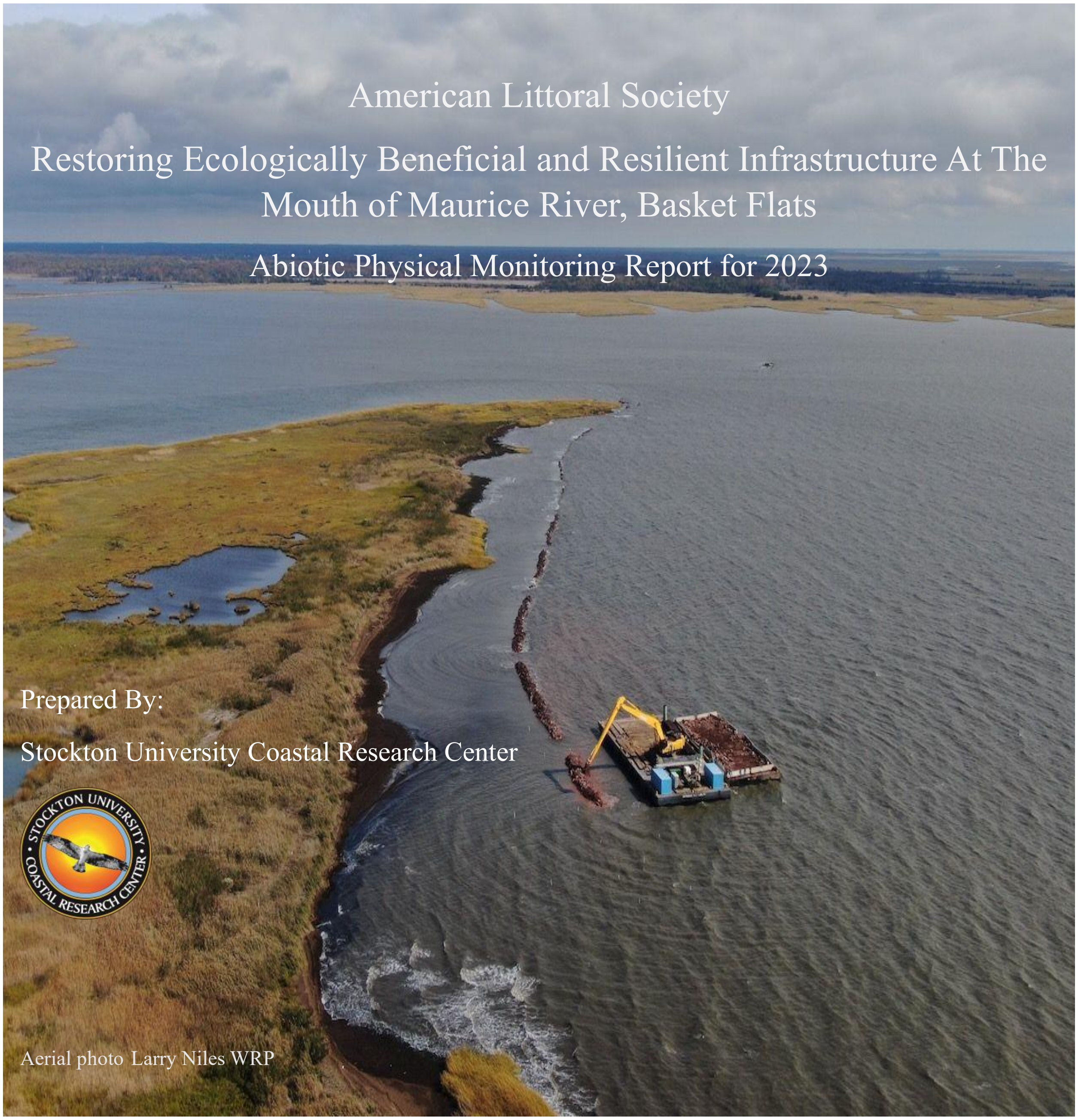
American Littoral Society

Restoring Ecologically Beneficial and Resilient Infrastructure At The Mouth of Maurice River, Basket Flats

Abiotic Physical Monitoring Report for 2023

Prepared By:

Stockton University Coastal Research Center



Aerial photo Larry Niles WRP

The Stockton University Coastal Research Center (CRC) Abiotic Monitoring Report was prepared for the American Littoral Society (ALS) Ecologically Beneficial and Resilient Infrastructure project at the mouth of Maurice River (Basket Flats), to determine annual post project performance, changes to the project shoreline, changes to the nearshore breakwater structures and changes to the adjacent project beaches and nearshore characteristics. The American Littoral Society was awarded National Fish and Wildlife Foundation (NFWF) National Coastal Resiliency Fund Grants to support design, permitting and project implementation to protect the mouth of the Maurice River. The objective is to aid in reducing risk of storm impacts at the inlet of the Maurice River and to its upriver communities. Project goals include enhancing storm and flooding protection, restoration of coastal habitats, creation of salt marsh through restoration actions, and the installation of 1,800 linear feet of hybrid breakwater reefs. The reefs are configured to aid in protection of marsh habitat, community infrastructure, support local improvements, and enhance economic opportunity.   The project was implemented and construction completed in fall 2022. The CRC conducted post project abiotic monitoring in 2022 and 2023, results are presented in this report.

Acknowledgments

The ALS Restoring Ecologically Beneficial and Resilient Infrastructure at the Mouth of the Maurice River project was funded through the NFWF National Coastal Resiliency Fund Grant Opportunity for implementation and monitoring. The project plan was developed by the Stockton University Coastal Research Center with Dr J. Richard Weggel Ph.D., P.E. Professor Emeritus in the Department of Civil, Architectural and Environmental Engineering, Drexel University collaborating with ACT Engineering, ALS and its partners. Project construction was guided and managed by ALS and its partners. Special thanks to the USFWS, NJ Division of Fish & Wildlife, Commercial Township and Maurice River Township for their cooperation and support. In memory of Dr J. Richard Weggel, the CRC and its staff would like to honor him for his dedication and contributions to this project and the coastal community.

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Cover photo: Aerial image of the Mouth of Maurice Basket Flats site during construction courtesy of Larry Niles, Wildlife Restoration Partnerships.

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Introduction

The American Littoral Society (ALS) was awarded NFWF National Coastal Resiliency Grant funds for the planning, implementation and monitoring of the Restoring Ecologically Beneficial and Resilient Infrastructure at the Mouth of the Maurice River project (Basket Flats). The Mouth of the Maurice River has suffered from decades of chronic erosion and loss of the surrounding marshes, in response the navigation channel has migrated over time since the 1950s. Basket Flats is one of those exposed marshes, a peninsula feature in Commercial Township that in 1985 still extended 4,000 feet east across the mouth of the Maurice River providing significant protection and shelter for the upstream marshes and communities. Erosional forces have reduced the length by 2,000 feet from 1985 to 2021 and completely exposed the NW reach marsh which has now been converted to open water to the Matts Landing Road dike. Continued loss of Basket Flats would expose the community of Bivalve and Shell Pile to direct bay wave climate impacts.

Baskett Flats and the Mouth of the Maurice River are subject to wind waves generated in the Delaware Bay from a range of directions. However, the longest wind fetches the over-water to generate waves is to the south. This direction makes the region vulnerable to summer storms and tropical system with waves that typically approach the shoreline from the south. Therefore, further erosion of Basket Flats would result in exposing the town of Bivalve to periodic relatively large waves and potential infrastructure damage.

Figure 1 shows a portion of the USGS Port Norris quadrangle map from 1956 showing conditions at the mouth of the Maurice River. Figure 2 is an aerial image from 2010 that shows the changes in the navigational channel and Basket Flats. During this period Fowlers Island had virtually disappeared, and Basket Flat had eroded significantly. As Fowlers Island and Basket Flats have eroded the navigation channel has migrated. Fowlers Island was once an extension of East Point that extended west into the mouth of the river as this feature eroded and eventually breached on the interior side Fowlers Island was formed. The breach exposed the southeast end of Basket Flats to open water and as Fowlers Island continued to erode the river mouth widened, reconfiguring the navigation channel and further exposure of the interior marsh to direct wave impacts.

Figure 1. 1956 Quad Map of Mouth of Maurice River

Figure 2. 2010 Aerial Image of Mouth of Maurice River

Initial physical condition studies at the Mouth of the Maurice River were conducted which included wind and wave climate, bathymetry and shore-normal beach profiles for an engineering study. The engineering study was conducted to determine a recommended program to provide enhanced shore protection at Basket Flats and restore some of the marsh area lost. Recommended design was for construction of a stone revetment at the easterly end of Basket Flats and a series of nearshore detached breakwater structures along the southerly shore of Basket Flats to protect the marsh and shoreline from further erosion.

Pre-Project beach conditions were chronically erosional with the shoreline and marsh edge subject to frequent waves and storm overwash with severe flooding combining to jeopardize existing community infrastructure and the ecology in the region. Planned activities to preserve and restore the shoreline and improve ecological function include installation of a series of nine detached stone breakwater reefs designed to attenuate the local wave climate and reduce erosional forces acting to degrade shoreline and marsh edge conditions. The breakwater reefs were constructed of stone (230-285 lbs) that is small enough to prevent horseshoe crabs' impingement (max space opening 0.5 feet) but large enough to provide wave attenuation with minimal deformation expected over time. The structures were placed on a fabric foundation mattress filled with small stones to reduce long-term settling rates. Elevation of the breakwater structures was designed for a maximum of 4 feet NAVD88 (North American Vertical Datum of 1988). The overall length of each breakwater is 200 feet with typical 25-foot gaps between adjacent structures. Each structure's crest width is designed to be 3 feet while the base width is approximately 25 feet. Mean High Water (MHW) is 2.43 feet NAVD88, the crest of each unit is partially emergent during normal tides even at times of high tide. As a result, during normal tidal ranges the incident wave height is reduced to the transmitted wave height by 90 to 100%. The engineered design for the breakwaters for a 10-year water level event reduced the anticipated incident wave height (7.3 feet) to a transmitted wave height by approximately 48% (3.5 feet). Complete project included a proposed revetment structure at the eastern end of Basket Flats to reduce erosion and stabilize the end of Basket Flats that protects the town of Bivalve from direct wave impacts (figure3).

Proposed Basket Flats Project Layout

Figure 3 is a project layout sketch showing Basket Flats and the proposed project treatments.

As part of the project the ALS team designed a monitoring framework to evaluate whether our management actions have achieved the desired result. The data shown in the sections contained within this report will evaluate the project performance one year following installation and inform adaptive management actions if project goals are not met over time. For the purpose of this report breakwater units were labeled #1-9 from west to east, unit #10 is the combined sill and revetment structure at the eastern end of basket flats.

Beach Profiles

1) **Methods and Equipment –** Beach profiles provide useful information for coastal studies monitoring shoreline and nearshore changes. Using standard survey techniques with Leica VIVA RTK GPS systems connected to Leica Smart Network and a Leica TS06 plus Electronic Total Station accurate measurements are taken along a predetermined transect at regular spaced intervals or changes in slope. Each data point contains elevation and position coordinate data (northing, easting). Connecting these data points along a single transect line allows for the creation of a graphic depiction of the current beach contours known as a beach profile. Comparison between surveys at the same transect (beach profile) allows for calculations of shoreline position, elevation and sand volume changes over time.

The CRC uses Matlab and BMAP (Beach Morphology Analysis Package) computer programs to analyze and determine these morphologic and other dynamic beach profile changes.

At Basket Flats the CRC established a shore parallel baseline leeward of the breakwaters with a series of 25 profile stations labeled 00+00 to 24+00 set at regular 100-foot intervals and a control line (31+00) set 700 feet west of the project site to help monitor changes along the project site shoreline. At the east end of basket flats a denser set of 14 profiles at a 50-foot interval and radial lines was established to monitor changes near the tip of Basket Flats. Each of the profile lines was surveyed prior to construction, immediately following construction and one year post construction. Those results are shown in this section with a series of beach profile plots, shoreline and volume change table. Figure 4 is the profile location map showing the profile layout at the Basket Flats project site.

Basket Flats Beach Profile Layout

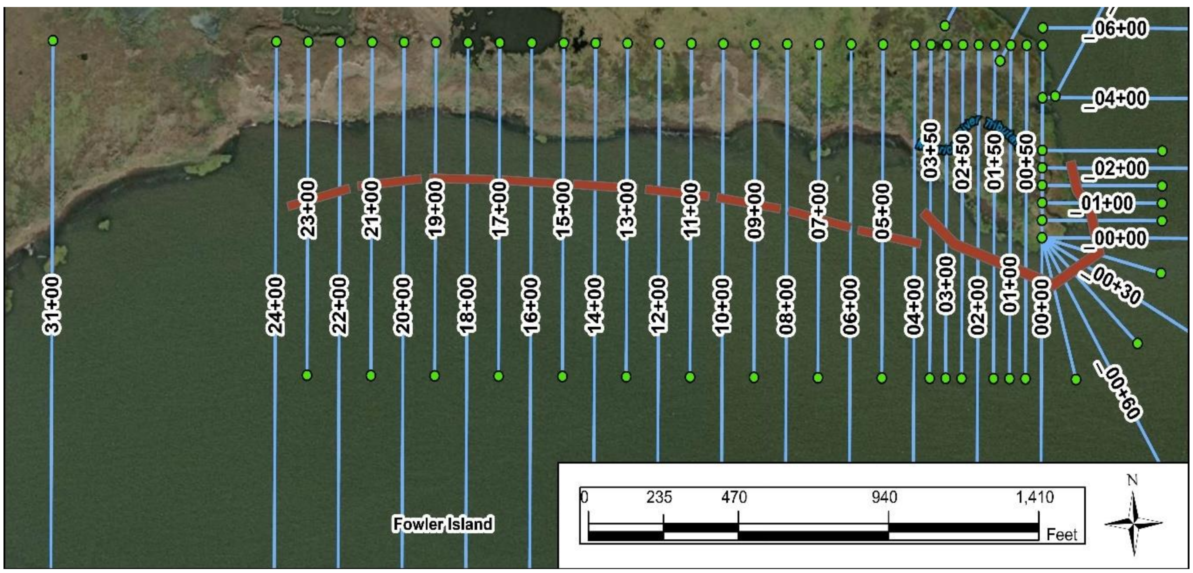


Figure 4 shows the beach profile layout established to monitor change at the Basket Flats project site. Breakwater units for this report are numbered 1-9 from west to east with #10 the combined sill and revetment unit at the east end of Basket Flats.

2) Profile Plots

Figures 5-15 are beach profile plots showing the cross-sectional configuration of the shoreline at each site located along the shoreline leeward of the breakwater units. Each plot shows a comparison between the preconstruction survey completed in July 2022, immediate post construction survey completed in December 2022 and the one-year post project survey completed in October 2023. The representative plots included are Line 4 – Line 24 and are located east to west across the project area. The distance between each site is approximately 200 feet. Each plot shows topographic changes in the region immediately seaward and landward of the installed breakwater units (1-9) up onto the marsh edge and further offshore. The breakwater units are not shown in these plots that are focused on terrain changes only.

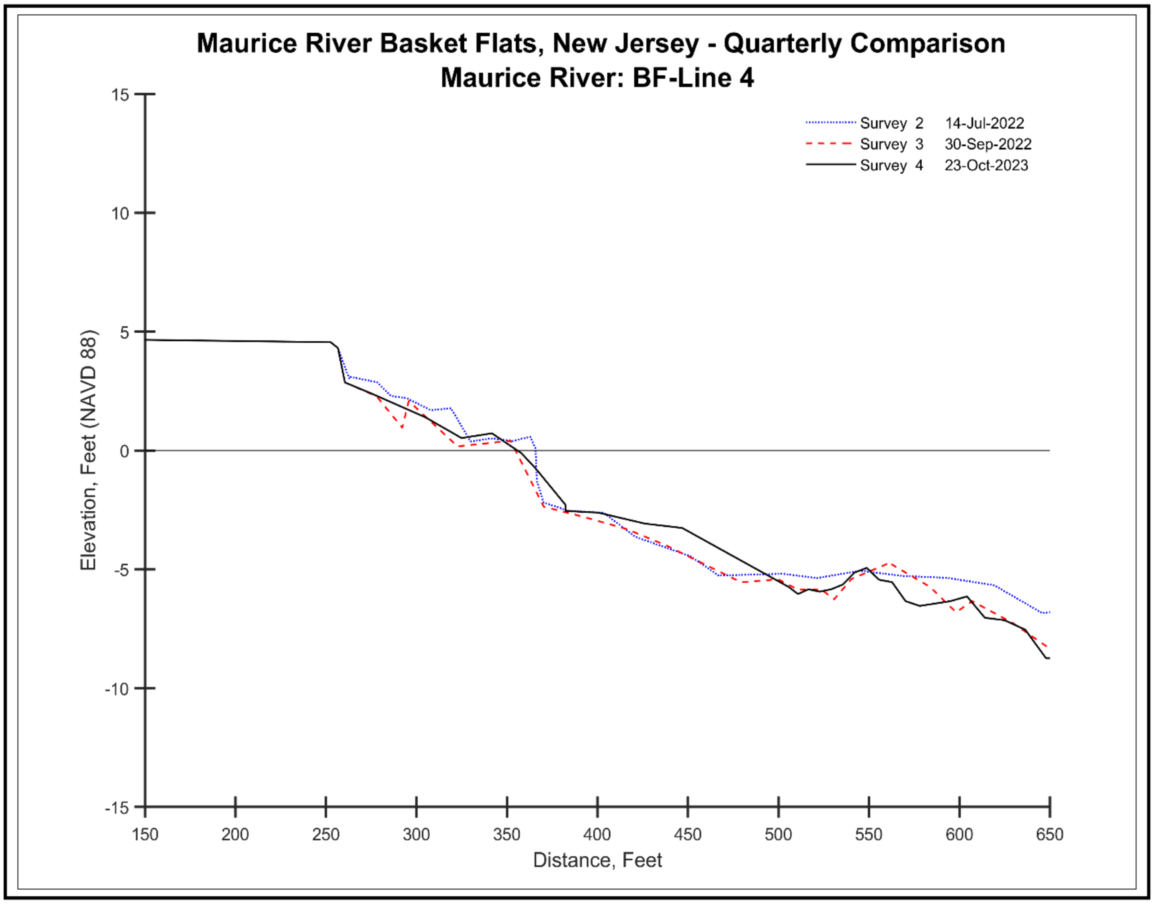


Figure 5. Line 4 is located leeward of breakwater unit #9 near the eastern end of the project. Direct survey comparisons show onshore sediment losses (-2.03 yds^3/ft) between the pre and post construction surveys (survey 2-survey 3). The shoreline position shifted landward -11 feet between the pre, and post construction surveys. Further offshore, there was pattern of scouring that occurred seaward of the breakwater location. One year following construction the onshore volume changes stabilized (0.63 yds^3/ft) with minor inflation in elevation above the zero-elevation datum. The marsh edge remained unchanged. The shoreline position leeward of breakwater unit #9 advanced seaward slightly (1 foot) from fall 2022 to fall 2023. Immediately nearshore within the breakwater lee the elevation inflated with an accumulation of sediment (3.38 yds^3/ft). Further offshore, beyond the breakwater location, additional sediment accumulated (6.98 yds^3/ft) on the bay floor and resulted in a net gain below the zero datum of 10.36 yds^3/ft of sediment.

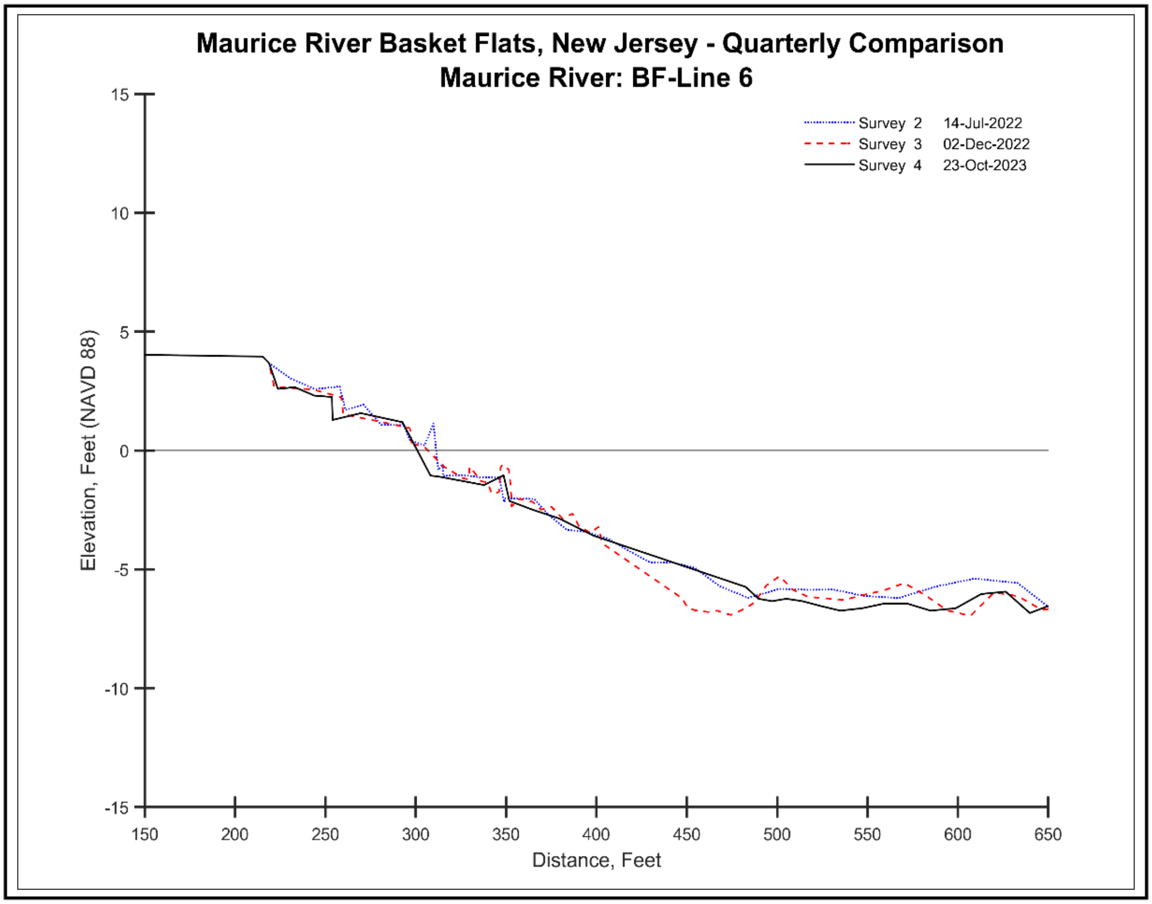


Figure 6. Line 6 is located between breakwater unit #8 and #9 in the 25-foot gap. Comparisons between the pre and post construction surveys show some erosion of the marsh edge and platform (-0.87 yds^3/ft) and sediment (-1.87 yds^3/ft) and elevation loss along the nearshore bay floor. The shoreline position responded with an 11-foot shift landward between the pre and post construction surveys. One year following construction the onshore volume change was minor (-0.16 yds^3/ft) with modest elevation deflation on the lower marsh platform while the marsh edge was stable from fall 2022 to fall 2023. The shoreline position at this site shifted landward (-6 feet) from December 2022 to October 2023. Immediately nearshore a modest volume of sediment accumulated (2.45 yds^3/ft) in the breakwater lee while seaward there was some scouring. Additional accretion occurred further offshore prior to October 2023 that resulted in a net change below the zero datum of 5.35 yds^3/ft of sediment.

