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A Review of Innovative Sediment Delivery Systems

PURPOSE:

This Coastal and Hydraulic Engineering Technical Note (CHETN) provides a review of recent innovations in methods to deliver sediment to placement areas for Regional Sediment Management (RSM) activities such as beach nourishment projects.

BACKGROUND:

Conventional sediment delivery methods for beach nourishment or dredging projects typically fall into two categories, which are: (1) piped slurry transport systems, and (2) vehicular transport (e.g., dump trucks). When a pipeline system is employed, the dredged sediment must be transported in the form of a sand and water mixture known as a *slurry*. The sediment fraction is usually on the order of 15% to 20% by weight of the slurry, which creates a significant dewatering issue at the discharge location. By contrast, truck hauling operations can transport wet or dry sediment from point to point, but frequently encounter access issues for confined work areas and are often seen as more disruptive to the general public and surroundings due to the continuous traffic and loud noises associated with construction vehicles. Usage of heavy trucks frequently creates the need for significant site restoration following completion of the construction activities due to damage incurred from creating access roads and the continual heavy traffic.

Recently, sand transport and delivery methods have been developed which utilize advanced air blowing techniques for sediment conveyance through a pipeline system without the addition of water. Similarly, covered conveyor belt systems have been devised that allow wet or dry sand to be transferred along narrow easements and be discharged directly to the stockpile or placement area. Additionally, there are existing and developing technologies which are not yet employed, or are minimally utilized for sand transport, however they show promise for use in sediment delivery.

This RSM Technical Note documents the current state-of-the-art in terms of beach sediment transport technology, and is based on literature research and direct input from willing parties in the private sector.

CONVENTIONAL TECHNIQUES:

Truck Haul – One of the most common forms of sand transport and delivery for beach nourishment is by truck haul. As the name suggests, this method involves the mechanical loading of dump trucks with wet or dry sand, which then transport the material to the beach or other stockpile location. Each truck typically carries 12 to 18 cubic yards of sediment. Larger projects have the potential for significant damage to public roadways due to the repetitive movement of heavy vehicle traffic.

The Waikiki Beach Maintenance project (Oahu, Hawaii, 2012) utilized 26-ton capacity articulated off-road dump trucks to transport 24,000 cy of sand up to 2,500 feet along the beach from the dewatering basin/stockpile site. Working 5 hours per day, three trucks could move 1,500 cy of sand for final placement and grading. Safety was a major concern on this crowded beach, and extensive use was made of safety fencing and human traffic guards to keep the surfers and trucks separated.

Figure 1. Truck hauling during the 2012 Waikiki Beach nourishment project.

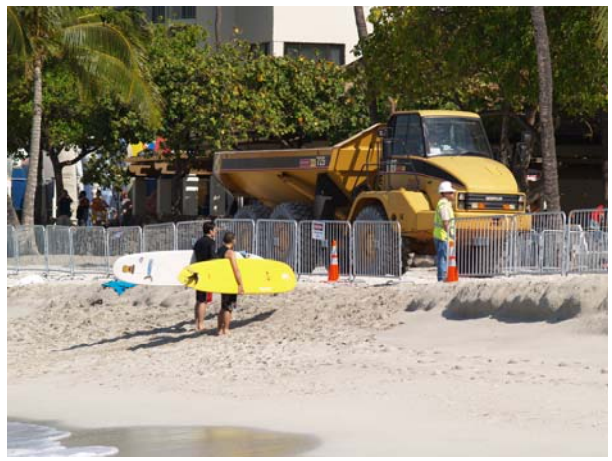

Figure 2. Waiting for a break in the traffic.

