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# IMPROVEMENTS FOR DREDGING AND DREDGED MATERIAL HANDLING

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## ABSTRACT

The cost of dredging is requiring more efficient dredging systems. Dredging of contaminated sediments is requiring more accurate dredging meaning that only the contaminated sediments are removed. The desire to beneficially use dredged material suggests more separation and use of the dredged material for beaches, land reclamation, and recreational facilities. Dredging systems are usually either hydraulic, meaning the dredged material is transported using water, or mechanical, meaning the dredged material is excavated with mechanical systems (e.g. buckets). Advances in global positioning systems, dredging software, dredging control systems, dynamic positioning, cutters, dragheads, dredge pumps and others should be incorporated in future dredge systems. The objective of this paper is to discuss improvements for dredging systems and dredge material handling. For example, improvements in the suction pipe inlet may lead to less spillage and less resuspended sediments for hydraulic cutter suction dredges and reduce turbidity. Advances in dynamic positioning systems for cutter suction dredges could provide a means of eliminating spuds and anchors and provide propulsion. Beach nourishment and land reclamation for US shorelines will need larger hopper dredges to mine the sediments necessary to maintain existing shorelines and wetlands. Floating separation systems may be needed to separate sand from silts and clays so that the sediments can be used beneficially or separately placed in dredged material placement areas. Dredge control systems need to be more fully used in the dredging operation of all dredges to improve efficiency, accuracy, and data analysis of dredge production.

**Keywords:** Dredging, improved dredges, dredge automation, remotely controlled dredges, beneficial uses, and accurate dredges.

## INTRODUCTION

Dredging and dredged material placement are described in Herbich (2000), Randall (2004), van der Schrieck (2010), Bray, Bates, and Land (1997), Turner (1996), and Bray (2008). The US Army Corps of Engineers maintains the Dredging Operations Technology Support (DOTS) web site: (http://el.erdc.usace.army.mil/dots). Two additional sources of dredging information are the Western Dredging Association (WEDA) (www.westerndredging.org) and the Center for Dredging Studies (http:\\oceaneng.civil.tamu.edu).

Dredging systems are used to maintain and excavate navigation channels, ports, marinas, lakes, and waterways. Contamination of rivers, harbors, waterways, bays and estuaries has required dredging systems to cleanup/remove contaminated sediments, and subsequently, the sediment and water is cleaned of the contaminants. Dredging systems are also used to mine sand and gravel for the aggregate industry.

Commonly, dredges are classified as either hydraulic or mechanical. A hydraulic dredge uses water to transport the dredged sediments to the final destination using a pipeline, barge, or hopper. The mechanical dredge removes the sediments by a physical process such as using a clamshell attached to a crane or a bucket loader and uses barges, trucks, and rail cars to transport the dredged material to its final destination. In recent years, these hydraulic and mechanical dredges are using more advanced technology for global position navigation systems, and partial automatic control systems to improve dredging productivity and efficiency. Dredges have increased in size from a common 610 mm (24 in) pipeline dredge to 813 – 914 mm (32 – 36 in) cutter suction dredge and mechanical buckets have increased capacity from 14 to 42 $m^3$ (18 to 55 $yd^3$).

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Environmental dredging is generally the term used for a dredge system that is designed for the precise removal and handling of contaminated sediments. Several special dredges were developed for contaminated sediments and these dredges needed to accurately remove the contaminated material while minimizing the resuspension of residual contaminated sediment in the water column. Advances in environmental dredging continue to evolve with the increasing demands for safe and efficient handling of contaminated sediment.

## HYDRAULIC DREDGES

A hydraulic dredge removes sediment from bodies of water using pumps coupled with a cutter head or water jets to disturb and suspend the sediment for transportation with water to a barge, through a pipeline, or in a hopper to a designated dredged material placement site. There are two main types of hydraulic dredges and these are the cutter suction (pipeline) dredge and the trailing suction hopper dredge. Cutter suction dredges range in size from 152 mm to 914 mm (6 in to 36 in). Hopper dredges have large trailing dragheads that are connected to centrifugal pumps that bring the dredged material into the hopper in the center of the dredge and once the hopper is full the dredge raises the dragarms and sails to the placement area where the hopper contents are dropped through bottom opening doors or is pumped to the placement area.

### Trailing Suction Hopper Dredges

Hopper dredges are used for maintenance dredging of ship channels and for sand hauling for beach nourishment and land reclamation. The largest land reclamation projects in recent years are the creation of the Chek Lap Kok Airport in Hong Kong, land expansion in Singapore and the islands in the Arabian Gulf off the coast of Dubai. The first hopper dredge, General Moultrie was operated in the US in 1855 using steam power and a 483 mm (19 in) centrifugal pump. The newest hopper dredges in the United States are the Great Lakes Dredge and Dock's Liberty Island and Manson Construction's Glenn Edwards shown in Figure 1. The Glenn Edwards has a length of 119 m (390 ft), beam of 23 m (76 ft), suction and discharge diameter of 965 mm (38 in), a hopper capacity of 10,300 m$^3$ (13,500yd$^3$), a maximum digging depth of 28 m (90 ft), loaded draft of 8.5 m (28 ft), and total installed power of 8951 kW (10,000 hp). The Liberty Island hopper dredge has a length of 96 m (315 ft), beam of 18 m (59 ft), loaded draft of 7.8 m (25.5 ft), a maximum digging depth of 33m (108 ft), a suction diameter of 800 mm (31.5 in), suction diameter of 762 mm (30 in), a hopper capacity of 5003 m$^3$ (6540 yd$^3$), and a total installed power of 12,353 kW (16,566 hp). Currently, Great Lakes Dredge and Dock has 10 trailing suction hopper dredges with the largest capacity of 5600 m$^3$ (7300 yd$^3$). Manson Construction has four trailing suction hopper dredges with the largest capacity of 10,321 m$^3$ (13,500 yd$^3$). Weeks Marine has two hopper dredges and the RN Weeks has the largest capacity of 3058 m$^3$ (4000 yd$^3$). The US Army Corps of Engineers operates the hopper dredge Wheeler that has a capacity of 6312 m$^3$ (8,256 yd$^3$).

**Figure 1. Trailing suction hopper dredges Liberty Island (left) (Courtesy of Great Lakes Dredge and Dock) and Glenn Edwards (right) (Courtesy of Manson Construction).**

As a comparison, the Jan De Nul Group operating out of Belgium has significantly larger capacity trailing suction hopper dredges in addition to greater sailing speeds. The largest hopper dredge is the Christobal Colon that was built in 2009 that has a capacity of 46,000 m$^3$ (60,000 yd$^3$) and a sailing speed of 18 knots. The Vasco da Gamma (Figure 2) hopper dredge was built in 2000 and has a capacity of 33,000 m$^3$ (43,000 yd$^3$) is another large dredge operated by the Jan De Null Group. These large hopper dredges are primarily used for land reclamation and not for maintenance of ship channels due to the vessel size and maneuvering limitations inside the channel. In the future, the US may need to dredge large amounts of sand far away from the beaches or land where renourishment or land reclamation is desired. The US dredging companies might consider investing in the construction of larger and faster hopper dredges in the future to haul sand to the coast line to renourish or reclaim land or beaches and wetlands lost to erosion, subsidence, or sea level rise. These larger vessels would have the capability to partner for work on the international market.

