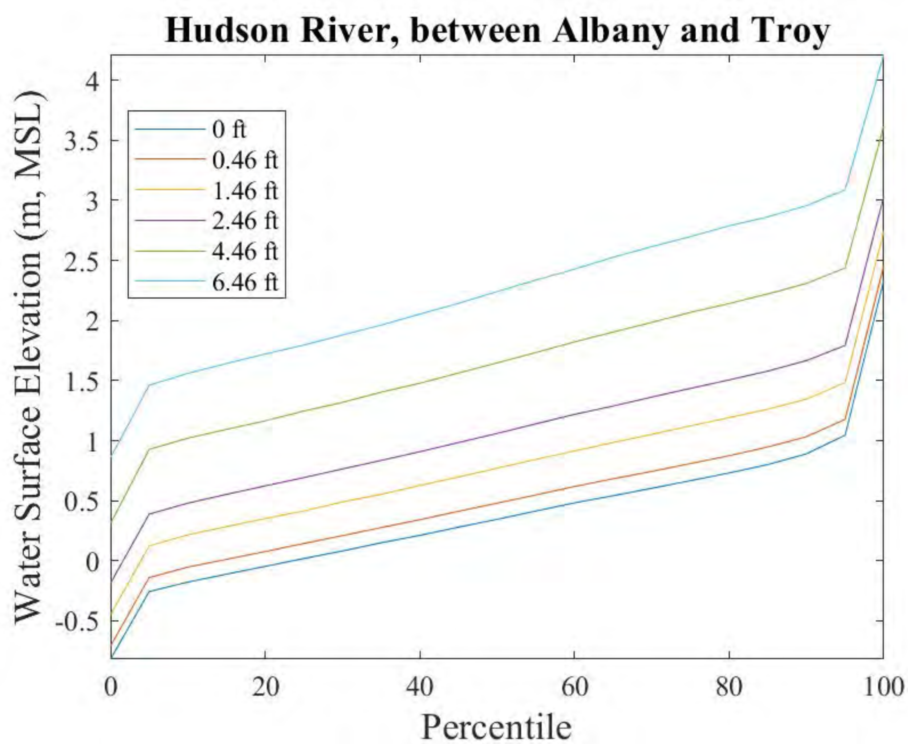


Figure 569. Alt 3b, Hudson River between Albany and Troy WSE Variation with SLR.



15.4.2 Velocity Point Percentiles

Velocity percentiles for Alternative 3b for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 570 to Figure 605. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prisms.

Figure 570. Alt 3b, V1 Velocity Variation with SLR.

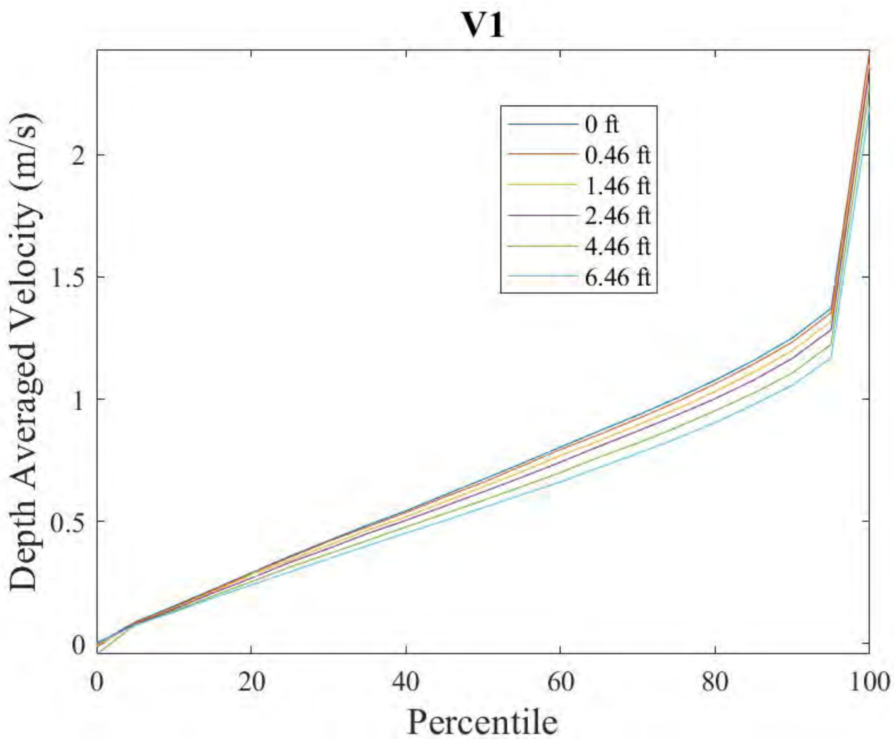


Figure 571. Alt 3b, V2 Velocity Variation with SLR.

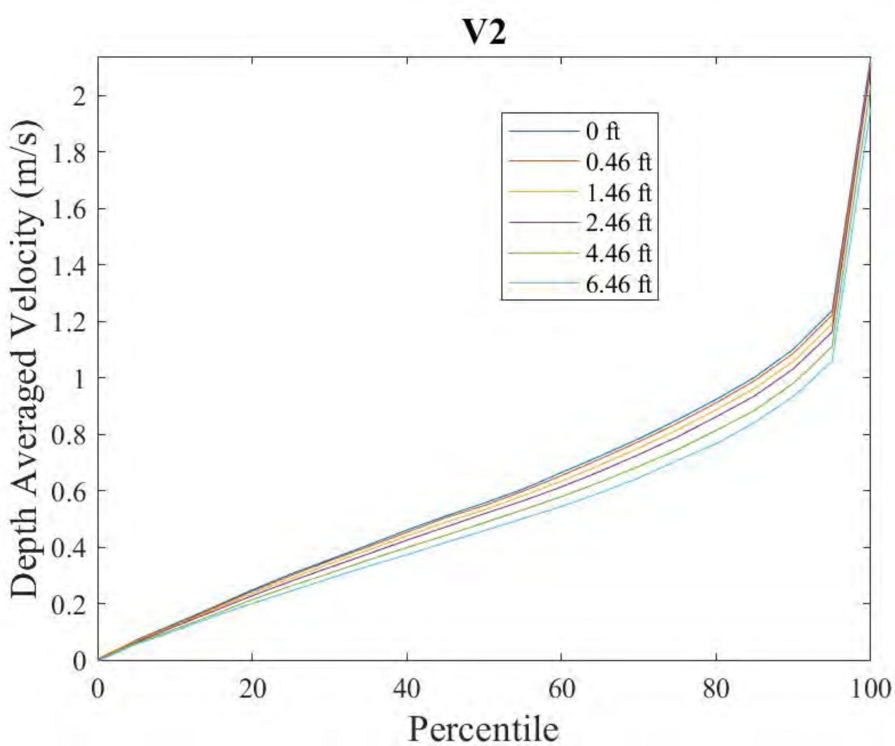


Figure 572. Alt 3b, V3 Velocity Variation with SLR.

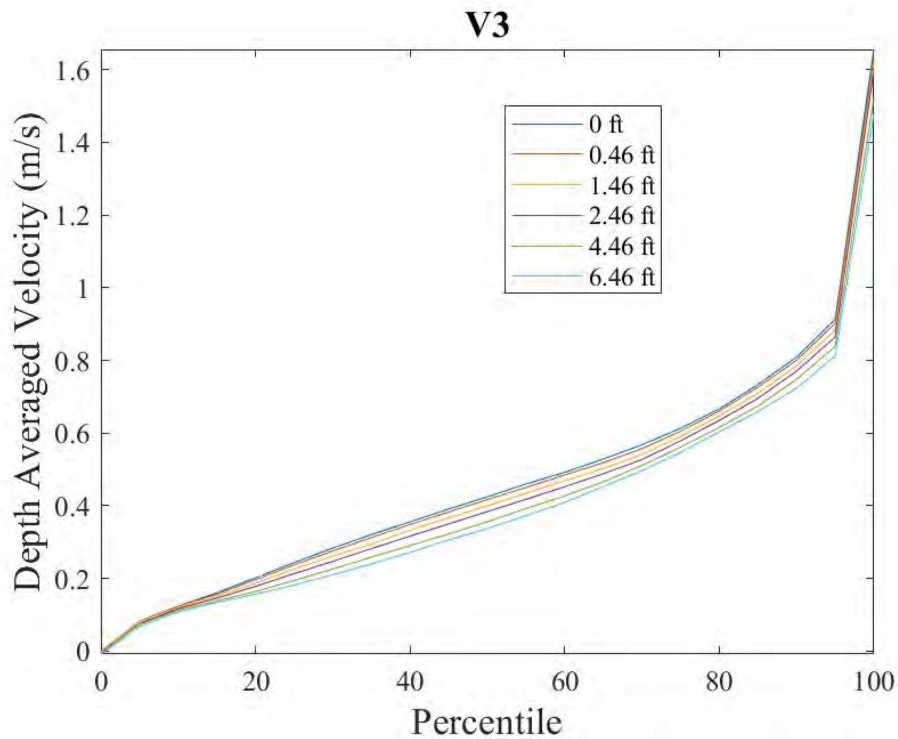


Figure 573. Alt 3b, V4 Velocity Variation with SLR.

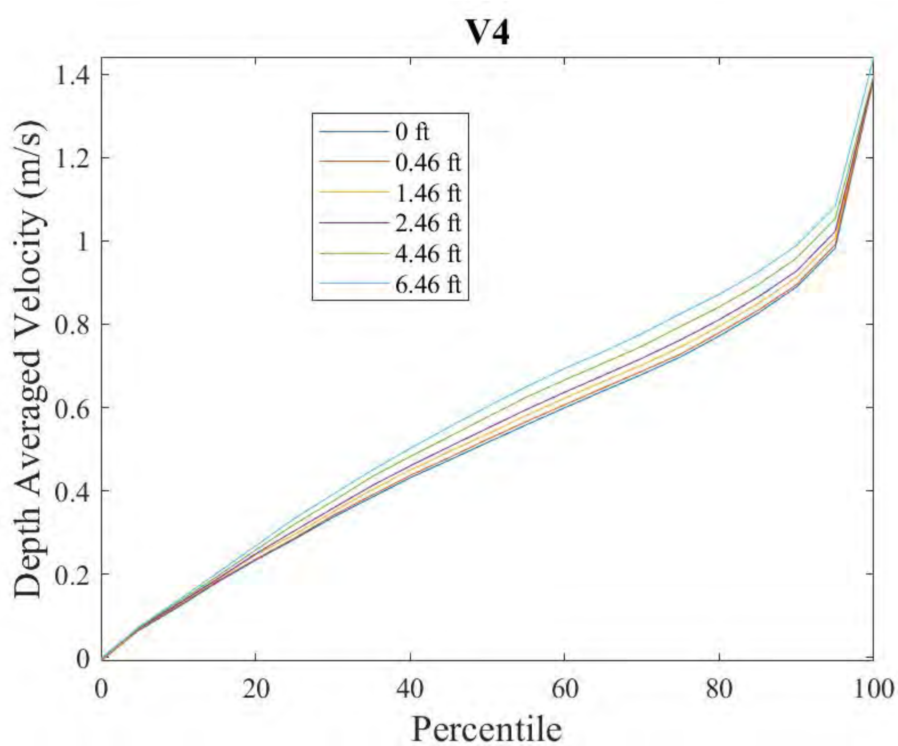


Figure 574. Alt 3b, V5 Velocity Variation with SLR.

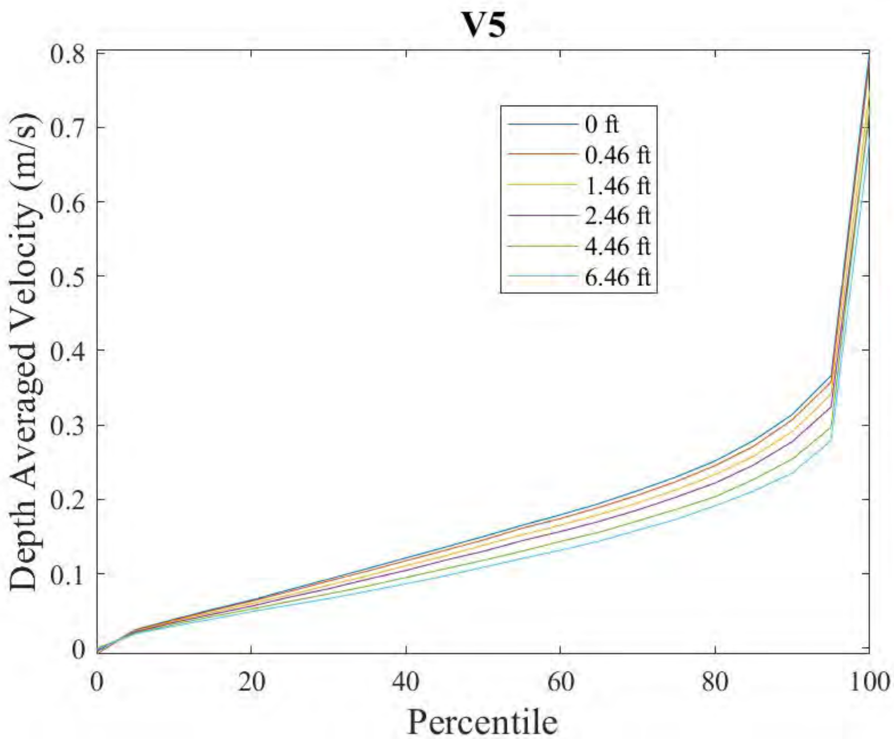


Figure 575. Alt 3b, V6 Velocity Variation with SLR.

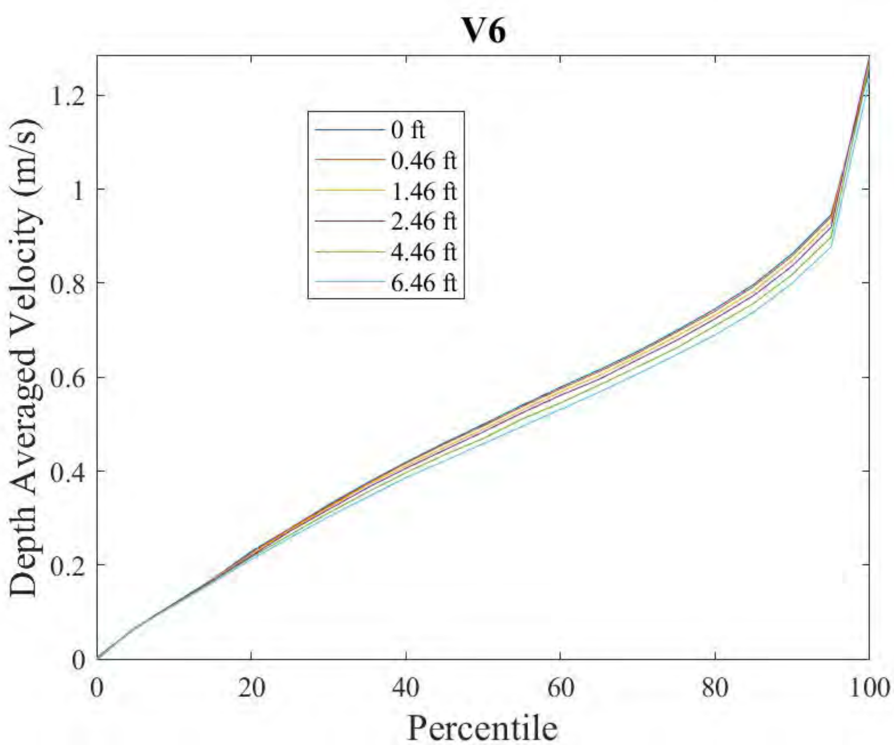


Figure 576. Alt 3b, S1 Velocity Variation with SLR.

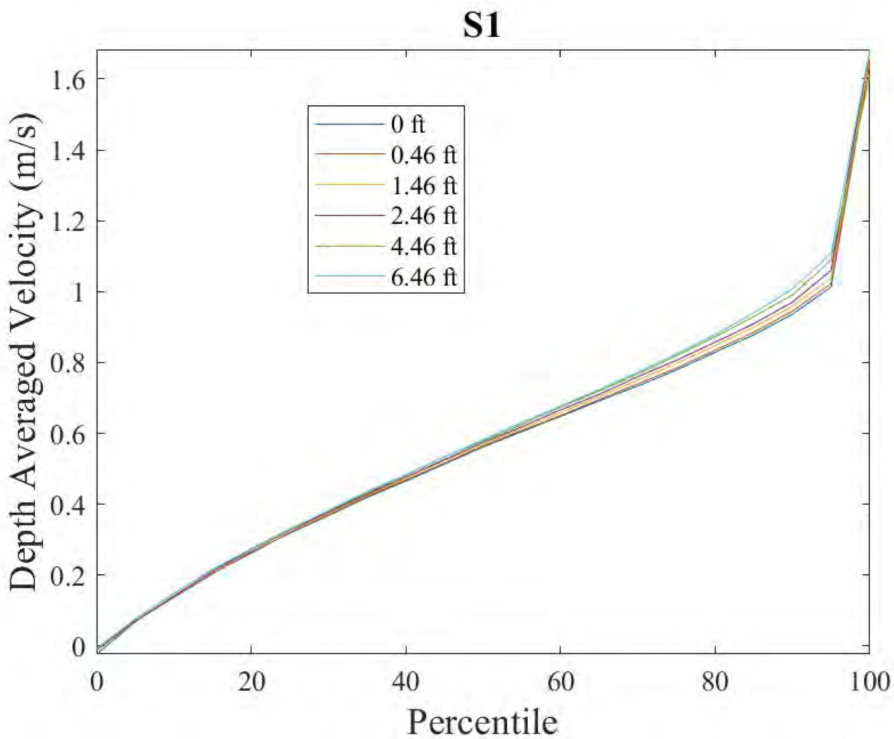


Figure 577. Alt 3b, S2 Velocity Variation with SLR.

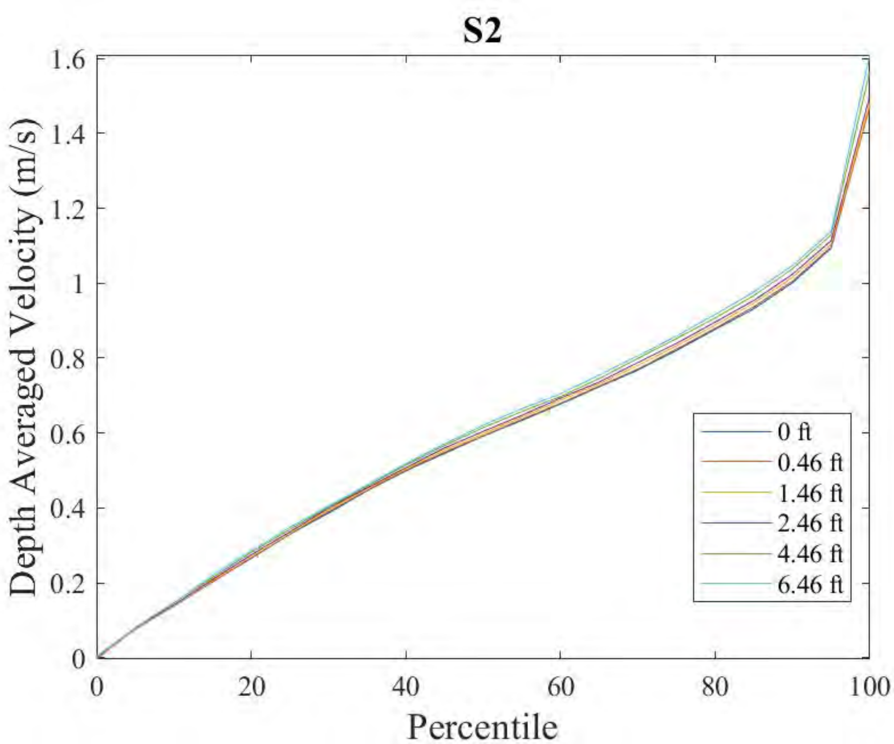


Figure 578. Alt 3b, S3 Velocity Variation with SLR.

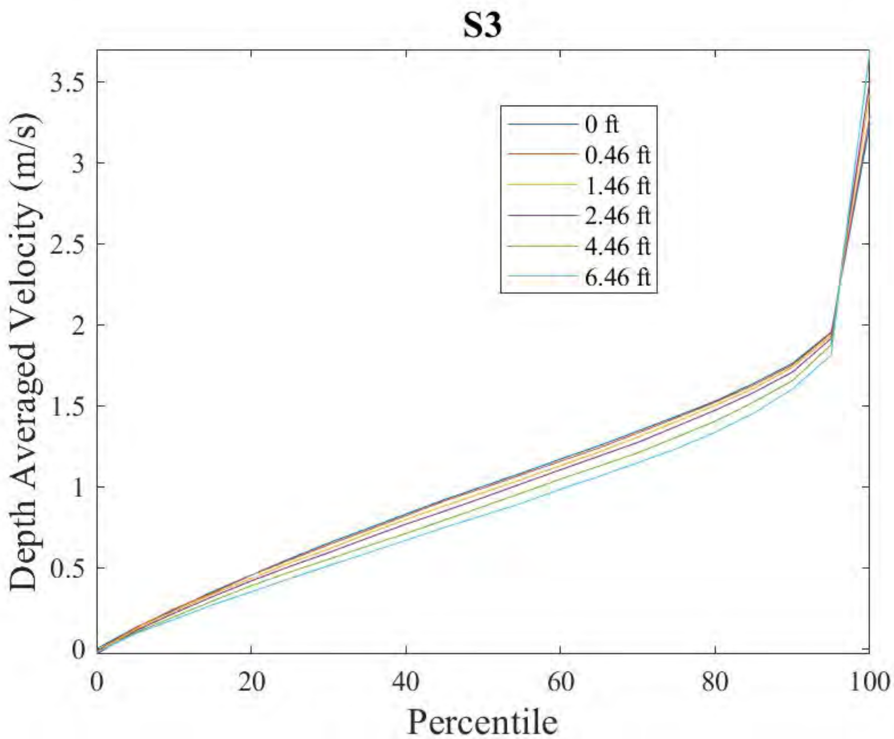


Figure 579. Alt 3b, S4 Velocity Variation with SLR.

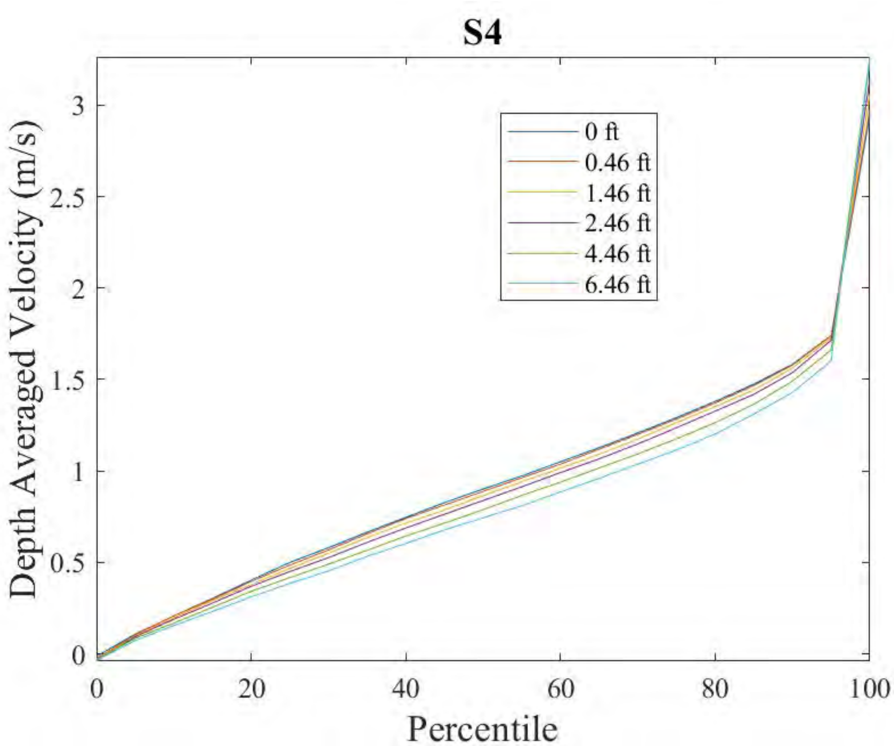


Figure 580. Alt 3b, S5 Velocity Variation with SLR.

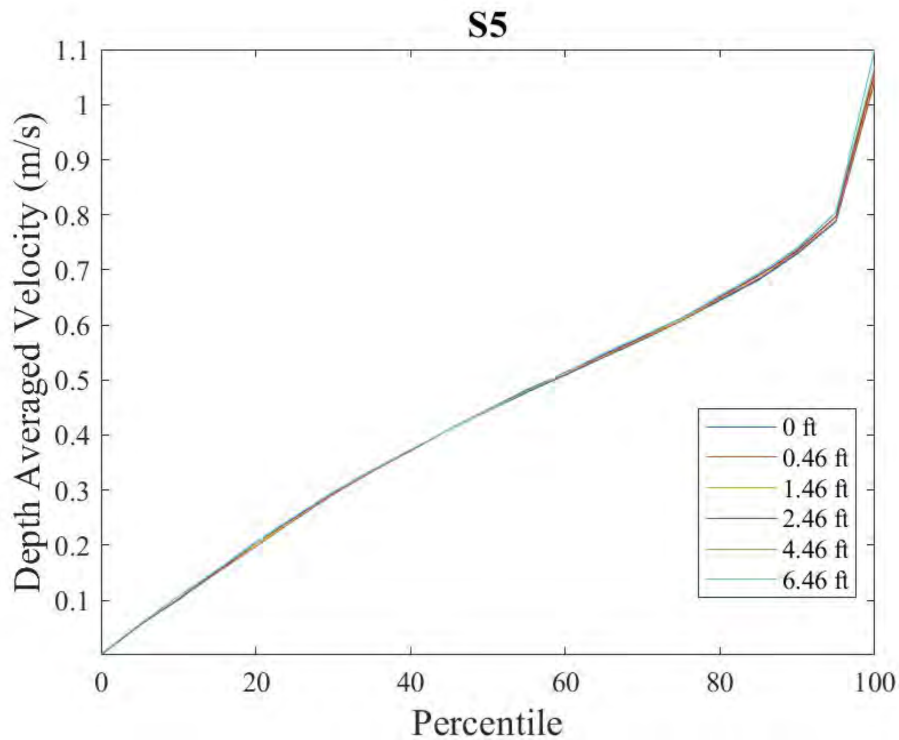


Figure 581. Alt 3b, T1 Velocity Variation with SLR.

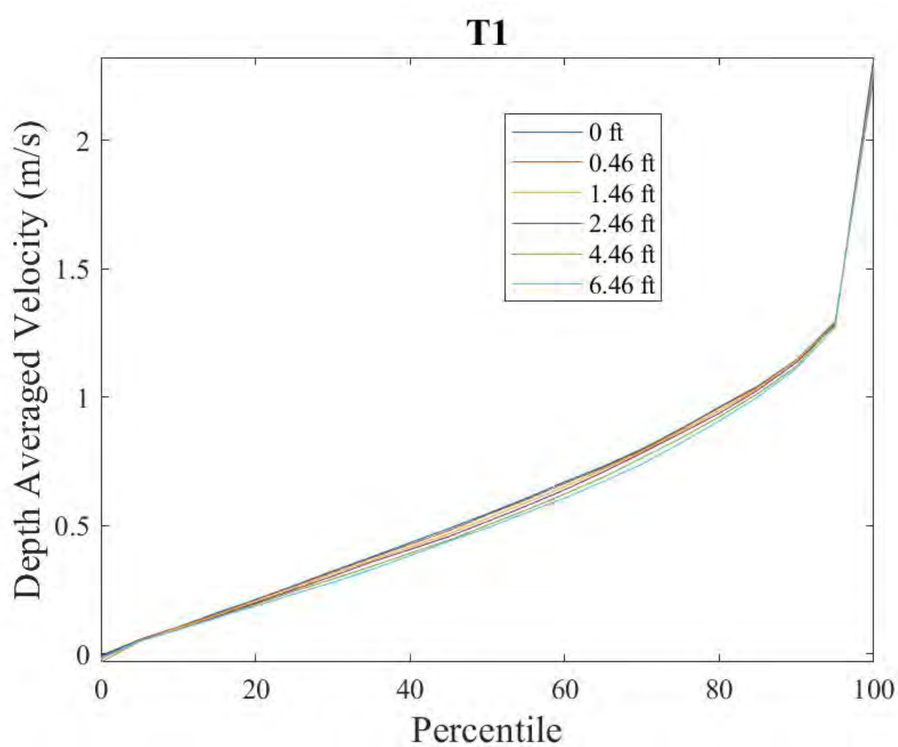


Figure 582. Alt 3b, T2 Velocity Variation with SLR.

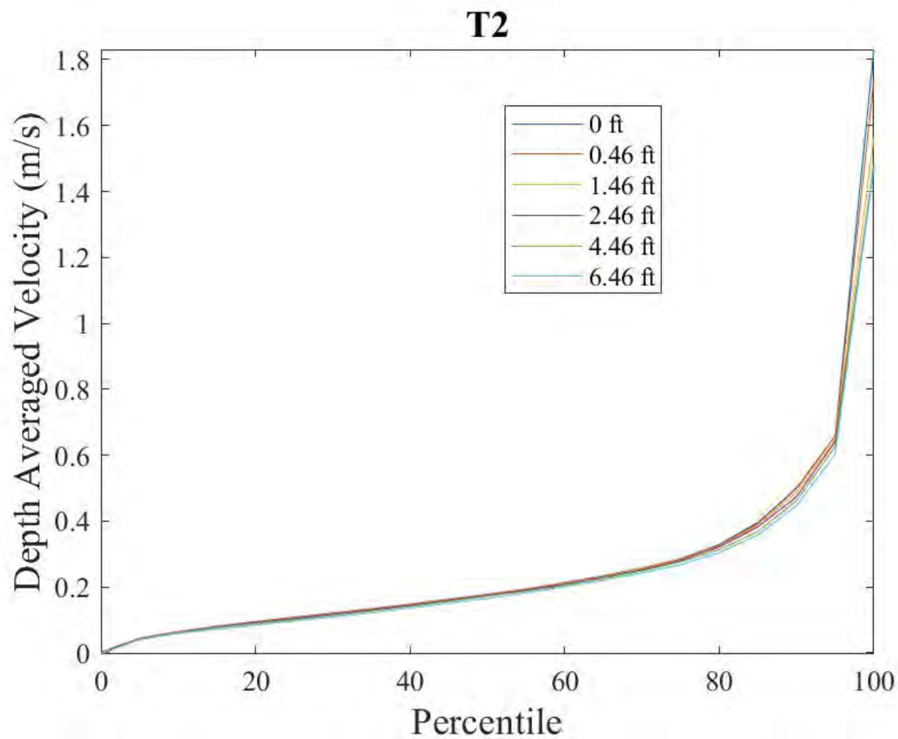


Figure 583. Alt 3b, T3 Velocity Variation with SLR.

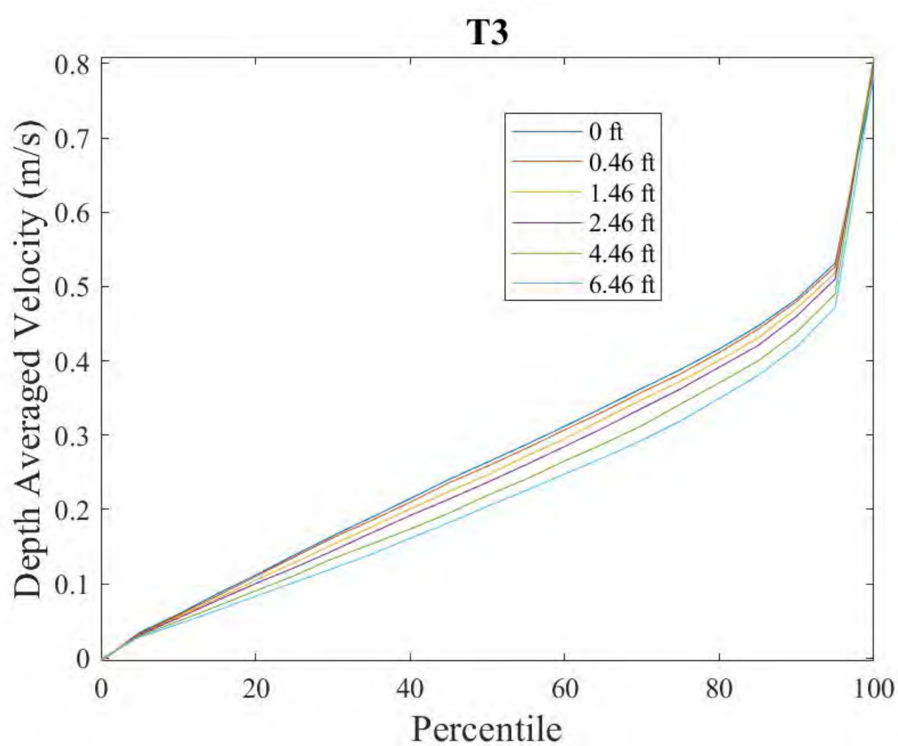


Figure 584. Alt 3b, T4 Velocity Variation with SLR.

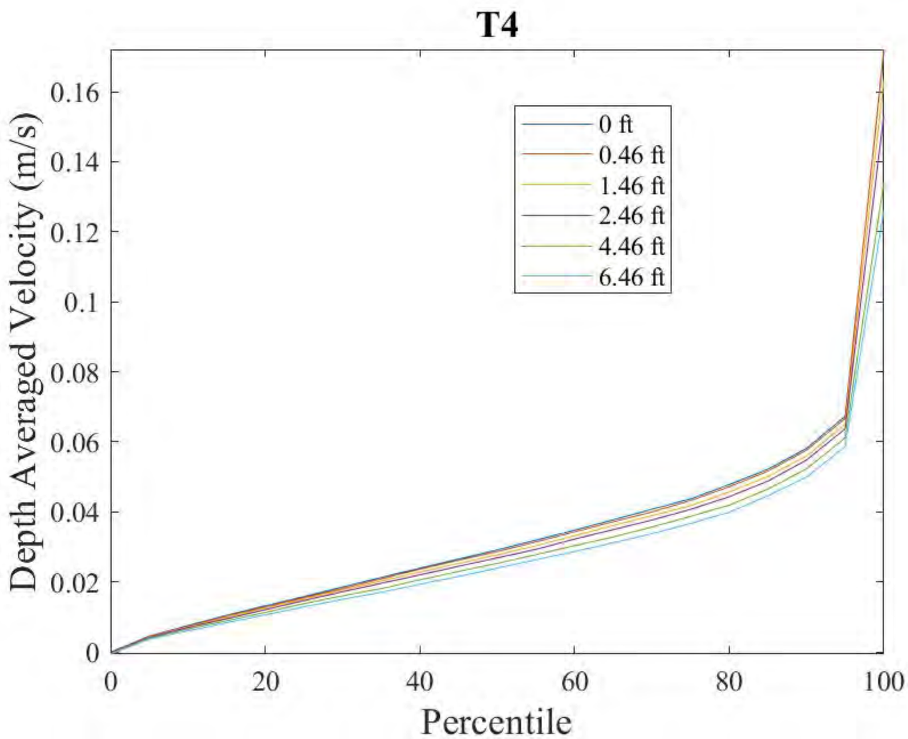


Figure 585. Alt 3b, T5 Velocity Variation with SLR.

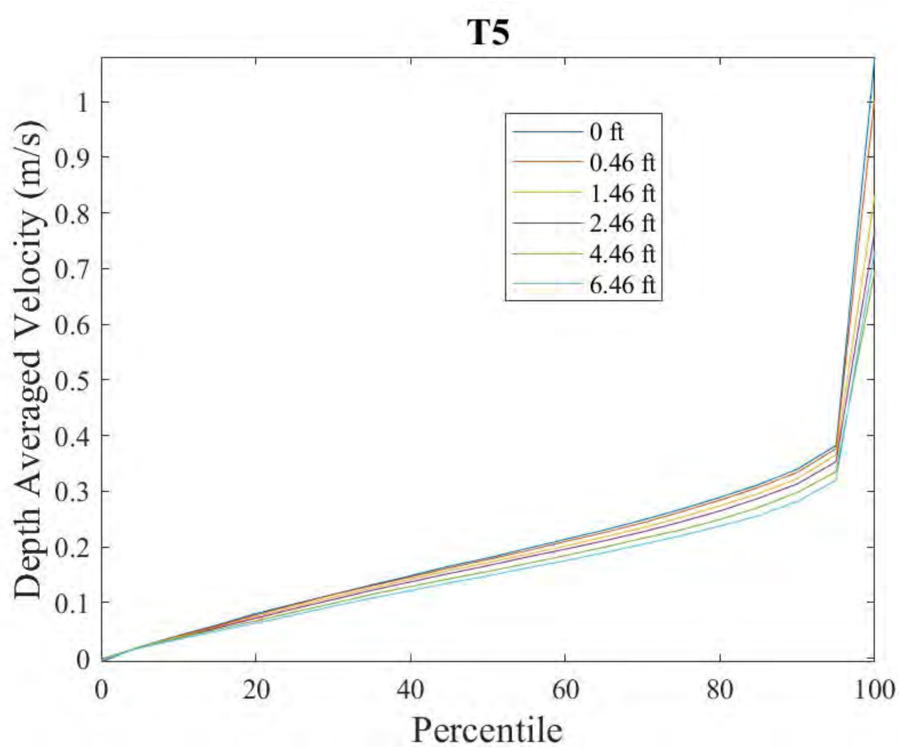


Figure 586. Alt 3b, R1 Velocity Variation with SLR.

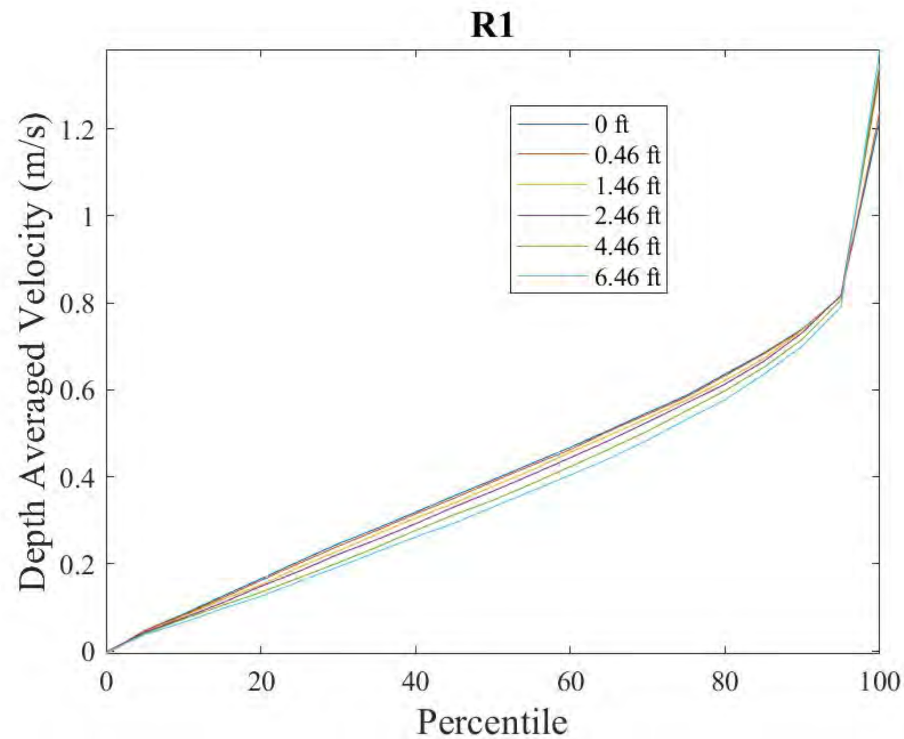


Figure 587. Alt 3b, Sandy Hook Velocity Variation with SLR.

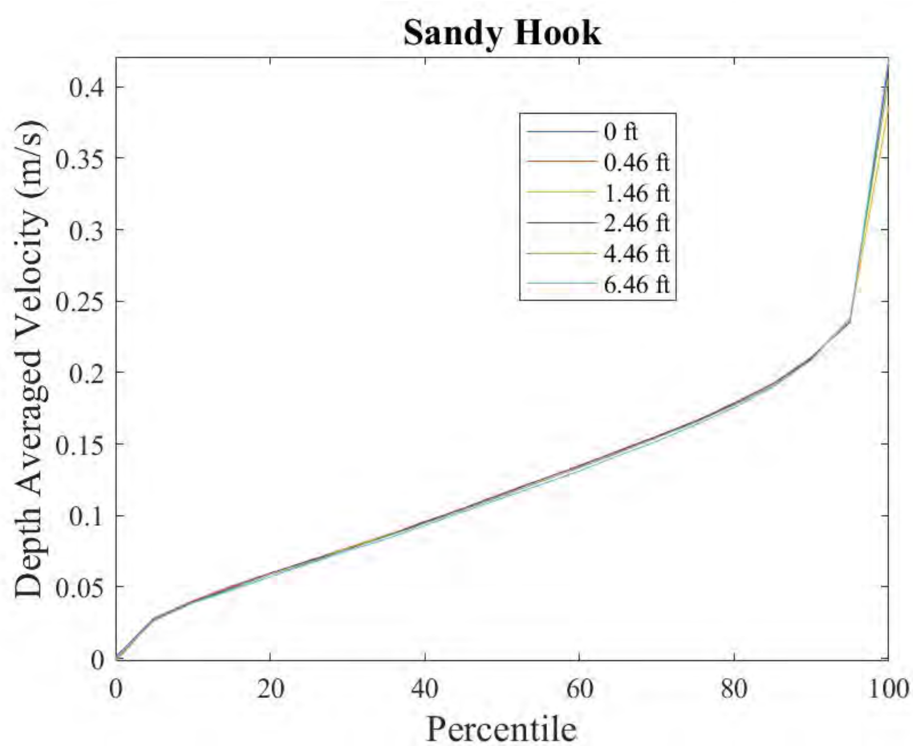


Figure 588. Alt 3b, Fresh Kills Velocity Variation with SLR.

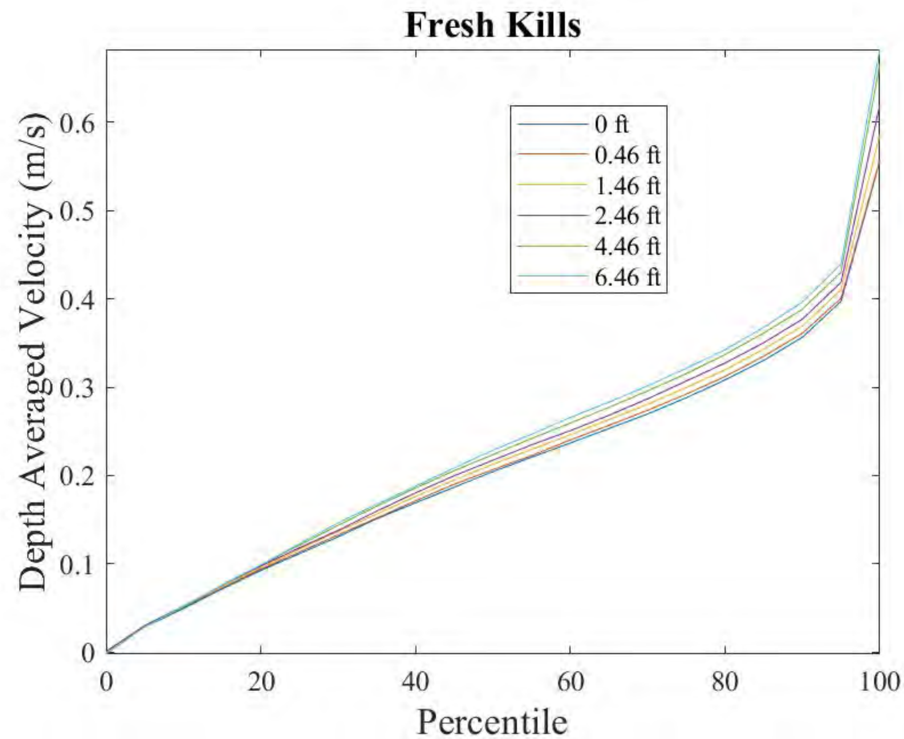


Figure 589. Alt 3b, Mariners Harbor Velocity Variation with SLR.

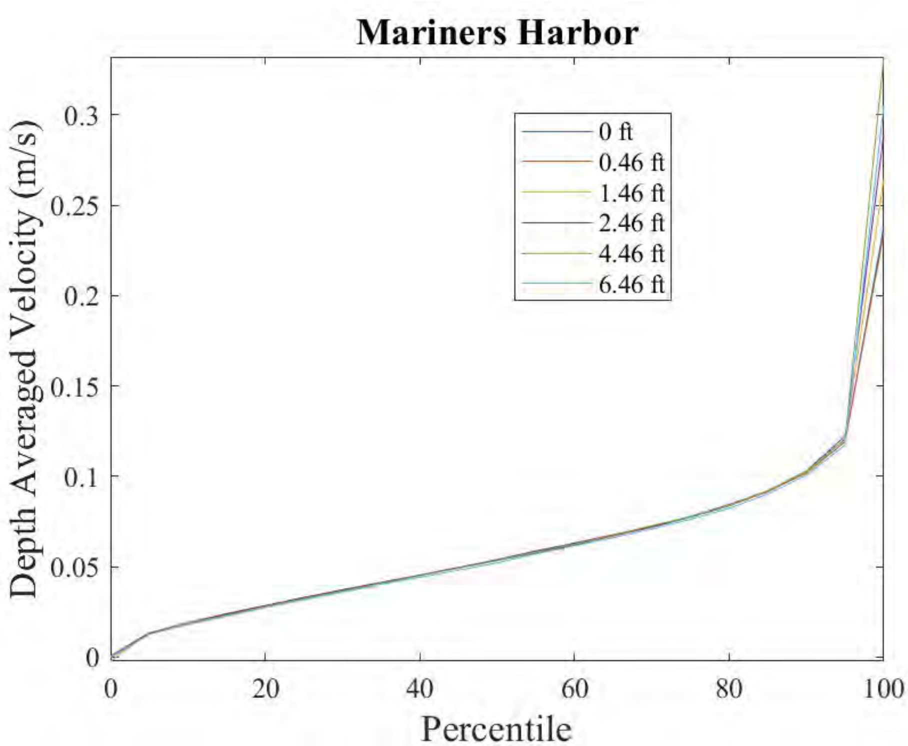


Figure 590. Alt 3b, North Reach Velocity Variation with SLR.

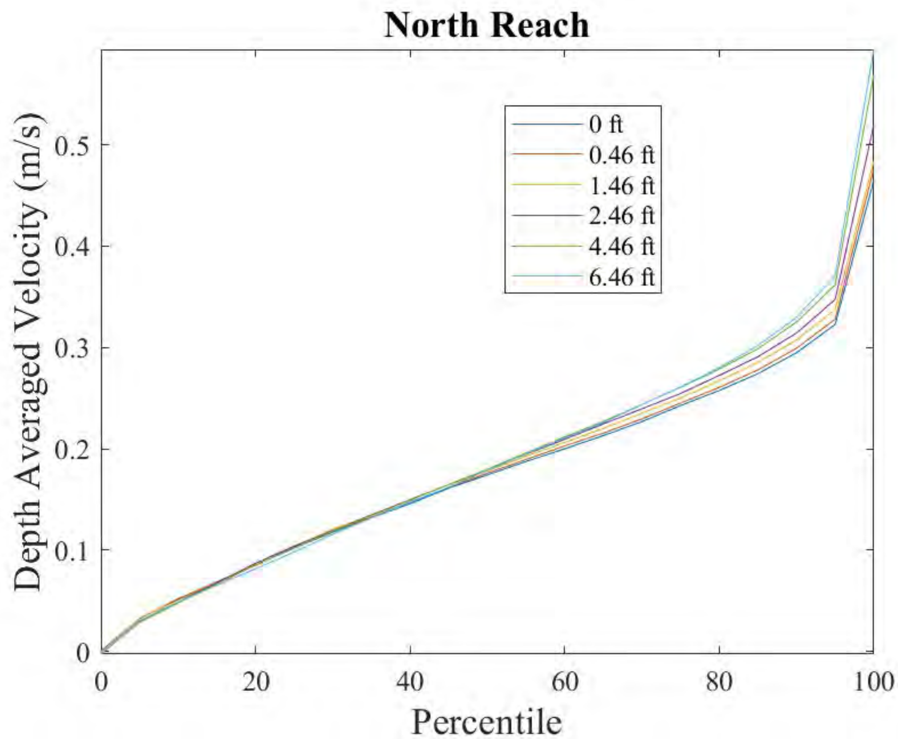


Figure 591. Alt 3b, Hackensack River Velocity Variation with SLR.

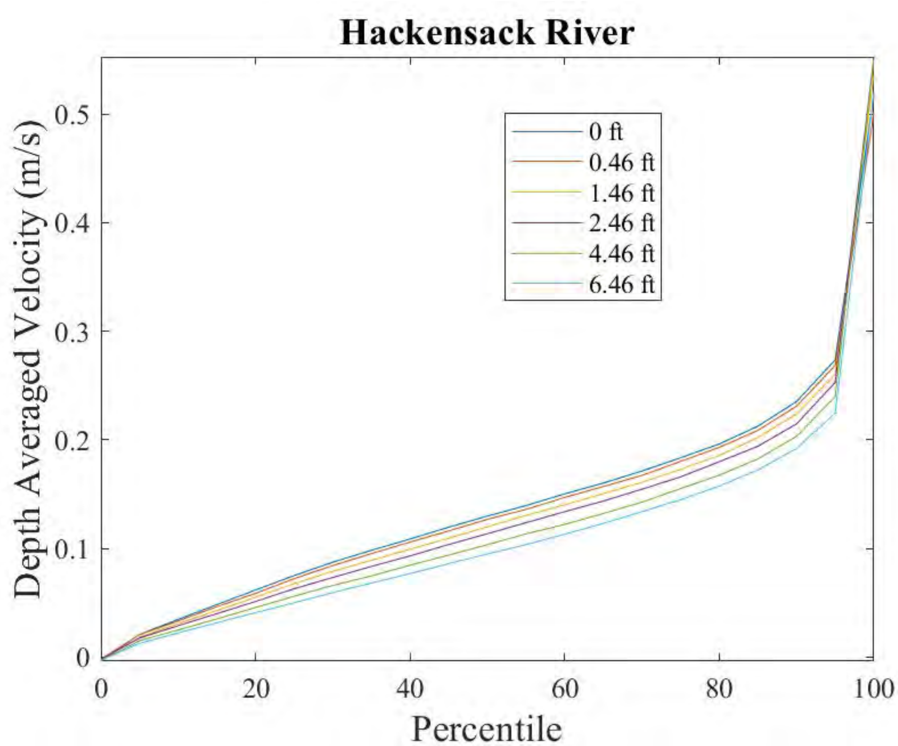


Figure 592. Alt 3b, Robbins Reef Velocity Variation with SLR.

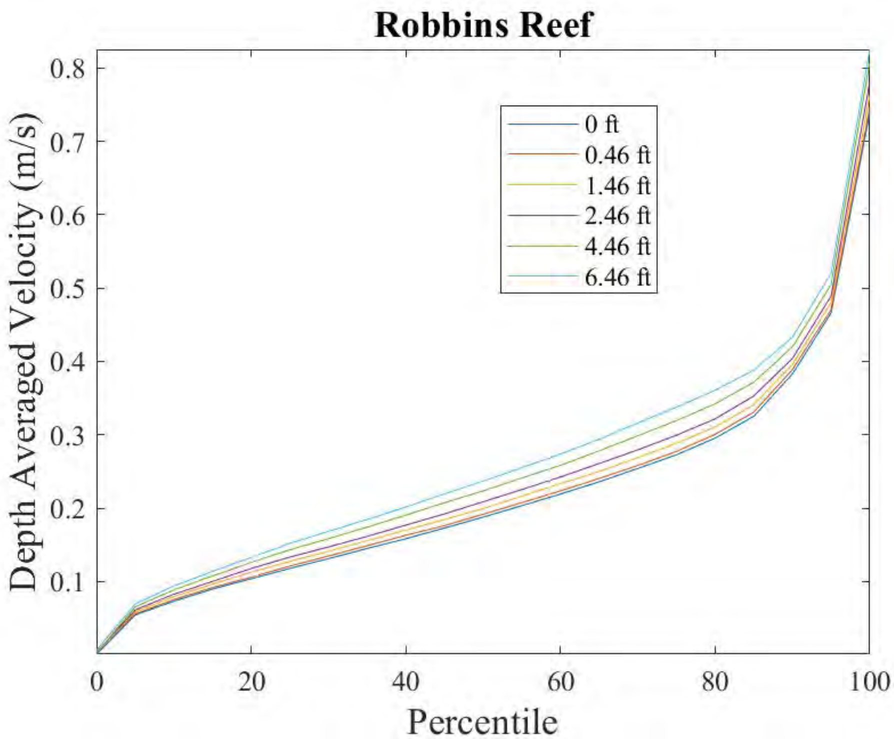


Figure 593. Alt 3b, The Battery Velocity Variation with SLR.

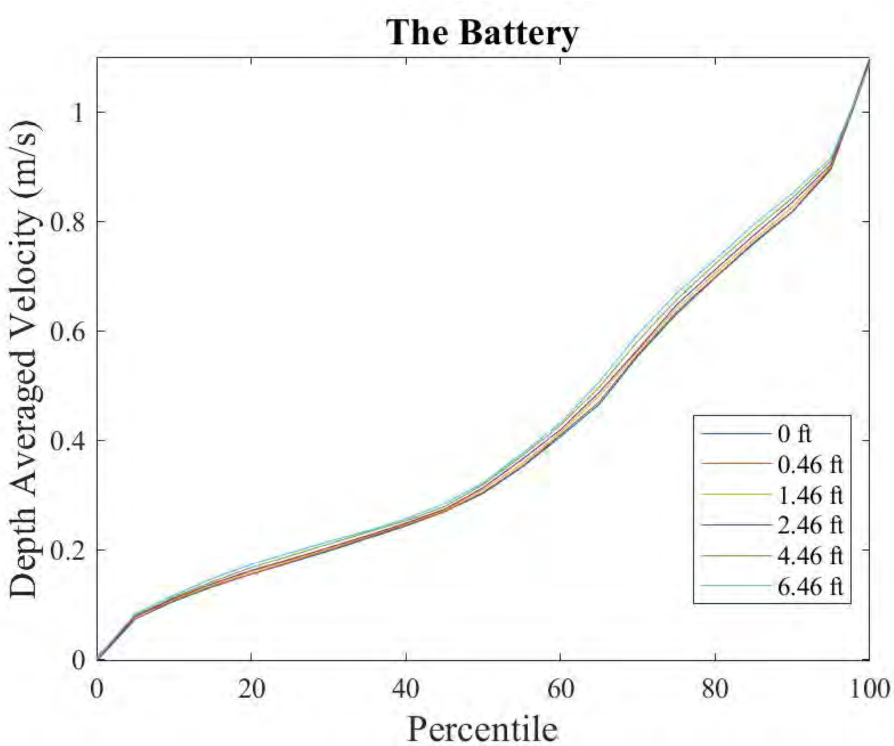


Figure 594. Alt 3b, Manhattan Velocity Variation with SLR.

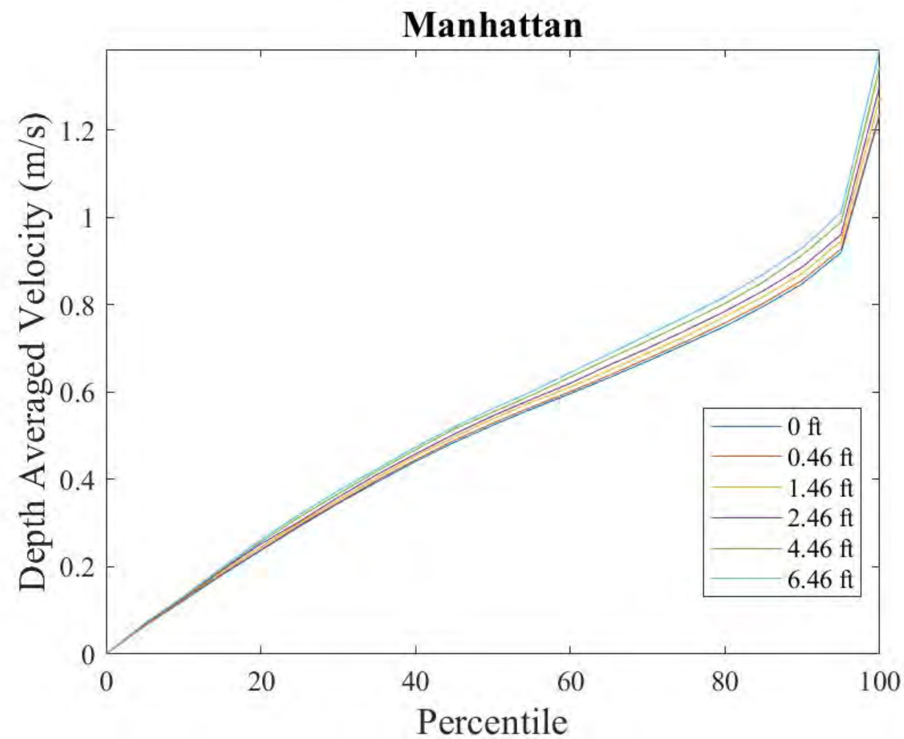


Figure 595. Alt 3b, Hudson River, Haverstraw Bay Velocity Variation with SLR.

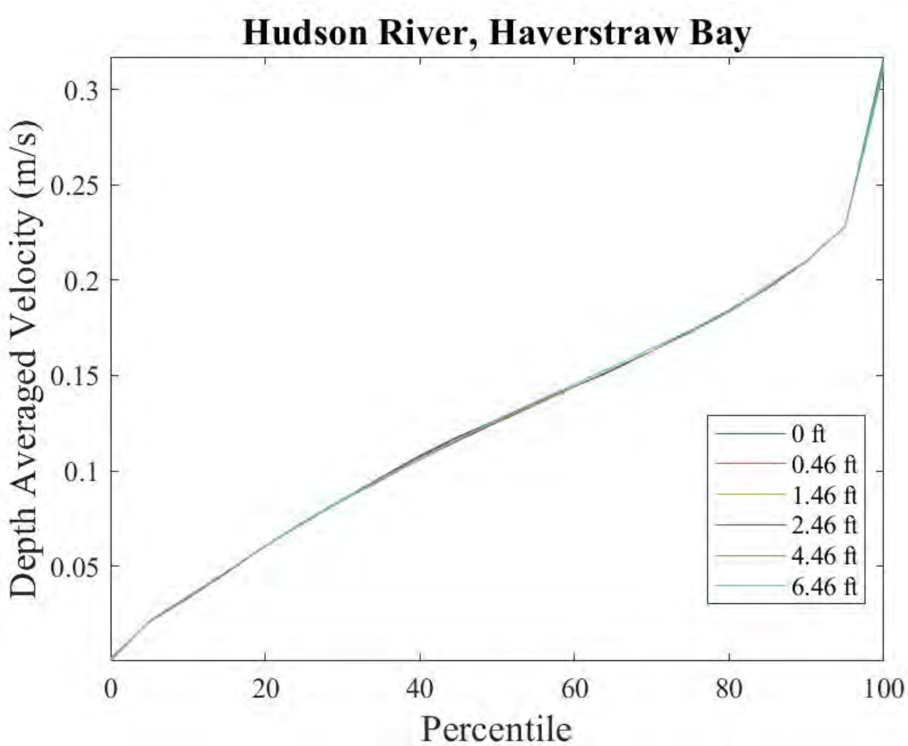


Figure 596. Alt 3b, Hudson River near Poughkeepsie Velocity Variation with SLR.

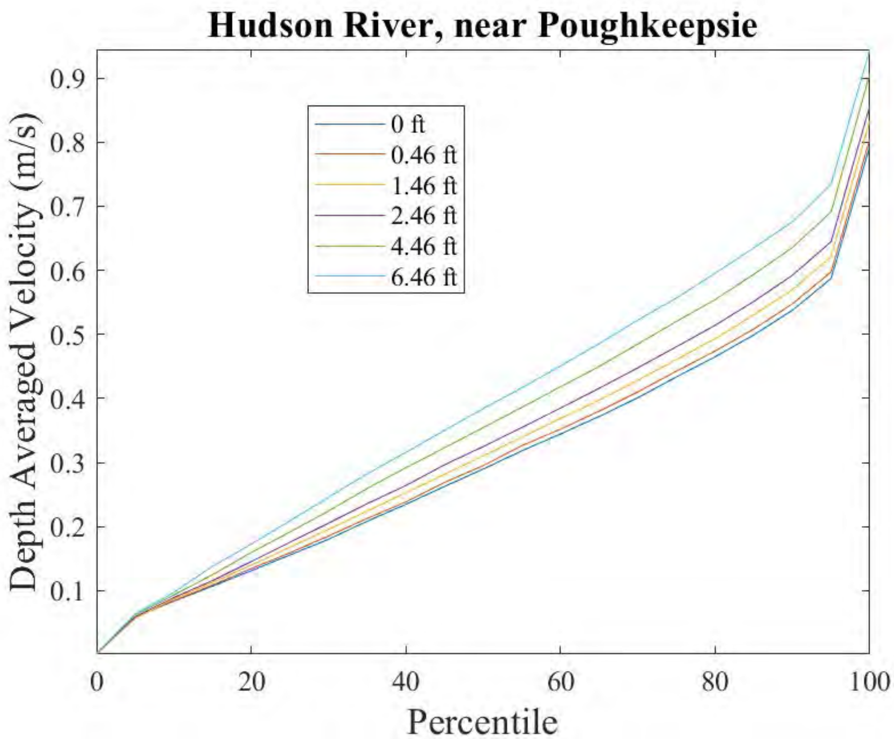


Figure 597. Alt 3b, Hudson River between Catskill and Hudson Velocity Variation with SLR.

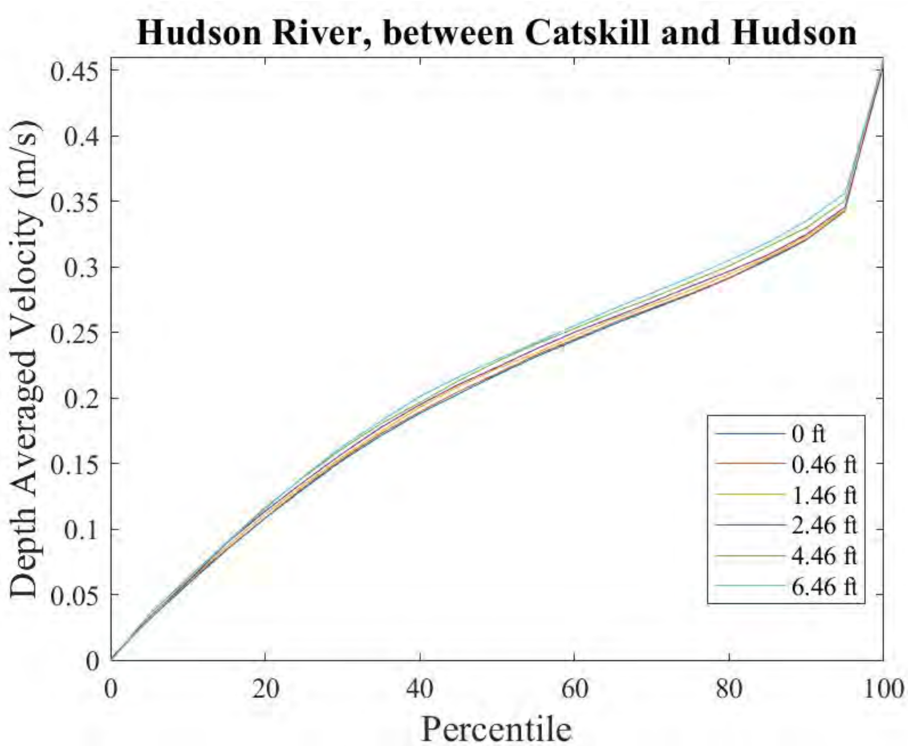


Figure 598. Alt 3b, Hudson River between Albany and Troy Velocity Variation with SLR.

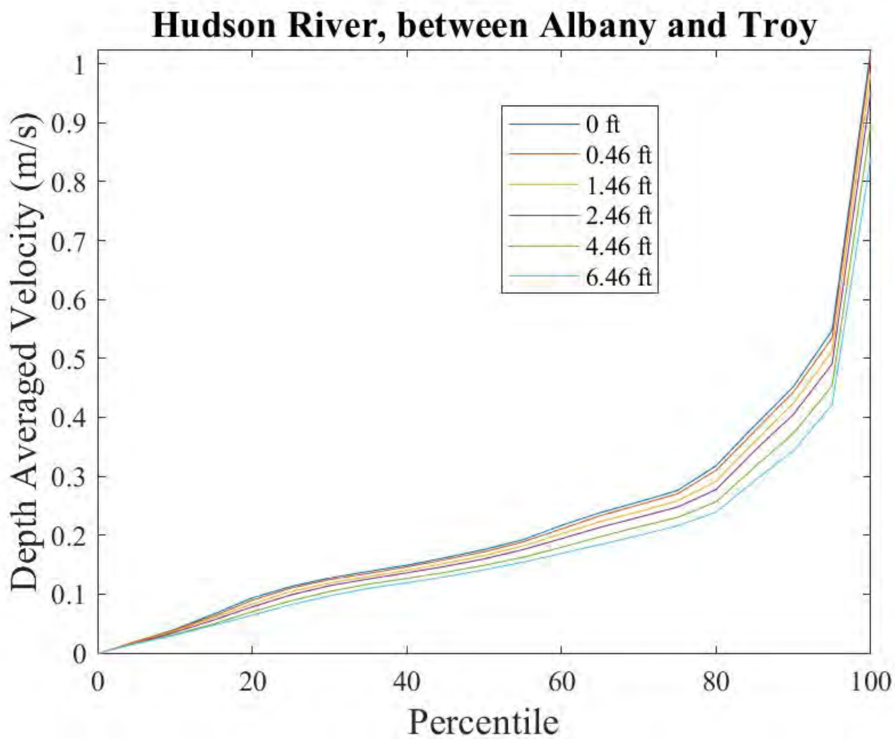


Figure 599. Alt 3b, KLGA Velocity Variation with SLR.

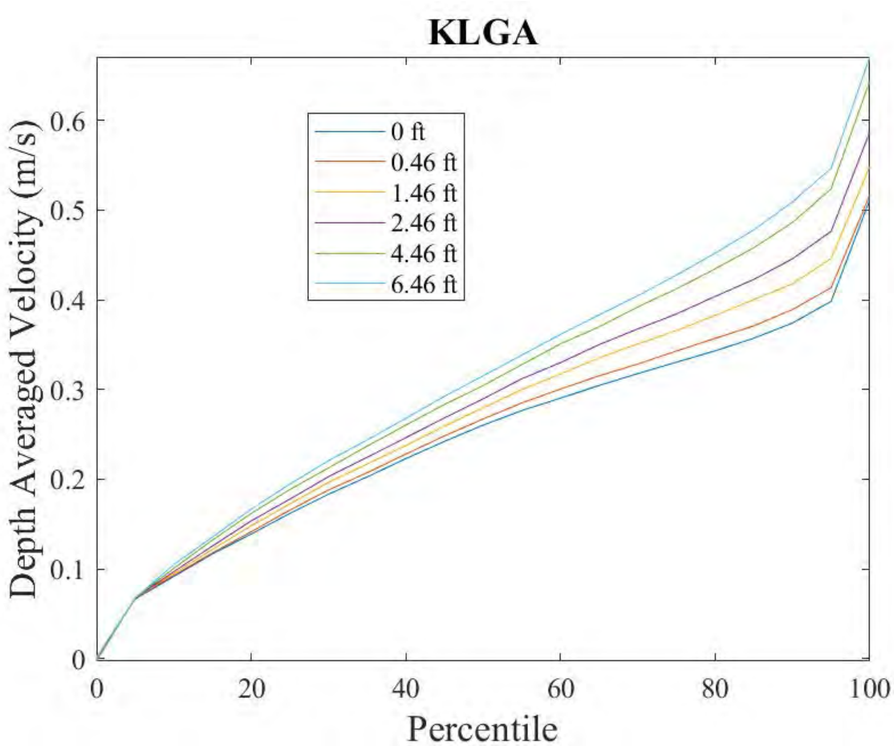


Figure 600. Alt 3b, LIS near Stepping Stone Lighthouse Velocity Variation with SLR.

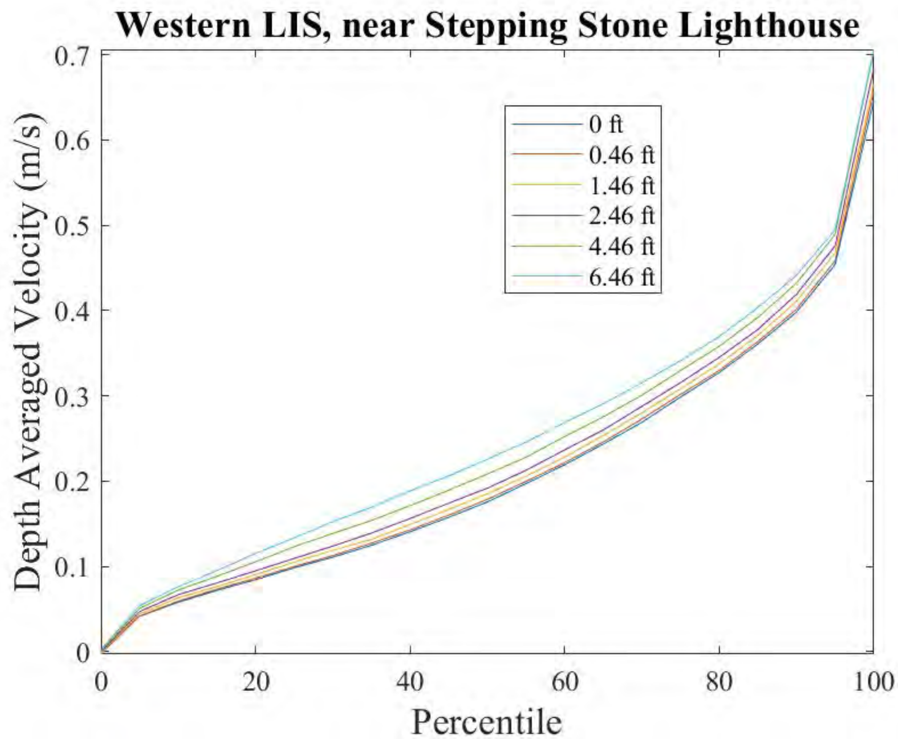


Figure 601. Alt 3b, LIS near Execution Rock Lighthouse Velocity Variation with SLR.

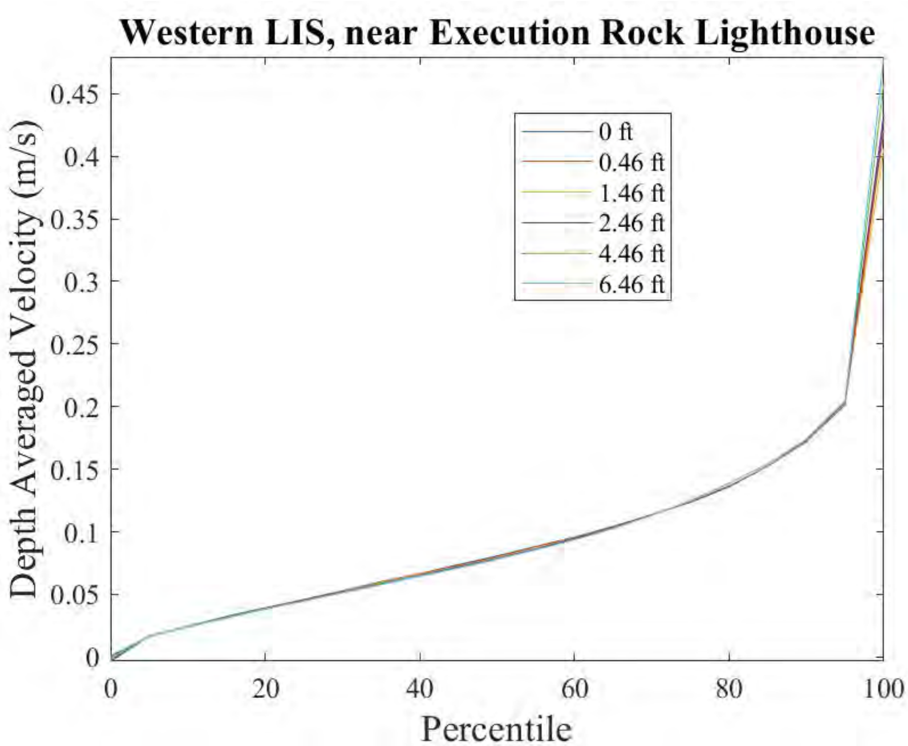


Figure 602. Alt 3b, LIS south of NY/CT border Velocity Variation with SLR.

