Assessing Sediment Budgets in Support of Beach Nourishment and Coastal Community Resiliency

Bathymetric Change and Sand Dynamics in the Kennebec River and Offshore Popham Beach

Technical Report

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Part 1. Bathymetric Change and Sand Dynamics in the Kennebec River

Introduction

Kennebec River sand reaches the ocean by downstream transport in sand waves, mostly during high freshwater discharge during spring floods (Fenster, et al., 2001). In the river channel studied, and based on prior sampling, the river bottom sediment is extremely well sorted sand with less than 5% silt and clay. More muddy sediment is present along the margins of the river and in the intertidal zone where current speeds are slower, and the floodplain is depositional for fine sediment. During spring floods, mud is discharged into the ocean (Stumpf and Goldschmidt, 1992).

This work focused on the Kennebec River sand budget to better understand its role in the creation and preservation of beaches. Multibeam surveys of the Kennebec River collected backscatter and bathymetry in 2017 and 2019. Three sections or reaches of the river were analyzed for change detection to quantify a 2-year sediment budget (Figure KR-1). The total area compared was 8.2 square kilometers (3.2 square miles). Around 85% of the area studied underwent riverbed elevations change in excess of 10 centimeters vertically. The analysis indicated a net gain of 1.3 million (+/- 0.5 million) cubic meters of sand over two years from the study area. There are no large sedimentary depositional environments within the Kennebec River channel that can accommodate such a large volume of sediment. Therefore, volume loss most likely represents beach sand export to the ocean.

Doubling Point Sand Waves

The northernmost section north of Doubling Point and south of the U.S. Route 1 bridge in Bath is relatively wide and a known bedload convergence zone. Sand carried downstream from the confluence of the Kennebec and Androscoggin Rivers through a bedrock sill called The Chops. This constriction is north of Bath and sand passing through The Chops enters a more estuarine setting with significant tidal exchange and measurable salinity (Fenster and FitzGerald, 1996). In this section of the river, the interplay of seasonal varying freshwater discharge and estuarine circulation driven by semidiurnal tidal currents results in time-varying sediment transport that converges in a wide section of the river.

Rising tides create currents that flow upstream at speeds sufficient to carry sand to the north from south of Doubling Point and through the turbulent Fiddler Reach. The widest portion of the river results in slowing of all upstream and downstream currents that leads to the convergence zone. In this zone, sand waves shift position, change elevation, and cause shoaling that must be dredged to maintain a deep navigation channel for ships built at General Dynamics Bath Iron Works. Sand dredged from these sand waves is transported south of Doubling Point and placed in the next southern reach at an in-river location north of Bluff Head.

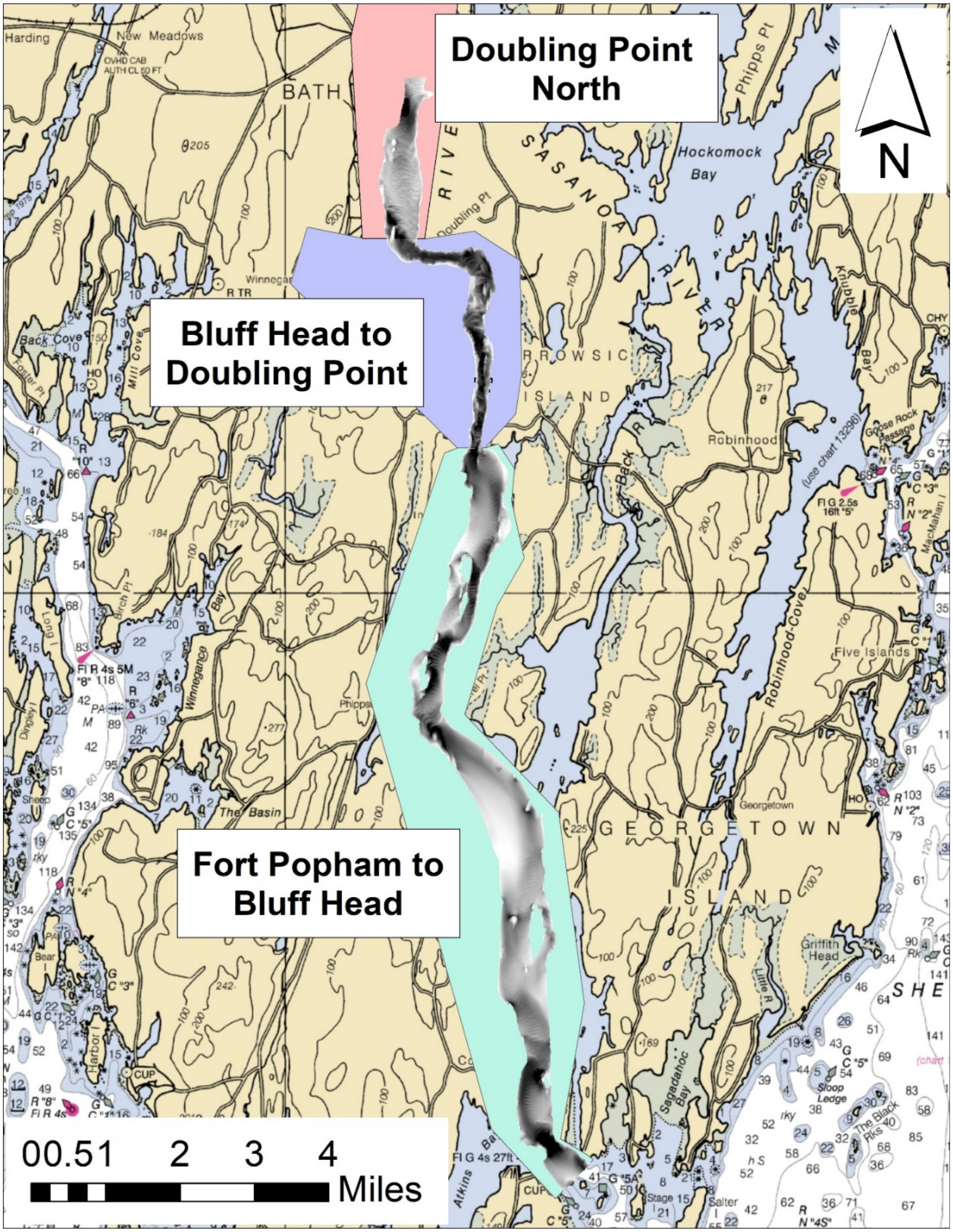

Figure KR-1. Sediment dynamics from Bath to the mouth of the Kennebec River at Fort Popham was examined for three reaches of the river. These sections were divided based on the river geomorphology including width and depth. The gray tint of the riverbed is the backscatter recorded by multibeam echosoundings. Harder bottom results in a darker image and includes bedrock or ledge. The lighter shades of gray include sand. Silt and clay are not common in the deep river channel, but that sediment type produces a very light gray shade. Almost all the image above is from either ledge or sand.

Change in the sand wave field north of Doubling Point over two years is shown in the difference map below (Figure KR-2). The striped color pattern represents the shallowing or deepening of as much as two meters in the north-south direction. These rhythmic changes are the likely results of very large sand waves migrating in the navigation channel. The net loss in some areas was 227,000 cubic meters while other areas had a net gain of 226,000 cubic meters. Despite the active shifting of sand waves, the net sediment volume change in the river was minimal (Table KR-1; Figure KR-3).

In 2017 multibeam surveys were completed in this reach of the river just weeks after the Federal Navigation Channel was dredged to lower the sand waves. Dredging removed the tops of sand waves but left definite troughs recognizable. Comparison of the data with that about a month later shows the rapid regrowth of sand waves (Figure KR-4).

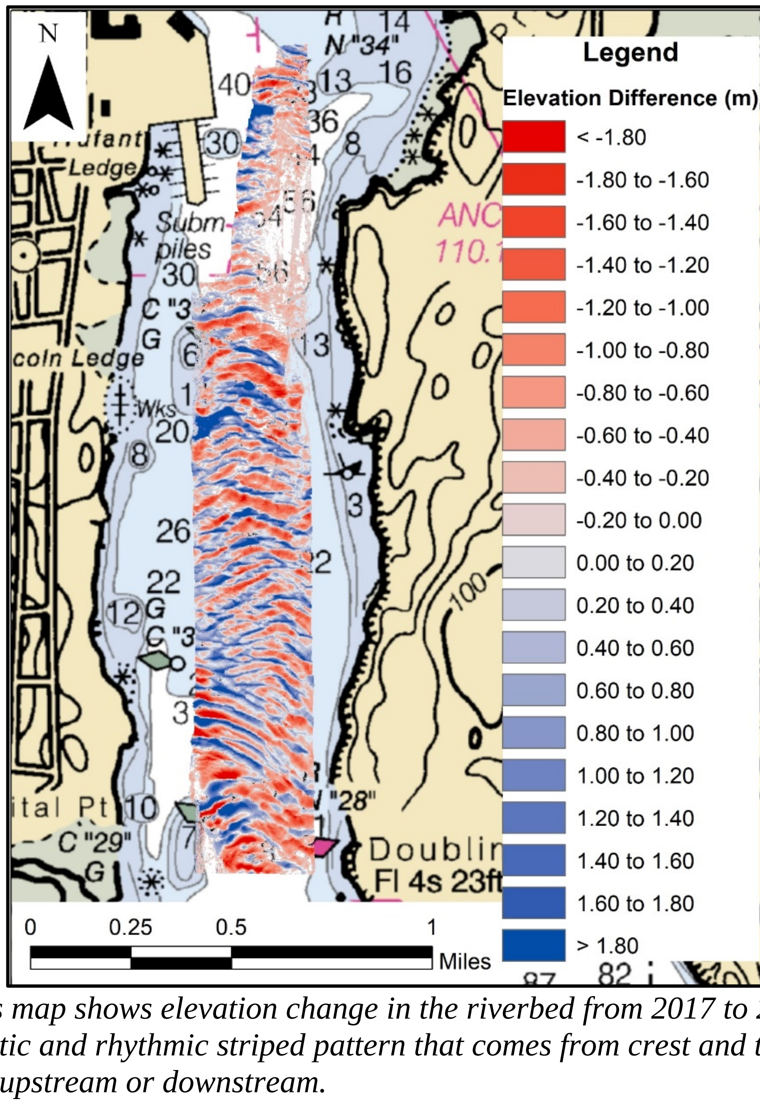

Figure KR-2. This map shows elevation change in the riverbed from 2017 to 2019 in meters. There is a systematic and rhythmic striped pattern that comes from crest and trough migration of sand waves either upstream or downstream.

Attribute	Raw	Thresholded DoD Estimate:			Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m²)	410,188	348,928			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m²)	303,504	262,592			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change (m²)	NA	611,520			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m²)	713,692	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	86%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a proability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering (m³)	230,494	227,180 ±	34,893	15%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut or deflation) summed
Total Volume of Surface Raising (m³)	225,899	224,002 ±	26,259	12%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) summed
Total Volume of Difference (m³)	456,393	451,182 ±	61,152	14%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m³)	-4,595	**-3,179 ±**	**43,670**	-1374%	The net difference of erosion and depostion volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering (m)	0.56	0.65 ±	0.10	15%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising (m)	0.74	0.85 ±	0.10	12%	The average depth of raising (surace raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.64	0.63 ±	0.09	14%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	-0.01	**0.00 ±**	**0.06**	-1374%	The total net volume of difference dividied by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.74 ±	0.10	14%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**-0.01 ±**	**0.07**	-1374%	The total net volume of difference dividied by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	51%	50%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	49%	50%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	-1%	0%			The percent depature from a 50%-50% equilibirum lowering/raising (i.e. erosion/ deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	-1%	-1%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table KR-1. Volumetric change in the Kennebec River north of Doubling Point from 2017 to 2019.

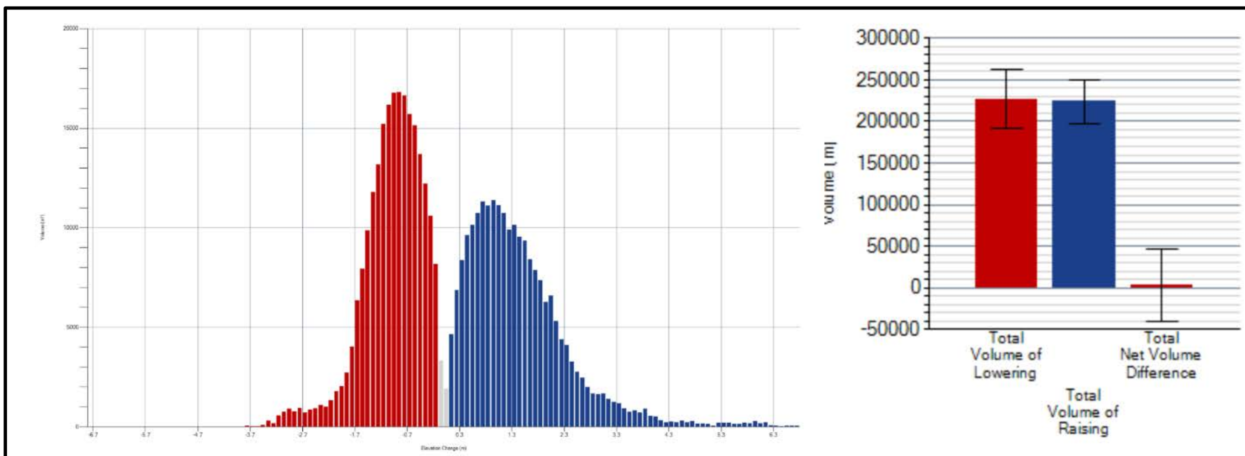

Figure KR-3. In this section of the river, the net volume change was minimal and not statistically significant. This gain-loss analysis shows how sand is in motion in large volumes yet conserved in the bedload convergence zone north of Doubling Point.

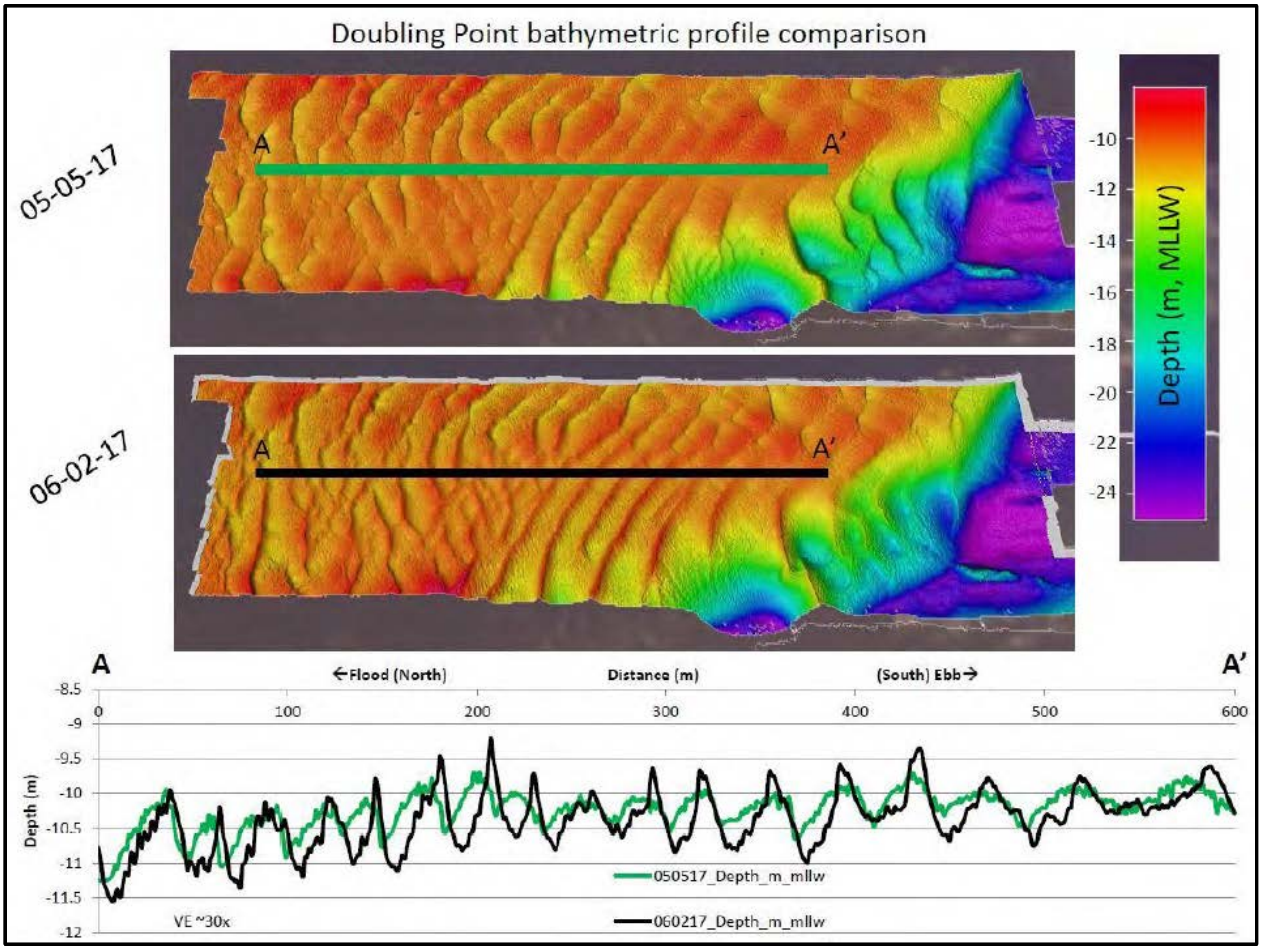

Figure KR-4. The Federal Channel was dredged in April 2017 and the first survey (top panel) shows the reduced relief of the sand waves compared to a month later in June (lower panel). The graph along transect A-A' shows that the crests increased in height and the troughs deepened in just one month. Source: Dobbs (2017).

Bluff Head to Doubling Point

Change in the sand bedload from Bluff Head to Doubling Point from 2017 to 2019 shows a variety of elevation changes over two years (Figure KR-5). The in-river dredged material disposal site, called the Bluff Head disposal site, is delineated by the two east-west horizontal dashed lines. North of the disposal area is an area of mixed size sand waves. In general, this northern section shows net lowering.

South of the disposal site, a rhythmic patter of lowering and rising sand elevations suggests long wavelength sand waves from the migration of crests and troughs. The asymmetry of these sand waves seen in bathymetry suggests net downstream sand transport. It is possible that the sand placed at the in-river disposal site migrates south out of the disposal area in the form of a discrete sand bar. The trough areas (red) have minimal sand so that suggests scouring to bedrock. What remains to be confirmed is whether each disposal event creates a discrete sand wave that then migrates to Bluff Head and disperses into the next reach.

Over the two years from 2017 to 2019, the net sand volume gain in this reach was around 230,000 cubic meters (Table KR-2; Figure KR-6). The sediment flux is twice that due to the dynamics of small sand waves and bed elevation changes. Lowering was on the order of a half a meter. In other words, about half of the volume in motion slipped out of the reach for an annual rate of loss of about 115,000 cubic meters per year. The relatively disproportional loss in the northern end of this area hints that some of this sand may have moved north through Fiddler Reach and to the sand wave field north of Doubling Point.

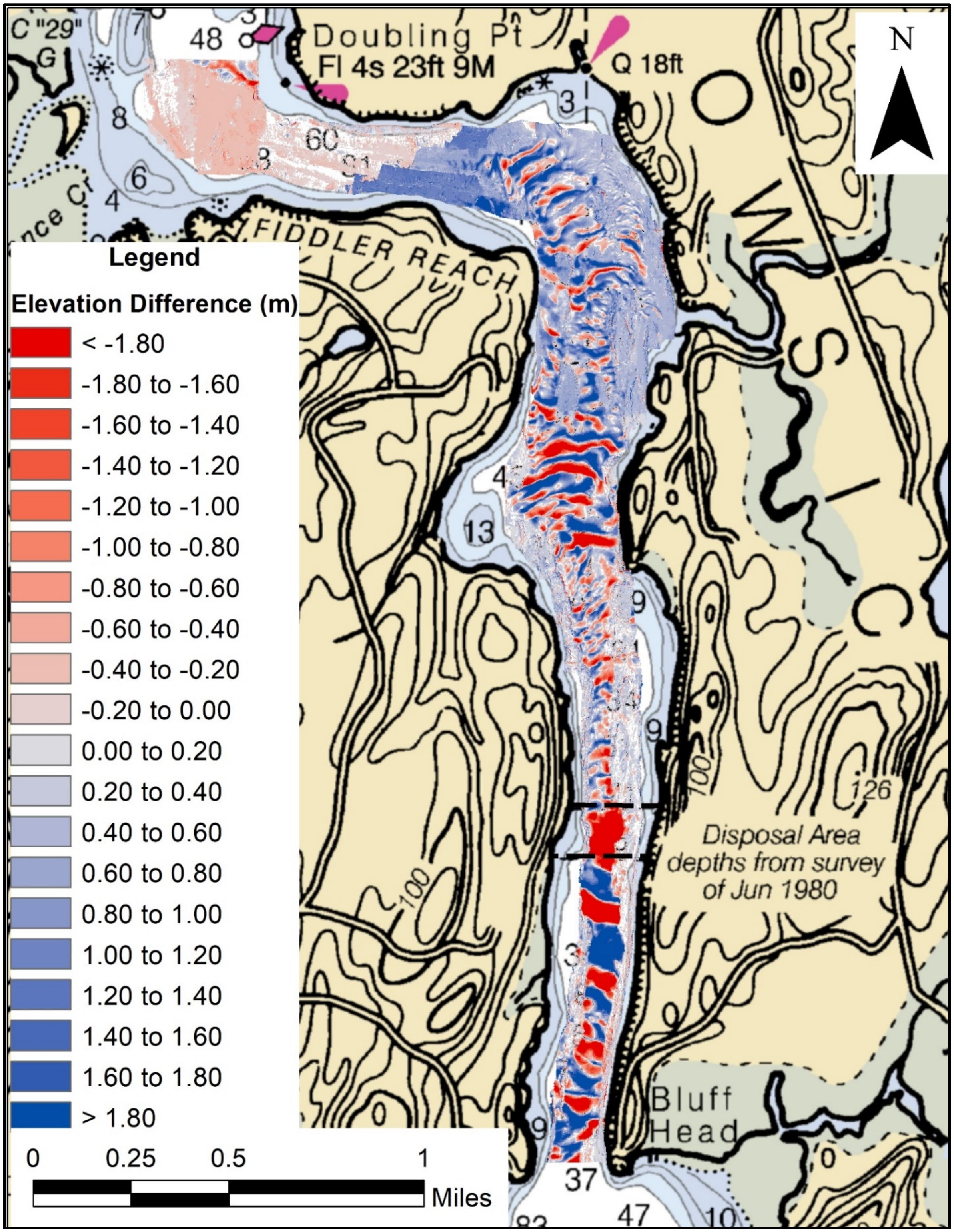

Figure KR-5. Bathymetric change in the Kennebec River from Bluff Head to Fiddler Reach. This section of the river includes the Bluff Head Disposal Site (the area between the black lines) used for dredged sand disposal from the sand wave field to the north of Doubling Point at the top of the map (see the sand waves in Figures KR-2 and KR-4).