**Figure 2. Trailing suction hopper dredge, Vasco da Gamma (Courtesy of Jan de Nul).**

### Cutter Suction Pipeline Dredges

The workhorse of the dredging industry is the cutter suction pipeline dredge that consists of a dredge pump, ladder, suction and discharge pipes, winches, spuds, and often a ladder pump. The dredge is typically not self- propelled but relies on a support crew of tugs and anchor handling boats. The ladder pump is used to provide slurry to the main pump to overcome cavitation limitations when dredging deeper that 10 m (33 ft). Ladder or submerged dredge pumps overcome the barometric (cavitation) limitations or a cutter suction pipeline dredge with an in-hull dredge pump and improve production. A modern cutter suction dredge should use a ladder pump. The main pump is powerful enough to deliver the slurry a distance up to 8 km (5 mi) through a floating and shore pipeline. Longer pumping distances can be obtained using booster pumps. There are over 170 cutter suction dredges in the US (World Dredging, 2010) and the maximum pipe diameter is 864 mm (34 in) with a total installed power of 14,914 kW (20,000 hp). Large cutter suction pipeline dredges in the US are shown in Figure 3.

**Figure 3. Large cutter suction dredges, Texas (left), RS Weeks (middle), and HR Morris (right) (Courtesy of Great Lakes dredge and Dock, Weeks Marine, and Manson Construction, respectively).**

The Texas has a spud carriage barge attached to the stern of the dredge and this spud carriage increases the efficiency of the dredging operation. A majority of US large cutter suction dredges are using two fixed spuds to advance and that system is less efficient than the spud carriage. When using the fixed spuds the cutter swings over areas that it has already dredged in order to advance, but a spud carriage only looses time when the dredge has to move the spud to the front of the stroke position. Generally, a fixed spud advance system is excavating material 40% to 50% of the time and a spud carriage is excavating 70-80% of the time. Future or retrofitted dredges can increase efficiency and shorten dredging time by retrofitting a spud carriage or adding a spud carriage barge. Some research of using thrusters to swing the ladder instead of using wire rope, winches and anchors. This would increase dredging time since the dredge would not have stop with moving anchors. The ladder would have to be strengthened to accommodate the weight and force of the thrusters. A GPS system could be interfaced to a system to control the thruster speed and maintain the desired swing speed.

Additionally, large US cutter suction dredges have no propulsion and must be moved to location by tugs or push vessels. A future track for large cutter suction dredges may be to add propulsion as has been accomplished on international cutter suction dredges such as the J.F.J. Jan de Nul (Figure 4). This dredge has a pipe diameter of 1000 mm (39.4 in), dredging depth of 36 m (118 ft), length of 141 m (462 ft), draft of 5.5 m (18 ft), and total installed power of 27,240 kW (35,626 hp) and can travel at a speed of 12.5 knots. The dredge has a ladder weighing 1450 metric tons and is capable of dredging rock. A large self-propelled cutter suction dredge with heave compensation can operate further offshore and excavate sand for beach nourishment or land reclamation. The dredge can pump to hopper dredges that can pump the material to the beach or land reclamation project location.

**Figure 4. Self propelled cutter suction dredge.**

### Small Cutter Suction Pipeline Dredges

Small hydraulic cutter suction pipeline dredges have a discharge line diameter of 305 mm (12 in) or less. A standard cutterhead or an auger cutter is commonly installed on these small hydraulic dredges. An Ellicott auger dredge and a Dredging Supply swinging ladder dredge with a cutter head are shown in Figure 5. The auger head dredge can work on wires and has wheels on the auger head so that it can work in water bodies that have liners. The swinging ladder dredge works well in creeks where larger swings are not desirable. The two front spuds are used to hold the dredge in place while swinging, and the dredge is advanced with the rear kick spud when the forward spuds are raised.

**Figure 5. Small auger dredge (left) and a 203 mm (8 in) swinging ladder dredge with cutter head (right) (Courtesy of Ellicott and Dredging Supply Co., respectively).**

A 203 mm (8 in) discharge and 305 mm (10 in) suction cutterhead dredge with two fixed spuds and hull mounted main pump is illustrated in Figure 6. The dredge is 13.1 m (43 ft) long, breadth is 3.6 m (11.7 ft), draft is 0.6 m (1.9 ft) and is capable of digging to a depth of 5 m (16.3 ft). The total power is 142 kW (190 hp) and the cutter has 15 kW (20 hp). This Dredgemaster cutter suction pipeline dredge is typical for operating in shallow water bodies such as small lakes and ponds. A self propelled auger dredge manufactured by Crisafulli is shown on the right side of Figure 6. The dredge has 152 mm (6 in) discharge and 203 mm (8 in) suction and is 9.91 m (32.5 ft) long with a draft of 0.7 m (27 in). It is powered by a hydraulic outboard motor that variable speed and adjustable steering with a maximum thrust of 1,243 N-m (11,000 in-lb). The dredge production can reach 115 $m^3$/hr (150 $yd^3$/hr) at depths up to 6.1 m (20 ft). The dredge has option for a pivoting traverse system that allows the dredge to pivot 180 degrees that improves production over a cable traverse system.

**Figure 6. A 203 mm (8 in) discharge and 305 mm (10 in) suction fixed spud dredge (left) ( Courtesy of Dredgemasters International) and a Rotomite dredge (right) (Courtesy of Crisafulli).**

Sand and gravel dredging uses hydraulic systems and are designed to operate in ponds and quarries. The Twinkle Company's 356 mm (14 in) linear cutter sand and gravel dredge is illustrated in Figure 7. These dredges have discharge diameters that range from 203 mm to 406 mm (8 in to 16 in) and can be equipped with a linear or rotary cutter. The dredge uses a ladder pump to overcome suction limits. Control systems are installed to maximize production and these control systems are discussed in the dredge automation section that follows.

**Figure 7. A 356 mm (14 in) sand and gravel dredge with linear cutter (Courtesy of Twinkle Company).**

The small hydraulic dredge manufacturers and operators have been innovative and use automation to maximize the production. Innovative systems such as swinging ladders and kick spuds have improved efficiency and production. These small dredges are being used in dredging contaminated sediments and reducing the residuals with the development more accurate depth control and increased vacuum at the dredge head in order to improve the sediment capture around the cutterhead and reduce the resuspension and spillage of the sediments.

### Remotely Operated Dredges

A number of dredges in use today are controlled by a remote operator. These dredges are designed to work on the surface, while a few are capable of working beneath the water surface and on the seafloor. The remotely operated dredge, Flump as shown in Figure 8, is built by Crisafulli and operates in lined ponds. Sub-surface designs such as trenchers are used to excavate trenches for laying sub-sea pipelines, but these trenchers do not transport the excavated material to the surface rather, the sediment is left on the side of the trench. Allseas' Digging Donald as shown in Figure 8 is a mechanical crawler controlled through an umbilical to a pipelay vessel and is capable of digging trenches of 2.1 m (7 ft) for laying pipe of up to 1.2 m (48 in) outside diameter in up to 350 m (1148 ft) of water. The installed power is 1000 kW (1341 hp) and a working speed of 500 m/hr (1640 ft/hr). The dimensions of the crawler are 17.7 m (58 ft) long, 9.6 m (32 ft) wide, and 6.7 m (22 ft).

