# Assessing Sediment Budgets in Support of Beach Nourishment and Coastal Community Resiliency: Topographic and Bathymetric Beach Change Analyses for Wells, Saco, and Scarborough Study Areas

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## Introduction

MGS completed topographic and volumetric change detection analyses on UAS, NSS, and MBES gridded surfaces using the Geomorphic Change Detection (GCD) software for ArcGIS developed by the Riverscapes Consortium. For each study area, Area of Interest (AOI) masks were established for each survey dataset (UAS, NSS, and MBES). Masks were created so that there was slight overlap between the different datasets. These AOIs were used as the basis for performing change detections for area, volume, and vertical averages, and differ slightly from the AOIs used in Appendix B (UAS surveys only). Difference surfaces were created for each dataset and each season. A vertical threshold of ±10 cm was used to account for uncertainty in gridded surfaces. Although every effort was made to collect datasets as close to each other as possible, this was not possible due to a variety of reasons (field conditions, equipment issues, COVID pandemic). Note that no spring/early summer 2020 NSS or UAS data was collected at any of the study areas due to the COVID pandemic. Thus, data varied by season, as shown in Table 1. MGS also investigated bathymetry at a potential nearshore placement site along Old Orchard Beach, described below.

| Season - Year | Wells | | | Saco | | | Scarborough | | |
|---|---|---|---|---|---|---|---|---|---|
| | UAS | NSS | MBES | UAS | NSS | MBES | UAS | NSS | MBES |
| **Late Summer/Fall - 2018** | 10/1 | 8/9-8/10 | 8/9 | 10/5 | 8/27-9/5 | N/A | 10/4 | 8/17-8/24 | 8/30 |
| **Spring/Early Summer - 2019** | 3/26 | 8/12-8/13 | 6/19 | 3/27 | 7/25-7/31 | 5/3,5/9 | 3/29 | 6/24-6/28,7/16,8/5-8/7 | 6/4 |
| **Late Summer/Fall - 2019** | 10/3 | 9/25,11/23 | 9/9 | 10/24 | 10/30, 11/7, 11/14-11/15 | 9/19,9/27,10/8 | 10/25 | 9/23-9/24,9/27,10/29 | 10/14 |
| **Spring/Early Summer- 2020** | N/A | N/A | 6/16 | N/A | N/A | 5/18,5/25 | N/A | N/A | 6/4,6/8,6/9 |
| **Late Summer/Fall - 2020** | 9/15 | 8/21,8/23 | 8/19 | 9/18 | 8/24-8/26,9/9 | N/A | 9/17 | 8/14-8/15,8/20,8/26 | 10/5 |

*Table 1. Time of year for Unmanned Aircraft Systems (UAS), Nearshore Survey System (NSS), and Mulitbeam Echosounder (MBES) surveys for the three study areas.*

## Beneficial reuse of dredged materials in the study areas

Two of the three study areas received either nearshore placement (Wells, June 2018 and July 2020) or direct beach nourishment (Saco, March 2019) by the US Army Corps of Engineers (USACE) during the project study period. Western Beach at the Scarborough River received beach nourishment in April 2015 (Table 2).

| Study Area | Volume ($yd^3$) | Volume ($m^3$) | Disposal Month - Year | Placement |
|---|---|---|---|---|
| Wells Beach, Wells | 30,000 | 22,937 | June - 2018 | Nearshore |
| Wells Beach, Wells | 20,000 | 15,291 | July - 2020 | Nearshore |
| Camp Ellis Beach, Saco | 62,000 | 47,402 | March - 2019 | Onshore |
| Western Beach, Scarborough | 116,325 | 88,937 | April - 2015 | Onshore |

*Table 2. Information on beneficial reuse of dredged materials within the study areas during or just prior to the project study period.*

## Results

Results from change analyses for each collected data set are presented below for the different study areas. For each study area and as data was available, topographic (and volumetric) change comparisons were developed for:

- Late Summer/Fall 2018 to Spring/Summer 2019;
- Spring/Summer 2019 to Late Summer/Fall 2019;

- Late Summer/Fall 2019 to Spring/Summer 2020;
- Spring/Summer 2020 to Late Summer/Fall 2020; and
- Late Summer/Fall 2018 to Late Summer/Fall 2020.

Images showing observed topographic changes and tables summarizing topographic, volumetric, and vertical changes are provided for each study area.

Wells Beach, Wells, ME – the Wells Beach study area extended approximately 1,700 m south from the southern jetty of the Webhannet River to Casino Point and extended about 900 m offshore to depths ranging from -8 to -10 m NAVD. It included UAS, NSS, and MBES AOIs.

*Late Summer/Fall 2018 to Spring/Summer 2019* - NSS and MBES surveys were completed in late summer (August 2018), about 8 weeks after completion of a dredge of the Webhannet River Channel and nearshore placement of dredged materials (June 2018, approximately 30,000 $yd^3$, 22,937 $m^3$, placed in the NSS and MBES AOIs). The UAS survey was completed in October 2018. An UAS survey was completed in March 2019, but MBES data was not collected until June 2019 and NSS data not until August 2019 due to equipment difficulties and weather. Volumetric and vertical loss was noted in all AOIs (Figure 1, Table 3). The UAS AOI mostly lost sediment with a slight gain near the jetty. In the NSS AOI, volumetric gains were noted in the nearshore in the form of bars (possibly from redistribution of disposed sediments), but the AOI mostly lost sediment. In the MBES area, losses occurred near the disposal area and closest to the southern

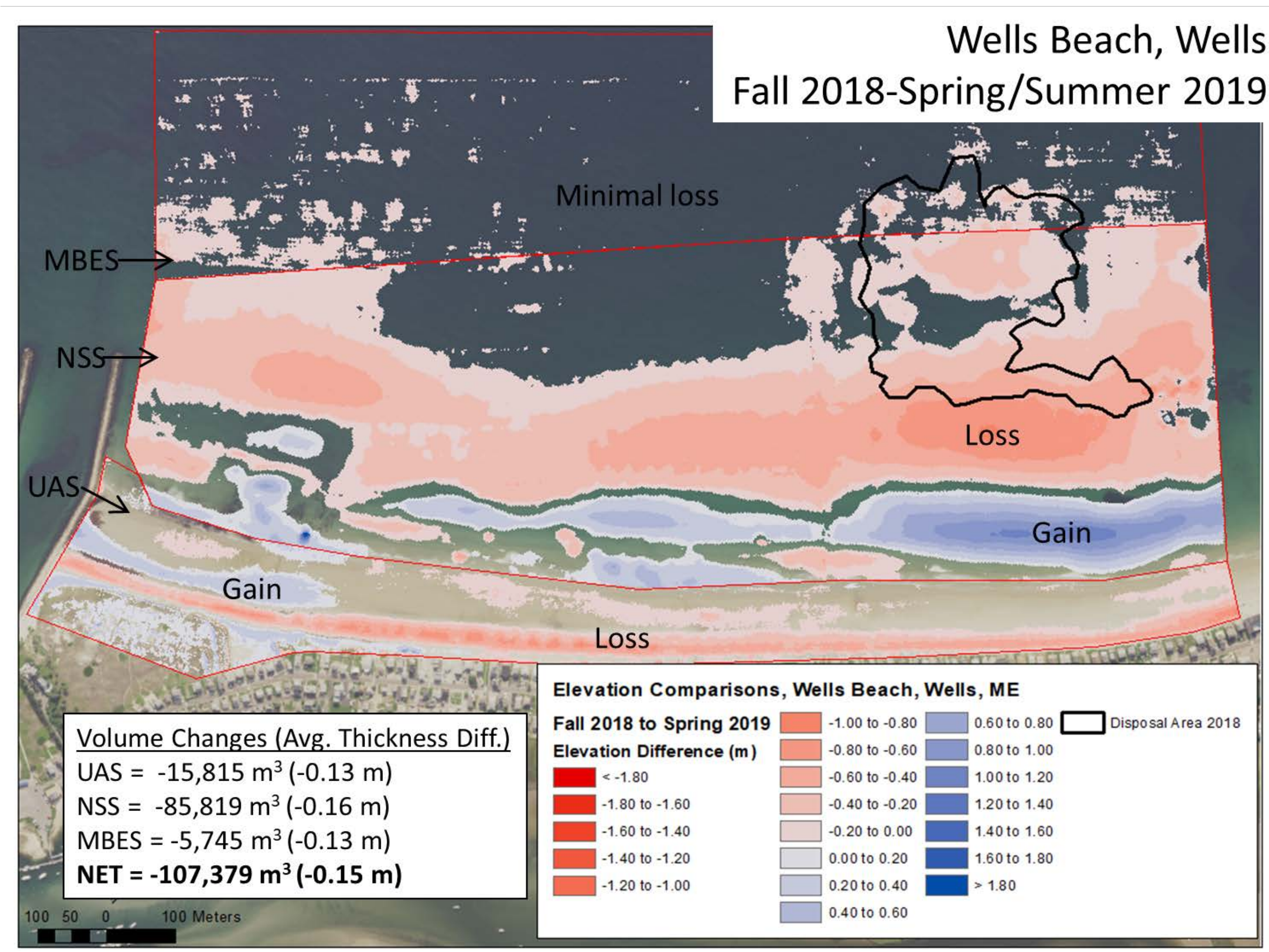


*Figure 1. Vertical elevation changes for Wells Beach, Wells (late summer/fall 2018 to spring/summer 2019).*

| WELLS BEACH, WELLS | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Spring/Summer 2019 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 378364 | 12% | -5745.52 | ± 4,519 | -0.13 | ± 0.10 |
| NSS | 755196 | 73% | -85818.95 | ± 45,061 | -0.16 | ± 0.08 |
| UAS | 237304 | 52% | -15815.11 | ± 9,320 | -0.13 | ± 0.08 |
| Total of All Compared | 1370864 | | -107379.59 | ± 58,637 | -0.15 | ± 0.08 |

*Table 3. Areal, volumetric, and vertical difference changes for Wells Beach, Wells (late summer/fall 2018 to spring/summer 2019).*

jetty. The overall AOI lost over 107,000 $m^3$ of sediment, with an average vertical loss of -0.15 m. Such changes are not surprising; most of Maine's later winter/spring beaches undergo sediment loss from the dry beach/berm and storage in in nearshore bars.

*Spring/Summer 2019 to Late Summer/Fall 2019* – Subsequent late summer/fall 2019 UAS data was collected in early October, NSS data in late September and late November, and MBES data in mid-September. UAS data showed dramatic volumetric gains along the entire beach area, likely due to nearshore placement material coming to the beach and seasonal beach growth (Figure 2, Table 4). The NSS AOI showed loss along the beach, gains in nearshore bars, with an

