Empirical Formula to Estimate Borrow Sediments Ultimate Beach Capability through Case Studies, in Florida and Texas

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Abstract: Environmental and anthropogenic sources often negatively impact coastal areas and commonly sandy shorelines. These challenges have to be met by developing new engineering solutions and advancing existing practices to achieve a balance within the confines of law and environmental practice. One of the most common approaches that is employed to achieve this balance is beach nourishment. However, beach quality sediment is a finite resource and in many regions of the world is becoming extremely scarce. The composition of sediment is altered during the dredging and beach placement process, typically improving in sediment beach compatibility. Since there is not an accepted methodology to predict these changes to the sediment, regulators typically take the conservative approach of regulating nourishment and beneficial use projects sediment based on the borrow source characteristics. This paper utilized data collected at various projects in Florida and Texas to generate an empirical formula to estimate the loss of fine sediments during dredging and ultimately through the beach placement process. The formula estimates losses due to dredging equipment operations, slope of the effluent return channel at the beach, sediment settling velocity, and sorting parameter.

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.

In an effort to understand the physical processes, the U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC) monitored several projects to determine how sediment changes as it undergoes dredging and placement on beaches. The goal of this research was to determine how grain size characteristics, color, and compaction are modified from in situ to ultimate placement as a new beach (Maglio et al. 2015a).

Case Study I – Egmont Key, 2014

During fall and winter of 2014-2015, a project was constructed in Egmont Key, FL and closely monitored to measure and quantify changes to the placed sediment characteristics. The sediment was maintenance dredged material from the Tampa Bay Entrance Channel, with a hopper dredge and then pumped-out to the beach. The placement of dredged material was performed in two discrete areas using two completely distinct methods, see Figure 1. The northern region of the project was placed using traditional beach placement methodologies (slurry hydraulically pumped, with the bulk of material retained through longitudinal dikes and other sediment capture construction strategies). Near the center of the island dredged material was hydraulically pumped directly into the swash zone using a method termed "Cross Shore Swash Zone Placement" (slurry discharged into the active surf zone with no sediment retention techniques employed) (Maglio et al. 2015b).

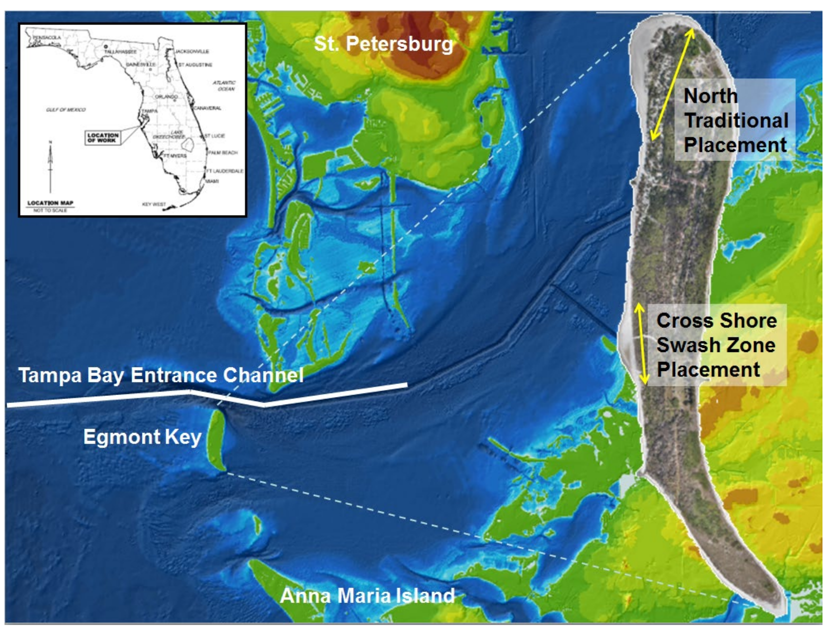

Figure 1. Location map of Egmont Key and placement areas (bathymetry image from, Tyler et al. 2007).

Over 200 samples were collected over the course of the project along various section of nourishment and at several phases and from these samples laboratory testing was conducted. The grain size results were compared to the native beach (pre-placement), during placement, and within 72 hours post placement. The results show that the in-situ material (borrow area sediment) had approximately 21% fines (material passing the 230 sieve) and the post placement material had approximately 0.5% fines, see table 1.

Table 1. Grain Size Analysis Sampling at Egmont Key*

	# of Samples	**Avg. % by wt. passing 0.063 mm**
Pre-construction berm (native beach)	6	0.03
In situ channel composite	80	20.7
Channel material placed in the Traditional placement area	45	20*
Channel material placed in the CSSZ placement area	35	24*
Post-construction beach	21	0.51**
Post-construction beach in the Traditional placement area	14	0.52**
Post-construction beach in the CSSZ placement area	7	0.49**
* Based on Dredged Quality Management (DQM) and in-situ core boring data, i.e. recoded dredge location correlated to in-channel core boring collection location		

*Average in situ in channel dredged material, analytically segmented geospatially into dredged material that went to the traditional placement versus CSSZ placement, native beach, post-construction beach placement material also separated into traditional placement versus Cross Shore Swash Zone placement.

When paying for beneficial use dredging projects the channel dredging location is surveyed to determine the amount removed. In this project since a hopper dredge and pumpout operation was utilized the hopper displacement per load minus ponding water is the calculation used to estimate the volume of material pumped to the beach. During beach placement projects the dry beach to wading depth is typically surveyed, however on this project the volume to the toe of fill was surveyed. Table 2 demonstrates the approximate quantity of material lost in the dredging process, and then the placement process as material is winnowed, additionally erosion of this newly placed material happens at a higher rate until a new equilibrium is attained.

Table 2. Egmont Key, FL Volume of Dredged Material from Channel*

Traditional (North) Placement Area:		
	Cubic Yards (cy)	% of Total
Dredged in Channel	500,037	100.0%
Pumped to Beach	319,712	63.9%
Surveyed on Beach	268,000	53.6%
Cross Shore Swash Zone Placement Area:		
	Cubic Yards (cy)	% of total
Dredged in Channel	180,512	100.0%
Pumped to Beach	107,225	59.4%
Surveyed on Beach	80,500	44.6%

*Pumped to the beach from the dredges hopper, surveyed at the beach post-placement to approximately 10 feet depth and the associated percentages of placed material.