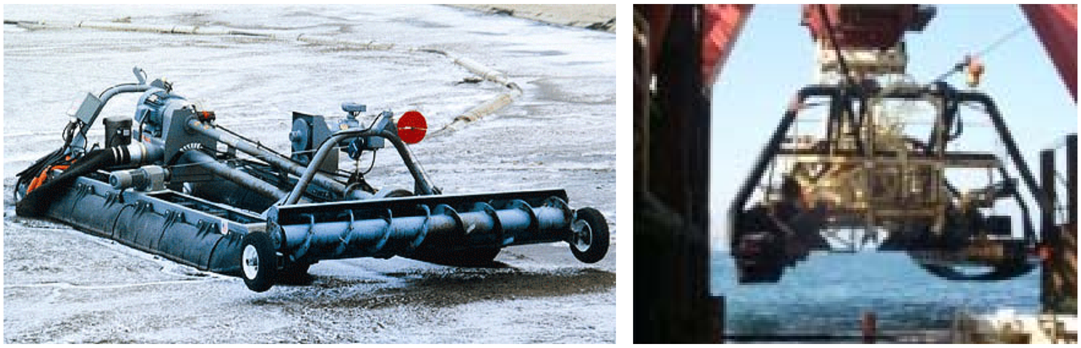

**Figure 8. Remotely operated dredge Flump (left) (Courtesy of Crisafulli) and the trencher Digging Donald (right) (Courtesy of Allseas).**

There is good reason to apply sub-sea technology for use in the dredging community, the continual expansion of the world's shipping industry places additional constraints and demands on the dredging industry. By eliminating the physical surface presence of operations in major channels, dredging can be accomplished without hindering traffic. While the required technology and infrastructure to develop functional remotely operated dredges may seem insurmountable, examples are available. For example, hydraulic powered pool cleaners propelled by the very fluid the cleaner is working in by the coupling of high volume and pressure pumps to hydraulic motors and jets via a length of flexible pipe. The wheels propel it along as the venturi nozzles continuously scrub sediment from the bottom of the pool floor; why not take this technology to the next level?

A modern hopper dredge could be refitted as the "mother ship" as illustrated in Figure 9, a submerged umbilical bundle consisting of a high-pressure feed line and two return discharge lines connects to a “bottom feeder” Remotely Operated Dredge System (RODS). The reconfigured hopper dredge would have the ability to pay out the umbilical lines via a spool system similar to pipe laying vessels. A retrieval winch and ROD docking station mounted on the stern of the hopper allows for a secure method of mobilization and transit. The hopper would draw in relatively low turbidity surface water to its high pressure pumps, sending the environmentally friendly working fluid down the feed line to the ROD. The propulsion system on the RODS would use hydraulic motors coupled to tracks instead of wheels. The tracks can be selected depending on the working sediment. For example in soft silt situations, the operator can choose to put on large paddle tracks to provide the required traction or in hard bottom environments replace the previous with appropriately sized studs. The excavator would be a forward mounted auger configuration leading to a venturi chamber that would effectively separate out the fines from the coarse grains, as illustrated in Figure 10. The fines would bypass an adjustable mill through the larger diameter discharge pipe leading to a dedicated bin within the hopper. The coarse material would enter the mill where it would be uniformly sized as a function of the second smaller diameter discharge pipe’s critical velocity.

This smart separating system would be a source for valuable beach nourishment sand or aggregate for construction use. Side effects may include more efficient use of designated placement sites and the ability to stratify land reclamation or armor caps. Safety features such as tether quick disconnects and emergency buoyancy tanks could be activated if necessary to allow retrieval and repair of the ROD. The hopper should also store on board a backup ROD allowing for seamless transition between consumable maintenance intervals. Measurement devices on board the RODS would communicate to the operator the loads placed on the auger, mill, and traction system. Active acoustics systems would relay the precise location of the ROD relative to the ship location. In addition pressure depth gauges and inclinometers would allow for bathymetric mapping in real-time over the cutting area.

There are obvious drawbacks to the use of a remotely operated dredge system. The durability and service life of the tether bundle is to be questioned and the capital costs would be large. Moreover, production values and power requirements would have to be evaluated on a model scale. The benefits of such a system would be the ability to work free from the constraints of trailing suction arms, winch lines, anchor handling equipment, and ladder pumps to name a few. System-wide benefits would be reduced mobilization costs and transit time, unhindered traffic flow, and discharge pipeline maintenance. Consideration should also be given to the public's perspective; a reduced visual impact during dredging activity may promote and advance project approval in the public domain. Facilities such as the Haynes Coastal Engineering Laboratory in collaboration with industry leads can provide the support necessary to investigate the future of remote dredging technology.

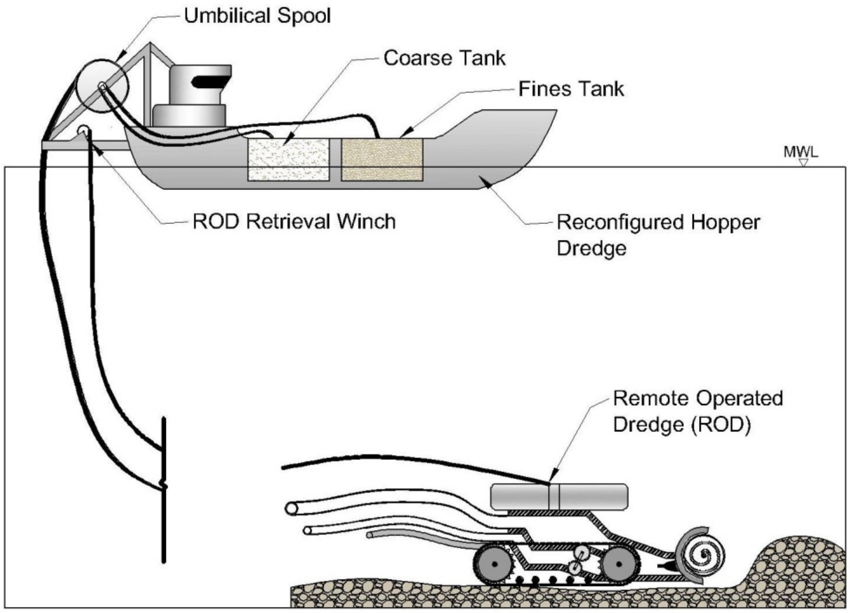

**Figure 9. Schematic of remotely operated dredge system.**

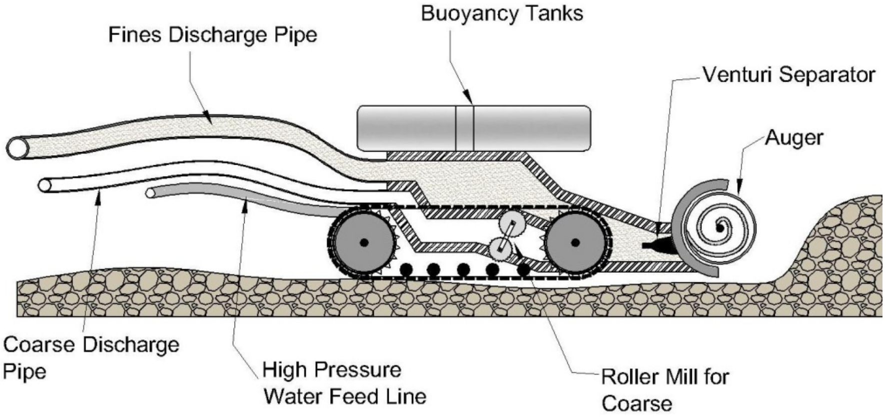

**Figure 10. Remotely operated dredge (ROD) profile and internals.**

### Mechanical Dredges

Mechanical dredges use mechanical means to excavate the underwater sediments and do not rely on water as a fluid to transport the dredged sediment through a pipeline. Mechanical dredges include dipper, backhoe, dragline, clamshell, grabble, and bucket ladder dredges, Figure 11 shows a backhoe, clamshell, and a bucket ladder dredge. The clamshell bucket sizes range up to38 $m^3$ (50 $yd^3$) and are the most common bucket used for mechanical dredges.