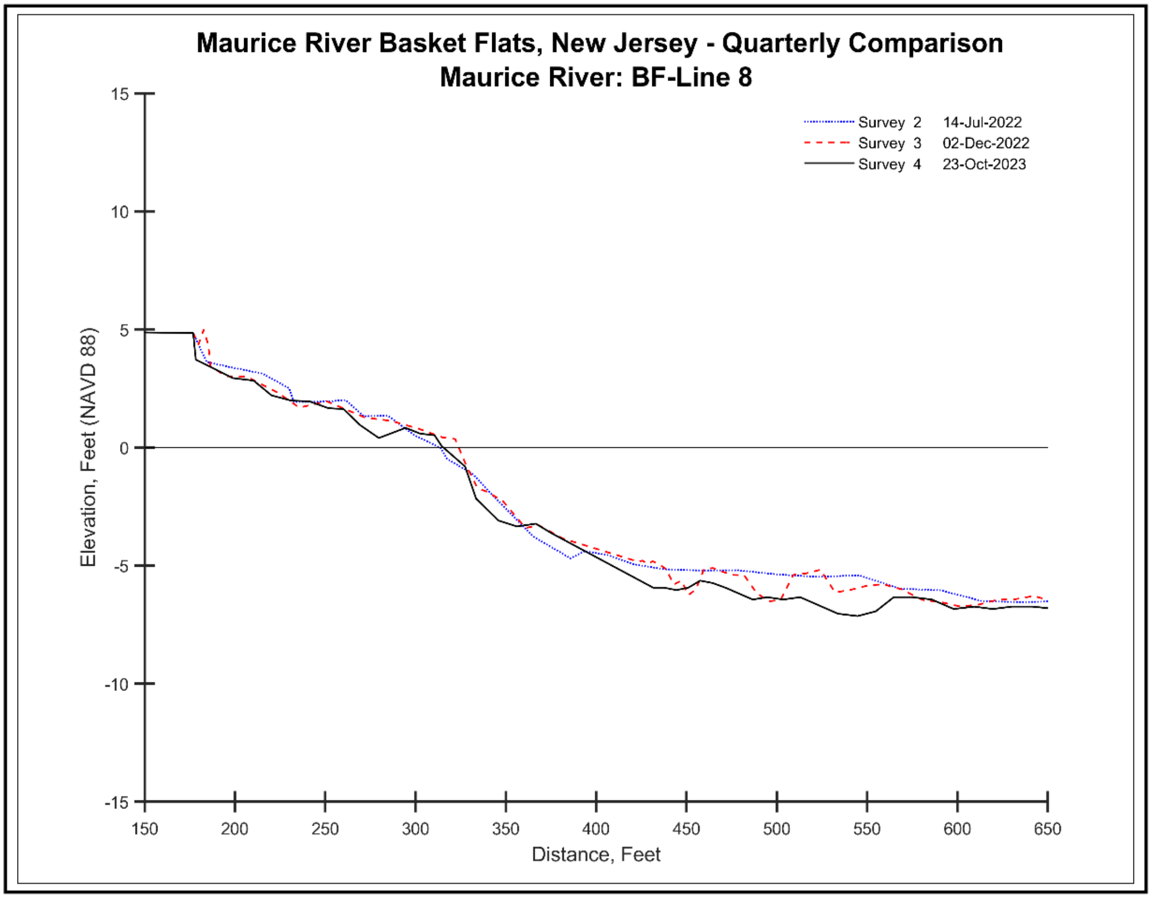


Figure 7. Line 8 is located between breakwater unit #7 and #8 in the 25-foot gap. Survey comparisons show minor onshore sediment losses (-0.39 yds^3/ft). But shoreline position shifted seaward 11 feet between the pre, and post construction surveys. Nearshore, there was pattern of scouring that occurred seaward of the breakwater location. One year following construction the onshore volume changes remained small (-1.23 yds^3/ft) with modest elevation deflation from the marsh edge to the shoreline. The shoreline position within the gap between the breakwaters shifted landward (-9 feet) from December 2022 to October 2023. Immediate nearshore lost a modest volume of sediment (-1.71 yds^3/ft) to scouring while further offshore scour deflated the bay floor elevation and resulted in a loss of -3.28 yds^3/ft of sediment.

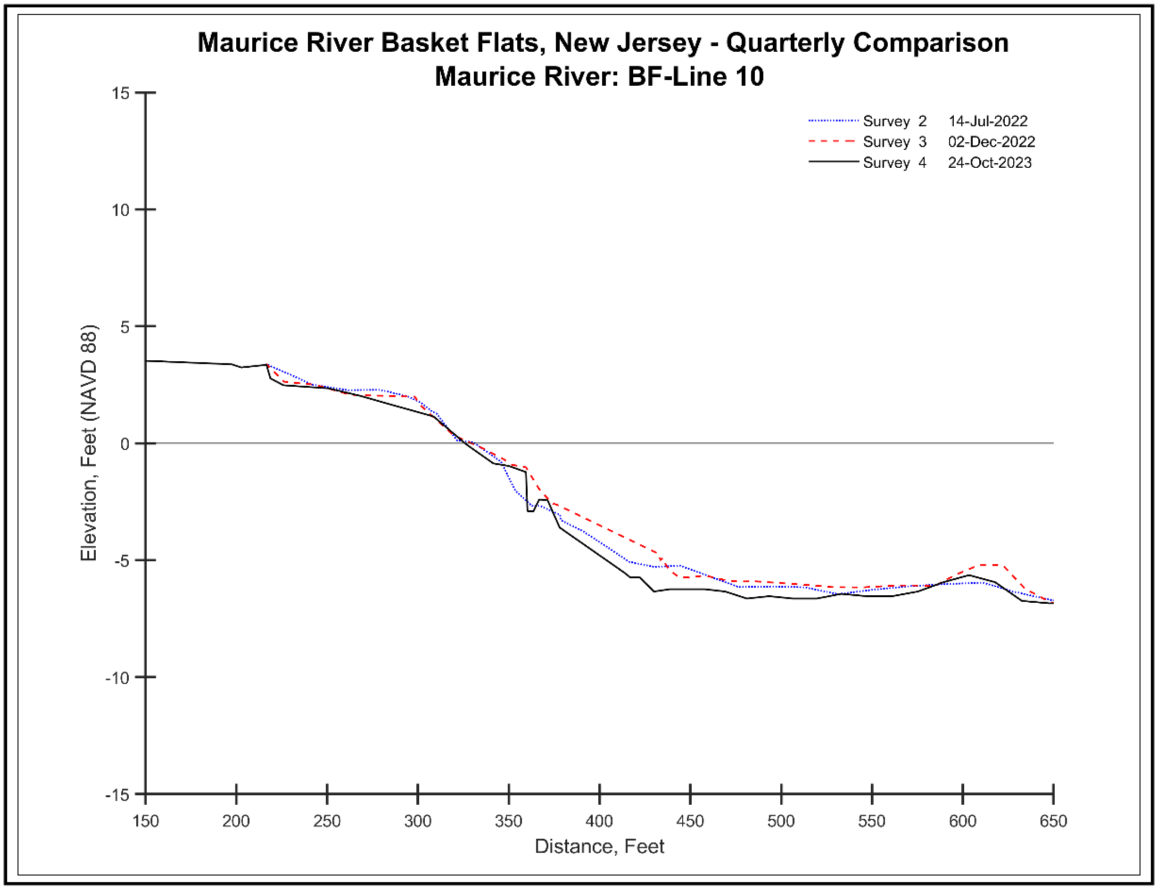


Figure 8. Line 10 is located on the leeward of breakwater unit #7. Survey comparisons show minor onshore sediment losses at the marsh edge but relative stability along the beachface slope net onshore volume loss was -0.53 yds^3/ft with less than 2 feet of landward shift in the shoreline position between the pre, and post construction surveys. Nearshore, sediment accumulated (2.48 yds^3/ft) on the lower slope in the lee of the breakwater elevating the bay floor in between the pre and post construction surveys. One year following construction the onshore volume changes were modest (-0.64 yds^3/ft) from the marsh edge to the shoreline. The shoreline position shifted landward (-3.5 feet) from December 2022 to October 2023. Nearshore suffered scouring for a loss of elevation and volume (-6.36 yds^3/ft).

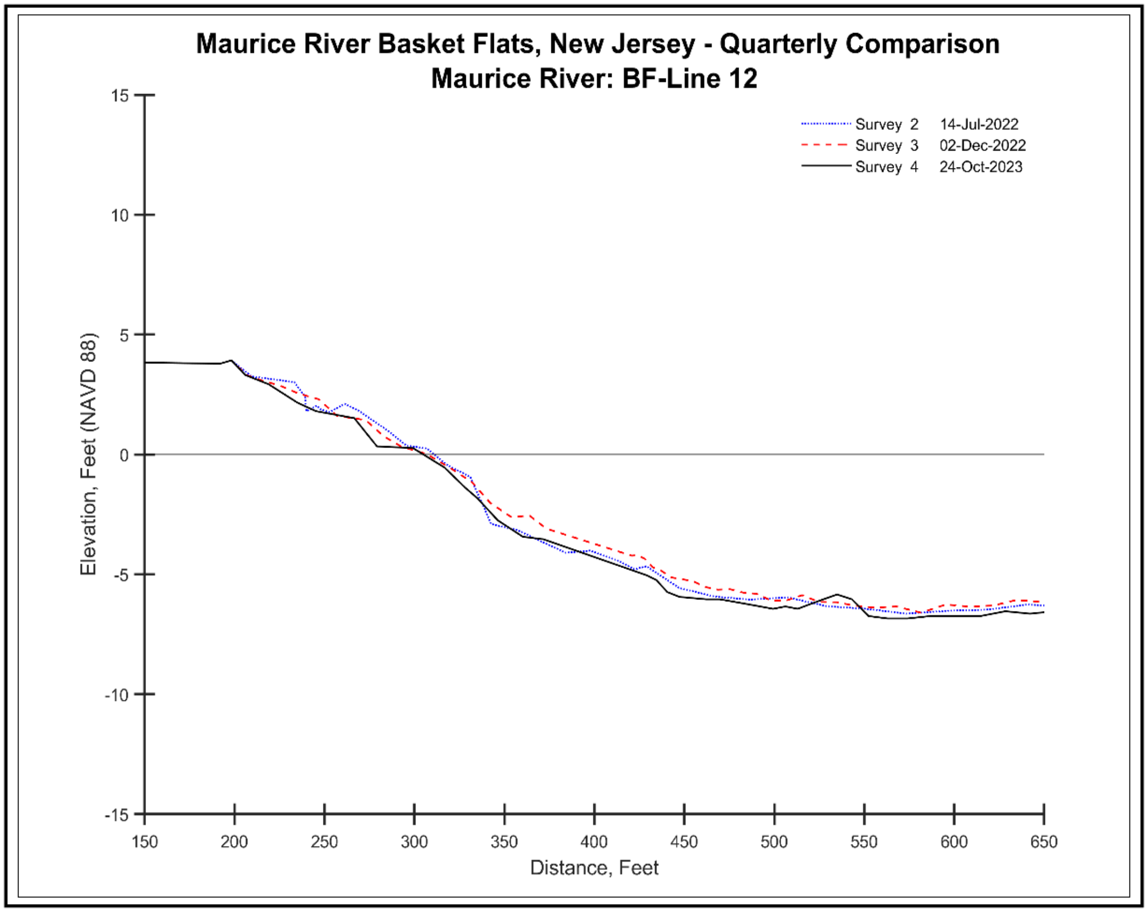


Figure 9. Line 12 is located on the leeward of breakwater unit #6. Survey comparisons show minor onshore sediment losses (-0.62 yds^3/ft) between the pre, and post construction surveys focused on the upper marsh edge and along the lower beachface slope. Erosion at the beachface toe of slope resulted in a landward shift (-4 feet) of the shoreline position. Nearshore, sediment accumulated (5.02 yds^3/ft) across the bay floor as a thin layer in between the pre and post construction surveys that inflated the nearshore elevation along the profile. One year following construction the onshore volume changes were modest (-0.82 yds^3/ft) from the marsh edge to the shoreline. The shoreline position shifted slightly landward (-2 feet) from December 2022 to October 2023. Nearshore suffered scouring across the profile for a loss of elevation and volume (-7.34 yds^3/ft).

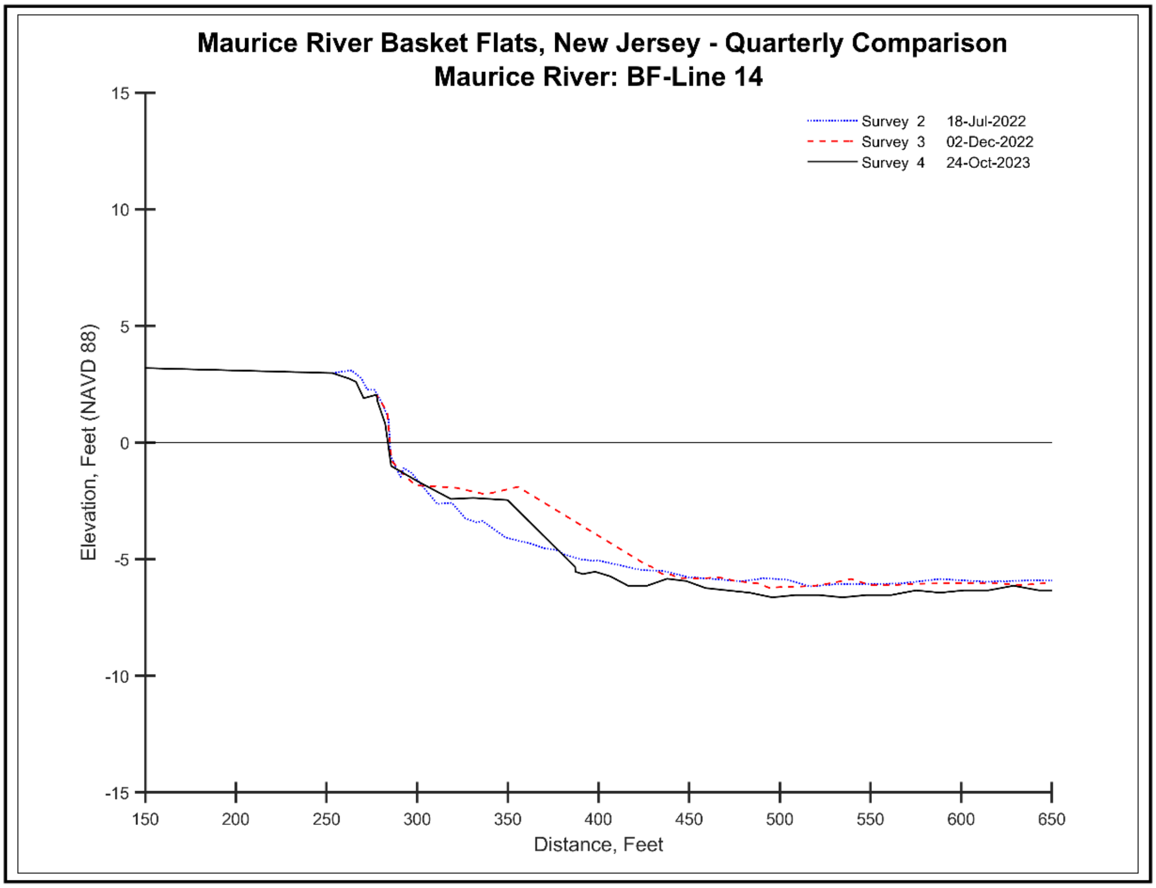


Figure 10. Line 14 is located on the leeward of breakwater unit #5. Survey comparisons show minor onshore sediment losses (-0.29 yds^3/ft) between the pre, and post construction surveys focused on the upper marsh edge while the shoreline position was stable (0.05 foot). Nearshore, sediment accumulated (5.84 yds^3/ft) behind the breakwater installation between the pre and post construction surveys that inflated the nearshore elevation. One year following construction the onshore changes were minor (-0.14 yds^3/ft) from the marsh edge to the shoreline position that also remained relatively stable (-1 foot) from fall 2022 to fall 2023. In the lee of the breakwater the shallow nearshore suffered from scouring for a loss of elevation and volume (-8.16 yds^3/ft). Seaward of the breakwater unit the loss of sediment continued removing a thin layer across the bay floor.

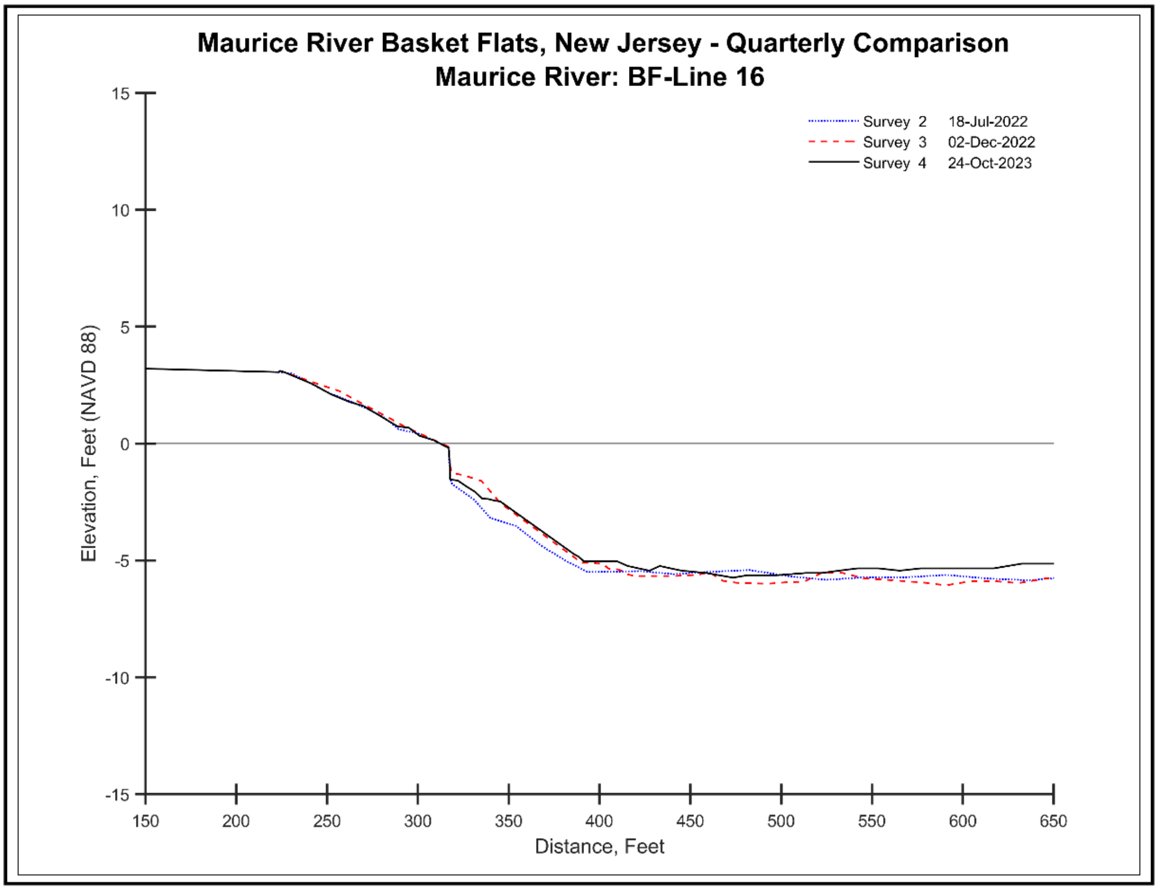


Figure 11. Line 16 is located on the leeward of breakwater unit #4. Survey comparisons show minor onshore gains (0.37 yds^3/ft) between the pre and post construction surveys while the shoreline position shifted landward slightly (-1 foot). Nearshore behind the breakwater installation there was a modest increase in the bottom elevation where sediment accumulated (2.0 yds^3/ft). One year following construction the onshore changes were minor (-0.36 yds^3/ft) from the marsh edge to the shoreline position that also remained stable (1 foot). In the lee of the breakwater the shallow nearshore accumulation was modest with 0.77 yds^3/ft added. Seaward the breakwater unit there was significant accretion of sediment (30.64 yds^3/ft).

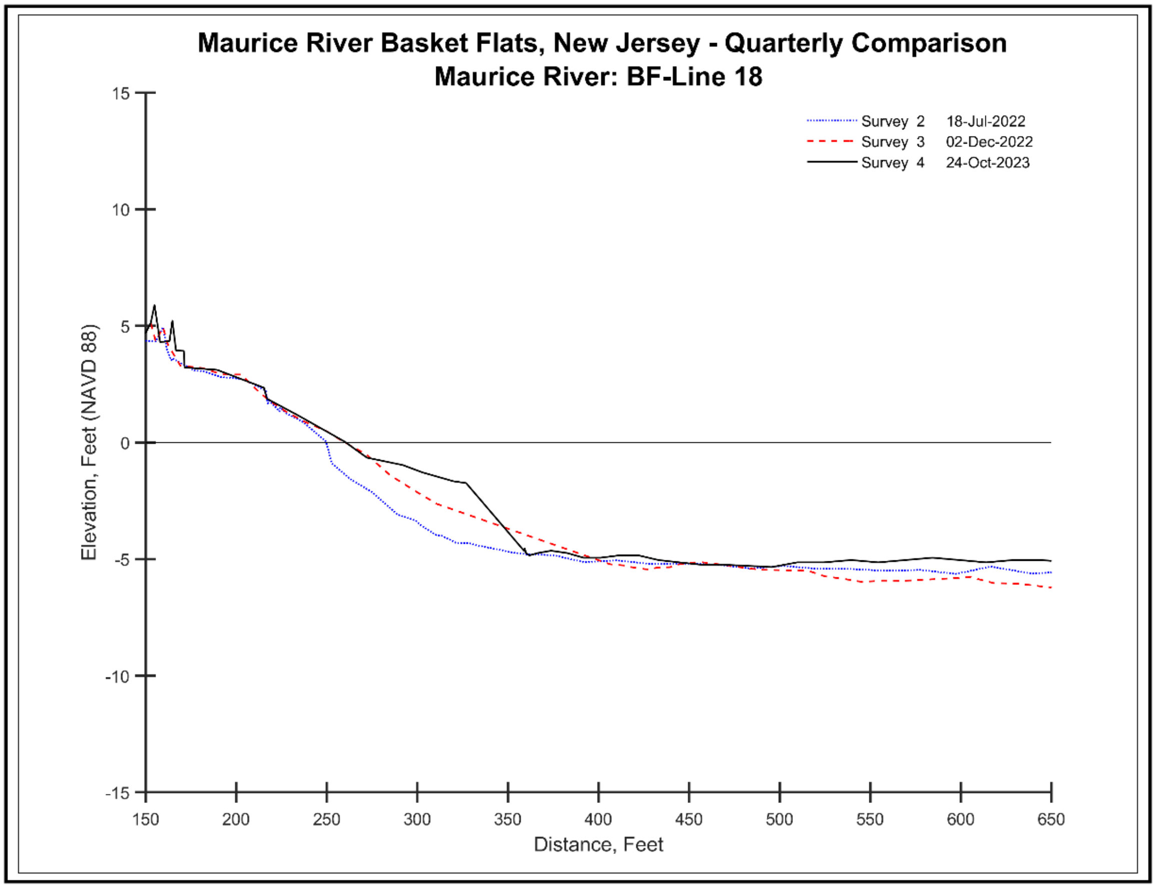


Figure 12. Line 18 is located on the leeward of breakwater unit #3. Survey comparisons show minor onshore gains (0.41 yds^3/ft) between the pre and post construction surveys but nearshore behind the breakwater installation there is considerable change in the bottom elevations where sediment rapidly accumulated (5.95 yds^3/ft). The addition of this sediment in the shallow nearshore advanced the shoreline position seaward 10 feet. One year following construction the onshore changes were modest with minor sediment accumulation (0.43 yds^3/ft) from the marsh edge to the shoreline position that also remained stable (0.4 feet). In the lee of the breakwater the shallow nearshore accumulated an additional 2.2 yds^3/ft of sediment inflating the elevation. Seaward the breakwater unit there was significant accretion of sediment (34.34 yds^3/ft).

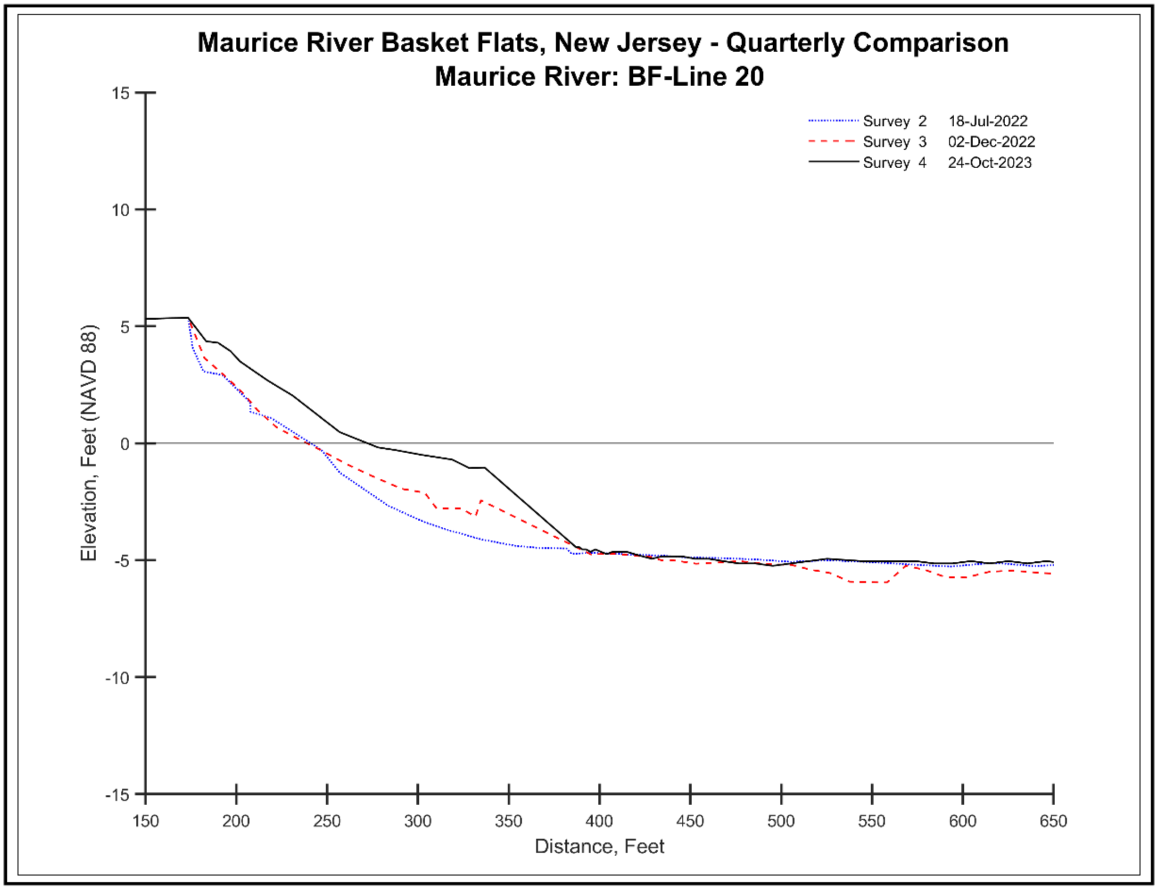


Figure 13. Line 20 is located on the leeward of breakwater unit #2. Survey comparisons show minor onshore gains (0.29 yds^3/ft) between the pre and post construction surveys but nearshore there is considerable change in the bottom elevations where sediment accumulated (2.90 yds^3/ft). The breakwater was not included in the cross-section to show terrain changes only. One year following construction the onshore changes were significant with sediment accumulation from the marsh edge to the landward toe of the breakwater unit (11.25 yds^3/ft) and the shoreline position advanced seaward 33 feet. On the nearshore platform additional sediment accumulated adding 12.67 yds^3/ft of material to the bay floor one year following construction. This site clearly demonstrates the capacity for natural accretion in the lee of the breakwater unit overtime.

