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Discharge of navigation dredged material from the Dodge Island for beneficial use on Egmont Key, Florida. Photo courtesy of Coraggio Maglio, US Army Corps of Engineers.

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EDITOR'S NOTE

There seems to be a sea change on its way regarding beneficially using dredged sediment, especially from navigation channels. The Federal Standard has often been cited as a significant barrier to beneficial use in the U.S. It has been interpreted as requiring comparison of only direct costs when comparing sediment management options. Section 125 of Water Resources Development Act (WRDA) 2020 allows more inclusive considerations of costs and values that should be considered as part of the Federal Standard. This expansion could significantly change the way sediment management alternatives and potentially increase beneficial use in the U.S.

This issue of WEDA's Journal of Dredging starts with a paper that highlights water quality benefits that can result from dredging nutrient rich sediments from channels and waterways. Nutrient-rich sediments are problematic for many waterbodies. The second paper continues our focus on beneficial use of dredged sediments. This manuscript describes the results of a particle tracing study conducted during the construction of an underwater feeder berm near South Padre Island, Texas.

Documenting examples of beneficial use projects in the Journal of Dredging could not be timelier whether successful or not. Two additional papers on beneficial use are under review for the next issue of the Journal.

Familiar with other beneficial use projects that deserve documentation? The Journal of Dredging welcomes manuscripts on beneficial use and all aspects of dredging and dredged material management, including those related to cost, environmental compliance, and other important issues. If you have questions, please inquire. I gladly help authors determine the best way to document their projects.

I am wishing us all of us a prosperous 2021!

Don Hayes
Editor, WEDA Journal of Dredging
January 2021

ENVIRONMENTAL BENEFITS REALIZED DURING NAVIGATION MAINTENANCE DREDGING: A CASE STUDY IN THE INDIAN RIVER LAGOON, FLORIDA

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ABSTRACT

The potential deleterious effects associated with a dredging operation are the primary focus of stakeholders and regulators. The net positive environmental benefits associated with traditional navigation maintenance dredging projects are rarely identified and almost never quantified. The dredging of a portion of the Intracoastal Waterway in Indian River County, Florida was monitored to determine the ultimate fate of the dredged material and its associated nutrient load through the dredging and dewatering operations. The quantities and types of materials removed and residual bedload was also monitored along with various biological indicators.

The project removed approximately 211,000 cubic meters (276,000 cubic yards) of material and included in this volume was an estimated 240 metric tons (260 short tons) of nitrogen and 130 metric tons (140 short tons) of phosphorus. Minimal return water was released back into the lagoon, so virtually all this dredged material was permanently removed from the aquatic system and placed in the upland dredged material management area (DMMA). Thus, this project not only restored the required navigational depth but also permanently removed a significant quantity of anthropogenic nutrients from the lagoon, benefiting its overall environmental health.

Keywords: Dredging, Indian River Lagoon, dewatering, dredged material disposal, nutrients.

INTRODUCTION

Navigation maintenance dredging took place in the Indian River Lagoon in 2015, an impaired waterbody and an important estuary. This lagoon was the focus of international attention due to harmful phytoplankton blooms in 2011 and large die-off events of not only seagrasses but also marine mammals. As a result of international and local interest, a partnership between the Florida Inland Navigation District (FIND), the non-federal sponsor, the U.S. Army Corps of Engineers (USACE), and the Florida Institute of Technology (FIT), was formed to monitor the operations associated with dredging this portion of the Intracoastal Waterway (IWW), which had not been

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maintained since original deepening in 1957. It was a timely opportunity to monitor a relatively rare but overall standard maintenance dredging event in an imperiled system.

The USACE and FIT collaborated to evaluate the impacts of this shallow draft maintenance navigational dredging project on muck movement, water quality, nutrient removal, and local biota. Dredging has historically been viewed as harmful to the surrounding environment in this region, primarily due to direct impacts of benthos and secondary impacts primarily associated with turbidity plumes. Recently, there has been a move to utilize dredging to help restore the impaired ecosystem of the Indian River Lagoon (IRL). Dredging is a significant component of the overall restoration plan for the IRL to remove undesirable sediments (Weaver et al, 2015).

Two separate yet concurrent events led to a significant decline in submerged aquatic vegetation in the IRL. A 2010 bloom was dominated by a mix of cyanobacteria, diatoms and dinoflagellates in the Melbourne area and diatoms and dinoflagellates in the Sebastian and Vero areas. As the first bloom continued, a second bloom began in the spring of 2011 and reached immense proportions, deserving the label "superbloom." The 2011 superbloom covered approximately 53,000 hectares of open water, including and surpassed all previously documented blooms in intensity (SJWMD, 2012). By the end of summer 2011, seagrass loss was substantial (Morris et al., 2015). These events led to significant die-off of benthos and even marine mammals. Evidence suggests that the loss of seagrasses resulted primarily from decreased light penetration during and after the superbloom, but other events may have played important roles in creating the observed conditions. The near absence of drift algae throughout 2011 and 2012 could have increased the supply of nutrients available to phytoplankton because drift algae were not acting as a "sponge" that soaks up nutrients. Therefore, the combined loss and absence of both drift macroalgae and seagrass may have freed up nutrients to initiate and sustain the superbloom (Morris et al., 2015).

There are deposits of fine-grained silts and clay sediments mixed with up to a quarter of organic matter that store anthropogenic chemicals and nutrients. These deposits exist throughout the IRL and are termed "muck". The IRL was once a sandy bottom estuary, with a modest accumulation of organic detritus from shoreline and aquatic vegetation loss. Much of the lagoon bottom is now covered in a layer of muck, a highly mobile via resuspension, and fine material that has accumulated over decades of excess runoff and sedimentation. Fine particles and organics carried in by tributaries, canals, and storm drains accumulate and break down on the bottom, forming a thick black ooze. This muck builds up in channels and deep pockets where it has reached depths of up to 4.6 meters (m) (15 feet (ft)). The muck smothers and blocks light from benthic grasses and organisms and it serves as a legacy load that slowly releases nutrients back into the water column (Fox and Trefry, 2018). These muck sediments are potentially significant contributors to lowering the overall environmental health of the IRL.

Sources of shoaling sediments and nutrients within the IRL are numerous: natural streams, rivers, creeks, drainage canals, stormwater outfalls, overland runoff, groundwater seepage, septic-tank leachate, and infrequent wet-weather wastewater discharges (Tetra Tech and Closewaters, 2020). The IRL is still continually receiving urban and construction runoff, various marina pollutant inputs and, possibly, internal pollutant loading from the IRL's sediments (Steward et al., 2003; Fox and Trefry, 2018). The impacts to the lagoon habitat have become so significant that the State of Florida has appropriated millions of dollars to clean up the IRL in Brevard County (Waymer, 2015). Projects have been completed and planned to address the continued input loads, improve water quality, and remove or contain deleterious materials already within the system. This research project was devised to help establish the environmental effects or benefits associated with a navigational maintenance dredging project in the IRL and to assist in guiding and determining associated impact of ongoing and future restoration dredging efforts in the IRL.

DATA COLLECTION AND RESULTS

The USACE conducted a maintenance dredging project in conjunction with the FIND along the Intracoastal Waterway (IWW) in the northern five miles of Indian River County, Florida. This portion of the waterway has not been maintenance dredged since its 1957 deepening to its present depth of 3.7 m (12 ft) Mean Lower Low Water (MLLW) (Taylor, 1999). The project commenced in January and dredging was completed in June 2015 with approximately 211,000 cubic meters (m^3) (276,000 cubic yards (cy)) of material removed. The research effort monitored four inter-related components in relation to the dredging project: dredging operations, muck movement, nutrient removal, and biological impacts.

Dredging Operations and Sediment

USACE Jacksonville District pre-dredging surveys were used for volume computations of soft sediments in the channel prior to dredging. To perform this analysis, both high (200 kHz) and low frequency (28 kHz) data for the IWW Indian River County Reach 1 were compared. The basic principle employed for this analysis is that the high frequency survey data refracts off the top layer of soft silt, which is present in Indian River Reach 1, while low frequency returns penetrate to the bottom of the soft silt layer and reflects off a denser substratum (e.g., Foster et al., 2018). The difference in these two frequency returns is the thicknesses of soft silt; i.e., isopach (Figure 1) (Weaver et al, 2015). In order to qualitatively confirm the accuracy of the soft silt thicknesses, push cores and core borings were collected and analyzed in the project area. The subsurface sampling confirmed the presence of soft silt deposits as presented in the isopachs. The bulk of the soft silts were located within the channel footprint and side slopes.

Given the isopach volume and channel dimension, the soft silts that could potentially be removed within the channel's dredging footprint were calculated. There are gaps in the low-frequency coverage from station 43+00 to station 82+00, thus volume calculations (Table 1) only span station 0+00 to station 42+00. Push core samples were used to measure an average bulk density of 1.54 g/cm^3 (2,596 lbs/cy) in-situ. Based on the measured bulk density, the associated mass of soft silts based on volume was estimated along with the average thickness of soft silts (Table 1) (Weaver et al, 2015).

The IWW channel has a congressionally authorized 38.1 m (125 ft) bottom width with a 3.7 m (12 ft) depth relative to MLLW with 3 horizontal to 1 vertical side slopes. There is an allowable over-depth allowance of 0.61 m (2 ft) which results in an allowable maximum pay dredging depth of 4.3 m (14 ft) MLLW.

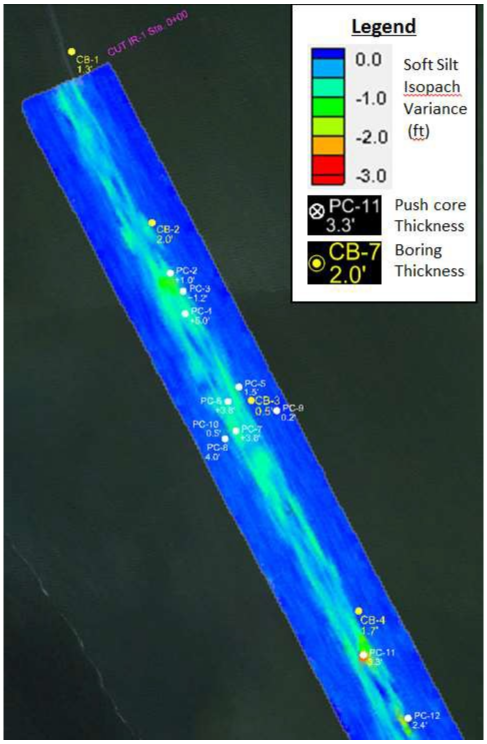

Figure 1. Isopach of high versus low frequency return in IR and push core and boring locations (Weaver et al, 2015).