Attribute	Raw	Thresholded DoD Estimate:	± Error	% Error	Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m^2)	409,116	340,172			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m^2)	636,804	580,180			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change	NA	920,352			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m^2)	1,045,920	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	88%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering	291,944	288,282 ±	34,017	12%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut or deflation) summed
Total Volume of Surface Raising (m^3)	519,839	517,029 ±	58,018	11%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill) depth multiplied summed
Total Volume of Difference (m^3)	811,783	805,311 ±	92,035	11%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m^3)	227,895	**228,747 ±**	**67,255**	29%	The net difference of erosion and depostion volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering	0.71	0.85 ±	0.10	12%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising	0.82	0.89 ±	0.10	11%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.78	0.77 ±	0.09	11%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	0.22	**0.22 ±**	**0.06**	29%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.88 ±	0.10	11%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**0.25 ±**	**0.07**	29%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	36%	36%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	64%	64%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	14%	14%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	28%	28%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table KR-2. Volumetric change in the Kennebec River between Bluff Head and Doubling Point from 2017 to 2019.

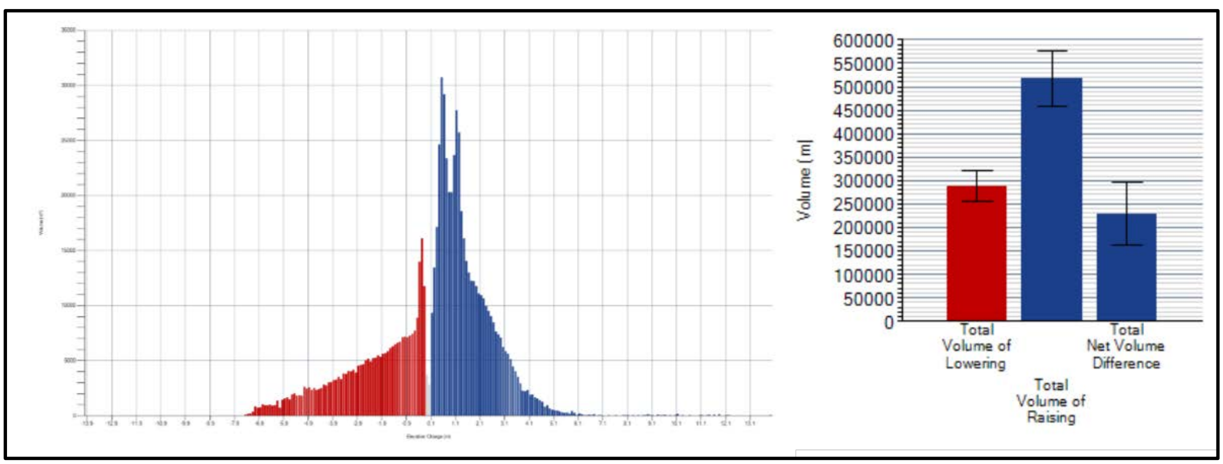

Figure KR-6. Change analysis for the reach between Bluff Head and Fiddler Reach shows a 510,000 cubic meters of sand gain and 290,000 cubic meters of sand loss in other areas. This led to a net gain of 230,000 cubic meters of sediment between 2017 and 2019.

Estuarine Reach

This reach from the river mouth at Fort Popham to Bluff Head is a vertically mixed estuary that is relatively wide and shallow with smaller amplitude sand waves. Where the bedrock valley is narrowest, the greatest vertical change in bed elevations occurs (Figure KR-7). This is due to the higher amplitude sand waves in areas of accelerated tidal flow. The net difference can be as high as 6 to 7 meters due to the crest-to-trough height of a few large sand waves.

The lower Kennebec River reach between Fort Popham and Bluff Head experienced a net gain of sand from 2017 to 2019 (Table KR-3; Figure KR-8). The average amount of riverbed raising was about 0.2 meters. The net shoaling of 1,900,000 cubic meters over two years was offset by bed lowering of about 800,000 cubic meters for a net gain of 1,120,000 cubic meters from this river reach. This represents an annual rate of 560,000 cubic meters per year of sand export.

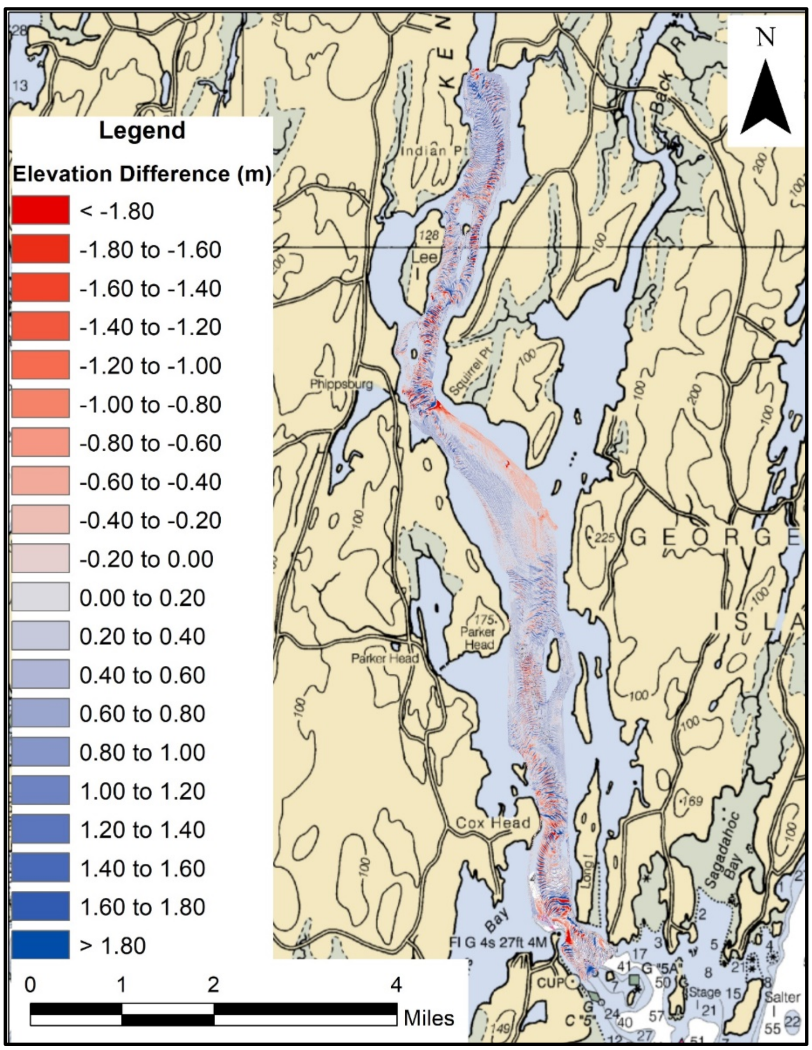

Figure KR-7. Change analysis for the lower Kennebec Estuary from 2017 to 2019. This reach has a variety of channel widths with wide margins that are shallow and muddy in the intertidal zone. The main channel has abundant sand waves that shifted over two years.

			± Error	% Error	
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m^2)	2,123,992	1,629,288			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m^2)	4,295,000	3,688,700			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change	NA	5,317,988			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m^2)	6,418,992	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	83%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering	807,903	784,027 ±	162,929	21%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut) and summed
Total Volume of Surface Raising (m^3)	1,935,454	1,904,412 ±	368,870	19%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) and summed
Total Volume of Difference (m^3)	2,743,357	2,688,439 ±	531,799	20%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m^3)	1,127,551	**1,120,386 ±**	**403,250**	36%	The net difference of erosion and deposition volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering	0.38	0.48 ±	0.10	21%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising	0.45	0.52 ±	0.10	19%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.43	0.42 ±	0.08	20%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	0.18	**0.17 ±**	**0.06**	36%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.51 ±	0.10	20%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**0.21 ±**	**0.08**	36%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	29%	29%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	71%	71%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	21%	21%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	41%	42%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table KR-3. Volumetric change in the Kennebec River between Fort Popham and Bluff Head from 2017 to 2019.

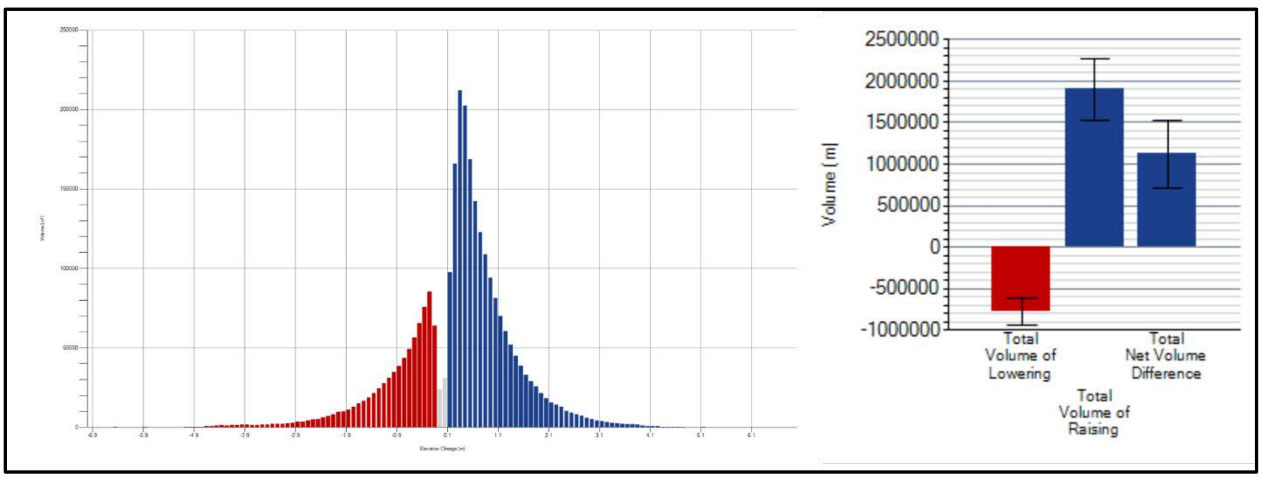

Figure KR-8. Volumetric analysis shows considerable shoaling up to 1,900,000 cubic meters and riverbed erosion of slightly less than half that volume, around 800,000 cubic meters. In addition to being dynamic, this stretch of river exported 1,120,000 cubic meters of sand.

Bluff Head Disposal Site

The Bluff Head Disposal site in the Kennebec River has been used for at least four decades as a location to place sand dredged from the Federal Navigation Channel and the General Dynamics Bath Iron Works dry dock sinking basin. Disposal in the river can help keep the sediment balance and habitat structure of the riverbed intact. Conservation of the river sand bedload (volume transport) is important for the long-term preservation and sustainability of beaches at the mouth of the river such as Popham Beach State Park. Monitoring and analysis of the disposal site with data from this project is useful for understanding river sand budgets as well as future impacts to beaches if disposal were to take place in an upland setting or some other process that removes it from the river system. These data provide a two-year look at sediment dynamics and establish a baseline for future monitoring related to additional dredged sand disposal anticipated for at least another decade.

Dredging for the sinking basin deposited sand, including some silt, at the Bluff Head site in February and March 2017. Previously the sinking basin was dredged in 2009 and 2012. Between April 21 and 26, 2017, the U.S. Army Corps of Engineers dredged 37,000 cubic meters (48,167 cubic yards) of sand from the Federal Navigation Project. This sediment was placed at the in-river disposal site. To put this most recent disposal volume in context, from 1991 to 2011 Bluff Head Disposal Site received a total of 240,000 cubic meters (315,000 cubic yards) from five dredges.

In 2020, Bath Iron Works proposed to dredge approximately 23,000 cubic meters (30,000 cubic yards) between the fall of 2020 and spring of 2021 for the dry dock sinking basin. This effort would also dispose of sand in the Bluff Head Disposal Site. Future full sinking basin dredges could dispose of as much as 54,000 cubic meters (70,000 cubic yards) at the Bluff Head Disposal Site per event.

2017 Site Conditions

The first two multibeam surveys in the Bluff Head Disposal Site were completed on May 5 and June 2, 2017 (Figure KR-9; Dobbs, 2017). The May data represents the river morphology about three months after sediment from the sinking basin was placed there and 1 month after sediment from the Federal Channel was placed there. The June data allows for a monthly change analysis.

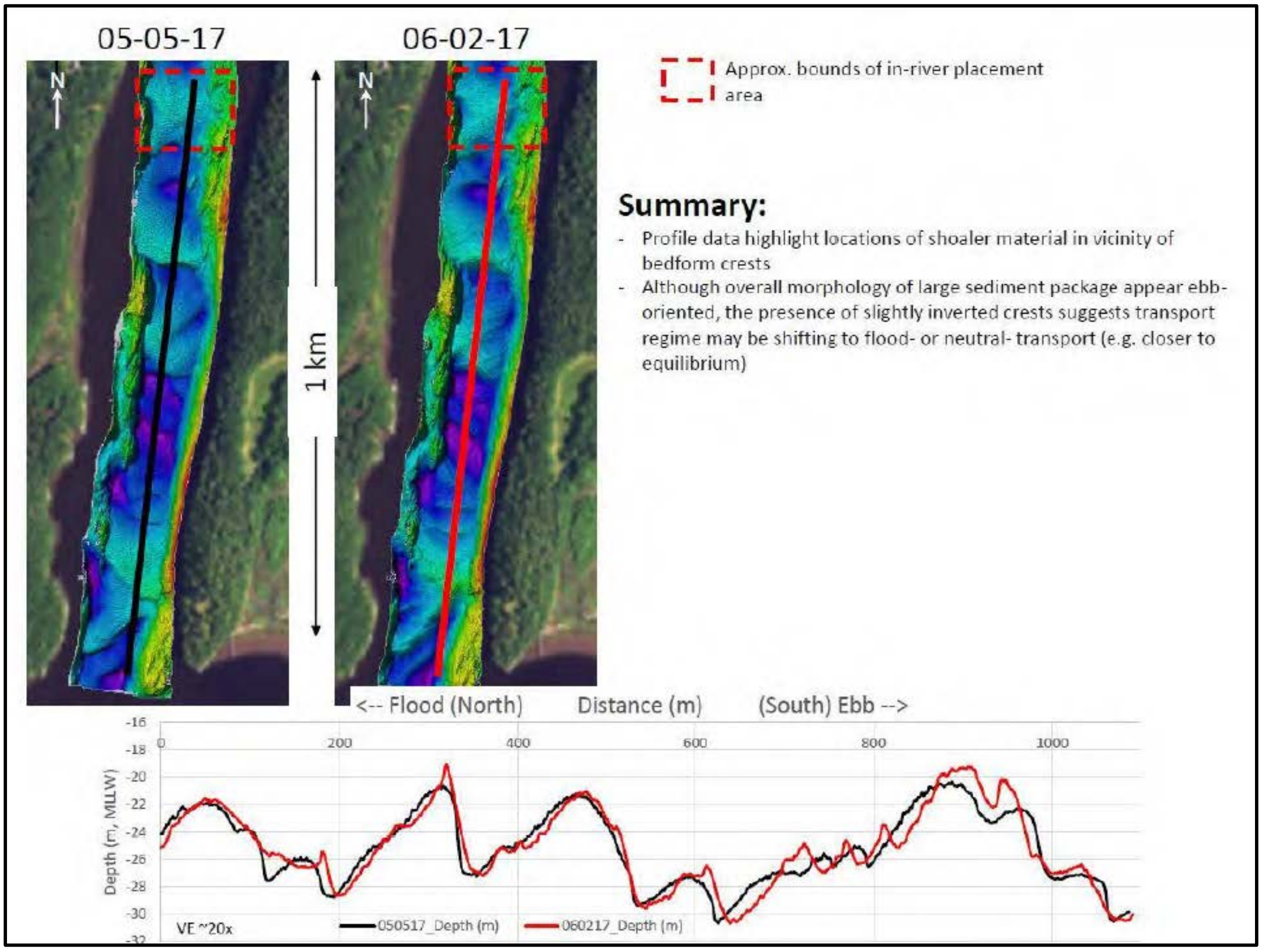

Figure KR-9. Bathymetry and backscatter of the Bluff Head disposal site in 2017 in shaded relief shows the bedrock-framed river channel with center channel depths in the 30-meter range. Nautical chart depths are in feet below Mean Lower Low Water while the shaded relief is in meters MLLW. Source: Dobbs (2017).

Disposal Site Change

The third multibeam survey in this project was completed over several days in 2019. This survey was used to compare the Bluff Head Disposal Site to a 2017 survey. Over the two years there is a clear loss of sediment from the disposal site that led to deepening of the river channel and a change from a smooth riverbed to one that was more irregular (Figure KR-10). From 2017 to 2019 the backscatter shows more ledge outcrops on the bottom, particularly on the western side of the channel (Figure KR-11).

Bluff Head disposal site elevation change from 2017 to 2019 shows a meter to meter and a half of sediment loss (Figure KR-12). The volume at the disposal site decreased by 47,000 cubic meters over two years (Table KR-4; Figure KR-13). This dispersal and deepening are in contrast to the larger river reach from Bluff Head to Fiddler Reach, even when including the disposal area (see the section above), where there was a net gain of sand.

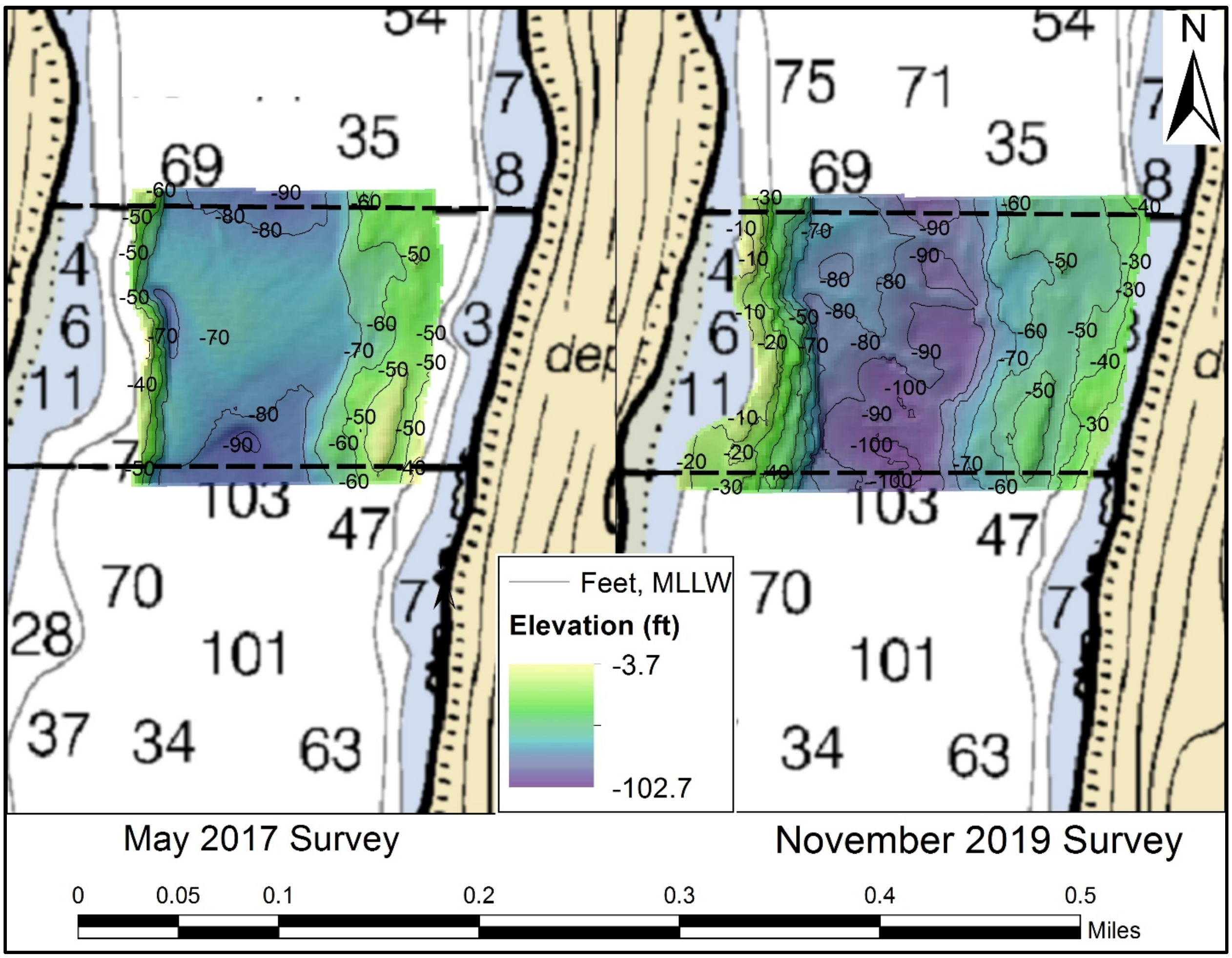

Figure KR-10. Bathymetry of the Bluff Head disposal site in 2017 and 2019 in shaded relief. The images show the bedrock-framed river channel with center channel depths in the 20 to 26-meter (70 to 90-foot) range. Nautical chart depths are also in feet below Mean Lower Low Water MLLW.