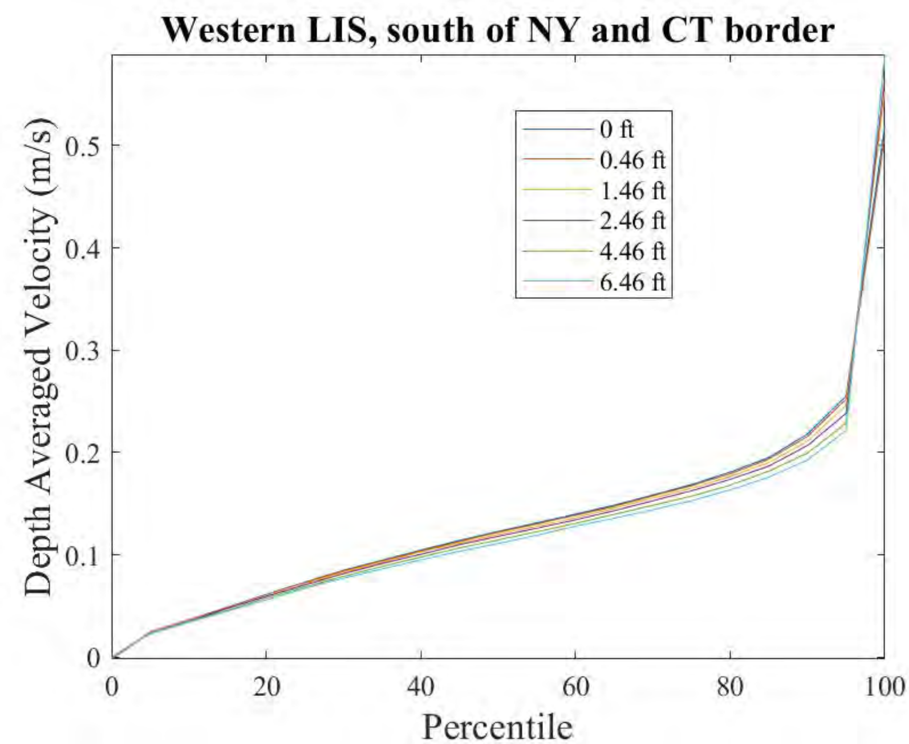


Figure 603. Alt 3b, Jamaica Bay Velocity Variation with SLR.

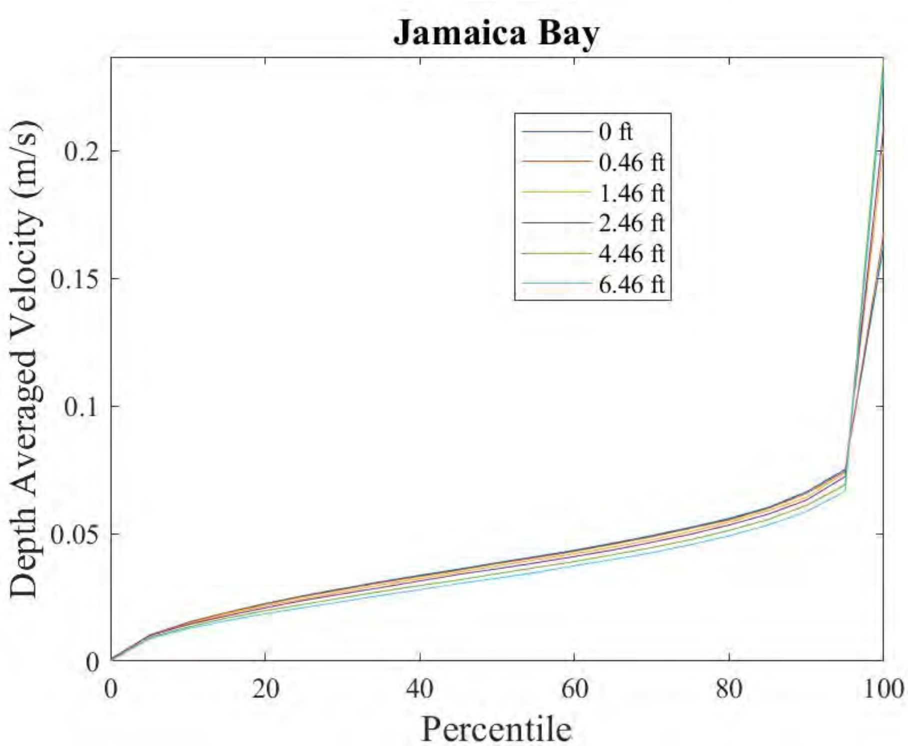


Figure 604. Alt 3b, Jamaica Bay near Spring Creek Velocity Variation with SLR.

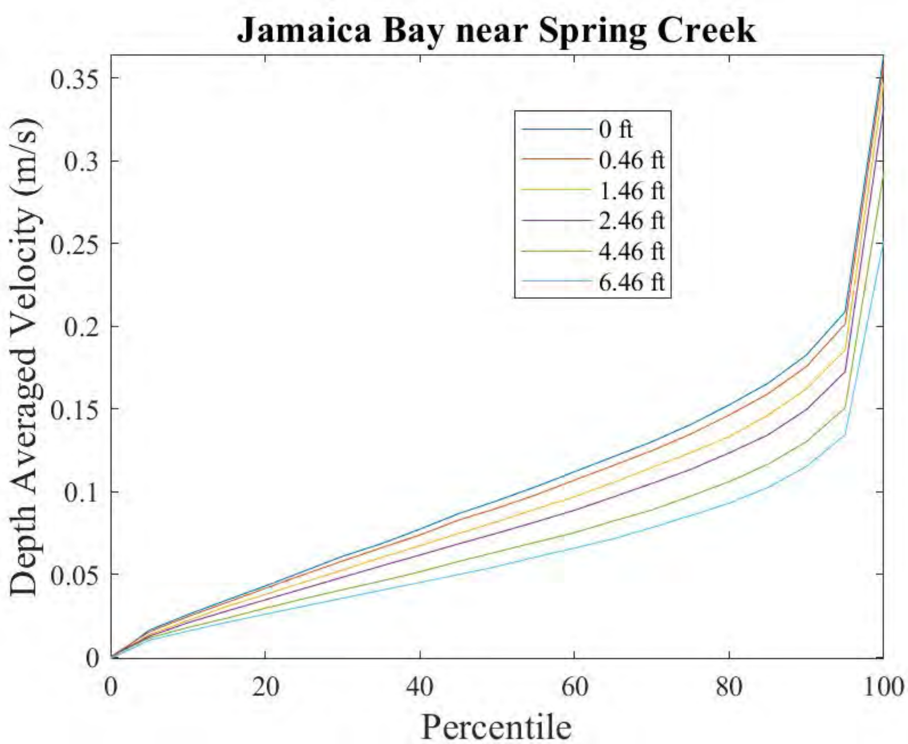
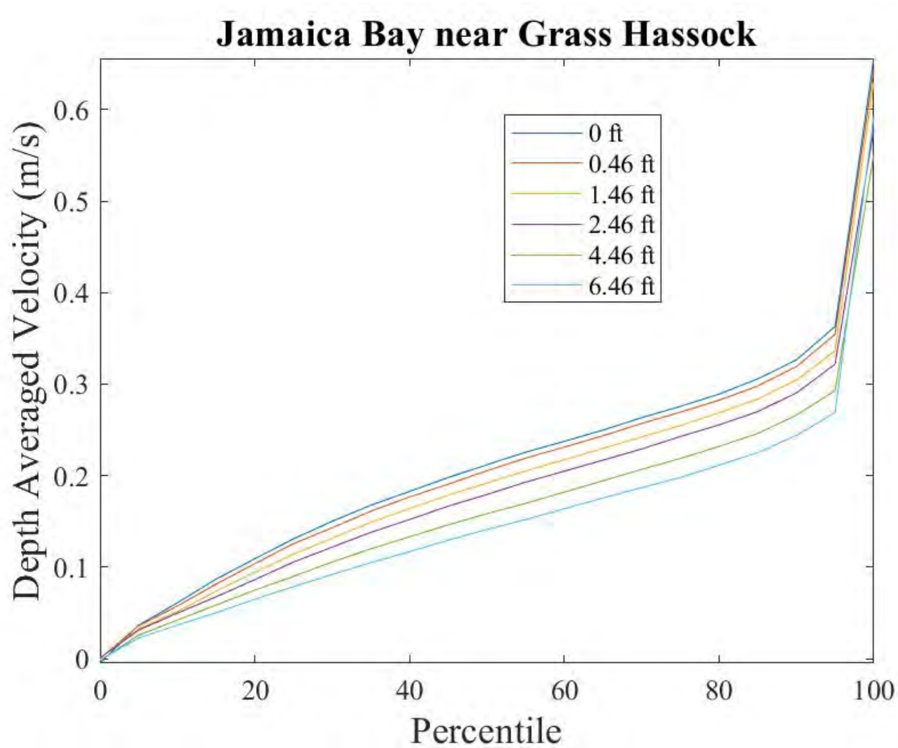


Figure 605. Alt 3b, Jamaica Bay near Grass Hassock Velocity Variation with SLR.



15.4.3 Salinity Point Percentiles

Salinity percentiles for Alternative 3b for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 606 to Figure 638. In general, increased sea levels result in increased salinities.

Figure 606. Alt 3b, V1 Salinity Variation with SLR.

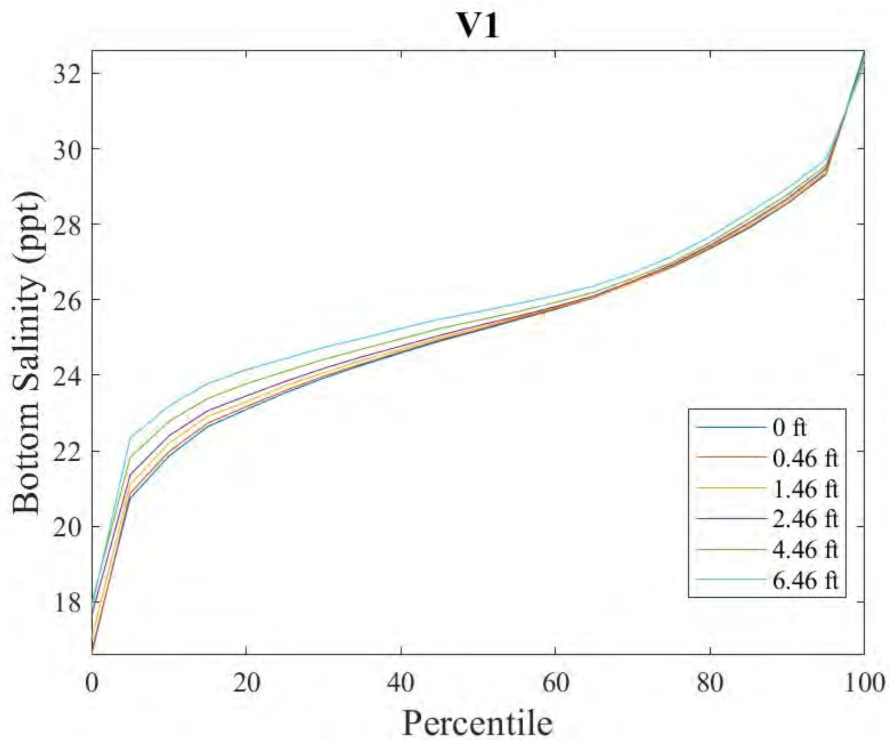


Figure 607. Alt 3b, V2 Salinity Variation with SLR.

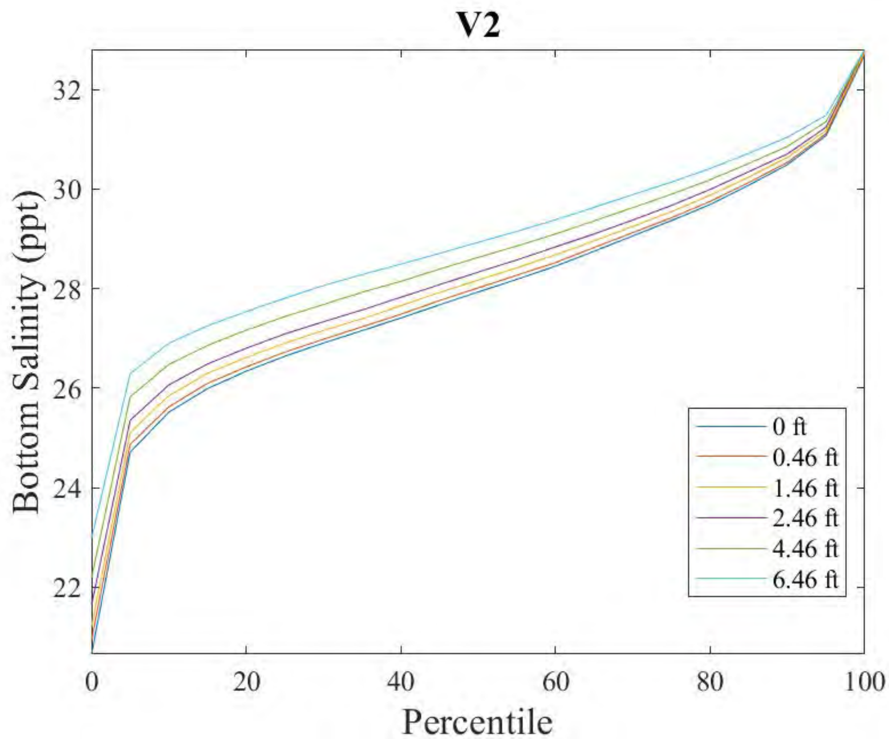


Figure 608. Alt 3b, V3 Salinity Variation with SLR.

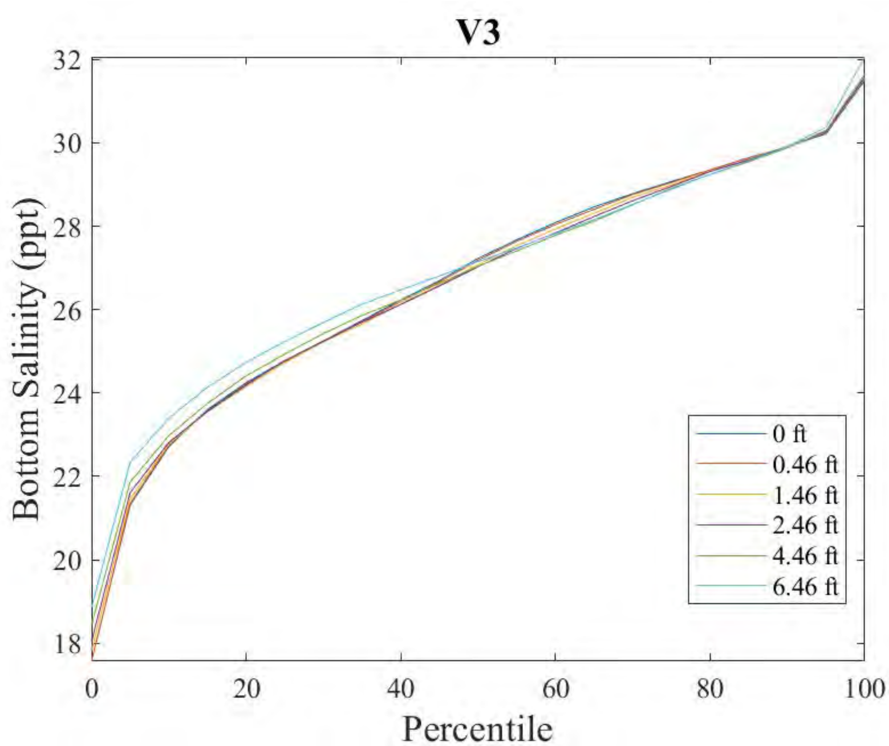


Figure 609. Alt 3b, V4 Salinity Variation with SLR.

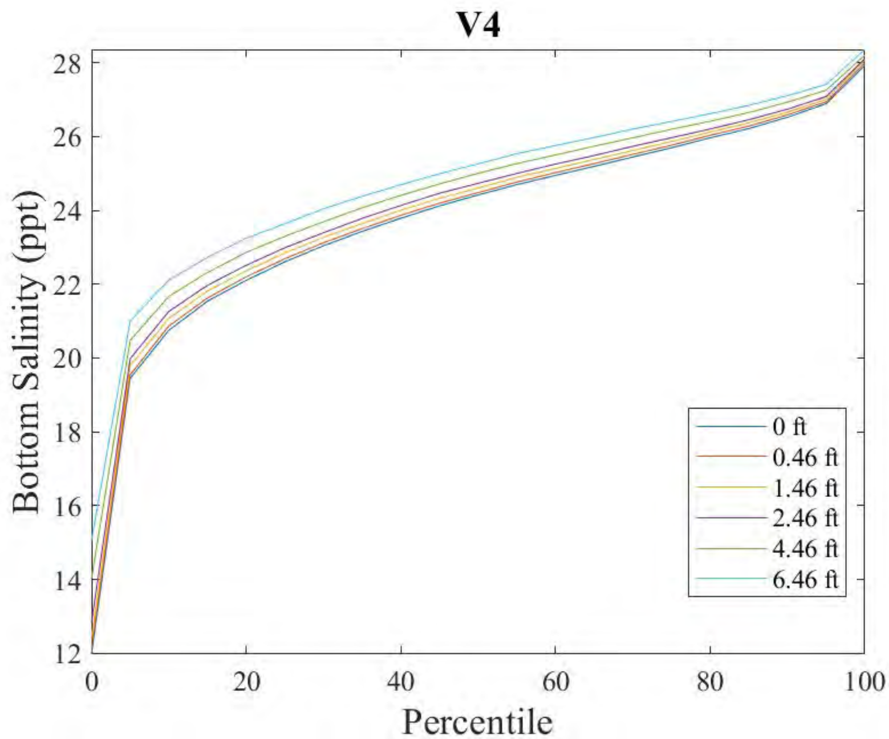


Figure 610. Alt 3b, V5 Salinity Variation with SLR.

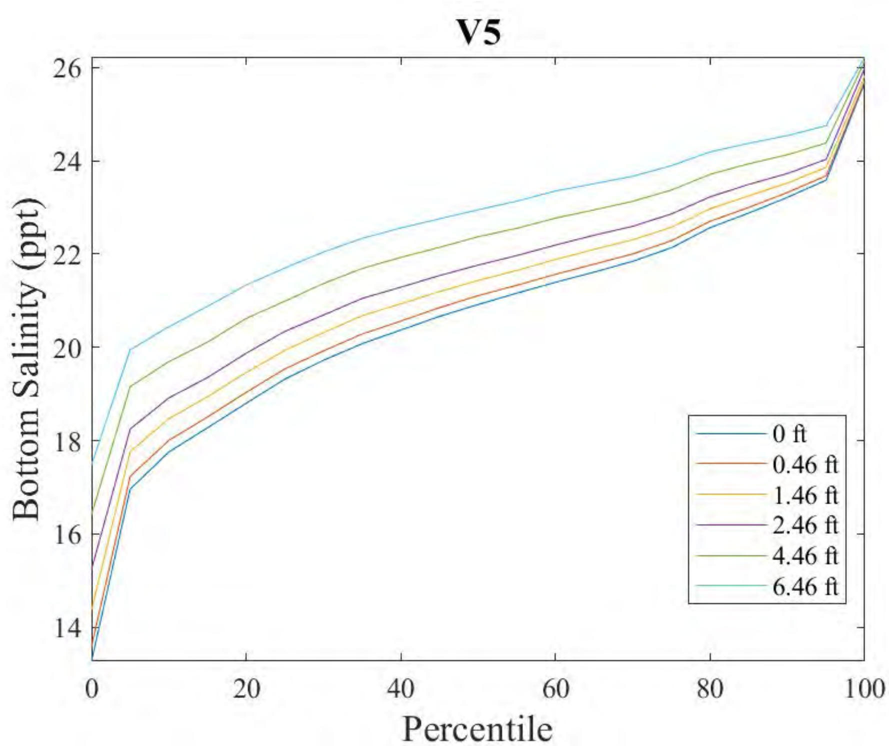


Figure 611. Alt 3b, V6 Salinity Variation with SLR.

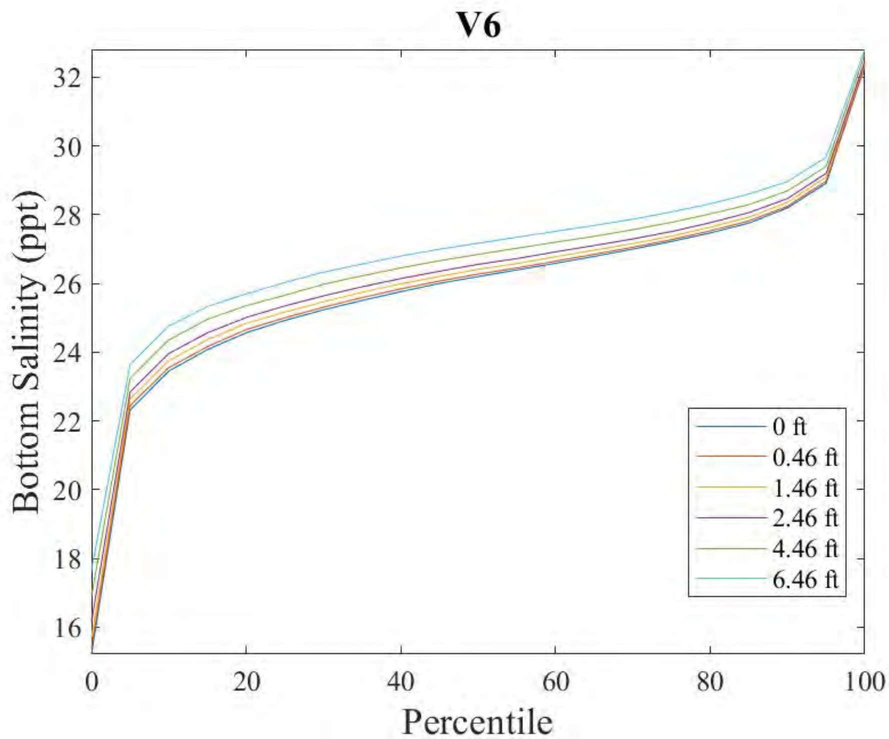


Figure 612. Alt 3b, S1 Salinity Variation with SLR.

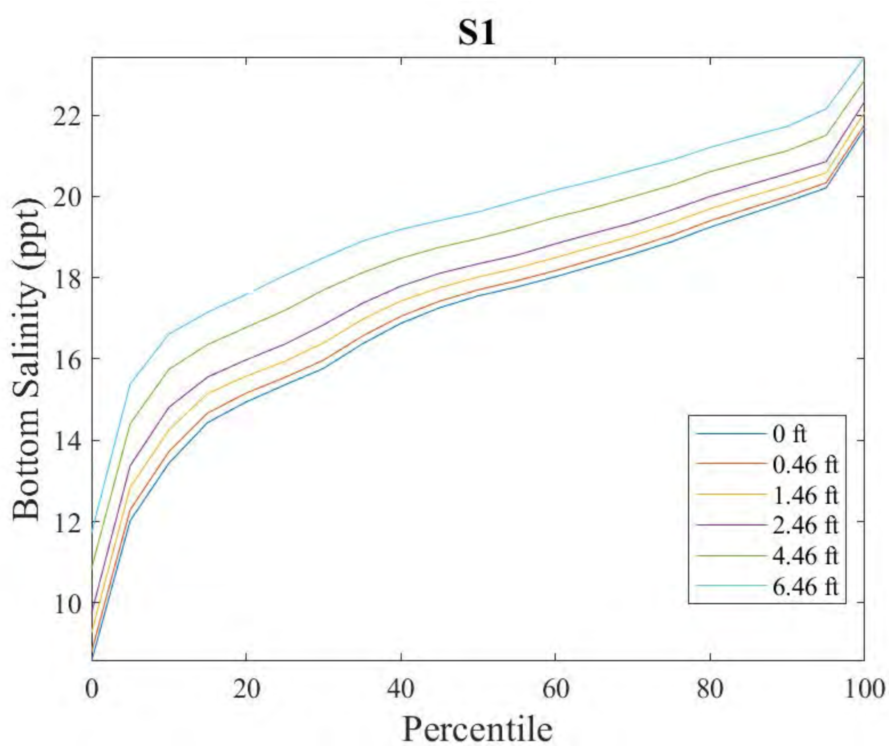


Figure 613. Alt 3b, S2 Salinity Variation with SLR.

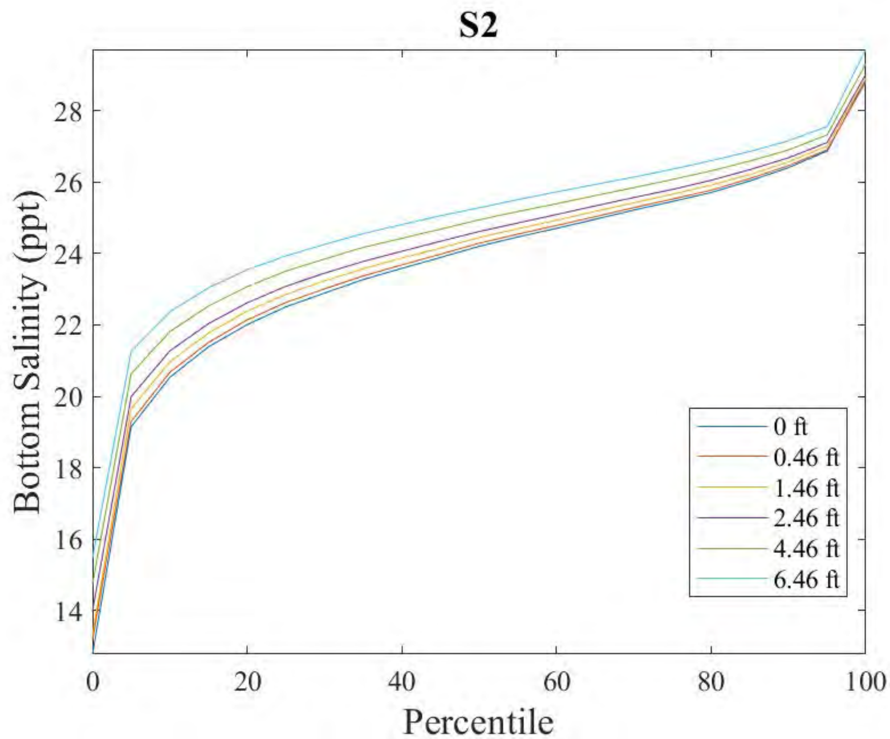


Figure 614. Alt 3b, S3 Salinity Variation with SLR.

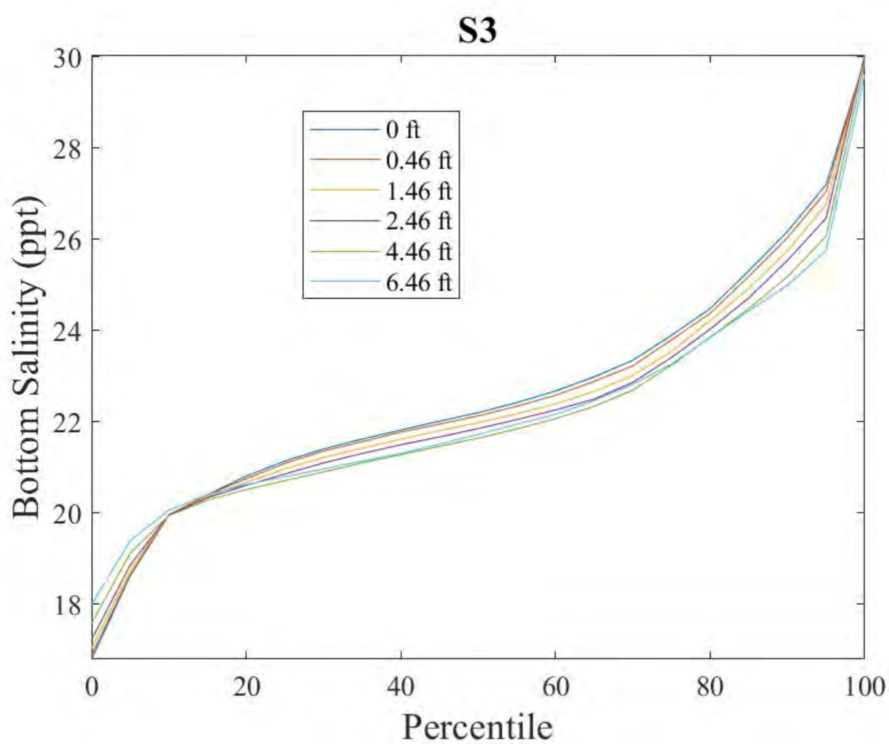


Figure 615. Alt 3b, S4 Salinity Variation with SLR.

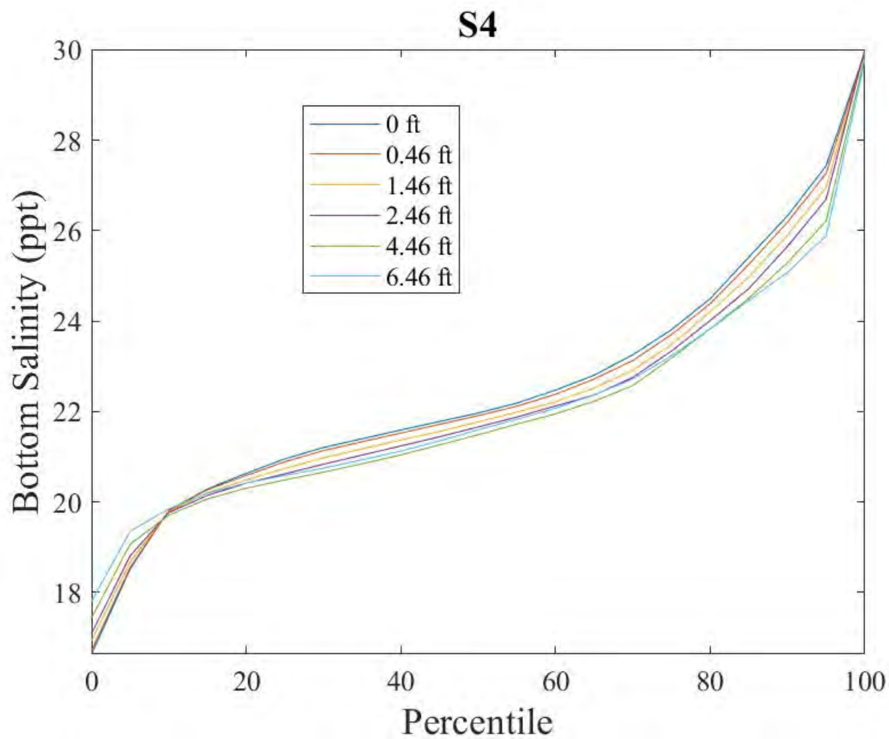


Figure 616. Alt 3b, S5 Salinity Variation with SLR.

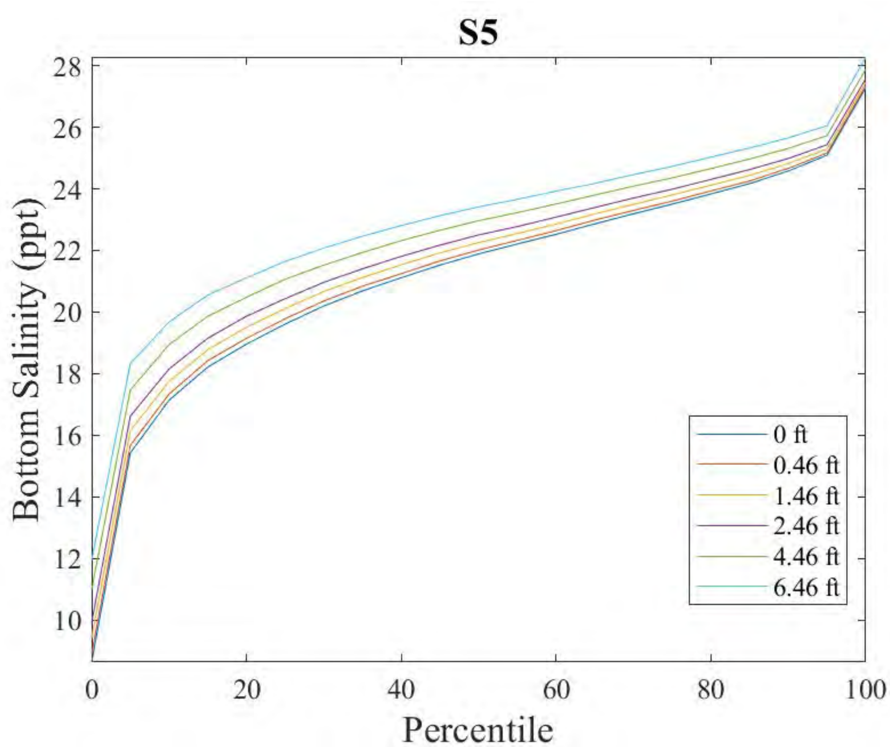


Figure 617. Alt 3b, T1 Salinity Variation with SLR.

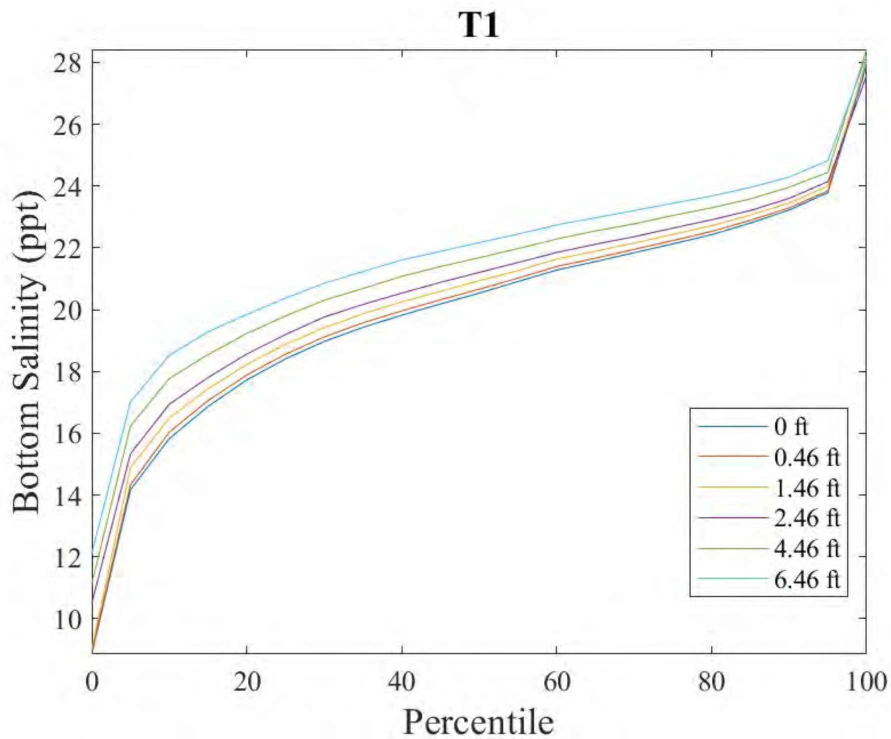


Figure 618. Alt 3b, T2 Salinity Variation with SLR.

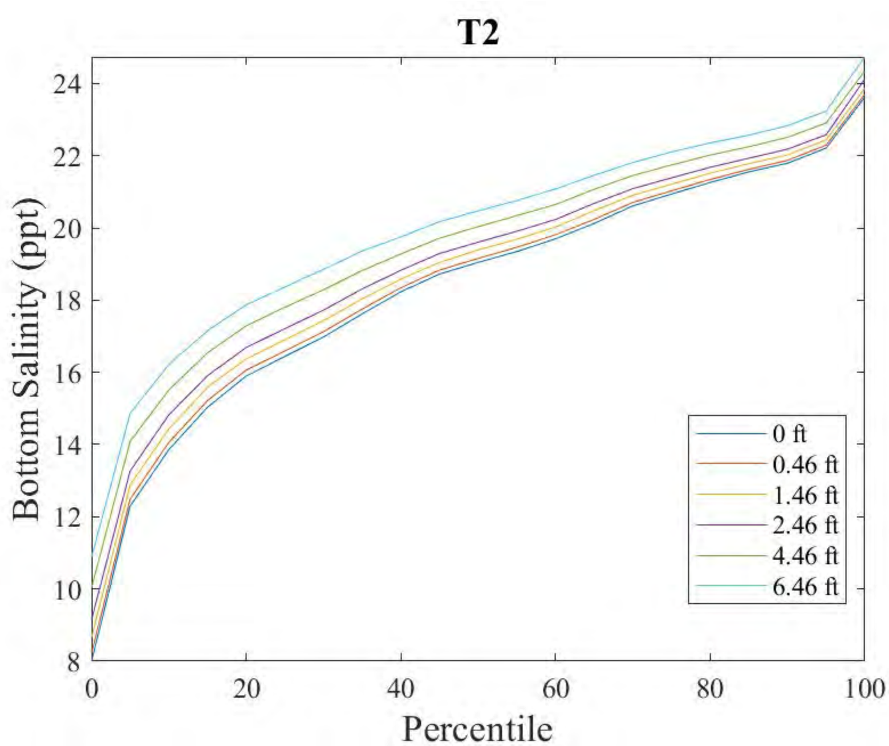


Figure 619. Alt 3b, T3 Salinity Variation with SLR.

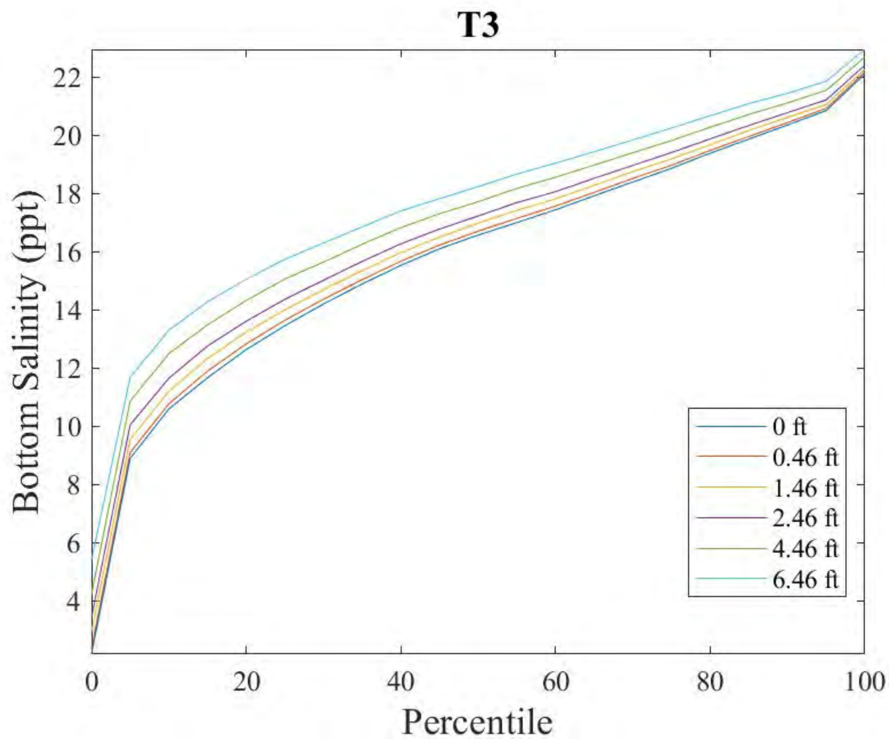


Figure 620. Alt 3b, T4 Salinity Variation with SLR.

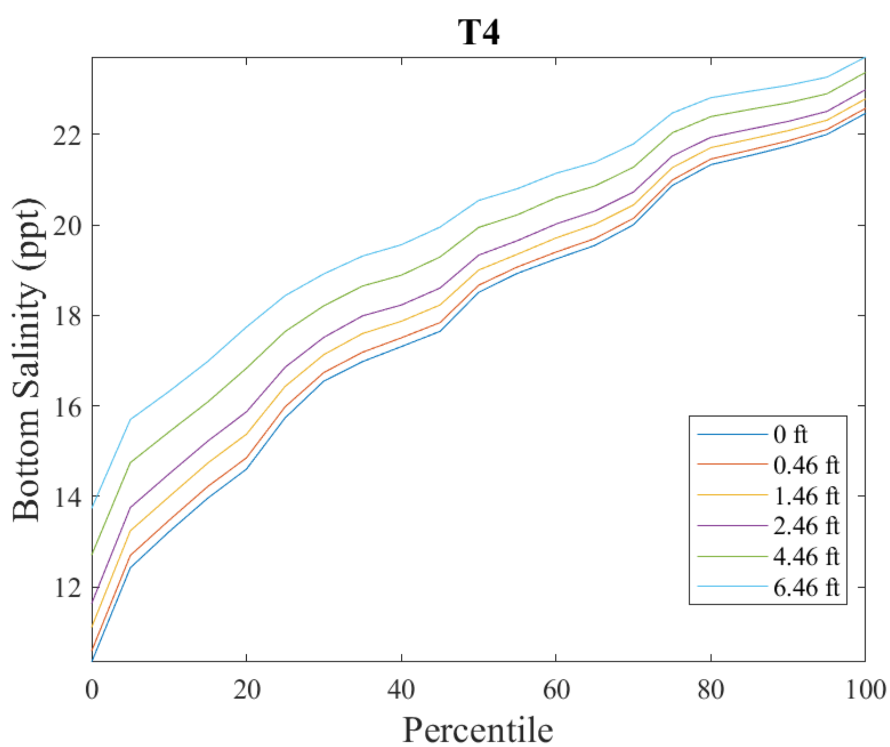


Figure 621. Alt 3b, T5 Salinity Variation with SLR.

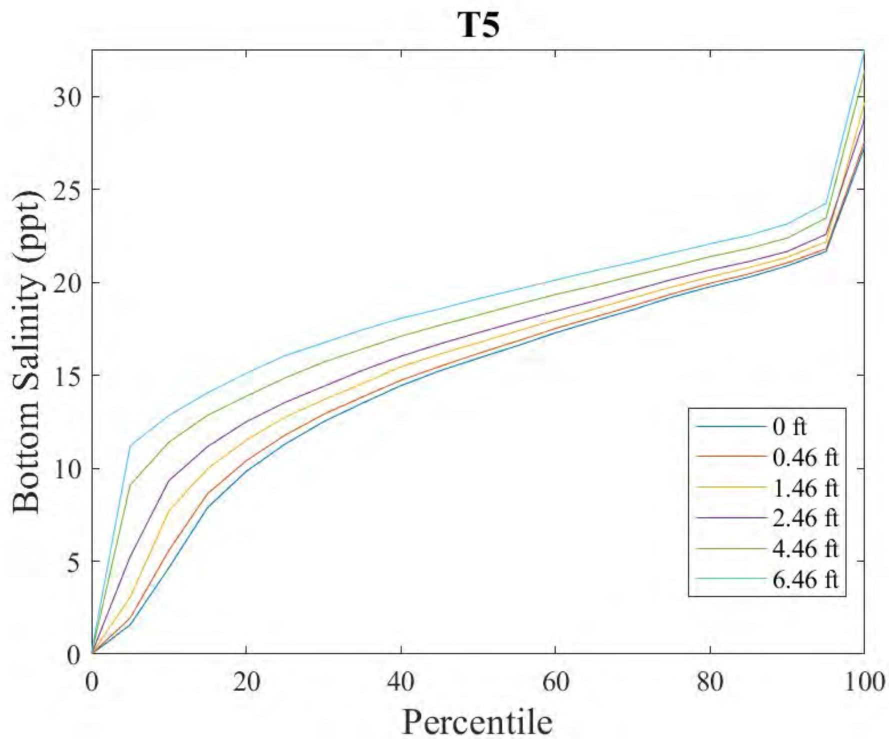


Figure 622. Alt 3b, R1 Salinity Variation with SLR.

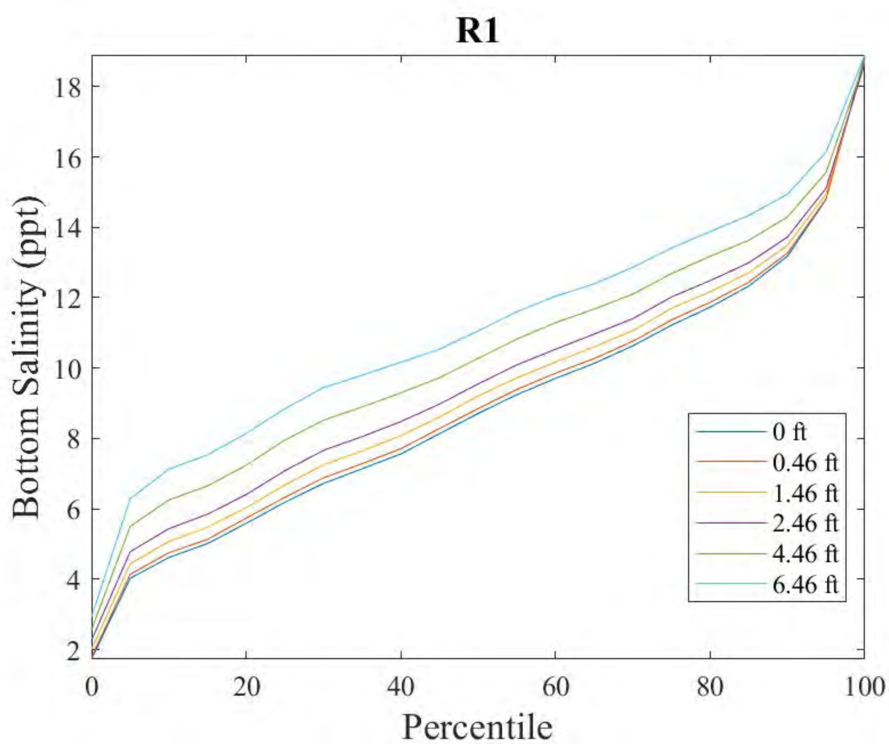


Figure 623. Alt 3b, Sandy Hook Salinity Variation with SLR.

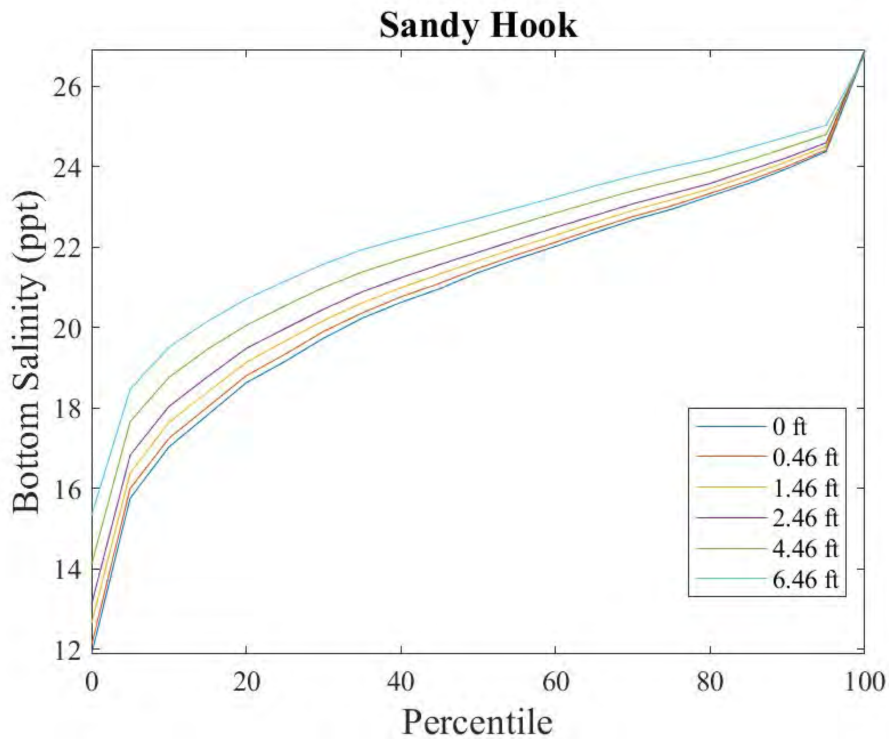


Figure 624. Alt 3b, Fresh Kills Salinity Variation with SLR.

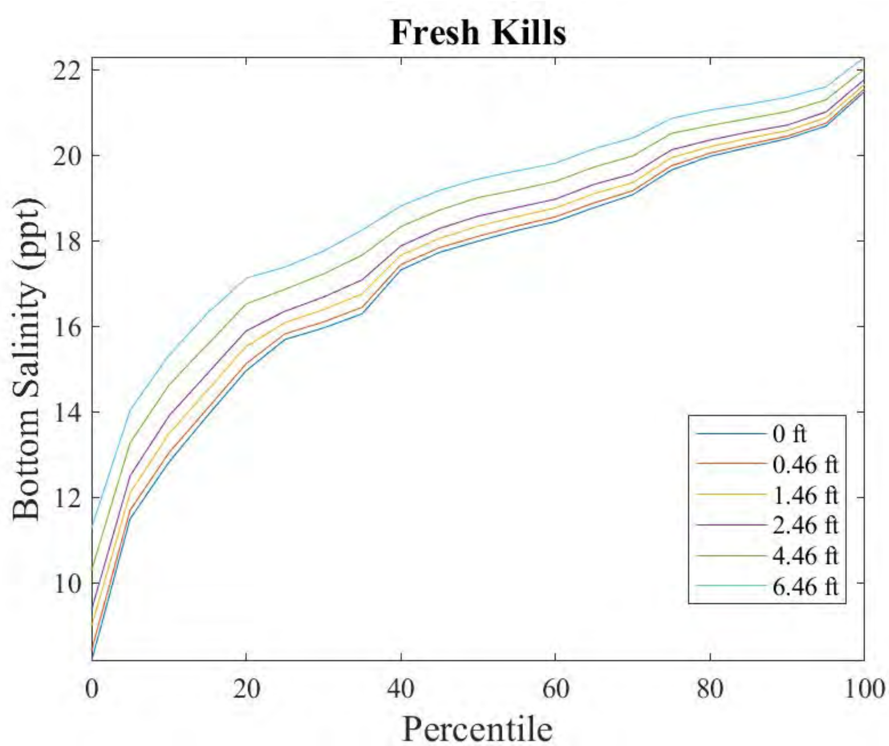


Figure 625. Alt 3b, Mariners Harbor Salinity Variation with SLR.

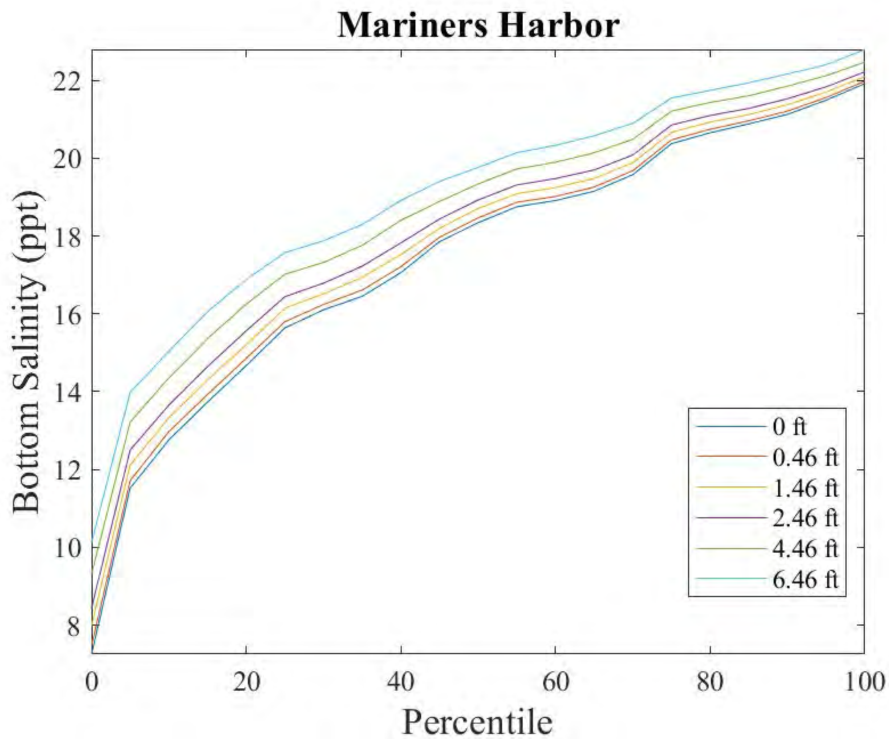


Figure 626. Alt 3b, North Reach Salinity Variation with SLR.

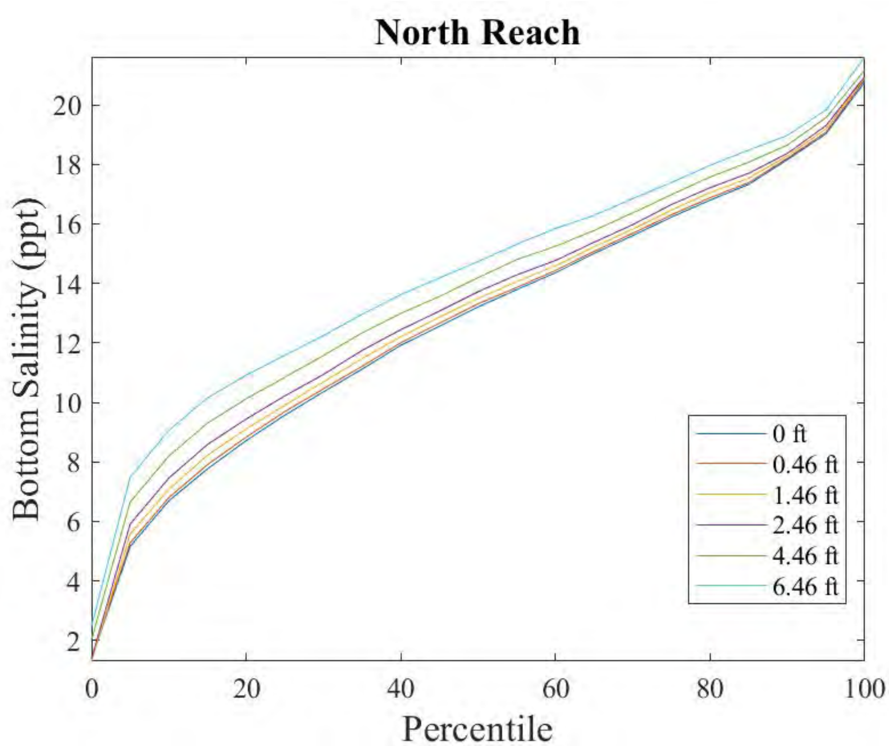


Figure 627. Alt 3b, Hackensack River Salinity Variation with SLR.

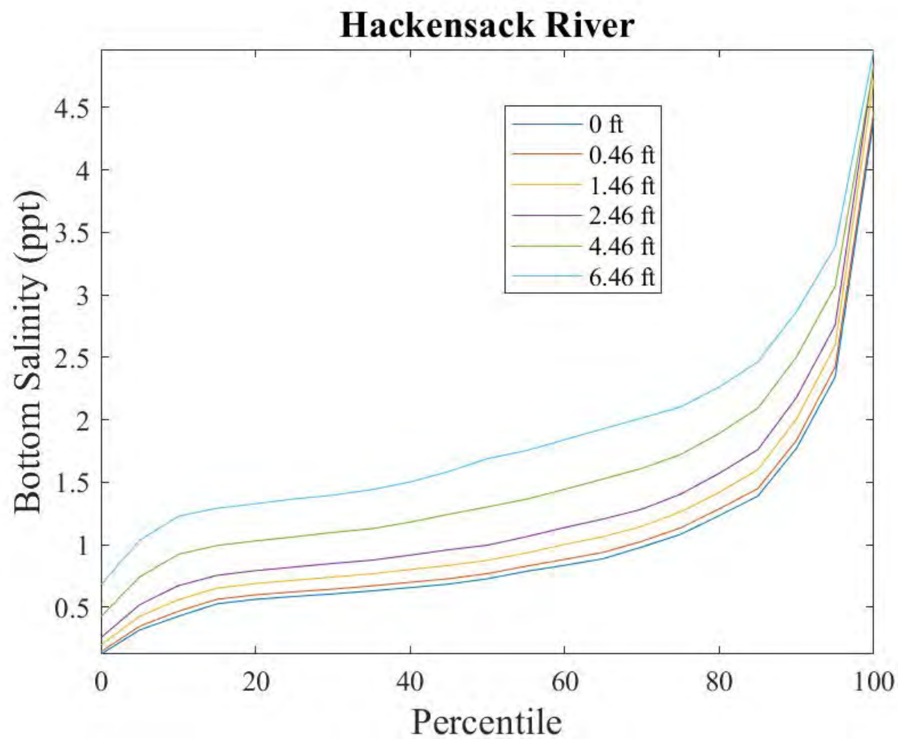


Figure 628. Alt 3b, Robbins Reef Salinity Variation with SLR.

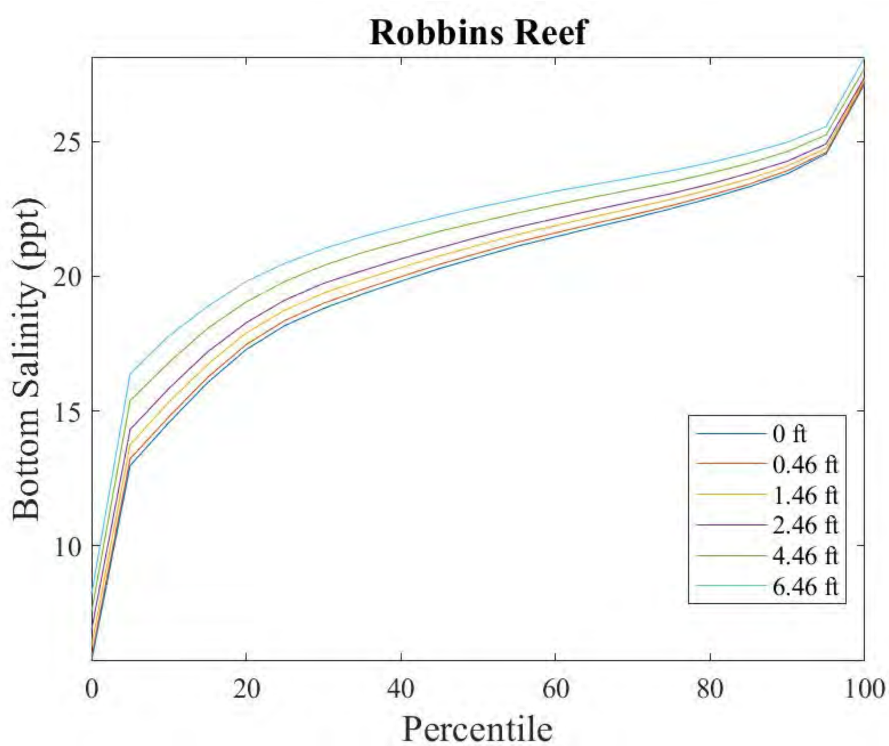


Figure 629. Alt 3b, The Battery Salinity Variation with SLR.

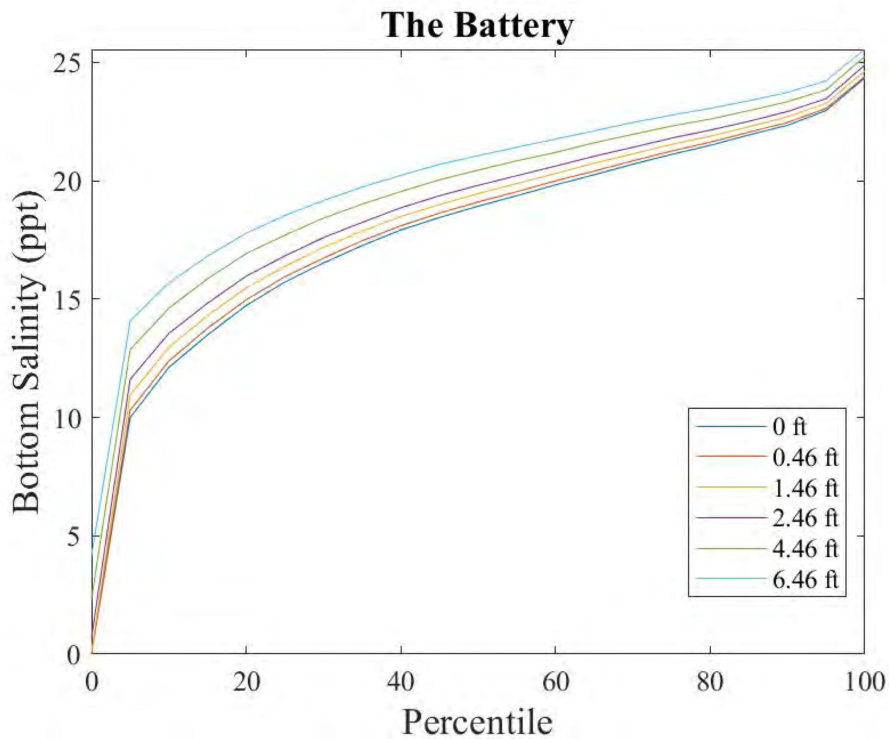


Figure 630. Alt 3b, Manhattan Salinity Variation with SLR.

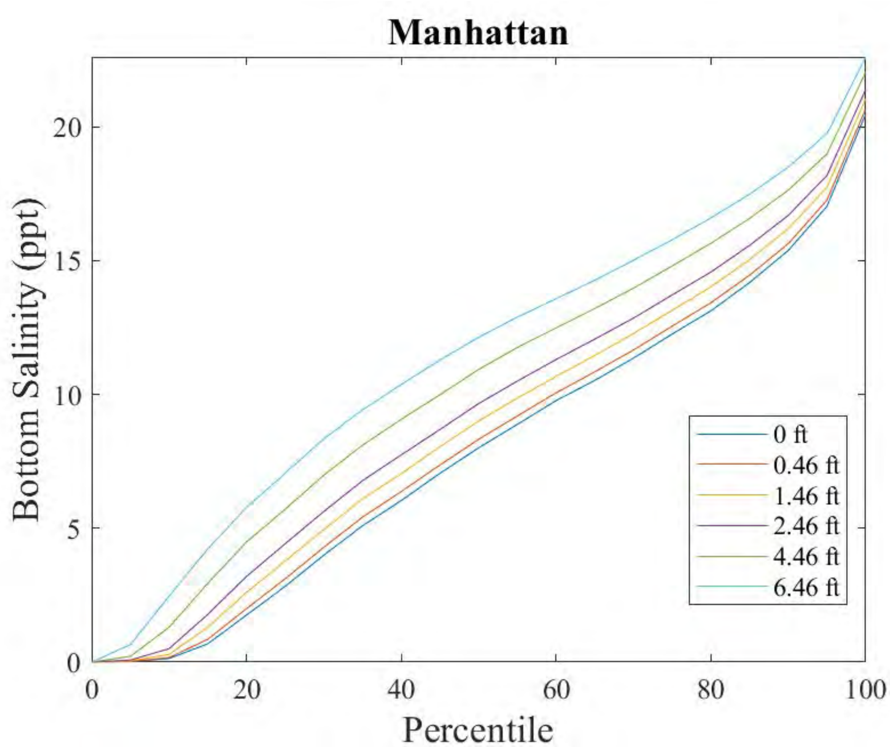


Figure 631. Alt 3b, Hudson River Haverstraw Bay Salinity Variation with SLR.

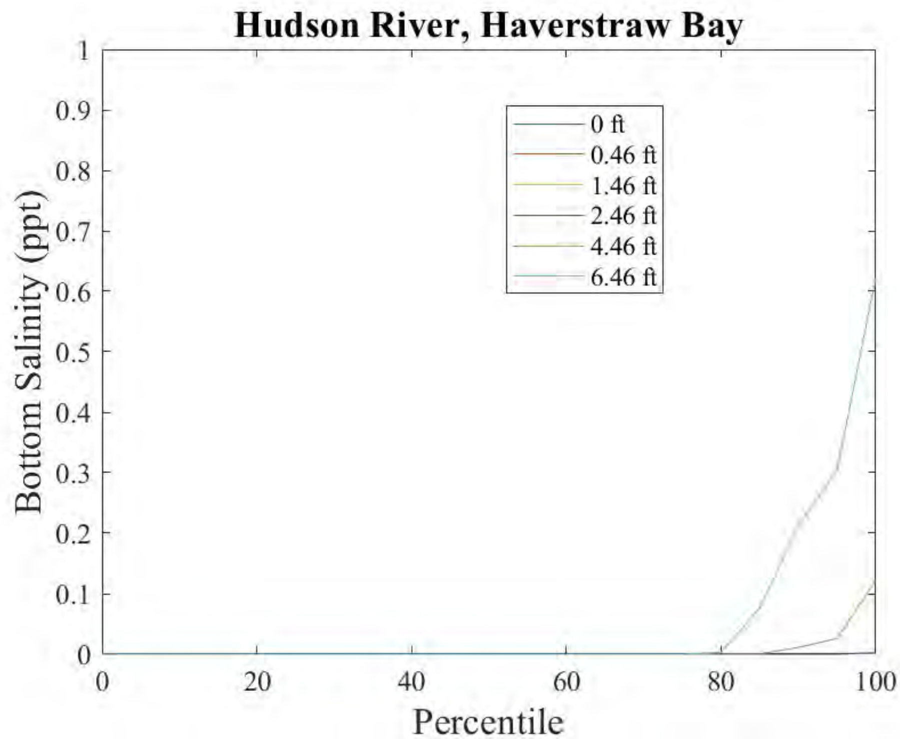


Figure 632. Alt 3b, KLGA Salinity Variation with SLR.

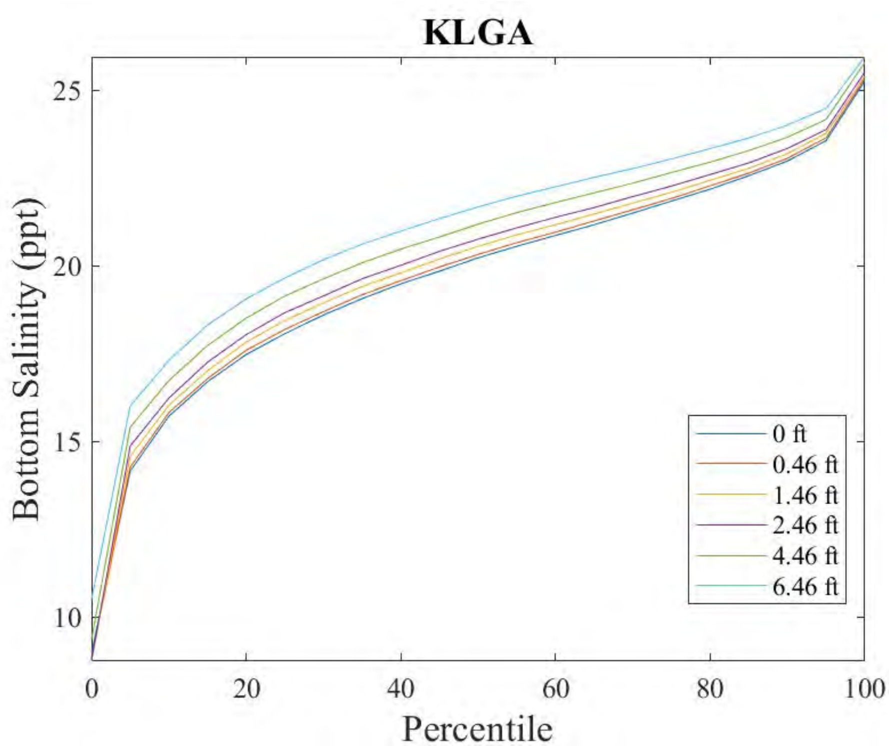


Figure 633. Alt 3b, LIS near Stepping Stone Lighthouse Salinity Variation with SLR.

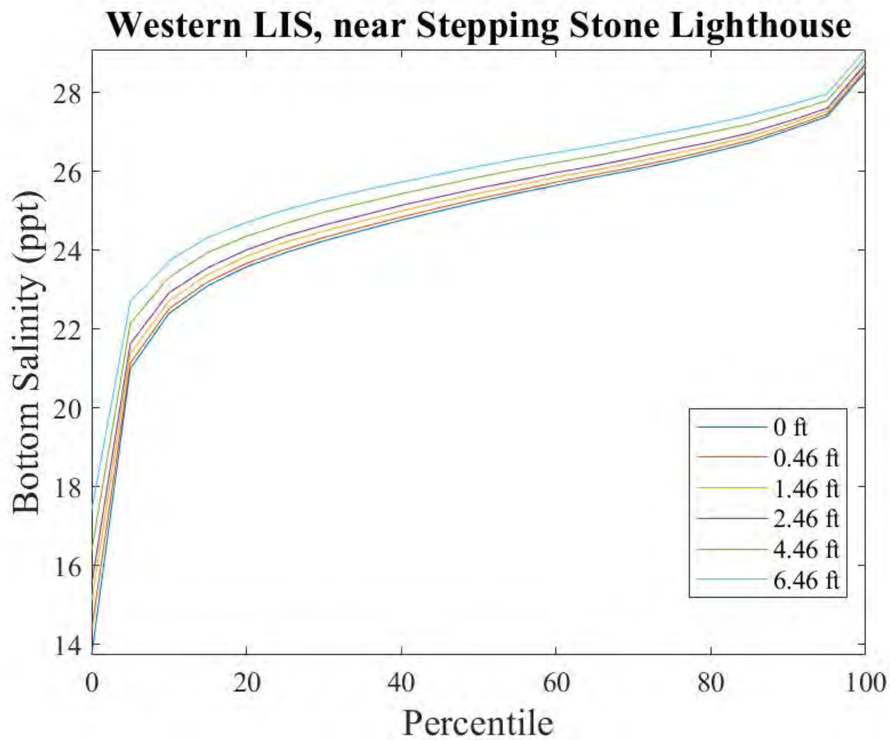


Figure 634. Alt 3b, LIS near Execution Rock Lighthouse Salinity Variation with SLR.

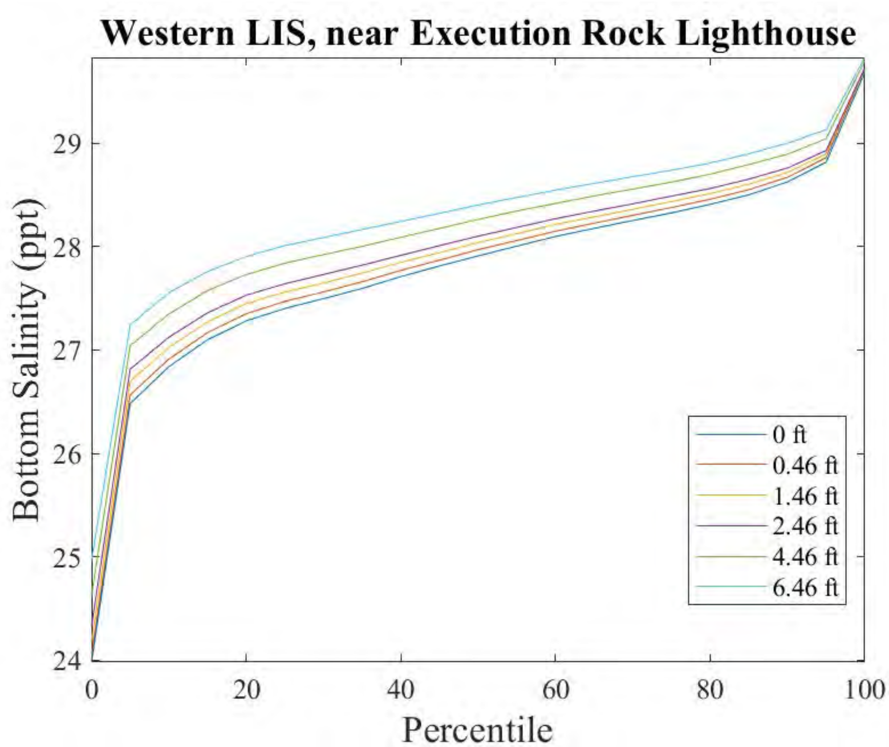


Figure 635. Alt 3b, LIS south of NY/CT border Salinity Variation with SLR.

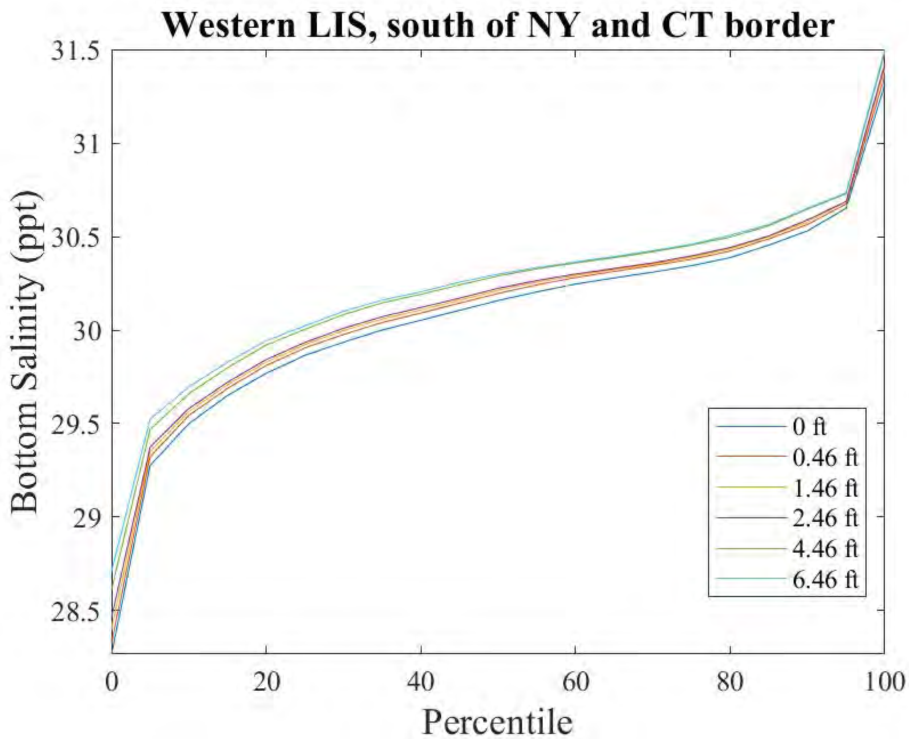


Figure 636. Alt 3b, Jamaica Bay Salinity Variation with SLR.

