Report on the sand grain size analysis and suitability of Bermuda beach sand, Bermuda terrestrial crushed limestone sand, Bermuda South Channel sand, Bermuda Pompano Channel sand and Bahamas oolitic sand for use as artificial beach sand in Bermuda.

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Introduction

Hotel developers in Bermuda are currently expanding the resort amenities for tourists and local residents. Hotelco Bermuda Holding Ltd. is constructing the new St. Regis hotel and condominiums in St. George's. Morgan's Point Ltd. is constructing a Ritz Carlton resort hotel and residences on the Morgan's Point Peninsula in Sandy's Parish.

Beaches at luxury resorts, whether naturally occurring or artificial, are considered an imperative amenity and Bermuda is globally renowned for its unique pink beaches. Beach sand is a natural resource which is subject to seasonal changes, including both erosion and deposition. In order to maintain a consistent beach year round, several hotels apply for a permit to dredge a limited amount of local marine sand at designated approved locations for relocation to the hotel's beach. The Department of Environmental and Natural Resources (DENR), Government of Bermuda has a policy that prohibits the importation of unsterilized sand from overseas in order to prevent the introduction of non-native species to Bermuda's natural environment. Sand must be from a quarried location (so as not to be infested with soil contaminants). A certificate of fumigation, a certificate of heat treatment or a sample produced for nematode testing must be supplied with the application.

Morgan's Point Ltd was successful in its application for a dredging permit (September 27, 2016) to obtain 6,000 cubic yards of sand from the South Channel (for use as beach fill) and 4,000 cubic yards of sand from the Pompano area (located off Pompano Beach Club, Southampton for use as top sand) for the creation of one of the artificial beaches. They were then given permission to harvest an additional 6,000 cubic yards of sand from the South Channel (January 27, 2017). This amount (16,000 cubic yards) was not sufficient to create the desired artificial beach. Therefore, as the maximum allowable quota had been reached, another source of sand is required.

Marshall Enterprises Ltd. & Bermuda Stone Company Ltd, contractors for the St. Regis hotel and residences in St. George's, submitted two samples of sand to DENR for consideration as beach fill for the Morgan's Point development. One sample, submitted on April 4, 2016 was oolitic sand from the Bahamas which was declared to be mostly composed of calcium carbonate (91-99%), the same as Bermuda's sand. DENR tested a sample provided by Tidewater (same location, different supplier) as there was not enough of the product provided by Mr. Marshall to sample. Permission for a permit to import oolitic sand from the Bahamas for use as beach sand was denied because it is ocean sourced and therefore has biosecurity issues. It was approved for importation for construction purposes.

The excavation of the site on which the St. Regis hotel and residences are to be constructed produced a large quantity of limestone rock/sand, the origin of the second sand sample submitted to DENR on October 25, 2017. Marshall Enterprises Ltd. & Bermuda Stone Company Ltd.

crushed this material to a consistency similar in size to natural beach sand and requested that this material be used to supplement the beach sand at the Morgan's Point Ltd. development.

DENR officers collected a third sample of beach sand from John Smith's Bay, a fourth sample of dredged sand from the South Channel and a fifth sample of dredged sand from Pompano Channel. Both channel sands had been stored on land at Morgan's Point. All five samples underwent sand grain size and turbidity analyses to determine which sand type would be most suitable for use as artificial beach sand.

Methods

Dry sieving of the sand fraction (adapted from Eleftheriou and McIntyre 2005)

Five samples of sand were dried in separate open glass pans in the oven at 150° C for four hours. Then 200 ml of each sand type (oolitic, crushed limestone, Bermuda beach, South Channel and Pompano Channel) was transferred to the uppermost sieve (i.e. coarsest) of a stacked series of graded sand sieves (Fisherbrand U.S. standard brass test sieves). The sieves used for the analyses were, in descending sizes: 1, 0.5, 0.25, 0.125 and 0.063 mm mesh size. The pan underneath the 0.063mm mesh size sieve captured sediment smaller then 0.063mm. Based on terminology of the (Udden/Wentworth scale (Wentworth 1922), all particles retained on a 2 mm sieve are gravel and those passing through a 2 mm sieve are sand. The retention of material in each of these sieves corresponds to coarse sand (>1 mm grain size), medium sand (0.5 mm grain size), fine sand (0.25 mm grain size) very fine sand (0.125 mm grain size), course silt (0.063 mm grain size) and medium silt (<0.063 mm grain size: passed through and retained in the bottom pan).