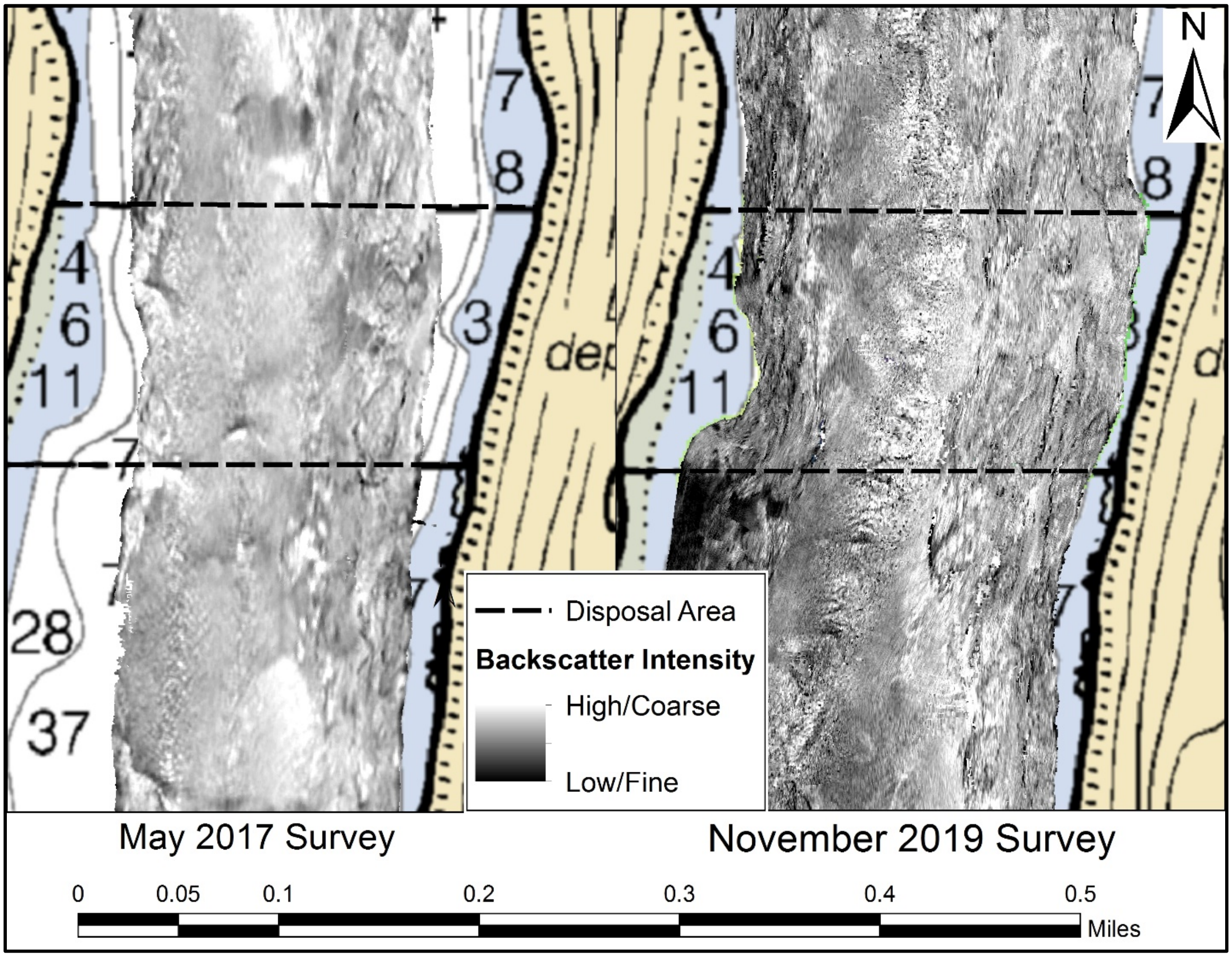

Figure KR-11. Backscatter of the Bluff Head disposal site in 2017 and 2019. More ledge is visible in the 2019 survey, particularly on the west side (left) of the channel in the disposal area. Differences in data processing account for some of the textural differences.

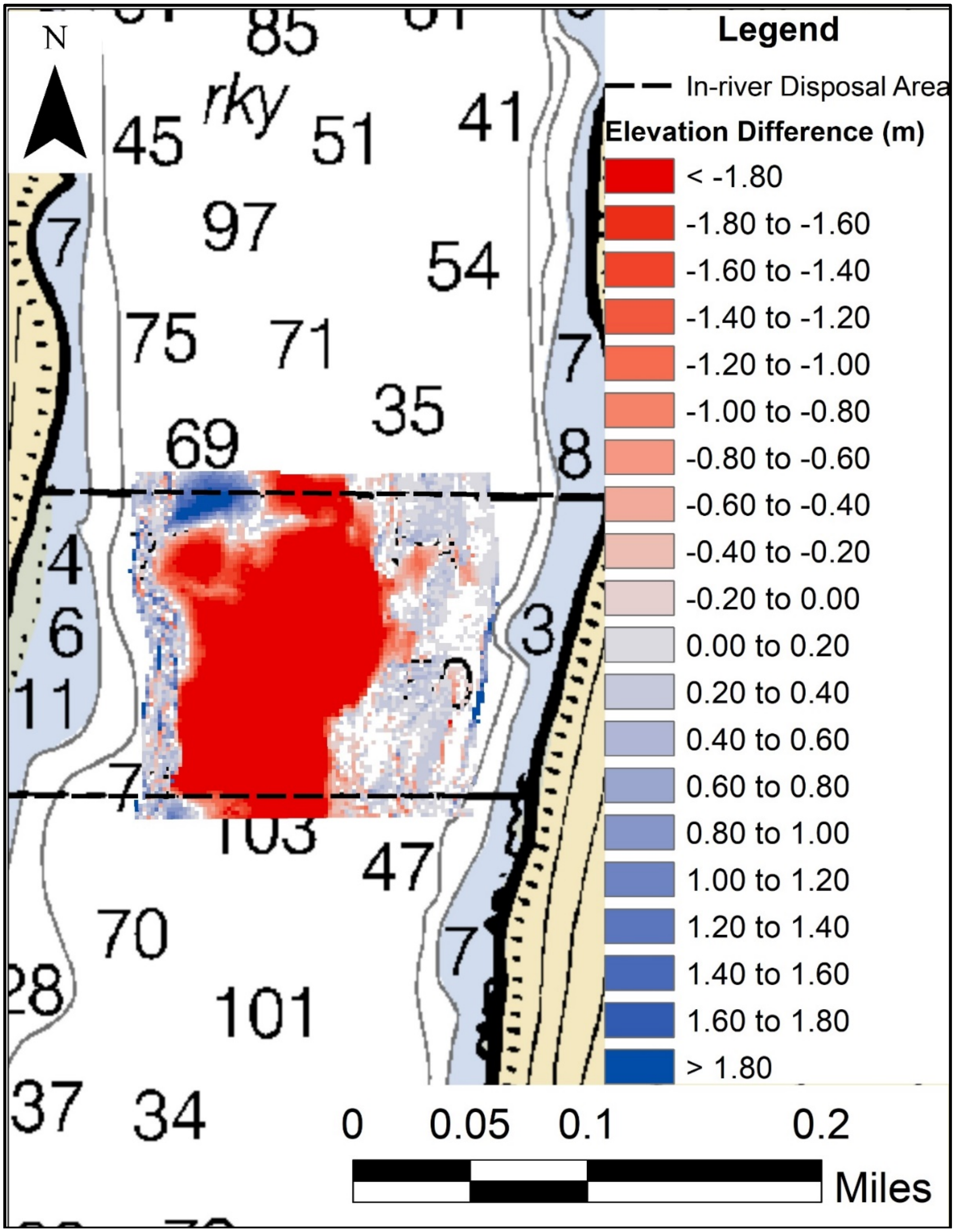

Figure KR-12. Bathymetric change for the Bluff Head Disposal Site from 2017 to 2019. The center of the channel in the disposal area lost about 1.5 meters of elevation from the center of the channel.

Attribute	Raw	Thresholded DoD Estimate:			Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m²)	18,684	17,268			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m²)	10,780	8,384			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change	NA	25,652			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m²)	29,464	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	87%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering	50,656	50,584 ±	1,727	3%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut) and summed
Total Volume of Surface Raising (m³)	4,134	4,005 ±	838	21%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) and summed
Total Volume of Difference (m³)	54,790	54,589 ±	2,565	5%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m³)	-46,522	**-46,579 ±**	**1,920**	-4%	The net difference of erosion and deposition volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering	2.71	2.93 ±	0.10	3%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising	0.38	0.48 ±	0.10	21%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	1.86	1.85 ±	0.09	5%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	-1.58	**-1.58 ±**	**0.07**	-4%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	2.13 ±	0.10	5%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**-1.82 ±**	**0.07**	-4%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	92%	93%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	8%	7%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	-42%	-43%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	-85%	-85%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table KR-4. Volumetric change in the Bluff Head Disposal Site from 2017 to 2019.

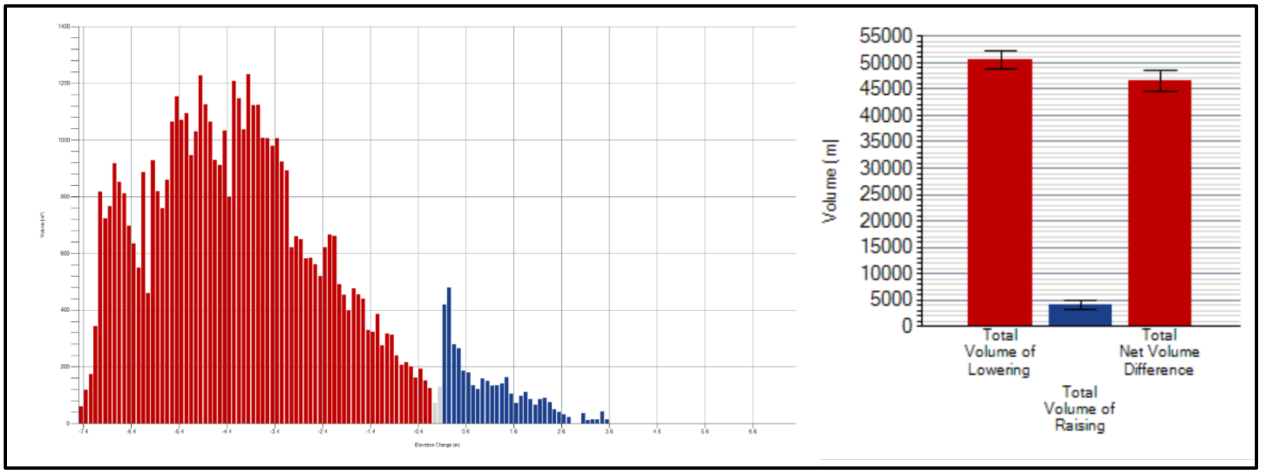

Figure KR-13. Change analysis for the Bluff Head Disposal Site from 2017 to 2019. The net sediment loss was about 47,000 cubic meters. Unlike the full reach that gained sand, this area lost volume as dredged sand dispersed over the two years.

Part 2. Beach Nourishment and Sand Dynamics off Popham Beach

Dredging of Sand from the Lower Kennebec River

The interaction of river bedload sand transport with the open ocean results in sediment accumulation at the Kennebec River mouth near Popham Beach. The Sugarloaf Islands are in the center of the channel and affect wave refraction as well as river and tidal currents. The interplay of spring floods and reversing tidal currents creates sand waves (Figure PB-1). Large sand waves cause shoaling in the Federal Navigation Channel and, since they rebuild naturally, there is a need for repeated dredging and placement of sand at a nearshore disposal site.

Dredging in the Federal Navigation Channel between Popham Beach and the Sugarloaf Islands deepens the channel by removing the crests of sand waves. Since the late 1980s, dredged sand has been transported by ship to the Jackknife Ledge disposal site several times from 2011 to 2017.

In the absence of dredging, Kennebec River sand bypasses the Sugarloaf Islands, reaches the sea in this area, and experiences wave reworking that forms a sandy delta. The modern depositional delta is the Pond Island Shoal (FitzGerald et al., 2000). Over the last 15,000 years, river sand was deposited at lower sea levels in enough volume to bury bedrock and create the Kennebec Paleodelta estimated to have a sand volume of 2.1 billion cubic meters (Barnhardt et al., 1997).

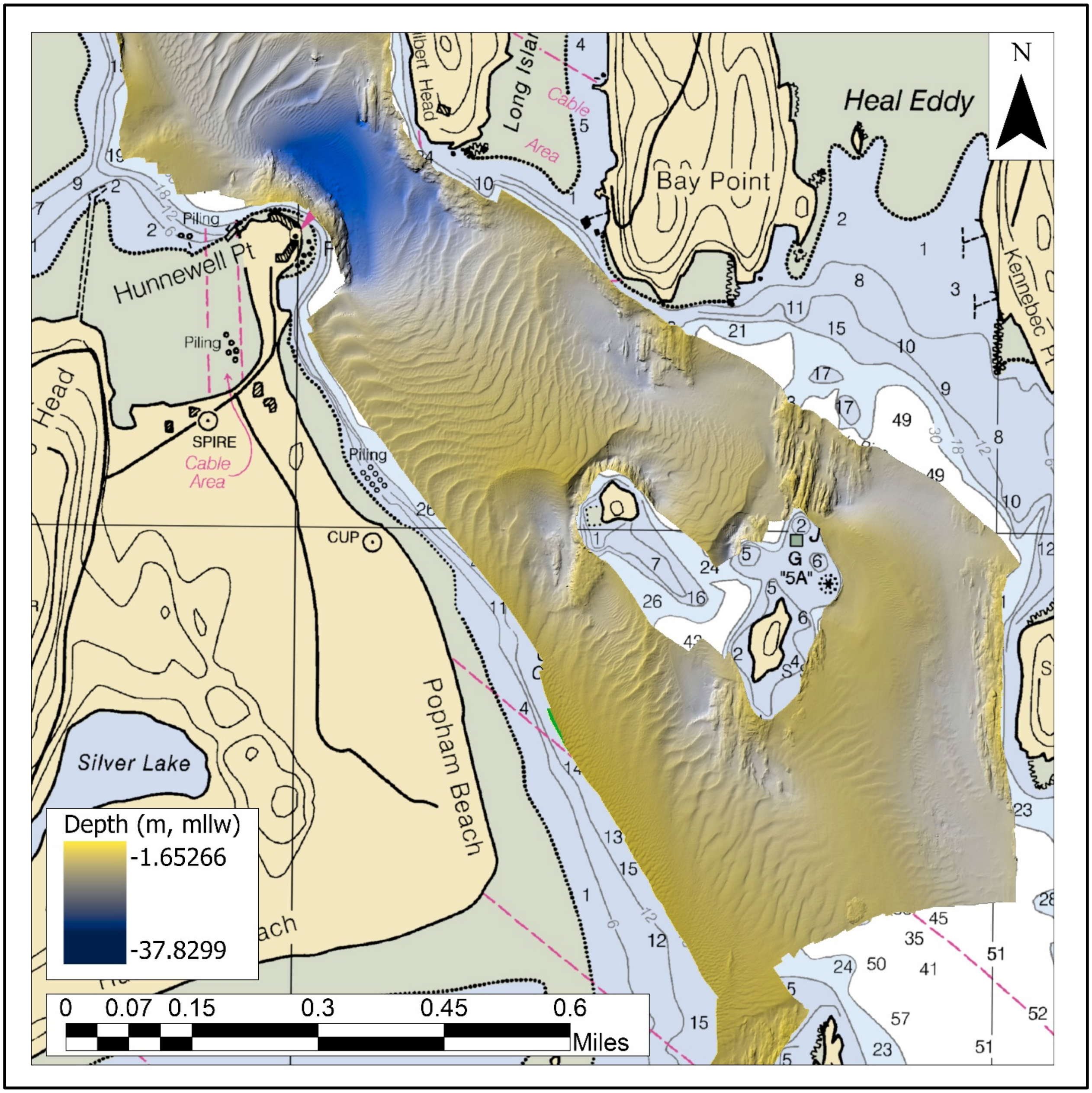

Figure PB-1. This figure shows a shaded relief map made from multibeam data. Sand waves are common in the Kennebec River from Fort Popham to Pond Island in the south. These sand waves form from reversing flood- and ebb-tidal currents.

Jackknife Ledge Nearshore Disposal Site

Between April 21 and 26, 2017, river dredging of 11,000 cubic meters (14,186 cy) of sand from the Federal Navigation Project was placed at the Jackknife Ledge disposal site. This project investigated change from 2016 through 2020 to look for sand dispersal and effectiveness of the site for beach nourishment.

Change Analysis at Jackknife Ledge 2016 to 2017

Repeated multibeam surveys over the Jackknife Ledge Disposal Site were used to compare bathymetric changes within and adjacent to the disposal area used in 2017. An August 2016 survey provided the "before" condition and a May 2017 survey provided the "after" survey about 3 weeks after dredging was completed. The two bathymetric surfaces were compared by Dobbs (2017; Figure PB-2) and a net volume change of 11,300 cubic meters was detected in the southwest quadrant of the disposal area. This volume matches the U.S. Army Corps of Engineers dredged volume.

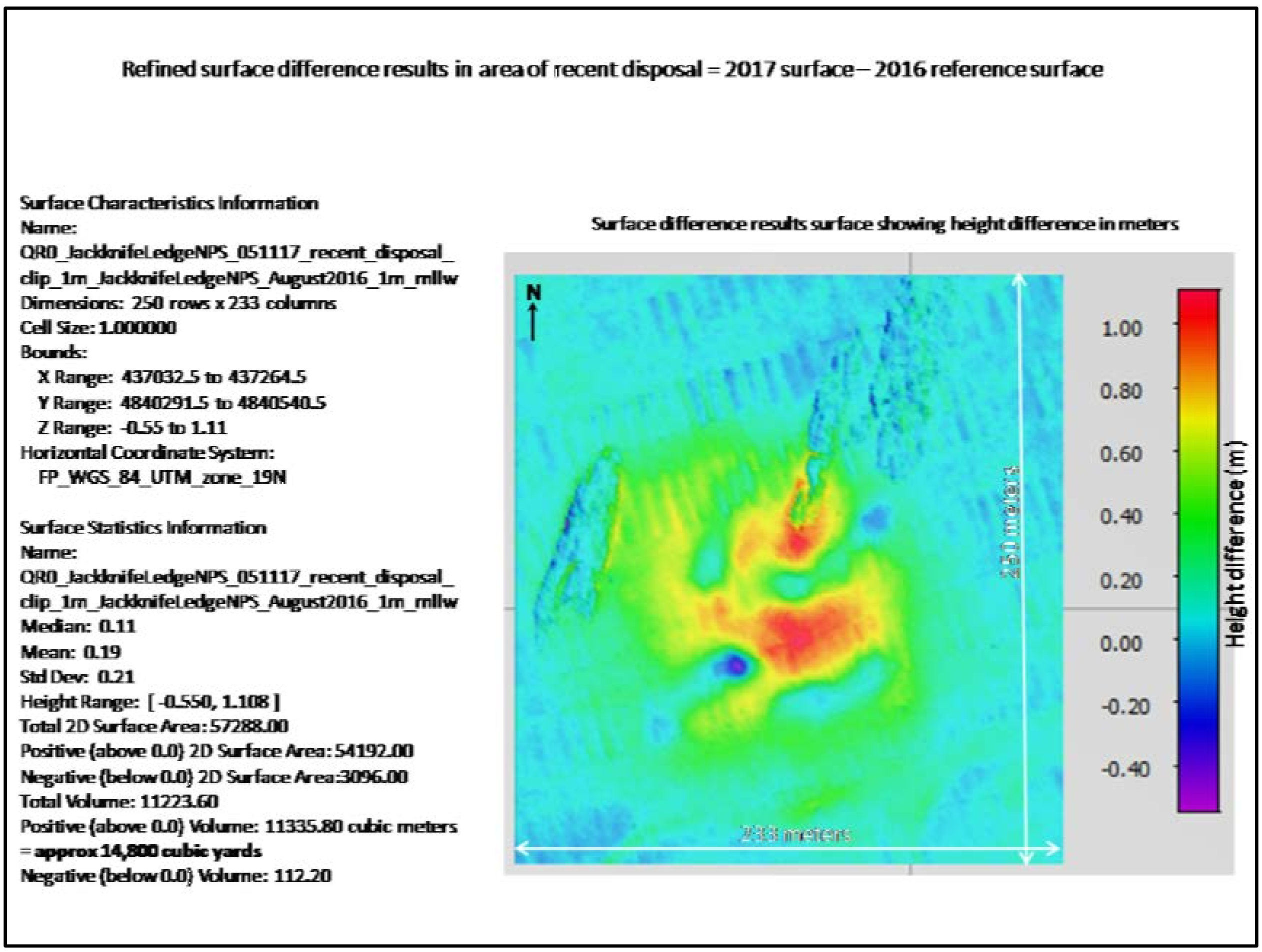

Figure PB-2. Change thickness map from 2016 to 2017 with scale on right. Bathymetric change detected disposal of 11,300 cubic meters (14,800 cubic yards) at the Jackknife Ledge disposal site between 2016 and 2017. The morphology shows an uneven mound with sediment added to an elevation up to a meter and averaging half a meter of deposition. Image by K. Dobbs, MCMI.

A broader area of interest (AOI) surrounding the Jackknife Ledge Disposal Site was selected to examine movement of sand and changes in seafloor elevation into and out of the disposal site (Figure PB-3). The full AOI is 788,000 square meters. A net lowering of a few centimeters across a large area resulted in a net loss of sediment from the full AOI of 12,000 cubic meters (Table PB-1). Figure PB-3 does show the disposal mound in a similar shape as in Figure PB-2 and this net loss appears from areas outside of the disposal site.