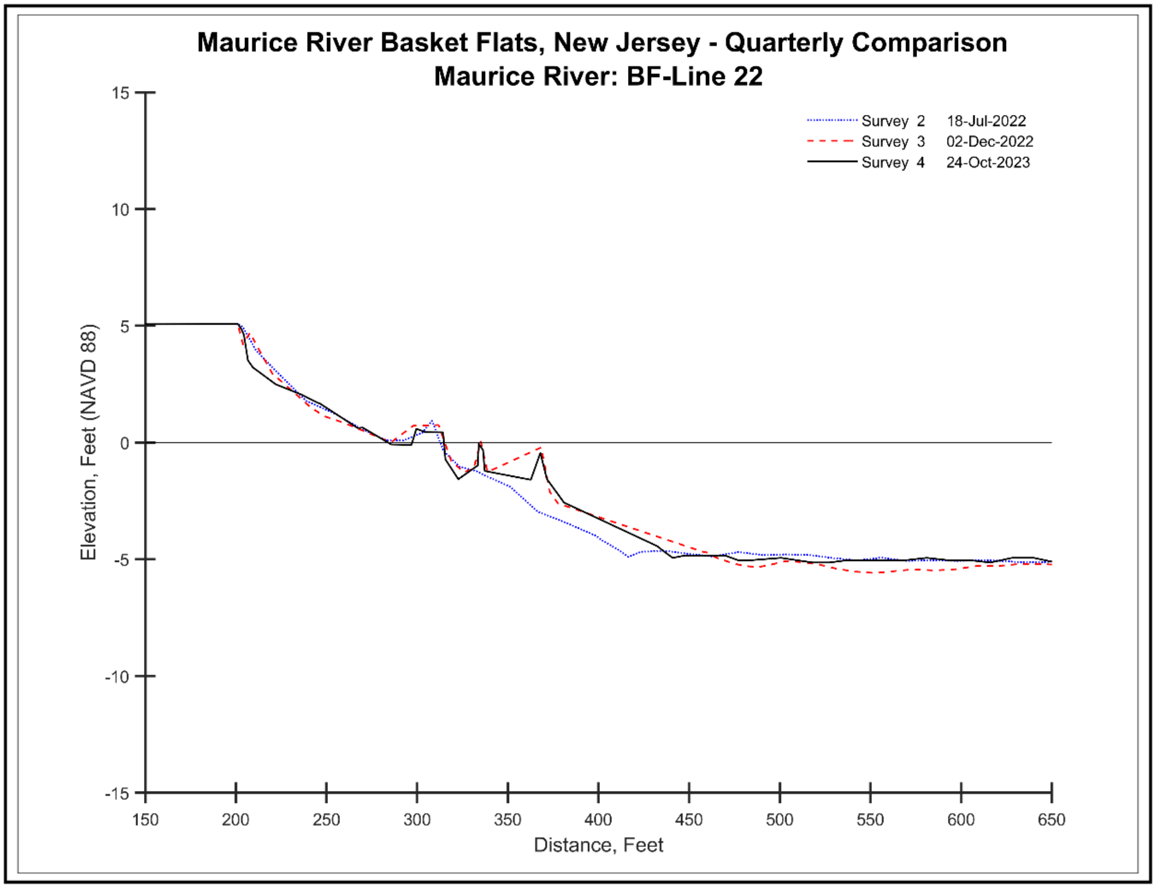


Figure 14. Line 22 is located leeward of breakwater unit #1. Survey comparisons show little onshore change between the pre and post construction surveys but nearshore there is considerable change in the bottom where sediment accumulated. The breakwater was not included in the cross-section to show terrain changes only. Onshore volume changes from the pre to post construction surveys were minor (-0.16 yds^3/ft) with a minor advance in the shoreline position (2 feet). One year following construction the onshore changes remained minimal with little volume change (-0.48 yds^3/ft) and the shoreline was essentially stable (-0.4 feet). On the nearshore platform sediment accumulated adding 20.63 yds^3/ft of material to the bay floor one year following construction.

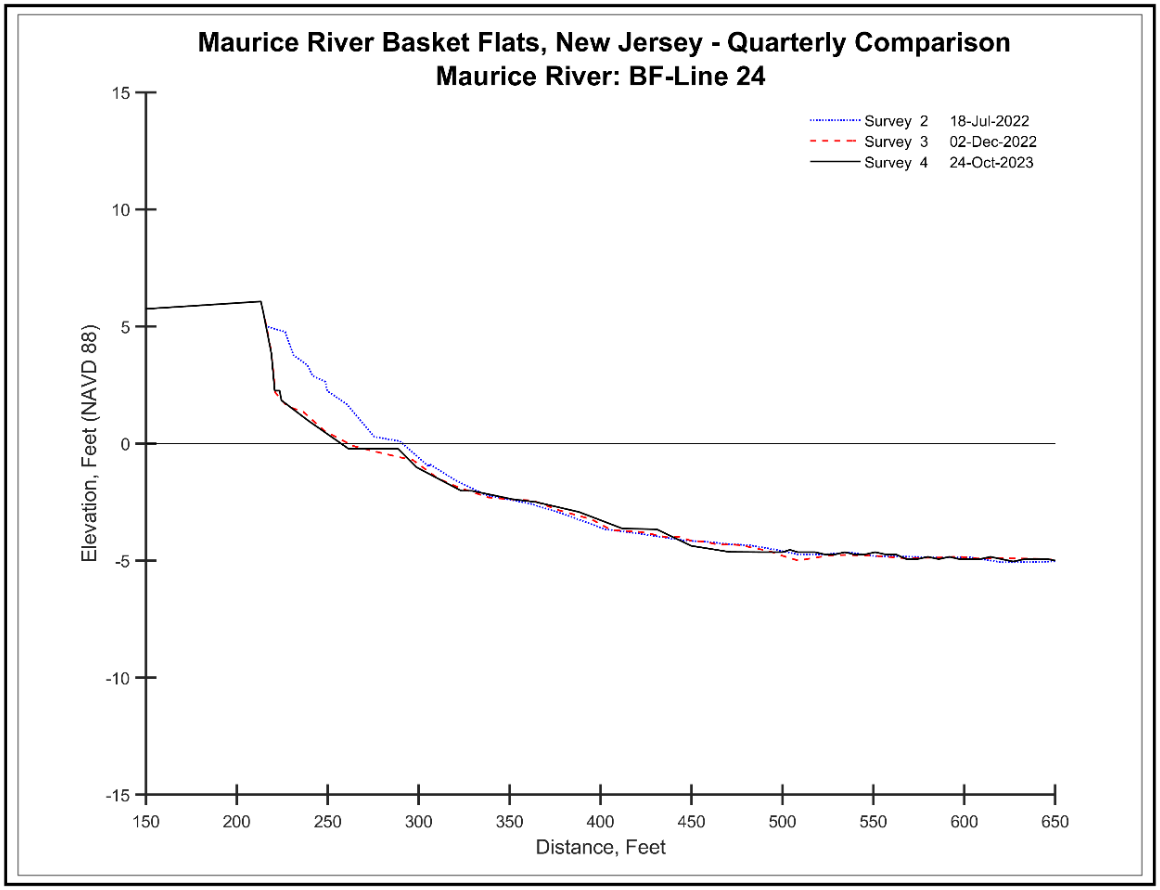


Figure 15. Line 24 is located at the cove formed by the Basket Flats spit extension and orientation of the adjacent marsh. Comparison of the surveys shows a significant loss of sediment (-4.87 yds^3/ft.) onshore and shoreline retreat (-30 feet) between the pre (July 2022) and post construction (December 2022) surveys. The shoreline stabilized during the year following installation of the breakwater units with minor changes (-0.12 yds^3/ft. & -4 feet of shoreline loss). Line 24 is located just west of breakwater unit #1 outside the immediate lee of the structure but still receives partial shelter from approaching waves into the cove.

3) Shoreline and Volume Change Tables

Table 1 shows annual individual sand volume and shoreline changes that were calculated with BMAP using survey data sets collected by the CRC from December 2022 to October 2023. Included in the table are average volume changes (yds^3/ft) calculated for adjacent profiles then multiplied by the distance between sites (ie. cell distance) to determine a net cell volume. Cell volumes at the project boundaries were calculated by multiplying the volume change in cubic yards per foot for the adjacent profile by the distance (ie. cell distance feet) to the project end. The summation of the cell volumes provided an estimated net sand volume change.

Table 1 Maurice River Cove Shoreline & Sand Volume Changes (Entire Profile)						
December 2022 to October 2023						
Profile	Shoreline Change (feet)	Volume Change (cu yds/ft.)	Avg. Volume Change (cu yds/ft.)	Distance Between (feet)	Net Cell Volume Change (cu yds)	Cumulative Volume Change (cu yds)
Maurice River Cove						
00+00	-46	2.01				
			6.35	200	1,271	1,271
02+00	-3	10.70				
			10.84	200	2,168	3,439
04+00	1	10.99				
			8.09	200	1,617	5,056
06+00	-6	5.19				
			0.34	200	68	5,124
08+00	-9	-4.51				
			-2.96	200	-591	4,533
10+00	-4	-1.40				
			-4.78	200	-956	3,577
12+00	-2	-8.16				
			-10.53	200	-2,107	1,470
14+00	-1	-12.91				
			9.13	200	1,826	3,296
16+00	1	31.17				
			34.04	200	6,809	10,105
18+00	0	36.92				
			30.52	200	6,104	16,209
20+00	33	24.13				
			19.36	200	3,873	20,081
22+00	0	20.16				
			10.08	200	2,016	22,097
24+00	-4	14.60				
			Total Change =		**22,097**	

The net annual sediment volume change along the entire southern facing Basket Flats study area was a gain of 22,097 cubic yards of material using the closed end methodology. A large portion (20,628 cubic yards) of accumulated sediment was on the western 1,000 feet of project shoreline. Shoreline position changes ranged from -46 feet at -00+00 located on the northeast tip of Basket Flats to a seaward advance of 33 feet at line 20+00 located along the southwestern side of Basket

Flats leeward of breakwater unit # 8. These were extremes values while most of the sites showed single digit shoreline changes one year post construction.

Table 2 shows annual individual sand volume change within the lee of the breakwaters and onshore along with shoreline changes. This table excludes the volume changes calculated further offshore of the immediate project area. These volumes and shoreline changes were calculated with BMAP using survey data sets collected by the CRC from December 2022 to October 2023.

Table 2
Maurice River Cove
Shoreline & Sand Volume Changes (Breakwater Leeward)
December 2022 to October 2023

Profile	Shoreline Change (feet)	Volume Change (cu yds/ft.)	Avg. Volume Change (cu yds/ft.)	Distance Between (feet)	Net Cell Volume Change (cu yds)	Cumulative Volume Change (cu yds)
Maurice River Cove						
00+00	-2	-6.93				
			-7.63	200	-1,526	-1,526
02+00	-3	-8.33				
			-2.92	200	-584	-2,110
04+00	1	2.49				
			0.68	200	137	-1,973
06+00	-6	-1.13				
			-1.59	200	-317	-2,290
08+00	-9	-2.05				
			-1.71	200	-342	-2,632
10+00	-4	-1.37				
			-1.63	200	-326	-2,958
12+00	-2	-1.89				
			-1.27	200	-254	-3,212
14+00	-1	-0.64				
			-0.64	200	-129	-3,341
16+00	-1	-0.65				
			0.35	200	71	-3,270
18+00	0	1.35				
			4.97	200	994	-2,276
20+00	33	8.59				
			4.46	200	891	-1,384
22+00	0	-0.05				
			-0.02	200	-5	-1,389
24+00	-4	0.32				
			Total Change =		**-1,389**	

Included in the table are average volume changes (yds^3/ft) calculated for adjacent profiles then multiplied by the distance between sites (ie. cell distance) to determine a net cell volume. Cell volumes at the project boundaries were calculated by multiplying the volume change in cubic yards per foot for the adjacent profile by the distance (ie. cell distance feet) to the project end. The summation of the cell volumes provided an estimated net sand volume change within the immediate project area leeward of the breakwater units. The net annual sediment volume change along the southern facing Basket Flats shoreline leeward of the breakwater units was a minor loss of -1,389 cubic yards of material. Within the breakwater area the largest volume change was a gain of 8.59 yds^3/ft at line 20+00 while the largest loss was small with -2.05 yds^3/ft lost at 08+00. Most of the losses were in the range of a foot or less yds^3/ft, indicating shoreline stability within the lee of the units.

Topographic & Bathymetric Surveys

1) **Methods and Equipment –** The CRC conducted bathymetric surveys of the nearshore, continuing seaward beyond the installed Basket Flat structures using a research vessel equipped with a hypack system RTK GPS and single beam echo sounder to determine bay bottom conditions and changes over time. Bathymetric data was collected prior to construction, immediately following construction and one year post construction to track project area changes overtime. These data sets will be combined with the previously described beach profile data sets that provide topographic information at the project site to create comprehensive topographic and bathymetric surveys of the project area.

   Data collected during the three surveys was combined using ArcGIS with the creation of a Digital Elevation Map (DEM) of these surfaces. Separate DEM's were created for the pre-construction, post-construction and one-year surveys. Comparing the immediate post construction DEM to the one-year post construction survey DEM an Elevation Change Map was created in ArcGIS with sand volume changes calculated between the two surfaces.

2) **Digital Elevation Models (DEM) –** Three DEMs were created for each of the different surveys conducted. The initial DEM shows the surface conditions prior to construction efforts in July 2022. A second DEM shows the surface conditions following completion of construction in December 2022. The final DEM shows the surface conditions in October 2023, one year following the start of construction. Elevation contours are depicted by changes in colors with red and orange representing higher elevations while blue and purple colors represent regions with lower elevations

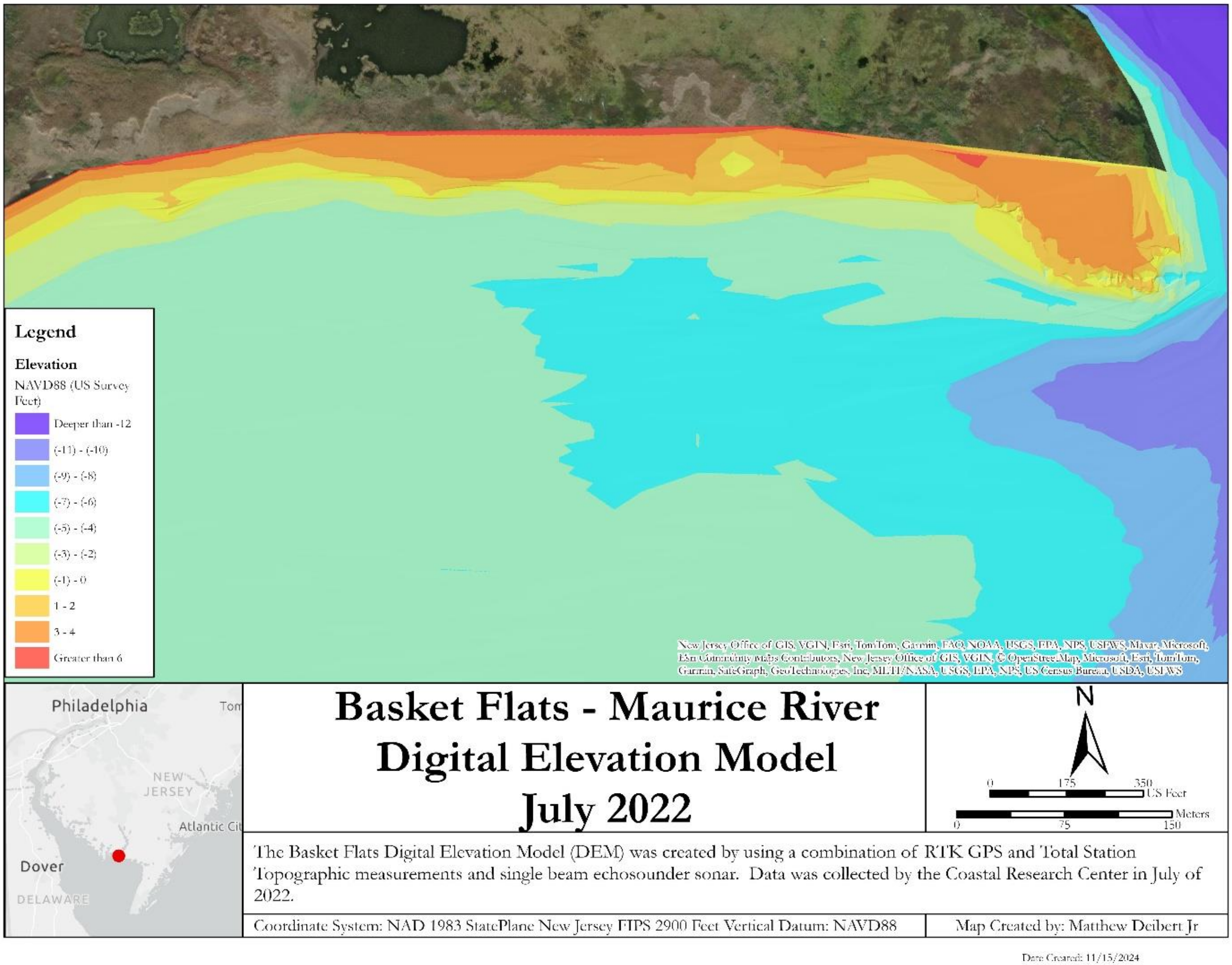


Figure 16. The July 2022 DEM shows surface conditions prior to project construction. Red colors indicated the higher marsh edge elevations while orange are the lower marsh edge platform elevations. Yellow colors are representative of the intertidal regions while light green is shallow nearshore platforms. Blue colors show regions where the nearshore elevations are deeper while the purple colors indicate the main Maurice River channel edge. The western portion of the nearshore platform is a wide shallow cove area. At the eastern end of Basket Flats the channel margins have extended westward around the end of Basket Flats increasing the vulnerability of the tip to wave impacts and erosion.

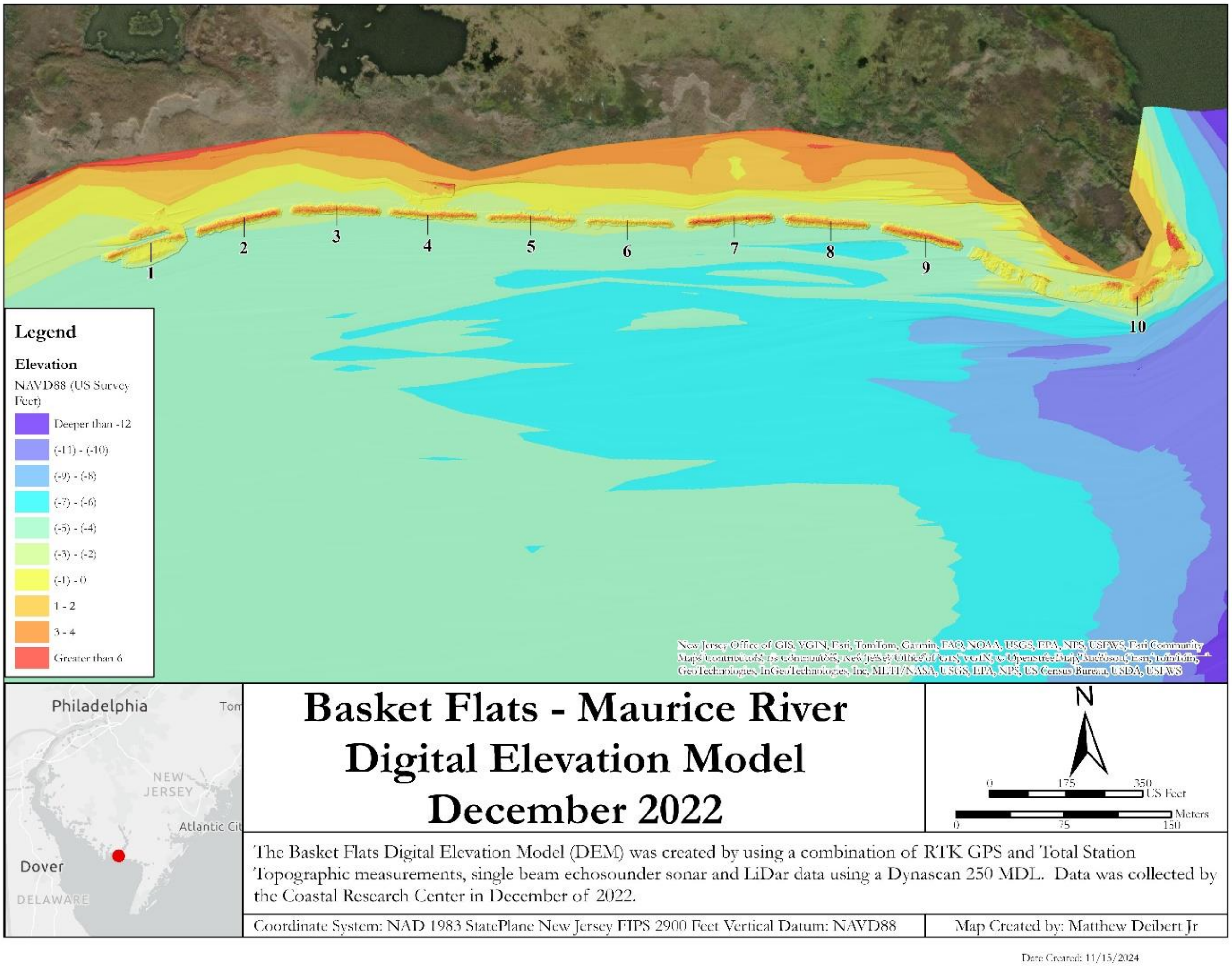


Figure 17. The December 2022 DEM shows surface conditions following installation of the breakwater units and the partial revetment/sill. Breakwater units are labeled 1-9 from west to east while the revetment/sill is labeled as number 10. The color pattern again indicates reds and orange are regions with higher elevations while blues and purple are regions with lower elevations.