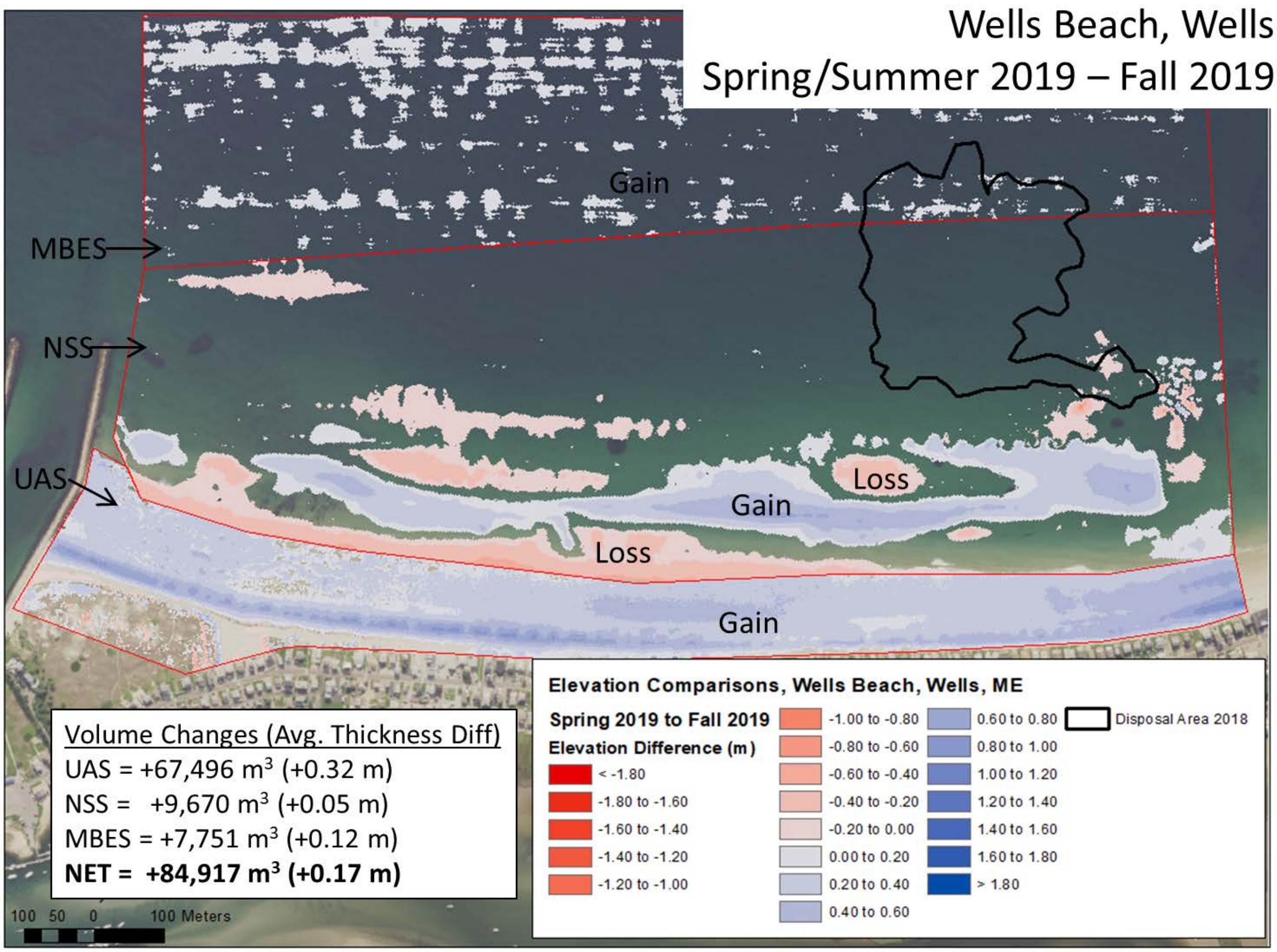


*Figure 2. Vertical elevation changes for Wells Beach, Wells (spring/summer 2019 to late summer/fall 2019).*

| WELLS BEACH, WELLS | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Spring/Summer 2019 to Late Summer/Fall 2019 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference ($m^3$) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 481708 | 14% | 7750.57 | ± 6,713 | 0.12 | ± 0.10 |
| NSS | 755416 | 28% | 9670.35 | ± 14,925 | 0.05 | ± 0.07 |
| UAS | 237796 | 88% | 67495.82 | ± 20,403 | 0.32 | ± 0.10 |
| Total of All Compared | 1474920 | | 84916.73 | ± 39,571 | 0.17 | ± 0.08 |

*Table 4. Areal, volumetric, and vertical difference changes for Wells Beach, Wells (late summer/fall 2018 to spring/summer 2019).*

overall slight gain. This difference from the UAS data was likely caused by a delay in completion of NSS surveys until mid-November, and after a storm event. MBES data indicated positive volumetric gains in the offshore. Overall AOI changes were net positive with a gain of almost +85,000 $m^3$ and an average vertical difference of +0.17 m.

*Late Summer/Fall 2019 to Late Summer/Fall 2020* – No spring/early summer UAS or NSS data was collected. In July 2020, an additional 20,000 $yd^3$ (15,291 $m^3$) of sediment was disposed in the nearshore off the beach, in the NSS AOI. UAS data was collected in September, and NSS and MBES data in August. UAS data showed consistent losses along the beach, while NSS AOI showed large net gains in the nearshore, closer to the beach and towards the jetty, with some trough formation adjacent to the beach (Figure 3). MBES data showed losses in the offshore, closest to the Webhannet River jetties. Net volume changes were just over +102,000 $m^3$, with a net vertical difference of +0.12 m (Table 5).

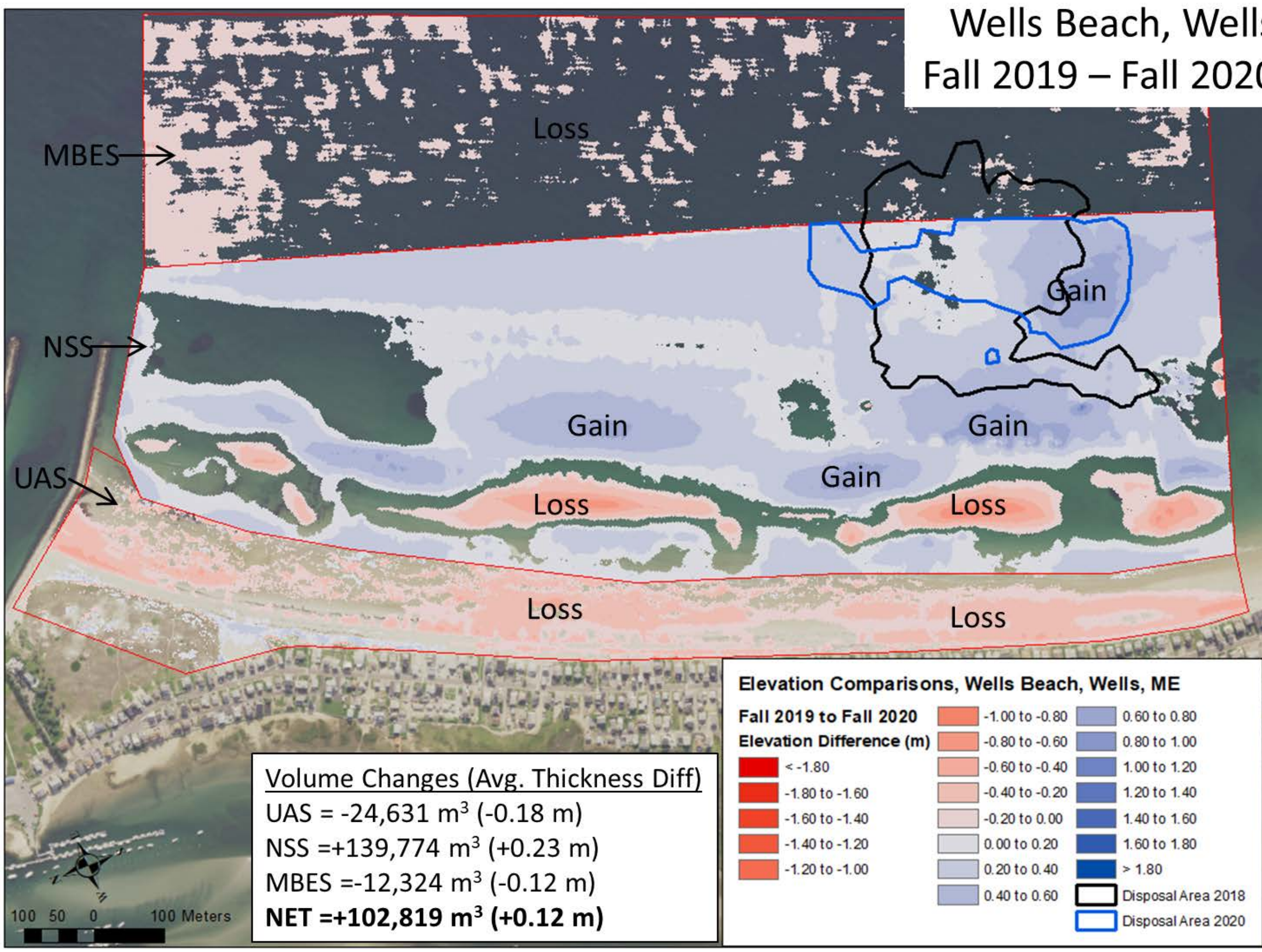


*Figure 3. Vertical elevation changes for Wells Beach, Wells (late summer/fall 2019 to late summer/fall 2020).*

| WELLS BEACH, WELLS | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2019 to Late Summer/Fall 2020 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference ($m^3$) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 481516 | 21% | -12324.10 | ± 10,109 | -0.12 | ± 0.10 |
| NSS | 755668 | 81% | 139774.35 | ± 55,562 | 0.23 | ± 0.09 |
| UAS | 235996 | 59% | -24630.77 | ± 12,782 | -0.18 | ± 0.09 |
| Total of All Compared | 1473180 | | 102819.48 | ± 63,291 | 0.12 | ± 0.07 |

*Table 5. Aerial, volumetric and vertical difference changes for Wells Beach, ME (late summer/fall 2019 to late summer/fall 2020).*

*Late Summer/Fall 2020* – This comparison is between the first and last surveys conducted during the study period and includes the placement of approximately 50,000 cubic yards of dredged sediment in the nearshore on 2 separate occasions (June 2018 and July 2020). UAS data indicated a *positive net volumetric gain* along the beach of over +22,000 $m^3$, with losses in the southwest but gains to the north (Figure 4 and Table 6). UAS data had the largest individual vertical change (+0.32 m) and largest net positive vertical change (+0.15 m) over the 2-year period. In the NSS AOI, a net positive gain of almost +51,000 $m^3$ occurred, with the highest gains along the beach zone and near the disposal area. Losses due to trough formation occurred in between. The average net vertical difference, however, was only +0.09 m

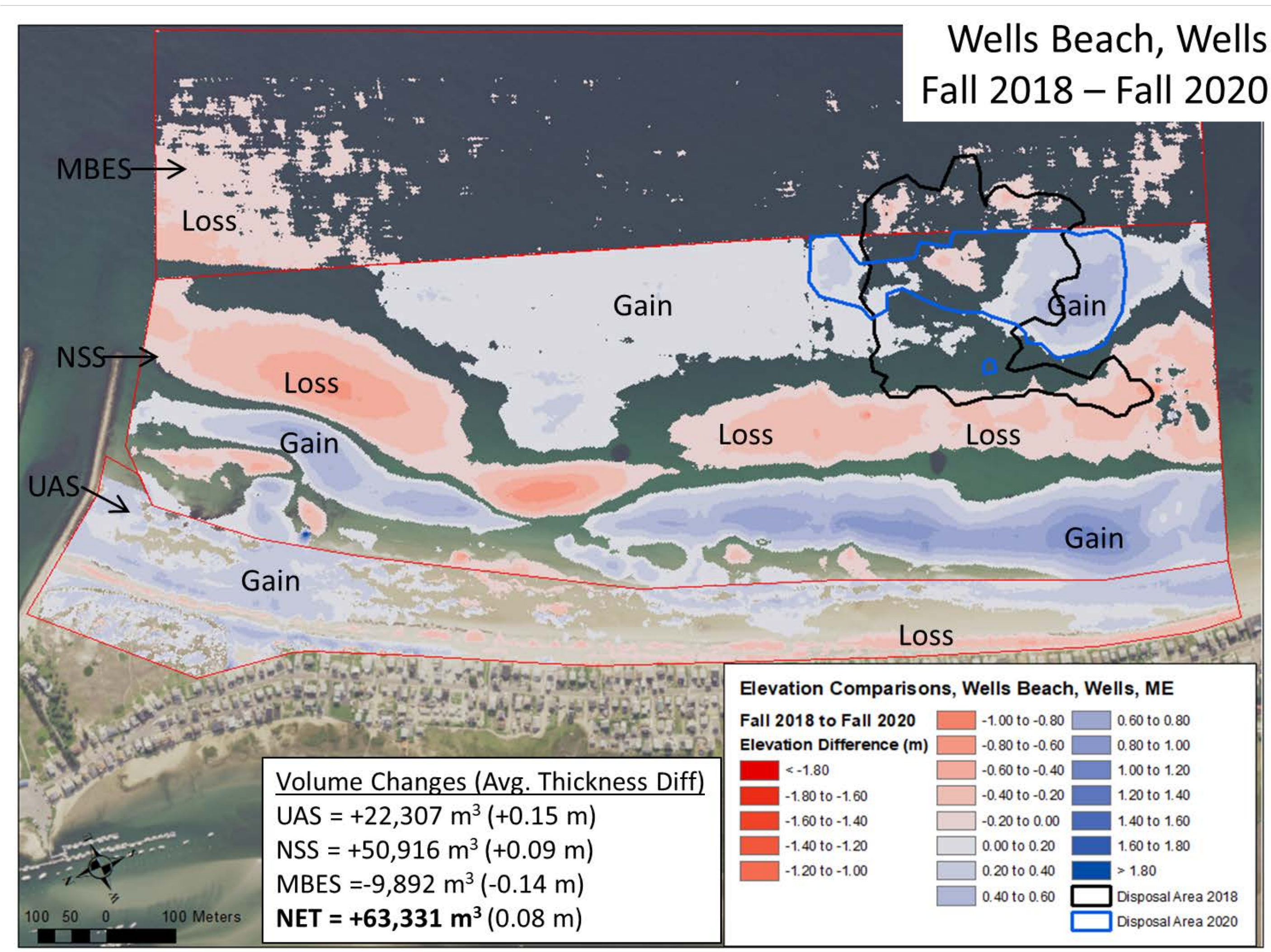


*Figure 4. Vertical elevation changes for Wells Beach, Wells (ate summer/fall 2018 to late summer/fall 2020).*

| WELLS BEACH, WELLS | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Late Summer/Fall 2020 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference ($m^3$) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 378364 | 18% | -9892.02 | ± 6,988 | -0.14 | ± 0.10 |
| NSS | 755432 | 71% | 50915.69 | ± 39,574 | 0.09 | ± 0.07 |
| UAS | 236192 | 63% | 22307.15 | ± 12,497 | 0.15 | ± 0.08 |
| Total of All Compared | 1369988 | | 63330.82 | ± 55,053 | 0.08 | ± 0.07 |

*Table 6. Areal, volumetric, and vertical difference changes for Wells Beach, Wells (late summer/fall 2018 to late summer/fall 2020).*

indicating changes were spread out along the study area. Net loss of almost -9,000 $m^3$ occurred in the MBES AOI. The overall net volume change was +63,000 $m^3$, with a very slight average vertical difference of +0.08 m.

