MODAL GRAIN SIZE EVOLUTION AS IT RELATES TO THE DREDGING AND PLACEMENT PROCESS – GALVESTON ISLAND, TEXAS

Coraggio Maglio[1], Himangshu S. Das[1] and Frederick L. Fenner[1]

During the fall and winter of 2015, a beneficial-use of dredged material project taking material from the Galveston Entrance Channel and placing it on a severely eroded beach of Galveston Island was conducted. This material was estimated to have 38% fines. This operation was conducted again in the fall of 2019 and monitored for estimation of the loss of fines, changes in compaction and color from the dredging source to the beach. The local community and state funded the incremental cost at approximately $8 a cubic yard in 2015, and $10.5 a cubic yard in 2019 to have this material pumped to the beach. The projects were closely monitored by the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) and the USACE Galveston District. The data from this placement project was used to calculate and better understand the loss of fines during the dredging and placement process as well as aid in the generation of an empirical formula to estimate the loss of fine sediments during dredging and beach placement. This formula takes into account: losses due to dredging equipment operations, slope of the effluent return channel at the beach, sediment settling velocity, and sorting parameter.

Keywords: beneficial use; dredging process; fines loss; fate of fines; beach nourishment; beach placement

INTRODUCTION

The scarcity of quality sediments for beach placement projects has become a challenge in United States of America and internationally. This precious sand material is frequently utilized in beach nourishment and infrastructure projects. The desire of local stakeholders to maintain the aesthetics and the collective memory of their optimum beach state combined with tightening environmental regulations, has led to increased nourishment cost and in some locations compatible sediment scarcity (Berkowitz et. al 2018). This has led to a situation where in many parts of the nation beach nourishment is approaching the tipping point of no longer being an economically sustainable solution if the benefit to cost ratio alone is considered. However, cost increases are not entirely driven by market factors or scientific principles guiding policy, therefore a new approach is necessary that relates all of these drivers and influences through scientific research that guides decision makers to an overall less impactful and sustainable approach.

Coastal areas are plagued with environmental and anthropogenic challenges. Often infrastructure development and the operations and maintenance associated with those structures disrupts natural sedimentary depositional environments. This, coupled with marine transgression and in some areas coastal subsidence, has yielded shorelines that experience high rates of erosion as a result. These challenges must be met by developing new engineering solutions and advancing existing practices to achieve a balance within the confines of legal restrictions and environmental guidance.
One of the most common practices that is employed to achieve this balance is beach re-nourishment through the beneficial use of dredged material. The U.S. Army Corps defines beneficial use as: all productive and positive uses of dredged material. Beach nourishment is not always a beneficial use of dredge material. For example, sediment compatibility requirements force engineers to source material from many miles offshore or from upland sources due to restrictions on the placement of sediment codified in state statutes. The statutes give guidelines for both grain size and color for sediment placed on their beaches.

In the State of Florida, the Department of Environmental Protection issues water quality permits for beach nourishment projects based on in-situ pre dredge boring data, “Florida Sand Rule” (62B-41.007 (2) (j), F.A.C.). This practice is problematic because the boring data is unrepresentative of the actual sediment that ultimately ends up being placed on the beach in terms of compatibility. Throughout the dredging process the average sediment size not only coarsens but, in some cases, lightens in color. In the case of the Houston-Galveston entrance channel sediment, the color change is a direct effect of the coarsening due to the overall reduction of fines (silts and clays). For this article fines are defined as any sediment passing through #230 sieve/62 µm or 4Φ. Due to the application of statutes conservative approach of applying compatibility at the borrow area, sediment that would be compatible once dredged and placed on a beach is prohibited. This is due to the fact that very few

[1] U.S. Army Corps of Engineers Galveston District, 2000 Fort Point RD, Galveston, TX 77550, U.S.A. Email: Coraggio.Maglio@usace.army.mil

datasets and scholarly articles exist that clearly demonstrate the change that occurred to sediment throughout the dredging and placement processes.