**Figure 11. Backhoe dredge, New York, (left) and a clamshell dredge (center) (Courtesy of Great Lakes Dredge and Dock) a bucket ladder dredge underway (right).**

The accuracy of positioning the bucket on the bottom while minimizing the resuspended sediments is a continuing effort for improvements. Instrumentation for determining closure of bucket and distance off the bottom are often used. Future design improvements should include position assistance with small propulsion packs mounted on the bucket. Software such as Winops and HyPack are available for aiding bucket footprint mapping. Hopper barges, scows, and conventional barges are used to receive the excavated material and are towed or self-propelled to the unloading location.

## Environmental Dredges

The environmental dredges are specially designed for the removal of contaminated sediment. These dredges tend to have lower production values (less than 448 $m^3$/hr or 600 $yd^3$/hr) as a condition of the need to very precisely excavate the contaminated sediment so that the costly treatment procedure processes only the contaminated sediment. Small hydraulic auger and cutter dredges are used for dredging contaminated sediments. Nearly watertight clamshell buckets are used, and the bucket is totally enclosed to prevent sediment resuspension as the bucket rises through the water column. The top of the environmental clamshell bucket has vent flaps that allow water to escape while the bucket is being lowered to the bottom. The bucket jaws are closed as the bucket excavates the bottom sediment and then the bucket is raised through the water column. The dredge swings the bucket to the waiting barge/scow. The excavated contaminated sediment is delivered to sediment dewater systems where the sediments and water are treated to remove the contamination. Innovative bucket wash systems have been developed and used by CableArm to remove sediment from the outside of the bucket before lowering the bucket through the water column for the next cycle.

### *Mechanical*

The enclosed nearly water tight bucket is a common tool used in environmental dredging. The CableArm Company has developed some of the most used environmental buckets as shown in Figure 12 and designed, constructed and donated a 0.75 $m^3$ (1 $yd^3$) environmental clamshell bucket to the Haynes Coastal Engineering Laboratory. This small environmental clamshell bucket was used to remove mud from a 42 $m^3$ (55 $yd^3$) sediment pit. The mud overplayed a 152 mm (6 in) layer of sand and the clamshell bucket had the ability to extract the mud with minimal removal of the sand as illustrated in Figure 13. Winrowing is a term used to describe the escape of sediment through the seam of the closing clamshell bucket. Cable Arm constructed overlapping sides to minimize the loss of sediment during bucket closing as shown in the top pictures of Figure 13. Avoiding winrowing reduces the resuspension of the dredged sediments and decreases the turbidity in the water column.

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**Figure 12. Environmental clamshell bucket (Courtesy of CableArm, Inc)**

**Figure 13. Laboratory environmental clamshell bucket constructed by CableArm Inc for the Haynes Laboratory at Texas A&M University.**

## DREDGE AUTOMATION AND SIMULATORS

### Automation

All dredge types can benefit from improved dredging efficiency by using automation controls. Sassano (2007) discussed the important capabilities of dredge automation. The first step is to have a monitoring system that acquires pertinent data such as: slurry density, flow velocity, discharge and downstream pipeline pressures, pump speed, position of cutter and/or draghead, etc. The data is transmitted to computers that calculate production, run time and other items to give real time information for the benefit of the operators in their decision making. Programmable logic controllers can be used to govern certain dredge operations such as cutter depth, pump speed, and ladder swing rate to optimize the production. Fully controlled dredge operations have included:

- Automation of ladder swing speed to keep optimum suction pressure
- Control of slurry concentration by monitoring slurry density and adjusting the suction relief valve
- Detection and prevention of pipeline plugs by monitoring discharge velocity and governing swing speed and ladder depth
- Monitor discharge velocity and control pump speed to maintain optimum velocity in pipeline
- Control winch cables and spuds for advancing the dredge

The use of automation systems should be accelerated in its use in order to improve dredging operation and assist the dredge operators.

Global positioning systems (GPS), digital global positioning systems (DGPS), and real time kinematic (RTK) global position systems are capable of providing accurate real time position information of dredges. Moreover, the GPS can be interfaced with other equipment to inform operators of the digging elevation as well as the current position with respect to the dredge plan boundaries, and thereby minimizing excess removal or undercutting.

Digital Automation and Control Systems (DACS), Dredging Supply, Ellicott Dredge, Kruse Control, Twinkle Dredging, and others have developed various control systems for dredging. In addition, the aggregate and mining industry has employed automation resulting in improved efficiency and production of their respective material.

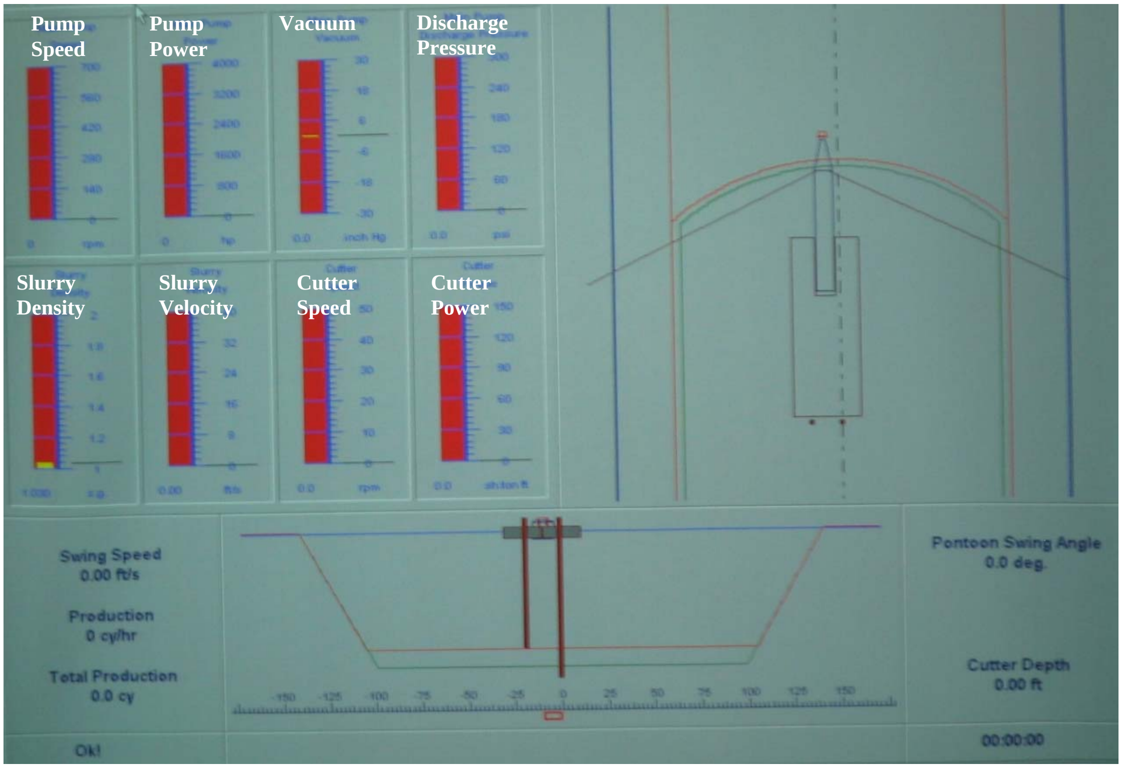
The US Army Corps of Engineers responsible for developing the National Data Quality Management (DQM) System that was formally known as the Silent Inspector (SI) is currently designing a system for automated dredge monitoring Gwin (2010). This program is being applied to hopper dredges and scows in the US and is planned to expand to large cutter suction dredges. The automatic collection of data includes: date /time, vessel and draghead longitude and latitude, dredge heading and speed, draft, ullage, hopper volume and displacement, draghead depths, slurry density and velocity, and pump rpm (Allen 2011). The sensors and data can be used to develop automation of hopper dredge operation controls such as draghead depth, slurry density and velocity control, and vessel loading.