*Findings*

Significant vertical and volumetric changes occurred within the UAS and NSS AOIs, with vertical changes of up to a meter or more occurring along the beach and in the nearshore. Large percentages of the AOIs had detectable changes, with UAS and NSS AOIs averaging 66% and 63%, respectively. This is not necessarily surprising given that these are more dynamic, wave and current influenced areas of the study area. Positive influence from nearshore sediment disposal of about 50,000 $yd^3$ (38,228 $m^3$) was evident in both AOIs.

Relatively large (over 10,000 $m^3$) volumetric changes were observed in the MBES AOI, mostly concentrated within a small portion of the AOI (accounting for an average of 16% of the AOI), adjacent to the Webhannet River jetties. The rest of the MBES AOI underwent no significant detectable changes. Observed changes in the MBES AOI are likely related to sediment storage/loss associated with the Webhannet River ebb tidal shoal. This indicates that MBES maximum survey depths of -9 m NAVD captures most *beach change and may indicate the approximate depth of closure along Wells Beach*. See the section on morphogically defined depth of closure (MDDOC) discussed later.

*Beach Management Implications*

Surveys along the Wells Beach study area indicated that most topographic changes were located within the UAS and NSS AOIs, with a smaller portion of the MBES AOI (nearer to the jetties and the ebb-tidal shoal of the Webhannet River) showing changes outside of threshold values. Two nearshore placements (June 2018 and July 2020) totaling 50,000 $yd^3$ of dredged material placed in generally the same areas resulted in positive net changes for most of the study area and study time periods, except for Late Summer/Fall 2018 to Spring/Summer 2019. This time period resulted in a large net loss and it was not clear where within the beach system sediment migrated to – possibly laterally, along the beach or into the ebb-tidal shoal at the mouth of the river. However, large net gains in subsequent surveys showed that sediment returned to the study area, in addition to material placed in a subsequent disposal (July 2020). Volumetric changes in the study area exceeded 100,000 $m^3$ were observed, indicating that the beach can exchange very large volumes of sediment from season-to-season or year-to-year.

Previous larger dredges (exceeding 100,000 $yd^3$) of the Webhannet River were part of beach nourishment projects, resulting in a more direct benefit to the terrestrial beach. This study indicates that *nearshore placement has a positive net benefit to the Wells beach system.* The disposal area used in 2018 and 2020 appears to be effective in allowing sediment to migrate landward on the beach profile. The role that the ebb-tidal shoal of the Webhannet River might play in seasonal storage of sediment is one that may need to be investigated further in order to fully understand sediment migration in the Wells Beach study area. The Town of Wells should coordinate with property owners on the timing of dune planting/restoration in order to capitalize on the timing of any nearshore placement efforts in the future.

Saco Beaches, Saco, ME – the Saco study area extended 3,800 m north from the northern jetty of the Saco River to Goosefare Brook and between 550 and 1,750 m offshore to depths ranging from -6 m at its northern end (near Goosefare Brook) to -12 m NAVD at its south central point. It included UAS, NSS, and MBES AOIs.

The timing of surveys along Saco beaches varied. UAS and NSS data collection occurred in each time period except for Spring/Summer 2020 due to the COVID pandemic. NSS data collection took, on average, around 4-5 total survey days, which was significantly impacted by weather and spread data collection over long periods of time. MBES surveys were only completed in Spring 2019, Fall 2019, and Spring 2020. This impacted data comparison between all three AOIs.

*Late Summer/Fall 2018 to Spring/Summer 2019* – NSS data was collected in late August to early September, while UAS data was collected in early October 2018. No MBES data was collected in late summer/fall 2018. Over the winter of 2019, the Saco River was dredged (ending in March 2019) and 62,000 $yd^3$ (47,402 $m^3$) of sediment was placed adjacent to the northern jetty of the Saco River. Subsequent UAS data collection occurred in the end of March 2019, and MBES data was collected in early May 2019. Unfortunately, equipment problems delayed NSS data collection until July 2019.

Large (>1.5 m) elevation gains along the beach nearest the northern jetty were noted in the UAS AOI, some slight gains along the low tide terrace along the beach, and gains in the low tide terrace near Goosefare Brook (Figure 5). The largest elevation losses in the UAS AOI were in front of a seawall at the central portion of the beach, and in the dune area near the Goosefare Brook spit. The UAS AOI had a net gain of almost +44,000 $m^3$ with an average vertical difference of +0.18 m (Table 7). The NSS study area showed detectable losses which were largest adjacent to the jetty,

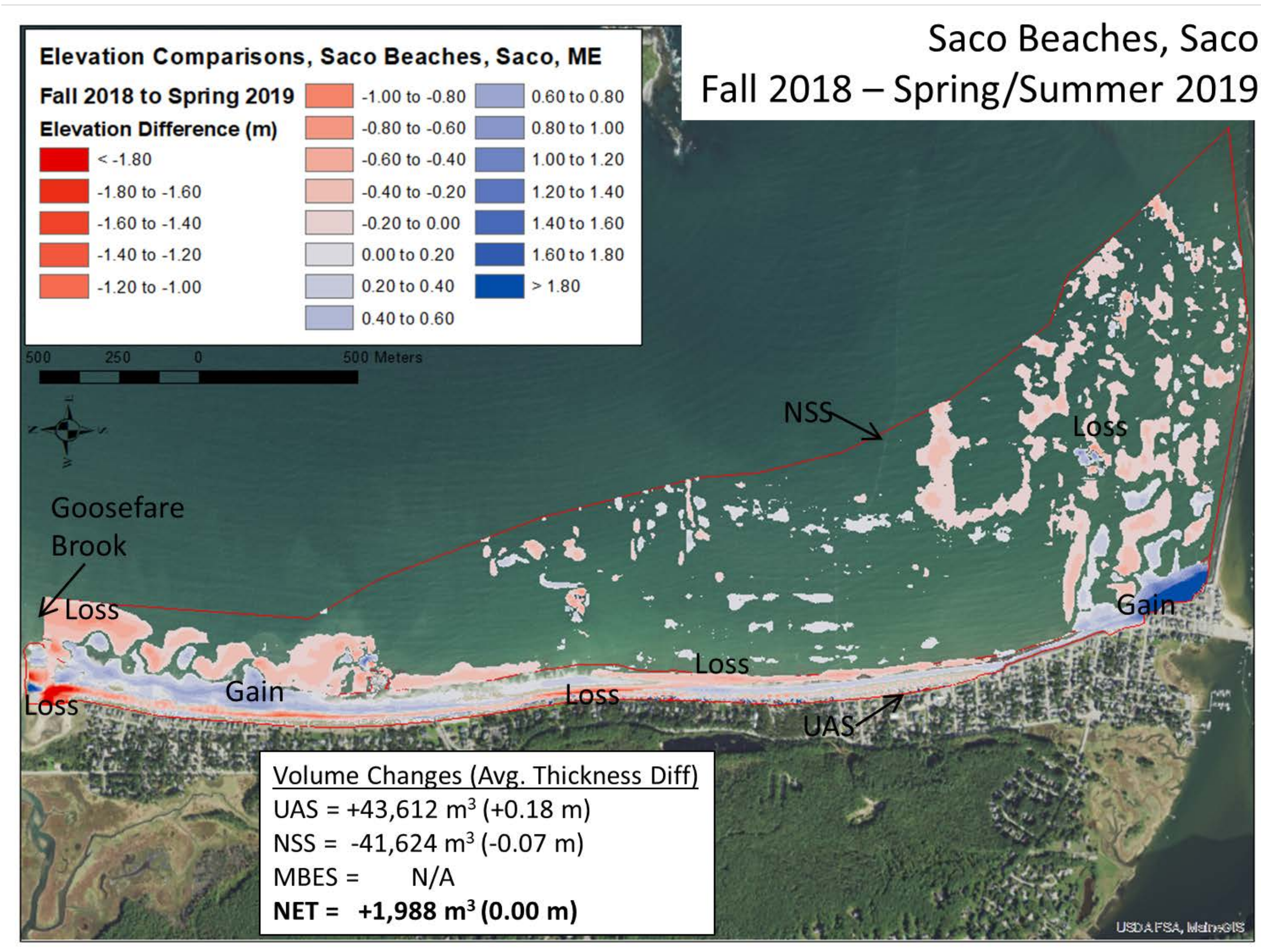


*Figure 5. Vertical elevation changes for Saco Beaches, Saco (late summer/fall 2018 to late summer/fall 2020).*

| SACO BEACHES, SACO | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Spring/Summer 2019 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| NSS | 2327220 | 24% | -41624.63 | ± 43,873 | -0.07 | ± 0.08 |
| UAS | 336032 | 74% | 43611.59 | ± 17,921 | 0.18 | ± 0.07 |
| Total of All Compared | 2663252 | | 1986.96 | ± 59,200 | 0.00 | ± 0.07 |

*Table 7. Areal, volumetric, and vertical difference changes for Saco beaches, Saco (late summer/fall 2018 to spring/summer 2019).*

and off Goosefare Brook, with a net volumetric loss of -42,000 $m^3$, which almost perfectly balances the net gain along the beach in the UAS AOI. This indicates a generally balanced, seasonal shift of sediment within the study area over this time period.

*Spring/Summer 2019 to Summer/Fall 2019* – UAS data was collected at the end of October 2019. NSS data was collected in late October to mid-November. MBES data was collected in mid-September and early October.

Changes in the UAS AOI showed large (>1.5 m) losses adjacent to the jetty and losses in the south-central and northern portions of the beach (Figure 6). Gains along the beach north of the disposal area indicated that sediment moved to the north. A net volumetric loss of -38,000 $m^3$ occurred, and about 76% of the AOI underwent detectable change (Table 8).