Slurry Pipeline System – For dredging or beach nourishment projects where the borrow source is relatively close to the fill location, a piped slurry is often employed for transporting the material. This type of sediment transport requires the borrow material to be submerged, allowing suspension of sand within the water as it is agitated and sucked up by the hydraulic dredge, creating a sand-water slurry which is typically between 15 and 20 percent sand by weight. Under controlled conditions, with uniform sand free of rocks, cobbles, and other debris, transport rates up to 50% sand by weight are possible. The slurry is then pumped ashore or to the desired location via pipeline to a dewatering area to allow settling of fines and silt before the water drains back to the source river, lake, or ocean--a mitigation procedure often required by environmental water quality regulations. During transport, velocities within the flow must be sufficient to keep the largest grain size fractions entrained, otherwise the grains may fall out of suspension and begin to clog the pipeline. Maintaining the necessary flow rate can become energy intensive for larger projects, with required power increasing exponentially with pipe diameter. A number of inefficiencies exist with piped slurry transportation system, the primary one being that typically 80 to 85 percent of the energy consumed is spent on moving the water, which is unused and may also be classified as an environmentally harmful byproduct at the endpoint.

Slurry pipelines are often used in sand bypassing systems, which protect navigation projects from natural siltation and sand accretion. Manmade structures such as dredged navigation channels, jetties, and dams act as barriers to the migration of sand under natural processes, resulting in an impoundment of sediment at these locations. To mitigate the buildup of material at these locations, sand bypass or sand transfer facilities have been used to hydraulically dredge the material and transfer the sand slurry via pipeline to a down-drift fill location.

PNEUMATIC SEDIMENT CONVEYING SYSTEMS:

Pneumatic (air) conveyance systems are commonly used in industrial settings for transfer of bulk materials such as grain, cement, fly ash, and other dry bulk products, typically over short distances. Recently, a firm known as EcoSensitive Solutions, has advertised the application of a unique model of pneumatic conveyance specifically for the transport of sand and other sediments over long distances. The following is a description excerpted from their promotional literature:

The material to be conveyed is fed into the inlet hopper section of the pump, and an auger imparts an initial mechanical velocity towards an acceleration cone. The bulk materials are then introduced into an inline or linear flow of low pressure, high velocity air moving past the end of the auger barrel towards the conveying line, where it moves into the center of the high velocity air stream. It is reported by manufacturers/operators of this equipment that regardless of variations in the shape, size, weight or type of material, the entire mass moves and behaves within the system as though it was a homogeneous gas. The conditions created tend to separate and keep the material particles from touching each other and from touching the wall of the pipeline, thus there is minimal degradation to the material being transported or the pipeline itself, and low friction in the pipeline. The system is low pressure, 2 to 8 psi, and reportedly can move material through a pipeline as long as 3,000 feet, and into hard to reach areas.

Figure 2. Loading sand into the hopper.

Figure 3. The pumping system.

Figure 4. The pipeline.

Figure 5. The sand discharge.

Sea Engineering, Inc. observed a demonstration of the EcoSensitive Solutions air conveyance system in December 2009. The pump system and approximately 1,000 feet of 8-inch HDPE pipe were staged in an abandoned quarry near Seattle, WA. Due to the small size of the demonstration area the pipeline had to make a 180 degree turn halfway along its length. The photographs in Figure 2 through Figure 5 were taken at the demonstration and illustrate the system components and operation.

It was estimated that approximately 40 cubic yards per hour of wet sand were being conveyed through the pipeline, however no quantitative volume-rate measurement was made.

An attempt was made to use an air conveyance system to transport and place sand from the dewatering basin along 2,500 feet of beach during a recent (2012) Waikiki Beach Maintenance project in Hawaii. The construction specifications for the project required that "The dredged sand shall be conveyed from the dewatering basin along the shore for placement to the lines and grades shown on the drawings by means of a pneumatically driven, low pressure system capable of delivering wet sand through a pipeline to the required locations along the shoreline in the project area. Pressure in the pipeline shall not exceed 12 PSI. The system must be capable of conveying a minimum of 100 cubic yards of wet sand-sized material per hour over a maximum distance of 2,500 feet." It was thought that the air conveyance method of sand transport would be the best alternative for the very congested and heavily used Waikiki Beach. Figure 6 to Figure 8 show the system deployed at Waikiki Beach.