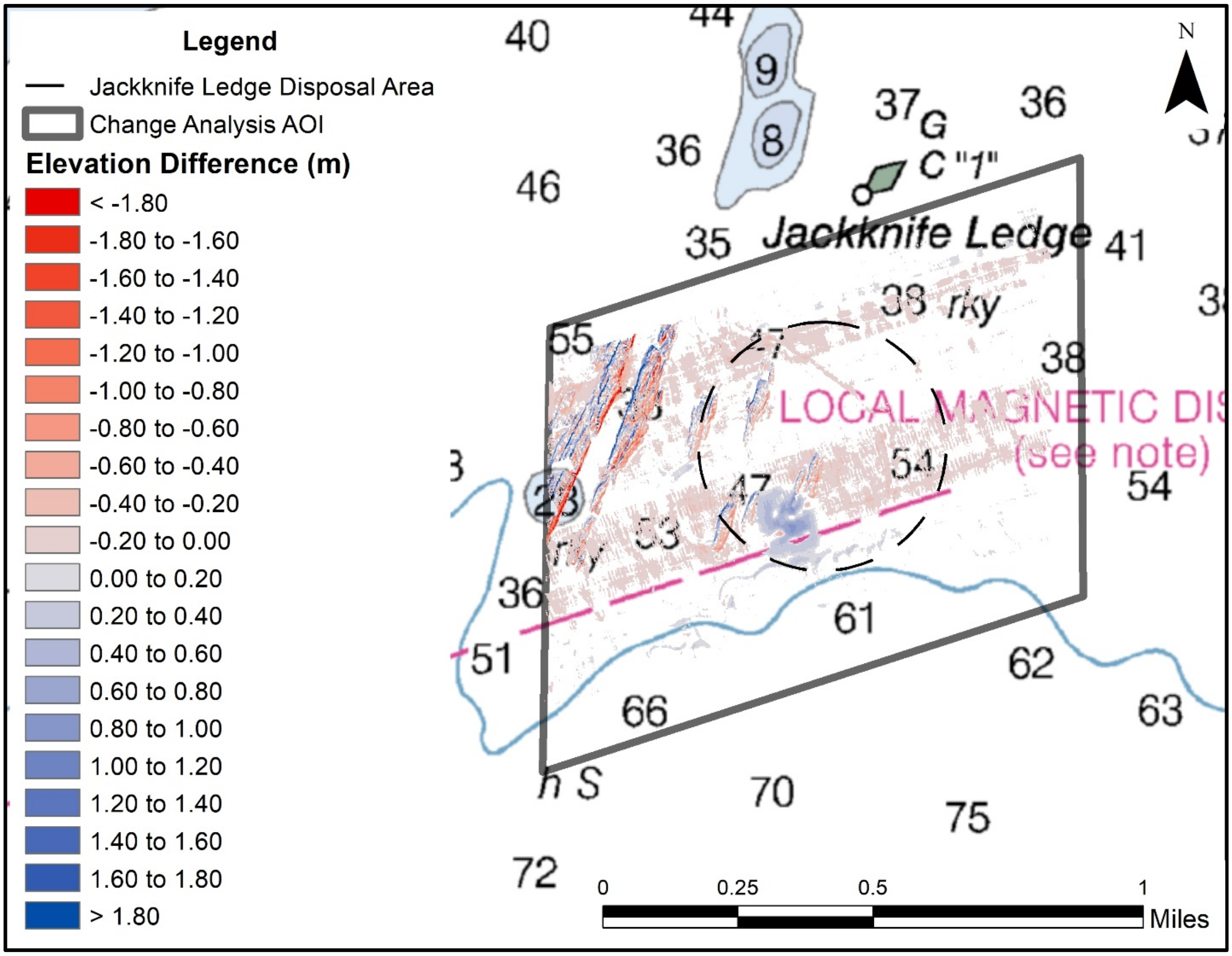

Figure PB-3. Bathymetric change from 2016 to 2017 at Jackknife Ledge. The southwest quadrant of the circular disposal area shows the mound created by dredged material disposal a few weeks before the 2017 survey.

Attribute	Raw	Thresholded DoD Estimate:			Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m²)	516,448	169,788			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m²)	271,232	53,760			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change (m²)	NA	223,548			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m²)	787,680	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	28%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering (m³)	52,033	34,629 ±	16,979	49%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut) and summed
Total Volume of Surface Raising (m³)	31,224	22,834 ±	5,376	24%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) and summed
Total Volume of Difference (m³)	83,258	57,463 ±	22,355	39%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m³)	-20,809	**-11,795 ±**	**17,810**	-151%	The net difference of erosion and deposition volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering (m)	0.10	0.20 ±	0.10	49%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising (m)	0.12	0.42 ±	0.10	24%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.11	0.07 ±	0.03	39%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	-0.03	**-0.01 ±**	**0.02**	-151%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.26 ±	0.10	39%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**-0.05 ±**	**0.08**	-151%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	62%	60%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	38%	40%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	-12%	-10%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	-25%	-21%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table PB-1. Volumetric change at Jackknife Ledge AOI from 2016 to 2017.

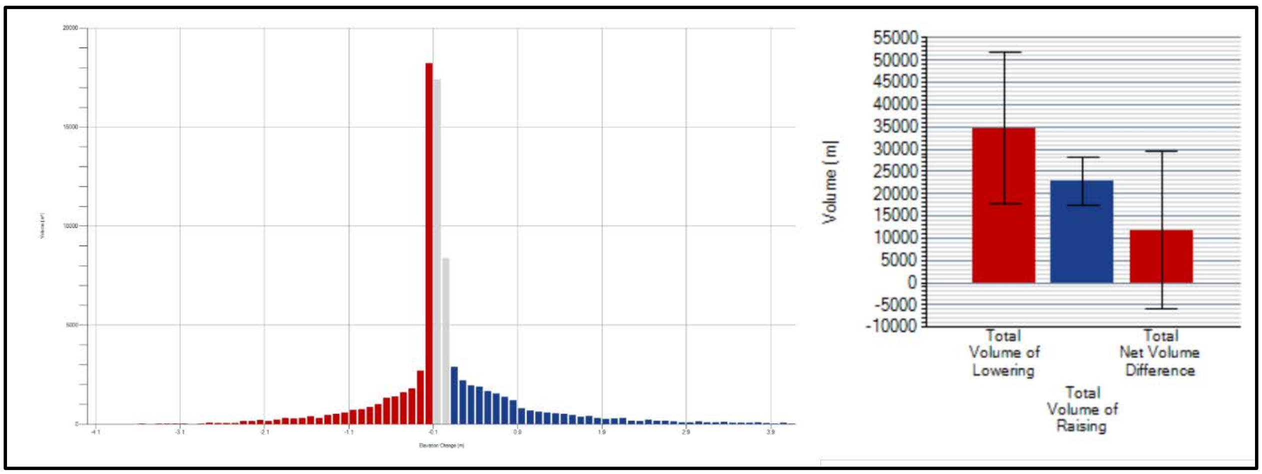

Figure PB-4. Change analysis for the Jackknife Ledge AOI from 2016 to 2017. The net loss of a few centimeters of sand (tall red bar in left histogram) occurred over a wide area to result in a net loss of sediment from within the AOI.

Change Analysis at Jackknife Ledge 2017 to 2020

Multibeam surveys over the Jackknife Ledge Disposal Site were used to compare bathymetric changes within and adjacent to the disposal from 2017 to 2020 (Figure PB-5). The height of the 2017 disposal mound lowered slightly, and some net gain was detected in the center of the disposal area. This suggests that, over 3 years, sand deposited in 2017 did not leave the disposal site but may have moved a quarter of a mile north-northeast within the site.

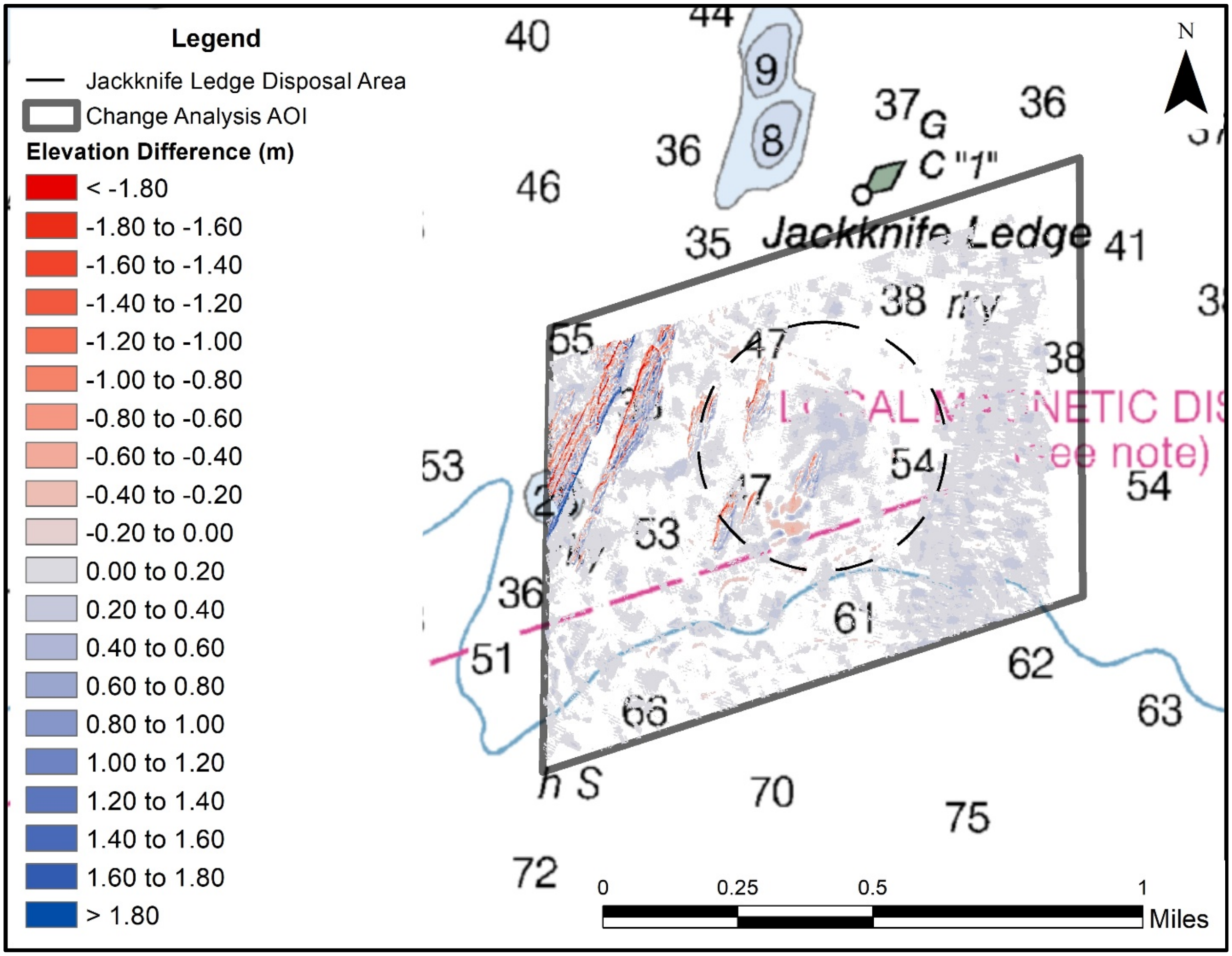

Figure PB-5. Bathymetric change from 2017 to 2020 at Jackknife Ledge showed only a few centimeters of change across the larger area of interest (AOI).

Across the full area of interest, comparison of elevations shows about 51,000 cubic meters of net change (Table PB-2). Most of this change was from a few centimeters of vertical difference across a wide area (Figure PB-6). There does not appear to be a net area of erosion or deposition in the AOI. As in the 2016-2017 comparison, these small differences over a rather flat surface may be related to data processing to account for tidal elevations.

Attribute	Raw	Thresholded DoD Estimate:			Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m²)	115,988	33,580			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m²)	816,148	380,436			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change (m²)	NA	414,016			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m²)	932,136	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	44%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering (m³)	19,679	17,092 ±	3,358	20%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut) and summed
Total Volume of Surface Raising (m³)	93,169	68,565 ±	38,044	55%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) and summed
Total Volume of Difference (m³)	112,848	85,657 ±	41,402	48%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m³)	73,490	**51,473 ±**	**38,192**	74%	The net difference of erosion and deposition volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering (m)	0.17	0.51 ±	0.10	20%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising (m)	0.11	0.18 ±	0.10	55%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.12	0.09 ±	0.04	48%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	0.08	**0.06 ±**	**0.04**	74%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.21 ±	0.10	48%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**0.12 ±**	**0.09**	74%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	17%	20%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	83%	80%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	33%	30%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	65%	60%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table PB-2. Volumetric change at Jackknife Ledge from 2017 to 2020.

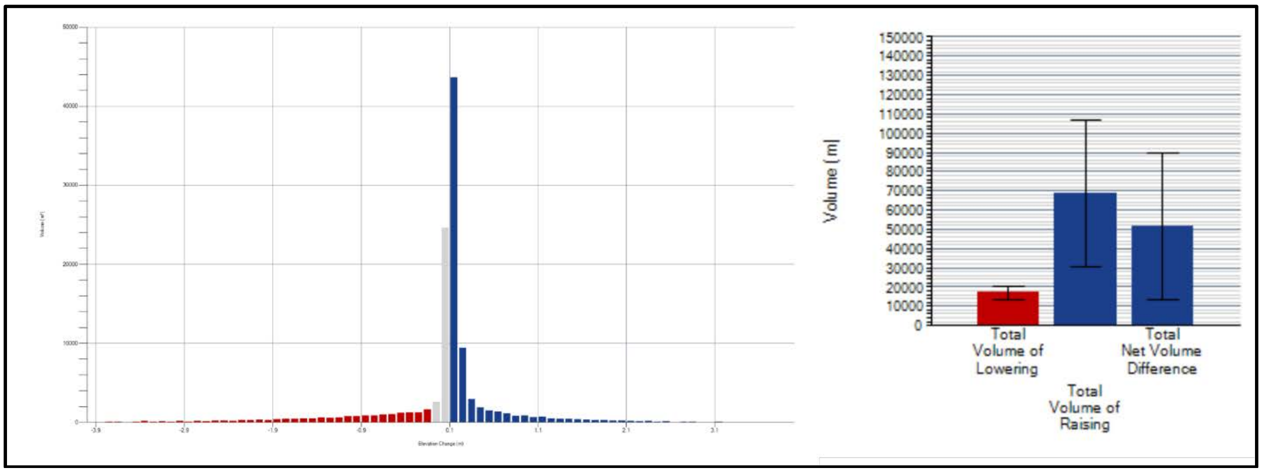

Figure PB-6. Change analysis for the Jackknife Ledge Disposal Site from 2017 to 2020.

Change Analysis at Jackknife Ledge 2016 to 2020

Multibeam surveys from 2016 to 2020 over the Jackknife Ledge Disposal Site were used to compare bathymetric changes within and adjacent to the disposal over the full 3 years of this project (Figure PB-7). The largest change was the increase in seabed elevation at the disposal mound created in 2017. The remainder of the disposal site and surrounding area of interest changed very little.

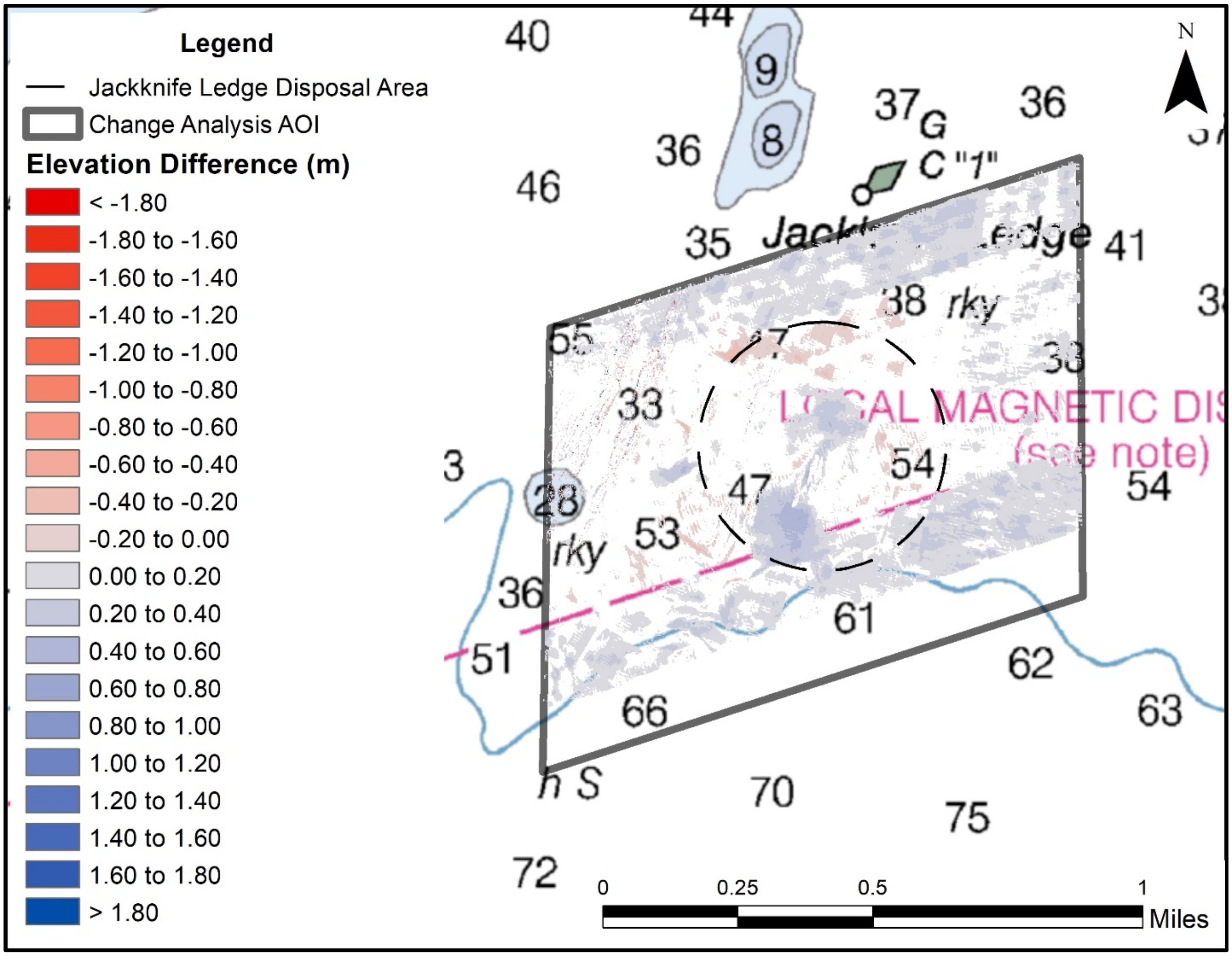

Figure PB-7. Bathymetric change from 2016 to 2020 at the Jackknife Ledge area of interest (AOI).

The net volume difference detected from 2016 to 2020 was an increase of 46,000 cubic meters with an error estimate of plus or minus 30,000 cubic meters (Table PB-3). This is a result primarily of a gain in elevation of about 13 +/- 9 centimeters across a large area (Figure PB-8).

Attribute	Raw	Thresholded DoD Estimate:			Description
AREAL:					**AREAL METRICS**
Total Area of Surface Lowering (m^2)	257,936	36,488			The amount of area experiencing a lowering of surface elevations
Total Area of Surface Raising (m^2)	667,884	301,932			The amount of area experiencing an increase of surface elevations
Total Area of Detectable Change (m^2)	NA	338,420			The sum of areas experiencing detectable surface elevation changes
Total Area of Interest (m^2)	925,820	NA			The total amount of area under analysis (including detectable and undetectable)
Percent of Area of Interest with Detectable Change	NA	37%			The percent of the total area of interest with detectable changes (i.e. either exceeding the minimum level of detection or with a probability greater then the confidence interval chosen by user)
VOLUMETRIC:			± Error Volume	% Error	**VOLUMETRIC METRICS**
Total Volume of Surface Lowering (m^3)	14,804	6,136 ±	3,649	59%	On a cell-by-cell basis, the DoD surface lowering depth (e.g. erosion, cut) and summed
Total Volume of Surface Raising (m^3)	69,968	51,721 ±	30,193	58%	On a cell-by-cell basis, the DoD surface raising (e.g. deposition, fill or inflation) and summed
Total Volume of Difference (m^3)	84,772	57,858 ±	33,842	58%	The sum of lowering and raising volumes (a measure of total turnover)
Total **Net** Volume Difference (m^3)	55,165	**45,585 ±**	**30,413**	67%	The net difference of erosion and deposition volumes (i.e. deposition minus erosion)
VERTICAL AVERAGES:			± Error Thickness	% Error	**VOLUMETRIC METRICS NORMALIZED BY AREA**
Average Depth of Surface Lowering (m)	0.06	0.17 ±	0.10	59%	The average depth of lowering (surface lowering volume divided by surface lowering area)
Average Depth of Surface Raising (m)	0.10	0.17 ±	0.10	58%	The average depth of raising (surface raising volume divided by surface raising area)
Average Total Thickness of Difference (m) for Area of Interest	0.09	0.06 ±	0.04	58%	The total volume of difference divided by the area of interest (a measure of total turnover thickness in the analysis area)
Average **Net** Thickness Difference (m) for Area of Interest	0.06	**0.05 ±**	**0.03**	67%	The total net volume of difference divided by the area of interest (a measure of resulting net change within the analysis area)
Average Total Thickness of Difference (m) for Area With Detectable Change	NA	0.17 ±	0.10	58%	The total volume of difference divided by the total area of detectable change (a measure of total turnover thickness where there was detectable change)
Average **Net** Thickness Difference (m) for Area with Detectable Change	NA	**0.13 ±**	**0.09**	67%	The total net volume of difference divided by the total area of detectable change (a measure of resulting net change where the was detectable change)
PERCENTAGES (BY VOLUME)					**NORMALIZED PERCENTAGES**
Percent Elevation Lowering	17%	11%			Percent of Total Volume of Difference that is surface lowering
Percent Surface Raising	83%	89%			Percent of Total Volume of Difference that is surface raising
Percent Imbalance (departure from equilibrium)	33%	39%			The percent departure from a 50%-50% equilibrium lowering/raising (i.e. erosion/deposition) balance (a normalized indication of the magnitude of the net difference)
Net to Total Volume Ratio	65%	79%			The ratio of net volumetric change divided by total volume of change (a measure of how much the net trend explains of the total turnover)

Table PB-3. Volumetric change at Jackknife Ledge AOI from 2016 to 2020.