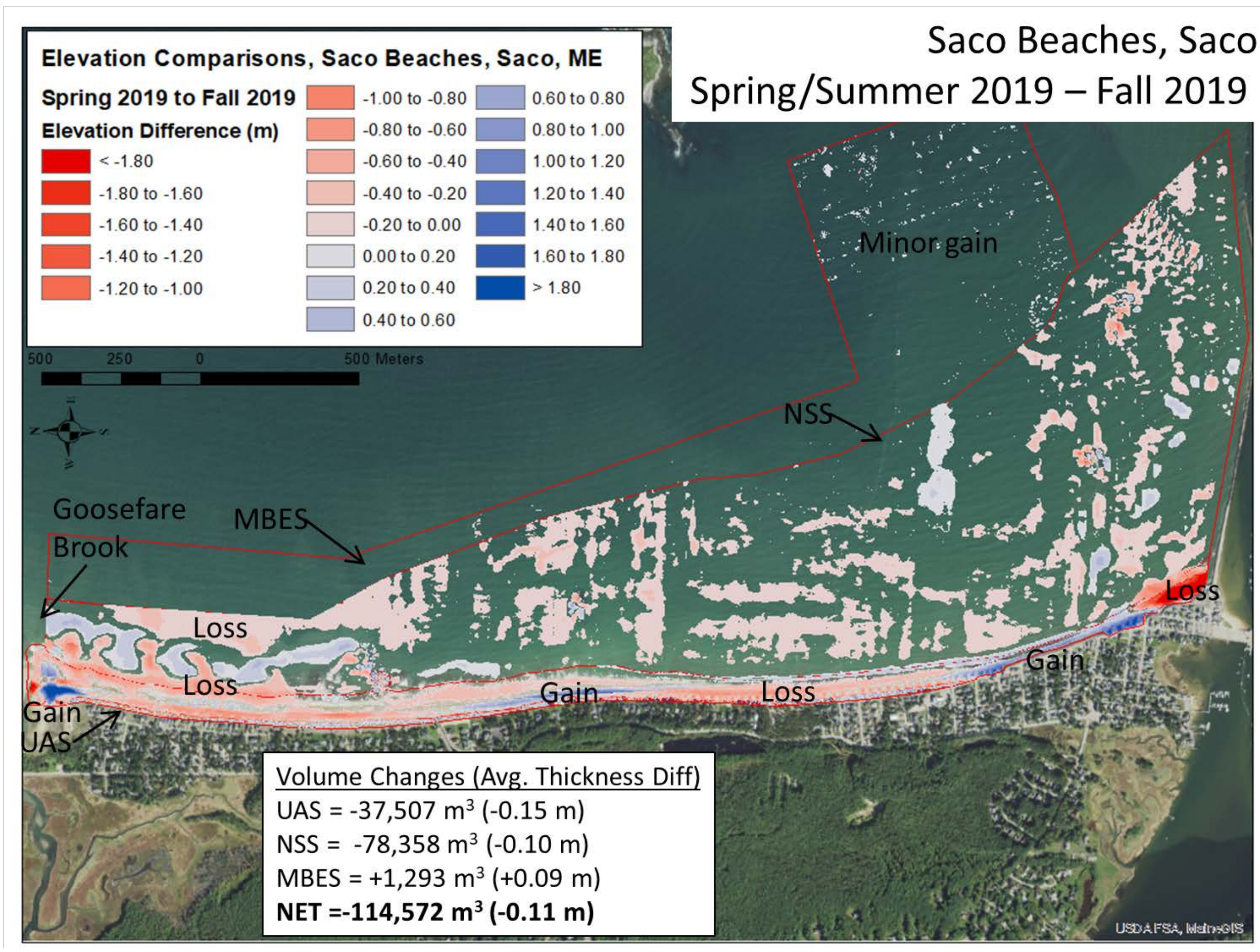


*Figure 6. Vertical elevation changes for Saco beaches, Saco (late summer/fall 2018 to spring/summer 2019).*

| SACO BEACHES, SACO | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Spring/Summer 2019 to Late Summer/Fall 2019 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference ($m^3$) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 1032744 | 1% | 1292.78 | ± 1,283 | 0.09 | ± 0.09 |
| NSS | 2327740 | 34% | -78357.63 | ± 66,181 | -0.10 | ± 0.08 |
| UAS | 329892 | 76% | -37506.67 | ± 18,430 | -0.15 | ± 0.07 |
| Total of All Compared | 3690376 | | -114571.51 | ± 84,618 | -0.11 | ± 0.08 |

*Table 8. Areal, volumetric, and vertical difference changes for Saco beaches, Saco (spring/summer 2019 to late summer/fall 2019).*

The NSS AOI showed 34% detectable change, and an overall net volumetric loss of over -78,000 $m^3$. MBES AOI indicated 1% detectable change. An overall loss of over -114,000 $m^3$ occurred though vertical differences were quite small (-0.11 m).

*Summer/Fall 2019 to Summer/Fall 2020* – No spring/summer 2020 UAS or NSS data was collected. Summer and fall 2020 UAS data were collected in mid-September and late August to mid-September for the NSS. No MBES data was collected in late summer/fall 2020. UAS data had 72% detectable change, with a net volume gain of over +15,000 $m^3$ (Figure 7, Table 9). Large beach elevation losses (>1m) occurred within 600 m of the jetty, indicating northward distribution of sediment.

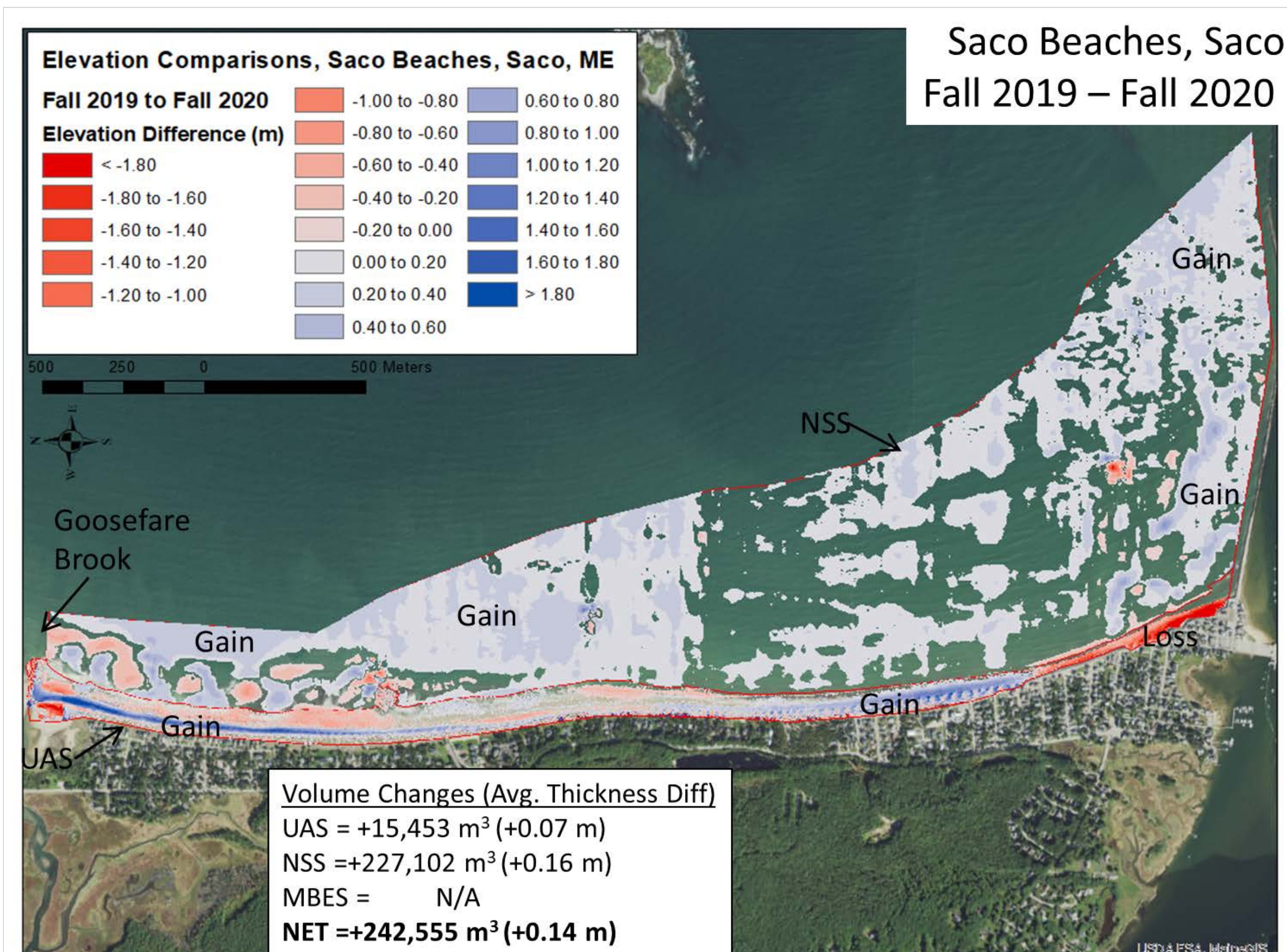


*Figure 7. Vertical elevation changes for Saco beaches, Saco (late summer/fall 2019 to late summer/fall 2020).*

| SACO BEACHES, SACO | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2019 to Late Summer/Fall 2020 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| NSS | 2350100 | 62% | 227101.86 | ± 137,470 | 0.16 | ± 0.09 |
| UAS | 324600 | 72% | 15452.62 | ± 16,631 | 0.07 | ± 0.07 |
| Total of All Compared | 2674700 | | 242554.48 | ± 151,324 | 0.14 | ± 0.09 |

*Table 9. Areal, volumetric, and vertical difference changes for Saco beaches, Saco (late summer/fall 2019 to late summer/fall 2020).*

Elevation gains up to +1.5 m occurred along most Saco beaches, concentrated just north of the end of the seawall, and along beaches in the northern half of the study area (to Goosefare Brook). The NSS AOI showed 62% detectable change, with an extremely large net volume increase of over +227,000 m$^3$, and an average net vertical difference of +0.16 m indicating that most changes were small and spread out in the AOI. Gains were noted adjacent to the jetty in a waffle pattern (due to wave reflection and refraction off the jetty), and in the nearshore for the northern half of the NSS study area up to near Goosefare Brook. This net volume increase was larger than expected.

*Summer/Fall 2018 to Summer/Fall 2020* – The UAS AOI showed 72% detectable change, with a net volume increase of over +19,400 m$^3$. Influence from the spring 2019 beach nourishment was evident in the largest gains along the beach nearest the jetty (where disposal occurred), north of the end of the seawall, and in the northern third of the beach up to

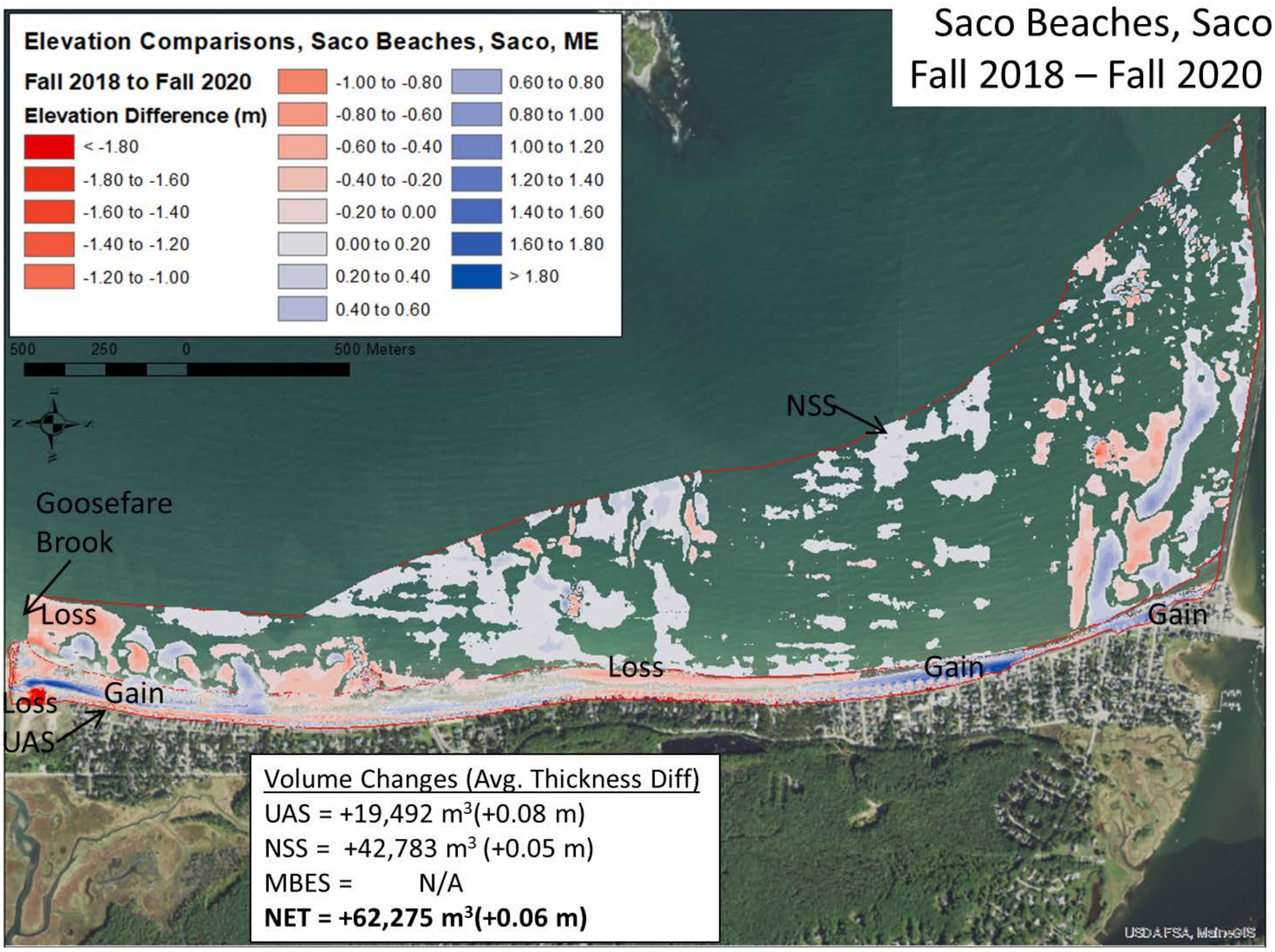


*Figure 8. Vertical elevation changes for Saco beaches, Saco (late summer/fall 2018 to late summer/fall 2020).*

| SACO BEACHES, SACO | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Late Summer/Fall 2020 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| NSS | 2350092 | 35% | 42783.52 | ± 63,584 | 0.05 | ± 0.08 |
| UAS | 327564 | 72% | 19492.21 | ± 16,698 | 0.08 | ± 0.07 |
| Total of All Compared | 2677656 | | 62275.73 | ± 79,562 | 0.06 | ± 0.07 |

*Table 10. Areal, volumetric, and vertical difference changes for Saco beaches, Saco (late summer/fall 2018 to late summer/fall 2020).*

Goosefare Brook (Figure 8, Table 10). Overall NSS volumetric gains exceeded +42,700 m$^3$, though vertical differences were within the error. Combined, NSS and UAS data showed a net positive volume increase of over 62,000 m$^3$. This positive change correlates relatively well with the 62,000 yd$^3$ (47,402 m$^3$) beach nourishment project completed in winter/spring 2019 plus a potential high end of annual sediment supplied from the Saco River (Kelley et al., 2005).