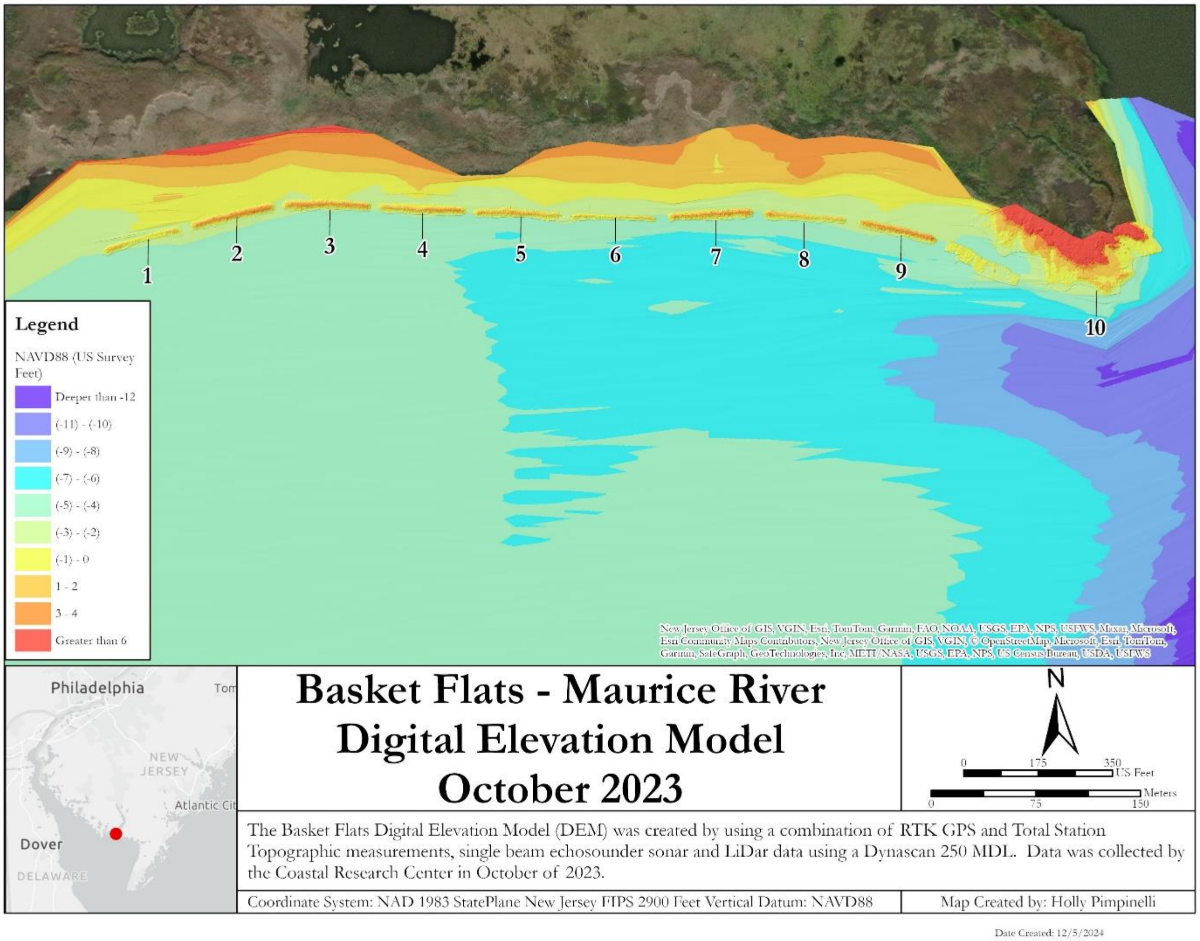


Figure 18. The fall 2023 DEM shows surface conditions one year following installation of the breakwater units and the partial revetment/sill. Breakwater units are labeled 1-9 from west to east while the revetment/sill is labeled as number 10. The color pattern again indicates reds and orange are regions with higher elevations while blues and purple are regions with lower elevations. Elevations on units #2, #3, #7 and #9 show relative stability while the other units have shown minor deflation in the crest elevation over the initial year.

3) **Elevation Change Map –** Two project Elevation Change Maps (ECM) were created using ArcGIS by comparing the pre-to post construction DEMs (July 2022 to December 2022) and the post construction DEM to the one-year postconstruction DEM (December 2022 to October 2023). The changes in elevation between the two surfaces allowed for the calculation of volume changes between surveys. Elevation changes are depicted on the map using colors with greens representing areas of elevation and volume gain while areas of loss are shown as regions colored in red. Areas with little or no elevation and volume change are represented on the map by tan- or yellow-colored regions.

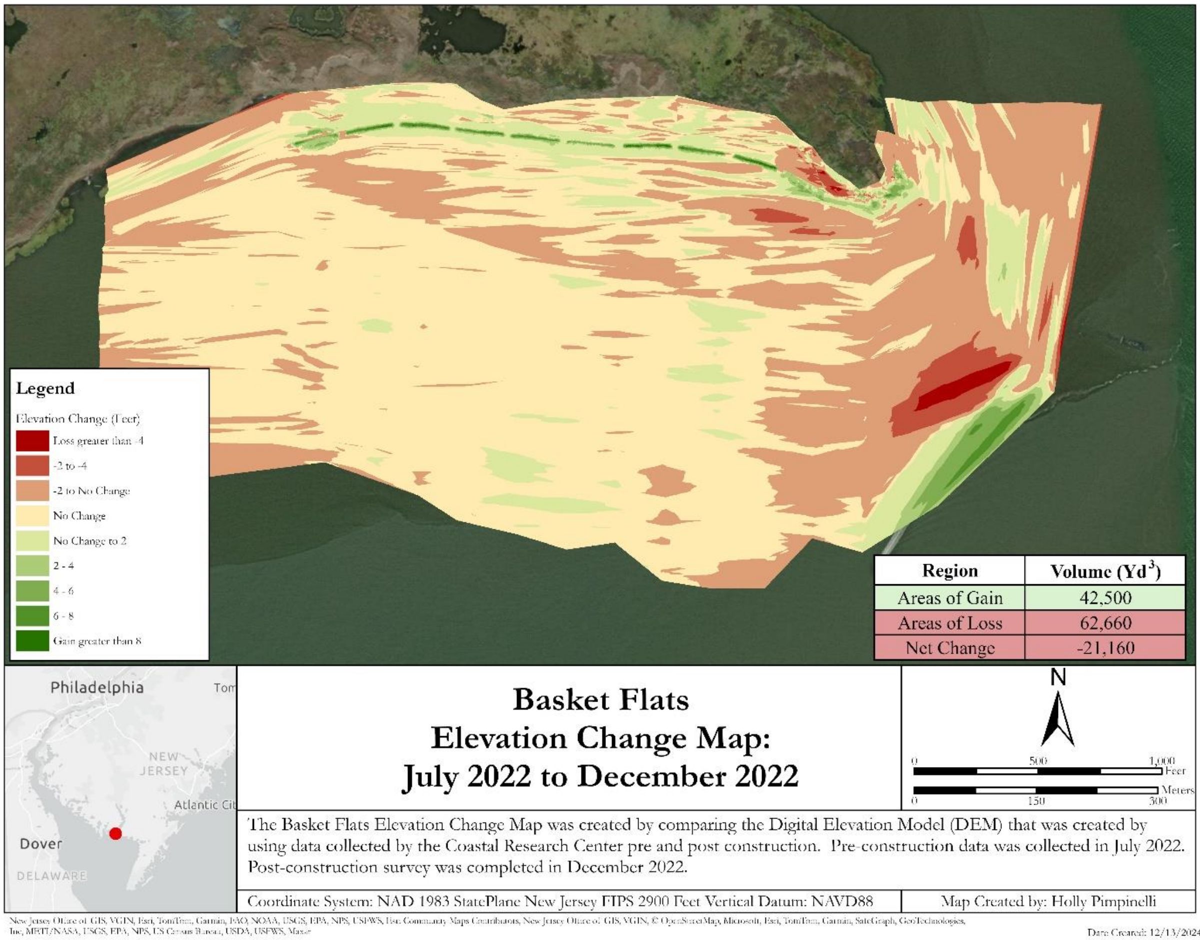


Figure 19. The July 2022 to December 2022 elevation change maps show the immediate post construction elevation changes within the study area. Regions shaded in green colors are areas of elevation gain while red show areas of elevation loss. Yellow colors and lighter color shades show areas of little to no change in elevation between the preconstruction and post construction surveys. Within the project area the darker green areas represent the installation of the breakwater units and revetment structures along the southern Basket Flats shoreline.

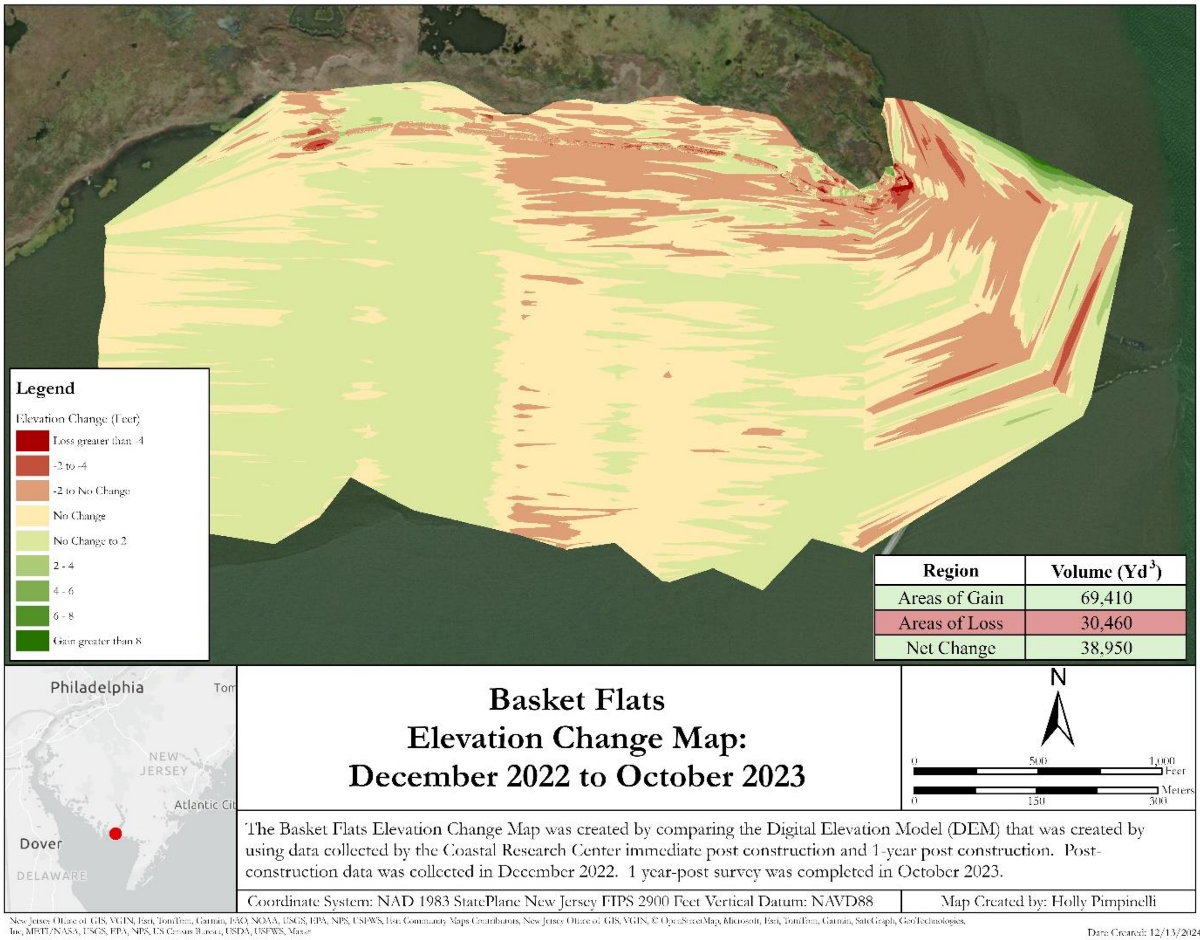


Figure 20. The December 2022 to October 2023 elevation change maps show the one-year post construction elevation changes within the study area. Regions shaded in green colors are areas of elevation gain while red show areas of elevation loss. Yellow colors and lighter color shades show areas of little to no change in elevation between the preconstruction and post construction surveys. Within the project area the green areas at the west end of the project region represent a volume gain of sediment and modest increases in elevation. Along the breakwater units the crest elevations have shown modest elevation deflation. Despite the modest settlement in crest elevation the breakwater units remained in place as protection for the southern facing shoreline of Basket Flats.

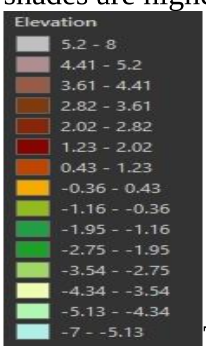
The net study area volume changes include a gain of 69,410 cubic yards of sediment, widespread elevation gains nearshore and onshore contributed but the area of greatest gain was towards the channel margin at the northeast tip of Basket Flats outside the immediate project area. During this time frame, the study region lost 30,460 cubic yards of sediment. Elevation losses in the region of the breakwater units were small while changes at the tip of Basket Flats and further offshore in the channel were greater. The net change for the annual study window was a gain of 38,950 cubic yards of sediment over the entire study area. The minimal elevation changes seen in the ECM along the lee of the breakwater units and onshore along the southern shoreline of Basket Flats indicate the units have provided stability to this area of the project.

Mobile & Static LiDAR Structural Scans

1) **Methods and Equipment –** The CRC conducted structural surveys of the installed breakwater units and the proposed revetment structures soon after construction then again one-year post construction. Static structural surveys were conducted using a Lecia Nova MS50 precision 3D terrestrial scanner. These terrestrial static scans conducted at low tide captured the exposed crest and leeward side of the breakwater rocks. The seaward sides and crest of the breakwater and revetment rocks were scanned using a Dynascan MDL mobile LiDAR unit. The Dynascan pod is a fully integrated high speed laser scanner, high accuracy GPS positioning system and inertial measurement unit capable of quick collection of precision data. The system is small in size and lightweight allowing deployment on a small research vessel to capture scans of the seaward breakwater and revetment face.

2) **LiDAR Structural Scan Images**

Figure 21-29 shows the combined mobile and static LiDAR scan images of each breakwater unit. The first image shows the "As Built" elevation conditions for the breakwater unit while the second image in each figure shows the elevation conditions one year post construction. In general, green colors are areas of lower elevation while red shades are higher elevations.



This scale shows the elevation ranges and associated colors for figures 21-30. Breakwater units are displayed in the figures with "As Built" on the left and one year post construction on the right in order from west to east starting with breakwater unit #1.

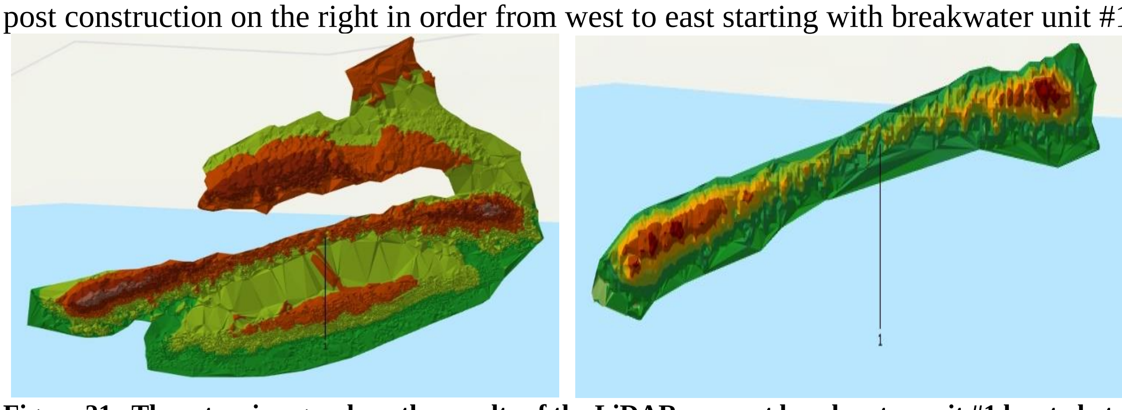


Figure 21. These two images show the results of the LiDAR scans at breakwater unit #1 located at the western end of the project area. The left image is the immediate post construction scans and shows the separation of the foundation mattress that shifted from under the unit on both sides creating a depression towards the middle (subaqueous, no data or image). The image on the right is the one-year scan, both ends of the unit remained relatively stable while the mid-section has settled where the foundation mattresses shifted.

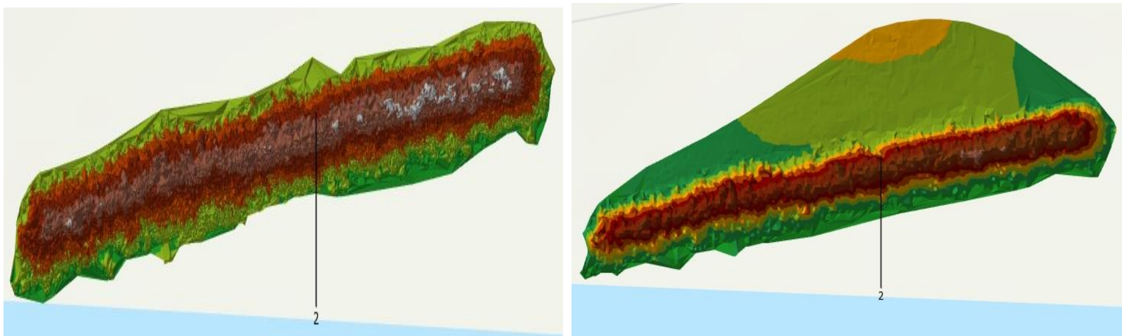


Figure 22. These two images show the results of the LiDAR scans at breakwater unit #2 located at the western end of the project area. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the structure. On the far right the crest elevations are slightly higher (grayish/white). The image on the right is the one-year scan, both ends of the unit remained relatively stable with no indication of major settlement or deformation.

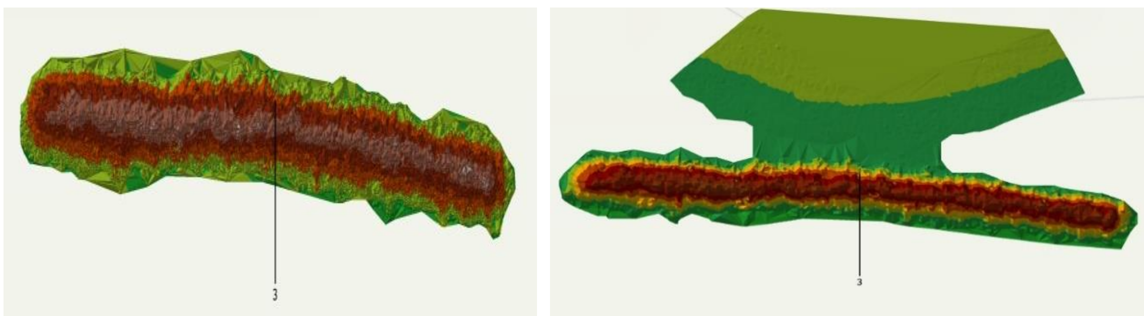


Figure 23. These two images show the results of the LiDAR scans at breakwater unit #3 of the project area "as built" and one year later. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the structure. The image on the right is the one-year scan, the unit has remained relatively stable with no indication of major settlement or deformation.

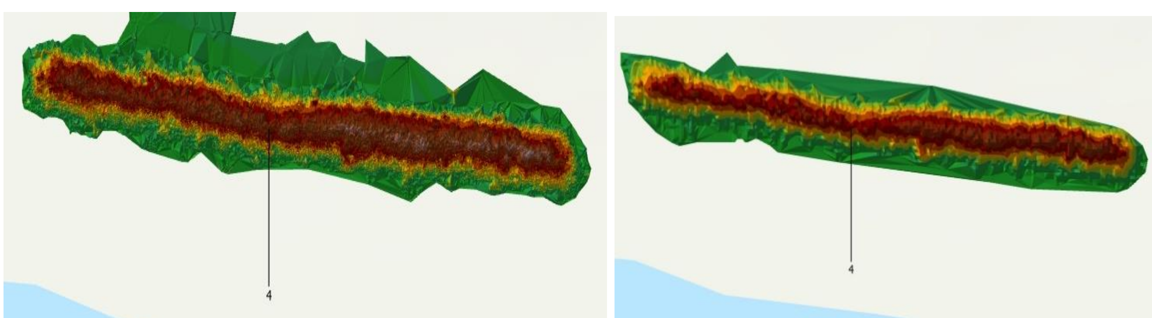


Figure 24. These two images show the results of the LiDAR scans at breakwater unit #4 located towards the middle of the project area. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the structure. The image on the right is the one-year scan, the unit has remained relatively stable with no indication of major settlement or deformation.

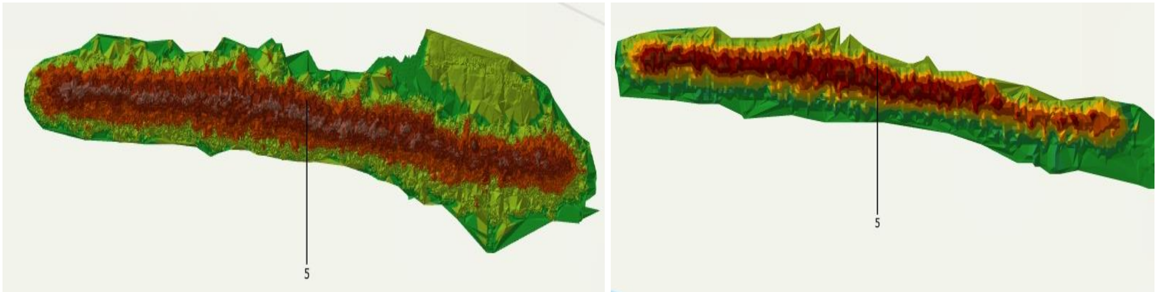


Figure 25. These two images show the results of the LiDAR scans at breakwater unit #5 located with the project mid-section. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the western and middle of the structure. There is evidence that the eastern end is slightly lower in elevation on the crest based on the while color scattering along the crest ridge. The image on the right is the one-year scan, the unit has remained relatively stable with minor settlement along the western and mid-section, the eastern end shows some evidence of modest deformation but within the anticipated engineered design range.

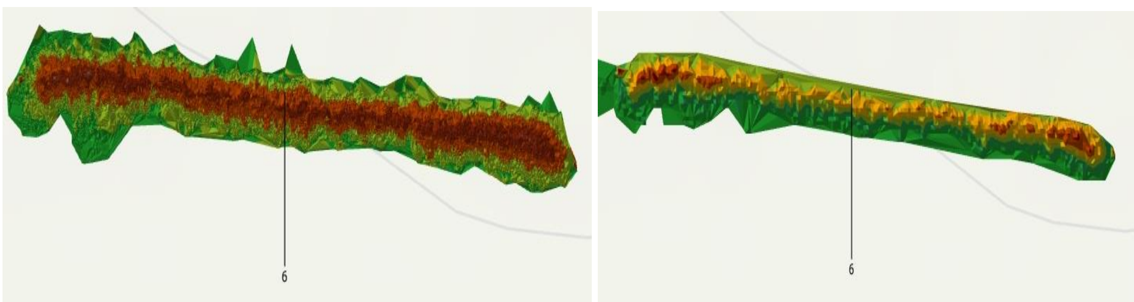


Figure 26. These two images show the results of the LiDAR scans at breakwater unit #6 located with the project mid-section. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the structure. The image on the right is the one-year scan, the unit has adjusted and shows signs of significant settlement in the midsection but is more stable on the ends. There is no indication of scattering of stone along the edge of the units in this image indicating the primary reason for this deformation is elevation settlement.

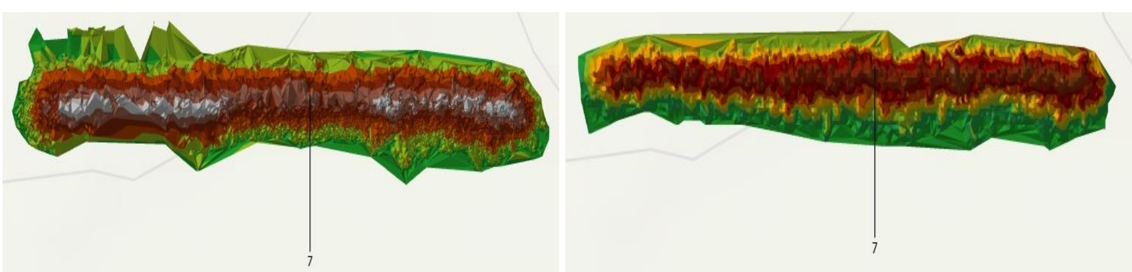


Figure 27. These two images show the results of the LiDAR scans at breakwater unit #7 located towards the eastern end of the project area. The left image is of the immediate post construction scans and shows the unit was relatively consistent in elevation across the structure with higher elevations on both ends and slightly lower conditions in the middle of the unit. The image on the right is the one-year scan, the unit has adjusted and shows reduced elevations and signs of settlement across the structure, focused on the ends but remains relatively intact in the center with little deformation of configuration, scattering of stones or loss of structural integrity indicated.