The State of Texas has no such codified restriction thus allowing for more frequent beneficial use projects along the Texas Gulf Coast as local funding allows. This portion of coastline was renamed Babe's Beach after former state Senator A.R. "Babe" Schwartz who was an early leader in Texas helping protect the public's right to access the beach, and he was a co-sponsor, advocate, and supporter of the Texas Open Beach Act passed into law in 1959. The placed sediment was obtained from the periodic maintenance dredging of the Galveston Ship Channel between Bolivar Peninsula and Galveston Island, in the fall of 2015 and winter of 2016.

COLLECTION AND LABORATORY METHODS

Sampling

During the course of this project approximately 400 individual physical samples were taken from 6 different areas associated with the dredging and placement process. These areas included the dredge inflow to the hopper, dredge hopper overflow, beach discharge, beach return water, newly formed berm, and post placement fill. Samples of native beach sediment were also collected for comparison.

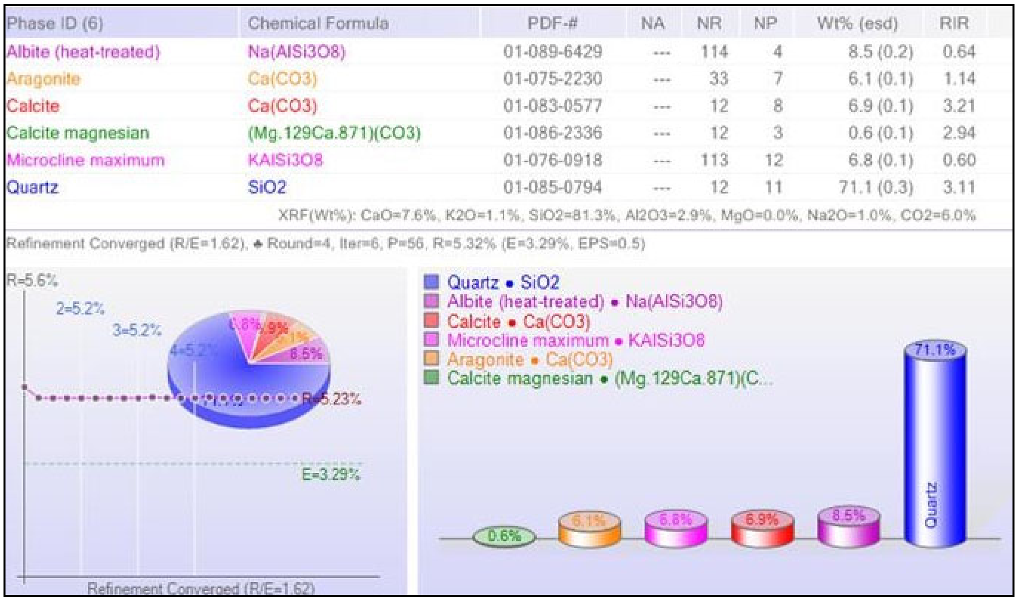
Table 1. Dredging process sampling grain size and standard deviation.

Sample Area	Number of Samples	Average Grain Size	Standard Deviation
In-Flow	31	243.2	299.4
Overflow	38	236.8	157.2
Discharge	116	335	444.9
Return	110	34.4	67.7
Berm	76	460.4	533.2
Placed Beach	30	213.7	180.4
Native Beach	2	104.8	9.9

Figure 1. Beach grab sampling and compaction testing using a cone penetrometer (left), grab samples of native beach material (right) at the dune, berm and swash, respectively.

Surface push core grab samples were taken from 3 to 6 inches below the surface. Post collection the samples were sent to ERDC for processing by oven drying followed by disaggregating using an ultra-sonic shaker table. Post processing, the samples were either sieved or analyzed using a laser diffraction particle size analyzer or a combination of both techniques as deemed appropriate.

A small subset of the native beach samples were further analyzed using a mass spectrometer for mineralogical data, see Figure 2. Over 20% of the native beach material was determined to be composed of weathered shell or other carbonate sources, with the bulk of the material being fine quartz sand.