*Findings*

Direct beach nourishment (62,000 yd$^3$, 47,402 m$^3$) showed a *clear benefit* along Saco beaches, although it appears that it took approximately 19 months for sediment to redistribute from the nourishment site up to Goosefare Brook, mostly along the nearshore and upper beach. However, all the sediment placed along the northern end of the jetty was removed during redistribution, so the benefit to this immediate area (from beach nourishment) was short-lived.

Changes from late summer/fall 2019 to late summer/fall 2020 indicated an extremely large gain of net sediment volume (+227,000 m$^3$) in the nearshore (NSS AOI). This volume *is much larger than expected* from previous studies on expected annual sediment transport and sediment budgets, which ranged from 20,000 to about 80,000 yd$^3$ of sediment (Kelley et al., 2005; Morang, 2016). Closer inspection indicate that volumetric errors were quite large (±137,470 m$^3$) and that the net vertical difference (over the entire NSS AOI) was only +0.16 m (±0.09 m). Accuracy checks of collected NSS data (in overlap areas with UAS data on hard grounds) indicated that no systematic NSS errors could account for this volume difference. Although summer and fall 2020 had optimal conditions for beach growth, it is *currently unclear to us where this excess volume of sediment in the nearshore originated from*.

From fall 2018 to fall 2020, the study area underwent a net positive volume increase of +62,276 m$^3$ (81,454 yd$^3$). This net volume is close to the combined volume of sediment placed as beach nourishment (62,000 yd$^3$ or 47,402 m$^3$) in late winter/spring 2019, plus estimated annual sediment volumes from the Saco River, which range from 13,000 to 20,900 yd$^3$ per year (Normandeau Associates, 1994).

*Beach Management Implications*

Survey results showed that beach nourishment placed adjacent to the southern jetty in late winter/spring 2019 had a net benefit to the entire stretch of Saco beaches by late summer/fall 2020. The relatively small (62,000 yd$^3$) volume of sediment placed as beach nourishment is still roughly 3 to 5 times larger than the historic annual sediment supply from the Saco River. Because the sediment budget of the beach along the first few hundred meters north of the jetty at the Saco River is generally negative (due to continued erosion of the beach on the order of -20,000 yd$^3$ per year; Morang, 2016), nourished sediment dispersed rather quickly (within about a year-and-a-half) from the nourishment site, offering only limited benefit within the first several hundred meters along the beach.

Similar to the most recent dredge/nourishment project, future dredges of the Saco River should consider relatively substantial overfill of the beach nourishment area (vertically and horizontally) in order to help balance the generally negative sediment budget, provide immediate protection to at-risk development along the beach, and to maximize dispersal time along the remainder of Saco beaches. The City of Saco should coordinate with private property owners to plan on timing dune restoration/planting efforts post-nourishment in order to maximize sediment lifetime on the beach.

Scarborough River Beaches, Scarborough, ME – this study area includes: Pine Point Beach, which extends 715 m south of the jetty at the Scarborough River; Ferry Beach, a 1,000 m long arcuate beach within the Scarborough River estuary; and Western Beach, a 1,000 m beach fronting the Prouts Neck Country Club. NSS surveys extended seaward from Pine Point Beach approximately 900 m, and approximately 600 m seaward of Western Beach. MBES surveys continued an additional 650 m seaward from Pine Point. NSS and MBES surveys captured sections of the ebb tidal shoal/bar system. Depth in the NSS survey area reached about -6 m (in the river channel), while MBES data reached about -11 m NAVD88. Pine Point, Ferry Beach, and Western Beach were combined into one larger AOI for this analysis.

*Late Summer/Fall 2018 to Spring/Summer 2019* –NSS and MBES data was collected in late August 2018, while UAS data was collected in early October. Note that no UAS data was collected along Western or Ferry Beach in late summer/fall 2018, only at Pine Point Beach. For spring/summer 2019, UAS data for all three beaches was collected in the end of March. MBES data was collected in June and NSS data was collected between June and August.

UAS data (available at Pine Point Beach only) showed a detectable change of 52% and net volumetric loss of over -8,515 $m^3$ of sediment with an average vertical difference of -0.17 m (Figure 9, Table 11). In the NSS AOI, detectable change was 55% of the AOI and the nearshore underwent volumetric loss of -78,830 $m^3$, with a thresholded vertical difference of -0.10 m. In the NSS AOI, gains were noted in the ebb-tidal sandbar seaward of Pine Point, and in the Scarborough

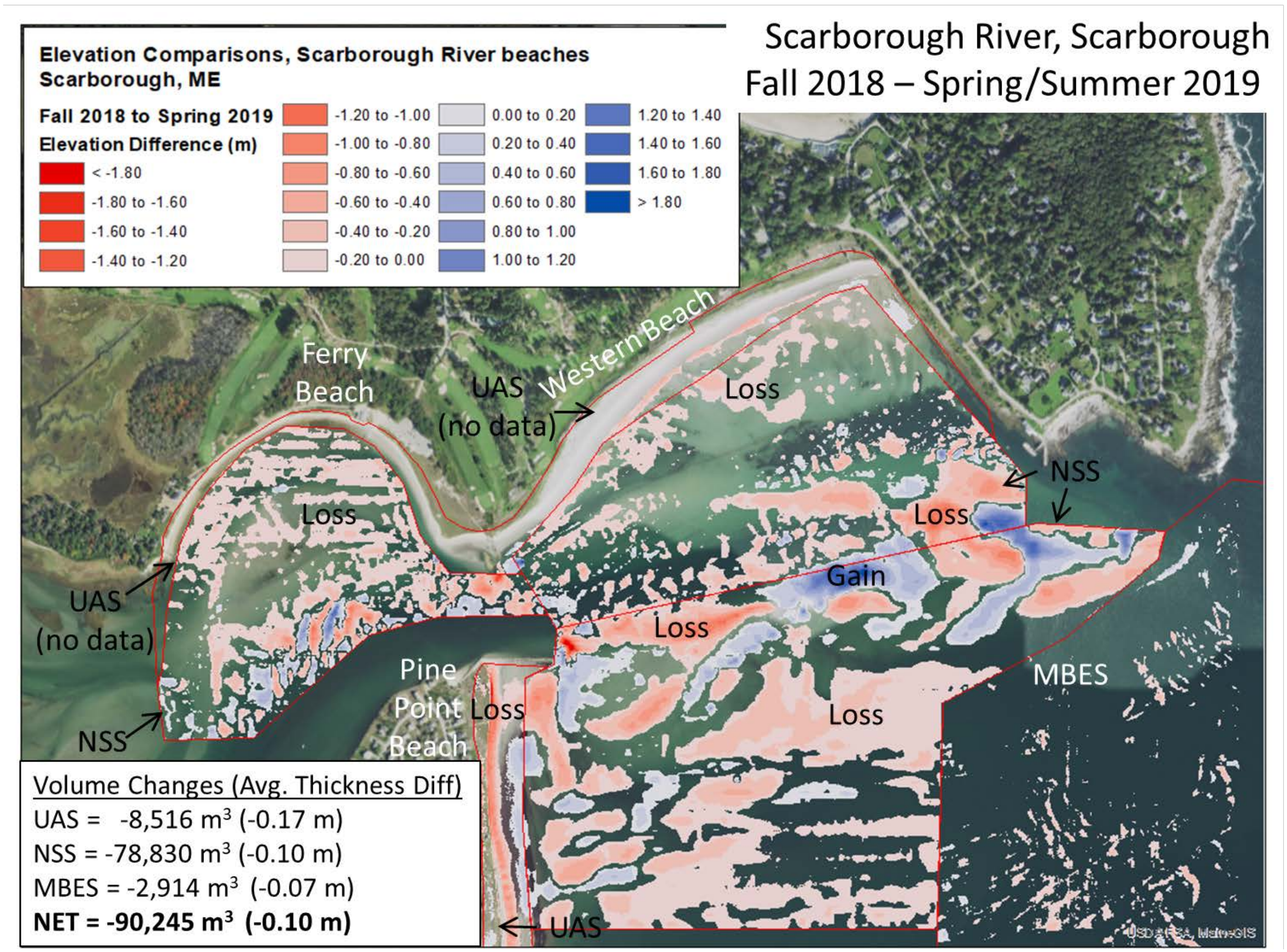

*Figure 9. Vertical elevation changes for Scarborough River beaches, Scarborough (late summer/fall 2018 to late summer/fall 2020).*

River channel. Slight losses were seen in the flood tidal shoal along Ferry Beach and along Western Beach. Seaward of Pine Point Beach, losses dominated though small pockets of gain did occur closer to the beach. MBES AOI underwent

| SCARBOROUGH RIVER BEACHES, SCARBOROUGH | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Spring/Summer 2019 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 443328 | 9% | -2914.69 | ± 3,333 | -0.07 | ± 0.08 |
| NSS | 1436500 | 55% | -78830.02 | ± 63,938 | -0.10 | ± 0.08 |
| UAS | 94900 | 52% | -8515.69 | ± 3,638 | -0.17 | ± 0.07 |
| Total of All Compared | 1974728 | | -90260.40 | ± 70,824 | -0.10 | ± 0.08 |

*Table 6. Areal, volumetric, and vertical difference changes for the Scarborough River beaches, Scarborough (late summer/fall 2018 to spring/summer 2019).*

only 9% detectable change, accounting for approximately -2,900 m$^3$ but vertical differences were negligible. Combined, the Scarborough River AOI underwent -90,260 m$^3$ of volumetric loss, with an average net vertical difference of -0.10 m.