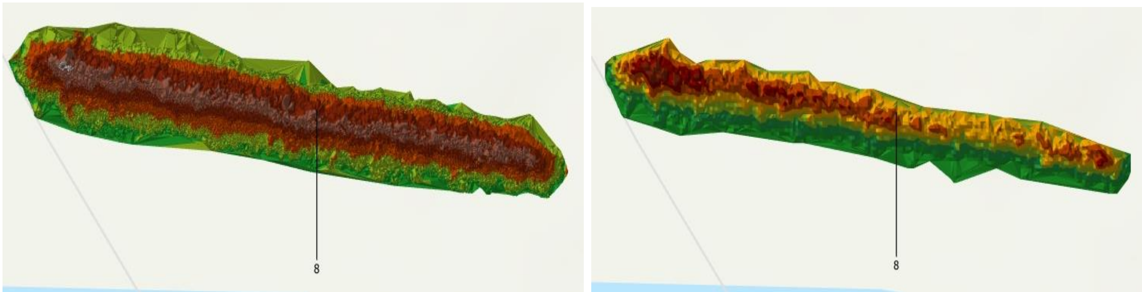


Figure 28. **These two images show the results of the LiDAR scans at breakwater unit #8 located towards the eastern end of the project area. The left image is of the "As Built" post construction scans and shows the unit was consistent in elevation and width across the structure with uniform elevations along the ridge. The image on the right is the one-year post construction scan. The unit has adjusted and shows signs of settlement across the structure with the worst elevation loss on the eastern (right) end and towards the mid-section. The structure remains functionally intact but with diminished elevation and exposure at times of high tide. The scan does not reveal any scattering of stone with little deformation of the overall configuration. Elevation loss appears to be related to settlement.**

Figure 29. **These two images show the results of the LiDAR scans at breakwater unit #9 located at the eastern end of the breakwater project area. The left image is of the "As Built" post construction scans and shows the unit was relatively consistent in elevation and width across the structure with slightly higher elevations seen along the mid-section and eastern side of the crest. The image on the right is the one-year post construction scan. The unit shows signs of settlement in crest elevations across the structure but remains within anticipated ranges and in fully functional condition. These scans do not reveal any scattering of stone with little deformation of the overall configuration. The minor elevation loss appears to be related to settlement rather than wave impact deformation.**

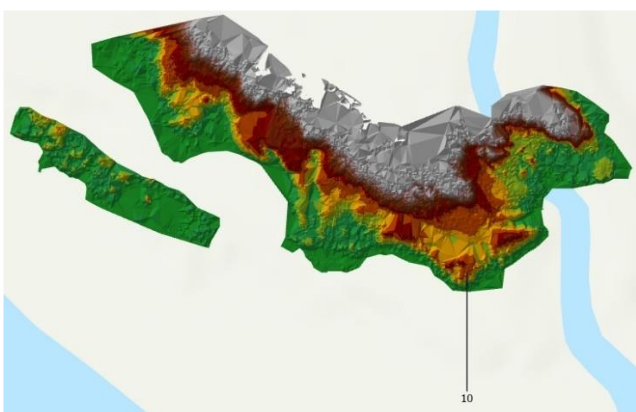


Figure 30. **The image shows the results of the LiDAR scans at the revetment and sill unit #10 located at the eastern end of the Basket Flats project area. The image shows conditions during the one-year scan. The sill on the left was built at a lower elevation than the breakwater units and not well defined. The revetement edge is the orange to red area, gray is the marsh vegetation. There is an indication of stone scattering along the base of the revetment at the tip. Probably related to construction issues.**

3) Structural Elevation Changes

Figure 31 shows the elevation changes between survey 3 (“As Built”) and survey 4 (one year post) focused on and immediately surrounding the breakwater units. The elevation change map was created using ArcGIS comparing the post construction DEM to the one-year postconstruction DEM (December 2022 to October 2023). Areas in green indicate an increase in elevation while yellow areas are regions of little or no change. Areas in red are regions with elevation loss, the darker the red the greater the loss.

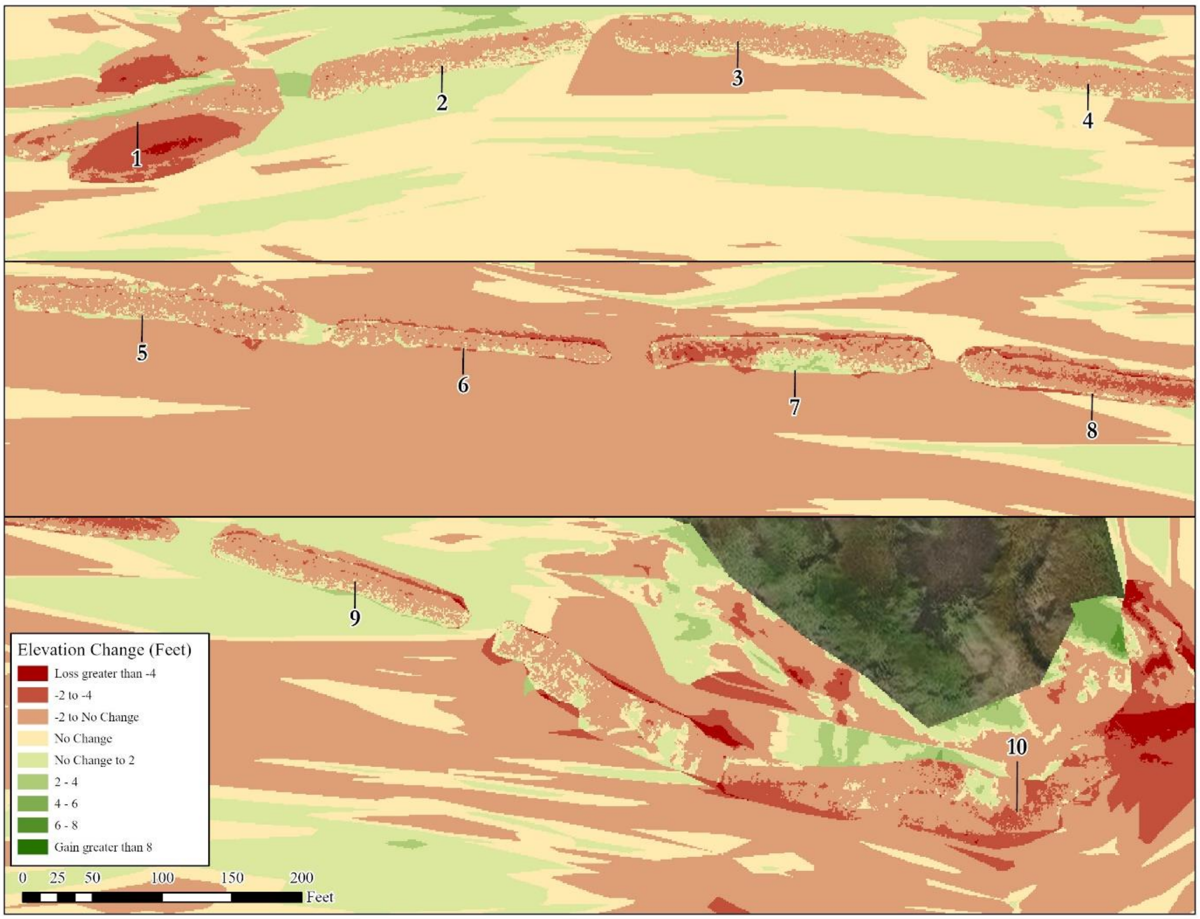


Figure 31. The elevation changes show most of the breakwater units remained relatively stable during the first year with most units settling less than 2 feet, well within the anticipated deformation range. There are local exceptions, focused on units 1, 6, 7 & 8. At unit 1, the foundation mattresses that shifted from under the units have settled on either side of the breakwater unit which itself continued to settle and deform beyond the anticipated deformation range. Unit 6 showed some deformation on the landward slope toe while most of the unit was subject to elevation settlement of less than 2 feet. Unit 7 showed a deformation of elevation on the west end in the 2–4-foot range while minor elevation gains in the 2-foot range occurred towards the mid-section of the unit. It is uncertain if this deformation was caused by a shift of stones during the impact of wave climate or another event. The eastern end remained relatively stable with minor elevation loss. Unit 8 also showed elevation settlement along the structures crest line in the 2-foot range and along the edges while the slopes remained relatively stable.

4) Structural Cross-Sections

Figures 32-41 are a series of cross-sections across each of the breakwater units. Data was a combination of LiDAR scans, traditional survey data collection (RTK GPS, electronic total station) integrated with single and multi-beam sonar bathymetry data. The individual cross-sections represent changes in the breakwater configuration between the 'As Built" survey and one-year post construction survey. Immediate nearshore bay floor changes within 50 feet of the units were included to show adjacent changes in topography possibly associated with bottom scouring, sediment accretion or scattering of stone off the units.

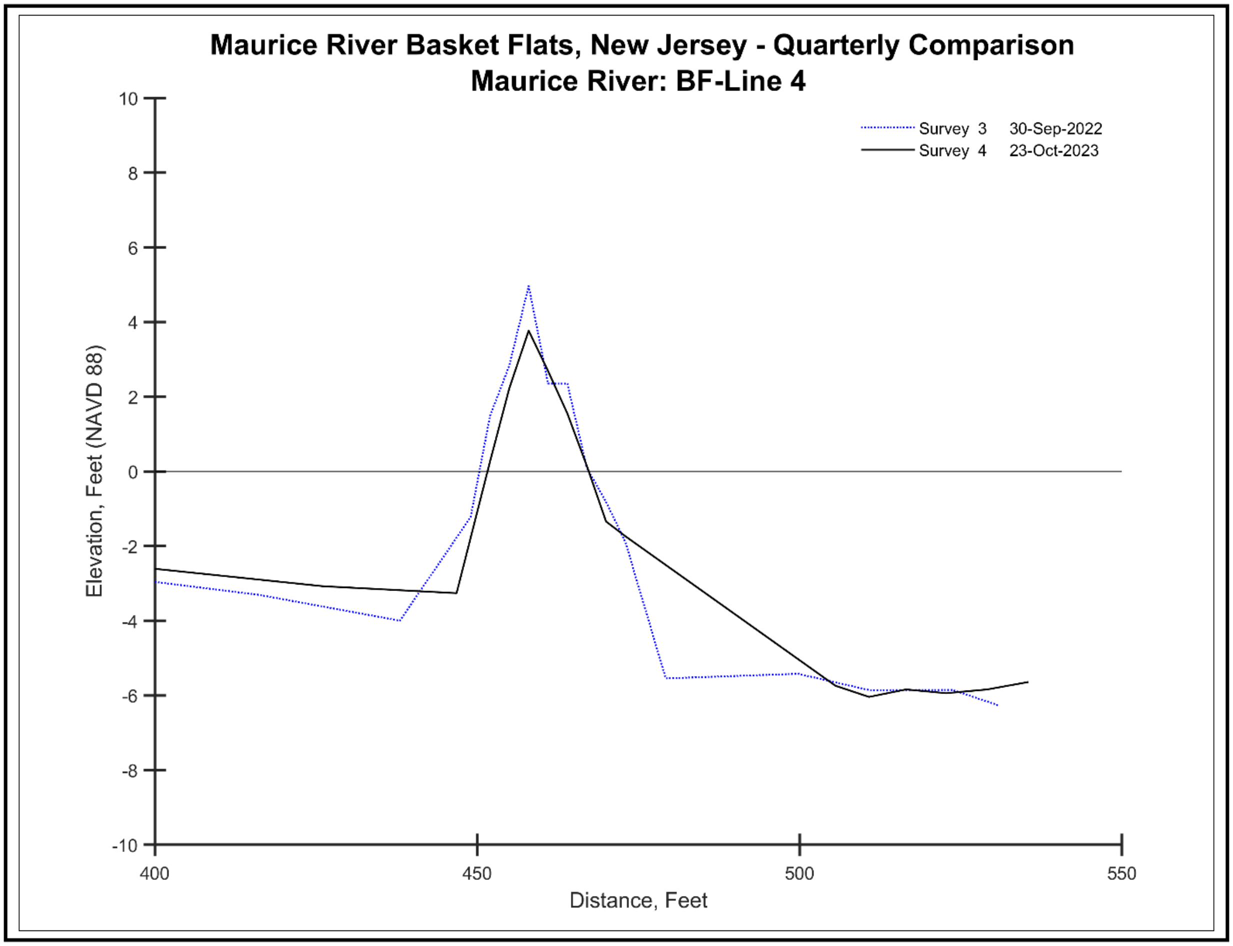


Figure 32. Line 4 crosses the eastern side of breakwater unit #9. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023 one-year post construction. Review of the "As Built" survey shows the crest elevation was above the 4-foot design target elevation at nearly 5 feet NAVD88. One year post construction data shows the crest elevation has settled less than 2 feet in this location but remains at or near the design target elevation (3.75 to 4 feet NAVD88). While there was settlement the general configuration of the breakwater slopes remained intact. There is sediment accumulation along both the landward and seaward base of the units. The slight change in configuration on the unit slopes indicate minor deformation.

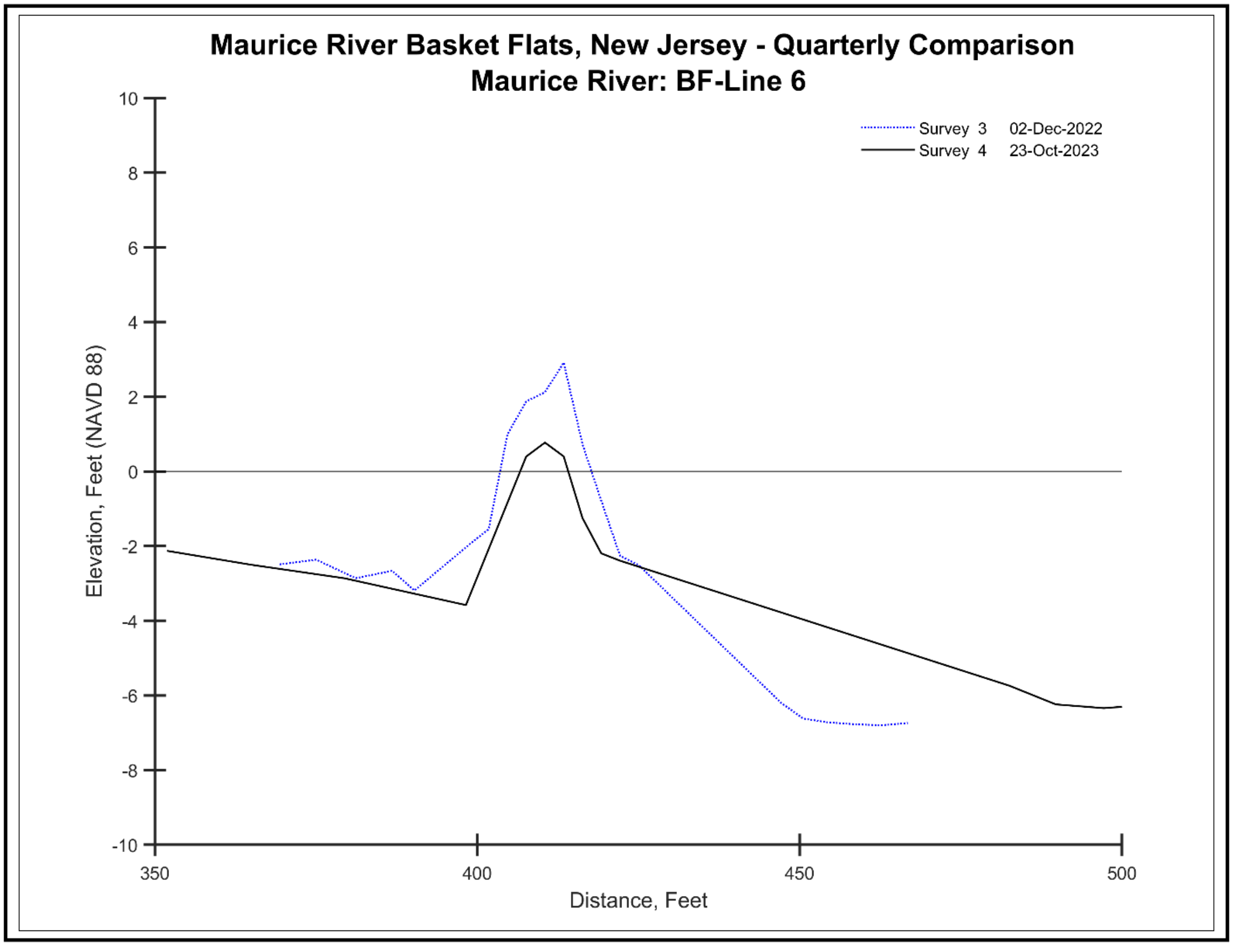


Figure 33. Line 6 crosses the eastern side of breakwater unit #8. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023 one-year post construction. "As Built" surveys show the crest elevation did not achieve the design target elevation of 4 feet NAVD88, maximum crest elevation in this location was 3 feet NAVD88 with just over 2 feet typical. A year later, the maximum crest elevation has settled 2 feet in this location lowered to approximately 1-foot NAVD88. There is a general reduction in the seaward and landward slope configuration of the breakwater unit that may indicate wave influenced deformation in addition to settlement. There is sediment accumulation along the seaward base of the unit with minor scouring along the landward toe of the unit.

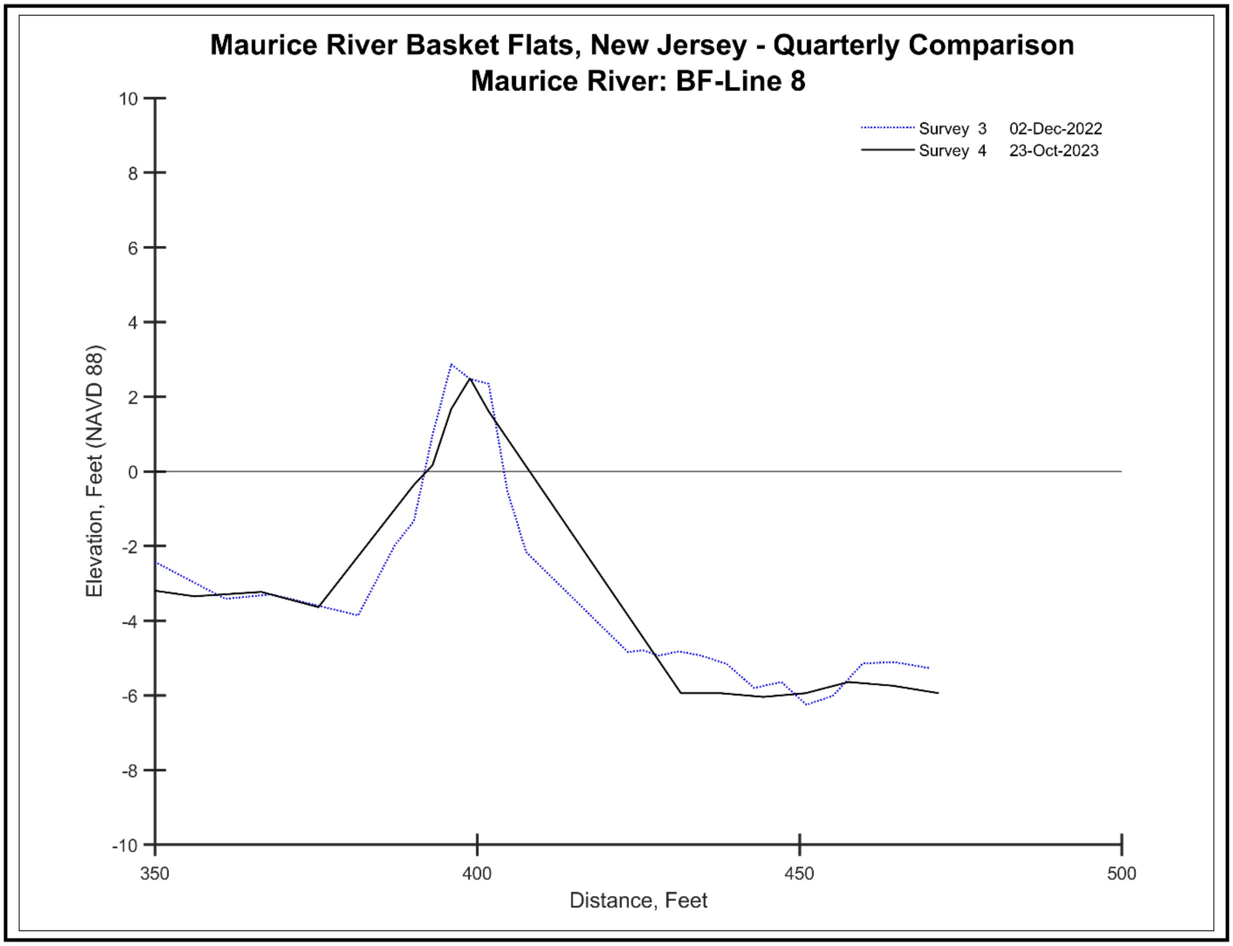


Figure 34. Line 8 crosses the western edge of breakwater unit #8. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023 one-year post construction. Initial survey shows the design target elevation of 4 feet NAVD88 for the crest was not achieved with the peak elevation reaching 3 feet NAVD88. At this location the typical crest elevation was just above MHW (2.43' NAVD88). One year post construction the peak crest elevation remained near MHW elevation in this location, but the seaward and landward top was reduced in overall width from the "As Built" suggesting some deformation due to wave impacts rather than settlement along this portion of the unit. Along both the landward and seaward slopes there was an increase in width and elevation to the base, likely a combination of sediment accretion and adjustments in rock orientation. There was a modest reduction in the bay floor elevation seaward of the unit and landward.

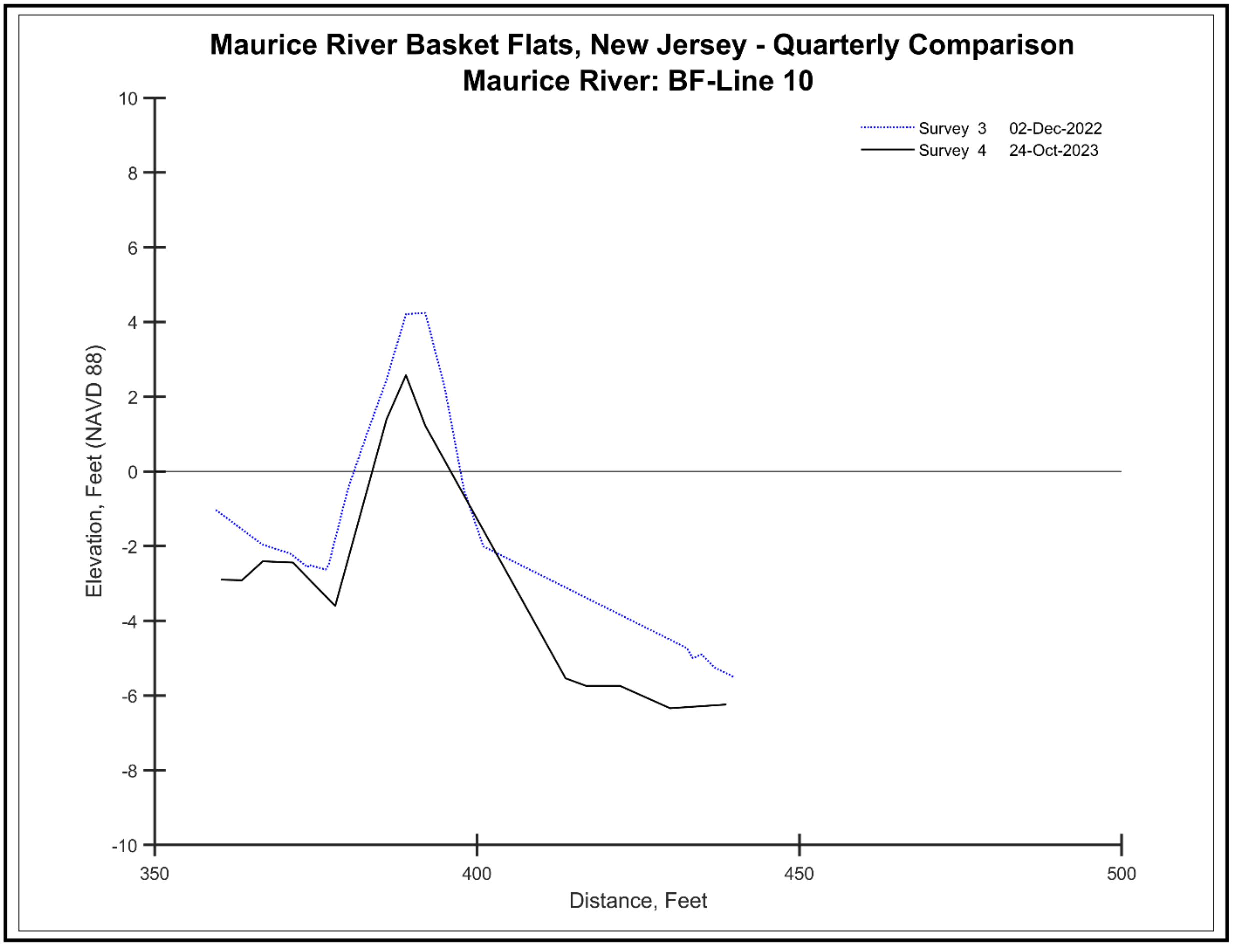


Figure 35. Line 10 crosses the western edge of breakwater unit #7. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" survey shows the crest elevation was achieved at the 4-foot NAVD88 target elevation and width. During the year following construction, the crest elevation diminished going from 4 feet NAVD88 to approximately 2.5 feet NAVD88 or just above the local MHW level. The crest width was narrower, and the slopes appear to have deformed along with the crest. On both the landward and seaward bases the bay floor elevation was scoured decreased in elevation in conjunction with the structural settlement.