A lid was placed on the stack of five sieves and pan. The tower was placed on an automatic sieve shaker (FRITSCH, Analysette 3 Spartan) for 15 minutes. The material on each sieve and in the pan was emptied onto a sheet of paper and any grains lodged in the sieve were removed with a sieve brush. The contents were then transferred to a pre-weighed tissue culture dish (100x20mm) for final weighing (OHAUS Explorer Pro balance) (Figures 1-5).

>1 mm 0.5 mm 0.25 mm 0.125 mm

Figure 1. Oolitic sand sorted by mesh size (mm)

>1 mm 0.5 mm 0.25 mm 0.125 mm 0.063 mm <0.063 mm

Figure 2. Crushed limestone sand sorted by mesh size (mm)

>1 mm 0.5 mm 0.25 mm 0.125 mm 0.063 mm <0.063 mm

Figure 3. Bermuda beach sand sorted by mesh size (mm)

>1 mm 0.5 mm 0.25 mm 0.125 mm 0.063 mm <0.063 mm

Figure 4. South Channel sand sorted by mesh size (mm)

>1 mm	0.5 mm	0.25 mm	0.125 mm	0.063 mm	<0.063 mm

Figure 5. Pompano Channel sand sorted by mesh size (mm)

Salt water mixing of the sand samples

The five sand types were placed in individual one litre containers (Figure 6). 500 ml of seawater was added to each container and it was inverted 21 times until all of the sand and salt water had thoroughly mixed (Figure 7). The samples were placed side by side with a ruler placed behind the containers to help assess water clarity. The samples were photographed and filmed over a two hour period.

Figure 6. A comparison of the five (Bahamas oolitic, Bermuda crushed limestone, Bermuda South Channel, Bermuda beach and Bermuda Pompano Channel) dried sand samples.