Table 1. Pre-dredging volumes and mass of soft silts in the IWW in Indian River (Weaver et al, 2015).

Pre-dredge Survey	**Soft Silt (C.Y.)**	**Soft Silt (m^3)**	**Mass* (Short Tons)**	**Mass* (Tons)**
Channel bottom at 12 ft depth	15,085	11,534	19,579	17,762
Channel bottom at 14 ft depth	31,255	23,896	40,564	36,799
Channel and side slopes at 12 ft depth	32,096	24,539	41,657	37,790
Channel and side slopes at 14 ft depth	62,790	48,007	81,494	73,930
Outside of channel and side slope	34,350	26,262	44,582	40,444
			Soft Silt (in.)	**Soft Silt (cm)**
Avg. thickness 12 ft channel and side slopes			5.3	13.4
Avg. thickness outside of channel and slopes			3.1	7.9

*Mass estimate computed by 15 March 2015 push core collection in situ measured bulk density of 1.54 g/cm^3 conversion of 2,596 lbs/C.Y. Short tons equals 2,000 lbs.

The volume of soft silt within the 3.6 m (12 ft) deep channel with side slopes is 24,539 m^3 (32,096 cy) with a weight of 37,790 metric tons (41,657 short tons). The volume of soft silt was also calculated within the 38.1 m (125 ft) bottom width without including side slopes (box cut) of

11,534 m^3 (15,085 cy) with a weight of 17,762 metric tons (19,579 short tons). The volume of soft silt that would be removed in the 4.3 m (14 ft) deep channel with side slopes is 48,007 m^3 (62,790 cy) with a weight of 73,930 metric tons (81,494 short tons). The volume of soft silt was also calculated within the 38.1 m (125 ft) bottom width of the channel at a 4.3 m (14 ft) channel bottom without side slopes and was 23,896 m^3 (31,255 cy) with a weight of 36,799 metric tons (40,564 short tons) (Figure 2).

The volume difference between the 12 ft design channel and the 14 ft design channel can be attributed to the fact that the low frequency surveyed surface drops beneath the design surface of the 12 ft channel in various locations, this resulting in a smaller volume. The high frequency and low frequency survey data spanned a width greater than the design channel's dredged footprint. The average thickness of soft silt outside of the channel limits was 7.9 cm (3.1 in.) while within the channel 12 ft template it was 13.4 cm (5.3 in.) (Weaver et al, 2015).

The dredged material was all placed into the Dredged Material Management Area (DMMA) IR-2. The DMMA can also be termed an upland placement area (PA) or a confined disposal facility (CDF). The site was of sufficient size that percolation and evaporation were adequate to dewater the placement area without the need for controlled releases of decanting water. Several days of decanting utilizing the weir structures was performed at the beginning of the project to test the water control and decanting systems as this was the first operation of the placement area (Figure 3), but ended up being unnecessary during operation.

Fluid Mud Measurements

Movement of highly turbid unconsolidated bottom material creates a lutocline or near bottom nephelometric layers, reducing the penetration of light reaching the lagoon's bottom. Monitoring and measurement systems recently developed for use in shallow marine areas, such as the IRL,

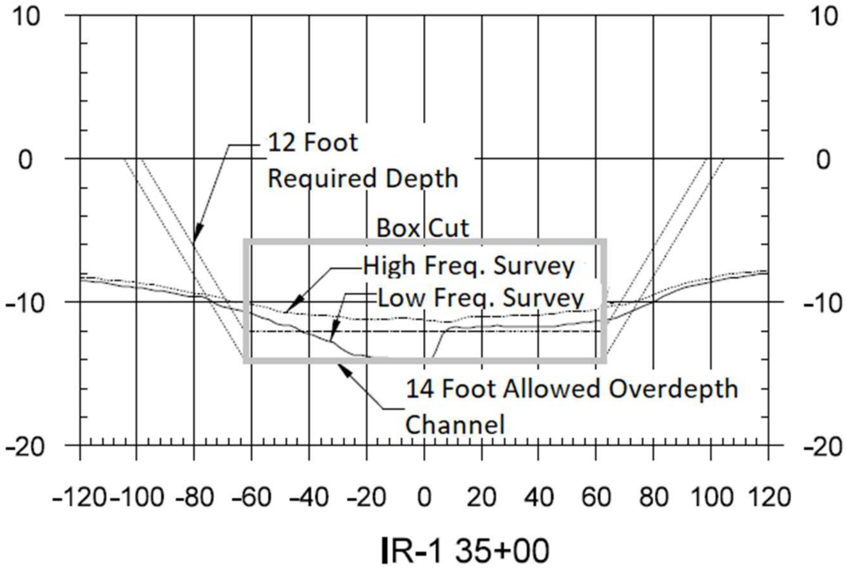

Figure 2. IWW dredging template; box cut, required depth and allowable over-depth.

Figure 3. Dredged Material Management Area IR-2 and water control weirs 14 May 2015. Photo credit Cavache Inc.

called passive sondes were utilized to estimate suspended fluxes along and across the channel. These sondes are essentially horizontal facing no-flow-through sediment traps that employ the principal of inertia to capture suspended sediment fluxes (Weaver et al, 2015). Four locations within the IWW channel to be dredged were selected for deployment of the sondes prior to, during, and post-dredging.

The variability between the transect cross sectional average horizontal fluid mud fluxes within the bottom layer are shown in Figure 4. The results of extrapolation of the results to a cross sectional bottom water layer followed by applying a nonparametric Kolmogorov test indicate that the pre, during and post sonde fluxes are significantly different from each other ($p<0.001$) at each transect.

A layer of fluidized sediment was found to be in constant flux along the bottom of the IRL in the vicinity of the dredging operations. Though generally low, the fluxes increased during dredging and remained elevated post dredging. The increase in total flux post-dredging in three of the four transects is typically assumed to be residuals from the excavation operations. Future studies are required to determine the length of time that these residuals will remain suspended. Future efforts should also focus on determining if soft silt material is migrating into the channel footprint and if the IWW channel is functioning as a sediment trap. One recently conducted study did look at this potential and found that at Turkey Creek, a tributary of the IRL, the migration of fines is likely (Fox and Trefry 2018).

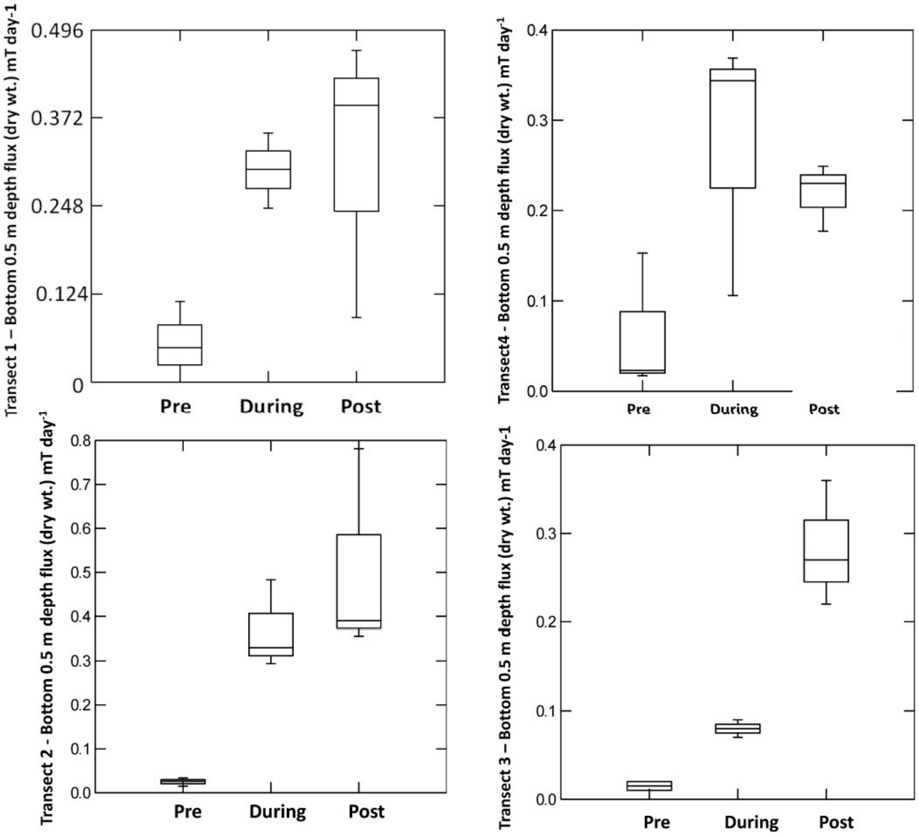

Figure 4. Fluxes in metric tons per day (mT day^{-1}) at each transect applied to a 0.5 meter bottom cross-sectional area indicates the fluid mud mass flux or movement between the pre dredge, during and post dredge conditions was significantly different, showing cross section variability with error bars (Weaver et al, 2015).

Slurry, Dewatering, Nutrient Containment and Testing

Water and slurry samples were collected on four occasions (February 19, March 25, April 21 and May 6, 2015) at five locations within and around the DMMA (Figure 5). These water samples were filtered and analyzed for the following: total suspended solids (TSS), dissolved phosphate, dissolved ammonium and nitrate + nitrite plus dissolved organic carbon, dissolved iron and manganese, as well as particulate aluminum, silicon, iron, organic carbon, total nitrogen and total phosphorus. Data for salinity, temperature, dissolved oxygen and pH also were collected on site during each sampling trip (Weaver et al, 2015).

Concentrations of dissolved ammonium and phosphate in the incoming dredged material (at #1, Figure 5) were quite variable with ranges of 0.2-11 mg N/L for ammonium and 0.1-4 mg P/L for phosphate, most likely in response to changes in the composition and water content of the sediment being dredged. By the time water reached the weir (#2), concentrations of ammonium and phosphate averaged 0.3 mg N/L and 0.2 mg P/L, respectively; these values are lower than found in the wetland at the end of the discharge pipe leaving the DMMA and at the outfall from the

Figure 5. Map of DMMA IR-2 showing approximate sampling locations: #1 at the incoming pipe from the dredge, #2 at the weir inside the DMMA, #3 at the pipe leaving the DMMA, #4 at the outfall to the IRL and #5 in the IRL away from the outfall site (Weaver et al, 2015).

wetland (#3 and #4) but 3-4 times greater than in two samples from the open IRL offshore of the DMMA (#5). Low values for ammonium and phosphate at the weir suggest uptake of these dissolved nutrient elements by plants (primarily Cattails) or algae within the DMMA, thus the placement area was acting as natural filter, similar to a wetland. Increased concentrations of ammonium and phosphate at the discharge pipe and in the outfall likely represent release of these two nutrients from decomposing organic matter in the surrounding wetland because no discharges from the DMMA occurred during the sampling events as the placement area naturally infiltrates into the surficial aquafer as it is situated on a sand ridge.