This brings up the question where did the fines end up? Fortuitously the University of South Florida was conducting research at the same time on Egmont key and they were collecting beach profile surveys along with grab samples to an average depth of approximately 10 feet. Their data shows that the fines winnowing from the beach fill during placement initially and deposited at the toe of the beach profile, in relatively high concentrations, 34.3% and 72.3%. Then they were removed from the vicinity of the surveyed beach profile during subsequent high-energy wind and wave events.

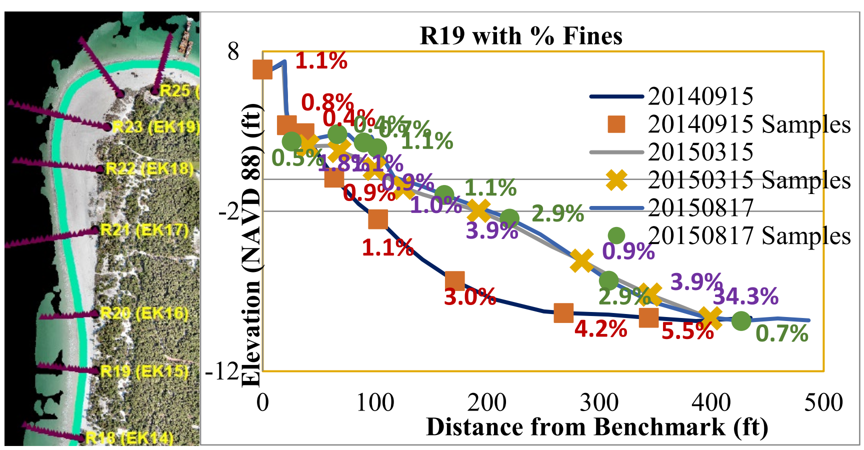

Figure 2. Beach profile line R-19 and associated fines content from grab samples from Traditional Beach Placement Area on Egmont Key. Native material September 2014, immediately post placement March 2015, five months post placement August 2015 (Tyler, 2016).

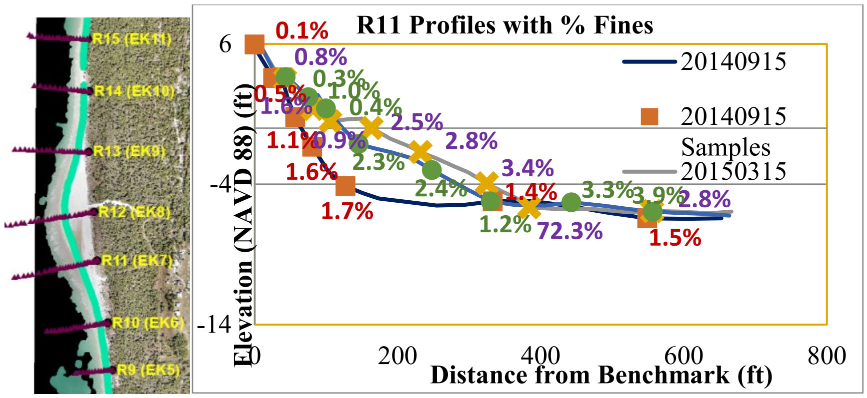

Figure 3. Profile line R-11 along the CSSZ placement area on Egmont Key (Tyler, 2016).

These two profiles (Figure 2 and 3) each from separate placement methodologies demonstrate that the fine material migrated to the beach fill toe and was likely either buried or mobilized from the sediment sampling area by subsequent high energy events in the more energetic portion of the year; the winter months in this area. The sediment transport in the central west gulf coastal region during the winter is strongly south due to periodic frontal passages.

Prior to grab sample collection, cone penetrometer measurements were conducted during both pre-and post-placement sampling events. The results of this data collection is show below in (Tables 3 and 4) for both pre and post-placement, the values are in Cone Penetrometer Test units (CPT). It is standard for the beach monitoring project to assume that the CPT units are equivalent to pound per square inch (psi). The results between both pre and post were very similar however there was an increase in refusals (unable to penetrate). This increase was attributed to the inter-bedding of shell hash layers within newly placed hydraulic fill which prohibited penetration of the instrument. This was confirmed via excavation at each refusal sample location.

Table 3. Cone penetrometer pre-construction sampling statistics.

Depth (in)	0"-6"	6"-12"	12"-16"
Min (psi)	100	100	198
Max (psi)	580	700	617
Avg (psi)	293	406	457
Median (psi)	295	431	515
# samples	19	18	13
Refusals	0	1	5
% Refusal	0%	6%	38%

Table 4. Cone penetrometer post-placement sampling statistics.

Depth (in)	0"-6"	6"-12"	12"-16"
Min (psi)	50	125	200
Max (psi)	600	700	600
Avg (psi)	328	482	436
Median (psi)	300	500	500
# samples	21	17	12
Refusals	4	5	5
% Refusal	19%	29%	42%

The color of the sediment was also monitored as it changed from in-situ to post-placement. The same sediment samples used for grain size were analyzed using the standard methodology for comparing the sediment to a Munsell color chart. All 61 subsequent samples were analyzed using a Konica Minolta CR-400 digital colorimeter, see table 5. Munsell color is used in the state of Florida to determine acceptable lightness of beach placement material. The usual accepted Munsell color value in Florida is anything greater than 5, and anything below the native beach wet Munsell color value is normally rejected for direct beach placement. The dredged material was significantly darker than is typically allowed on the beaches of Florida having a Munsell color value of 4.36. This placement material was allowed regardless of the color due to the severe erosion occurring at Egmont Key however, ultimately Munsell color value at both placement areas reached five or greater during post placement sampling, which is in the acceptable range in Florida.