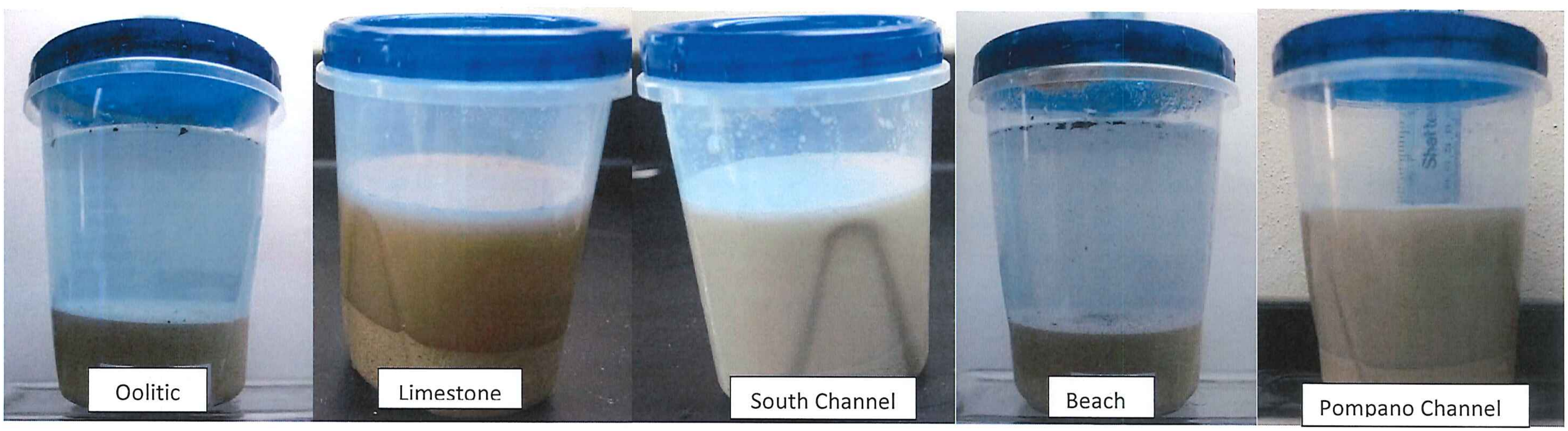

Figure 7. A comparison of the five (Bahamas oolitic, Bermuda crushed limestone, Bermuda South Channel, Bermuda beach and Bermuda Pompano Channel) sand samples immediately after mixing with salt water.

Results

The percentages of the size classes of grain sizes varied markedly between the five (oolitic, limestone, beach, South Channel and Pompano Channel) sand samples. Each sand sample was comprised of more than 50% of one dominant grain size; approximately 52% of the South Channel sand sample consisted of grain particles larger than 1 mm, nearly 60% of the crushed limestone sand sample consisted of particles ranging from 0.5 mm to 1 mm in size, approximately 80% of the oolitic sand sample and 56% of the Pompano Channel sand sample consisted of grain particles ranging from 0.25 mm to 0.5 mm, and nearly 60% the Bermuda beach sand sample consisted of particles ranging from 0.125 mm to 0.25 mm. The South Channel, Pompano Channel and Bermuda beach sand all contained shell fragments; the South Channel sand had more and larger shells than the Pompano Channel and beach sand. The results of the dry sieving of the five sand samples are shown in Table 1 and Figure 8.

Table 1. Percentage of sand grain size per 200 ml sample of the five different sand types

Sand type	**Oolitic sand**	**Limestone sand**	**Bermuda beach sand**	**South Channel sand**	**Pompano Channel sand**
Mesh size (mm)	**Individual weight percent %**	**Individual weight percent %**	**Individual weight percent %**	**Individual weight percent %**	**Individual weight percent %**
1	0.5	11.3	2.2	51.61	9.12
0.5	5.3	59.5	6.8	24.60	16.03
0.25	79.7	23.9	29.8	12.65	55.53
0.125	14.5	5	59.4	6.26	17.11
0.063	0.1	0.3	1.6	2.93	1.44
pan	N/A	0.1	0.1	1.96	0.77