Phase ID (6)	Chemical Formula	PDF-#	NA	NR	NP	Wt% (esd)	RIR
Albite (heat-treated)	Na(AlSi3O8)	01-089-6429	---	114	4	8.5 (0.2)	0.64
Aragonite	Ca(CO3)	01-075-2230	---	33	7	6.1 (0.1)	1.14
Calcite	Ca(CO3)	01-083-0577	---	12	8	6.9 (0.1)	3.21
Calcite magnesian	(Mg.129Ca.871)(CO3)	01-086-2336	---	12	3	0.6 (0.1)	2.94
Microcline maximum	KAlSi3O8	01-076-0918	---	113	12	6.8 (0.1)	0.60
Quartz	SiO2	01-085-0794	---	12	11	71.1 (0.3)	3.11

XRF(Wt%): CaO=7.6%, K2O=1.1%, SiO2=81.3%, Al2O3=2.9%, MgO=0.0%, Na2O=1.0%, CO2=6.0%

Refinement Converged (R/E=1.62), ♣ Round=4, Iter=6, P=56, R=5.32% (E=3.29%, EPS=0.5)

Figure 2. Mass Spectrometer mineralogical data for a Galveston native beach sample (Berkowitz et.al 2018).

The slurry pumped into the hopper dredge Terrapin Island was sampled using a 1000 ml wide mouth jar attached to a pole rapidly dipped into the dredged inflow slurry approximately every 3 minutes. This process was conducted over two dredge filling operations.

Figure 3. Inflow into the dredge's hopper.

The dredge inflow sampling is a very difficult operation given the multiple inflow ports into the hopper, presence of strainer baskets to capture large debris, and high velocity of the flow. A hinged weather-vain jar sampling device was ultimately successful at capturing reasonably representative inflow samples as shown in Figure 4.

Figure 4. Dredge hopper inflow samples for an entire load, left bottle initial sample once dredging commenced, right bottle sample taken 66 minutes later.

The dredges overflow (decanting) was a similarly challenging location to collect representative samples. The height of the discharge over the adjustable weirs was continually in flux as well as the elevation of the weirs themselves. An ISCO diastolic sampling drum pump system was utilized to take samples every three minutes from the dredges skimming weir as shown in Figure 5.

Figure 5. Dredge hopper overflow sampling.

This overflow sampling operation was conducted over the same two dredge cycles as the inflow sampling. The relative loss of fine material through the dredging cycle due to overflow is readily apparent in these samples. As the dredge's hopper filled with sand, reducing settling time combined with increased mixing velocities, higher relative losses of finer material occured as shown in Figure 6.

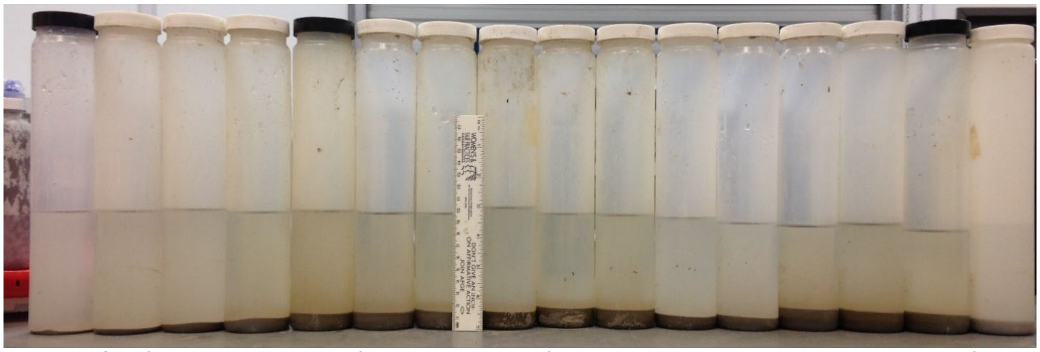


Figure 6. Overflow sample bottles of discrete samples from the dredge hoppers skimming weir, left bottle initial sample once overflow commenced, right bottle sample taken 48 minutes later.