*Spring/Summer 2019 to Late Summer/Fall 2019* – UAS and MBES data was collected in late summer/fall 2019 (in October); NSS data was collected along Ferry Beach and Western Beach, but unfortunately, due to weather and tides, no NSS data was collected at Pine Point. UAS data had 50% detectable change and showed a gain of +13,736 m$^3$ and +0.14 m vertical difference, most of concentrated along Pine Point Beach (Figure 10, Table 12). NSS data (for Western and

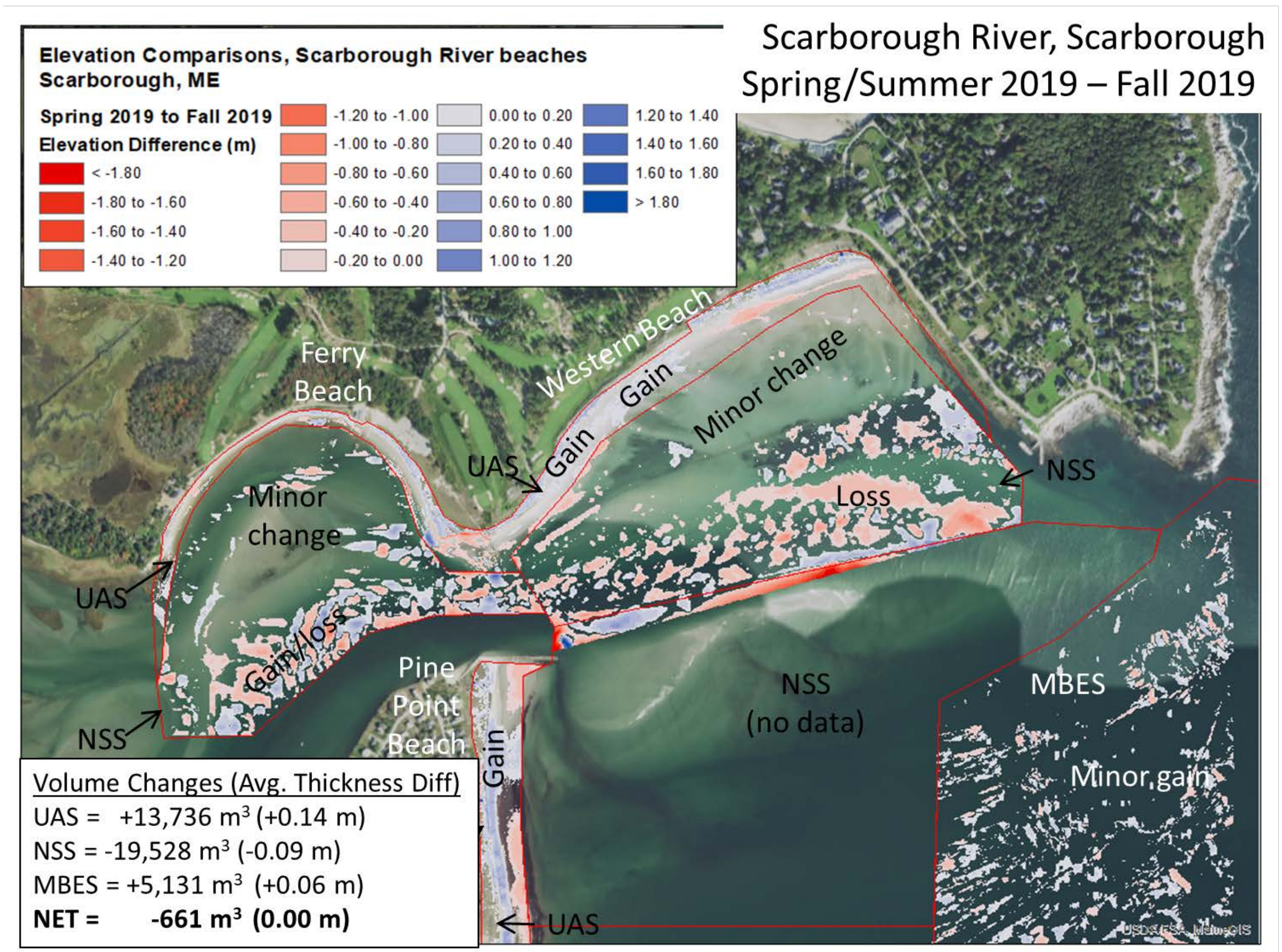


*Figure 10. Vertical elevation changes for Scarborough River beaches, Scarborough (late spring/summer 2019 to late summer/fall 2019).*

| SCARBOROUGH RIVER BEACHES, SCARBOROUGH | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Spring/Summer 2019 to Late Summer/Fall 2019 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 464416 | 18% | 5130.95 | ± 6,377 | 0.06 | ± 0.08 |
| NSS | 733508 | 31% | -19528.19 | ± 16,943 | -0.09 | ± 0.07 |
| UAS | 201352 | 50% | 13736.23 | ± 7,808 | 0.14 | ± 0.08 |
| Total of All Compared | 1399276 | | -661.01 | ± 29,144 | 0.00 | ± 0.07 |

*Table 12. Areal, volumetric, and vertical difference changes for Pine Point Beach, Scarborough (spring/summer 2019 to late summer/fall 2019).*

Ferry Beaches) showed a net loss of -19,528 m$^3$, with the larger changes within the river channel and at the ebb-shoal sandbar. Most of the changes along Western Beach and Ferry Beach were minimal (within the threshold). MBES data showed 18% detectable changes totaling +5,131 m$^3$. Combined (excluding Pine Point NSS data which was not collected) net volume changes were only slightly negative.

*Late Summer/Fall 2019 to Late Summer/Fall 2020* – Along Pine Point, no data was collected in late summer/fall 2019, so no comparison is available. UAS, MBES and NSS data was collected for the rest of the AOI. Overall, the UAS AOI had 55% detectable change and showed a net loss of -7,010 m$^3$ (Figure 11, Table 13) with the highest vertical loss at the

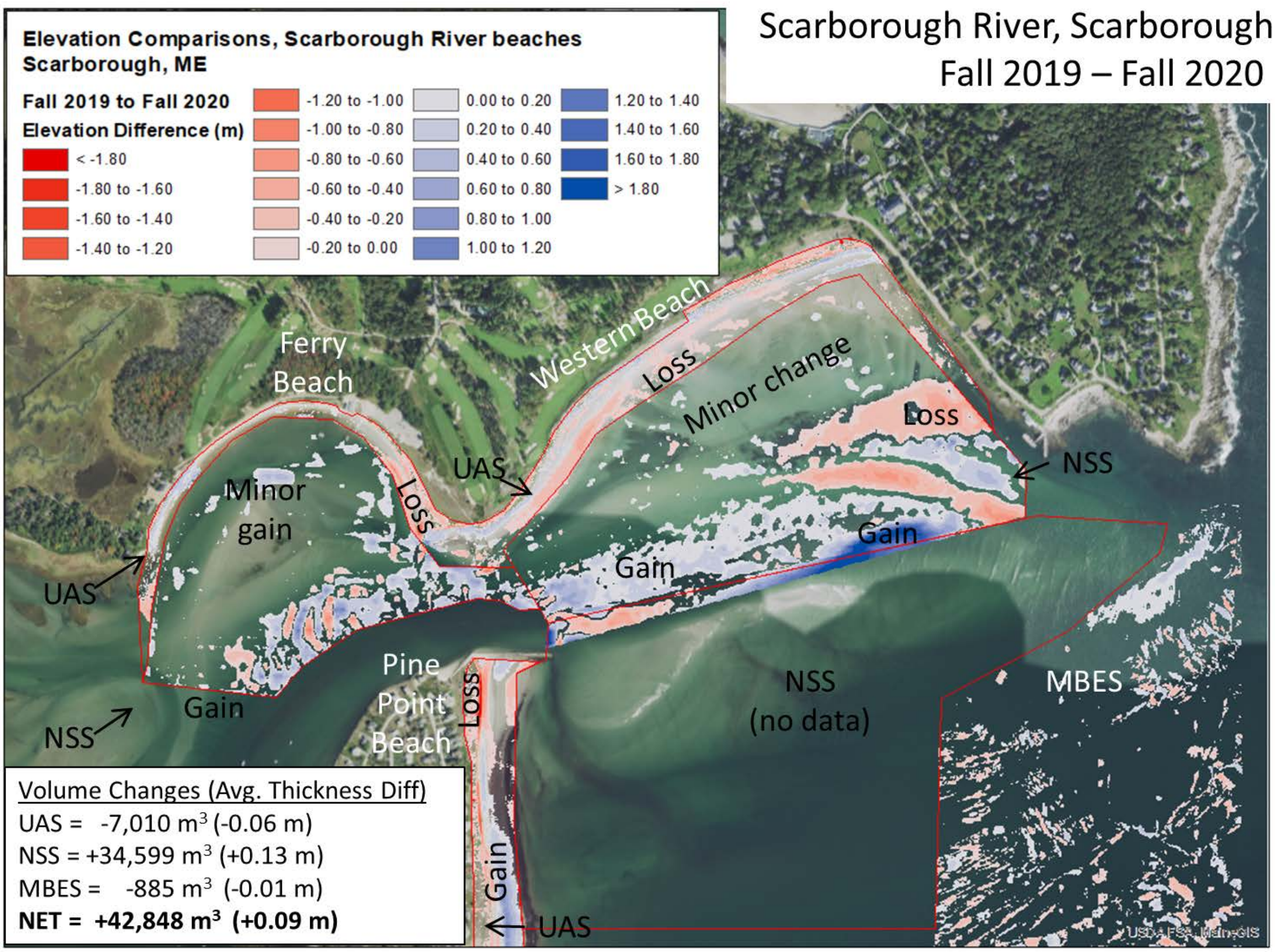


*Figure 11. Vertical elevation changes for Scarborough River beaches, Scarborough (late summer/fall 2019 to late summer/fall 2020).*

| SCARBOROUGH RIVER BEACHES, SCARBOROUGH | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2019 to Late Summer/Fall 2020 | Total Area of Interest ($m^2$) | AOI % with Detectable Change | Total Net Volume Difference ($m^3$) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 462632 | 20% | -885.26 | ± 6,545 | -0.01 | ± 0.07 |
| NSS | 706288 | 37% | 34598.86 | ± 19,380 | 0.13 | ± 0.07 |
| UAS | 208364 | 55% | -7009.57 | ± 8,372 | -0.06 | ± 0.07 |
| Total of All Compared | 1377284 | | 26704.03 | ± 33,130 | 0.06 | ± 0.07 |

*Table 13. Areal, volumetric, and vertical difference changes for Pine Point Beach, Scarborough (late summer/fall 2019 to late summer/fall 2020).*

dune adjacent to the jetty at Pine Point Beach, and consistent beach loss along Western Beach. Along Ferry Beach, loss occurred near the point, and gains occurred at its western end. In the NSS AOI (excluding Pine Point due to no data from Fall 2019), 37% showed detectable change, with large gains in the ebb-tidal sandbar and within the river channel and losses at the seaward end of Western Beach. Overall NSS changes reached +34,600 $m^3$ with a net vertical gain of +0.13 m in the AOI. MBES data showed a net change of -885 $m^3$ with minimal net vertical differences. Overall, the AOI gained over +42,800 $m^3$, concentrated in the river channel, flood tidal shoal, and ebb-tidal shoal/sandbar.

*Late Summer/Fall 2018 to Late Summer/Fall 2020* – No UAS data was collected in fall 2018 at Western Beach or Ferry Beach and was not included in this analysis. For the combined two-year study period, the UAS AOI (at Pine Point Beach) underwent loss of -4,941 $m^3$, with largest losses nearest the jetty at the Scarborough River. In the NSS AOI, net volumetric losses totaled -39,500 $m^3$. These were concentrated mostly in the NSS study area off Pine Point and Western Beach. Gains were within the river channel and in the ebb-tidal sandbar. It appears that sediment loss from Pine Point and Western Beach is potentially sequestered in the ebb-tidal sandbar. MBES data indicated the largest gains (+1,275 $m^3$) just off Prouts Neck, at the seaward end of the river channel. Vertical differences for all data types were within thresholded errors. The rest of the AOI showed little changes (Figure 12 and Table 14).

*Findings*

Beaches in the vicinity of the Scarborough River act quite differently than the more open coast beaches of Wells and Saco, and their changes are driven strongly by three factors: 1) Scarborough River tidal dynamics and sediment transport; 2) alongshore sediment transport; and 3) wave focusing (at Pine Point). Pine Point Beach saw alongshore dominated gains at its southern end; however, closer to the jetty, it saw elevation losses, likely associated with sediment movement by Scarborough River tidal currents and loss to the river channel/ebb-tidal sandbar. The largest consistent volumetric changes occurred in the river channel and in the ebb-tidal shoal/sandbar, which appears to receive sediment from both Western Beach and Pine Point Beach. The western end of Ferry Beach appears to have gained sediment, while the central section lost. Western Beach, which was the location of beach nourishment in 2015, has undergone relatively consistent losses in the beach and nearshore over the project study period.

*Beach Management Implications*

Erosion at these beaches is a complex process dominated by Scarborough River currents. Historical analyses of beach changes at Pine Point and Western Beach (Woods Hole Group, 2013) show that long-term shoreline changes (1864-1998) at both were generally positive. More recent shoreline change data (Slovinsky et al., 2019; Slovinsky, 2020a) show largely negative changes along both the beach and dune of these beaches. Survey results indicate that sediment removed from both beaches is likely stored in the ebb-tidal sandbar off Pine Point and within the river channel, not necessarily within the large flood tidal shoal located off Ferry Beach. Past studies (Slovinsky, 2006) suggest that shoal bypassing from the ebb-tidal shoal/sandbar to Western Beach was a dominant source of sediment to the beach, and jetty construction and previous dredging (and removal of sand from the system) led to continued erosion.