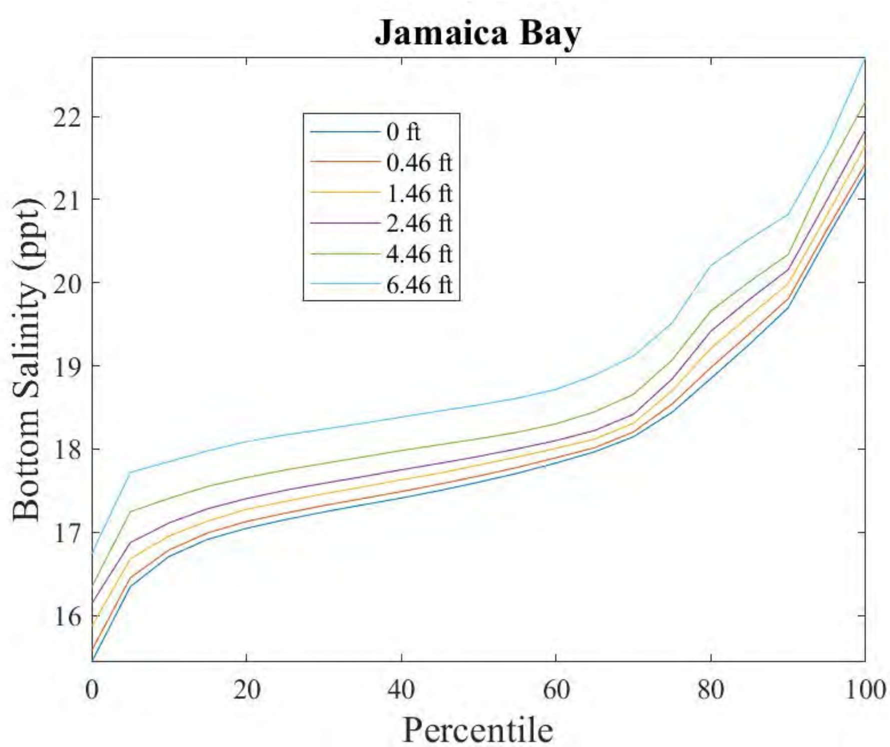


Figure 637. Alt 3b, Jamaica Bay near Spring Creek Salinity Variation with SLR.

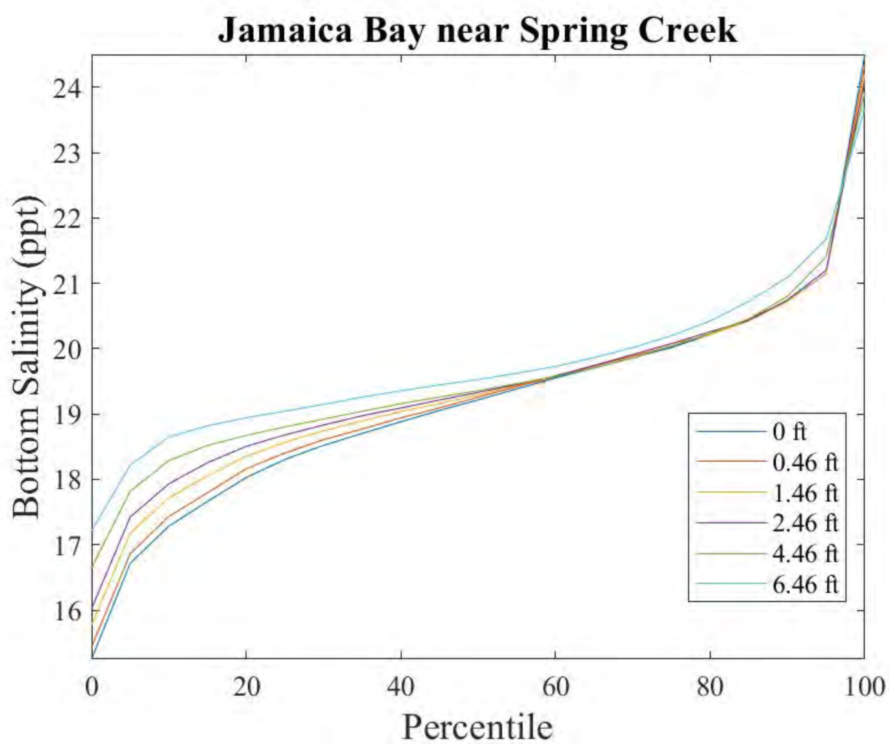
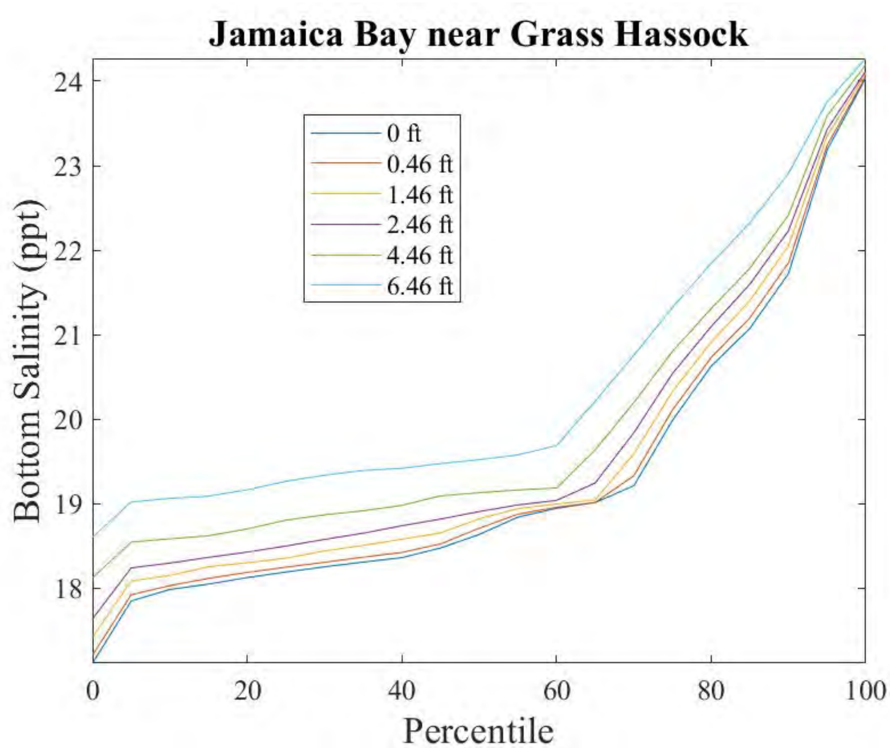


Figure 638. Alt 3b, Jamaica Bay near Grass Hassock Salinity Variation with SLR.



15.4.4 Spatial Velocity Percentiles

Spatial figures of the velocity magnitude percentiles for Alternative 3b for the 50th and 75th percentiles are provided in Figure 639 to Figure 650.

Figure 639. Alternative 3b/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

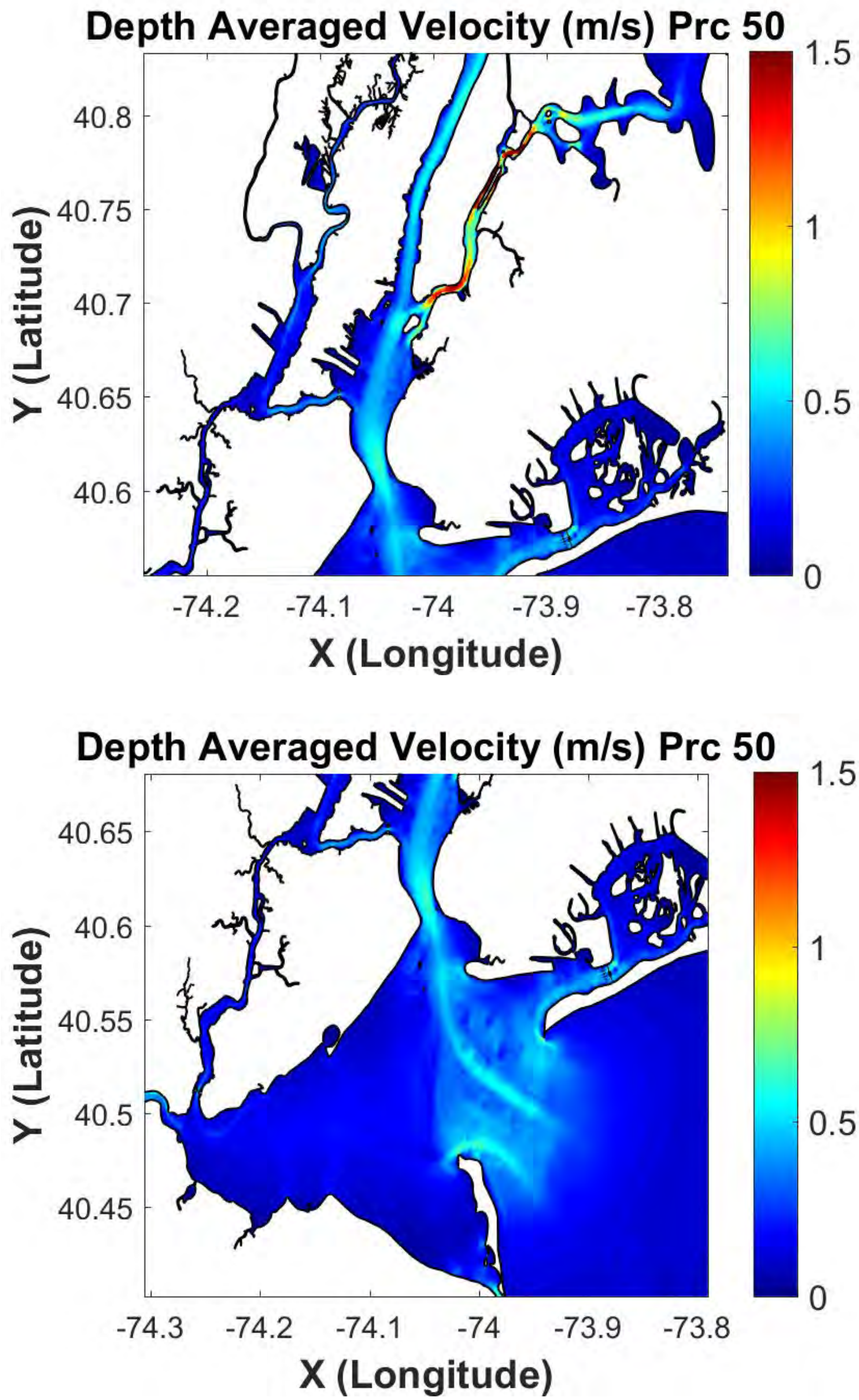
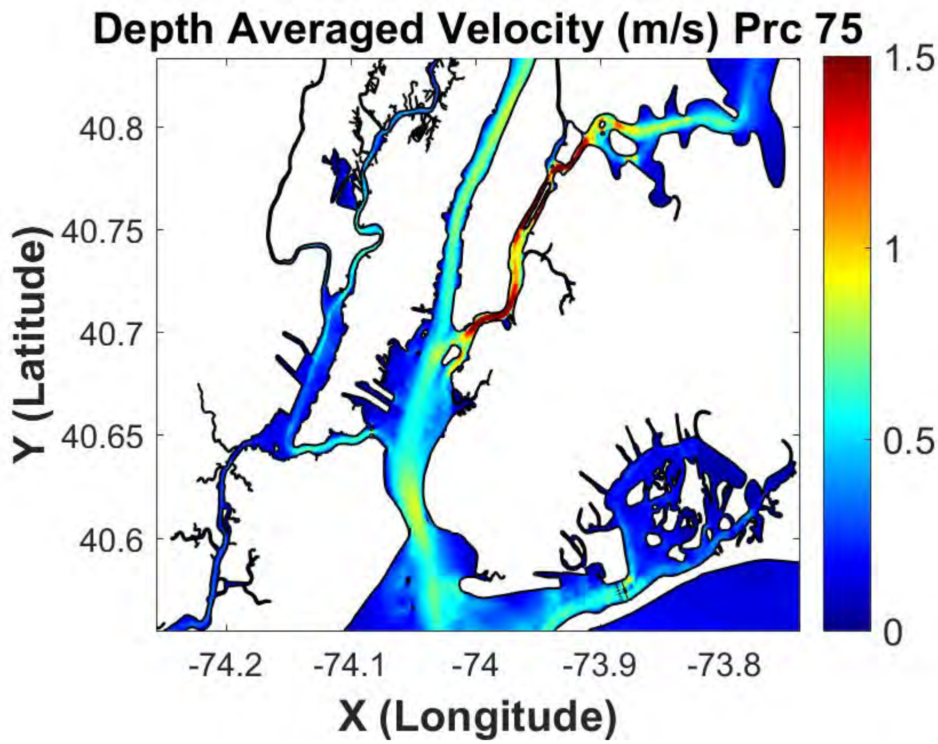


Figure 640. Alternative 3b/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



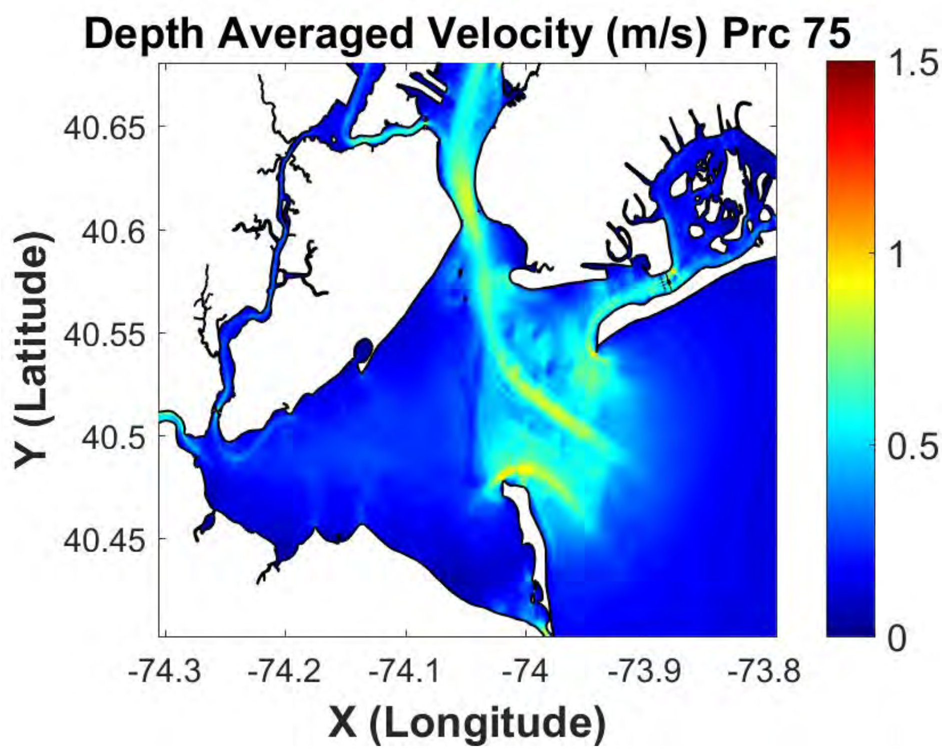
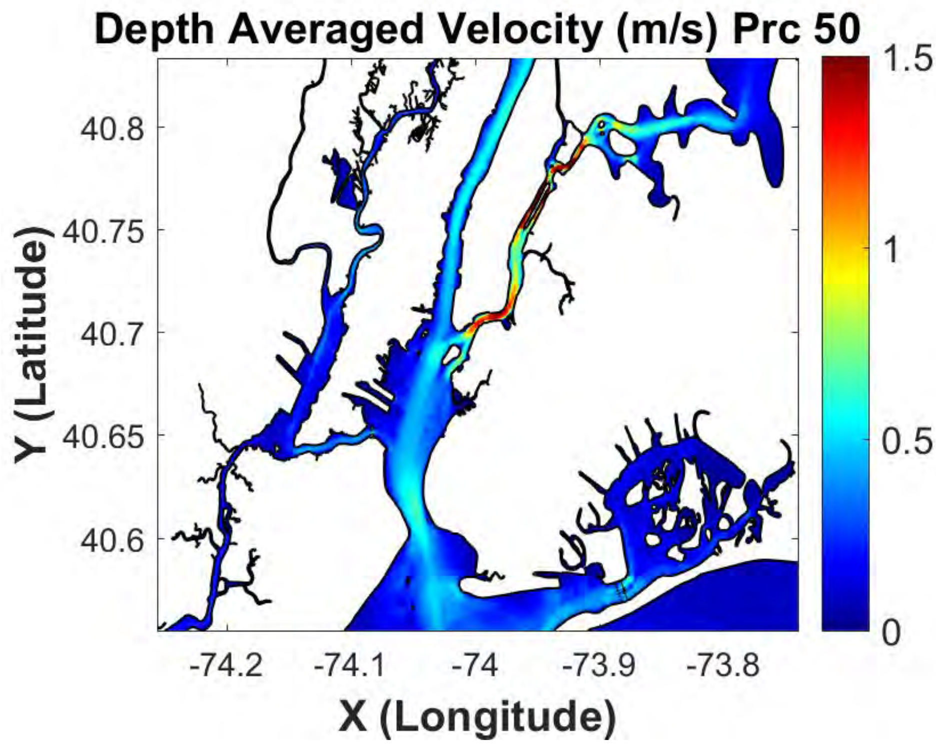


Figure 641. Alternative 3b/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



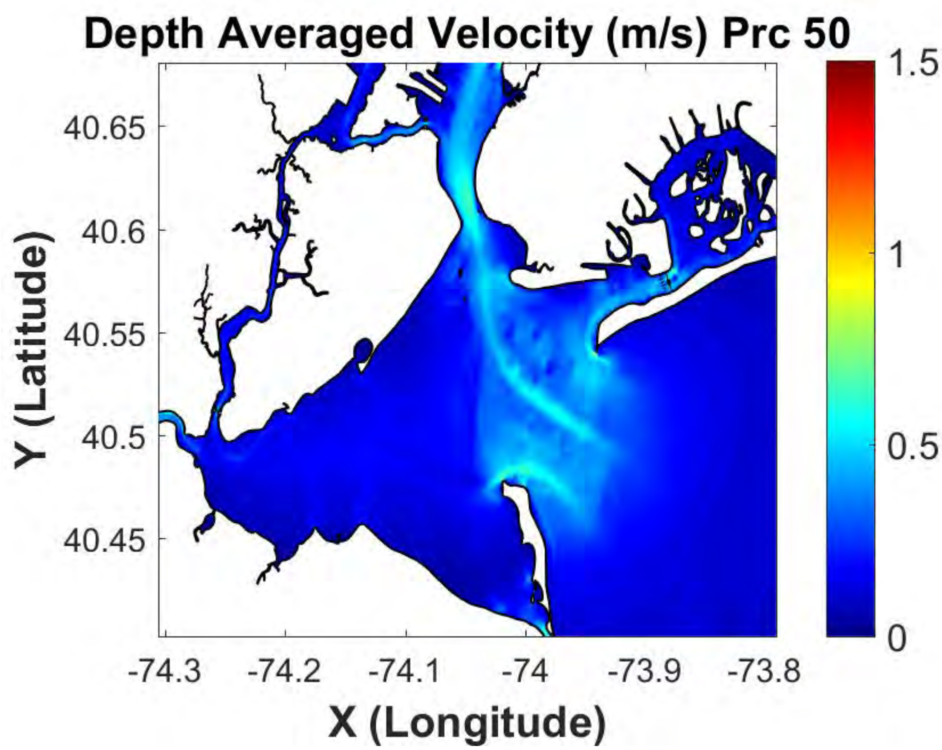
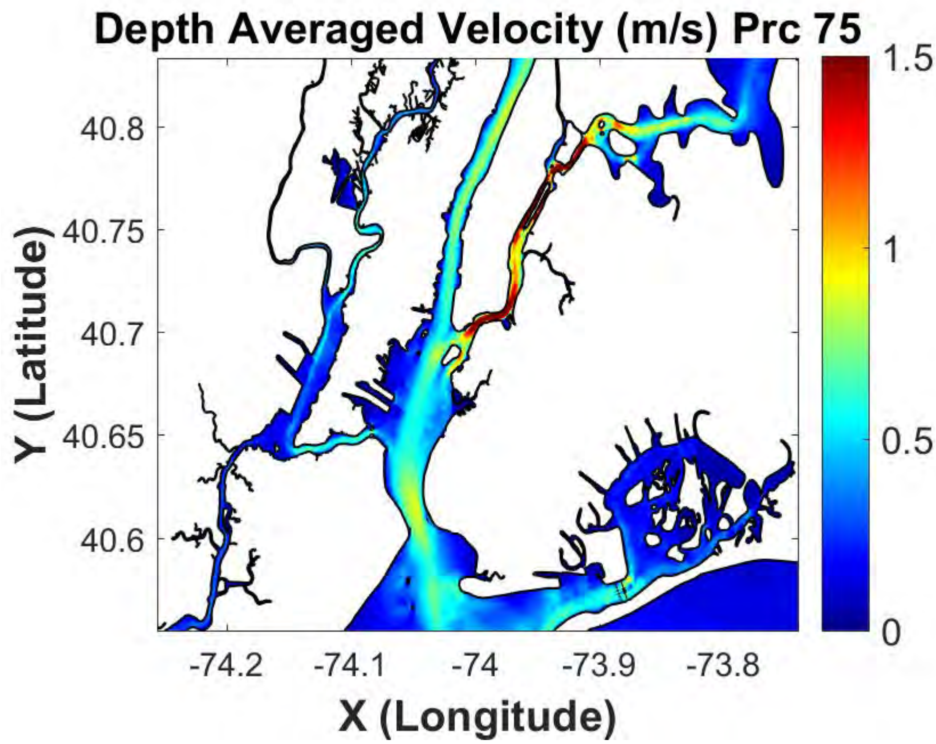


Figure 642. Alternative 3b/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



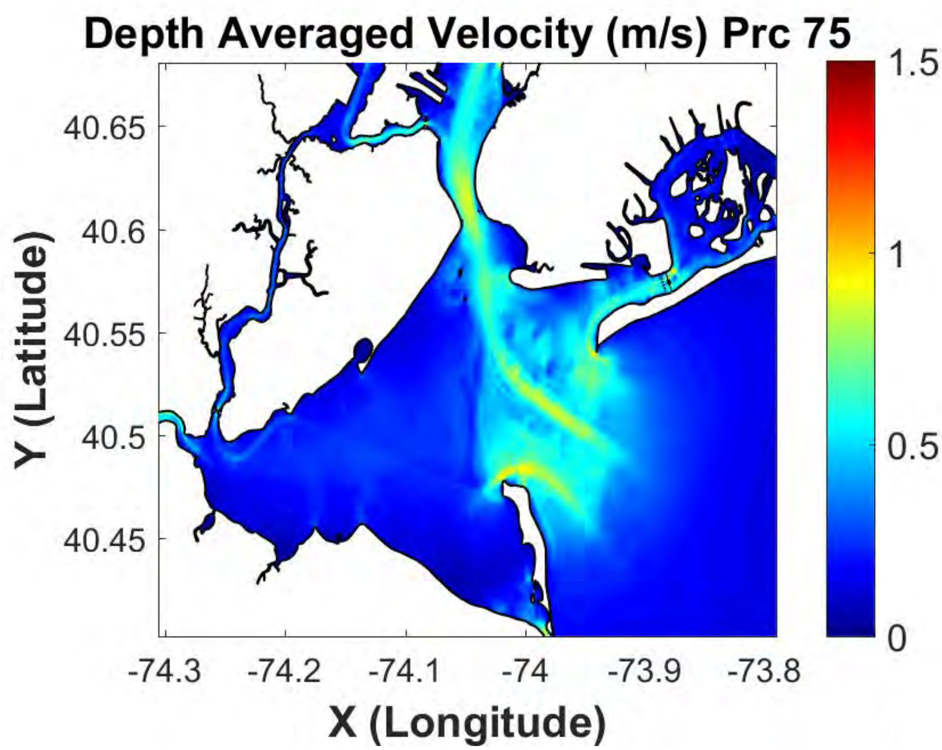
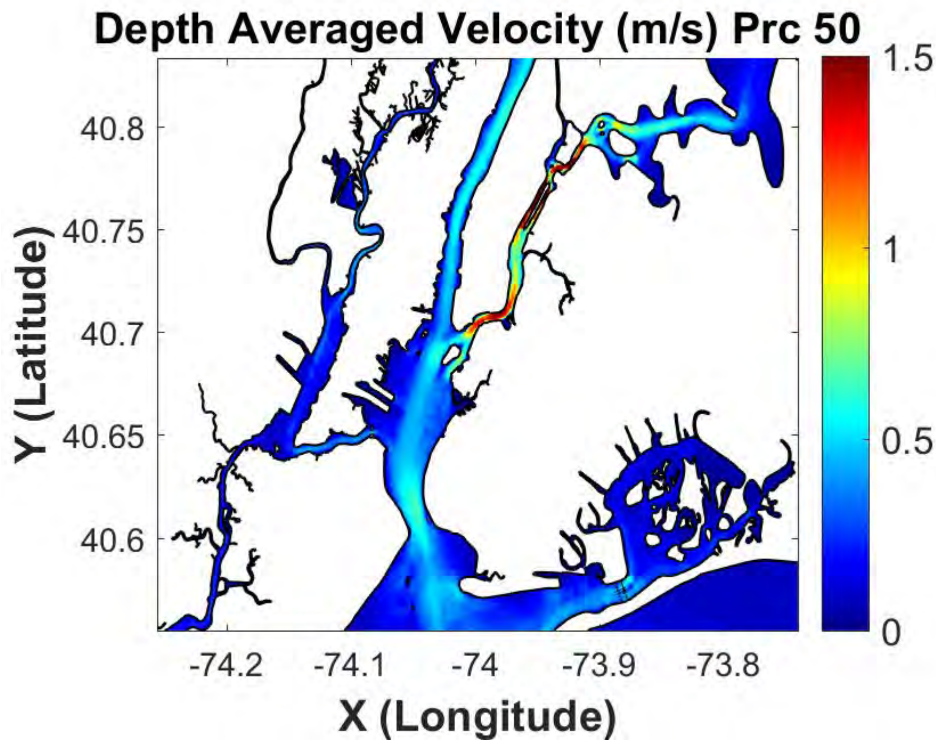


Figure 643. Alternative 3b/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



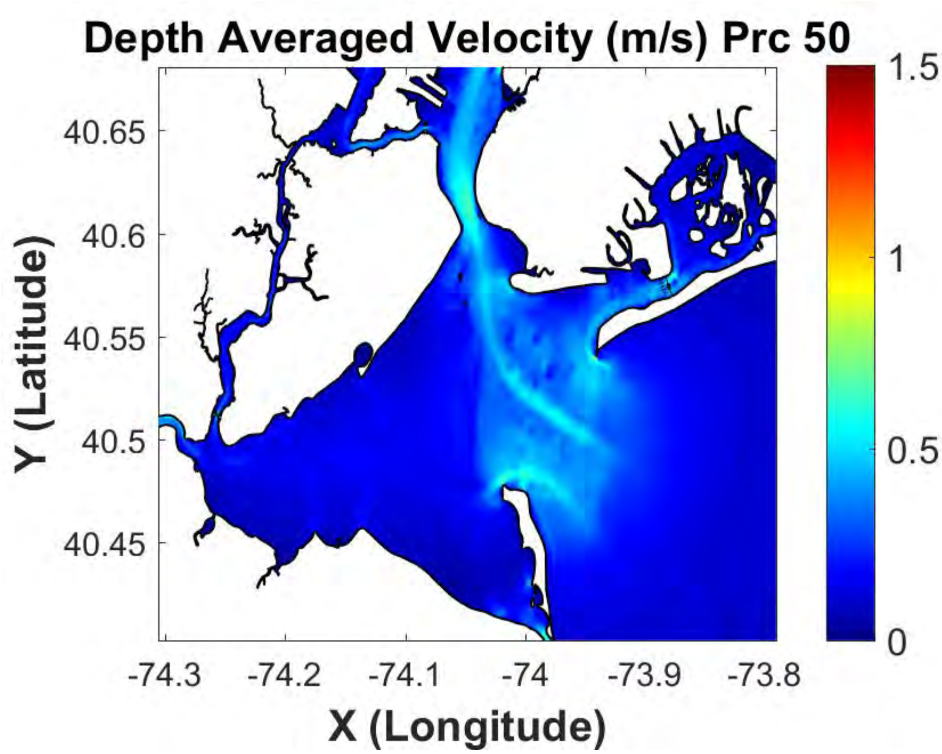
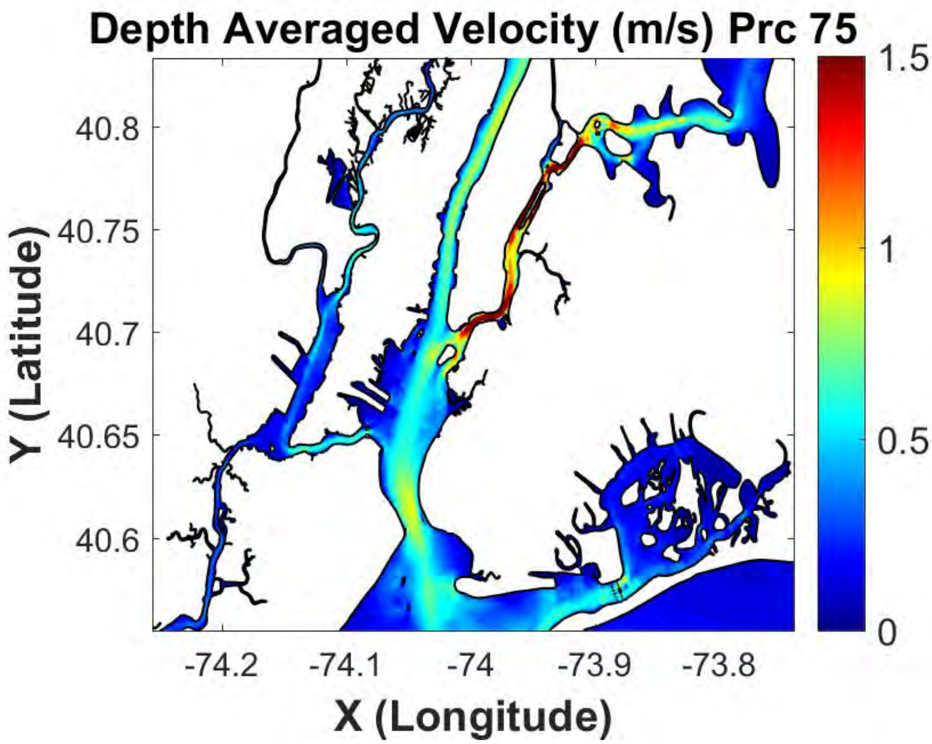


Figure 644. Alternative 3b/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



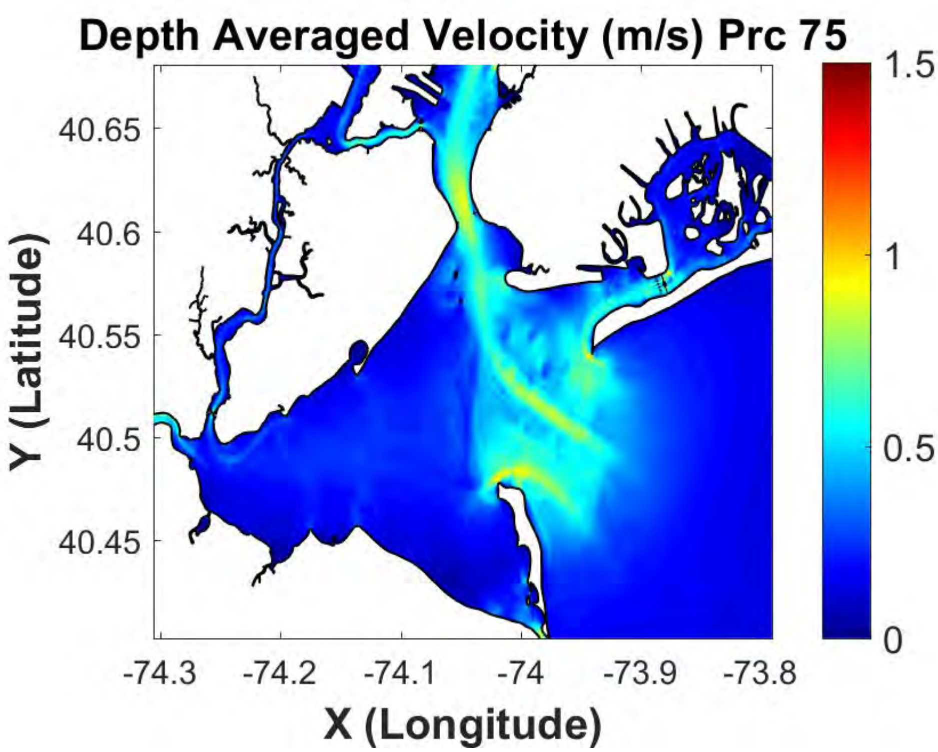
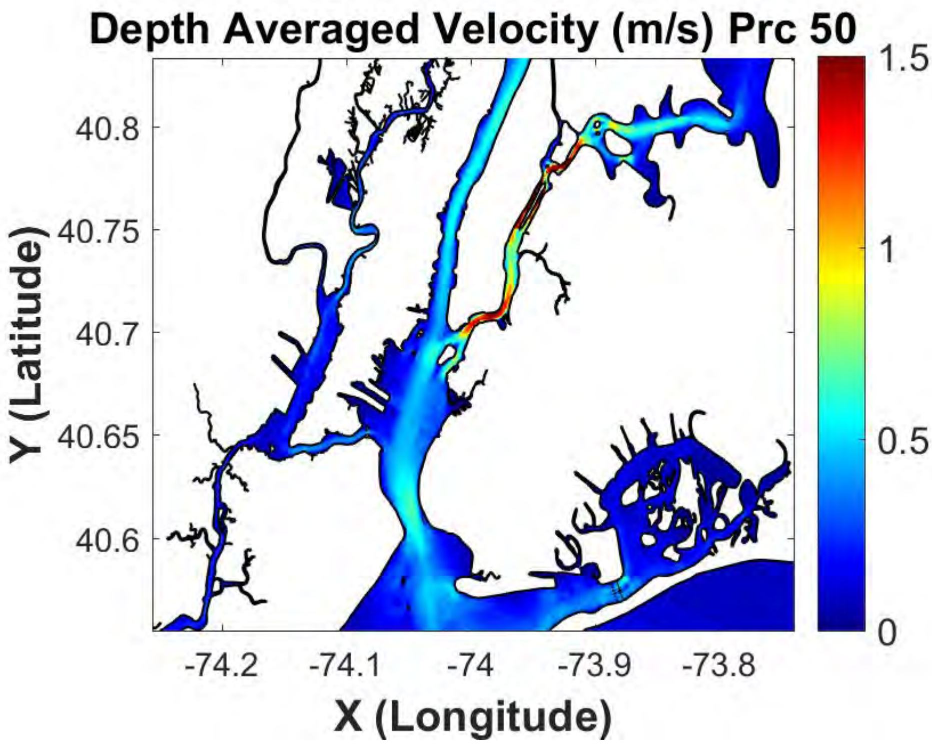


Figure 645. Alternative 3b/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



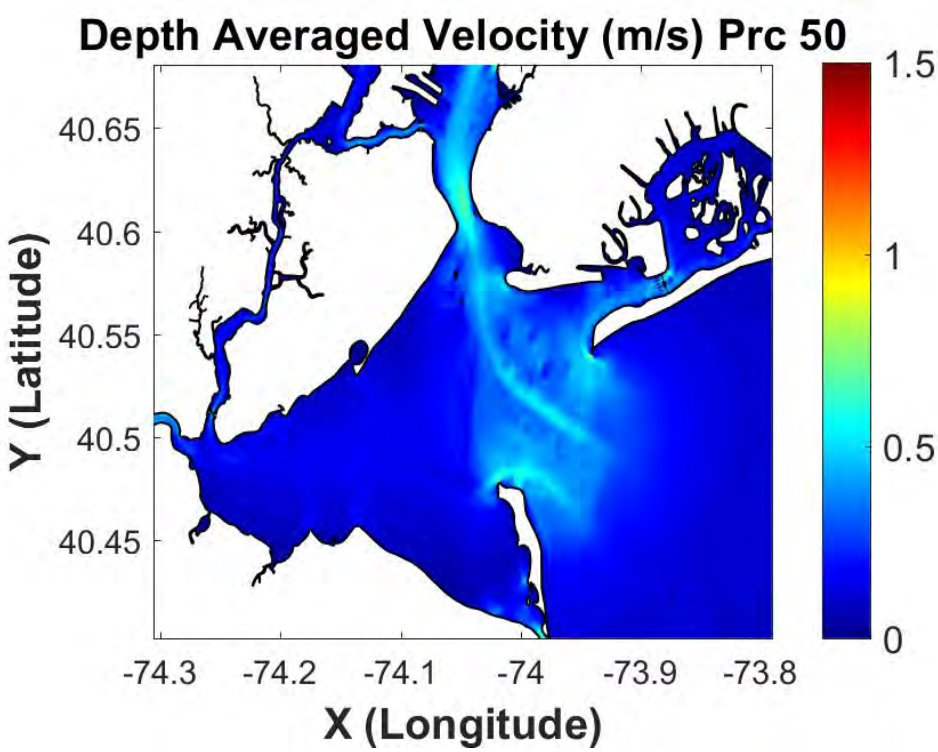
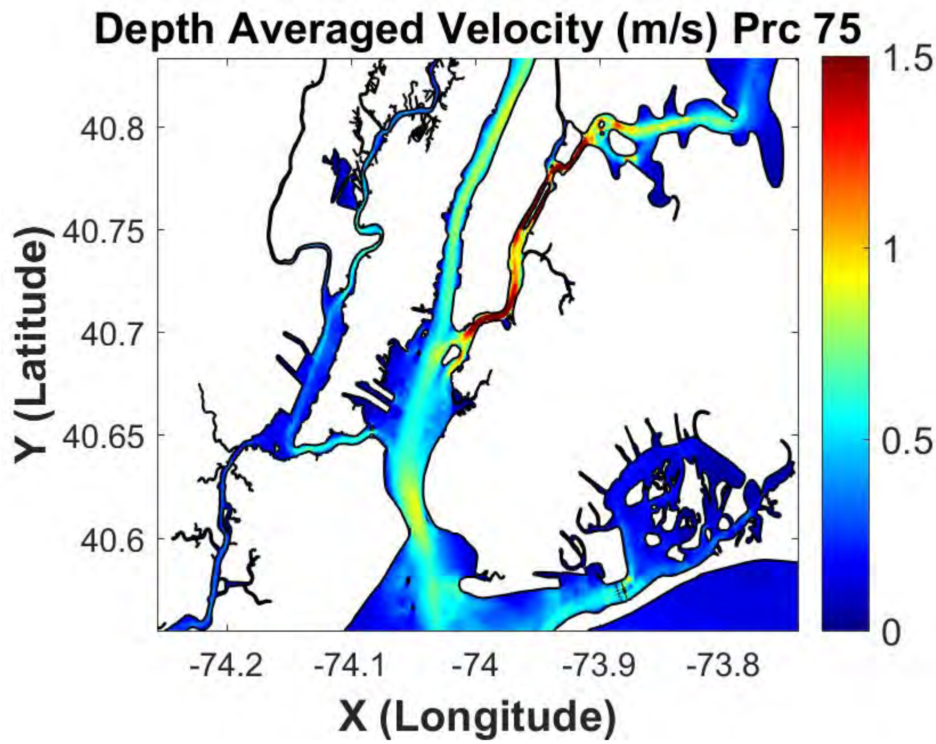


Figure 646. Alternative 3b/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



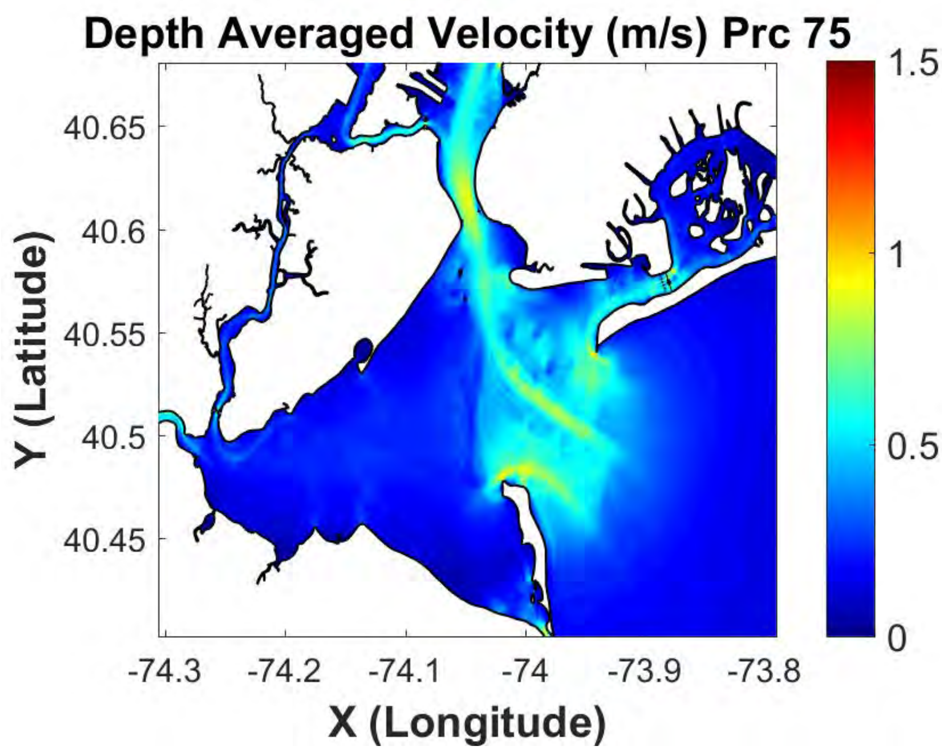
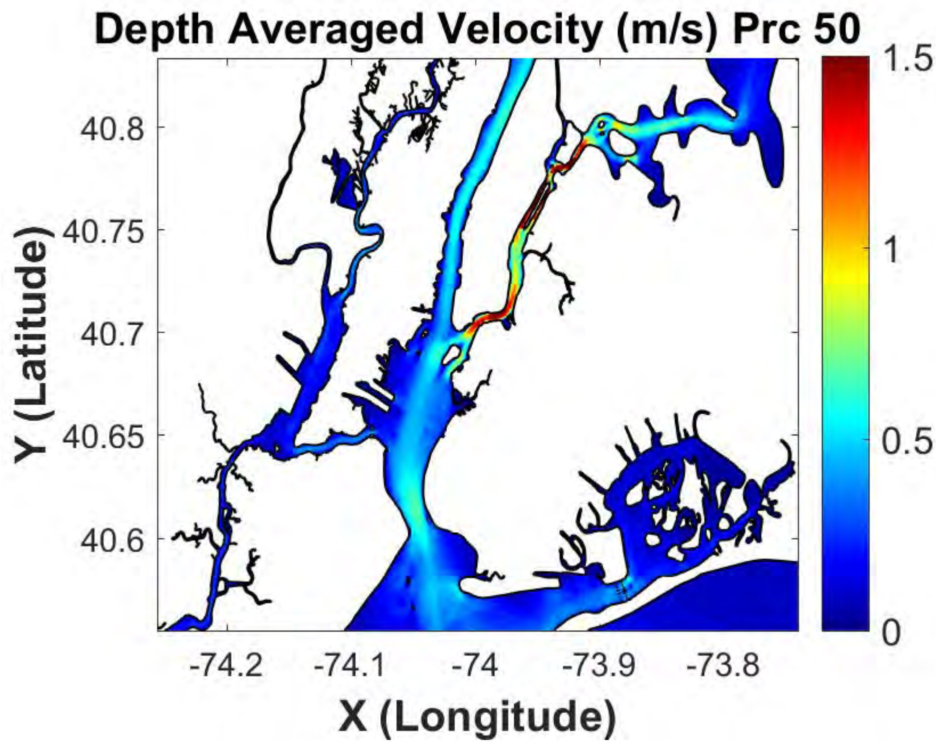


Figure 647. Alternative 3b/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



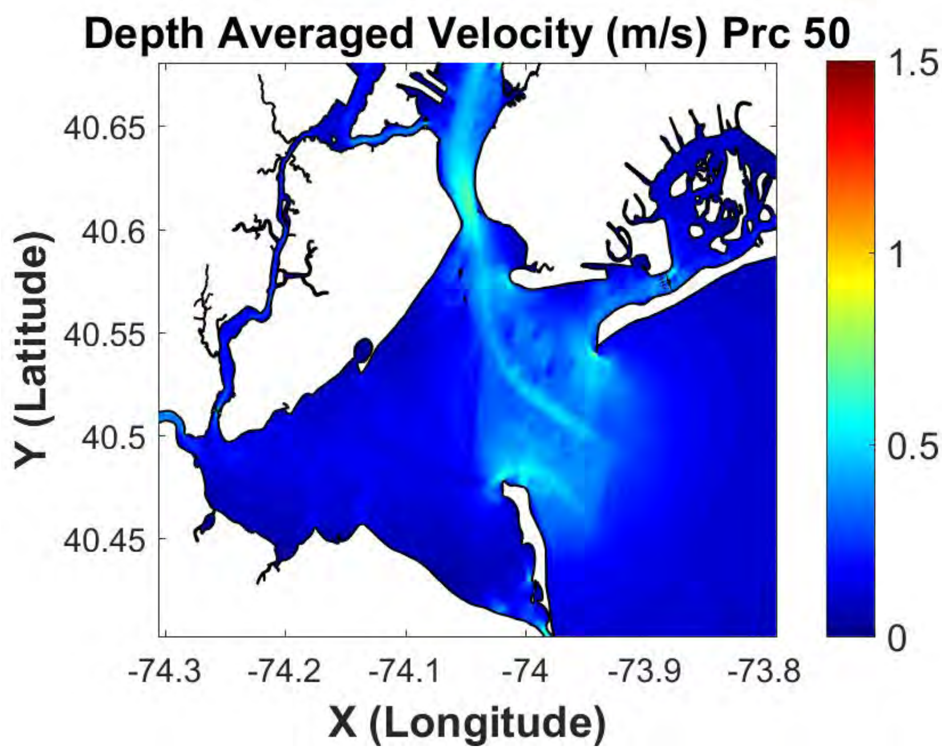
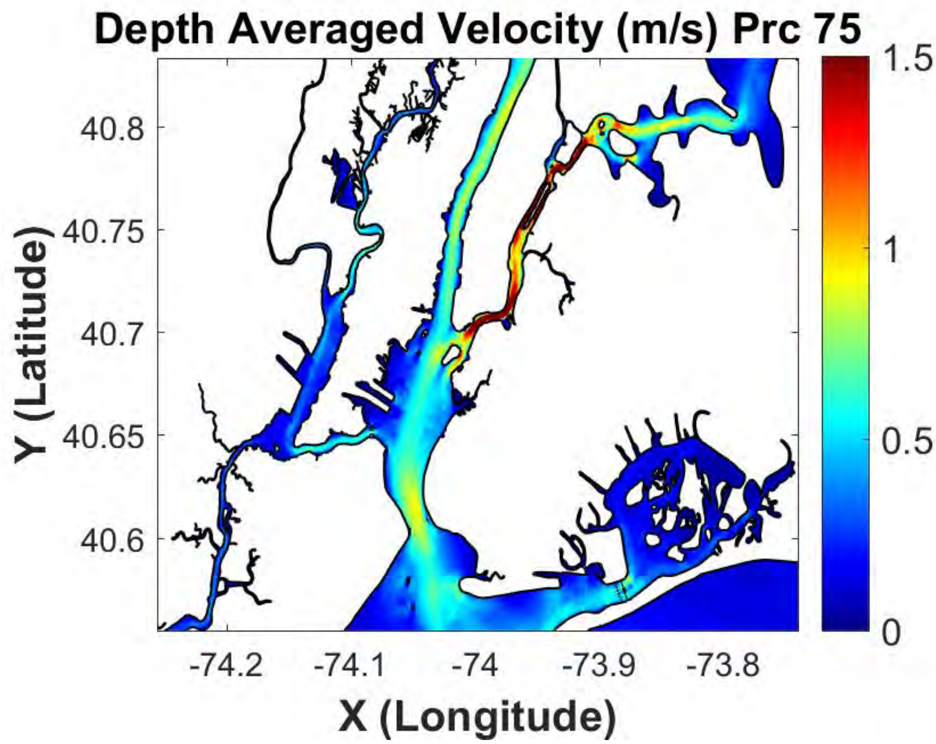


Figure 648. Alternative 3b/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



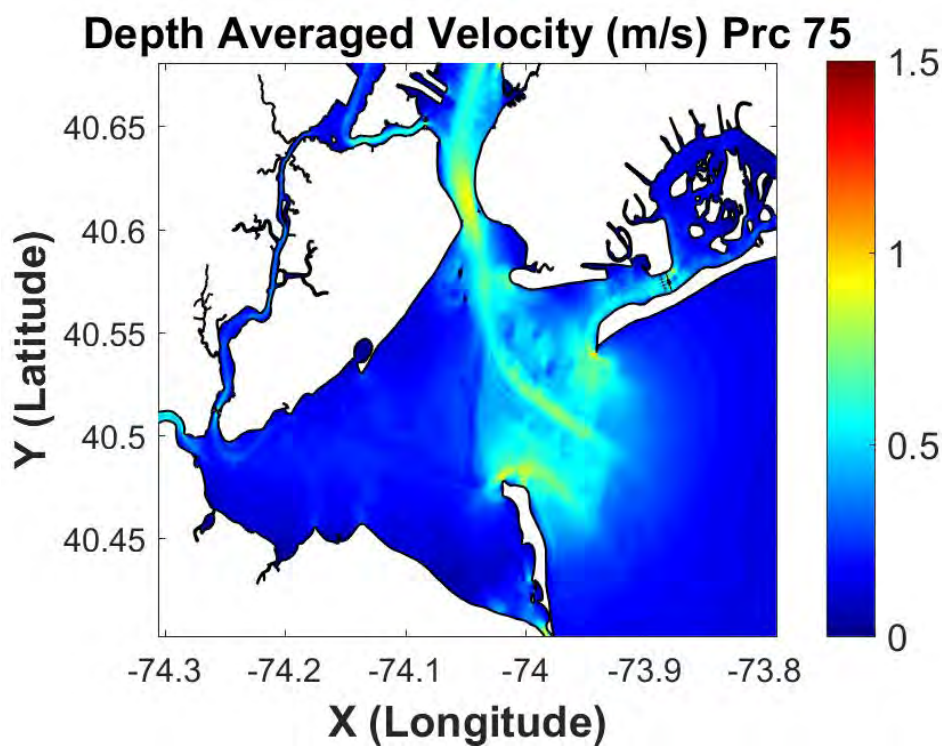
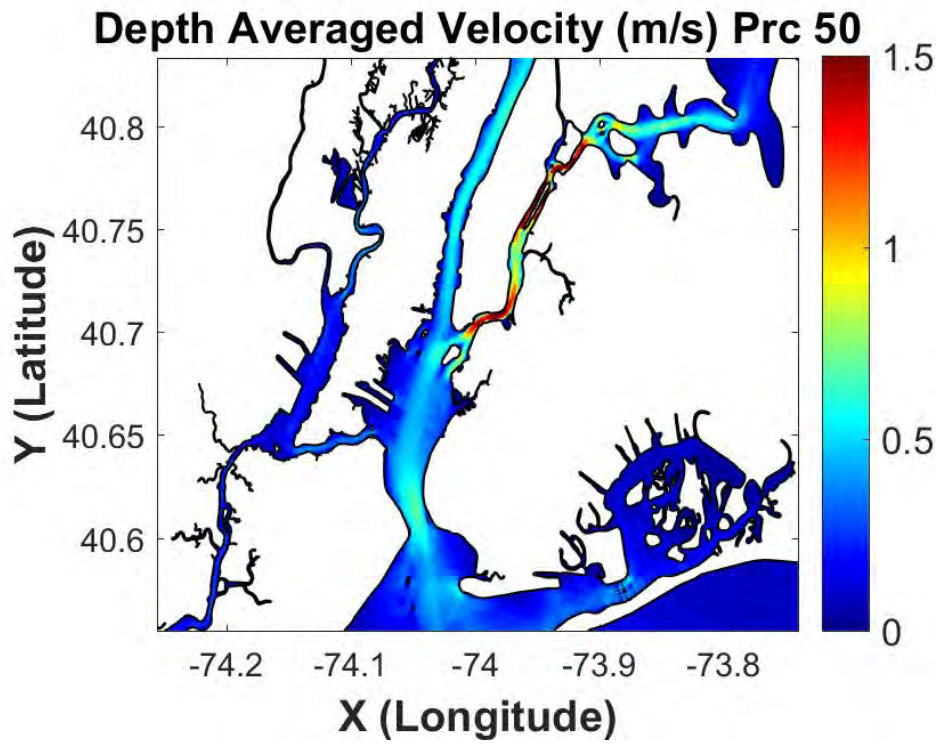


Figure 649. Alternative 3b/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



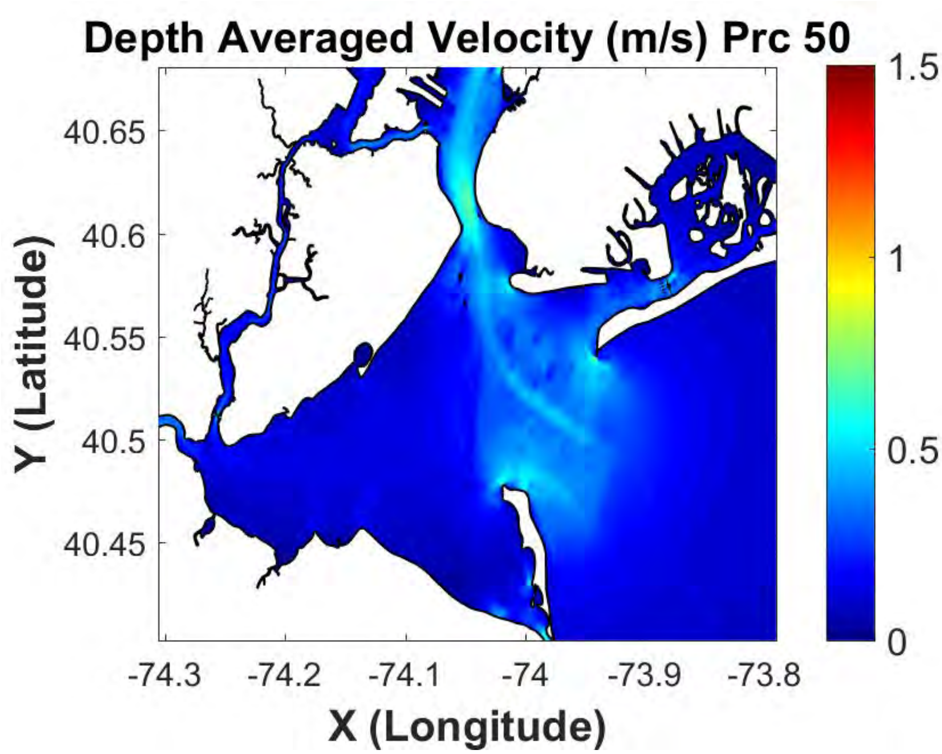
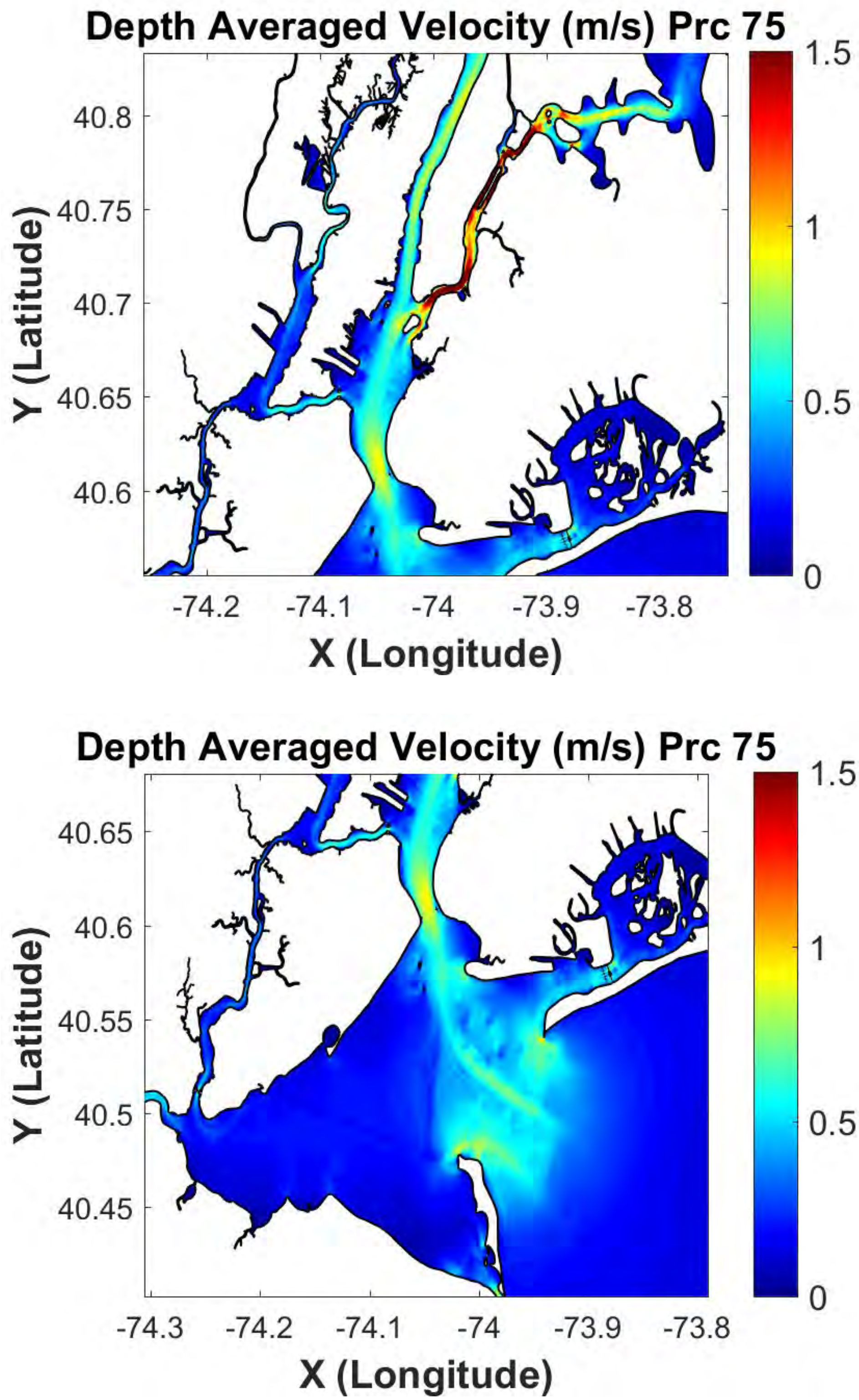


Figure 650. Alternative 3b/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



15.4.5 Spatial Salinity Percentiles

Spatial figures of the salinity percentiles for Alternative 3b for the 50th and 75th percentiles are provided in Figure 651 to Figure 662.

Figure 651. Alternative 3b/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

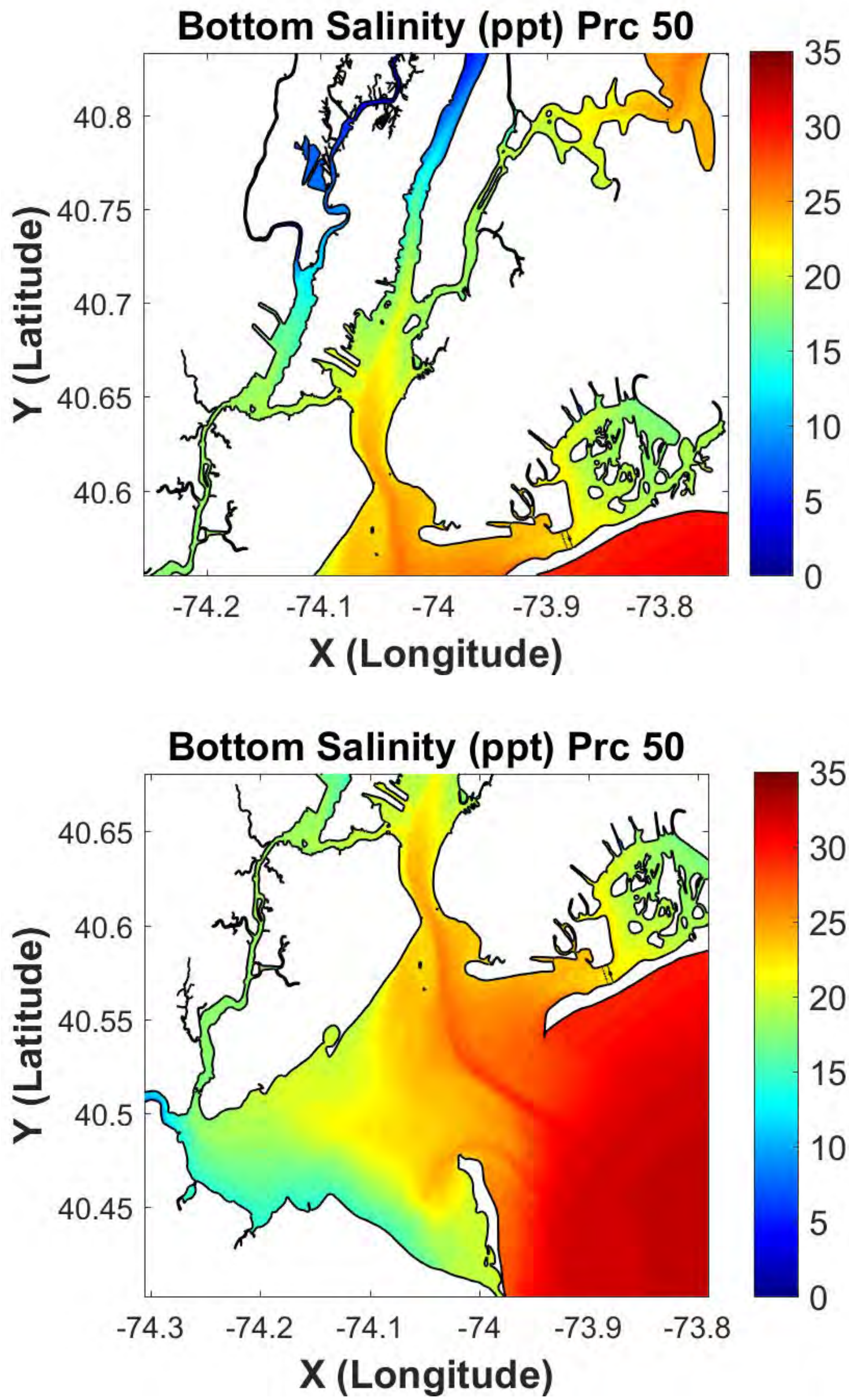


Figure 652. Alternative 3b/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

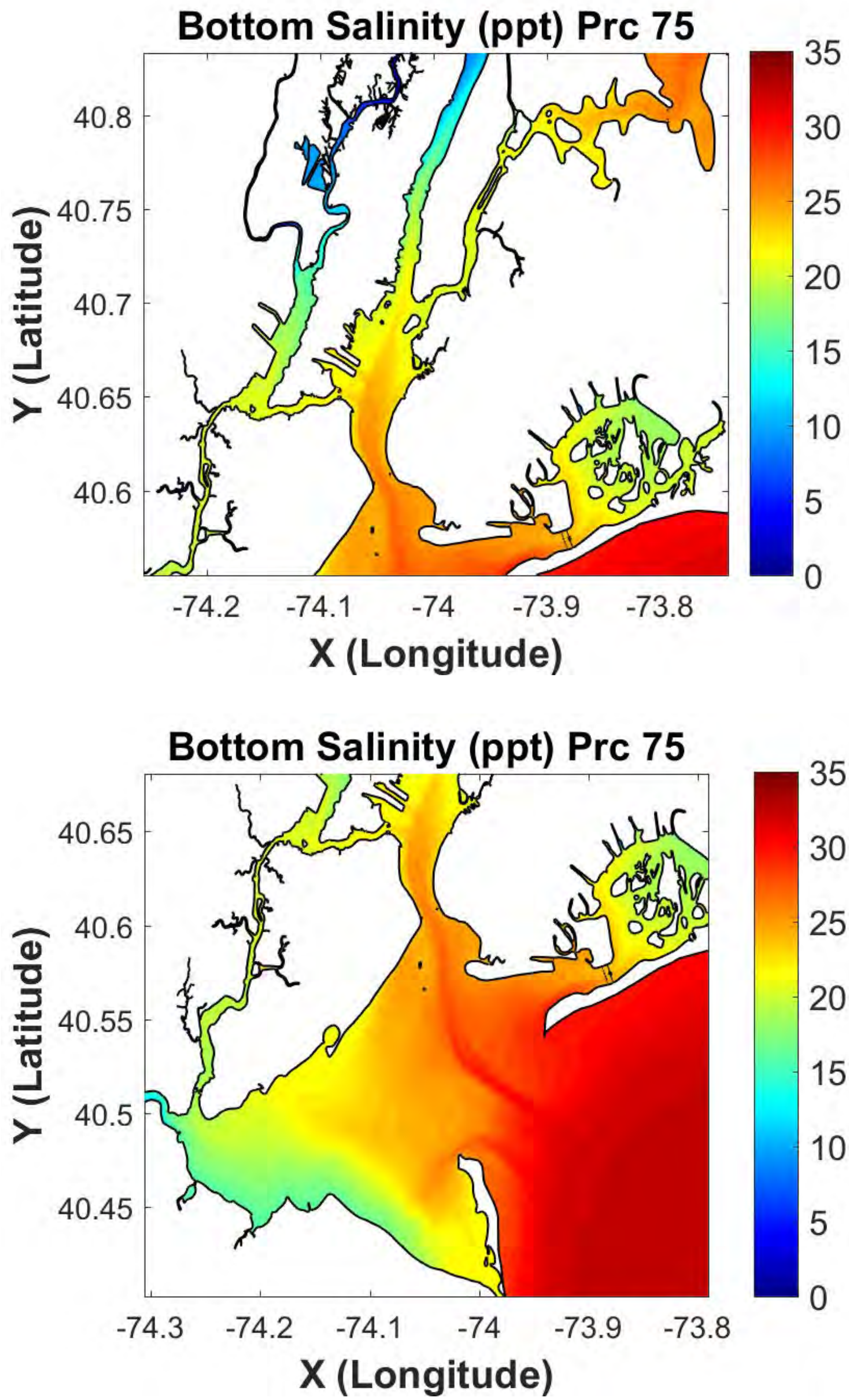


Figure 653. Alternative 3b/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

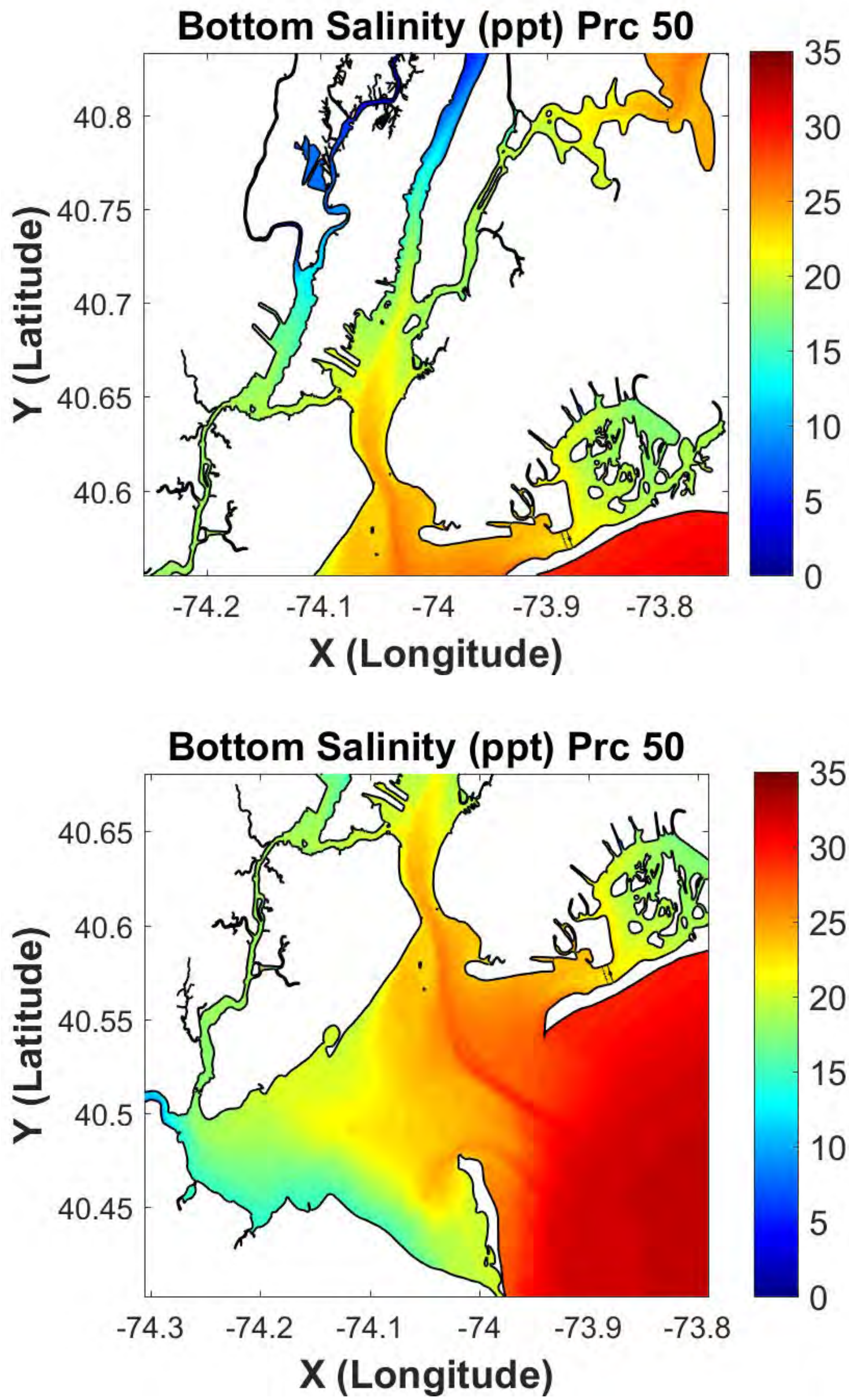
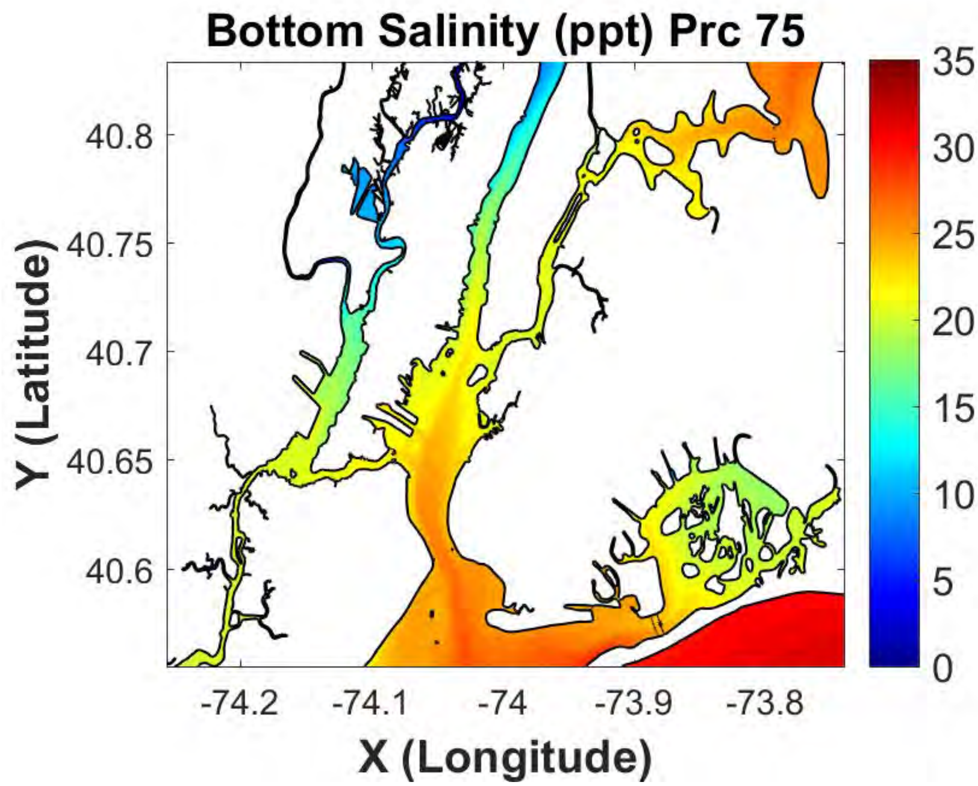