Unfortunately, the subcontractor responsible for providing and operating the air conveyance system was unable to perform in accordance with the project specifications. After several weeks of equipment trial, alteration, more trial, it became clear that the system was incapable of moving more than about 20 cy of sand an hour a distance of about 1,000 feet, far too slow a rate to be effective for the needs of the project. Additional issues with the air conveyance system were noise generated by the pump, a high frequency piercing noise similar to a jet engine winding up, and considerable fine dust at the pipe discharge which drifted with the breeze. A decision was made to abandon the air conveyance system, and move the sand using conventional truck haul methodology. Fortunately the contractor was able to develop a truck haul system which minimized inconvenience to the beach users and the resort hotels, and maximized safety. The ability to move large volumes of sand quickly by truck also resulted in very rapid placement of the sand.

At the time of preparation of this technical note, the EcoSensitive Solutions website was taken offline or otherwise unavailable, and there were no known alternative providers of pneumatic sediment conveyance systems designed for use in beach or dredging projects.

Figure 6. EcoSensitve system deployed at Waikiki Beach – air intake is on the left, and sand hopper is on the right.

Figure 7. Feeding the hopper.

Figure 8. Pneumatic delivery system during active transferring operations at Waikiki Beach.

CONVEYOR BELT SYSTEMS:

Recently, conveyor belt systems have been increasingly used for beach nourishment projects where limited access and minimization of post-construction site restoration are significant issues. Conveyor belts have been used for beach nourishment projects on both the East and West Coasts of the U.S. In 1988, 700,000 cubic yards (540,000 cubic meters) of dune sand were excavated from inshore dunes during the expansion of Hyperion Waste Water Treatment Plant, and delivered to El Segundo Beach as nourishment via conveyor belt that snaked through an existing 9 ft culvert running under California's famous Highway 101 (Dean, 2003). The town of Palm Beach, on Florida's Atlantic coastline, recently placed 293,000 cubic yards (224,000 cubic meters) of beach nourishment via conveyor belt which utilized narrow corridors between existing structures.

A primary supplier of project-ready mobile sand conveyor belt systems, Sand Transfer Systems (STS), has a collection of electrically powered conveyor belt units roughly 50 ft in length each, which may be linked together in series to accommodate varying transfer distances, as shown in Figure 9. To date, their longest transfer of beach nourishment via conveyor system is 1000 feet, however, STS states that that the limitation is based purely on the number of available conveyors. The system requires a minimum corridor width of 4 ft, and can be supplied at the entry point using a space with a minimum width of 12 ft. Maximum production rate is reported to be 600 tons per hour, roughly equivalent to 440 cubic yards per hour (336 cubic meters per hour) depending on sand density. The sand may be up to 12% moisture content.

A primary benefit of conveyor belt systems is their proven ability to deliver significant quantities of sand through challenging access corridors. Areas where shoreline erosion is most threatening are often the same areas where shoreline development and infrastructure are densest. Developed areas create access restrictions for heavy equipment to replenish the beach. A conveyor belt system sidesteps this issue by its ability to be installed along narrow pathways, easements, or lawns with minimal damage to the surroundings and a respectable production rate. In theory, once sand is loaded into the dump trucks, it does not hit the ground until the final stockpile location at the end of the conveyor.

The complete conveyor belt transfer system is assembled by linking the individual conveyors in a cascading daisy chain, where the upstream conveyor simply drops its load into the reception hopper of the next conveyor, allowing for a wide degree of flexibility in terms of alignment angles for each conveyor, as shown in Figure 9.

The conveyor chain is initiated by a primary supply hopper which feeds the first conveyor in the chain. The supply hopper is in turn fed by dump truck, as shown in Figure 10. The last conveyor in the chain is able to rotate horizontally in a sweeping motion in order to facilitate spreading of the stockpile. This can be accomplished either automatically or manually. The entire system is powered by a quiet 230 kW power-pack.