## Dredge Simulators

Mechanical, pipeline, and hopper dredges have increased instrumentation and automation technology, and todays dredge operators and production engineers need to have computer skills in addition to understanding the fundamentals of dredging. There are currently a few dredge simulators available to provided valuable training for new operators and production engineers. The simulators give exposure to the automation and controls technology. The simulators primarily are designed for cutter suction dredges, but mechanical and hopper dredge simulators are in the works.

The Center for Dredging Studies at Texas A&M University and Digital Automation and Control Systems - have three dredge simulators that have been used for training since 1999. Randall, deJong, and Henriksen (2008) describe the simulators and training results. The training with these simulators (Figure 14) focuses on demonstrating the fundamentals of advancing the dredge (two fixed spuds, spud carriage), cavitation limitation, winch power limitation, long pipeline limitation on production, different channel materials, effect of currents in the channel, ladder pump advantages, and powerful pumps. Some 20 exercises are available for 16, 24 and 30 inch cutter suction dredges. The computer display (Figure 15) shows the output of simulated instrumentation ( pump speed and power, vacuum and discharge pressure, slurry density and velocity, cutter speed and power) and top and side views of the navigation channel, and parameters such as instantaneous and total production, swing speed, depth of cutter, swing angle and time of dredging. Due to the versatility of the DACS simulator, nearly any dredging scenario can be simulated, and therefore the lesson plan can be changed depending on the project for which training is desired. The latest version allows the user to create and modify dredge configurations relatively easily. The user can also track every variable output easily by viewing graphs created automatically.

**Figure 14. TAMU/DACS cutter suction dredge simulators.**



Swing Speed 0.00 ft/s
Production 0 cy/hr
Total Production 0.0 cy
Ok!
Pontoon Swing Angle 0.0 deg
Cutter Depth 0.00 ft
00:00:00

**Figure 15. Computer screen for the TAMU/DACS cutter suction dredge simulator.**

The Training Institute of Dredging is part of MTI Holland in the Netherlands and has simulators for cutter suction dredges and now has a simulator for a hopper dredge (Figure 16). These simulators have full control consoles and panoramic views of the dredging and can simulate dredging sounds, communications with other vessels in channel as well as the hydraulic dredging fundamentals.

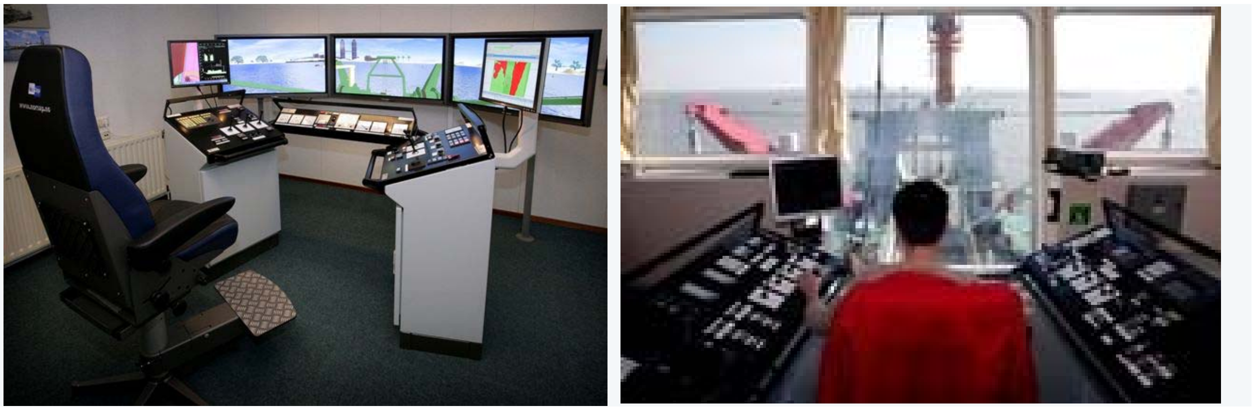


**Figure 16. Cutter suction dredge (left) and hopper dredge (right) simulators used at the Training Institute of Dredging in the Netherlands (Courtesy of TID).**

In the future, dredge simulators are expected to be included in the curriculum of operator and engineer training. These simulators can be arranged to simulate the look and feel of the actual dredge on which the operator is working. Knowledge and specifics of pumps, winches, pipelines, cables, cutters and various drive motors are available as input to the simulator enabling the dredge to be tailored to the trainees dredge. Companies can have their own simulator to train their operators and Great Lakes Dredge and Dock has a simulator similar to the TAMU/DACS simulator.

## DREDGING RESEARCH

Dredging research and development is not well funded in the United States. Research and development in Europe by IHC and Deltares is admirable and has led to the development of large jumbo hopper dredges, self propelled cutter suction dredges, and more efficient cutter heads and dragheads. The US Army Corps of Engineers have conducted large research programs such as Dredging Operations and Environmental Research (DOER), Dredging Research Program (DRP) and Dredged Material Research Program (DMRP) and others. These programs have been successful and contributed new information on dredged material management and environmental planning and technical documents. However, research related to dredging plants and equipment has not been well funded in the opinion of the authors.

The Texas Engineering Experiment Station at Texas A&M University invested in the development of a dredge/tow carriage and tank (Figure 17) that is 45.7 m (150 ft) long, 3.7 m (12 ft) wide, and 3 m (10 ft) deep with a 7.6 m (25 ft) long, 3.7 m (12 ft) wide and 1.5 m (5 ft) deep sediment pit. A model dredge system that has a 102 mm (4 in) suction and 76 mm (3 in) discharge is installed on the carriage. Figure 18 shows the graphical user interface that controls the dredge carriage and allows for automatic (computer) control and manual control. The model dredge is instrumented with pressure gauges, flow meter, nuclear density gauge, cutter speed, pump speed, ladder speed (vertically and across the tank), cutter torque sensor, and six loads measure forces on the ladder. A sand/water separation system and a hopper barge are also available.