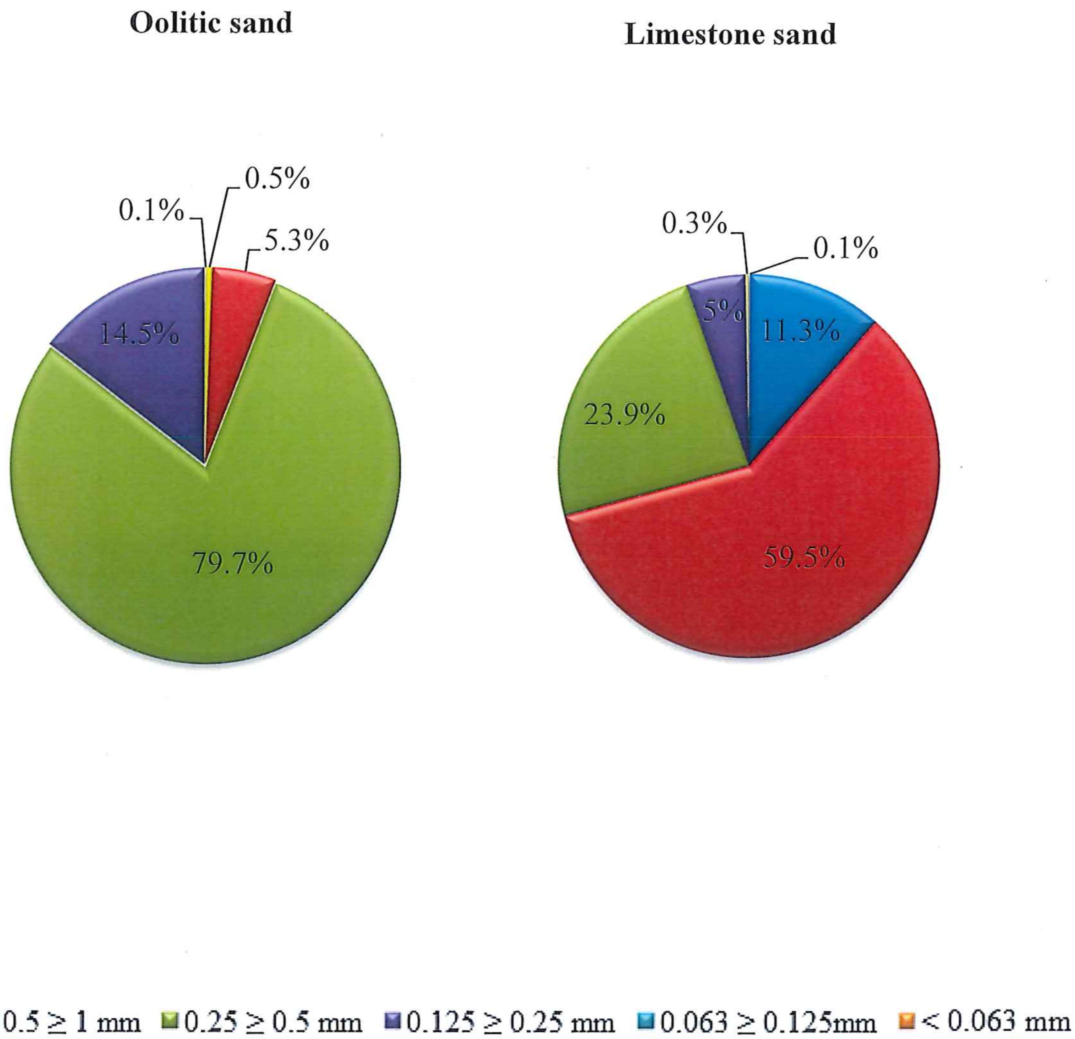

Figure 8. Composition of various grain sizes of oolitic, limestone, Bermuda beach, South Channel and Pompano Channel sand.