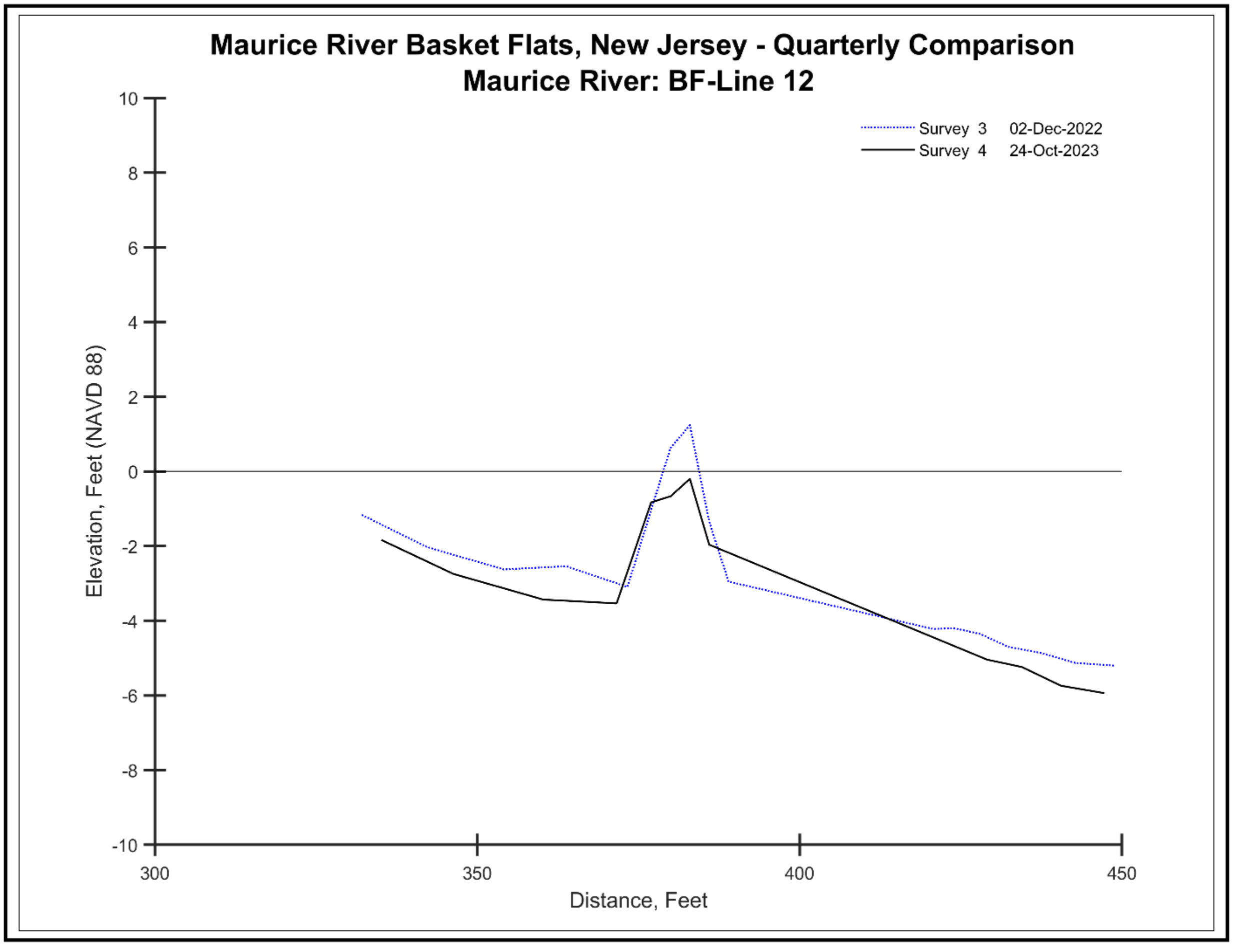


Figure 36. Line 12 crosses in the western third of breakwater unit #6. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" survey indicates the maximum crest elevation achieved during installation was at approximately 1.75 feet NAVD88, well below the design elevation of 4 feet NAVD88. A year later the crest elevation continued to settle losing an additional 2 feet and by fall 2023 was just below the zero NAVD88 datum. On both the landward and seaward sides the slopes remained stable below the zero datum with some sediment accumulation along the seaward base of the unit. Unfortunately, the lower crest elevation allows for more wave energy to be transmitted across the unit especially during higher tides and appears to have resulted in scouring nearshore where the bottom elevation deflated from fall 2022 to fall 2023. The wave attenuation functionality of this structure has been impaired by the crest elevation deficit both "As Built" and due to settlement overtime. Elevation and width of this structure will need to be monitored for further settlement and deformation over time.

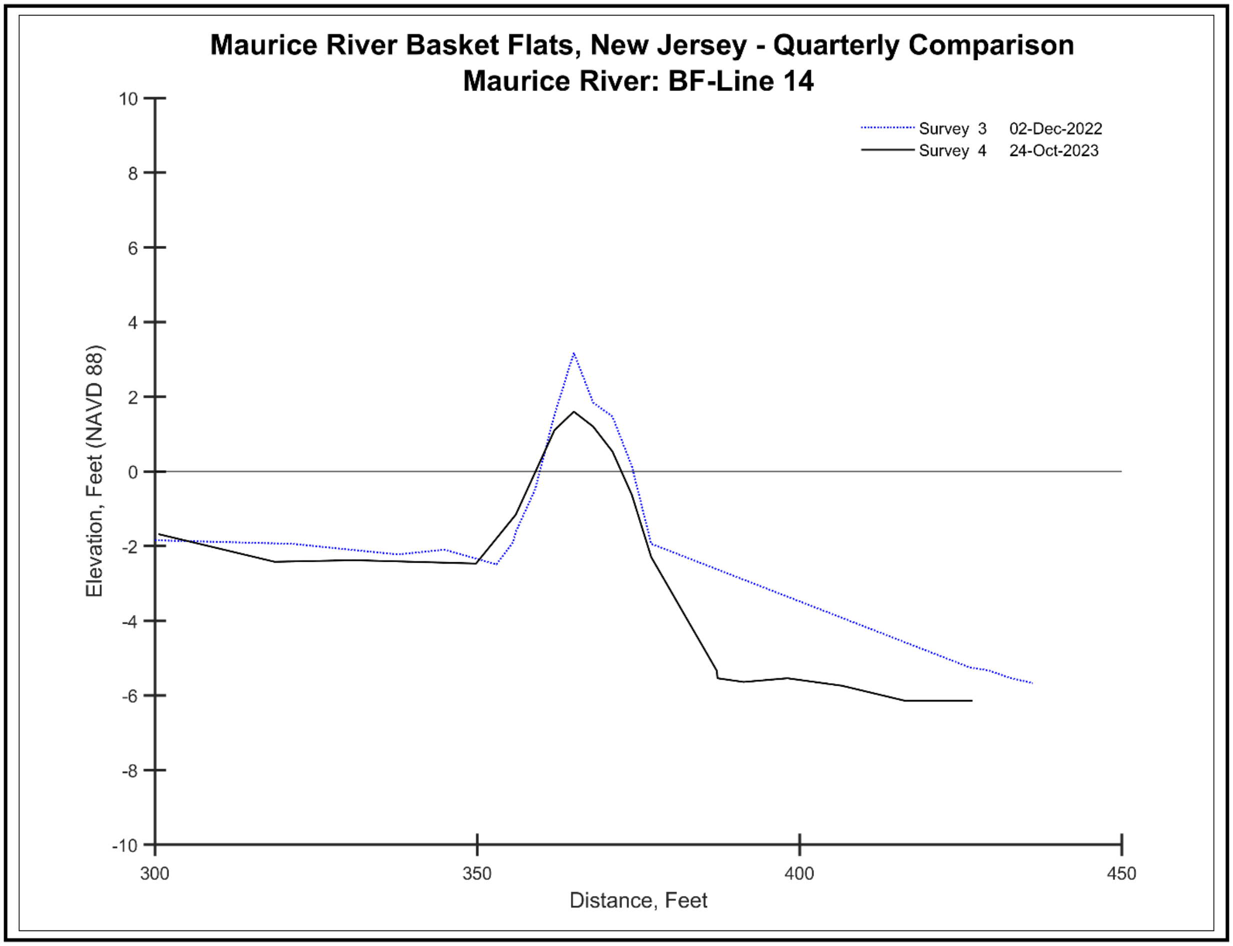


Figure 37. Line 14 crosses near the middle of breakwater unit #5. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. "As Built" data shows the crest elevation was below the 4-foot design elevation with the maximum peak at between 3 to 3.25 feet NAVD88. The crest elevation during the year decreased nearly 1.5 feet to just under 2 feet NAVD88 or below current MHW (2.43' NAVD88) levels. While the crest settled the seaward slope showed minor deformation while the landward slope showed minor expansion likely caused by a shift in stone as anticipated in the engineering design of the units. Seaward of the unit, sediment was scoured along the base of the structure deflating the bay floor elevation. Landward of the structure nearshore elevation deflation was minimal.

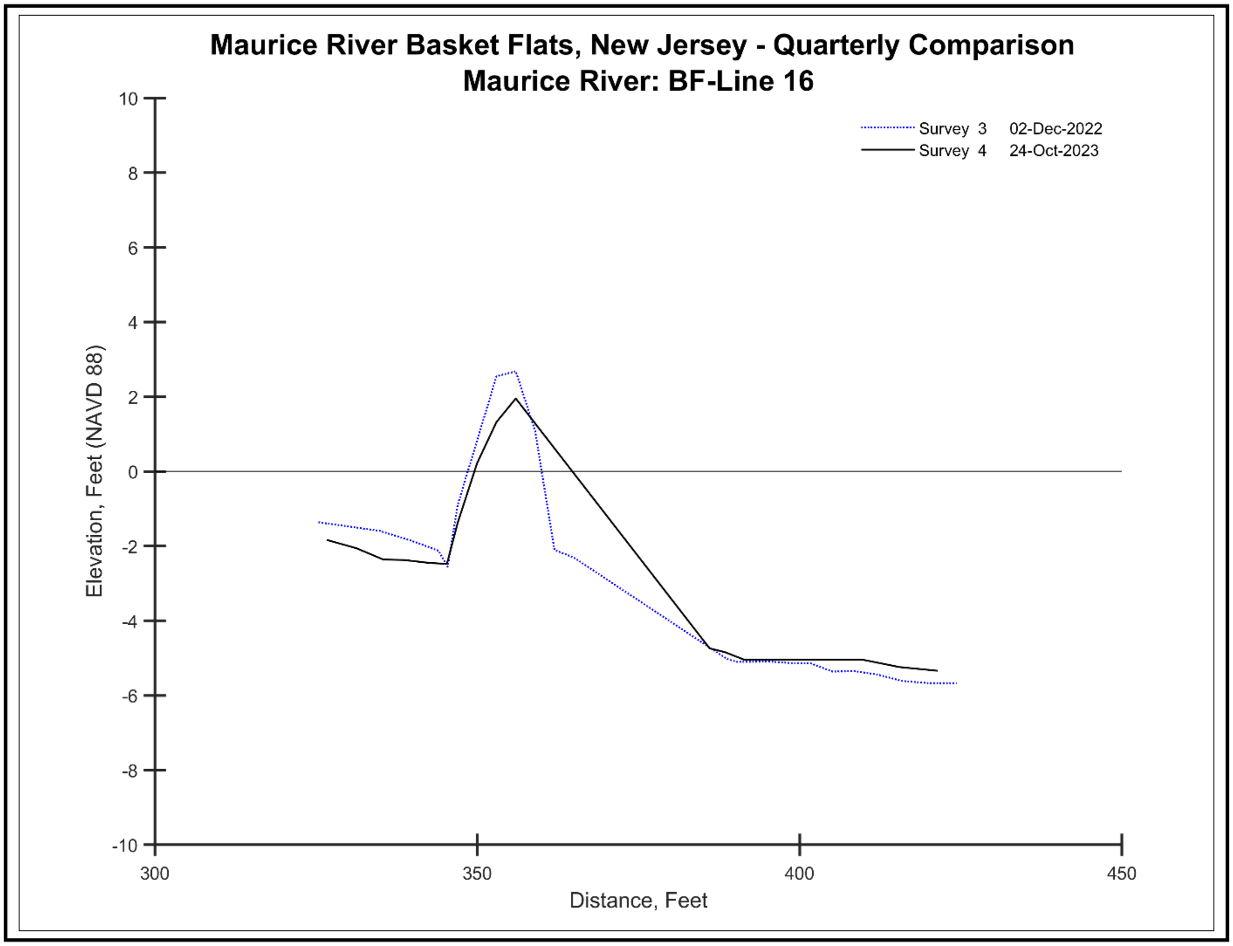


Figure 38. Line 16 crosses the mid-section of breakwater unit #4. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" crest elevation was approximately 3 feet NAVD88 or one foot below the design target elevation of 4 feet NAVD88. By fall 2023, the crest elevation was reduced by nearly a foot to just above 2 feet NAVD88. This crest elevation is just below the MHW (2.43' NAVD88) level but still provides significant wave attenuation benefits through most of the tidal range. The crest width is narrower a year after installation indicating some deformation, but the landward slope was stable in configuration. There is deflation of the nearshore elevation, indicating minor scouring adjacent to the landward base of the unit. Along the seaward slope there was significant sediment accumulation during the year following installation. It is uncertain if any stone displacement is covered by this sediment accretion.

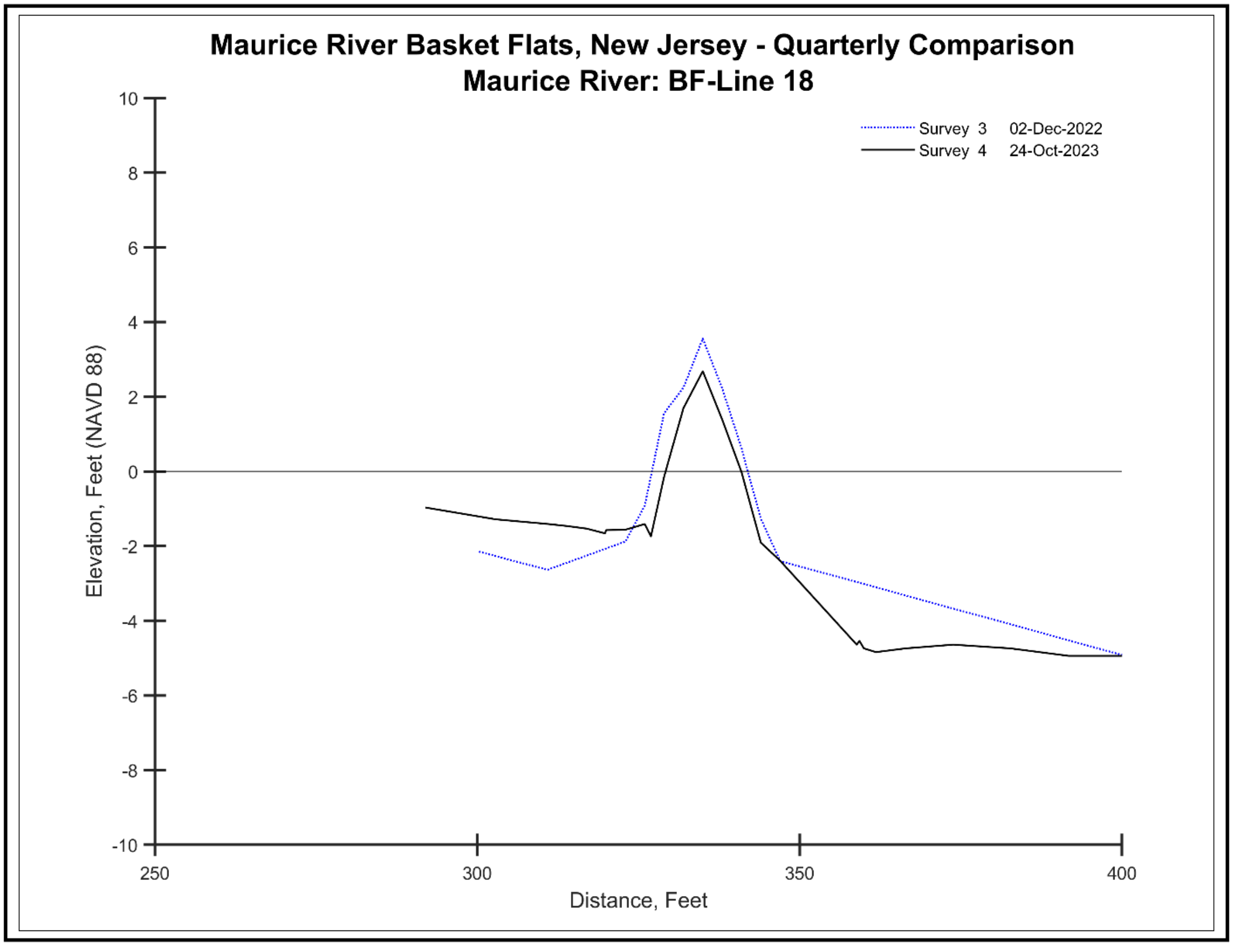


Figure 39. Line 18 crosses the mid-section of breakwater unit #3. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" crest configuration shows the design target elevation of 4-foot NAVD88 was achieved. By fall 2023, the crest elevation was reduced by nearly a foot to approximately 3 feet NAVD88. This crest elevation is still above the MHW (2.43' NAVD88) level and provides significant wave attenuation benefits. The crest and slope width are narrower a year after installation indicating some deformation. There is significant elevation inflation of the nearshore leeward of the breakwater, it is uncertain how much stone if any was covered by the sediment accretion in this region. Seaward of the unit there was elevation deflation of the bay floor due to scouring adjacent to the seaward base of the unit.

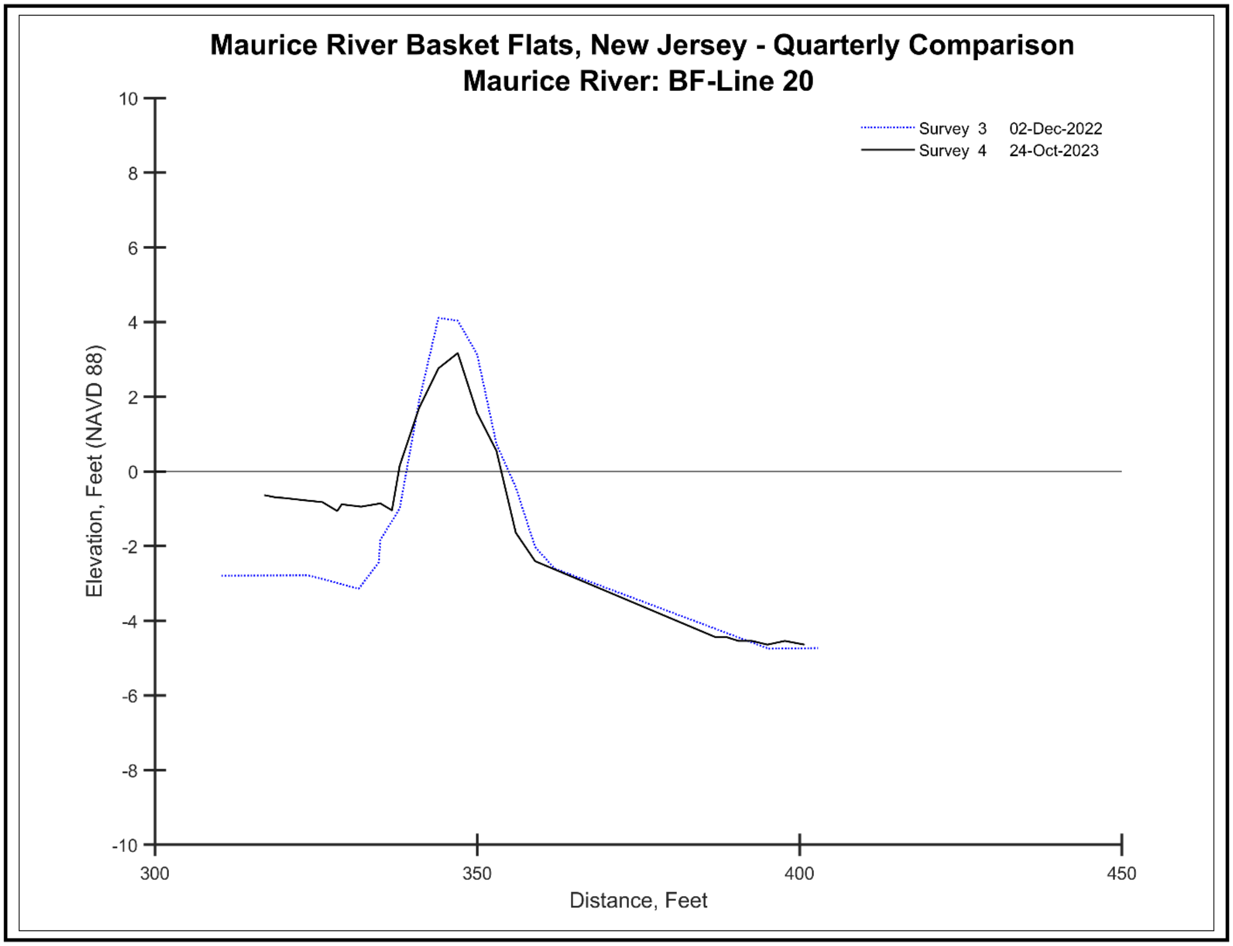


Figure 40. Line 20 crosses the eastern side of breakwater unit #2. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" crest elevation shows the full 4-foot NAVD88 design target elevation and crest width was achieved at this location. By fall 2023, the crest elevation was reduced by nearly a foot to approximately 3 feet NAVD88 while the crest width was narrower indicating some deformation along the crest in addition to settlement. This crest elevation is still well above the MHW (2.43' NAVD88) level and provides significant wave attenuation benefits. The unit slopes remained largely intact a year after installation with some minor deformation along the seaward slope and expansion along the landward base. There is significant elevation inflation (2 feet) of the nearshore leeward of the breakwater as sediment accumulated. On the seaward side, the bay floor elevation adjacent to the base of the unit was stable with little or no changes in elevation.

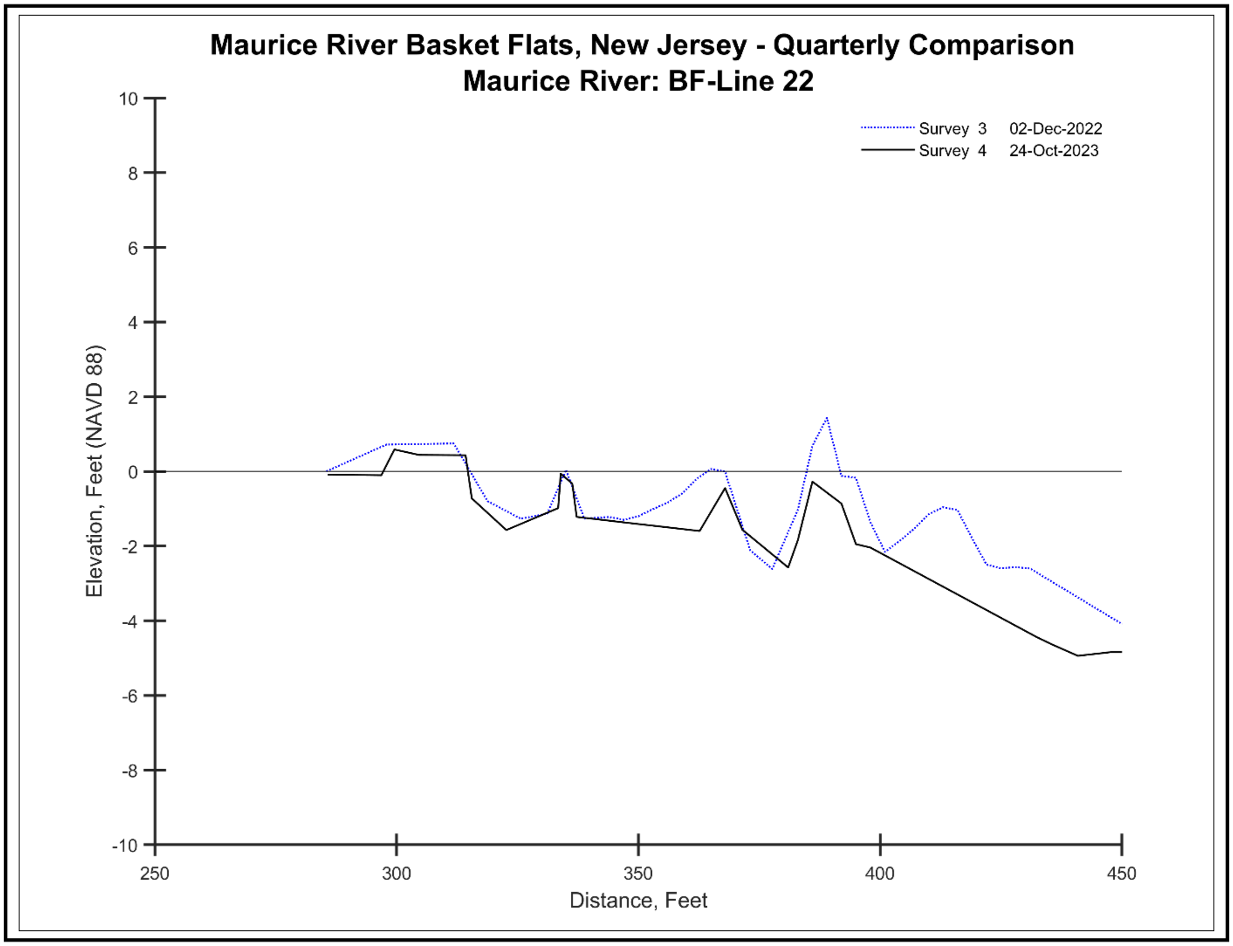


Figure 41. Line 22 crosses the eastern side of breakwater unit #1. The cross-section compares conditions surveyed and scanned during the "As Built survey (fall 2022) with the survey data collected in fall 2023, one-year post construction. The "As Built" survey shows the crest design target elevation was never achieved as the foundation mattresses shifted and the breakwater stones settled rapidly below the design elevation. The result was the unconsolidated structure with differential peak elevations and width. Fortunately, the western end of the unit was more intact but still well below the design target elevation. By fall 2023, the unit elevation showed continued settlement with the worst rates occurring on the seaward side of the unit. On the seaward side, sediment was scoured and the bay floor elevation deflated along the seaward base of the unit.