Concentrations of TSS carried by the incoming pipe from the dredge averaged 290,000 mg/L (290 g/L). By the time the sediment-water mixture reached the weir, TSS values decreased by about 19,000-fold to an average of 15 mg/L (Figure 6). The typical range of TSS values is 2-25 mg/L for the overall IRL and 2-13 mg/L in the immediate project area. Therefore, if any discharges from DMMA IR-2 via the weir occurred, they would have had TSS values within or slightly higher than values for the IRL.

Trends for particulate nitrogen and phosphorus (in mg/L) followed those for TSS with about 200- and 1800-fold decreases, respectively, in the masses of particulate nitrogen and phosphorus per liter during transit between the incoming pipe from the dredge and at the weir. Smaller decreases in values for particulate nitrogen and phosphorus, relative to those for TSS, were observed along the length of the DMMA due to increased organic matter (containing carbon, nitrogen, and phosphorus) in the much smaller concentrations of TSS at the weir (Figure 6). Concentrations of particulate aluminum and iron (in mg/L) decreased by about 365,000- and 400,000-fold, respectively, from the incoming dredge pipe to the weir. These extremely large decreases in particulate aluminum and iron along the length of the DMMA show the near complete removal of the clay-rich and low organic matter dredged material well before the weir (Weaver et al, 2015).

The 211,000 m^3 (276,000 cy) of sediment dredged contained approximately 154,000 metric tons (169,000 short tons) of dry sediment, 240 metric tons (260 short tons) of nitrogen and 130 metric tons (140 short tons) of phosphorus. Greater than 99% of the nitrogen and phosphorus carried into the DMMA was bound to sediments and not dissolved (Table 2). This DMMA was a highly

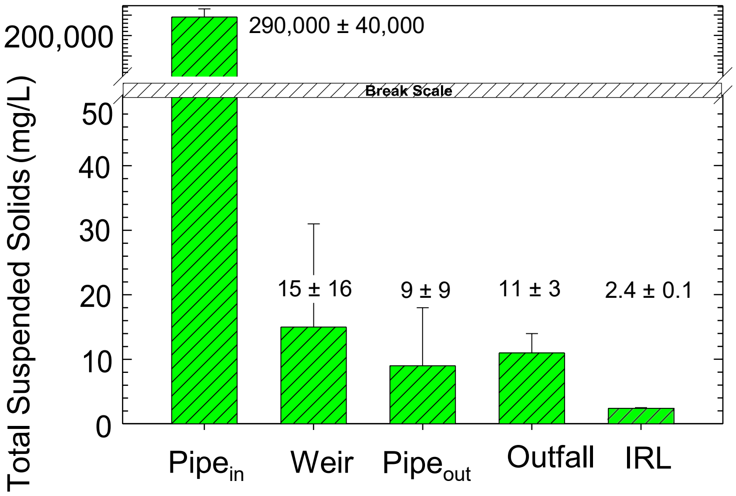

Figure 6. Concentrations of total suspended solids (TSS) for samples from the following locations in DMMA IR-2: at the incoming pipe from the dredge (#1, Pipe$_{in}$), at the weir inside the DMMA (#2, Weir), at the pipe leaving the DMMA (#3, Pipe$_{out}$), at an outfall to the IRL (#4, Outfall) and in the open IRL away from the outfall site (#5, IRL) (Weaver et al, 2015).

efficient trap for the volume and rate of sediment and water deposited during the dredging project (Weaver et al, 2015).

Biological Assessment

Given future plans to expand dredging efforts to remove muck along much of the IRL this project was monitored for changes to seagrasses, fish and macroinvertebrate abundance. The potential discharge of turbid water from the IR-2 placement area into the IRL was monitored for secondary effects from the nutrients returned and suspended solids associated with the project. The concern was that nutrients might trigger algal production (phytoplankton, drift macroalgae, and epiphytic algae), similar to the superbloom. Algae, and suspended solids in the discharge water, could impact the recovery of the little seagrass remaining in what once was a lush seagrass habitat not too distant from the discharge location of the DMMA (Weaver et al, 2015) (Morris et al, 2015).

The relatively sparse nearby seagrass and fish populations were monitored for potential regional effects that might be due to the dredging discharge activity itself, or possibly associated with undetected seepage or regional effects of the DMMA. The condition and responses of seagrasses and fishes were monitored before, during, and after the dredging project. A background site on the shoreline immediately north of the placement area, was monitored for a controlled comparison to the responses of seagrasses nearest the DMMA's outfall location, sampling location #4 (Weaver et al, 2015).

Table 2. Dredged slurry, discharge, background sampling on February 19, March 25, April 21 and May 6, 2015.

Parameter	Sample Location					
	Incoming Pipe	**DMMA at Weir**	**% Removal by DMMA**	**DMMA Discharge**	**Outfall area in IRL**	**Open IRL Background**
Sampling Locations	2 or 3	4		4	4	2
Salinity	31 ± 2	26 ± 4	16.1	21 ± 10	19 ± 8	29 ± 1
Temperature (˚C)	-	16-27		15-25	15-24	25-26
pH	7.8 ± 0.2	7.2 ± 0.3	7.7	7.2 ± 0.2	7.4 ± 0.4	8.0 ± 0.2
Dissolved Concentrations (mass/volume)						
O_2 (% saturation)	75	26 ± 21	65.3	26 ± 19	34 ± 45	107 ± 61
Ammonium (mg N/L)	4 ± 6 (0.2-11)	0.3 (0.06-1)	92.5	0.8 ± 0.7	0.4 (0.1-1.2)	0.08 ± 0.06
Nitrate + Nitrite (mg N/L)	<0.001[1]	0.008 ± 0.008	-700.0	0.02 (0.005-0.07)	0.007 ± 0.003	0.004 ± 0.002
Phosphate (mg P/L)	3.9 ± 0.6[1]	0.24 ± 0.16	93.8	0.60 ± 0.37	0.39 ± 0.30	0.05 ± 0.03
DOC[2] (mg/L)	27 ± 8[1]	25 ± 5	7.4	23 ± 6	20 ± 10	7.7 ± 0.8
Silica (mg Si/L)	12 ± 2[1]	4.1 ± 2.3	65.8	4.9 ± 1.8	3.8 ± 2.2	0.4 ± 0.1
Iron (µg Fe/L)	5.3 ± 0.3[1]	<0.2-22	96.2	13-220	1.3-200	1.0 ± 0.6
Manganese (µg Mn/L)	45 ± 11	290 ± 120	-544.4	410 ± 190	1.4-570	11 ± 11
Particulate Concentrations (mass/volume)						
TSS[3] (mg/L)	290,000 ± 40,000[1]	15 ± 16	99.995	9 ± 9 (1-22)	11 ± 3	2.4 ± 0.1
Particulate Al (mg/L)	7,300 ± 500[1]	0.02 ± 0.02	99.9997	0.02 ± 0.02	0.11 ± 0.06	0.062 ± 0.004
Particulate Fe (mg/L)	3,800 ± 60[1]	0.007 ± 0.008	99.9998	0.019 ± 0.016	0.16 ± 0.10	0.068 ± 0.005
Particulate Si (mg/L)	72,000 ± 18,000[1]	0.12 ± 0.07	99.9998	0.14 ± 0.08	0.6 (0.2-1.4)	0.35 ± 0.04
POC[4] (mg/L)	4,600 ± 1,900[1]	5.9 ± 7.5	99.87	3.8 (0.5-10)	2.6 ± 1.4	0.56 ± 0.02
Particulate N (mg/L)	380 ± 30[1]	1.9 ± 2.8	99.50	1.1 ± 1.0	0.8 ± 0.4	0.31 ± 0.04
Particulate P (mg/L)	240 ± 70[1]	0.13 ± 0.13	99.95	0.08 ± 0.07	0.08 ± 0.05	0.009 ± 0.002
Particulate Concentrations (% dry mass)						
Aluminum (%)	2.9 ± 0.6	0.16 ± 0.10		0.25 ± 0.11	1.2 ± 0.9 (0.5-2)	2.5 ± 0.1
Iron (%)	1.7 ± 0.6	0.05 ± 0.01		0.26 ± 0.11	1.7 ± 1.2	2.8 ± 0.3
Silicon (%)	23 ± 4	1.6 ± 1.3		4.4 (0.6-14)	6 (3-17)	14.2 ± 1.3
POC[3] (%)	1.7 ± 0.7	42 ± 16		39 ± 8	22 ± 7	23 ± 2
Particulate N (%)	0.16 ± 0.04	11 ± 5		11 ± 4	7 ± 4	12.8 ± 2.2
Particulate P (%)	0.092 ± 0.028	1.0 ± 0.2		0.85 ± 0.22	0.7 ± 0.5	0.37 ± 0.08

[1]Average based on the two most representative samples (March 25 and May 6); [2]DOC = Dissolved Organic Carbon; [3]TSS = Total Suspended Solids; [4]POC = Particulate Organic Carbon

The measures of seagrass abundance showed no statistically significant differences when making temporal comparisons. The variability and trends of loss or gain comparing transects near the DMMA and dredging activities to control transects at the away sites display seasonal growth patterns (Figures 7 and 8). For example, where data are available to show mean percent presence of Shoal Grass *(Halodule wrightii)* near the DMMA site before and after dredging, the nonsignificant trends at the control transects are universally in the increasing direction. The lack of statistically significant temporal differences suggests no proximal effects of DMMA discharge or seepage, nor any effects of nearby dredging. Nonsignificant trends tend toward an increase of seagrass following dredging, but this is also true of the control transects where no dredging was occurring. Therefore, any perceived changes in the seagrass *H. wrightii* cannot be differentiated from regular seasonal changes due to environmental factors unassociated with dredging (Weaver et al, 2015). This increasing trend likely points to the ongoing natural recovery of seagrasses in the IRL.