The sampling at the beach was conducted for each and every load of the placement operation. Samples were collected of the slurry discharge directly out of the pipe, the return water right before it went into the swash zone, and a grab sample of the newly created beach berm post-pumpout. A double barrel 250 ml wide mouth jar sampler was utilized to capture these samples as shown in Figure 7.

Figure 7. Discharge sampling at beach directly at the end of pipeline.

Sampling of an entire pumpout cycle also was conducted on an approximately five minute interval. This included both this discharge slurry at the beach and periodic return water sampling.

Figure 8. Pumpout slurry discharge samples collected at the beach, left two bottles are the initial sample pair, right two bottle sample taken 38 minutes later.

Sediment Data

The collected samples were analyzed primarily for grain size, however samples were also analyzed for Munsell Color. The Munsell Color measurement were collected using triplicate measurements from three areas on each moist sand sample using a digital colorimeter CR-400, Konica Minolta. The product of the lab tests yielded a sample weight, weight and percentage retained per sieve. The grain size data from the laser diffraction analyzer was presented in form of percentage of the sample per grain size. The grain size interval increased from 0.004µm intervals to 2000.00µm.

Volumetric Data

Hydrographic surveys and beach surveys were performed prior to, during, and immediately post the project for quantity determinations. The dredging contractor Great Lakes Dredge and Dock provided volumetric ullage hopper load estimates using their displacement sensors. Pre and post surveys to wading depth were used to measure material retained on the beach. This shows that significant changes/losses occur during the dredging and placement process.

Table 2. Sediment volumes removed from the channel (in-situ), estimated in the hopper, and surveyed at the beach (Maglio, et. al 2019).

	Cubic Yards (cy)	% of total
Dredged in Channel	642,279	100%
Pumped to Beach	537,185	83.60%
Surveyed on Beach	357,000	55.60%

RESULTS

Sediment data

The grain size data of solids throughout the dredging and placement process were used to compute average grain size (D50) through each step in the dredging and placement cycle. The average inflow grain size was 240.03µm. Once the dredged slurry enters the hopper the finer sediment remains in suspension, thus is more likely to be lost with the overflow water from the hopper. This proves to be the case in our study with an overflow average of 236.817µm. Once the sediment is placed onto the beach and decanted further reduction of fines is observed, with a return/runoff value of 34.442 µm which ends up leaving a berm with an average grain size of 460.438µm. What was observed is an overall change in grain size average from 240.03 to 460.44 µm, an increase of 220.41µm. The coursing of the dredged material is very apparent in Figure 9 below. The significantly courser final berm than the native samples is likely a result of shell hash in the upper layers of the newly placed berm versus the native sample being mostly composed of aeolian transported sediment which naturally favors finer sediment.

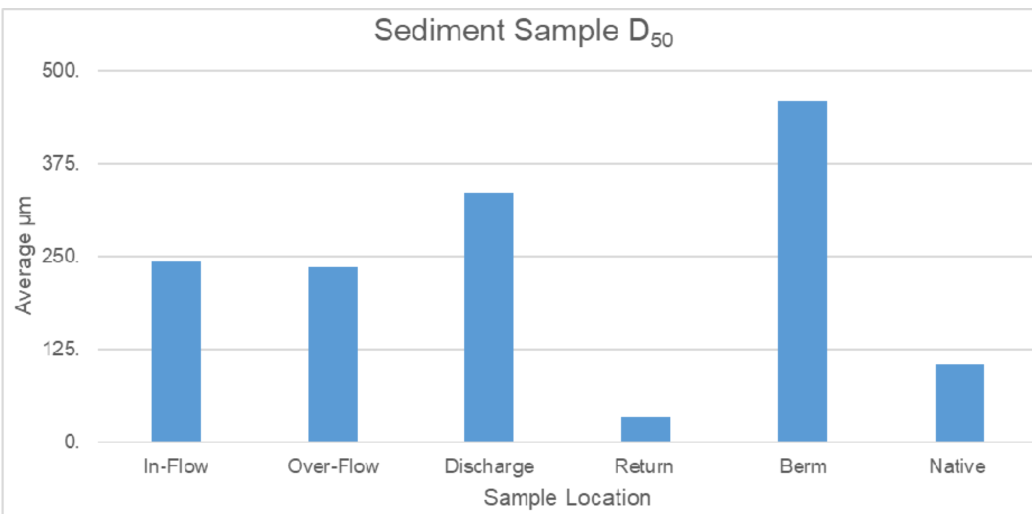


Figure 9. Median Diameter of sediment at each stage in the dredging process.