Multi Beam and Side Scan Sonar Structural Survey

1) Introduction

This document outlines the survey work performed by the Stockton University Marine Field Station marine operations group (SUMFS) while carrying out a co-registered side scan/multibeam survey of nine rock pile installations and one rock sill along the southern shoreline of Basket Flats.

2) Personnel

Hydrographic surveys were undertaken by SUMFS marine operations and hydrography personnel. The Stockton staff have greater than 10 years of survey and data analysis experience aboard the utilized vessel and with the utilized instrumentation. Staff are trained in QPS Qinsy software data acquisition, QPS Qimera processing for multibeam echosounder sonars and general best practices for MBES surveys including patch testing, SVP requirements and survey design.

3) Site Conditions

The project site is located at Basket Flats, Commercial Township in Cumberland County, NJ, a marsh peninsular south of community of Bivalve, a small bayfront community and port. The Basket Flats marsh has been exposed to wave and flood damage over the years and continued to erode retreating over 2,000 feet during the last four decades. As the tip of Basket Flats retreated, marshes and communities upstream are increasingly more vulnerable to the bay wave climate, flooding and storm surge damages. Continued loss of Basket Flats would result in the community of Bivalve being exposed directly to the bay wave climate and loss of valuable marsh habitat at Basket Flats. The project included a series of nine 200-foot-long detached rock breakwaters, and one rock sill installed nearshore to diminish wave energy at the shoreline, improve conditions for accreting sediment, reduce marsh edge loss and diminish loss of high marsh on Basket Flats. The breakwaters would also enhance ecological and community resilience during storm events by attenuating wave energy.

4) Scope of Work

The scope of work included the collection of co-registered side scan and multibeam data in the treatment area consisting generally of 9 rock pile and one rock sill installations along the southern shoreline of Basket Flats at the mouth of the Maurice River.

5) Survey Vessel, Instrumentation and Software Descriptions

5.1 Survey vessel; The *R/V Osprey* is a 24’ x 8’ x 2’ Chesapeake-style boat design with a single outboard engine.

5.2 Multibeam Sonar; The *R/V Osprey* is equipped with an Edgetech 6205 combined side scan and shallow water interferometric multibeam system mounted over-the-side further stabilized with an additional connection point on the X-arm to the interior deck. The IMU and GPS antennas are on an arm above the sonar (Figure 2). The system co-collects side scan data at 555 kHz and 1600 kHz along with multibeam data to 6-8x water depth. Water depth data for multibeam acquisition was limited to 6x water depth for this survey.

- Frequency = 540kHz and 1600 kHz
- Ping Rate = Up to 60 kHz
- Beam Density = 256 Beams
- Max Swath Width = 200m
- Beamwidth = 1.0° x 0.5°
- AML Sound Velocity Sensor integrated at Sonar Head

5.3 Inertial Motion Unit; Motion corrections were provided by a Applanix I2NS Type II Wavemaster IMU mounted directly on top of the sonar mount pole when deployed over the side. The IMU location is referenced to the center point of the vessel, or the center of gravity (CoG) of the vessel.

- Position Accuracy: RTK = 0.02m
- Roll & Pitch Accuracy: 0.02°
- Heave Accuracy: 5 cm (real time)
- Heading: 0.03° (2m baseline)

5.4 GNSS; Positioning was provided by a dual Trimble 540AP GNSS antennas mounted on fore and aft on an antenna arm on top of the sonar pole. A Leica SmartNet GNSS network was used for RTK corrections. Using cellular data connection to the Internet, Smartnet's Nearest Base Station corrections were utilized in Real-Time and resulting in sending RTK positions directly to The I2NS. The g2012b-CONUS model was applied to the raw RTK GPS height within the NAVD88 vertical datum.

5.5 Sound Velocity Profiler; The water column sound velocity profiles were measured with an AML-3 LRG Sound Velocity profiler approximately every 30 minutes during the survey

5.6 Quality Positioning systems (QPS)

- **Qinsy for data acquisition**
- **Qimera for data processing resulting in outputs in x, y, z format**

6) Survey Checks and Calibrations

6.1 Patch Test; To calculate the mounting angle corrections associated with the multibeam transducer with respect to the IMU, an industry standard and manufacturer recommended patch test was conducted. Patch test data was collected locally to the survey area over the slope of the channel of Nantuxent Creek and adjacent flat bay floor and the resulting values were within expected values when compared to previous efforts with the same installation parameters. The 6205 uses dual head multibeam transducers requiring Roll values for each the port and starboard heads.

Port head	Pitch: 2.75	Roll: -0.188	Heading: 1.00
Starboard head	Pitch: 2.75	Roll: 0.373	Heading: 1.00

Figure 1. *R/V Osprey Patch* Test Values as collected on site during the survey

6.2 Sound Velocity; The 6205 has an integrated AML sound velocity sensor order to measure instantaneous sound velocity, which is interfaced to the sonar processor for the integral 'beamforming' process of the system to occur. The water column sound velocity profiles were measured with an AML-3 sound velocity and depth profiler. A check of the sonar head SV was made at the beginning of the survey by comparing the values to those recorded by the AML profiler held at the sonar head level.

Sound velocity profiles were conducted using the AML system at an interval of approximately every 30 minutes or when noticeable difference in sound velocity occurred as a result of changing environmental conditions.

7) Survey design

The survey was conducted at a higher-than-normal lunar tide to provide the greatest ability to collect multibeam data at a safe distance from the sonar head to the rock installations. Initial passes were conducted in a west to east direction (up and down the shoreline) from the seaward side of the rock piles to establish their locations. Subsequent passes relied on sonar and vessel operator communication to allow maximum swath collection and safe navigation in the shallow survey area. Data collection was stopped during all turns. At the conclusion of multibeam data collection several side scan-only lines were planned at distances to allow placement of the rock installations in the middle of the selected range.

- Low frequency side scan was co-registered with the multibeam data using a range of 50 meters during the multibeam portion of the survey. Vessel lines were run to maximize swath data collection and safe navigation while ensuring that all areas were insonified at least two times.

Low and high frequency side scan-only lines were established at ranges of 50 meters and 20 meters, respectively and run on the seaward of the rock installations, landward side was too shallow to safely operate a vessel.

8) Side Scan Images

The side scan images figures 42-50 show the subaqueous configuration of the breakwaters on December 14, 2023, approximately one year following installation. Unfortunately, due to the shallow water landward of the breakwaters it was impossible to safely operate a vessel and scan the leeward side of the units. This results in a large shadow extending off the units towards the shoreline. Breakwater units were labelled 1-9 extending from west to east along Basket Flats project area.

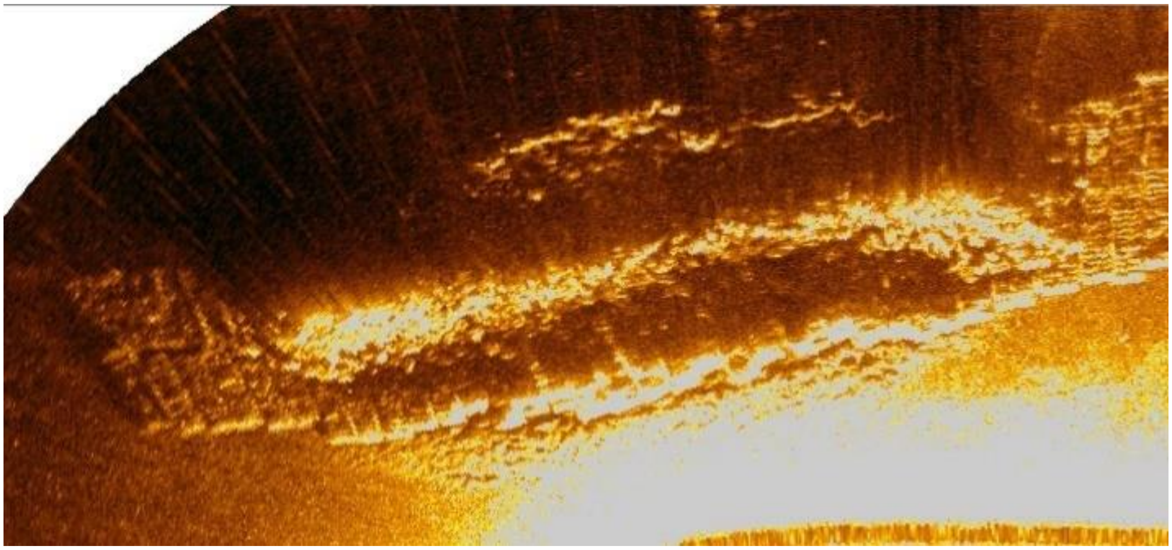


Figure 42. Breakwater 1 is located at the northwest end of the Basket Flats project area. The side scan image shows the structure below the water level. The rows of rectangular foundation mattresses are visible with the rock breakwater located towards the center of the image. Bright colors in the image are representative of higher elevations with more light refraction while the darker regions are caused by the shadows cast. The water levels landward of each structure is too shallow to operate a vessel preventing scans along the leeward side.

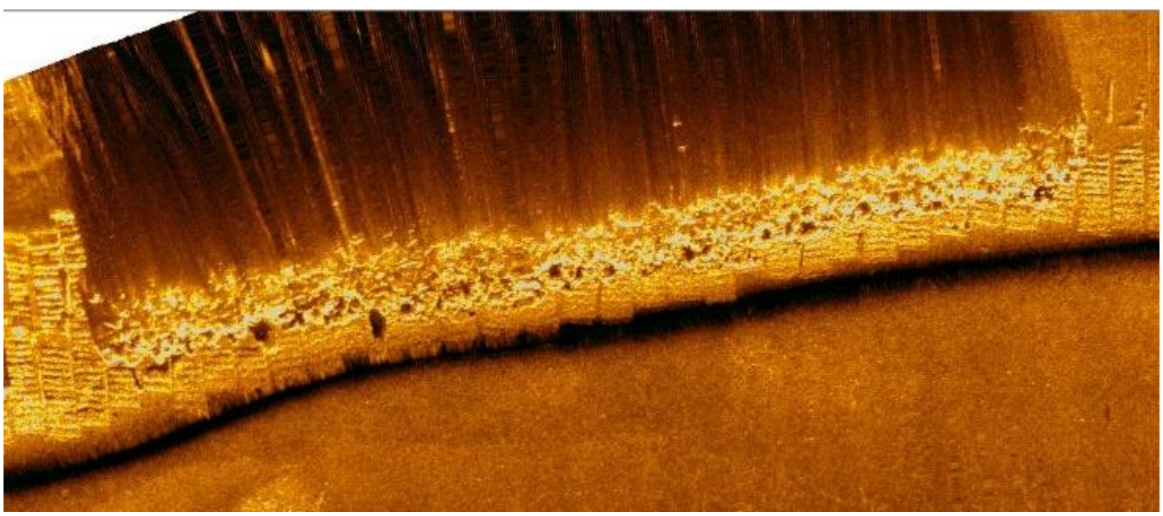


Figure 43. Breakwater 2 is located to the east of unit 1 along the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain intact below the rock breakwater located towards the center of the image. Bright colors in the image are representative of higher elevations with more light refraction while the darker regions are caused by the shadows cast off the rock breakwater structure.

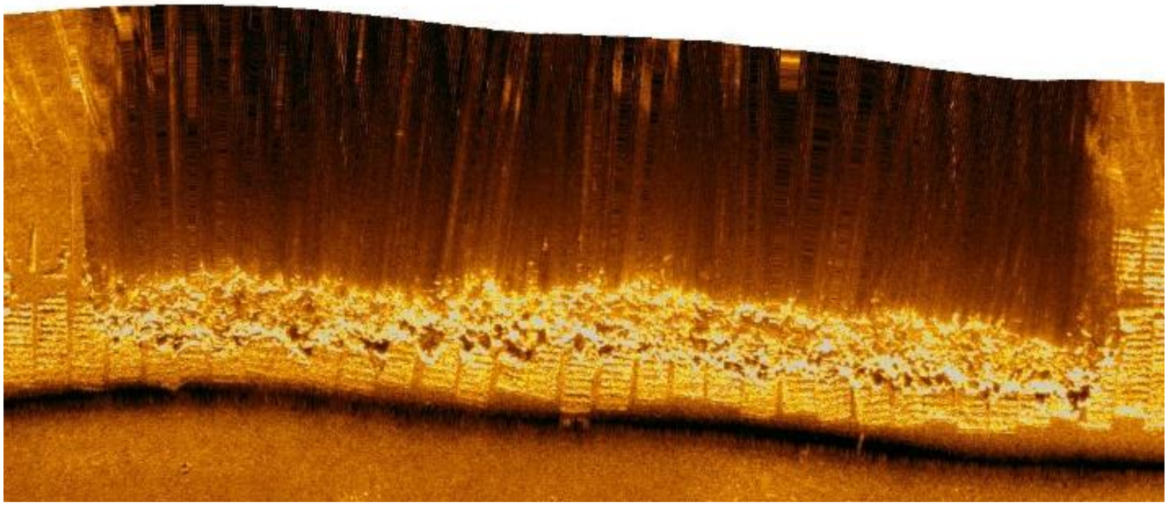


Figure 44. Breakwater 3 is located to the east of unit 2 along the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain intact but there is evidence of minor separation between adjacent mattress units. The breakwater rocks remain in place towards the center of the image with little evidence of deformation or scattering of rocks. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

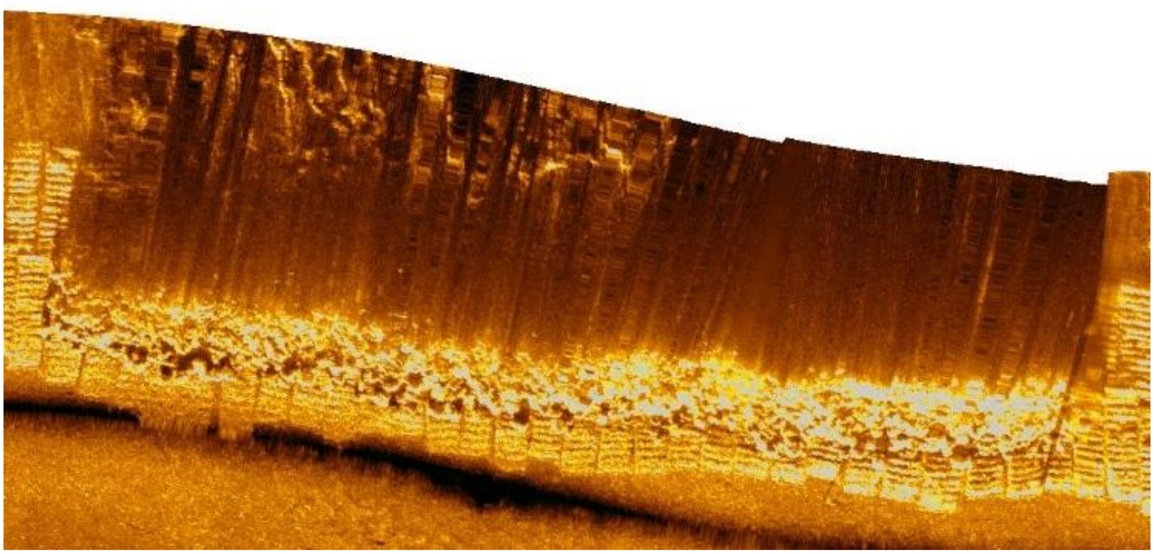


Figure 45. Breakwater 4 is located to the east of unit 3 along the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain largely intact as originally placed. The breakwater rocks also remain in place towards the center of the image with little evidence of deformation or scattering of rocks of the units. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

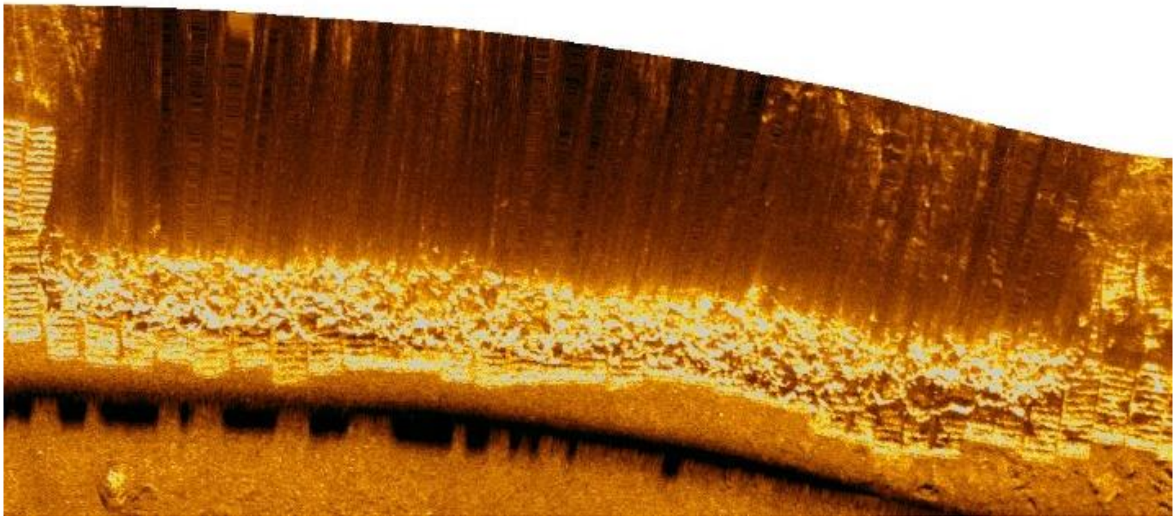


Figure 46. Breakwater 5 is located to the east of unit 4 towards the mid-section of the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain tightly together and intact as originally placed. The breakwater rocks towards the center and right of the unit appear to show evidence of r scattering of rocks off the units towards the seaward edge of the mattresses. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

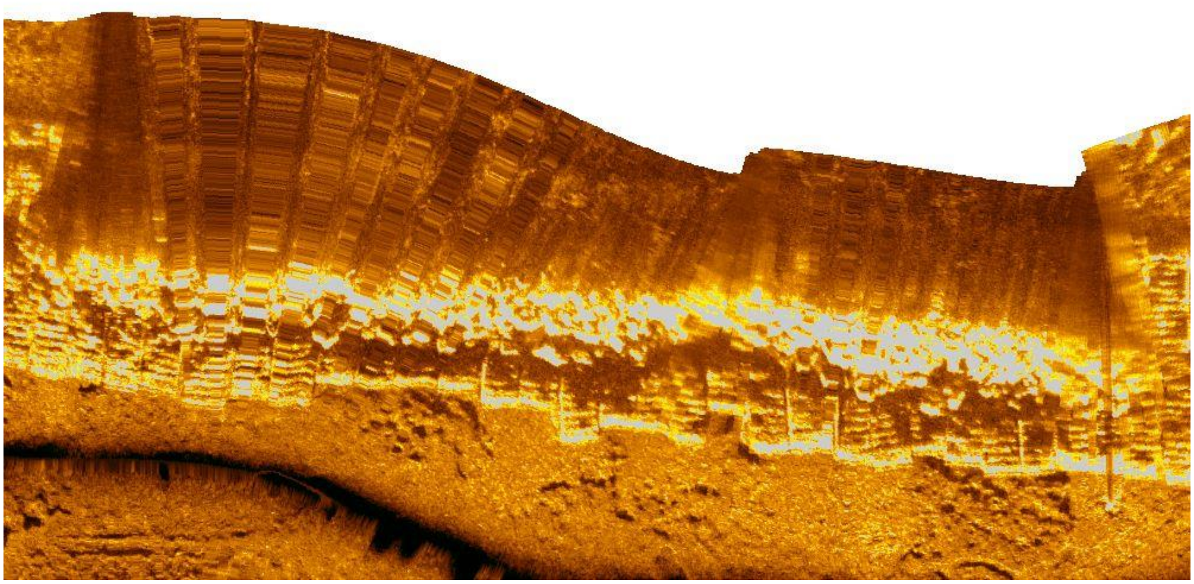


Figure 47. Breakwater 6 is located to the east of unit 5 towards the mid-section of the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain tightly together and intact as originally placed. The breakwater rocks remain in place and show no evidence of scattering of rocks off the units or deformation of the structure. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

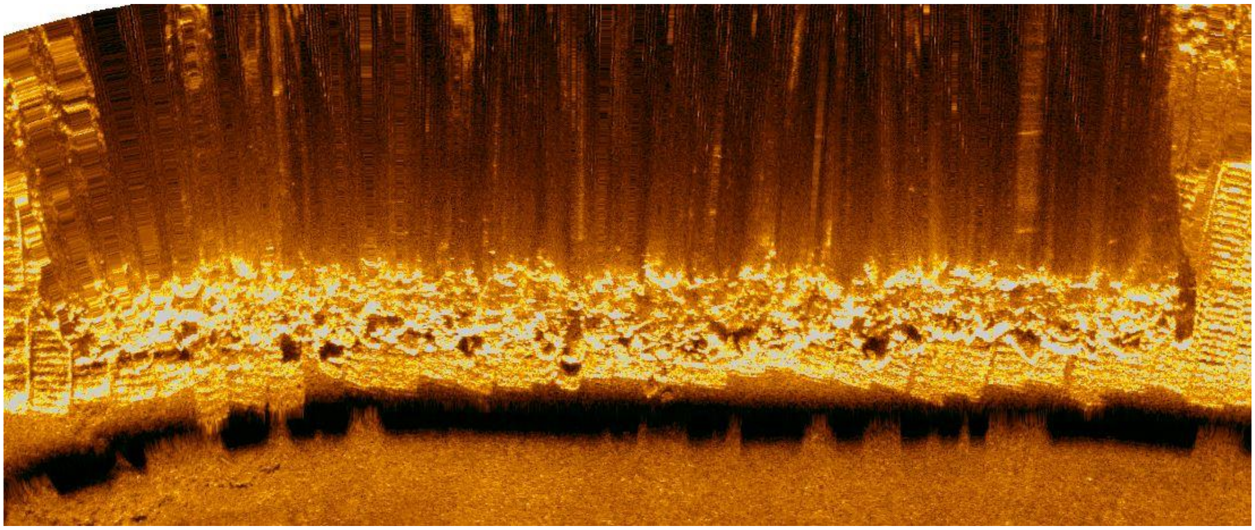


Figure 48. Breakwater 7 is located to the east of unit 6 towards the eastern section of the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses remain tightly together and intact as originally placed. The breakwater rocks remain in place with some evidence of rock scattering in the midsection along the seaward base. and show no evidence of scattering of rocks off the units or deformation of the structure. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