Figure 654. Alternative 3b/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



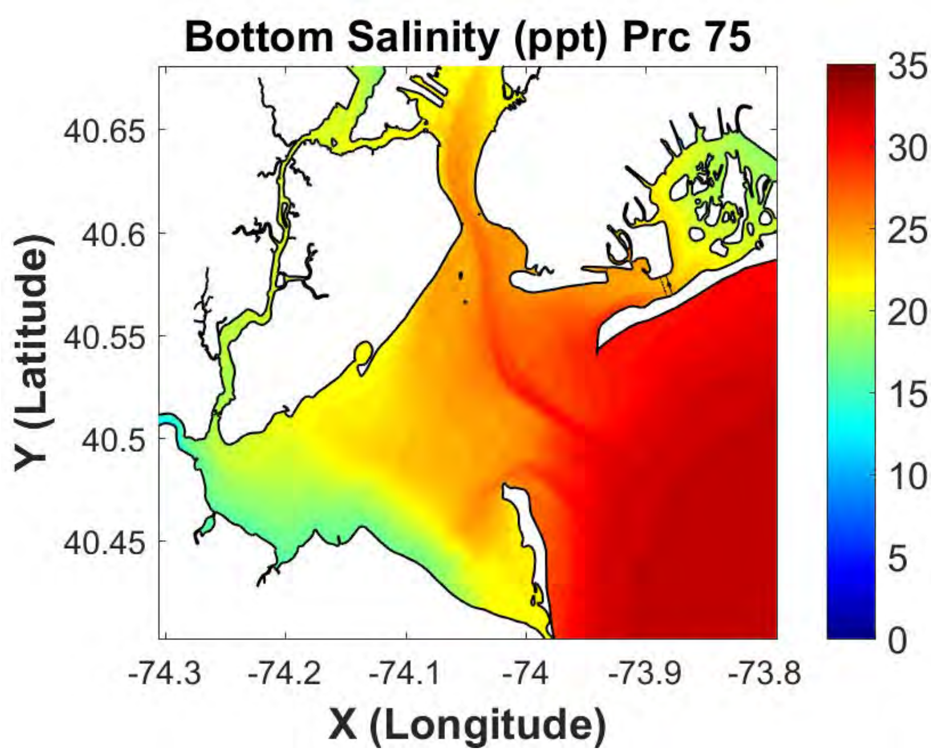
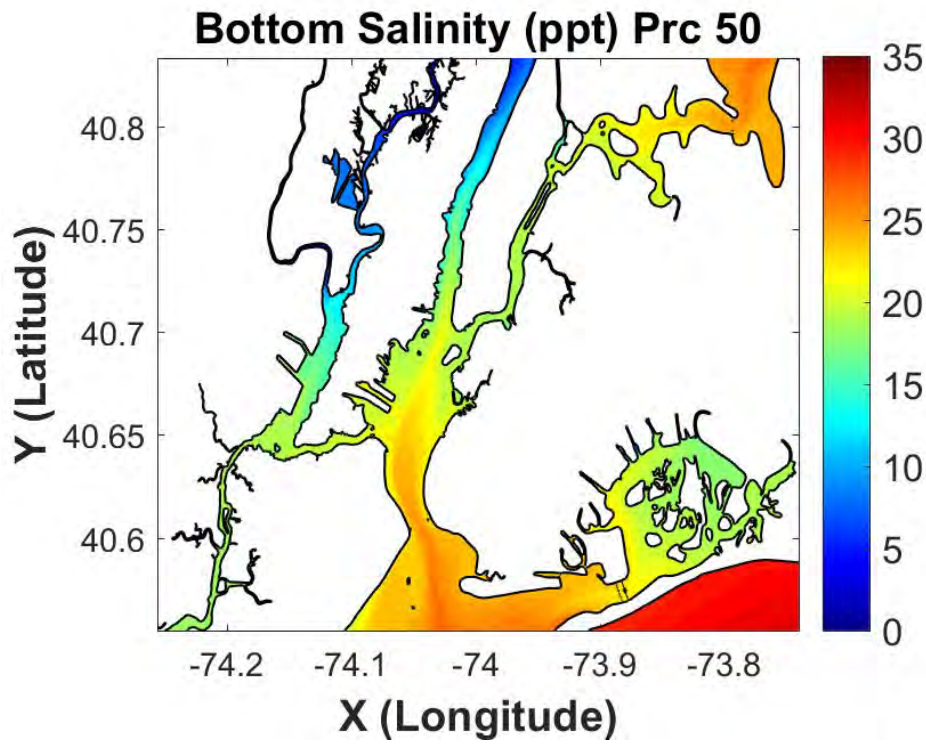


Figure 655. Alternative 3b/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



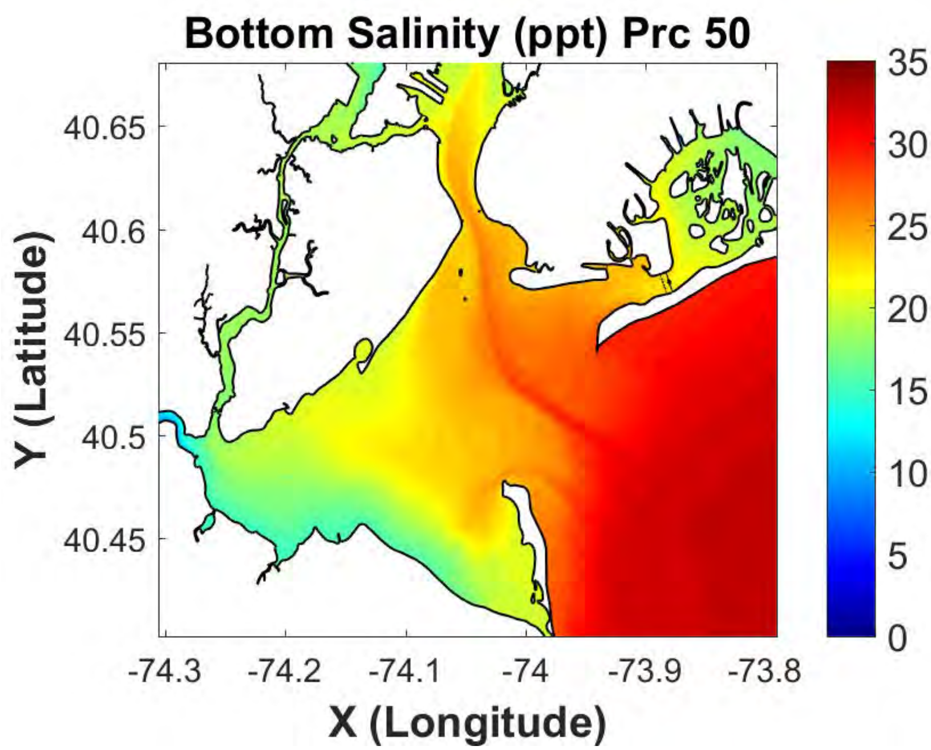


Figure 656. Alternative 3b/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

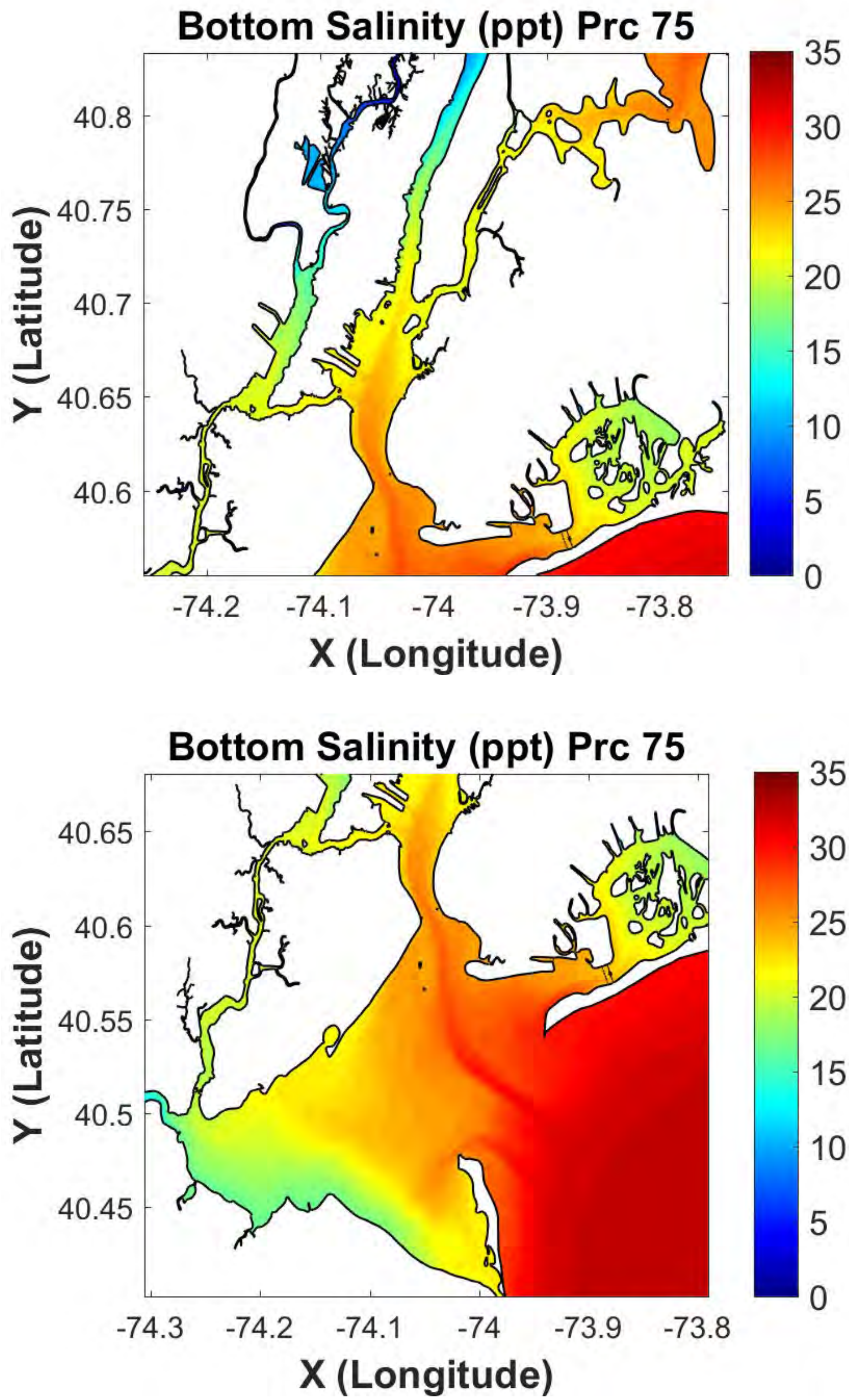
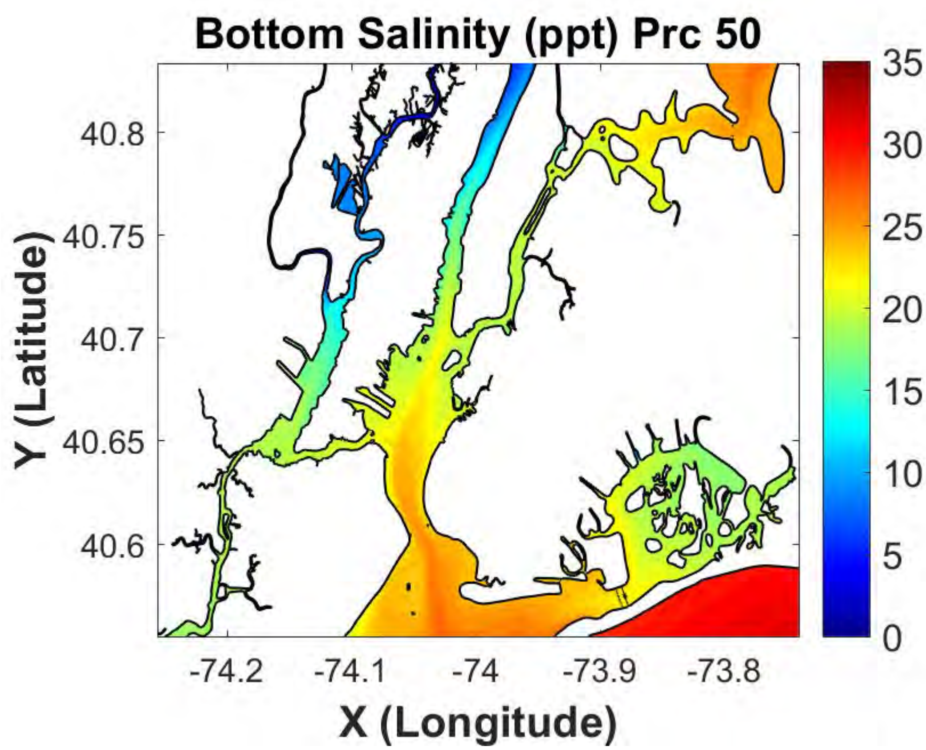


Figure 657. Alternative 3b/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



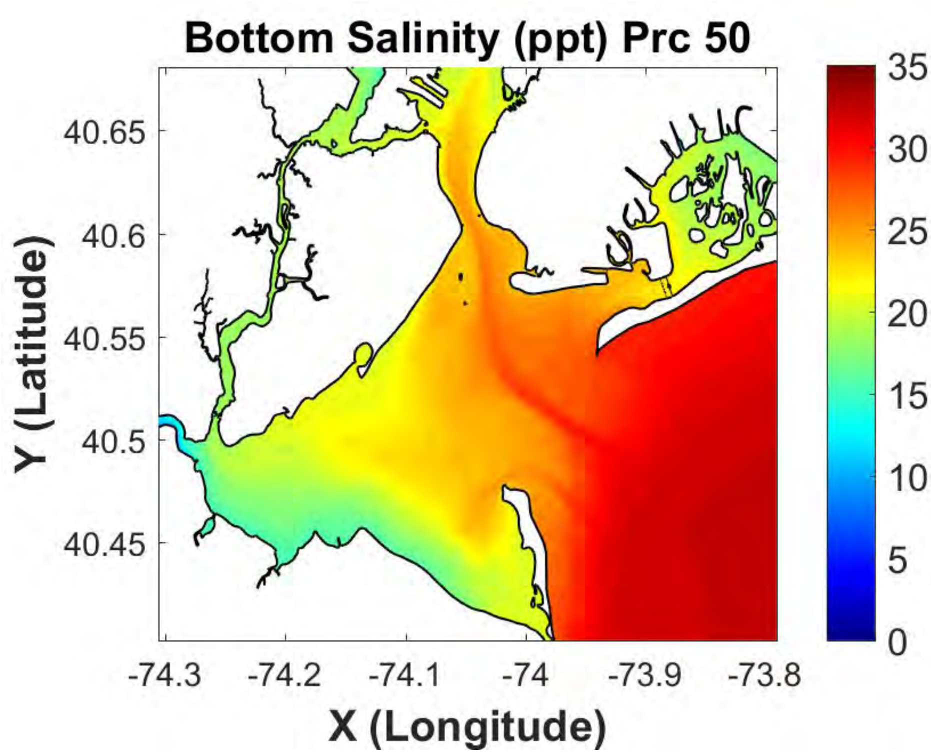
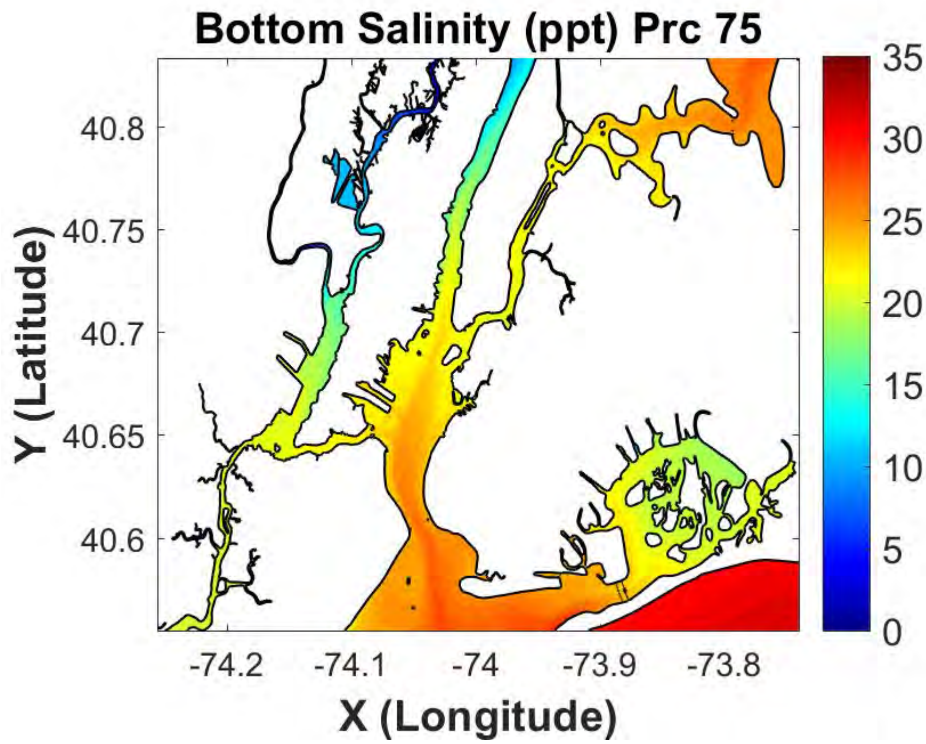


Figure 658. Alternative 3b/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



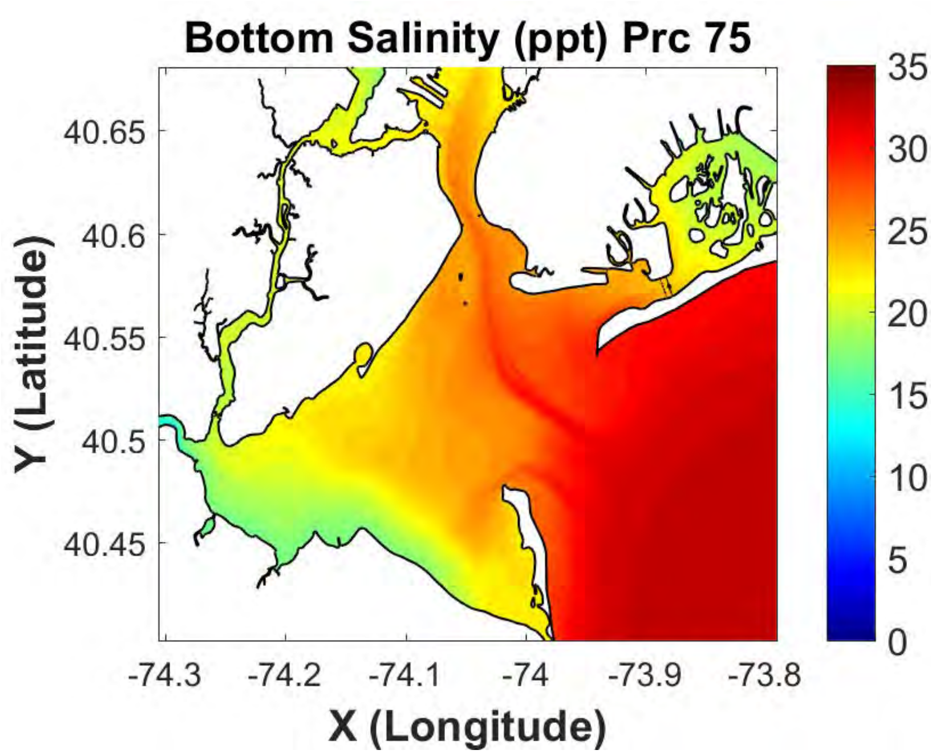


Figure 659. Alternative 3b/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

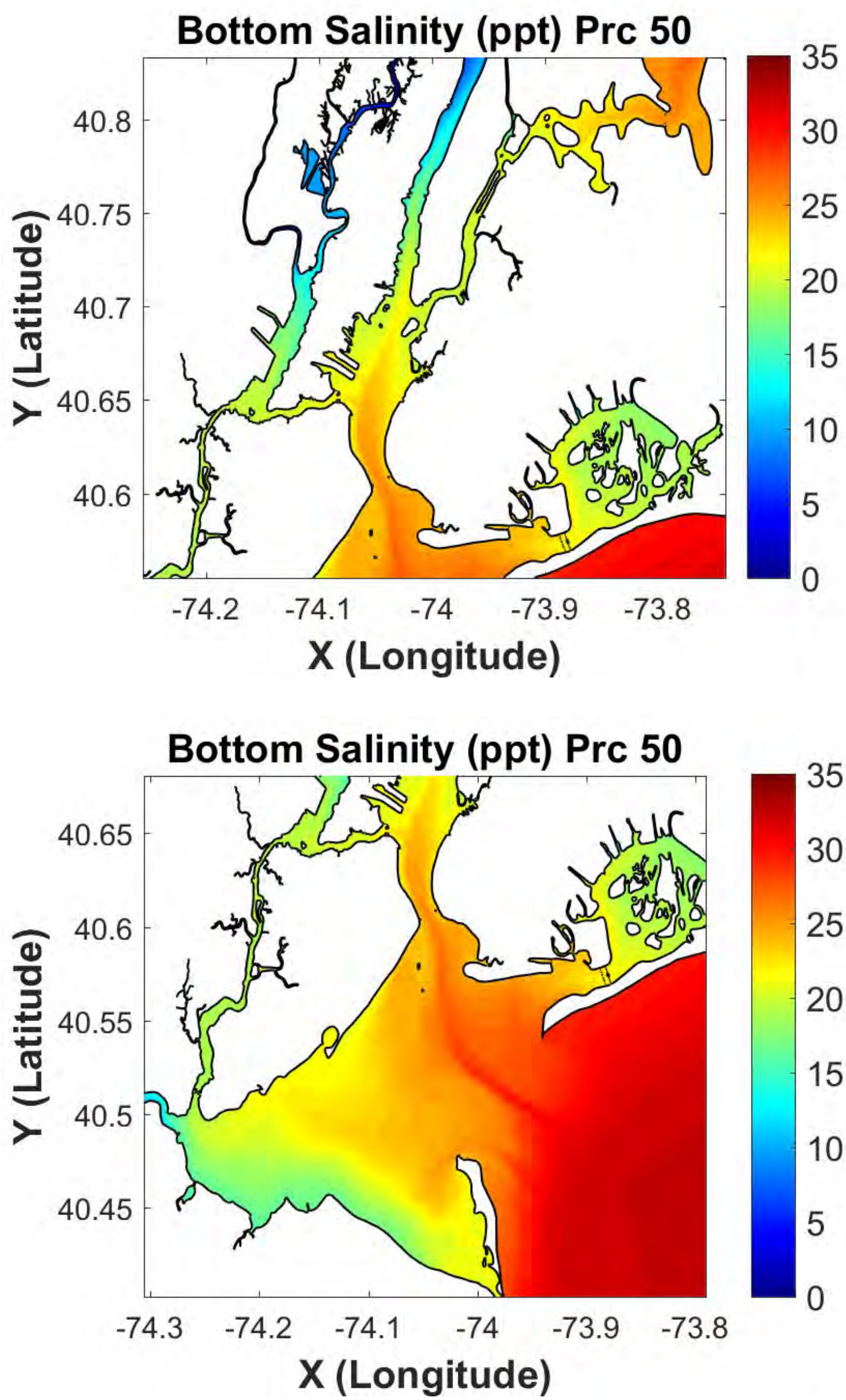
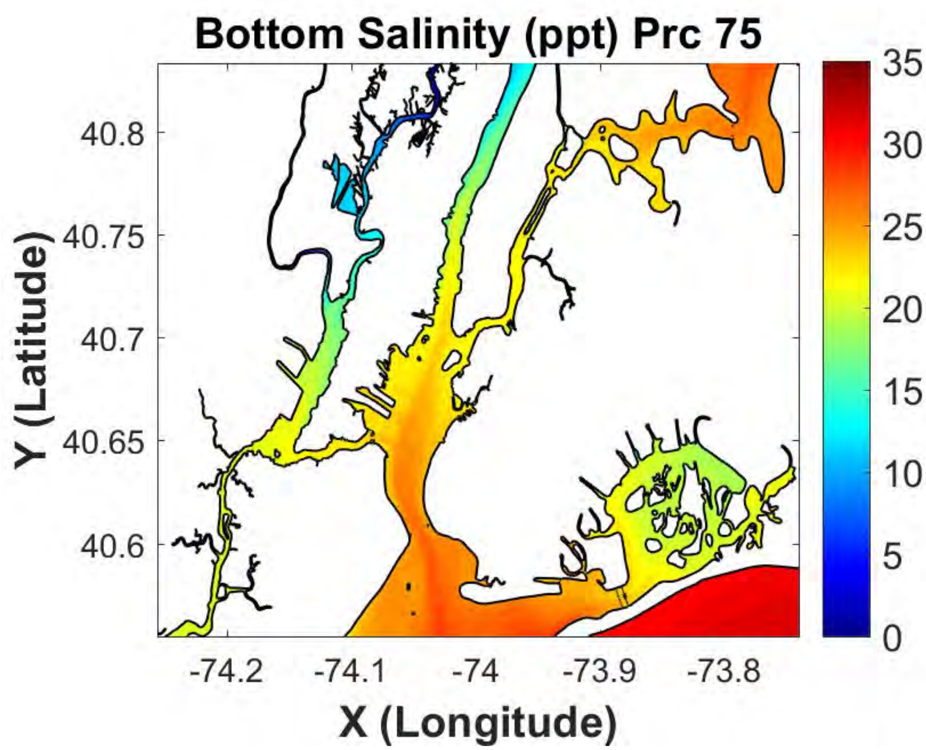


Figure 660. Alternative 3b/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



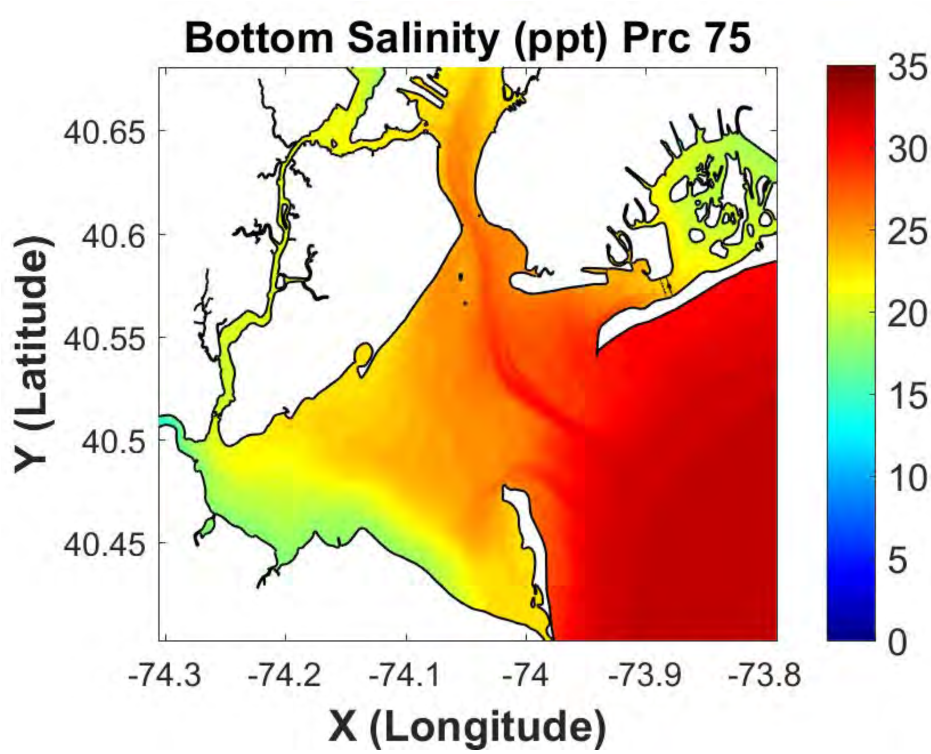
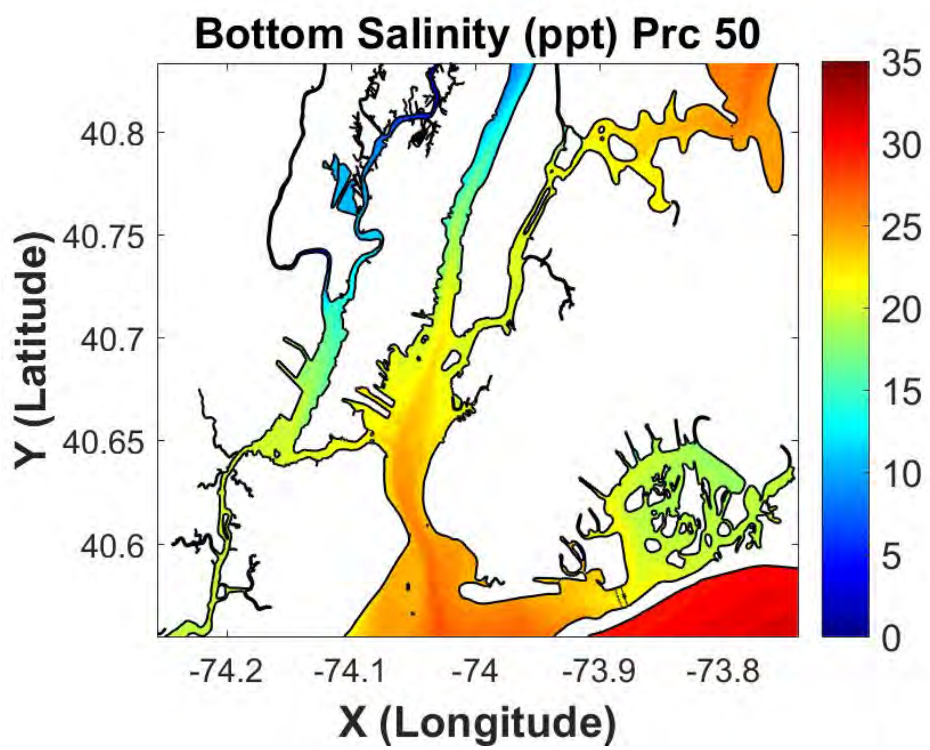


Figure 661. Alternative 3b/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



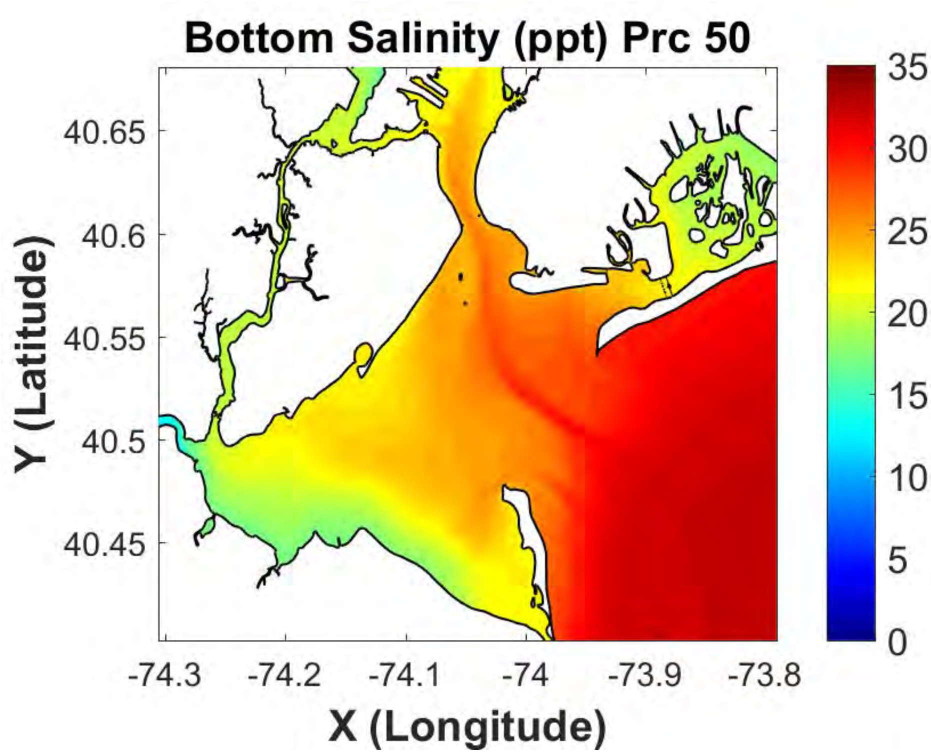
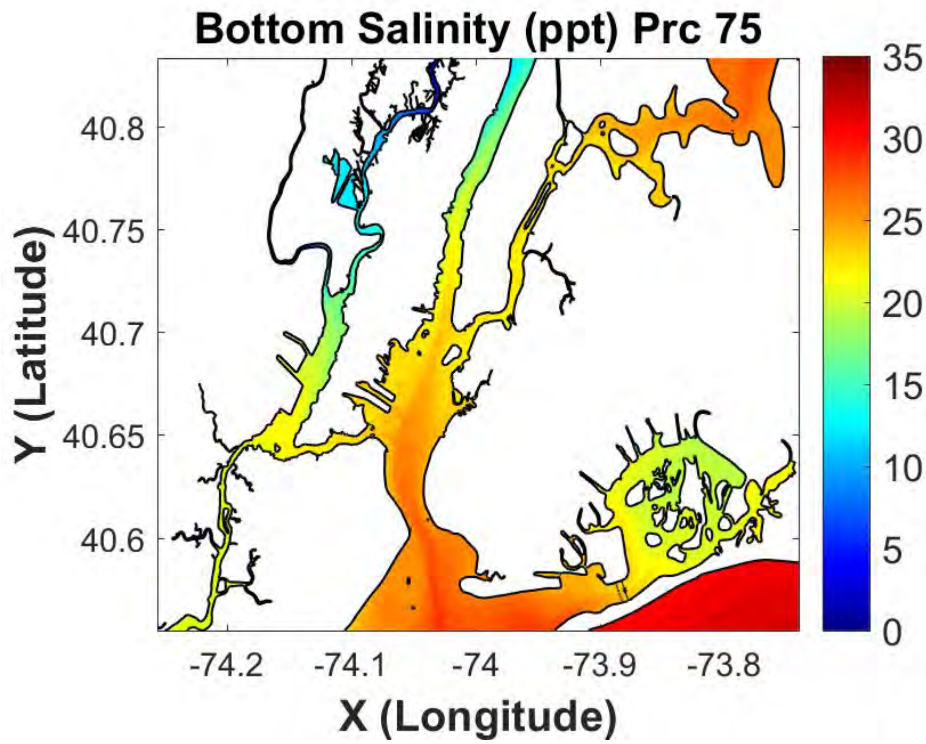
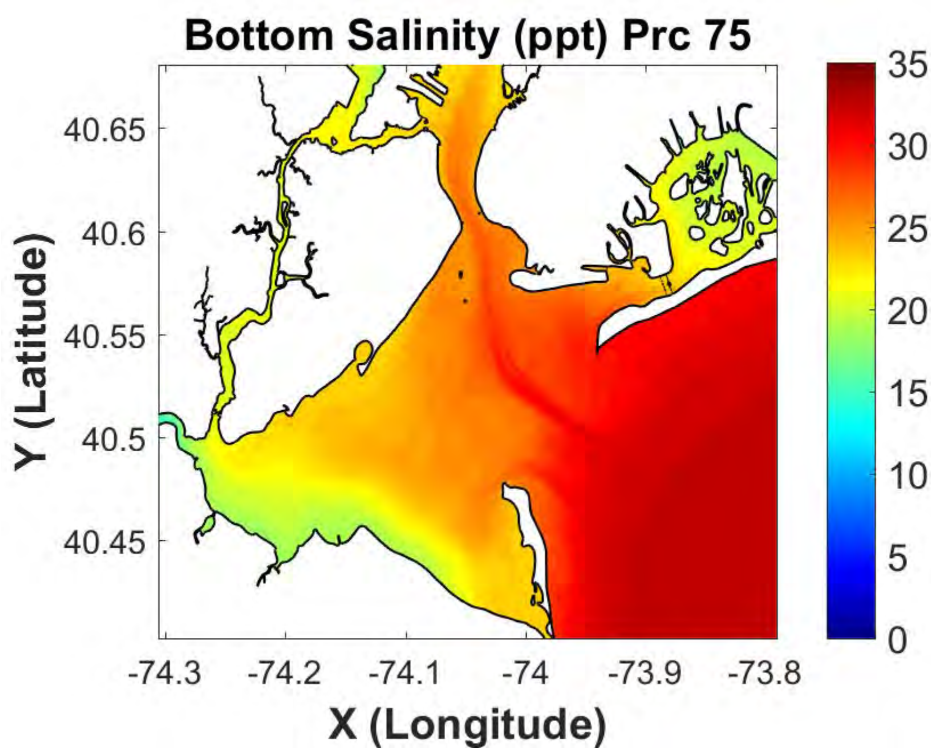


Figure 662. Alternative 3b/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.





15.4.6 Water Flux Analysis

Discharge percentiles for Alternative 3b for the previously shown locations (Figure 28) are provided in Figure 663 to Figure 666. These locations indicate increased tidal exchange for increasing water levels. Table 10 shows the mean flows for the various pathways and sea levels.

Figure 663. Alternative 3b Variation in Throgs Neck Discharges with sea level.

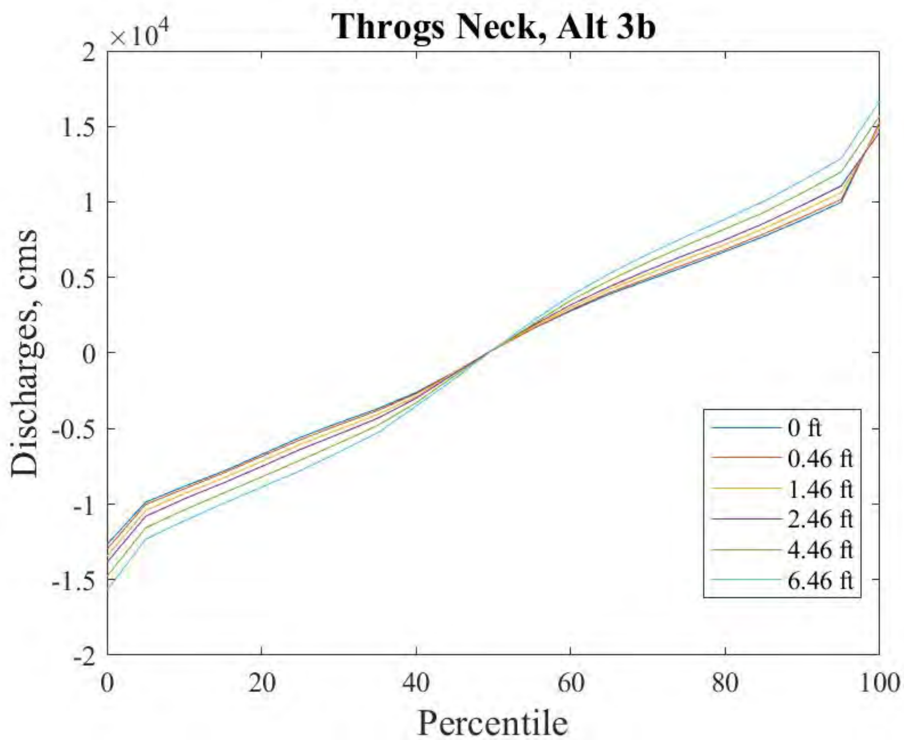


Figure 664. Alternative 3b Variation in Verrazano Narrows Discharges with sea level.

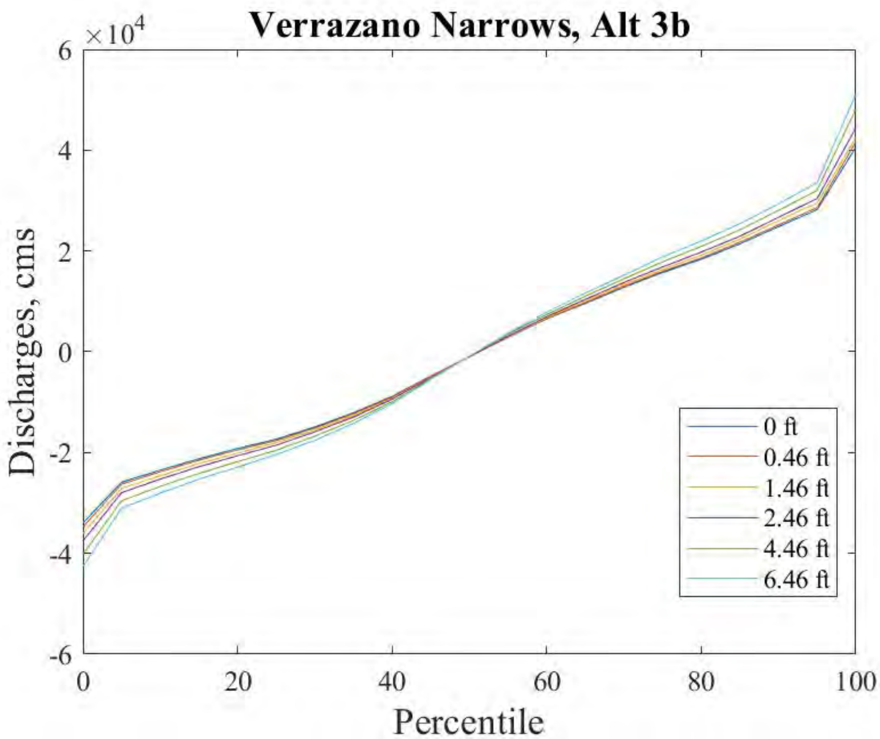


Figure 665. Alternative 3b Variation in Kill Van Kull Discharges with sea level.

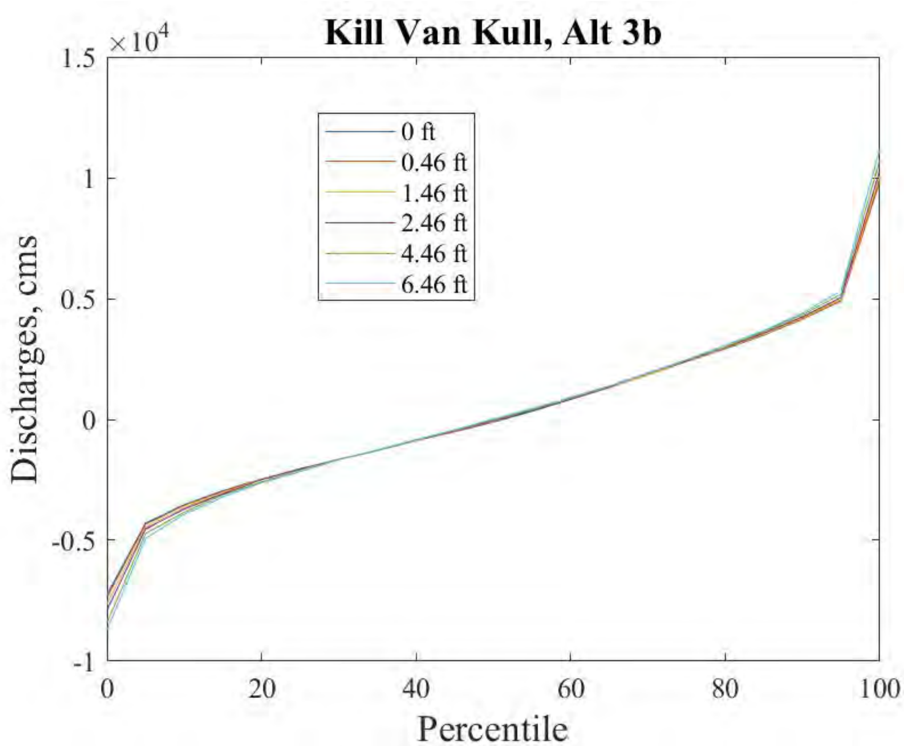


Figure 666. Alternative 3b Variation in Arthur Kill Discharges with sea level.

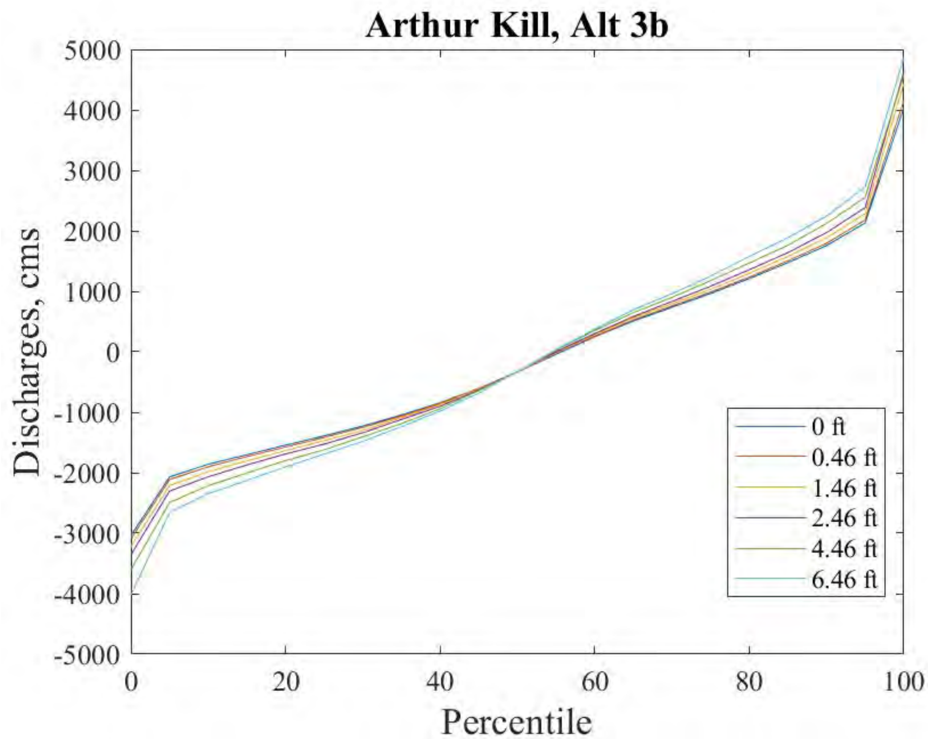


Table 10. Alternative 3b, Sea Level Rise Impacts of Flows in CMS.

Location	0.0 ft. MSL	0.46 ft. MSL	1.46 ft. MSL	2.46 ft. MSL	4.46 ft. MSL	6.46 ft. MSL
Throgs Neck	80	81	87	91	99	115
Verrazano Narrows	-302	-304	-314	-319	-329	-344
Kill Van Kull	146	145	144	143	142	143
Arthur Kill	-177	-177	-176	175	-175	-177

15.4.7 Tidal Prism Analysis

Tidal prisms were calculated, and a percentile analysis was performed to evaluate the impact of sea level rise on the tidal exchange. Figure 667 and

Figure 668 show the tidal prism for all sea level values for the impounded areas for Alternative 3b previously shown in Figure 38. These results indicate higher sea level values result in high tidal prisms and associated tidal exchange/mixing. The Jamaica Bay area behaves slightly different with lower tidal prism values for the lower percentiles and higher values for the higher percentiles.

Figure 667. Tidal Prism Percentile Analysis for Alternative 3b for Material 1.

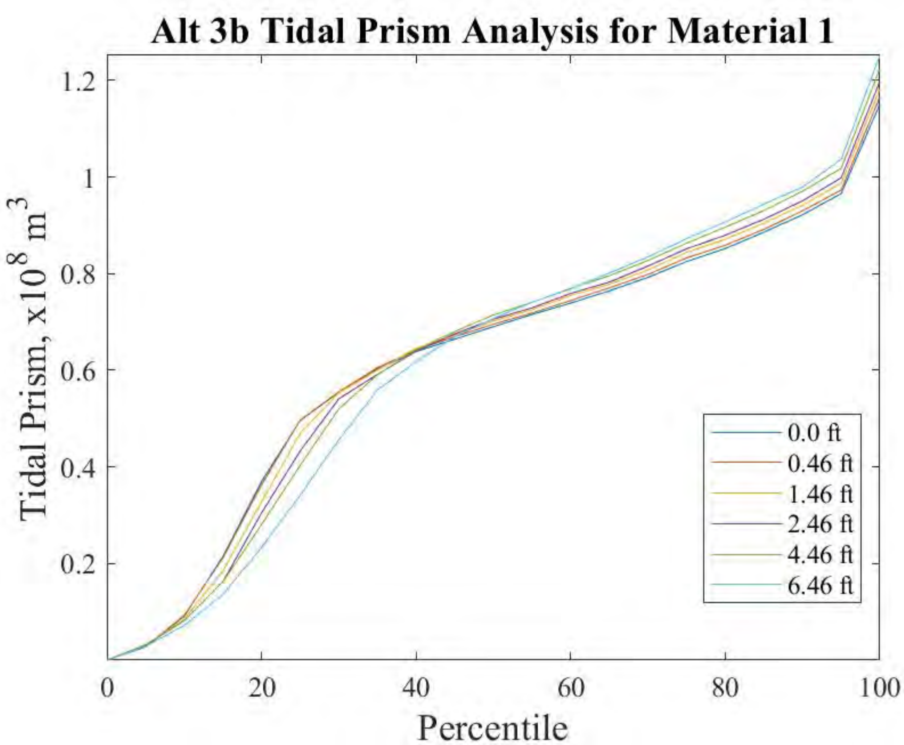
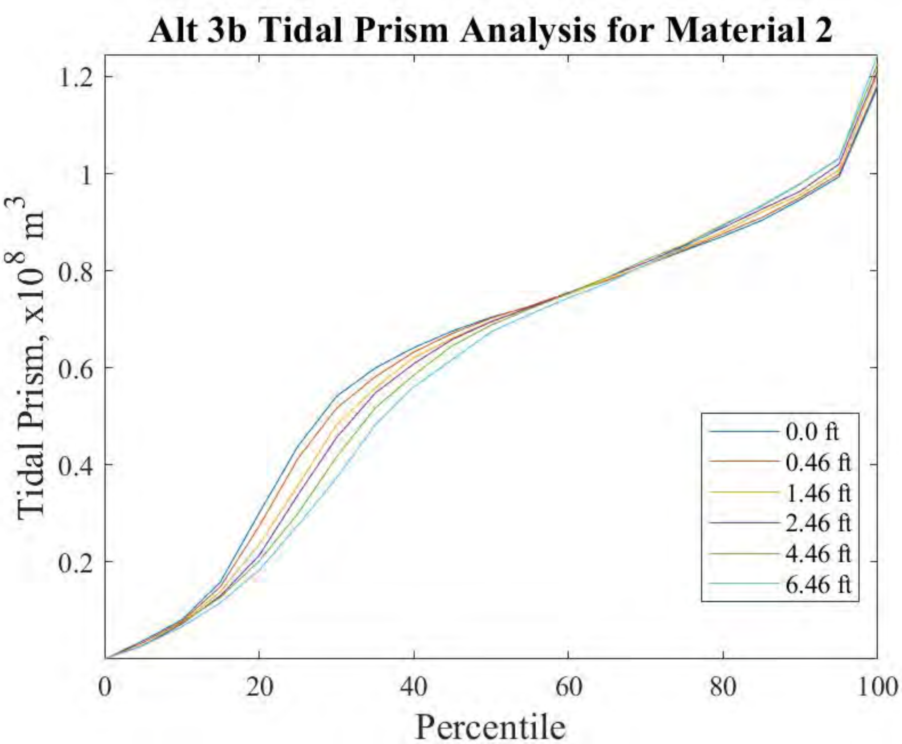


Figure 668. Tidal Prism Percentile Analysis for Alternative 3b for Material 2.



15.5 Alternative 4

For increased sea levels, Alternative 4 possesses increasing tidal exchange, tide ranges, and salinity intrusion. The velocities are also increased as the increases in the tidal exchange override the increased depths also present in the sea level rise alternatives.

15.5.1 Water Surface Elevation Point Percentiles

Water surface elevation (WSE) percentiles for Alternative 4 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 669 to Figure 693. The datum in these plots is relative to Mean Sea Level for 1995. The datum Mean Sea Level will increase with sea level rise (SLR) but for the purposes of these comparisons it is held constant, so all water levels are relative 0.0 MSL for 1995.

Figure 669. Alt 4, Sandy Hook WSE Variation with SLR.

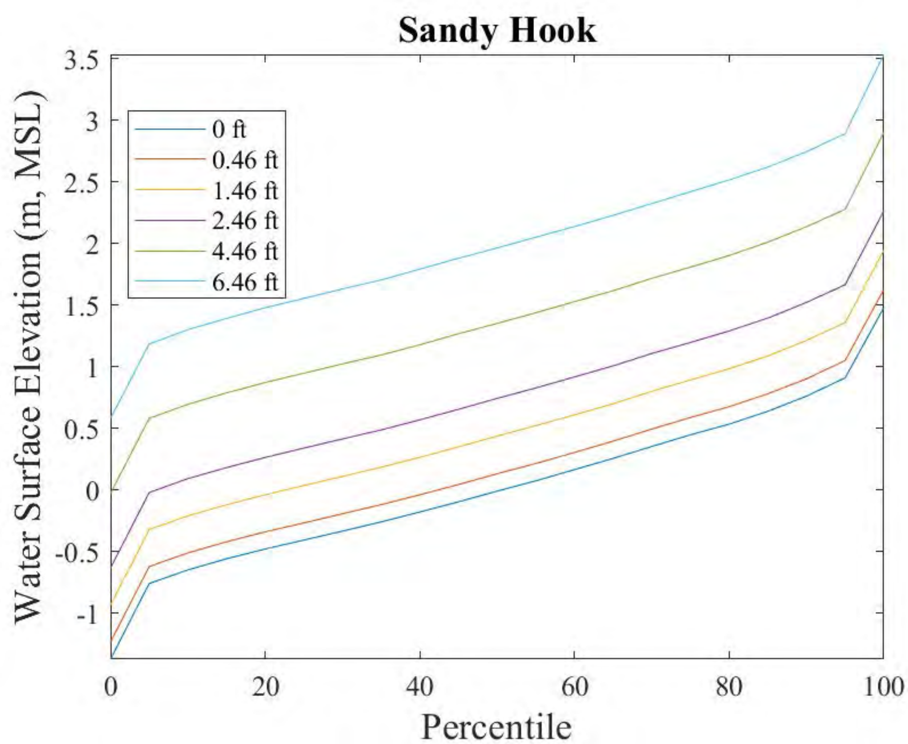


Figure 670. Alt 4, V5 WSE Variation with SLR.

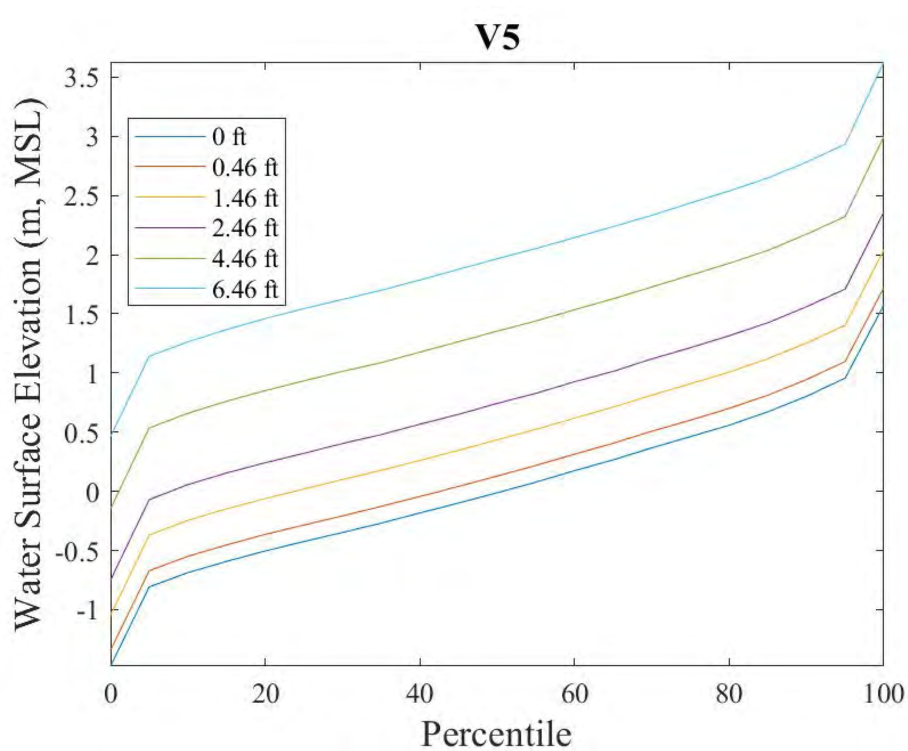


Figure 671. Alt 4, V6 WSE Variation with SLR.

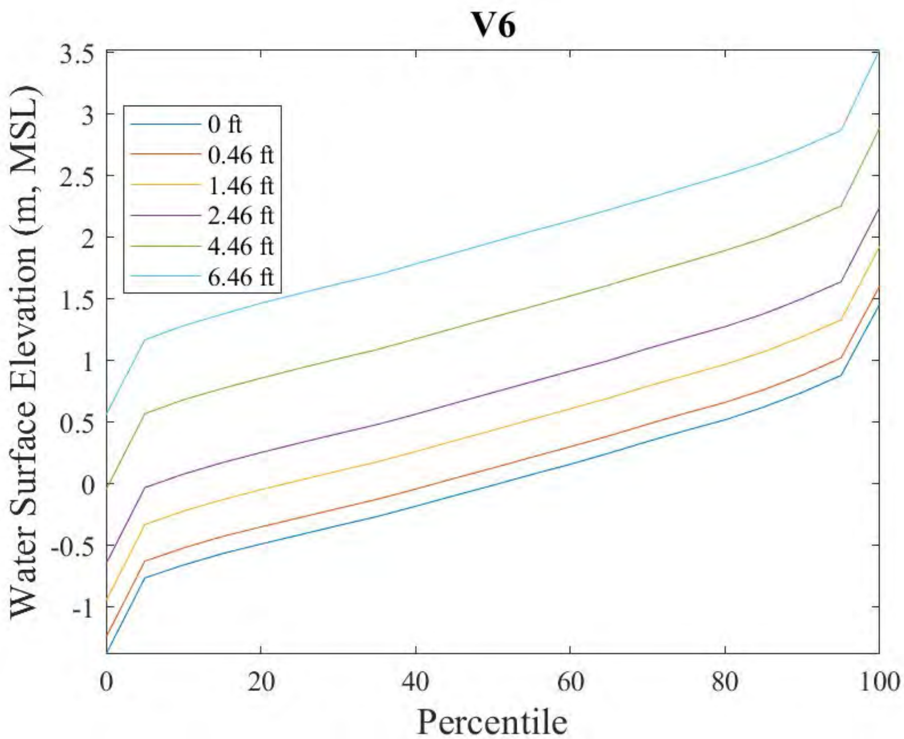


Figure 672. Alt 4, Fresh Kills WSE Variation with SLR.

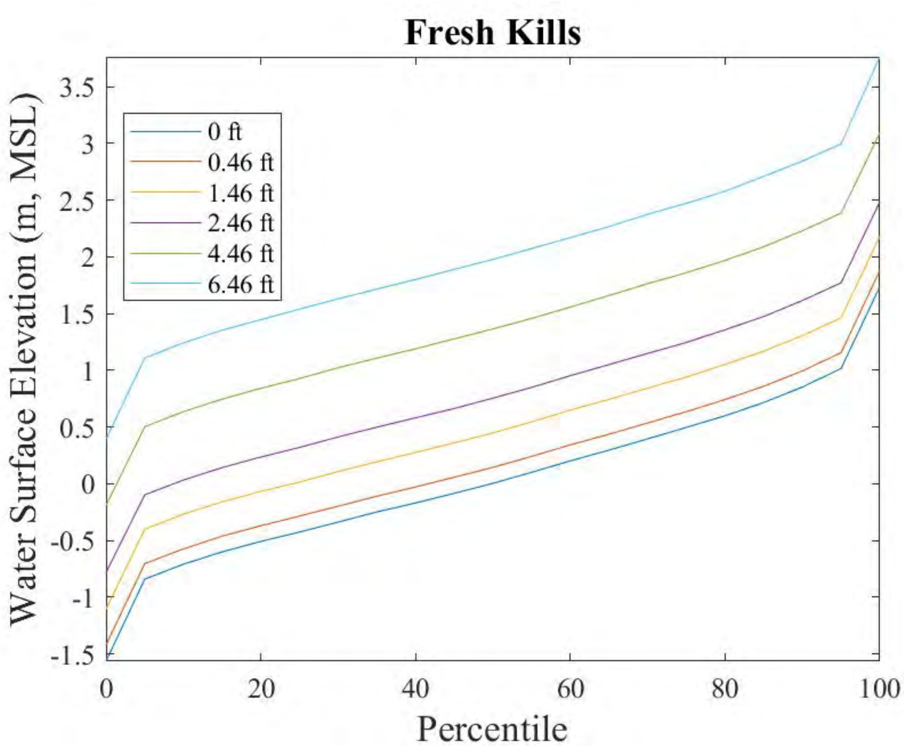


Figure 673. Alt 4, Mariners Harbor WSE Variation with SLR.

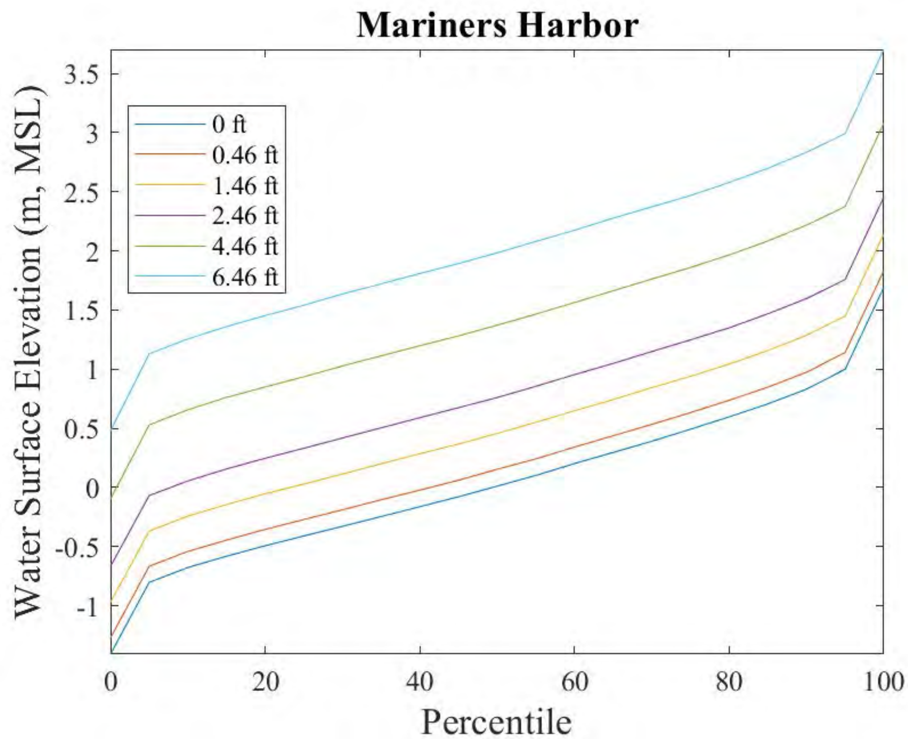


Figure 674. Alt 4, T2 WSE Variation with SLR.

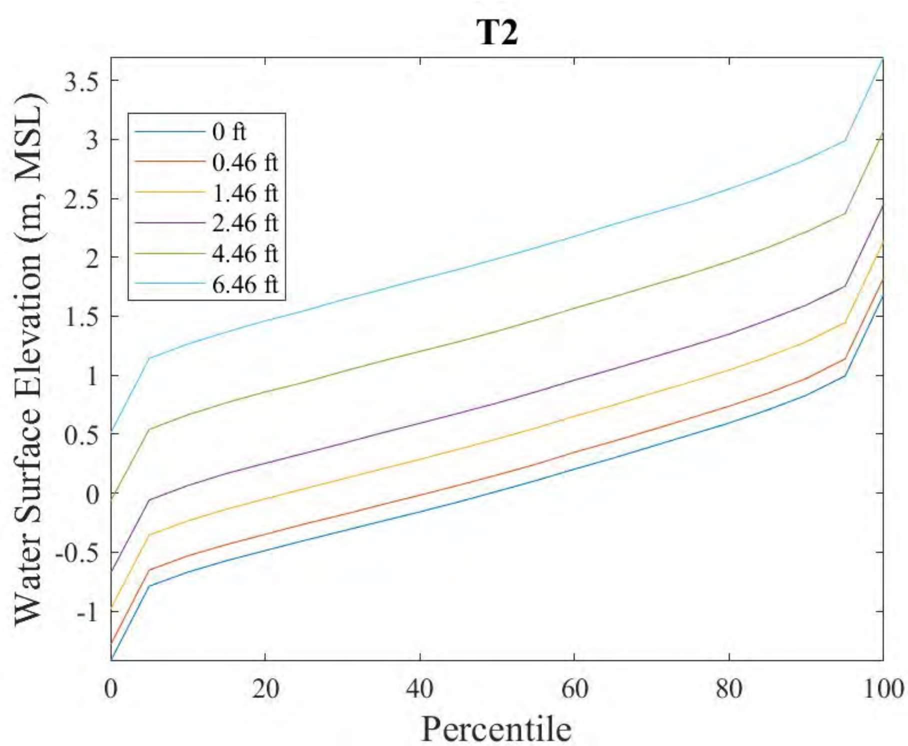


Figure 675. Alt 4, T3 WSE Variation with SLR.

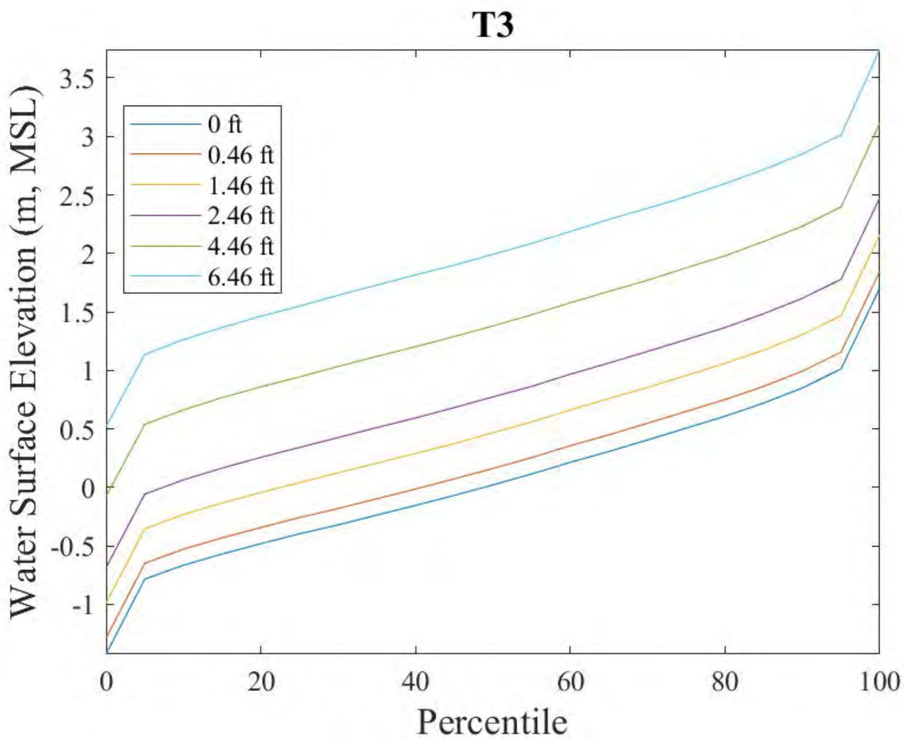


Figure 676. Alt 4, North Reach WSE Variation with SLR.

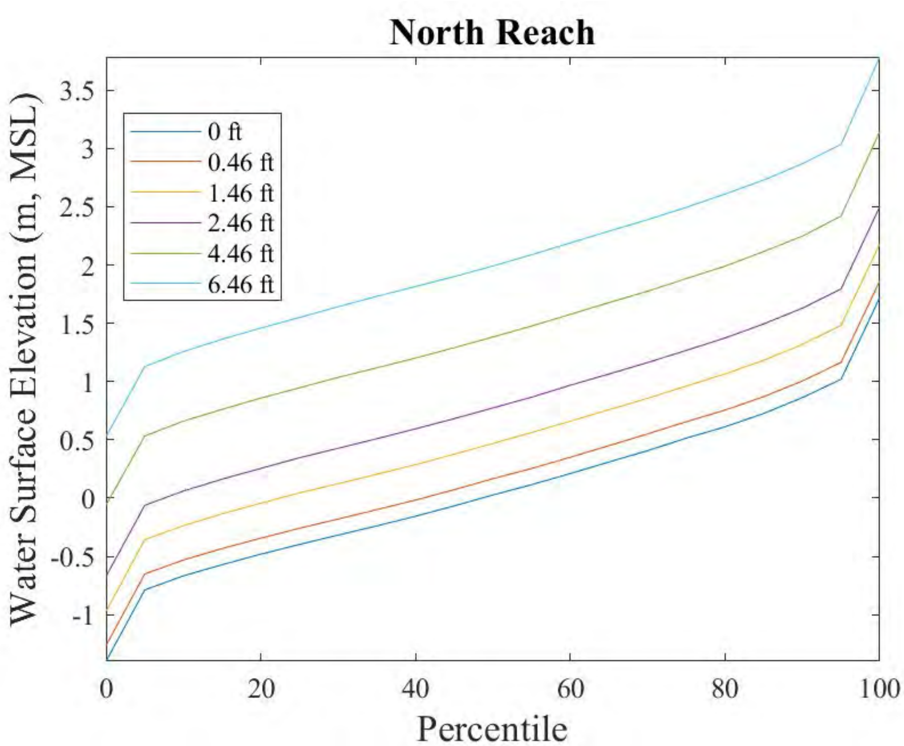


Figure 677. Alt 4, Hackensack River WSE Variation with SLR.

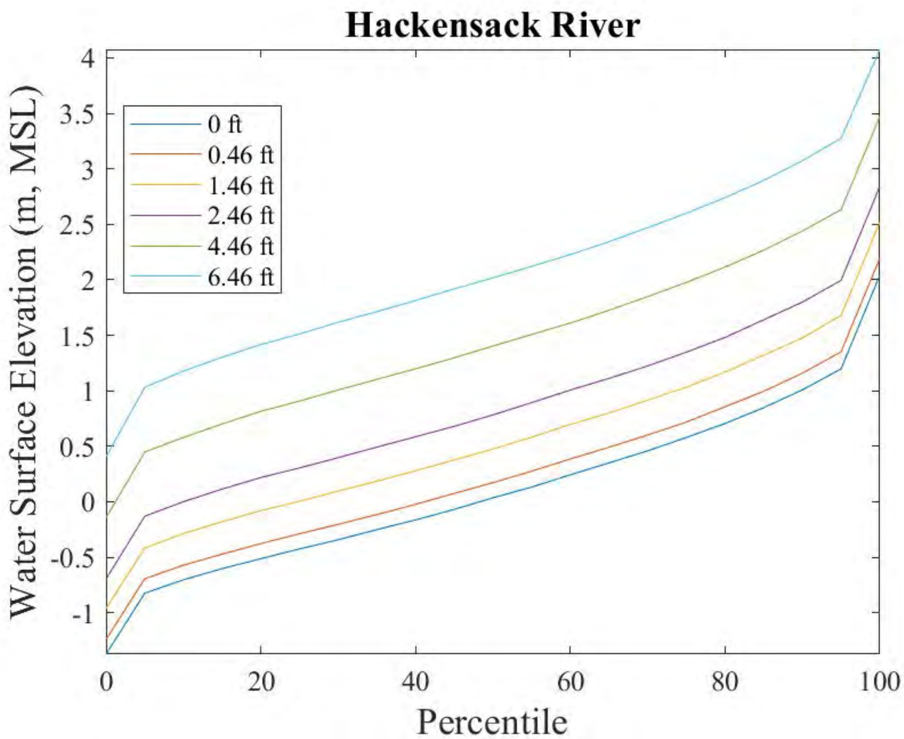


Figure 678. Alt 4, Robbins Reef WSE Variation with SLR.

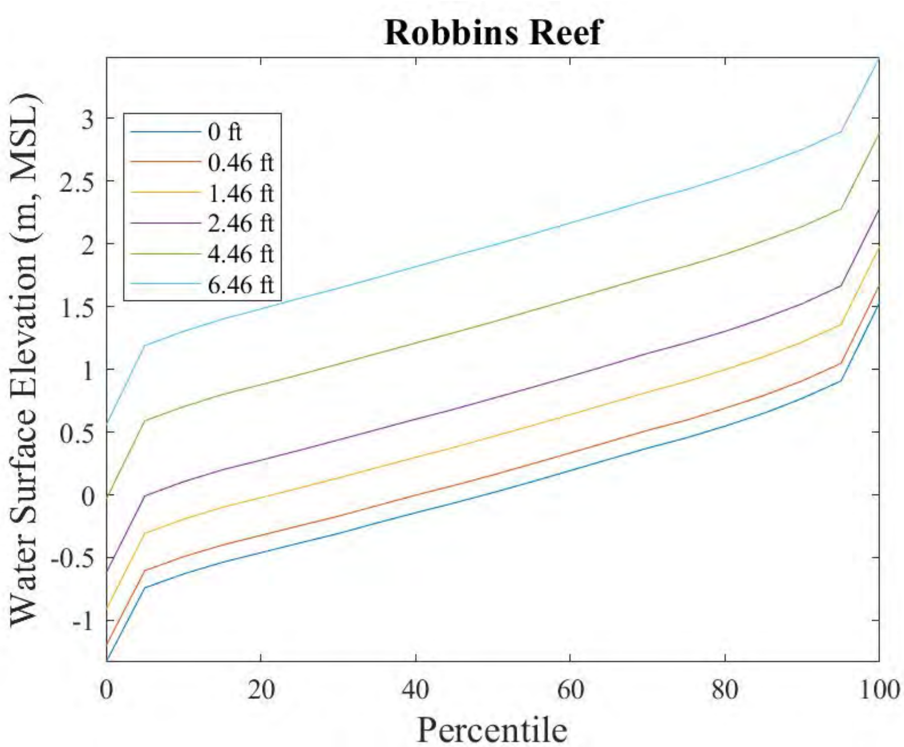


Figure 679. Alt 4, S2 WSE Variation with SLR.

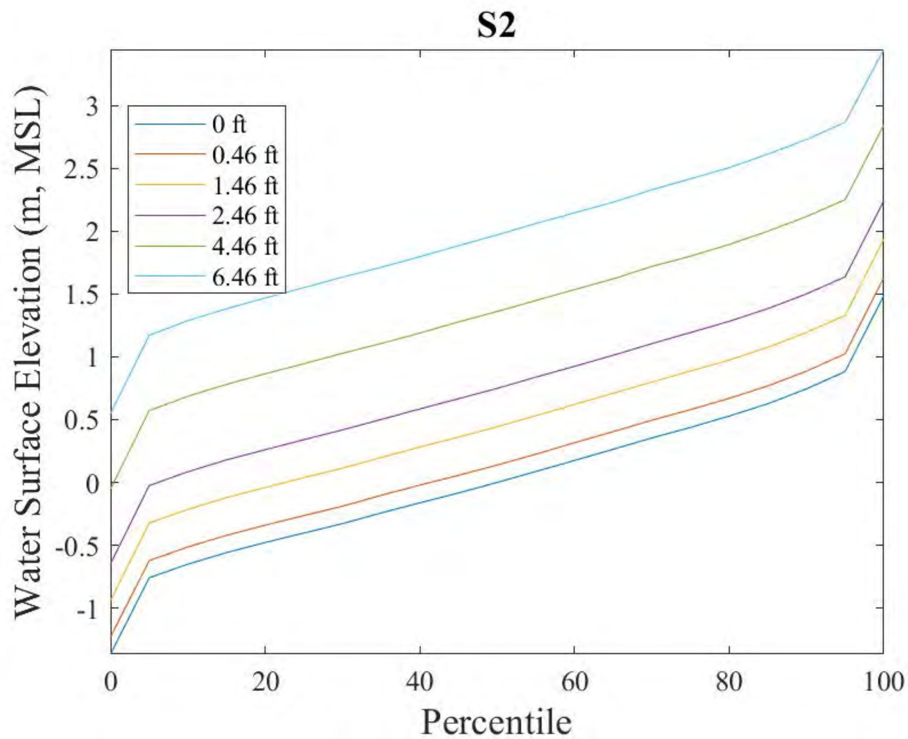


Figure 680. Alt 4, S5 WSE Variation with SLR.