Table 5. Munsell Color Values Pre and Post-placement; with Relative Greyscale for Clarity.

	# of Samples	Average Munsell Value	
Pre-construction berm	13	5.9†	
In situ channel	80	4.36*	
Post-construction composite berm	24	5.3†	
Post-construction berm in the Traditional placement area	16	5.0†	
Post-construction berm in the CSSZ placement area	8	5.9†	
* Munsell measurements taken using standard visual Munsell color chart. † Triplicate Munsell measurements of hue, value, and chroma were collected from three areas on each moist sand sample using a digital colorimeter (CR-400, Konica Minolta, Osaka, Japan).			

Case Study II - Galveston Island Beneficial Use, 2015

The ERDC closely monitored another project conducted in fall of 2015 which was a maintenance dredging project in the Galveston entrance channel. The material was also being beneficially placed on the beach using a hopper dredge pump out operation, even though the in-situ material contained 38% fines. The material that was pumped to the beach placement area was from within the entrance channel jetties and the offshore portion of the dredging project was placed in the offshore dredged material disposal site (ODMDS) No. 1, see figure 4.

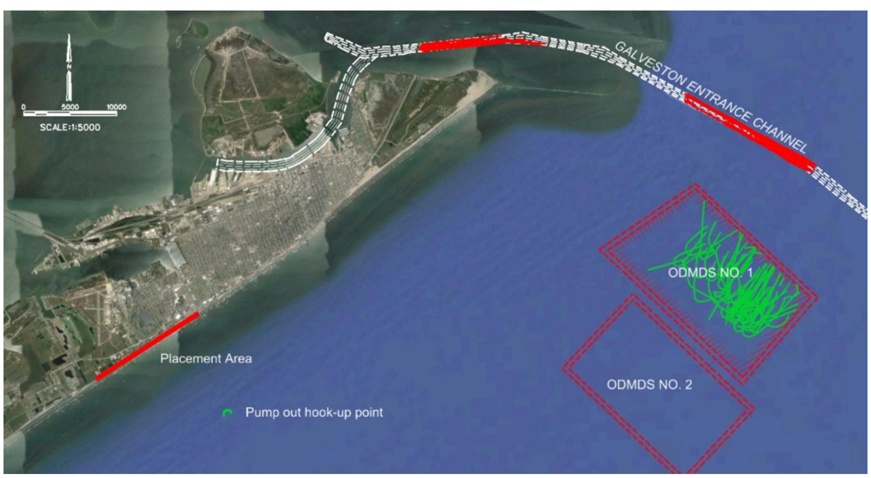

Fig. 4. Galveston Entrance channel dredging 2015 and placement locations. DQM dredging location data is shown in red in the channel, and green shows placement and pump out locations.

Ultimately the beach placement material contained slightly over 1% fines post-placement. This material was placed with minimal containment of the fill thus the fines were allowed to winnow out rapidly during the placement operation. The material was placed along a section of shoreline that had been chronically eroded for decades and only had beach in front of the Galveston Seawall at low tide. The volume of material dredged during this project and placed on the beach is shown below in Table 6.

Table 6. Galveston, TX Volumes Dredged from Channel Pumped to the Beach and Surveyed on the Beach to Wading Depth.

Volumes Galveston 2015:		
	Cubic Yards (cy)	% of Total
Dredged in Channel	642,279	100.0%
Pumped to Beach	537,185	83.6%
Surveyed on Beach	357,000	55.6%

This demonstrates the approximate losses of material through the dredging and placement process and the quantity of material contained out to wading depth, approximately 3 feet, as this is as far as the beach surveys extended, once the material is pumped to the beach.

During this project, cone penetrometer data was also collected both pre and post-placement and in the fillet areas where the material had been reworked and deposited on the beach, see table 7. At this project location since the native sediment is predominately very fine sand the pre-placement samples were more compact than both the post-placement and reworked sediment.

Table 7. Cone penetrometer pre, post-placement, and reworked data.

	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%	33%	14%	22%	44%	0%	0%	0%

The changes in Munsell color were also measured using the colorimeter at each stage of the dredging and placement process. Samples from the inflow into the hopper dredge were analyzed along with material overflowing out of the top of the hopper dredge as well as native beach sediment and post-fill. The results show that at each stage and the dredging a placement process the retained materials color lightened, and darker sediments were decanted (i.e. lost while in suspension), see Table 8.

Table 8. Galveston grab samples Munsell color value: inflow, overflow, native, and post-fill; with relative greyscale for clarity.

Munsell Color	**Value**
Inflow Grab Samples	3.28
Overflow Grab Samples	3.02
Pre-Fill Berm/Swash/Dune	3.96
Post-Fill Berm/Swash/Dune	4.15
Total Change	0.87

This significant lightening of color was a result of the mixed sediment material mineralogy that was being dredged. The fines were relatively dark as they were made up of primarily dark gray silts and clays. The bulk of the remaining material was fine unstained white silica sand. These samples were collected within several days post-placement with the exposed sediments removed, thus no bleaching has occurred.

Case Study III - Galveston Island Beach Nourishment, 2017

A subsequent beach nourishment project occurred on Galveston Island Texas in 2017. This was a more standard beach nourishment project where the material was mined from within the inlet of the Galveston Entrance channel, by a large cutter suction dredge and pumped directly to the beach. It was used to fill groin cells along the Galveston Seawall from 12th to 61st street the material was borrowed from the South Jetty Borrow Area, see figure 5.

Fig. 5. Galveston Island Beach Nourishment 2017 (HDR 2015).

The contractor employed traditional beach building methodologies to contain as much dredged material as possible, using multiple longitudinal dikes, spur dikes, and weirs to contain fill and minimize sediment losses. As a result of this construction methodology, far more fines were incorporated into the newly placed fill than the previous two case studies both of which in-situ sediment contained substantially more fines, see Table 9.

Table 9. Grain size composite sampling Galveston Texas 2017 native beach, borrow area, and post-fill samples.

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

This was a locally sponsored project funded by FEMA thus the USACE did not have a monitoring presence on this project.