**Dredge/Tow Tank**
**Length - 45.7 m (150 ft)**
**Width - 3.7 m (12 ft)**
**Depth - 3 m (10 ft)**

**Sediment Pit**
**Length - 7.6 m (25 ft)**
**Width - 3.7 m (12 ft)**
**Depth - 1.5 m (5 ft)**

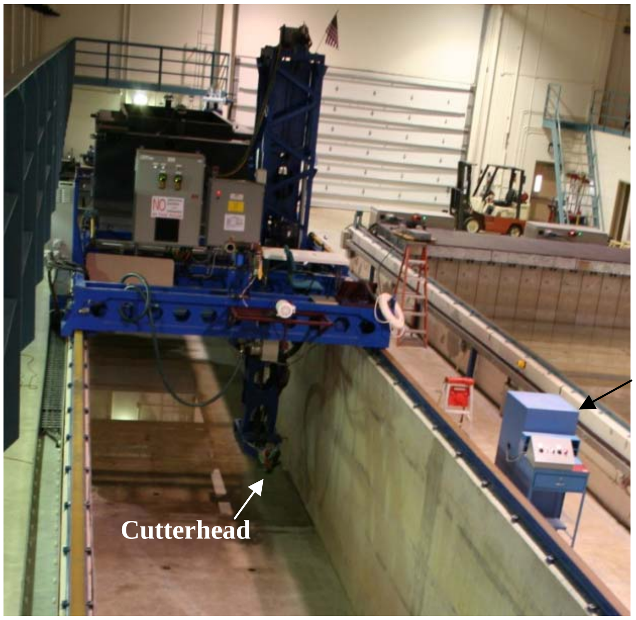


**Figure 17. Dredge carriage in laboratory and data acquisition and control system in Texas A&M's Haynes Laboratory.**

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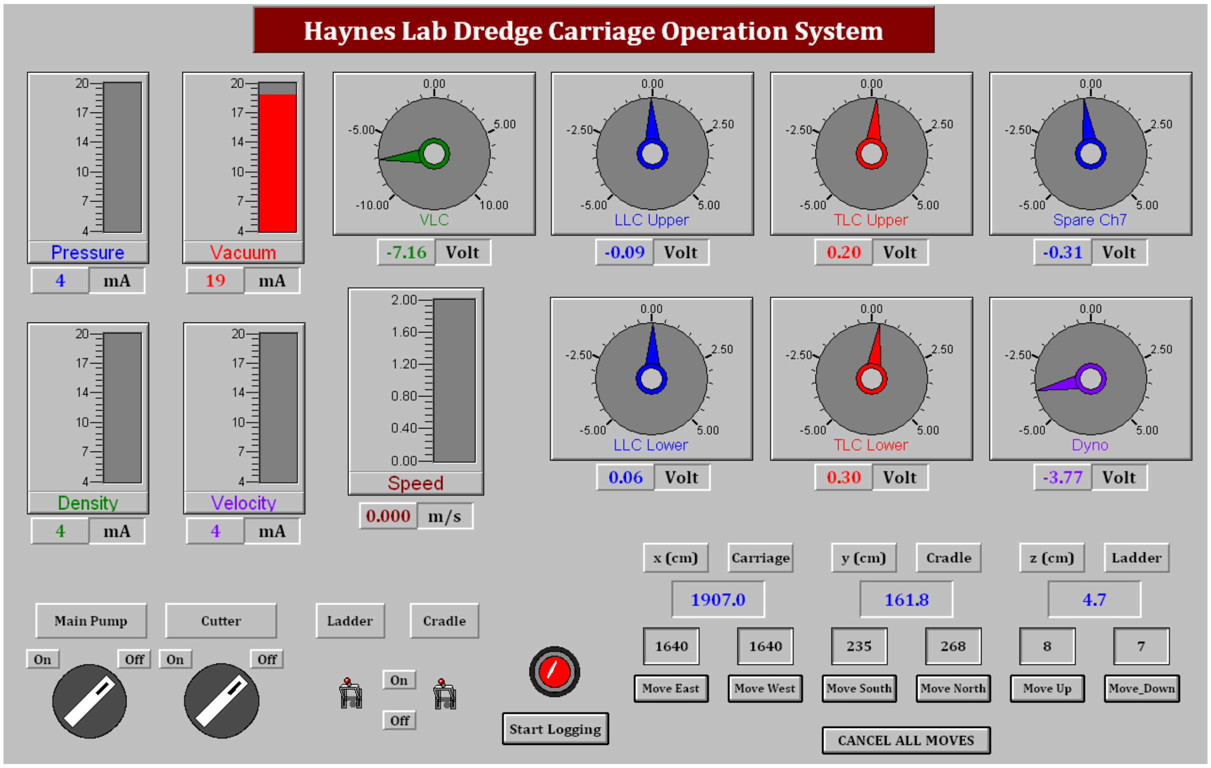

**Figure 18. Example screen for model dredge.**

A large research and testing facility (Figure 19) for dredge pumps is located in Groveton, Georgia. This facility has a 214,000 liter (56,400 gallon) water tank and four pipe test loops with the largest being 1219 mm (48 in) diameter. Centrifugal pumps with impellers as large as 2870 mm (113 in) and flow rates as large as 378,500 liters/min (100,000 gallons/min). Testing of pipeline slurry effects, deposition velocity and other parameters can be evaluated using the Hydraulic Testing Laboratory that has been in operation for over 30 years.

**Figure 19. Exterior view of GIW Industries' centrifugal dredge pump research and testing facility in Groveton, Georgia (Courtesy of GIW Industries).**

The improvement of dredging and dredging efficiency depends on research and development of dredging plants and dredge components such as cutters, buckets, dragheads, pumps, flow fields, sediment spillage and residuals, sediment resuspension, cutting forces, draghead environmental deflectors, draghead modifications and other equipment advances. The computer controlled dredge carriage has the ability to follow different dredging patterns within the sediment pit.

## DREDGED MATERIAL PLACEMENT AND RECLAMATION

The locations to place dredged material are open water placement sites as shown in Figure 20 and Figure 21, and the typical bathymetry for an open water placement site is illustrated in Figure 22. The location of two mounds are evident as well as the uneven bottom at the placement area. If these placement sites were non dispersive sites or confined so that the material stay at the sited, then the material could be re-dredged and used for land reclamation or beneficial uses.