The inflow data showed that across all samples collected 46.3% of the inflow sediment was larger than 126.0µm. Volumetrically 297,420.8 cubic yards of material that passed through the intake was 126.0µm or larger with a total of 642,279.0 cubic yards dredged.

The overflow hopper data showed an average across all samples collected that 34.8% of the overflow sediment measured 113.0µm. However, the overflow hopper averaged 236.85µm overall. None of this sediment was placed on the beach as it was decanted overboard the hopper dredge.

The beach discharge pipe samples showed an average grain size of 334.98µm with the mode being 8.4% at 200µm, which accounts for 45,412.40 cubic yards of sediment. Three other slightly less prominent peak sizes were also seen at 3.4%, 3.2%, and 3.0% with respective grain sizes of 1000µm, 1410µm, and 2000µm. A multi peak curve was also observed in the berm and post-fill data, but absent from the return data, and is assumed to be retained in the berm fill.

The return samples showed an average grain size of 34.44µm with a dominant mode of 178µm at 8.35% which accounts for 23,168.96 cubic yards

Berm samples had a median grain size of 460.44µm with the most commonly occurring grain size measuring 200.0µm. This 200.00µm size accounted for 12.1% (42,974.09 cubic yards), of placed material. The post fill data yielded a dominant modal curve of 12.3% at 212.0µm which would account for 43,221.56 cubic yards of placed material. The three other peaks shown Figure 10, aligned with the discharge curve exactly at 1000µm, 1410 µm, and 2000µm (we believe this to be shell hash) with the difference being the percentages which were 2.04%, 1.98%, and 1.59% respectively.