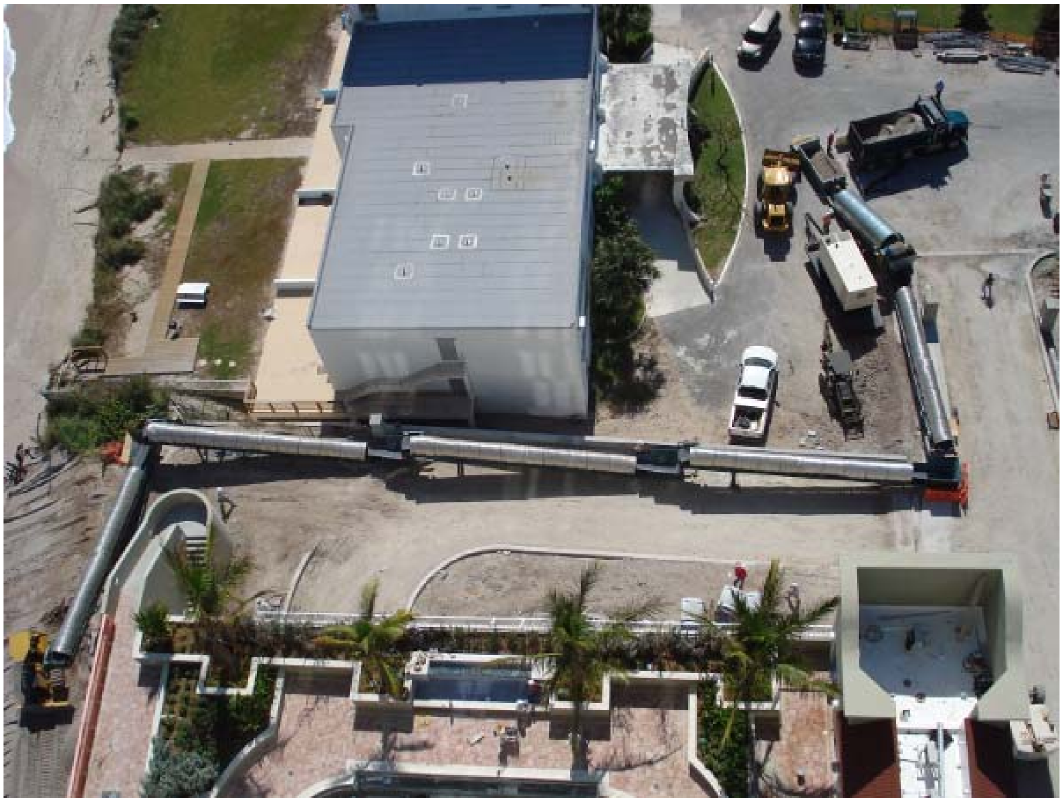

Figure 9. Sand Transport System's conveyor belt system, delivering beach fill through a narrow access way.

Figure 10. STS conveyor system, illustrating the feed end of their system with dump truck supplying the feed hopper.

Figure 11. Photograph illustrating the cascading action of linked conveyors.

Transportation of the complete STS conveyor system for up to 1000 feet of transfer distance can be accomplished using three low-boy trailers, or alternatively three intermodal containers for shipping.

Alternative conveyor belt systems appear to be available from the growing hydraulic fracturing (*fracking*, shale gas recovery) industry, which use large quantities of sand as *proppants* which are pumped underground as a sand-water slurry under great pressure to prop open, or fracture subsurface cracks and faults in the earth to stimulate release of natural gas for harvesting. Industry manufacturers are supplying self-propelled, diesel powered conveyor belts capable of carrying 200 tons of aggregate material per hour, with diameters up to 2 inches (51 mm), as shown in Figure 12. This equates to roughly 150 cubic yards per hour (115 cubic meters per hour) depending on sand density. And as *fracking* becomes more widespread, the supporting equipment such as mobile conveyors will likely become more prevalent and therefore available at reduced costs, making them a possible option for beach nourishment projects when used in series similar to that shown in Figure 9.

Figure 12. A self-propelled aggregate conveyor manufactured by Wilson Manufacturing and Design, Inc.