Development of the Maglio-Das Empirical Formula

The above case studies demonstrate that sediment characteristics change during the dredging and placement process in a variety of ways and significant losses of sediment can occur during the dredging and placement process, greatly altering its ultimate gradation. This is due to a variety of reasons, such as: the type of material being dredged, the dredging process, the placement methodology, and quantifiable physical characteristics of the sediments (Barber et. al. 2012). The data from the above three case studies, and several other projects that were monitored over the years, were utilized to develop an empirical formula to better estimate borrow area sediment post-beach placement characteristics. This formula was developed with a few objectives in mind. It was envisioned that the formula be non-dimensional, that it be applicable to varied construction methodologies and not to be site specific. Dredging projects are highly variable in terms of the construction methodology and when trying to compare methodologies, the controlling factor in-terms of sediment change appears to be the number of times the material was slurried, as losses of finer and lighter particles occur due to economic load decanting and return water flows (Palermo et. al. 1990). When developing this formula a few key parameters appeared to control sediment changes: the number of times dredge material is slurried, the slope of the discharge return water channel on the beach (i.e. return water velocity), and the sediment grain size characteristics (i.e. fall velocity). The fall velocity of sediments are dependent on a variety of factors such as: specific gravity, particle size, shape factor, water salinity, and water temperature (Jianga et. al. 2015).

Parameterization of Particle Fall velocity

Sediment fall velocity plays an important role in redistribution of sediments in high energy environment such as the swash zone. Recognizing that particle fall velocity depends on many physical parameters such as, particle diameter, shape, and viscosity of ambient water, which opens an excellent avenue to parameterize through the non-dimensional particle Reynolds Number (Rep) adjusted using shape factor to represent fall velocity. Here, the Modified Julian equation (Julien 1995) has been used to extract the non-dimensional Particle Reynolds Number validated through USGS published chart. Figure 6 shows that the modified Julian equation using non dimensional Particle Reynolds Number matches fairly well with the USGS published fall velocity values under wide range of nominal diameter and various shape factors.

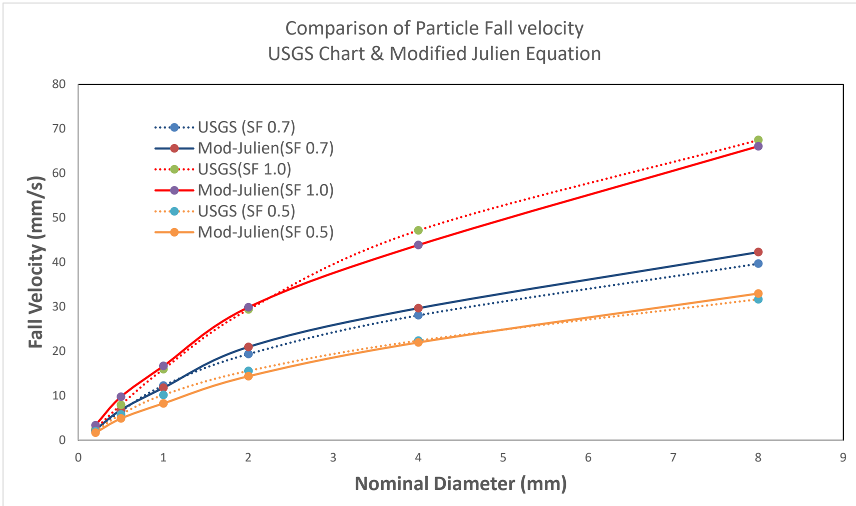

Fig. 6. Validation of Particle fall velocity using modified Julian equation and USGS estimates (USGS 1957).

The Reynolds number is defined as:

Reynolds No. = Rep * Z, for sphere, Z = 1

$$Rep = (1 + 0.222\frac{(S-1)gd3}{16\upsilon 2})^{0.5}-1$$

where S = Specific Gravity of sediment, υ = Kinematic viscosity of water (m^2/s), d = Nominal diameter (m), g = acceleration of gravity = 9.81 m/s^2, Z = Shape Factor Adjustment (Fitted) = [0.16 ln(d) +1.7] * SF, SF = Shape factor (0.3 to 1.0)

Here, particle fall velocity (w) is calculated as:

$$w = R_{ep} * Z * (\upsilon/d)$$

So, basically, non-dimensional modified particle Reynolds No (R_{ep}) is used as a surrogate for particle fall velocity in the developed equation on the assumption that smaller particles should remain in suspension longer when compared to large particles.

Finally, through trial and error, and by studying previous efforts on the subject, an empirical formula was ultimately developed, which is called the "Maglio-Das formula". With this empirical formula, the loss of dredged and beach placement sediment is calculated as:

$$\%\ Loss\ for\ each\ sieve = \sqrt{X}e^{(-10(2\sigma-1)\sqrt{RS})}$$

where X = No. of times the sediment is slurried, S = berm return channel slope, R = Shape Factor adj. Particle Reynolds No. = Rep, σ = sediment sorting parameter (Folk 1968).

$$\sigma = \frac{\phi_{84}-\varphi_{16}}{4}+\frac{\phi_{95}-\varphi_{5}}{6.6}$$

where $\sigma < 0.5$ (Well sorted); σ = 0.5-1.0 (Moderately sorted); σ = 1-2 (Poorly sorted). The sorting parameter plays an important role in estimating sediment redistribution as finer particles in a poorly sorted conditions tend to be winnowed more easily compared to well sorted sediments distributions in coastal environments.

Application of Maglio-Das Formula

The Maglio-Das Formula is applied to each of the sieves of the particle size distribution curve to determine the percent reduction for each sieve. This results in a new modified curve that estimates the anticipated changes to the sediments due to the dredging and placement process, see Table 10.

Table 10. Palm Beach 2014 Example Calculations for the Maglio-Das Formula with Results Displayed in Figure 12.