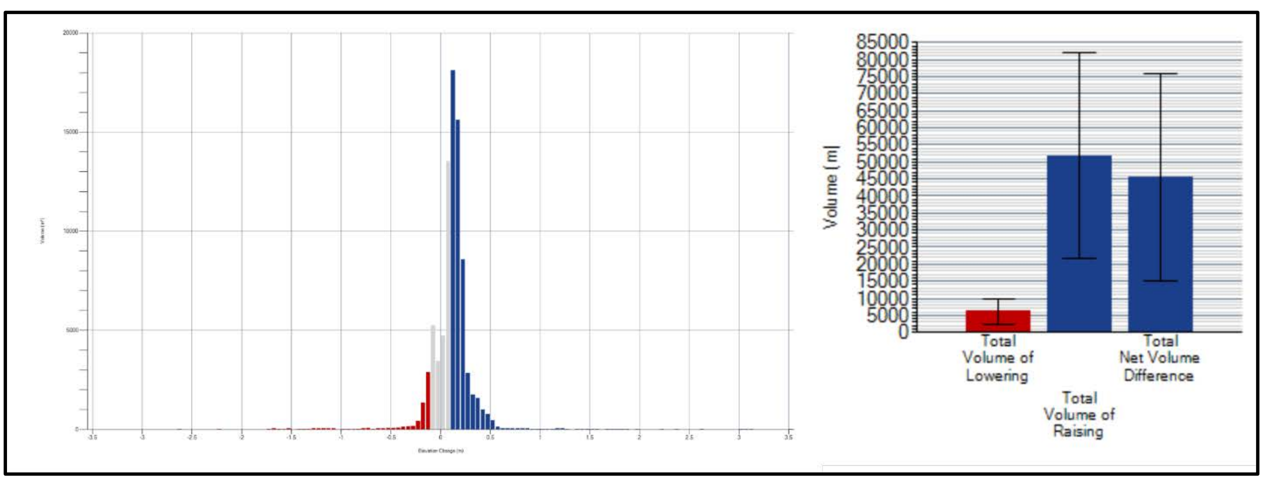

Figure PB-8. Change analysis for the Jackknife Ledge AOI from 2016 to 2020 shows the primary volume gain appears to be from a widespread area of seafloor shoaling of a few centimeters. These small vertical differences over a rather flat surface may be related to data processing to account for tidal elevations.

Backscatter comparison between the 2016 and 2020 survey shows high-resolution spatial detail of the coarser sand in and around the disposal area (Figure PB-9). The morphology of patches of contrasting grain sizes shows very little sediment dispersal over three years. Over three years, very little sediment transport appears to have changed the seabed morphology or sedimentary texture at the Jackknife Ledge Disposal Site or to have led to net sand transport onshore to provide beach nourishment.

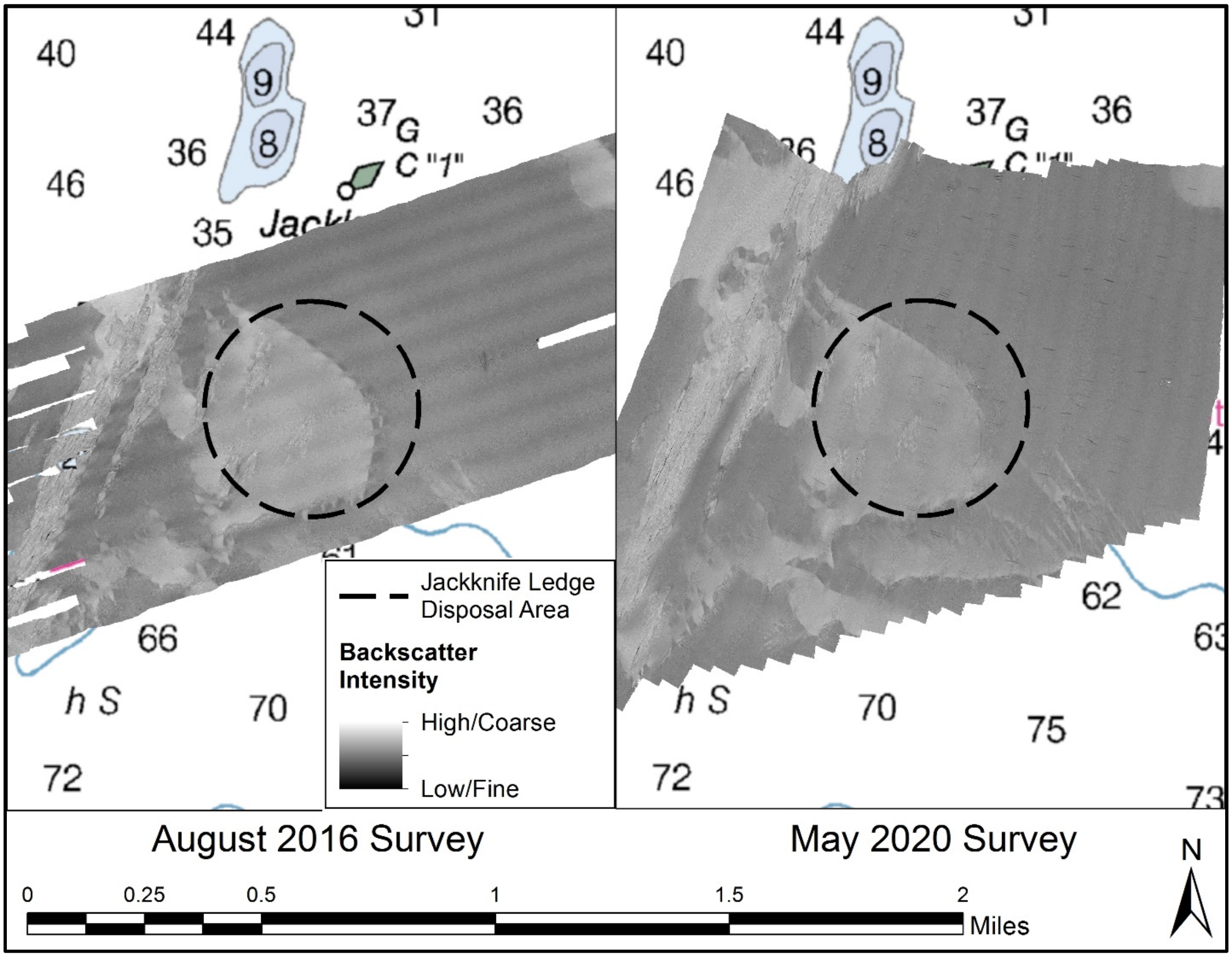

Figure PB-9. Backscatter comparison from 2016 and 2020 shows no major changes within the disposal site or the surrounding area.

Jackknife Ledge Alternate Site

A new area of interest was mapped between 2018 and 2019 to explore a potential new dredged material disposal site south of Popham Beach State Park. Bathymetry, backscatter, and grab samples were used to characterize the nearshore geology and geomorphology of Popham Beach. The site search was constrained by the need to move to shallower water for improved onshore transport of sand by storm swells and ocean circulation. Site selection with these data also sought to avoid the rock outcrops of Jackknife Ledge that were unknown for the 1989 site selection (Figure PB-10; Appendix D Presentation of February 21, 2020). The grain size samples were selected based on backscatter intensity and used to provide a preliminary understanding of the suitability within the area of interest for a nearshore disposal site with improved beach nourishment potential. Within the area of interest, this site was selected in this project for further evaluation and a suitability determination by the Navy and U.S. Army Corps of Engineers (Figure PB-11). Geologically both sites are part of the Kennebec paleodelta and recipients of sand discharged from the Kennebec River.

The alternate site is shallower and expected to provide a superior onshore migration of sand over time (Appendix D Presentation of February 21, 2020). Proximity between the existing site and the proposed one is important for determining if this is to be a newly regulated site or considered within an existing disposal area. This information will also be of use in scoping economics and logistics for future site selection of a preferred alternative. This alternate area would be a geologically suitable disposal site if the logistics and access of placement there could be arranged.

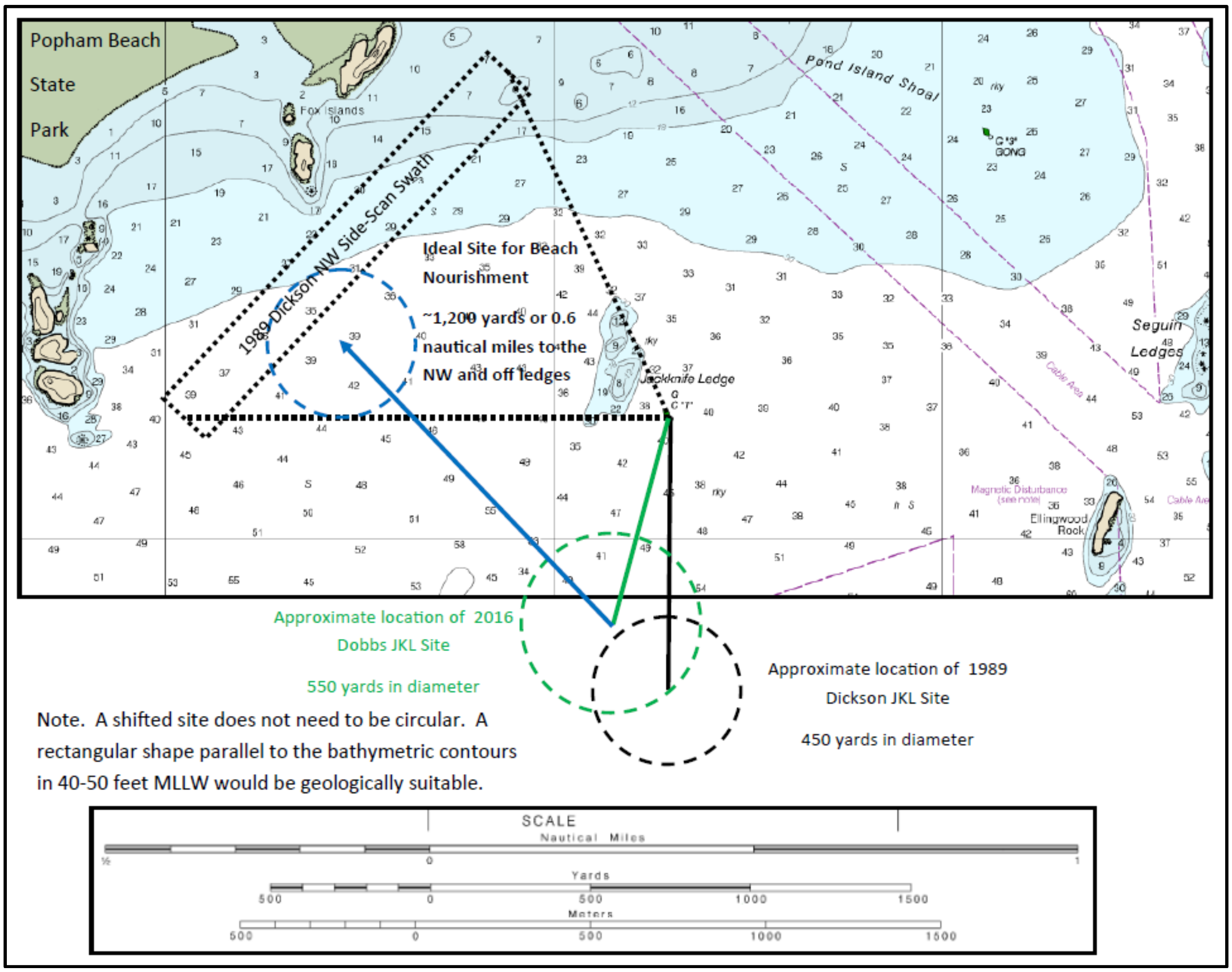

Figure PB-10. The geographic relationship between the existing Jackknife Ledge disposal site proposed in 1989 (black circle) and the one monitored in this project (green circle). The proposed alternate site is north northwest about 1,100 meters (0.6 nautical miles) of the existing site.

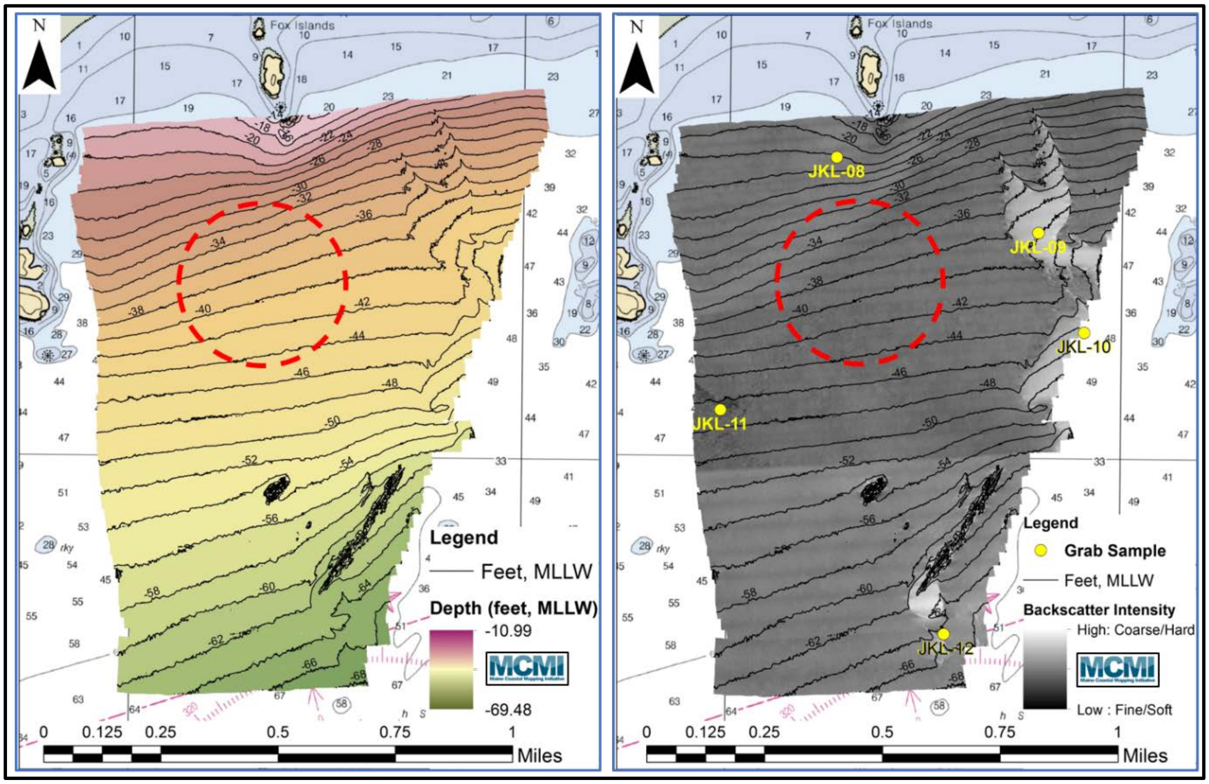

Figure PB-11. MCP multibeam bathymetry (left) and backscatter (right). Popham Beach State Park is at the north edge of this map. The red circle represents a preferred site within the area of interest.

Pond Island Shoal Alternate Site

A second alternate disposal site was mapped for consideration. Based on previous geological investigations and local interest, the area between Wood Island and Pond Island was examined. This narrow area is where strong Kennebec River flow transports sand in a seaward direction. After passing through the islands, sand is reworked on the Pond Island Shoal and transported to the west toward Popham and Hunnewell Beaches in a clockwise circulation. This path brings sand ashore toward the state park and adjacent beaches.

The seabed between the islands has a deep scour area that is a likely dispersal site. Bathymetry and backscatter show shallow bedrock ledges to the north and in the direction of the dredge site. The south side of the islands is relatively shallow across Pond Island Shoal (Figure PB-12). These data form the basis for site evaluation as an alternative disposal site with consideration of the logistics of access and disposal of dredged sand from the lower Kennebec River.

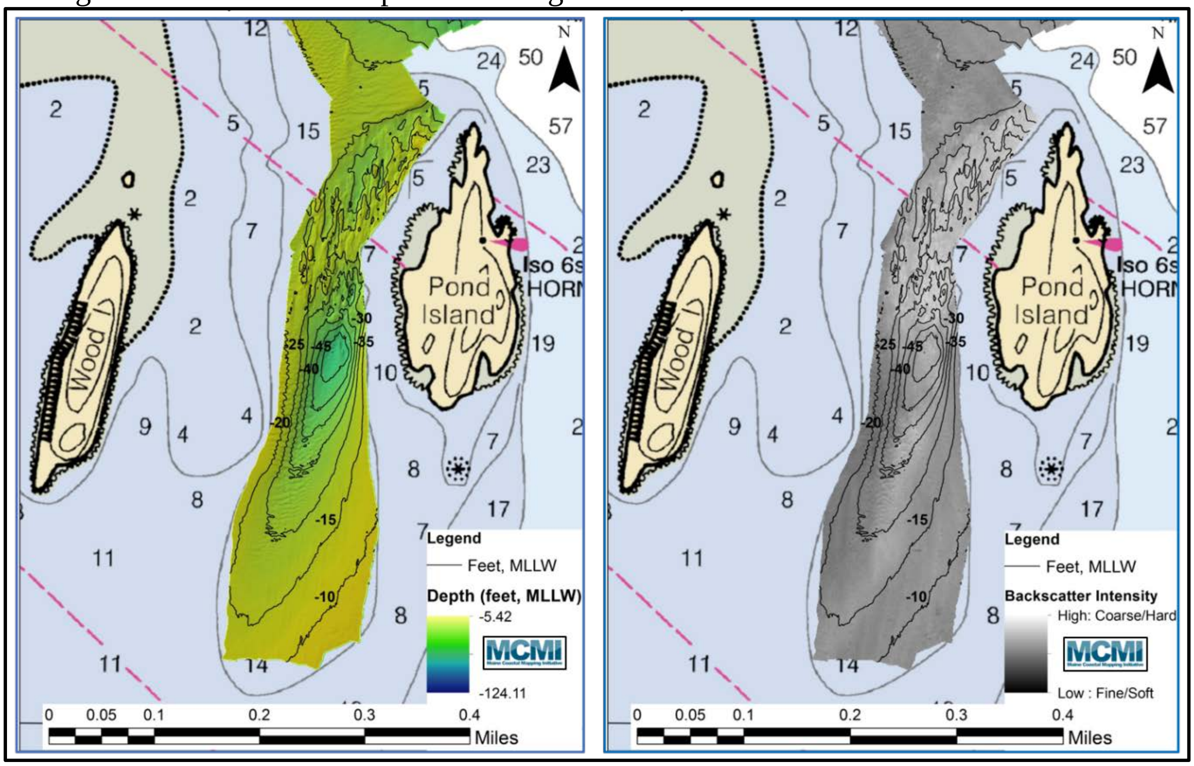

Figure PB-12. The Pond Island Shoal is an area where sand from the Kennebec River is dispersed to the sea. The depths and geomorphology of the area between Pond Island and Wood Island as well as the Pond Island Shoal were investigated as an alternative disposal area to JKL. The depression or the shoal south of the islands would be a geologically suitable disposal site if the logistics and access of placement there could be arranged.

References

Barnhardt, W. A., Belknap, D. F., & Kelley, J. T., 1997, Stratigraphic evolution of the inner continental shelf in response to late Quaternary relative sea-level change, northwestern Gulf of Maine: *Geological Society of America, Bulletin* 109: 612-630.

Dobbs, K., 2017, Kennebec River MBES Summary Report, unpublished results of Maine Coastal Mapping Initiative bathymetric surveys on May 5 and June 2, 2017, 15 p.

Fenster, M., & FitzGerald, D. M., 1996, Morphodynamics, stratigraphy, and sediment transport patterns of the Kennebec River estuary, Maine, *Sedimentary Geology* 107:99–120.

Fenster, M. S., FitzGerald, D. M., Kelley, J. T., Belknap, D. F., Buynevich, I. V., & Dickson, S. M., 2001, Net ebb sediment transport in a rock-bound, mesotidal estuary during spring-freshet conditions: Kennebec River estuary, Maine, *Geological Society of America Bulletin* 113(12), 1522-1531.

FitzGerald, D., Buynevich, I., Fenster, M., & McKinlay, P., 2000, Sand dynamics at the mouth of a rock-bound, tide-dominated estuary, *Sedimentary Geology* 131(1-2), 25-49.

Stumpf, R. P., & Goldschmidt, P. M., 1992, Remote sensing of suspended sediment discharge into the western Gulf of Maine during the April 1987 100-year flood, *Journal of Coastal Research* 218-225.