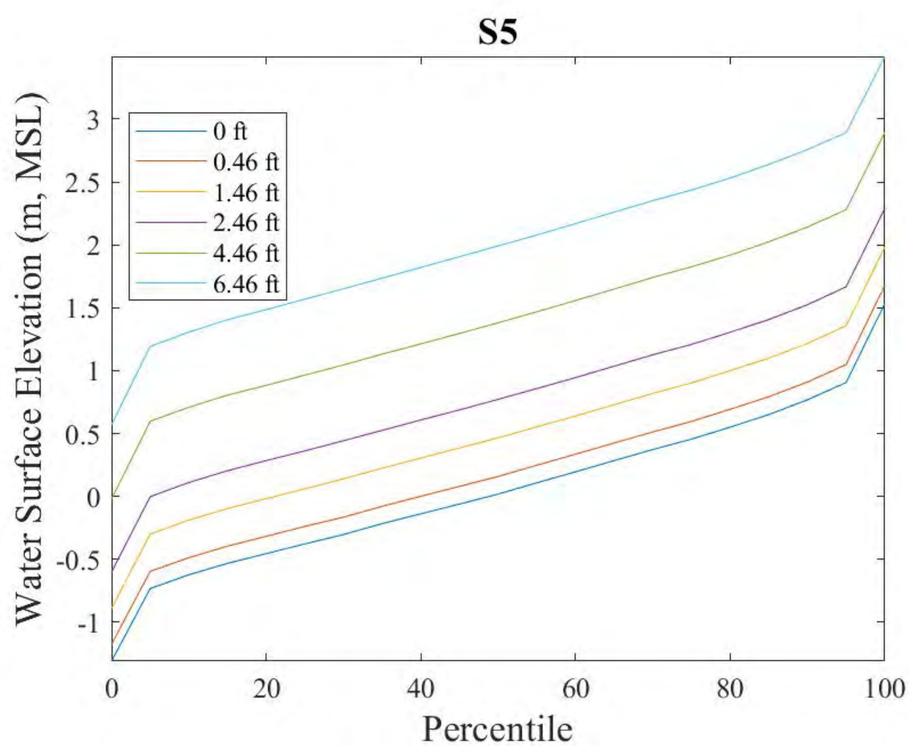


Figure 681. Alt 4, The Battery WSE Variation with SLR.

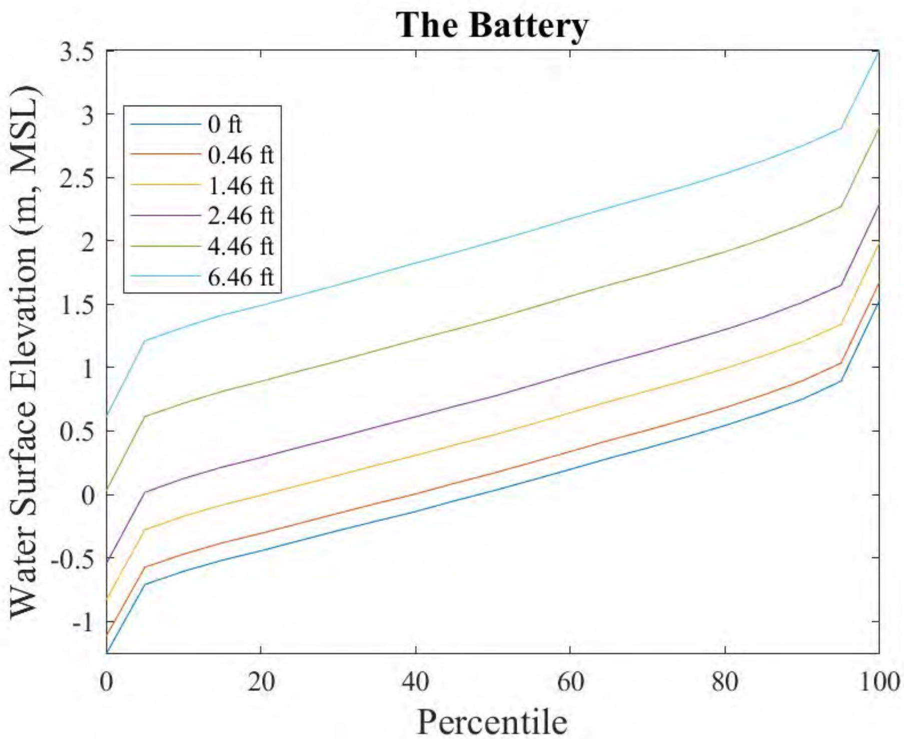


Figure 682. Alt 4, Manhattan WSE Variation with SLR.

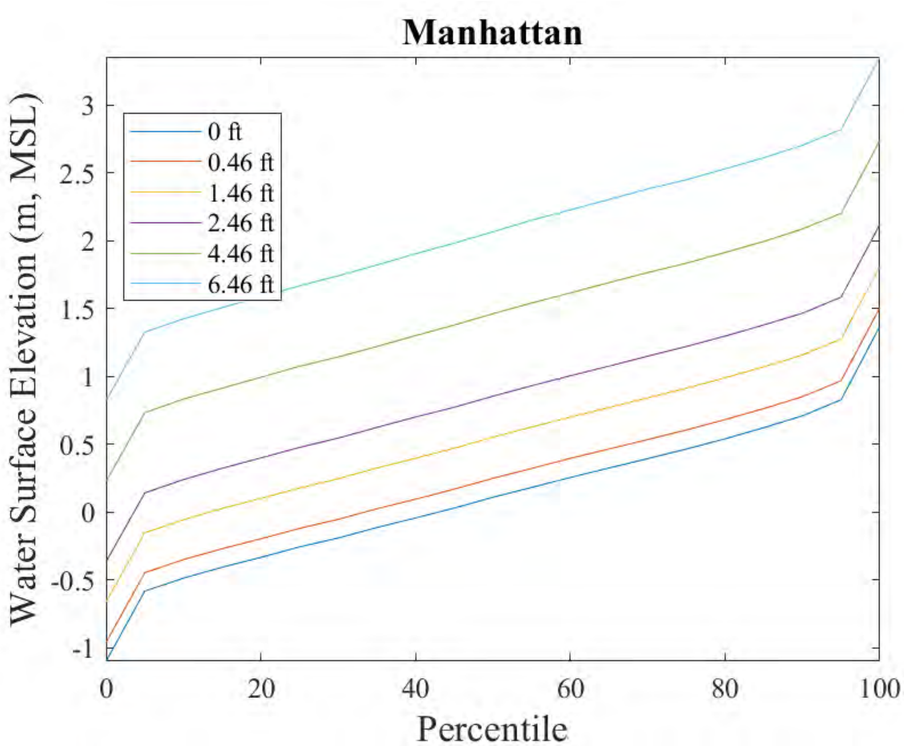


Figure 683. Alt 4, Jamaica Bay WSE Variation with SLR.

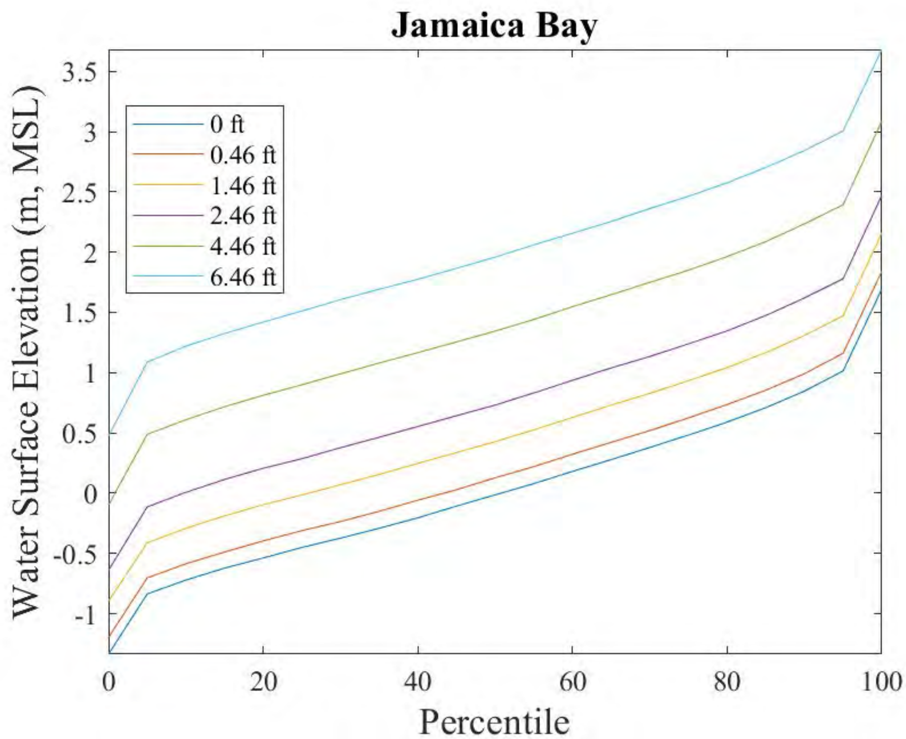


Figure 684. Alt 4, Jamaica Bay near Spring Creek WSE Variation with SLR.

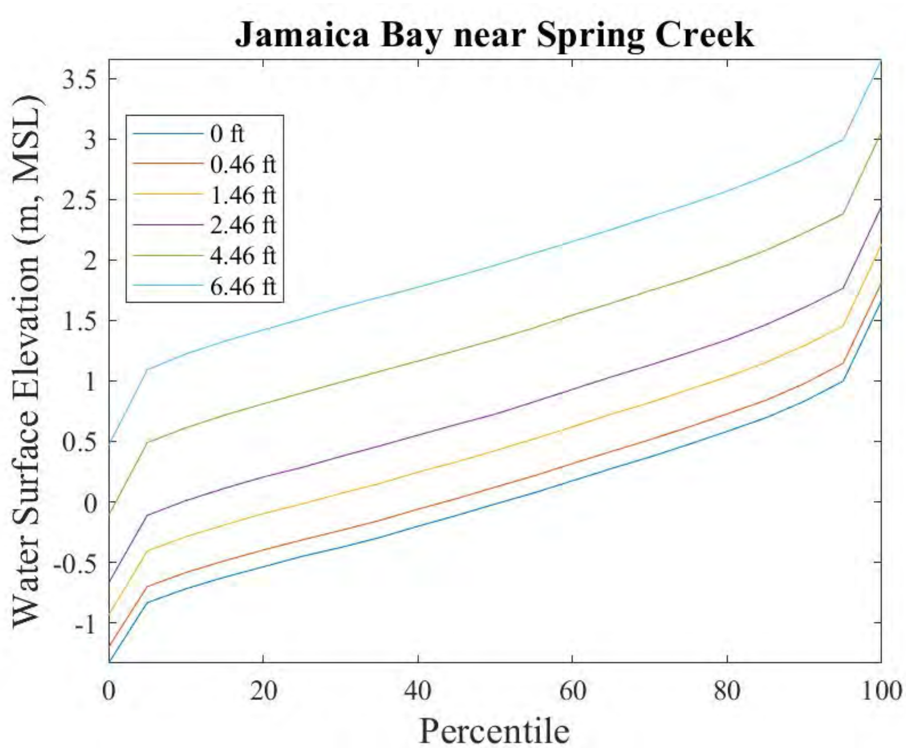


Figure 685. Alt 4, Jamaica Bay near Grass Hassock WSE Variation with SLR.

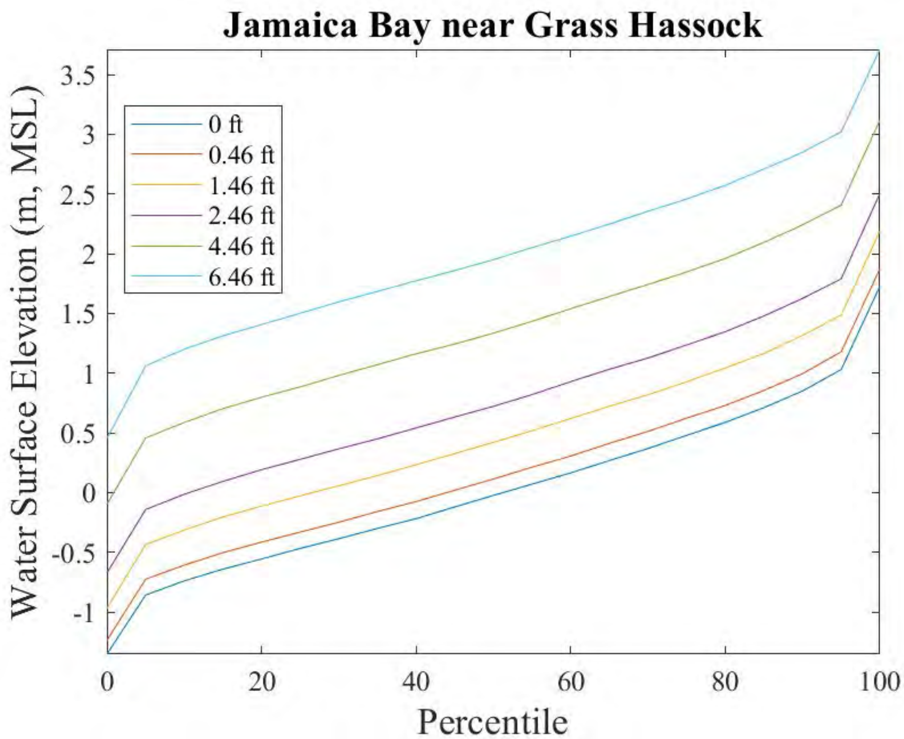


Figure 686. Alt 4, KLGA WSE Variation with SLR.

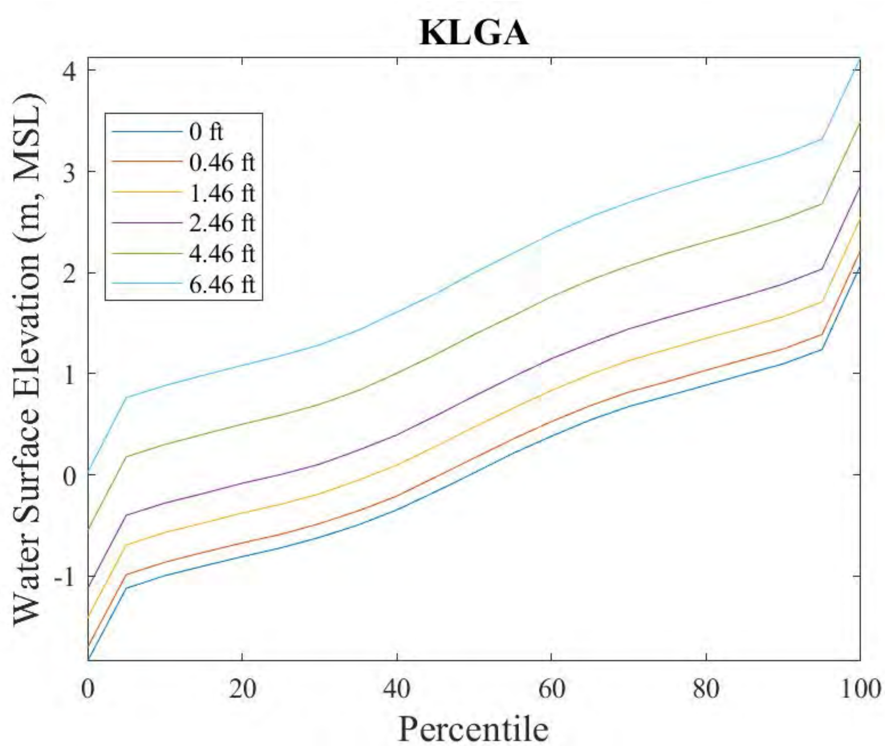


Figure 687. Alt 4, LIS near Stepping Stone Lighthouse WSE Variation with SLR.

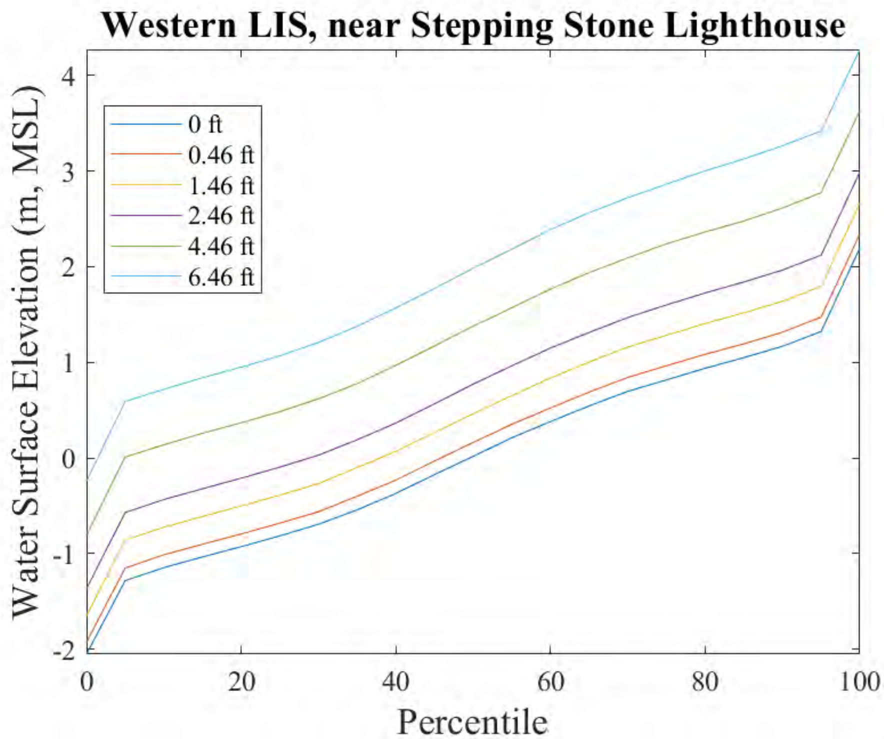


Figure 688. Alt 4, LIS near Execution Rock Lighthouse WSE Variation with SLR.

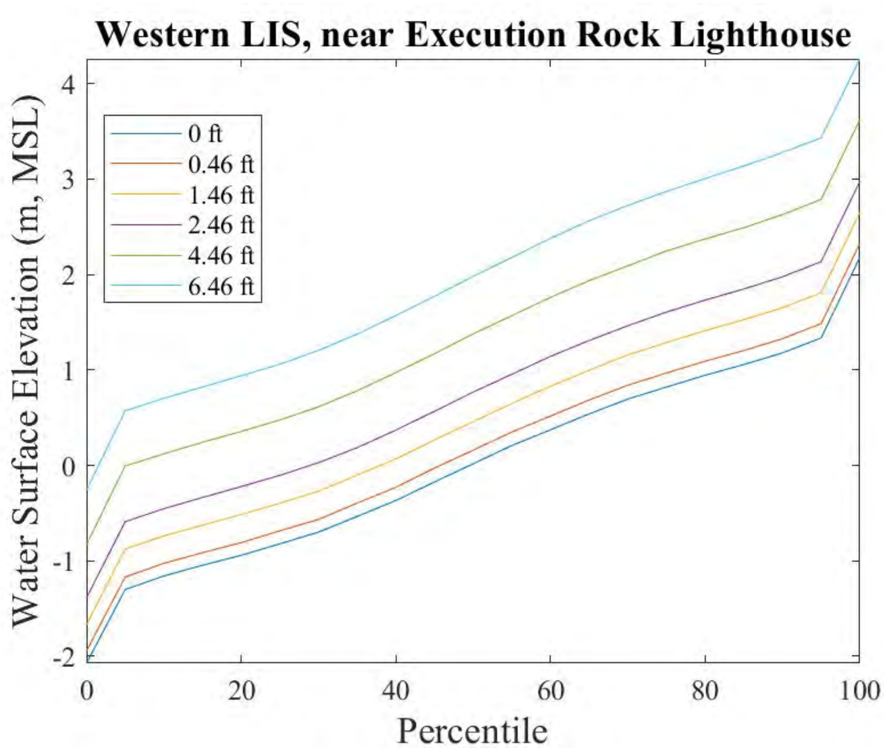


Figure 689. Alt 4, LIS south of NY/CT border WSE Variation with SLR.

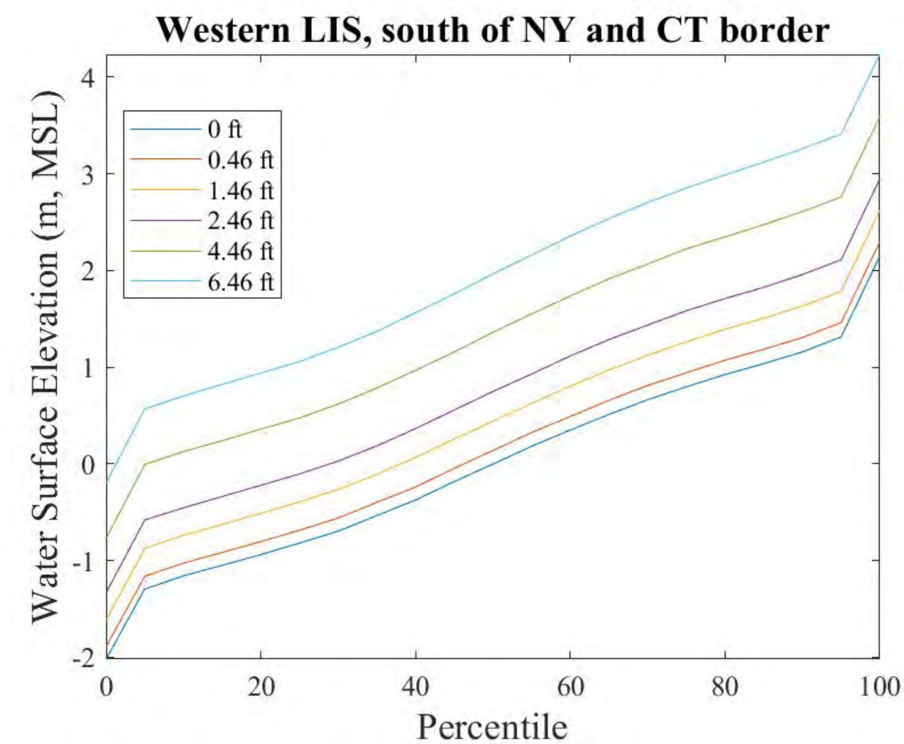


Figure 690. Alt 4, Hudson River, Haverstraw Bay WSE Variation with SLR.

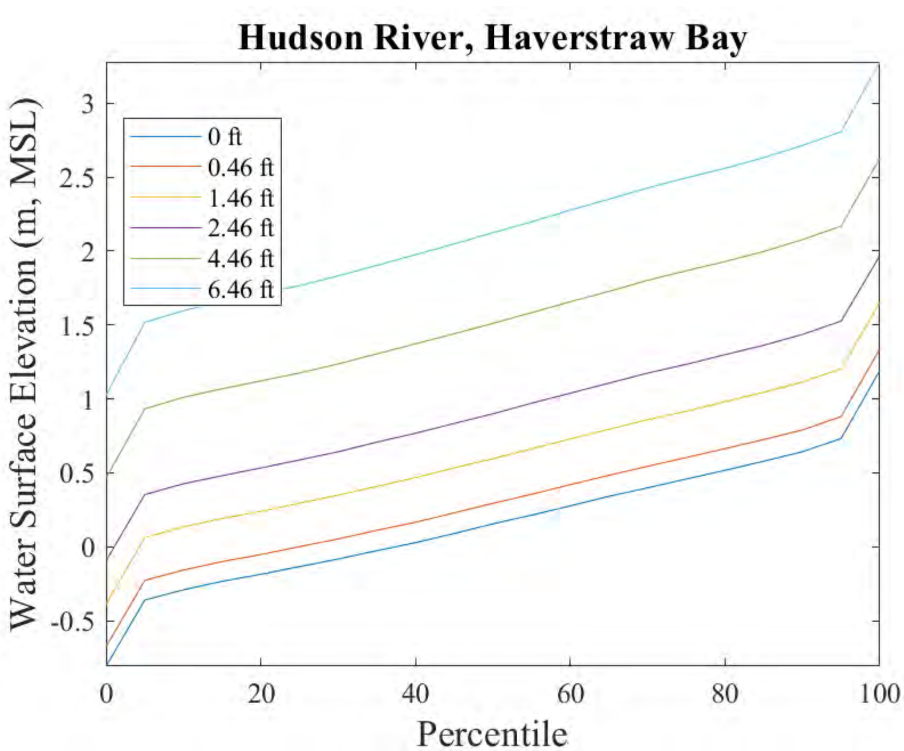


Figure 691. Alt 4, Hudson River near Poughkeepsie WSE Variation with SLR.

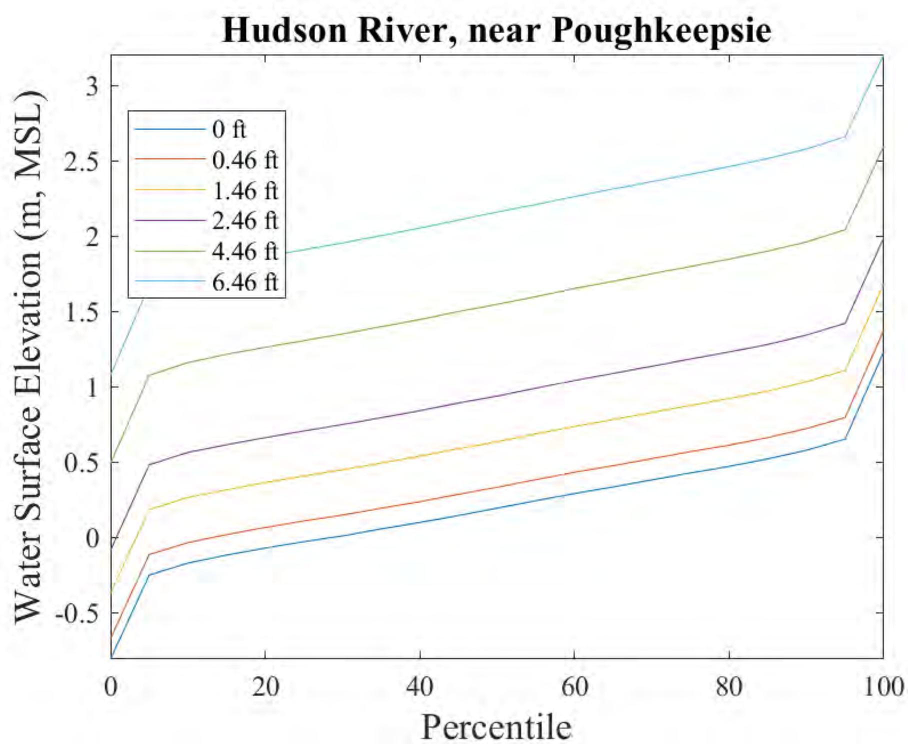


Figure 692. Alt 4, Hudson River between Catskill and Hudson WSE Variation with SLR.

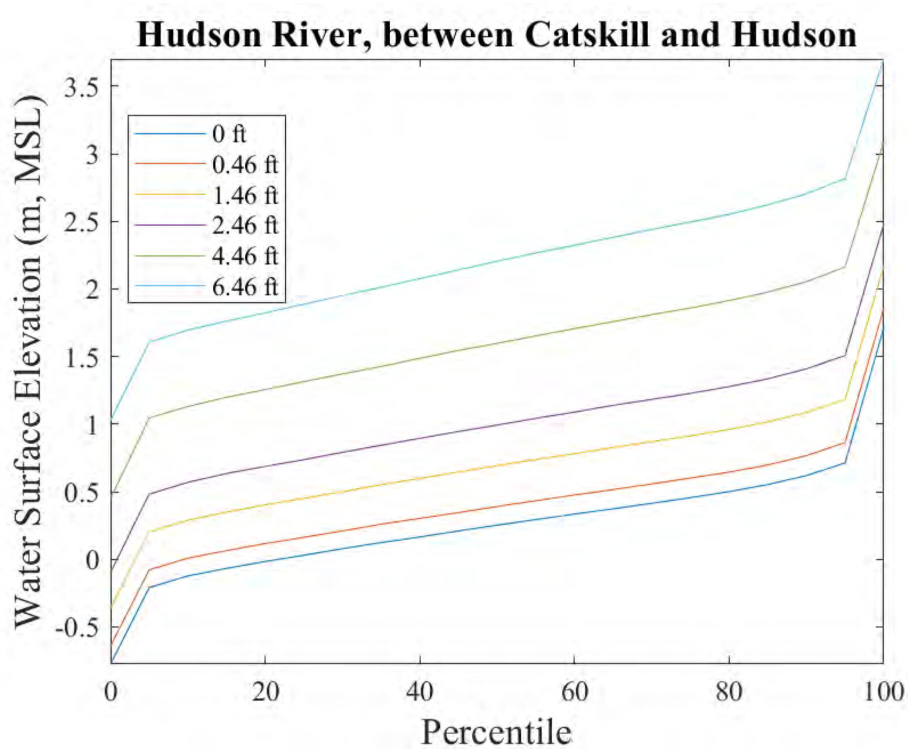
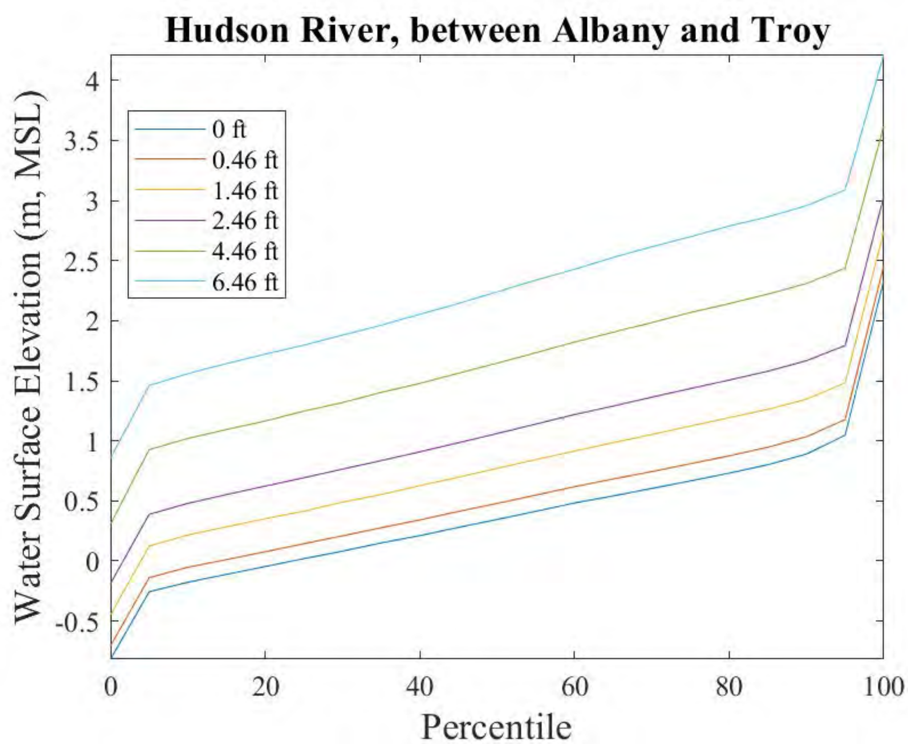


Figure 693. Alt 4, Hudson River between Albany and Troy WSE Variation with SLR.



15.5.2 Velocity Point Percentiles

Velocity percentiles for Alternative 4 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 694 to Figure 729. Some locations experience increased velocities and some decreased velocities depending on the locations. This is a complex interaction between the increased depths and tidal prisms.

Figure 694. Alt 4, V1 Velocity Variation with SLR.

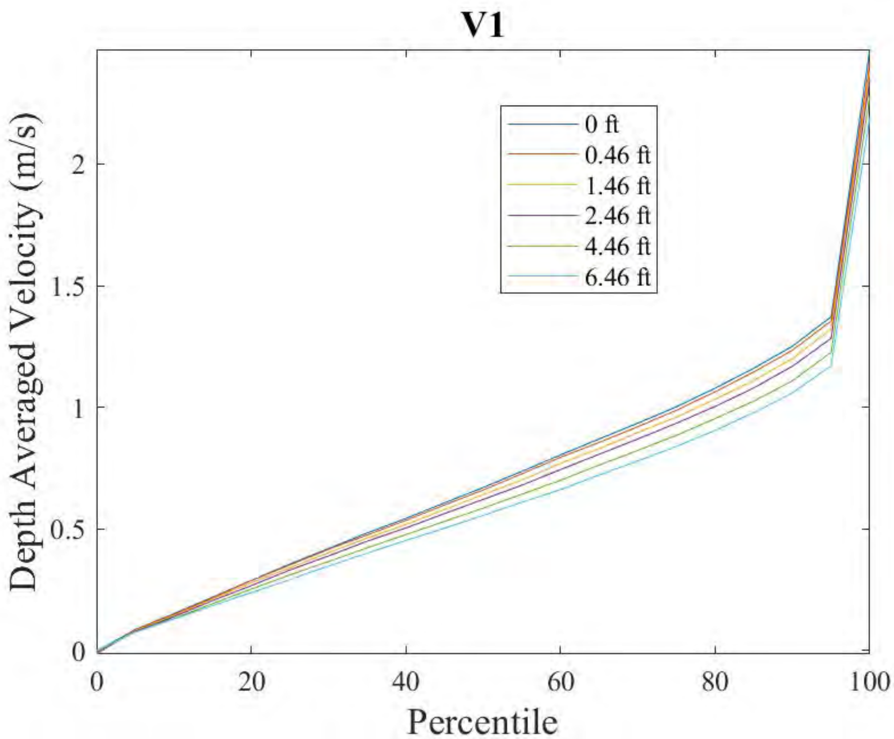


Figure 695. Alt 4, V2 Velocity Variation with SLR.

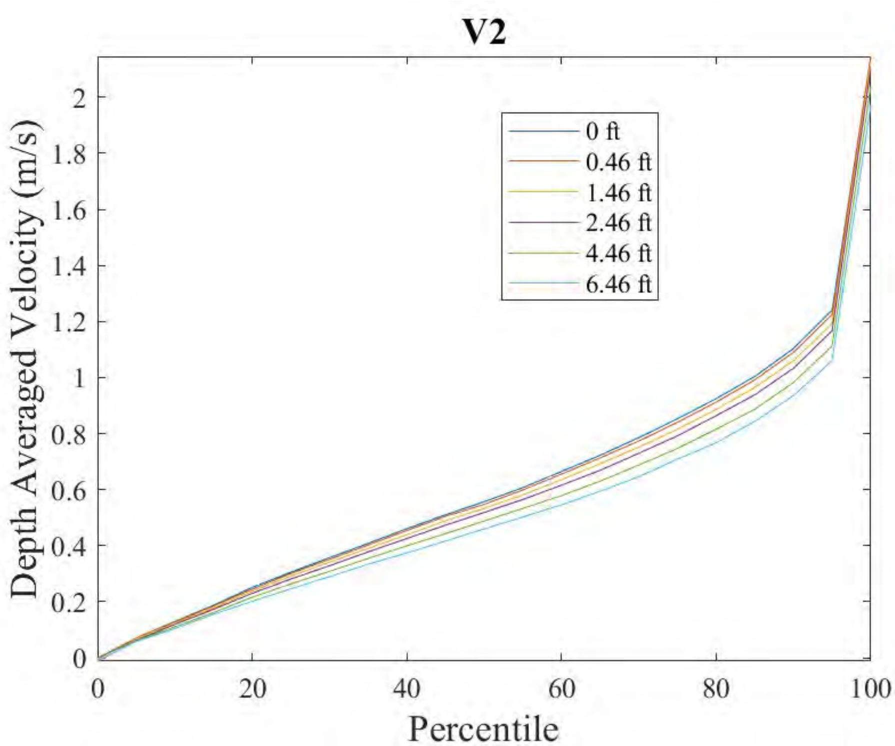


Figure 696. Alt 4, V3 Velocity Variation with SLR.

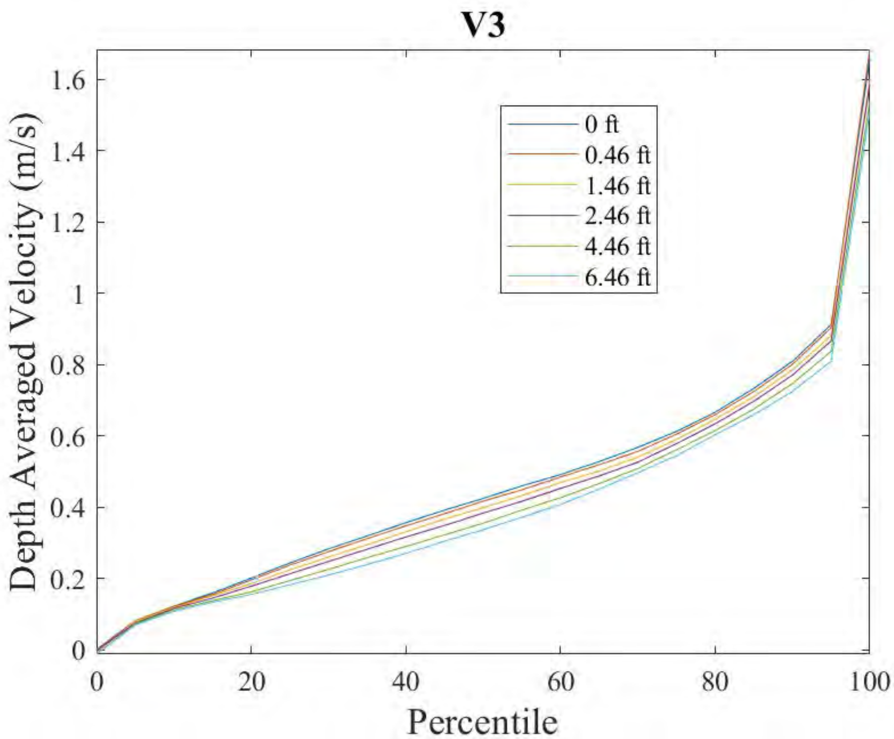


Figure 697. Alt 4, V4 Velocity Variation with SLR.

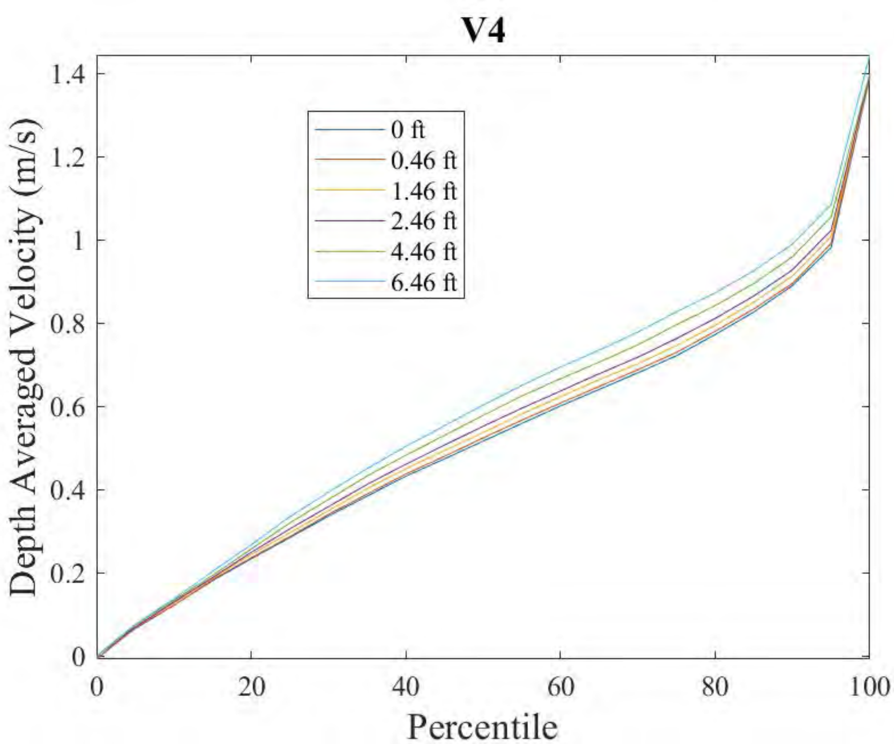


Figure 698. Alt 4, V5 Velocity Variation with SLR.

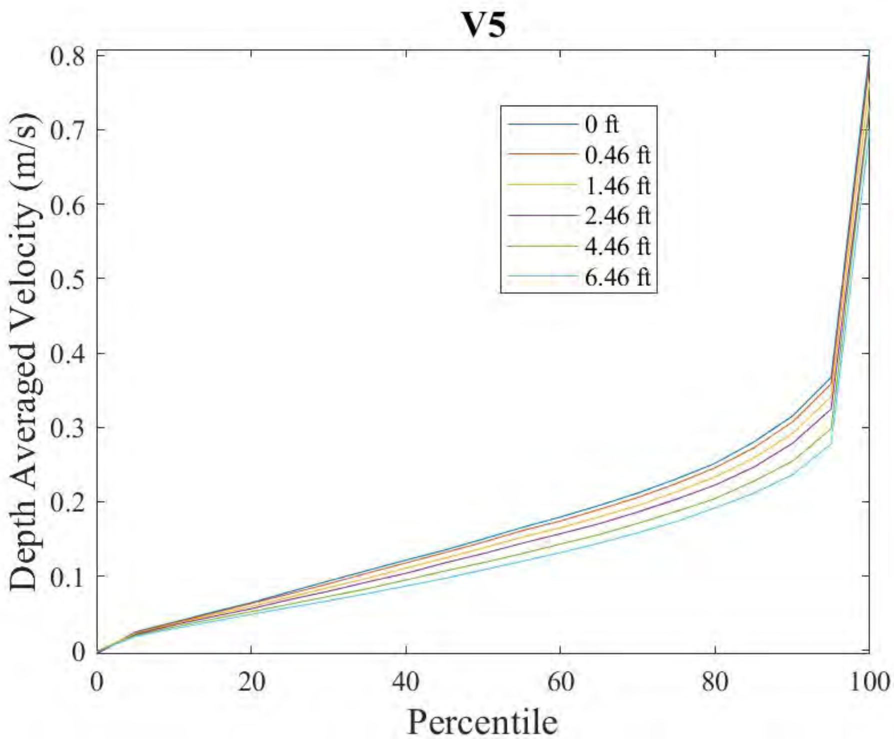


Figure 699. Alt 4, V6 Velocity Variation with SLR.

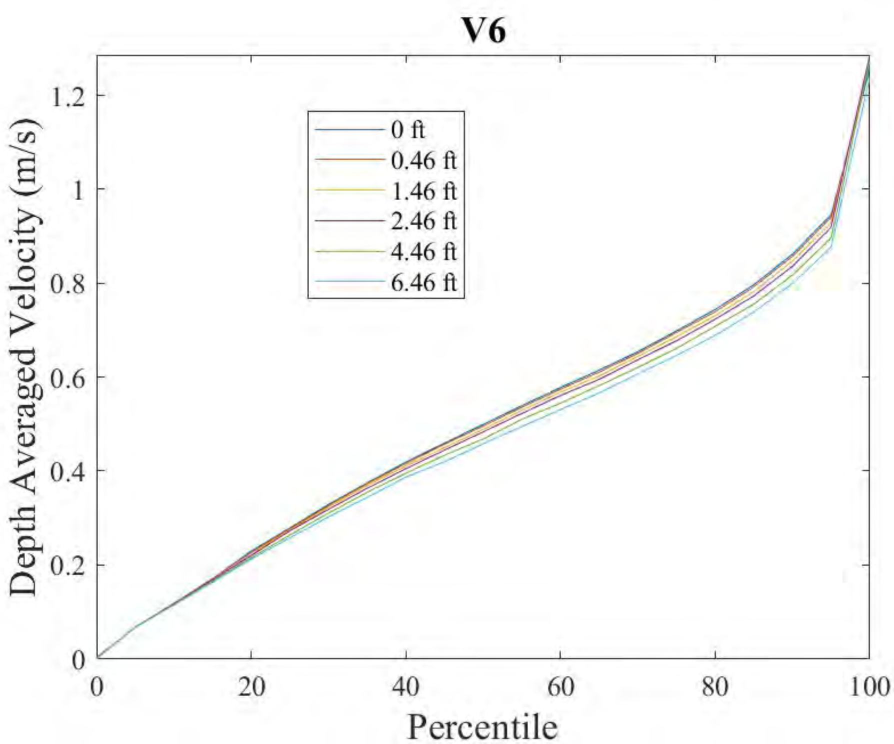


Figure 700. Alt 4, S1 Velocity Variation with SLR.

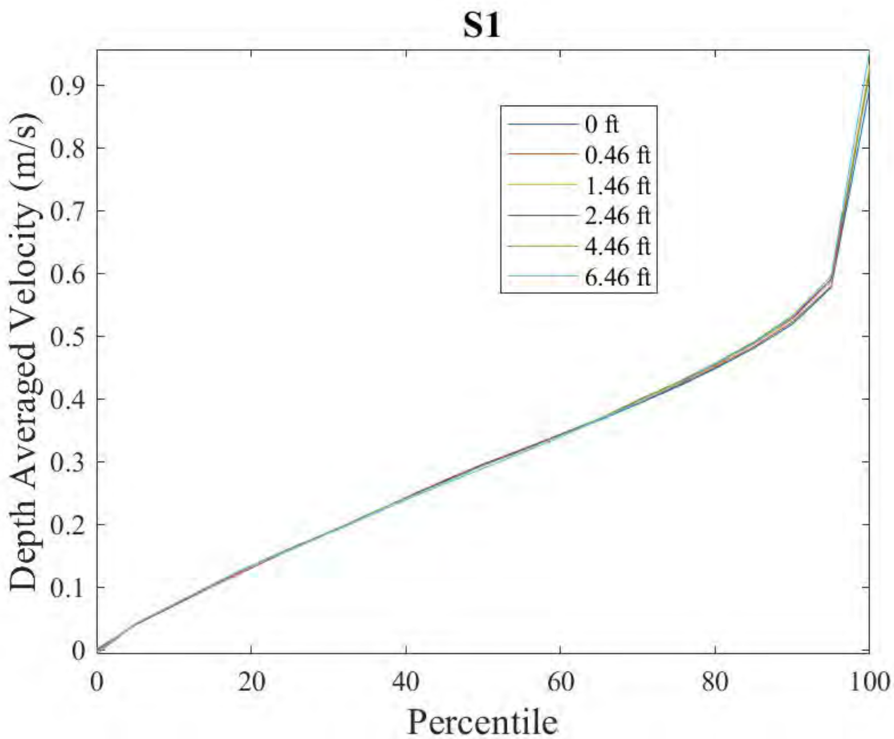


Figure 701. Alt 4, S2 Velocity Variation with SLR.

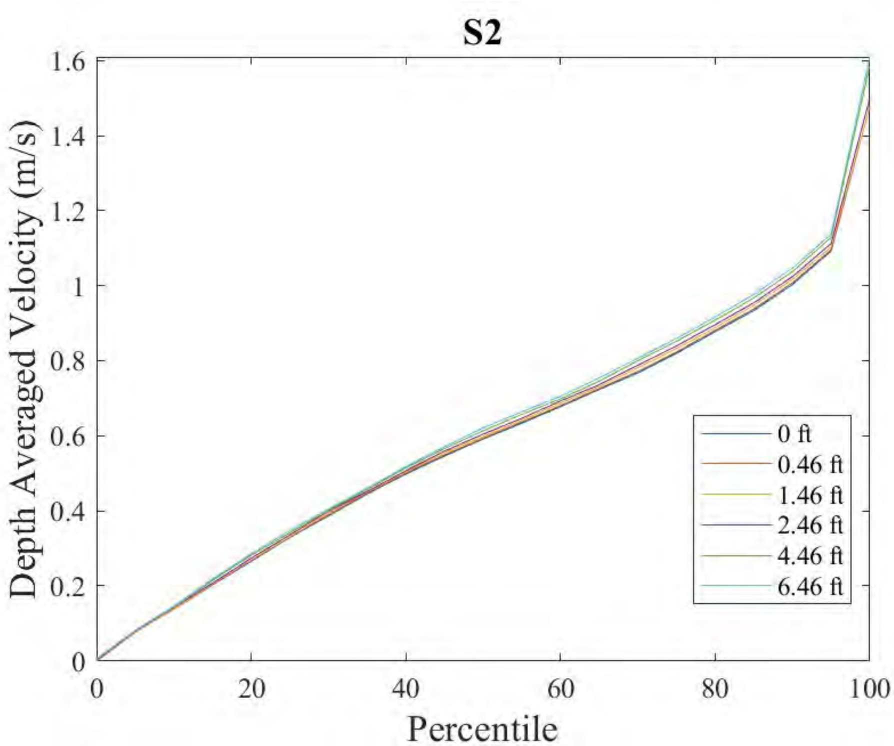


Figure 702. Alt 4, S3 Velocity Variation with SLR.

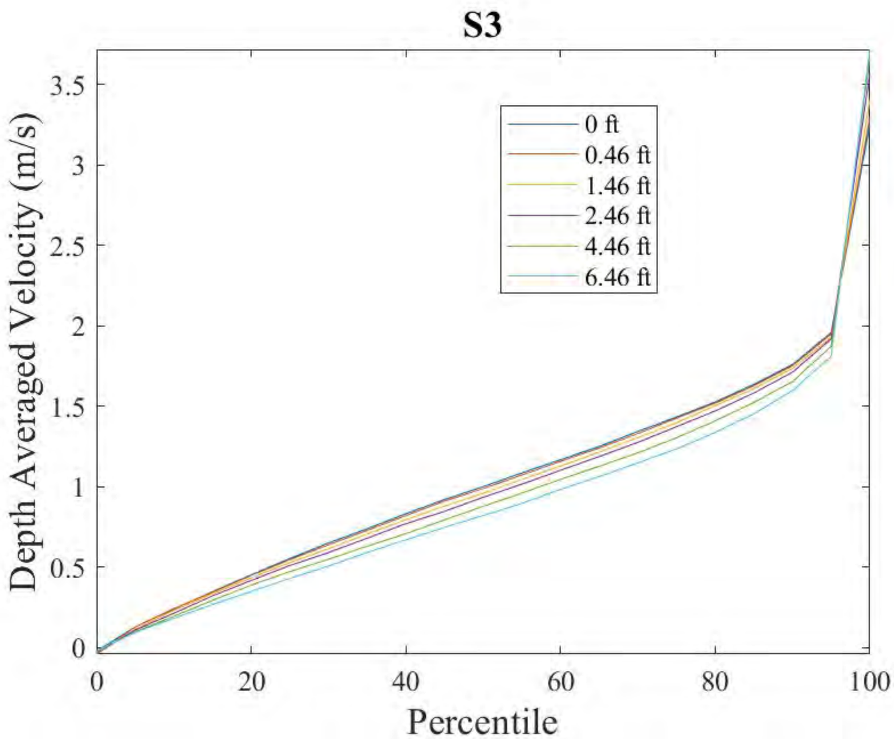


Figure 703. Alt 4, S4 Velocity Variation with SLR.

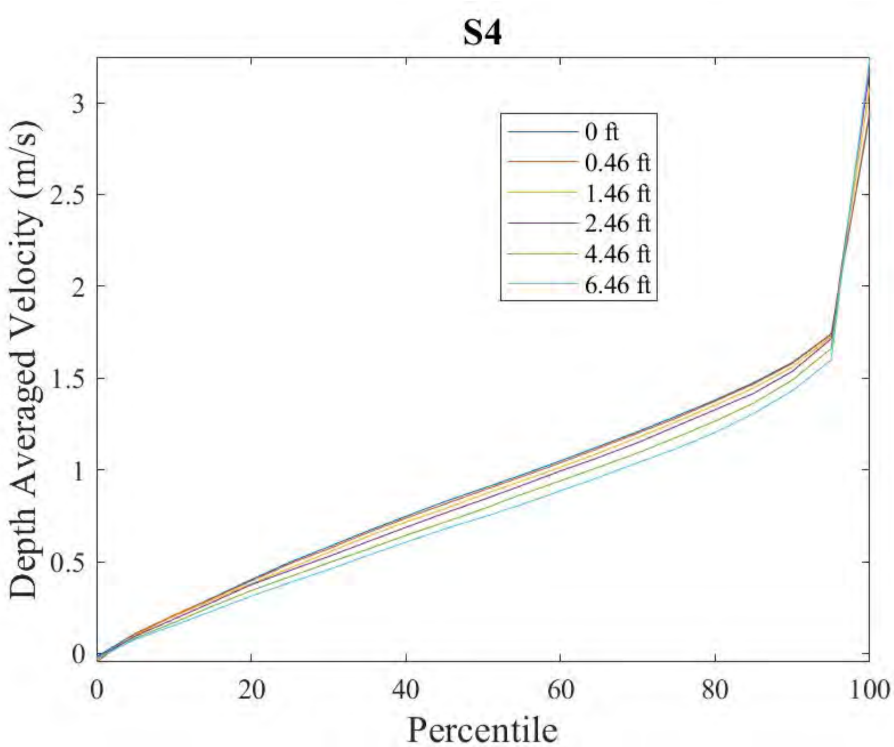


Figure 704. Alt 4, S5 Velocity Variation with SLR.

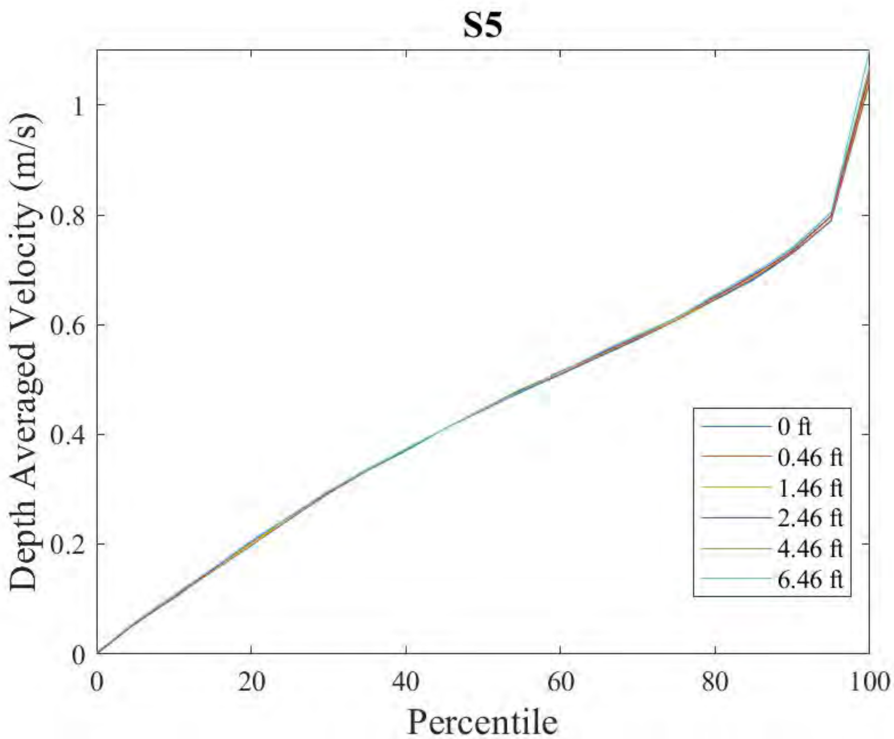


Figure 705. Alt 4, T1 Velocity Variation with SLR.

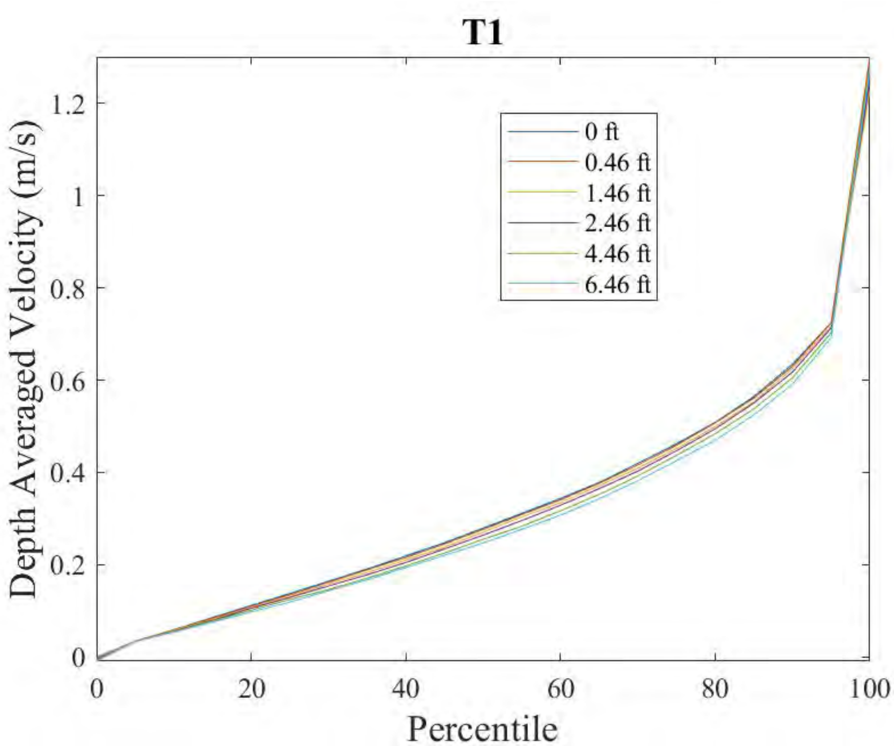


Figure 706. Alt 4, T2 Velocity Variation with SLR.

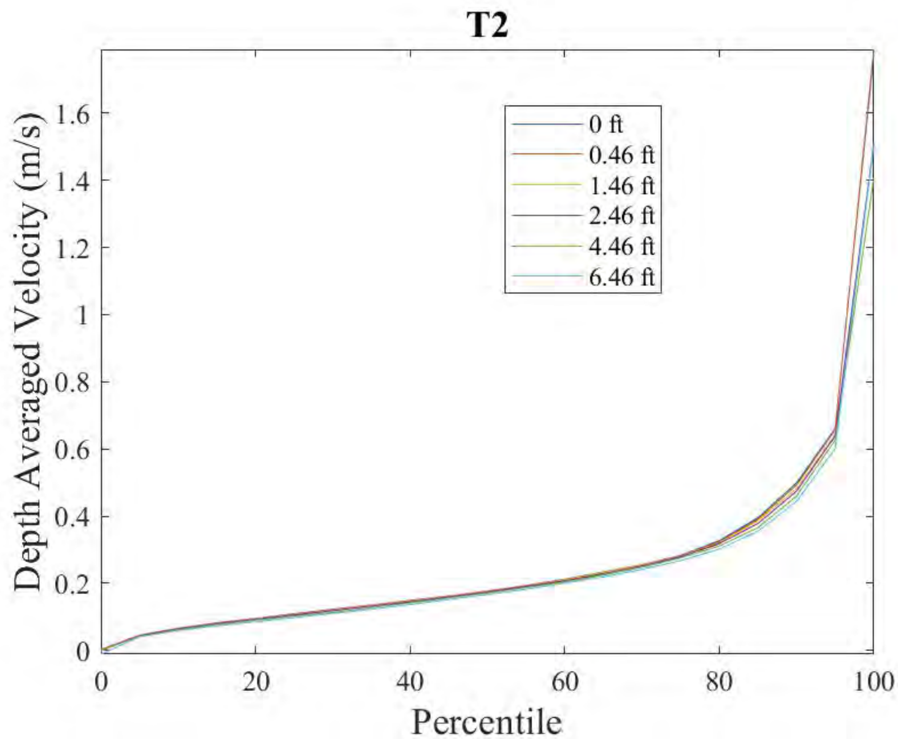


Figure 707. Alt 4, T3 Velocity Variation with SLR.

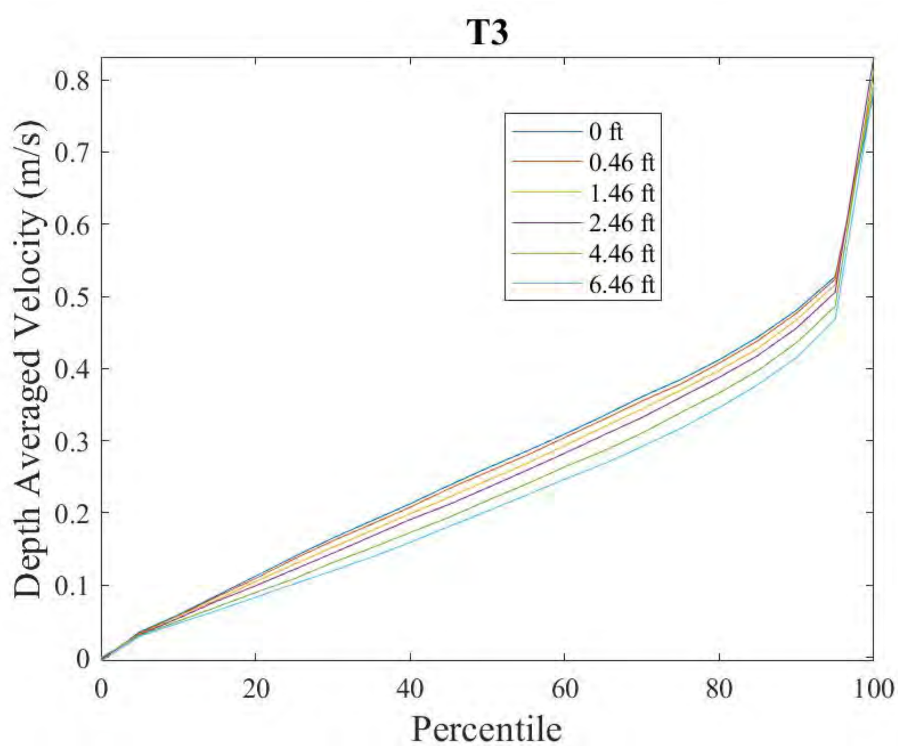


Figure 708. Alt 4, T4 Velocity Variation with SLR.

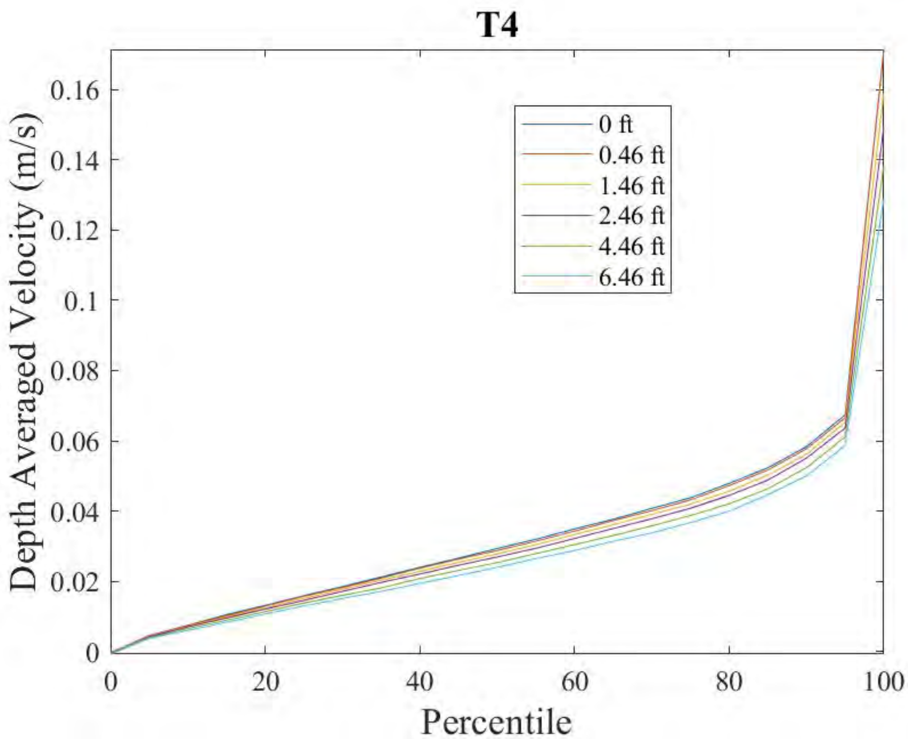


Figure 709. Alt 4, T5 Velocity Variation with SLR.

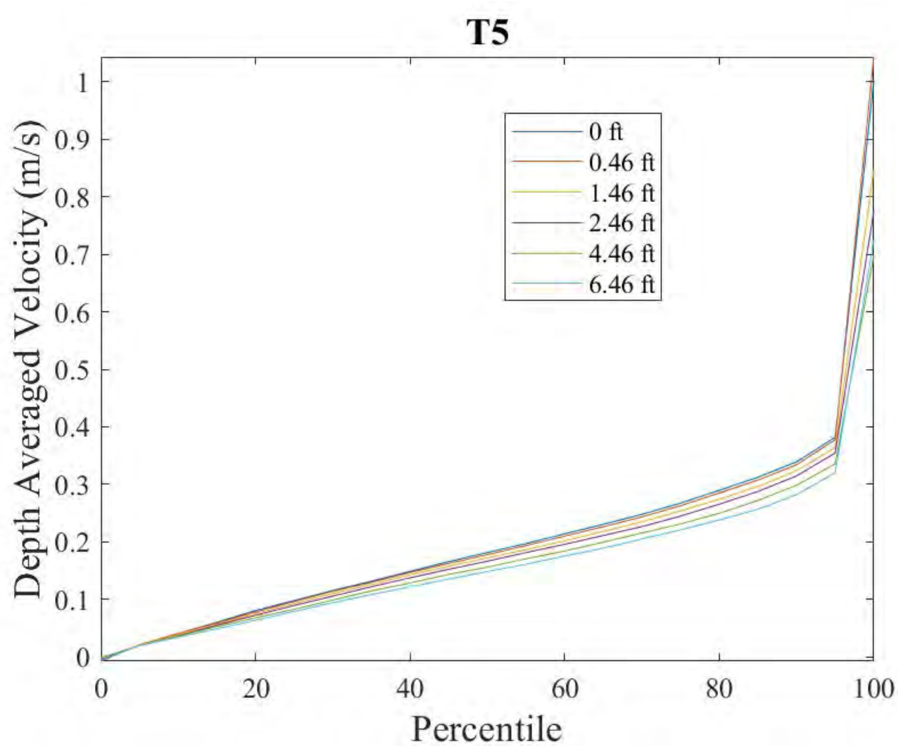


Figure 710. Alt 4, R1 Velocity Variation with SLR.

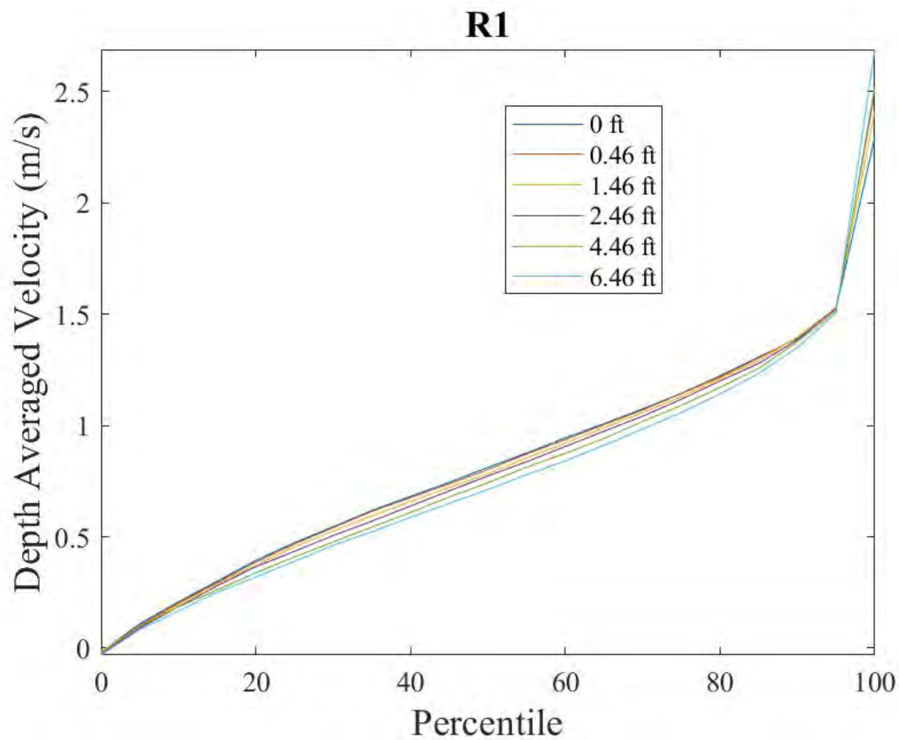


Figure 711. Alt 4, Sandy Hook Velocity Variation with SLR.

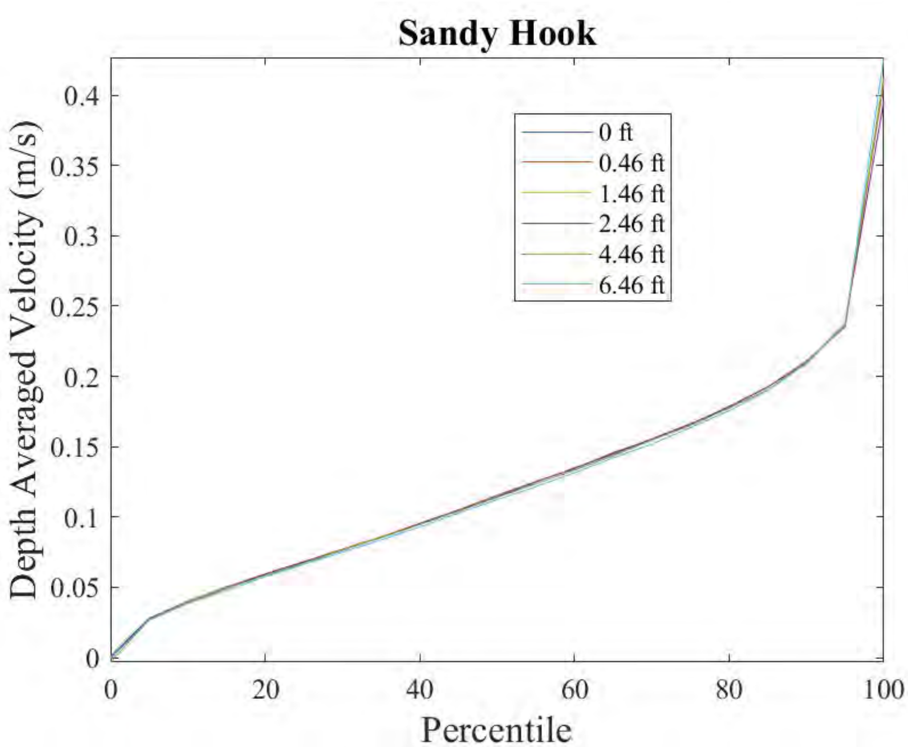


Figure 712. Alt 4, Fresh Kills Velocity Variation with SLR.

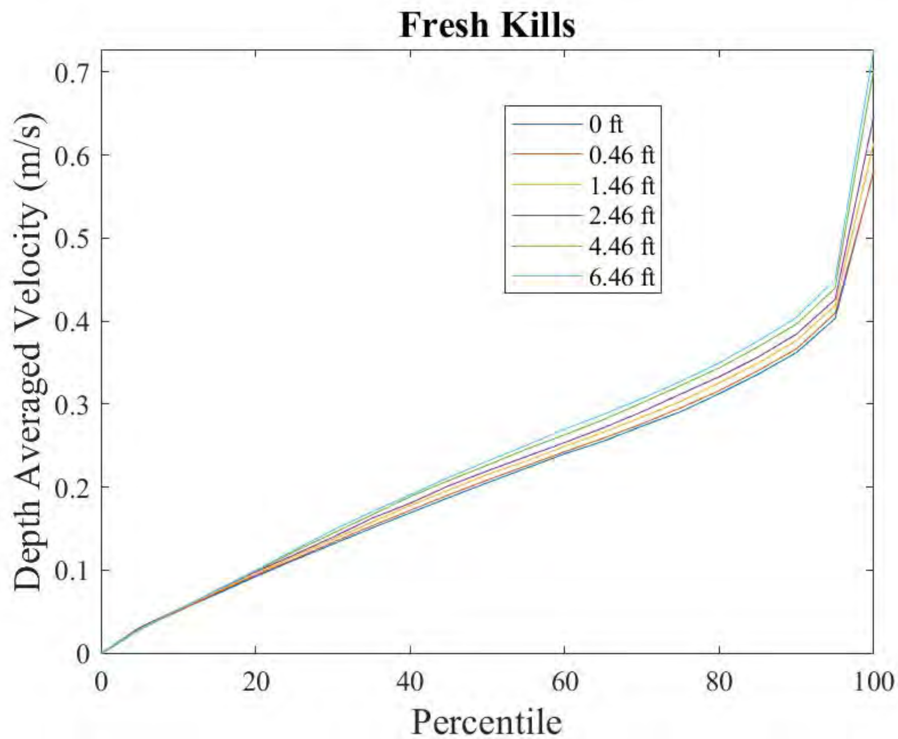


Figure 713. Alt 4, Mariners Harbor Velocity Variation with SLR.