Observed Postfill	100	99.76	99.04	98.57	97.22	95.49	93.35	89.61
13.Calculated Post Fill [100 - Col 12]	100	99.30022	98.6787	97.99185	96.67527	95.15293	93.30742	89.54223
12. Normalized Freq. [100*Col10/ sum(col	0	0.699777	0.621521	0.686852	1.316584	1.522333	1.845512	3.765187
11. Factor [Col 10-Col10*Col9]	0	0.1173	0.1042	0.1151	0.2207	0.2552	0.3093	0.6311
10. Frequency (percent retained on	0	0.11957537	0.1152017	0.13781316	0.29441614	0.39063694	0.55917197	1.38645435
9. % Loss (Maglio-Das)	0.00128	0.01914	0.09575	0.16466	0.25049	0.34683	0.44683	0.54483
8. Rep	958.1205	338.1016	118.8942	70.29403	41.39931	24.2236	14.01958	7.966813
7. m slope of return flow	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
6. L length of return flow	150	150	150	150	150	150	150	150
5. h height of berm	6	6	6	6	6	6	6	6
4. x No. of times slurried	1	1	1	1	1	1	1	1
3. BA Composite	100	99.88	99.765	99.627	99.333	98.942	98.383	96.997
2. Nominal Dia (mm)	16	8	4	2.8284	2	1.4142	1	0.7071
1. Phi Scale	-4	-3	-2	-1.5	-1	-0.5	0	0.5

81.62	68.4	46.02	18.45	2.71	0.65	0.61	0.59	
81.86783	70.09783	43.51173	14.9954	1.679815	0.210187	0.189454	6.66E-16	
7.674403	11.77	26.5861	28.51633	13.31558	1.469628	0.020733	0.189454	100
1.2863	1.9727	4.456	4.7795	2.2318	0.2463	0.0035	0.0318	16.761
3.54403397	7.07878981	21.8522718	33.9645223	24.3613163	4.3118259	0.07781316	0.91333333	99.1071762
0.63706	0.72132	0.79609	0.85928	0.90839	0.94287	0.95534	0.96523	
4.391981	2.305369	1.123484	0.496891	0.199436	0.074749	0.045091	0.02705	
0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	
150	150	150	150	150	150	150	150	
6	6	6	6	6	6	6	6	
1	1	1	1	1	1	1	1	
93.453	86.374	64.522	30.557	6.1958	1.884	1.8062	0.8928	
0.5	0.3536	0.25	0.1768	0.125	0.0884	0.0743	0.0625	
1	1.5	2	2.5	3	3.5	3.75	4	SUM

Figures 7 to 12 demonstrate the application of the empirical formula to estimate post-fill sediment characteristics using the borrow area sediment properties and compare them to actual post-fill physical samples collected on the beach. A single sample would not be representative of an entire borrow area or a post-fill beach, thus several samples at each location were taken and physically mixed to produce a composite or the composting was performed analytically.

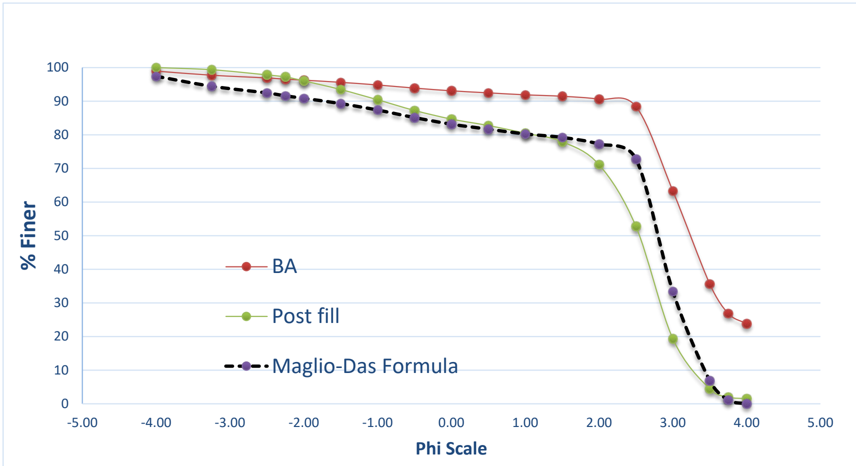

Fig. 7. Egmont Key, FL 2014/5 borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

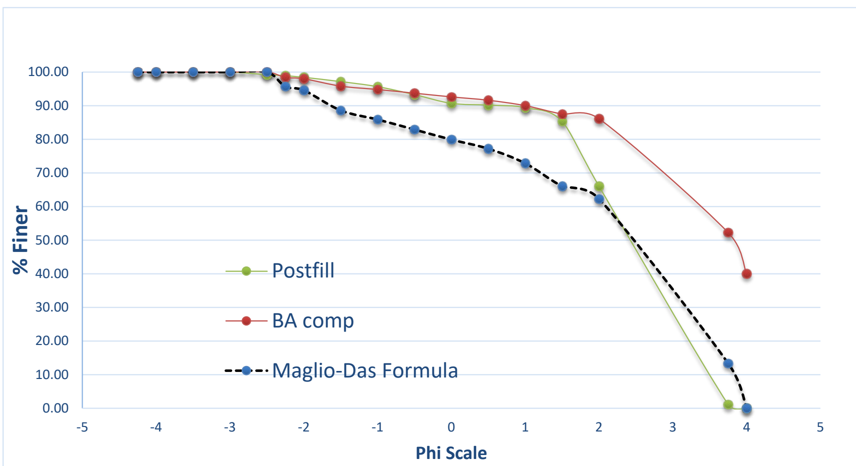

Fig. 8. Galveston, TX 2015, borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