Part 3. Presentations

Beach Nourishment

Restore Eroded Beaches: Protect dunes and homes from storms
Widen the recreational beach

Beneficial Placement: Onshore or Nearshore

Stephen M. Dickson, Maine Geological Survey, DACF

Maine State Dredge Team Meeting, March 16, 2017, Augusta, Maine

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Report to the Maine Legislature

Members

Department of Environmental Protection

Department of Agriculture, Conservation and Forestry

Department of Inland Fisheries and Wildlife

Maine Office of Tourism

Save Our Shores Maine

Maine Audubon Society

Report to the Environment and Natural Resources
128th Legislature, First Session

Protecting Maine's Beaches for the Future: 2017 Update

January 2017

Contact: Tina Zabierek, Work Group Chair
Phone: (207) 287-5219
Email: christina.s.zabierek@maine.gov

MAINE DEPARTMENT OF ENVIRONMENTAL PROTECTION
17 State House Station | Augusta, Maine 04333-0017
www.maine.gov/dep

January 31, 2017

Maine Beach Nourishment Need

20 of 32 miles (62%)

Beach Name	Municipality	Public Ownership**	Total Beach Length (mi)	Estimated Nourishment Length Need (mi)***	MBMAP Shoreline Change Rate (to 2015) **^*	Estimated renourishment cycle (yrs)	Estimated Single Nourishment Volume (cy) ****	Estimated Nourishment Cost ($Millions) *****	Estimated 20-yr Nourishment Volume (cy) ******	Estimated 20-yr Nourishment Cost ($Millions)
Reid - Mile Beach (S. Park)	Georgetown	Yes	0.7	0.3	None	20	75,000	1.88	75,000	1.88
Reid - Half Mile Beach (S. Park)	Georgetown	Yes	0.4	0.2	None	20	50,000	1.25	50,000	1.25
River Beach	Phippsburg	Yes	0.6	0.3	None-Low	20	75,000	1.88	75,000	1.88
Hunnewell Beach	Phippsburg	Yes	0.7	0.7	High	5	175,000	4.38	700,000	17.50
East Beach (S.Park)	Phippsburg	Yes	0.4	0.4	High	5	100,000	2.50	400,000	10.00
Popham Beach (S. Park)	Phippsburg	Yes	0.5	0.3	High	5	75,000	1.88	300,000	7.50
Small Point Beach	Phippsburg	Yes	1.5	0.2	None	20	50,000	1.25	50,000	1.25
Willard Beach	South Portland	Yes	0.4	0.4	Low	20	100,000	2.50	100,000	2.50
Kettle Cove (S. Park)	Cape Elizabeth	Yes	0.1	0.1	Low	20	25,000	0.63	25,000	0.63
Crescent Beach (S.Park)	Cape Elizabeth	Yes	0.8	0.4	Low	20	100,000	2.50	100,000	2.50
Higgins Beach	Scarborough	Yes	0.5	0.25	Mod	10	62,500	1.56	125,000	3.13
Scarborough Beach	Scarborough	Yes	1.4	0.5	Low	20	125,000	3.13	125,000	3.13
Western Beach	Scarborough	No	0.6	0.4	High	5	100,000	2.50	400,000	10.00
Ferry Beach	Scarborough	Yes	0.6	0.2	Low	20	50,000	1.25	50,000	1.25
Pine Point Beach	Scarborough	Yes	1.4	0.5	Mod	10	125,000	3.13	250,000	6.25
East Grand (to pier)	Old Orchard	Yes	1.6	0.5	None	20	125,000	3.13	125,000	3.13
Ocean Park (to Goosefare)	Old Orchard	Yes	1.4	0.5	None	20	125,000	3.13	125,000	3.13
Kinney Shores/Bayview	Saco	Yes	1.0	0.3	None-Low	20	75,000	1.88	75,000	1.88
Ferry (incl. S.Park)	Saco	Yes	0.7	0.7	High	5	175,000	4.38	700,000	17.50
Camp Ellis Beach	Saco	Yes	0.5	0.5	High	5	712,000	17.80	1,144,000	28.60
Hills Beach	Biddeford	No	1.0	0.5	Low	20	125,000	3.13	125,000	3.13
Mile Stretch Beach	Biddeford	Yes	1.3	0.5	Low	20	125,000	3.13	125,000	3.13
Fortune Rocks Beach	Biddeford	Yes	0.8	0.4	Low	20	100,000	2.50	100,000	2.50
Goose Rocks Beach East	Kennebunkport	Yes	0.7	0.7	Low	20	175,000	4.38	175,000	4.38
Goose Rocks Beach West	Kennebunkport	Yes	1.2	0.8	Mod	10	200,000	5.00	400,000	10.00
Goochs Beach	Kennebunk	Yes	0.6	0.6	Mod	10	150,000	3.75	300,000	7.50
Mother's Beach*	Kennebunk	No	0.5	0.5	Low	20	125,000	3.13	125,000	3.13
Great Hill Beach *	Kennebunk	No	0.3	0.3	Low	20	75,000	1.88	75,000	1.88
Crescent Surf Beach*	Kennebunk	No	0.7	0.4	Low	20	100,000	2.50	100,000	2.50
Parsons Beach*	Kennebunk	No	0.7	0.4	Low	20	100,000	2.50	100,000	2.50
Laudholm Beach	Wells	Yes	0.4	0.4	High	5	100,000	2.50	400,000	10.00
Drakes Island Beach	Wells	Yes	0.9	0.9	Mod	10	225,000	5.63	450,000	11.25
Wells Beach	Wells	Yes	1.2	1.2	Mod	10	300,000	7.50	600,000	15.00
Casino Cove*	Wells	No	0.6	0.6	Low	20	150,000	3.75	150,000	3.75
Fisherman's Cove*	Wells	No	0.4	0.4	Low	20	100,000	2.50	100,000	2.50
Moody Beach*	Wells	No	1.2	0.7	Mod	10	175,000	4.38	350,000	8.75
Ogunquit Beach	Ogunquit	Yes	1.4	0.7	Mod	10	175,000	4.38	350,000	8.75
Short Sands Beach*	York	Yes	0.2	0.2	Low	20	50,000	1.25	50,000	1.25
Long Sands Beach	York	Yes	1.3	1.3	Mod	10	325,000	8.13	650,000	16.25
Seapoint Beach	Kittery	Yes	0.4	0.4	Mod	10	100,000	2.50	200,000	5.00
Crescent Beach	Kittery	Yes	0.3	0.3	Low	20	75,000	1.88	75,000	1.88
TOTAL/AVERAGE	**N/A**	**N/A**	**0.8**	**0.5**	**Low-Mod**	**15**	**5,549,500**	**138.74**	**9,994,000**	**249.85**

Notes:

cy - cubic yards

* indicates that the beach is not surveyed as part of MBMAP; loss rates estimated

** Public Ownership - a yes in this category indicates that at least a portion of the beach is owned by the public; ownerhsip has not been verified.

*** Estimated nourishment length - the estimated length of nourishment needed for a likely project, *regardless of actual need (e.g., includes areas with a "None" shoreline change rate)*

^ MBMAP Shoreline Change Rate - calculated shoreline change rate of the length of beach estimated to need nourishment using data from the Maine Beach Mapping Program

None - beach is stable or growing

Low - shoreline change is -1 ft/yr or less

Mod - shoreline change is -1 to -2 ft/yr or more

High - shoreline change is -2 ft/yr or more

**** Estimated Single Nourishment Cycle - based on the shoreline change rate; None-Low or Low = 20 year cycle; Mod = 10 year cycle; High = 5 year cycle

**** Estimated Single Nourishment Volume - based on 250,000 cy per mile except for Camp Ellis Beach, which was estimated by the USACE for Section 111 project (beach fill only alternative).

***** Estimated Nourishment Cost - based on an average estimated cost rate of $25 per cubic yard of material

****** Estimated 20-year Nourishment Volume - Estimated Single Nourishment Volume multiplied by the Estimated Renourishment Cycle.

http://www.maine.gov/dep/legislative/reports.html

Volume for 20 miles:

5,500,000 cubic yards

Renourishment for 20 years:

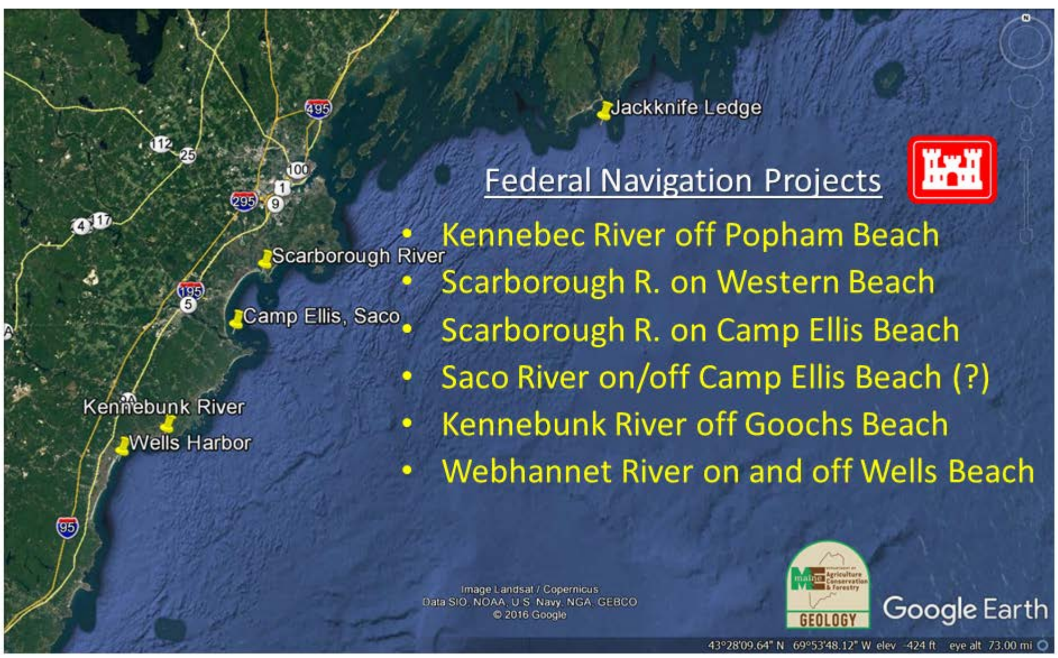
10,000,000 cubic yards

Total dredged since 1800's:

2,700,000 cubic yards

Source: Protecting Maine's Beaches for the Future: 2017 Update, Maine DEP, January 31, 2017

Dredged Sand Nourishment Sites



Research

How beneficial is "beneficial use"?

Can it be more beneficial?

Where is more offshore sand?

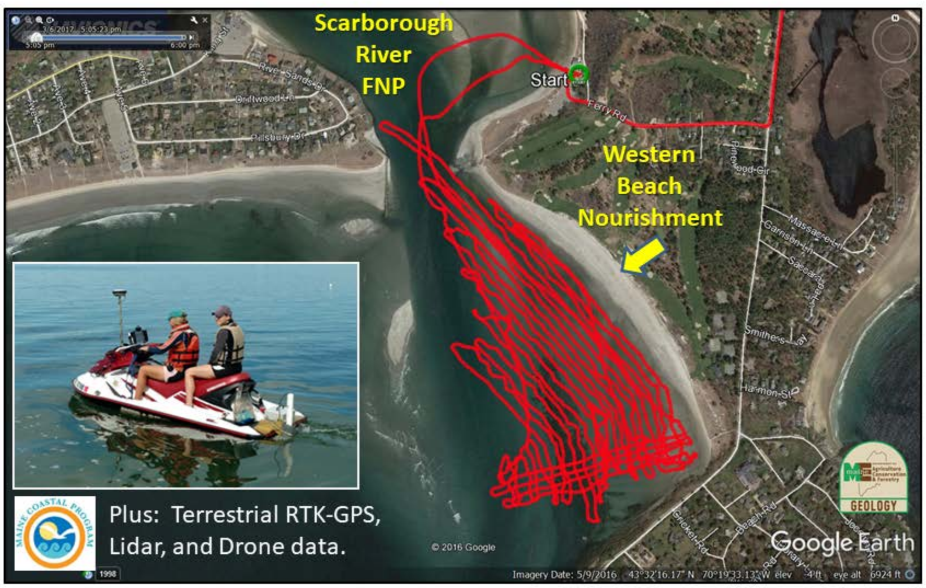
Current and Pending Funding

<u>NOAA Project of Special Merit</u>
Assessing Sediment Budgets in Support of Beach Nourishment and Coastal Community Resiliency

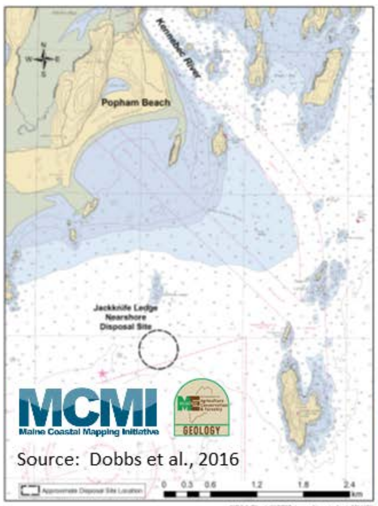
<u>NOAA Coastal Zone Management Act</u>
Coastal Hazard Adaptation at Municipal, Regional, and State Levels

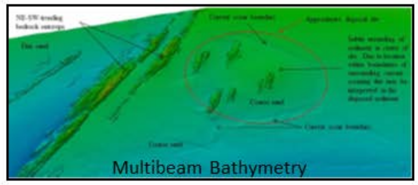
<u>Bureau of Ocean Energy Management</u>
Aggregate Exploration and Habitat Classification: Tools for Building Resiliency in Maine

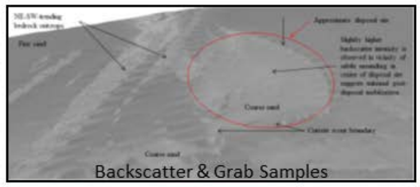
Scarborough River & Western Beach



Kennebec River & Jackknife Ledge







Beach Nourishment Research

Beneficial Placement:	Sand Budgets – Natural vs. Enhanced
Monitoring:	Longevity & Reworking
Mapping:	Depth of Closure; Sand Sources

Stephen M. Dickson, Maine Geological Survey, DACF

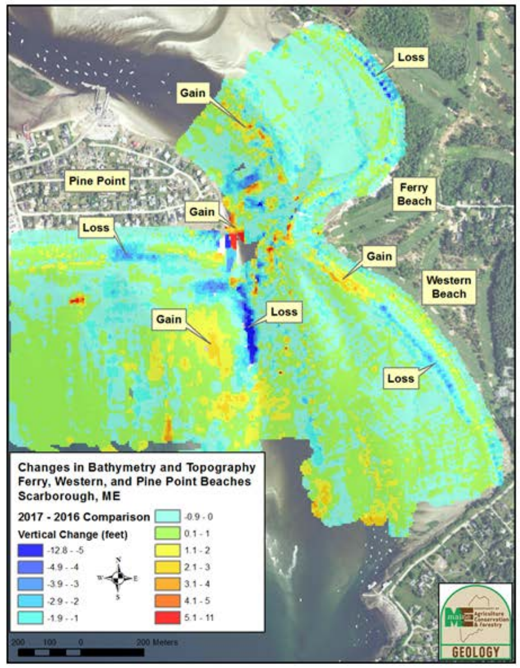
maine Department of Agriculture Conservation & Forestry
GEOLOGY

BOEM Bureau of Ocean Energy Management

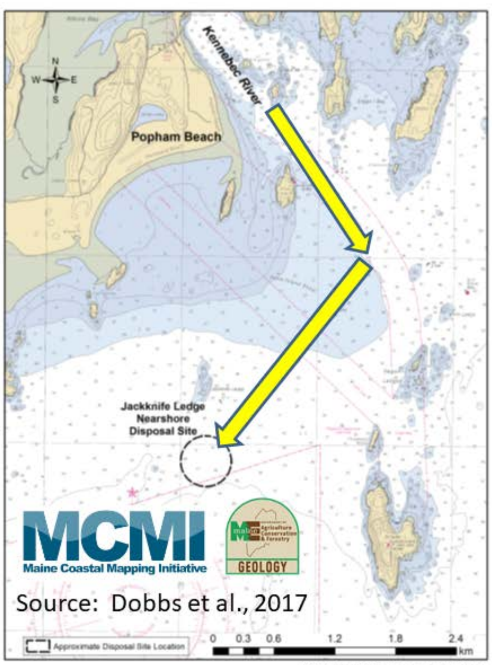
Maine State Dredge Team Meeting, October 18, 2017, Portland, Maine

Scarborough River Sand

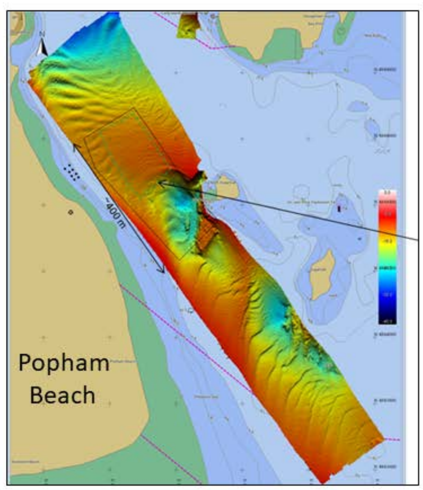
Shifting Sand in 1 Yr
- Beach nourishment
- Dune erosion
- Channel bars



Kennebec River & Jackknife Ledge



Source: Dobbs et al., 2017



Dredged Sand Waves

Placed at Jackknife Ledge

R/V Amy Gale, MCMI/MCP

Kennebec River Sand

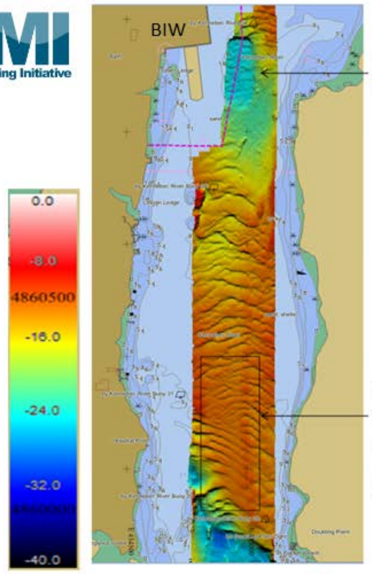
MCMI
Maine Coastal Mapping Initiative

May 5, 2017
K. Dobbs

Multibeam
Backscatter
Bathymetry
50 cm grid

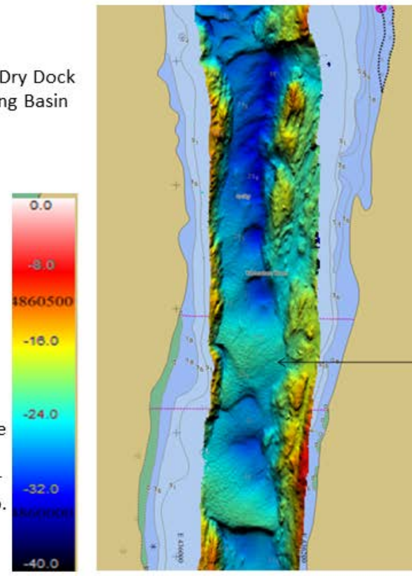
Grab samples
Grain size
Fauna

Video images



BIW Dry Dock
Sinking Basin

Sand
Wave
Field
After
2 mo.



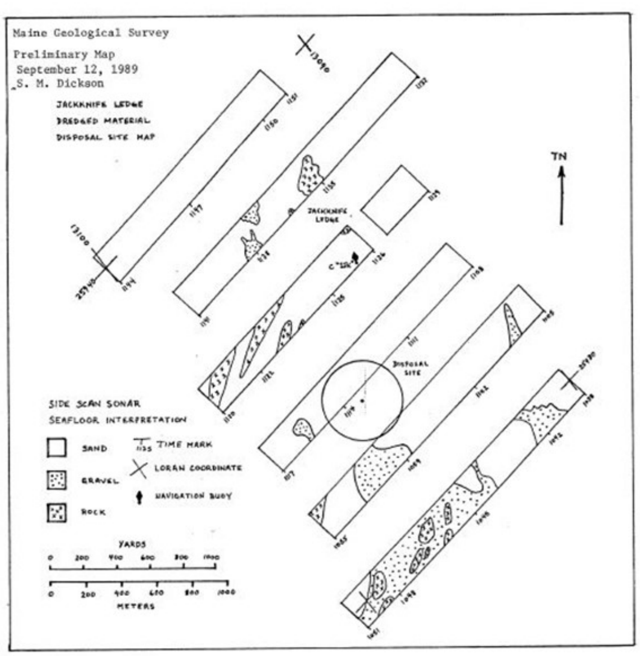
Disposal
Area

Jackknife Ledge Alternative Sites

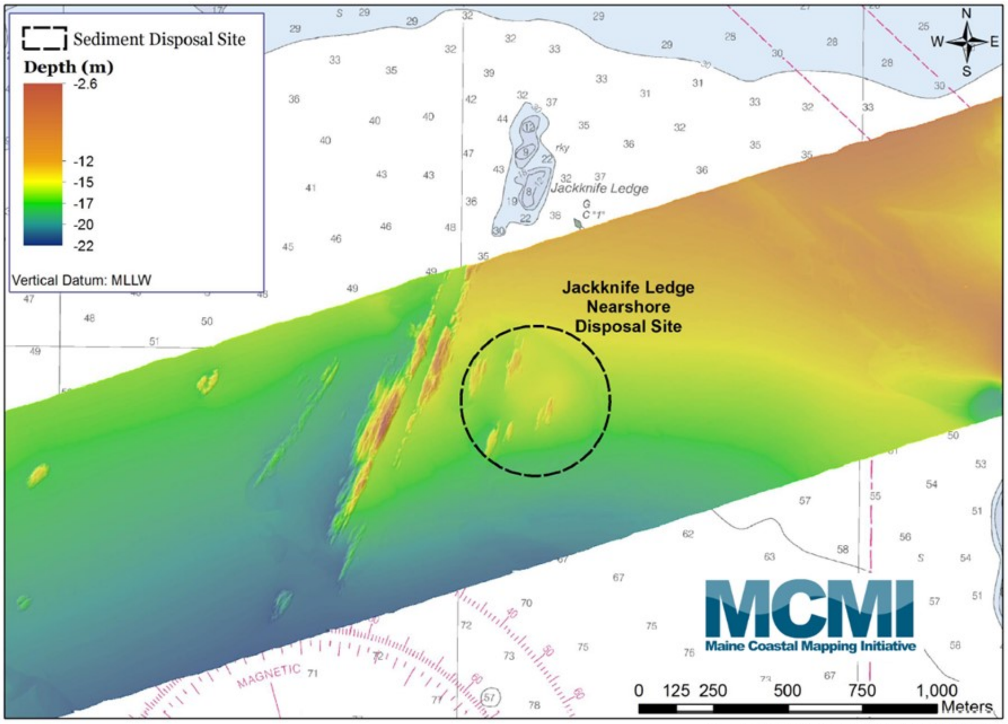
Stephen M. Dickson, Ph.D.
Marine Geologist
Maine Geological Survey
DEPARTMENT OF AGRICULTURE, CONSERVATION & FORESTRY

February 21, 2020

1989 Jackknife Ledge Site Selection



S. M. Dickson, 9/2019

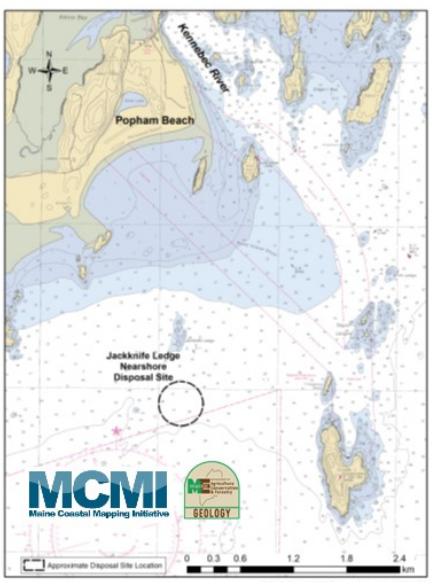


NOAA Chart #13295 (soundings in feet, MLLW)

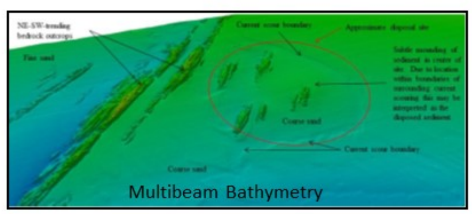
2

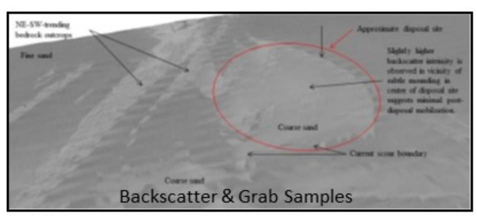
S. M. Dickson, 9/2019

Recent Monitoring: Minimal Dispersal



Source: Dobbs et al., 2016





3

S. M. Dickson, 9/2019

USACE Sediment Mobility Tool

Popham Beach State Park

Cross-shore Sediment Migration:

Sediment Migration (1980-2013) WIS Station 63033, 71° Shoreline Angle, Nearshore Placement Depth: 50.00 ft	
d_{50}	**Predicted Sediment Migration**
0.1 (mm)	94% onshore
0.2 (mm)	100% onshore
0.3 (mm)	100% onshore
0.4 (mm)	100% onshore
0.5 (mm)	100% onshore
N/A .	N/A

Cross-shore sediment migration direction for various sediment sizes using the Dean Number and an empirical relationship described by Larson and Kraus (1992).