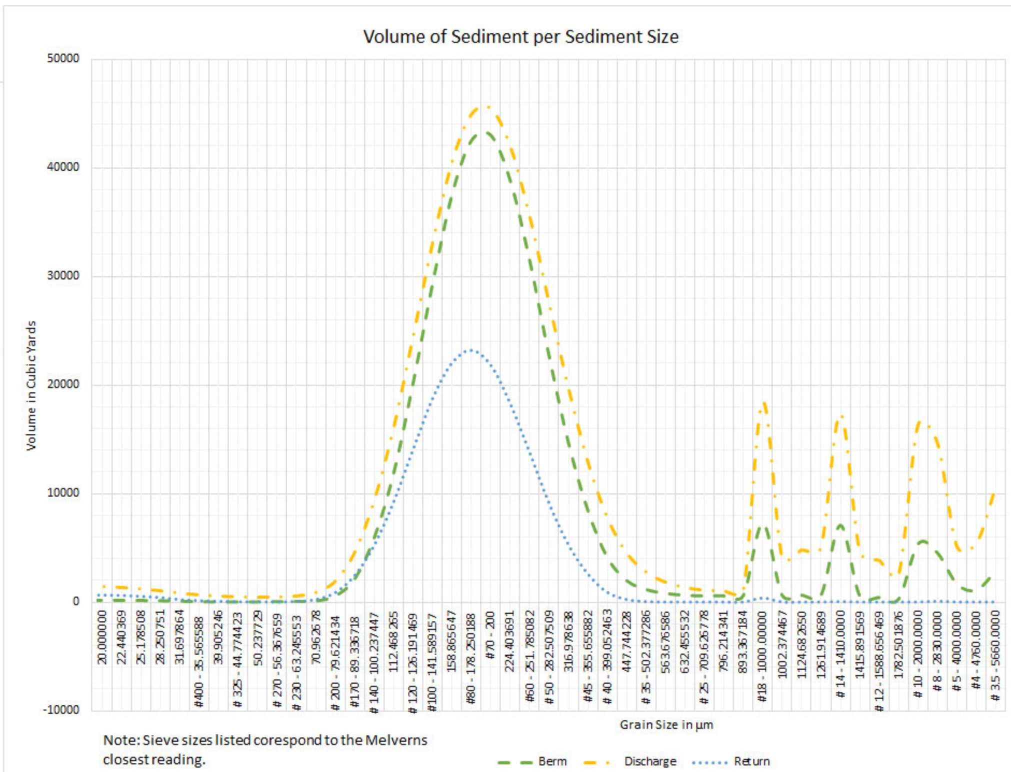


Figure 10. Volume of sediment at beach discharge, return water, and berm based on grain size.

Munsell Color Data

In addition to grain size analysis Munsell Color analysis was performed throughout the dredging and placement process. These samples were collected at the pre-fill (native): swash, berm, and dune; dredge inflow, dredge overflow; as well as the post-fill: swash, berm, and dune. The Munsell Color measurement were collected using triplicate measurements from three areas on each moist sand sample using a digital colorimeter CR-400, Konica Minolta. This method was chosen over the traditional and less accurate technique of visual estimation by the human eye using a Munsell Color chart. The results showed a lightening effect throughout the dredging and placement process in hue, value, and chroma; lower values correlate to darker sediment. Over sixty samples were analyzed, and the results are shown in Table 3. The results show that the sediment lightened in color, which was expected given the finer material is significantly darker in location then the pure quartz sand.

Table 3. Munsell Color of collected samples.

	Hue	Value	Chroma
Inflow Grab Sample	2.25	3.28	1.52
Overflow Grab Sample	2.46	3.02	1.59

Pre-Fill Berm/Swash/Dune	17.61	3.96	1.63
Post Fill Berm/Swash/Dune	5.18	4.15	1.77
Total Change	2.93	0.87	0.25

Cone Penetrometer

Prior to dredging pre-fill (native) cone penetrometer data was collected with a standard Humboldt Mfg. Co.© cone penetrometer which collects results in Cone Penetrometer Units (CPU). Post-fill a discrete area that had been previously filled but subjected to overwash and reworking in the swash zone was also sampled. This area that was subject to beach sorting processes was sampled to provide insight into how the newly placed sediment would evolve due to typical coastal processes. What was observed was that the comparison in beach compaction between and pre and post samples was overall very similar in magnitude. In areas that re-worked by coastal processes the compaction values were also very similar, as shown in Table 4 (Maglio, et. al, 2019).

Table 4. Cone Penetrometer Pre-Fill (Native Beach), Post-Fill, and Swash Reworked.

	Pre-fill		Post-fill			Swash Reworked		
Depth (in)	0-6”	6-12”	0-6”	6-12”	12-18”	0-6”	6-12”	12-18”
Min (PSI)	350	400	100	400	450	400	550	600
Max (PSI)	600	650	600	750	700	450	600	700
Avg (PSI)	475	525	386.11	538.46	590	425	575	650
Median	475	525	350	575	575	425	575	650
# of Samples	6	6	21	23	9	2	2	2
Refusals	0	2	3	5	4	0	0	0
% Refusals	0	0.33	0.14	0.22	0.44	0	0	0

Galveston Nourishment 2017

In 2017 the Galveston Park Board nourished an adjacent section of the beach from 12th to 61st street that eroded and need of sediment. The sediment borrow area was within the nearest inlet to the project area. The largest difference between the 2015 and 2017 projects was in placement methodology. During the 2017 event the dredging and placement methodology employed made effort to retain sediment, via longitudinal and cutoff dikes as well as elevated culverts, and reduce the amount dredged sediment loss. As a result, there was a large increase of fines post-placement in contrast to the pre-placement native sediment. Another result of the active retention efforts was a reduced sediment plume during placement. However, that sediment winnowed fines over a longer period of time and especially during storm events, when the material was being re-worked due to high tides or waves. The 2017 Galveston project offers a great contrast to the 2015 project and demonstrates that by changing dredging techniques you can tailor your modal grain size to your needs based on the placement methodology.