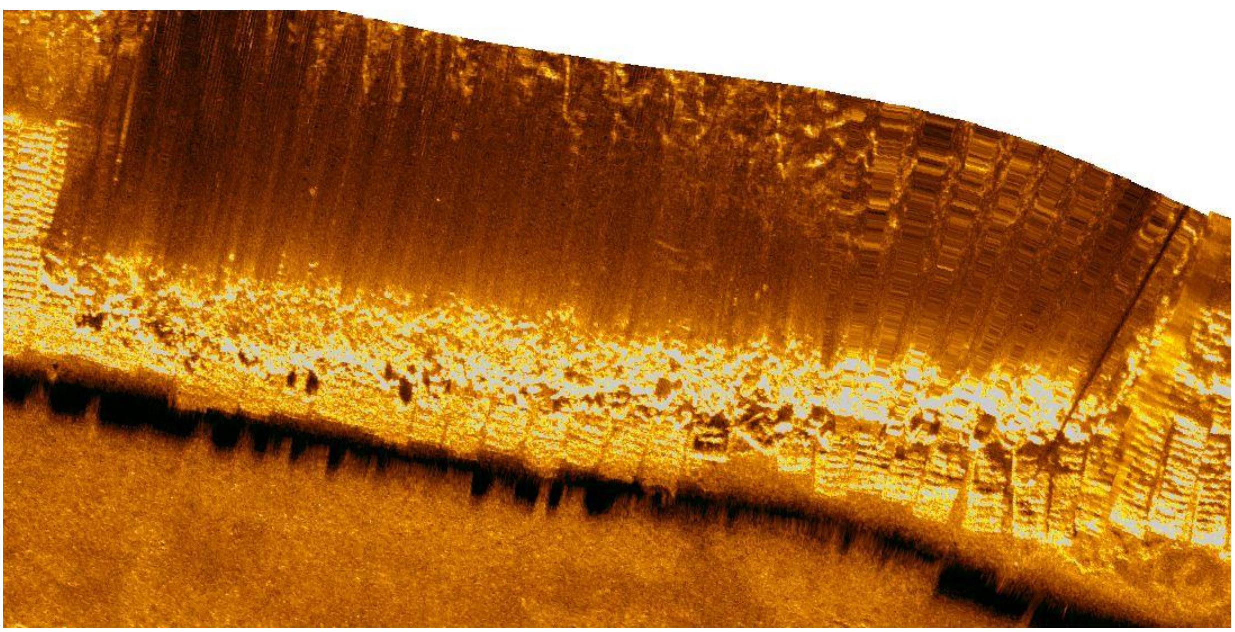


Figure 49. Breakwater 8 is located near the east end of the Basket Flats project area. The side scan image shows the rows of rectangular foundation mattresses on the left side remain tightly together and intact as originally placed. Towards the center right there are a few rows that appear to have been placed offset towards the land and have separated. The breakwater rocks remain in place with minor evidence of rock scattering off the units. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure

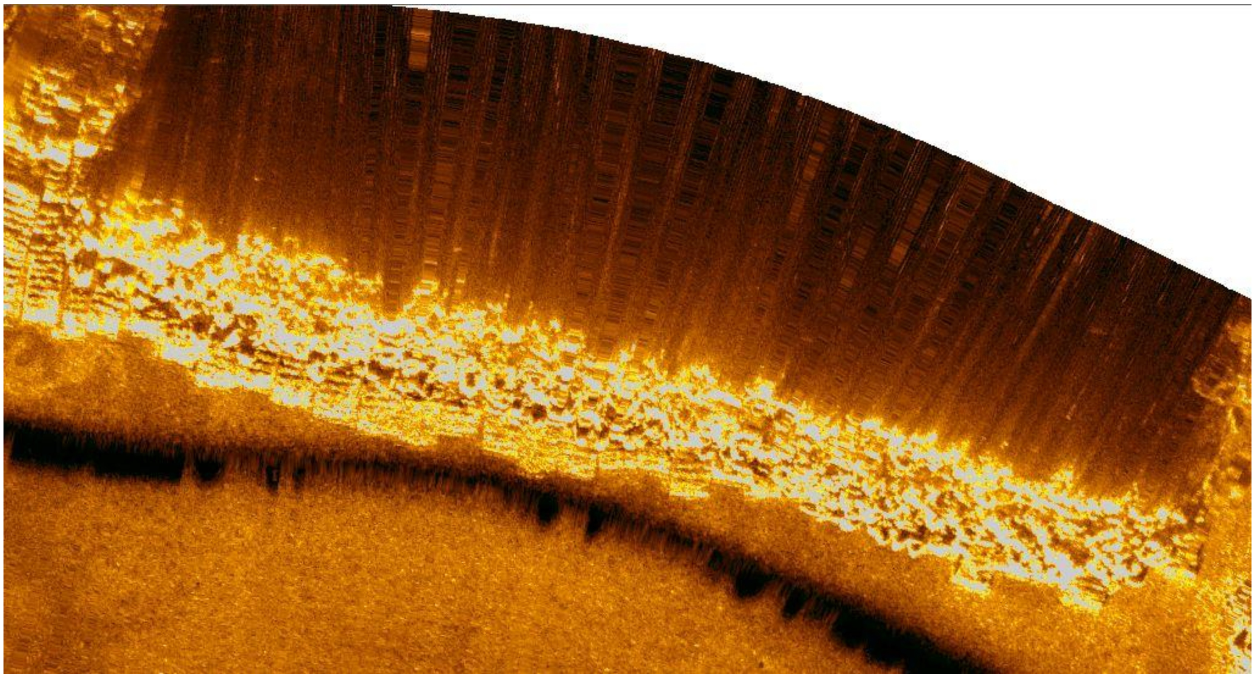


Figure 50. Breakwater 9 is located at the east end of the Basket Flats breakwater project area. The side scan image shows the rows of rectangular foundation mattresses remain tightly together and intact as originally placed. The breakwater rocks remain largely in place but show evidence of rock scattering off the units or deformation along the eastern end of the structure. Bright colors in the image again are representative of higher elevations while the darker regions are caused by the shadows cast off the rock breakwater structure.

9) Multi Beam Images

The Multi Beam images figures 51-55 show the subaqueous elevations of the breakwaters and bay floor bottom elevations immediately seaward of the units on December 14, 2023, approximately one year following installation. Unfortunately, due to the shallow water landward of the breakwaters it was impossible to operate the Multi Beam system along the leeward side of the units. This results in an incomplete image of the units on the landward slope and of the bay floor towards the shoreline. Breakwater units were labelled 1-9 extending from west to east along Basket Flats project area. The image colors represent changes in elevation with reds indicating the highest elevation and greens to purple lower elevations.

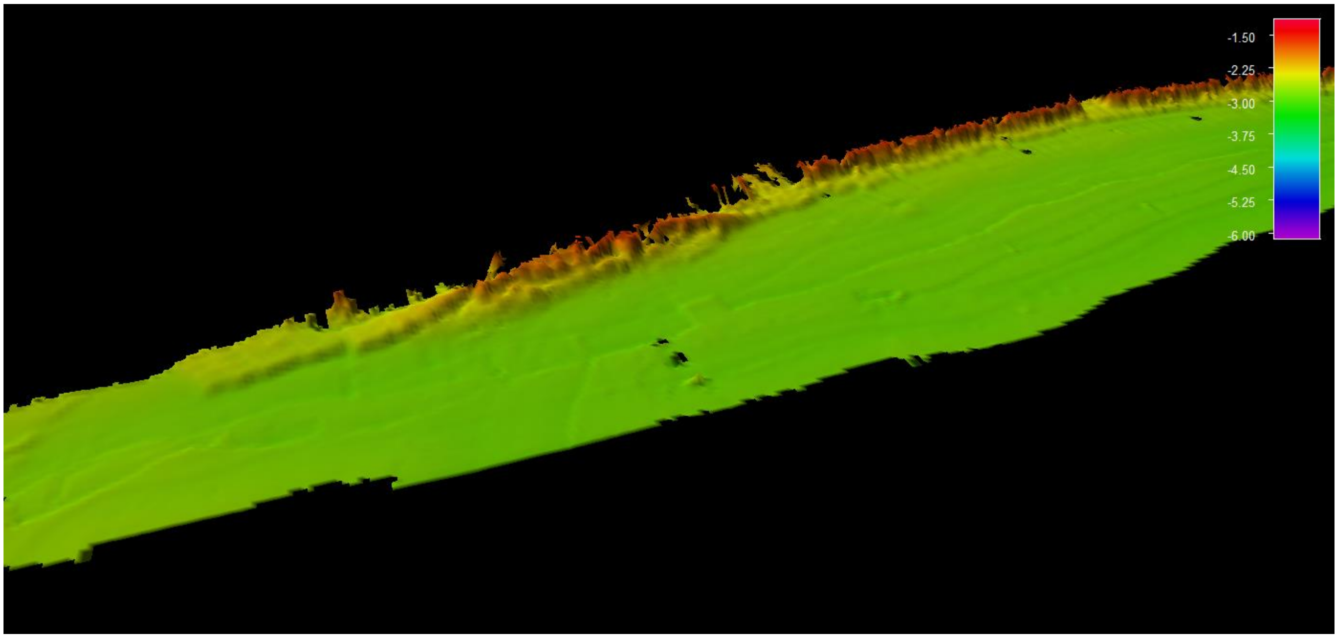


Figure 51. Shows the spatial relationship between Breakwater unit #1 and #2 (left to right) with a portion of unit #3 visible in the upper right corner. Brownish to red colors indicate the higher portions of the breakwater but none exceed -1.5 feet NAVD88 due to limitations of the multi beam recording elevations below the water surface. Green colors indicate the bay floor bottom while yellow are the foundation mattresses. Unit #2 is very uniform in elevation across the structure while Unit #1 has some elevation deflation on the seaward slope along the western (left) side of the unit.

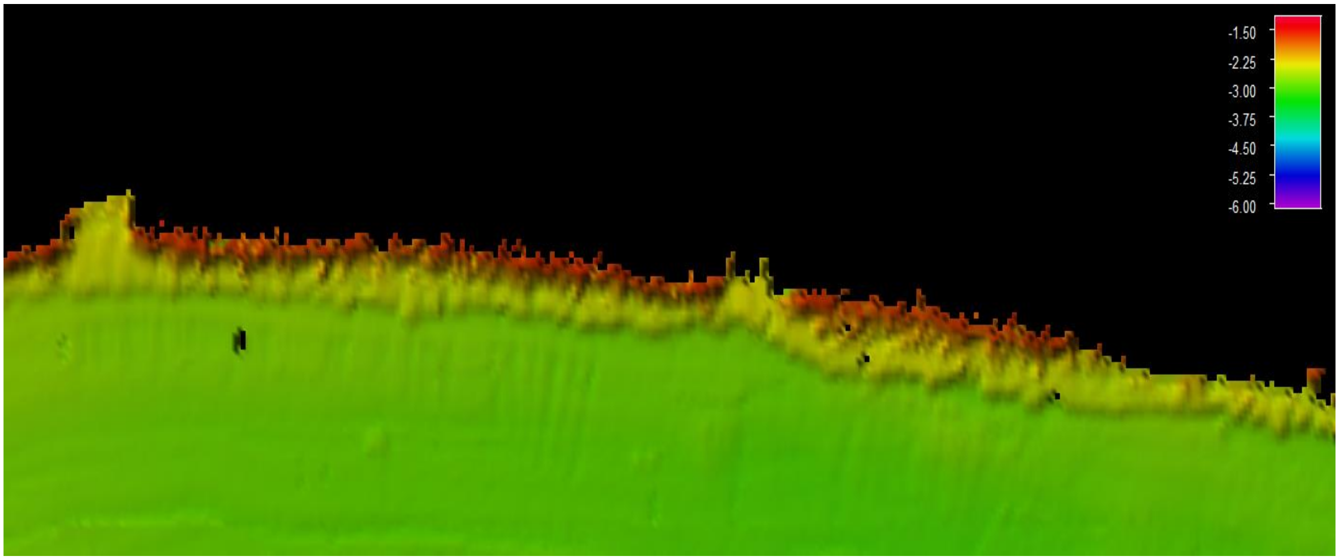


Figure 52. Shows the spatial relationship between Breakwater unit #3 and #4 (left to right). Brownish to red colors indicate the higher portions of the breakwater, none exceed -1.5 feet NAVD88 due to limitations of the multi beam recording elevations below the water surface. Green colors indicate the bay floor bottom while yellow are the foundation mattresses and gaps between the units. Unit #3 is very uniform in elevation across the structure while unit #4 has some elevation deflation on the seaward slope along the eastern (right) side of the unit.

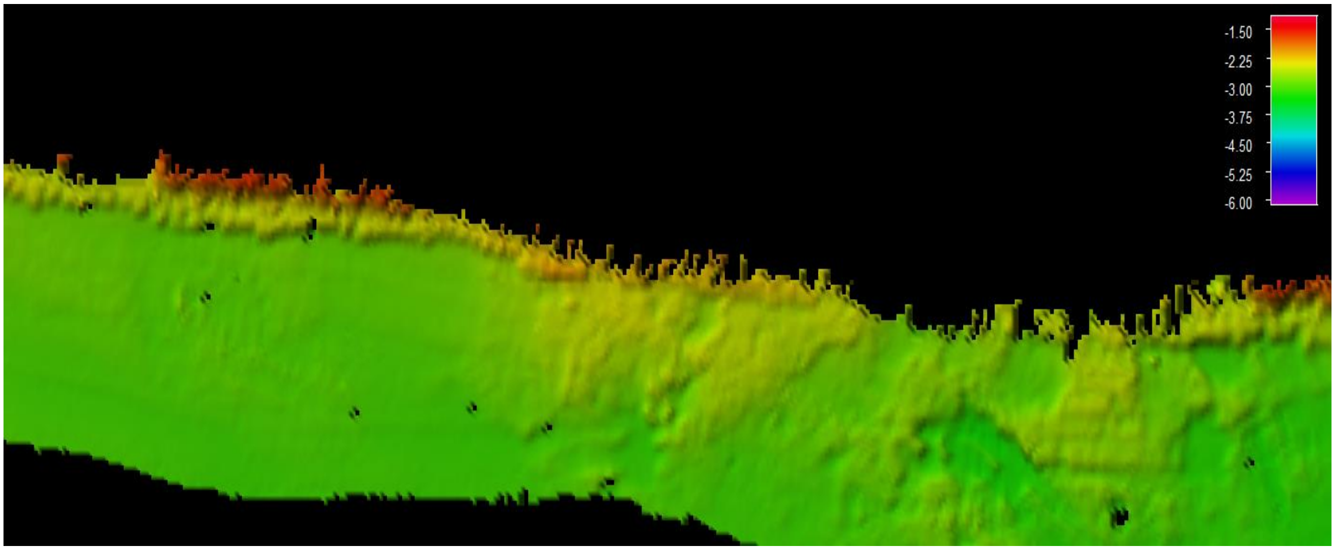


Figure 53. Shows the spatial relationship between Breakwater unit #5 and #6 (left to right). Brownish to red colors indicate the higher portions of the breakwater on unit #5. Unit #6 is mostly yellow in color indicating deflation on the seaward slope. Green colors indicate the bay floor bottom while yellow are the foundation mattresses and gaps between the units. Seaward of Unit #6 there is an extension of yellows indicating slightly higher elevation than the surrounding bay floor. The side scan image of unit #6 confirms the presence of this pattern. This pattern may be caused by shifted stones, misplaced stones or another surface unconformity.

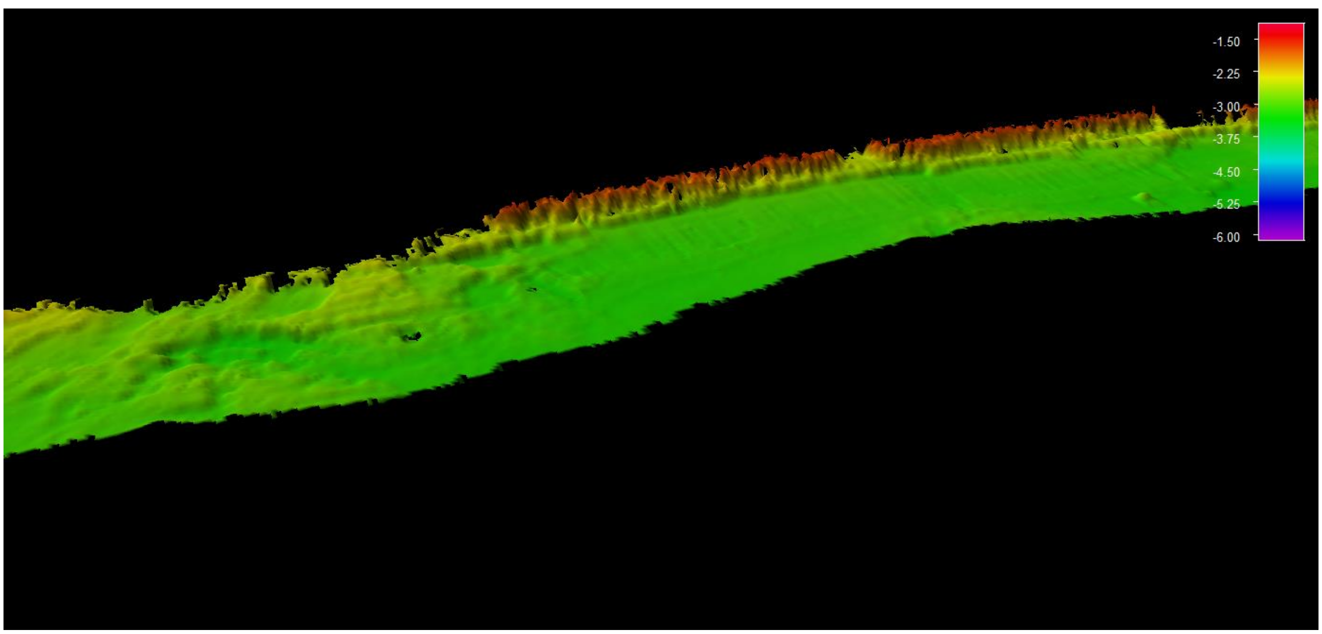


Figure 54. Shows the spatial relationship between Breakwater unit #7 and #8 (left to right center) to the far right a portion of breakwater 6 is included with the unconformity on the bay floor. The bay floor seaward of units 7 and 8 is more consistent in elevation as are the seaward slope elevations of each breakwater. Brownish to red colors again indicate the higher portions of the breakwater seaward slope with yellow typically indicating the foundation mattress below the rocks and in the gaps between units.

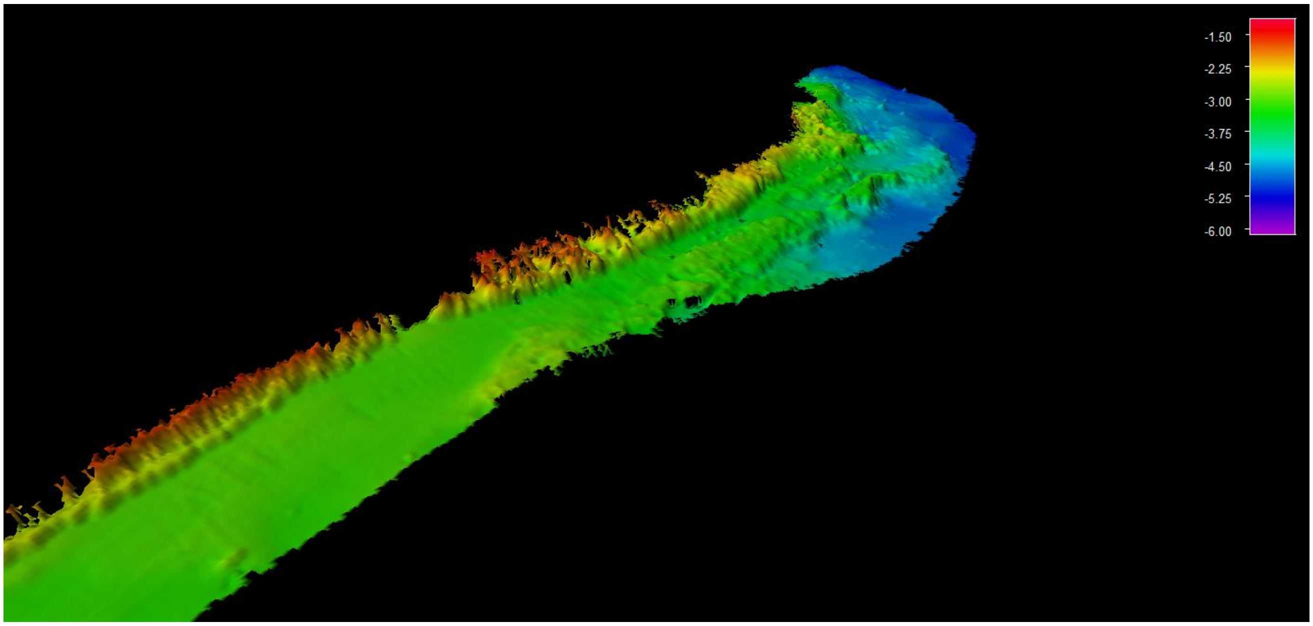


Figure 55. Shows the spatial relationship between Breakwater unit #9 and the sill and revetment #10 to the far right. The bay floor seaward of unit #9 is consistent in elevation while towards unit #10 the bay floor quickly drops into the deeper channel off the tip of Basket Flats. The seaward rock slope elevation also decreases moving towards the tip on unit #10.

Summary Discussion

Imagery and post project monitoring shows the "As Built" breakwater units installed along the southern shore of Basket Flats has created a quiescent area leeward of the breakwater units. The units are effective at reducing the approaching incident wave height to a much smaller transmitted wave impacting the shoreline. Shoreline monitoring shows a beneficial reduction in erosion during the year following installation of the breakwater units. Most of the beach profile stations monitored showed minor single digit changes in the shoreline position ranging from an advance of 1 foot to -6 feet of retreat. Only two of the 13 sites behind the breakwater units showed an extreme change. At line 20, located towards the western end of the project area, the shoreline position shifted seaward 33 feet as up to 2 feet of sediment accumulated within the lee of the breakwater unit. Towards the eastern end of the project a landward shift in the shoreline position of -9 feet occurred at line 8. Sediment volume changes over the year of monitoring at 10 of the 13 sites ranged from a small gain of 2.49 yds^3/ft to a minor loss of -2.05 yds^3/ft. Line 20 at the western end of the project area gained 8.59 yds^3/ft of sediment during the year, leeward of the breakwater unit the largest single increase. Line 0 and line 2 located at the east end of the project area near the low-profile sill where exposure to waves is greatest losses were -6.93 yds^3/ft and -8.33 yds^3/ft respectively. The minimal shoreline changes and modest volume changes recorded in the lee of the breakwater units support the aerial drone evidence of general sediment build up seaward from the marsh edge towards the breakwater units during the first year following installation.

Structurally the breakwater units performed within anticipated ranges for settlement and deformation at 6 of the 9 units, based upon the engineer study expectations associated with the project design. At these sites, the design crest elevation (4 feet NAVD88) was achieved or exceeded. Deformation and settlement varied but was within the design tolerance range, limited to less than 2 feet during the year following installation. This settlement rate resulted in crest elevations at or near MHW (2.43 ' NAVD88) levels. Units 1, 6, and 8, numbered from west to east for this report each had elevation issues associated with these units. The western unit #1 was subject to immediate issues due to failure of the foundation mattress. "As Built" scans showed the design crest elevation was not achieved with a maximum elevation of 1.5 feet NAVD88. Separation and shifting of the mattress from below the rock breakwater during construction caused immediate settlement and deformation of the structure and prevented design specifications from being achieved at this site. During the year following construction, settlement continued at a similar rate (1 – 2 feet) resulting in a crest elevation below the zero-datum level. The "As Built" survey elevation of unit #6 shows the breakwater crest elevation was at 1.75 feet NAVD88 well below the targeted design elevation of 4 feet NAVD88. This unit was also subject to the additional 2 feet of settlement and deformation, resulting in the crest elevation below the zero-datum level. At unit #8 the design target elevation of 4 feet NAVD88 was not achieved with the "As Built" survey showing a crest elevation of 3 feet NAVD88. During the year following installation, this unit located near the eastern end of the project area suffered deformation and settlement that reduced the crest elevation over 2 feet, currently at one foot below the MHW (2.43'NAVD88) level.

The project goal of attenuating wave energy to reduce erosion along the southern Basket Flats shoreline was achieved. The breakwater units, except for three units (1, 6 & 8), have settled within anticipated deformation ranges and remain at or near MHW levels and continue to attenuate approaching waves. There is visual and quantitative data that indicates sediment is building up leeward of the units. This material is largely organic and silt detritus loosely consolidated. The buildup in the first year was from west to east with the greatest accumulation at line 20 and less material accumulation towards the eastern units while erosion lingered east of the breakwater units at lines 0 and 2.

Recommendations based upon this monitoring effort include:

- Placing additional stone on the breakwater units, with particular attention to units 6 & 8, where crest elevations are currently below MHW levels.
- Unit #1 will require complete restoration as the foundation is compromised and further loading of stone will likely be unsuccessful at achieving elevation goals.
- Extend the breakwater units around the eastern tip of Basket Flats starting with adding stone onto the sill, unit #10, to raise the elevation to a minimum of at or above the MHW level, preferably to the target elevation of 4 feet NAVD88.
- Continue periodic monitoring of the nearshore and marsh edge platform to document changes and determine long term effectiveness of the breakwater installation.
- Continued LiDAR scans of the units to determine elevation and deformation changes.