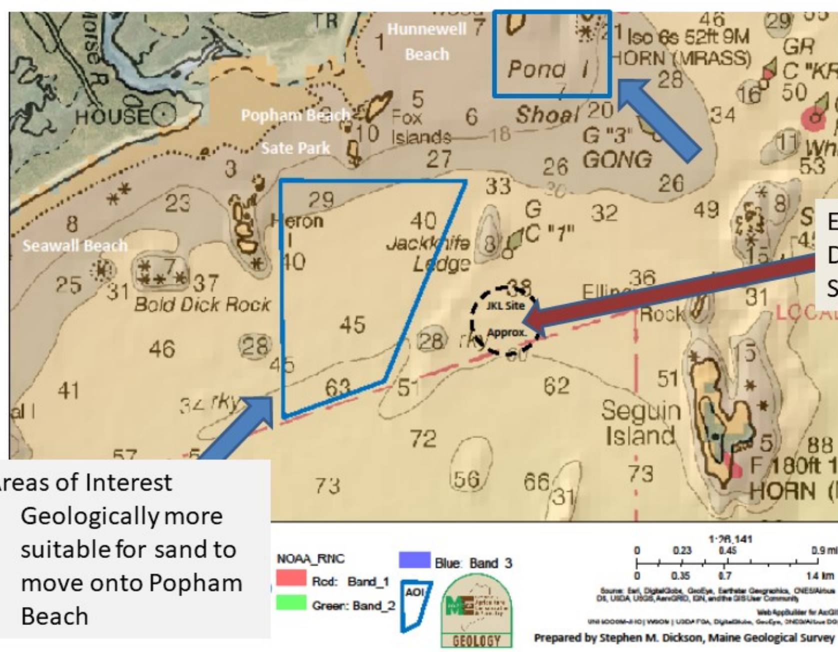
Nearshore placement of fine to medium sand should result in onshore transport toward Popham Beach and beneficial reuse of dredged materials.

http://navigation.usace.army.mil/SEM/SedimentMobility

4

S. M. Dickson, 9/2019

Jackknife Ledge and Areas of Interest



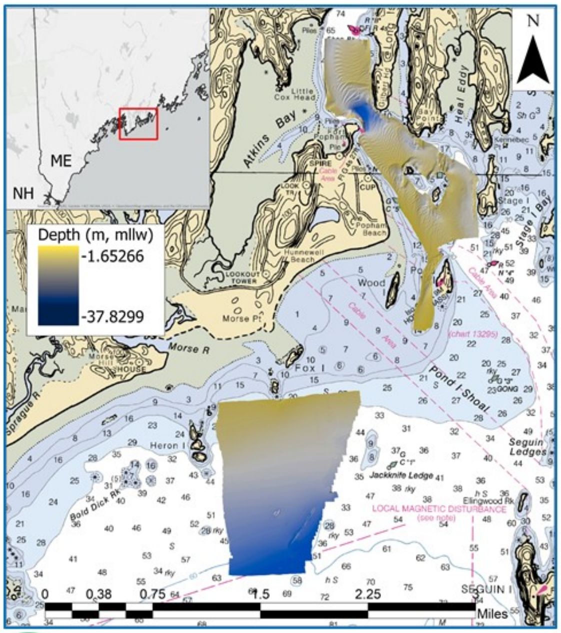
Existing Disposal Site

Areas of Interest

- Geologically more suitable for sand to move onto Popham Beach

5

S. M. Dickson, 2/2020



Overview

Multibeam Bathymetry and Backscatter

2018 & 2019 MCMI Mapping

Maine Coastal Mapping Initiative

6

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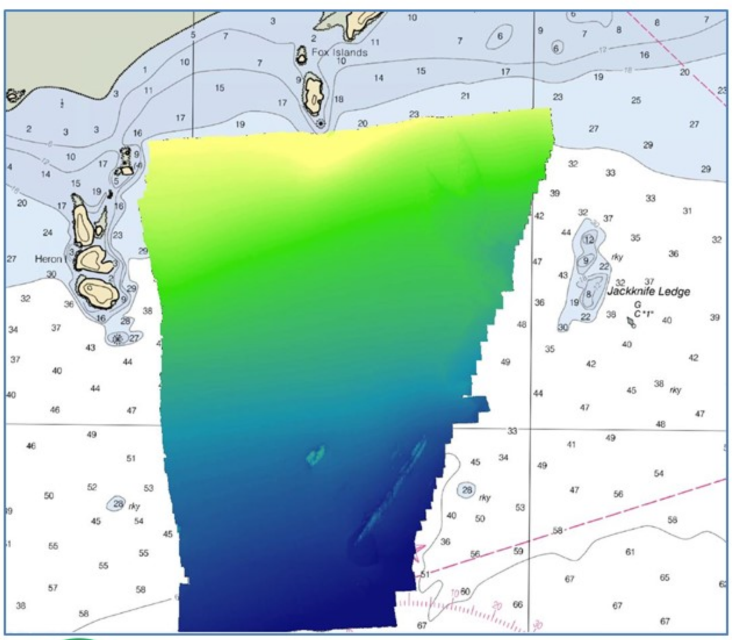

JKL II Bathymetry

Depth 12-22 m MLLW

Uniform Slope

Mapped in fall 2018 & 2019.
Five grab samples taken.

Maine Coastal Mapping Initiative

7

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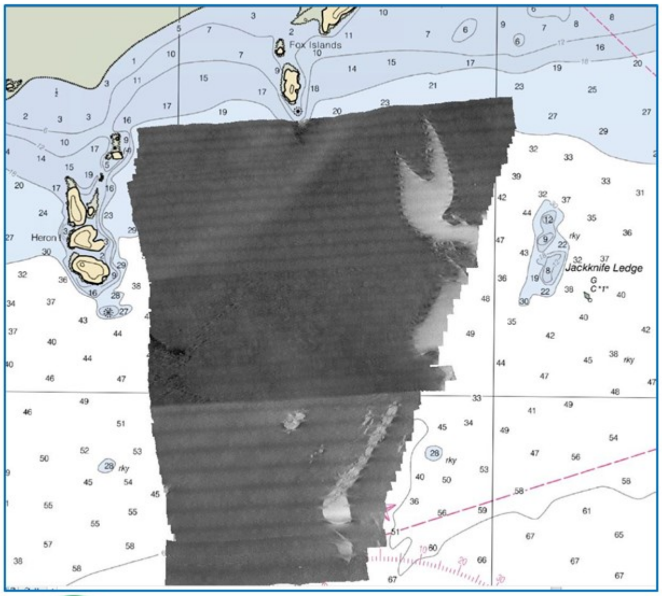
JKL II Backscatter



Depth
12-22 m
MLLW

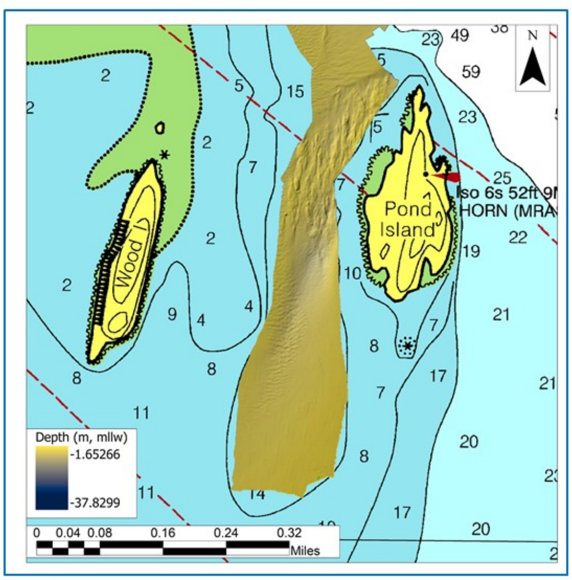
Dark Gray is Sand

MCMI
Maine Coastal Mapping Initiative

Mapped in fall 2018 & 2019.
Five grab samples taken.

S. M. Dickson, 2/2020

Pond Island Shoal Bathymetry



Depth
~4-14 m MLLW

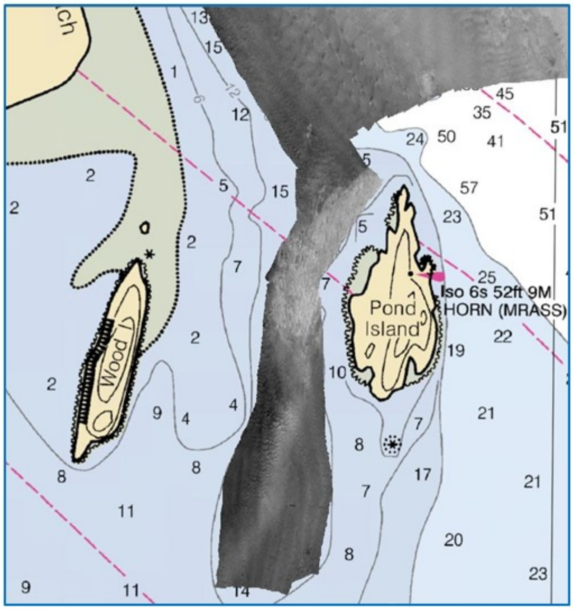
Channel & Ramp

Sand Gyre

MCMI
Maine Coastal Mapping Initiative

Mapped in fall 2019.
No grab samples taken.

S. M. Dickson, 2/2020



Pond Island Shoal

Dark Gray is Sand

Light Gray is Coarse Sand or Bedrock

Maine Coastal Mapping Initiative

Mapped in fall 2019.
No grab samples taken.

S. M. Dickson, 2/2020

Jackknife Ledge & Alternate Sites

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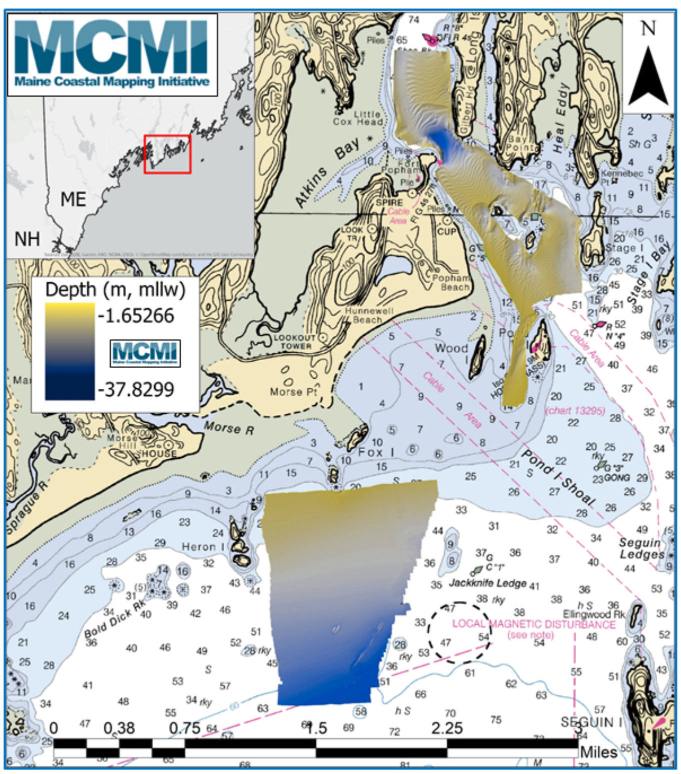
Marine Geologist
Maine Geological Survey
DEPARTMENT OF AGRICULTURE, CONSERVATION & FORESTRY

February 26, 2020

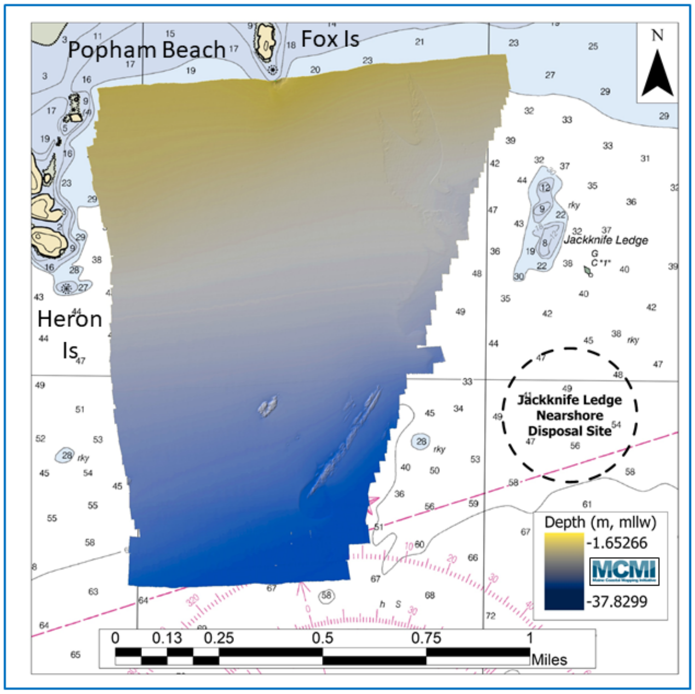


Kennebec River Mouth and Jackknife Ledge

Dashed circle is the dredged sand disposal site. 2018 and 2019 multibeam bathymetry and backscatter areas are shaded. MCMI survey by Ben Kraun, Caleb Hodgdon, Mira Kelly-Fair, Allison Potter, and Tom Trott.

S. M. Dickson, 2/2020

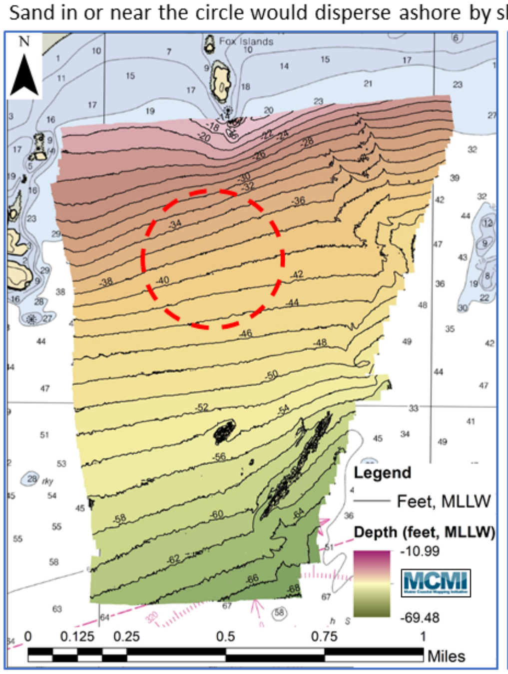
Jackknife Ledge Alternate Site

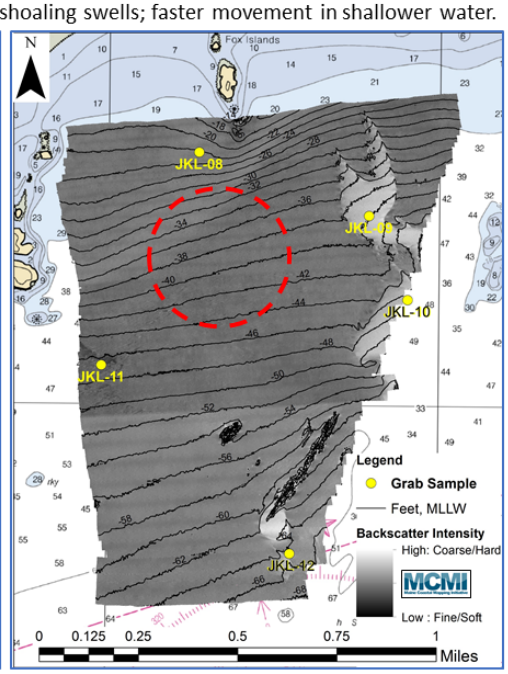


S. M. Dickson, 2/2020

Jackknife Ledge Alternate Site

Sand in or near the circle would disperse ashore by shoaling swells; faster movement in shallower water.

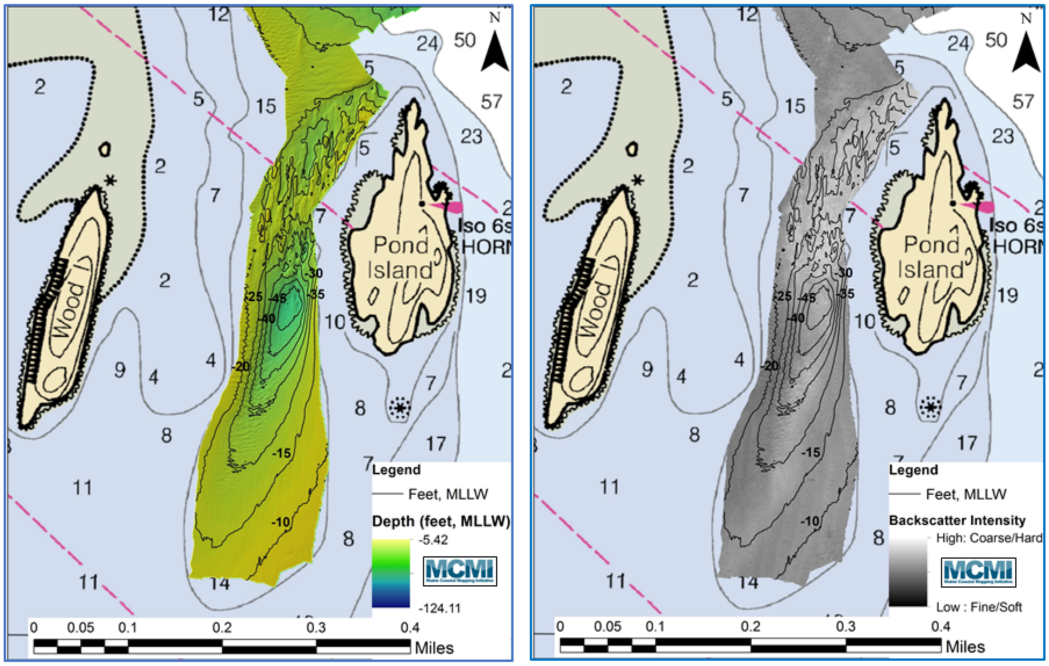




S. M. Dickson, 2/2020

Pond Island Shoal Alternate Site

The 45-foot deep basin and shoal to the south would disperse sand ashore via a clockwise current.



S. M. Dickson, 2/2020

From the Dunes to the Depths

Imaging Maine's Beaches to Understand Sediment Movement and Further Beach Resiliency

Peter A. Slovinsky, Maine Geological Survey, DACF
Stephen M. Dickson, Maine Geological Survey, DACF
Sam F. Rickerich, Maine Geological Survey, DACF
Stefan Claesson, NearView LLC
Benjamin Kraun, Maine Coastal Program, DMR

Northeast GSA, March 17, 2019

Objectives

- Create seamless topo-bathy maps of the beach and dunes
- Quantify seasonal beach volume changes
- Track movement of intertidal beach nourishment
- Evaluate dispersal from nearshore disposal sites
- Calculate beach sediment budgets
- Map the envelope or depth of closure
- Improve longevity of beach nourishment projects

Multibeam Echosounder (MBES)

- Kongsberg EM2040C multibeam transducer
- Dual GNSS antennas
- Motion reference unit (MRU)
- AML MicroX surface sound speed probe
- Teledyne Odom Digibar sound speed profiler

Maine Beach Nourishment Need

20 of 32 miles (62%)

Volume for 20 miles:

5,500,000 cubic yards

Renourishment for 20 years:

10,000,000 cubic yards

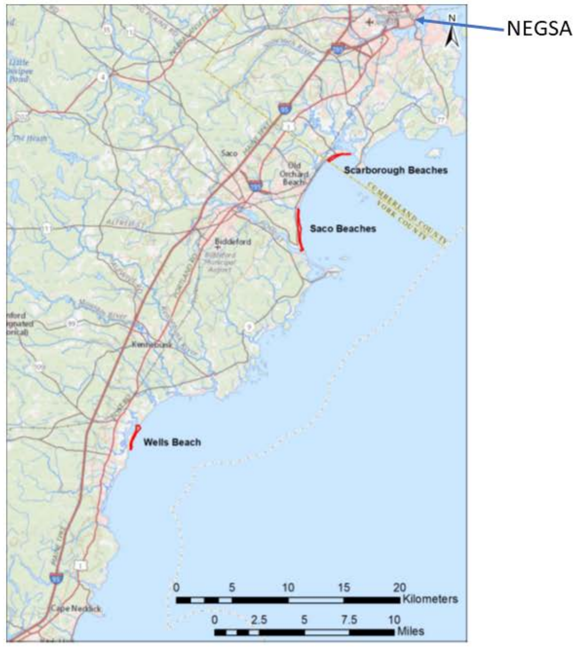
Total dredged since 1800's:

2,700,000 cubic yards

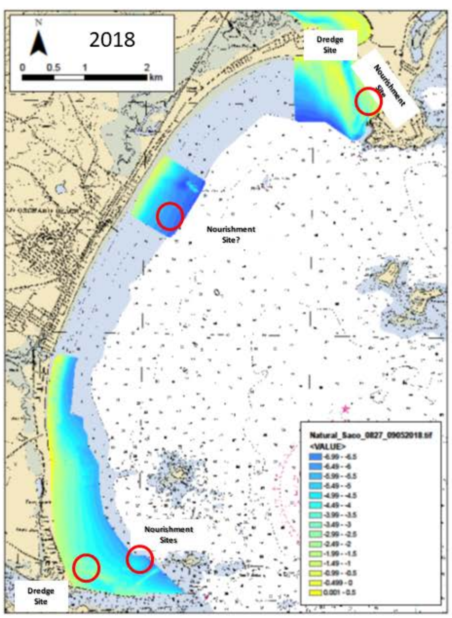
Source: Integrated Beach Management Program Working Group Report, Maine DEP, January 2017

Annual coastal tourism in York County, home to many beaches is $1.6 Billion (Island Institute, Waypoints, 2016)

Study Sites



Regional Sediment Management



Scarborough

Old Orchard Beach

Saco

Wells
(not shown)

Multibeam Echosounder (MBES)