Sampling for fish and macroinvertebrates occurred in March, May and July 2015 and determined that the nearshore region of the Indian River Lagoon near the DMMA supported an abundant and diverse array of juvenile fishes that were vulnerable to collection with the 15 m (50 ft) seine net. The most abundant taxa showed distinct changes in abundance with season that reflects their recruitment periodicity. For example, Pinfish and grunts typically spawn in winter and recruit into

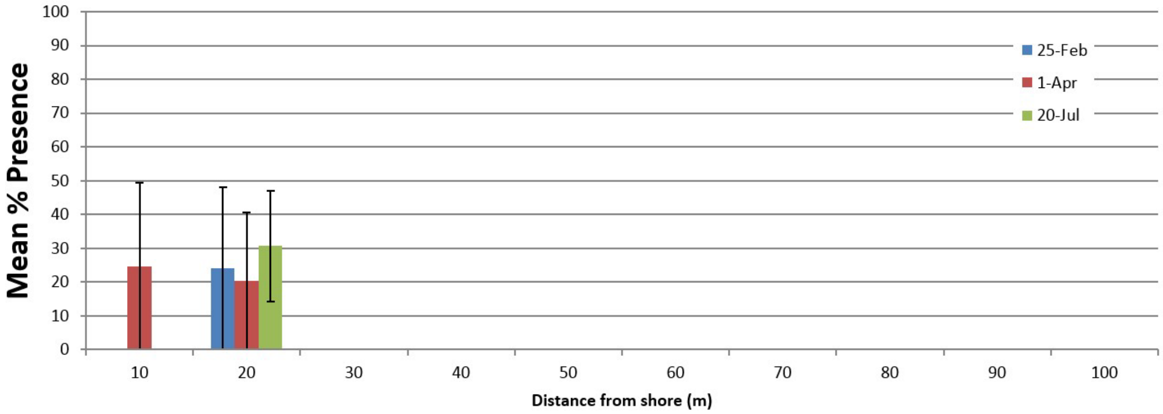

Figure 7. Seagrass *H. wrightii* near DMMA outfall.

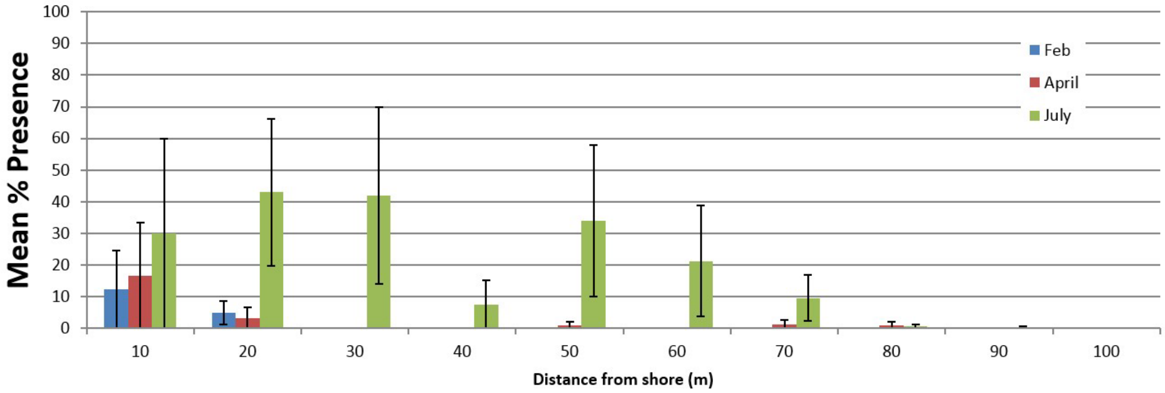

Figure 8. Seagrass *H. wrightii* at control site, immediately north of DMMA.

estuarine nurseries in the spring. The increase generally observed in mean size over the seasons reflects growth of the juveniles.

A primary goal of this portion of the field sampling was to determine if water released from the DMMA impacted the fauna in the nearshore region of the IRL near the discharge site. Since the DMMA never filled to capacity, and did not release water into the Lagoon, it was not possible to evaluate any discharge effects (Weaver et al, 2015).

CONCLUSIONS

Due to the fact that there were no releases from the DMMA other than a few days during the initial dredge operation to test the weir outfall structures, all of the dissolved and particulate nutrients pumped into the DMMA were contained within the placement site. Based on the quantity of dredged material removed and the approximate dry sediment weight: 154,000 metric tons (169,000 short tons), the total weight of nutrients removed can be extrapolated from the measured inflow samples: 240 metric tons (260 short tons) of total nitrogen, and 130 metric tons (140 short tons) total phosphorus.

Focusing on the samples taken from the discharge pipe as slurry entered the placement area and inside the DMMA at the weir, a measurement of the nutrient reduction taking place as the water migrated through the DMMA can be obtained. A greater than 99.9% reduction in suspended solids, 99.5% reduction in particulate nitrogen and 99.9% reduction in particulate phosphorus was measured at the weir although no releases were taking place, as shown in Table 2. The dissolved phosphate was reduced by 93.8%. The concentrations of dissolved nutrients were reduced to the background levels as measured in the IRL. The design of the DMMA and the size of the dredging operation resulted in all of the dredged material and all of the carrier water being contained in the DMMA and slowly percolating. Had there been a need to release, due to the size and configuration of the DMMA, it is likely that nearly all of the particulates would remain settled out and the dissolved nutrients in the released water would have the same or similar levels as those found in the adjacent IRL waters.

From a biological standpoint, with no releases to impact water quality, and the dredging operation being efficient with no turbidity plumes noted, there should not be any expected impact on the biology at the timescales of this project. As expected, seagrasses in the vicinity of the DMMA expressed no significant difference in growth than the seagrass beds selected as the control site to the north. The changes in fish populations cannot be attributed to the dredging, rather are most likely natural seasonal variations in populations (Weaver et al, 2015). This navigational maintenance dredging project achieved the mission of re-establishing the IWW's congressionally authorized design depths, while removing hundreds of tons of deleterious nutrients from the IRL, all without creating a measurable impact to adjacent resources. Future research should focus on whether more frequent dredging of the IRL navigation channels could lead to improved lagoon health.

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SOURCE

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PARTICLE TRACER ANALYSIS FOR SUBMERGED BERM PLACEMENT OF DREDGED MATERIAL NEAR SOUTH PADRE ISLAND, TEXAS

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ABSTRACT

The fate of unconfined dredged sediment placed as a submerged "feeder" berm in the nearshore region of South Padre Island (SPI), Texas, was investigated through a particle tracer study over the duration of 15 months. Unconfined sediment feeder systems can be a desirable alternative to traditional direct beach placement of nourishment material because the feeder systems are less intrusive to the beach environment and often less expensive. Placing sediment as close to the active beach profile, as practicable, and relying on natural nearshore processes to slowly distribute the sediment to the beach can keep a finite resource within the littoral zone. One challenge with this indirect approach is predicting the short- and long-term effects on the coastal system and shoreline in light of the complex nearshore dynamics involved. This study aims at elucidating sediment transport pathways at SPI after tracer release over the feeder berm via assessment of tracer particle counts obtained from nine sediment sampling campaigns (950 surface-sediment grab samples) between August 2018 and November 2019, covering a grid of 60 seabed and 50 dry beach locations. Tracer counts were performed in the laboratory making use of the fluorescent and ferrimagnetic properties of the engineered particles to separate them from other sediment material. Results indicate that although the highest tracer counts remained near the initial release site of the feeder berm during the duration of the study, appreciable amounts of tracer moved throughout the study region. Even though fluctuations of tracer migration were observed, the most prominent appearance of tracer particles outside the initial placement site occurred south and immediately west of it, indicating net alongshore and onshore transport in those directions. Relatively few tracer particles were found on the dry beach, indicating appreciable deposition of feeder material there may take years rather than months.

Keywords: Beneficial Use Dredge Material (BUDM), sediment tracer, fluorescent, ferrimagnetic, Gulf of Mexico

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INTRODUCTION

Beach-nourishment projects are important components of coastal risk-reduction strategies but can be intrusive to coastal ecosystems and beach use. Beach-quality dredged material can be used as nourishment material if sediment characteristics closely match the native beach sand. However, transporting the dredged material to the beach and distributing it via heavy machinery is expensive. Sustainable sediment management practices that are less expensive and less intrusive are desirable (e.g., Berkowitz et al. 2019, Brutsché et al. 2019, McFall et al. 2016, and Welch et al. 2016).

At South Padre Island (SPI), Texas, a submerged "feeder" berm located outside the surf zone in nearshore waters (Work and Otay 1997) is being evaluated as an alternative means to supply sediment to the beach and reduce ongoing coastal erosion. This part of the Gulf of Mexico features an average diurnal tide range of 0.38 m (1.25 ft). The City of SPI is a densely developed tourist destination at the southern Texas Gulf coast. Since 1988 SPI has undertaken intermittent submerged berm nourishment projects as part of a Beneficial Use of Dredged Materials (BUDM) scheme (Aidala et al. 1992). Sediment removed by maintenance dredging is regularly placed back into the littoral system, and thus available for cross-shore and alongshore sediment transport to the beaches. For nearshore placement, maintenance material is placed by a hopper dredge in nearshore "feeder" berm sites (Fig. 1). Previous monitoring of material placed at these feeder berms indicated movement toward the beach and dispersal with movement primarily from alongshore sediment transport (both north and south) but direct tracer verification had not been accomplished prior to this study. An emergency dredging contract has been utilized to remove material from the Brownsville Santiago Pass. For this project, the dredged material was again placed at the feeder-berm sites 2A and 2B closer to the beach, rather than in the available Ocean Dredge Material Disposal Site (ODMDS) as shown in Fig. 1. However, considerable uncertainty remains regarding the timing and quantity of material being mobilized and transported to the littoral zone and the dry beach (Phillips et al. 2017). Although nearshore placement is typically less expensive than beach placement, quantitative evidence is needed to understand how the material spreads and to determine whether it is eventually delivered to the active surf zone and deposited on the upper beach template.

As part of the most recent BUDM placement, a 15-month sediment tracer study was conducted as a collaboration between the City of SPI, U.S. Army Corps of Engineers Galveston District (USACE SWG), U.S. Geological Survey (USGS), Partrac GeoMarine Inc., and Texas A&M University (TAMU). A total of 2,000 kg (4,400 lb) of engineered ferrimagnetic fluorescent tracer particles were deployed to map sediment pathways after initial placement on the berm (Fig. 2). Prior to the tracer deployment, USACE SWG placed more than 382,000 m^3 (500,000 cu.yd) of dredged material from nearby Brazos Santiago Pass approximately 1,220 m (4,000 ft) offshore at a depth of 9.1 m (30 ft). During the duration of the study, more than 900 surface-sediment grab samples from dry beach (at low tide) and offshore grid points in water depths ranging from approximately 7.9 m (26 ft) to 11 m (36 ft) were collected at increasing time intervals after initial tracer deployment.