VEHICLE-CONVEYOR HYBRID:

New advances in bulk transport and handling are producing hybrid technologies which combine the mobility of vehicular transport with the agility of conveyor belt delivery. A company known as Conveyor Application Systems (CAS) is producing a line of tracked and wheeled conveyor systems that can sling moist or dry bulk material such as beach sediment over large obstacles in a directed stream from an integrated hopper.

The CAS equipment has recently been used successfully in medium scale shore protection projects along Florida's Atlantic and Gulf Coasts. An example of usage at one such project in Palm Beach is shown in Figure 13, where CAS's remote controlled AT7 is shown placing sand fill behind a shore protection structure with its articulating conveyor.

Figure 13. CAS's remote controlled AT7, which is suitable for sand placement in inaccessible areas off-road, around buildings or behind obstacles.

The AT7 is primarily used to quickly and efficiently sling sand (or other aggregate) into inaccessible locations which would be difficult to service with larger excavators, as demonstrated in Figure 13. The hopper may be fed at the placement location or loaded at a nearby staging area and then driven remotely to the placement site.

A larger variant of the AT7 is the TR30, which features a tracked vehicular platform and increased hopper capacity. The TR30 is also designed to facilitate filling of geotextile tubes or flood control barriers, as shown in Figure 14. Both the AT7 and TR30 feature hoppers which may be fed by front end loaders, stationary conveyors, or any other means.

A third variant of this technology is CAS's Super Track, which is essentially a modified dump truck with an integrated conveyor capable of slinging dry bulk material such as sand or rock directly from its hopper-bed to the placement location, as demonstrated in Figure 15. A benefit of this apparatus is that the same vehicle which is used for long distance hauling is also used for the final placement, saving time and reducing labor.

Figure 14. A tracked hopper loader TR30 made by CAS, which is used for low ground impact and for the filling of sand tubes and flood barriers.

Figure 15. CAS's truck-mounted conveyor, which allows for direct placement of material from the truck.

TUBULAR DRAG CONVEYOR:

The tubular drag conveyor systems are typically used for industrial bulk material transportation within factories or plants, and although not currently used in the beach nourishment and sediment transport industry, the core technology of tubular drag conveyors do offer potential for use. The technology consists of a stationary outer casing through which a chain is pulled by a sprocket drive. Flights (circular disks) are attached to the chain at regular intervals. As this endless chain and flight assembly moves through the casing, bulk material (i.e., sand or gravel) is pulled from the feed-in location to the discharge port.

Figure 16. Tubular conveyor, with transparent wall illustrating the chain and flight system.

While similar in some ways to cable and aero-mechanical style conveyors, tubular drag technology is said to be superior to these systems in that it utilizes a heavy-duty chain to move dense material at a low velocity, resulting in a conveying method that is rugged, with virtually no maintenance and requires low power consumption. The typical tubular drag conveyor is operated by a single, low-horsepower electric motor, making it an energy efficient method of conveying. The slow-moving, positive displacement action of the chain assembly is ideal for handling gritty or sticky material such as wet sand. The slow movement also assures long conveyor life, dependable service and minimal noise levels with the ability to operate continuously or intermittently. Currently, the maximum diameter for the tube system is said to be 12 inches, which can be fabricated from galvanized or stainless steel. Maximum length of transport for a single system is approximately 400 ft (122 m) and can involve multiple changes in direction both horizontally and vertically. Conveying capacity is said to be up to 114 cubic yards per hour (84 cubic meters per hour), which may be adjusted by varying the casing and flight size as well as the speed at which the chain operates.

Drawbacks are that the system does not appear to be highly mobile and is oriented more for factory usage. However, it appears that with some modifications the system may be utilized effectively in certain beach nourishment projects with very limited access.

PASSIVE TRANSPORT OR “SUPER NOURISHMENT”:

The *Super Nourishment* idea is based on the principle of analyzing site-specific hydrodynamics, employing numerical wave, current, and morphology models to optimize an offshore stockpile placement site and geometry, and then once placed, allowing natural processes to redistribute the beach material to the intended locations. Put simply, it is the placement of a large amount of sand in a specific location and form so that it will be naturally transported to the desired place, with no human intervention, providing significant savings by reducing construction costs.