- Kongsberg EM2040C multibeam transducer
- Dual GNSS antennas
- Motion reference unit (MRU)
- AML MicroX surface sound speed probe
- Teledyne Odom Digibar sound speed profiler

MBES

15,000 m^3 of Webhannet River harbor sand at Wells Beach by the USACE was mapped pre-placement by USACE JALBTCX and by our surveys in August

R/V Amy Gale and Captain Hodgdon

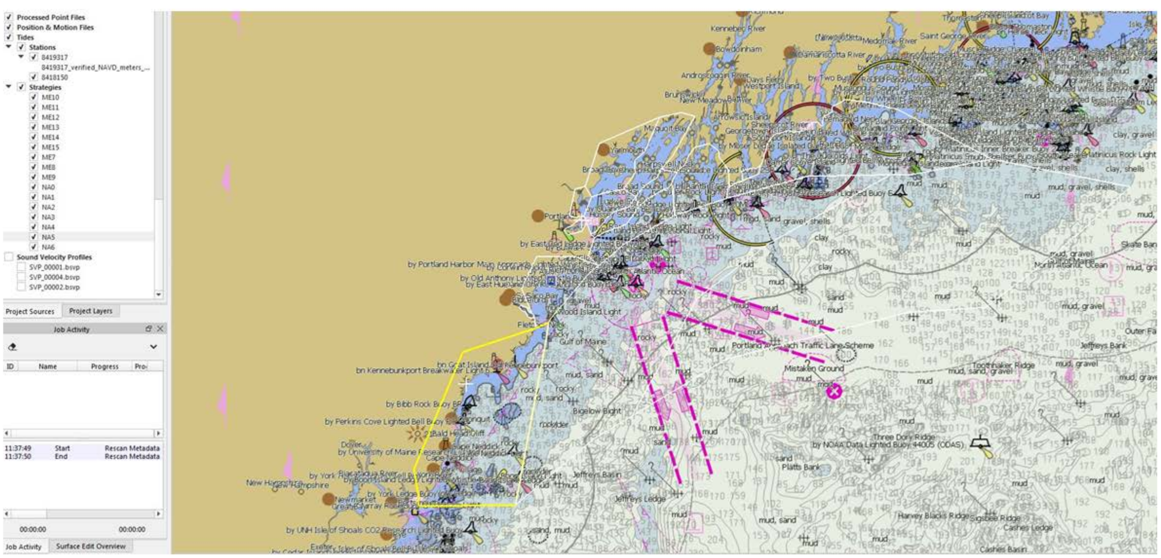
Wells Beach, Wells (August 9, 2018)

Scarborough River vicinity, Scarborough (August 30, 2018)

Multibeam Data Processing

- Data acquisition with Quality Positioning Services (QPS) QINSy (Quality Integrated Navigation System)
- QINSy integrated all systems and was used for real-time navigation, survey line planning, data time tagging, data logging, and visualization
- Parallel lines were mostly run shore-normal or shore-parallel with a minimum of 20% overlap between full swaths
- Soundings from beam angles outside of ±60 degrees from the nadir were blocked

Tide Model



MGS Nearshore Survey System (NSS)

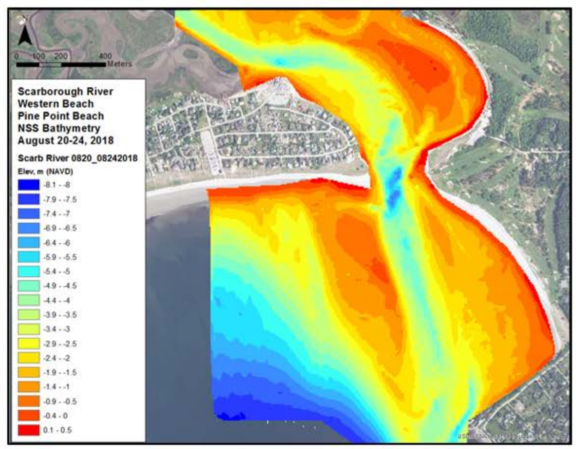
- SeaDoo with a **Leica** GS-14 RTK-GPS
- CEE Hydrosystems **CEE-ECHO** single-beam echo sounder with 200kHz transducer
- Onboard computer with Eye4Software's **Hydromagic** software
- 20-m spaced transects at a sampling rate of 20 Hz for both position and depth while traveling approximately 7 km/h
- 2-m point spacing along transects
- Alongshore transects with some shore-normal crossing lines

NSS

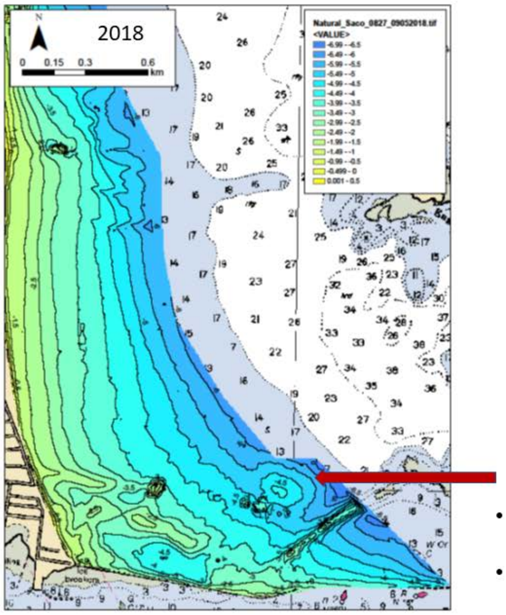
Wells Beach, Wells (August 9-10, 2018)

Scarborough River vicinity, Scarborough (August 20-24, 2018)

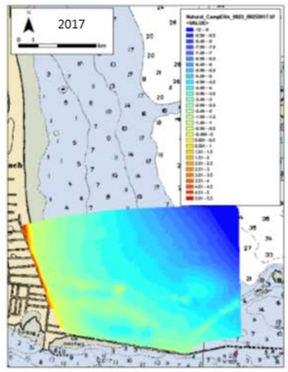
Saco beaches, Saco (August 27 – September 5, 2018)

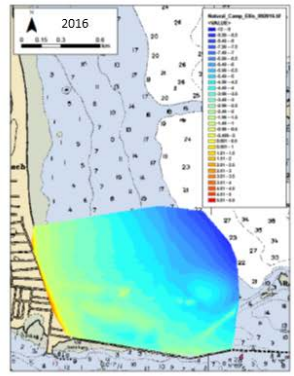


Slovinsky, 2018, Scarborough Inlet Depth & Volume Changes, https://digitalmaine.com/mgs_publications/533/.



Bathymetric Resurveys





- 1996, 73,000 m^3 of Scarborough River sand placed off Saco.
- Beach contours migrate inland from erosion of the subtidal beach.

UAS

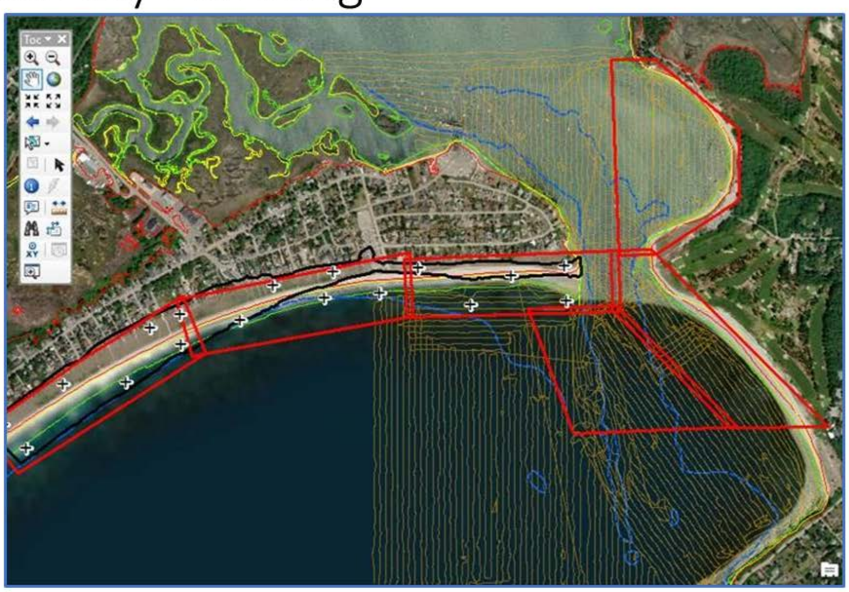
Fall 2018 Surveys

- Wells
- Saco
- Scarborough

UAS Accuracy

Area	Orthomosaic Type	Mean RMS Error (m)	Checkpoint RMS Error (m)		
			X	Y	Z
Wells	RGB	0.02 m	0.04	0.02	0.05
Saco	RGB	0.04 m	0.02	0.04	0.05
Scarborough	RGB	0.02 m	0.02	0.03	0.03

Survey Planning



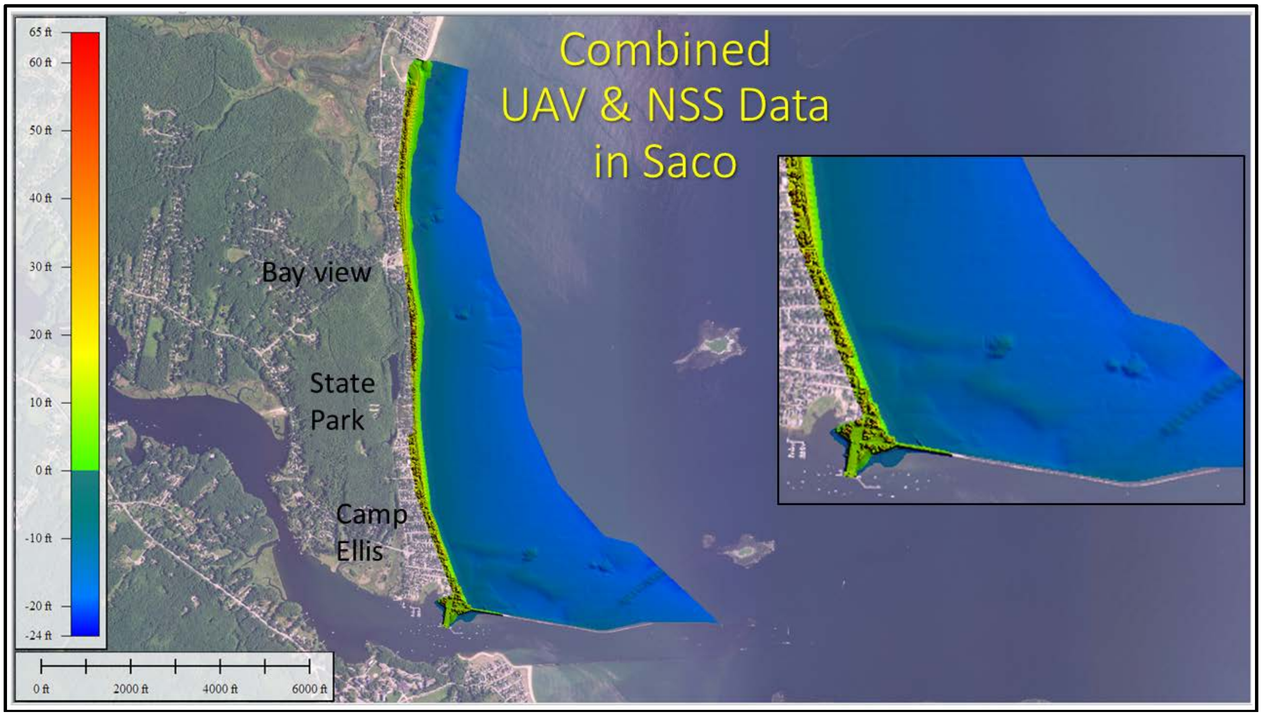
GCPs in flight area

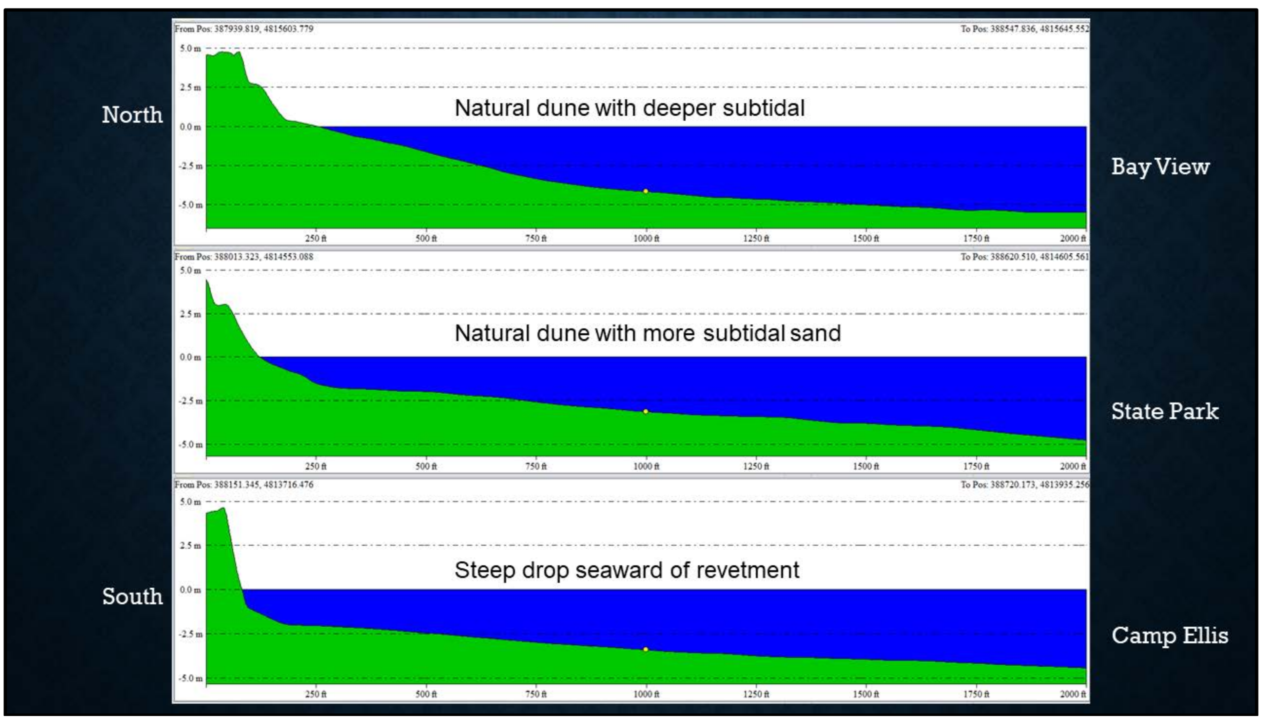
Flight lines overlap

NSS tracks 10 & 20 m spacing

High tide NSS checks with RTK at low tide

Patch tests at crossing lines


Combined
UAV & NSS Data
in Saco
Bay view
State
Park
Camp
Ellis
65 ft
60 ft
50 ft
40 ft
30 ft
20 ft
10 ft
0 ft
-10 ft
-20 ft
-24 ft
0 ft
2000 ft
4000 ft
6000 ft


North
South
Bay View
State Park
Camp Ellis
Natural dune with deeper subtidal
Natural dune with more subtidal sand
Steep drop seaward of revetment
5.0 m
2.5 m
0.0 m
-2.5 m
-5.0 m
250 ft
500 ft
750 ft
1000 ft
1250 ft
1500 ft
1750 ft
2000 ft

MARCH 2019 USACE BEACH NOURISHMENT

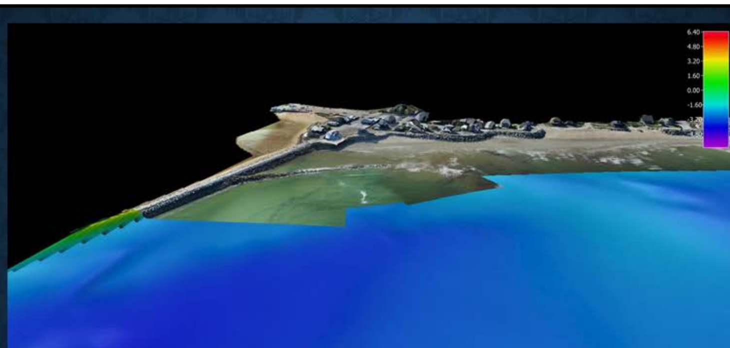
Saco River Dredging

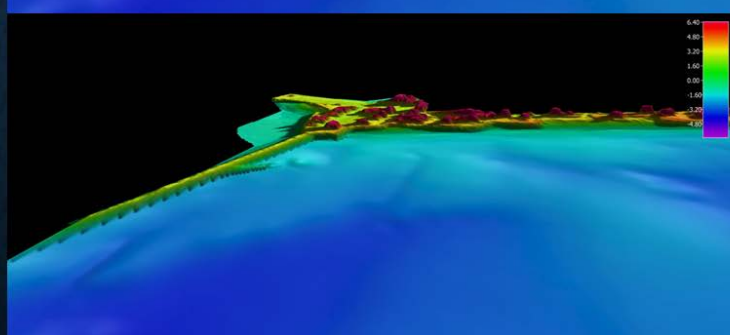
Camp Ellis Beach, Saco

75,000 m^3 of river sand pumped onto the intertidal beach this month

Orthomosaic

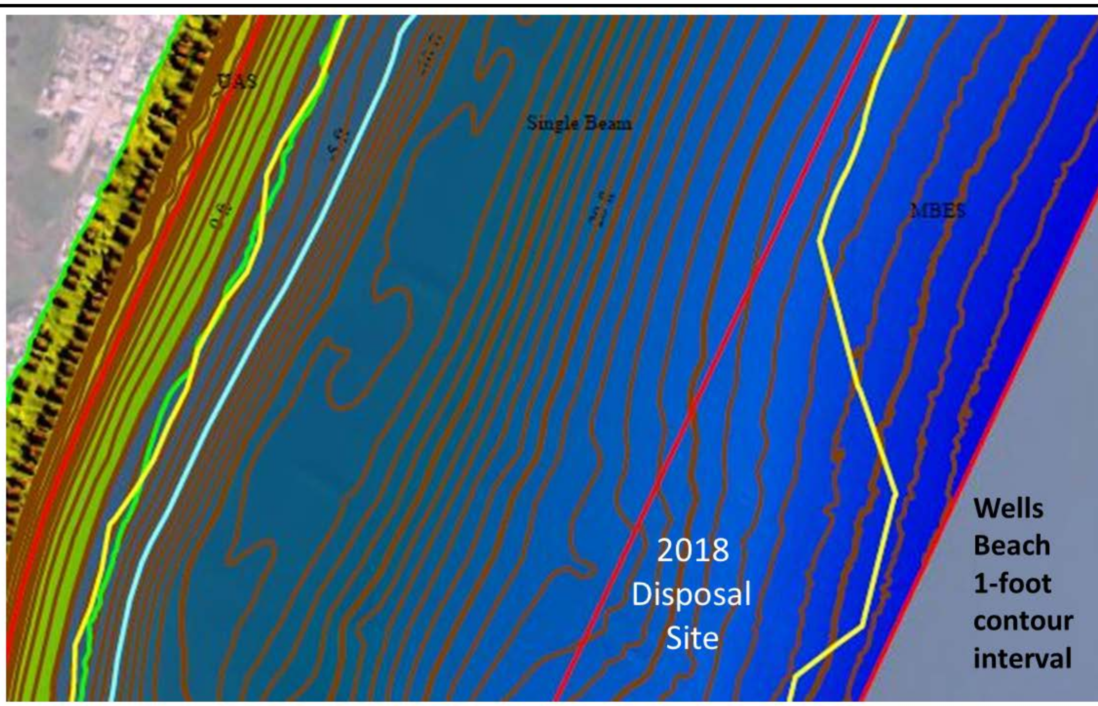
3-inch resolution





Vertical scale in meters

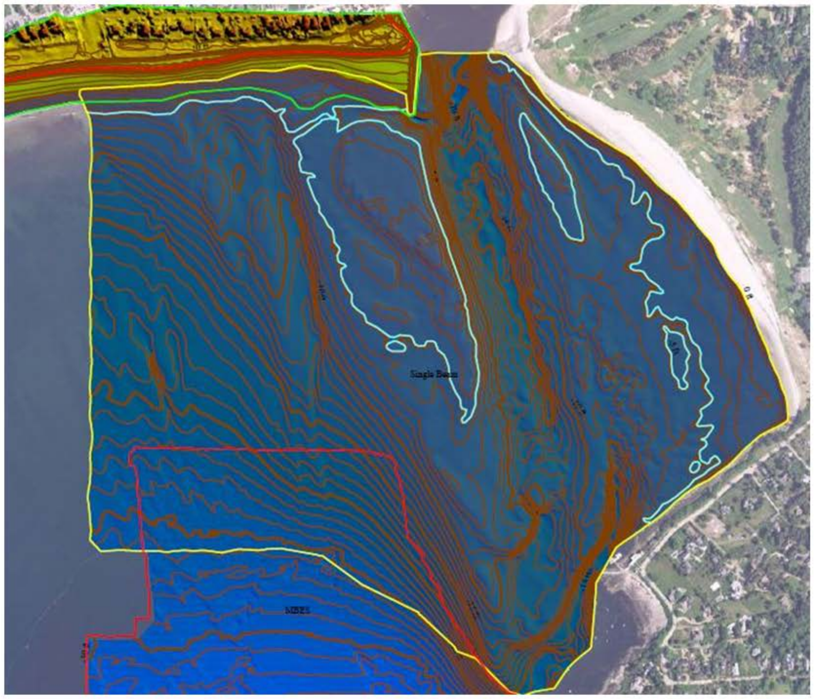
Project Partner	Survey System	Positional Accuracy	Data Resolution
NearView, LLC	UAS with Sony A7RII RGB Camera and Loki Airgon PPK GPS	< 0.02 m RTK positioning	0.07-meter orthomosaic
Maine Geological Survey	Nearshore Survey System SeaDoo PWC equipped with CEE Hydrosystems Singlebeam Echosounder and Leica GS-14 RTK-GPS	< 0.02 m RTK positioning	2-meter interpolated grid
Maine Coastal Mapping Initiative	R/V Amy Gale – 35-foot former lobster boat Kongsberg EM2040C Multibeam Echosounder, dual GNSS GPS antennae and Seapath 330 IMU	0.5 m DGPS horizontal positioning only	0.5-meter grid



Scarborough River

Tidal Channel

Ebb Tidal Shoal



Western Beach

Nourishment Site

Channel Bypassing