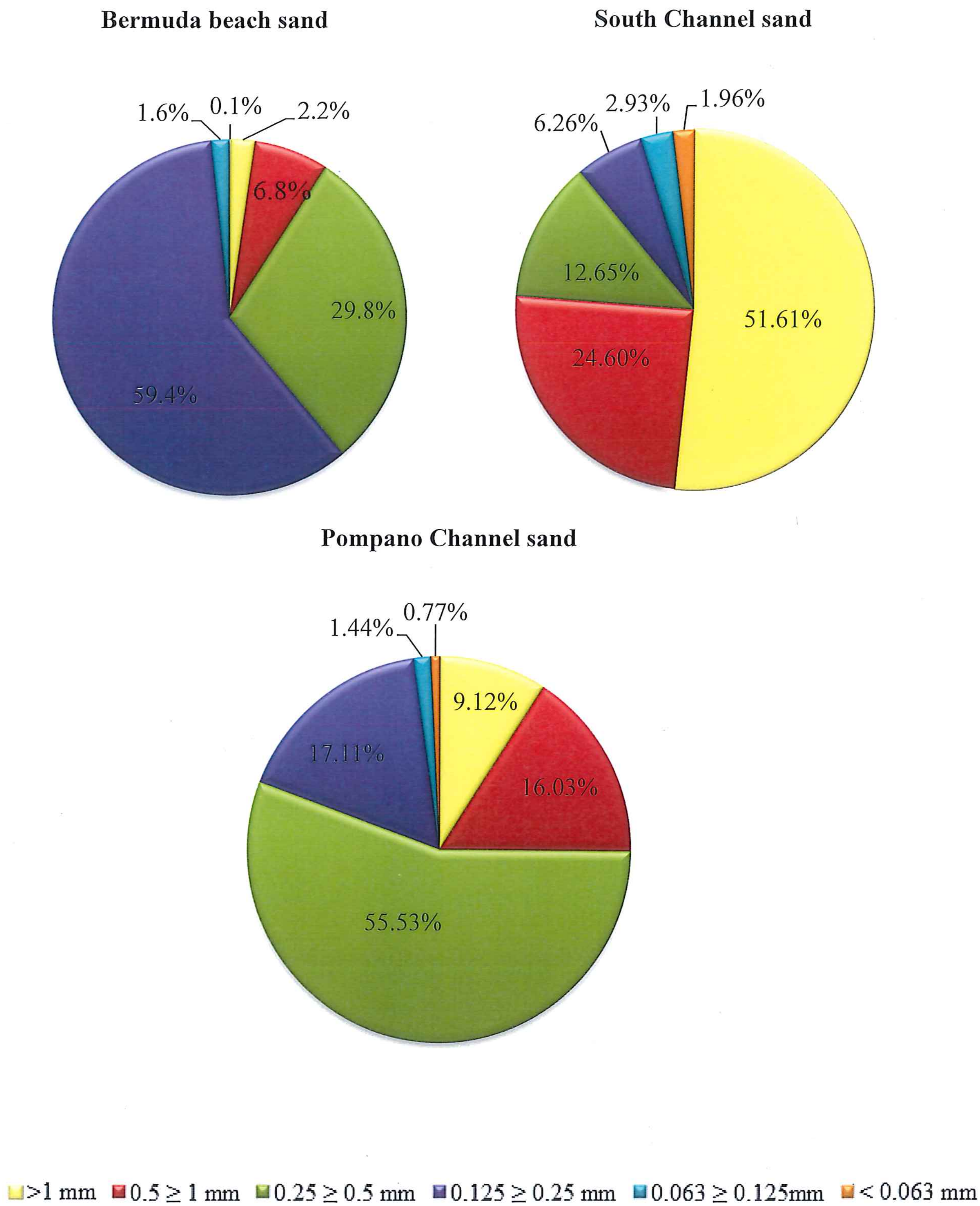

Figure 8. Composition of various grain sizes of oolitic, limestone, Bermuda beach, South Channel and Pompano Channel sand.

A short video clip of the simultaneous mixing of the sand samples (Bermuda beach, Bahamas oolitic and Bermuda crushed limestone) with salt water can be viewed at https://vimeo.com/243251256 (password: sand). The seawater in the Bermuda beach sand container and the oolitic sand sample became clear equally quickly, within 30 seconds. Both sand samples appeared to contain some traces of organic matter (seaweed for the Bermuda beach sand and unknown material for the oolitic sand) which were seen floating on the surface of the samples after settlement. Both of these sand samples had a negligible amount (<0.15%) of silt.

In contrast, immediately after mixing, the water in the crushed limestone, Pompano Channel and South Channel samples was opaque (Figure 9). The crushed limestone (made from terrestrial limestone rock and soil) sample water was brown. The Pompano Channel and South Channel water was chalky in color, similar to the plume that is left behind when the cruise ships navigate the South Channel. After the samples had been left undisturbed for a 24 hour period of time, the crushed limestone water was the cloudiest, the Pompano Channel water was the clearest and the South Channel water was clearer than the crushed limestone however, the inside of the container was coated with a layer of fine white sediment (Figure 10). Forty eight hours after settling, the crushed limestone water remained brown tinged and was still the cloudiest of the three samples (Figure 11). There was a thin brown silt layer on the surface of the crushed limestone sediment. The sand grain size was uniform throughout the sample. The Pompano sample had the clearest water. The sand was an off white color and the sand particles had settled into layers from smallest grains on the surface to largest grains on the bottom. Approximately half of the sand was very fine. The South Channel water sample was almost as clear as the Pompano water. The sand color was slightly pink and there was a thin layer of fine sand on the surface. One hundred and twenty hours later the clarity of the water had further improved (Figure 12). The clarity of the water in the South Channel sample was occluded by the fine silt that settled on the inside of the container and by the glare on the outside of the container. There was no way of removing the silt without increasing the turbidity of the water sample. Therefore the photographs do not accurately show the true transparency of the South Channel water sample.