The passive transport idea has been developed on a large scale in the Netherlands, where a recent project involved the placement of 28.1 million yd^3 (21.5 million m^3) of sand in the nearshore waters of Ter Heijde, in a specifically designed template resembling the shape of a hook that rises approximately 1 to 2 meters above sea level. The shape was designed via morphodynamic modeling using the SWAN[1] model coupled with the TRANSPOR2004[2] model to utilize predominant wind, waves, and currents to redistribute the deposit along the coast over time, as depicted in Figure 17. Construction of the Super Nourishment was completed in late 2011, and it will gradually change in shape over time, eventually becoming fully incorporated into the dunes and beach, and nearly uniformly widening the beach over a length of approximately 2.5 miles (4 km).

By depositing a large amount of sand in a single operation and allowing natural forces to redistribute the sediment to the intending location, the project aims to prevent repeated disruption of the vulnerable seabed. Natural forces will gradually take the sand to the desired location. If the Super Nourishment fulfills project expectations, sand replenishment off the Delfland Coast will be unnecessary for the next 20 years, whereas previously it was necessary every 5 years. Figure 18 shows the Super Nourishment project near the end of construction, with observations indicating that the hook form was already beginning to mobilize.

Although not applicable for most typical small to medium scale beach nourishment projects, Super Nourishment seems to be well suited for very large scale projects along relatively straight and homogenous shorelines, such as found on the U.S. East and Gulf Coasts. Shoreline reconstruction following major hurricane damage may be one possible application in the United States.

More information on the Super nourishment concept is available in the 2010 International Conference on Coastal Engineering (ICCE) paper titled, “Sand Engine: Background and Design of a Mega-Nourishment Pilot in the Netherlands”, by Mulder and Tonnon.

The U. S. Army Corps of Engineers (USACE) has established a strategy to foster environmentally friendly projects similar to the Super Nourishment approach, in the United States, through implementation of it’s *Engineering With Nature* (EWN) program. The program is intended to align natural forces and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes, including: Strategic placement of sediments for beneficial use of dredged material – making use of hydrodynamics and natural transport processes to build near-shore habitats; Use of engineering features to focus natural processes to minimize navigation channel infilling and to transport and focus sediments for positive benefits; and, Optimizing the use of natural systems, such as wetlands and other features, to reduce the effects of storm processes and sea level rise on shorelines and coasts.

[1] Simulating Waves Nearshore is a hydrodynamic wave model developed by Delft University of Technology for modeling of wave propagation, shoaling, refraction and many other wave behaviors.

[2] TRANSPOR2004 is a sediment morphology model used for computation of sand transport in current and wave conditions, implemented in the software Delft3D-ONLINE.