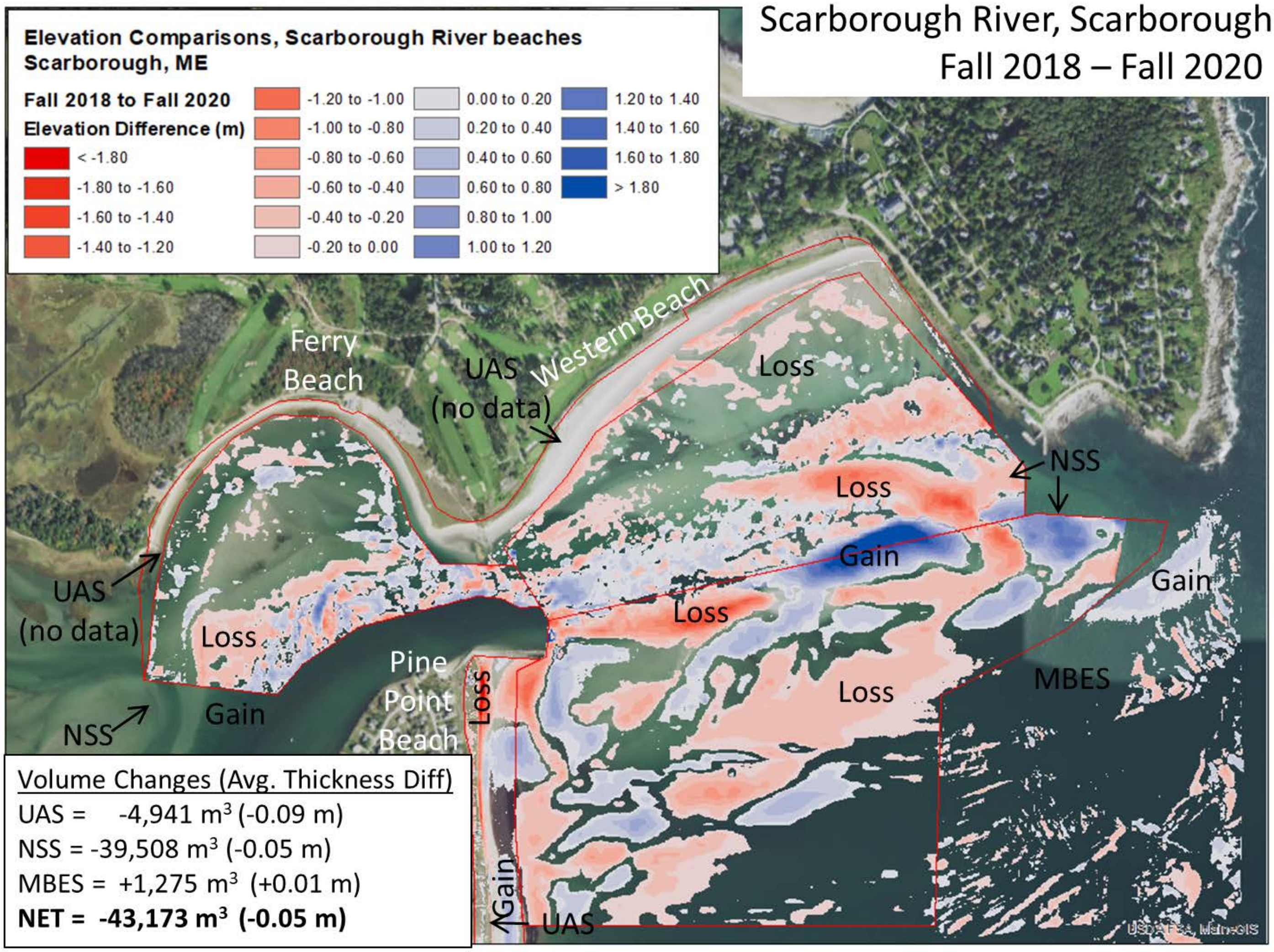


*Figure 12. Vertical elevation changes for Scarborough River beaches, Scarborough (late summer/fall 2018 to late summer/fall 2020).*

| SCARBOROUGH RIVER BEACHES, SCARBOROUGH | AREAL | | VOLUMETRIC | | VERTICAL DIFFERENCE | |
|---|---|---|---|---|---|---|
| Late Summer/Fall 2018 to Late Summer/Fall 2020 | Total Area of Interest (m²) | AOI % with Detectable Change | Total Net Volume Difference (m³) | | Average Net Thickness of Difference (m) | |
| | | | Thresholded | Error | Thresholded | Error |
| MBES | 445668 | 23% | 1275.23 | ± 7,231 | 0.01 | ± 0.07 |
| NSS | 1399616 | 53% | -39507.76 | ± 55,809 | -0.05 | ± 0.07 |
| UAS | 101944 | 53% | -4941.23 | ± 3,845 | -0.09 | ± 0.07 |
| Total of All Compared | 1947228 | | -43173.76 | ± 66,350 | -0.05 | ± 0.07 |

*Table 14. Areal, volumetric, and vertical difference changes for Pine Point Beach, Scarborough (late summer/fall 2018 to late summer/fall 2020).*

Because the channel is maintained by dredging, Western Beach does not appear to naturally receive needed sand at a regular interval to maintain a healthy beach and dune aside from sediment that is placed through beach nourishment (Slovinsky, 2011; 2014). In the 2015 beach nourishment design at Western Beach, MGS worked with Woods Hole Group and the USACE to optimize the previous (2005 nourishment) design. This included a higher (12-foot MLLW) and wider berm (150 feet at its widest point, tapering to narrower beach at the edges) and a longer overall nourishment project. This helped optimize recreational, habitat-related, and protective beach space along the beach and appears to be holding up better than the previous design. It is suggested that future dredging of the Scarborough River place sediment directly onto Western Beach to maintain the beach and habitat. The Town of Scarborough should work with the Prouts Neck Country Club (who owns Western Beach) to ensure that dune restoration is performed when beach nourishment occurs.

Erosion at Pine Point Beach appears to be caused by tidal inlet dynamics combined with nearshore bathymetry which can focus wave attack (Slovinsky, 2020b). Surveys from this study indicate that sediment eroded from the beach (especially nearest the jetty) appears to be moved into the river channel and the ebb-tidal sandbar. Complicating management of the Pine Point Beach area is a 1973 conservation easement which would limit dune restoration or beach nourishment in an approximate 2,000-foot section of the beach. The Town of Scarborough should consider working with the USACE and the Town of Old Orchard Beach to consider nearshore placement of dredged sediment from the Scarborough River in an area off Old Orchard Beach (see next section, Old Orchard Beach Potential Nearshore Placement Site).

Old Orchard Beach Potential Nearshore Placement Site – At the request of the USACE, MGS suggested a secondary location for nearshore placement of sediment associated with future dredging of the Scarborough River. This was requested due to concerns about increased erosion along Pine Point Beach, and current limitations (due to a long-standing conservation easement) on sand placement activities within 2,000 feet of the Scarborough River jetty.

MGS located a site just seaward and north of the pier at Old Orchard Beach, near Little Rock, as a potential site for nearshore placement. The site is approximately 3.3 km southwest of Pine Point Beach. This location was chosen to provide a sediment budget benefit to the beaches along northern Old Orchard Beach and eventually Pine Point Beach in Scarborough. Previous studies (Kelley et al., 2005; Woods Hole Group, 2013; Morang, 2016) suggest that alongshore currents will likely redistribute sediments placed in this area northwards into the Pine Point Beach littoral cell.

In early July 2018, MGS captured nearshore bathymetry in the vicinity of Little River Rock (Figure 13) to provide preliminary site information to the USACE. The survey found relatively smooth beach contours into the offshore, with depths ranging from -4 m to -7 m NAVD88, appropriate for nearshore placement with a barge.

*Management Implications*

Should the USACE consider nearshore placement of dredged materials at this location, the Town of Old Orchard Beach and the Town of Scarborough should consider working with property owners to be prepared for dune restoration, American beach grass planting, and sand fencing activities in order to maximize sediment trapping potential as the sediment migrates northwards into Pine Point.

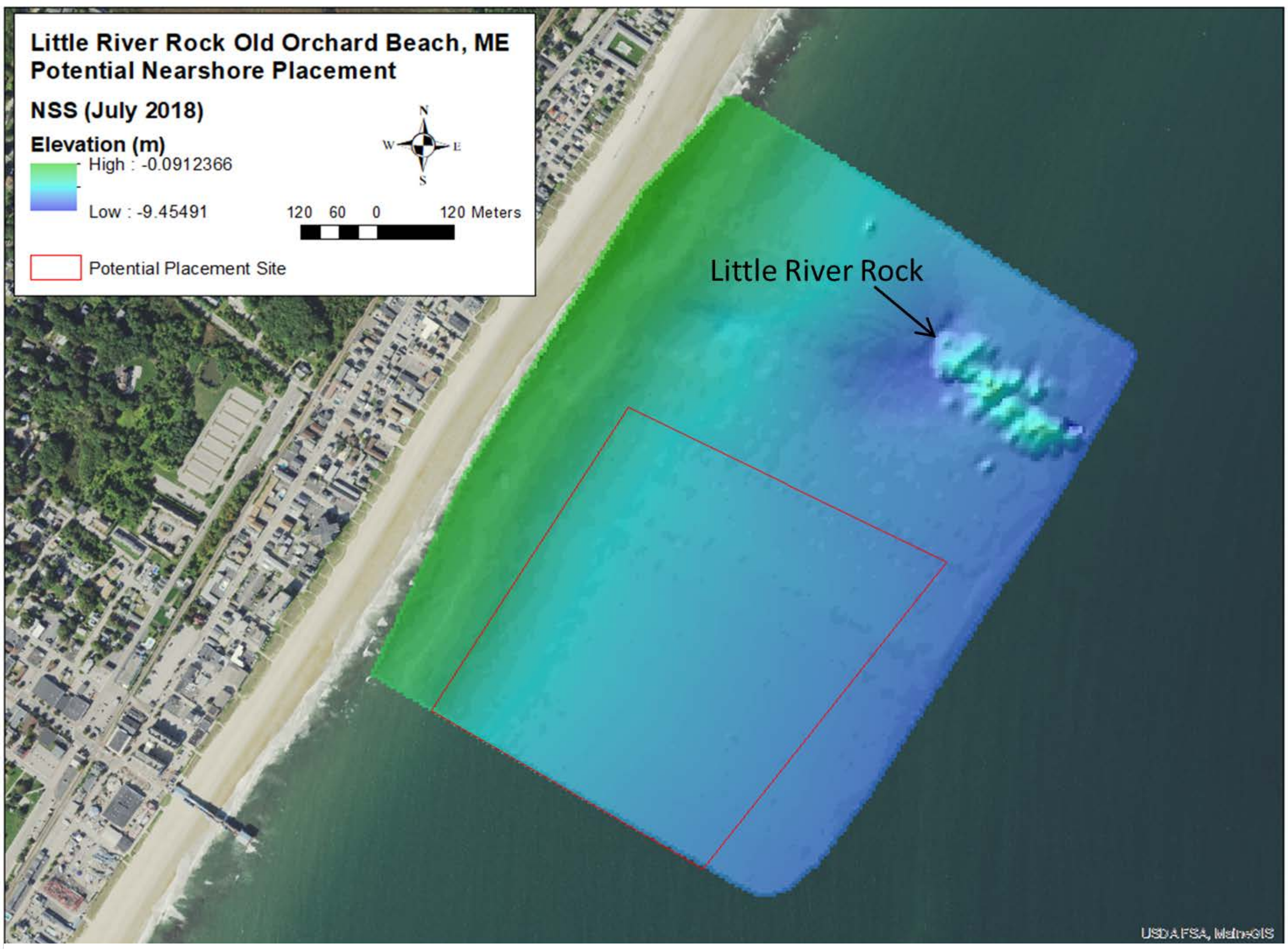


*Figure 13. Bathymetry in the vicinity of the potential Little River Rock nearshore placement site, Old Orchard Beach, ME.*

**Summary for All Study Areas**

All three beaches (in all 3 AOIs except for UAS in Saco, which was influenced by beach nourishment) underwent *loss* from fall 2018 to spring 2019. It is expected that the subaerial beach would undergo loss from fall (when beach berms are most developed) to spring (when sediment builds up into nearshore bars). We would thus expect to see losses in the UAS AOIs but gains in the NSS and possibly MBES areas (as sediment moved and was stored offshore). Similarly, from spring to fall, we would expect gains in the subaerial beach, possible gains in the nearshore, but losses from farther offshore as sediment moved landward due to calmer summer and fall conditions. This seasonal trend is observed along Wells Beach, but not along Saco or Scarborough beaches (Table 15).

| Change Detection Period | Wells | | | | Saco | | | | Scarborough | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UAS | NSS | MBES | TOTAL | UAS | NSS | MBES | TOTAL | UAS | NSS | MBES | TOTAL |
| Late Summer/Fall 2018 - Spring/Summer 2019 | ▼ | ▼ | ▼ | ▼ | ▲ | ▼ (gray) | X | ▼ (gray) | ▼ | ▼ | ▼ (gray) | ▼ |
| Spring/Summer 2019 - Late Summer/Fall 2019 | ▲ | ▲ (gray) | ▲ | ▲ | ▼ | ▼ | ▲ | ▼ | ▼ | ▼ | ▲ (gray) | ▼ (gray) |
| Late Summer/Fall 2019 - Late Summer/Fall 2020 | ▼ | ▲ | ▼ | ▲ | ▲ (gray) | ▲ | X | ▲ | ▼ (gray) | ▲ | ▼ | ▲ (gray) |
| Late Summer/Fall 2018 - Late Summer/Fall 2020 | ▲ | ▲ | ▼ | ▲ | ▲ | ▲ (gray) | X | ▲ (gray) | ▲ | ▼ | ▲ (gray) | ▼ (gray) |

LEGEND

| | |
|---|---|
| ▼ | Net erosion |
| ▲ | Net accretion |
| (gray) | net thresholded volume difference is *below* the calculated error |
| X | no data collected for this time period |

*Table 15. Summary erosion and accretion trends for the different change detection periods at each study area. Gray boxes indicate that volume differences are below the calculated error.*

It appears that Wells and Saco underwent more similar changes than Scarborough. In terms of dominant processes of sediment transport and erosion, this makes sense. Both Wells and Saco are more open to direct wave attack, onshore-offshore and alongshore sediment transport than the Scarborough beaches. Changes at the Scarborough beaches, especially Ferry and Western Beach, are driven more by tidal inlet dynamics. Pine Point Beach is more exposed to wave attack, though it is also heavily influenced by tidal currents (Slovinsky, 2020a).