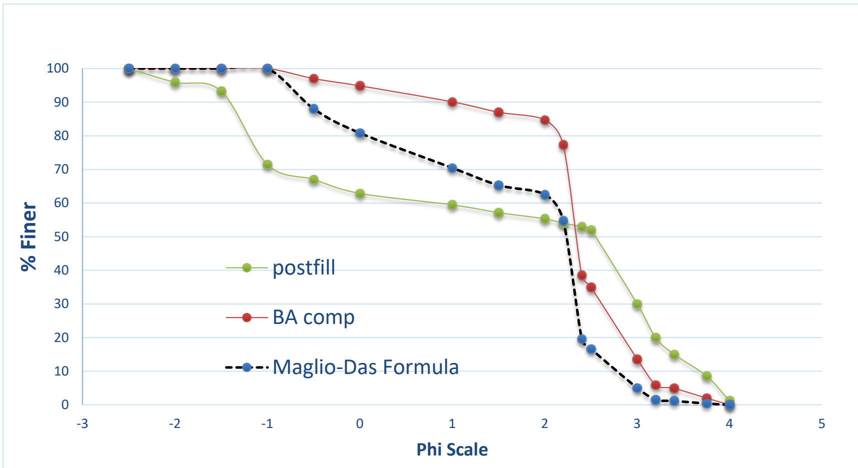

Figure 9. Galveston, TX 2017, borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

The following projects are relatively standard nourishment projects utilizing offshore borrow sources constructed by the USACE or municipal governments along the southwest and Atlantic coasts of Florida. The data was obtained from post placement sediment compatibility data obtained from the Florida Department of Environmental Protection (FDEP). The first of these projects compared below is the Bonita Beach nourishment in Lee County in 2014-2015, from the ebb shoal of Big Carlos Pass (FDEP 2018). This project was performed utilizing a cutter suction dredge excavating and pumping the material directly to the beach.

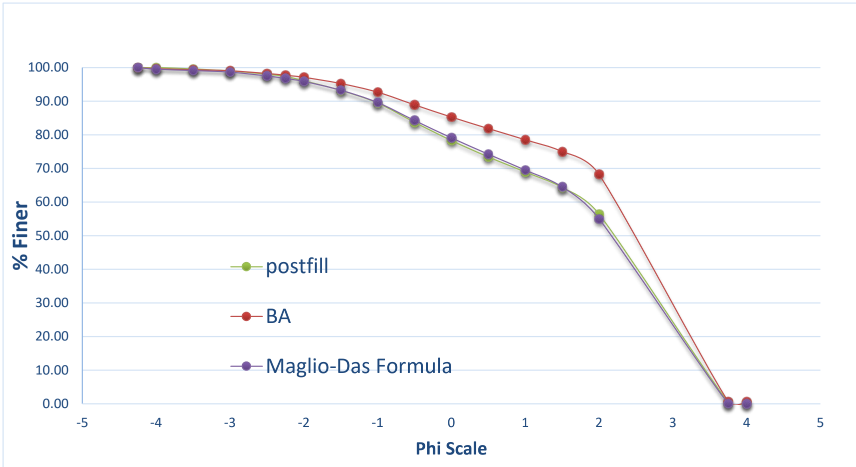

Fig. 10. Bonita (Lee Co.), FL 2015 borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

The 2005 Duval Shore Protection Project was dredged from an offshore borrow source using a hopper dredge and ultimately pumped to the beach (Hodgens et. al 2016). This type of operation requires that the dredged material is slurred and decanted twice allowing for an increased loss of finer material.

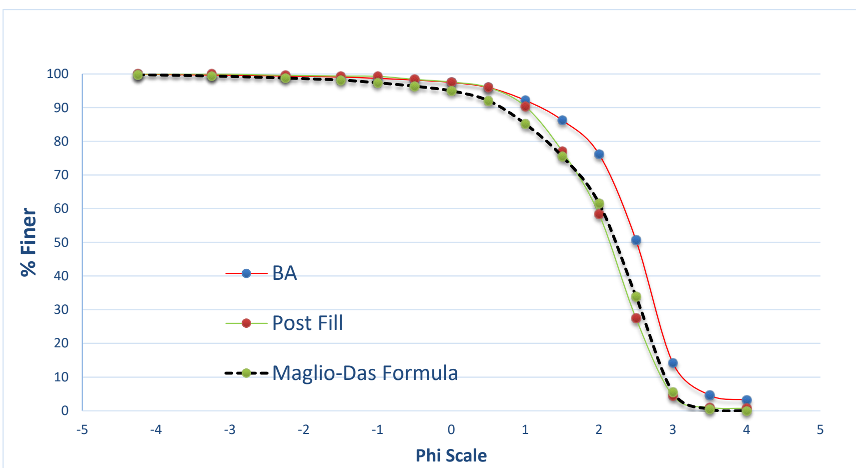

Fig. 11. Duval County, FL Shore Protection Project 2005 borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

In 2014 Delray Beach, Florida was nourished using an offshore borrow source that was directly pumped to the beach by a cutter suction dredge.

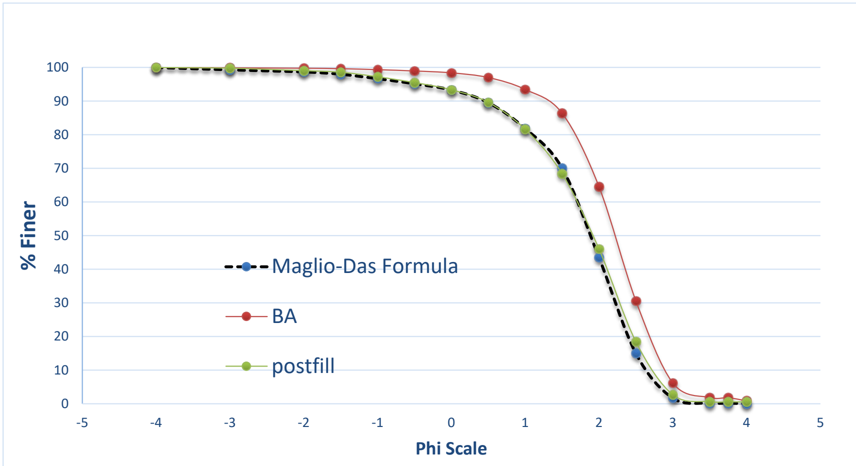

Fig. 12. Palm Beach, FL 2014 borrow area composite, post-fill composite samples, and the Maglio-Das formula results.