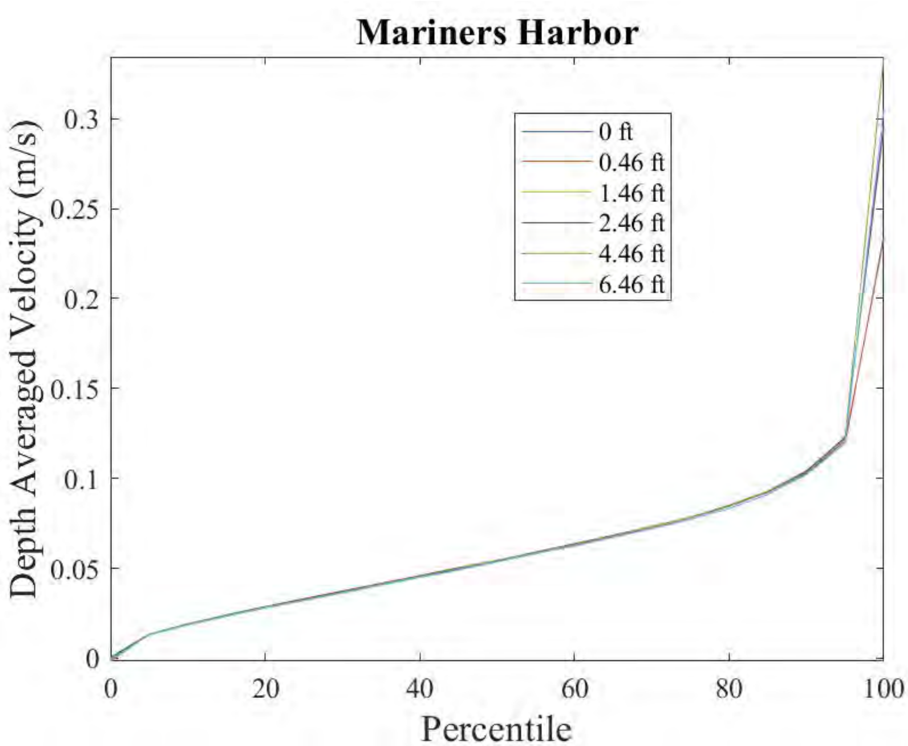


Figure 714. Alt 4, North Reach Velocity Variation with SLR.

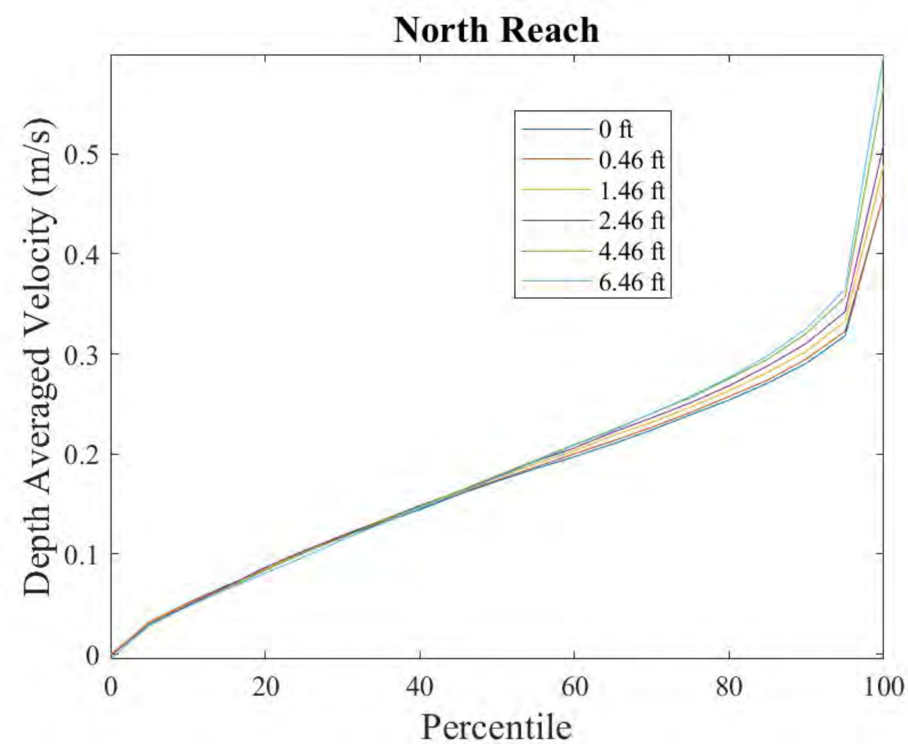


Figure 715. Alt 4, Hackensack River Velocity Variation with SLR.

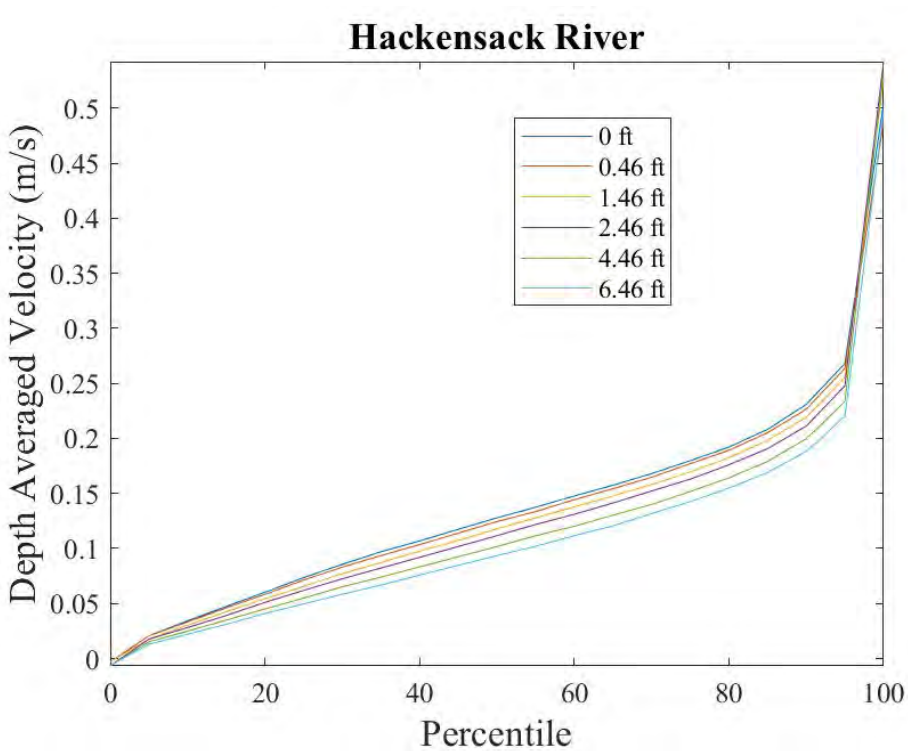


Figure 716. Alt 4, Robbins Reef Velocity Variation with SLR.

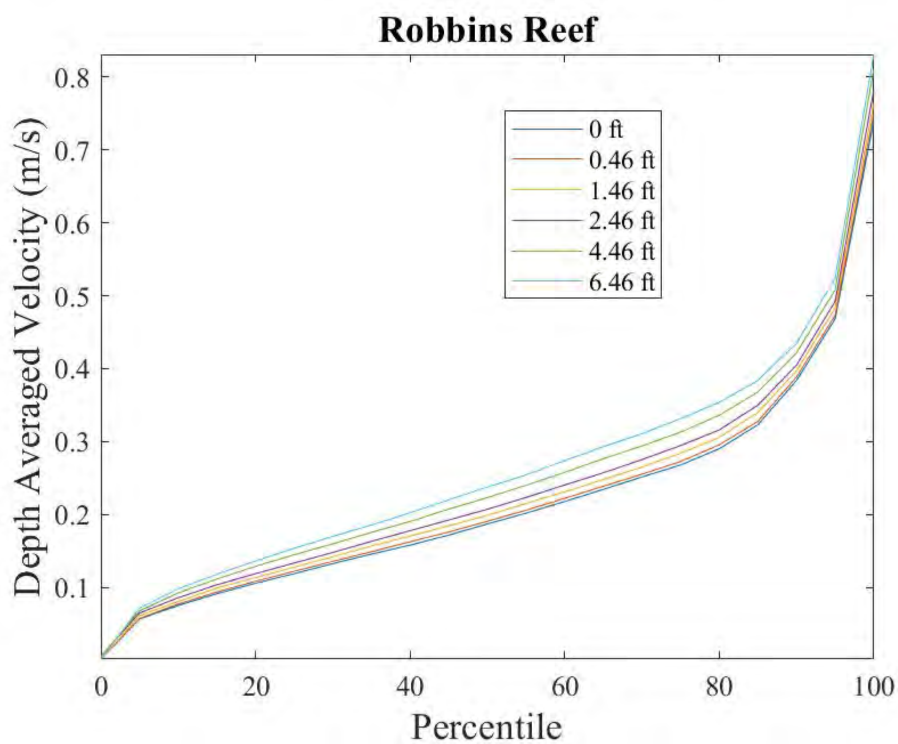


Figure 717. Alt 4, The Battery Velocity Variation with SLR.

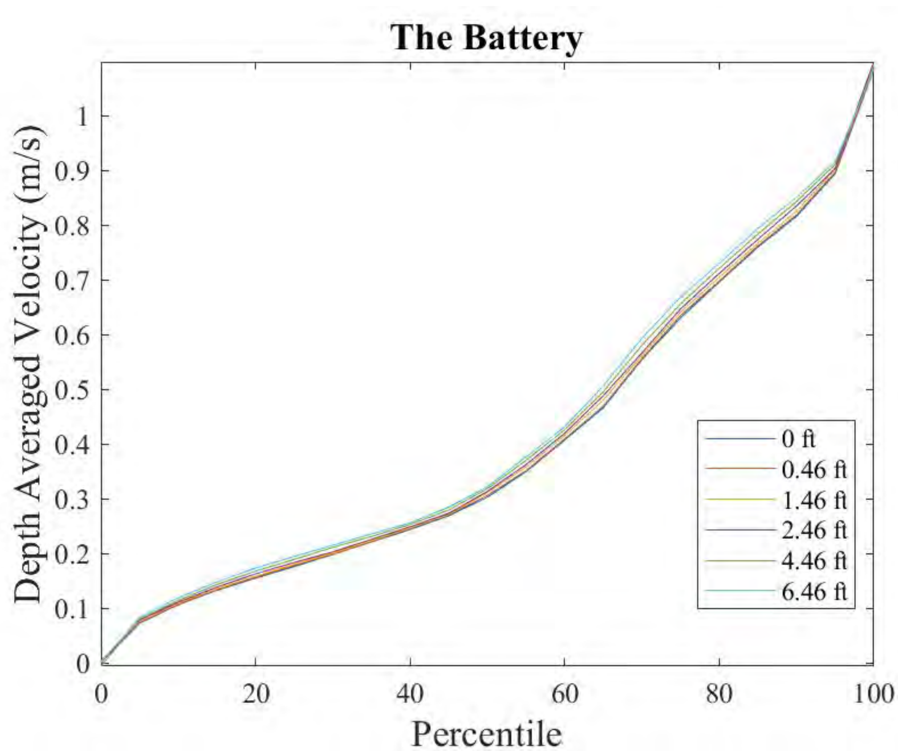


Figure 718. Alt 4, Manhattan Velocity Variation with SLR.

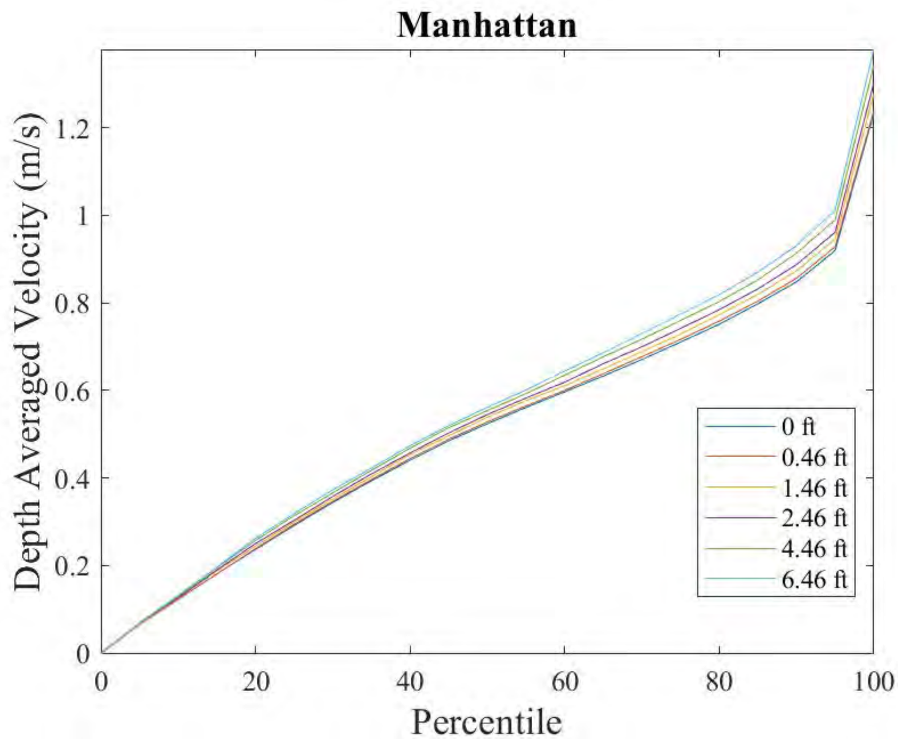


Figure 719. Alt 4, Hudson River Haverstraw Bay Velocity Variation with SLR.

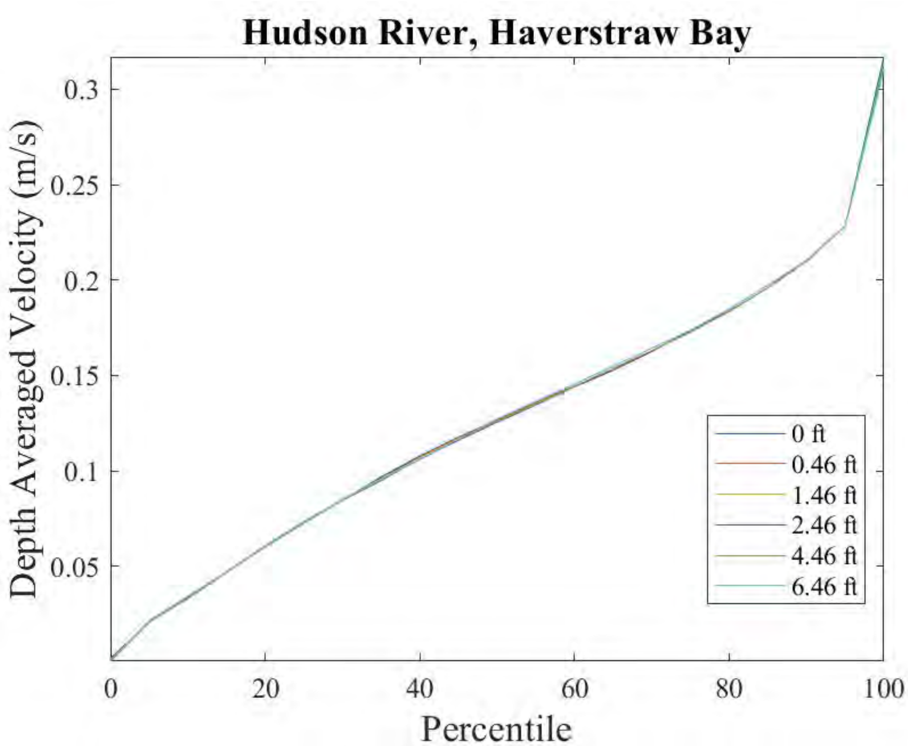


Figure 720. Alt 4, Hudson River near Poughkeepsie Velocity Variation with SLR.

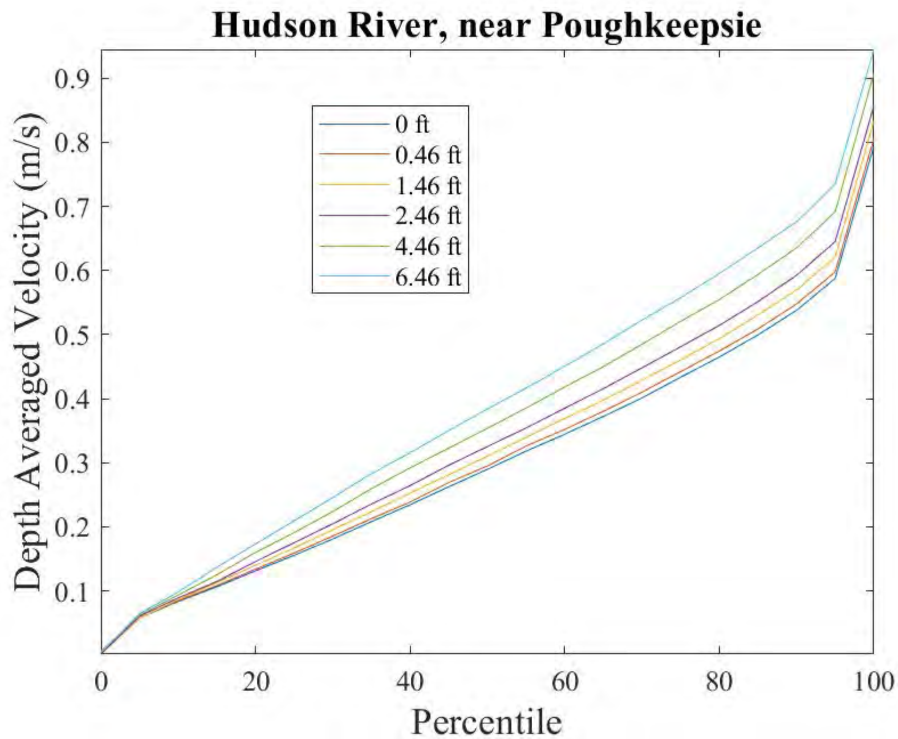


Figure 721. Alt 4, Hudson River between Catskill and Hudson Velocity Variation with SLR.

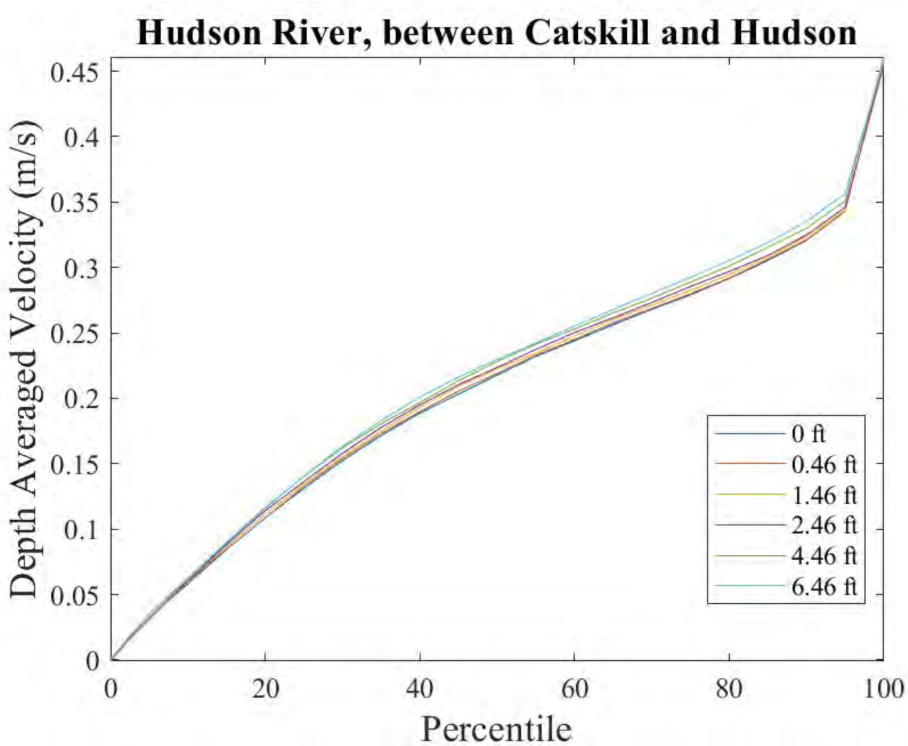


Figure 722. Alt 4, Hudson River between Albany and Troy Velocity Variation with SLR.

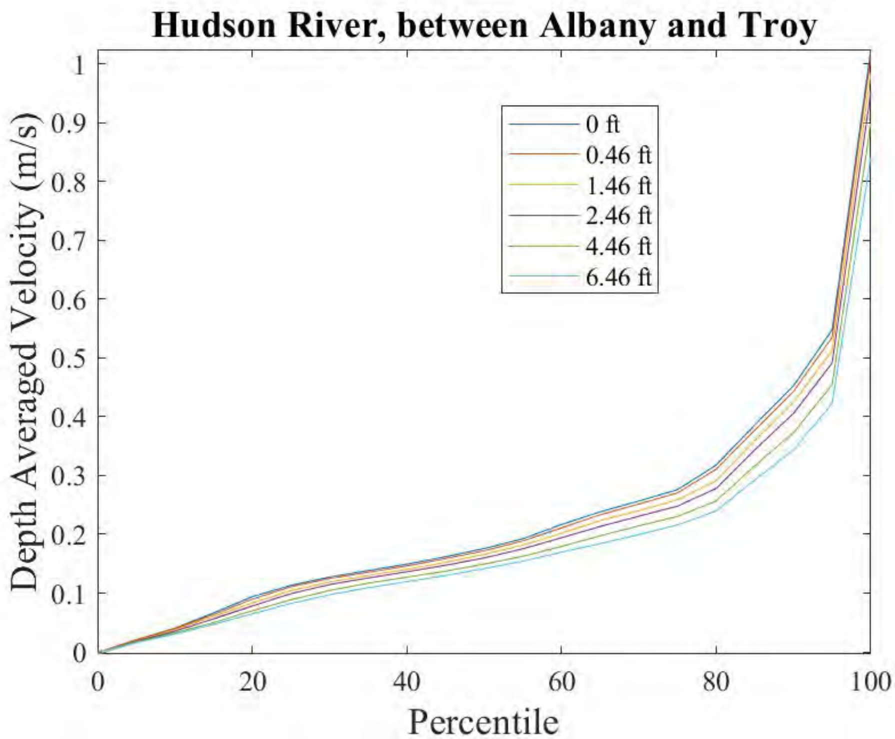


Figure 723. Alt 4, KLGA Velocity Variation with SLR.

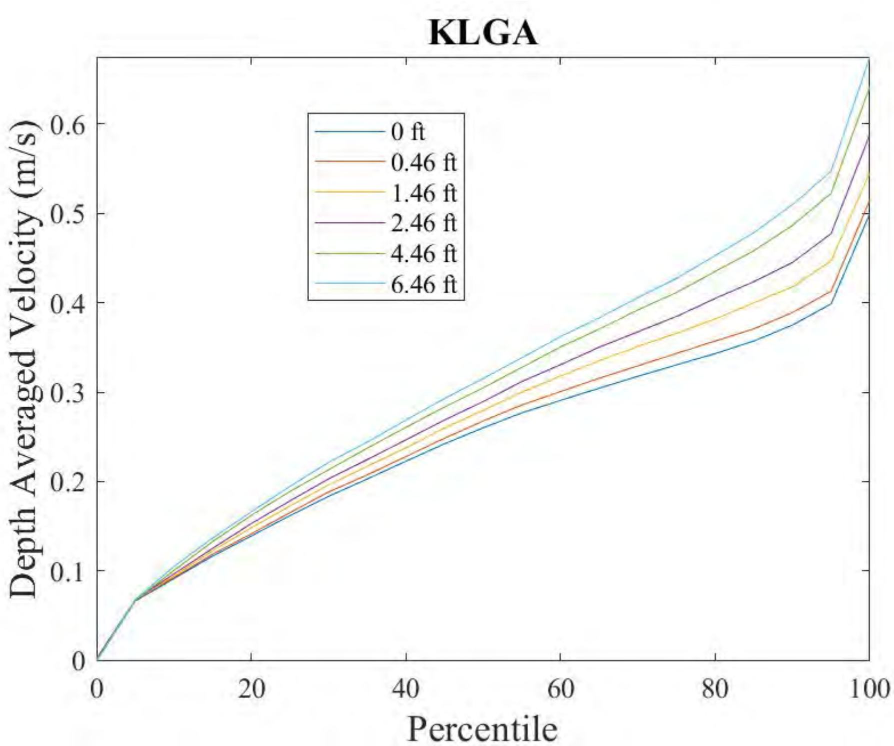


Figure 724. Alt 4, LIS near Stepping Stone Lighthouse Velocity Variation with SLR.

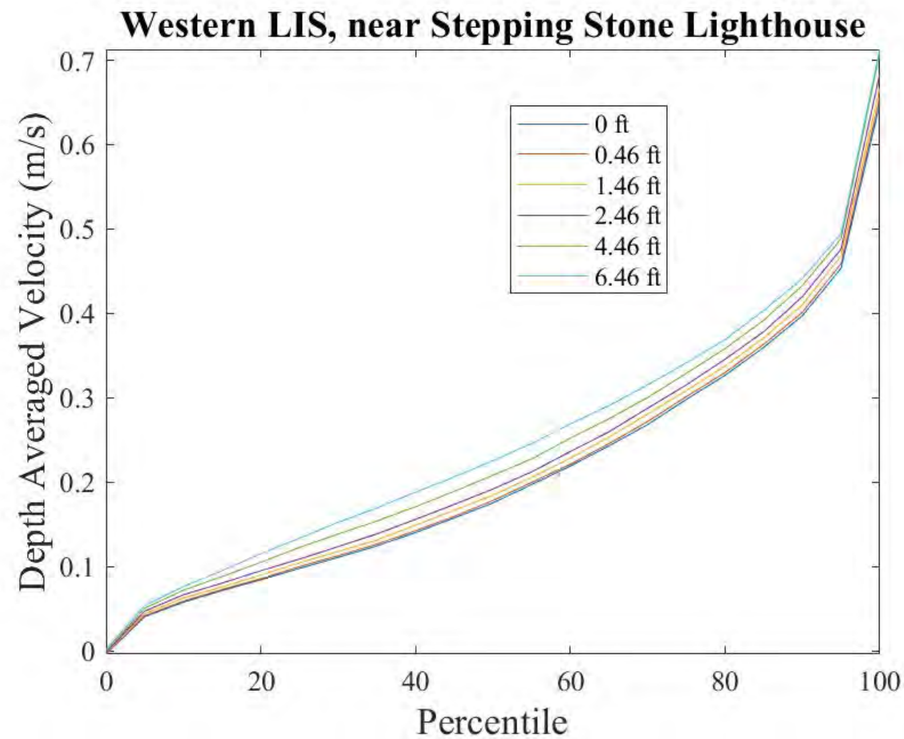


Figure 725. Alt 4, LIS near Execution Rock Lighthouse Velocity Variation with SLR.

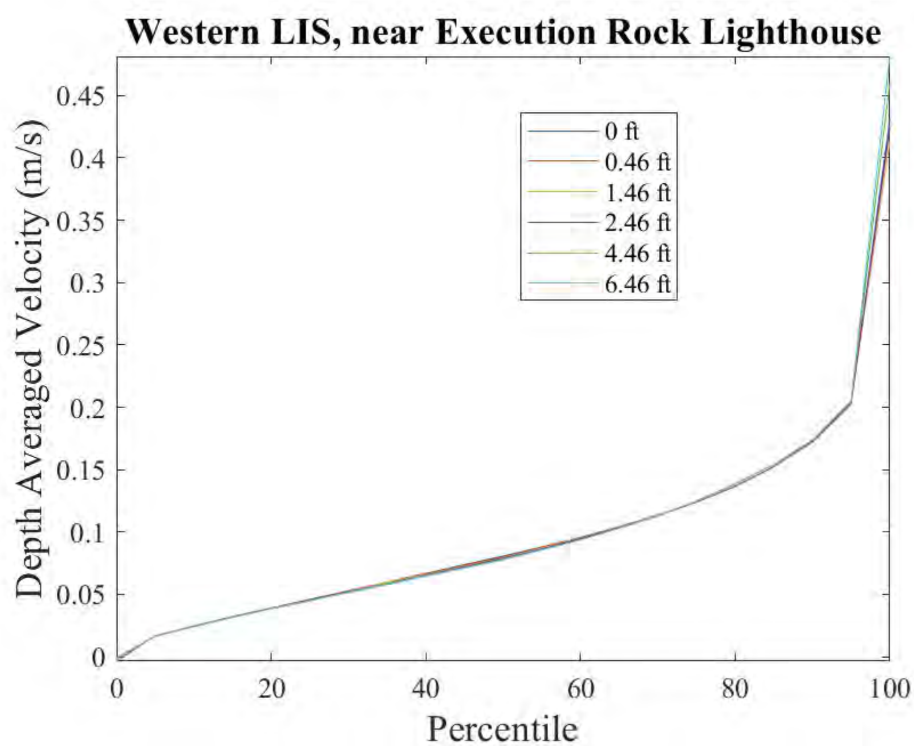


Figure 726. Alt 4, LIS south of NY/CT border Velocity Variation with SLR.

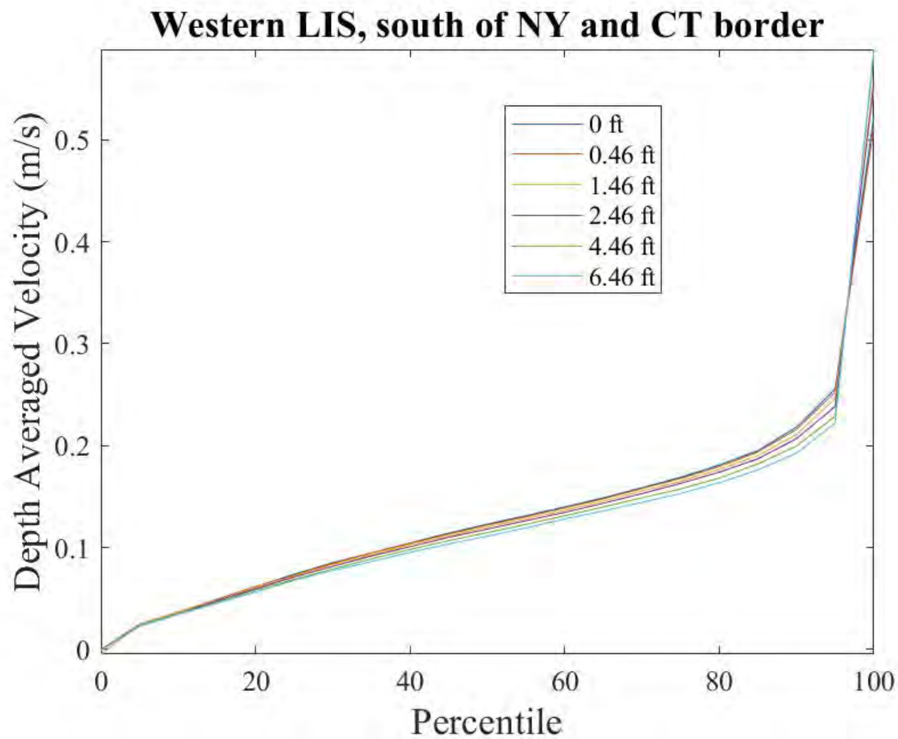


Figure 727. Alt 4, Jamaica Bay Velocity Variation with SLR.

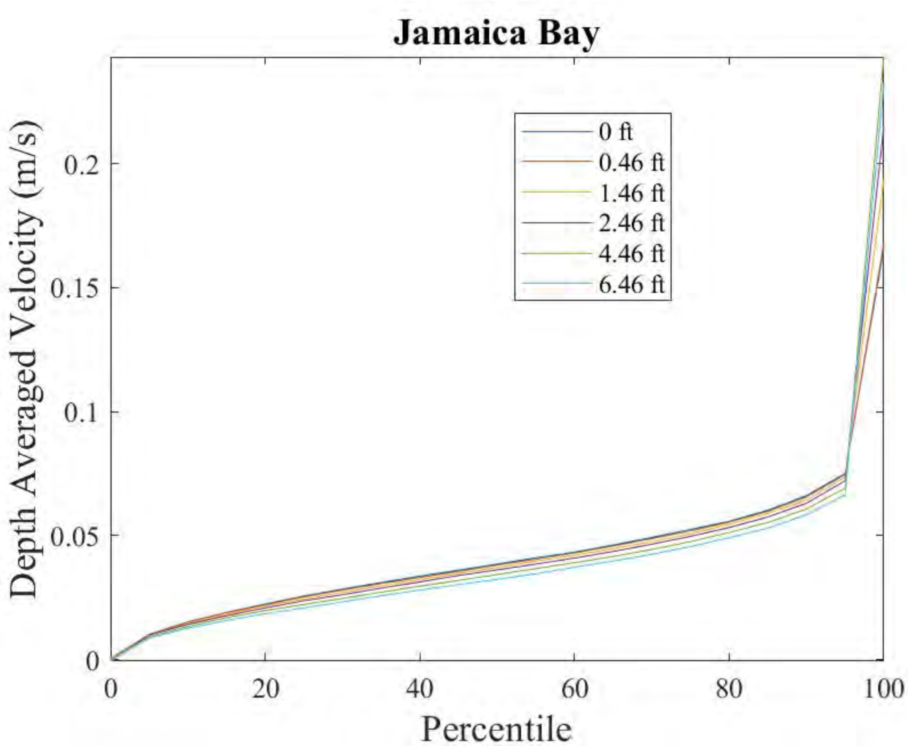


Figure 728. Alt 4, Jamaica Bay near Spring Creek Velocity Variation with SLR.

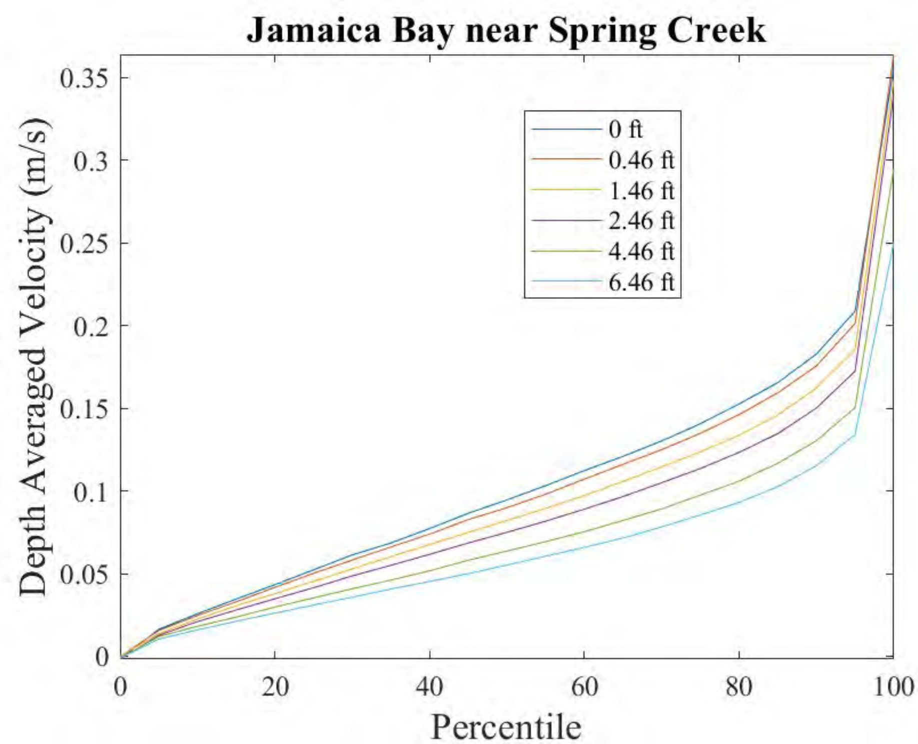
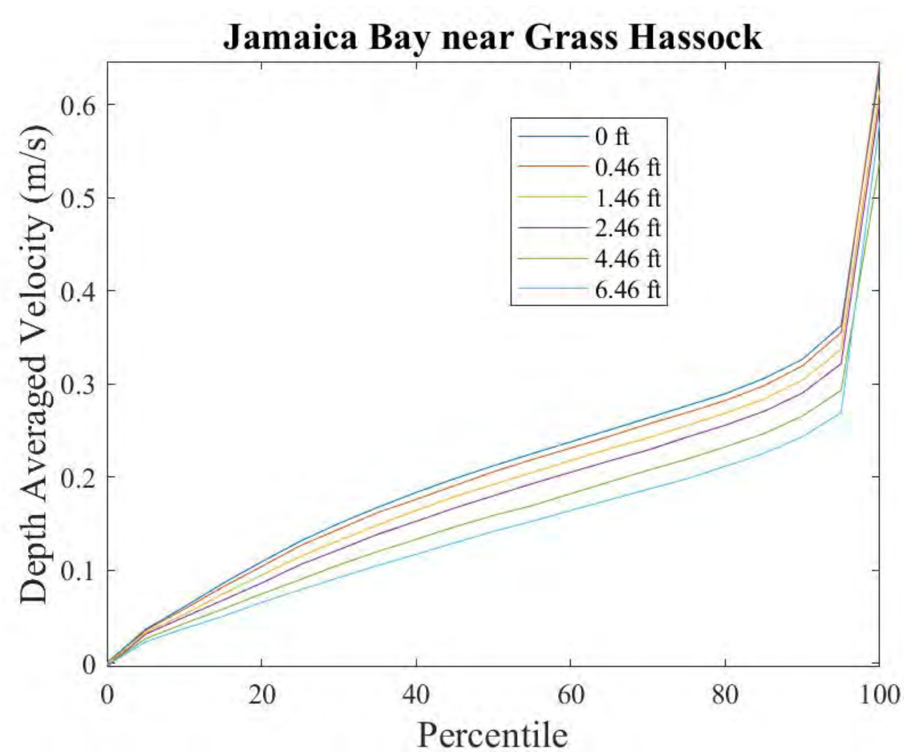


Figure 729. Alt 4, Jamaica Bay near Grass Hassock Velocity Variation with SLR.



15.5.3 Salinity Point Percentiles

Salinity percentiles for Alternative 4 for the previously shown locations (Figure 17 to Figure 20 and Table 3) are provided in Figure 730 to Figure 762. In general, increased sea levels result in increased salinities.

Figure 730. Alt 4, V1 Salinity Variation with SLR.

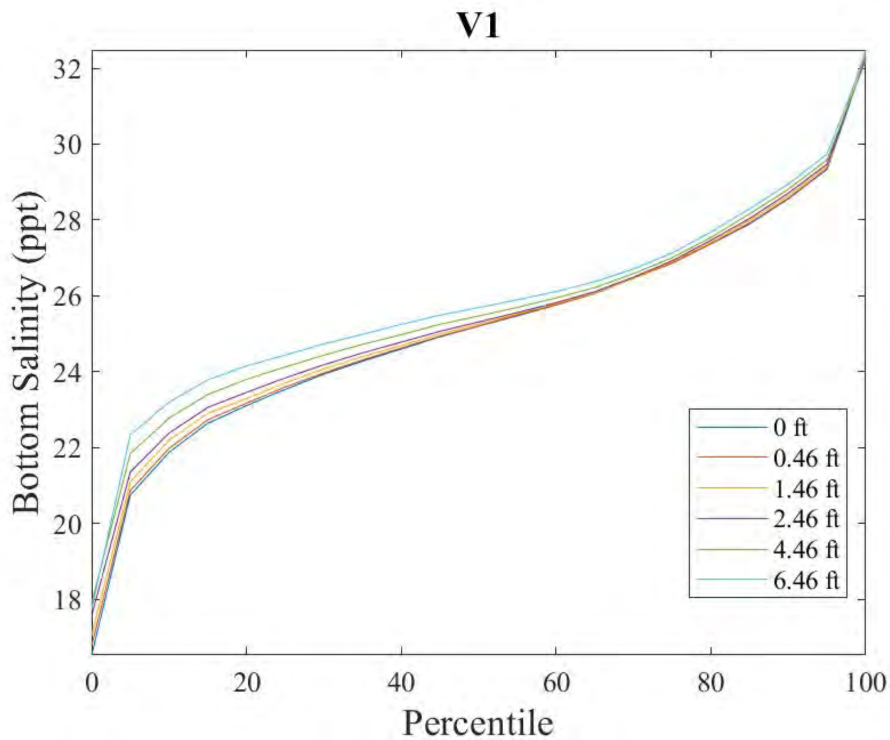


Figure 731. Alt 4, V2 Salinity Variation with SLR.

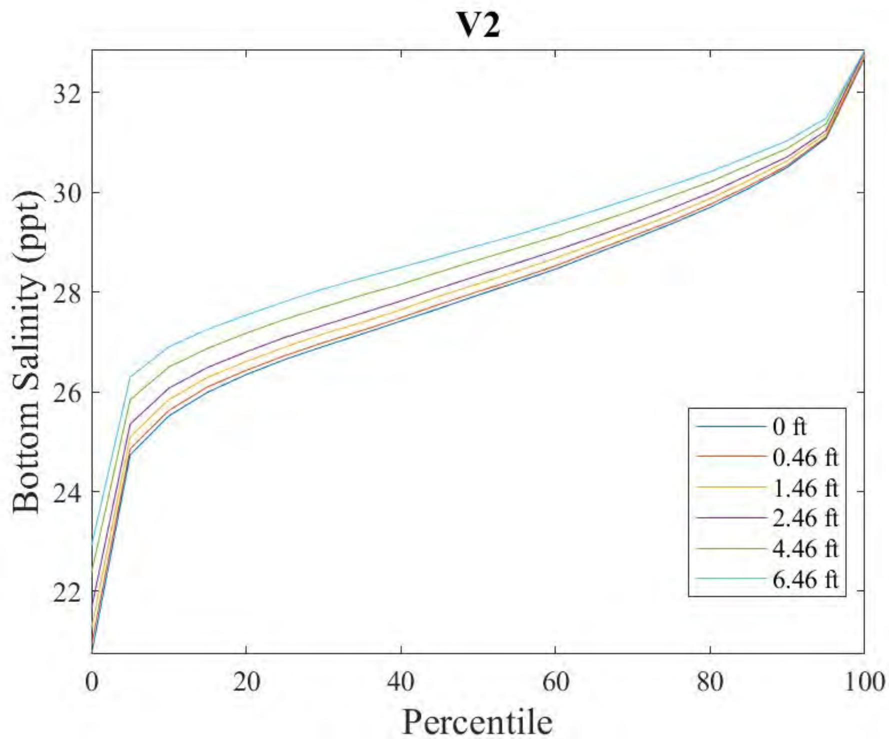


Figure 732. Alt 4, V3 Salinity Variation with SLR.

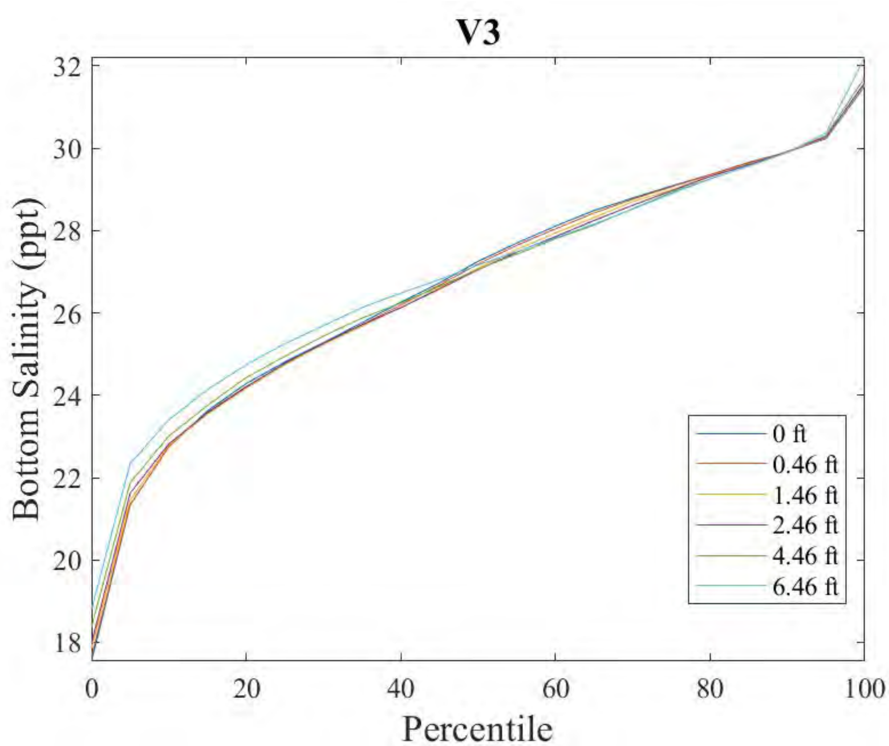


Figure 733. Alt 4, V4 Salinity Variation with SLR.

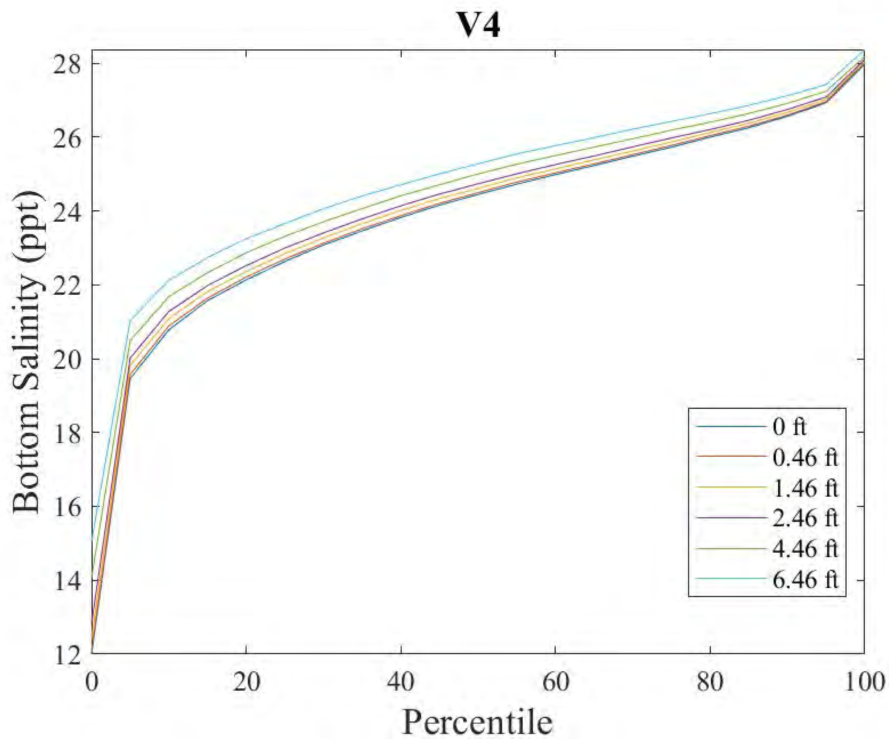


Figure 734. Alt 4, V5 Salinity Variation with SLR.

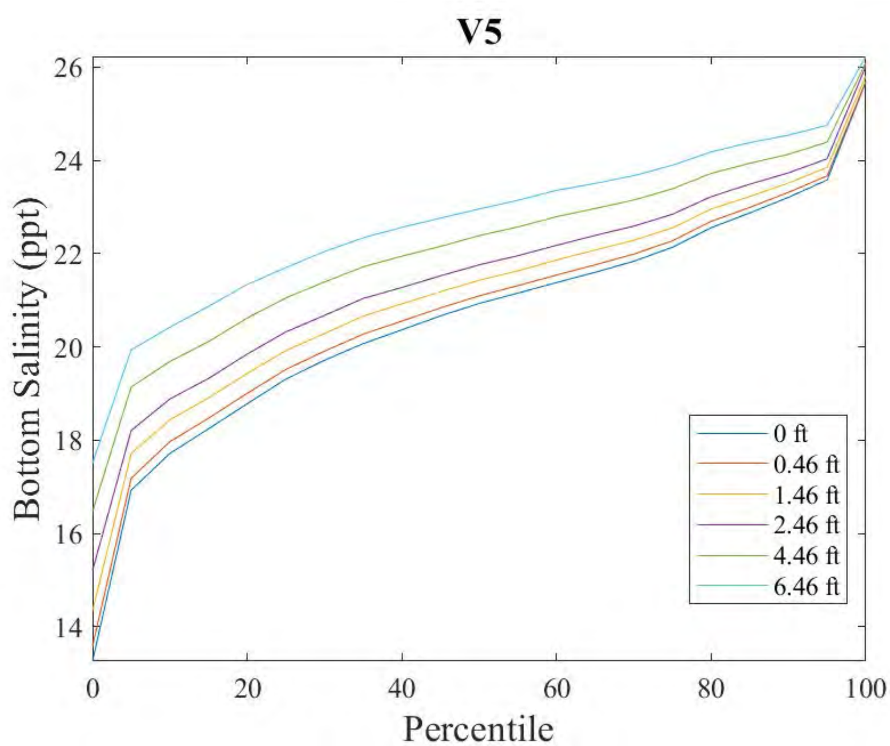


Figure 735. Alt 4, V6 Salinity Variation with SLR.

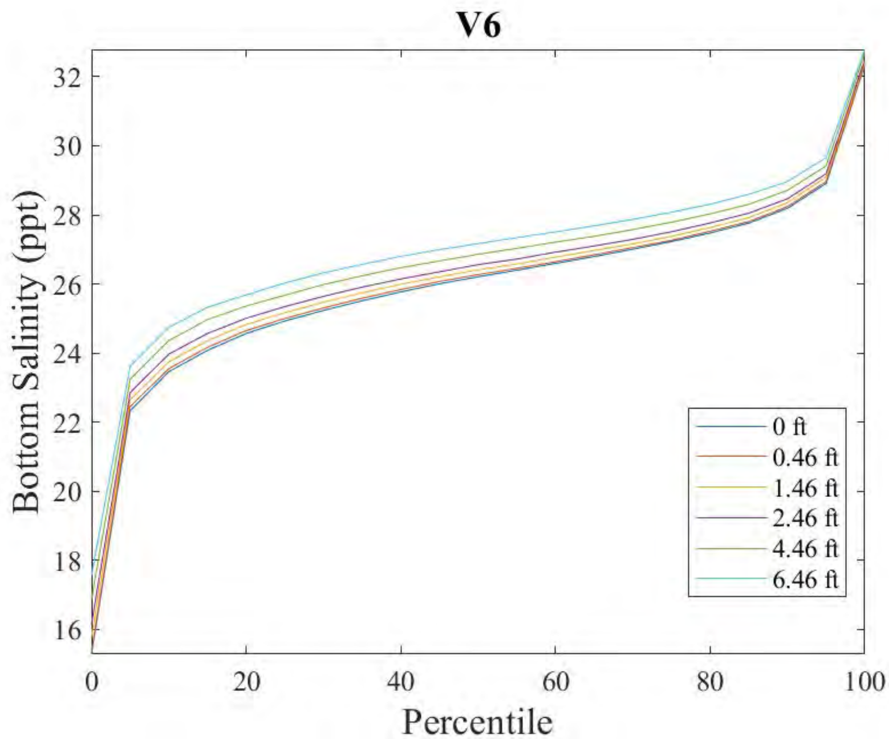


Figure 736. Alt 4, S1 Salinity Variation with SLR.

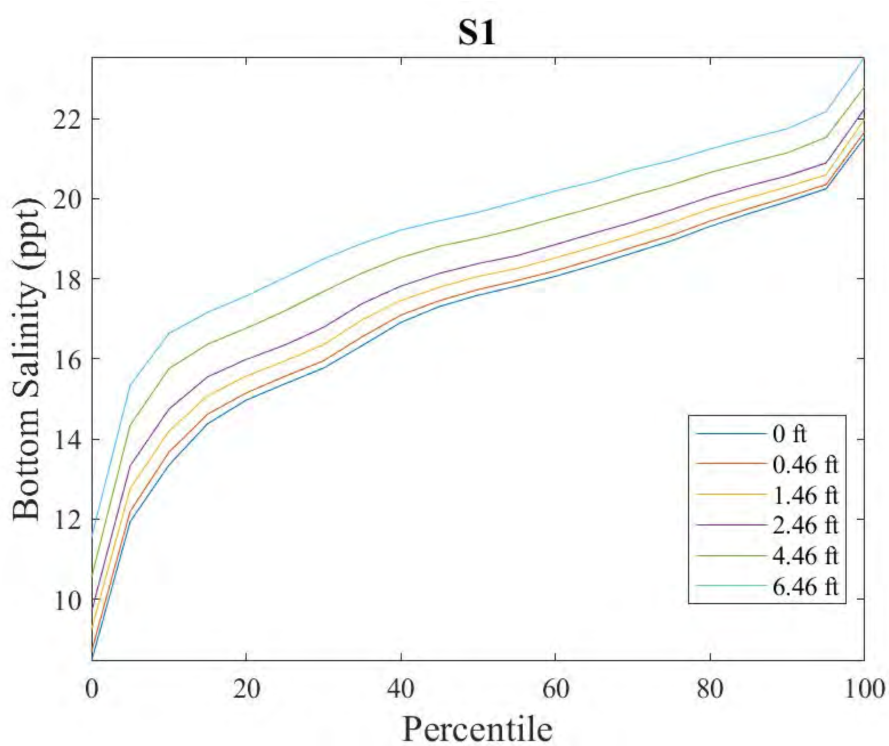


Figure 737. Alt 4, S2 Salinity Variation with SLR.

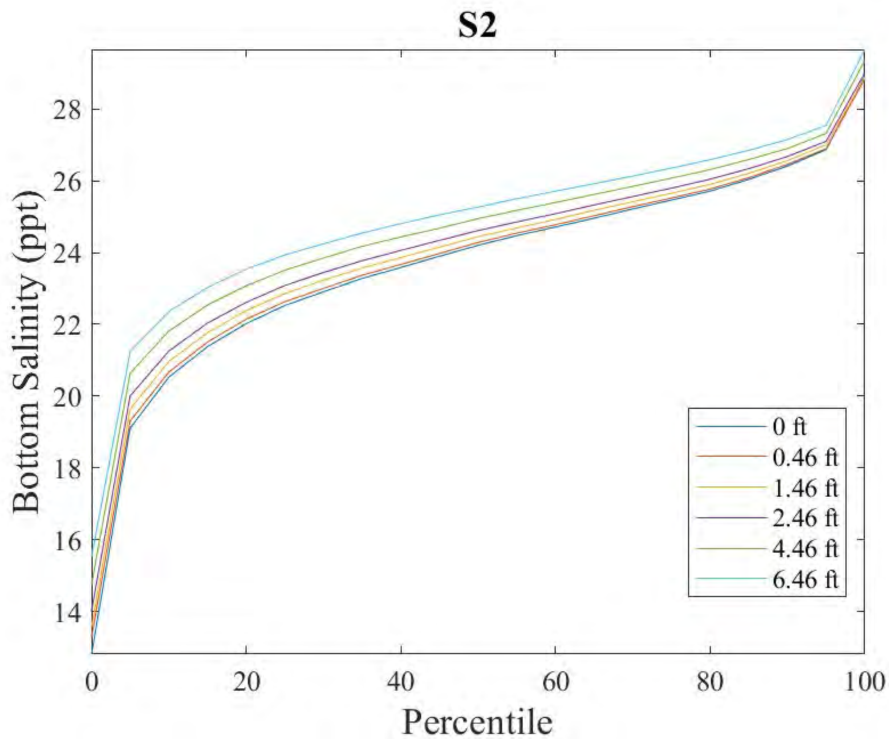


Figure 738. Alt 4, S3 Salinity Variation with SLR.

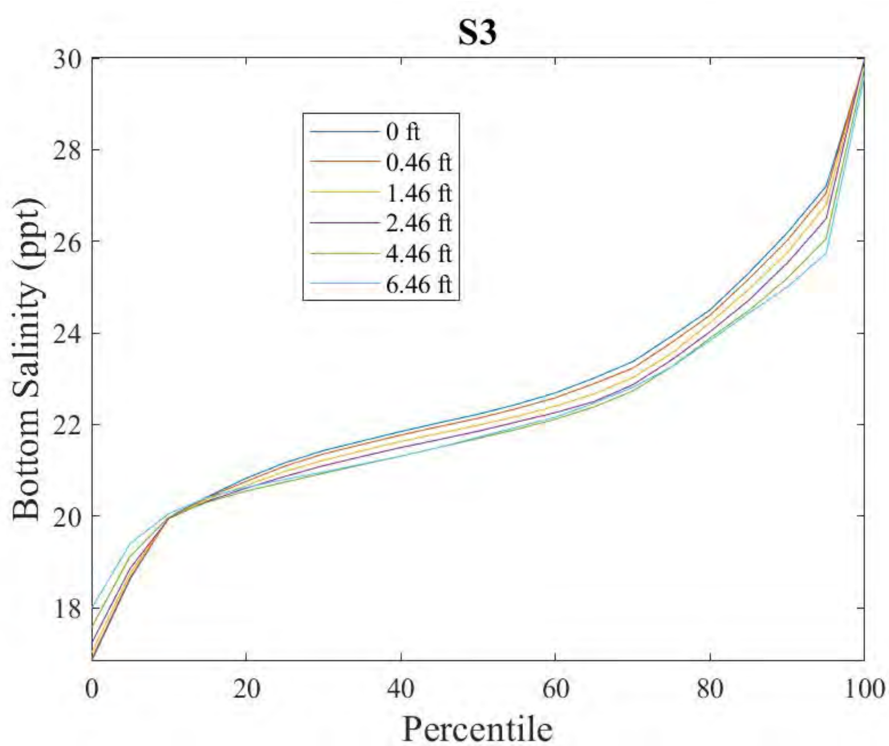


Figure 739. Alt 4, S4 Salinity Variation with SLR.

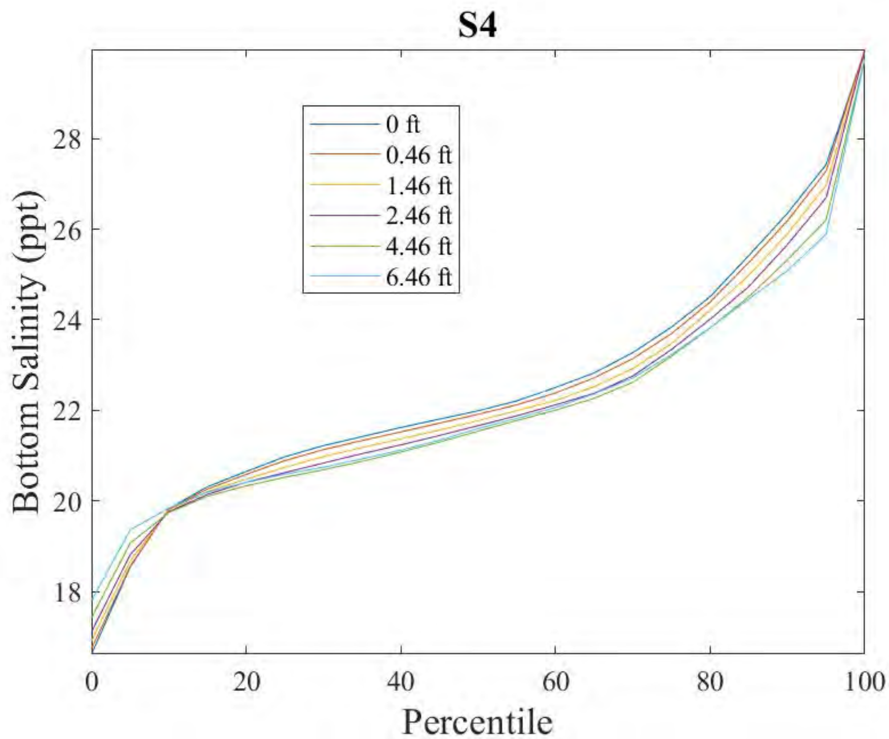


Figure 740. Alt 4, S5 Salinity Variation with SLR.

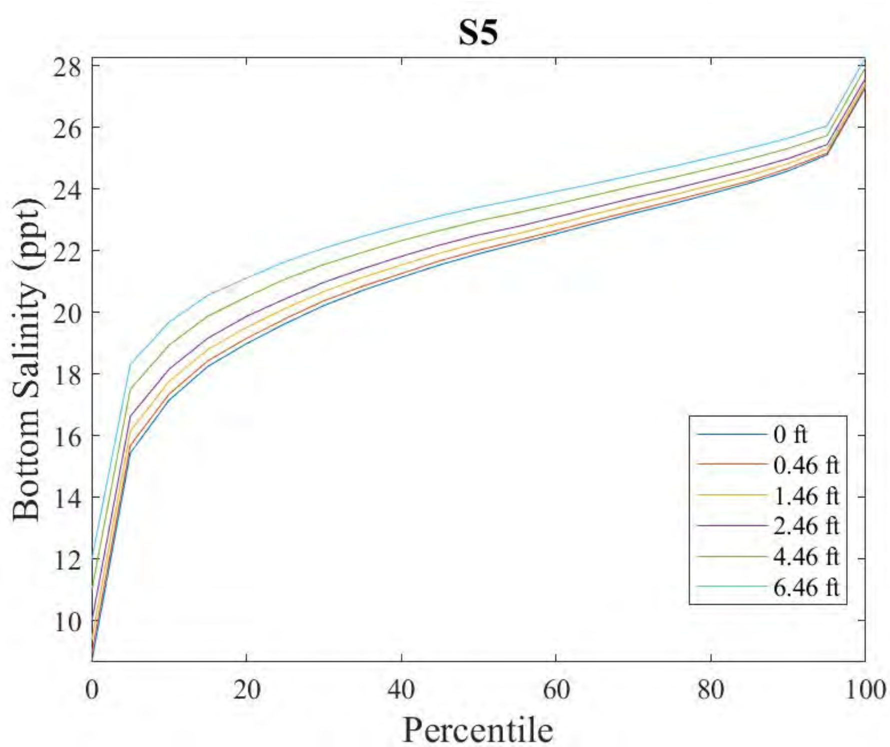


Figure 741. Alt 4, T1 Salinity Variation with SLR.

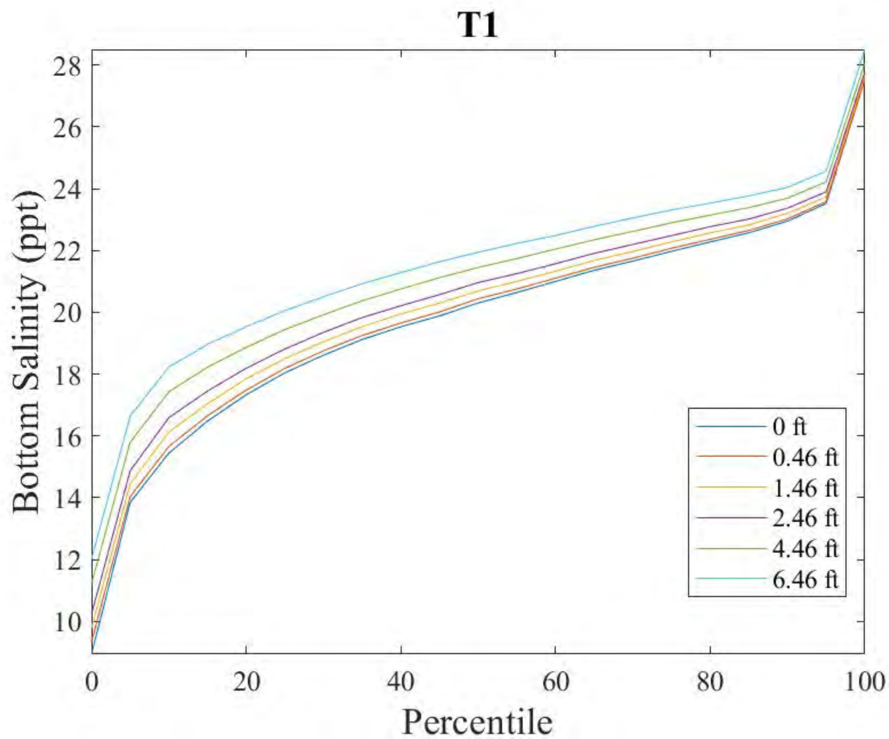


Figure 742. Alt 4, T2 Salinity Variation with SLR.

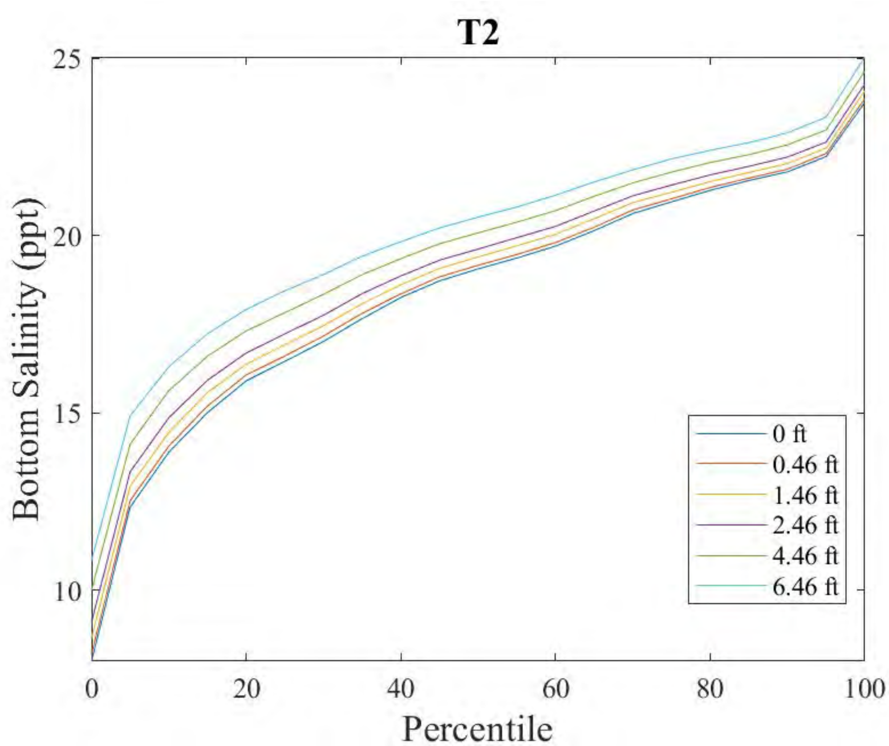


Figure 743. Alt 4, T3 Salinity Variation with SLR.

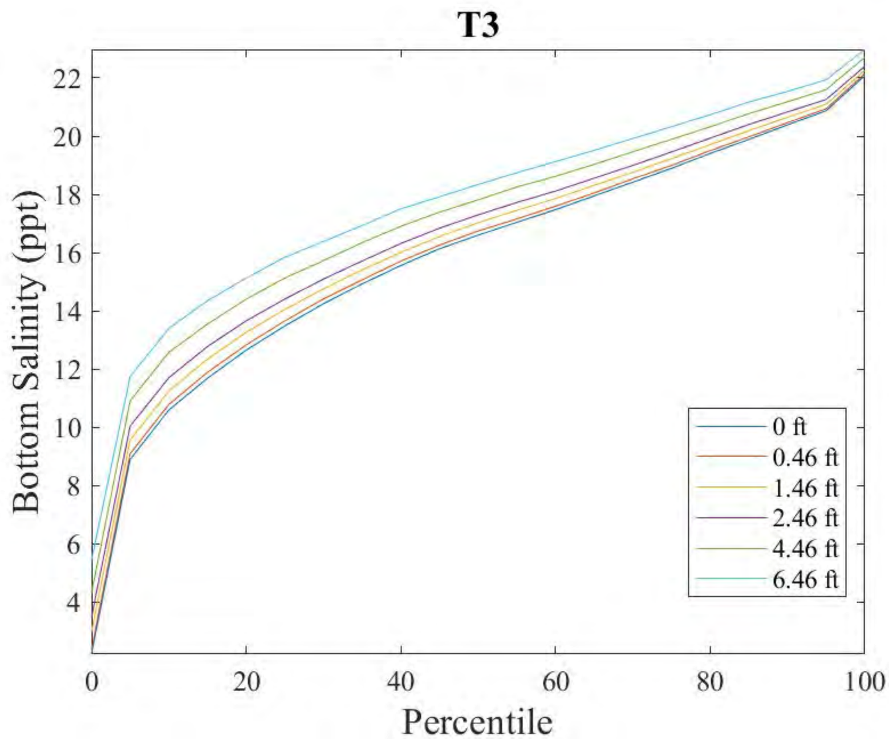


Figure 744. Alt 4, T4 Salinity Variation with SLR.

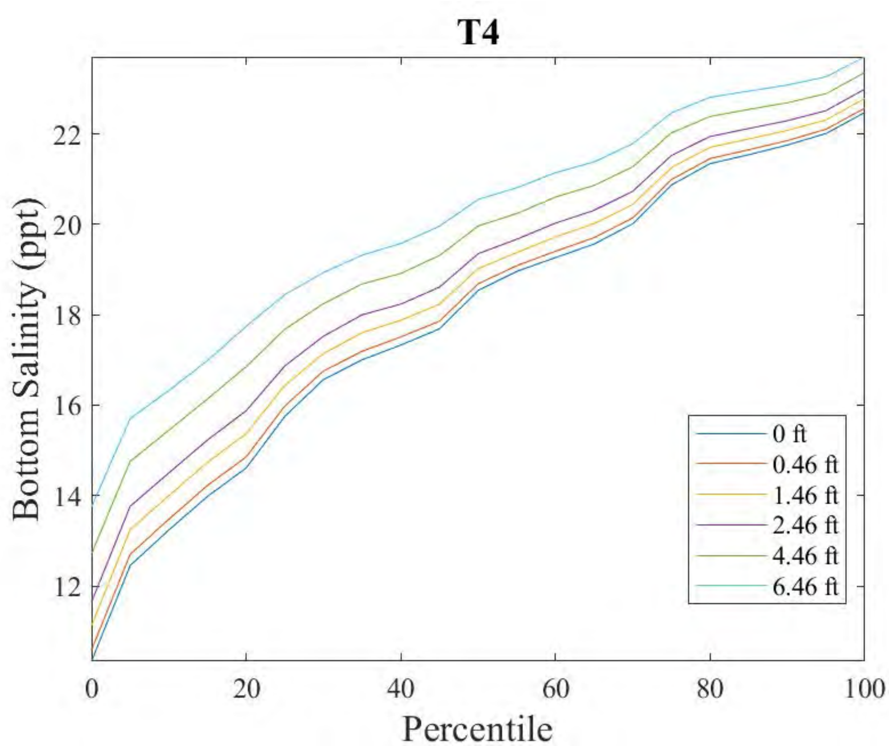


Figure 745. Alt 4, T5 Salinity Variation with SLR.

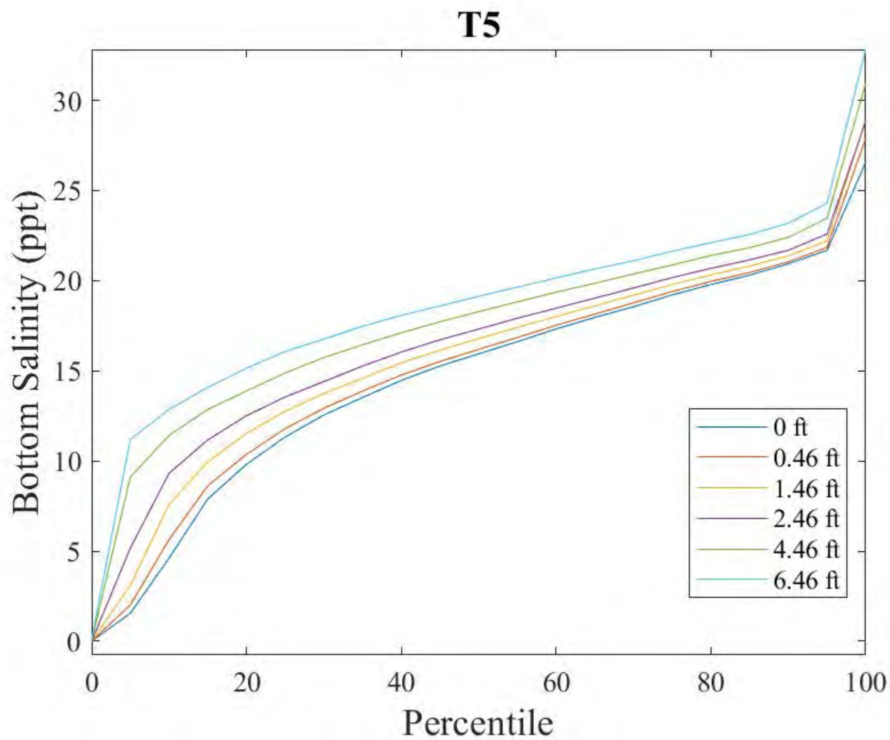


Figure 746. Alt 4, R1 Salinity Variation with SLR.

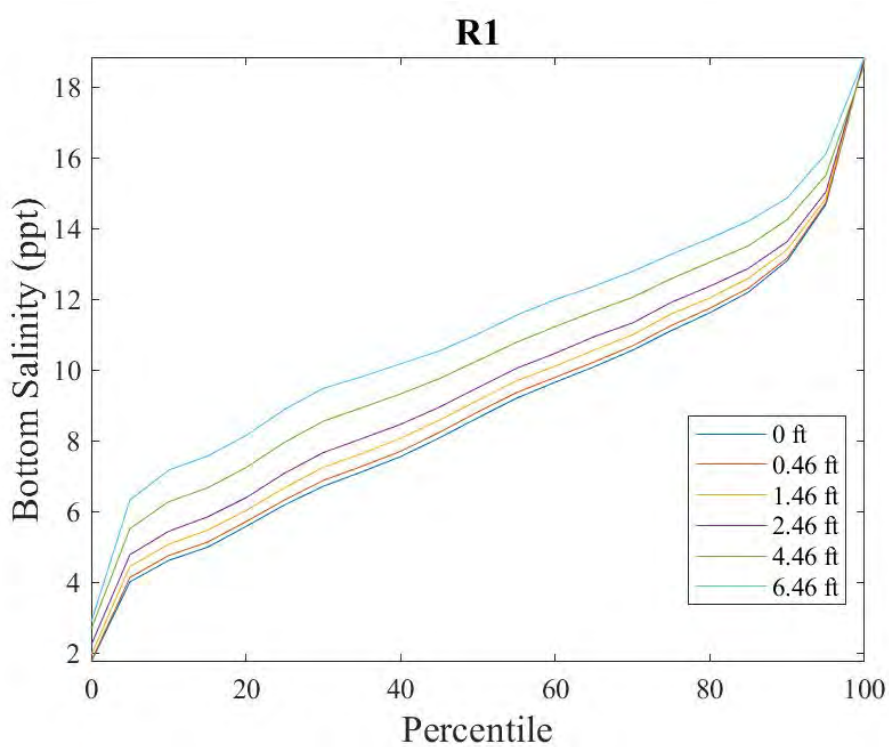


Figure 747. Alt 4, Sandy Hook Salinity Variation with SLR.