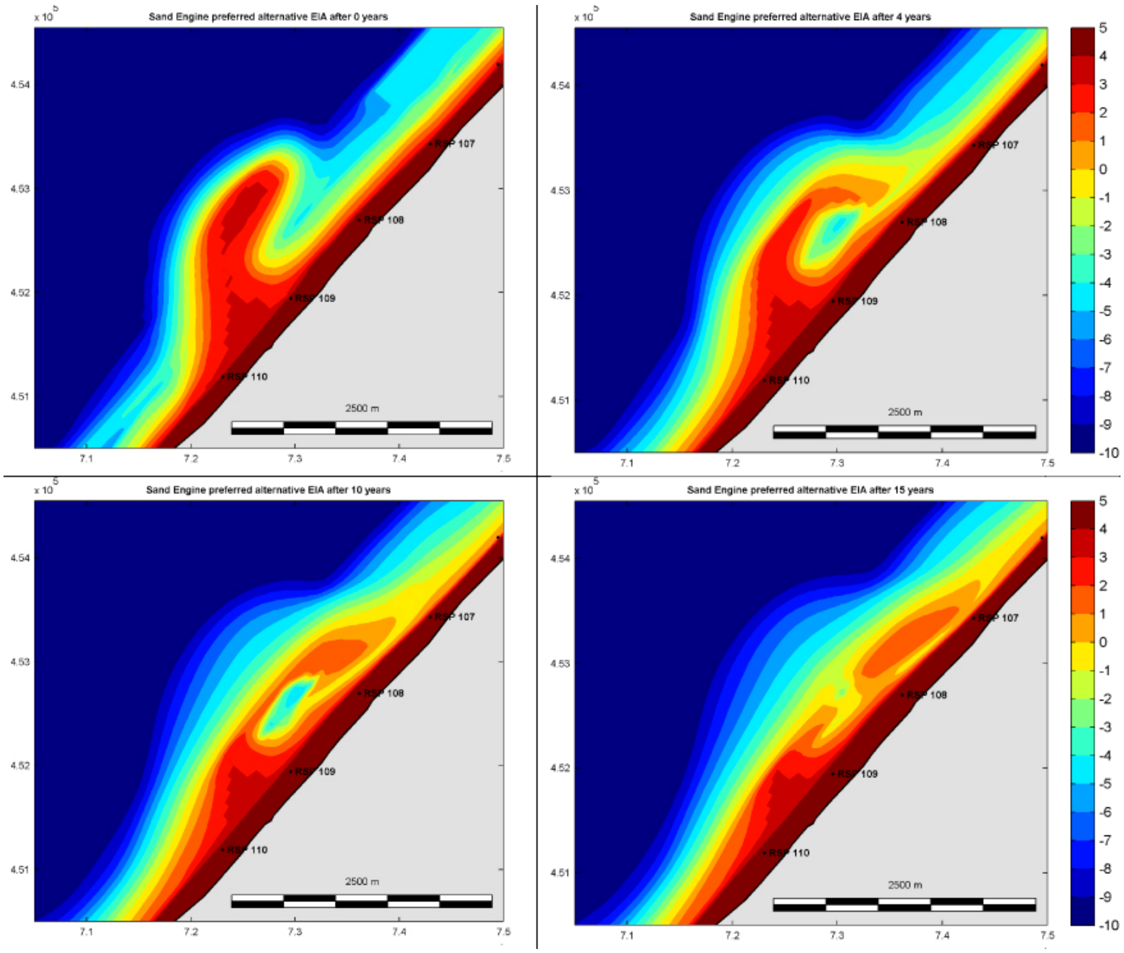

Figure 17. Numerically modeled morphology of the Super Nourishment concept.

Figure 18. Aerial photograph of Super Nourishment, Ter Heijde, Holland.
Picture taken on or about 11 October 2011

SUMMARY:

This Technical Note serves to document the state-of-the-art in terms of sediment transport technology, specifically relating to beach nourishment and regional sediment management (RSM) programs. It was found that, in addition to the conventional methods of truck hauling and piped slurries, there are alternative technologies and methods that are currently in use, or are in development as emerging technologies. These technologies range from modular conveyor belt systems and enclosed conveyor variants, to conveyor belt and vehicle hybrids, to waterless pneumatic conveyance pipelines, and to large scale passive *Engineering With Nature* approaches.

ADDITIONAL INFORMATION:

This CHETN was produced for the U.S. Army Corps of Engineers, Honolulu District. Questions about this CHETN can be addressed to Mr. Smith at (e-mail: Thomas.D.Smith@usace.army.mil). Note that reference to commercially available products does not constitute endorsement by the U.S. Army Corps of Engineers.

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United States Army Corps of Engineers, "Engineering With Nature", source: (http://el.erdc.usace.army.mil/ewn/), 2012. Contact Dr. Todd Bridges at (todd.s.bridges@usace.army.mil) for more information.

Wypych, P, "Modes of Pneumatic Conveying", article found at (http://www.all-con.com/newsletter/newsletter1.html). Dr. Wypych is director at the Key Centre for Bulk Solids Handling & Particulate Technologies, University of Wollongong, NSW, Australia.