Results and Discussion

The projects presented above were used to support that the Maglio-Das formula well represents the trends in sediment changes through the dredging and placement process at a variety of geographically distinct areas and sediment distributions. The Egmont Key and Galveston Beach projects had a very high percentage of relatively fine sediment that were obtained by dredging within barrier island inlets. The Duval, Lee, and Palm Beach County projects were from offshore borrow area sand resources that contained substantially less fines and more closely matched the native beach sediments. The input parameters necessary of the calculation for each of the Maglio-Das Formula are shown in table 11 for each of the referenced projects.

Table 11. Input Values for Each Referenced Project for Maglio-Das Formula Comparison to Post-fill Data.

Site Location	No. of times sediment is slurried (X)	Berm Slope (S)	BA Sediment Sorting Parameter (σ)
Bonita 2	1	0.04	1.448
Duval	1	0.04	0.764
Palm Beach	1	0.01	0.654
Egmont Key	2	0.06	1.133
Galveston (2015)	2	0.066	1.51
Galveston (2017)	1	0.01	0.6

In an effort to determine the accuracy of the formula, the predicted versus the field collected (observed) percent finer sample data are plotted in figure 13. The trendline fits with almost 45 degree slope with an R-squared value of $R^2 = 0.967$. The trendline is slightly skewed toward the observed data indicating that the formula on average slightly under-predicts the fines loss, thus making it conservative. This high R^2 value demonstrates that there is significant correlation between observed and predicted data using Maglio-Das formula. Given that the formula has been applied on several projects covering a wide geographical area, it is anticipated that the formula can be applied to most dredging and placement beneficial use and nourishment projects.

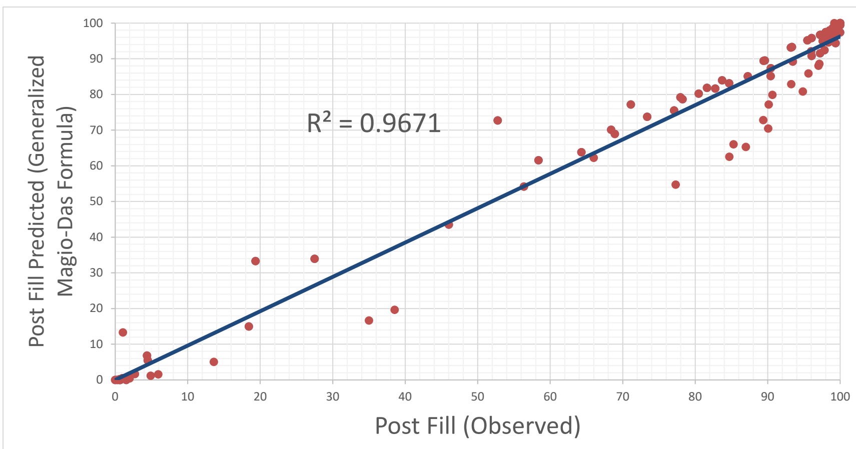

Fig. 13. Post fill predicted result from Maglio-Das Formula versus post-placement physical sediment sampling.

Conclusion

The Maglio-Das Formula appears to recreate the changes that occur to dredged and placed sediments utilized beneficial use and nourishment projects. Its application may allow for regulators to permit the usage of sediment resources currently deemed non-compliant and allow for a regulatory shift to performance based conditions. This will allow design engineers and contractors the flexibility to modify their operations to meet sediment "quality" permit requirements increasing the quantity of acceptable sediment lowering costs and increasing the life span of limited sediment resources.

The next step in this effort is to conduct a sensitivity analysis on the developed formula to understand the role of each individual parameters in sediment distribution. It appears that this formula may be useful in predicting and ultimately regulating beach compatibility based on post-placement anticipated performance results rather than purely on in-situ borrow area data. This could allow for significantly increased beneficial use opportunities of dredged materials, thus keeping the precious resource of sand within the littoral system and reducing the amount placed in upland and offshore placement areas.

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References

Barber, D., O'Dowd, B., Lee, M. 2012. Attrition of material during cutter suction dredging and pipeline transport: a summary. HR Wallingford Ltd, Howbery Park, Wallingford, Oxfordshire OX10 8BA, United Kingdom. Published in the proceedings of CEDA Dredging Days, Abu Dhabi, United Arab Emirates, 12-13 December 2012.

Berkowitz, J. VanZomeren, C. and Priestas, A. 2018. Potential Color Change Dynamics of Beneficial Use Sediments. Journal of Coastal Research In-Press. https://doi.org/10.2112/JCOASTRES-D-17-00161.1

FDEP 2018. Strategic Beach Management Plan: Southwest Gulf Coast Region, Division of Water Resource Management, Florida Department of Environmental Protection. May 2018. https://floridadep.gov/sites/default/files/SBMP-SouthwestGulfCoastRegion.pdf

Folk, R.L. 1968, Petrology of Sedimentary Rocks. Austin, Texas: Hemphill's.

Hodgens, K., Neves, P. 2016. Northeast Florida Regional Sediment Management Implementation Strategies and Recommendations for Nassau County and Duval County, Florida, ERDC/CHL TR-16-3. March 2016.

Jianga, C., Wua, Z., Chena, J., Denga, B., Longa,Y. 2015. Sorting and sedimentology character of sandy beach under wave action. 8th International Conference on Asian and Pacific Coasts. Procedia Engineering 116 (2015) 771 – 777.

HDR Design Memorandum, November 30, 2015. "Beach Nourishment along Galveston Seawall (12th to 61st Street)." By Daniel Heilman, HDR project 260554.

Julien, Y.P. 1995. Erosion and Sedimentation. Cambridge University Press, Cambridge.

Maglio, C., Ousley, J.D., and Coor, J.L. 2015a. Sediment Engineering Thru Dredging And With Nature (Setdwn) – Fate Of Fines In The Dredging And Placement Process. Coastal Sediments 2015. https://doi.org/10.1142/9789814689977_0117

Maglio, C., Ousley, J.D., Hershorin, A., Mora, M. 2015b, Western Dredging Association Conference (WEDA TAMU 2015), "Tampa Harbor Maintenance Dredging with Egmont Key Beneficial Re-use of High Silt Content Material using a Traditional Template versus Cross Shore Swash Zone Placement". Houston, TX. 23 June 2015.