Table 5. Galveston Seawall Beach Nourishment 2017.

Material Source	D50 (mm)	% Fines (200 Sieve)
Native Beach Sand	0.14*	2.9*
South Jetty Borrow Area	0.16*	9.2*
Post-Fill Samples	0.15	8.6

* data from HDR Design Memo dated 30 Nov 2015

DISCUSSION

Clay and silt in this location compose the darker sediment in this area whereas quartz makes up the lighter sediment. In the case of the 2015 Galveston beneficial use project sediment lightening can be attributed to coarsening modality. As the fines are washed out in the runoff, overflow hopper, or not entrained at the dredge head, the sediment lightens. This case may not be unique to this location, but it is a byproduct of our sediment’s mineralogical constituents. The sediment showed a mineralogical make up of 71.1% Si02 (unstained Quartz) and a total of 13.0% Ca(CO3) Calcite and Aragonite combined total. Mineralogical and grain size analysis combined with Munsell color measurements by sieve, can lead to initial determination of, if and how, significantly dredged and placed material will change through the process. In this case sediment lightening can be attributed to coarsening modality. The majority of the fines are washed out in the runoff, overflow hopper, or not entrained at the dredge head, thus the sediment lightens. This situation may not be unique to this location, but it is a byproduct of our sediment's mineralogical constituents

The grain size beach placement data in Figure 10, shows a multi peak curve. In an attempt to better understand this odd modality, one berm sample that had been already analyzed and recorded was inspected under a microscope. What was found was the #14 sieve had approximately 20% carbonate material. The remaining 80% were quartz aggregates and flocculated clay. This continued through the #35 sieve. At the #35 sieve the percentage of carbonate material increased to approximately 25% and only aggregates of very fine quartz sand and flocculated clay remained. The remainder was made up of quartz sand. At the #120 sieve all flocculated clay, aggregates, and carbonate material had been retained by larger subsequent sieves and only fine grained quartz sand remained. Clay and silt in this location make up the darker sediment whereas quartz makes up the lighter sediment. As the sediment proceeded through the sieve stack starting at the #60 sieve an obvious color lightening was noticed. This lighter color sediment continued through the sieve stack until the #230 sieve. All of the sediment in the pan was noticeably darker.

While the failure to completely disaggregate and de-flocculate the sediment may have altered the sediment analysis to show a slightly coarser berm average, the real detriment to the data is in the overflow and inflow data. The inflow and overflow data is skewed much coarser because of the relatively higher percentage of flocculated fines in relation to the overall sediment, due to where the samples were collected in relation to the overall process. The inflow and overflow samples were taken early in the dredging process on the dredge. Even though the inflow and overflow data shows a larger average grain size than what is in-situ we can observe a very significant coursing trend throughout the process. This is accompanied in our case with a lightening trend as well due to the mineralogical make up of our dredge sediment.

CONCLUSION

In-situ sediment samples that are typically collected for beach compatibility analysis are often processed in their natural state as a conservative approach. However, the scientific body of evidence is growing and the prediction of changes to dredged material can judiciously be approximated. Methods and techniques to estimate these changes can be found in the following references: Berkowitz et. al 2019, Coor et. al 2019, Maglio et. al 2019, and Smith et. al 2019). In-lue of taking a conservative approach of assuming no change has occurred, we can with the data and analyses outlined in these references, estimate changes likely to occur to the dredged and placed sediment in terms of color and grain size.

In-situ samples have to be taken for analysis, but instead of looking at them and taking them at face value in terms of color and grain size they need to be looked at using a mass spectrometer to gain a better understanding of the sediments mineral constituents. This would give a better understanding of how the sediment's overall color will change through the dredging and placement process. Post-placement grain size should be estimated in terms of in-situ grain size while taking into account such variables as beach slope, mineralogy, coastal processes, seasonality, placement procedures, and dredging method, to be able to better understand how the overall grain size distribution of the in-situ sediment will coarsen through the dredging and placement process.

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