In addition to tracer release and grab sample collection (dry beach and offshore) a nearshore acoustic Doppler current profiler (ADCP) was deployed to record the local wave and current conditions over the course of the study. The focus of this paper is on the results from the laboratory

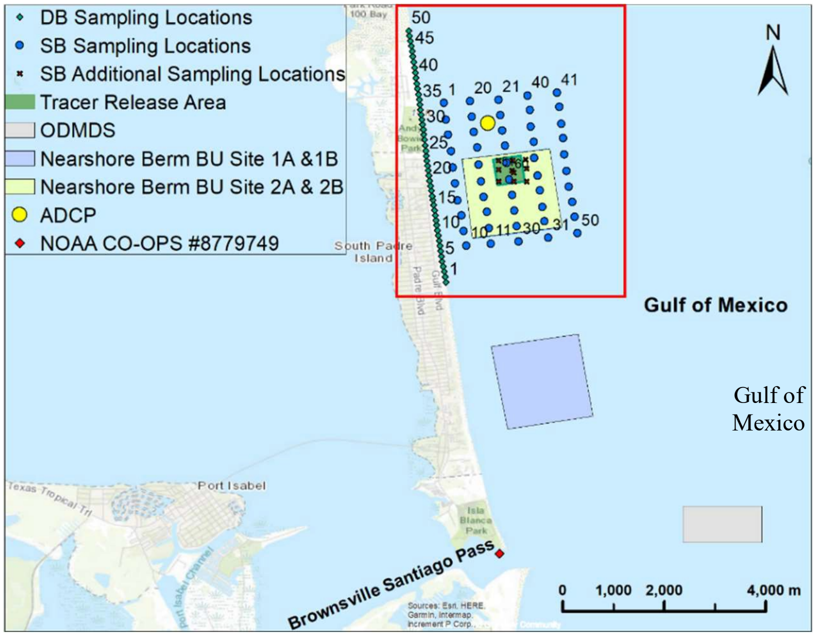

Figure 1. Map of SPI and nearshore berm site (DB: dry beach; SB: seabed).[a]

Figure 2. Photo of tracer deployment. 2000 kg (4,400 lb*)* of ferrimagnetic fluorescent tracer particles (top left inset) engineered to match the hydraulic characteristics of the dredged material were released via a chute on the side of the boat (bottom right inset) over the top of the nearshore berm in August 2018 (Inset photograph in the upper left courtesy of Partrac GeoMarine Inc.; large photograph and inset photograph in the lower right courtesy of the City of South Padre Island).

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[a] All base maps throughout this document were created using ArcGIS® software (ArcMap 10.4.2) by Esri (Esri 2006). Base map data were downloaded from the ArcGIS® online data base (Esri, 2012).

tracer analysis. However, these data are also important to verify numerical modeling approaches that will be used to gain a better understanding of the local sediment-transport dynamics.

METHODS

On August 15, 2018, 2000 kg (4,400 lb*)* of dual-signature tracer particles (ferrimagnetic and fluorescent) were released as a slurry at the location of the newly created submerged feeder berm in approximately 9.1 m (30 ft) of water 1,220 m (4,000 ft) offshore of SPI (Fig. 2). The method applied during this study reflects the method presented by Poleykett et al. (2018) and follows the methodological framework for the use of sediment tracers in marine and coastal environments detailed by Black et al. (2017). The particles were manufactured by Partrac Ltd. to closely match the hydraulic characteristics of the beneficial use dredged material making up the feeder berm (□ $_{50}$ = 0.19 mm, sediment density □ $_{s}$ = 2,600 kg/m^3, Gaussian distribution). Black et al. (2007) discussed optimal characteristics of engineered sediment tracers. The resultant tracer was a unimodal, well sorted fine sand (σ = 0.044 mm) (Folk 1980). The settling velocities of the tracer particles were determined using the Soulsby criterion (Soulsby 1997): wd_{10}, wd_{50}, wd_{90} = 0.007 cm/s, 0.014 cm/s, 0.024 cm/s, respectively. The slurry release into the water was accomplished via a chute over the side of a slowly moving vessel. The area of tracer deployment spanned approximately 500 m by 500 m (1,640 ft by 1,640 ft).

An initial grid of offshore surface-sediment grab sampling locations consisting of 10 alongshore points (□□ = 300 m or 984 ft) by five cross-shore points (□□ = 300 m or 984 ft) was set up. These 50 seabed (SB) sampling locations were complemented by an additional 10 SB locations near the initial tracer placement area. In addition, 50 dry beach (DB) sampling locations were set up along the SPI shoreline (□□ = 100 m or 328 ft) as indicated in the left panel of Fig. 3. Nine sediment-sampling campaigns were completed at increasing time intervals commencing 24 hours after tracer deployment (Table 1). Ten pre-deployment DB and SB grab samples, respectively, were collected

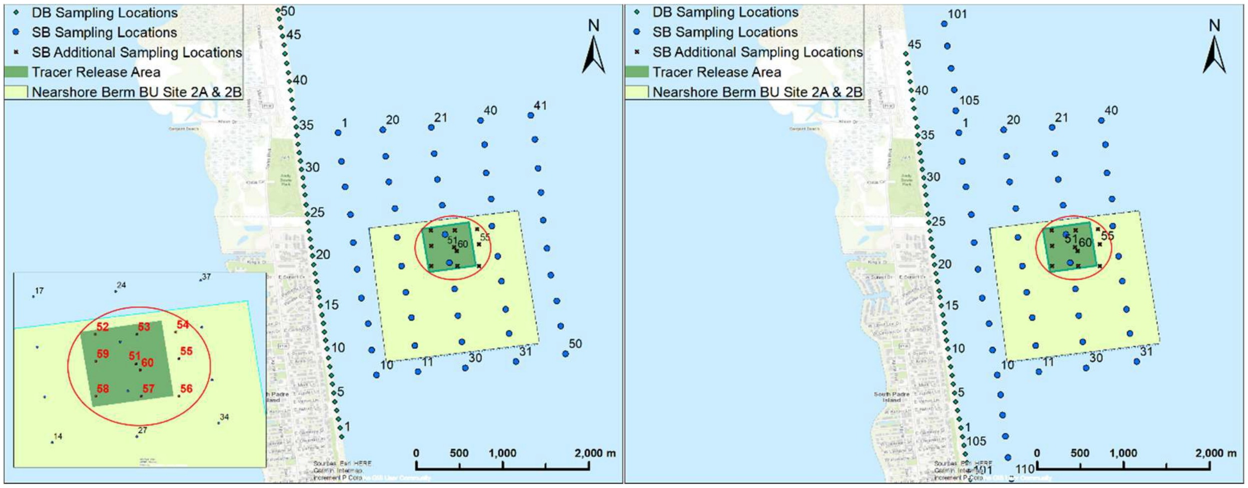

Figure 3. Grid layout for surface-sediment grab samples. Left panel: sampling locations for sampling campaigns 1 – 6. Right panel: modified sample-location scheme for sampling campaigns 7 – 9.

Table 1: Sediment Sampling Campaign Overview.

Campaign	Time past initial tracer deployment	# of surface-sediment grab samples (DB / SB)
0	pre-deployment	10 / 10
1	24 hours	50 / 60
2	3 days	50 / 60
3	1 week	50 / 60
4	2 weeks	50 / 60
5	1 month	50 / 60
6	2.5 months	50 / 60
7	6.5 months	50 / 60
8	10 months	50 / 60
9	15 months	50 / NA
Total # of Samples:		950
Note: Campaigns 1-8 were conducted by the USGS; Campaign 9 was conducted by Partrac GeoMarine Inc. and City of SPI.		

to establish base-line conditions (campaign 0). Starting with campaign 7, the sampling grid was modified slightly in response to measured tracer counts (see right panel of Fig. 3). The line of 10 farthest offshore grid points was removed and replaced by 10 alongshore points, five north and five south of the initial offshore grid, respectively. In addition, the five northernmost DB locations were moved to the south and renamed. The last campaign (campaign 9) only included DB samples.

All 950 surface-sediment grab samples were analyzed at the TAMU Coastal Engineering Laboratory (CEL) on the Galveston Campus. Each sample consisted of approximately 1.0 kg (2.2 lb) of sediment from the top 2 – 4 cm (0.79 – 1.58 in) of the bed. Sample weight was determined before and after drying. The drying process included 24 hours of air-drying at room temperature, followed by 24 hours in a sediment oven at 40° C (105° F), and an additional 24 hours of air-drying afterward to remove all moisture content. The weight of water removed through drying typically ranged between 10 and 30% of the total wet sample weight. Anytime samples were not actively being processed, they were stored in dry, enclosed crates sealed in a double layer of sealable plastic bags to prevent contamination and sample mixing.

Once completely dried, each sample was evenly spread out to an approximate grain monolayer on a 1 by 2 m (3.3 by 6.6 ft) black PVC tray. Lumped particle accumulations were gently separated by using a kneading stick or hand-held rolling pin. The monolayer was then inspected visually with a blue light torch (~ 395 nm) in a dark room (Partrac Ltd. 2018) and the number of tracer particles was counted manually (Fig. 4).

For samples with large tracer amounts present, the sediment monolayer was divided into six rectangles of equal size and counting was done for two of them only. The resulting particle counts were then multiplied by three to stay consistent across all samples. Under the blue light torch, the fluorescent tracer particles appear bright green and are easily discernible. The bright green appearance is due to the inclusion of a chartreuse dye pigment in the tracer manufacturing process. However, samples also contained some micro-plastic fibers of 2–5 mm (0.079–0.197 in) length exhibiting a blue reflection. Owing to their distinctive shape, the plastic fibers were usually easily

Figure 4. Photo of laboratory tracer assessment. Surface grab samples were dried and spread out on a flat PVC tray. A 12,000-Gauss cylindrical magnet was used to extract the ferrimagnetic fluorescent tracer particles for subsequent counting under blue light illumination.

identifiable but to avoid erroneous tracer particle counts, the ferrimagnetic tracer particles were extracted from the sample by using a 12,000-Gauss neodymium magnet prior to counting. The magnet was cylindrical with a diameter of 25 mm (0.98 in) and a length of 300 mm (11.81 in) and was enclosed in a removable plastic sheath. The cylindrical sheath with the magnet was rolled over the sediment monolayer surface repeatedly. Ferrimagnetic particles attached themselves to the outer surface of the sheath allowing for easy transfer to a separate tray by simply removing the magnet from inside the sheath. The resulting residue contained both native dark gray non-fluorescent iron-bearing sediment particles and the green fluorescent, ferrimagnetic tracer material. Tracer particle counting was then completed manually using the blue light torch. Finally, the individual dry pan or plastic bag where the dried sediment sample was emptied out was inspected under the blue light torch and any tracer particle detected from the residual dirt was added to the final tracer count. Two different researchers repeated the procedure independently and all samples were kept in dark, dry storage protected by double-sealed plastic bags for potential future analyses.