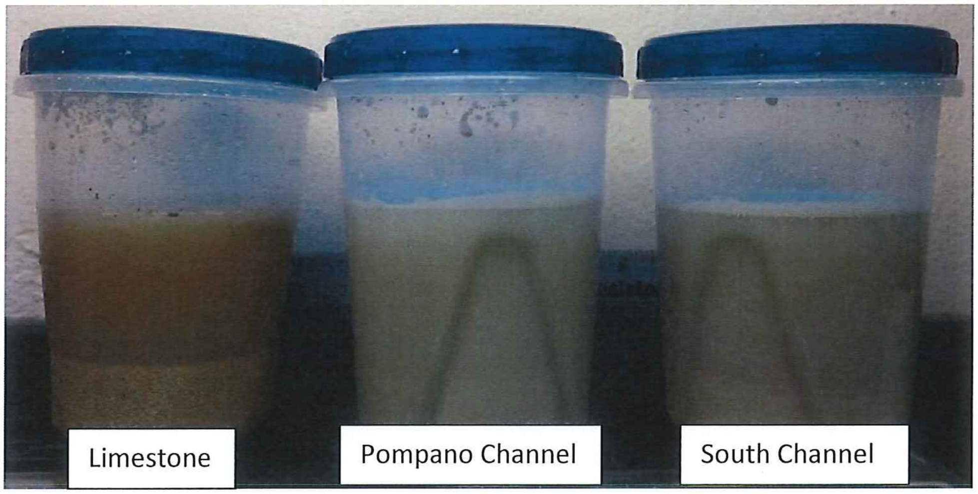

Figure 9. Immediately after mixing

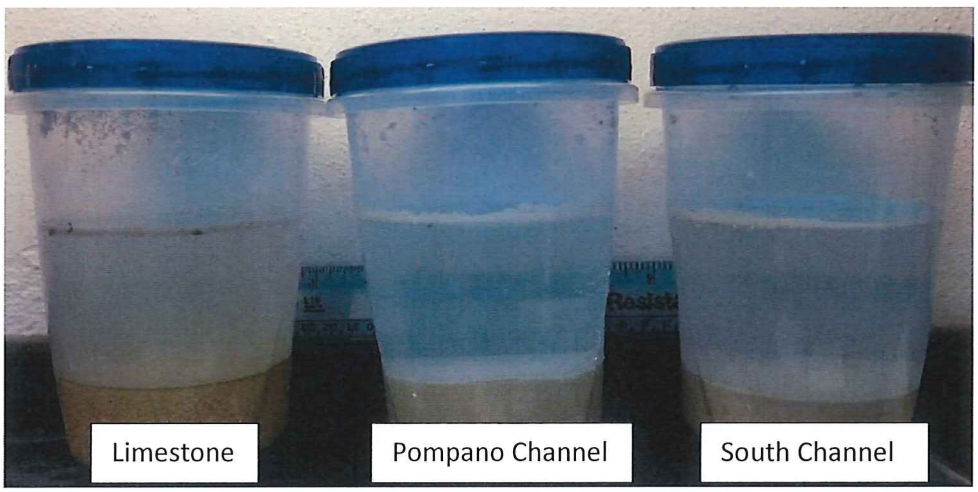

Figure 10. 24 hours after mixing

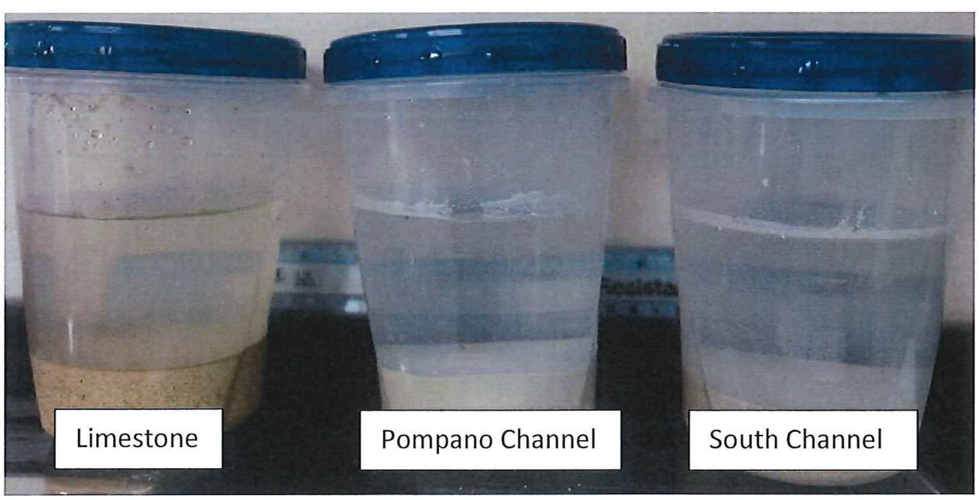

Figure 11. 48 hours after mixing

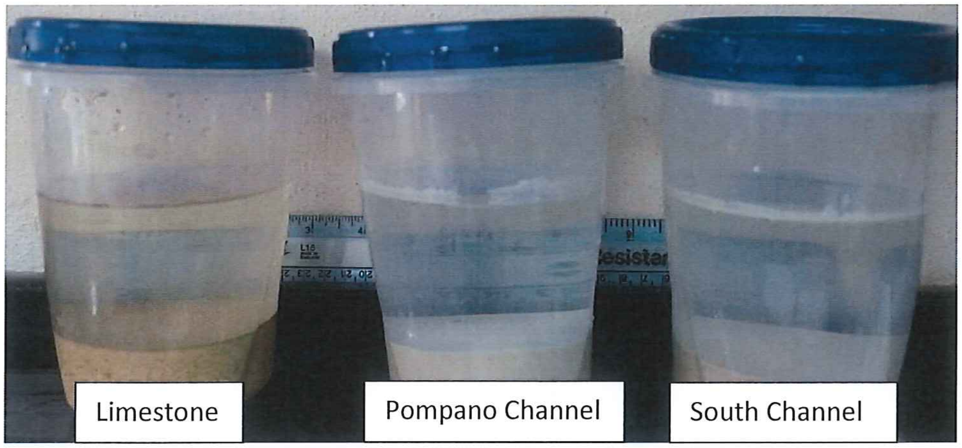

Figure 12. 120 hours after mixing

Discussion

These tests were conducted under lab (ideal) conditions that in no way reflect the natural environment. Many factors affect the behavior and interaction of various sand types in the environment. Therefore, for a more thorough analysis, grain texture such as sphericity (shape) and roundness (smoothness) should be tested, photomicrographs could be taken and turbidity and total suspended matter measured. Additionally, the sand samples could be tested using a wave machine to simulate more realistic field conditions.

The sand from Bermuda's beaches, South Channel and Pompano Channel, has biological origins in the skeletal remains of corals, calcareous algae, phytoplankton, foraminifera, radiolarians, mollusks, parrot fish excreta etc. Sediments structure benthic communities because of grain size preference by various organisms. For example, grain size makes a difference in the ability of flatfish (flounder) to bury in benthic sediment. Suspended sediments have been shown to cause stress and gill damage to fish, smother coral reefs and decrease benthic primary production within seagrass meadows due to increased turbidity (Lowe et al. 2015, Rogers 1990). All corals and seagrasses are protected in Bermuda under the Protected Species Act (2003).

Based on this simple experiment, the recommendation is to harvest more sand from appropriate locations in the marine environment. The crushed limestone is a natural component of Bermuda's geology however it is very dirty. If it could be thoroughly cleaned so that the seawater was clear after mixing then this would be acceptable. However, this was attempted on a small scale in this experiment and clear salt water was not achievable. Importing oolitic sand is both timely, costly (the money could instead fund the restoration of seagrass and mangrove habitats in the area), increases the risk of alien species introduction, and is not a natural component of the Bermuda environment. When it is used to build beaches in Florida it constantly erodes due to heavy wave action (K. Burch personal communication November 17, 2017). However, this would be an acceptable alternative, if the sand was guaranteed to be biosecure.

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Acknowledgements

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