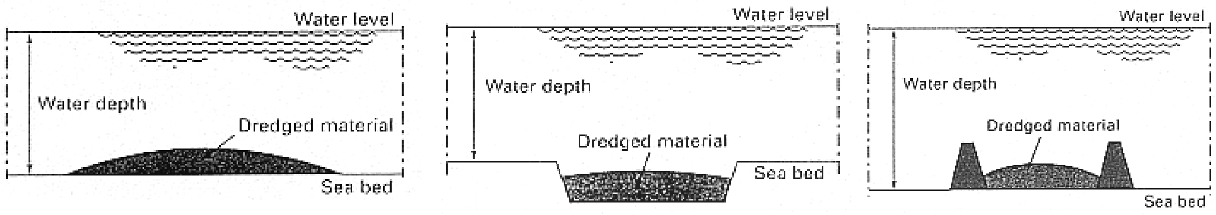

**Figure 20. Schematic of selected open water placement options. (Courtesy of USACE)**

**Figure 21. Open water placement through bottom of hopper barge (left) and rainbowing (right). Courtesy of USACE and Jan de Nul.**

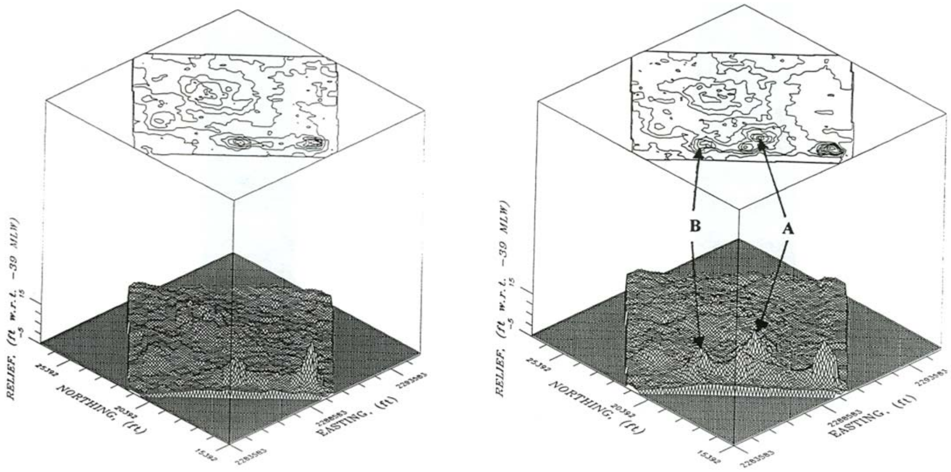

**Figure 22. Open water disposal site bathymetry post disposal (left) and computer simulation (right) Mortiz and Randall (1995).**

Upland (confined) placement sites are illustrated in Figure 23. The upper left site is an upland site showing trenching to allow for water to drain off the site. On the upper right, a filled upland site is shown. If this material could be excavated and used beneficially, then the site capacity is regained for subsequent storage of new dredged material. The possibility of segregating different grain size material using separation equipment should be researched so that sand material can be re-excavated for use. The lower left site is Hart Miller Island that has been filled and is being used for recreational and park activities. A near shore confined placement area is shown in the lower right showing a breakwater bordering the near shore site. .

**Figure 23. Example confined placement areas upland (top), island (bottom left), and near shore (bottom right). (Courtesy of Mike Palermo)**

Additionally, the dredged material may be used beneficially which means the dredged material is used to construct a habitat (left), restore wetlands, (center left) create recreational use, aquaculture (center right), develop port facilities (right), agriculture uses, etc as illustrated in Figure 24. These beneficial uses cost more to develop in the short term, but in the long term, they are popular with the public and are cost effective.

**Figure 24. Examples of beneficial uses and land reclamation such as habitat development (upper left), diked tidal marsh (upper right), aquaculture (lower left), and port development (lower right).**

Future placement of dredged material should consider the possibility of segregating the coarse and fine materials is such a way that the dredged material resource can be re-excavated for other uses. Sand could be re-dredged from an open water site and used for beaches or fill. Fine grain material could be excavated from upland sites for manufactured soils and wetland restoration. Coarse grained sand and gravel can be used for fill and aggregate material. Island and near shore placement sites can be used in a similar way or can be filled to capacity and used for recreational facilities, habitat for wildlife, or new port development.

## CUTTERHEADS AND DRAGHEADS

Hydraulic dredging systems use cutterheads and draghead to excavate or erode sediments from the bottom of navigational waterways. Typical cutterheads are illustrated in Figure 25 showing serrated edge cutter for sand and toothed cutters used for clay, cemented sands, and soft rock. The cutter excavates the sediment/rock and the material enters the suction inlet just behind the cutter back ring as shown in the far right photograph in Figure 25. The flow field entering the suction inlet is complicated because of the rotating cutter and swinging action. Studies are encouraged for optimizing the pickup of the excavated bottom material and understanding the flow field properties and the improved suction inlet size and location. Laboratory facilities are useful for these types of model scale studies. Reducing spillage, residuals, and resuspension is the goal of suction inlet studies.

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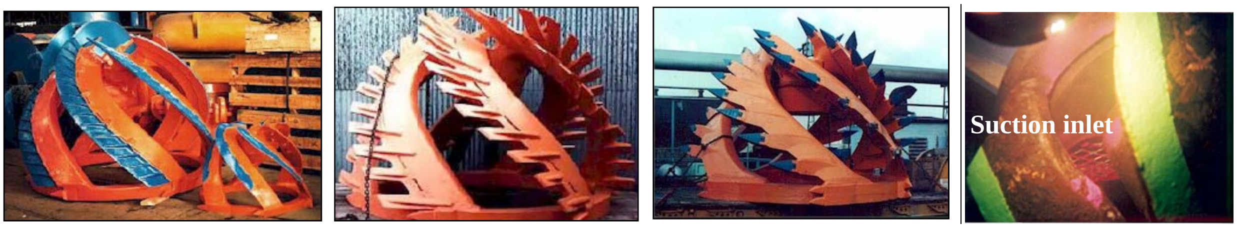

**Figure 25. Typical cutterheads used on cutter suction dredges.**

Example dragheads for trailing suction hopper dredges are shown in Figure 26. The draghead on the left has high pressure water jets to assist in loosening the sediment and making it available to the suction inlet. The California draghead is show in the center of Figure 26 and it is a split draghead that depends on high velocity water entering the suction inlet and eroding the bottom sediment. The photograph on the right is a common draghead known as a Dutch draghead, and the visor adjustment is shown that can vary the angle in contact with the bottom. The draghead is located at the end on the long suction pipe that trails below the hopper dredge. Control of the draghead's position on the bottom is difficult and future control of the draghead could include acoustic pingers other sensors to provide position information to a propulsion system on the draghead to maintain horizontal position. The use of turtle excluding devices to prevent turtles from entering the suction inlet have been studied, but the problem has not been solved. Cutting devices such as cutting blades and high pressure water jets need to be further developed to provide excavation capabilities for dragheads.

**Figure 26. Common dragheads used by trailing suction hopper dredges.**

## SEPARATION SYSTEMS ON THE DREDGE

Dredged material is a resource rather than a waste and is beneficially used for beach nourishment, wetland restoration, construction fill, manufactured soil, etc. However, not all dredged material is acceptable for these types of uses and some material may require other placement due to environmental concerns. Therefore, mechanical separation of the beneficial material and the waste material is primarily used in dredging applications. Excavated material separation technology has evolved over many years in the mining industry and certain processes are being used in dredged material separation technology.

The principles of physical material separation are based on the differences in particle size and density. Using these principles, a series of material treatment steps are taken to separate materials in a continuous fluid flow. There are numerous techniques available commercially to separate material through the use of five treatment steps. First, the dredged material must use a prescreening process to remove large debris (e.g. large rocks, stumps) so the debris does not damage the subsequent separation processes. Next, the material passes a physical size separator, followed by a density separator that feeds a solid/liquid separator, where the material is finally solidified with a dewatering process. However, this section is concerned about systems and technologies which may be implemented on a dredging vessel, and therefore, limits the types of technologies.