Wet and dry weight of each sample, along with tracer count results were recorded in table format (Figlus and Song 2020) and displayed graphically using geographic information system (GIS) software (Fig. 5 and Fig. 6). Previous studies using similar manual counting approaches have reported errors of 5 – 10% attributed to counting fluorescent tracer grains by eye (Carrasco et al. 2013).

RESULTS AND DISCUSSION

The results for the tracer particle counts vary based on tracer distribution at the time of sample collection. Particle counts range from zero to just below 3,000 for individual samples. The assumption is that the tracer particles behave in a similar way as the placed beneficial-use dredged sediment because they were designed to have the same hydraulic characteristics. Sediment and tracer movement is inherently tied to the complex nearshore dynamics at the site and is influenced by currents, water level fluctuations, waves, surf-zone processes, and morphology evolution (Ingle 2011). Hydrodynamic data are available from a bottom-mounted acoustic Doppler current profiler (ADCP) specifically deployed for this study (Engel et al. 2020) and from nearby National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) Station # 8779749 (NOAA 2020), as explained in more detail in the discussion that follows. In addition, tracer particle counts merely represent snapshots in time and grab samples were only collected near the sediment surface. This means tracer particles observed at a specific location at previous time steps can become buried by new sediment with none or varying amounts of tracer.

Despite these caveats, the results reveal patterns of tracer movement. Figs. 5 and 6 provide graphical representations of measured tracer counts, *N*, over the study area for all sediment-sampling campaigns where tracer counts are represented by circle size and corresponding number at each sample point by using GIS visualization techniques (ESRI 2006). Sample wet and dry weights, as well as tracer particle counts for all sampling campaigns and all grid points are reported by Figlus and Song (2020). Throughout the entire study period, the highest tracer counts were found at or near the initial release location (up to nearly 3,000). These findings indicate that it takes on the order of years rather than months to fully redistribute sediment placed at the feeder berm under the given hydrodynamic conditions. However, a portion of tracer particles moved out of the initial placement area within 24 hours (campaign 1) after placement: large numbers (between $N = 15$ and $N = 189$) of tracer particles were detected just offshore and south of their original location outside the initial placement area indicating a predominantly southward littoral drift was likely during the initial 24 hours. This pattern continued over the next week, manifesting itself in the results from campaign 2 where tracer numbers between $N = 21$ and $N = 2{,}337$ were recorded at all sampling locations south and immediately offshore of the initial placement area. Several locations just north and offshore of the initial placement area also showed elevated numbers of tracer particles between $N = 3$ and $N = 36$ indicating that dispersion of sediment was not purely unidirectional. During this first week, only negligible amounts of tracer migrated onshore and only sporadic counts of six or less tracer particles were found in DB samples.

By week 1 (campaign 3) the pattern had slightly changed (see Fig. 5). While a majority of elevated tracer counts outside the initial placement area were still located south of it, a fair amount of particles per sample had migrated onshore (between $N = 6$ and $N = 156$) as well as north (between $N = 12$ and $N = 72$) showing up in most samples collected at the two most shoreward alongshore rows of sampling locations. This means that onshore migration and alongshore transport in both directions had occurred. Incidentally, no appreciable tracer amounts were found in the farthest shore-parallel offshore row of samples during campaign 3, further highlighting the shift to onshore sediment movement during the preceding time step.

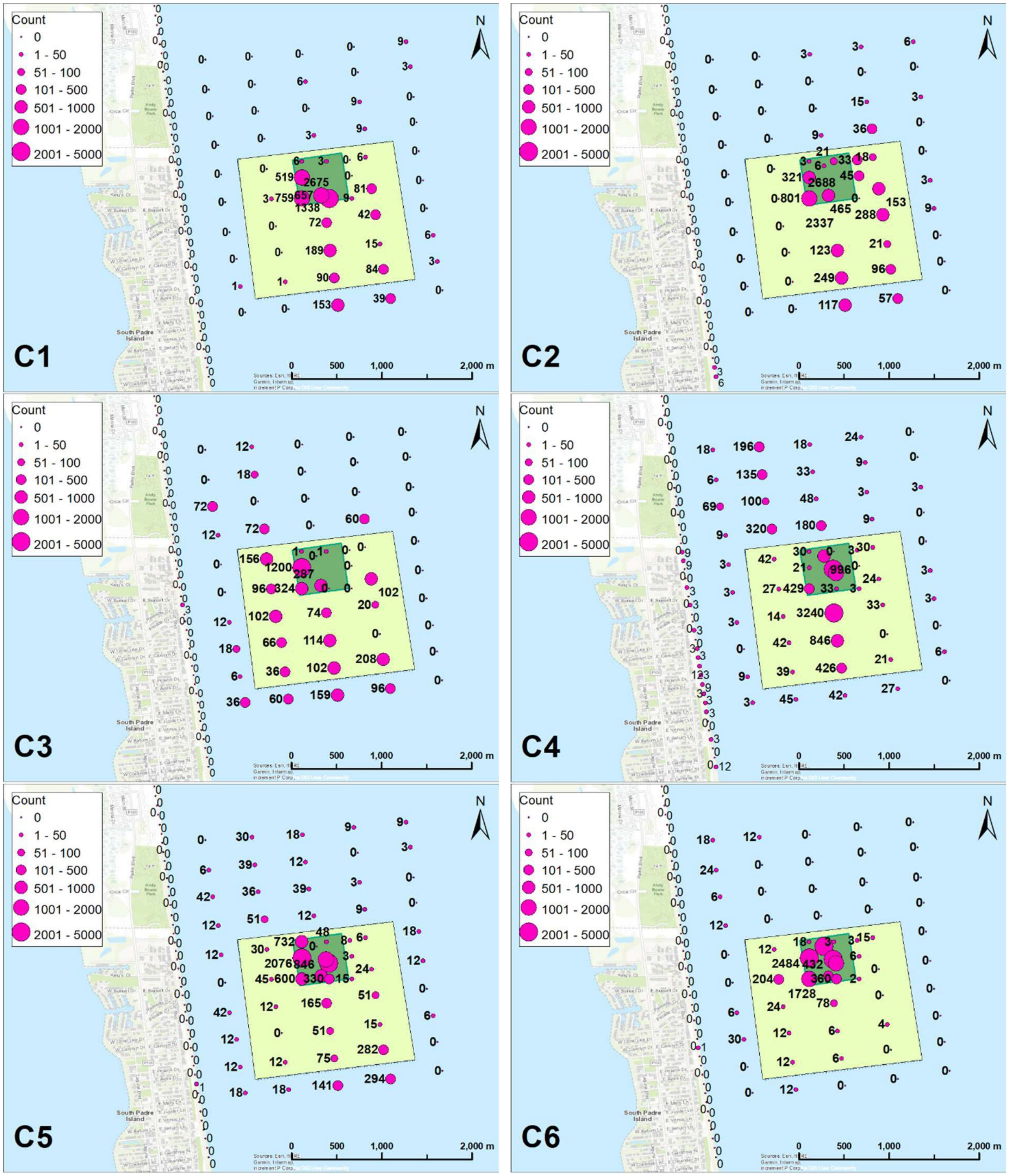

Figure 5. Tracer count results post release for sampling campaigns 1 – 6. C1 (24 hours), C2 (3 days), C3 (1 week), C4 (2 weeks), C5 (1 month), C6 (2.5 months). The number of tracer particles, *N*, is given at each sampling location and visualized by circle size.

Campaign 4 (two weeks post-deployment) revealed yet another shift in sediment dynamics. Large numbers of tracer particles were collected both south and shoreward (N = 14 to as much as N = 3,240 per sample) and north and shoreward (N = 18 to as much as N = 320 per sample) of the original placement area as well as in the nearshore region between the feeder berm and the beach with decreasing concentration toward the shoreline. About half of the DB points also registered small amounts (N = 3 to 12) of tracer particles indicating that onshore transport from the feeder berm and deposition on the dry beach was occurring, albeit at low volume. After one month (campaign 5), the highest concentrations were still apparent in the initial placement area; some tracer was found at most SB sampling locations, although at reduced concentrations from those observed in campaign 4, a week prior. The only exceptions were some sampling locations on the southern edge of the measurement grid, where an increase in numbers from double digits to triple digits was observed. This increase went hand-in-hand with a decrease in counts at locations between the original placement area and the southern edge of the grid, highlighting the possibility for particles to move southward out of the sampling area.

Campaign 6 (2.5 months post deployment) showed appreciable overall count reductions outside the initial placement area, to mostly zero offshore and lower two-digit numbers in the area shoreward of it. This could indicate that tracer particles had migrated out of the sampling area or had been covered by additional sediment as a result of storm activity as discussed below. DB samples did not show any appreciable tracer counts. These observations prompted the modification of the sampling grid detailed in the methodology section for the remaining campaigns (Fig. 6).

Six and a half months into the field experiment (campaign 7), the measured tracer distribution resembled that after 1 week but with an apparent onshore shift of appreciable tracer counts across almost all sampling locations. At that point, the majority of tracer particles outside of the initial placement area could be found south and onshore of it with numbers ranging from the low tens to 615 per sample. Only one DB location south of the feeder berm recorded nine tracer particles.

Ten months post initial deployment (campaign 8), the count numbers looked similar but sampling locations shore- and southward of the initial tracer release area revealed increased particle counts. This indicates that some onshore movement of sediment occurred over the three and a half months between campaign 7 and 8. The final campaign after 15 months (campaign 9) only consisted of DB samples. Counts ranged from zero to N = 21 tracer particles per sample, with zero counts making up over half of the samples. Only one sample with a count over nine particles (N = 21) was found. This sample was from the most southward DB location. This pattern in tracer particle counts indicates that onshore transport and deposition on the dry beach likely occurred but the stretch of beach with the most benefit may not be the one immediately landward of the feeder berm depending on the prevailing nearshore dynamics. The tracer results show that placed material moved to within 150 m (500 ft) of the beach face, and therefore well within the closure depth. The residence time for material this close to the beach face, and its subsequent along-shore or cross-shore transport pathways, are not known. It is clear, however, from the present study that material moves from the nearshore berm to within the closure depth, and therefore is capable of nourishing the beach.