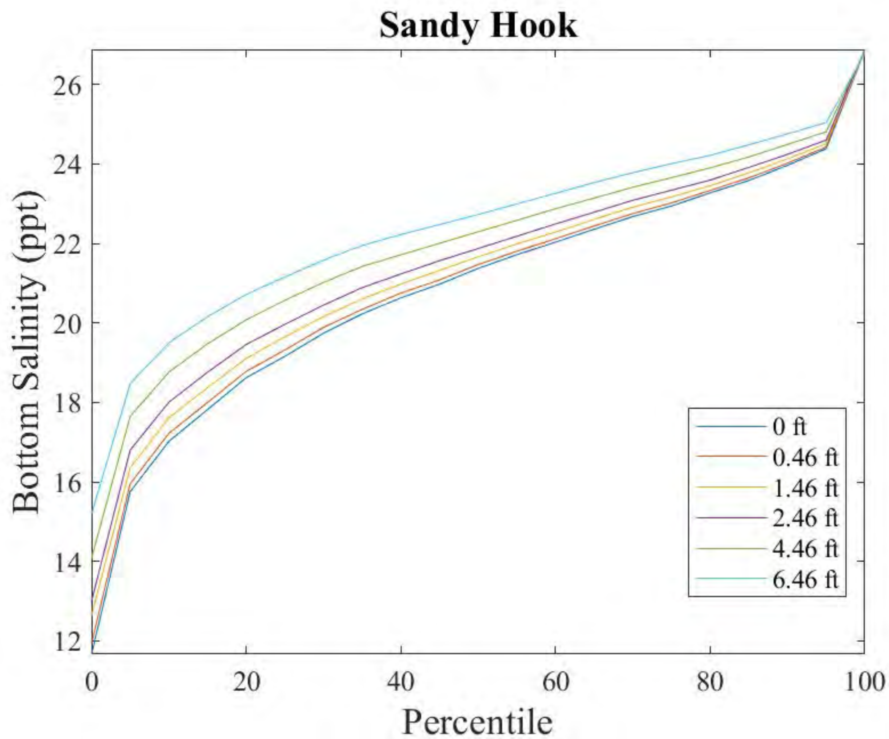


Figure 748. Alt 4, Fresh Kills Salinity Variation with SLR.

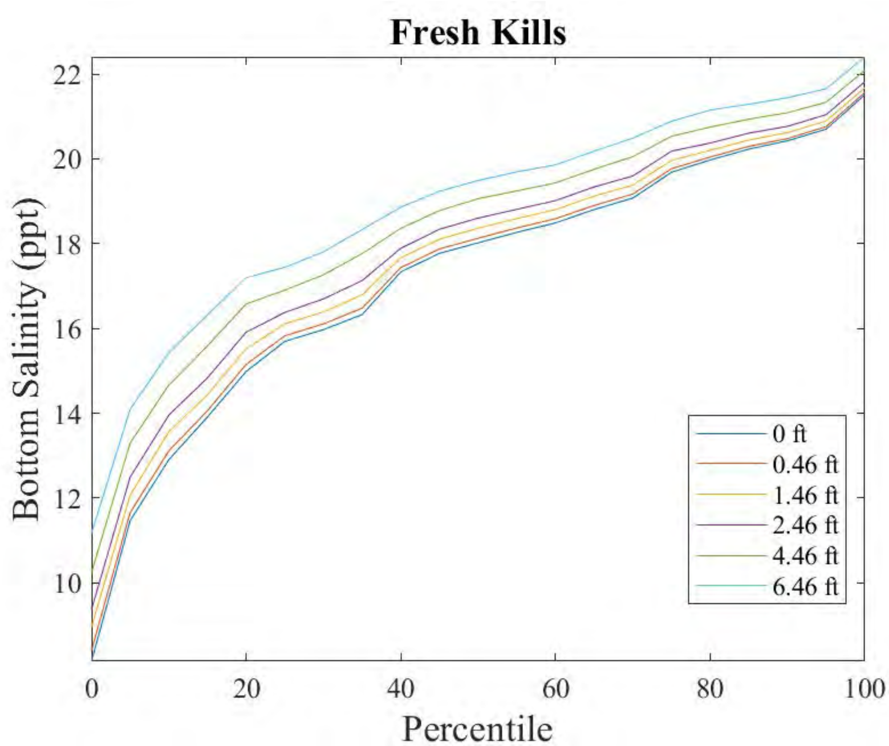


Figure 749. Alt 4, Mariners Harbor Salinity Variation with SLR.

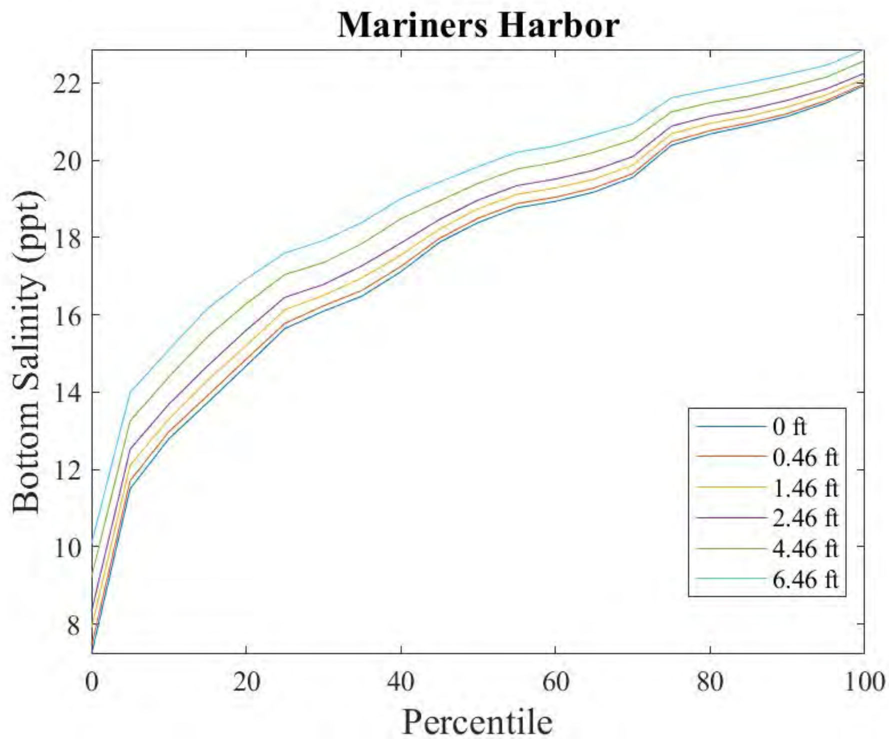


Figure 750. Alt 4, North Reach Salinity Variation with SLR.

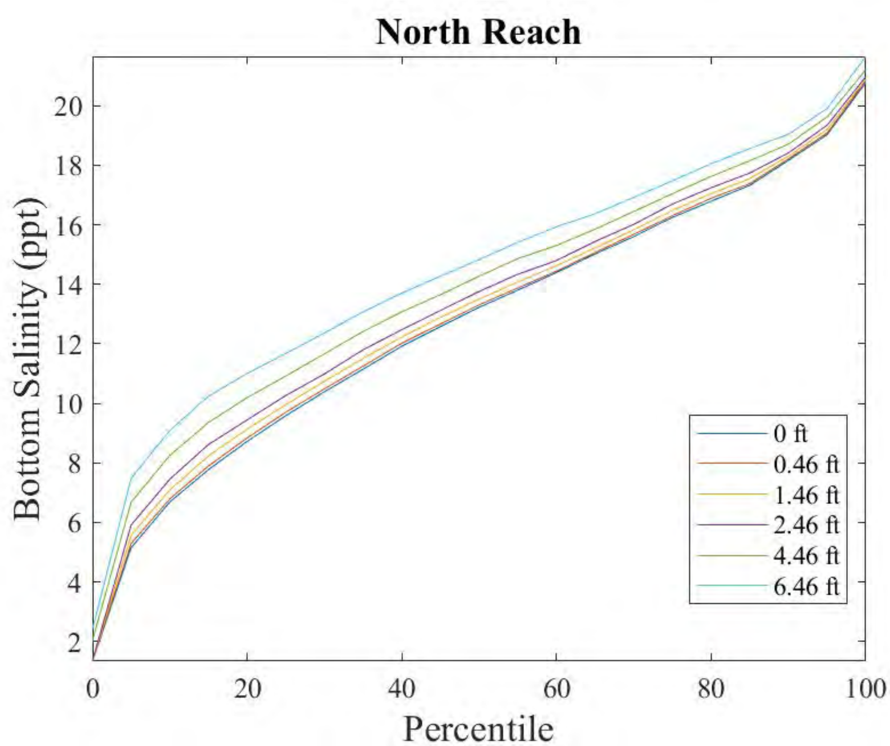


Figure 751. Alt 4, Hackensack River Salinity Variation with SLR.

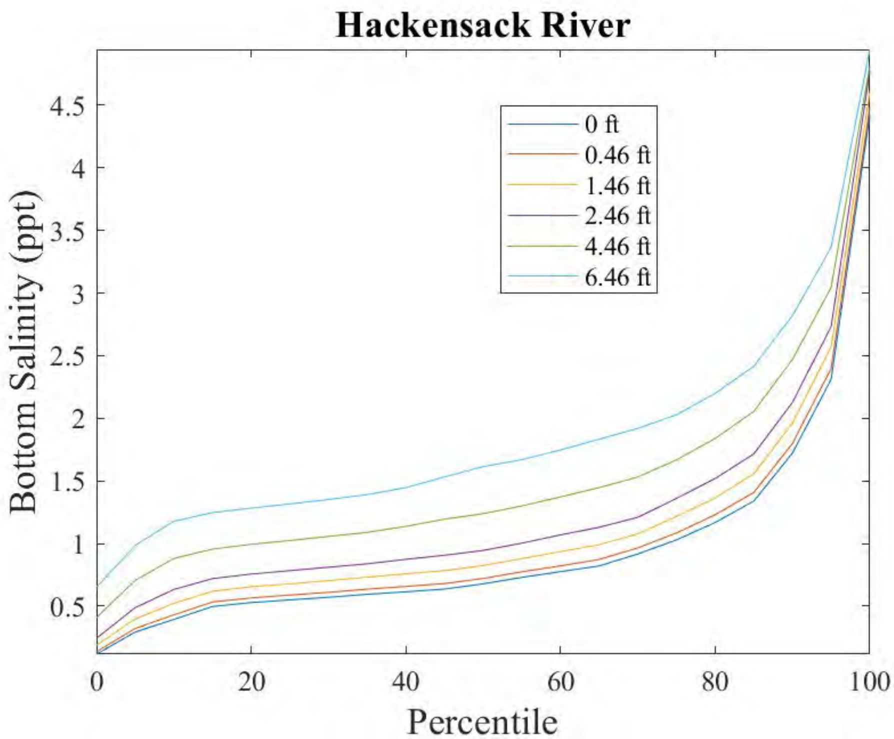


Figure 752. Alt 4, Robbins Reef Salinity Variation with SLR.

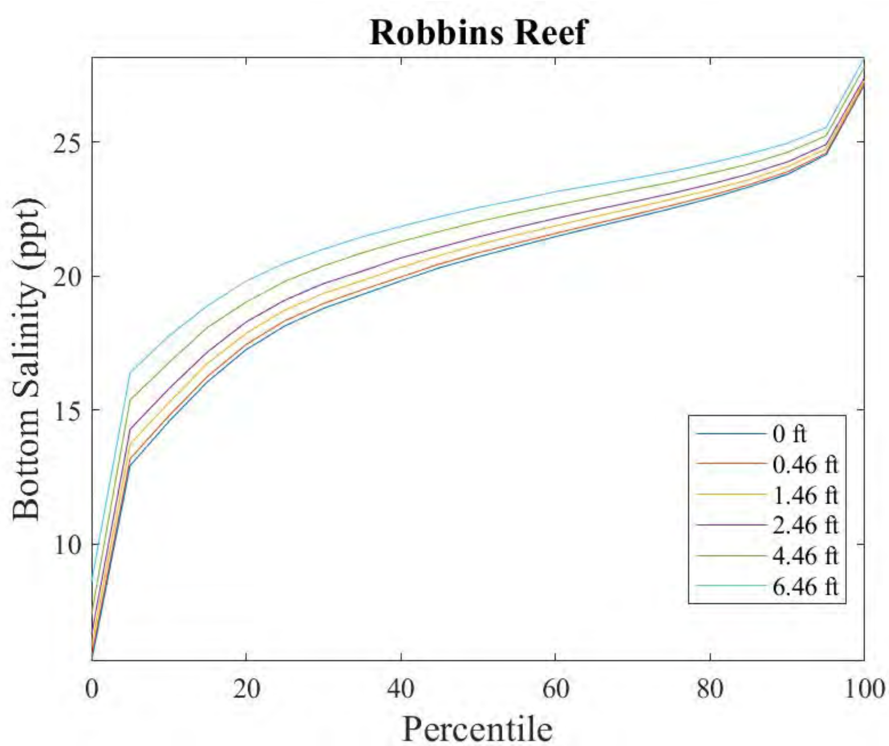


Figure 753. Alt 4, The Battery Salinity Variation with SLR.

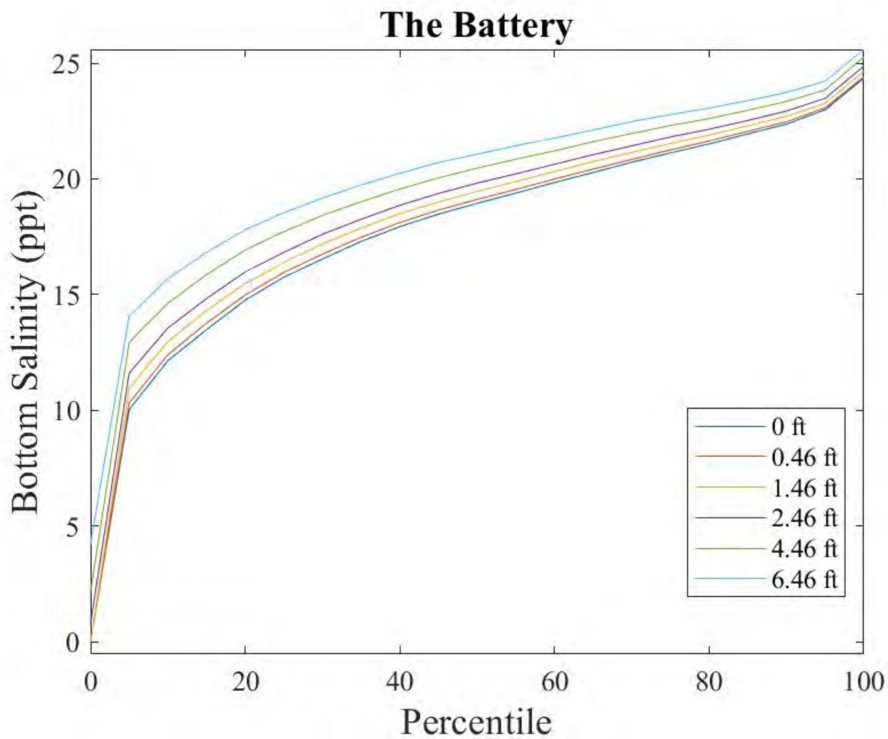


Figure 754. Alt 4, Manhattan Salinity Variation with SLR.

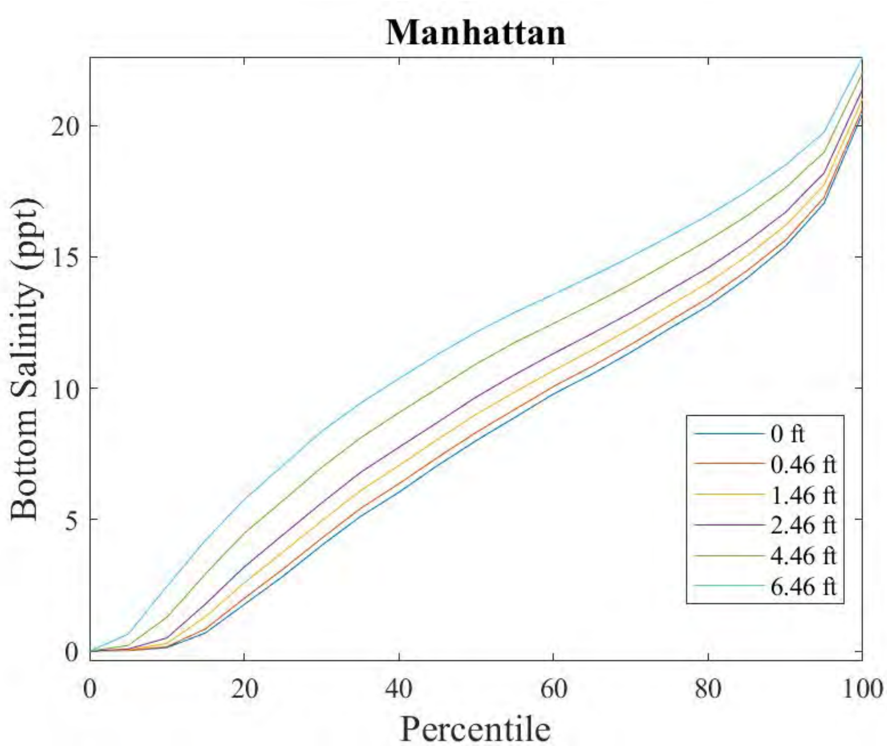


Figure 755. Alt 4, Hudson River Haverstraw Bay Salinity Variation with SLR.

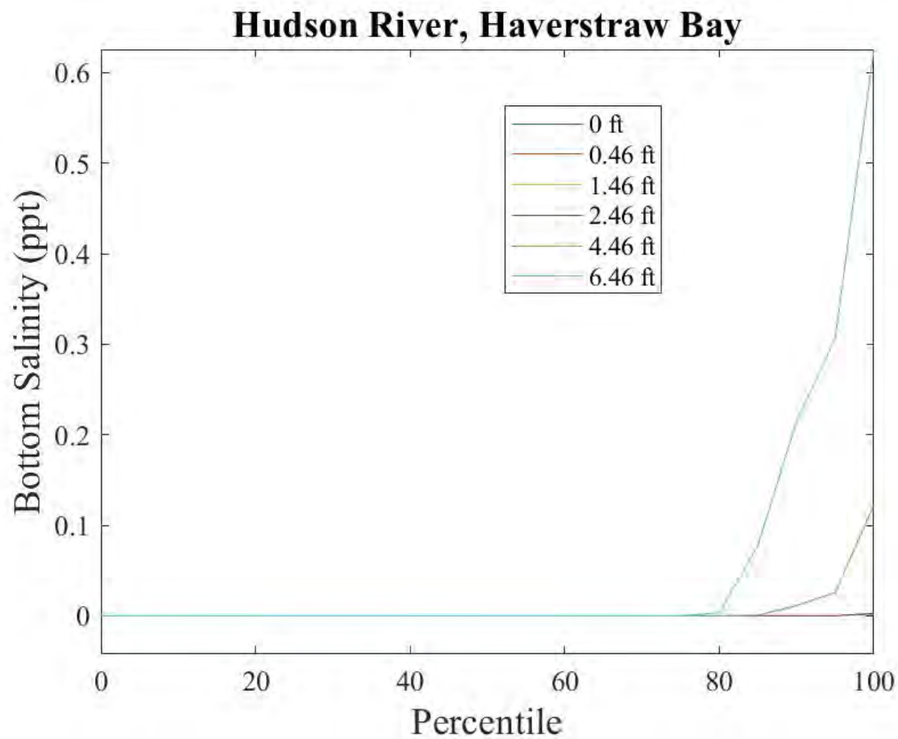


Figure 756. Alt 4, KLGA Salinity Variation with SLR.

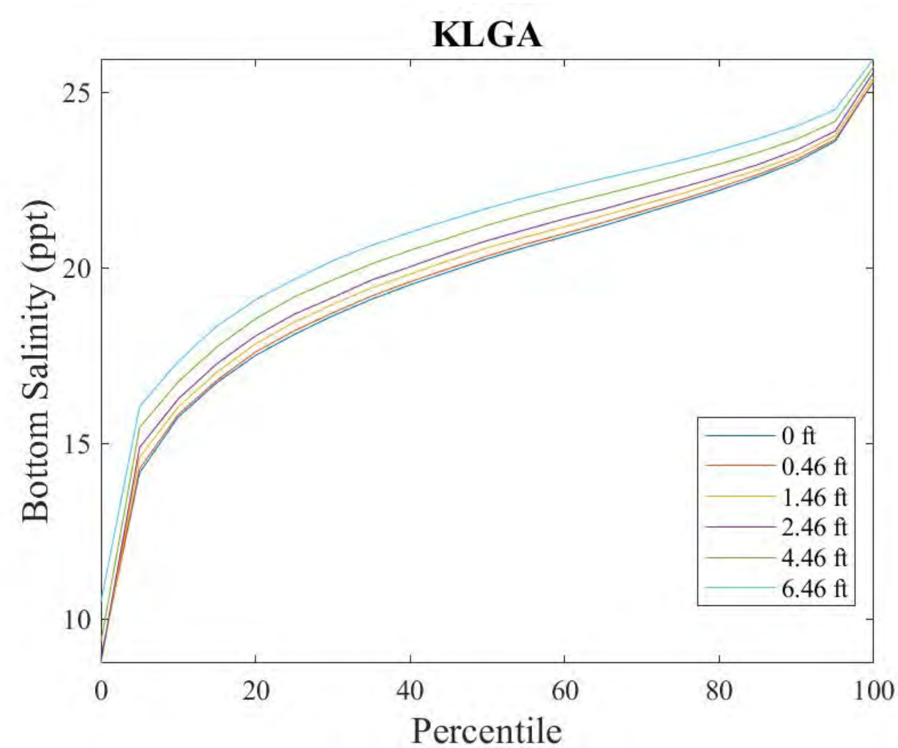


Figure 757. Alt 4, LIS near Stepping Stone Lighthouse Salinity Variation with SLR.

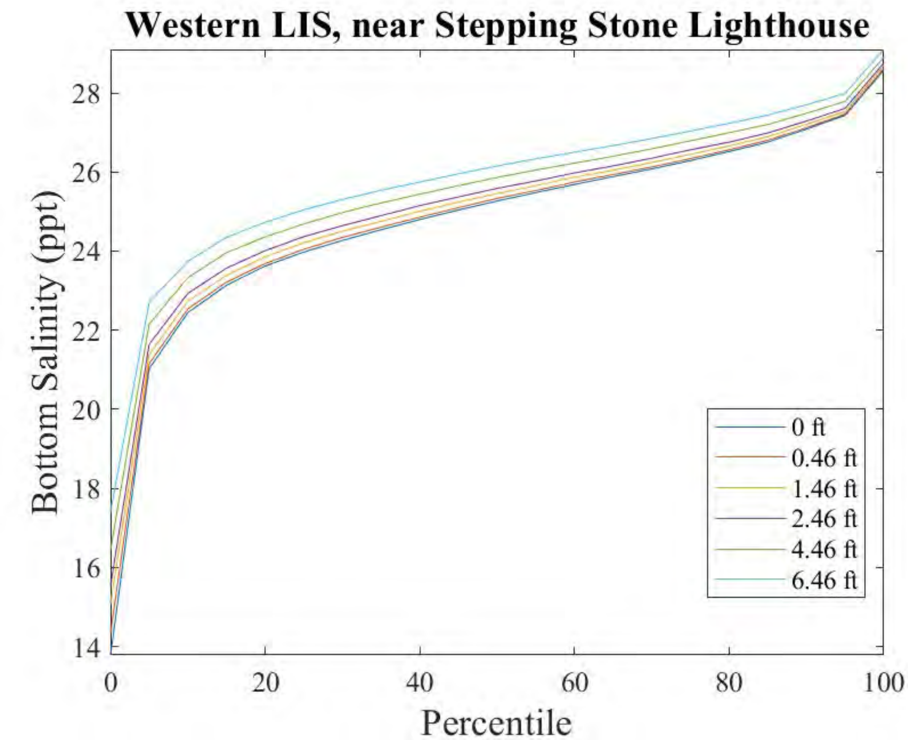


Figure 758. Alt 4, LIS near Execution Rock Lighthouse Salinity Variation with SLR.

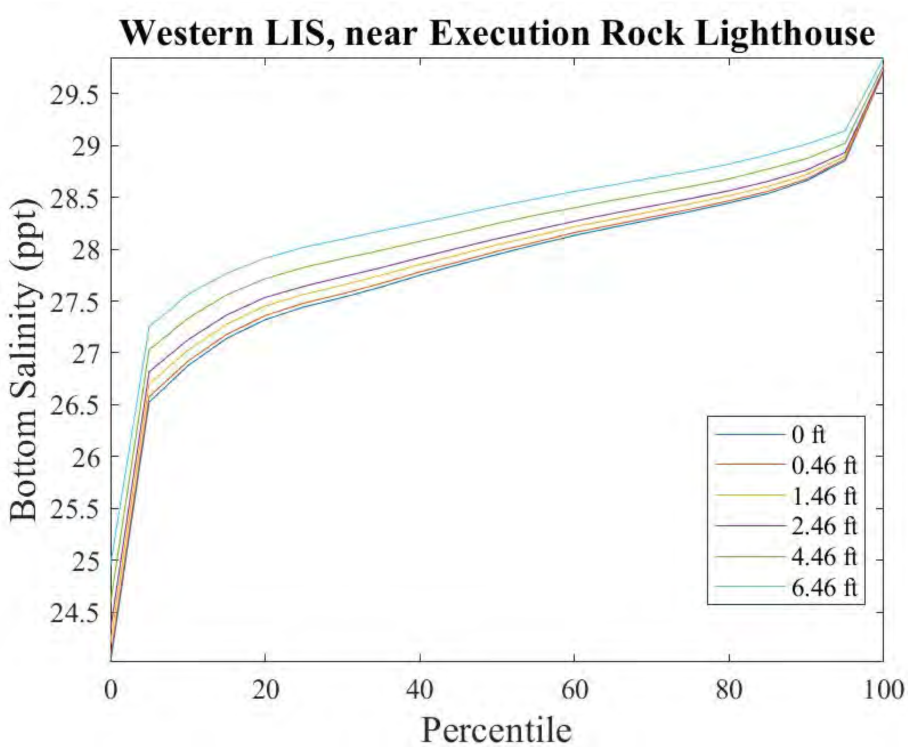


Figure 759. Alt 4, LIS south of NY/CT border Salinity Variation with SLR.

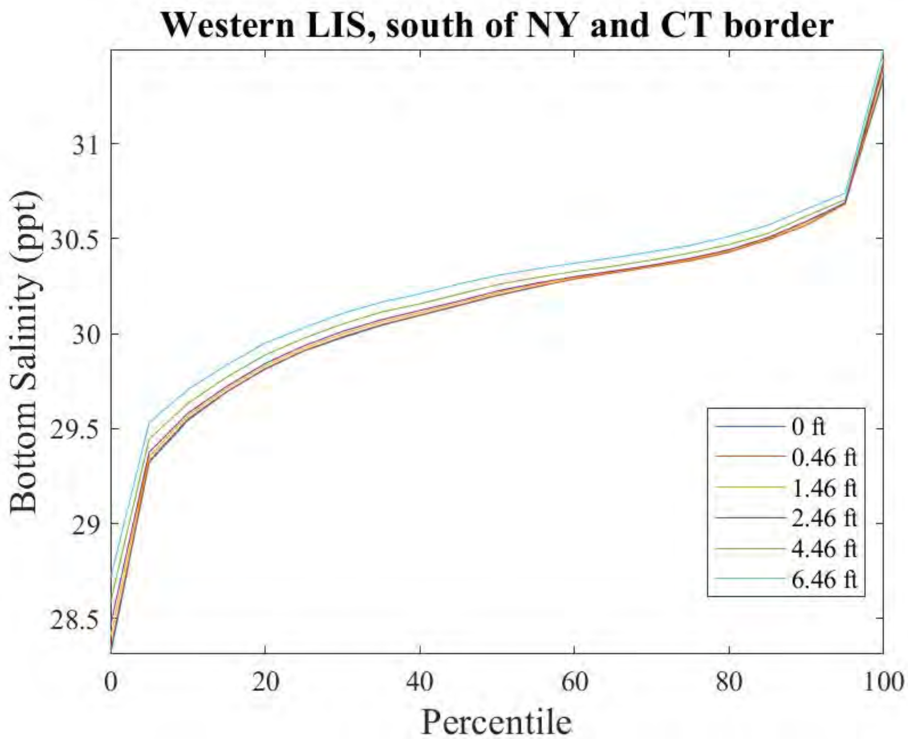


Figure 760. Alt 4, Jamaica Bay Salinity Variation with SLR.

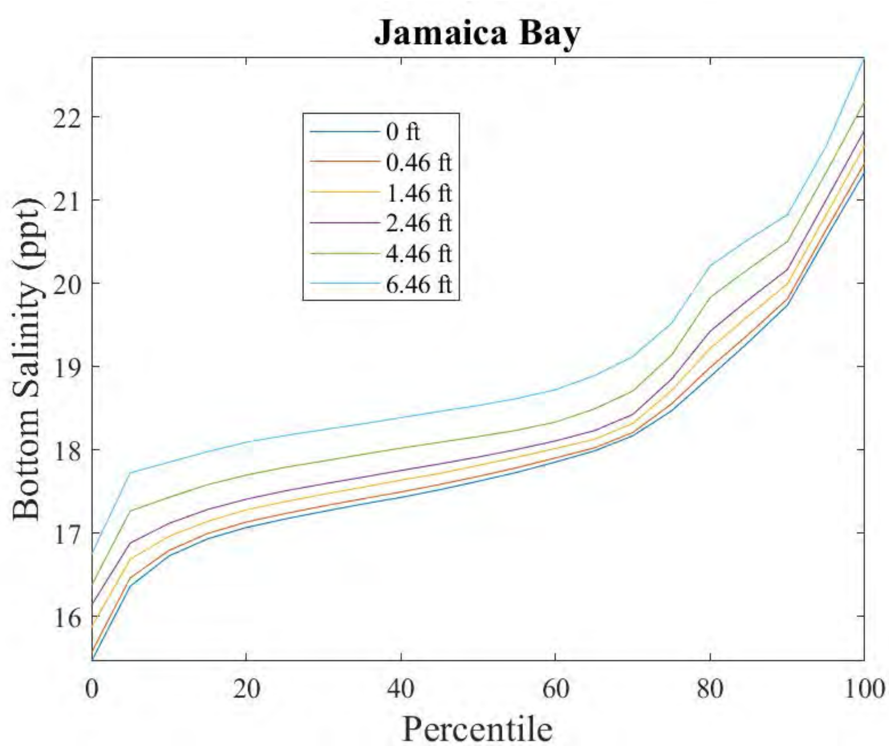


Figure 761. Alt 4, Jamaica Bay near Spring Creek Salinity Variation with SLR.

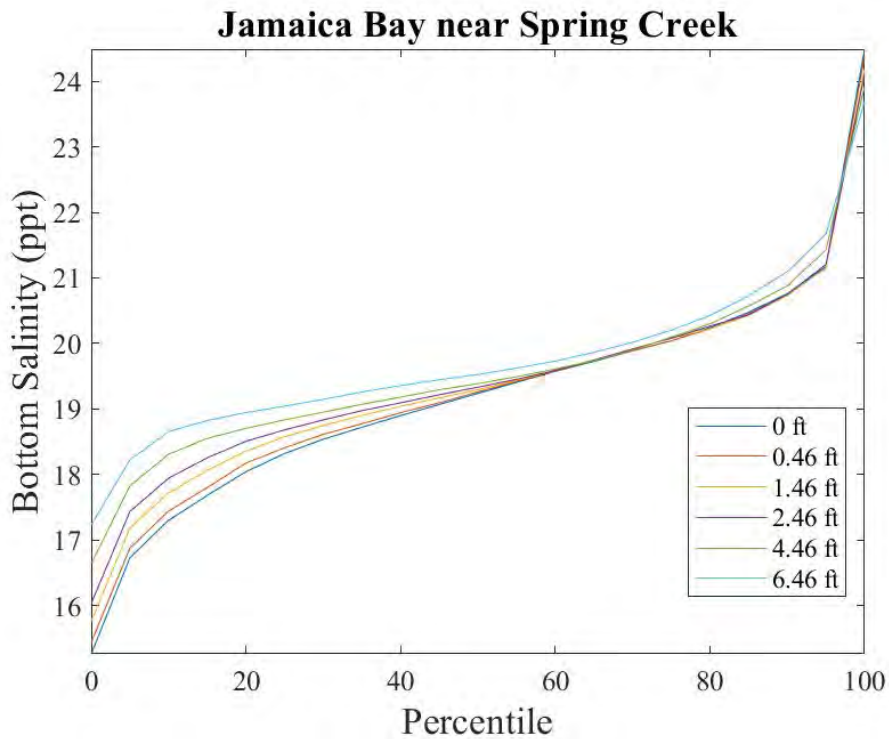
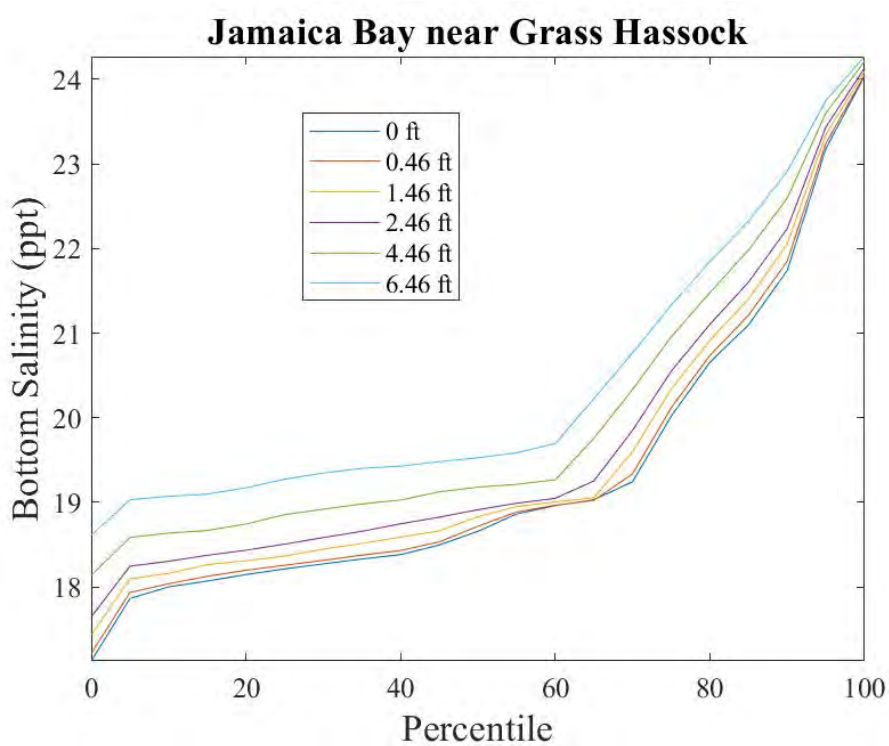


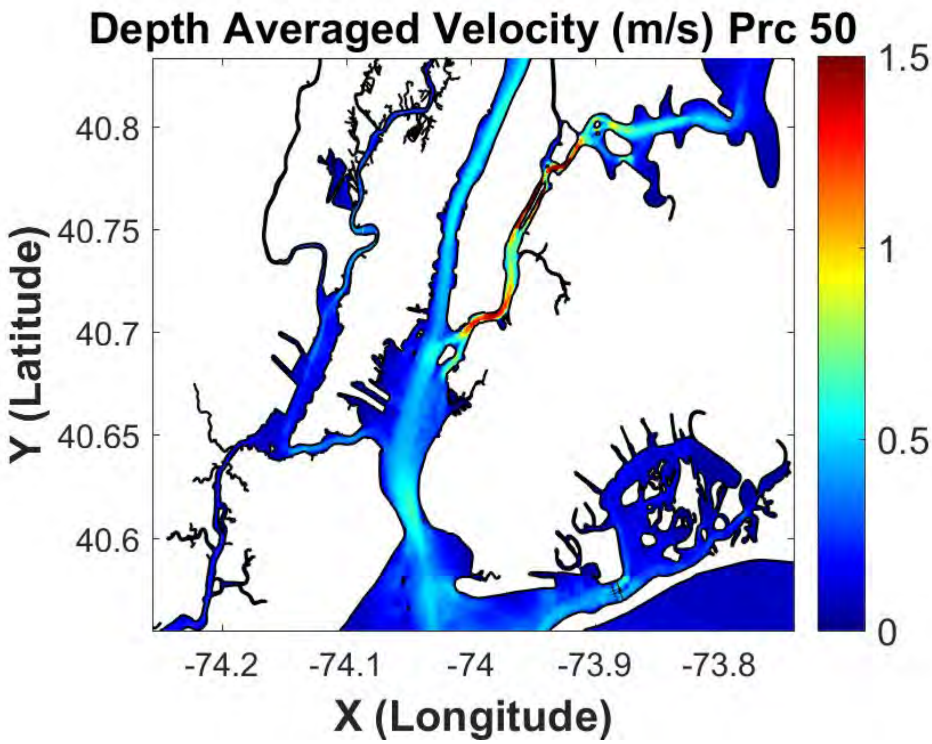
Figure 762. Alt 4, Jamaica Bay near Grass Hassock Salinity Variation with SLR.



15.5.4 Spatial Velocity Percentiles

Spatial figures of the velocity magnitude percentiles for Alternative 4 for the 50th and 75th percentiles are provided in Figure 763 to Figure 774.

Figure 763. Alternative 4/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



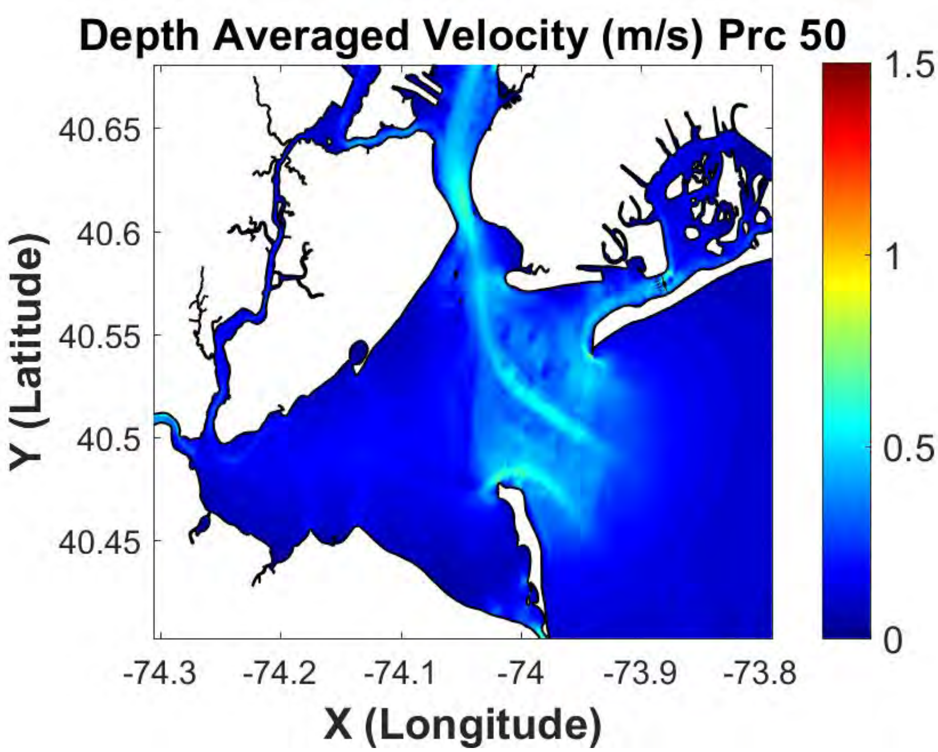
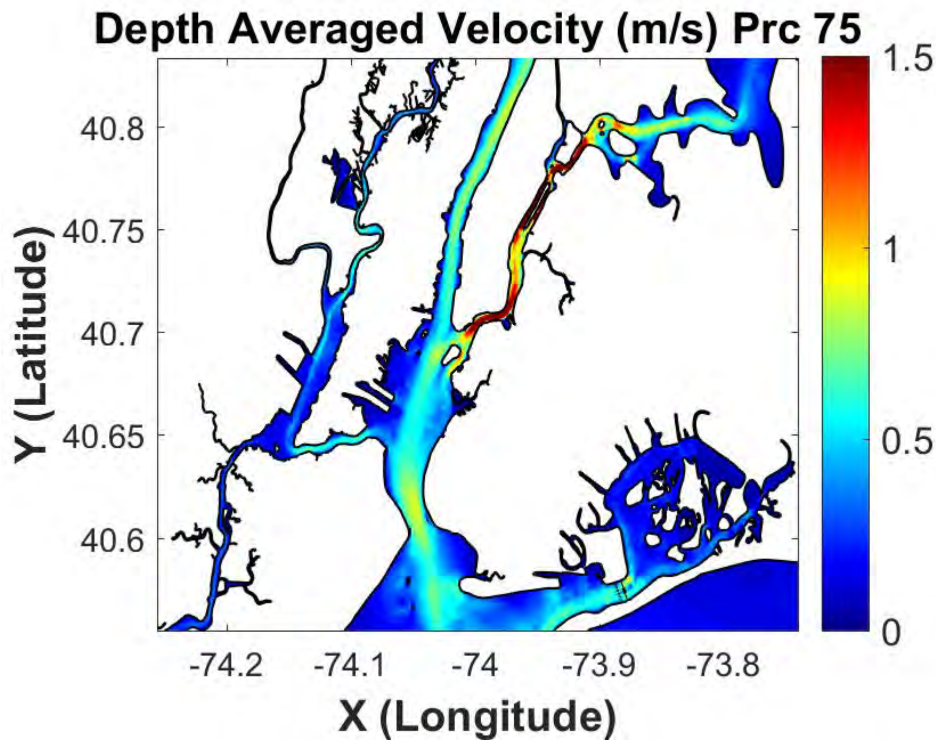


Figure 764. Alternative 4/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



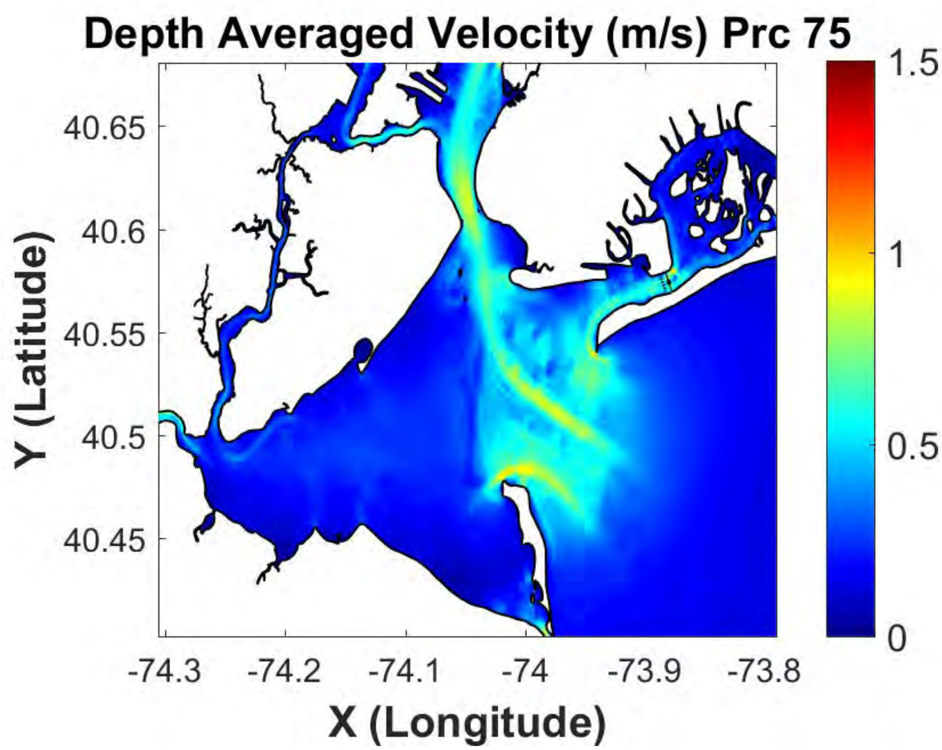
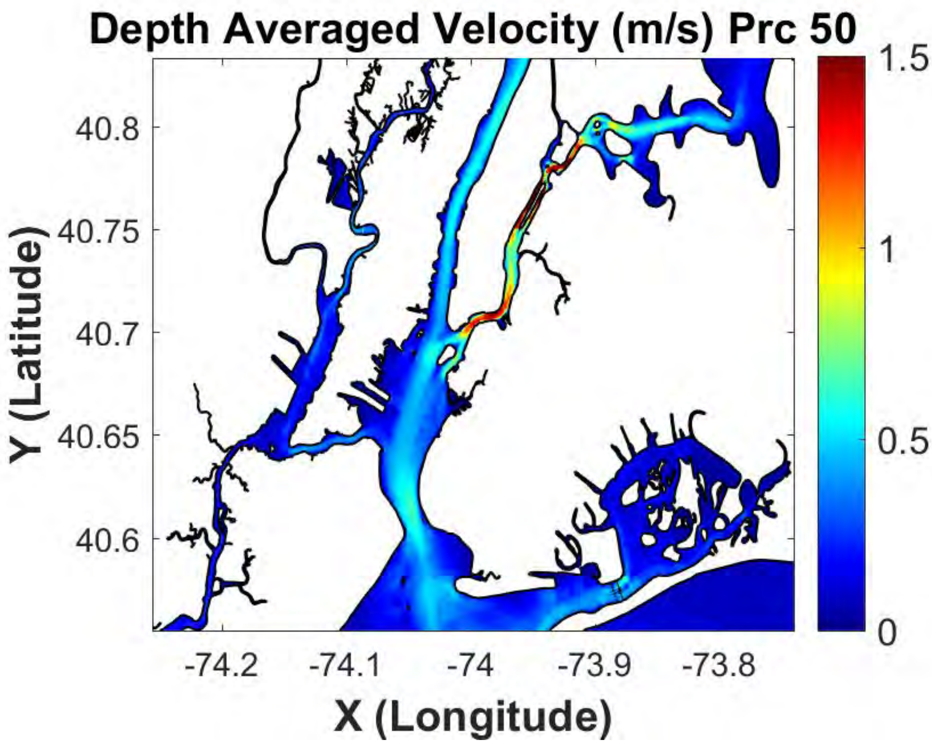


Figure 765. Alternative 4/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



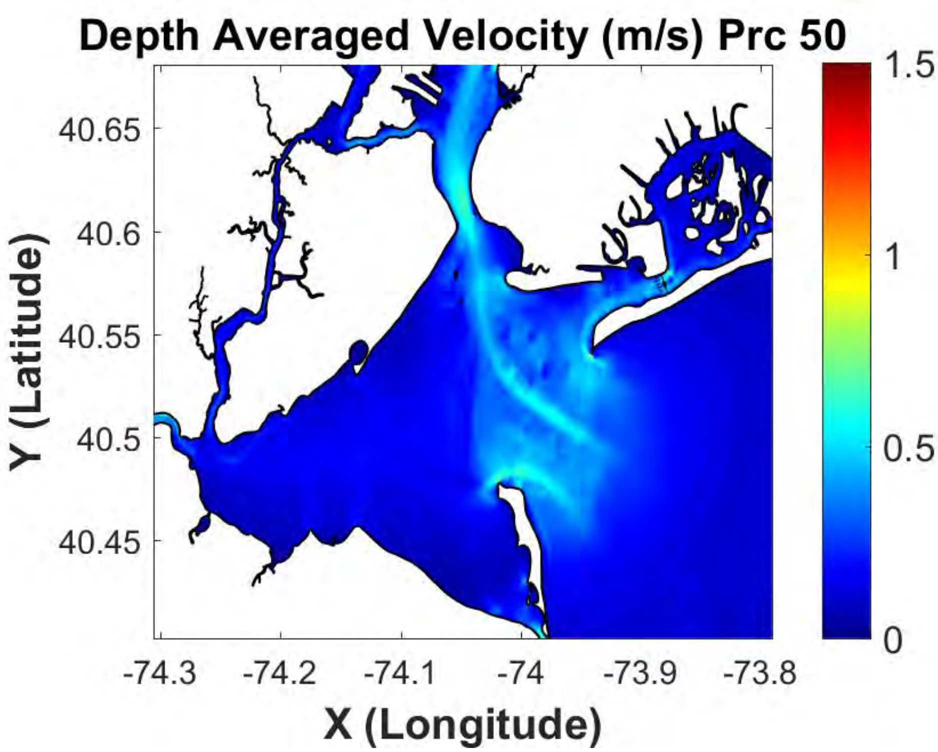
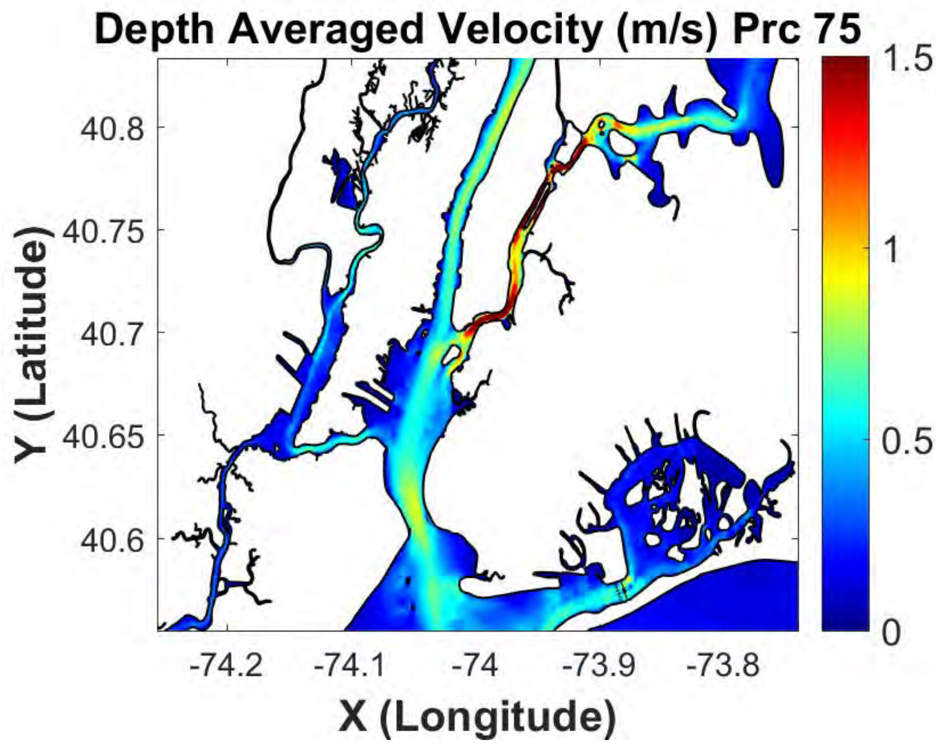


Figure 766. Alternative 4/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



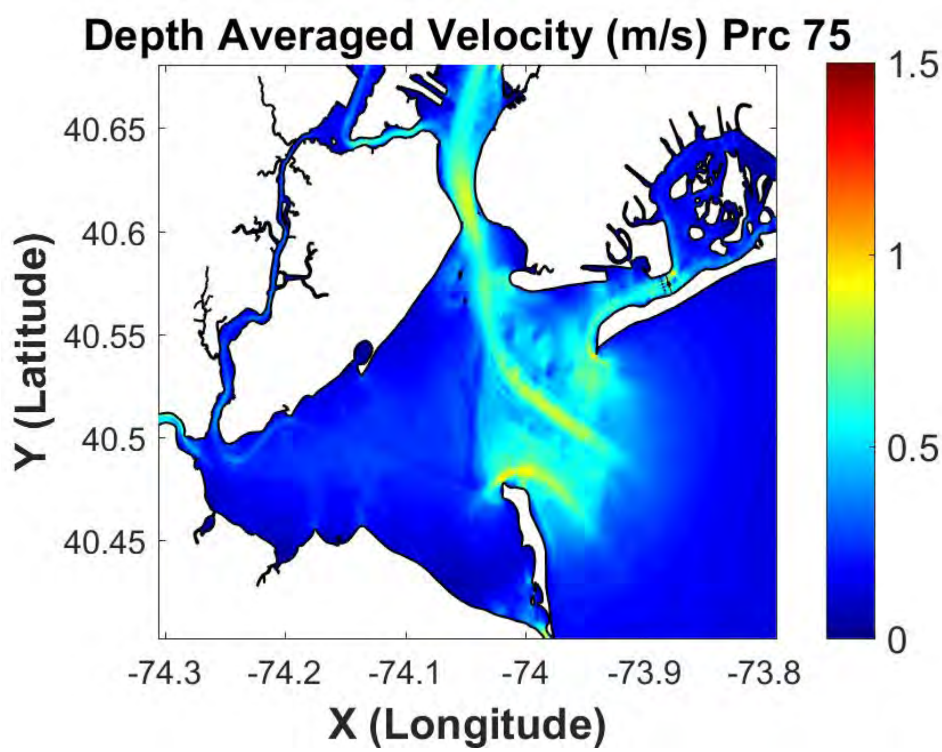


Figure 767. Alternative 4/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

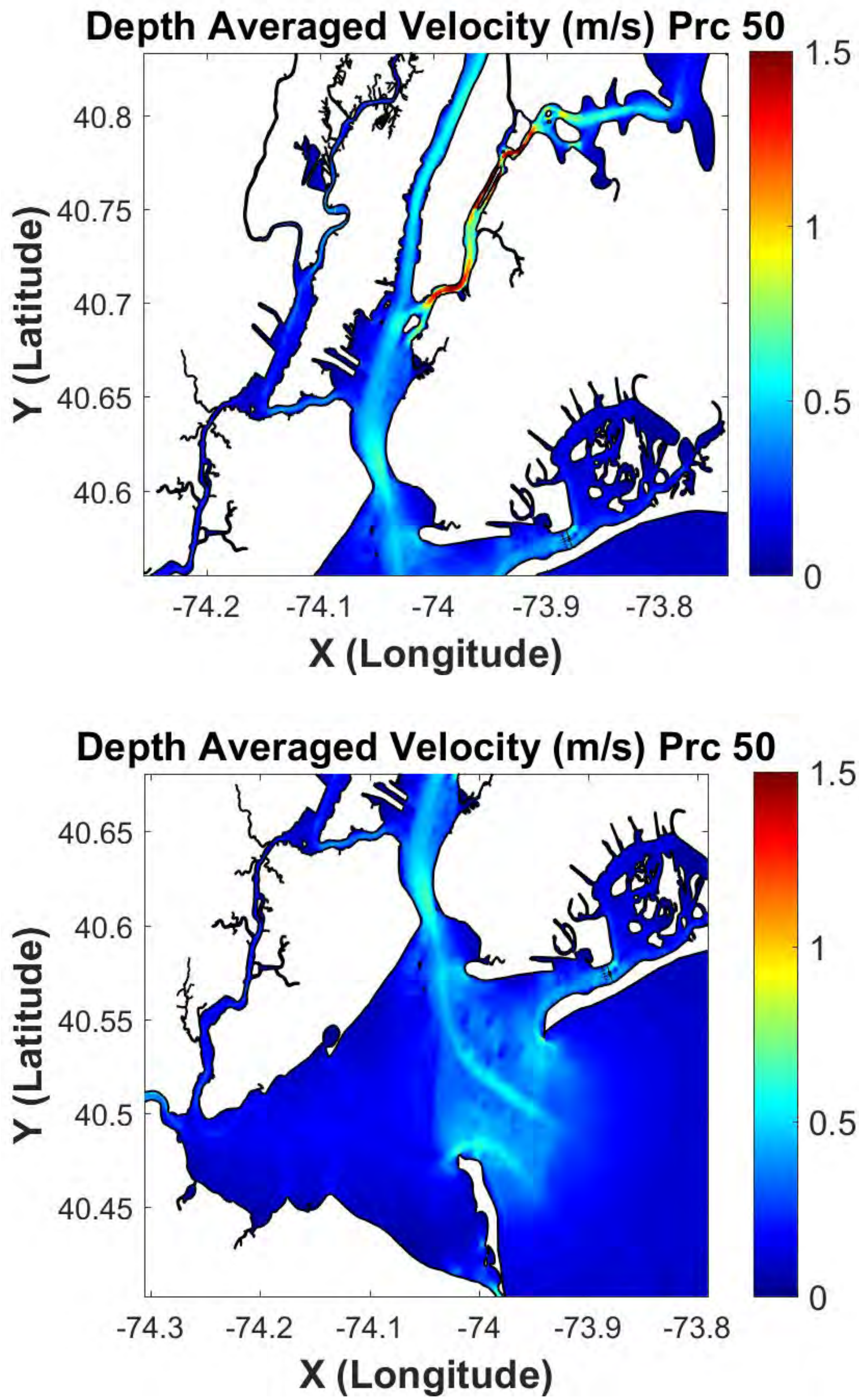
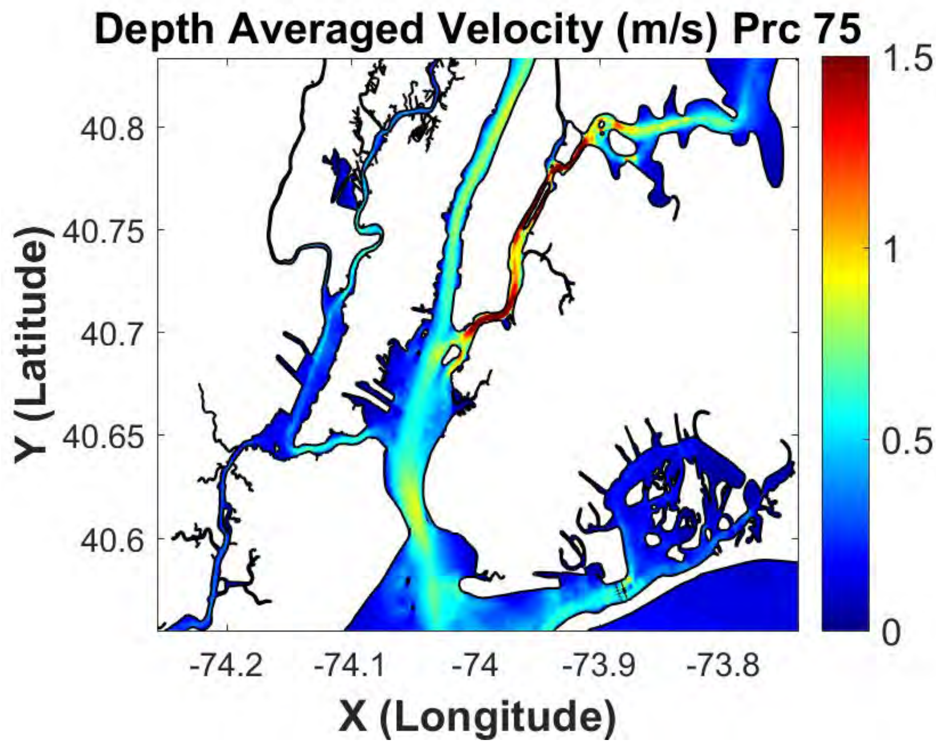


Figure 768. Alternative 4/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.



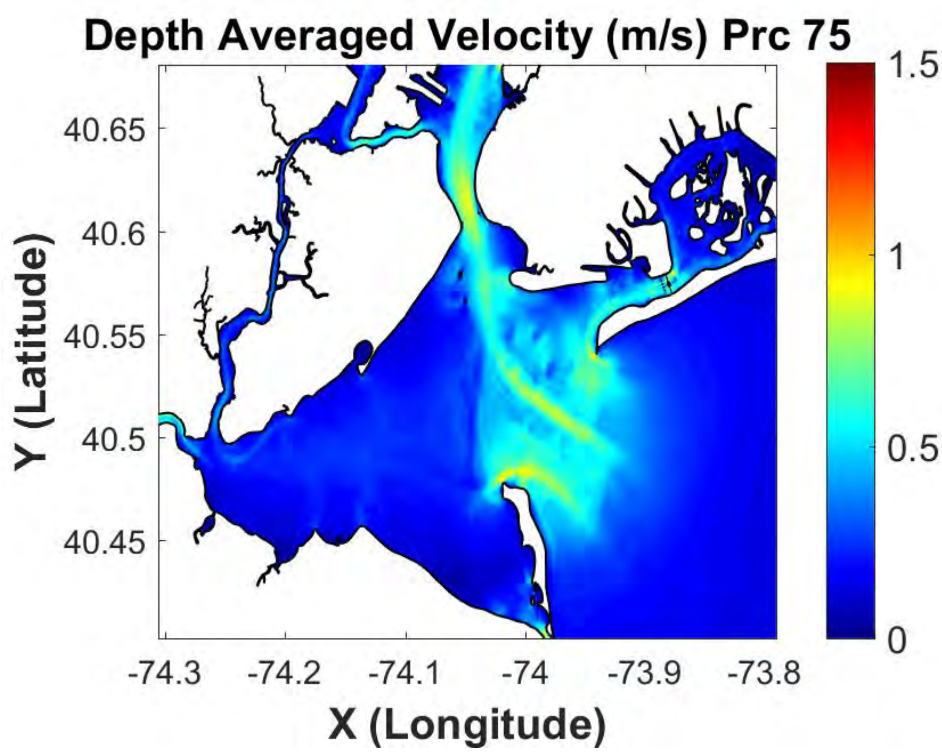
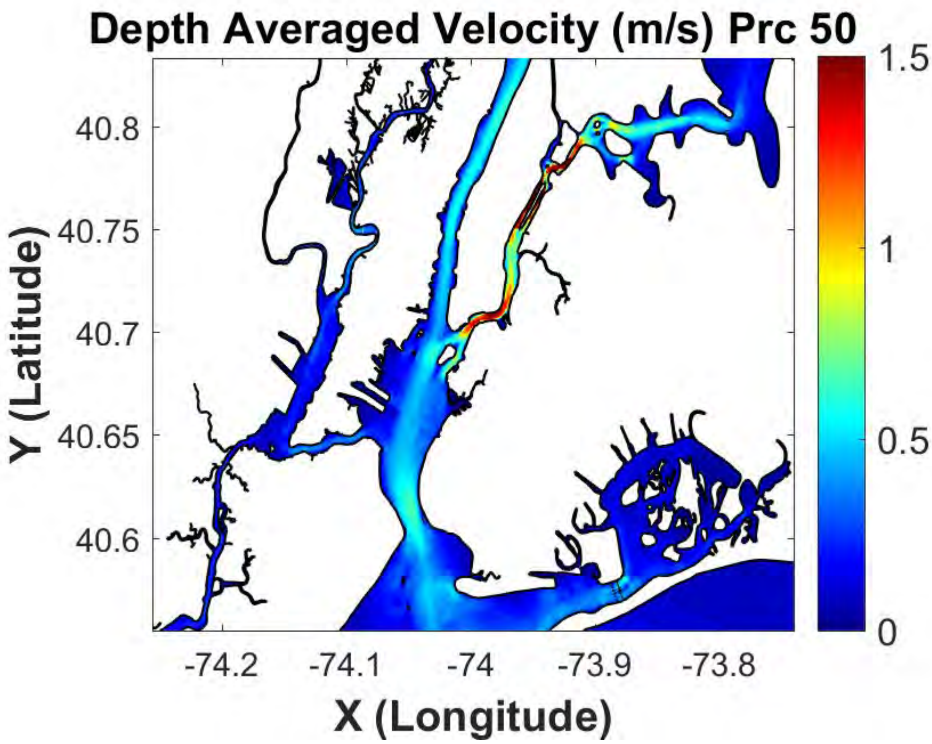


Figure 769. Alternative 4/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



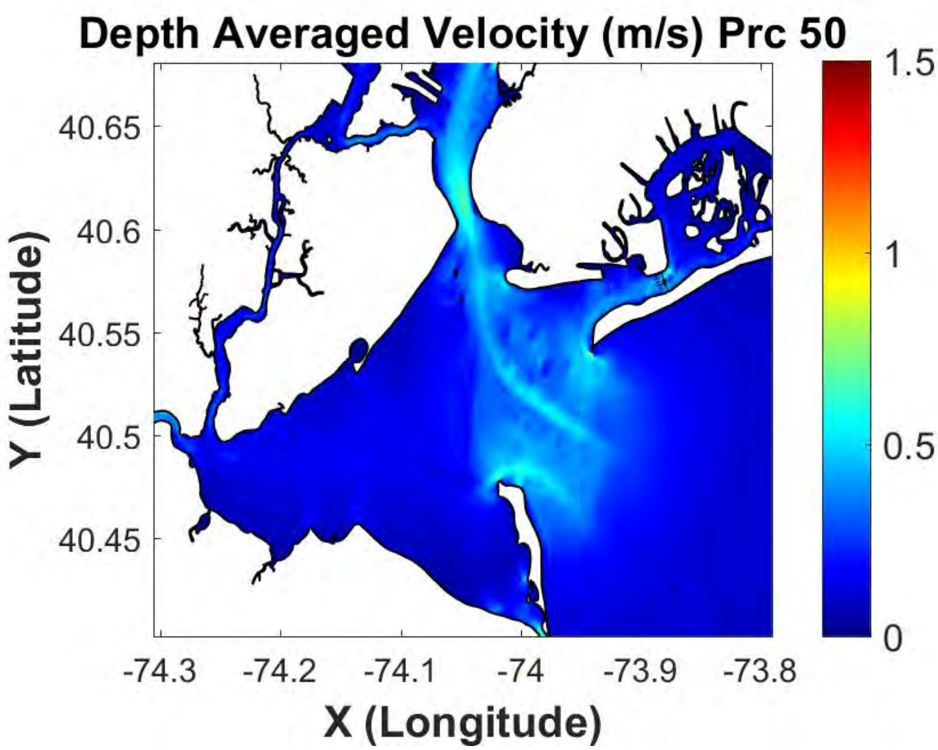


Figure 770. Alternative 4/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

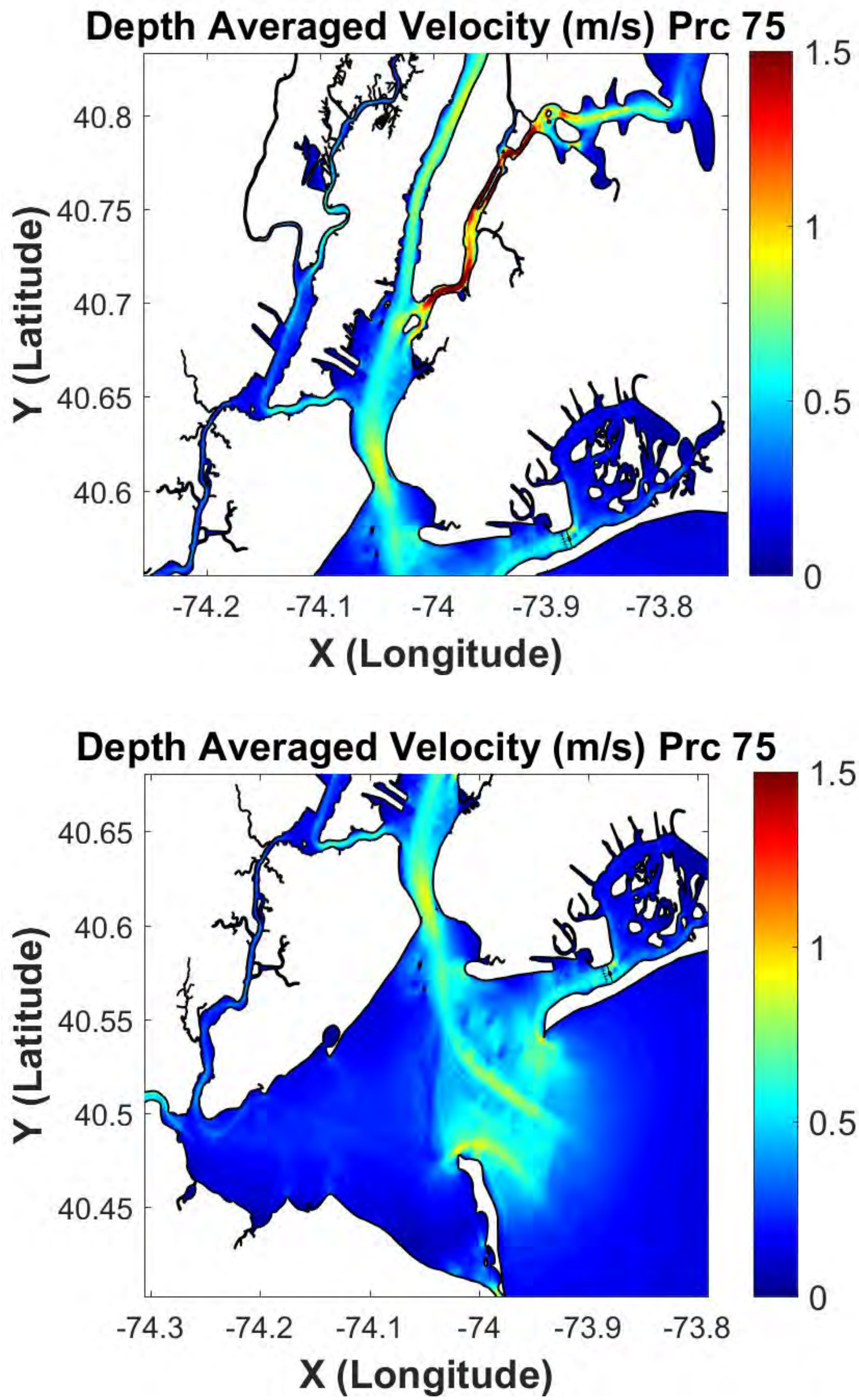


Figure 771. Alternative 4/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.