Initially, the very large objects in a dredged material are separated from the remaining material. Fixed bar screens, comminutors, attritioners, or log washers may be employed on dredging vessels. A fixed bar screen is used for blocking large objects while allowing smaller objects to pass. These screens are applicable to mechanical or bucket dredges, because the large objects would not pass into a cutter-suction dredge or a trailing hopper dredge pumps. A comminutor pulverizes objects into smaller pieces. A log washer uses macerating screws and water jets to clean and

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break apart rocks from sand/clay. An attritioner drives particles into each other to break apart into smaller pieces. Comminutors and attritioners shred and grind the large debris into particle sizes that the subsequent system may handle. Log washers are used to separate rocks from sand and clays in the mining industry. However, efficient use of a log washer on a dredge requires a relatively large dredge, because the commercially available washers are quite large. For smaller dredges, bar screens, comminutors, and attritioners are a more viable option. Improvements in this area of material separation may be self-cleaning bar screens or scaling down the size of log washers.

After the prescreening process, the material is then subjected to physical size separation. This step may use wet or dry screens that are fixed or vibrating, hydrocylones, or sieve bends. The screens and the sieve bends separate material much like the fixed bar screens found in prescreening by filtering the material according to size (Olin-Estes & Palermo, 2000). However, hydrocyclones separate material by using centrifugal force from high rotational velocities to separate larger, denser material from smaller, less dense material in a conical shaped apparatus. Hydrocyclones are a rapidly evolving technology, and the latest advancement is the replacement of the impervious conical section with a filtering wall conical section. This filtering wall improves material separation performance and improves capacity (Vieira *et al*, 2010). Hydrocyclones (Figure 27) are advantageous on a dredging vessel because it reduces material volume through dewatering and densification, which improves production and lowers dredging costs. Furthur research into hydrocyclone modifactions tailored for site specific dredging projects could enhance material seperation efficieny (Pandit *et al*, 2009).

The third stage of separation exploits differences in density to separate dredged material. Spiral concentrators (Figure 27), mineral jigs, multi-gravity separators (Figure 27), dense media, shaking tables, and pinched sluices separate the material according to density. However, for dredging system applications that are placed on a dredging vessel, the spiral concentrators, mineral jigs, multi-gravity separators, and pinched sluices have adequate capacity to handle the material produced from dredging operations on a scale to fit on a vessel. These devices have been continuously evolving in the mining industry to more efficiently acquire precious material with a specific density, such as gold. Therefore, the knowledge gained from perfecting these systems may apply to dredged material separation. At this point in processing the material, water that has been pumped by the dredging equipment has been the primary means of conveyance of the material. The remaining steps aim to remove the water from the dredged material.

**Figure 27. Spiral concentrator (left) (Courtesy of Zhongke Engineering & Technology Co, Ltd.), gravity separator (middle) (Courtesy of Spectrum Industries), hydrocyclone (right) (Courtesy of GN Solids Control).**

The fourth and fifth steps in the separation process pertain to separating the material from the water. Generally, the fourth system aims to separate the larger and denser material from the water through the use of clarifiers, sedimentation basins, lamella clarifiers, or floatation cells. However when trying to implement these systems on a dredging vessel, the lamella clarifiers and floatation cells do not require as much deck space compared to regular clarifiers and sedimentation basins. The final step in the separation process is finally dewatering the material. This is achieved by the use of screens, belt filter press, plate and frame filter processes, centrifuges, screw classifiers, or rotary vacuum filters. For dredging vessels, belt filter presses and screw classifiers are the systems that would be able to fit on a dredge (Olin-Estes & Palermo, 2001). However, separating the sediments from water would disallow the use of pumps to transport the dredged material, which would greatly hinder operations on cutter-suction dredges.

Dredged material separation systems do not necessarily have to be placed on the dredging vessel. Barges may be implemented with separation systems, increasing mobility and limiting transportation costs. Systems may also be placed at dredged material placement sites where material separation is requested or environmentally required. In conclusion, dredged material separation systems which may be used on a dredge are available commercially. These systems could enhance the dredgers ability to turn dredged material into a resource rather than a waste.

## CONCLUSIONS

In the US and other coastal nations, there is likely to be a need to dredge large amounts of sand further away from the beaches or land where renourishment or land reclamation is desired. The US dredging companies should consider investing in the construction of larger and faster hopper dredges to haul sand to the coast line to renourish or reclaim land or beaches or wetlands lost to erosion, subsidence, or sea level rise. These larger vessels could also partner for work on the international market.

Current large cutter suction dredges can increase efficiency and shorten dredging time by retrofitting with a spud carriage advance system or adding a spud carriage barge. New large cutter suction dredges should consider adding propulsion similar to what has been accomplished on international cutter suction dredges. A large self-propelled cutter suction dredge with heave compensation can operate further offshore and excavate sand for beach nourishment or land reclamation. The addition of thrusters to control swing is a possibility and would eliminate the need for anchors and improve production.

The small hydraulic dredge manufacturers and operators use automation to maximize production. Innovative systems such as swinging ladders and kick spuds have improved efficiency and production. Small hydraulic dredges are being used in dredging contaminated sediments and reducing the residuals with the development more accurate depth control and increased vacuum to improve the sediment capture around the cutterhead and reduce sediment resuspension and spillage.

The positioning accuracy of the bucket on the bottom while minimizing the resuspended sediments is a continually improving area. Instrumentation for determining closure of bucket and distance off the bottom are often used. Future design improvements could include position assistance with small propulsion packs mounted on the bucket.

A remotely operated dredge system has the ability to work free from the constraints of trailing dragarms, winch lines, anchor handling equipment, and ladder pumps. Benefits include reduced mobilization costs and transit time, unhindered traffic flow, and discharge pipeline maintenance. The reduced visual impact during dredging may promote and advance project approval in the public domain.

The placement and beneficial use of dredged material in open water and upland placement sites can be improved by segregating coarse and fine material in such a way that the sediment resource can be re-excavated for other uses. Sand could be re-dredged from an open water site and used for beaches or fill. Fine grain material could be excavated from upland sites for manufactured soils and wetland restoration. Coarse grained sand and gravel can be used for fill and aggregate material. Island and near shore placement sites can be used in a similar way or can be filled to capacity and used for recreational facilities, habitat for wildlife, or new port development.

Dredge automation using programmable logic controllers should be used increasing to govern certain dredge operations such as cutter depth, pump speed, and ladder swing rate to optimize the production. Global positioning systems (GPS) can be interfaced with other equipment to inform operators of the digging elevation as well as the current position with respect to the dredge plan boundaries, and thereby minimizing excess removal or undercutting.

Dredge simulators are expected to be used more to train operators and engineers. These simulators can be set up to simulate the actual dredge the operator is going to run. Knowledge of pumps, winches, pipelines, cables, cutters and various drive motors can be input to the simulator so the dredge is tailored to the trainees dredge.

Dredged material separation systems can be placed on barges or placed at the material placement sites where material separation is requested or environmentally required. The dredged material separation systems are available commercially, and these systems can enhance the ability to turn dredged material into a resource rather than a waste.

The improvement of dredging and dredging efficiency depends on research and development for dredging plants and dredge components such as cutters, buckets, dragheads, pumps, flow fields, sediment spillage and residuals, sediment resuspension, cutting forces, draghead environmental deflectors, draghead modifications and other equipment advances.

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