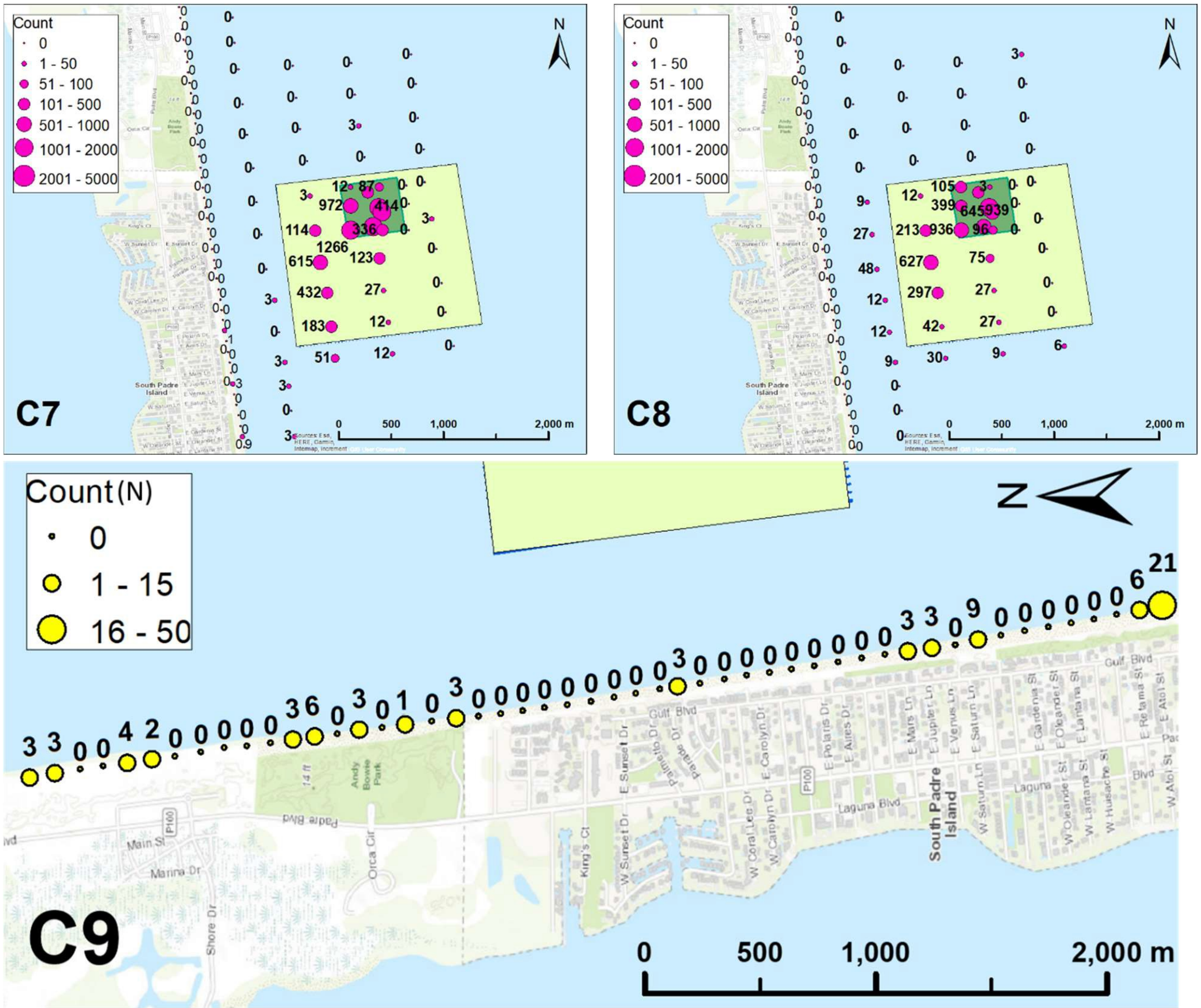

Figure 6. Tracer count results post release for sampling campaigns 7 – 9. C7 (6.5 months), C8 (10 months), C9 (15 months, DB samples only). The number of tracer particles, *N*, is given at each sampling location and visualized by circle size.

Publicly available environmental data near the project site from the NOAA CO-OPS Station # 8779749 (NOAA, 2020) are plotted in Fig. A1 in the appendix. These data include predicted and measured water level and wind velocity over the 15-month duration of the study. Between 13 August 2018 and 11 February 2019, a bottom-mounted ADCP measured hydrodynamics at 26.142417N / 97.157028W (Lat./Lon.) in approximately 10 m of water depth. At its position just north of the tracer release site (see Fig. 1), the ADCP recorded current velocity profiles, hourly time series of significant wave height, H_s, mean wave period, T_m, peak wave period, T_p, and wave angle of approach, δ, from true north (Engel et al. 2020). These data give some insight into local hydrodynamic conditions from placement of the ADCP almost to the date of campaign 7 on 27 February 2019. Fig. 7 shows the measured time series. Sediment-sampling campaign times are indicated by solid vertical lines (C0 – C7) and the time of tracer deployment is shown by a dotted vertical line in each subpanel. The shore-normal wave angle of approach is 82° from true north (clockwise rotation) and is indicated by the dashed horizontal line in the bottom panel of Fig. 7. Waves approaching the shoreline from an angle below 82° generally tend to produce currents and littoral transport toward the south, particularly in the surf zone, whereas waves with a direction above 82° may induce northward currents and transport. The measured data however show that the situation is much more complex. Near-bottom currents (V_1 in Fig. 7) and waves may have differing, sometimes even opposing directions. The detailed analysis of the hydrodynamic forcing conditions and linkages to sediment transport are beyond the scope of this paper but are under investigation. Only a brief synopsis is presented here.

Between tracer release and campaign 1, wave heights ranged from 0.7 to 0.9 m (2.3 to 3.0 ft) with mean and peak periods around 4 and 6 s, respectively. Wave approach angles during that time as well as bottom currents stayed above 82°; therefore, longshore currents toward the north would be expected, although this was not manifested in the tracer counts, which indicated a preferred southward transport direction from the initial release site for campaign 1. This could be because offshore counter-currents compensated for opposing nearshore currents or could hint at other complex circulation patterns affecting the movement of sediment material. During the next two days until the start of campaign 2, wave heights reduced to around 0.5 m (1.6 ft) but wave direction remained above 82° with a trend to more oblique approach. Near-bottom currents were small (around 5 cm/s or 0.16 ft/s) moving primarily northward. The tracer counts for campaign 2, however, show increased levels at points south of the initial release site.

These observations again indicate the complexity of the nearshore sediment dynamic regime indicative of an offshore counter-current moving southwards, compensating for water mass moving northwards with the longshore current.

The conditions preceding campaign 3 (1 week) were characterized by increasing wave heights (as large as 1 m or 3.3 ft) and periods (as large as $T_m = 5$ s and $T_p = 6.1$ s), maintaining wave directions above 82°. The increasing energy levels seem to have contributed to the apparent onshore movement and general dispersal of some tracer particles throughout the nearshore zone by the time campaign 3 was conducted. The general trend of predominant southward transport, however, was still apparent. The bottom current directions during this period had actually shifted to predominantly southward-directed flow but with some notable reversals at the beginning and end of this period. The following week preceding campaign 4 (2 weeks) revealed some changes in the measured hydrodynamics that were also manifested in the tracer counts. First, wave heights decreased below 0.5 m (1.6 ft). A decrease in both wave periods to around 3 s was observed simultaneously. Then, wave heights increased in intervals to about 1 m (3.3 ft), again, accompanied by corresponding increases in both wave periods. During this time, wave directions fluctuated greatly, at times decreasing well below 82°. The near-bed current changed from predominantly southward-directed to northward-directed during this time. This shift in hydrodynamic conditions apparently led to tracer particles being transported northward in large numbers to several sample stations north of the initial release site. A small number of tracer particles were also recovered at some dry beach locations. The continued shift between north- and south-directed currents seemed to have the effect of distributing the tracer particles more widely throughout the entire study area.

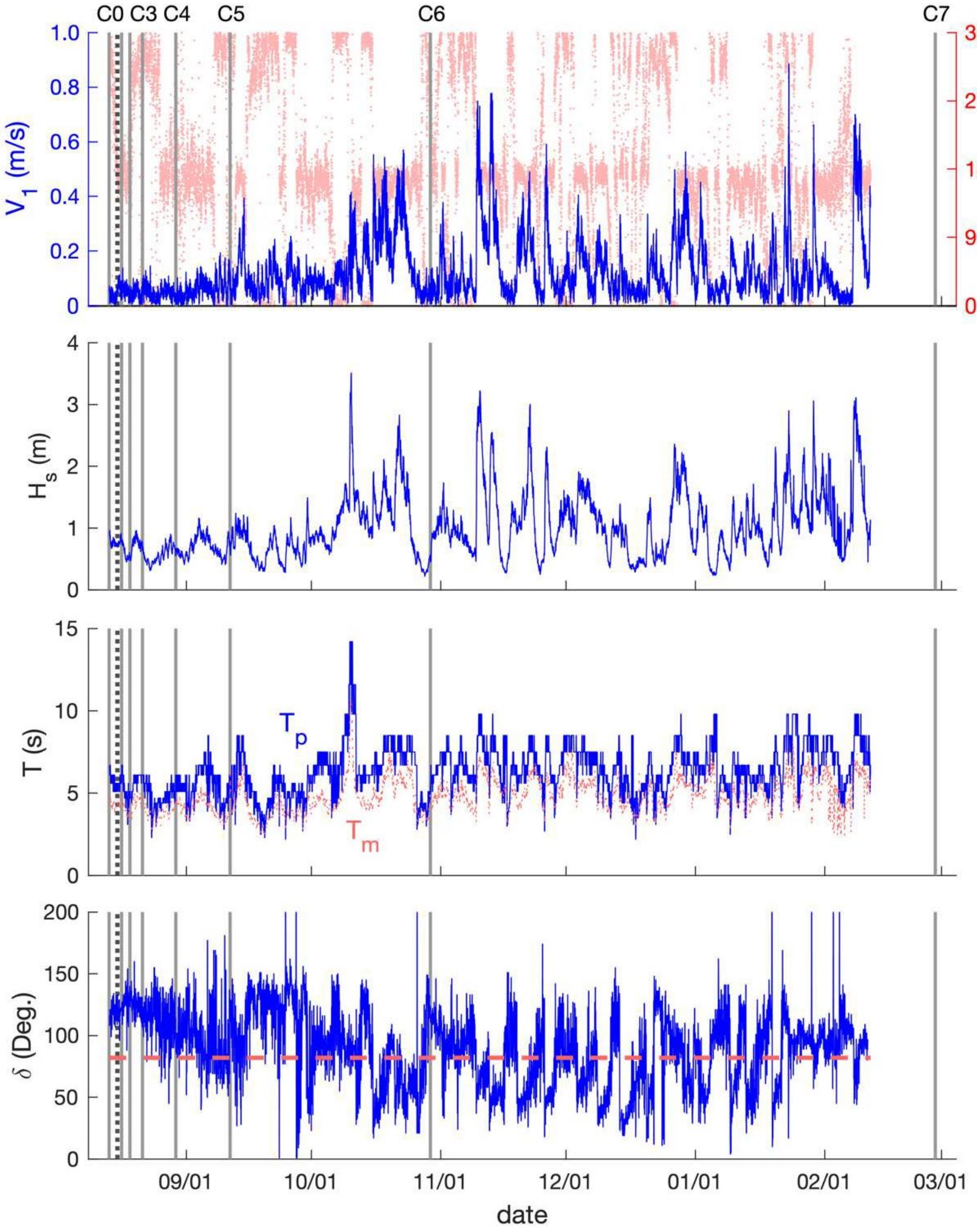

Figure 7. Measured time series of hydrodynamics at the project site (8/13/2018 – 2/11/2019). Sediment-sampling campaign times are shown by solid vertical lines (C0 – C7) in each panel. The tracer release time is indicated by the dotted vertical lines. The top panel shows near-bed current magnitude (V_1 in m/s) and direction from which current is approaching (red dots) for the bottom ADCP bin (0.85 m above the bed), followed by hourly significant wave height (H_s) in meters. The next panel shows both mean (T_m) and peak (T_p) wave periods in seconds. The bottom panel displays the measured direction from which waves are approaching where shore-normal is indicated by the dashed line (82° from true north in the clockwise direction).