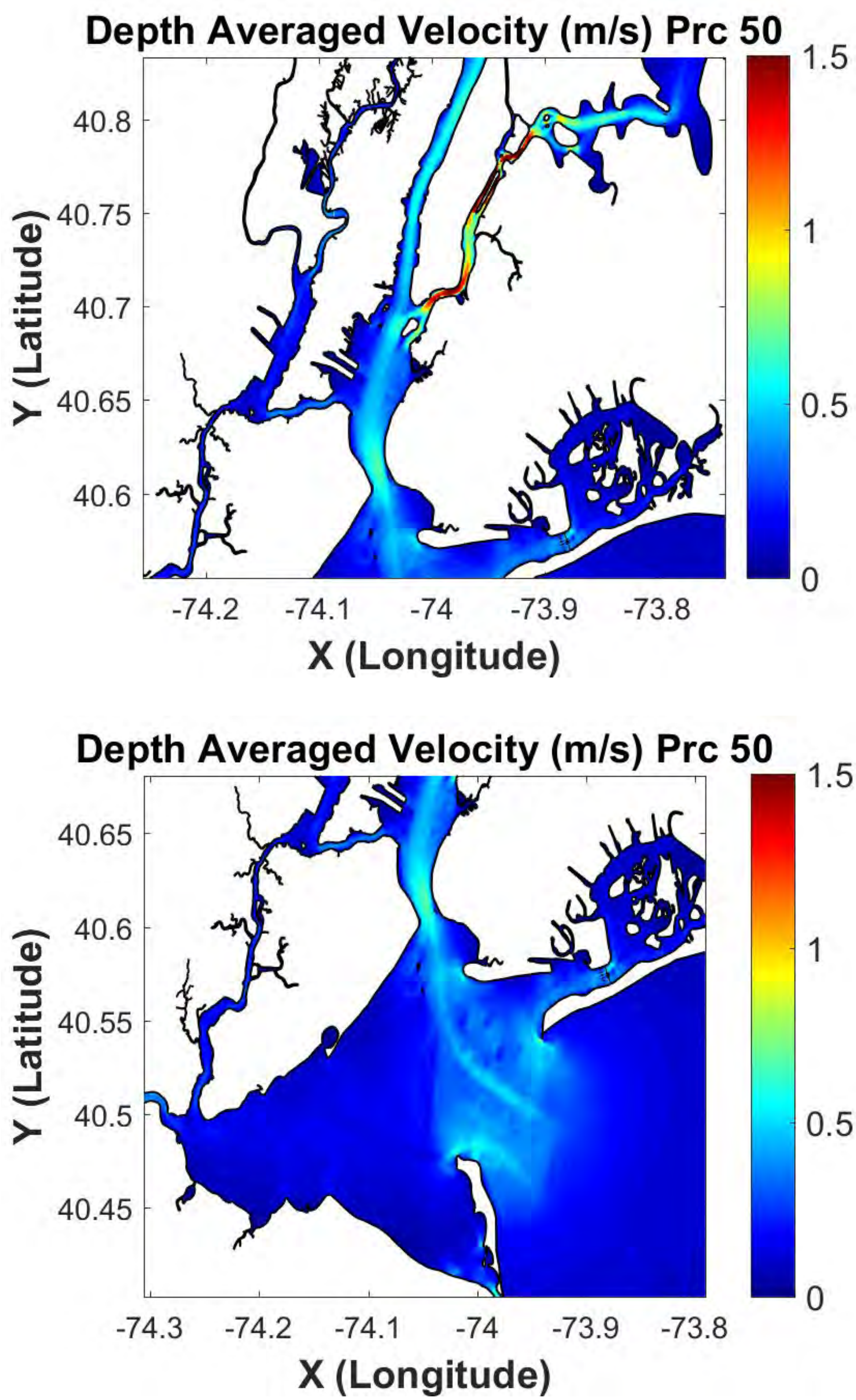


Figure 772. Alternative 4/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

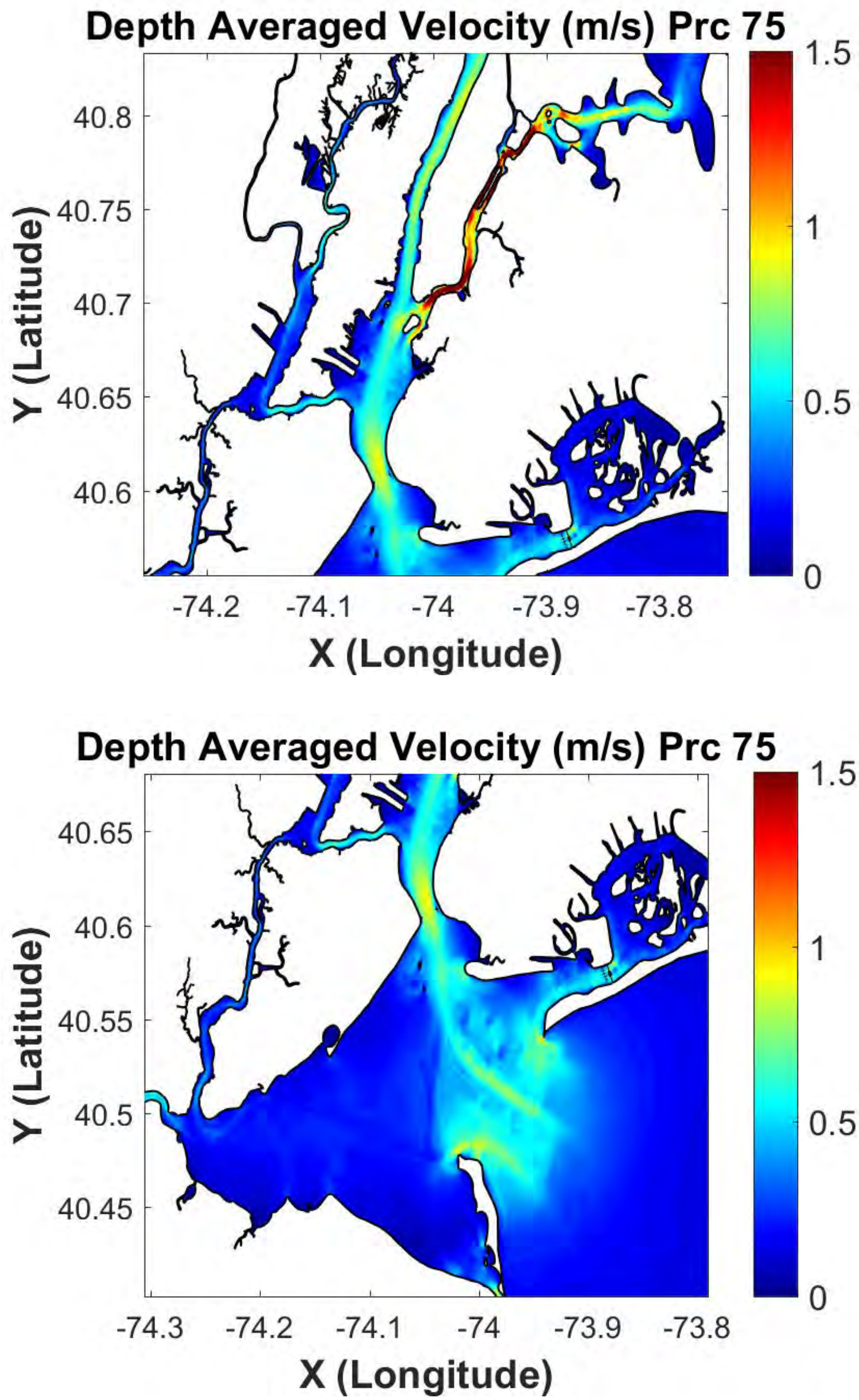
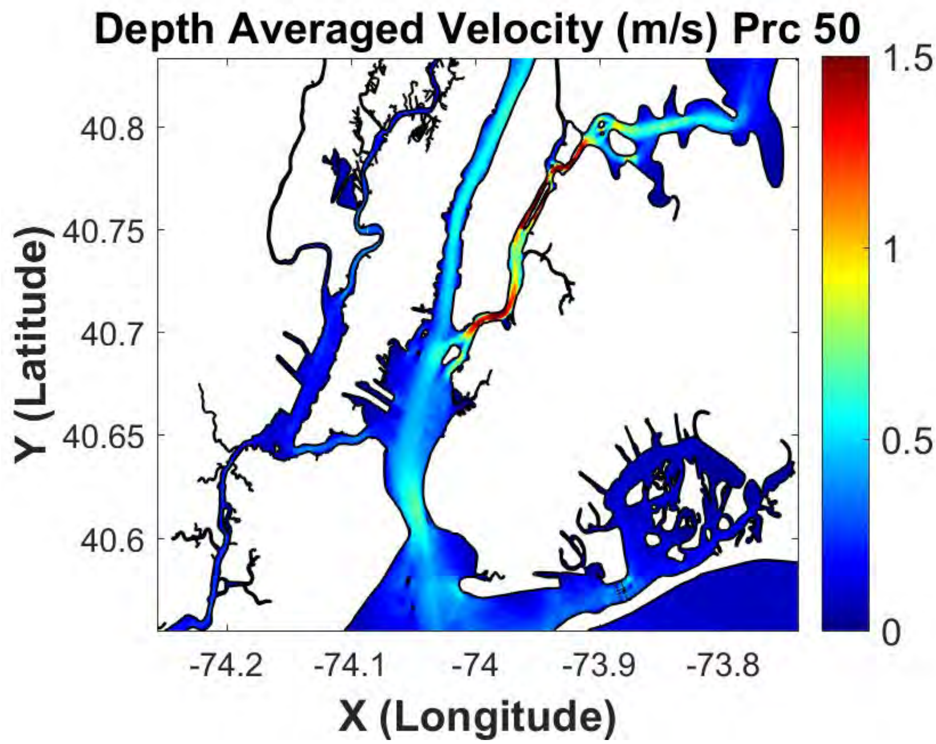


Figure 773. Alternative 4/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Depth Average Velocities.



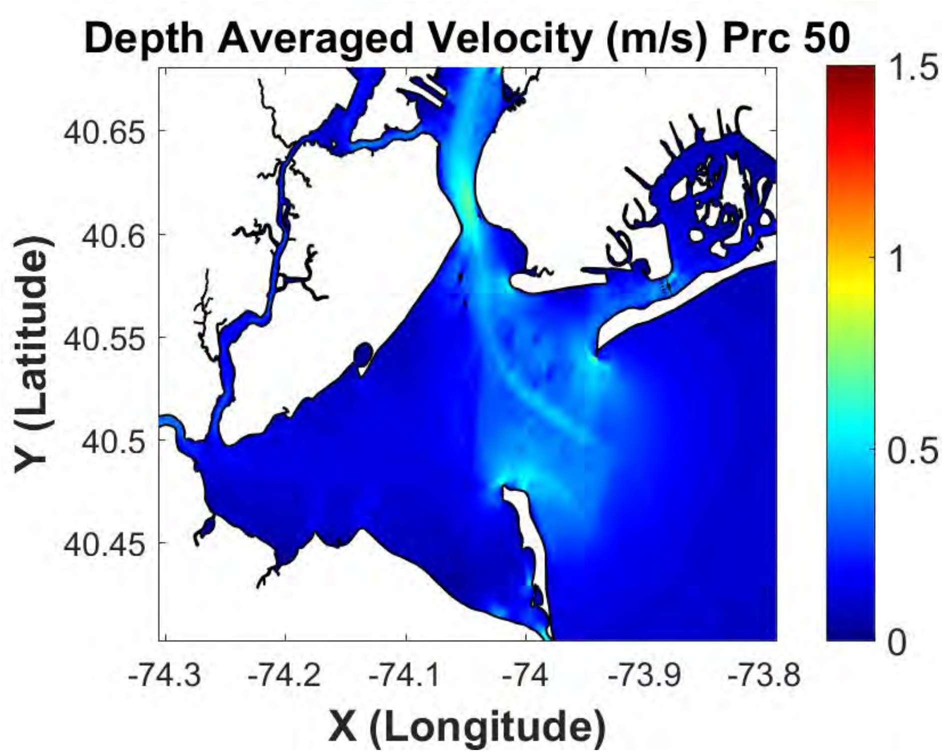
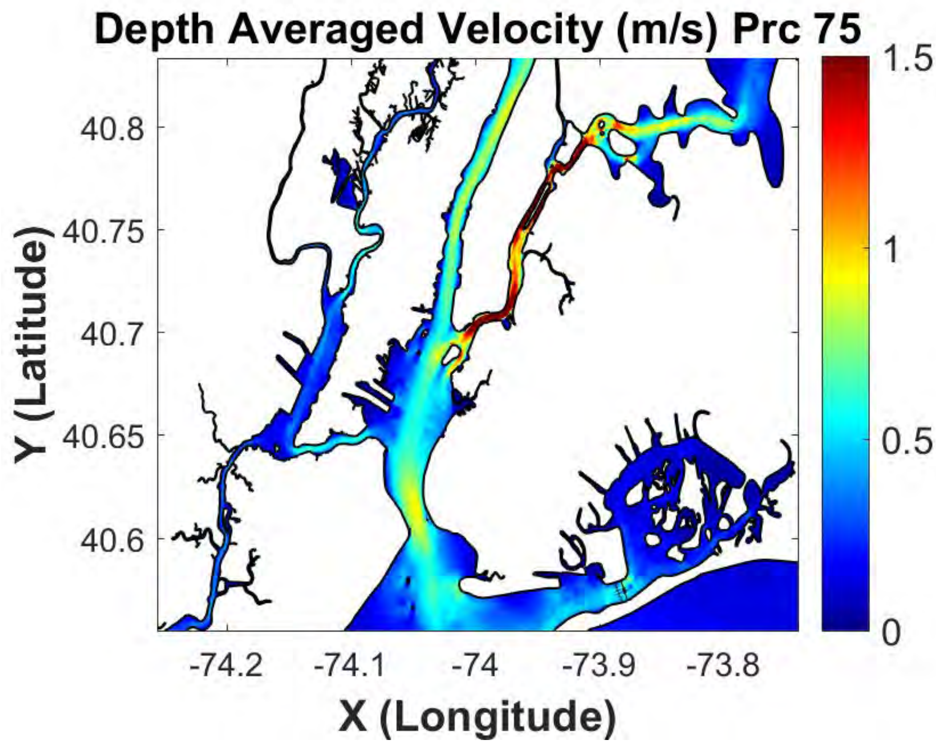
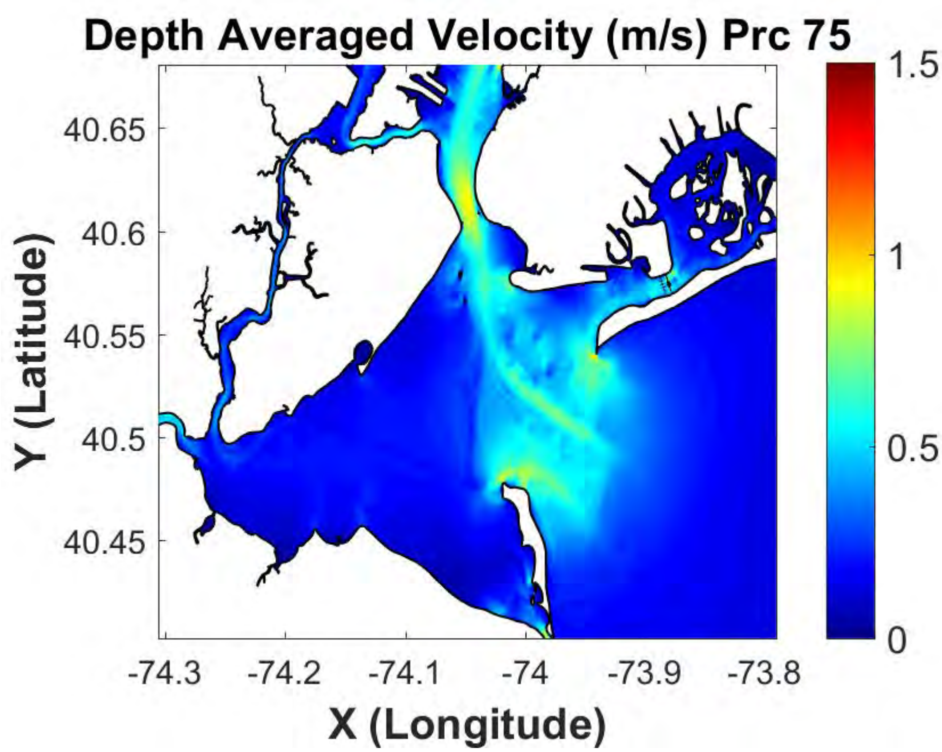


Figure 774. Alternative 4/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Depth Average Velocities.

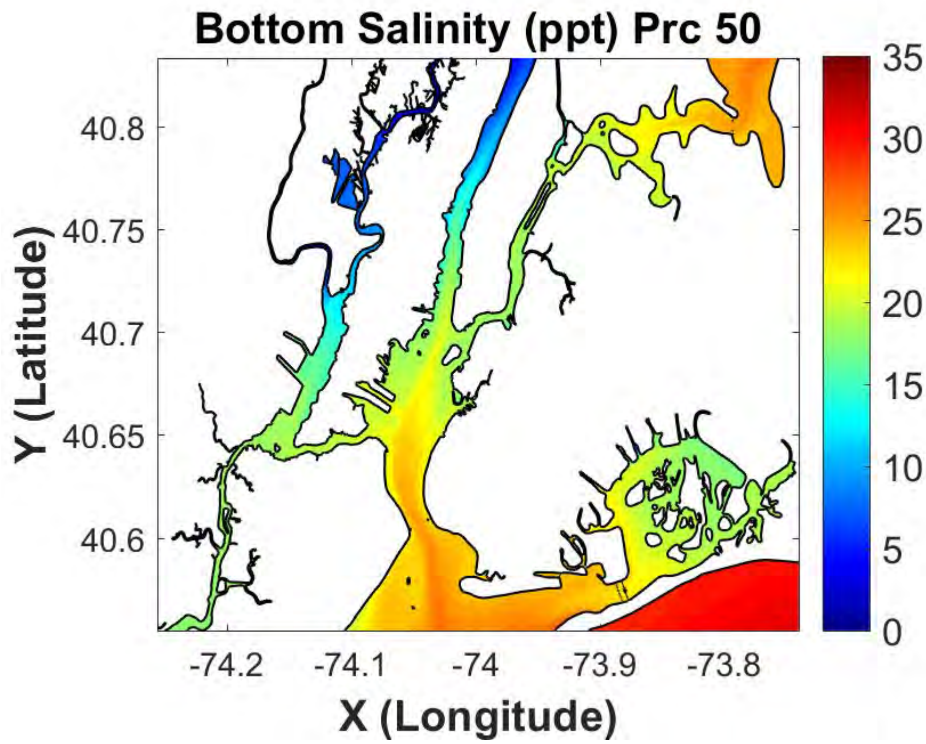




15.5.5 Spatial Salinity Percentiles

Spatial figures of the salinity percentiles for Alternative 4 for the 50th and 75th percentiles are provided in Figure 775 to Figure 786.

Figure 775. Alternative 4/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



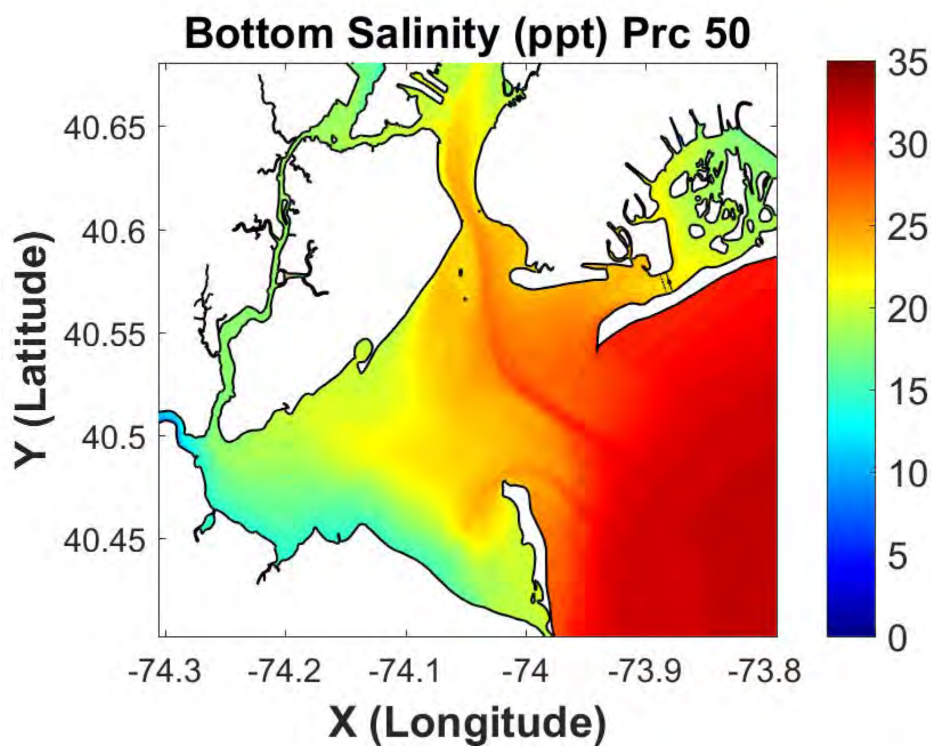


Figure 776. Alternative 4/Existing Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

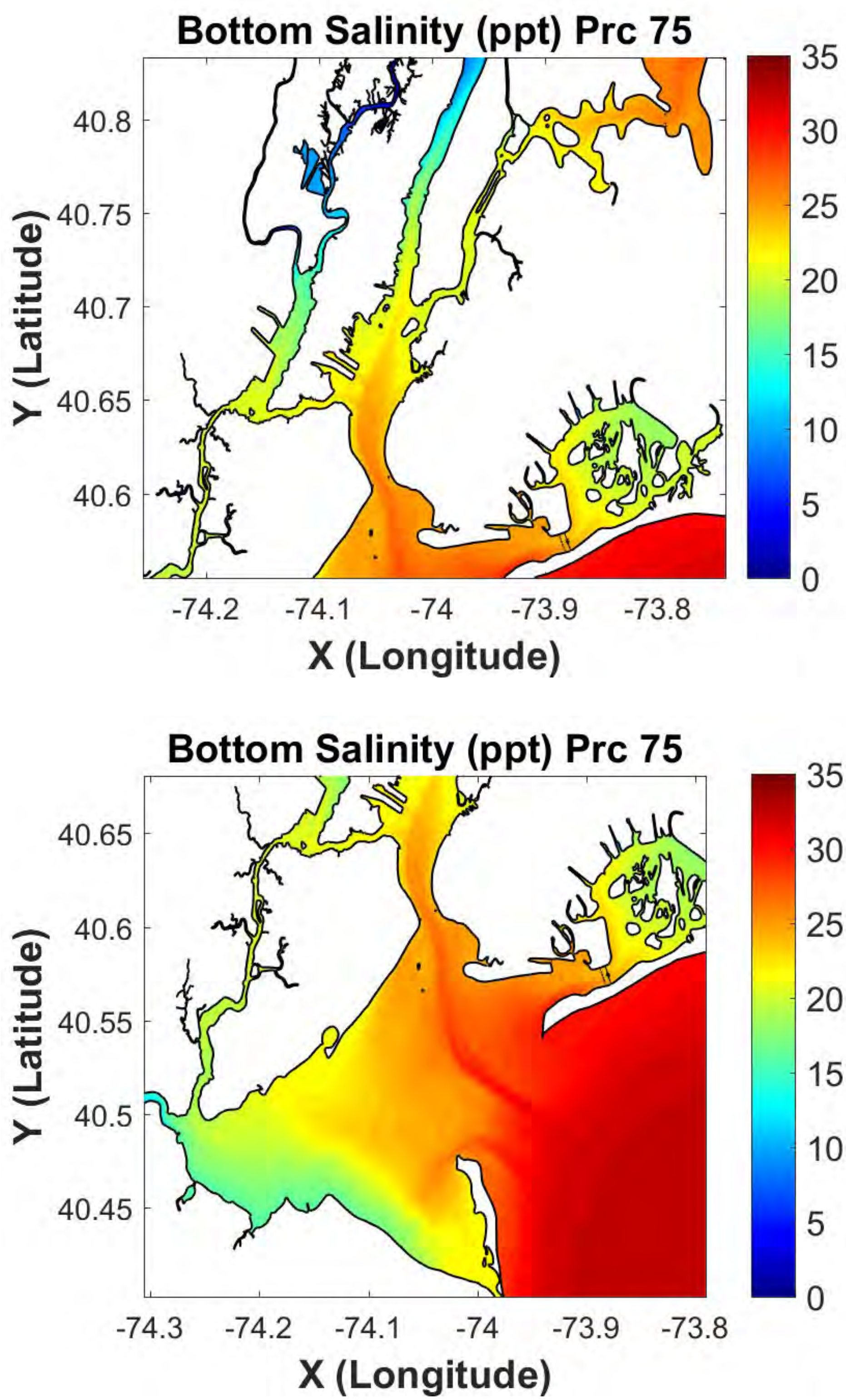


Figure 777. Alternative 4/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

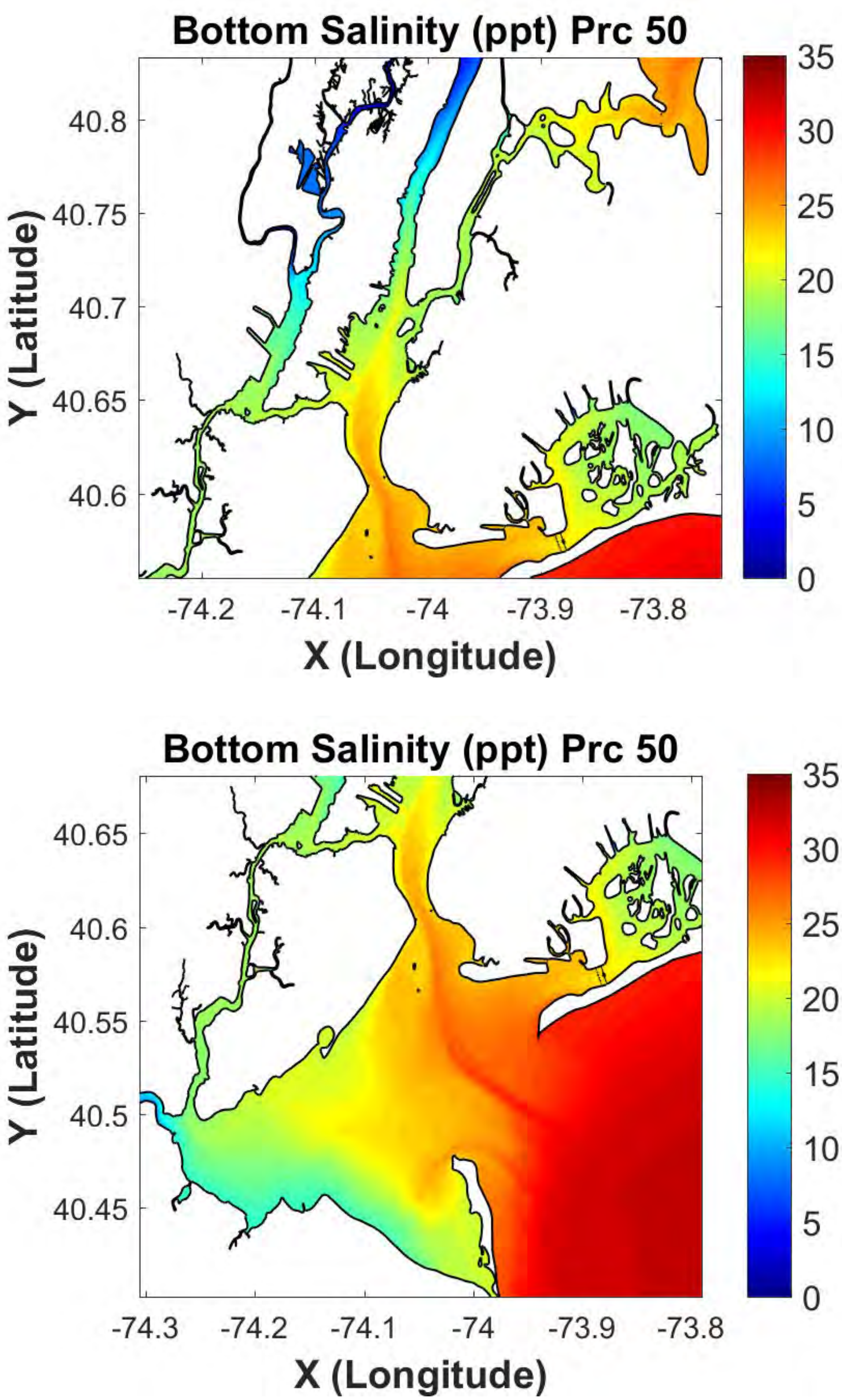
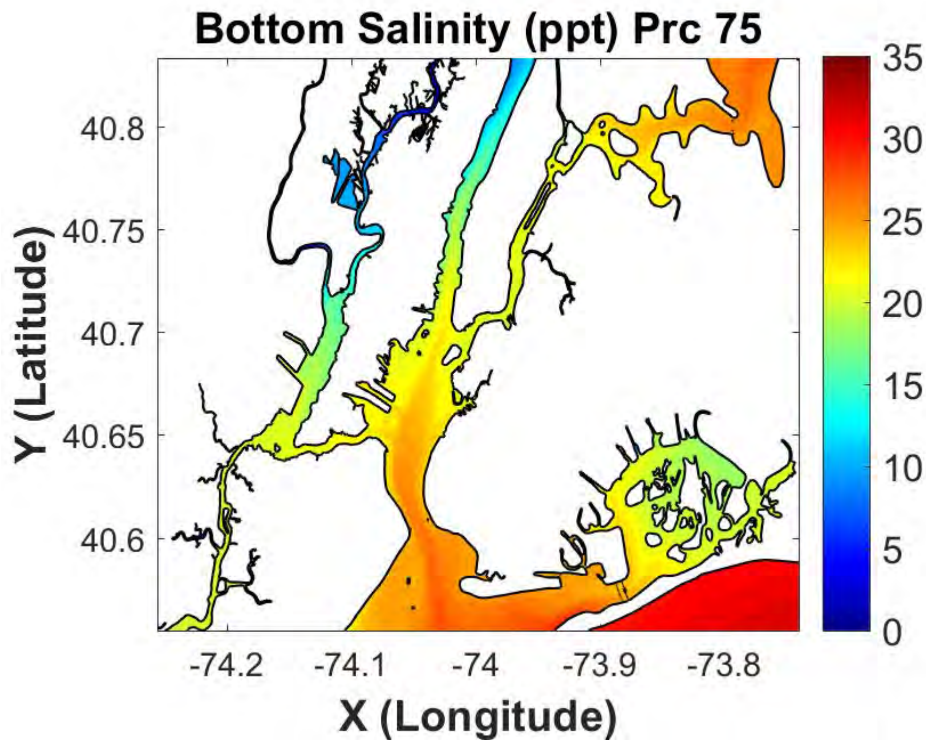


Figure 778. Alternative 4/0.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



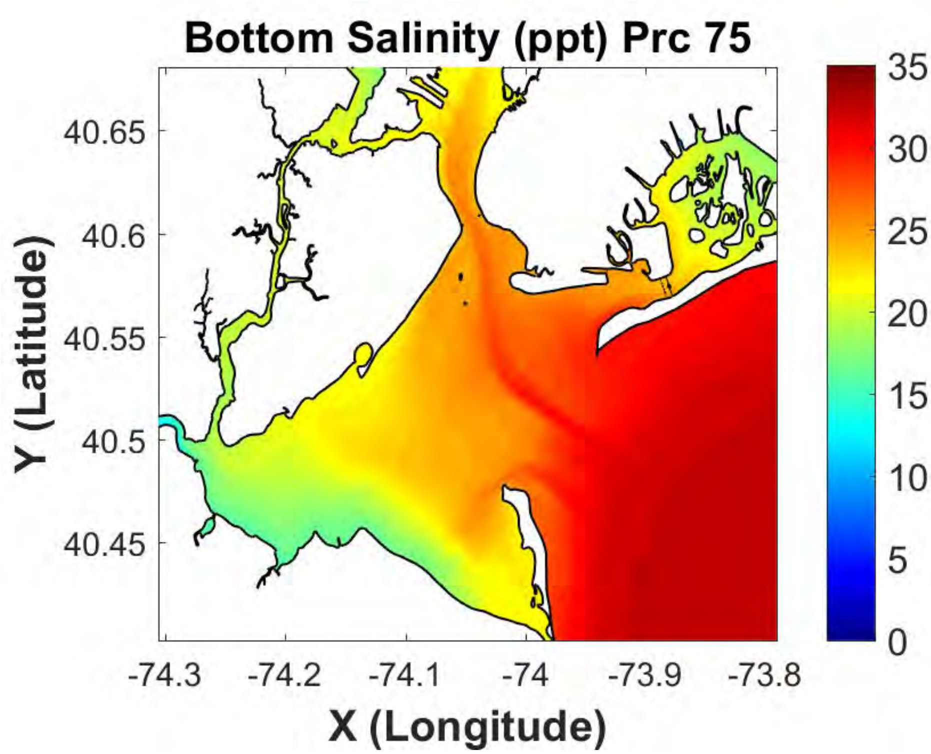


Figure 779. Alternative 4/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

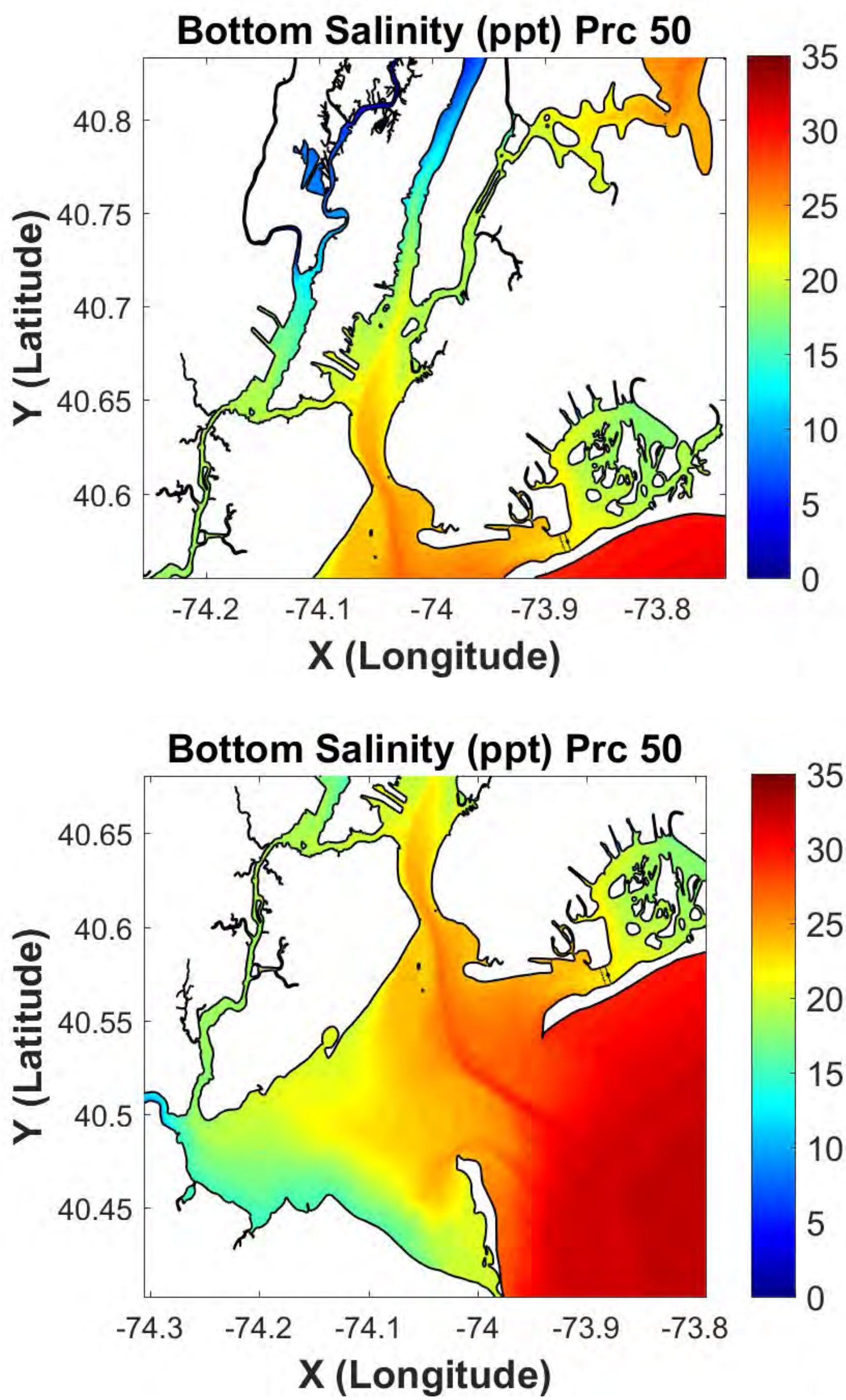


Figure 780. Alternative 4/1.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

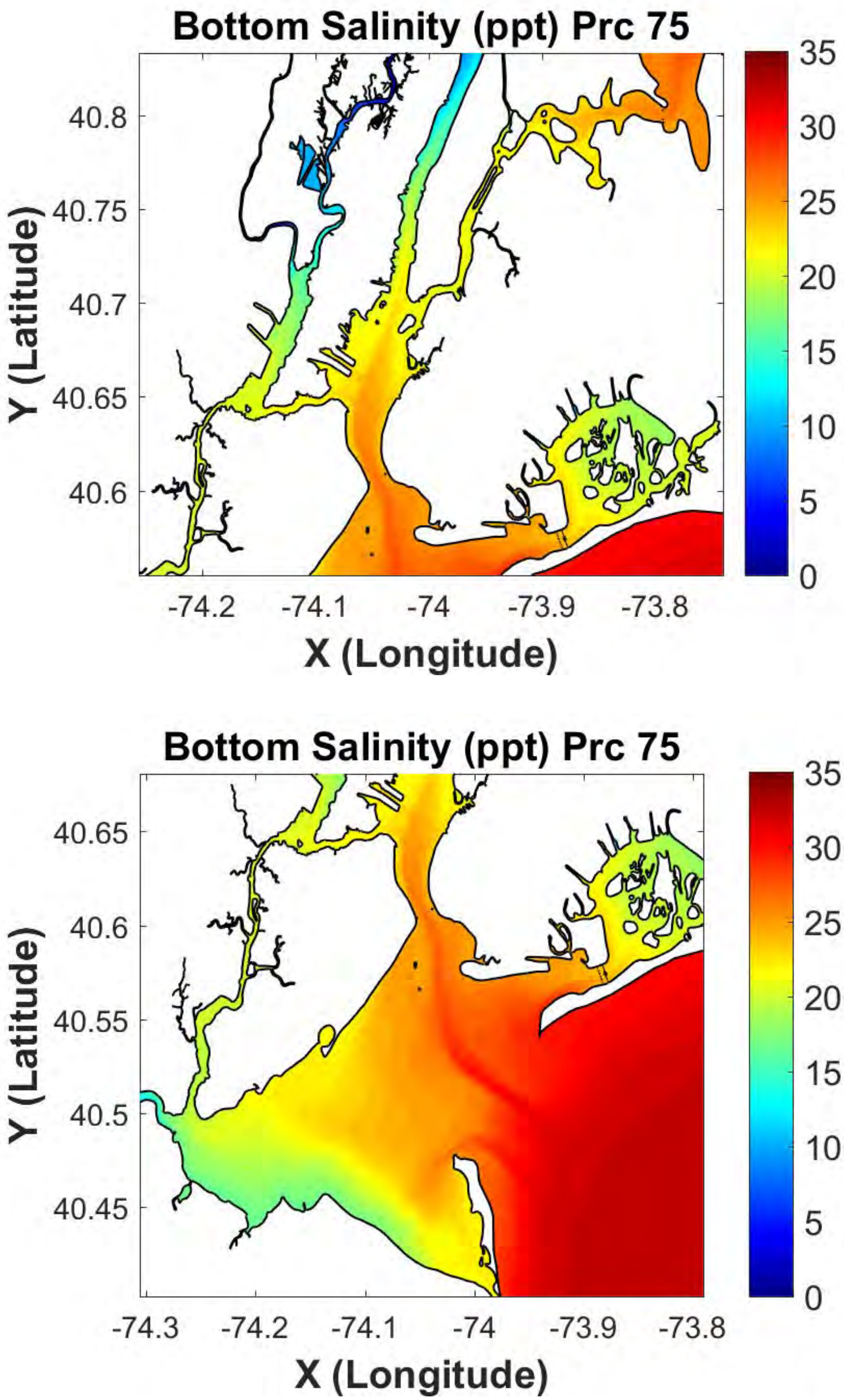


Figure 781. Alternative 4/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

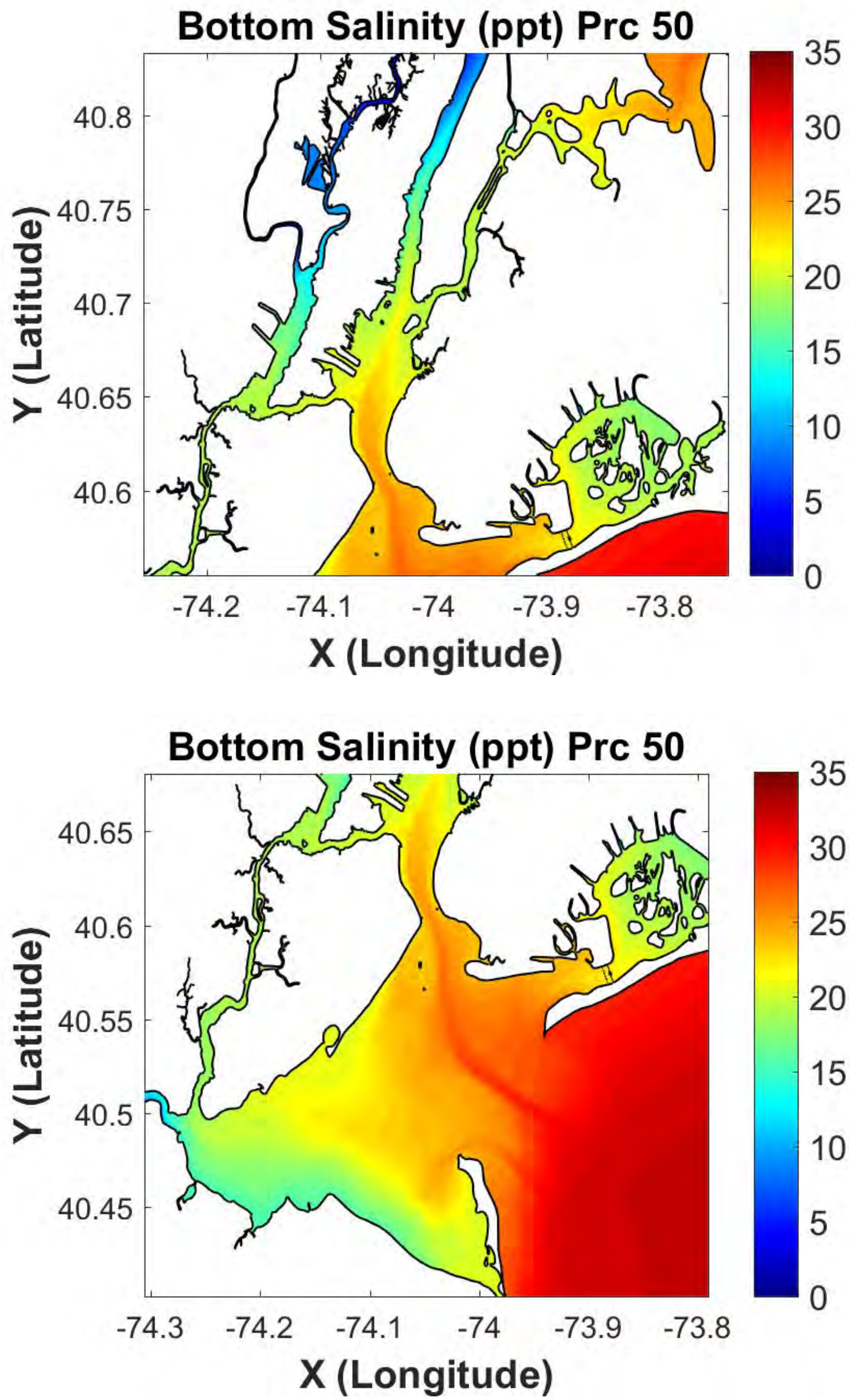
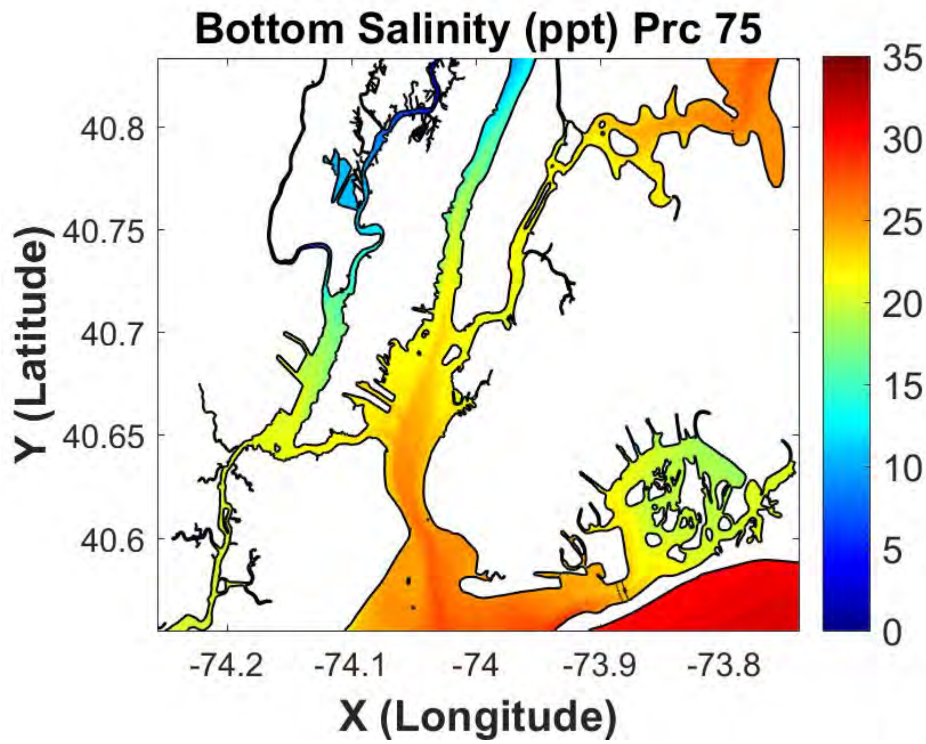


Figure 782. Alternative 4/2.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.



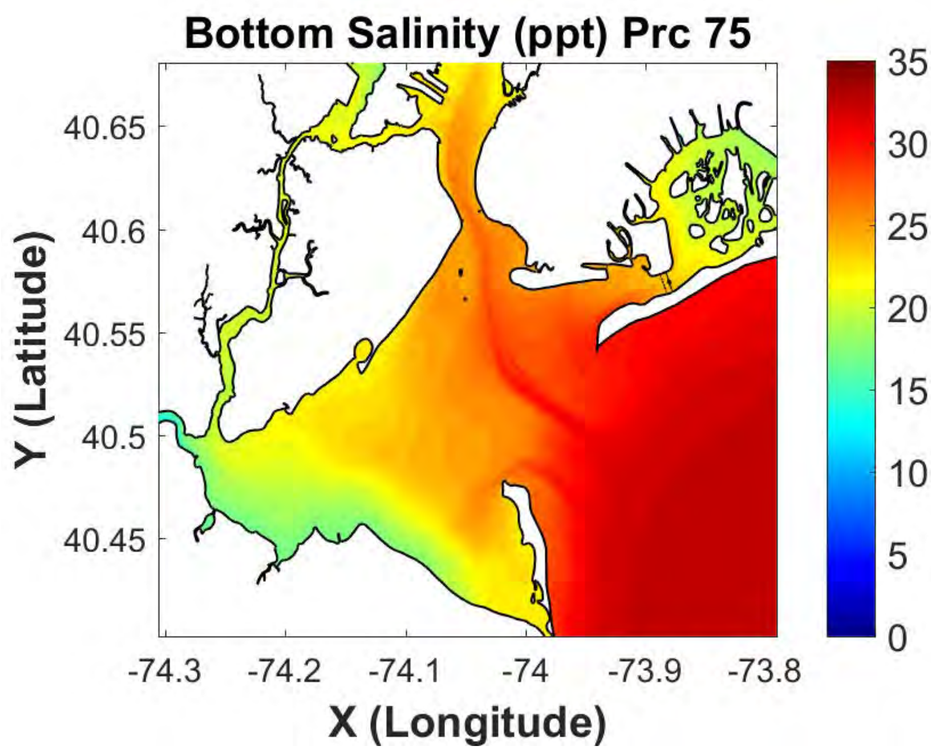
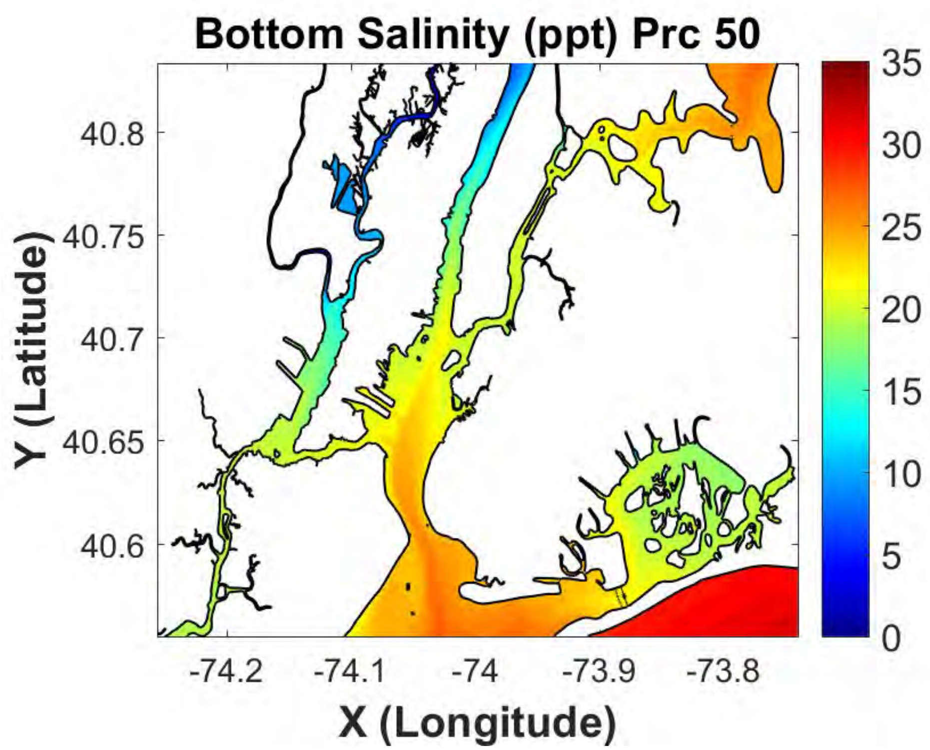


Figure 783. Alternative 4/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.



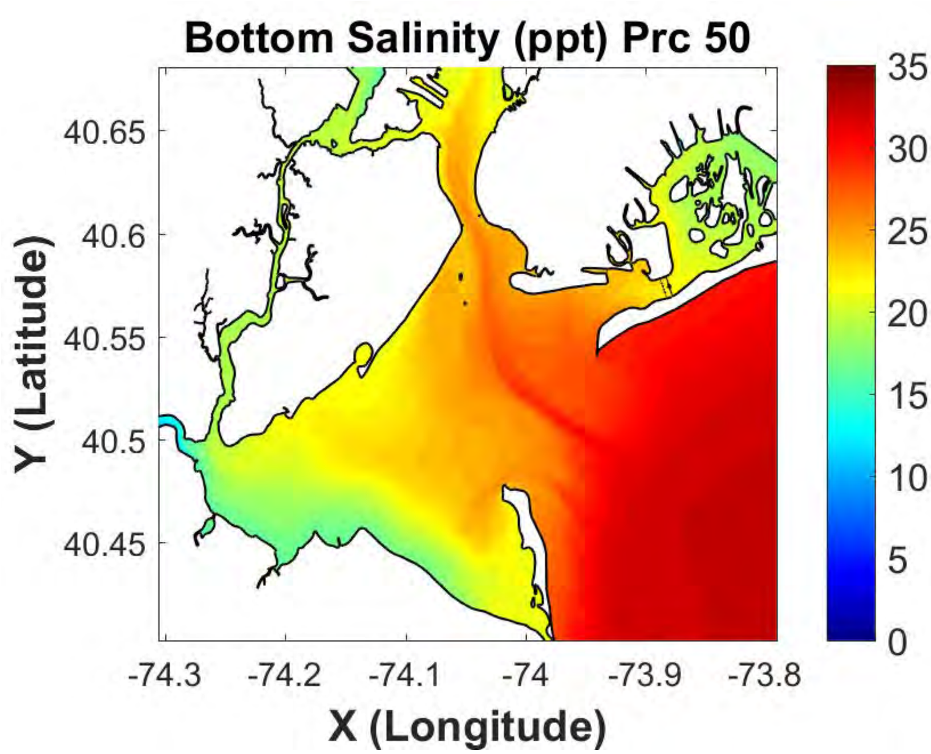


Figure 784. Alternative 4/4.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.

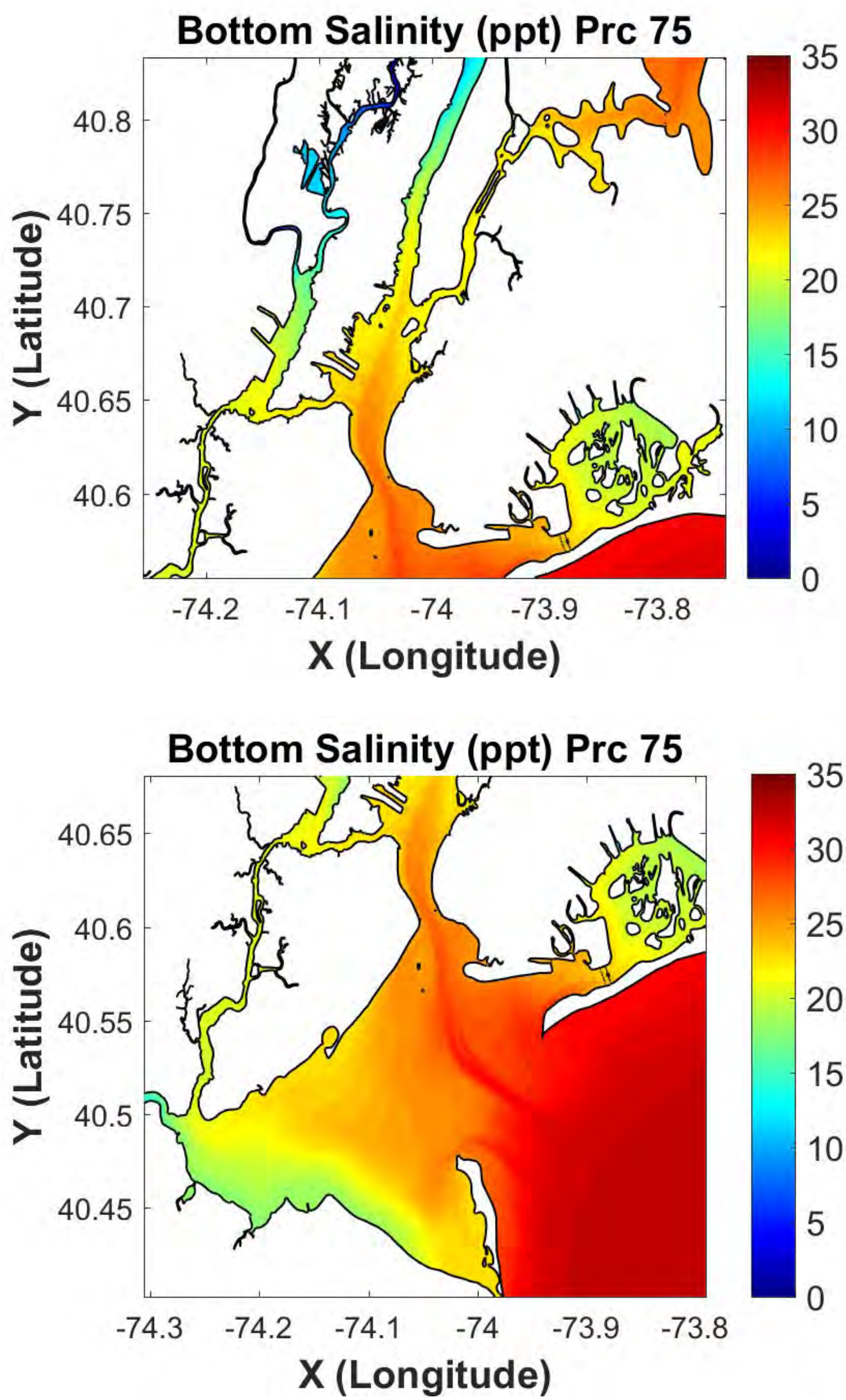


Figure 785. Alternative 4/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 50th Percentile Bottom Salinities.

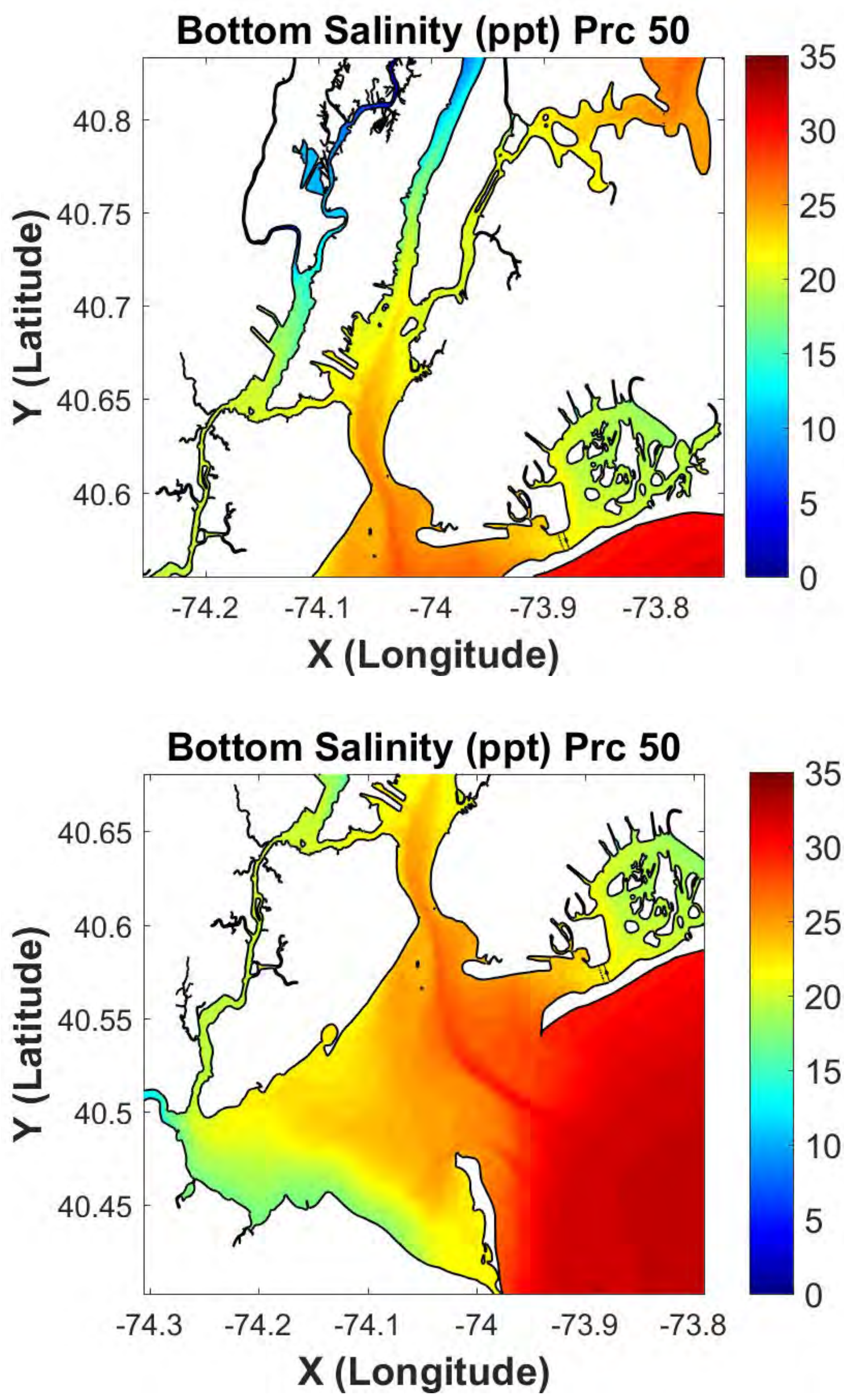
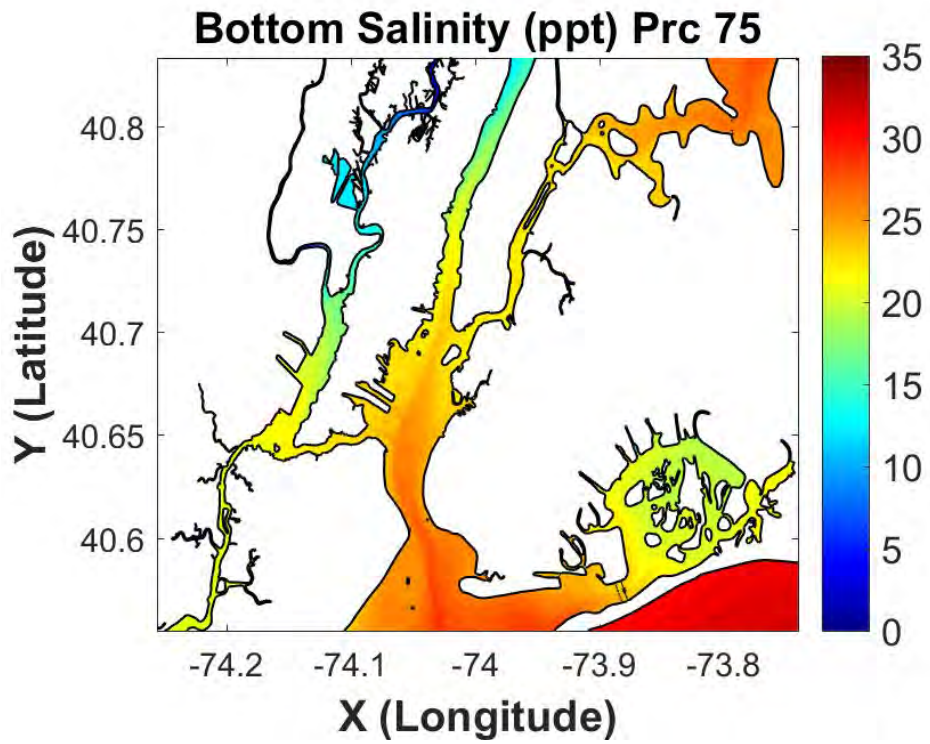
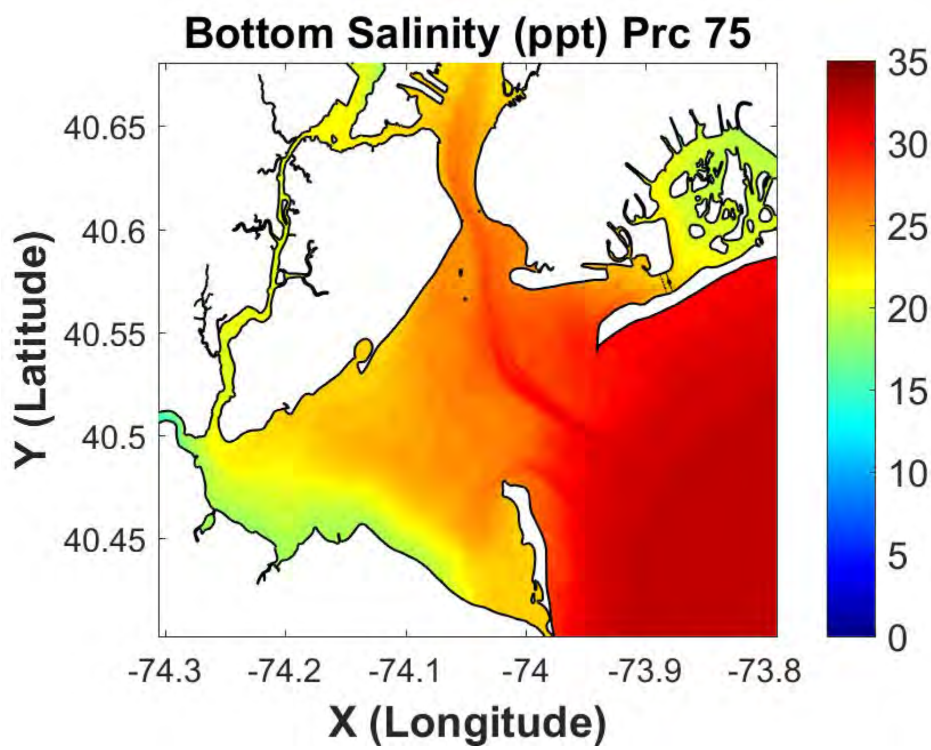


Figure 786. Alternative 4/6.46 ft Sea Level, Upper Bay (top) and Lower Bay (bottom) 75th Percentile Bottom Salinities.





15.5.6 Water Flux Analysis

Discharge percentiles for Alternative 4 for the previously shown locations (Figure 28) are provided in Figure 787 to Figure 790. These locations indicate increased tidal exchange for increasing water levels. Table 11 shows the mean flows for the various pathways and sea levels.

Figure 787. Alternative 4 Variation in Throgs Neck Discharges with sea level.

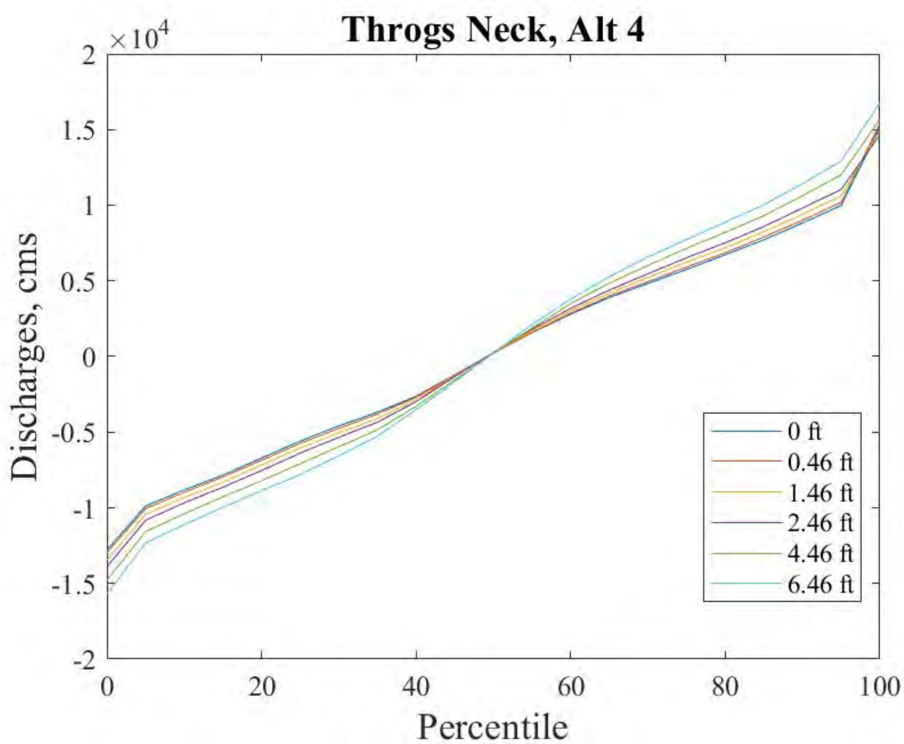


Figure 788. Alternative 4 Variation in Verrazano Narrows Discharges with sea level.

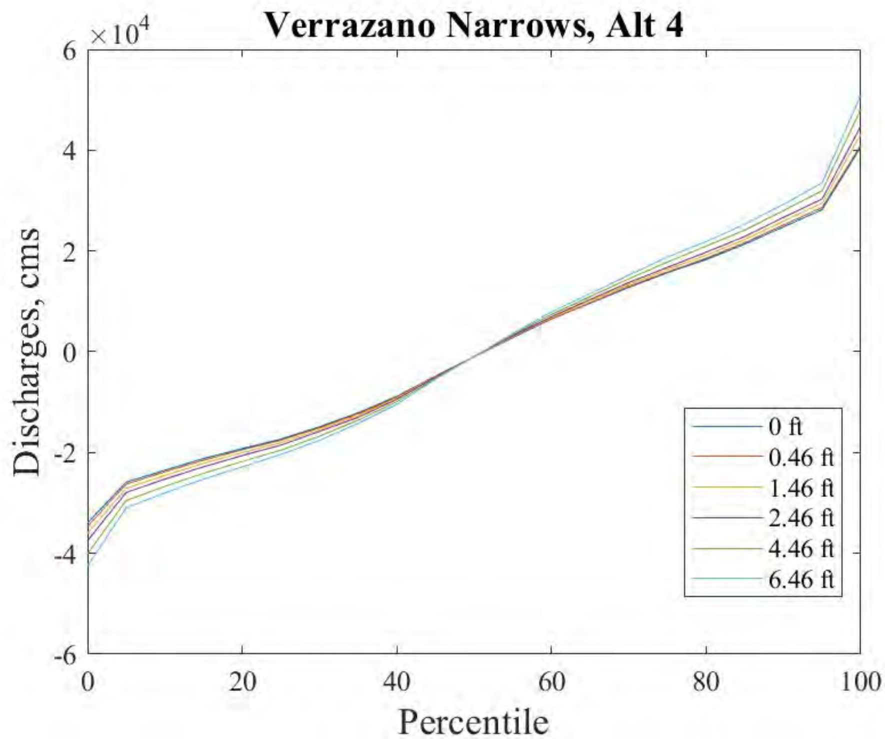


Figure 789. Alternative 4 Variation in Kill Van Kull Discharges with sea level.

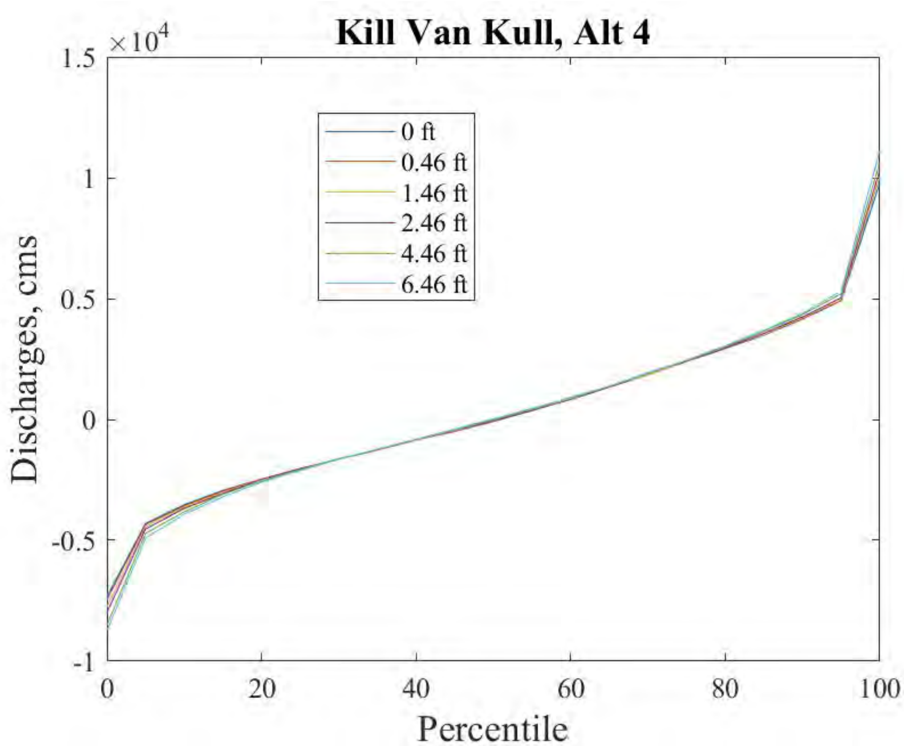


Figure 790. Alternative 4 Variation in Arthur Kill Discharges with sea level.

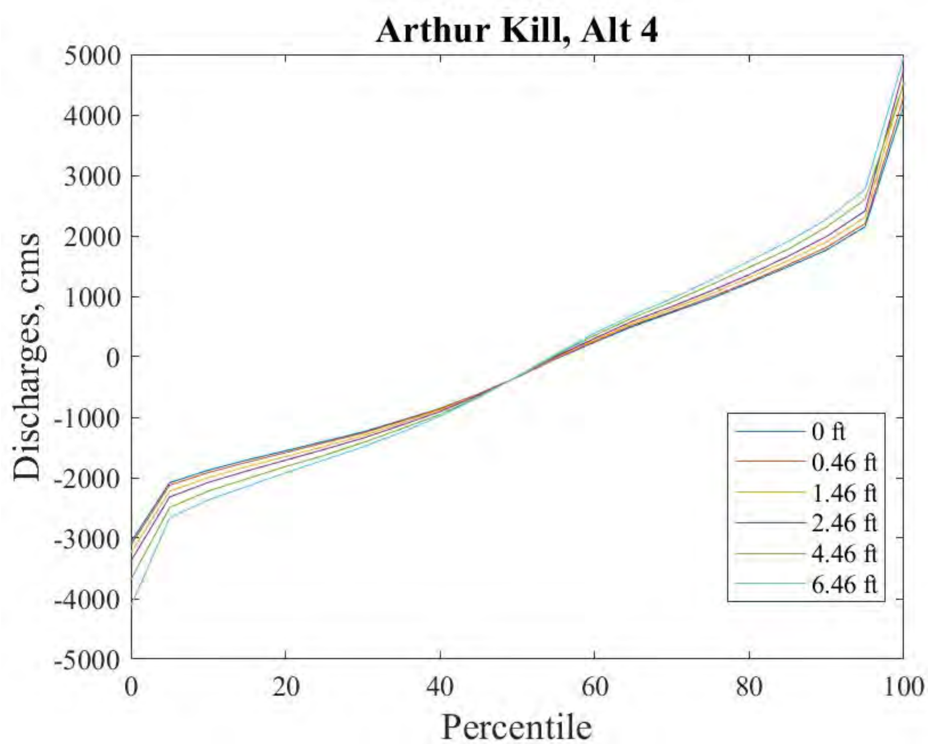


Table 11. Alternative 4, Sea Level Rise Impacts of Flows in CMS.

Location	0.0 ft. MSL	0.46 ft. MSL	1.46 ft. MSL	2.46 ft. MSL	4.46 ft. MSL	6.46 ft. MSL
Throgs Neck	81	83	87	91	100	117
Verrazano Narrows	-305	-306	-314	-320	-325	-345
Kill Van Kull	152	151	149	148	147	147
Arthur Kill	-179	-177	-176	-175	-173	-173

15.5.7 Tidal Prism Analysis

Tidal prisms were calculated, and a percentile analysis was performed to evaluate the impact of sea level rise on the tidal exchange. Figure 791 and Figure 792 show the tidal prism for all sea level values for the impounded areas for Alternative 4 previously shown in Figure 41. These results indicate higher sea level values result in higher tidal prisms and associated tidal exchange/mixing. The Jamaica Bay area behaves slightly different with lower tidal prism values for the lower percentiles and higher values for the higher percentiles.

Figure 791. Tidal Prism Percentile Analysis for Alternative 4 for Material 1.

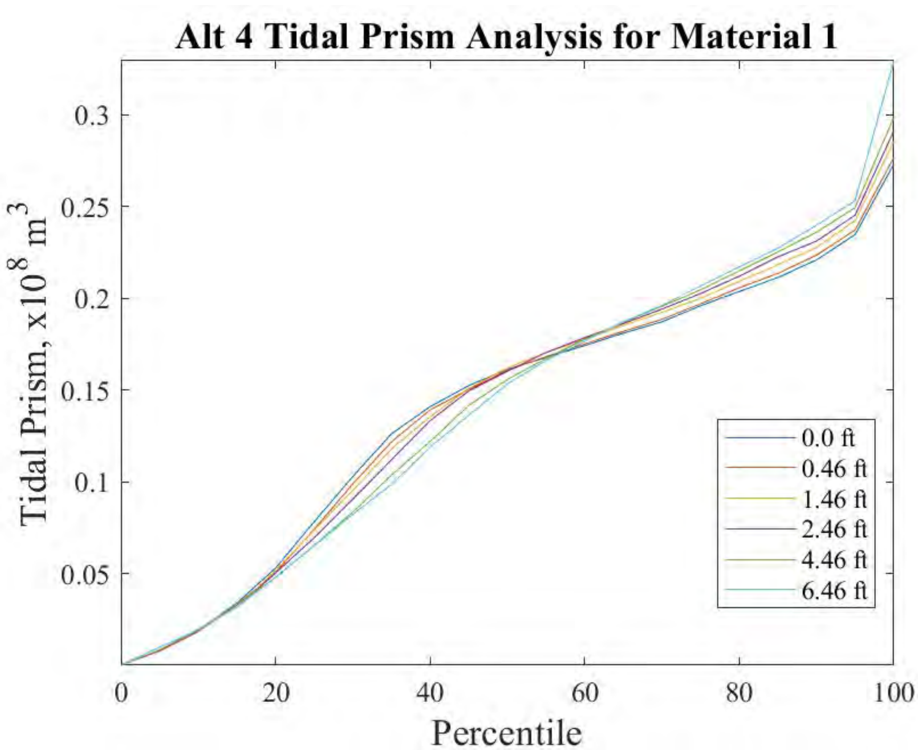


Figure 792. Tidal Prism Percentile Analysis for Alternative 4 for Material 2.