Palermo, M., Randall, R. 1990. Practices and Problems Associated with Economics Loading and Overflow of Dredge Hoppers and Scows. Dredging Research Program, Environmental Laboratory, Waterways Experiment Station, Technical Report DRP-90-1.

Tyler, D., Zawada, D.G., Nayegandhi, A., Brock, J.C., Crane, M.P., Yates, K.K., and Smith, K.E.L., 2007, Topobathymetric data for Tampa Bay, Florida: U.S. Geological Survey Open-File Report 2007-1051 (revised), U.S. Department of Interior http://pubs.usgs.gov/of/2007/1051/.

Tylor, Z., 2016. Morphodynamics of Egmont Key at the Mouth of Tampa Bay: West-Central Florida. Graduate Theses and Dissertations. University of South Florida, 13 April 2016.

USGS 1957. Report No. 12: Some Fundamentals of Particle size analysis, Interagency Committee on Water Resources, December 1957.

Appendix – Example project data

Table 12. Galveston Entrance Channel 2017, Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA comp	Postfill	Maglio-Das Formula
-2.5	100.00	100	100
-2	100.00	95.94201	100
-1.5	100.00	93.28835	100
-1	100.00	71.47764	100
-0.5	97	67.01199	88.04736
0	94.85	62.88415	80.82403
1	90.08	59.47561	70.44927
1.5	87	57.16726	65.31403
2	84.72	55.32311	62.53762
2.2	77.32	54	54.74182
2.4	38.55	53	19.62542
2.5	35	52	16.65633
3	13.61	30	5.029539
3.2	5.93	20	1.56416
3.4	4.90	15	1.179753
3.75	2	8.571985	0.411685
4	0	1.166334	1.17E-15

Table 13. Galveston Entrance Channel 2015, Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA comp	Postfill	Maglio-Das Formula
-4.25	100.00	100.00	100
-4	100.00	100.00	100
-3.5	100.00	100.00	100
-3	100.00	100.00	100
-2.5	100.00	99.20	100
-2.25	98.40	98.87	95.65327
-2	98.00	98.40	94.56659
-1.5	95.80	97.13	88.58983

-1	94.80	95.63	85.87312
-0.5	93.70	93.26	82.88474
0	92.60	90.66	79.89636
0.5	91.60	90.14	77.17966
1	90.00	89.38	72.83304
1.5	87.50	85.28	66.04479
2	86.10	66.00	62.26287
3.75	52.23	1.07	13.28275
4	40.00	0.00	1.42E-14

Table 14. Bonita (Lee Co.), FL 2015 Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA	Postfill	Maglio-Das Formula
-4.25	100	100.00	100
-4	99.67	100.00	99.59418
-3.5	99.39	99.55	99.25818
-3	99.05	98.97	98.86168
-2.5	98.25	97.99	97.93115
-2.25	97.73	97.32	97.32639
-2	97.11	96.05	96.6194
-1.5	95.26	93.19	94.55899
-1	92.69	89.43	91.74196
-0.5	88.93	83.71	87.70743
0	85.28	78.27	83.86437
0.5	81.86	73.39	80.31406
1	78.53	68.92	76.90346
1.5	75.00	64.30	73.32456
2	68.22	56.38	66.53217
3.75	0.64	0.44	0.093287
4	0.55	0.30	-1.2E-14

Table 15. Egmont Key, FL 2015 Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA	Post fill	Maglio-Das Formula
-4.00	98.9202	100	97.37405
-3.25	97.7023	99.36224	94.41226
-2.50	96.886	97.82463	92.42732
-2.25	96.528	97.22767	91.55658
-2.00	96.2244	96.05437	90.81826
-1.50	95.5806	93.47754	89.25263
-1.00	94.7926	90.42933	87.33647
-0.50	93.87	87.24893	85.09282
0.00	93.058	84.67519	83.11832
0.50	92.4514	82.7641	81.64338
1.00	91.8659	80.48851	80.2226
1.50	91.4367	77.96014	79.1923
2.00	90.5727	71.11919	77.20241
2.50	88.388	52.75483	72.73511
3.00	63.2905	19.35414	33.33114
3.50	35.6165	4.39017	6.822819
3.75	26.8273	1.987383	1.102355
4.00	23.8153	1.533139	3.35E-14

Table 16. Duval, FL 2005 Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA	Post Fill	Maglio-Das Formula
-4.25	99.9	100	99.79729
-3.25	99.7	100	99.39186
-2.25	99.4	99.6	98.78373
-1.5	99.1	99.4	98.17567
-1	98.7	99.3	97.36563
-0.5	98.2	98.4	96.35721
0	97.5	97.6	94.96363
0.5	96	96	92.06921

1	92.2	90.4	85.17344
1.5	86.3	77.1	75.53969
2	76.2	58.4	61.57407
2.5	50.7	27.5	33.9457
3	14.2	4.5	5.478383
3.5	4.6	1	0.465826
4	3.2	0.7	-2E-14

Table 17. Palm Beach, FL 2014 Borrow Area Composite, Post-fill Composite Samples, and the Maglio-Das Formula Results

Phi	BA	Postfill	Maglio-Das Formula
-4	100	100	100
-3	99.8804	99.76	99.300223
-2	99.7652	99.04	98.678702
-1.5	99.6274	98.57	97.99185
-1	99.333	97.22	96.675267
-0.5	98.9424	95.49	95.152934
0	98.3832	93.35	93.307422
0.5	96.9967	89.61	89.542234
1	93.4527	81.62	81.867831
1.5	86.3739	68.4	70.097831
2	64.5216	46.02	43.511728
2.5	30.5571	18.45	14.995396
3	6.1958	2.71	1.6798152
3.5	1.88397	0.65	0.210187
3.75	1.80616	0.61	0.1894537
4	0.89282	0.59	6.661E-16