Both Wells and Saco beaches received either nearshore placement (Wells, June 2018, July 2020) or beach nourishment (Saco, March 2019). This beneficial reuse of dredged materials *clearly had a positive influence in the UAS and NSS AOIs through fall 2020*. Western Beach in Scarborough was nourished in 2015, but has been eroding relatively consistently since (Slovinsky, 2019; Slovinsky, 2020). Erosion trends in the Scarborough River beaches AOI are more driven by Scarborough River tidal inlet dynamics than open beach erosion/accretion (like Wells and Saco).

**Morphologically Defined Depth of Closure (MDDOC) Analysis**

According to Kraus (1998), the depth of closure (DOC) "…is the most landward depth seaward of which there is no significant change in bottom elevation and no significant net sediment transport between the nearshore and the offshore." It is an important proxy in determining maximum depths where nearshore placement materials may still be kept within the beach system, and varies based on wave height, wave period and grain size.

Depths of closure is estimated by the USACE' Coastal Inlets Research Program for different regions of the United States at Wave Information Study (WIS) stations using several different equations that account for nearshore wave height, period, and grain size. Two WIS stations (63038 and 63041) are located near the study areas. Site 63038 is north of the Scarborough River study area at the northern end of Saco Bay and Site 63041 is off Wells Beach. Cumulative WIS data for applicable stations was downloaded (in reference to MLW) and converted to NAVD88 using NOAA's VDATUM. Using a range of DOC calculation equations (variations of Hallermeier, 1981 and Birkemeier, 1998), the predicted depth of closure would vary as shown in Table 16.

| Equation | Estimated Depth of Closure (m, NAVD88) | | |
|---|---|---|---|
| | Wells | Saco | Scarborough |
| Birkemeier (1998) | -5.4 | -5.3 | -5.3 |
| Birkemeier *simplified* (1998) | -5.5 | -5.3 | -5.3 |
| Hallermeier (1981) | -7.6 | -7.4 | -7.4 |
| Hallermeier *simplified* (1998) | -6.6 | -6.6 | -6.6 |

*Table 16. Estimated depth of closure (in m, NAVD88) at each study area using equations from the USACE and nearest available cumulative WIS data.*

Additionally, Depths of closure in the Saco Bay area have also been estimated by the USACE using more detailed analyses (Woods Hole Group, 2013; Morang, 2016) to be -28 ft MLW (-7.1 m NAVD).

Based on analysis of MBES and NSS data, it appeared that most vertical changes below the ±10 cm threshold of change fell within the MBES AOIs as opposed to NSS or UAS areas. For the purpose of examining morphologically defined depths of closure, available MBES data were used. MBES raster data where the highest detectable change *exceeded* the thresholded error (±10 cm) was used to erase areas in the AOI to create an "area of minimal change" polygon. This polygon was then overlain onto the appropriate MBES DEMs and associated depths were extracted to determine an *average depth where minimal changes occurred*. Results from this analysis are shown below in Table 17.

| Study Area | MBES % AOI with changes below ±10 cm | Estimated Morphologically Defined Depth of Closure (MDDOC) in MBES AOIs (m, NAVD88) | | | | Closest Calculated Closure Depth | Difference (m) | Closest Closure Depth equation |
|---|---|---|---|---|---|---|---|---|
| | | Max | Min | StdDev | Mean | | | |
| **Wells** | 79% | -10.7 | -5.9 | 0.79 | -9.1 | -7.6 | -1.5 | Hallermeier (1981) |
| **Saco** | 99% | -13.5 | -4.7 | 2.35 | -7.6 | -7.4 | -0.2 | Hallermeier (1981) |
| **Scarborough** | 77% | -11.7 | -5.0 | 1.38 | -8.6 | -7.4 | -1.2 | Hallermeier (1981) |

*Table 17. Estimated depth of closure for study areas based on morphological changes in the MBES AOIs.*

Minimum depth values from the MDDOC (-4.7 m to -5.9 m) match relatively well with Birkemeier (1998) derived DOCs (-5.3 to -5.4 m). However, in each study area, there were large pockets of notable changes that exceeded these depths. Thus, mean MDDOC values were chosen for comparison with calculated DOC values.

The Saco study area had the closest relationship between morphologically defined DOC (-7.6 m NAVD) and predicted DOC (-7.4 m NAVD). However, note that the standard deviation was quite high, and distribution of the values was negatively skewed. The morphologically calculated depth is also closely related to the predicted DOC from Morang, 2016 (-7.1 m NAVD). The Hallermeier (1981) equation, which follows, matched the MDDOC most closely.

$$d_l = 2.28H_e - 68.5\left(\frac{H_e^2}{gT_e^2}\right)$$

$H_\epsilon = \overline{H}_s + 5.6\sigma_s$
$\overline{H}_s$ = mean significant wave height
$T_\epsilon$ = period associated with $H_\epsilon$
g = acceleration of gravity
σ = standard deviation of $\overline{H}_s$

For the Wells and Scarborough study areas, depth of closure values obtained using WIS station data and DOC equations were shallower than the morphologically defined closure depth. Distributions of extracted values were normal, and the standard deviation, especially for Wells, was lower. Again, the Hallermeier (1981) matched the MDDOC most closely but was on the order of +1 m too *shallow* when compared with the MDDOC for both Wells and Scarborough.

This finding is somewhat surprising. We expected Wells Beach, with a WIS station located just offshore and most exposed to waves and likely least impacted by riverine currents, to be the *most accurate* when comparing DOC with MDDOC. Conversely, we did expect disparity between the MDDOC and the DOC at the Scarborough study area because of proximity to the Scarborough River channel and the ebb-tidal shoal/sandbar that clearly influences sediment movement in this area. We expected a similar disparity at the Saco River beaches study area because of the influence of riverine sediment, and offshore islands and a deep offshore channel impacting wave refraction.

It is important to note that the morphologically defined depth of closure appears *to vary along each of the study areas, especially along Saco beaches* (Figure 6). For example, very little morphological change was observed in the MBES AOI seaward of the northern end of Saco beaches (near Goosefare Brook and in water depths of approximately -6 m NAVD), while large changes were observed just landward in the NSS AOI. This indicates that most of the vertical change is constrained closer to the nearshore along this section of beach. However, in the center portion of the study area, some morphological changes extended much farther offshore and into deeper water (-10 m NAVD and slightly deeper).

**Conclusions**

This project proposed to capture and analyze seamless topography and bathymetry from topographic, nearshore, and offshore data sources. We found it extremely difficult to complete surveys close to each other temporally due to equipment issues, weather, and the size of the survey areas (and thus the time required to survey them). This impacted the ability to compare surveys, as beach conditions can change dramatically even within a few weeks due to storms, etc.

As a result, we attempted to inspect sediment budgets at each study area by comparing each data type collected within just that data type. This worked for the most part but resulted in different snapshots in time at each study area, which impacted seasonal and yearly topographic and volumetric analyses.

Two of the three study areas (Saco and Wells) received beach nourishment or nearshore placement during the study two-year study period. We found that both projects resulted in positive net changes at each study area, indicating that sediment placement locations were appropriate.

We also investigated a morphologically defined depth of closure (MDDOC) at each of the study areas and compared these average values with DOC calculated using traditional equations. We found, in general, that calculated DOCs are shallower than MDDOCs and that sediment transport can occur seaward of the calculated DOCs.

At the Wells Beach study area:

- Nearshore placement in approximately the same areas in June 2018 and July 2020 clearly resulted in a positive net volume gain for the beach system;
- Overall, between 2018 and 2020, the beach system gained over 63,300 $m^3$ of sediment;
- Seasonal and yearly volumetric changes can exceed 100,000 $m^3$, which is larger than expected;
- Large volumetric losses and gains indicate that sediment may be moving into and outside of the study area (possibly into/from the river channel and ebb-tidal shoal);
- The morphologically defined depth of closure (MDDOC) indicated that sediment movement occurs out to depths of approximately -9.1 m NAVD, which is deeper than the equation derived DOCs; and
- Future Webhannet River dredging projects should consider lower-cost nearshore placement as an alternative to beach nourishment. Nearshore placement should be placed as close to the beach as possible and the Town of

Wells should coordinate with property owners on being prepared for dune restoration, planting, and fencing in order to maximize sediment trapping potential.

At the Saco beaches study area:

- Beach nourishment at the southern end of the study area in March 2019 clearly resulted in a positive net volume gain for the beach system;
- Overall, between 2018 and 2020, the beach system gained over 62,275 $m^3$ of sediment;
- Seasonal and yearly volumetric changes can exceed 100,000 $m^3$ and even approach 200,000 $m^3$ which is larger than expected;
- Large volumetric losses and gains indicate that sediment may be moving into and outside of the study area;
- The morphologically defined depth of closure (MDDOC) indicated that sediment movement occurs out to depths of approximately -7.6 m NAVD, which is similar to equation-derived DOC values;
- Future Saco River dredging projects should consider beach nourishment directly onto the beach at Camp Ellis, as it is unclear how nearshore placement may benefit the beach; and
- The City of Saco should coordinate with property owners on being prepared for dune restoration or planting and fencing prior to nourishment occurring in order to maximize sediment trapping potential.

At the Scarborough River beaches study area:

- Beach nourishment along Western Beach in 2015 did result in positive beach growth, but it appears that erosion of the beach has been consistent;
- Overall, between 2018 and 2020, the entire beach system lost over 43,170 $m^3$ of sediment;
- Seasonal and yearly volumetric changes can approach 90,000 $m^3$, though a lack of data at the Pine Point NSS study area precluded full analysis of volumetric changes;
- Large volumetric losses and gains occurred within the Scarborough River channel and in the ebb-tidal shoal/sandbar. Much smaller than expected topographic/volumetric changes were observed in the flood-tidal delta off Ferry Beach;
- The morphologically defined depth of closure (MDDOC) indicated that sediment movement occurs out to depths of approximately -8.6 m NAVD, which is deeper than equation derived DOC values;
- Future Scarborough River dredging projects should consider beach nourishment directly onto the beach at Western Beach and nearshore placement (Little River Rock, Old Orchard Beach) south of Pine Point Beach. A conservation easement along Pine Point Beach currently precludes direct placement of sediment on the beach within 2,000 feet of the jetty. Nearshore placement is not recommended near Western Beach due to tidal inlet circulation patterns;
- The Town of Scarborough should coordinate with property owners (including the Prouts Neck Country Club) on being prepared for dune restoration, planting, and fencing in order to maximize sediment trapping potential after nourishment or nearshore placement is completed; and
- The Town of Scarborough should work with property owners along Pine Point Beach and the State's Bureau of Parks and Lands to determine what kinds of sediment trapping activities (e.g., fencing, staking, etc.) and dune restoration activities may be permissible within the state-owned conservation easement along Pine Point Beach.

The Maine Geological Survey proposes to continue to annually monitor (data collection in late summer) the fate of beach nourishment and nearshore placement sites at these 3 project study areas in the future with the Maine Beach Mapping Program and the MGS Nearshore Survey System.

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