Between campaign 4 (2 weeks) and campaign 5 (1 month), wave heights up to 1.2 m (3.9 ft) and periods up to $T_m = 5.2$ s and $T_p = 8.5$ s were measured with swings in wave direction from above 82° to below 82° and back within hours. Measured near-bed current directions toward the latter half of that time interval showed primarily southward-directed flow with magnitudes intermittently reaching 20 cm/s (0.66 ft/s) at times. While this dynamic could have resulted in further tracer dispersal throughout the entire area, it also seemed to have produced some onshore migration of the highly concentrated tracer particles at the initial release site over the feeder berm.

The conditions over the one and a half months between campaign 5 and 6 included the largest single significant wave height, $H_s = 3.5$ m (11.5 ft), and peak period, $T_p = 14.2$ s, measurements for the recorded duration. These occurred during a storm on 10 October 2018. Prior to that date, significant wave heights had been mostly around or below 1.0 m (3.3 ft) and peak periods had fluctuated between 2.3 s and 8.5 s. Before the storm, waves were mostly directed toward the north with only few episodes of several days where waves were directed toward the south. The near-bed current velocity exhibited elevated values compared to previous time segments with peak velocities up to 42 cm/s (1.4 ft/s) at the height of the storm. The near-bed current direction fluctuated between northward and southward directions, shifting from southward-directed right before the storm to northward-directed with the arrival of the storm. The days and weeks after the storm were marked by elevated levels of wave height, wave period, and near-bed current speed with various distinct peaks in current up to $V_1 = 57$ cm/s (1.9 ft/s). During this time, near-bed current direction was primarily toward the north whereas waves were mostly directed toward the south. The last five days before campaign 6 were characterized by calm conditions with wave heights, periods, and current levels reduced to minimal values. The tracer counts from campaign 6 displayed an overall reduction in the amount of tracer particles found at most sampling locations outside the initial placement area. Certainly, the storm and subsequent energy peaks had the ability to mobilize large amounts of bed material from near the shoreline to well offshore the feeder berm and introduce these sediments to the project area. The calm conditions just prior to campaign 6 then provided ideal conditions for sediment to settle out of the water column, potentially leading to surface grab samples being collected outside the initial placement area with reduced tracer counts as shown in Figure 5. Only few sampling locations landward of the initial placement area show elevated tracer counts hinting at the potential of onshore sediment movement from the feeder berm prior to campaign 6.

Available ADCP data end on 11 February 2019, 16 days before campaign 7. The hydrodynamic conditions recorded up to that point cover 87% of the four-month duration between campaign 6 and campaign 7. This time frame was characterized by several high-energy storm events with significant wave heights near or exceeding 3 m. Peak wave periods ranged from 2.2 s to 9.8 s where the higher T_p values coincided with the larger wave heights. Wave directions fluctuated between northward and southward but were primarily directed toward the north over the last three weeks of the available measurements. Near-bed currents exhibited their largest recorded speeds between campaigns 6 and 7 with a maximum of $V_1 = 89$ cm/s on 23 January 2019, and several other peaks reaching current speeds over 60 cm/s. Near-bed current directions fluctuated between northward and southward directions with a slight skewness toward the northward-directed flows. Tracer counts from campaign 7 revealed a dominant onshore and southward-directed migration of tracer particles from the feeder berm (Figure 6) which further highlights the complexities of nearshore circulation and the difficulty in linking hydrodynamics recorded at a single point to larger-scale sediment transport revealed in this study. Nonetheless, the information collected up to that point helps shed some light on the hydrodynamic processes influencing sediment movement, but further detailed analysis is needed to understand the full picture.

CONCLUSIONS

A 15-month long particle tracer study was conducted to map sediment pathways in the nearshore region of South Padre Island (SPI), Texas. The objective was to better understand the dynamics associated with unconfined placement of beneficial-use dredged material placed in a submerged feeder berm. In addition, the viability of such a placement option to supply the SPI beach with sediment was assessed. The analysis of collected field samples consisted of counting fluorescent ferrimagnetic tracer particles in the laboratory. A total of 950 surface-sediment grab samples from nine sampling campaigns plus base-line samples collected from around the feeder-berm area and on the dry beach were analyzed. The results showed that the highest concentration of tracer particles in all campaigns remained at the location of the initial tracer release. This indicates that the time scale may be on the order of years rather than months to fully redistribute sediment placed at the feeder berm under the given hydrodynamic conditions.

Outside of the feeder-berm area, tracer counts indicated sediment movement primarily toward the south and onshore, but with temporal and spatial variability hinting at the complexity of prevailing hydrodynamics in that area. Offshore loss of sediment from the feeder berm was not apparent from the tracer results. A small number of tracer particles were observed on the dry beach north and south of the feeder berm at times throughout the study period. These results indicate that a portion of the placed sediment can move to the dry beach and potentially help mitigate shoreline erosion, although the actual tracer particle numbers recorded near the shoreline remained low throughout.

In addition, results of this study indicate that an appreciable amount of material moved onshore from the nearshore berm to within the closure depth, and therefore is capable of nourishing the beach. Ideally, sediment sampling for tracer content would be conducted for as long as is feasible after initial deployment to obtain the longest possible time series of tracer behavior. In practice, the length of the sampling period is limited by available project funding and also by the stability of the tracer grains under the prevailing hydrodynamic conditions at the site. In summary, the results of this tracer and data collection effort support the case that dredged material placed in a nearshore berm at this location will eventually be incorporated into the active beach profile as a result of background and episodic coastal processes. The results of this study indicate that placement of sediment material in a nearshore berm may be a useful, cost effective alternative to direct placement of sediment material on the beach when direct placement is not feasible because of funding or seasonality constraints.

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APPENDIX

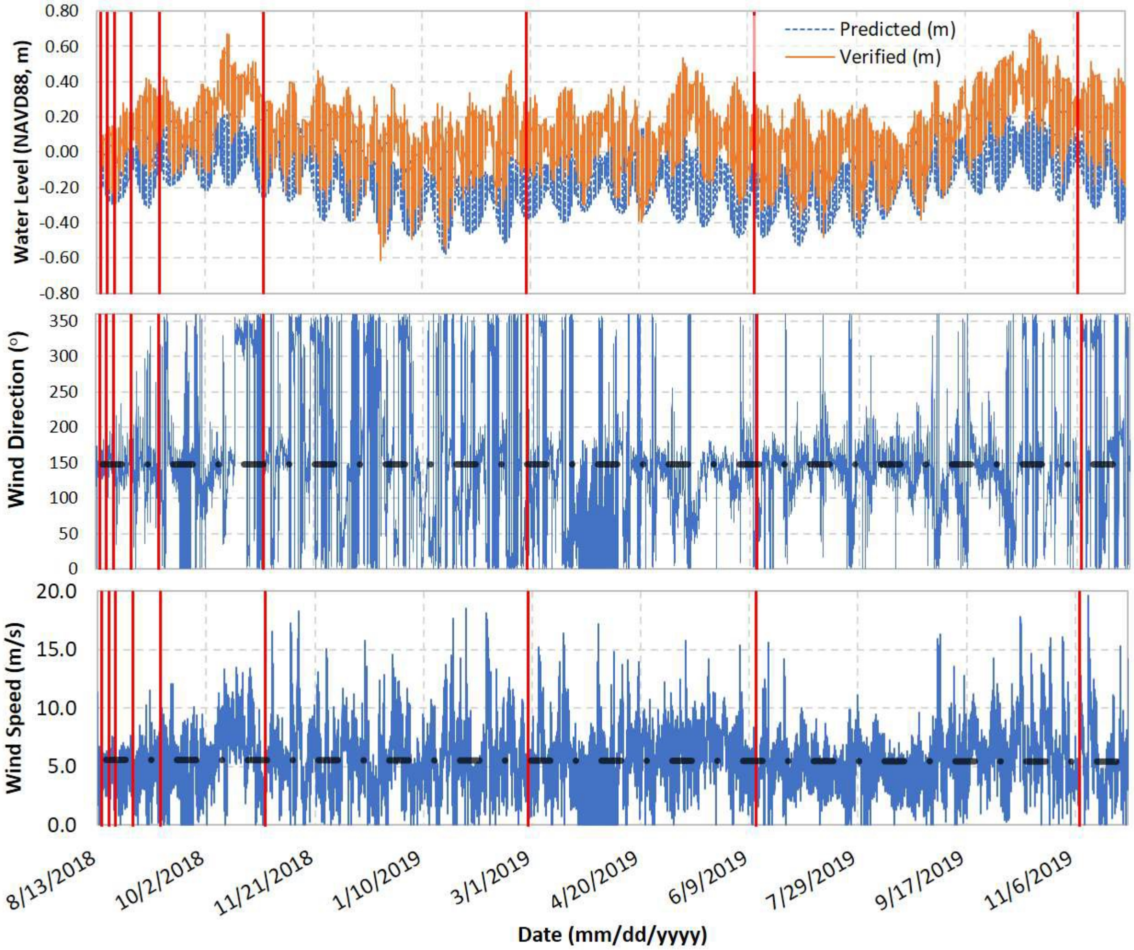

Figure A1. Water level and wind velocity near the study area. The time series of hourly data were obtained from National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) Station # 8779749 (NOAA 2020). The location of the station is shown in Fig. 1. Sediment- sampling campaigns are indicated by red vertical lines. Wind direction indicates the angle from which wind was approaching relative to true north in a clockwise rotation. Dominant direction (152°) and average wind speed (6.0 m/s or 19.7 ft/s) over the duration of the study are indicated by dashed-dotted lines in the middle and bottom panel, respectively.

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